CHAPTER 1

FORWARD & INTRODUCTION

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1.1 Forward

This document establishes uniform procedures to carry out the highway design functions of the California Department of Transportation. It is neither intended as, nor does it establish, a legal standard for these functions. The procedures established herein are for the information and guidance of the officers and employees of the Department.

The guidance incorporated within the following pages is neither intended to serve as a textbook nor as a substitute for engineering knowledge, experience or judgment. Many of the instructions given herein are subject to amendment as conditions and experience may warrant. Special situations may call for variation from the procedures described, subject to necessary approval as may be specifically called for.

1.2 Introduction

1.2.1 Purpose

Improperly designed or constructed road crossings have often become barriers to the migration and passage of aquatic organisms and have contributed to the decline in populations of many fish species in California and nationally. The purpose of this document is to provide designers with the necessary tools and information to adequately plan and design facilities that facilitate movement of fish and other targeted aquatic species in conformance with both state and federal regulations. The guidance contained within this document addresses both NOAA Fisheries and California Department of Fish and Game criteria and provides step-by-step instruction on incorporation of those features and concepts that will lead to regulatory approval.

1.2.2 Background

As a component of the Department's environmental stewardship commitments, the passage of fish past the many thousands of state highway crossings of rivers and streams has long been of concern to Departmental staff. For most fish species, migration for the purposes of spawning, rearing of young or for finding suitable habitat is essential to survival. With the 1973 passage of the federal Endangered Species Act, and the recent passage of California Senate Bill 857 which amends California Fish and Game Code to incorporate specific provisions regarding Caltrans' progress in removing barriers to fish passage, that stewardship commitment also carries a regulatory context whereby the Department must provide for the unimpeded passage of various aquatic species or potentially face litigation and/or penalties for non-compliance.

The National Oceanic and Atmospheric Administration National Marine Fisheries Service (more commonly, NOAA Fisheries), the California Department of Fish and Game (DFG), and the United States Fish and Wildlife Service are the three primary interfaces thru whom Departmental staff will work to ensure conformance with state and federal fish passage standards and regulations. NOAA Fisheries and DFG have produced publications providing guidance on fish passage criteria and in many situations both entities will need to approve of fish passage designs via the permitting process. NOAA Fisheries guidance is specific to those streams supporting anadramous species (i.e., those fish whose life cycle includes extended periods in ocean waters, returning to freshwater for spawning) while DFG guidance is far broader, and applies to all aquatic organisms sustained within the stream.

1.2.3 General Considerations

As a document aimed at an audience of designers, the information presented herein begins with the assumption that either a condition exists that impedes fish passage or a new crossing that could affect passage is being considered, and that a determination may be made to address that condition with a Departmentally sponsored project. This document makes no attempt to describe the various funding mechanisms available for fish passage projects nor does it provide detail on the processes used by District and Headquarters Environmental staff to identify species of concern, evaluate stream habitat value or conduct preliminary passage evaluation (i.e., green-grey-red designation) of the culvert.

While the body of this document picks up at the point that the engineering designer has begun the assignment of developing the project PS&E, that does not infer that the process of incorporating fish passage begins at this point. Early discussion and coordination in the project planning phase is necessary to ensure that cost and scope of necessary right-of-way certifications/acquisitions, easements and other required elements are addressed. The designer must confer closely with district Environmental staff to clearly understand the needs of the aquatic species of concern for the stream in question and have an understanding of both the engineering and resource goals of the project.

Successful implementation of the strategies contained in this document often requires that the designer take a non-traditional approach to the project. For instance, much of the project work, and certainly much of the project assessment will likely need to take place well beyond the highway right-of-way. Construction techniques and materials may not be typical of most roadway projects, and several of the requirements established by the resource agencies will seem unusual. The degree of plan detail and specification development and involvement of District hydraulic, biologic and landscape architectural staff will also generally exceed that required by other types of construction. It is these considerations that have led to the publication of the document which follows, and which requires the designer to ensure that the final project design contains an appropriate balance of environmental compliance and safety for the traveling public.

1.2.4 Responsible Charge Requirements

Historically, there have been many professions that have contributed to fish passage and stream restoration projects, and in many cases the lead individuals, regardless of profession, have signed off on the plans and/or specifications. While it is still imperative that close collaboration with multiple affected functional units take place, it is the responsibility of the registered civil engineer to sign the project plans for the designs that are discussed within this document, and which will be constructed and/or maintained by the Department. Stream grade control structures, step pools, bank protection, culvert replacements or retrofits and installation of culvert baffles are engineering works, and in keeping with the Business and Professions Code pertaining to such designs, must be signed by the appropriate registered professional.

CHAPTER 2

FISH PASSAGE CONSIDERATIONS FOR ROAD CROSSING DESIGN

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2 FISH PASSAGE CONSIDERATIONS FOR ROAD CROSSING DESIGN

Roads crossings over permanent or seasonal waterways are generally classified as one of three types:

- bridges,
- culverts, or
- low water crossings (also referred to as fords).

For the purposes of this manual, it is assumed that low water crossings are outside the scope of a typical Caltrans projects, and the discussion of road crossings will be limited to bridges and culverts. Bridges are defined by the National Bridge Inspection Standards (NBIS) as those structures which have at least 6 meters of length along the roadway centerline. A culvert is defined by the *Highway Design Manual* (HDM) as “a closed conduit which allows water to pass under a highway”, and it is noted that a single culvert site may actually have multiple barrels to accommodate the conveyance needs.

Traditional road crossing design procedures, such as the culvert design procedures described in *HDS No. 5,* typically focus on conveyance of the design flood, as a means to establish practical limits on the goal of perpetuating natural drainage. While these traditional procedures include consideration of backwater affects, excessive velocity, erosion, and traffic safety issues, they generally do not provide specific consideration of the needs for fish passage. Road crossing sites requiring fish passage must use design procedures that assess the conveyance characteristics from a “fish eye” view.

This chapter discusses several important concepts in fish passage design from three approaches. First, as a means to emphasize that the design procedures have a basis in the fish requirements, there is a discussion of key biological factors known to affect fish mobility and migration, as well as mention of broader environmental conditions that, while they may not affect fish mobility, have direct relation to fish survival. Secondly, there is discussion of hydraulics and hydrology issues that are of particular relevance to fish passage design, touching upon the interrelationship between geomorphic processes and ecosystem function. Finally, there is discussion of several engineering design, construction and maintenance topics that are commonly applied in any road passage design, but which may have special or unusual circumstances when applied to fish passage road crossings. In the subsequent chapters of this manual, specific design procedures are presented to allow more thorough evaluation of these engineering considerations.

2.1 Factors Affecting Fish Passage Success at Road Crossings

The most common problems typically associated with fish passage at road crossing structures are:

- water velocities that are greater than the swimming capabilities of the fish (Figure 2-1a.);
- perched outlet conditions that result in a vertical drop that exceeds the jumping and leaping capabilities of the fish (Figure 2-1b);
- shallow water depths or sheet flow conditions that do not provide adequate swimming depth for the fish (Figure 2-1c); and
- debris accumulations that cause physical blockage or create excessive turbulence that surpasses the swimming capabilities of the fish (Figure 2-1d).

a) high velocities

b) excessive jump heights

c) shallow water depths

d) debris accumulation

Figure 2-1. Common barriers to fish passage at road crossings. (Photos courtesy of FishXing 1999)

The ability to overcome these fish passage problems is dependent on a number of factors which are discussed in the following subsections.

2.1.1 Swimming and Leaping Capabilities of Fish

Aquatic systems exhibit tremendous diversity in their hydraulic conditions, ranging from the relative calm of lakes and reservoirs to the higher energy conditions of mountain streams. The types of fish that inhabit these diverse conditions have swimming capabilities that reflect their environmental surroundings. The swimming capabilities of various fish species exhibit differences both in the speed they can attain, as well as their endurance in maintaining these speeds over time. Discussions of fish swimming capabilities commonly address three different modes of swimming considering an average condition:

- Sustained speed: a speed that can be maintained indefinitely by the fish, reflecting the swimming mode commonly used for movement. Some researchers use the term cruising speed to described sustained swimming.
- Prolonged speed: a speed that can be maintained for a limited duration, such as might occur with passage through difficult areas. This is the mode of swimming typically used for design or analysis of road crossings. Prolonged swimming can be maintained from 15 seconds to 200 minutes, depending on the species. Some researchers use the term sustained speed in place of prolonged speed, creating unfortunate confusion with the slower classification of sustained/cruising speed.
- Burst speed or darting speed: a speed attained for a short burst of effort, such as in feeding or escaping predators, but not capable of prolonged effort.

Threshold levels for the sustained, prolonged and burst speeds have been identified for a number of fish species. In addition to significant variation between species, there is also variation between different age classes of the same species (Figure 2-2). Environmental factors such as location in watershed relative to other obstacles, increased water temperature, or poor water quality can influence the ability of a fish to maintain the typical speeds common for that species and age class.

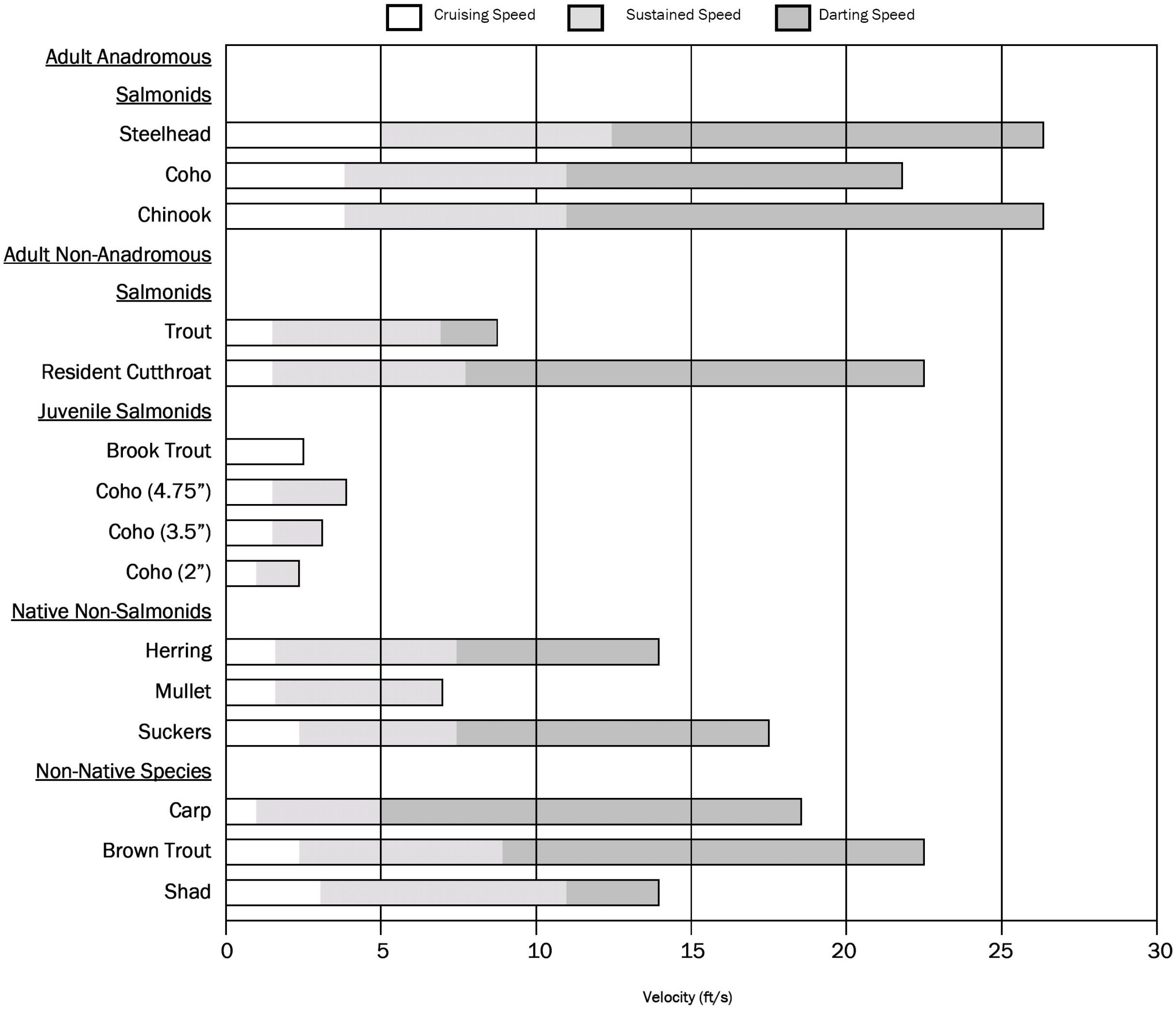


Figure 2-2. Swimming capabilities of various species and age classes of fish. The list organizes the data into five classifications of fish commonly referenced in California fish passage guidelines. (Adapted from Bell 1991)

The relevance of these swimming capability differences to fish passage design is to recognize that the design criteria for a specific road crossing site will depend on the fish species and age classes for which it is desired to provide passage. Identification of the fish species and age class of interest (frequently called the target species) should be obtained from Environmental staff prior to beginning the design for a fish passage road crossing. If the design process is initiated using assumed target species, there is risk the design efforts will have to be reinitiated if the target species is redefined.

2.1.1.1 Velocity Barriers

Road crossings create a geographic division in the habitat of a fish species. The ability of a fish species to utilize the adjacent habitat areas may be lost on a temporary or permanent basis if the velocities at the road crossing exceed the prolonged swimming capabilities of the target species. The phenomenon in which velocity conditions prohibit access is called a velocity barrier. Velocity barriers may result in direct loss or underutilization of available habitat, which is likely to result in reduced numbers of the fish population.

Road crossing design processes presented in this manual insure that velocity conditions remain below the prolonged swimming capabilities of the target species, for those flows typical of fish movement. (During flood conditions, fish are likely to be seeking refuge in calm water and not choosing to move upstream.) Alternatively, the road crossing design may provide resting areas spaced frequently enough to allow the fish to dart from one location to the next. The methods of analysis for insuring there are no velocity barriers vary depending on the type of road crossing selected for design.

2.1.1.2 Jump Height Barriers

Similar to the diversity in swimming capabilities, there is also great diversity in the leaping capabilities of various fish species. Of the fish species common to California, the leaping capabilities of adult Chinook, coho, and steelhead are especially notable. These species all exhibit life histories that involve both an ocean phase and a fresh water phase, and they may undergo upstream migrations of hundreds of miles from the ocean to reach their freshwater spawning grounds. These characteristics place them in a classification known as anadromous salmonids. Salmonids which do not exhibit the ocean-going trait include resident trout and resident cutthroat. The adults of these non-anadromous salmonids do not have the same leaping capabilities as the anadromous salmonids. Similarly, the jumping capabilities of juvenile salmonids and non-salmonids (such as most species that inhabit lakes and reservoirs) are not nearly as strong as those of adult salmon.

Culverts installed in the past without consideration to fish passage were most frequently placed to match the natural streambed elevation. However, in some cases (such as sites requiring very high fills), culverts were installed considerably above the stream elevation, resulting in a perched condition at the culvert outlet. It is a testimony to the persistence of nature that some adult anadromous salmonids are able to leap in to and successfully pass these perched culverts. There is a much lower likelihood of juveniles or any other classification of fish being able to pass these perched culverts.

New and replacement culverts installed where fish passage is a requirement are generally required to place the culvert so that there is no change in elevation between the thalweg of the stream and the bed of the culvert. In limited cases, such as when an existing culvert is being retrofit to enhance fish passage, a drop in the water surface of 6 to 12 inches may be allowed, depending on the target species. These inherent measures to ensure there are no jump height barriers vary according to the road crossing design option that is selected.

2.1.1.3 Shallow Water Depths

Fish movement requires sufficient water depth for the following reasons:

- Fish that are only partially submerged do not achieve the same level of thrust as occurs from body and tail movements of fully submerged fish.

- If the gills of the fish are not fully submerged, they will experience reduced oxygen uptake, which may affect swimming ability and endurance.
- Shallow water depths may increase the level of physical contact with the stream bed, increasing the risk of physical injury or predation.

Factors that can cause shallow water depths at road crossings include placing the culvert at a steep slope, and the use of wide, flat-bottomed culverts and aprons. The fish passage road crossing design processes presented in this manual insure that water depth conditions are within threshold levels for the target species, or that they are similar to natural stream conditions, depending on the design option that is selected.

2.1.2 Debris

As runoff accumulates from a watershed, it naturally carries certain floatable material with it. In watersheds with significant vegetation, natural growth cycles as well as cutting or clearing operations may contribute to debris and drift in the runoff. As this debris approaches and passes through a highway drainage facility, it has potential of becoming hung up or jammed. Because urbanization continues to increase across the State, urban debris, such as tires and shopping carts, is becoming more widespread and blocking low-flow routes. Significant accumulations of debris can reduce hydraulic efficiency, cause local scour, and cause physical damage to the facility and adjacent property and features. With even low to moderate accumulations of debris at a road crossing, the velocity and turbulence affects may be significant enough to create a fish passage barrier.

Debris accumulation is a common characteristic of any drainage feature, natural or manmade, in which there is a constriction in the flow path. Though it is not possible to eliminate the risk of debris accumulation entirely, there are road crossing design strategies that can reduce those risks. Very generally, the larger the conveyance opening, the less risk there is of having debris problems. Since fish passage road crossings tend to be larger than culverts designed through traditional cross drainage methods, there is some reduction of risk inherent with any of the fish passage road crossing design methods. Additional measures are presented in Chapter 3 that may help the designer understand the potential for debris accumulation and damage, and assist with the design of protective devices and access features to facilitate debris maintenance operations.

2.1.3 Bed Load

The bed load in a stream is defined as sediment that moves by rolling, sliding, or skipping along the bed. Effectively, sediment load means the same thing. The bed load or the sediment load in an undisturbed stream system is, over the long term, usually in a state of equilibrium, in which eroded material is replaced by deposited material. Changes in hydrology as occur in nature over seasons or over the duration of a flood event may create erosion (or channel degradation) on the rising and peak flows of a cycle, while deposition (or channel aggradation) occurs with the falling flows.

Road crossings that present a significant constriction in channel geometry may produce erosive velocities that cause channel degradation below a culvert. Constrictions may also produce backwater conditions above the culvert that result in deposition and channel aggradation. Both of these conditions tend to steepen the channel slope in the vicinity of the culvert, with the potential result of creating a velocity barrier in the channel approaching or exiting the culvert.

Since design methods for fish passage road crossings generally aim to maintain velocities in the range of the swimming capabilities of fishes, these same design methods inherently reduce the problems of bed load erosion or deposition that sometimes occur with traditional culvert design methods. Depending on the design method selected, there are varying degrees of attention given to ensuring that bed load movement continues unhindered through the road crossing. In special cases, analyses may be conducted on the stability of bed material under flood conditions, to minimize the risk of significant channel degradation and aggradation over the life of the project.

2.1.4 Ambient Lighting Conditions

The response of fish to lighting conditions varies with species and age. Some fish are known to be attracted to light, other fish are indifferent to it, and others try to avoid it. Adult salmon tend to avoid strobe lights. Juvenile salmon use light to orientate themselves and are attracted to light, but they also appear to establish a threshold to that attraction, perhaps as an innate protection against predation.

Adult salmon approaching the minimally-sized Hells Gate Fishway on the Fraser River in British Columbia exhibited reduced delay entering the fishway following installation of lights. At the same time, Washington State has numerous culverts more than 1,000 feet long under the cities of Olympia, Tacoma, West Seattle, and Bellingham. Monitoring reports indicate these culverts have good fish passage, even though there are no lights in these culverts (P. Klavas, WDFW, pers. comm., October 2004).

In some instances, fisheries agencies may require that ambient or artificial supplemental lighting be provided in proposed culverts over 150 feet in length. Environmental staff should identify at the onset of a fish passage design whether fisheries agency representatives will require application of this criterion for culvert crossings at specific project sites.

2.1.5 Uncertainty of Fish Passage Streamflows

Traditional culvert design methods focus on hydraulic conditions resulting from the design flood, frequently defined as the 25-, 50- or 100-year event. Fish passage design methods, on the other hand, are concerned with the hydraulics resulting from the typical year-to-year conditions in which the target population inhabits the stream. Depending on the type of fish passage road crossing selected for design, it may be necessary to determine the flow rate for certain frequently-occurring flows, such as the 2-year flow (Q_2). Additionally, since it may be necessary to check that the design provides adequate depth for fish passage (again being dependent on the design type), it may be necessary to estimate the lowest expected discharge occurring when the target species is present.

Stream gage data, if available, provide the most accurate way to calculate fish passage flow rates. However, few gaged streams exist in comparison to the total number of streams in California, and the probability of having gage data for the specific project site is low. It is more likely that the fish passage streamflows will be estimated using a hydrologic method such as those described in Section 3.2. However, because of the uncertainty of these methods, and because of importance of velocity on assessing the fish passage conditions, it is recommended that the estimates be used conservatively. Engineering judgement should be applied to fish passage flow estimates in steeper watersheds and urbanized or urbanizing watersheds, where land use and basin hydrology may change during the life of the project, thereby affecting the maximum and minimum flows.

2.2 Types of Fish Passage Road Crossings

There are several types of structures that can be involved with fish passage at road crossings. Those discussed in this manual include the broad classifications of bridges, culverts, grade control structures, and fishways. Bridges and culverts are the two classifications that provide the actual function of cross drainage for the road crossing. Grade control structures and fishways are two classifications of fish passage facilities that, when applied to road crossings, generally function to insure fish passage is maintained in the stream channel on either side of the road crossing. Each of these broad classifications have several design subtypes that differ according to factors such as structural capability or design objective. The following section discusses each of the four classifications of fish passage road crossing structures and identifies the major design subtypes that are most relevant to Caltrans projects. Key differences of each subtype with respect to fish passage function are discussed.

2.2.1 Bridges

From a fish passage perspective, bridges are the preferred method of providing a fish passage road crossing, for the simple reason they cause the least change in the stream channel. This general openness of a bridge crossing allows the greatest degree of ecological connectivity between the watershed basin upstream and downstream of the road crossing. The connectivity is important to not only to fish populations in the stream, but also to other aquatic organisms and wildlife that utilize the stream corridor. Bridges also allow the most natural form of transport for large debris, sediment, and other stream elements that are important in stream forming processes and in the health and maintenance of the entire stream ecosystem.

Bridge crossings (without aprons) may be the only form of road crossing that can accommodate fish passage requirements when the stream grade is over 8%. If the stream grade is in the range of 5% to 8% and flowing over bedrock, an embedded culvert is likely to be the practical alternative.

Bridge design for fish passage road crossings should require little more hydraulic and hydrologic analyses than is typically required for a typical bridge design. At complex sites were there is limited data regarding stream hydrology, selection of a bridge crossing design may eliminate the need and uncertainty of evaluating fish passage over a range of flow rates.

Figure 2-3. Bridge crossing

The relatively large flow area of bridges, as compared to culverts, generally produces a greatly improved condition of reduced risk of plugging from debris and sediment.

The main drawback to bridges, in comparison to culverts, is the significant difference in construction cost. As a general guideline, however, the cost of a bridge may become comparable to that of a culvert once the culvert dimensions begin to require multi-plate designs in excess of 10 feet in diameter or 15 feet in span (Robison et al. 1999).

When conducting a benefit-cost analysis that includes consideration of the long-term costs associated with maintenance, however, it is worth noting that bridges may offer an increased benefit over culvert alternatives when applied to a fish passage projects, as compared to the typical analysis involving non-fish passage culverts. Debris and sediment removal is essential for all road crossings, whether they are required to provide fish passage or not, from the standpoint of preventing highway overtopping and protecting the structural integrity of the road crossing.

2.2.2 Culverts

As knowledge regarding fish passage at culverts has progressed in recent years, it has become common to classify culverts by the design method used for their development. This manual focuses on four classifications of culvert design that, very generally, provide differing degrees of culvert openness as a means to promote ecological connectivity. The four classifications, presented in decreasing order of culvert openness, are:

- stream simulation design
- active channel design
- hydraulic design
- existing culvert retrofit.

The following subsections provide a brief introduction to each style of culvert and the common application where the style is used.

2.2.2.1 Stream Simulation Culvert

Stream simulation is a culvert design method intended to create and maintain natural stream processes in a culvert. It is based on the premise that the simulated channel inside a culvert presents no more of a challenge to movement of water, organisms, sediment and debris than the adjacent natural channel. As such, the stream simulation design method is expected to provide passage to all species and age classes of fish, as well as to all other aquatic organisms in the stream.

In the stream simulation design approach, basic culvert characteristics of slope, cross-sectional size, and culvert bed elevation are derived from characteristics of nearby stream reaches that are similar to the road crossing location (Figure 2-4). This method therefore can provide fish passage at sites having stream slopes up to 6%, and in some cases, even higher.

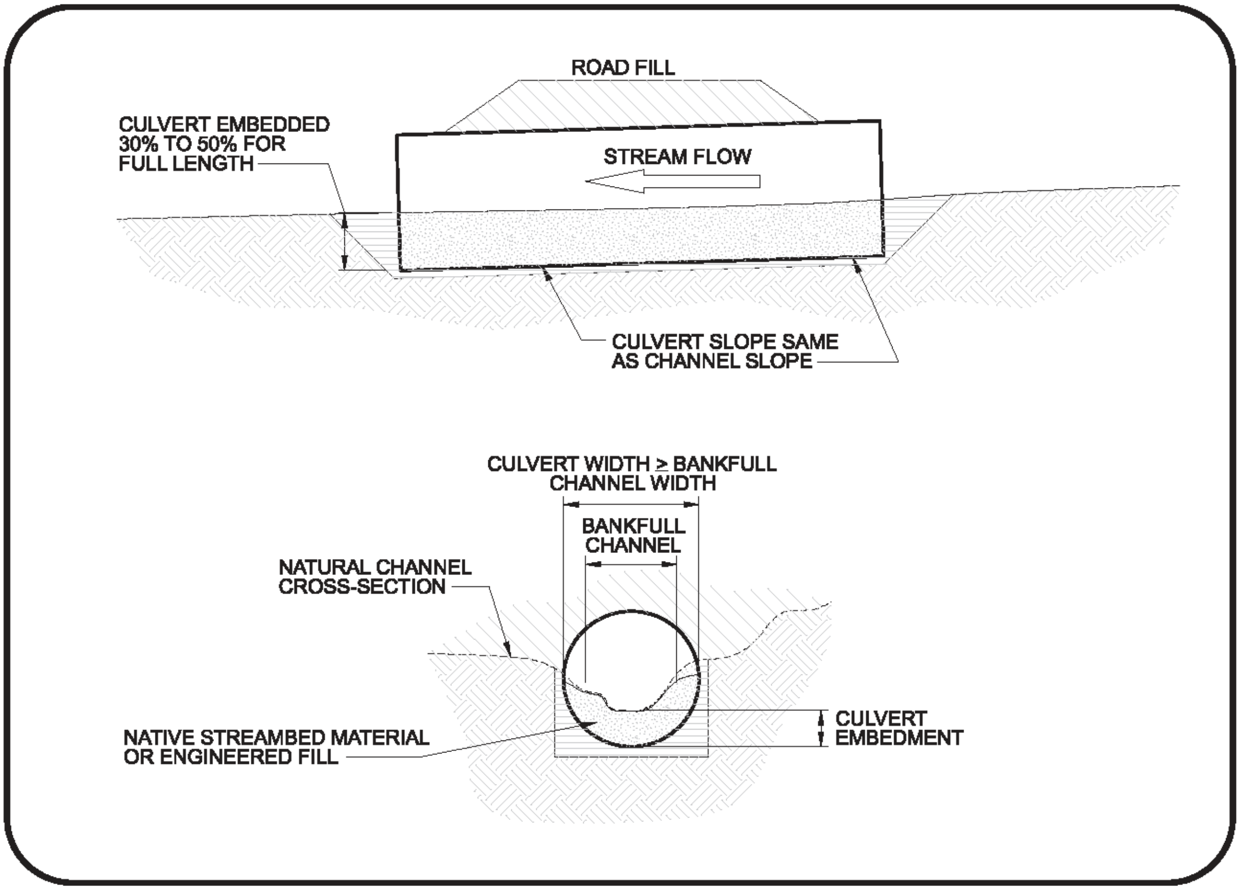


Figure 2-4. Basic sizing and embedment concepts of stream simulation culverts.

The general premise that hydraulic conditions in the culvert will mimic those in the natural stream reduces the amount of hydrologic and hydraulic analysis necessary for design development. Sites that have limited hydrologic data may choose to select a streambed simulation design approach as a means to reduce the risk associated with uncertain conditions for fish passage flows.

Streambed simulation culverts are sized to be at least as wide as the natural stream channel, and there is high probability they will be larger than culverts designed by the active channel or hydraulic design methods for the same site. As such, the streambed simulation method is likely to yield designs having higher capital cost than the other two culvert design methods. At the same time, the long-term maintenance costs of a streambed simulation design should be lower than the two culvert alternatives, for the same reasons of reduced maintenance as described for the bridge option. The lowest ratio of comparative construction cost between streambed simulation and the alternative culvert design methods is most likely to occur at road crossings located in narrow stream valleys.

2.2.2.2 Active Channel Culvert

An active channel design employs a culvert placed at a level grade, sized sufficiently large enough to encourage the natural movement of bedload and the formation of a stable bed inside the culvert. The active channel design method originally was developed with the intent of providing a simplified stream simulation design for private landowners with short crossings under driveways and similar sites. For those limited projects satisfying specific criteria regarding channel slope and culvert length, the active channel design method can greatly reduce the engineering effort necessary to develop a culvert design approved by State and Federal fisheries agencies. The tradeoff for the reduced engineering effort is that it provides a road crossing culvert that is commonly larger than would be required under more rigorous hydraulic design approaches.

In the active channel design approach, basic culvert characteristics cross-sectional size and culvert bed elevation are derived from characteristics of adjacent stream reaches that are similar to the road crossing location (Figure 2-5). Key differences from the stream simulation method are 1) the culvert is placed at a flat slope, and 2) the culvert is sized in relation to the active channel width of the stream, instead of the bankfull width. (Section 3.1 provides definitions and greater detail regarding data collection for channel characteristics.)

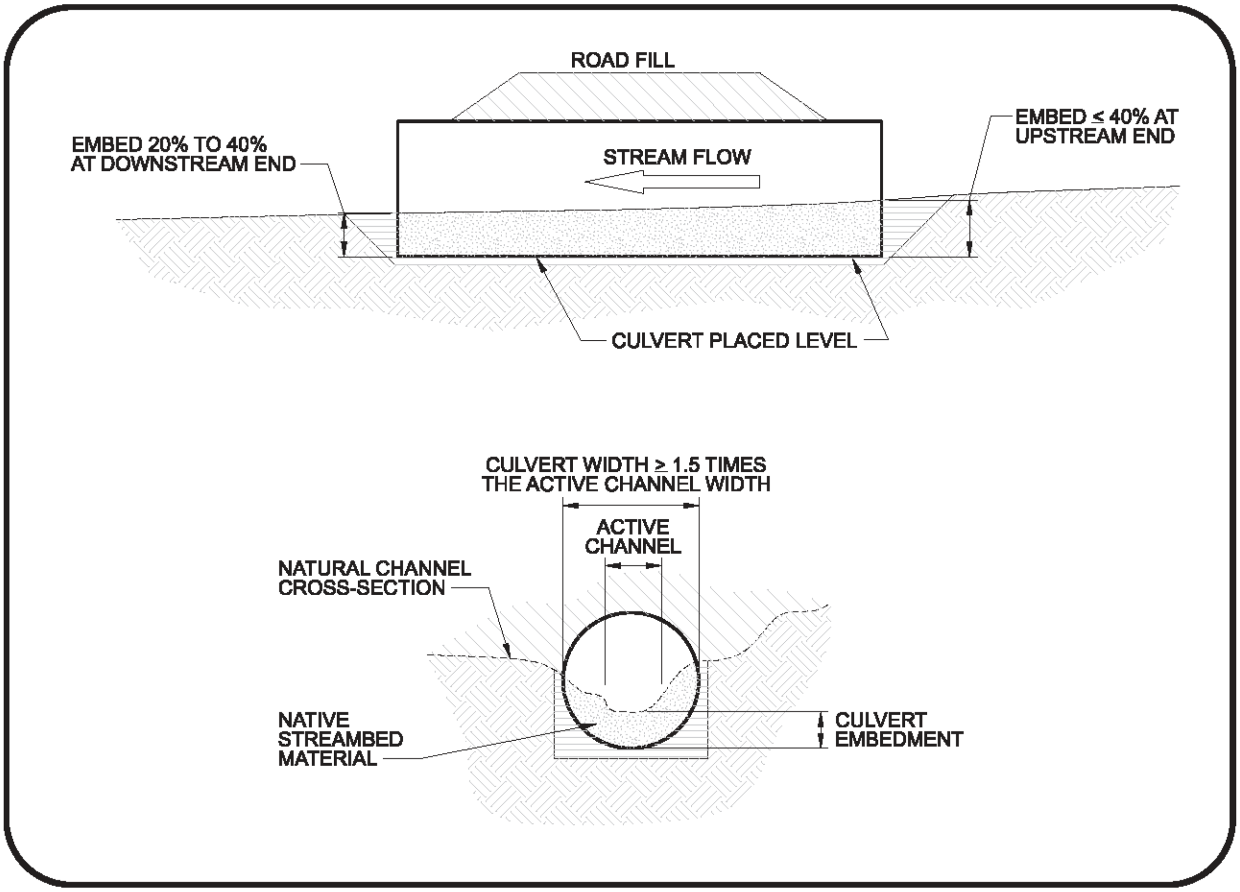


Figure 2-5. Basic sizing and embedment concepts of active channel culverts.

The active channel method can be used only at sites having stream slopes of 3% or less, and in cases where the culvert length will be less than 100 feet. Because it is necessary to embed the culvert, this method should not be used where there is bedrock near the stream surface.

2.2.2.3 Hydraulic Design Culvert

The hydraulic design option for new fish passage culverts is the option most similar to the conventional method of designing culverts for highway cross drainage. However, there is a significant difference between these two methods in the design parameter that plays the key role in determining the culvert configuration. In the conventional approach to hydraulic culvert design, the design parameter that most frequently determines the culvert size is the allowable headwater elevation. In contrast, the fish passage approach to hydraulic culvert design will most frequently size the culvert using a design parameter specifying the maximum average velocity within the culvert barrel.

Adaptation of the conventional culvert hydraulic design method to fish passage applications has led to the development of "fish passage criteria" that must be satisfied by the design. In California, there are five distinct classifications of fish species and life stage groupings that have unique fish passage criteria. Use of the hydraulic design option for culvert design requires that the fish species and life stage classification, commonly referred to as the "target population", be identified so that the appropriate fish passage criteria can be applied. The general premise of the design is to size the culvert so that velocities do not exceed the prolonged swimming capabilities of the target species. Fish that are weaker swimmers than the target population may be unable to pass the crossing.

Because of the requirement that the culvert velocity stay within certain limits, the hydraulic design method generally requires much more analytical effort than the active channel or stream simulation methods. A hydrologic analysis is performed to define the upper and lower flow conditions for fish passage, as well as to determine the peak flood. Hydraulic analyses are performed to evaluate flow characteristics below the culvert outlet, within the culvert barrel, and above the culvert inlet. Multiple iterations are often required to find a successful solution.

Successful application of hydraulic design culverts is generally limited to sites having channel slopes of 3% or less. Project sites located in areas classified as anadromous salmonid spawning areas are not allowed to construct new or replacement culverts using hydraulic design methods. Hydraulic design culverts are likely to be smallest structure that can satisfy fish passage criteria. Because they involve the smallest structural size, the construction costs of hydraulic design culverts are likely to be less than active channel or stream simulation culverts. However, design costs and maintenance costs for hydraulic design culverts are likely to be greater, both on a per site basis and expressed as a percentage of the construction cost.

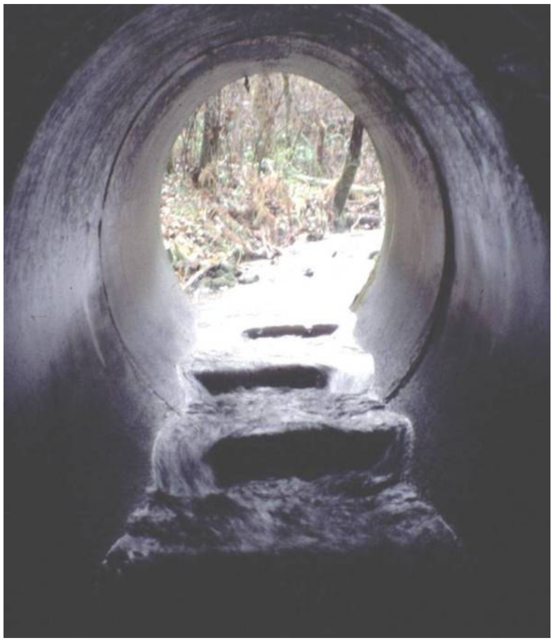


Figure 2-6. Baffles under low-flows

2.2.2.4 Existing Culvert Retrofit

Many existing culverts were developed without consideration of fish passage. Fish passage evaluations conducted by Caltrans and other entities throughout California have identified individual culverts that inhibit fish migration. Some of these culverts are included in prioritized lists of fish passage improvement projects that give consideration to factors such as the amount of spawning habitat that would become available if passage were restored.

The most effective solution for improving fish passage through an existing culvert is to replace it with a new structure designed using relevant fish passage design criteria. However, there are cases in which culvert replacement is difficult to justify, such as when the existing culvert is relatively new and has a significant remaining design life, or when there are plans to replace the culvert 5 or 10 years in the future as part of other planned roadway improvements. In such cases, a decision may be made to improve fish passage through the existing culvert to the extent possible, using culvert retrofit methods included in this manual.

Culvert retrofit projects use the same design methods as hydraulic design culverts, with improvements addressing the needs of specific fish classifications. Retrofit measures typically involve the addition of roughness elements within the barrel of the existing culvert, either through the use of baffles or roughened channels. Since these projects retain the same barrel size as the original design, the risk of debris accumulation and sediment retention upstream of the culvert rarely improves from the original installation, and indeed culvert retrofits have high potential to make debris and maintenance issues even worse. Considerable engineering design effort is required to insure the improvements achieve fish passage improvements without excessive impact to transport of flood waters, debris and bed load.

2.2.3 Grade Control

Basic sizing and embedment concepts of stream simulation culverts. Grade control structures are used in fish passage culvert projects to enhance fish passage conditions in the stream channel upstream and downstream of the culvert, as well as in the culvert itself. The three most common uses of grade control structures involve 1) developing an outlet pool below the culvert that increases water depth and backs water into the culvert barrel, 2) creating a series of small pools or resting areas in steep sections of channel above or below the culvert, and 3) stabilizing the channel streambed near the culvert.

Figure 2-7. Concrete Weirs

Two common types of grade control structures used in stream channels are rock or concrete weirs and roughened channels. Weir types of grade control create a step-pool arrangement in the stream, and they are usually limited to channel slopes of 5% or less. Roughened channels use large rocks to create small pools behind each rock which fish can dart between; roughened channels routinely have slopes as high as 6%, and there are examples of successful installations having slopes 8% and above.

2.2.4 Fishways

Figure 2-8. Concrete fishway

Fishways are defined as a structure that allows fish passage around a natural or man-made barrier, such as at dams or natural waterfalls. As applied to road crossing design, fishways might be used in rare cases where the elevation differential necessary to achieve fish passage is so great that normal in-stream grade control measures will not be feasible. A common example is a culvert that was originally designed strictly for hydraulic performance that has its outlet located high above the stream channel. The drop at the outlet may be so steep that it would require an unacceptably long horizontal distance to accomplish the grade change using the usual maximum slopes of grade control weirs or roughened channels. In such cases, a fishway may provide a solution. A fundamental difference between fishways and grade control measures is that fishways are designed to pass only a portion of the stream flow (usually around 10%), while grade control measures accommodate the entire stream flow. This operational difference adds another level of complexity to the design, and passage performance is dependent on fish being able to distinguish the fishway entrance discharge from the impassable streamflow discharge. Fishways require significant design effort, capital cost, and commitment to facility maintenance, and they are generally considered a “last resort” after all other potential solutions have been explored.

2.3 Design, Construction and Maintenance Considerations

This section discusses several engineering design, construction and maintenance topics that are commonly applied in any road passage design, but which may have special or unusual circumstances when applied to fish passage road crossings. Topics include:

- Limited right of way
- Durability
- Construction schedules
- Constructability
- Best management practices
- Maintenance risks
- Maintenance access
- Monitoring requirements
- Mitigation requirements

2.3.1 Limited Right of Way

In developing the design of a culvert it is always preferable to stay within the existing Right of Way. However for those circumstances where a new installation cannot be maintained within the existing Right of Way it is incumbent upon the designer to identify the need for additional right of way and construction easements as soon as possible due to the time required to secure new right of way.

Culvert retrofitting projects often require additional rights of way to allow the development of hydraulic conditions conducive to fish passage at the downstream and upstream ends of the culvert. Conditions such as scour and channel headcutting can create an impassable condition at the downstream end of a culvert due to excessive vertical differential in the stream channel.

Conditions such as aggradation can lead to impassable conditions in a channel upstream of a culvert inlet as the acceleration of the flow entering the culvert can cause a benching of aggraded sediments in the channel upstream of the inlet.

In both of thee circumstances grade control structures such as weirs can be utilized to maintain a passable hydraulic condition. As these types of structures typically allow for an overall average slope of 5% to be maintained, it is not uncommon to have a need to install several of these structures to step down or up to tie into existing grades. The required spacing of the structures and need for clearances to allow construction often times requires the work for a considerable distance up or downstream of the channel and can create the need for more channel length than is contained within the existing right of way. Channel side slopes can also become problematic as grades within the channel are modified. Often times headcutting and scour holes create side slopes of questionable stability, the grading back of these slopes to a more stable configuration often control the width of the additional right of way needed for a retrofit project. When determining the needs for additional right of way, future access for maintenance purposes should also be considered.

An alternative to weirs is the use of a roughened channel. These channels are created with large riprap and use rock “weirs” to provide hydraulic paths for fish passage with the allowable gradients being dictated by hydraulic criterion. These are still somewhat experimental in nature but typically can be designed to function at steeper slopes than can be achieved with series of weirs leading to less overall area being required for an installation.

2.3.2 Durability

Any Caltrans fish passage road crossing structure must be designed to the same drainage design standards and objectives as described in HDM Chapter 800. These standards usually require a 25 to 50 year service life for any designed installations. In addition to the cross drainage conveyance structure, these standards apply to any fish passage features constructed in the stream channel above and below the crossing, such as grade control structures and fishways. Grade control structures should be constructed of extremely durable materials such as rock and reinforced concrete. Additionally, materials specified for use in a project must be appropriate to the environment in which they are being installed.

2.3.3 Construction Schedules

Construction schedules for fish passage facilities are often confined to certain seasonal periods and time durations when construction is allowed to take place in a stream. These periods, commonly called the construction window, are typically set by regulatory authority on a case by case basis and depend on the types of species present in any given reach of stream. Often times these windows are rigidly maintained and must be adhered to even if it means abandoning a project in a non-finished state.

This information should be obtained early on the design process for consideration of time constraints possibly ruling out certain types of construction. This information should also be clearly spelled out in the specifications and if it is determined that there is a risk of a contractor being unable to complete the work within the specified Construction Window, an abandonment plan should be included in the project.

There will also be instances where a construction window will be granted on a One Time Basis due to the need to minimize the impact of an installation. In this circumstances it is suggested considerable attention be paid to monitoring the contractor's activities and even consider an alternative award process to ensure a highly qualified contractor is doing the work.

2.3.4 Constructability and Estimating

Constructability is always a consideration relative to the cost of a project. In considering the constructability of a project thought must be given to access of equipment and personnel relative to work that must take place in the riparian corridor and that which must occur within any culvert structure. Given that most of the work in any given stream will be subject to time constraints allowed by a permitted Construction Window, thought must be given to the time required to build a given design and the ability to work around any other constraints at a given site.

When estimating the cost of a project consideration must be given to such factors as:

- "Construction Windows" for when the work can take place
- Special restrictions as to what equipment can be used in the actual channel
- Size and production capability of smaller equipment required for work in confined areas such as within culverts
- The amount of labor required for certain construction such as the hand labor in the construction of bedrock channels
- Onsite monitoring, direction and modification required for placement of rock weirs or other boulder features.
- Specialty equipment required for boulder placement and adjustment
- Dewatering and diversion requirements

Much of this can be conveyed to the construction contractor through project plans and specifications where final configurations are clearly delineated, requirements for the final installation clearly defined and any restrictions or constraints required by permits are spelled out.

Certain special functions, such as that associated with the adjustment of boulders forming rock weirs are more typically covered by the specification of the contractor having a certain machine of given capability with operator available for a certain duration.

2.3.5 Permit Conditions

Construction activities for fish passage projects may require permits that place conditions or constraints on work activities. Often times these permit conditions refer to Best Management Practices, which may be established by local, state, or federal entities for various activities. These should be clearly spelled out for the contractor as they can impact cost and the scheduling of certain construction activities. Failure to identify these requirements can lead to fines and stoppage of work and the subsequent activities to establish responsibility can be a long process.

2.3.6 Maintenance Risk

Road crossings located where there is significant movement of large woody debris or accumulation of bed materials should account for the natural transport of these materials past the crossing or accept the need to conduct periodic maintenance to remove accumulations. Natural deposition zones are often created where there is a significant decrease in the channel gradient, such as occurs at the junction of a tributary entering the floodplain of a larger river. Culverts installed in these locations tend to fill with bed materials, and periodic sediment removal may be necessary. Bridges or streambed simulation culverts are the most appropriate design strategy for road crossing locations having high loadings a debris or sediment, as these styles are large enough to allow more natural transport of channel materials.

2.3.7 Maintenance Access

Design should provide means to access the road crossing structure for routine maintenance and monitoring. Locations where access is poor might give greater consideration to selecting a bridge or streambed simulation culvert road crossing design, in order to reduce the maintenance requirements.

2.3.8 Monitoring Requirements

- Structural Integrity – monitoring routinely conducted by Caltrans for facility condition.
- Passage Performance – additional monitoring that may be required by fisheries agencies as condition of design approval. The designer will need to coordinate with the Environmental unit to ascertain that permit conditions and the facility design are coordinated and reflect anticipated performance conditions.

2.3.9 Mitigation Requirements

Depending on the circumstances of project siting, project designs may result in unavoidable impacts to wetlands or other special habitats that support plants or wildlife of special significance. In these cases, it may be necessary to provide mitigation to compensate for the impacts. Mitigation measures might include additional plantings along a stream, improvements to water quality control systems (grass lined swales, small sedimentation basins) or efforts to minimize sedimentation from other sources. These types of improvements may also assist in obtaining additional right-of-way where required, as a landowner will indirectly benefit from these activities.

The designer should work closely with the District Environment Unit to identify protected or sensitive habitat as soon as possible after project startup. Efforts should be made to avoid these areas, or to minimize the direct impact when it is not possible to avoid them altogether.

2.4 Preliminary Selection of Fish Passage Road Crossing Type

With an understanding of the basic issues associated with fish swimming performance, road crossing performance, and the various considerations of design, construction and maintenance, it is usually possible to identify the one or two fish passage road crossing types that are the best candidates for design development. A preliminary screening balances measures that provide the greatest advantage to fish passage, with other measures that may provide significant economic advantage. An underlying premise is the potential requirement of obtaining approval from the State and Federal fisheries agencies, and hence it is necessary to be aware of conditions where certain types a crossings are not allowed. For new and replacement culverts, the key factors contributing to selection of appropriate road crossing type are described below and summarized in Table 2-1.

- **Target Species** – Identification of the target species for which passage is required can be a key factor in deciding type of road crossing should be used. When passage is required for juvenile fish, it is often difficult to achieve compliance with the velocity criteria of the hydraulic design method, except in cases where the channel slope is essentially flat.
- **Length** – Culverts having lengths greater than 100 feet are not appropriate for the active channel design method, since the requirements for vertical embedment generally result in an uneconomical amount of culvert volume being used for non-conveyance purposes.
- **Spawning Areas** – Anadromous salmonid spawning areas are a limited resource protected by the California Department of Fish and Game (CDFG) and the National Oceanic and Atmospheric Administration Fisheries Division (NOAA Fisheries). These agencies specify that proposed road crossings in anadromous salmonid spawning areas must use bridges, the stream simulation design method, or the active channel design method. Areas containing spawning habitat are not allowed to use the hydraulic design method.
- **Slope** – Sites having slopes up to 3% may be able to develop a successful fish passage structure using any of the design methods, especially if the outlet can be backwatered or if the culvert is designed to be embedded. Slopes greater than 3% will probably require used of the stream simulation culvert method or a bridge. Slopes greater than 6% will probably require a bridge.
- **Economics** – The presence of surficial bedrock generally requires use of a bridge or open bottom stream simulation culvert. Hydraulic design culverts in general are significantly lower in cost than stream simulation culverts, which in turn are usually less costly than bridges. The trend is most apparent with smaller streams, less than 10 to 15 feet in width. The cost differential between hydraulic and stream simulation designs is usually less significant where the stream is located in a narrow valley.

Table 2-1. Key parameters for preliminary selection of road crossing type.

Site Parameter	Bridge	Stream Simulation Culvert	Active Channel Culvert	Hydraulic Design Culvert
Anadromous salmonid spawning habitat				Not allowed
Target fish species	All	All	All	Must identify; juveniles difficult
Maximum slope		6%	3%	3%
Maximum length			100 feet	
Minimum width		Greater than bankfull width; 6 ft min.	Greater than 1.5 x active channel width	3 feet

CHAPTER 3

FISH PASSAGE DESIGN ELEMENTS

LIST OF TABLES

LIST OF FIGURES

3 FISH PASSAGE DESIGN ELEMENTS

This chapter describes design elements that are common to all fish passage road crossing types, regardless of the specific design method used to size the conveyance structure. It includes discussion of the following topics:

- data collection and site assessment needs
- hydrologic methods to determine fish passage flows
- basic culvert design for fish passage
- basic and applied hydraulic principles for fish passage road crossing design
- other considerations for the fish passage road crossing design process

In this chapter, emphasis is placed on how the process of designing road crossings for fish passage differs from the design process for traditional, non-fish passage road crossings. Details regarding specific design aspects of the alternative design methods are presented in the remaining chapters of this manual.

Items discussed in this chapter and elsewhere throughout the manual may refer to terms that are not commonly used in roadway engineering. Appendix A provides a glossary of terms used in fish passage road crossing design, defined with the usage common in California. These terms may vary slightly in their precise definition as compared to the usage in other states and countries.

3.1 Site Assessment for Fish Passage Road Crossing Design

The design of any road crossing installation requires the evaluation of a large amount of data. Guidelines for collection of this data can be found in many design guidelines for traditional, non-fish passage culverts, including the FHWA Hydraulic Design Series No. 5, "Hydraulic Design of Highway Culverts", and HDM Chapter 800. This section discusses areas where fish passage analysis requires additional data or more precise data than normally used for culvert design. These areas include:

- channel slope
- channel width
- channel cross sections
- channel roughness
- bed load composition
- channel stability

3.1.1 Channel Slope

Channel slope is a key factor in selecting the most appropriate fish passage road crossing type, and it plays a critical role in subsequent design development. Channels having slopes less than about 3 percent should be able to accommodate road crossings of any type. Channels with slopes in the moderate to high range of 3 percent to 6 percent are not likely to provide successful fish passage conditions for culverts designed through the active channel or hydraulic design methods. Bridges or streambed simulation culverts are the recommended road crossing types for sites having moderate to high channel slopes.

The channel slope should be determined using field data collected at the proposed road crossing site. Data that defines the channel slope may already have been collected during the fish passage field assessment conducted by the Environmental Division. Therefore, check with the District Environmental Unit or the District Hydraulics Unit to obtain a copy of the completed Caltrans Fish Passage Data Collection forms developed for the site. If the forms have not been completed or they lack the channel slope information, use pages 4 and 5 of the Caltrans Fish Passage Data Collection - Second Pass Survey Information to collect the necessary information.

As compared to a survey done to determine channel slope for a non-fish passage road crossing, a survey for a fish passage road crossing requires significantly greater detail in the longitudinal profile along the deepest point (the thalweg) of the stream. Key features of interest for fish passage purposes are presented in Figure 3-1; background information regarding the relevance of these features to fish passage success can be found in Part IX of the California Salmonid Stream Habitat Restoration Manual (CDFG 2003).

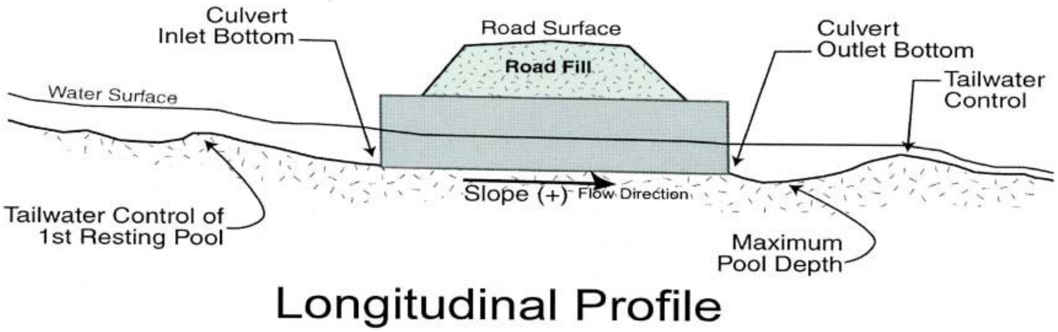


Figure 3-1. Key features of a longitudinal profile of interest for design of fish passage road crossings. (CDFG 2003)

HDS No. 5 indicates the channel slope for a traditional culvert design usually can be obtained using the lowest point from three channel cross-sections: one where the centerline of the proposed roadway intersects the centerline of the stream, and two more taken about 100 feet on either side of the crossing. In contrast, for a fish passage road crossing, it is much more important to determine the slope using data that includes the elevations of the tailwater control points above and below the crossing.

The tailwater control point below the culvert location is an especially important feature for fish passage design, because it is an elevation in the stream that may influence the depth of water in the culvert barrel. The tailwater control point is usually created by one of the following features (CDFG 2003):

- *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.
- *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.
- *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.

In cases where there is evidence of significant changes in channel slope in the vicinity of the culvert, it may be necessary to extend the limits of the longitudinal survey a significant distance upstream and downstream of the crossing location in order to determine an accurate assessment of the average slope conditions. This need may also apply to culvert replacement projects where the channel has been affected by the existing culvert and created a scour hole. With an elongated longitudinal survey, the designer can predict the natural channel slope and elevation at the crossing location by interpolating from unaffected conditions upstream and downstream.

3.1.2 Channel Width

Accurate data regarding channel width is very important for fish passage road crossing design, because channel width values are used directly in the culvert sizing process for the stream simulation and active channel design methods. The active channel width is the width of the channel at the ordinary high water level (OHW), and it delineates the highest water level regularly experienced for a given water body. The active channel width is typically determined in the field and is commonly associated with any of the following:

- the bank elevation at which cleanly scoured substrate of the stream ends and terrestrial vegetation begins (Figure 3-2)
- natural line impressed on the bank
- presence of wood debris.

The bankfull width is defined as the point on a streambank at which overflow into the floodplain begins. The floodplain is a relatively flat area adjacent to the channel constructed by the stream. If the floodplain is absent or poorly defined, other indicators may identify bankfull, such as:

- a change in vegetation, slope or topographic breaks along the bank (Figure 3-2)
- a change in the particle size of bank material
- undercuts in the bank.

The recurrence interval of the active channel flow is slightly more frequent than the 2-year flood and varies from stream to stream. If possible, field determination of bankfull event should be calibrated to known stream flows or to regional relationships between bankfull flow and watershed drainage area.

The values of active channel width and bankfull channel width used for design are determined by averaging the widths of several measurements. It is common to take five or more measurements to determine the average active channel and bankfull widths. The measurements should be taken on straight reaches outside the influence of any existing culvert or structures.

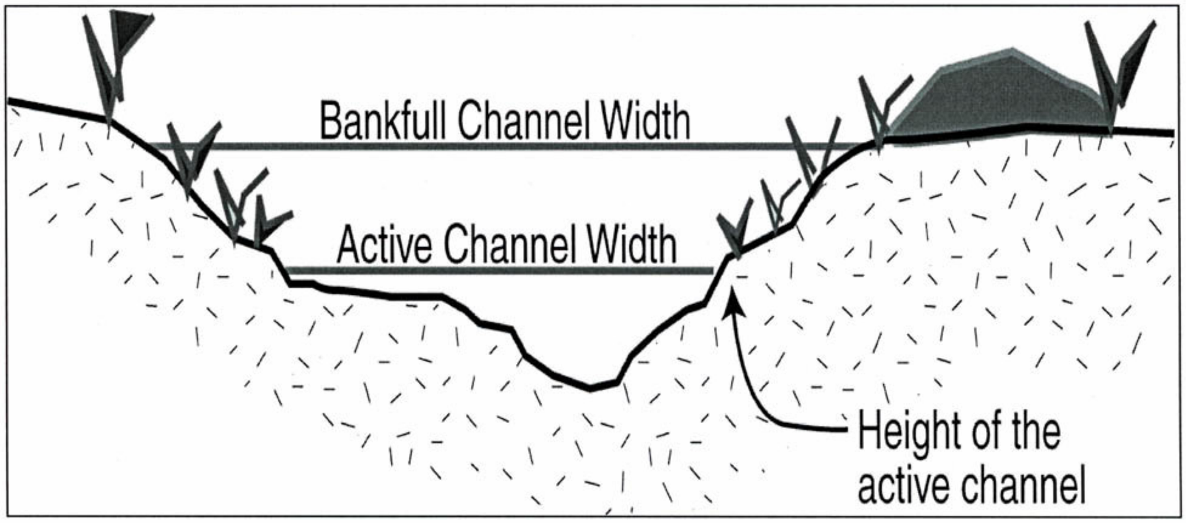


Figure 3-2. Field characteristics for identifying active channel and bankfull channel margins. (CDFG 2003)

Documentation of this data may be facilitated (or may have been previously prepared for planning purposes) using the active channel portion (page 7) of the form for Caltrans Fish Passage Data Collection - Second Pass Survey Information. Additional information describing the identification and measurement of the active channel width can be found in Part IX of the California Salmonid Stream Habitat Restoration Manual (CDFG 2003) at http://www.dfg.ca.gov/nafwb/index.html.

3.1.3 Channel Cross-sections

In Section 3.1.1., it was noted that longitudinal profile data is essential to the accuracy of a fish passage road crossing design. Similarly, good cross-section data is important. Cross-sections should be completed for a minimum of five locations: one each at the tailwater control points upstream and downstream of the crossing location, one each at a distance about 5 feet above and 5 feet below the crossing structure, and one at the structure centerpoint. Cross sections should note the elevation of both the active channel margin and the bankfull channel margin.

Most flow analysis models used for road crossing design and analysis are one-dimensional models. These models are based on equations that assume the streamlines are all parallel to each other. Therefore, cross-sections to be used in channel analysis computations should represent geometry which is "normal" (perpendicular) to stream lines. In cases where the stream is undergoing a significant expansion or contraction in width, a 'dog-leg' in the cross-section will provide more accurate analytical results (Figure 3-3). The breakpoint in the section should occur at the deepest point in the channel.

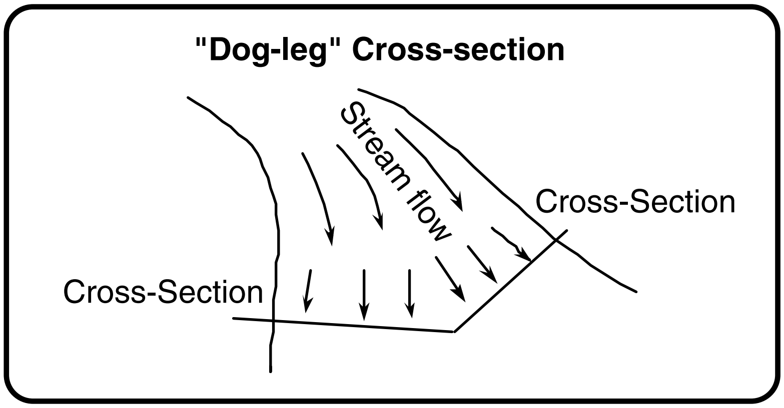


Figure 3-3. Illustration of a dog-leg cross-section.

3.1.4 Channel Roughness

Flow analysis models give considerable weight to the assigned roughness coefficient (Manning's n value) to estimate discharge, velocity and flow depth conditions. Guidelines for traditional culvert design frequently focus only on the roughness characteristics of the culvert material itself. In comparison, fish passage road crossing design will commonly assess flow conditions in the channel above and below the crossing. This will commonly require a more detailed assessment of roughness conditions than occurs with traditional culvert design.

The recommended method for assessing channel roughness subdivides a given cross-section into subsections for varying roughness elements and geometric characteristics. With the section subdivision, a roughness coefficient should be assigned for each change in vegetation and geometry. Figure 3-4 shows an example cross-section in which the channel has been subdivided to simulate flow characteristics reasonably.

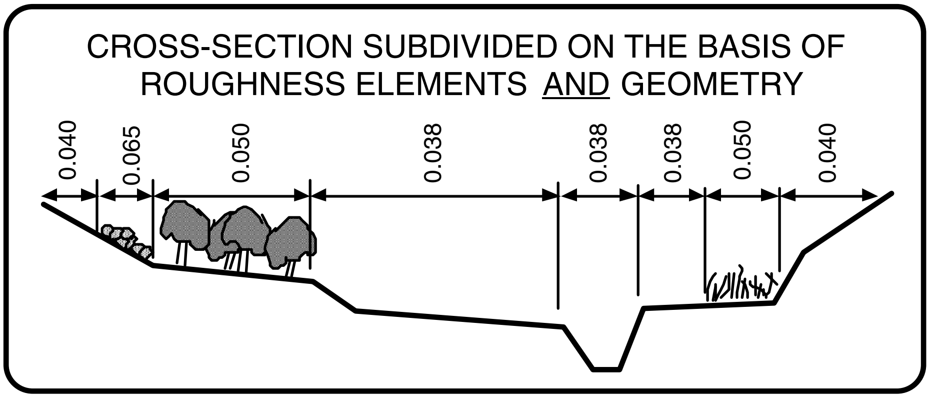


Figure 3-4. Example of subdividing a channel cross section to assign varying channel roughness values.

There are several guide tables that relate suggested roughness values to channel cover and configuration descriptions, including:

- FHWA publication HDS No. 3, "Design Charts for Open-Channel Flow"
- Chow's "Open Channel Hydraulics", which suggest 'normal' values along with a typical range of n-values
- FHWA Report No. FHWA-TS-84-204, "Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains". This report presents a system in which several components contribute an additive amount to a total coefficient. The components considered include stability of channel, bank irregularities, vegetation, alignment of channel, and depth of flow.

Selection of roughness values for pipe or culvert structures may find the following guides especially helpful:

- FHWA Hydraulic Design Series No. 5, "Hydraulic Design of Highway Culverts"
- HDM Table 851.2

3.1.5 Bed Load Composition

Bed load is characterized as sediment (silt, gravel, and rock debris) that moves by sliding or rolling very near the creek or river bed. Related to bed load, suspended load is the portion of the total sediment load that is created from upward momentum during turbulent flows. Because flow conditions can vary, particles comprising bed load may become suspended and later roll along the bed once again as part of the bed load. This means that the distinction and identification of bed load versus suspended load can be nebulous.

Given the variability in bed load composition, a project site must be investigated for potential types and sizes. A bed load consisting of just silt and gravel can cause capacity problems in any culvert. If baffles are introduced into an existing culvert, capacity can be further compromised due to increases accumulation of this bed load. Also, the silt and gravel can cause abrasion of concrete and steel baffles over time, leading them to failure. Of course, this problem of damage is exasperated with rock and large organic debris. Depending on flow conditions, larger rocks and woody debris can be carried as bed load, which could level a series of baffles. If this occurred, not only would fish passage be affected, but the rocks and debris can be lodged inside a culvert and create objectionable backwaters.

Therefore, bed load is an important consideration in developing a sound fish passage design. For both rehabilitated and replacement culverts, excessive bed load can cause capacity problems and structural damage. With this possibility of high bed load volume and/or size, fish passage design strategy may change, for instance, a culvert may require being replaced instead of being rehabilitated with baffles solely because of bed load concerns. A new culvert could be sized properly to address fish movement, as well as convey the higher flood flows with potential bed load deposition.

3.1.6 Stream Stability

Fish passage road crossing project analysis should include a geomorphic processes assessment to ensure the long term viability of a structure. FHWA's "Stream Stability at Highway Structures (HEC 20)" outlines a detailed process for assessing stream stability. This is typically outside the requirements of a traditional culvert project. However, since strategies for fish passage road crossing design are tied closely to emulating stream conditions, the following qualitative assessments should be made prior to the design process.

- Land Use Changes – Large scale changes to a watershed can have dramatic impacts to the sediment yield of the watershed. Examples of large scale changes can be the result of logging activities, forest fires, dams, or development activities. Changes to the hydrology of a watershed will affect sediment yield and can impact both the vertical and lateral stability of a stream. Because of possible impacts to stream stability, it is important to develop a "long profile," as described in Chapter 5, in order to identify channel forming influences.
- Lateral Stability – Lateral stability of a stream can impact a crossing structure by increasing bank erosion. Bank failure can undermine structural components and road prisms and can block flow through the culvert, significantly reducing the conveyance capacity. Lateral instability can be the result of natural processes but can also be the result of a culvert that is not aligned properly. A qualitative assessment should be conducted early in the process to for past or anticipated changes in the stream alignment. Historical aerial photos and interviews with local residents are good tools for this qualitative assessment. In cases showing high risk of channel migration, selection of a bridge road crossing may provide the best means to accommodate the risk.
- Vertical Stability – Vertical instabilities refer to a stream going through and aggradation (sediment accumulation) or degradation (sediment scour). A channel experiencing aggradation is typically expected to widen ultimately resulting in shallower flow depths. Aggradation can also reduce the effective flow area beneath a crossing structure. A channel going through degradation may eventually threaten structural components of a crossing structure. A common example of a degradation process is the presence of a headcut. Headcuts can look like tiny water falls and progress upstream. If unaccounted for a headcut may progress upstream and create a perched outfall. Even worse, if a bottomless culvert is installed, a headcut can progress through the culvert, threatening both the bottomless culvert and upstream habitat.

If stream instabilities are identified during this qualitative assessment, a more thorough evaluation may be required. Ultimately, engineered stabilizing measures may be required to ensure long-term functionality of the fish passage structure.

The replacement of existing culverts may result in temporary channel instability:

- In cases involving replacement of an undersized culvert, an evaluation will be necessary regarding the potential for upstream bed instability following replacement. The upstream instability potential is created due to the fact that, at high flows, undersized culverts create a backwater, which increases the probability that bed material will be deposited in the channel upstream. With elimination of the backwater condition, the upstream channel profile will be expected to lower over time. Channel bed and bank protection measures may be required.
- Outlet velocities from traditional road crossings can be potentially erosive. Of particular concern to fish passage is the potential for creation of a scour hole immediately downstream from the road crossing. In severe cases, a road crossing may become perched above the stream bed due to these erosive forces. Design processes are presented in this manual which provide rehabilitation of these degraded conditions and protect against future degradation. Sites with banks or beds susceptible to erosion may require special consideration. Indications of poor channel stability may suggest the used of a bridge as the road crossing type.

3.2 Hydrology for Road Crossing Design

California exhibits a very diverse environment in terms of hydrologic characteristics, ranging from extremely arid to near rain-forest conditions. This diversity presents a challenge to the design of highway drainage systems. Traditional culvert design methods focus on peak flow conditions that occur on an infrequent basis, say, every 25 or 100 years. Fish passage road crossings, on the other hand, also emphasize evaluation of flow conditions that occur every year when the target populations are present.

3.2.1 Overview of Hydrologic Methods

This section presents three methods that can be used to calculate high and low design flows for fish passage road crossings. Design flows can be determined using 1) local stream gage data to estimate annual exceedance factors; 2) USGS regional regression equations; and 3) the Natural Resources Conservation Service (NRCS) Urban Hydrology for Small Watersheds Technical Release 55 (TR-55). A detailed description and example calculation for a fourth method, the Rational Method, can be found in the Caltrans Highway Drainage Design course materials.

A general discussion on the hydrologic process is not presented in this section because numerous textbooks discuss the hydrologic process in detail. As a refresher, a good discussion on hydrology is presented in Chapter 810 of the Caltrans Highway Design Manual (HDM). Additional references that may be useful include:

- The Natural Resources Conservation Service, Urban Hydrology for Small Watersheds Technical Release 55 (TR-55). This document can be found at the U.S. Department of Agriculture’s website http://www.info.usda.gov/CED/
- Rantz, S.E., 1969, Mean annual precipitation in the California region: U.S. Geological Survey Open-File Map (Reprinted 1972, 1975).
- Miller, J.F., Frederick, R.H., and Tracey, R.J., 1973, Precipitation – Frequency Atlas of the Western United States, Volume XI – California, NOAA.

3.2.2 Selecting the Appropriate Method

In most instances, watershed characteristics control which hydrologic method is used for analysis. Contributing to the method selection is the available information for the watershed.

For instance, it is unlikely that a stream gage would be located at or even near the stream crossing under consideration. Gage data is typically recorded on large streams where stream crossings have already been designed and constructed.

Table 3-1 below provides guidance on which method is appropriate to use based on the watershed characteristics and available information.

Table 3-1. Guidance on selection of hydrologic methods.

METHOD	ASSUMPTIONS	DATA NEEDED
Exceedance**	▪ At least five years of recorded daily average flows, and preferably more than ten-years (do not need to be consecutive years) ▪ Drainage area less than 129.5 km^2 (50 mi^2) (preferably less than 25.9 km^2 (10 mi^2)) ▪ Unregulated flows (no upstream impoundment or water diversions)	▪Gage Data from nearby stream ▪Drainage area of both watersheds
Regional Regression*	▪ Catchment area limit varies by region ▪ Ungaged channel ▪ Basin not located on floor of Sacramento and San Joaquin Valleys ▪ Peak discharge value for flow under natural conditions unaffected by urban development and little or no regulation by lakes or reservoirs	▪Drainage area ▪Mean annual precipitation ▪Altitude Index
TR-55*	▪ Small or midsize catchment (< 8 km^2 (< 3.1 mi^2)) ▪ Concentration time range from 0.1 to 10-hour (tabular hydrograph method limit < 2 hour) ▪ Runoff is overland and channel flow ▪ Simplified channel routing ▪ Negligible channel storage	▪24-hour rainfall ▪Rainfall distribution ▪Runoff curve number ▪Concentration time ▪Drainage area

*Refer to the Caltrans Highway Design Manual for further information

**Refer to the California Salmonid Stream Habitat Restoration Manual for further information

CDFG and NOAA Fisheries recommend that if stream gage data is available, the exceedance flow method is the preferred option to calculate the fish passage flows (CDFG 2002, NOAA-SWR 2001). Table 3-2 shows the percentages of the annual exceedance flow recommended to be used for each of five classifications of fish species listed in the criteria. If stream gage data is not available, then the discharge for the 2-year flow should be calculated using either the regional regression or TR-55 methods, and a percentage of the 2-year is used for high fish passage design flow, as shown in Table 3-2.

Table 3-2. Factors for determining high fish passage flow rate. (CDFG 2002)

Species/Life Stage	Percentage of Annual Exceedance Flow	Percentage of 2-year Recurrence Interval
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%

In determining lower fish passage flow, again, if stream gage data is available, the exceedance flow method should be used to calculate the flow, applying a percentage factor to the average annual exceedance flow as shown in Table 3-3. If gage data is not available, then the alternate minimum flow should be used.

Table 3-3. Factors for determining low fish passage flow rate. (CDFG 2002)

Species/Life Stage	Exceedance Flow	Default Minimum Flow (ft³/s)
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

The following sections provide more information for determining the high and low fish passage flow rates using each of the exceedance flow, regional regression, and TR-55 methods.

3.2.3 Exceedance Flow Rates using Gage Data

Figure 3-5 shows a typical distribution of flow data representing an average annual flow. The figure points out three exceedance flow rates and notes how they frequently relate to fish passage concerns. The 95% exceedance flow, for example, is the flow rate which is exceeded 95% of the time on an annual basis; the lowest 5% of flow rates below this threshold may be so low as to result in flow depths that are too shallow for fish to swim in. It is important to note that these **average annual exceedance flows rates are not to be confused with exceedance flow probabilities**, which involve statistical analysis using **annual peak flows**.

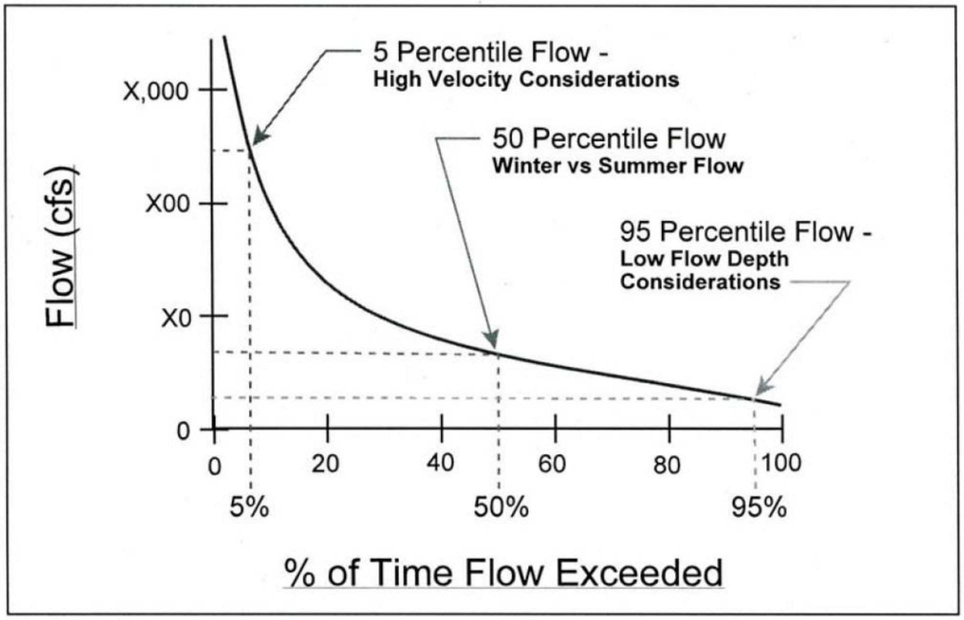


Figure 3-6. A typical flow duration curve for average annual flow data. (CDFG 2003)

Identifying exceedance flows requires obtaining average daily stream flow data. If the stream flow rate is known based on gage data collected for that stream, then the crossing should be sized based on that data. Often times, a crossing is to be designed on a stream where gage data is not available. However, if a nearby stream has gage data and the stream where the crossing is to be designed has similar watershed characteristics, then the available gage data can be adjusted and used for design. District Hydraulics should be contacted to assess comparable watershed characteristics. The method presented below describes how to adjust nearby stream gage data to estimate the peak stream flow rate. The following method was abstracted from Part IX of the California Salmonid Stream Habitat Restoration Manual (CDFG 2003). For more information please reference that Manual.

1. Flow records for nearby streams should be acquired from the USGS and/or the California Department of Water Resources. The information must 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 (130 km^2), and preferably less than 10 square miles (26 km^2)

- 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.

2. 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 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:

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

3. Round values to the nearest whole number. The flows corresponding to those ranks are the 50 percent and 1 percent exceedance flows for the gaged stream.
4. To apply these flows to the ungaged stream, multiply the flows obtained in the above step, $Q_{50\%}$ and $Q_{1\%}$, by the ratio of the gaged 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.

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.

Other things to consider when using gage data includes:

- This method is limited in a number of ways, one of which is the fact that it only considers a narrow time frame in the life time of the stream crossing. For example, stream flow data may have only been collected during a drought. This would result in sizing a fish passage that is too small. Inversely, the fish passage could be sized too large if the gage data was taken during years of high rainfall.

- A second limitation of this method is the transfer of stream flow data from one watershed to another. Although the watersheds may be near each other, there will still be differences between the two. Cover, detention, soil type, slope, and even rainfall could vary between the two watersheds. Careful inspection of the two watersheds should be conducted to determine if it is reasonable to transfer the data.

An example calculation of fish passage flow rates using the exceedance flow rate method is provided in Appendix E.

3.2.4 Regional Regression Equations

Regional Regression equations have been developed for the state of California to estimate the peak discharge for a watershed for recurrence intervals of 2, 5, 10, 25, 50, and 100 years. The state is divided into six hydrologic regions and each region has specifically derived equations unique to that region. A map showing the different regions is shown in Figure 3-7. The parameters for the equations include drainage area (A), in square miles; mean annual precipitation (P), in inches; and an altitude index (H), which is the average altitudes in thousands of feet at the points along the main channel at 10 percent, and 85 percent of the distances from the site to the divide (USGS 1993).

Area and altitude index are determined from a topographic map, and mean annual precipitation is determined from a map in Rantz (1969). The USGS provides non-proprietary software that may be used to calculate the flows using the regression equations. The software is available at their website, www.usgs.gov, and is called the National Flood Frequency Program (NFF). Table 3-x shows the equations used to calculate the design flow rates for the six hydrologic regions in California.

Figure 3-7. Flood-frequency region map for California. (USGS 2004)

Table 3-4. Regional regression equations for the six regions of California. (USGS 1993)

North Coast Region

$Q_2 = 3.52A^{0.90}P^{0.89}H^{-0.47}$

$Q_5 = 5.04A^{0.89}P^{0.91}H^{-0.35}$

$Q_{10} = 6.21A^{0.88}P^{0.93}H^{-0.27}$

$Q_{25} = 7.64A^{0.87}P^{0.94}H^{-0.17}$

$Q_{50} = 8.57A^{0.87}P^{0.96}H^{-0.08}$

$Q_{100} = 9.23A^{0.87}P^{0.97}$

In the North Coast region, use a minimum value of 1.0 for the altitude index (H).

Northeast Region

$Q_2 = 22A^{0.40}$

$Q_5 = 46A^{0.45}$

$Q_{10} = 61A^{0.49}$

$Q_{25} = 84A^{0.54}$

$Q_{50} = 103A^{0.57}$

$Q_{100} = 125A^{0.59}$

Maximum drainage basin is 40 km^2 for the Northeast region.

Sierra Region

$Q_2 = 0.24A^{0.88}P^{1.58}H^{-0.80}$

$Q_5 = 1.20A^{0.82}P^{1.37}H^{-0.64}$

$Q_{10} = 2.63A^{0.80}P^{1.25}H^{-0.58}$

$Q_{25} = 6.55A^{0.79}P^{1.12}H^{-0.52}$

$Q_{50} = 10.4A^{0.89}P^{1.03}H^{-0.41}$

$Q_{100} = 15.7A^{0.77}P^{1.02}H^{-0.43}$

Central Coast Region

$Q_2 = 0.0061A^{0.92}P^{2.54}H^{-1.10}$

$Q_5 = 0.118A^{0.91}P^{1.95}H^{-0.79}$

$Q_{10} = 0.583A^{0.90}P^{1.61}H^{-0.64}$

$Q_{25} = 2.91A^{0.89}P^{1.26}H^{-0.50}$

$Q_{50} = 8.20A^{0.89}P^{1.03}H^{-0.41}$

$Q_{100} = 19.7A^{0.88}P^{0.84}H^{-0.33}$

South Coast Region

$Q_2 = 0.14A^{0.72}P^{1.62}$

$Q_5 = 0.40A^{0.77}P^{1.69}$

$Q_{10} = 0.63A^{0.79}P^{1.75}$

$Q_{25} = 1.10A^{0.81}P^{1.81}$

$Q_{50} = 1.50A^{0.82}P^{1.85}$

$Q_{100} = 1.95A^{0.83}P^{1.87}$

South Lahontan-Colorado Desert Region

$Q_2 = 7.3A^{0.30}$

$Q_5 = 53A^{0.44}$

$Q_{10} = 150A^{0.53}$

$Q_{25} = 410A^{0.63}$

$Q_{50} = 700A^{0.68}$

$Q_{100} = 1080A^{0.71}$

Maximum drainage basin is 40 km^2 for the South Lahontan-Colorado Desert regions.

Where:
A = Drainage area, mi^2
P = Precipitation, inches
H = altitude index

Other things to consider when using the Regional Regression equations include:

- Ground conditions play a significant role in the peak flow rate of a stream. Bare ground with little infiltration and a steep slope will result in a higher peak flow rate because water will reach the point of interest faster than the same area that has lush ground cover, absorbent soils, and a flat slope.
- Drainage area and altitude index are easily calculated from a topographic map. Mean annual precipitation, on the other hand, is a general estimate for an area and not specific to a particular watershed. Rainfall amounts collected at various gages throughout a region are extrapolated over that region to get isohyets, or lines of equal rainfall. Mean annual precipitation for a region is based on these isohyets that are drawn from information collected over a number of years. A number of publications can be consulted for further discussion on the derivation and applicability of mean annual precipitation.
- Inherent in the regression equations are errors of estimate. According to the USGS, the standard error of estimate for the California regression equations ranges from 60 to 100 percent.
- Regression equations should be used when little is known about the watershed. If sufficient information about the watershed is available, use of the other methods described in this section is recommended for analysis.
- For more information of the development and use of regression equations refer to the U.S. Geological Survey Water-Resources Investigations Report 94-4002.

An example calculation of fish passage flow rates using the regional regression equation method is provided in Appendix E.

3.2.5 TR-55 Method

The TR-55 method presents simplified procedures for estimating runoff and peak discharges in small watersheds. The method is geared towards estimating runoff in urban and urbanizing watersheds; however, the procedures apply to any small watershed in which certain limitations are met.

The method begins with the assumption that rainfall is uniformly imposed on the watershed over a specified time distribution. TR-55 includes four regional rainfall time distributions for a 24-hour period. The rainfall distributions were designed to contain the intensity of any duration of rainfall for the frequency of the event chosen.

Mass rainfall is converted to mass runoff by using a runoff curve number (CN). CN is based on soils, interception, and surface storage. Runoff is then transformed into a hydrograph by using unit hydrograph theory and routing procedures that depend on runoff travel time through segments of the watershed (TR-55 1986).

Three steps are performed to calculate the peak discharge of a drainage area. The three steps are to calculate the Q in inches, calculate the time of concentration in hours, and then calculate the peak discharge. The three steps are described in the following sub-sections.

The TR-55 method is used for a single hydrologically homogenous watershed. If the watershed is heterogeneous, made up of several homogenous subareas, then the TR-55 publication should be consulted. TR-55 also addresses how to use detention basins to reduce the peak flow rate of an urbanizing watershed.

An example calculation of fish passage flow rates using the TR-55 method is provided in Appendix E.

3.3 Basic Hydraulics for Fish Passage Road Crossing Design

Basic hydraulic principles of open channel flow must be understood for application in fish passage road crossing design, as well as for other aspects of highway drainage. Flows in the natural stream channels above and below a road crossing are governed by the principles of open channel flow. Flows through culverts and under bridges also are governed by these basic principles, as long as there is a free surface.

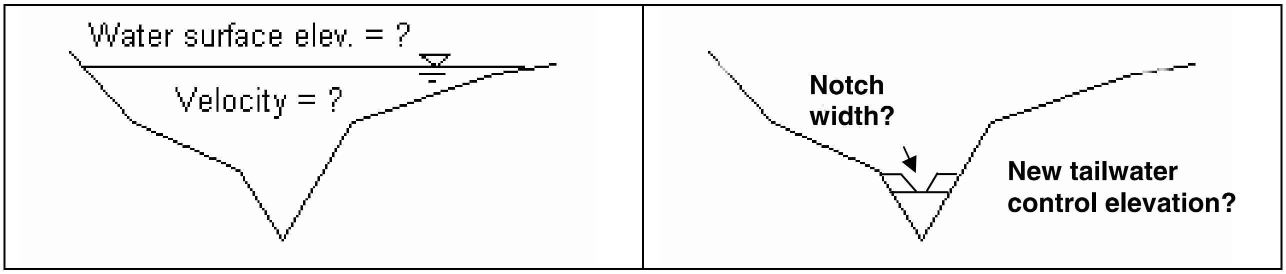
The following materials are adapted largely from a Caltrans Highway Drainage Design Course developed as an aid for the design of traditional road crossings where fish passage is not an issue. Materials have been added or deleted as appropriate to make them relevant to fish passage road crossings. There are numerous useful published references that can provide additional background on the principles of open channel flow. Some of these references are:

- Caltrans Highway Design Manual, Chapter 800,
- "Open Channel Hydraulics" by Ven Te Chow,
- "Handbook of Hydraulics" by Brater and King,
- FHWA Hydraulic Design Series No. 4, "Design of Roadside Channels",
- FHWA Hydraulic Design Series No. 5, "Hydraulic Design of Highway Culverts",

Principles of open channel flow are applied to fish passage road crossings from the perspective of both analysis and design. Channels usually are analyzed for the purpose of determining the characteristics of the stream flow. In the analysis of existing channels, the designer is working with geometric parameters that are fixed. Analysis is performed using the fixed stream channel parameters to determine the relationship between stream discharge, depth or water surface elevation, and flow velocities.

When designing an open channel feature, on the other hand, the designer controls many of the geometric parameters of the feature. Design of the feature typically involves a trial and error process, where a trial configuration is assumed and an analysis is made to affirm or negate the assumed configuration. This process is repeated until the feature design is shown to satisfy the specified design criteria.

The design of fish passage road crossing facilities often involves analysis of the existing stream channel. Depending on the conditions of the project site, it may also be necessary to design open channel features to enhance fish passage conditions. Schematically, the contrasts between analysis and design of channels are illustrated by Figure 3-8.



Analysis	**Design**
Given: Discharge (usually), channel geometry, slope, roughness characteristics. Find: Velocity and discharge vs. water surface elevation relationship.	Given: Discharge, certain design constraints (min. depth, max. velocity, range of slopes). Find: Optimum geometry for fish passage enhancements

Figure 3-8. Contrasting elements of open channel analysis versus open channel design.

3.3.1 Types of Flow

Open channel flow frequently classifies flow according to changes in flow depth with respect to time and space.

Steady flow is defined as flow in which there is no variation of depth of flow with respect to time. This definition is extended to mean that there is no variation in the discharge with respect to time. The opposite of steady flow is *unsteady flow*, which often is referred to as dynamic flow. Most of the common channel analysis procedures assume steady flow.

Uniform flow is used to indicate the depth of flow is the same at every section of the channel. The opposite of uniform flow is *varied flow,* in which the depth of flow is not the same at every section of the channel. *Rapidly varied flow* is classified by a sudden change in water depth over a comparatively short distance. This type of flow frequently occurs as the result of significant changes in channel configuration, such as occurs with flow through orifice, flow over weirs, or sudden changes in channel slope. Varied flow that changes depth over longer distances is classified as *gradually varied flow*.

Steady, uniform flow is the assumed condition for many open channel analyses. The simplest procedures for determining flow characteristics use one-dimensional uniform flow models. These models assume the velocity vectors within a channel are all more or less parallel with one another; with no horizontal or vertical transfer of flow taking place. For standard, non-fish passage culvert design concerned primarily with headwater depth and outlet velocity, these one-dimensional flow models usually provide the level of detail necessary for analysis.

Culvert and road crossing designs frequently add features such as tailwater control weirs and baffles that are likely to result in rapidly varied flow. In cases where the hydraulic conditions of water depth and velocity must be assessed in the vicinity of such structures, it may be advisable to refine channel and backwater analyses through the use of two-dimensional models.

3.3.2 Flow Regimes

The specific energy (E) of a channel section may be represented by the sum of the flow depth and the velocity head associated with that flow depth. In equation form,

$$E = y + \frac{v^2}{2g} \qquad \text{Equation 3-1}$$

where: E = specific energy (m),
y = depth of flow (m),
V = velocity of flow (m/s),
g = acceleration due to gravity; 9.81 (m/s^2)

For a given specific energy, there are two possible depths at which the open channel flow may occur. One depth occurs at a low stage in the supercritical flow regime, and the other occurs at a high stage in the subcritical flow regime. At the point where specific energy is a minimum, the flow is at a critical state of flow, and hence the associated depth is termed the critical depth (d_c). The specific energy diagram for open channel flow shown as Figure 3-9 illustrates the relations between supercritical, critical, and subcritical flow.

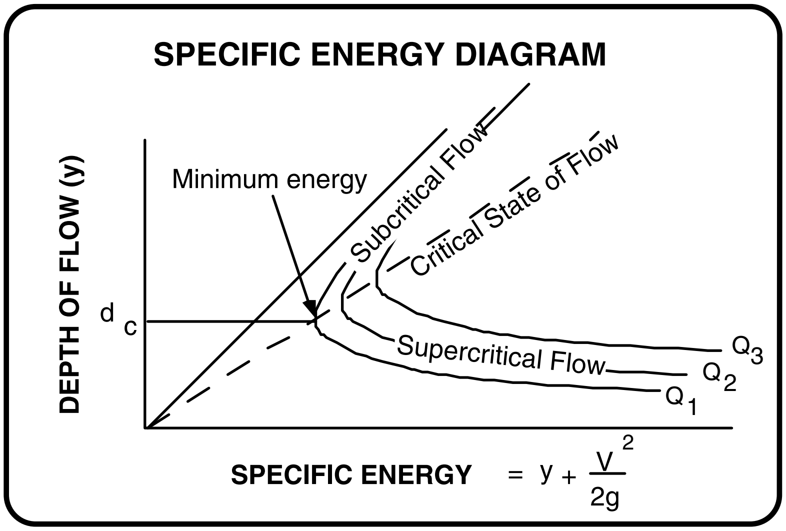


Figure 3-9. The specific energy diagram for open channel flow.

The significance of the specific energy diagram to fish passage is to note that the conditions of subcritical flow are generally significantly more favorable to fish passage than supercritical flow. For a given energy level, the subcritical flow condition has a greater flow depth and a lower velocity than its supercritical counterpart. Measures which promote the flow of a stream or road crossing structure to operate under subcritical flow will promote fish passage.

The flow regime occurring in natural stream channels is largely dependent on the slope of the channel. On a much more localized level, the slope of a road crossing structure will also factor into the flow regime.

- **Supercritical flow** - In mountainous or hilly terrain, the stream bed is often very steep and will result in supercritical flow. Similarly, in the localized realm of a road crossing structure, a culvert installed with a steep slope will be prone to supercritical flow. Supercritical flow is also called steep slope regime.
- **Subcritical flow** - Subcritical flow commonly occurs when the stream bed slope is relatively flat; therefore it appears in foothills, alluvial areas, and most areas outside of mountains. Culverts place at a mild slope will commonly exhibit subcritical flow as well. Subcritical flow is also called mild slope regime.
- **Critical flow** - For a given discharge and channel geometry, there is one depth of flow that will result in minimum energy required to maintain the given discharge. The depth usually is referred to as critical depth (d_c). Critical flow is the threshold between supercritical and subcritical flow, and it commonly occurs where there are sudden changes in channel configuration, such as at weirs or perched culvert outfalls.

Determination of whether a stream is flowing in the supercritical, subcritical, or critical flow regime can be determined by calculation of the Froude number:

$$Fr = \frac{Q^2 T}{g A^3} \qquad \text{Equation 3-2}$$

where: Q = discharge (m^3/s),
T = top width of free surface (m),
g = gravitational acceleration, and
A = cross-sectional area of flow (m^2).

and: Fr = 1 is critical flow,
Fr > 1 is supercritical flow, and
Fr < 1 = subcritical flow,

3.3.3 Average Velocity

In any channel section, the discharge Q is related to the cross-sectional area through the equation,

$$Q = VA \qquad \text{Equation 3-3}$$

where: Q = rate of discharge in cubic meters per second (m^3/s),
V = average velocity of the water in meters per second (m/s), and
A = cross-sectional area normal to the direction of flow in the channel or conduit, in square meters (m^2).

The average velocity V is a defined entity; that is, V is simply defined as the actual discharge Q divided by the actual cross-sectional area A. Because open channel flow involves both a free surface and friction along the channel perimeter, the actual velocities in a channel are not uniformly distributed in the channel section. The maximum velocity usually occurs slightly below the free surface, while the minimum velocities are typically at the boundary layer of channel flow. Figure 3-10 illustrates the typical velocity distribution in channels of various cross-sectional shape. Velocity distribution will also be affected by factors such as the presence of bends and the degree of roughness at the channel perimeter.

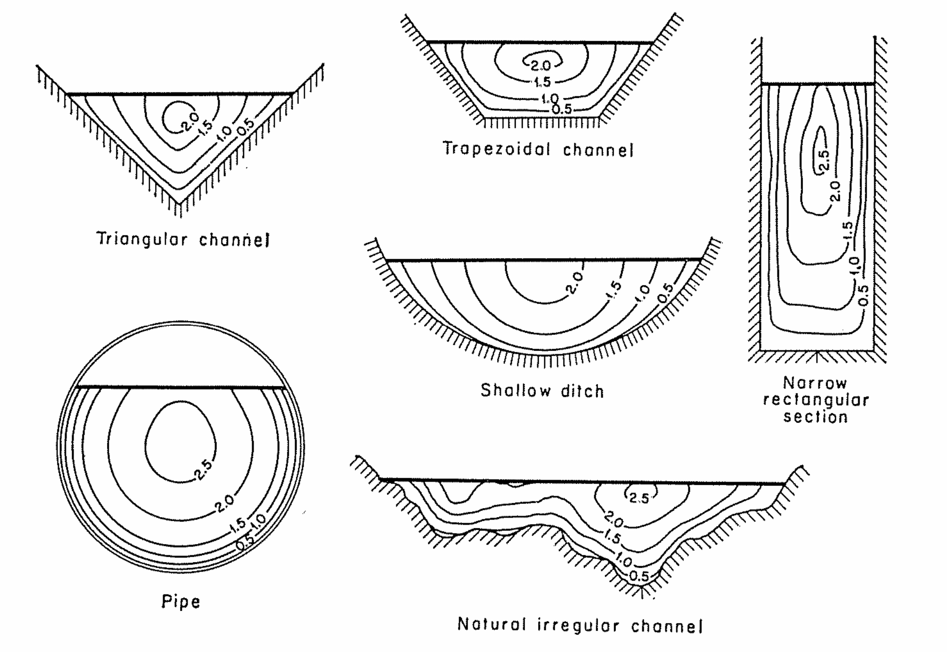


Figure 3-10. Typical velocity distributions in various channel sections, noting lines of equal velocity. (Chow 1958)

Fish passage criteria for road crossings often establish a maximum velocity that should not be exceeded during fish passage flows. These criteria are presented in terms of the average velocity within the channel, as calculated by Manning's equation or other flow analysis models. It should be noted there is an inherent safety factor in designing to the average velocity, since actual flow velocities at the boundary layer of the channel are likely to be lower than the average velocity.

3.3.4 Manning's Equation

Manning's equation is a widely-used uniform flow formula for determining flow characteristics on open channels. The basic form of Manning's equation is:

$$V = \left[\frac{R^{2/3}}{n}\right] S^{1/2}$$ Equation 3-4

where: V = velocity of flow (m/s),
R = hydraulic radius (m) = cross-sectional area of flow A (m^2) divided by the wetted perimeter P (m),
S = longitudinal slope of the water surface (m/m),
n = the roughness coefficient (dimensionless); (Manning's n).

Merging the original Manning's equation with the continuity equation relationship of Q = VA yields another popular form of the Manning's equation:

$$Q = \left[\frac{A\,R^{2/3}}{n} \right] S^{1/2} \qquad \text{Equation 3-5}$$

In either form, it is worth noting that the velocity of discharge is inversely related to the roughness coefficient, commonly referred to as the Manning's n value. An example of the significance of this relationship is seen in the fact that, for a channel of given slope and geometry, the velocity will be cut in half if the roughness coefficient is doubled. Very generally, a channel lined with grass and weeds, with little or no brush ($n = 0.30$ to 0.35) would have a velocity about twice as fast the same discharge flowing through the same channel lined entirely with dense willows ($n = 0.060$ to 0.080). Measures that increase roughness within a channel used for fish passage can have a tremendous benefit in reducing velocities to levels the fish can negotiate.

3.3.5 Normal Depth Calculations

Manning's equation can be used to evaluate normal flow conditions in an open channel. Normal flow assumes that the water is neither accelerating or decelerating, and that it has constant velocity and depth. While this is a gross simplification of natural stream conditions, the calculation of normal depth provides a starting point for determining the actual depth for a given set of stream conditions. It can be used to estimate the depth of water at the tailwater control point under various flows, such as the low and high fish passage flows.

The difficulty of calculating the normal depth for a given discharge is that both the area A and the hydraulic radius R are determined using the unknown depth. One common solution is to assume several values of depth and plot the resulting discharge using Manning's equation. This type of graphical output is commonly called a stage discharge curve. The graph can subsequently be used to find the expected normal water depth for any selected discharge. An example is described below.

1. A cross-section of the tailwater control point is developed, noting the roughness coefficients for the various geographic sections. (Figure 3-11.)
2. A water elevation and associated water depth is assumed, and the discharge is calculated using Manning's equation. As intermediate steps, values for area A, wetted perimeter P, and hydraulic radius R are approximated using properties of triangles applied to each geometric section. Where the flow area crosses more than one roughness element, a composite roughness value is developed based on the weighted value of roughness in relation to the wetted perimeter (see section 3.4.x). The slope assumed for the calculation is the slope of the channel. [It may be helpful to provide a table here that shows the calculations and results for A, P, R and n.]
3. A tabulation and/or plot is made showing the computed discharges versus corresponding assumed water surface elevations. (Figure 3-12).
4. From the tabulation or plot, an approximate water surface elevation can be derived for any discharge desired. Since there is an assumption of uniform flow for this method, the associated water depth can be transferred up or down the stream to other locations not influenced by other hydraulic control points.

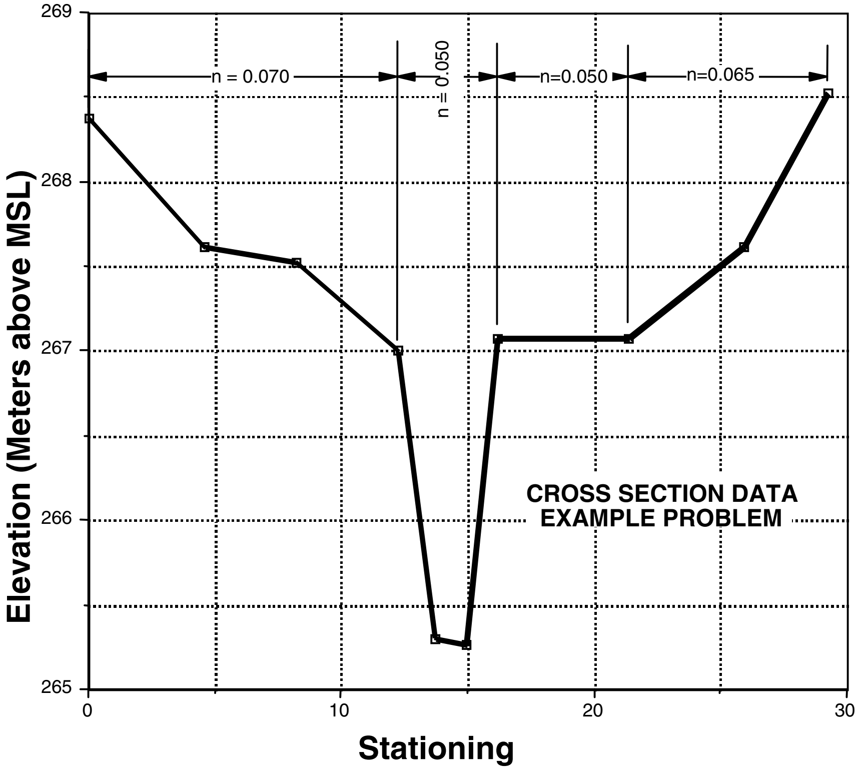


Figure 3-11. Example cross section data showing assigned roughness elements.

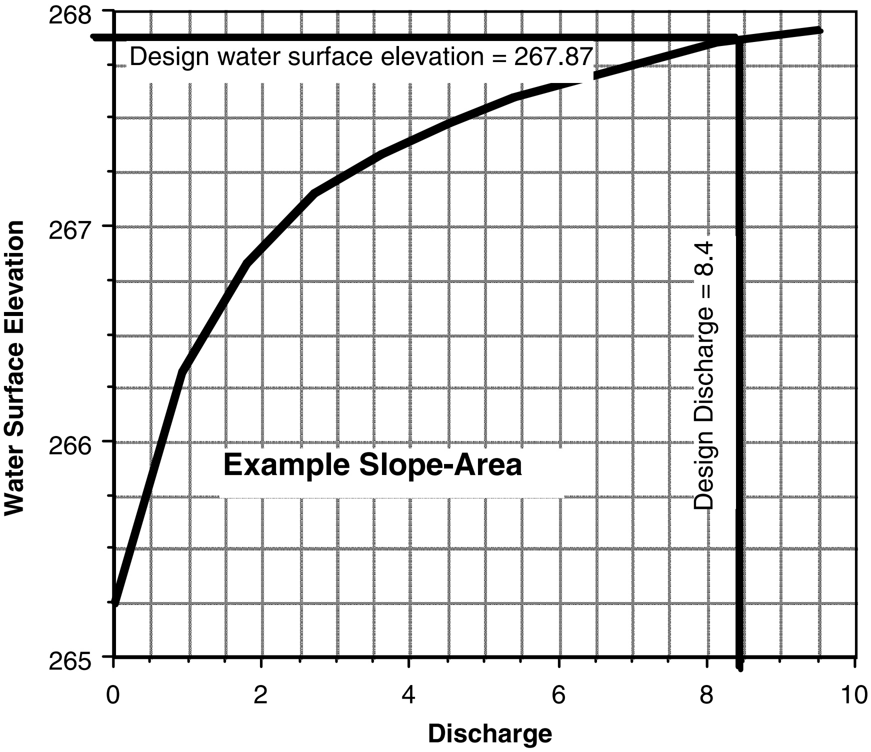


Figure 3-12. An example stage-discharge curve. The vertical and horizontal lines illustrate its use to determine flow depth at the selected design discharge.

This approach is simple and convenient and can be used effectively in most cases where uniform flow can be assumed. Examples of its application might include crossings where the channel slope if very consistent and there is no noticeable tailwater control point below the culvert.

3.3.6 Backwater Concepts

Flow in an open channel is rarely uniform. Even when discharge conditions are steady, the changes in channel slope and presence of hydraulic control points usually causes the flows to accelerate or decelerate along the channel. A common condition with fish passage road crossings is the deceleration that occurs as water approaches a tailwater control point, such as a rock weir constructed below a culvert outlet to increase water depths. Without the weir, the water might flow at the normal flow depth. With the weir in place, the water will slow down and deepen until it reaches the height which allows flow to pass over the weir crest at its critical depth. These control points are convenient starting points of known water depth where it becomes possible to determine upstream water depths using step-backwater methods.

Standard step-backwater methods involve the principle of conservation of energy as depicted in the Energy Equation, shown below for a channel of "small slope". Small slope usually is described as a slope less than 10%.

$$z_1 + y_1 + \alpha_1 \frac{V^2_1}{2g} = z_2 + y_2 + \alpha_2 \frac{V^2_2}{2g} + h_f \qquad \text{Equation 3-6}$$

where: z_1 and z_2 = elevations (either arbitrary or above mean sea level) of the streambed at the upstream and downstream sections respectively (m);

y_1 and y_2 = depths of flow at the upstream and downstream sections respectively (m);

α_1 and α_2 = velocity distribution coefficients at the upstream and downstream sections respectively (dimensionless). The value of the velocity distribution coefficient depends, in large part, upon the subdivisions available in the cross-section for conveyance computations. It is derived exactly in most computer programs but is commonly assigned a value of 1.0 for hand calculations where the cross-section is divided into several subsections. The velocity distribution factor serves to accommodate the varying velocity across the cross-section.

V_1 and V_2 = average velocity of flow at the upstream and downstream sections respectively (m/s);

h_f = friction head loss from upstream to downstream (m). The friction head loss equals the distance between cross-sections multiplied by the slope of the energy line. Reference is made to texts on open channel flow for further discussions.

Other losses, such as eddy losses, expansion losses, and contraction losses may be considered in some cases.

g = acceleration due to gravity - 9.81 m/s^2.

Figure 3-10 is a graphical representation of the energy equation. By stepping from one cross-section to the next in succession (in an upstream direction for sub-critical flow regimes and a downstream direction for super-critical flow regimes), one can define the profile of the water surface of an irregular channel for gradually varied flow. Thus the term <u>step</u> backwater computations.

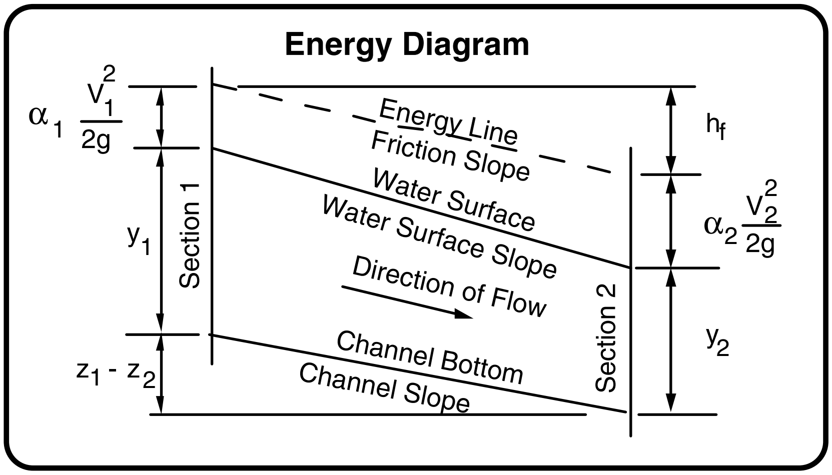


Figure 3-13. The energy diagram illustrating the principles of step-backwater analysis.

Even though they are direct calculations, manual computations of a standard step backwater procedure can be very tedious, especially for irregular cross-sections in natural streams. For this reason, several computer models have been developed to facilitate this analytical process.

3.3.7 Software for Fish Passage Road Crossing Hydraulics

There are several situations within this manual for which a backwater hydraulic calculation is recommended. The following paragraphs provide summaries of backwater model software commonly used for road crossing design.

A backwater model calculates subcritical hydraulic characteristics at a point in a channel based on the water surface just downstream plus the energy loss due to friction and change of channel shape between the two points. It may also calculate supercritical hydraulic characteristics and indicate which hydraulic flow regime exists at the point for the flow being analyzed.

The reasons for these analyses in road crossing design might be to do an analytical channel design, to compare an analytical design to a reference reach design, to evaluate whether the culvert inlet becomes submerged at a high flow, or to calculate the maximum capacity of a culvert. Designs that include long culverts and/or significant floodplain contractions should include backwater analyses to derive hydraulic slopes and shear stresses for comparison to the reference channel and to verify flow is subcritical throughout the project.

If a backwater analysis is conducted for a stream simulation design, verify that the Froude number in the stream simulation channel is similar to that in the reference channel. It is generally desirable that flows be subcritical at all flows up to at least the stable bed design flow.

Culvert hydraulic nomographs can be used for some of these purposes, but they are not available for embedded culverts with various bed materials, roughness, and depths, and therefore they generally are not suited for analysis of many fish passage culverts. Backwater calculations are generally too intense for hand calculation. There are several computer backwater models available for the evaluation and design of culverts. They typically calculate headwater depth upstream of a culvert and/or average cross-section velocities, but not the velocity or turbulence in the pathways used by fish.

River Analysis Software (HEC-RAS) is a backwater model developed by US Army Corps of Engineers Hydrologic Engineering Center for any open channel flow calculations including bridges, culverts, divided flow, multiple culverts, and unsteady flow. It is available from Hydrologic Engineering Center and it is packaged into several commercial products as well. It can model complex channel hydraulics and calculate instream and floodplain velocities, shear stresses and more. Roughness can vary across the cross-section and with changing flow. It contains a module for culverts that includes beds inside of culverts but it does not specifically report the hydraulics inside the culvert. To work around that limitation, an open channel can be modeled with a lid over it, which acts as a culvert. Being a universal backwater model, it can directly compare the hydraulics of a natural channel to various culvert and bridge options. The software is well documented. It requires substantial data and knowledge of modeling.

FishXing (version 2.2) was developed by the US Forest Service. It is a backwater model with the capability of a variety of culvert shapes. It is the only model that directly examines hydraulics inside a culvert with a bed. The bed material must be flat in cross-section but can have a specified roughness other than the culvert walls. It cannot model a variable depth of streambed. The latest version (3.0) can accommodate multiple culverts. It will calculate culvert capacity for inlet control, pressurized, and outlet controlled embedded culverts. It directly calculates culvert hydraulics using headloss equations. The tailwater is modeled using a downstream channel cross-section. It easily generates tabular and graphic reports.

HY7 and **HY8** are companion hydraulic models developed by Federal Highways Administration. HY7 is an open channel flow model and HY8 calculates hydraulics of culverts. HY8 can analyze multiple parallel culverts of different dimensions and elevations. It can model a variety of culvert shapes but it will not model bed material in the culvert. It calculates inlet and outlet control and sub- and supercritical flow. It will calculate roadway embankment overtopping. HY8 version 6.1 provides tailwater options that include user-defined tailwater rating curves having up to 11 rating curve points; calculation of uniform flow in the downstream channel for regular or irregular channel cross-sections having up to 15 cross-section points and roughness assignments; or a constant tailwater elevation. Graphic and tabular reports include water surface elevation, discharge, velocity, rating curves, and more.

CulvertMaster™ (version 3.0) is a commercial backwater model by Haestad Methods. It can model multiple culverts with different dimensions and elevations and composite profiles can be used within a culvert. It includes modules for quick calculation of specific characteristics, culvert dimensions based on culvert size, skew and road fill, road overtopping, and tailwater curves or tailwater channel. It includes the option of a flat bed within the culvert but it will not model a variable roughness of the bed and culvert. Tailwater options include channel cross-section, variable cross-section roughness, and overbank flows assuming uniform flow in the downstream channel or a tailwater rating curve. Graphic and tabular reports include water surface elevation, discharge, velocity, rating curves, and more.

FlowMaster™ (version 6.0) is a companion to CulvertMaster by Haestad Methods. It is a program for the design and analysis of pipes, ditches, open channels, weirs, orifices, and inlets. It is a one-dimensional model based on open channel and pressurized flow, not backwater calculations. FlowMaster's "Hydraulics Toolbox" can solve or rate any unknown variable using common hydraulic formulas. FlowMaster's inlet computations comply with the latest FHWA Hydraulic Circular Number 22 and AASHTO inlet computation guidelines.

Application of these models and proper interpretation of output requires that the user have a background in surface-water hydraulics. Even with sufficient experience, however, it is not always easy to determine what data are necessary to adequately define the physical system for numerical analysis. Similarly, determining whether or not the output from a model adequately represents the real-world situation can be very difficult.

The hydraulic programs listed above consider 1-dimensional flow, where the following general assumptions are applied: the slope of the channel bottom is small, the channel is prismatic and lateral inflows or outflows do not exist, head losses are determined considering uniform flow, and flow can only move in the downstream direction.

In more complex hydraulic problems, 2-dimensional modeling can be performed using finite element methods. For example, 2-dimensional analysis could be used to better model the effects from intersecting flows within a floodplain, tidal influences, and rapid variations in velocity within a tightly meandering river.

Generally speaking, computer programs that use finite element theory are very difficult to use and require a great amount of expertise in creating, calibrating, and interpreting models. For most cases, 1-dimensional analysis will be accepted in performing hydraulic modeling and design for fish passage projects.

3.4 Applied Hydraulics for Fish Passage Road Crossing Design

3.4.1 Flow Path Geometry for Embedded Culverts

When culverts are designed to be embedded, it is necessary to account for the reduced cross-sectional area when conducting open channel flow calculations such as Manning’s equation. Figure 3-14 illustrates the defined elements d_b and d_w pertaining to the embedment depth and the water depth above the embedment, respectively. The equations in Table 3-5 can be used to calculate the embedment area, flow area, and other geometric properties of the embedded culvert.

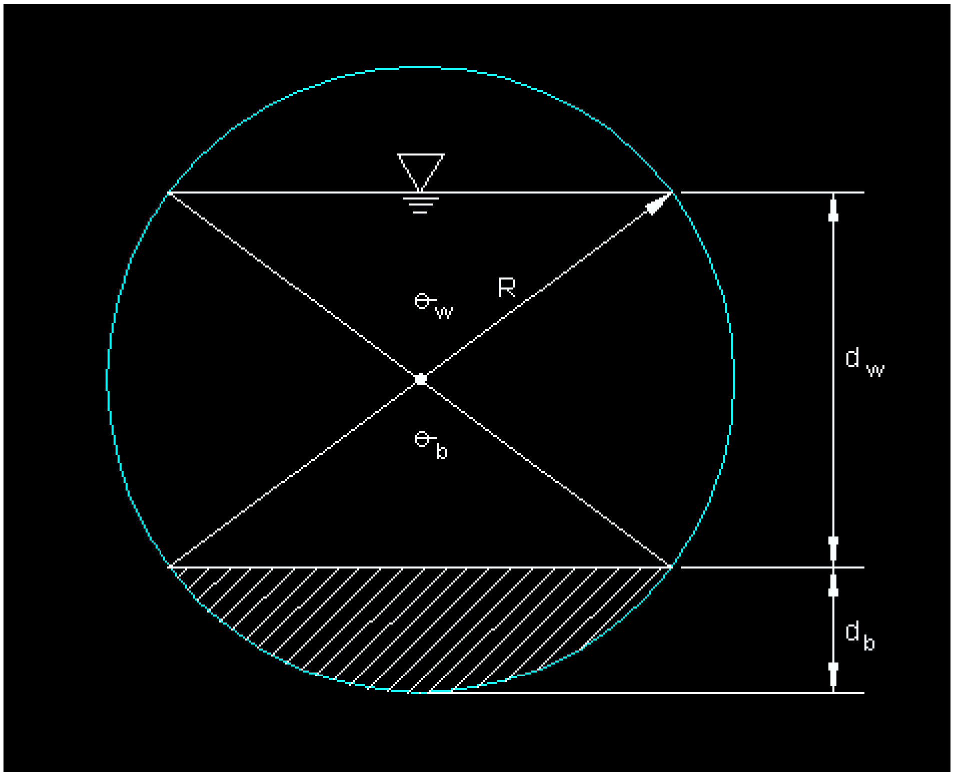


Figure 3-14. Elements of circular geometry used to calculate embedment area.

Table 3-5. Equations for calculating area and perimeter of embedment in circular pipes.

Depth of Embedment	d_b
Angle of Embedded Area	$\theta_b = 2\cos^{-1}[(R-d_b)/R]$
Embedded Area	$A_b = R^2 [\theta_b - \sin\theta_b] / 2$
Width of Embedment Surface	$P_b = 2R\sin(\theta_{b/}2)$
Embedded Pipe Perimeter	$P_p = 2R\cos^{-1}[(R-d_b)/R]$
Depth of Water	d_w
Angle of Water Surface	$\theta_w = 2\cos^{-1}[(R-(d_{b+}d_w))/R]$
Flow Area	$A_w = R^2 [\theta_w - \sin\theta_w] / 2 - A_b$
Width of Water Surface	$W_w = 2R\sin(\theta_{w/}2)$
Wetted Pipe Perimeter	$P_w = 2\theta_w - P_p$
Total Wetted Perimeter	$P = P_b + P_w$

The area of embedment in elliptical pipes can approximated with the same equations, with pipe rise substituted for diameter. More exact results can be calculated with the following equation:

$$A = b\ (\text{pipe rise})^a \qquad \text{Equation 3-7}$$

The coefficients a and b are given in Table 3-6. Note that two sets of coefficients are given, for corner radii of 457 mm (18 in) and 787 mm (31 in). These coefficients were developed by regression analysis from the exact tabulated areas (Maine DOT 2002).

Table 3-6. Function coefficients for open area in embedded elliptical pipe.

Corner Radius		Depth of Embedment			
		0 in	6 in	9 in	12 in
18 in	a	2.246	2.316	2.371	2.428
	b	0.743	0.613	0.530	0.453
31 in	a	2.260	2.291	2.320	2.351
	b	0.631	0.571	0.524	0.475

Note: Open Area (Ao, in ft^2) = b x $(\text{Pipe Rise})^a$, where Pipe Rise given in ft.

3.4.2 Composite Roughness

When there is more than one roughness condition present, it is possible to develop a single n-value based on a weighted average of the roughness value in relation to the wetted perimeter of its flow segment. This weighted roughness coefficient is also called a composite roughness coefficient. In equation form, it is

$$n = \frac{n_1 p_1 + n_2 p_2}{p_1 + p_2} \qquad \text{Equation 3-8}$$

where,

n = weighted roughness coefficient,
n_1, n_2 = roughness coefficient of culvert and channel substrate, and
p_1, p_2 = wetted perimeter of culvert walls and channel bottom.

It is recommended that weighted roughness coefficients be used when calculating flow conditions in culverts containing channel substrate, such as for bottomless culverts or embedded culverts. The length of the wetted perimeter of the substrate area can be calculated using methods presented in Section 3.4.1.

If a site has actual field data that provides paired data relating the river stage to a discharge Q, a single n-value may be back-calculated for each data pair using Manning's equation. In cases where a high level of accuracy is desired, this field-calibrated n value may be compared to the composite n-value calculated for individual channel sections. It is worth emphasizing, however, that the calculated n from field data for stage-discharge data pairings is valid only for that combination. It is not recommended that single n values as determined from field data be applied to other stage or discharge conditions. It is more reasonable to assign individual "n" values to localized and quantified subsections of the channel cross-section.

3.4.3 Weir Controls

Weir controls provide a convenient measure for controlling water depths upstream of the structure. Most often with fish passage road crossing structures, a weir will include a notch or other opening located at the deepest part of the channel, and an elevated crest that is highest at the stream banks and slopes downward towards the notch. These features ensure that, during low flow conditions, the flows are channeled through a relatively narrow area, rather than being spread out across the width of the channel.

Generally, weirs notches are constructed with simple geometric shapes to simplify flow measurement. However, some of the flow measurement accuracy is lost as soon as the downstream water level submerges the crest of the weir, and a submerged crest is almost always the preferred condition with fish passage facilities.

Weir controls may be used to establish a tailwater control point below the culvert outlet. The standard contracted weir is one whose crest and sides are sufficiently far away from the channel sides to allow contraction to develop. A V-notch weir is especially useful when the lowest flow rates are small. The following equations are the weir formulas that relate discharge to the depth of flow over the crest:

- Standard contracted weir: $Q = 3.33\ (L - 0.2H)^{3/2}$
- V-notch weir: $Q = C_d\ (\tan \theta/2)\ H^{5/2}$

3.4.4 Headwater

The constriction caused by the presence of the road crossing structure in the natural stream path may cause an increase in depth of flow in the channel upstream of the crossing. This total water depth, called the "headwater", represents the potential energy necessary to force the water into and through the culvert.

The calculation of headwater depth varies depending on whether the culvert flows under the influence of inlet control or outlet control. With inlet control, the culvert flow at the inlet is in the supercritical flow regime. With outlet control, the culvert is flowing in the subcritical flow regime. Subcritical flow is generally preferred for fish passage. Under the high flow conditions associated with peak flood events, it is feasible that even large culverts may become submerged at the inlet, increasing the chances of inlet control.

3.4.4.1 Inlet Control Headwater Calculation

If the culvert configuration is operating in supercritical flow, the headwater must be determined by reference to empirical relations which are based upon culvert model studies. The empirical relations correlate headwater to discharge and culvert face geometry. Since inlet control only occurs for supercritical flow, the parameters of barrel geometry, slope, roughness characteristics, and (usually) tailwater do not influence the headwater.

The empirical relations for various culvert shapes and materials are represented graphically by nomographs found in FHWA HDS #5. These relations are included in most culvert analysis software programs as well.

3.4.4.2 Outlet Control Headwater Calculation

If the culvert configuration is operating in subcritical flow, the headwater may be determined by analysis of the various losses which must be overcome by the potential energy represented by the headwater. These include the velocity head loss, entrance head loss, and friction head loss.

$$H = H_v + H_e + H_f \qquad \text{Equation 4-10}$$

Calculations that determine headwater for culverts flowing under outlet control are included in most culvert analysis software programs. Several guidebooks for traditional culvert design can provide more information regarding the principles of outlet control flow

3.4.5 Outlet Velocity

Due to the decreased area of flow in the culvert, the flow velocity increases in the culvert from the natural stream velocity. The culvert outlet velocity, then, is an important parameter to be derived from the hydraulic analysis of the designed culvert. An excessive outlet velocity may be influential in the ultimate design configuration of the culvert. It usually is not cost effective to configure the culvert entirely upon the basis of outlet velocity.

3.4.5.1 Inlet Control Outlet Velocity

For inlet control configurations (supercritical flow), the backwater profile in the culvert tends toward normal depth as water passes from upstream to downstream. Since culverts are relatively short, normal depth of flow is rarely attained. Rather some depth greater than normal depth usually occurs at the outlet end of an inlet control culvert operation.

The calculation of the actual depth of flow at the outlet end of an inlet control culvert is tedious and usually unjustified. The conventional approach is to assume normal depth of flow at the outlet and use the associated cross-sectional area of the culvert barrel in the continuity equation to estimate culvert outlet velocity. This results in a conservative estimate of outlet velocity for manual calculations.

3.4.5.2 Outlet Control Outlet Velocity

The outlet velocity for a culvert operating in outlet control is calculated according to the following.

- Condition A-Outlet velocity is based upon full flow at the outlet of the culvert.
- Condition B-Outlet velocity is based upon the tailwater depth at the outlet of the culvert.
- Condition C-Outlet velocity is based upon the critical depth of flow in the culvert.

Most fish passage road crossings will be designed to flow under Condition B.

3.4.6 Estuary Flows

Fish passage designs for facilities located in estuaries must account for the unique hydraulic conditions caused by changes in tidal elevation. During ebb flow conditions when the tidal elevation is dropping, stream flow velocities are greater than the normal stream velocity due to the additional outflow of the tidal storage prism. Also, streams located in tide flats may exhibit water depths that are so shallow during low tide as to become impassable. HDM Index 821.5 specifies that for road crossings located where tailwater elevation is controlled by tides, special studies are normally required to determine the tailwater stage consistent with the design storm frequency of the facility.

Considering the difficulty in achieving the standard fish-passage criteria, new culverts that create a barrier due to tidal extremes are not generally permitted, and removal is a preferred action for restoration. Where removal is not possible but there is a need to achieve the best possible fish-passage restoration, objectives that are different from the standard fish-passage criteria might be acceptable. Defining alternative objectives should be done in conjunction with a careful and thorough review of allowable upstream water levels and timing.

3.5 Basic Culvert Design for Fish Passage

3.5.1 Culvert Alignment

Guidelines regarding culvert location and alignment presented in HDM Topic 823 generally recommend alignment of the thalweg of the stream with the centerline of the culvert. The HDM additionally recommends, however, that for economic reasons, small skews should be eliminated, moderate skews retained and large skews reduced.

Road crossings requiring fish passage are strongly encouraged to retain the natural alignment of the stream, regardless of the skew. Alignment of the culvert centerline with the channel approach angle should reduce the likelihood of the crossing plugging with debris during storm flows and minimize hydraulic turbulence which might impede fish passage. Additionally, curvature within culverts should be avoided at all fish passage road crossings.

As a general guideline, cases in which it is unavoidable to have a channel approach angle less than 30°, and cases where the channel curves or meanders at the road crossing location, may be better served by providing a bridge crossing instead of a culvert.

Where opportunities arise to evaluate alternative road crossing locations, preference should be given to sites where the stream channel has straight alignment 100 feet above and below the culvert. At a minimum, there should be at least 50 feet of straight alignment in the natural stream channel above the culvert.

3.5.2 Culvert Slope

The slope of most culverts installed without consideration to fish passage are placed so that the upstream and downstream flow line elevations approximately match the natural streambed elevations at those locations. HDM Topic 823 describes cases for non-fish passage culverts where, as a practical matter, the culvert flow line elevations may differ from the thalweg elevation of the stream. These cases include very high fills, where it may be uneconomical to install and operate a culvert at the thalweg elevation, and cases where the drop in stream elevation from one side of the roadway to the other is considerable. These latter cases might provide a broken back profile that incorporates a steep upstream segment of the culvert with a mild slope unit usually in the downstream end of the culvert. These common slope configurations for non-fish passage culverts are illustrated in Figure 3-15. As shown, there is little likelihood either of these configurations would obtain approval from fisheries agencies as acceptable for fish passage.

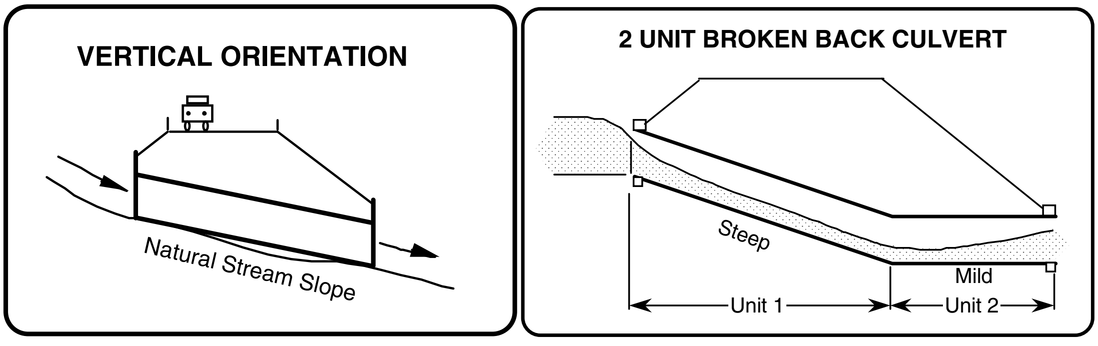


Figure 3-15. Common slope configurations for non-fish passage culverts.

Road crossings designed to accommodate fish passage generally place the bottom of the road crossing structure below the elevation of the stream thalweg (Figure 3-16).. In the case of bridges and culverts designed through the stream simulation or active channel options, the structures are generally placed to ensure that native stream bed material is recruited into and through the crossing to maintain the same gradient as the stream channel. Culverts designed by the hydraulic design option may vary the culvert slope as long as the velocities and water depths occurring within the fish passage flow range satisfy conditions related to the swimming capabilities of the target species. Specifics regarding design of the structure slope vary according to the culvert design option selected, and they are detailed in Chapters 4, 5 and 6.

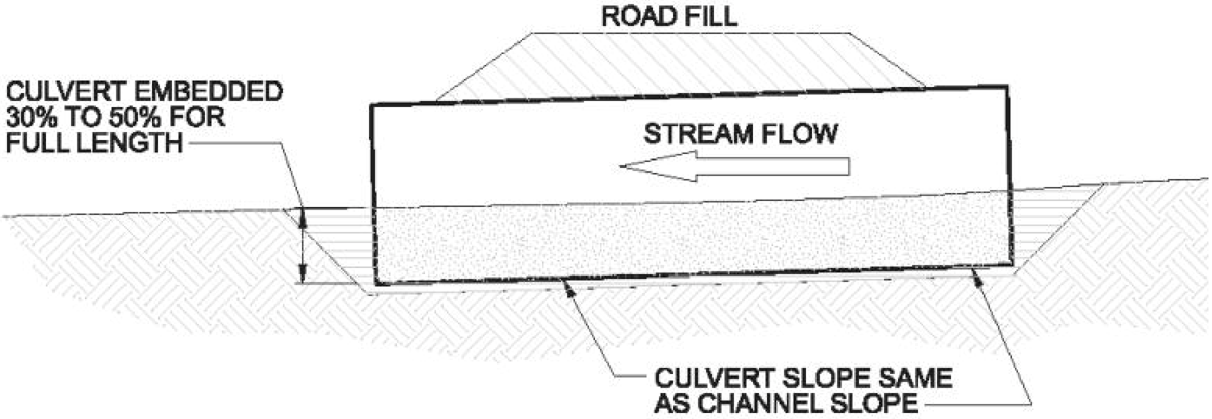


Figure 3-16. Preferred slope configurations for fish passage culverts.

3.5.3 Culvert Material and Shape

No single culvert material or shape is best for all fish passage road crossings. Figure 3-17 shows shapes of culverts commonly used for fish passage road crossings. All of these culvert shapes can be sized large enough to accommodate natural streambed materials within them. If the bankfull channel widths and bed characteristics are the same as the natural channel, and there is adequate hydraulic capacity to sustain the stream simulation characteristics though the life of the project, there is little difference among these designs from the point of view of fish passage performance.

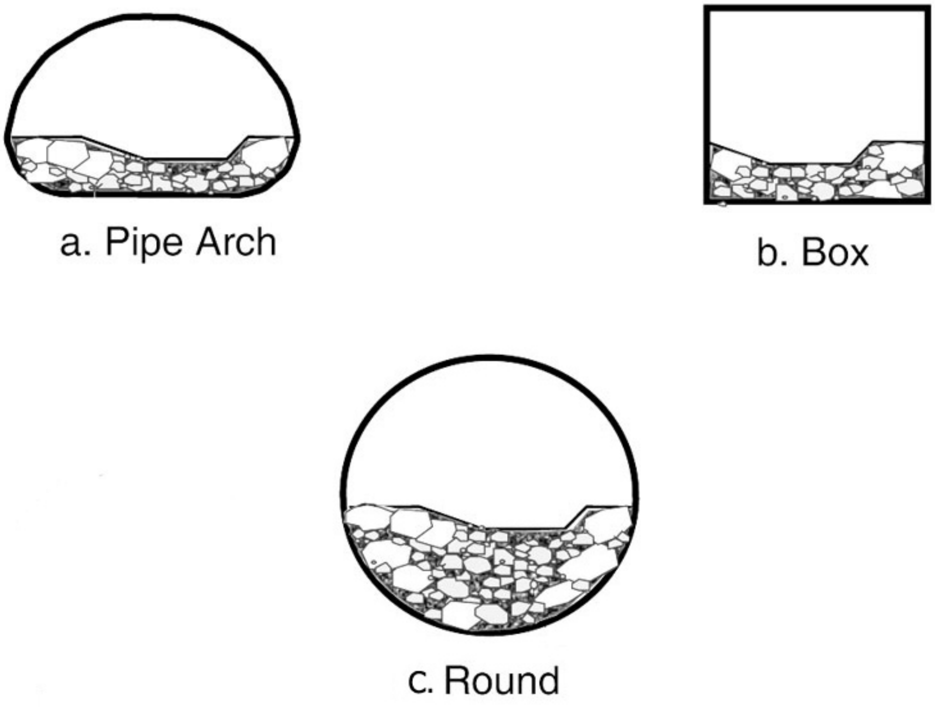


Figure 3-17. Common shapes for fish passage culverts, showing typical accommodation for embedment.

The shape and material of a culvert can substantially affect the initial and life-cycle costs of a project however. Cost differences may be due to material costs, project sequencing, limitations of project duration, competence of soils for structural loading, location and availability of materials, excavation volume, excavation limitations such as bedrock, and the cost of delivery to remote locations. Other differences include reliability, limitations of hauling over-sized materials, durability and resistance to corrosion and abrasion, risk of vertical instability, debris passage, hydraulic characteristics for stream simulation, and experience of the construction crew.

No universal recommendation is made for culvert shape or material. General categories that might be used to compare various culvert products for a project are:

- Full pipe;
- Precast or cast in place;
- Prefabricated or fabricated in place;
- Concrete, steel, or aluminum; and
- Arch, round, or box

Pipes are defined here as fully enclosed structures with an invert as an integral part of the culvert product.

An advantage of precast or prefabricated structures is that they can be installed in a single piece or a few pieces rather than being cast in place concrete or individual panels. In some cases structural plate pipes can be pre-assembled and installed in segments. The option of top loading a box culvert might be possible if a lid is installed after construction of the bed within the culvert.

Smooth-walled culverts have water velocities that are usually two to three times those in corrugated metal pipes when the slope, area, and other flow parameters are equal. Studies have shown that migrating fish, especially juvenile fish, use the corrugations along the pipe as resting areas as the migrate through the pipe. The passage enhancement is more pronounced with larger corrugations than smaller ones.

3.5.4 Culvert Size

There are several trade-offs of a larger culvert. A larger culvert obviously costs more, although the cost of culvert material for several feet greater diameter is often minor compared to the overall project cost. Sometimes there is greater cost in the extra excavation for installation, especially through a high road fill. There is also greater cost in materials and labor if selecting a larger culvert forces the design from a single piece corrugated pipe to a structural plate pipe. That threshold occurs at about twelve feet, which is generally the largest size of pipe available before going to a structural plate product. Some loading conditions may require structural plate pipes for smaller diameters.

There is also a lower practical limit to the diameter of culvert that can be constructed as stream simulation. A culvert with a diameter or rise of about five or six feet is a minimum because the bed cannot feasibly be constructed in a smaller pipe except with hand labor. Access may not be an issue if strong hand labor is available and the rock is not too large to manipulate by hand or with hand equipment. This size consideration should also be evaluated relative to future access for maintenance and repair.

3.5.5 Culvert Entrance Design

HDM Topic 826 provides guidance for the entrance design of non-fish passage culverts, noting inlet edge configuration is one of the prime factors that can influence hydraulic performance of culverts. However, these same entrance geometry refinements may be detrimental to conditions which promote fish passage.

The use of concrete aprons at culvert openings is not recommended for fish passage road crossings. The aprons have a smoother texture and therefore a lower roughness coefficient than the natural stream bed, which may increase velocities to the point of making fish passage difficult or impossible. Under lower flow conditions, aprons may produce sheet flow conditions that create a problem of shallow water depth. In cases where the use of an entrance apron cannot be avoided, the designer should depress the apron elevation below the culvert inlet, so that natural streambed materials can settle over smooth apron.

3.5.6 Culvert Outlet Design and Tailwater Control

Culverts designed for non-fish passage road crossings have outlet velocities that are usually higher than the maximum natural stream velocity. HDM Topic 827 provides guidance for determinations as to whether outlet velocities may be excessive and the design of corrective measures to reduce streambed scour and bank erosion below the culvert outlet. These measures, while appropriate for non-fish passage culverts, do not address the level of analysis or velocity reduction required to assure fish passage through a culvert.

Fish passage road crossings generally strive to keep flows subcritical and within 1.25 times the velocity of the natural stream. As a consequence, many of the standard concerns regarding excessive velocities at culvert outlets are not relevant to fish passage road crossing designs. Instead, outlet design for new fish passage road crossings focuses on the natural stream bed elevation at the outlet location of the culvert, along with the elevation of the tailwater control point located below the culvert.

Fish passage road crossings developed using the stream simulation or active channel design options are embedded culverts with inverts located below the natural stream grade. Analysis for determination of the culvert outlet elevation is the key element of outlet design for these two options. Generally, the outlet design entails:

- For both of these cases, assume that the bed elevation at the outlet will be equal to the bed elevation at the tailwater control point. This assumption is a conservative acknowledgement that natural sedimentation processes are likely to result in a filled bed in the channel above the tailwater control elevation.
- For stream simulation outlets: having established the design bed elevation, the invert elevation for full barrel culverts is located such that the bed elevation lies between 30% to 50% of the culvert height. For bottomless culverts, it is first necessary to determine the largest anticipated scour depth, and insure that the culvert footings or foundation are located below that depth.
- For active channel outlets: having established the design bed elevation, the invert elevation is located such that the bed elevation is between 20% to 40% of the culvert height.

For new culverts designed using the hydraulic design option, a more rigorous analysis is required to establish the outlet design. Hydraulic computations are completed to determine velocity and water depth at the outlet of the culvert at the high and low fish passage flow rates, to insure they are within the swimming capabilities for the target species. In some cases, the only mechanism for achieving the design criteria is to develop a new, higher tailwater control elevation below the culvert location as a means to backwater the culvert outlet.

Cases involving existing culverts being retrofit for fish passage enhancement also require hydraulic analysis of the outlet velocity and water depth conditions. In retrofit cases where there is a scour hole located below the culvert, it is common to use grade control measures to develop a new tailwater control point. In cases where these grade control measures still result in a hydraulic drop at the outlet, it is recommended that a jump pool be provided that is at least 2 feet deep, and the total drop be limited to 1 foot.

3.5.7 Culvert Lighting

As directed in the CDFG *Culvert Criteria For Fish Passage* document, interior illumination is required for both new and replacement culverts that are more than 150 feet in length. This illumination can be in the form of artificial lighting or natural light. Natural light can be conveyed through the use of solar tubes or even grated drainage inlets to identify a couple of alternatives. The spacing of supplemental lighting sources (artificial or natural) shall not exceed 75 feet.

3.6 Other Channel Considerations

It is important for the designer to have a firm understanding of the character of the stream upstream and downstream of a culvert or bridge. Proper design or analysis of open channel flow must include the consideration of such things as the sediment load of the streamflow, debris which may be carried by the stormwater, and the various means and ramifications of bank protection. The designer must have:

- knowledge of the stream's natural conditions,
- estimates of sediment and water discharge,
- a means of predicting the type and magnitude of potential stream response to the proposed highway facility,
- a knowledge of geology, soil mechanics, hydrology, and hydraulics of alluvial streams. Alluvial streams have beds and banks composed of clay, silt, sand, or gravel and various combinations of these materials that have been transported by and deposited in water,
- and bed elevation change

3.6.1 Sediment

As previously mentioned in this chapter, the bed load in a stream is defined as sediment that moves by rolling, sliding, or skipping along the bed and is essentially in contact with the stream bed. Effectively, sediment load means the same thing. The bed load or the sediment load in stream flow may result in one or more of three things. Specifically, this material may cause:

- erosion (degradation of the channel),
- deposition (aggradation of the channel),
- or there may be a state of equilibrium in which any eroded material is replaced immediately by deposited material.

The bed load in a stream must be considered by the designer from the standpoint of its potential for damage to the stream, the roadway embankment, the drainage facility, or upstream or downstream property.

3.6.2 Debris

As runoff accumulates from a watershed, it naturally carries certain floatable material with it, which includes urban debris or trash. In watersheds with significant vegetation, because of the natural life and death processes of that vegetation and also because of cutting or clearing operations, debris or drift may accumulate at the surface of channels carrying the runoff. As this debris approaches the usually constricted highway drainage facility opening, it is deposited on the upstream side of the highway. Significant accumulations of debris can reduce hydraulic efficiency, cause local scour, and cause physical damage to the facility and adjacent property and features.

There are no comprehensive models for managing debris flow, debris plugging, or sediment failure probabilities. Regional models or experience may be available in some regions. Furniss et al. (1998) identified four primary mechanisms at 258 culvert failures during floods in 1995 and 1996 in Pacific Northwest forested watersheds. They identified debris flow, debris plugging, sediment slug, and hydraulic exceedance as primary mechanisms. Of these, debris and sediment combinations accounted for 91% of the failures. Of the failures due to debris plugging, 23% were initiated by debris smaller than the culvert diameter. These observations, on top of hydrologic modeling uncertainties, demonstrate uncertainties of predicting probabilities of culvert failures. Large tree-size wood is unlikely to pass through many structures.

Furniss et al. (1998) demonstrated that culverts with a width similar to the channel convey large debris more efficiently than culverts narrower than the channel and culverts with wide channels at the inlet. The widened channel at the culvert inlet allowed wood to rotate perpendicular to the culvert and plug the inlet.

Consideration for how material can be removed from the culvert may be an important design element. Management of the risk of debris by optimizing the culvert alignment was discussed in the section on alignment.

3.6.3 Bank Protection

Caltrans is in the process of piloting several projects which are combining RSP and vegetation - typically using RSP from the estimated scourable toe up to some elevation approximating "bankfull", with either vegetation, or vegetation over the top of buried RSP above this elevation. However, as yet there are not any specific design procedures or protocols and such designs are developed on a case-by-case basis - typically with HQ input.

Bank protection design for fish passage road crossing should refer to the California Bank and Shore document, while being cognizant of the desire of resource agencies to incorporate softer treatments where possible. The designer is advised to contact either their District Hydraulic Unit for input, or for unique or special situations to contact the Caltrans Bank and Shore Protection Committee (see HDM Index 802.3) for assistance. Additional information is presented in Chapter 8 as it relates to the use of rock weirs for grade control and channel stabilization.

3.7 Preliminary Design

The preliminary design process for a fish passage project is somewhat similar to the usual engineering procedures with the exception that more detail is required in this phase to assure that the structural and hydraulic features meet the specific passage criteria. This is necessary not only to assure subsequent design is carried out efficiently but also to confirm the passage design review, at this point in the process, by the permitting agencies involved is complete from their perspective. This stage of design is sometimes referred to as the “30% design level” and is a refinement of the internally developed and approved conceptual plan (approved by resource agencies).

Once the conceptual plan and supporting engineering information is confirmed within the agency, the development of preliminary engineering should progress to a level that reflect the required hydraulic conditions for water conveyance and fish passage through the defined times of passage and storm flow events.

Permitting agency review should be initiated at this point following the appropriate PDWT for general review and comments with the understanding that the final design approval will be on the final design documents and will include any appropriate permitting agency comments.

3.8 Final Design

Final design includes the process of refining the preliminary design as required from permitting agency review and the engineering detail developed from all the disciplines involved in the PDWT sequence. A “90 %” submittal is required in the final design process for internal review to assure compliance with the overall project intent both of engineering and environmental nature. The structures, hydraulics, soils and related engineering features shall then be completed in final design plan and specification format (100% submittal), as required for any CalTrans project. This final design submittal shall address all internal and permitting agency concerns and be ready for advancing in the PDWT process toward District Engineer approval and advertising.

Elements of final design are likely to include:

- Bedding conditions and backfill.
- Installation conditions.
- Piping considerations.
- Debris control.

CHAPTER 4

NMFS ACTIVE CHANNEL DESIGN OPTION
OR
LOW-SLOPE CA FISH & GAME DESIGN OPTION

LIST OF FIGURES

LIST OF TABLES

4 ACTIVE CHANNEL DESIGN OPTION OR LOW SLOPE DESIGN OPTION

4.1 Design Method Applicability

As defined by NMFS in their *Guidelines for Salmonoid Passage at Stream Crossings* document, an active channel is “a waterway of perceptive extent that periodically or continuously contains moving water. It has definite bed and banks which serve to confine the water and includes stream channels, secondary channels, and braided channels. It is often determined by the ordinary high water mark which means that line on the shore established by the fluctuations of water and indicated by physical characteristics such as clear, natural line impressed on the bank, shelving, changes in the character of soil, destruction of terrestrial vegetation, the presence of litter and debris, or the appropriate means that consider the characteristics of the surrounding areas.” See Figure 3-2 from Chapter 3 for a graphical identification of active channel.

An active channel design employs a culvert placed at a level grade, sized sufficiently large enough to encourage the natural movement of bedload and the formation of a stable bed inside the culvert. The culvert width at the streambed elevation equals 1.5 times the active channel width. The active channel design method originally was developed with the intent of providing a simplified stream simulation design for private landowners with short crossings under driveways and similar sites. For those limited projects satisfying specific criteria regarding channel slope and culvert length, the active channel design method can greatly reduce the engineering effort necessary to develop a culvert design approved by State and Federal fisheries agencies. The tradeoff for the reduced engineering effort is that it provides a road crossing culvert that is commonly larger than would be required under more rigorous hydraulic design approaches. On a long-term basis, the larger culvert size is likely to enhance the effectiveness of passing storm flow, debris and fish.

The active channel design option will be allowed only if the following conditions apply:

- The natural slope of the stream is 3% or less.
- The culvert length is less than l00 feet.
- The design will be applied to a new culvert installation or to replacement of an existing culvert.

Sites having a natural streambed slope greater than 3%, or sites that require a culvert length greater than 100 feet, must have culvert designs based on the streambed simulation design option or the hydraulic design option. The active channel design option is not appropriate for the design of culvert retrofits.

In April 2009, CDFG developed Part XII: Fish Passage Design And Implementation of the *California Salmonid Stream Habitat Restoration Manual*. This new section modified the **old** Active Channel Option design criteria from the CDFG *Culvert Criteria For Fish Passage (2002)*, and has been renamed Low-Slope. CDFG has not officially updated their criteria document, but they have verbally stated that the design criteria for Low-Slope in Part XII will supersede the Active Channel Option.

The NMFS Active Channel criteria presented above has not changed, as of the date of this chapter update, and remains consistent with the CDFG *Culvert Criteria For Fish Passage (2002)*, which is the reason both options are shown and discussed. Most likely, the Low-Slope

Option will control because it is more conservative, but this final decision will be made on a project-by-project basis between NMFS, US Fish & Wildlife Service, and CDFG.

The changes in design criteria are displayed in Table 4-1.

	Active Channel	**Low-Slope**
Culvert Width	Minimum of 1.5 Times Active Channel Width	Minimum of 1.25 Times *Bankfull Width
Culvert Length	100 Feet or Less	75 Feet or Less
Culvert Slope	0% (Flat)	Match Natural Stream Slope
Channel Slope	3% or Less	1% or Less
Culvert Embedment	Equal or <40% (Upstream) 20%-40% (Downstream)	20%-40% Throughout
Bed Material (Backfill) Inside Culvert	Natural Recruitment	Natural Recruitment (Length<50 feet) OR Backfill With Native (Length 50-75 feet)
**Development of Long Profile	Not Required	Required

* See Figure 3-2 for presentation of bankfull width.

** See Figure 5.2 for Long Profile Example.

Table 4-1. Active Channel vs. Low-Slope

4.2 Active Channel or Low-Slope Design Process Overview

Step 1: Create a long profile drawing to show the upstream and downstream conditions of the culvert. Evaluate stability surrounding the culvert structure for both existing and proposed culvert conditions using the created long profile.

Step 2: Create HEC-RAS model of the existing culvert geometry design to identify capacity issues and create a water surface profile for later comparison to proposed conditions.

Step 3: Determine proposed culvert size by calculating Average Active Channel Width (Active Channel Design Option) or Bankfull Width (Low-Slope Design Option) to obtain Culvert Width. When using the Low-Slope Option for culverts 50 feet to 75 feet in length, calculate the largest immobile particle in natural streambed and multiply by 1.5 (minimum) to determine bed material (backfill) inside culvert.

Step 4: Calculate upstream and downstream embedment depth to determine culvert invert.

Step 5: Select remaining proposed culvert dimensions and physical characteristics to satisfy future culvert design needs.

Step 6: Model culvert geometry in Proposed Conditions HEC-RAS Plan. Note: HEC-RAS is limited to one constant embedment depth through the entire culvert. For the Active Channel Option, two embedment depths are required so the 0% slope criteria are satisfied. To account for the difference in depth between the inlet and outlet embedment depths, average embedment depth and enter into Proposed Conditions HEC-RAS Plan.

Step 7: View Proposed Condition HEC-RAS Plan results to identify possible proposed culvert design issues. Check culvert capacity based on proposed design conditions for the 100-Yr event. Summarize results in Form 6A (Appendix D) sections Maximum Allowable Inlet Water Surface Elevation, Allowable Hydraulic Impacts, and Velocity Summary.

4.2.1 Engineering Analysis and Reporting

The collected data will be used to perform an engineering analysis and complete the active channel or low-slope culvert design. Summary information from the analysis and design will be recorded in a report that shall include the following:

1. Data as described in Section 4.2.1.
2. Culvert design calculations as described in Section 4.3.
3. Roadway stationing of the culvert location.
4. Culvert length and size.
5. Culvert material.
6. Culvert profile, plus additional profile of the stream channel if required by Section 4.4.
7. Roadway cross-section and roadway profile, demonstrating the maximum height of fill over the culvert.
8. Calculations for flood capacity check.
9. Description of culvert end treatment and any additional culvert appurtenances.

4.3 Culvert Design

The active channel or low-slope method for culvert design uses a simplified approach to determine the size of the culvert, based generally on the dimensions of the stream in the vicinity of the road crossing. Although this reduces much of the hydraulic engineering effort required for the design, it is nonetheless necessary to conduct hydrologic, hydraulic and structural analyses to complete the design effort.

4.3.1 Culvert Shape

Any culvert shape can be used with the active channel design option. At this stage of the design, a preferred culvert shape should be selected. If the selected culvert shape is not circular, establish preliminary values for the culvert span and rise based on the minimum culvert diameter previously calculated, taking into account the standard dimensions of culvert products commonly used in the project area.

4.3.2 Culvert Invert

The active channel and the low-slope design options provide for the culvert to be installed with the culvert invert placed below the natural streambed elevation, allowing the natural movement of bedload to form a stable bed inside the culvert. Criteria established by CDFG (Appendix B) and NOAA Fisheries (Appendix C) require the invert at the culvert outlet to be embedded no less than 20 percent of the culvert diameter or rise. Additionally, the invert at the culvert inlet must be embedded no more than 40 percent of the culvert diameter or rise. Figure 4-1 illustrates the criteria requirements for an active channel design, while Figure 4-2 presents criteria for low-slope.

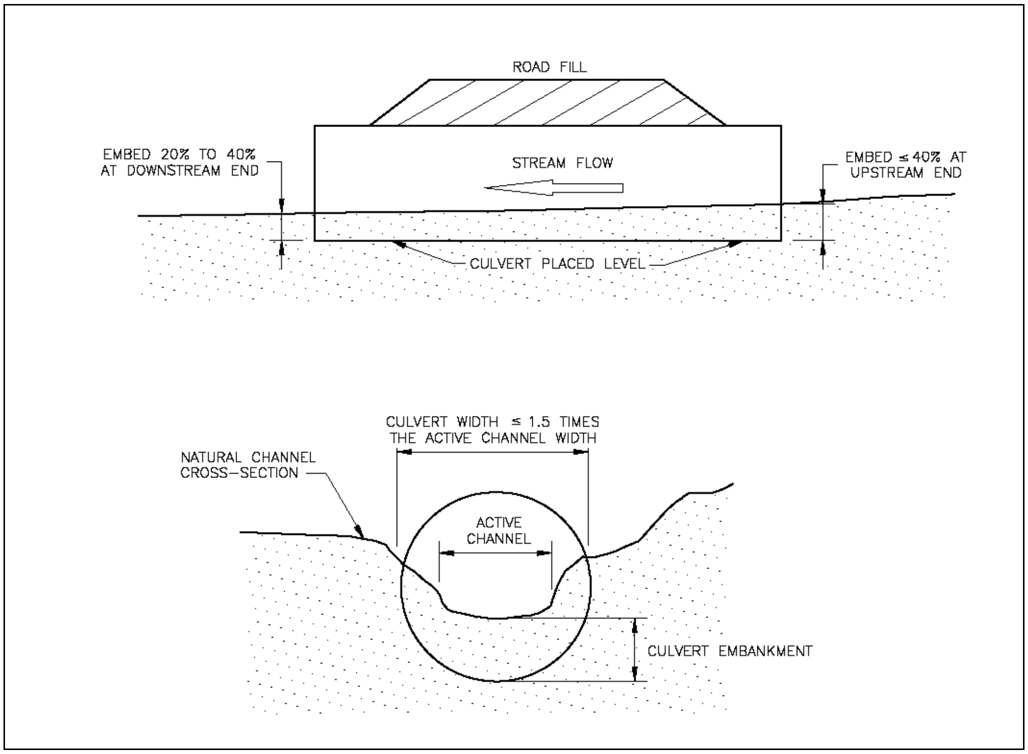


Figure 4-1. Active channel criteria diagram

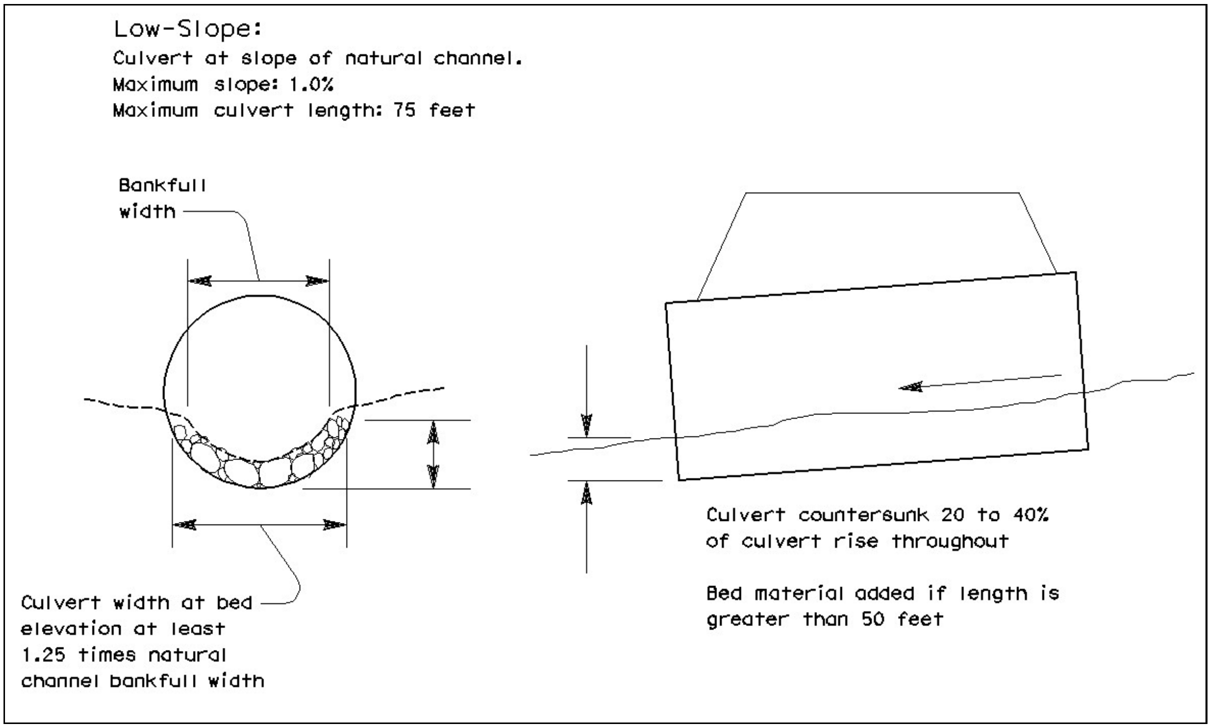


Figure 4-2. Low-slope criteria diagram

4.3.3 Flood Flow Capacity Check

At this stage of the active channel design, the preliminary size, shape and embedment characteristics of the culvert are analyzed to estimate water surface elevations that occur during discharges associated with a 100-year peak flood. In the CDFG (2002) Culvert Criteria document, for the 100-year peak flood, the upstream water surface elevation shall not be greater than 50 percent of the culvert height or diameter above the top (ceiling)of the culvert inlet.

The open area of an embedded circular or elliptical pipe can be estimated from basic geometric properties of the radius (or pipe rise), corner radius (where applicable), and depth of embedment. The open area of the pipe is then used in the determination of the water surface elevation under the peak flood discharge conditions. If either of the flood capacity criteria noted above are not satisfied with the selected pipe size, then the design process should be repeated with a larger pipe size until the flood capacity criteria are met. Section 3.5 provides equations and nomographs that facilitate the hydraulic analysis of the pipe flow capacity.

4.3.4 Culvert Appurtenances

The design of culvert end treatments may vary depending on site specific issues such as retention of roadway embankment, hydraulic efficiency, and debris control. In general, fisheries agencies encourage end treatments that provide a smooth hydraulic transition between the upstream channel and the culvert inlet, as a means to facilitate the passage of flood borne debris.

CHAPTER 5

STREAM SIMULATION DESIGN OPTION

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5 STREAM SIMULATION DESIGN OPTION

5.1 Design Method Applicability

5.1.1 Description of Stream Simulation

Stream simulation is a culvert design method intended to create and maintain natural stream processes in a culvert. It is based on the premise that the simulated channel inside a culvert presents no more of a challenge to movement of organisms than the adjacent natural channel. The basic elements of a stream simulation design that will be described in this chapter are:

- Site suitability for stream simulation or any culvert or road crossing;
- Reference reach that is simulated;
- Project profile;
- Culvert bed profile and elevation;
- Culvert length;
- Culvert/stream alignment;
- Effects of large scale floods;
- Effects of floodplain at crossing site;
- Culvert bed material;
- Width of culvert bed;
- Culvert material and shape or other solution; and
- Channel profile control, if necessary.

The “reference reach” is a natural channel in the same stream and in the vicinity of the project, used as a reference for the design. It is typically identified during the pre-design assessment and the selection is verified at several points in the design process. The reference reach serves as a real-world model of a channel configuration that can be self-sustaining inside a culvert and that satisfies the physical conditions (especially slope) of the project site. The term “self-sustaining” refers to the interaction of high flows, the bed, and the culvert to create and dynamically maintain bed material sizes and patterns within the culvert bed that accurately simulates the natural channel. Though a stream simulation project doesn’t necessarily reflect the average conditions of the reference reach, it shouldn’t reflect extreme conditions either. It should be recognized that we are not likely able to duplicate the natural channel precisely.

A key element of stream simulation design is width of the culvert. The width is generally similar to the reference channel bankfull width and will depend greatly on the objectives of the project. If objectives include passage of organisms that require shallow channel margins and/or banklines at high flows, the culvert width will likely include the banklines. Self-sustainability should be an objective. To be self-sustaining, a culvert located in a channel with a wide active floodplain will have to accommodate floodplain flows without disrupting the stream simulation bed.

The stream simulation bed is a sediment mix that emulates the character and dynamics of material in the natural channel; it erodes and deforms similarly to the natural channel. The material is placed inside the culvert in a pattern and shape to mimic the natural channel, and is allowed to adjust in minor ways to changing hydraulic conditions. Since the profile, cross section, and bed are similar to the natural channel, the hydraulics will also be similar.

A goal of stream simulation is to set the stage so that the channel can adjust to accommodate a range of flood discharges and sediment/debris inputs without compromising aquatic organism passage. Setting the stage means establishing basic channel characteristics of gradient, bed and cross-section shape, bank configuration, and bed material size and structure. Large floods can mobilize and disrupt the armor layer of the bed. Subsequent flows can reestablish the armor layer. Construction of the bed in culvert can be thought of as a disturbance (i.e., the armored layer is destroyed), but it has the necessary bed-material sizes and structure to form an armor layer.

Depending on the type and characteristics of the channel being simulated, the bed might be designed as mobile or key pieces might be designed to not be mobile. Bed material is entrained and becomes mobile at flows of various recurrence intervals based on channel type. Bed material in some streambeds will mobilize at bankfull flow or lower. Coarse material or key pieces in steeper streams with coarser material may not move at flows lower than thirty to eighty year recurrence floods.

In stream simulation design there is no target species of fish or other organism for passage. Timing of migration, swimming ability, and hydrology of migration are therefore not design parameters. As a result, the criteria of the hydraulic design option (velocity, depth, length, passage design flow) are not used to design the culvert. Instead, the physical properties of the natural channel are used as criteria, so that the culvert design produced creates the same passage conditions as the natural channel. By focusing on reproducing the performance characteristics of the natural channel as opposed to maintaining specific hydraulic criteria, passage by species for which criteria have not been developed is more likely to be achieved. Depending on the objectives and scope of the stream simulation project, there are broad categories of species that may or may not achieve passage. A specific design for example may or may not include streambanks and channel margins within a culvert, which might be important for passage of amphibians and small mammals.

It should be noted that the concepts behind stream simulation culvert design can also be applied to the design of short reaches of channel outside of culverts, particularly higher gradient streams where design guidance is not available in the general literature. The width considerations for culverts outlined below need not restrict the size of constructed channels. Guidance on the slope, structure and bed composition of a constructed channel can be found in following sections of this chapter.

The basic premise of stream simulation design is that the simulated channel inside a culvert presents no more of an obstacle to movement of organisms than the adjacent natural channel. Satisfying this premise is a complex relationship of all of the basic elements listed at the beginning of this chapter. Often a specific criterion must be exceeded to make a project practical. In that case the principles behind the criterion and the effect of varying it must be understood by the designer. A safety factor might be applied to other criteria to compensate. Special river engineering, geomorphic, and biological expertise are necessary to design such a project and verify it complies with project objectives.

Because the design of stream simulation culverts requires an understanding of flavial geomorphology, hydraulics, hydrology, and fish behavior, an interdisciplinary design team is essential. A typical design team would consist of a civil (hydraulics) engineer, biologist, geologist, and possibly a hydrologist.

5.1.1 Limitations of Stream Simulations

There are limitations of channels in which the stream simulation can be effectively and safely applied, and there are limitations of what natural stream characteristics the method can simulate. Natural stream characteristics that are not duplicated directly in the stream simulation design process include: channel-spanning wood (though experimental interior wood structures have been built), embedded wood, bankline vegetation and root strength, cohesive soils, riparian functions, and some forced configurations of debris and rigid bed forms. Some large geomorphic processes and features such as channel patterns and channel migration cannot normally be simulated in a culvert.

Though they cannot be duplicated, some of these characteristics can be simulated. Large wood that spans the channel provides roughness and complexity and structure. Debris embedded in the natural channel may anchor bed material and in some cases creates all of the elevation change (slope) of the channel. Rigid bed forms such as bedrock exposures stabilize the channel profile and provide roughness. The roughness of these features can be simulated with durable material such as large rock. These options are part of the design process described below.

Slope of the stream simulation cannot vary greatly from the natural reference channel. Stream simulation designs are therefore limited in that they cannot be designed steep to make up elevation lost by an extreme channel incision unless the steeper section is designed with bedforms that resemble a reference reach of that gradient. A stream simulation design can be combined with channel restoration and other profile control techniques to provide passage. However, if the culvert is just backfilled with oversized rock in a random unnatural manner strictly for roughness then it would be a roughened channel and may create a turbulence barrier.

Natural banklines created and supported by vegetation and root structure cannot exist in a culvert and banklines supported by cohesive soil are not possible to create inside of a culvert. These banklines can be simulated by an artificial bankline constructed of rock that is sized to be immobile up to the design flood flow. Other riparian functions are not simulated within the culvert. For example, riparian vegetation is not present for food and energy input.

The hydrology and surface-subsurface water exchange of active floodplains are altered when a culvert is installed with road approach fills that block flow in the floodplain and force the flow to be constricted through a culvert. The alterations might be at least partially mitigated with a larger culvert, additional culverts in the floodplain, and/or overflow dips in the road. These options are explained further in this Chapter.

5.2 Stream Simulation Design Process Overview

The stream simulation design process generally requires that each of the basic elements listed previously be addressed. Figure 5.1 is a graphical representation of the usual order of analysis and design for a stream simulation application.

The site assessment for stream simulation is generally completed during the pre-design phase of culvert design. The assessment focuses primarily on a geomorphic characterization of a defined reference reach and, where applicable, the channel that would be present if an existing culvert or other artificial influences were not present. A detailed description of the site assessment process is presented in Chapter 3 along with and other pre-design analyses recommended for culvert design.

During the design phase, the basic design process for stream simulation consists of: (1) design of the stream simulation channel, and then (2) design of the culvert to fit around it. The detailed steps necessary to complete these two design elements are presented in sections 5.4 and 5.5, respectively.

Ideally, much of the stream simulation design is empirical, based on the channel configuration of a reference reach from the same stream and near the crossing site that serves as a model to be simulated within the culvert. However, analytical methods may be required where reference reach information falls short. A design is often an iterative process; as design decisions are attempted and completed, previous steps in the design process may have to be repeated to include or compensate for them. A prudent design process would be to do a "rapid design" through the entire design process to verify that a stream simulation design can be accomplished. If it clearly cannot, the designer may wish to consider other options before expending too much effort.

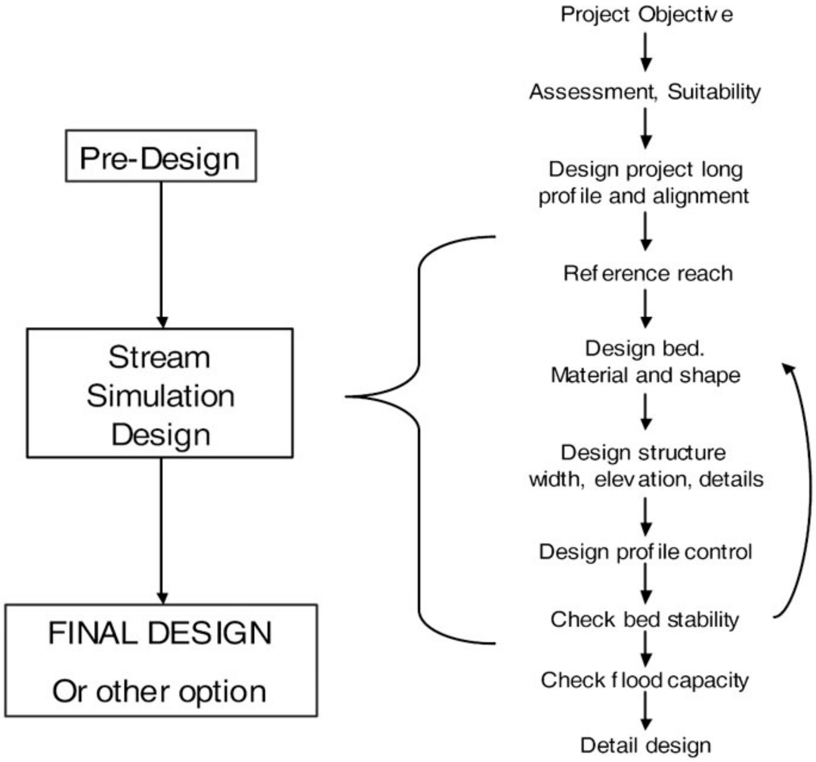

Figure 5.1. Stream Simulation Design Process

5.3 Stream Simulation Channel Design

This section describes the detailed steps necessary to design the bed material, bank material, key features, and channel shape of the stream simulation channel to be constructed inside the culvert.

The intent of stream simulation design is to simulate the natural bed and channel processes of the reference reach or the site. The key to the concept of stream simulation is to create a channel and bed dimensions, shapes, and patterns that affect the ability of animals to move through the crossing. The reference channel cannot usually be duplicated exactly. Some channel features such as wide floodplains, large channel processes, and debris can't be entirely simulated. The functions of these features are mimicked by other features such as floodplain culverts or extra width of the culvert.

Characteristics of the reference channel are used as the basis for design of the simulated bed. The reference channel cross section, profile, and plan form appropriate for the culvert site are simulated in the culvert. The strategy for the design of the bed material and key features varies depending on the mobility and structure of the bed of the reference channel. These characteristics should be reflected in the constructed channel. Table 5.1 shows channel types, dominant characteristics, and a summary of recommended design strategies. Channel types used here are generally defined by Montgomery and Buffington (1992).

One might design a stream simulation using the reference reach and then find that it doesn't fit the site conditions of the crossing. A common discrepancy that should not be continued in a design is a significant difference in slope between the reference channel and what is needed in the designed channel. In that case an alternative reference reach may have to be located. An analytical design might be required if a valid reference reach is not available.

5.3.1 Reference Reach and Long Profile

As shown in Figure 5.1, once the project objective has been identified and the suitability assessment has been performed, a reference reach is chosen, and ultimately a long profile is surveyed and generated. The long profile includes the reference reach, the road crossing, as well as a reach downstream of the crossing containing channel forming influences.

From the chosen reference reach, a representative cross section is developed including designation of bankfull width, channel features are noted (i.e., bedforms, banklines, etc.), the type of channel is identified (i.e. pool-riffle, step pool, etc.), and gradation curves are developed from bed samples.

Once the longitudinal limits of the long profile are determined and it has been surveyed, a plot of the existing stream profile can be generated that includes channel characteristics and processes that might affect the channel in the future. On this long profile plot, potential profiles of the stream and culvert are drawn considering project objectives and reference reach characteristics. An example long profile is shown in Figure 5.2 and contains a range of future profiles based on field conditions.

Table 5.1. Channel Type

Reference Channel Type	Bed Material	Dominant roughness (structural) elements	Streambed mobility	Recommended Design Strategies
Pool-riffle	Gravel; often armored	Bars, pools, grains, sinuosity banks	Armored beds usually mobilize near bankfull	• Simulated bed D_{84} and D_{max} are same as reference reach • Determine rest of bed mix using standard bed material distribution. • Add bands or clusters of material for diversity. • Key features may be important.
Plane bed	Gravel- cobble usually armored	Grains, banks	Near bankfull	• Same as pool-riffle.
Step-pool	Cobble-boulder	Steps, pools, grains, banks	Fine material moves over larger grains at frequent flows. Bed-forming rocks move at higher flows depending on size (can be >Q_{30})	• Steps are spaced same as reference reach. • Step-forming rocks are sized same as reference reach. • Rest of bed mix is based on sizes of non-step forming materials in reference reach.
Cascade	boulder	Grains, banks		• Bed material. • Key features are designed based on reference reach.
Dune-riffle	Sand - medium gravel	Sinuosity, bedforms (dunes, ripples, bars), grains, banks	“live bed”; significant sediment transport at most flows	• Simulated bed can be native bed material or standard borrow mix (no smaller than D100).
Bedrock	Rock with sediment of various sizes in transport over the rock surface	Channel boundaries: bed and banks	Sediment moves over bedrock surface at various flows depending on its size. Wood can strongly affect sediment mobility.	• Stream simulation bed is bedrock. • Banklines and roughness elements are more important and more difficult to place. • Condition, extent, and shape of bedrock are important. • Bottomless structure
Channels in cohesive materials	Silt-clay	Sinuosity, banks, bed irregularities	Fine sediment moves over immobile channel boundaries at moderate flows depending on its size.	• Cohesive bed and banks cannot be constructed. • Clay banks may be similar to culvert walls. • Bottomless structure might leave clay bed undisturbed..

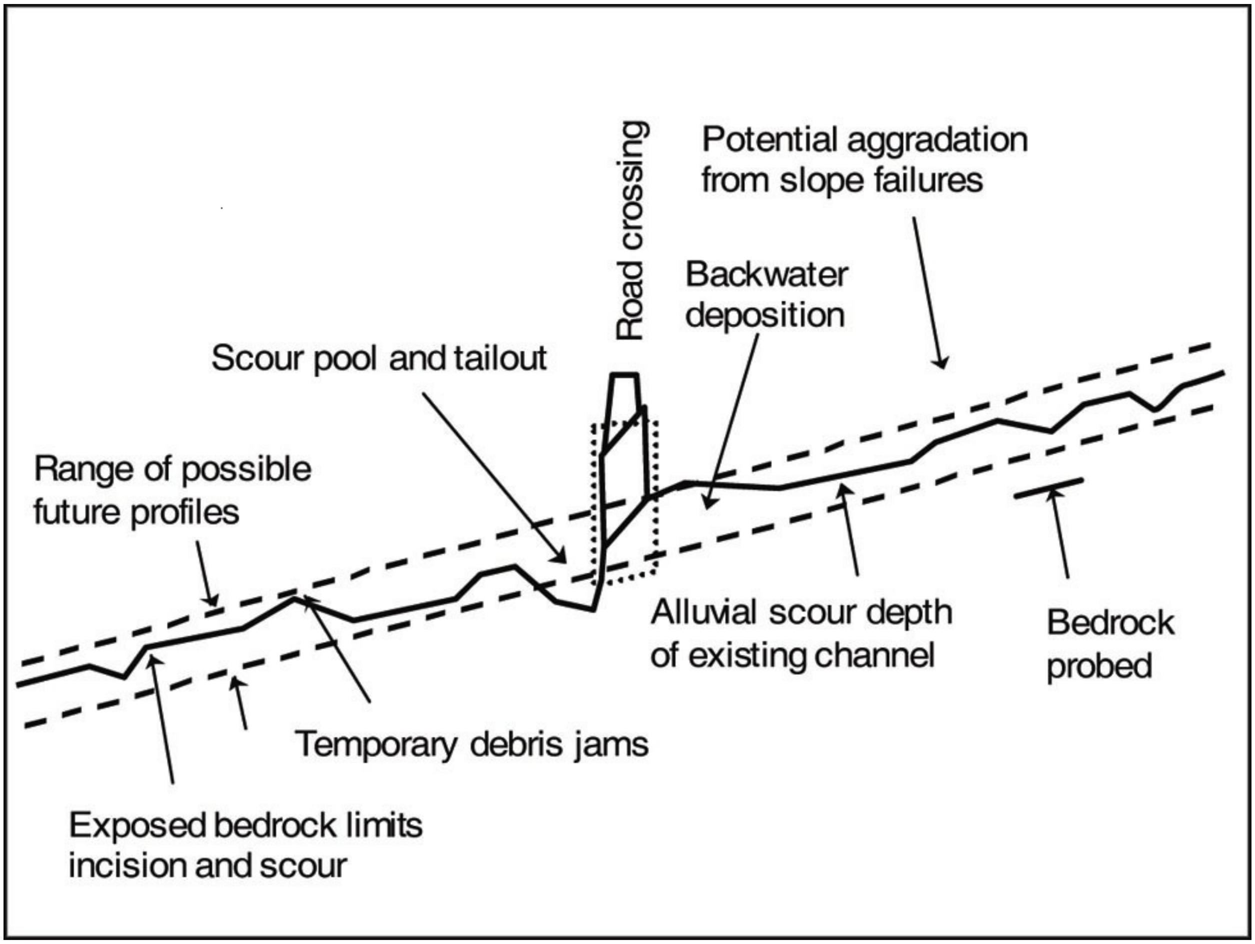

Figure 5.2. Long Profile Example

5.3.2 Bed Material

A key element of the stream simulation design is a well-graded bed material mix, including fines for permeability, which approximates the bed material size of the reference channel. Special cases are bedrock, sand-bedded, and clay channels that cannot be directly simulated as described in following sections. The simplest and most reliable stream simulation design is to incorporate channel bed material and other characteristics of the reference reach into the culvert channel since the reference reach will have the same hydrologic, geologic, and debris inputs as the constructed channel. The culvert bed should also be designed by an analytical process of bed stability.

The design of *pool-riffle and plane bed channels* is described first and most thoroughly. Many of the concepts described for these channels apply to other channel types as well. For example, channel cross-section shape, banklines, large roughness elements, and forcing features likely apply to all designs.

5.3.2.1 Pool-riffle and Plane Bed Channels

This section describes the stream simulation bed design for channels with mobile alluvial bed material; primarily pool-riffle and plane-bed channels. Bed material for channels in this section can vary from coarse gravel (D84 11.3mm) to small boulders.

The important characteristic of these channels is that the bed material is relatively mobile. It moves during flows that occur annually or every few years. The bed material design described in this section can also be used as the design process for the base material of step-pool channels, which are described later.

An alluvial channel is one that is self-formed and controlled by the sediment it transports. Truly alluvial channels are uncommon in some climates where vegetation, cohesive soils, debris, colluvium, and bedrock influence channels. In those cases, key features may control the channel. The design should be modified to account for those influences as described in a following section on key features.

The channel bed material is designed from field samples of the reference channel, and their gradation curves. The larger sizes of material provide channel stability, bed diversity, and control the most persistent bed forms. Smaller particles are important for controlling bed permeability.

Permeability of the streambed is very important. A bed that is porous can allow substantial flow to move through it, and the entire streamflow may flow in the void spaces below the surface of the streambed. There have been culvert installations where the entire summer streamflow went subsurface every year for at least a decade after construction. The issue is especially critical in spring-fed streams where there may be little bed material transported, and in steep channels where the hydraulic slope can drive the flow subsurface. This applies to designs by reference reach as well as the analytical design approach.

Smaller grain sizes are less important for bed form but are very important for bed permeability and possible bed stability. The stream simulation bed mix should have enough fine materials to fill the voids between the larger particles. There should not be a gap in sizes between any classes of material in the mix; all sizes are needed to create a dense bed. Ideally each class of bed material that makes up the mix will be well-graded so all sizes within the category are represented. This is especially important for the smallest size fractions in a mixture of large material. To reduced permeability of the mix, fill the interstitial spaces with five to ten percent sands and finer. The finer material is also helpful to lock the larger pieces together to help reproduce the stability of the reference channel.

There are commonly concerns about water quality and habitat impacts of including the fine material. Some fine sediment will likely be entrained and transported by low or moderate streamflows that would not normally move the material. Because fines are moved at low flows, they can very likely impact spawning beds and other habitats. These effects might be mitigated by jetting the fine material down into the bed and/or placing a veneer of washed gravel over the surface of the bed. These ideas are described in more detail in the construction chapter of this guide.

Rock can be too large for a culvert. In a culvert with rigid walls, an individual boulder can be too large and create a constriction or bridge with other large particles to form a drop structure across the width of the culvert. These may limit migration path opportunities and be more vulnerable to debris blockages. In a natural situation, a channel usually has the flexibility to scour around a large boulder or debris accumulation. In order to avoid constrictions within the culvert, the width of the bed should be at least four times the intermediate diameter of the largest alluvial particle. Individual permanent (non-alluvial) particles buried in the bed can be larger. Limits are described in the section on key features.

The bed mixture is placed without separating the armor and sub-armor layers. Most other bed characteristics such as clustering, textural patches, and grain imbrication and embeddedness are not constructed either. For the most part, the mixture is allowed to be distributed by the natural stream flow. An exception to this is for step-pool channels.

5.3.2.2 Step-pool Beds

Step-pools are important for dissipation of energy and the stability of the channel and should be included in the stream simulation design if they are present in the reference channel. Step-pool configurations and characteristics are described in the assessment chapter of this guide. Assessment of the reference channel should include characteristics of the step-pools such as step height and configuration, step spacing, and the size and alignment of key pieces.

Madej (2001) estimated that organization and roughness of the channel bed into regularly spaced steps probably takes several decades after being disrupted by a sediment pulse. Time scale depends on the occurrence of channel organizing flows as well as bed forcing features. Conditions following a sediment pulse are similar to a newly constructed channel bed with no significant sorting or compaction.

Step pools are formed by the largest particles in the bed accumulating and supporting each other to form a weir or step that is more resistant to movement than the individual pieces. Boulders form the framework of steps which supports smaller cobbles and boulders. Steps should be approximated in the initial construction with the expectation that individual rocks will adjust their position and location during high flows to lock together. The length and height of the steps and the step spacing are the important characteristics identified in the reference reach that should be considered in the culvert bed design. Place the step pools at the same spacing as the reference channel. Step pools in natural channels are typically spaced one to four channel widths apart and are closer in steeper channels.

Two classes of material are selected for step-pool channel beds. Additional classes might be needed for banklines and/or key features, which are described in other sections of this chapter. The bulk of the step-pool channel bed is the material between and beneath the step structures. It can be designed from a pebble count of the reference channel similar to what was described for pool-riffle channels. The pebble count in this case should be stratified to cover only areas between steps of the reference channel.

The second class of material is the particles that make up the steps. Key pieces in the reference channel steps should be characterized by size and shape. The steps are sized and designed for long term stability, and a stability analysis should be conducted to verify the material specified is stable during a high design flow. The material between steps will periodically scour and be replenished by the existing bedload moving through the system.

Other features such as channel shape, banklines, and wood and rock forcing features may be important elements to a step-pool channel. If these features are observed in the reference channel, include them in the design of the stream simulation. See the section on key features for more information.

5.3.2.3 Cascade Channel Beds

Bed stability is critical in cascade channels. The bed of natural cascade channels moves infrequently only during events that might recur in the scale of decades. Since cascade channels are steep, if the bed fails it is likely to leave a bare culvert that will not recover by natural replenishment of bed material.

An initial design of the cascade channel can be made by the same process as described for pool-riffle beds. The primary difference between the design of cascade channels and pool-riffle beds is due to the relative mobility of the bed. Cascade channel beds are much less mobile. A stability analysis should be conducted to verify the material specified is stable during a high design flow.

5.3.2.4 Dune Riffle Bed Channels

The key element for stream simulation in these channels is the bed material and its mobility rather than bedforms. The bed material is relatively mobile in these channels so no structure, other than rock bands, is built into the stream simulation bed and the sediment mix for the bed is less critical than for other channel types. It is important to use material that is similar to the natural channel to achieve more or less the same mobility. Bed material should be rounded unless the bed of the reference reach is naturally angular.

Other features such as channel shape, banklines, and wood and rock forcing features such as rock clusters may be important elements to a step-pool channel. See the section on Key Features in the pool-riffle bed design section. Clusters can be made of rock that is one to two times D_{100} but no smaller than coarse gravel. The larger material is used in beds that are more mobile.

5.3.2.5 Bedrock Channels

Bedrock channels often have bedrock exposed in the bed but have banks of other material. They may have other roughness elements such as debris and single or clustered boulders. If channel margins and/or banklines are important to the objective of the project, they should still be designed into the stream simulation. Exposed bedrock is often tilted, so when contained by a culvert, a deep and smooth channel is formed along one wall at low flow. Boulders might be added for roughness in such a case. Special considerations such as embedding, anchoring, or clustering of large boulders may be required to keep them from rolling or sliding out of a bedrock channel.

The condition, extent, and shape of bedrock under a road fill are often not clear even with geotechnical reconnaissance data. Flexibility for design changes based on what is found should be accommodated in the contract.

Bedrock channels sometimes exist where a bed of alluvial material has been scoured leaving the bedrock exposed. This most often occurs in mountain streams where woody debris has been removed and/or not naturally replenished due to urbanization or forest practices or where a debris flow has scoured the channel to bedrock. The lack of bedrock erosional features such as fluting, longitudinal grooves, and potholes may also indicate that the bedrock is typically covered by a thin veneer of alluvium which may have been recently mobilized during a large flood (the alluvium is typically stable during lesser flows). Restoration of the bed should be considered by placement of debris and/or colluvium to help develop a natural alluvial bed and/or stabilize a constructed bed. Channel restoration is further discussed in the channel profile section in this chapter.

Bedrock channels can also have a thin, continuous or discontinuous veneer of alluvial material that can be mobilized during high flows, only exposing the bedrock during high flows. Hence, flow hydraulics and sediment transport are strongly controlled by the underlying bedrock, not the thin veneer of alluvium.

Other features such as channel shape, banklines, and wood and rock forcing features may be important elements to a bedrock channel. If these features are observed in the reference channel, include them in the design of the stream simulation. See the discussion of key features in the following section.

5.3.3 Channel Shape and Form

This section discusses various elements of channel shape and form including cross-section shape, bed forms, banklines, and key features.

5.3.3.1 Cross-section Shape

The cross-sectional shape (Figure 5.3) of the reference channel is an important part of the stream simulation. If channel margins and banklines are important to satisfy project objectives, they should be included in the channel designs for stream simulation culverts. Channel margins are the shallow corridors commonly formed as gravel deposits near the edges of channels.

The bed of the constructed channel should include a low flow channel. The constructed low flow channel is only intended to provide some shape to the initial bed; it is not expected to persist through flood events. If designed with features as described here, floods will leave the channel with diversity and a thalweg. Construction of an initial low flow channel is especially important if the culvert bed material is larger than the natural bed material.

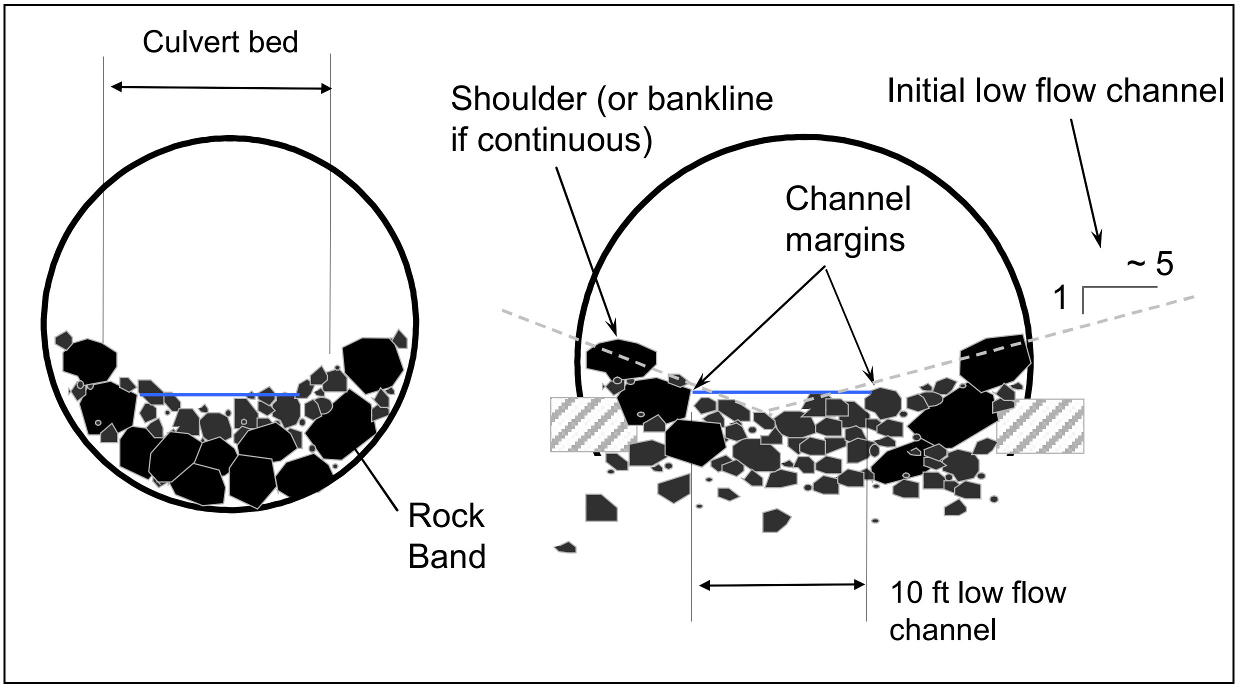

Figure 5.3. Cross-section Shape

The precise shape of the low flow channel is not critical. The lateral slope of the vee shape should be roughly five horizontal to one vertical. Only a portion of the bed width, perhaps a ten-foot corridor, should have the vee shape. The average bed elevation in the cross section is used as the control elevation for the profile design. The shape and lateral slope should be rough so the bed qualitatively resembles the bed variation in the natural channel.

Some initial sorting of bed material is important. In lower gradient channels, bed forms are fluid and it may take a number of high flows before channel structure is formed. In the meantime, and especially if no bankline is constructed, the bed will tend to be very flat and the flow will be very shallow. The shallowness might be a barrier to migration of fish. There is also a tendency for a trench to develop along one wall of the culvert. The relative smoothness of the culvert wall creates a higher local velocity there that will scour the trench. To prevent either of these situations, rock bands or clusters should be added. Bands and clusters are similar features but of different scales. Bands are diaphragms of rock that occupy the entire cross section of the bed and are spaced periodically through the culvert. Clusters are similar but simply a pile of rocks partially buried at each edge of the channel.

Bands and clusters are not permanent rigid structures; they should be modified by high flows. They are to create diversity in the cross section, which would be created in a natural channel by flow deflections from bankline irregularities, debris, rootwads or other structures. These features should be used in stream simulation culverts with bed gradients less than about four percent and when a continuous rough bankline is not included in the design.

Generally bands or clusters are made of rock that is about one to two times D_{100} but no smaller than coarse gravel. The larger material is used in beds that are more mobile. The features are not structured so a well sorted mix is not necessary. The crests of the bands are lower in the middle, encouraging the channel to move back to the central part of the culvert. The high points of clusters and bands are about two times the diameter of the rock they are made of above the elevation of the bed profile.

Since the rock bands are not persistent, their spacing is not critical. Spacing could vary with slope and channel width and could resemble the spacing of pool riffle sequences in the reference channel. The vertical difference between crests should be less than or equal to 0.5 feet. The vertical distance between crests is suggested only to prevent bands from being hydraulic drop structures.

The bands described here are similar in some ways to steps in step-pool channel configurations. The difference is that the purpose of rock bands in low gradient channels is to create shape and diversity and they are not permanent features. Step pools dissipate energy, create stability, define the longitudinal profile of steep channels, and are more persistent.

The intent is to simulate the roughness and diversity along the bank of a natural channel that provides a shallow migration corridor. In some cases the culvert walls might perform the same function when compared to a smooth vertical bank in the reference channel. Some diversity such as rock bands along the bankline should be provided in any case. Actual pool-riffle features and sorting of bed material are certainly necessary to achieve stream simulation but these are difficult and costly to construct and it is expected that the channel will, for the most part, create these characteristics.

5.3.3.2 Banklines

The diversity, roughness, and shape of banklines may be critical to satisfying objectives of passage of aquatic organisms. Banklines will often not form in constructed channels within culverts, because without root structure, cohesive soils, or the ability to scour into parent bed material, alluvial banklines cannot form. However, bars may form at least through part of the length and on one side of culvert and provide some of the benefits of a bankline.

To simulate a bankline that reflects the range of low flow widths and depths in the reference channel, a line of large rock is placed along each wall of the culvert and the spaces between and behind the rocks is filled with the bed material mix. Fill over the bank rock with bed material so it will wash into place between the rocks. The intent is to create a permanent bankline so material of adequate size to be stable during severe floods is required. An initial estimate of bank material size is based on experience and with consideration of the reference channel. Bank material might be up to twice the size of D_{100} in the channel or six-inch minus quarry spalls, whichever is greater. It might also be based on Dm of the reference channel if that material appears to be non-mobile. Later in the design process the size of the bank rock and other key pieces will be verified with a stability analysis.

Extra culvert width may be necessary to create a stable bankline without constricting the bankfull channel. In lieu of providing the culvert width necessary to place banklines, a bankline could be simulated by roughening the concrete of a footing wall on a bottomless pipe. Ideal roughening would be rocks embedded into the concrete. Embedded rocks could be simulated in the concrete with a special concrete form or commercial precast concrete elements might be built into the bankline. Partially grouted rock might be used to roughen a concrete footing wall. The objective is to increase the stability of the rock without sacrificing all of the flexibility of individual rocks within a limited bank width. Grout might be used to fill about half of the voids behind and between the rocks and it might be tied to the culvert footing wall. Another approach that has been employed is to attach vertical baffles to the walls of metal and concrete pipes. The purpose of the baffles is to create roughness and deposition along the wall rather than to control the overall velocity for fish passage. Baffles would have to be spaced no more than several feet apart so they would act as a continual roughness element.

5.3.3.3 Bed Forms

Bed forms other than rock bands and steps in step-pool channels are not generally constructed within stream simulation culverts. Constructed bedforms will not generally be stable since the materials are not sorted nor the forms built hydraulically by stream forces. The intent is that if the material is provided, bedforms will be created naturally during the first freshets experienced by the project.

Some designers recommend that bedforms be constructed inside the pipe to immediately simulate those bedforms identified in the reference reach. Cobbles and boulders may only be mobilized at flows greater than bankfull. Constructing features with those particles allows the constructed channel bed to respond more naturally during initial high flows. Channel-bed structures such as particle clusters, longitudinal bars, transverse clast dams, etc. can certainly be constructed if observed in the reference reach. Construction of bedforms will add to initial diversity. However, constructed bedforms should not be expected to be permanent features.

Rigidity of the bedforms is generally directly proportional to stream gradient. In reaches where the entire bed can mobilize, bedforms such as scour pool tailouts are flexible. In steep streams where the bedforms are persistent for long periods, sediment is moved from pool to pool with the key elements remaining stable and intact. In this case artificial steps or cascades should be designed to be stable during flood flows.

5.3.3.4 Key Features

Features that affect the channel form and stability such as colluvium, bedrock, and debris should be characterized in the reference channel and accounted for in the stream simulation design. The reference channel may also have large roughness elements that should be included in the channel design.

Colluvium is generally defined as rocks delivered to the channel by hillslope processes rather than alluvial processes. For the purpose of this guide, we consider colluvium to also include lag deposits from extreme flood events or debris flows, or erratics from glaciers. Forcing features might be partially buried in the bed, buttressing bed material and/or they might block part of the channel cross-section and create roughness. Debris in the reference channel might be in the form of small jams, buried wood that buttresses and/or forms steps, or wood protruding from a bank. The function of either key feature must be included in the simulated channel or the bed material must be modified to compensate for the lack of it. In addition to key features, initial cross section shape and permanent banklines as described previously may be required to achieve project objectives.

The scale and spacing of bed-forcing elements should be set to simulate reference reach conditions. If colluvial material in a reference channel is not recognized as being non-fluvial, a designed channel may end up with much larger bed material than what would truly simulate the reference reach. Colluvium can be recognized by its limited distribution through the length of the channel and by being a unique larger size class in the bed material distribution. There is usually a gap in size classes between the smallest colluvium and the largest alluvial material that can be seen as a bimodal size distribution in a particle size distribution analysis.

Forcing features buried in the bed can be simulated with large rock. Angular rock and clusters of rock have greater stability than round rock and individual rocks. The size and distribution of the rock might be similar to colluvium in the reference channel or as indicated by a stability analysis. The largest alluvial particle should not exceed a quarter of the culvert bed width. Non-mobile key features are not alluvial and may have to be larger. Key features often span the entire channel and should be simulated that way and built with a group of rocks similar to a step pool configuration. A cluster of rocks will provide some diversity of flow and migration paths, will conform better to walls of the culvert and prevent a narrow slot there, and be narrower in the streamwise direction similar to a buried log in a natural stream. The depth of the bed in a culvert should be at least one and a half times the median diameter of rocks used as key features. This will prevent individual rocks from interacting with or bearing directly on the floor of the culvert. Rocks used as key features should be buried by about three quarters of their diameter so they buttress and support the bed. Placement should be similar to step pool controls as described below. Similarly sized rock can be scattered in the surface of the bed to provide a roughness more or less equivalent to that created by forcing features.

There is some risk in depending on non-alluvial material in the culvert for stability. If colluvial material is scoured from the stream simulation culvert, it might not be replenished and therefore the structure of the project bed may be jeopardized. See the assessment chapter for more background on sources, implications, and identification of colluvium. An analysis should be conducted to verify the stability of colluvial material or individual elements placed to anchor other bed material in the stream simulation (see the section on stability analysis in this chapter). Potential solutions to increase stability include increasing the size of the culvert, increasing size of colluvial material in the culvert, and bed retention sills attached the culvert invert.

Large scale roughness includes bedforms, bank irregularities, large debris, and roughness of channel alignment. The function of large scale roughness is similar to forcing features described above though the features may be of a larger scale. Tight channel bends dissipate energy; if they are replaced by a straight channel, roughness should replace the function of the bends. Buffington and Montgomery (1999) describe the roughness effects of wood, bar formations, and bank irregularities. These characteristics should be described as part of the site assessment and accounted for in the stream simulation design. Unfortunately, there is no established procedure to simulate large scale roughness and simulate it with other materials. The difficulty is in characterizing it as roughness. The general approach of stream simulation is to characterize the roughness of the reference reach bed material and simulate it directly. Large roughness elements such as tight channel bends, channel-spanning debris, and bedrock and tree root outcroppings are not included in that simulation.

The large scale roughness might be simulated with large rocks scattered and embedded into the channel bed. Ferro (1999) describes the roughness created by various arrangements and concentration of boulders placed on a gravel streambed. Another simple method is to quantify the frontal area of all roughness elements in the reference channel and provide the same frontal area in the stream simulation with boulders. A third method is described by Arcemont et al. (1989). The method uses a base roughness value from bed friction, and applies correction factors for the effects of surface irregularities, variation in the shape and size of the channel cross section, channel obstructions, vegetation and flow conditions, and for meandering of the channel. For example, this method can be used to compensate for shape of the channel cross section by adding roughness with boulders or bed material. At this time, none of these methods have been fully developed or applied to stream simulation in practice.

Simulating a channel with large scale roughness elements may be more risky than a purely alluvial channel. These features must be constructed carefully to be successful. This is especially true for steeper channels where dissipation of energy by forcing features is critical to channel pattern, form, and stability. It may be prudent to oversize Dm and colluvium materials, and widen the culvert to reduce risk. See the stability analysis section of this chapter. It is recommended that special geomorphic and engineering expertise should be consulted in these cases.

5.4 Stream Simulation Culvert Design

Now, for the first time in the stream simulation design process, we consider the road crossing structure itself The design process to this point has defined the probable range of stream profiles at the site, and the shape and material of the stream simulation channel. In this part of the design process, we will determine the culvert elevation, style, shape, and dimensions (diameter or width and height). Culvert shape, dimensions, and elevation are determined iteratively because they affect each other. Design of the culvert itself must be preceded by the alignment, profile, and bed designs because those elements determine the width of the bed and therefore the size of the culvert. Simply put, the design of the crossing is just fitting a structure around the channel that has been designed. Because there are specific criteria that will influence culvert shape and dimensions, such as depth of cover over the pipe and minimum and maximum embedment depths, it may become apparent to the designer that a culvert is not the optimal solution. Considerations of self-sustainability may also influence the type, shape, and material of culvert structure that is used.

Several conditions might determine the size of the culvert, such as the range of bed profiles, maximum sizes of alluvium and colluvium, bed stability analysis and the width of the channel and banklines to be contained within the culvert. All of these conditions must be satisfied at the same time. The culvert will therefore likely be larger than needed to meet certain conditions that have traditionally been used for sizing culverts strictly for hydraulic capacity.

5.4.1 Culvert Elevation

Once the project bed profile and bed characteristics have been determined, the elevation and slope of the culvert structure itself can be established. The discussion of elevation in this section relates to the invert of a solid structure or to the footings of a bottomless structure. The elevation of the culvert relative to the streambed may be affected by the culvert shape, the expected variance in channel elevation overtime, flood capacity, and the maximum size material in the bed. A preliminary elevation of the culvert might be found but it may be changed later in the design of the culvert width and shape.

Set the culvert elevation and profile to allow the range of channel profiles expected for the life of the project and described in the project profile section. Remember that the stream channel may at some time be at any elevation within that range. One goal of establishing a stream simulation culvert profile is to prevent the invert of the culvert from becoming exposed during its design life. If the invert becomes exposed, the natural steam is certainly not simulated and the bed may not recover and rebuild on its own. A second goal is to maintain flood and debris capacity when the bed is at its highest possible elevation.

Depending on the risk and uncertainty of the range of profiles, provide a safety factor in depth of the culvert invert and height of the culvert. For example, the risk of scouring below the stable footing embedment depth of a bottomless structure may dictate the need for a deeper footing. A larger culvert may be needed where substantial profile change or scour is likely.

An economical design will set the bed near but below the maximum width of the culvert to avoid unnecessary structure width and so the water surface width does not contract with just a small increase in stage. Setting the high bed elevation at the mid-point of the culvert also ensures headroom above it for floodwater and debris. The high profile should be no higher than 50% of the rise of the culvert as measured from either the footings of a bottomless structure or the invert of a pipe.

A minimum bed depth must be provided to accommodate some bed width and depth for minimum bed thickness and to provide a safety factor. A circular culvert embedded into the streambed no less than 30% but no more than 50% of its rise is a good practical guide.

Figure 5.4 shows the relationship between the range of channel profiles and the culvert rise, which is the inside vertical dimension of the culvert. Using the recommended burial range of

30% to 50% given above, the culvert rise must be at least five times the vertical distance between the low and high profiles. For example, if we expect the bed elevation to vary two feet, then the height of the culvert has to be at least ten feet. This size may or may not hold when we size the width of the culvert. Bed stability and debris passage may affect the height of the culvert. Further, both depend on the culvert not becoming submerged during the design flood flow, which is discussed in the stability analysis section of this guide.

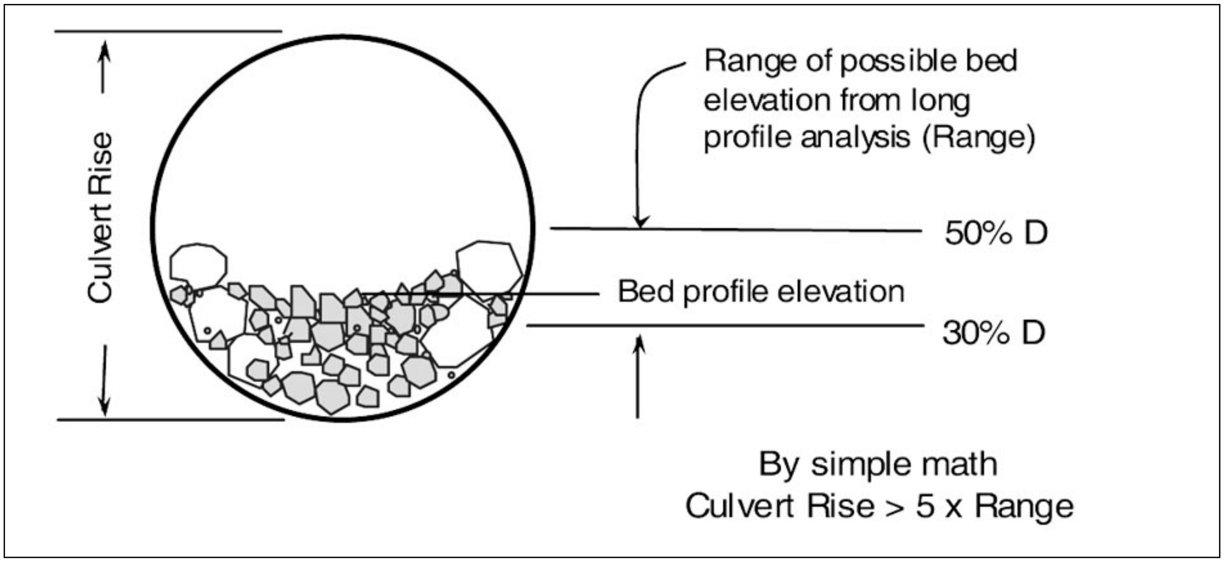

Figure 5.4. Profile Range

There are conditions that may affect these burial and culvert size recommendations. The size of the bed material may affect the depth of the culvert bed and therefore the culvert elevation. For the bed material to be well integrated and able to structure itself the depth of the bed should be at least one and a half times the diameter of the largest colluvial material and four limes the largest alluvial material in the bed as described in Section 5.3. The depth of the bed, and therefore the culvert invert elevation, should be checked after the bed material is designed

5.4.2 Culvert Width

The minimum width of a stream simulation culvert shall be equal to, or greater, than the bankfiill channel width, but not less than 6 feet. Culvert width addresses self-sustainability, which is the interaction of high flows, the bed, and the culvert to create and maintain bed material sizes and patterns within the culvert bed that accurately simulate the natural channel. Other things that affect culvert width are hydraulic capacity and stability of the culvert bed, as well as construction, repair, and maintenance considerations.

Conditions that might affect width of stream simulation culvert are as follows:

Based on project objectives:

- Width of channel and banks within the culvert
- Self-sustainability of the bed
- Hydraulic capacity of the culvert
- Stability of the bed

- Construction, repair, and maintenance needs
- Passage of mammals
- Reduce risk of blockage by floating debris or beaver activity
- Increased flood capacity and/or bed stability
- Meandering channel pattern part of project objectives

Based on channel characteristics:

- Active floodplain
- Flow concentrations in floodplain
- Channel migrating laterally or meanders translating longitudinally
- Wider channel expected in future
- Channel skewed to road crossing
- Ice plugging in severe cold climate
- Large bed material relative to culvert width
- High water level stage during floods or high tides.

For the stream simulation bed characteristics to be self-sustaining, the culvert must simulate the hydraulics of the natural channel at bed-forming flows. For many low to moderate gradient alluvial channels in humid climates, the bankfull flow is a useful measure for design of the channel. Constricting the channel at that flow will change the character of the bed and deviate from simulating the natural channel. To satisfy this objective, the channel width in the culvert must be at least bankfull width. It may have to be larger than that if water that would normally flow on the floodplain is confined to the culvert.

In cascade and step-pool channels, bankfull width is not directly relevant to the width of the culvert though it is a good initial estimate. It is well documented in semi-arid climates that when the ratio of relatively infrequent flood peaks to the mean annual flood is large, infrequent large floods typically control channel form rather than bankfull flow.

In a confined channel where the stream width does not change substantially with stage, the culvert channel may not need to be wider than the reference channel width as long as the bankline character in the culvert is characteristic of the natural channel and the culvert is sized to safely pass flood flows. Bankline character includes roughness of bank material and bank irregularities. As a word of caution, incised channels may look narrow early in their development but will widen with age (Schumm et al. 1984) or with recovery from disturbance, although widening due to channel evolution is usually gradual and not likely to be significant within the typical design life of a project. Channel widening following recovery from a disturbance should be accounted for. Stream simulation culverts should be sized to anticipate the expected evolution of the natural channel near the crossing as well as the confined channel within the culvert.

If an existing channel is unnaturally wide due to disturbance and you expect it to narrow in the future, the culvert should be sized for the existing channel width with the expectation that recovery will occur inside the culvert as in the adjacent reaches.

If a culvert is located in a channel within a wide active floodplain, flow will be forced from the floodplain into the constriction of the culvert. Three effects of the contraction are of concern.

The additional water forced through the culvert may cause bed scour in the channel at a flow lower than it would occur in the natural channel. The lower critical flow may cause a bed failure. The bed at the culvert inlet is the most vulnerable to failure due to constriction scour. The bed in the vicinity of the inlet is vulnerable to failure even though the hydraulic conditions in the rest of the culvert are similar to the reference channel. It may affect the bed shape or structure so it no longer simulates the natural channel. The third issue is that forcing flow off of a floodplain may affect habitats and movement of aquatic and terrestrial organisms within the floodplain.

Figure 5.5 shows several examples of culverts in channels with and without floodplain contractions. This situation is described thither in the stability analysis section of this chapter.

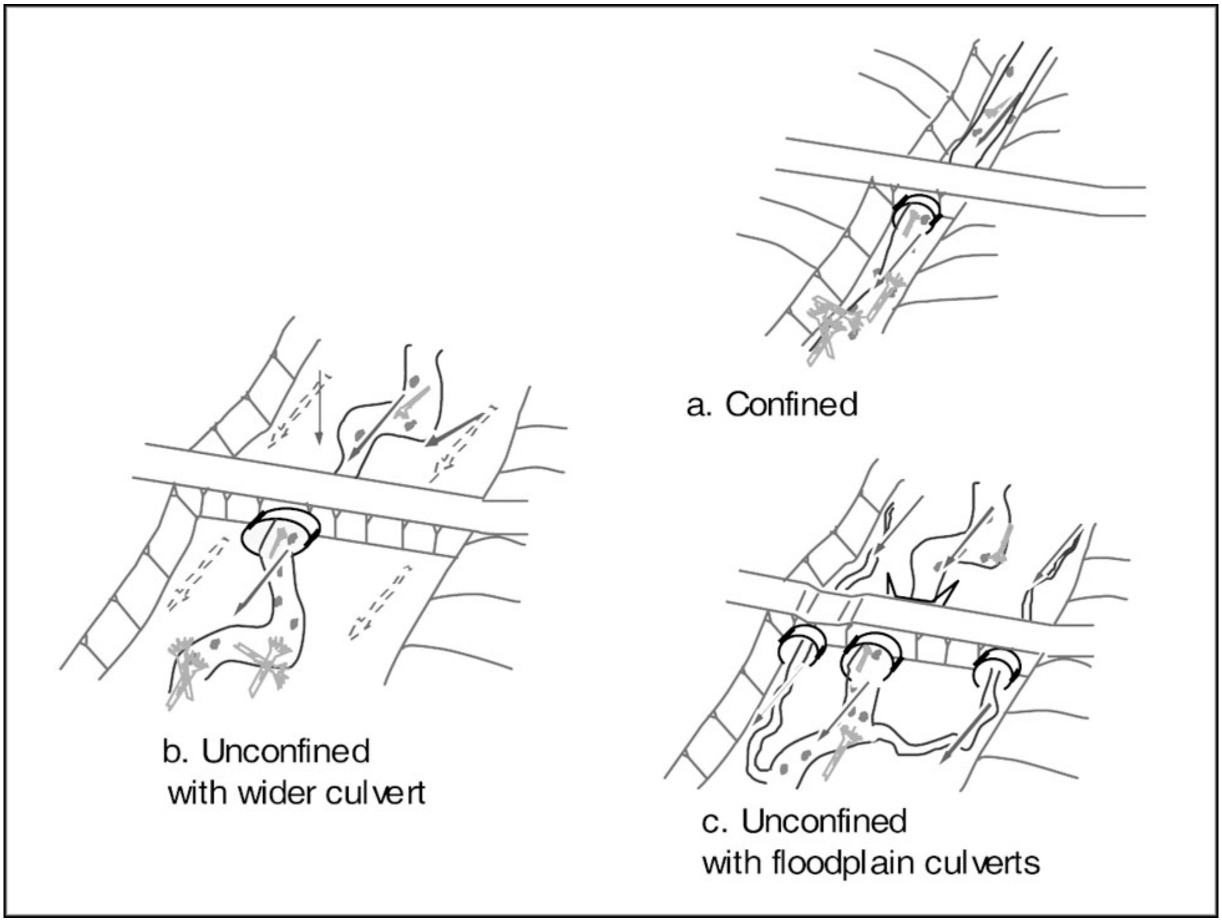

Figure 5.5. Floodplain Contraction

If the channel bends at the crossing site or meanders significantly and the intent is to include this characteristic in the project, the culvert can be enlarged to contain the width of the bend or meander or a portion of it. A special bank design would be required for an outside bend within a culvert. The bank would normally be considered rigid rather than deformable. It should be designed to be permanent and not allow a deep thalweg to be scoured along the bank toe. Some meander migration might also be accommodated by the width of the culvert. Some vertical and plan form variation can take place in a stream simulation culvert if the culvert is wider than the channel width and deeply embedded. Low flow channels will usually meander within the length of the pipe. Additional culvert width might be necessary if the culvert is skewed to the road alignment as described in the culvert alignment section of this chapter or if natural lateral migration of the channel will likely create a skewed inlet condition.

There is also a lower practical limit to the diameter of culvert that can be constructed as stream simulation. A culvert with a diameter or rise of about five or six feet is a minimum because the bed cannot feasibly be constructed in a smaller pipe except with hand labor. Access may not be an issue if strong hand labor is available and the rock is not too large to manipulate by hand or with hand equipment. This size consideration should also be evaluated relative to future access for maintenance and repair.

5.4.2.1 Floodplain Culverts

Relief pipes can be placed in the floodplain for connectivity through the floodplain. Size of floodplain culverts might be determined by the same parameters and criteria as the primary culvert but using the size of the side channel. Countersink them similar to the criteria for culverts placed in the main channel.

Floodplain culverts should be located at flood swales and side channels so floodplain flow patterns are preserved. If there are no signs of flow concentration, locate culverts at the center of floodplain conveyance. The center of conveyance is determined by calculating the centroid of the flow in the floodplain and if no swales are present it is controlled by the depth of flow and varying roughness across the floodplain. Johnson and Brown (2000) describe a precise calculation technique.

Floodplain culverts might also be necessary to preserve floodplain functions and passage of organisms through the floodplain. They become more useful with increasing width of the floodplain on either bank because that width implies increased separation of channel and floodplain hydraulics that are significant for floodplain form and features. When there are signs of flow concentration in the floodplain, such as swales and side channels, consider adding floodplain culverts. Based on visual assessment of side channels in a humid environment, side channels generally occur when the floodprone width on one bank is more than four times the bankfull channel width. The use of floodprone width for a threshold of floodplain function is an indicator of significant separation of floodplain hydraulics at flows that are effective in creating floodplain form. It might be more or less than that threshold if the floodplain has more or less conveyance.

Floodplain culverts that concentrate flow can create a risk of diverting and capturing the entire channel. If the floodplain is well developed with mature woody vegetation, blockage of the culvert by fallen debris may prevent an entire channel change and still meter flow through. If the floodplain culvert is small enough to create a backwater if the entire flood flow were passing through it, it will push flow and the channel back to the primary culvert. Multiple smaller culverts in the floodplain reduce the risk of channel capture.

5.4.3 Culvert Material and Shape

No single culvert material or shape is best for all stream simulation situations. Figure 5.6 shows shapes and nomenclature of culverts used in this guide. All of these culvert shapes can have natural streambeds within them. If the bankfull channel widths and bed characteristics are the same as the natural channel and there is adequate hydraulic capacity to sustain the stream simulation characteristics though the life of the project, there is little difference among these designs from the point of view of passage of aquatic organisms.

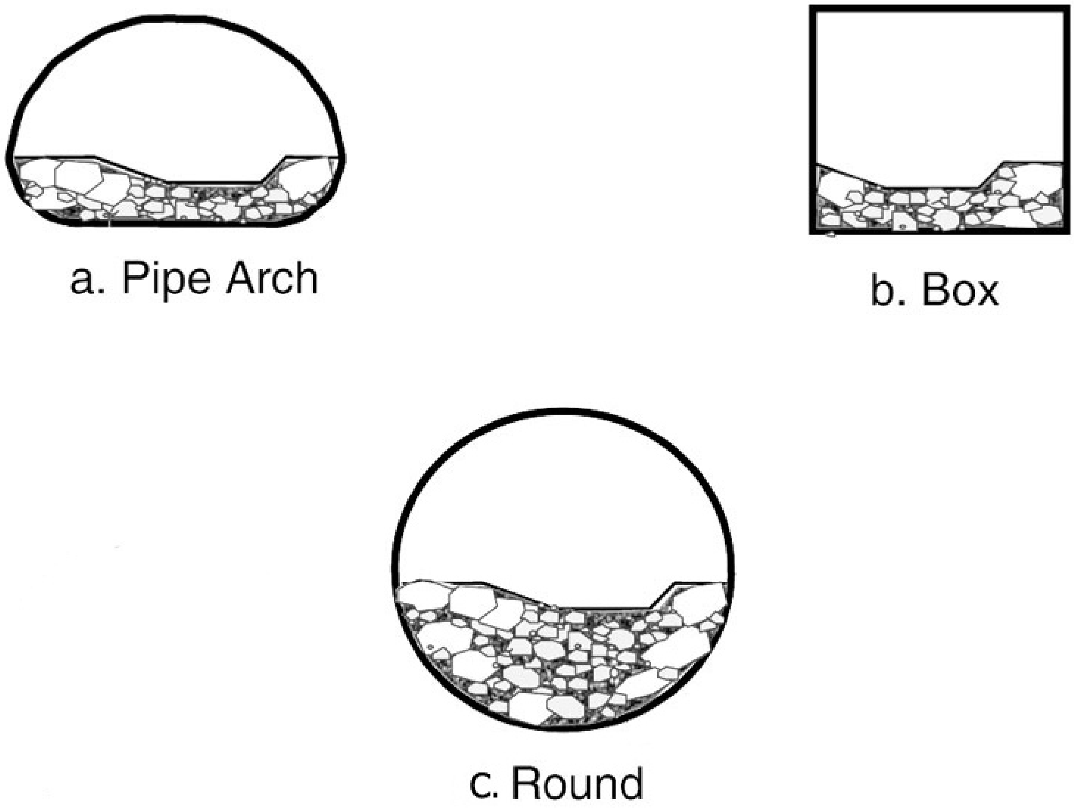
a. Pipe Arch
b. Box
c. Round

Figure 5.6. Culvert Shape

The shape and material of a culvert can substantially affect the initial and life-cycle costs of a project however. Cost differences may be due to material costs, project sequencing, limitations of project duration, competence of soils for structural loading, location and availability of materials, excavation volume, excavation limitations such as bedrock, and the cost of delivery to remote locations. Other differences include reliability, limitations of hauling over-sized materials, durability and resistance to corrosion and abrasion, risk of vertical instability, debris passage, hydraulic characteristics for stream simulation, and experience of the construction crew.

5.5 Stream Simulation Profile Control

This section contains suggestions on how to design and construct the channel profile.

If a channel steeper than the reference channel is needed in order to make up elevation differential through the project, profile control measures may be necessary. Profile control structures are structures that hold a profile in place. They function similarly to forcing features in a natural channel. They may be artificial or simulate natural conditions, and they may be permanent or temporary and/or deformable. They may or may not comply with the premise of stream simulation depending on whether similar structures are present in the reference channel. Biological monitoring may be necessary to determine the suitability of these constructed features with respect to passage of specific aquatic organisms.

There are several options for profile control; no single solution satisfies all situations. Depending on the desired project profile and site limitations, control structures may be necessary upstream or downstream of a culvert or a combination of the two. Figure 5.7 shows upstream and downstream options.

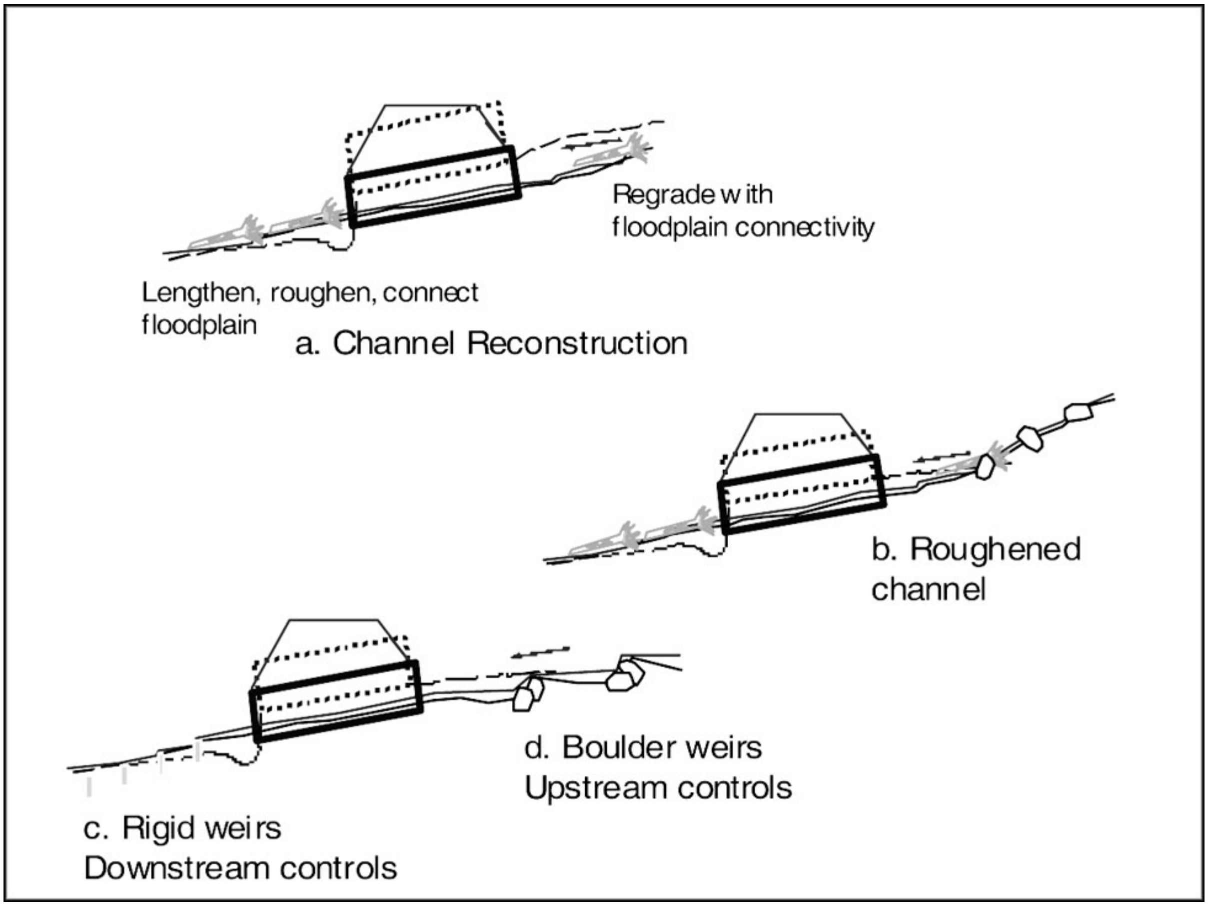

Figure 5.7. Profile Control Options

5.5.1 Headcut

If a decision is considered to allow an upstream headcut to create a new profile, the consideration of this section should be reviewed. The profile control scheme could to allow a headcut, but with structures included to control its extent and/or its rate. Temporary controls such as scattered, buried, or temporary rock structures that are expected to fail over time can mitigate some of the headcut impacts. If debris is to be employed, careful consideration should be given to the potential for its mobility.

5.5.2 Channel Restoration

An elegant and durable correction to achieve passage of aquatic organisms is one that is process-based and that solves the underlying problem rather than forces an artificial profile into a crossing site. Channel restoration as a profile control measure means the downstream (and/or upstream) channel is restored to a natural and self-sustaining condition and in the process the profile is changed to achieve passage at the crossing. This option can be used in channels that have incised due to unnatural changes in hydrology and/or removal of debris.

Channel restoration is the re-establishment of structure and function of the stream ecosystem with the goal of achieving a condition as close as possible to pre-disturbance conditions and functions. This goal is difficult to achieve in multiple use watersheds where land-use practices have greatly altered the watershed hydrology and sediment regimes.

Channel restoration can restore in-stream, riparian and floodplain habitats, restore channel processes, reverse bank erosion, and be more self-sustaining than other options of correcting passage barriers. Channel modifications can be used to address a variety of process- and function-related habitat problems that are often symptoms of disequilibrium. The channel restoration option should be considered at both new crossing installations and at culvert replacement projects.

Channel restoration may include reconstruction of the bed up to a natural grade, restoration of floodplains by removal of levees or other constrictions, construction of a floodplain by excavation, and/or building meanders to recreate channel length and diversity. Channels that have been scoured down to bedrock or cohesive channel beds might be converted back to natural alluvial channels. Design elements are channel cross section, profile and bedforms, planform, grade control, bed material, bank reconstruction, riparian revegetation, floodplain, and habitat considerations. A project that includes restoration of an incised channel can be extensive and can extend a considerable distance from the crossing.

Channel restoration can also be applied in aggraded channels upstream of culverts by reconstructing the channel and/or floodplain at a lower and natural grade.

Only some stream ecosystem functions will be recovered by manipulating certain components of the channel. In that case “channel rehabilitation,” as described by the Federal Interagency Stream Restoration Working Group (1998), might be a more appropriate term for culvert removals and replacements. Rehabilitation does not reestablish pre-disturbance conditions, but improves fluvial and ecological processes within the existing conditions of the watershed/channel

Reconstruction of an incised bed to a natural grade might be done with individual structures that are intended to trap bedload and fill over time or by filling the entire channel and building in the structure and diversity of the channel. If individual structures are used, it may be similar to the rigid bed control structures discussed below. The structures should simulate natural channel features and the overall profile should simulate the natural grade.

If an incision is caused by a change in hydrology, restoring to historic conditions will not be self-sustaining, and may ultimately fail. The channel should be designed to fit the current as well as future hydrologic regimes. It is necessary to understand the sensitivity of the channel and how it will be affected by hydrologic changes.

Specific design guidance for channel restoration and habitat components within it are beyond the scope of this document. Additional references and expertise should be applied.

5.5.3 Steepened Channel Options

A channel adjacent to a culvert can be steepened with artificial sills and/or a roughened channel. These designs do not comply with the principles of stream simulation but can complement an adjacent stream simulation culvert by establishing an appropriate profile without concentrating the most severe hydraulic conditions within the confined culvert. Steepened channel designs might also be used when a culvert is replaced with a bridge. Some aquatic organisms may not be capable of passing through a steepened reach. The project profile may have to be reduced to a range that is acceptable relative to the organisms that will be present.

5.5.3.1 Roughened Channel

A roughened channel is a well-graded mix of rock and sediment with roughness and hydraulic diversity to steepen a channel and provide conditions suitable for passage of some fish and/or other organisms. It provides profile control at a gradient steeper than the natural stream channel.

Although roughened channels can be designed to have banklines, shallow water margins, and other diversity similar to stream simulation designs, the difference between a roughened channel as defined by fish passage experts and stream simulation is that the roughened channel uses channel dimensions, slope, and material to create depths, velocities, low turbulence, and a hydraulic profile suitable for a target species to pass through. This is somewhat equivalent to the hydraulic design option for culverts as described in Chapter 6. The bed material of a roughened channel is not intended to evolve as a natural channel with bed material scouring and replenishing; it is a fixed semi-rigid structure. Individual rocks are expected to adjust position and location but the larger grain sizes are not expected to scour out of the reach. As a result it may be steeper and have more severe hydraulic conditions than other sections of the stream.

Ideally a channel is roughened to the point where the potential energy available at the upstream end of a reach is dissipated in turbulence consistently through the reach and that no excess kinetic energy is present within the reach or at the downstream end. The design for steepened channels downstream of culverts or other fixed structures where any degrading of the channel will result in the culvert countersink or velocity criteria to be exceeded should be conservative. Profile and elevation of the roughened channel are critical to success of the project. The culvert should be countersunk deeper than normally required with the expectation of some degrading of the backwater control.

In order for the roughened channel to be reliable for aquatic passage, it is essential that the bed material remains in the channel more or less as placed. It is expected that the bed material will shift slightly but not move any appreciable distance or leave the reach. Bed stability is essential because these channels are not alluvial. Since they are often steeper and more confined than the natural upstream channel, recruitment of the larger rock in the bed from upstream is not expected. Any large material that is scoured will not be replaced and the entire channel will degrade.

In order to prevent excess infiltration and loss of low surface flows, bed porosity must be controlled. Smaller grains that control the porosity in the roughened channel may gradually be washed out of the bed. This is similar to the bed porosity issue in stream simulation except in that case, material that seals the bed will be continuously replenished. If material transported from the natural channel is too small to be trapped in the voids of the roughened channel bed, the bed will become porous.

5.5.3.2 Artificial Sills

Artificial sills are rigid or gradually deforming structures built in the bed to control the channel profile. If profile control structures are placed downstream of a culvert or other rigid bed feature, and they are the sole means of maintaining the profile, they should be long lasting and stable to maintain the designed elevation. This is necessary because the culvert is a long-term feature at a fixed elevation. Any loss or lowering of the downstream controls could result in another barrier at the culvert or structural risk to the culvert.

Any grade control structures must anticipate future conditions and the probability that continuing channel incision will occur. Scour occurs below grade control structures. When profile control structures are built downstream of a perched culvert, some of the energy that was dissipated at the culvert is moved to the grade control structures. Downstream scour can be exacerbated if there will be substantial bedload infilling between grade control structures upstream. The last grade control structure downstream should always be at or below the existing streambed grade. Additional buried controls are recommended where there is significant variability in bed elevation or possible future incision is expected. Those controls would become exposed and effective only as the downstream channel incises.

When required, control structures upstream may either have rigid elevations or they might be designed with the expectation that they will gradually adjust overtime. The choice depends on project objectives and considerations from the profile design section of this manual. All or part of the upstream headcut may in some cases be allowed to occur uncontrolled. Profile control structures must not be placed near the culvert inlet. If the energy dissipated below the structure scours the culvert bed, the entire culvert bed can be affected and in some cases, entirely washed out of the culvert. The recommended distance to the nearest upstream control is a function of channel width and slope. In channels with slopes up to about four percent and with widths between ten and twenty feet the upstream control should be thirty to forty feet from the culvert inlet. In steeper channels, pools are naturally more closely spaced. Spacing upstream of a culvert might be twice the spacing of step-pools in the natural channel.

These structures are only generally described here, and this level of information is not adequate for design. More specific descriptions, design considerations, applications, and limitations are described by WDFW (2002), U.S. Department of Agriculture, Natural Resource Conservation Service (2001), and Rosgen (1996).

<u>Boulder (Rock) Control Weirs</u>

Low boulder sills have been built for many years to backwater perched culverts and low dams. Though many of those structures have deteriorated and disappeared overtime, they can be durable and effective if well designed and constructed. Their success depends to a very large degree on the size and quality of material used, the care and skill of the hand labor or equipment operator, supervision, and equipment used to place the rocks.

To create a permanent structure, rock should be durable and of a shape that allows individual rocks to be keyed together. Boulders with somewhat of a rectangular form are much more stable than round boulders. See Chapter 8 for sizing of rocks within weirs.

The cross section of the weir crest should slope toward the middle and approximate the cross section of the stream. Structures must be keyed into the banks. Well-graded seal material with fines is placed on the upstream side of the structure to control permeability and leakage. Much of the structural integrity and sealing of boulder weirs is provided by bed material that accumulates on the upstream face of the weir. If there is no continued recruitment of sediment to maintain the weirs, they will become more porous, leak, and be vulnerable to failure. Boulder weirs also carry the risk of domino failure. If one weir within a series of weirs fails, the risk of additional weir failures is increased as the added head differential increases plunging flow, scour, and hydrostatic forces on the next weir upstream.

Rigid Weirs

Rigid weirs are fixed, non-deformable structures used to control the channel profile permanently and precisely. They are often built out of logs, sheet piling, or concrete. An advantage of rigid weirs is they can often be built at a steeper grade than other steepened channel options, therefore minimizing the footprint of a project. Rigid weirs are usually considered to have a negative impact to habitat by forming a rigid channel and eliminating complexity and diversity. Full channel spanning structures lack the variety of passageways that stream simulation provides and therefore do not comply with the premise of stream simulation.

5.3 Risk, Problems, and Stability Analysis

There are several potential problems with stream simulation culverts each with varying levels of risk. If the project does not meet the objective of stream simulation because the bed does not adequately simulate the natural bed, it is a *bed form problem*. Passage of aquatic organisms or other project ecological objectives may not be achieved. For example a culvert that causes backwater effects and chronic bedload deposition that threatens the structure and must be maintained could be considered a bed form problem.

A *bed problem* occurs if the bed scours out of the culvert and is not replenished within a reasonable period of time. That problem can extend to the upstream channel in the form of a headcut. These problems can occur if the bed elevation and/or bed material are not appropriately designed, eroded by extreme flood events, or by degrading of the downstream channel. Problems might also occur if the bed structure, packing, and hydraulics of the constructed bed do not simulate the adjacent natural bed.

A *structural problem* may be a problem of a bottomless arch footing bearing capacity resulting in damaging to the structure or road fill. High headwater can cause damage of the road fill or diversion of flow down a road ditch to an area where no stream exists. These problems can occur due to a degrading or aggrading channel downstream, an undersized culvert, debris plugging, poor construction quality or an extreme flood. Considerable stream damage can be caused by fill damage and erosion in both instances.

5.5.4 Analysis for Bed Form and Bed Stability

Stability of bed forms and bed material is evaluated with bed stability models. Start with an understanding of the basis of stability in the natural channel. Does the reference channel depend on key wood features or rock steps? Is the bed fully mobile? Are there elements that are immobile and others that are not? Are key pieces mobile and at what flows?

For elements of the bed that are mobile, do the analysis in comparison to the reference channel. Compare the unit discharge (flow per width of active channel), average shear stress, or critical velocity of incipient motion and higher flows of the constructed channel to that of the reference channel. If they are the same, then the premise is that the channels behave the same at the flows analyzed. Do the analysis on the portion of the bed material that is characteristic of stability and roughness.

By comparing the hydraulics and sediment entrainment of the reference channel to the designed channel the uncertainties of estimating hydrology and sediment entrainment are reduced. We don't need to know exactly at what flow alluvial material is entrained as long as we know that it will behave the same in both channels. Applying the model this way essentially calibrates some of the model variables.

If key pieces are in the reference channel the designer has to decide whether they are to be considered permanent in the designed channel or not. There is some risk in considering them as not permanent. If colluvial material is scoured from the stream simulation culvert, it might not be replenished and therefore the structure of the project bed could be jeopardized. An analysis should be conducted to verify the stability of colluvial material or individual elements placed to anchor other bed material in the stream simulation.

Stability of colluvium, bank material, and key pieces is treated somewhat differently than alluvial material. Key pieces include colluvium too large to be mobilized, boulders that create banklines, and embedded boulders that are meant to be permanent. In addition to a comparison of hydraulic characteristics in the designed channel and reference channel, the stability of the key pieces should be analyzed at a Q_{25} to Q_{50} design flood.

Step material pieces of step-pool channels might also be analyzed as if they were permanent if they appear to not be very mobile in the reference reach. Key pieces in step-pool features are not likely to move until flood events in the range of thirty to eighty-year recurrence.

Stability of key pieces is analyzed using sediment entrainment models similar to the analysis described above for alluvial material. Two flows should be applied; the flow at which the same pieces in the reference channel are mobilized and a high structural design flow. Both methods are best applied and the results compared as a reality check. It may not be possible to find a flow at which these pieces are mobile in the reference channel. If the model indicates they are not mobile at a flow less than the selected structural design flow, revert to just the structural design flow analysis.

Solutions to increase stability include increasing the size of the culvert, increasing size of colluvial material in the culvert, and bed retention sills. If they are considered permanent, key pieces in the culvert may be designed larger than in the reference reach to compensate for larger shear in the culvert at those high flows and as a safety factor.

While several bed stability models exist for varying bed material distribution and stream slopes, Bathurst Critical Unit Discharge and Modified Shields are the recommended methods by U.S. Forest Service and CA Fish & Wildlife. In theory, the D_{84} particle controls channel roughness, channel form, and bed mobility. This is the target particle size for performing bed stability and mobility analysis. When the driving force in a stream bed is less than the shear stress or critical unit discharge that will entrain the D84 particle, this particle is stable. Once the critical shear or unit discharge is less than the driving force, the D84 particle will become mobile.

The equations for the two bed stability/mobility methods and their associated parameters are as follows:

Modified Shields Method

$$\tau_c = \gamma R_C S_e$$

$$\tau_{c-D_{84}} = 102.6\tau_{D_{50}} {D_{84}}^{0.3} {D_{50}}^{0.7}$$

Parameters: Bed slope < 5%

$R_c/D_{84} > 5$ [Note: D_{84} in (**ft**)]

$D_{84}/D_{50} <25$

Bed particle range between 0.39" – 9.75"

D_{84} = 84th percentile particle size (ft or int; see above equation notes)
D_{50} = 50th percentile particle size (ft)
τ_c = Driving Force: Boundary Shear Stress (psf)
γ = Unit Weight of Water (lb/ft^3)
R_c = Hydraulic Radius (ft)
S_e = Energy Slope or Bed Slope (ft/ft)
$\tau_{c\text{-}D84}$ = Critical Shear to Entrain D_{84} Particle (psf)
τ_{D50} = Shields Parameter to Entrain D_{50} Particle (dimensionless)

Critical Unit Discharge Method

$$q = \frac{Q}{W}$$

$$q_{c-D_{84}} = q_{c-D_{50}} \left(\frac{D_{84}}{D_{50}}\right)^b$$ [Note: D_{50} in (**in**)]

$$q_{c-D_{50}} = 0.15 g^{0.5} {D_{50}}^{1.5} Sc^{-1.12}$$ [Note: D_{50} in (**ft**)]

$$b = 1.5\left(\frac{D_{84}}{D_{16}}\right)^{-1}$$

Parameters: Bed slope between 2% - 5%

2.75" < D_{50} < 5.5"

6" < D_{84} < 9.75"

$R_c/D_{84} < 5$ [Note: D_{84} in (**ft**)]

q = Driving Force: Critical Unit Discharge (ft^2/s)
Q = Flow (cfs)
W = Active Channel Width (ft)
D_{84} = 84th percentile particle size (ft or in; see above equation notes)
D_{50} = 50th percentile particle size (ft or in; see above equation notes)
D_{16} = 16th percentile particle size (in)
$q_{c\text{-}D84}$ = Critical Unit Discharge to Entrain D_{84} Particle (ft^2/s)

$q_{c\text{-}D50}$ = Critical Unit Discharge to Entrain D_{50} Particle (ft^2/s)
S_c = Channel Bed Slope (ft/ft)
b = Particle Size Range Measure (dimensionless)
g = gravity (32.2 ft/s^2)

See Section 5.6.2 for the application of these two bed stability/mobility methods.

A thorough analysis should be completed if specific thresholds of slope, entrenchment ratios, or culvert length are exceeded as described previously. The models don't create solutions that are reliable by themselves. Consider them as tools to be applied with geomorphic and engineering expertise. Consider how a channel might be affected structurally and geomorphically, and use the analysis models to help quantify changes.

The models can be used to modify the channel bed width or the bed material size to compensate for a flow constriction or an increased slope in the simulation channel. For example, a natural reach with a slope steeper than the upstream channel will generally have larger bed material but may be narrower at flows when bed material is entrained. The channel may naturally narrow due to deposition at moderate flows but the increased width will help ensure that the stream simulation bed material will be stable at those flows even if deposited material over it comes and goes.

If size of the bed material is increased, each size class should be increased at the same ratio. The bed material can only be increased in size a limited amount (25%) and still be able to consider the design as simulating the reference channel.

5.5.5 Bed Material Sizing

Prior to analysis associated with bed mobility and material sizing, the stream simulation culvert diameter, slope, shape, and entrenchment depths should be determined and considered to be nearly final. If a bridge is chosen, instead of a culvert, bridge variables such as length height, and foundation type should also be nearly final. Depending on analysis results, these culvert or bridge design parameters (variables) may have to be modified to balance the hydraulic differences between the stream simulation culvert or bridge and the reference reach. This topic will be discussed in more detail in the process below.

The following is a process for bed stability/mobility analysis and bed material sizing:

In this guidance document, the process for analyzing stability/mobility and sizing the design bed material is based on the U.S. Forest Service method. This method of analysis and design is recognized by CA Fish & Wildlife.

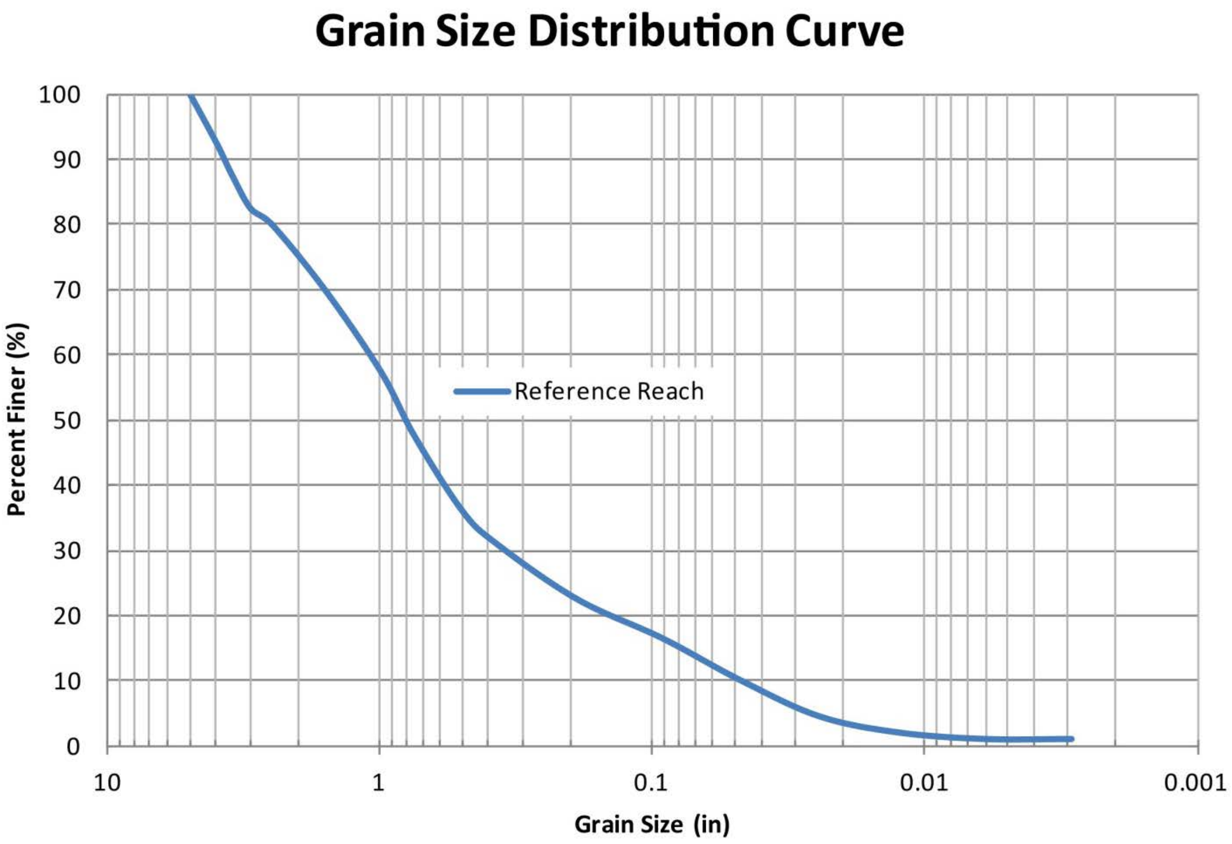

Figure 5.8. Grain Size Distribution Curve

Step 1. For the reference reach stream bed, request soil sampling (6-inch depth), sieve analysis, and gradation curve generation from District Materials Lab.

Step 2. From the gradation curve, determine D_{16}, D_{50}, D_{84} particle sizes of the reference reach streambed.

Step 3. Using reference reach cross-sectional and long- profile data, find the active channel width and stream gradient (slope).

Step 4. Create a HEC-RAS model that includes the reference reach, and iterate flow values until active channel flow width from Step 3 has been achieved. From results, find flow area and wetted perimeter for active channel discharge. Calculate hydraulic radius (R).

Step 5. Determine whether to use the Modified Shields or Critical Unit Discharge Method for stability/mobility analysis by calculating parameters unique to each method:

Modified Shields Method
Bed slope < 5%
$R_c/D_{84} > 5$
$D_{84}/D_{50} <25$
Bed particle range between 0.39” – 9.75”

Critical Unit Discharge Method
Bed slope between 2% - 5%
2.75” < D_{50} < 5.5”
6” < D_{84} < 9.75”
$R_c/D_{84} < 5$

Note: Choose the stability/mobility method where the most parameters are met.

**** For use of Modified Shields Method, follow Steps 6a through 18. For use of Critical Unit Discharge Method, follow Steps 19a through 25.**

Modified Shields Method

Step 6.

a. Choose a minimum of 5 flows between the zero and bankfull discharge values to be used in the mobility/stability discharge analysis.

Step 7.

a. Using HEC-RAS model that includes the reference reach, perform analysis for each of the flows chosen in Step 6a.

Step 8.

a. From HEC-RAS model results for each of the trial flows, find flow area, wetted perimeter, energy slope. Calculate hydraulic radius for each flow.

Step 9.

a. In table below, determine Shields parameter based on median bed material (D_{50}). This will be the value τ_{D50} to use in Step 10.

Table 5.2. Shields Parameter

Particle Classification Name	Range of Particle Diameters	Shields Parameter
	(in)	(dimensionless)
Coarse Cobble	5 – 10	0.054 – 0. 054
Fine Cobble	2.5 – 5	0.052 – 0.054
Very Coarse Gravel	1.25 – 2.5	0.05 – 0.052
Coarse Gravel	0.63 – 1.25	0.047 – 0.05
Medium Gravel	0.31 – 0.63	0.044 – 0.047
Fine Gravel	0.16 – 0.31	0.042 – 0.044
Very Fine Gravel	0.079 – 0.16	0.039 – 0.042
Very Coarse Sand	0.039 – 0.079	0.029 – 0.039
Coarse Sand	0.019 – 0.039	0.033 – 0.029
Medium Sand	0.0098 – 0.019	0.048 – 0.033
Fine Sand	0.0049 – 0.0098	0.072 – 0.048
Very Fine Sand	0.0025 – 0.0049	0.109 – 0.072
Coarse Silt	0.0012 – 0.0025	0.165 – 0.109
Medium Silt	0.000614 – 0.0012	0.25 – 0.165
Fine Silt	0.000307 – 0.000614	0.3 – 0.25

Step 10.

a. Find driving force: boundary shear stress and calculate entrainment threshold for D_{84} particle for each flow from Step 6a.

Table 5.3. Modified Shields Method

Modified Shields Method								
Hydraulics				Particle Mobility/Stability				
Discharge	Energy Slope	Hydraulic Radius	Driving Force: Boundary Shear Stress	D_{50}	D_{84}	Shield's Entrainment for D_{50}	Critical Shear Stress to Entrain D_{84} Particle Size	D_{84} Particle Mobile
Q (cfs)	S_e (ft/ft)	R_c (ft)	τ_c (psf)	(ft)	(ft)	τ_{D50}	$\tau_{c\text{-}D84}$ (psf)	(yes/no)
REFERENCE REACH CROSS SECTION								
6	0.0138	0.43	0.370	0.071	0.271	0.049	0.53	No
8	0.0135	0.50	0.423	0.071	0.271	0.049	0.53	No
10	0.0132	0.56	0.464	0.071	0.271	0.049	0.53	No
12	0.0131	0.62	0.504	0.071	0.271	0.049	0.53	No
14	0.0131	0.67	0.545	0.071	0.271	0.049	0.53	Yes
$\tau_c = \gamma R_c S_e$								
$\tau_{c\text{-}D84} = 102.6\ \tau_{D50}\ D_{84}^{0.3}\ D_{50}^{0.7}$								

Step 11.

a. Compare driving force and threshold movement values to determine D_{84} particle mobility at each flow. If D_{84} does not become mobile for any of the trial flows, select flows greater than bankfull discharge and repeat Steps 6a – 10a until a flow is found that moves the D_{84} particle. If all flows cause movement of D_{84} particle, choose lower flows until a flow is found where D_{84} particle is stable

Step 12.

a. Plot τ_c vs Q. Find the corresponding flow with $\tau_{c\text{-}D84}$ threshold shear. This will be the critical flow that causes incipient motion of the D_{84} particle within the reference reach.

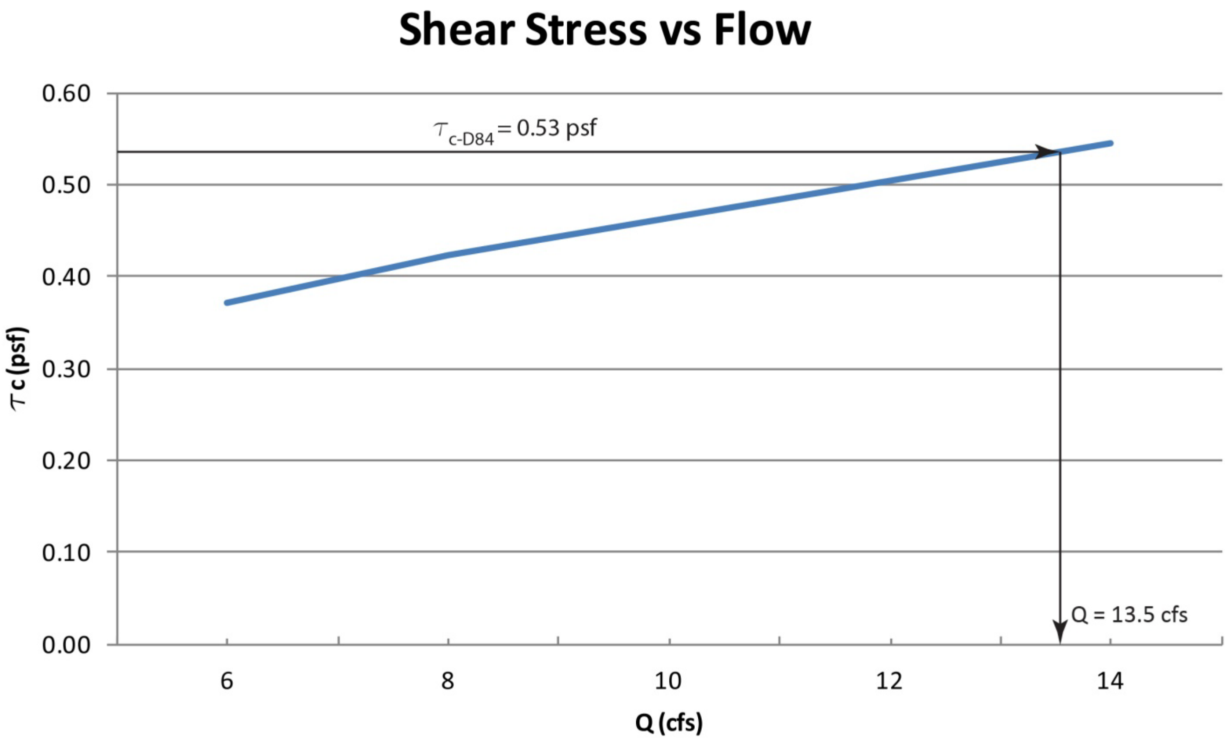

Figure 5.9. Shear Stress vs Flow

Step 13. Select an initial D_{84} particle size for the design bed material to be placed inside the stream simulation culvert or bridge. The goal is to select a size that will mobilize inside the culvert with a similar discharge as the reference reach. Based on the D_{84} estimate, shift the reference reach curve to match the D_{84} estimate and read D_{50} from trial curve. This trial parallel curve is temporary until all analysis is complete.

****Repeat Steps 6a – 12a for the design reach inside the stream simulation culvert or bridge.**

Note: The HEC-RAS model for Step 7a must include the stream simulation culvert or bridge. Also, the method for finding wetted perimeter and flow area (Step 8a) will be different for the culvert than the reference reach. In HEC-RAS, the culvert/bridge tabular results do not present wetted perimeter and flow area values. For the culvert or bridge, the flow area and wetted perimeter will need to be measured and calculated manually from the wetted cross section graphical results in HEC-RAS. Once these values are measured and calculated, hydraulic radius can be obtained.

Step 14. Compare critical flow of the reference reach and design reach that causes respective $\mathbf{D_{84}}$ particle to move. Also, compare $\mathbf{D_{84}}$ particle sizes between reference reach and design reach. Are the sizes within 25% of each other, and do they mobilize at similar flows?

Step 15. Once the final D_{84} particle diameter has been determined, shift the gradation curve from the reference reach to match the D_{84} design particle diameter. This will create parallel gradation between the reference reach and the design reach. This is the final gradation curve for the design reach.

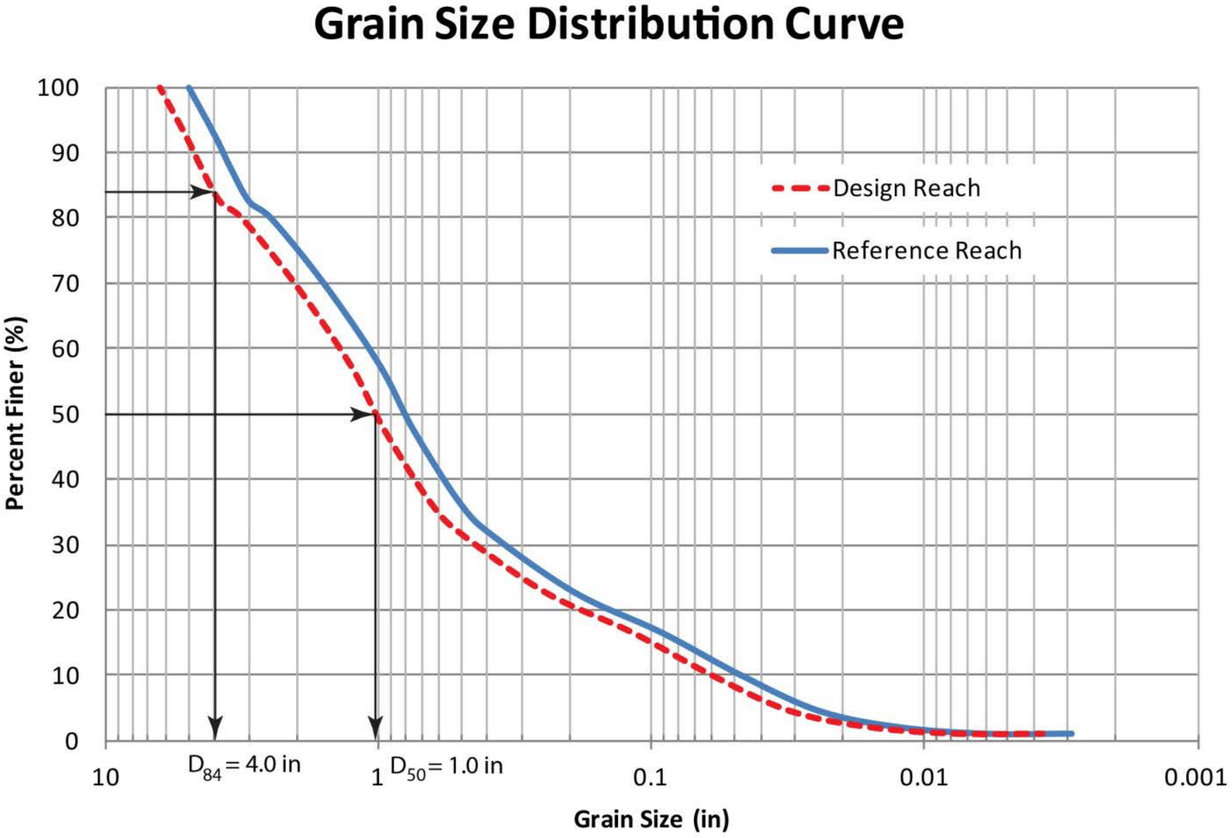

Figure 5.10. Grain Size Distribution Curve (Design)

Step 16. From the new design reach gradation curve, determine D_8 and D_{16} particle size.

Step 17. Using Fuller-Thompson method, calculate D_8 and D_{16} particle size to achieve a high density mixture to seal simulated bed and control permeability. In the equations below, use D_{50} from the design gradation curve. The values of “n” will typically range between 0.45 – 1.1 to meet the high density mixture desire. The goal in this analysis is to have D_8 particle diameter be approximately 0.08 in and the value of "n" should be chosen accordingly. If the reference reach D_8 and D_{16} particle sizes are below the calculated particle sizes, the gradation curve for the simulated culvert bed will not need to be adjusted.

$$\boldsymbol{D_{16} = 0.32^{1/n} D_{50}}$$

$$\boldsymbol{D_{8} = 0.16^{1/n} D_{50}}$$

Step 18. Calculate stream simulation bed minimum thickness.

Min. Thickness = 4 × D_{84} design reach

Critical Unit Discharge Method

Step 19.

a. Choose a minimum of 5 flows between the zero and bankfull discharge (or greater) values to be used in the mobility/stability discharge analysis.

Step 20.

a. From stream topography, find stream bed (channel) slope for each flow. Also, determine active channel width for cross section of interest.

Step 21.

a. Find driving force: critical unit discharge and calculate entrainment threshold for D_{84} particle for each flow from Step 19a.

Table 5.4. Critical Unit Discharge Method

Critical Unit Discharge Method										
Hydraulics				Particle Mobility/Stability						
Discharge	Active Channel Width	Driving Force: Unit Discharge	Channel Slope	D_{16}	D_{50}	D_{84}	Particle Size Range Measure	Critical Unit Discharge for D_{50}	Critical Unit Discharge to Entrain D_{84} Particle	D_{84} Particle Mobile
Q (cfs)	W (ft)	q (ft^2/s)	S_c (ft/ft)	(in)	(in)	(in)	b	$q_{c\text{-}D50}$ (ft^2/s)	$q_{c\text{-}D84}$ (ft^2/s)	(yes/no)
REFERENCE REACH CROSS SECTION										
15.00	12.00	1.250	0.01	0.07	0.82	3.25	0.03	2.64	2.76	No
20.00	12.00	1.667	0.01	0.07	0.82	3.25	0.03	2.64	2.76	No
25.00	12.00	2.083	0.01	0.07	0.82	3.25	0.03	2.64	2.76	No
30.00	12.00	2.500	0.01	0.07	0.82	3.25	0.03	2.64	2.76	No
35.00	12.00	2.917	0.01	0.07	0.82	3.25	0.03	2.64	2.76	Yes
$q = Q / W$										
$b = 1.5\,(D_{84}/D_{16})^{-1}$										
$q_{c\text{-}D50} = 0.15\, g^{0.5}\, D_{50}^{1.5}\, S^{-1.12}$										
$q_{c\text{-}D84} = q_{c\text{-}D50}\,(D_{84}/D_{50})^{b}$										

Step 22.

a. Compare driving force and threshold movement values to determine D_{84} particle mobility at each flow. If D_{84} does not become mobile for any of the trial flows, select flows greater than bankfull discharge and repeat Steps 6a – 10a until a flow is found that moves the D_{84} particle. If all flows cause movement of D_{84} particle, choose lower flows until a flow is found where D_{84} particle is stable

Step 23.

a. Plot q vs Q. Find the corresponding flow with $q_{c\text{-}D84}$ threshold shear. This will be the critical flow that causes incipient motion of the D_{84} particle within the reference reach.

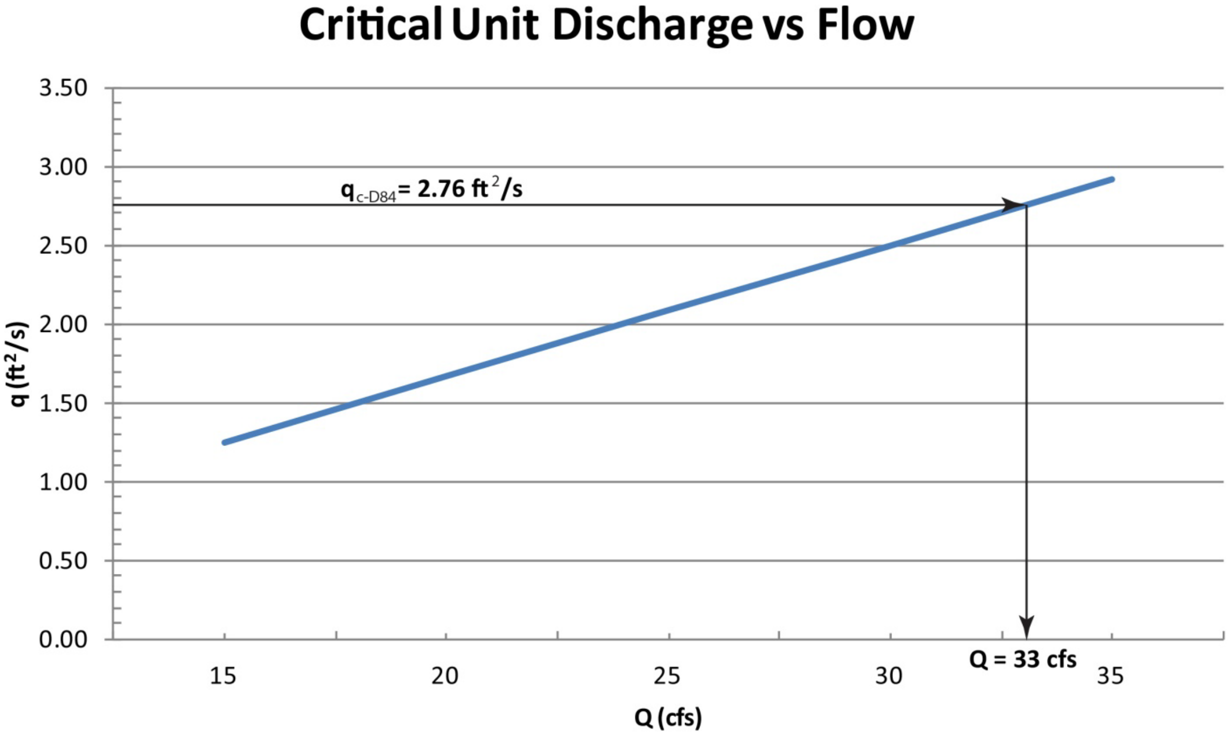

Figure 5.11. Critical Unit Discharge vs Flow

Step 24. Select an initial D_{84} particle size for the design bed material to be placed inside the stream simulation culvert or bridge. The goal is to select a size that will mobilize inside the culvert with a similar discharge as the reference reach. Based on the D_{84} estimate, shift the reference reach curve to match the D_{84} estimate and read D_{50} and D_{16} from trial curve. This trial curve is temporary until all analysis is complete.

****Repeat Steps 19a – 24a for the design reach inside the stream simulation culvert or bridge.**

Step 25. Follow Steps 14-18.

As described previously in this chapter, banklines, bed forms, and key features of the reference reach can be incorporated into the specified interior culvert bed material. The larger rocks forming such creek formations and features will most likely be too large for normal sampling and sieve analysis. Therefore, the designer must gather these rock sizes and their forms by method of field conditions as a guide. Any material used to mimic banklines , bed forms, and key features of the reference reach must resist movement for a Q_{25} to Q_{50} storm.

See CA Fish & Wildlife’s *Part XII: Fish Passage Design and Implementation* document for recommendations on placing this simulated bed material in the field.

CHAPTER 6

HYDRAULIC DESIGN OPTION FOR NEW CULVERTS

LIST OF FIGURES

LIST OF TABLES

6 HYDRAULIC DESIGN OPTION FOR NEW CULVERTS

6.1 Design Option Description

The hydraulic design option for new fish passage culverts is the option most similar to the conventional method of designing culverts for highway cross drainage. However, a significant difference between these two methods can be seen in the design parameter that plays the key role in determining the culvert configuration. In the conventional approach to hydraulic culvert design, the design parameter that most frequently determines the culvert size is the allowable headwater elevation. In contrast, the fish passage approach to hydraulic culvert design will most frequently size the culvert using a design parameter specifying the maximum velocity within the culvert barrel.

Adaptation of the conventional culvert hydraulic design method to fish passage applications has led to the development of "fish passage criteria" that must be satisfied by the design. In California, there are five distinct classifications of fish species and life stage groupings that have unique fish passage criteria. Use of the hydraulic design option for culvert design requires that the fish species and life stage classification, commonly referred to as the "target population", be identified so that the appropriate fish passage criteria can be applied. If the target population is not certain, the designer should contact the Biologist or Planner assigned to the project for more information, or another design option should be used.

At present, fish passage criteria regarding acceptable culvert velocity or minimum water depth have not been established for non-salmonid species or non-native species. Because of the lack of criteria, it is not possible to use the hydraulic design option for fish passage culverts needing to pass native non-salmonid fishes or non-native species, unless data can be provided regarding the swimming and leaping performance of the target population. Assuming the lack of such data, the hydraulic design option can be used only for those projects where salmonids are the only species requiring fish passage.

This chapter addresses the hydraulic design option specifically for cases that involve installation of new culverts or the total replacement of existing culverts. Cases that strive to address fish passage deficiencies without removing an existing culvert typically will require additional hydraulic analyses not presented in this chapter. The hydraulic design option for culvert retrofit projects is presented in Chapter 7.

Common language for highway cross drainage design refers to the "culvert design", but in actuality the design process addresses a broader system of components which must operate in coordination and simultaneously. Consideration of the various elements of a culvert system is useful to a discussion about the various design parameters and criteria associated with the hydraulic design option. The culvert system elements addressed during a hydraulic design typically include the following:

- Upstream channel characteristics – Topographic features influence the horizontal and vertical orientation of the culvert, and flow characteristics and associated water elevations determine compliance with the design criterion relating to allowable headwater elevation.
- Culvert entrance – The culvert entrance invert elevation and the selected end treatment influence the system hydraulic capacity and the response to sediment and debris loadings.
- Culvert barrel(s) – During the preliminary stage of fish passage design, it is common to establish the size and shape of the culvert barrel primarily on the basis of hydraulic criteria

regarding velocity limitations and minimum depth. The conduit material selection commonly depends on structural loading requirements, compatibility with durability factors, and economics.

- Culvert outlet and associated tailwater characteristics – The culvert outlet invert elevation and tailwater levels have a direct influence on the hydraulic operation of the culvert.
- Downstream channel characteristics - The shape, orientation, and material composition of the channel downstream of the culvert influence the tolerance of culvert outlet velocities during high discharge events and operating water depths inside the culvert.

Figure 6-1 shows an example of an installed 72 inch diameter fish passage culvert that was designed using the hydraulic design option. The culvert is located on a tributary of Bertrand Creek in Whatcom County, Washington. The view in the photograph shows the culvert outlet and the tailwater pool developed by placing grade control structures in the downstream channel.

Figure 6-1. Outlet view of a culvert replacement project developed through the hydraulic design option.

6.2 Design Process Overview

The design process for the hydraulic design option consists of several basic elements, as shown in the following flow chart (Figure 6-2). The broader design components as shown in the flow chart are discussed in the following sections of this chapter. A design example is provided in Section 6.8.

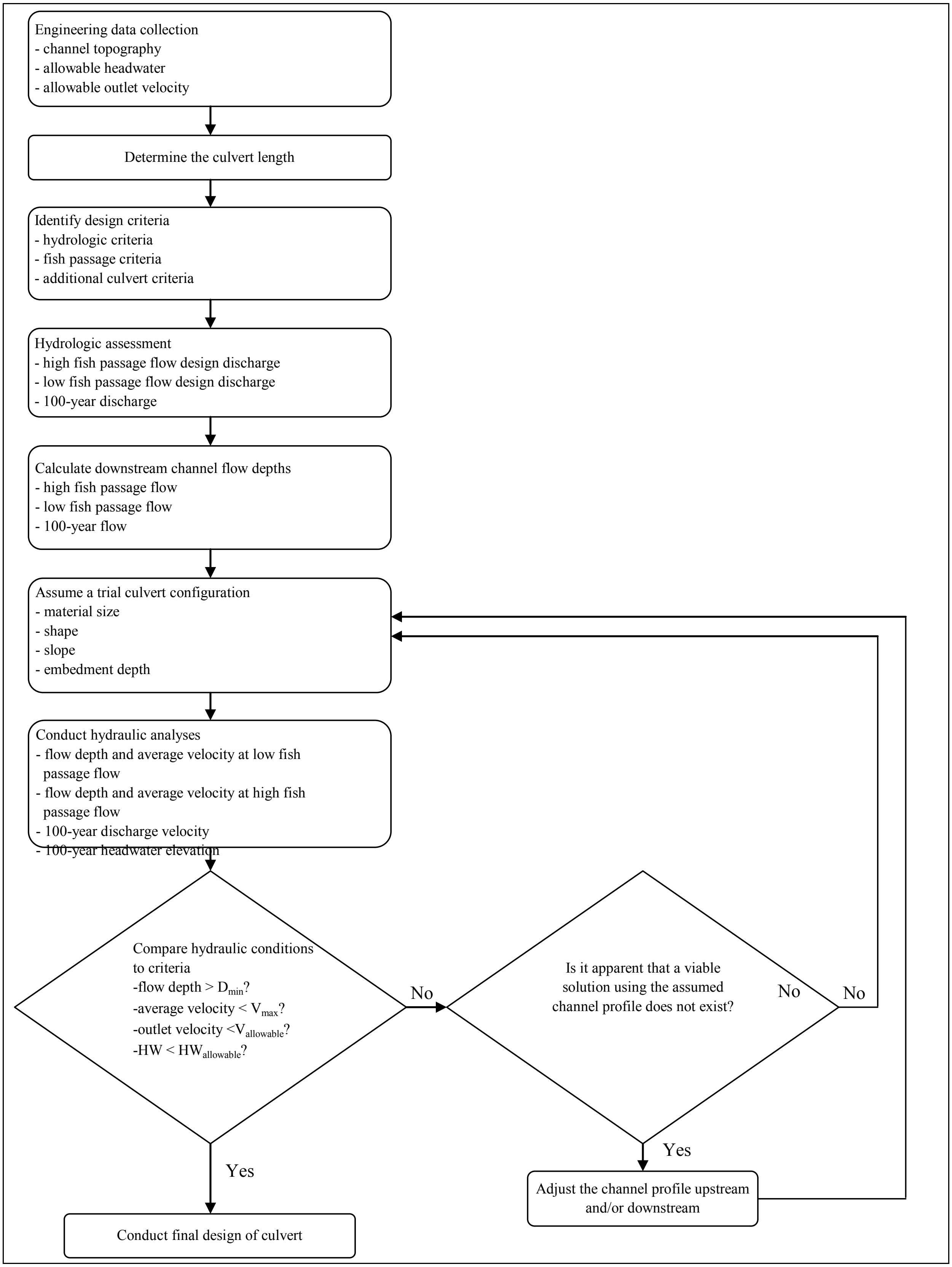

Figure 6-2. Flow chart of the hydraulic design process for new and replacement culverts.

6.3 Engineering Data Collection and Site Assessment

The following activities should be completed early in the hydraulic design process. These activities identify critical site conditions that are likely influence the design requirements necessary to achieve compliance with fish passage and culvert design criteria. In general, the accuracy and level of detail of these initial assessments have a strong influence on the accuracy of any preliminary design plans and their associated estimates of construction cost.

6.3.1 Channel Topography

A topographical survey should be completed to allow determination of the slope and width of the natural channel in the vicinity of the culvert site. The survey boundary and cross-section requirements will be dependent on the extent of significant changes in steam channel slope or width in the vicinity of the culvert. For culvert replacement projects where the channel has been affected by the existing culvert, it may be necessary to extend the survey upstream or downstream to areas unaffected by the culvert so that the natural channel slope and elevation at the culvert site can be interpolated.

6.3.2 Allowable Headwater

Headwater conditions that occur upstream of a culvert installation are a result of the fact that the culvert usually represents a severe constriction in the stream. The headwater is the potential energy necessary to overcome this constriction and associated effects.

In the conventional approach to hydraulic design of a culvert, the allowable headwater is the level to which the culvert headwater may rise before causing an unwanted inundation or damage under the circumstances of a selected design flood. The allowable headwater criterion must be established in reference to the site physical characteristics, such as fill height or elevation level of property or features which would be damaged if inundated. In the conventional approach, this allowable headwater criterion commonly is the limiting factor that establishes the required culvert size.

In contrast, the allowable headwater criteria for fish passage culverts in California is expressed in terms of maximum headwater depths for the 10-year and 100-year peak flood (see Section 6.5). These same criteria are applicable to all fish passage culverts, regardless of the method used for culvert design. A common effect of these explicit headwater limitations is a reduction in the velocities occurring in fish passage culverts, as compared to the velocities in conventional cross drainage culverts under the same design flow conditions.

6.3.3 Acceptable Outlet Velocity

Because a culvert represents a very significant constriction to flow from an unconstricted stream, the velocity of flow at the outlet end is often higher than the natural stream velocity. High velocities are most troublesome just downstream from the culvert outlet. Such high velocities represent high energy content in the discharge and can be potentially erosive. This high energy content is often dissipated by turbulence which removes material, undercuts foundations, erodes banks, and damages the culvert, channel, highway embankment, and property adjacent to or near the culvert outfall unless protection is provided,

Analysis of the natural channel velocity will provide estimates of the natural or equilibrium velocity for the stream. Engineering data collection at the site should include documentation of features such as existing slope angles, bank soil types, and rock size, to allow calibration of flow rate and velocity estimates. Because of the numerous variables involved, it is not reasonable to establish a universal "maximum outlet velocity". It is recommended that a limiting value for acceptable outlet velocity be defined that relates to site-specific conditions.

Basic configuration of the culvert through the design process is evaluated primarily with regard to the allowable barrel velocities and water depths. However, excessive outlet velocity characteristics may require additional treatments or adjustments to the culvert.

6.4 Fish Passage Criteria

6.4.1 Species and Lifestyle

Fish passage criteria established for the hydraulic design option set limits on the hydraulic conditions within the culvert in order to accommodate the swimming ability of target species and sizes of fish. In California, there are five distinct classifications of fish species and life stage groupings that have unique fish passage criteria, reflecting the differences in swimming capabilities of these groupings. The five classifications are:

- Adult Anadromous Salmonids
- Adult Non-Anadromous Salmonids
- Juvenile Salmonids
- Native Non-Salmonids
- Non-Native Species

Information regarding which of the classifications is present at a site should be obtained from the Biologist or Planner assigned to the project. In cases where more than one classification is present, the classification having the weakest swimming ability should be used (i.e. the more stringent fish passage criteria should be used). It is worth noting that, in the process of developing criteria for each of the classifications, the swimming capabilities of the weakest individuals within that classification were used to establish the limits.

At present, there is little data regarding the swimming capabilities of non-salmonid species or non-native species. As a result, the fisheries agencies have not yet established criteria for these two classifications regarding acceptable culvert velocity or minimum water depth. Because of the lack of criteria, it is not possible to use the hydraulic design option for fish passage culverts needing to pass native non-salmonid fishes or non-native species, unless data can be provided regarding the swimming and leaping performance of the target population. In the absence of such data, fish passage culverts for non-salmonid species or non-native species should use an alternative design option.

6.4.2 Hydrologic and Hydraulic Criteria

In addition to accommodating the swimming capabilities of the target population, the fish passage criteria also take into account migration timing and the risk of passage delay for each of the target population classifications. This is accomplished by establishing criteria to define the high design flow and low design flow for fish passage. As an example, adult salmon spawning migrations are commonly timed with freshets having very high flows, whereas juvenile salmon under these same flow conditions are unlikely to be migrating; hence the high design flow for adult salmonids is greater than the high design flow for juveniles.

The high design flow for fish passage is used to determine the maximum allowable water velocity within the culvert for the referenced event. Where exceedance flow data is available or can be synthesized, use the values for Percent Annual Exceedance Flow shown in Table 6-1 to determine the criterion for the high fish passage flow. If exceedance flow data is not available, the values shown for Percentage of 2-year Recurrence Interval Flow may be used as an alternative.

NOTE: Tables 6.1 through 6.5 are taken directly from the CDFG Culvert Criteria for Fish Passage document (See AppendixB).

Table 6-1. 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%

Where flow duration data is available or can be synthesized, use the values for Percent Annual Exceedance Flow shown in Table 6-2 to determine the criterion for the low fish passage flow. If the Percent Annual Exceedance Flow is determined to be less than the Alternate Minimum Flow, use the Alternate Minimum Flow. If exceedance flow data is not available, the values shown for Alternate Minimum Flow may be used.

Table 6-2. Low design flow for fish passage.

Species/Life Stage	Percent Annual Exceedance Flow	Alternate Minimum Flow
		(ft^3/s)
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

The maximum water velocity within a fish passage culvert for both the high and low fish passage flows shall not exceed the values shown in Table 6-3.

Table 6-3. Maximum average water velocity for various culvert lengths.

Species/Life Stage	Maximum Average Water Velocity (ft/s)				
	Culvert Length (ft)				
	<60	60 -100	100 -200	200 -300	>300
Adult Anadromous Salmonids	6	5	4	3	2
Adult Non-Anadromous Salmonids	4	4	3	2	2
Juvenile Salmonids	1	1	1	1	1
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					

The minimum depth of flow within a fish passage culvert for both the high and low fish passage flows shall not exceed the values shown in Table 6-4.

Table 6-4. Minimum depth of flow.

Species/Life Stage	Minimum Flow Depth (ft)
Adult Anadromous Salmonids	1.00
Adult Non-Anadromous Salmonids	0.67
Juvenile Salmonids	0.50
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	

Hydraulic drops between the water surfaces associated with the culvert, the adjacent channel, and any grade control structures should be avoided whenever possible. Where a hydraulic drop is unavoidable, its magnitude should be evaluated for both high and low fish passage flows and shall not exceed the values shown in Table 6-5. If a hydraulic drop occurs at the culvert outlet, a jump pool of at least 0.6 m (2 feet) in depth shall be provided.

Table 6-5. Maximum drop at culvert outlet.

Species/Life Stage	Maximum Drop (ft)
Adult Anadromous Salmonids	1.0
Adult Non-Anadromous Salmonids	1.0
Juvenile Salmonids	0.5
Native Non-Salmonids	Where fish passage is required for native non-salmonids, no hydraulic drop shall be allowed at the cu1vert outlet unless data is presented which will establish the leaping ability and leaping behavior of the target species of fish.
Non-Native Species	

Additional criteria are specified by the fisheries agencies regarding hydraulic conditions exhibited during the 100-year peak flood flow:

- Headwater Depth - The upstream water surface depth above the top of the culvert inlet for the 100-year peak flood shall not be greater than 50 percent of the culvert rise

6.4.3 Additional Culvert Criteria

The following criteria are additional items that may affect the design. It is worthwhile to identify all features of a proposed culvert on any preliminary drawings submitted to fisheries agencies for review, even if the design of those ancillary features is not likely to occur until the final design stage. This approach is also beneficial in developing accurate cost estimates for the project.

- Spawning Areas - The hydraulic design method shall not be used for new or replacement culverts in anadromous salmonid spawning areas.
- Culvert Width - The minimum culvert width shall be 0.9 m (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 0.3 m (1 foot).
- 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.
- 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 46 m (150 feet) in length. Where supplemental lighting is required, the spacing between light sources shall not exceed 23 m (75 feet).

6.5 Hydrologic Analysis

A hydrologic analysis is required for culvert design to derive the design discharge or “hydraulic load” of the proposed facility. There are many hydrologic methods in use. However, none are considered to be exact and all are estimating procedures only. Three methods commonly used for estimating streamflow rates for highway and culvert design purposes are:

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

Reference to a storm event or flow condition usually is made in terms of some statistical probability of occurrence. As an example, reference may be made to a 50-year flood frequency. Such a reference refers to the flood flow which occurs on average once every 50 years. The statistical probability that the 50-year flood will occur in any given year is the reciprocal of 50, or 2% (i.e., 50 = 1 / 0.02).

The flows that are used for the fish passage design are defined by policy and promulgated through the fish passage criteria described in Section 6.5. The fish passage criteria define the high and low fish passage flows in terms of an exceedance flow. Alternative criteria expressed as a percentage of the 2-year flood flow or an absolute value are provided for cases where exceedance flow data are not available.

The best way to determine streamflow values for design is to use average daily flow records from a USGS streamflow gage on the stream where the culvert is being designed. A more complete discussion of this process is provided in Section 3.4 and Appendix E.

Often there are no streamflow gage records for the stream where the culvert will be installed. When this occurs, it is possible to use regional flood estimation equations, such as those developed by the USGS for regions throughout California and presented as Figure 819.2C of the Highway Design Manual. A further discussion of the use and limitations of this method are presented in Section 3.4.

6.6 Hydraulic Analyses

Use of the hydraulic design option requires that hydraulic analyses be completed to assess flow velocities and water depths in the culvert and the adjacent channel, and to determine the headwater elevation at the culvert entrance. Several types of hydraulic design methods are acceptable for these determinations, varying in their complexity and level of accuracy. Section 3.5 provides a review of the basic hydraulic concepts that are encountered with culvert operations, and it discusses the more common design methods and computer programs that are used in the culvert design process.

Regardless of the specific method selected for hydraulic analysis, the general approach for culvert design is an iterative process. An initial culvert configuration is made with respect to the culvert material, shape, size, and entrance type. Then:

- hydraulic analysis is made for velocity, depth, and headwater elevation
- the results of the analysis are compared to the design criteria,
- if adjustments are necessary, analyze adjusted configurations until an acceptable design is found.

Often, if there is an adjustment to be considered, it will be in the assumed size and/or barrel configuration. In some cases, consideration toward changing the upstream or downstream channel profile may be necessary. Structures for that purpose are described in Chapter 8.

CHAPTER 7

CULVERT RETROFIT DESIGN

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7 CULVERT RETROFIT DESIGN

7.1 Design Method Applicability

The most effective solution for improving fish passage through an existing culvert is to replace it with a new structure designed using relevant fish passage design criteria. However, there are cases in which culvert replacement is difficult to justify, such as when the existing culvert is relatively new and has a significant remaining design life, or when there are plans to replace the culvert 5 or 10 years in the future as part of other planned roadway improvements. In such cases, a decision may be made to improve fish passage through the existing culvert to the extent possible, using culvert retrofit methods as described in this chapter.

When selecting a method for retrofitting a culvert to improve fish passage, the first step is to determine why the culvert is a fish passage barrier. If flow depths are too shallow in the culvert barrel, then baffles or weirs may need to be installed to create small pools (Figure 7-1a). If flow velocities are too high through the length of the barrel, then baffles may provide additional roughness and turbulence that disperses some of the excess energy (Figure 7-1b). In some cases, baffles can serve both functions, increasing flow depth during low flow conditions and reducing velocities under higher flow conditions.

a) b)

Figure 7-1. Applications for the use of culvert retrofit design include a) adding depth and b) adding roughness. (Photos courtesy of WDFW)

In some cases, poor passage conditions in the barrel may be further mitigated by increasing the level of the tailwater at the culvert outlet, using grade control structures such as rock weirs. Grade control techniques are also used if the culvert outlet is elevated above the water surface of the stream, due to original design intent or due to channel erosion or degradation occurring since original culvert installation. The design of grade control structures is addressed in Chapter 8. In extreme cases when the culvert outlet is several feet above the water surface of the stream, a fishway may need to be constructed at the downstream end of the culvert to allow fish to enter the culvert. An overview of fishway design methods is presented in Chapter 9.

In engineering literature, the term “weir” is commonly applied to structures that divert the flow or control the level of a waterway. A “baffle” is a device used to control or impede the flow of something and reduce its force. When a structure is designed to serve as a weir within a culvert, it may act more as a baffle once it is submerged, and conversely a structure designed to serve as a submerged baffle may effectively become a weir under low flow conditions. In this chapter, an effort is made to use the precise term when it is important to distinguish the function or the design approach for the structure. In more general discussions, however, the terms may be used interchangeably as a means to avoid repetitive listings of the two types of structures.

Figure 7-2 shows two views of a culvert retrofit project completed at Crooked Creek in Mono County, California. The left photo shows a longitudinal weir installed through the length of the flat bottom culvert to narrow the low flows and increase depth for fish passage. The right photo shows concreted rock weirs at the outlet end that provide a stepped pool transition to the stream below. Additional detail regarding the Crooked Creek project is included with other Caltrans projects presented in Appendix I of this manual.

Figure 7-2. Longitudinal channel weir and grade control rock weirs at the Crooked Creek retrofit project.

7.1.1 Retrofit Limitations

In the fisheries community, there is considerable debate as to whether baffled culverts are effective at improving fish passage on a long-term basis. A baffled culvert clogged with sediment or debris may temporarily reduce the fish passage effectiveness in comparison to the original open-barrel configuration (Figure 7-3a). Baffles installed with insufficient anchoring may dislodge during flood events and make the debris situation even worse (Figure 7-3b). Sites being evaluated for potential retrofit action that have high debris loading should give strong consideration to NOT construct baffles. Similarly, if there is a high degree of uncertainty as to whether there is available hydraulic capacity in the culvert, it may be better to reject any consideration of baffles.

a) debris caught on baffle b) failure due to insufficient anchoring

Figure 7-3. Baffles can contribute to passage problems. (Photos courtesy of WDFW)

The following situations describe some of the potential limitations of a culvert retrofit that should be considered during the design process:

- Any obstruction inside a culvert, including baffles and weirs, generates the potential for accumulation of debris and sediment. Weirs constructed with sharp edges and Vs, in particular, will tend to trap organic matter. In general, the lower and smoother the weir, the lower the potential for debris accumulation.
- The space occupied by the baffles or weirs, in conjunction with debris and sediment accumulation, can significantly reduce the flow capacity of the culvert.
- Baffles should generally not be considered for circular culverts less than 3.6” in diameter, due to difficulties accessing the culvert interior for installation and maintenance.
- The design life of baffles is typically substantially less than for a new culvert. As a result, baffles may have to be replaced during the remaining life of the culvert. (At the same time, a factor that leads to baffle installation is frequently that the culvert is nearing the end of its design life, and the baffles are intended to enhance passage during the interim period until the culvert is replaced.)
- Baffled facilities will generally require more frequent monitoring and maintenance than open-barrel culverts. These increased costs should be included in any analysis of the life-cycle costs of the retrofit.

7.1.2 Research and Understanding of Baffled Culverts

Extensive laboratory studies conducted by Shoemaker (1956) examined flow conditions in baffled box culverts, and Rajaratnam and Katapodis (1989, 1990) examined flow conditions for three styles of baffled circular culverts: offset weirs, slotted weirs, and weir baffles These studies provide methods for estimating average depth and average velocity in baffled culverts having similar design. See Appendix F for more information concerning the baffle weir research conducted by Rajaratnam and Katapodis.

More recently, several entities have completed field evaluations of existing baffled culvert installations (Browning 1990, OSU and ODOT in press, WDFW in press). These observations have led to the development of practical guidelines for baffle design and installation. These guidelines are described in Section 7.2.

The following bulleted items identify key issues relating to the design of baffled culverts.

- The methods for estimating average depth and average velocity are empirical methods based on measurements of flow conditions in baffled culverts having specific conditions for baffle height, baffle spacing, and culvert slope.
- Use of these methods to estimate water depth and velocity in culverts having other styles of baffles should be viewed with caution.
- The studies measured considerable range of velocities occurring within the baffled culverts. Areas of lowest velocity tend to occur near the side walls and along the upstream faces of the baffles.
- Field observations of fish movement through baffled culverts suggest fish tend to move through the zones of lower velocity, especially for juveniles and weaker swimming fishes (Behlke et al. 1991, OSU and ODOT in press, Powers 2000).
- Many engineers and fish biologists hold the strong opinion that design of baffled culverts should not be based on the same average velocity criteria as for open barrel culverts, as the fish movement occurs in zones of much lower velocity not evident in the average velocity calculation.
- Calculation methods developed to date are applicable only up to flow depths of approximately 0.9 D. Estimates for baffled culverts flowing full are highly speculative at present.

For additional background information regarding the hydraulics of baffled culverts, the reader can refer to Appendix F.

7.2 Retrofit Design Methods

7.2.1 Tailwater Control Weirs

Weirs located at the downstream end of an existing culvert are typically used to eliminate hydraulic drops at the outfall of the culvert. Additionally, tailwater control weirs are also used to increase flow depths in the culvert during periods of low flow to facilitate fish passage. Depending on the length and slope of the culvert and the height of the downstream weir, improvements can be realized for all or just a portion of the culvert.

Tailwater control weirs offer an advantage over baffles in that they are located outside the culvert barrel. Due to the more open expanse of a tailwater control weir, they are likely to exhibit lower risk of severe debris jamming than might occur with baffle weirs located inside the culvert barrel. In cases where debris jams occur, the maintenance requirement is likely to be more easily accomplished at the exterior tailwater control weir. As a first step in any retrofit design, it is strongly recommended that tailwater control weirs be evaluated first to determine whether they can accomplish the fish passage remediation without the need for baffles. Chapter 8 provides more information regarding the design of tailwater control weirs and other grade control measures to facilitate fish passage.

7.2.2 Baffles

Baffles can be installed in culverts to function primarily as weirs to increase flow depth, or to add roughness elements as a measure to reduce flow velocity. Regardless of their functional objective, it is important to recognize that baffles will exhibit different flow characteristic under low and high flow conditions. During low flow conditions, baffles will exhibit a step-pool effect with plunging flow characteristics. During high flow conditions, there will be streaming flow characteristics occurring in the flow above the baffle crests, while "hydraulic shadows" are created at the downstream face of the baffles (Figure 7-5).

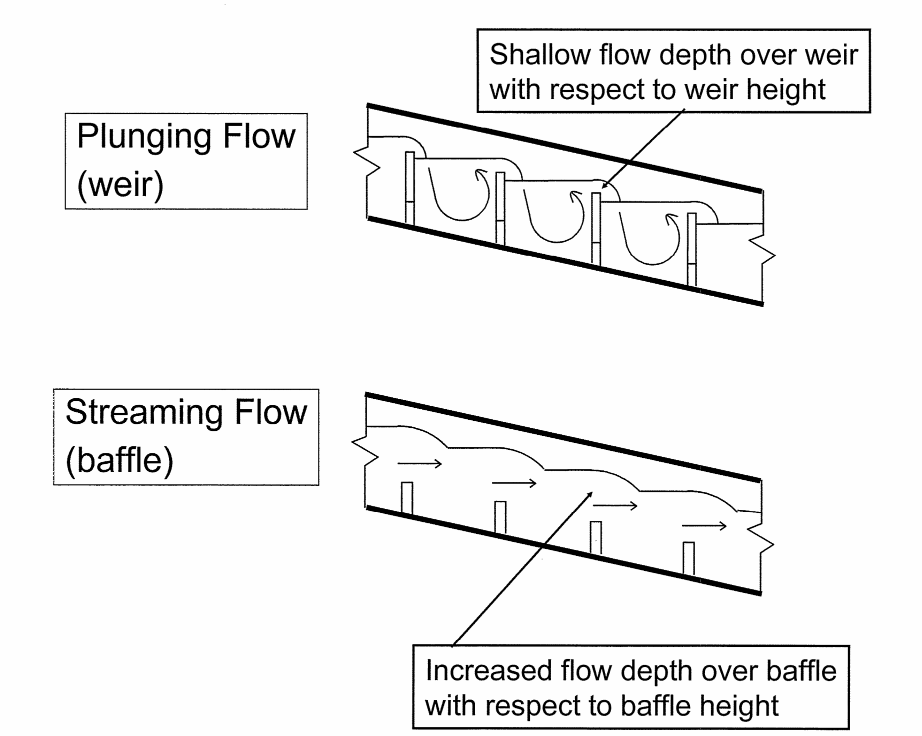


Figure 7-4. Baffles will exhibit plunging flow or streaming flow characteristics depending on the flow depth over the baffles. (WDFW in press)

Several entities have completed performance evaluations of baffled culvert installations and have summarized the findings as a means to provide design guidance for future projects (OSU and ODOT in press, Powers 2000). The WDFW evaluation (Powers 2000) investigated the use of baffles and their impact to Manning's roughness coefficient for culverts with slopes less than 3.5%. Based on these findings, WDFW had developed a methodology for evaluating the presence of baffles inside the culvert. There is a simplicity of this method that rests on the fact that only the value for Manning's roughness is changed in Manning's equation. This allows the designer to use standard tools (e.g. Manning's calculators, software programs, and hydraulic elements tables) to be used in design.

Table 7-1 presents the Manning's roughness values (n) recommended by WDFW (Powers 2000) in their baffled culvert design. The n value is dependent on the configuration of the weir.

Table 7-1. WDFW Baffle Design Guidelines

Culvert Slope (ft/ft)	Baffle Height, Z_0 (inch)	Baffle Spacing, L (ft)	Manning's n
0.005 to 0.009	6 to 8	0.10/slope	0.04 to 0.05
0.010 to 0.024	8 to 10	0.15/slope	0.06 to 0.07
0.025 to 0.035	10 to 12	0.20/slope	0.08 to 0.09

A first step to baffle design is to develop a preliminary baffle configuration and spacing.

Because of the potential for excessive turbulence inside a culvert, it is recommended that baffles have a minimum spacing of 6 feet. For a given culvert site, the baffle spacing will also be influenced by baffle height, culvert slope, and Manning's roughness. These variables, of course, will be adjusted during the hydraulics analysis in order to meet, or nearly meet, the fish-passage criteria under the Hydraulic Design option. Using the recommended value for Manning's n, normal flow depth (y_o) can be estimated for low fish passage flows and velocity (V) can be determined at high fish passage flows. For this analysis, the entire flow area is assumed available and is not reduced to account for the presence of the baffles. Based on the results of the preliminary analysis, the baffle configuration should be modified to meet the fish passage criteria for normal flow depth and velocity. Additionally, WDFW recommends that the ratio of the baffle height to the normal flow depth (Z_o/y_o) be between 0.4 and 0.6.

7.2.2.1 Box Culvert Installations

Based on several years of testing and evaluation (OSU and ODOT in press), ODOT has achieved a high level of success in using baffles to enhance fish passage conditions in concrete box culverts. These installations commonly focus on using the baffles to increase flow depth, as the broad, flat beds of box culverts are likely to require significant discharges before achieving the 6 inch to 12 inch minimum flow depths required by fish passage criteria. Added advantages of box culvert retrofits over circular or arch retrofits include the lower rate of change in HW/D response as the headwater approaches the soffit, thereby suggesting greater tolerance to the displaced hydraulic capacities resulting from the baffle cross-sectional area. Box culverts are also less likely to have debris problems than circular or arch culvert having equal width.

For box culverts having a slope less than 2.5%, ODOT has found the flow characteristics to be most effective when the baffle is angled at 30 relative to the wall. When the slope is greater than 3%, a full width weir baffle may be used to enhance the step-pool affect (Figure 7-6). Spacing between the baffles is determined by the slope, the minimum depth requirements, and the selected baffle height. A baffle height of 8' is commonly used, but in cases with higher slopes and if there is substantial excess hydraulic capacity, a 12' baffle will be evaluated. To accommodate the turbulence that occurs due to flow constriction at the inlet, ODOT typically places the uppermost baffle no closer than 12' to the inlet.

A low flow notch is desirable in either the mild or steep configuration. For mild culverts, the notch is commonly formed by the gap between the end of the angled baffle and the wall, and the gap size is set by determining the width which provides the minimum flow depth at the low fish passage flow. For steeper slopes having a full span baffle weir, it is common to provide a notch that is 300 to 600 mm wide and 25 to 50 mm lower than the baffle crest (Figure 7-7).

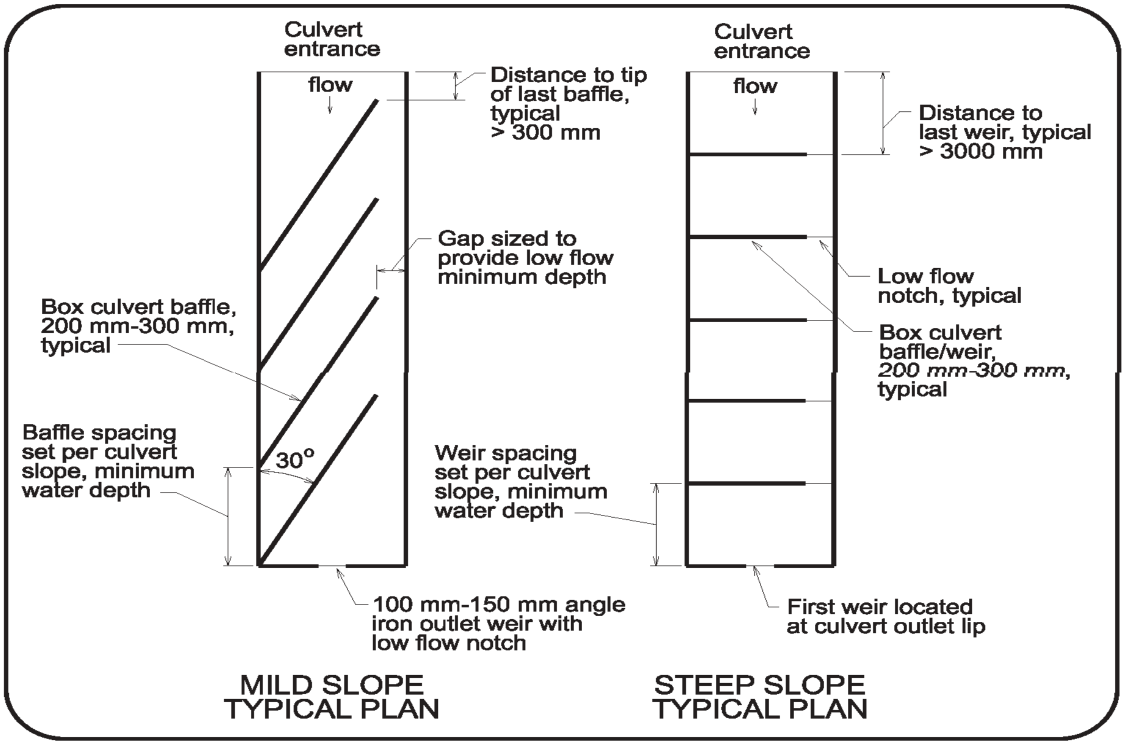


Figure 7-5. Typical plans for baffled box culverts on mild and steep slopes. (Adapted from ODOT)

Figure 7-6. Baffle weirs spanning a steep-slope box culvert. (Photos courtesy of ODOT)

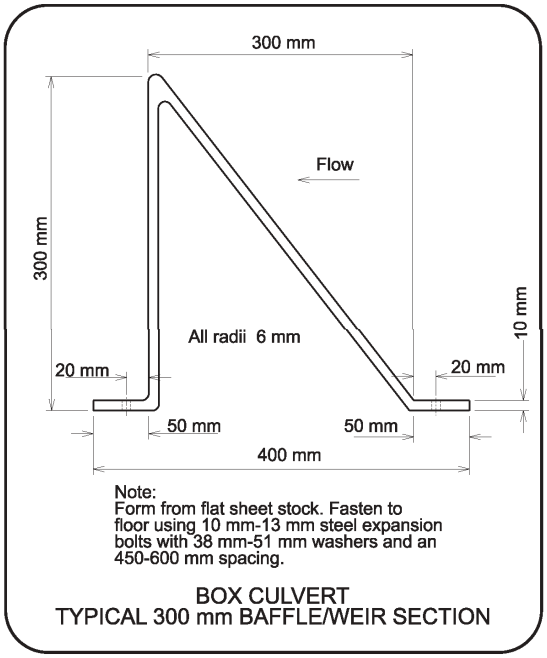


Figure 7-7. Section of standard 300 mm box culvert baffle/weir. (Adapted from ODOT)

ODOT has found that the success of the retrofit often relates to the ability to provide good entrance conditions below the culvert. A weir is always placed at the downstream edge of the culvert. When the apron has flared edges, ODOT has found it effective to provide low level concrete weirs from the outlet of the culvert extending to the end or the apron, to promote the same flow vectors as occur inside the culvert under low flow conditions (Figure 7-9). A metal sill with a low flow notch is placed at the edge of the apron to maintain the flow depth on the apron. Since these efforts to concentrate the flows under low flow conditions can produce relatively high velocities as the discharge increases, a second entrance is sometimes provided on the flared segment of the apron, supplied by a notch in the training wall (Figure 7-9).

Figure 7-8. Enhancements at box culvert outlets might include training walls and notched weir sills to maintain flow depth in the main channel section, along with secondary entrances to promote better conditions for juveniles during higher flow conditions. (Photo courtesy of ODOT)

7.2.2.2 Circular Pipe Installations

Baffles in circular pipes are commonly angled to one side, both to promote passage of debris as well as to create a low flow notch under the lowest flow conditions (Figure 7-10a). Typical dimensions for baffles of this type are included in Appendix J. In cases where the main objective is to add roughness, but at the same time there is concern regarding bedload or debris accumulation, it may be effective to position the baffles on the side of the culvert (Figure 7-10b).

Expansion-ring anchors work well in round pipes and can be installed without diverting flow from the work area. The rings are expanded out against the entire pipe circumference. A rod is rolled to the shape of the culvert interior and attached to an anchor plate. The rod and anchor plate are attached to the culvert by expanding the rod into the recess of a corrugation. This is done by tightening a nut on one end of the rod against a sleeve attached to the other end of the rod. Once the rod and anchor plate are secured, the baffle is bolted to the anchor plate. This system will also work in smooth culverts. A set of shear bolts must first be anchored to the culvert wall; the expansion ring is then installed against the upstream side of the shear bolts. An example sketch of an expansion ring anchor is included in Appendix J.

a) b)

Figure 7-9. Baffles in circular pipe culverts are most commonly positioned in the "corner", but can also be placed on the side. (Photos courtesy of Caltrans and ODOT)

7.2.3 Roughened Channel within Culvert

Flow depths can be increased and average culvert velocities can be reduced through the introduction of bed material on the interior of the culvert. This process involves placing hydraulically stable material inside the culvert. This method requires considerable hydraulic engineering expertise, and the District Hydraulic Unit should be contacted early in the preliminary design stage if this design option is to be evaluated.

7.3 Retrofit Design Process Overview

The design process for culvert retrofits consists of several basic elements, as shown in the list below. The broader design components as shown in the list are discussed in the following sections of this chapter. See Appendix M for a culvert retrofit design example.

1. Collect engineering data.
    - Confirm the maximum allowable headwater elevation.
    - Determine outlet pool and tailwater conditions
    - Determine the maximum acceptable 100-year flood discharge velocity for stability of the existing channel.
2. Identify the retrofit culvert design criteria.
3. Complete the design flow determinations for high fish passage flow, low fish passage flow, and 100-year flow.
4. Enter data regarding the culvert configuration being analyzed. (The existing conditions for the culvert and channel are used for the first iteration.)
5. Conduct the hydraulic analysis.
    - Identify flow depths and average velocities in the culvert at the high and low fish passage flows and compare to the limiting values.

  - Compute the 100-year discharge velocity and headwater depth and compare to the limiting value.

6. Evaluate the tailwater condition (i.e. develop a tailwater rating curve). Adjust tailwater configuration as needed through grade control measures. (Refer to Chapter 8 for guidance on grade control design.) Return to Step 4 unless no further tailwater adjustments are required.
7. Evaluate the barrel condition. Adjust configuration as needed by adding baffles. Return to Step 4 unless no further baffle adjustments are required.
8. Repeat steps 4 through 7 until the optimal configuration is identified.

The sequence for completing the first three steps can vary to some extent, as these steps include data collection and assessment activities that in some cases are independent of one another. Steps 4 through 8 reflect the iterative process that conducts the hydraulic analyses and optimizes the design.

7.4 Retrofit Design Elements

7.4.1 Data Collection

7.4.1.1 Existing Culvert Design Records

Many (but not all) of the culverts that become the subject of a Caltrans retrofit project should have documentation relating to their original design and installation. These documents should be reviewed initially to determine the extent of the information and to identify key design criteria used for the original design. While this information may provide insights in to the original design, none of the existing information should be used directly without a) completing a field verification of the existing condition of relevant items and b) reviewing the accuracy and current applicability of the methods and calculations used for design. Examples of existing culvert design data that should be obtained and verified include:

- Culvert length
- Culvert slope. Field assessment should investigate the presence of any settling or sagging within the culvert.
- Culvert diameter (or other relevant dimensions for non-circular culverts). Field assessment should investigate the presence of embedment material and any warping within the culvert.
- Culvert material and current condition of roughness. The depth and spacing of pipe corrugations should be verified when present.
- Culvert basin information, including any assumptions regarding land cover and developed area within the basin.
- The calculated or assumed elevation for allowable headwater.
- Calculated outlet velocity and assumptions used in designing slope protection, where present.

7.4.1.2 Site Assessment Data

Existing conditions at the project site must be assessed and, where appropriate, compared to conditions described for the original design. Prior to conducting field visits, it will be beneficial to review existing fish passage evaluations that may have been completed previously; the designer should check for their existence with the District Environmental Unit and obtain copies if available.

See Chapter 3 for guidance regarding data collection for the following items:

- Channel Topography
- Channel Stability
- Acceptable Outlet Velocity

7.4.1.3 Fish Passage Criteria

Fish passage criteria described by CDFG (2002) and NOAA-SWR (2001) classify culvert retrofit projects under the Hydraulic Design Option category. The fish passage criteria for this option require identification of the target species. Contact the District Environmental Unit early in the preliminary design stage if there is any uncertainty regarding the target species for a specific project.

Criteria for the Hydraulic Design Option also specify the methods for determining the low fish passage flow rate and high fish passage flow rate. The CDFG criteria are shown in Appendix B and the NOAA-SWR criteria are shown in Appendix C.

For a culvert retrofit project, however, it is recognized that velocity conditions within the existing culvert barrel may not be capable of being modified to the extent that would satisfy maximum average water velocity criteria used for new and replacement culverts. It is recognized that, in some cases, fish passage can be significantly improved for some species and life stages without fully meeting the hydraulic criteria. Therefore, for culvert retrofit projects, both CDFG (2002) and NOAA-SWR (2001) suggest that the same maximum average water velocity criteria used for new and replacements culverts should serve as the target for passage improvement and not the required design threshold. The velocity criteria are shown in Appendices B and C.

The existing conditions of a culvert retrofit project are unlikely to allow any significant reduction in the headwater level exhibited during the 100-year peak flood flow. As a result, if the HW/D ratio of the existing culvert is greater than 1.5, there is little likelihood of satisfying the CDFG criterion stating that the upstream water surface depth above the top of the culvert inlet for the 100-year peak flood shall not be greater than 50 percent of the culvert rise. Similar to the criterion for the maximum average water velocity, the HW/D criterion is generally considered a target for passage improvement and not the required design threshold.

7.4.2 Hydrologic Analysis

A hydrologic analysis needs to be performed using methodologies outlined in Chapter 3. As outlined in the fish passage criteria (CDFG 2002, NOAA-SWR 2001), design flows for high fish passage flow can be determined using either the Annual Exceedance Flow (AEF) or a percentage of the 2-year recurrence interval flow (Q2). If detailed stream records are available at the project area, the determination of AEF may be appropriate. However, in most cases flow records will not be available, in which case it will be necessary to determine the Q2 through other methods.

7.4.3 Hydraulic Analyses

Use of the hydraulic design option for culvert retrofit projects requires that hydraulic analyses be completed to assess water depths, drops in the water surface profile, and flow velocities in the culvert and the adjacent channel, and to determine the headwater elevation at the culvert entrance. Several types of hydraulic design methods are acceptable for these determinations, varying in their complexity and level of accuracy. Section 3.X provides a review of the basic hydraulic concepts that are encountered with culvert operations, and it discusses the more common design methods and computer programs that are used in the culvert design process. Throughout the remainder of this chapter, the discussion will use the terminology and typical procedures and results that follow from use of the HEC-RAS computer program.

The general approach for designing retrofit facilities is an iterative process. For a culvert retrofit, the first iteration will provide an analysis of conditions in the existing culvert. An analysis of an existing culvert using the HEC-RAS program typically requires an initial data input session providing data sets similar to the following:

- Data regarding the existing culvert configuration: culvert inverts, stationing, size, shape, material, roughness, entrance type
- Data relating to the tailwater conditions: channel cross section data; observed water surface elevations for a minimum of three specific discharge conditions
- Data regarding overtopping conditions
- Identification of the design flow discharges for which analyses will be provided

When data input is complete, the designer directs the HEC-RAS program to conduct the hydraulic analysis. The typical output from the program is a listing of 10 discharge flows (in addition to the no flow condition) that additionally itemizes the following associated conditions for each flow: headwater elevation, inlet and outlet control depth, flow type, normal depth, critical depth, outlet depth, tailwater depth, outlet velocity, and tailwater velocity.

At this point, results from the analysis are compared to design criteria limits. As an example, the normal depth of flow associated with the low fish passage flow will provide a determination as to whether the minimum depth criterion is satisfied in the existing culvert.

If adjustments are necessary, analyze adjusted configurations until an acceptable design is found.

7.4.4 Retrofit Features Design

The design of retrofit features will be dependent on several factors, including the effectiveness of tailwater control measures; whether the culvert is a box culvert or circular / arch culvert; the slope of the culvert; and the bedload and debris conditions. See Section 7.2 for guidance on design of the baffle features.

CHAPTER 8

GRADE CONTROL DESIGN

LIST OF FIGURES

8 GRADE CONTROL DESIGN

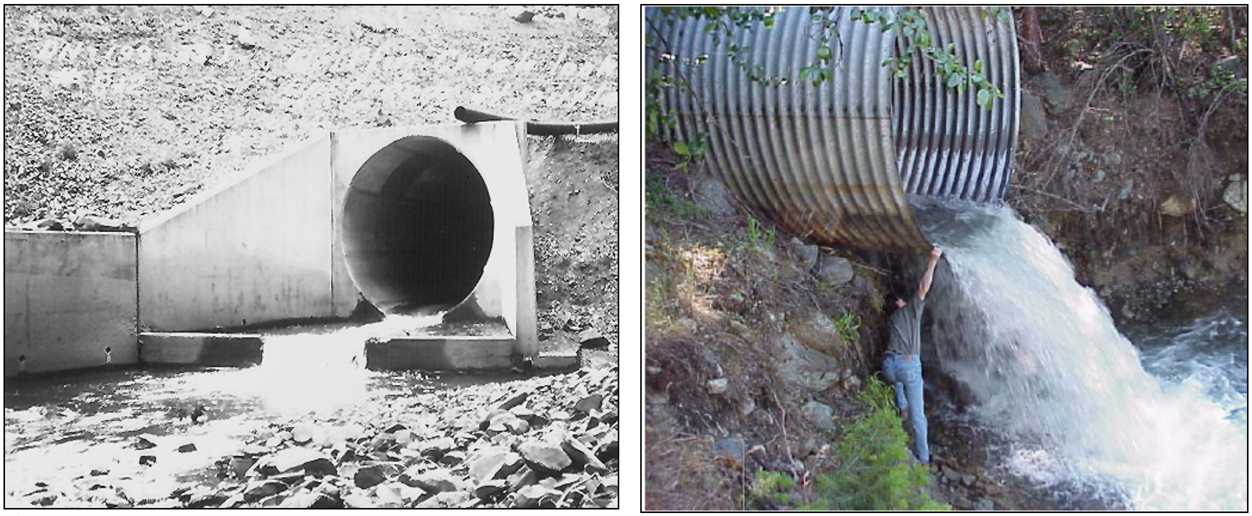
8.1 Grade Control Applicability

Grade control structures are used in fish passage culvert projects to enhance fish passage conditions in the stream channel upstream and downstream of the culvert, as well as in the culvert itself. The four most common uses of grade control structures are to:

- Increase the water depth a channel or culvert barrel,
- Raise the downstream channel up to the level of the culvert, or bridge and
- Stabilize the channel streambed near the culvert or bridge.

A frequent reason for having to increase water depth is when the geometry of the stream channel or culvert barrel has a large cross sectional area, producing shallow water depths. This condition can be especially prevalent with existing culvert facilities having broad, concrete outlet aprons (Figure 8-1a); and with box culverts or any large diameter culvert, whether new or existing. Placement of a grade control weir can help insure a minimum water depth upstream of the weir. A low flow notch, sized to contain the fish passage low flow, is commonly used to focus the flow pattern and encourage sediment transport through the low flow fish passage condition.

Grade control structures are also used to raise the downstream channel up to the level of the culvert. A common condition requiring this type of remediation is when existing culverts have been undersized, resulting in scour holes at the culvert outlet (Figure 8-1b). The two approaches generally used to correct these elevation differentials are 1) grade control weirs, which use a series of separate structures to produce incremental small drops in the water surface, and 2) roughened channels.



a)

b)

Figure 8-1. Applications for the use of grade control design include a) sites with concrete outlet aprons and b) perched culverts.

A third condition requiring grade control measures may occur when the existing streambed channel has potential to rise (agrade) or lower (degrade) over the life span of the project. A common need for this may occur with culvert replacement projects, where a substantial amount of sediment has accumulated upstream of the existing culvert over many years. When a larger culvert replaces the existing culvert, there is potential that the accumulated sediment will wash away during high stream flow events, resulting in downcutting of the channel from its pre-remediation condition. In such cases, grade control structures might be installed at the time of culvert replacement to promote stabilization of the revised channel configuration.

Retrofitting an existing culvert with grade control measures can be an attractive alternative to full culvert replacement. However, retrofitting an existing culvert with grade control structures may have unintended consequences. As an example, a project may propose the use of downstream weirs to improve stream depths at the outfall during periods of low flow. This downstream grade control structure may recruit bed material at the bottom of the culvert. While recruitment of this material may enhance fish passage, the conveyance capacity of the existing culvert may be reduced. This reduction can result in more frequent roadway overtopping and upstream flooding. Additionally, the ability for the existing culvert to pass debris during periods of high stream flow may also be reduced. Therefore, design criteria such as conveyance capacity and maintenance must be evaluated prior to full design and construction.

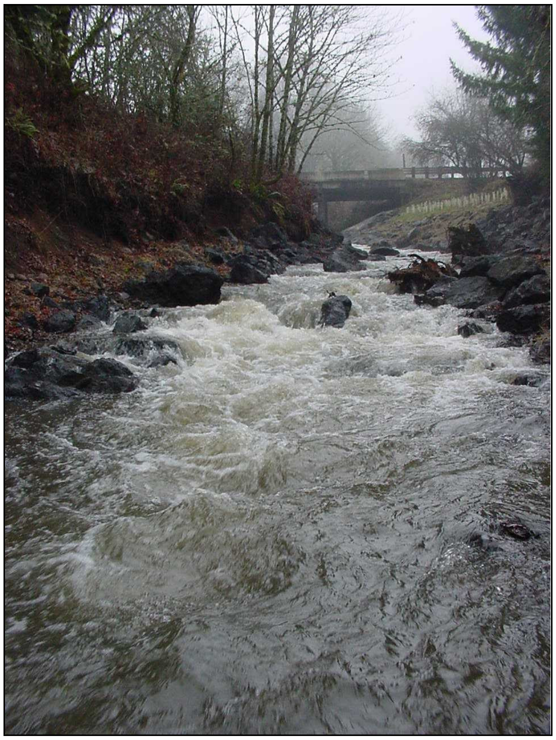
8.2 Control Structure Types

Three types of grade control structures most likely to be used for Caltrans projects (Figure 8-2):

- two types of grade control weirs: rock weirs or concrete weirs, and
- roughened channels.

a) rock weirs

b) concrete weirs



c) roughened channel

Figure 8-2. Common types of grade control structures.

8.2.1 Grade Control Weirs

Weirs are a common type of structure built in the channel to control the water surface profile. Weirs for Caltrans projects must be constructed to be as durable and long lasting as the road crossing structure they are associated with. Any loss or lowering of the grade control structures could result in a new fish passage barrier, or it could negatively affect the structural integrity of the culvert or road crossing structure.

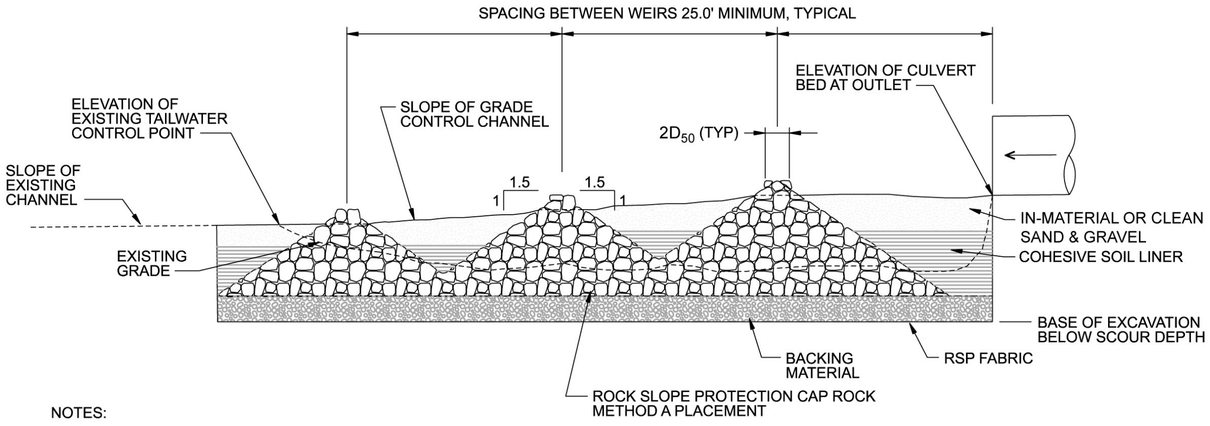
Any grade control structures must anticipate future conditions and the probability that continuing channel incision will occur. Scour may occur below grade control structures. When grade control structures are built downstream of a perched culvert, some of the energy that was dissipated at the culvert is moved to the grade control structures. Downstream scour can be exacerbated if there will be substantial bedload infilling between grade control structures upstream. The last grade control structure downstream should always be at or below the existing streambed grade. Additional buried controls are recommended where there is significant variability in bed elevation or possible future incision is expected. Those controls would become exposed and effective only as the downstream channel incises.

When required, control structures upstream may either have rigid elevations or they might be designed with the expectation that they will gradually adjust over time. The choice depends on project objectives and considerations from the profile design section of this manual. All or part of the upstream headcut may in some cases be allowed to occur uncontrolled. Grade control structures must not be placed near the culvert inlet. If the energy dissipated below the structure scours the culvert bed, the entire culvert bed can be affected and in some cases, entirely washed out of the culvert. The recommended distance to the nearest upstream control is a function of channel width and slope. In channels with slopes up to about four percent and with widths between ten and twenty feet, the upstream control should be thirty to forty feet from the culvert inlet. In steeper channels, pools are naturally more closely spaced. Spacing upstream of a culvert might be three times the stream width or a minimum of 25-feet apart.

8.2.1.1 Rock Weirs

Rock weirs have been used in recent years to backwater perched culverts and low dams. Their durability and passage effectiveness depends to a very large degree on the size and quality of material used, the care and skill of the hand labor or equipment operator, supervision, and equipment used to place the rocks. It should be noted that boulder weirs carry the risk of domino failure. If one weir within a series of weirs fails, the risk of additional weir failures is increased. Due to the potential for a domino style failure, construction quality at each structure is critical.

To create a permanent structure, rock should be durable and of a shape that allows individual rocks to be keyed together. Boulders with somewhat of a rectangular form are much more stable than round boulders. Specific rocks should be selected for boulder weirs, and the placement of each rock should be done carefully with an understanding of the design concept. See Figures 8-3 and 8-4 for examples of rock weir profile and cross section.



NOTES:

1. MAXIMUM DROP BETWEEN WEIRS IS DETERMINED BY FISH PASSAGE CRITERIA.
2. INITIAL ESTIMATE OF NUMBER OF WEIRS IS DETERMINED BY THE ELEVATION DIFFERENCE OF THE CULVERT OUTLET AND THE TAILWATER CONTROL, DIVIDED BY MAXIMUM DROP.
3. INITIAL ESTIMATE OF LENGTH OF GRADE CONTROL CHANNEL IS (NUMBER OF WEIRS x 25 FT) + 15 FT.
4. IF SLOPE OF GRADE CONTROL CHANNEL IS LESS THAN 125% SLOPE OF EXISTING CHANNEL, CONTACT FISHERIES AGENCIES FOR GUIDANCE REGARDING REVISED SPACING BETWEEN WEIRS.

Figure 8-3. Typical profile for a rock weir system.

In addition to the grade control structures, rock revetment on the banks will be required to prevent flanking of the grade control structures. The revetment should be installed to a height greater than the design flood or 100-year storm, as deemed appropriate by project goals (Figure 8-4).

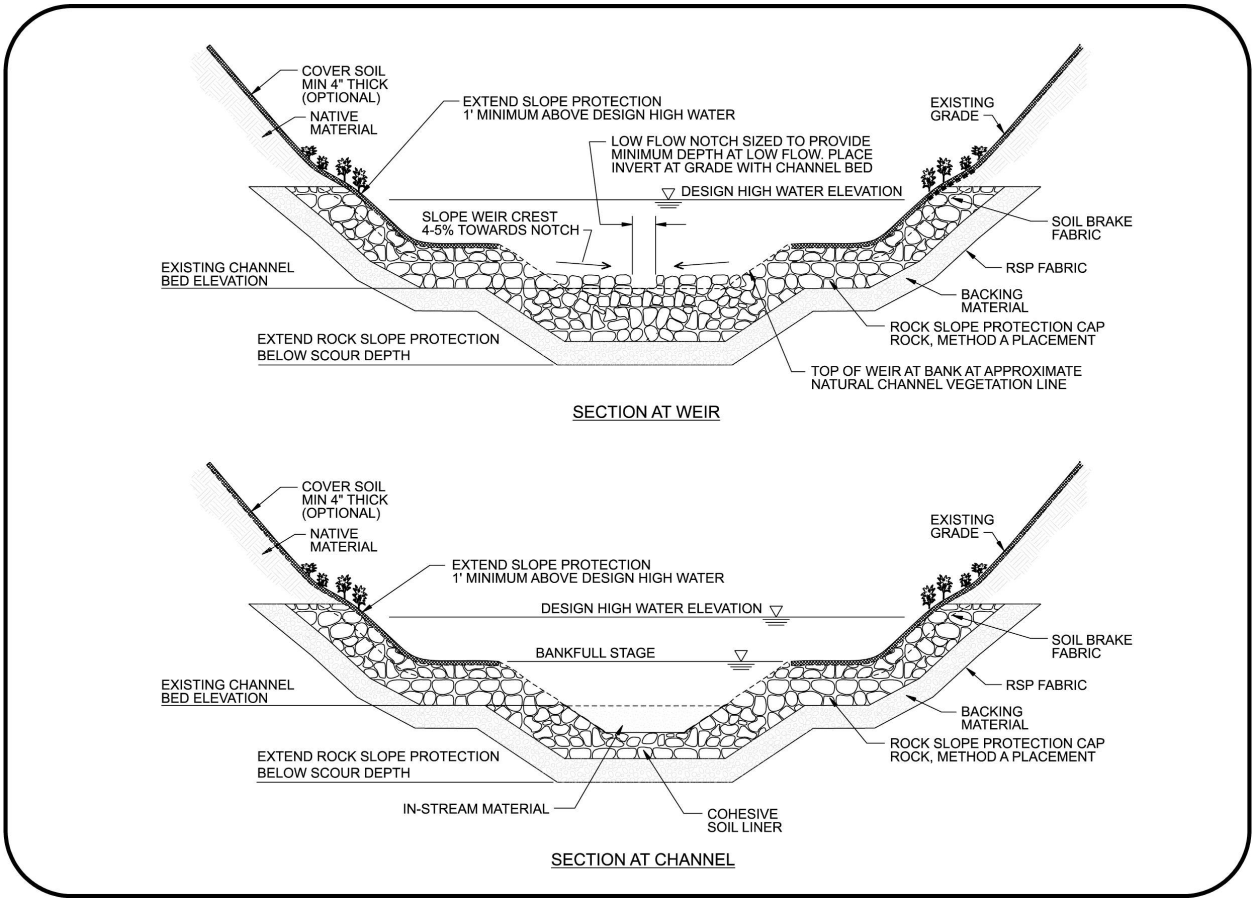


Figure 8-4. Typical sections for a rock weir.

The project area is excavated to provide proper keying depths into the bank, protect against scour, and provide sufficient layer depths as outlined in Table 5-3 of the RSP Manual. RSP fabric is placed over the native material and covered with the backing material. The outside layer and inner layer (if required) are placed over the backing layer. The plan view shape of the inner and outer layers, should be a vortex shape pointing upstream so rocks support each other in an arch pattern. The vortex orientation of weirs upstream of a culvert can be offset across the channel if necessary to improve culvert inlet alignment. Individual boulders need to be placed to ensure a minimum 3-point bearing on the underlying rock, as required by Method A placement. Special attention should be made to ensure the three-point bearing is provided on the downstream side of the individual boulder. This is critical to the longevity of the structure as the force of the streamflow and bedload is then transferred through the structure and into the banks and native material.

If bedrock is experienced prior to the proper depth being reached, the rock weirs should be keyed into the bedrock a minimum of eight to ten inches. Epoxy can be used to provide extra stability in areas with shallow bedrock depths. Hand labor may be required in this situation.

A low flow notch in typically provided to concentrate flow to the center of the grade control measure during periods of low flow. A 1-foot deep by 2-foot wide notch is typically the minimum size required but may be limited by the size of cap material. The cross section of the weir crest should slope toward the low flow notch at an approximate slope of 5%.

Much of the structural integrity and sealing of boulder weirs is provided by bed material that accumulates on the upstream face of the weir. It is therefore imperative that streambed material is recruited upstream of the structures. If material is not recruited, the structures may become porous, leak, and become vulnerable to failure. To that end, cohesive material can be placed over the backing material between the weir structures. The use of this material is intended to protect against subsurface flow.

In-stream material or imported clean sand and gravel is selected so that the material is mobile during more frequent flooding events. The intent is to provide a material that is similar to material already present in the stream. If the material is sized too small, it will be removed faster than upstream bed load can replace it and the stream will become degraded after construction. If the material, is specified too large, it will move slower than the upstream and aggrade over time potentially impacting culvert conveyance capacity. The best solution is to mimic the native material found at the site. It should be noted that there has been some reluctance from regulating agencies to reuse native material already at the project site. This problem may be attributed to potential deterioration of water quality immediately following construction.

8.2.1.2 Concrete Weirs

Concrete weirs are grade control structures that can be used to control the channel profile quite precisely. An advantage of concrete weirs is they can often be built at a steeper slope than rock weirs, therefore minimizing the footprint of a project. Concrete weirs are usually considered less desirable for fish passage than rock weirs, due to the lack of complexity and diversity in their structure. Full channel-spanning concrete weirs lack the variety of passageways that stream simulation provides and therefore do not comply with the premise of stream simulation.

Precast concrete weirs are a subset of the concrete weir grade control design. Advantages of a precast design are they can be precisely manufactured so that they seal well, have a varied cross-section similar to the natural channel, and have a crest shape that is specifically designed for fish passage. Another precast concrete design includes a weir, stilling basin, and wing walls in a single precast unit.

8.2.2 Roughened Channel

A roughened channel is n steep section of channel that has been engineered and constructed to provide sufficient roughness and hydraulic diversity to enable fish passage despite its steepness. A roughened channel provides grade control at a gradient steeper than the natural stream channel.

The bed material of a roughened channel is not intended to evolve as a natural channel with bed material scouring and replenishing; it is a fixed semi-rigid structure. Individual rocks are expected to adjust position and location but the larger grain sizes are not expected to scour out of the reach. As a result it may be steeper and have more severe hydraulic conditions than other sections of the stream.

Roughened channel designs use channel dimensions, slope, and material to create depths, velocities, low turbulence, and a hydraulic profile suitable for a target species to pass through. The rock used to provide a roughened channel must conform to rock sizing found in the *California Bank and Shore RSP Design* report.

8.3 Grade Control Design Process Overview

The design process for grade control design consists of several basic elements as follows:

1. Collect engineering data.
2. Identify the grade control design criteria.
3. Determine high fish passage flow, low fish passage flow, 10-year flow, 50-year flow, and 100-year flow.
4. Conduct a hydraulic evaluation of the culvert conditions, focusing on the conditions at the culvert or bridge outlet and in the channel just downstream of the culvert/bridge.
5. Conduct a hydraulic analysis based on preliminary the preliminary configuration.
6. Size grade control material.
7. Re-assess hydraulic conditions based on final configuration.
8. Finalize design.

CHAPTER 9

FISHWAYS

LIST OF FIGURES

9 FISHWAYS

9.1 Application

As identified in CDFG's Culvert Criteria for Fish Passage and NMFS' Guidelines for Salmonoid Passage at Stream Crossings, fishways are generally not recommended and should be used as a "last-resort" strategy where excessive drops and/or steep stream slopes occur. Fishways are an artificial means of correcting these types of situations. They are structurally intensive, site specific, and do not tend to mimic natural conditions. Detailed design of fishways requires significant expertise in hydraulic and structural analyses that go beyond the intended scope of this manual. Therefore, the information in this chapter provides an introduction to fishways for reference during the Planning Phase, and does not contain design direction.

All of the previously discussed design approaches for fish passage culverts are limited by a maximum slope that can be accommodated with the design. A common example is a culvert that was originally designed strictly for hydraulic performance that has developed a scour pool as a result of the high-energy discharge conditions. The drop at the scour pool combined with a degraded channel downstream may result in a change in elevation that cannot be corrected within the horizontal limits of the project using the maximum feasible slopes of the design approaches of the previous chapters. When the slope required exceeds the practical limits of other design approaches, a fishway may provide a solution when other strategy attempts have failed.

Some types of fishways, such as mechanical fish lifts, are appropriate only for large river systems or barriers where there is a large differential between the upstream and downstream water surfaces. The fishway classifications considered most appropriate for the range of stream sizes and hydraulic drops typical of a road crossing are:

- Step-pool ladders,
- Roughened channels, and
- Hybrid fishways.

These fishway classifications reflect basic differences in hydraulic design and the means used to dissipate excess energy. The first two classifications include more than one fishway type, providing design refinements to address various biological and physical parameters such as target species swimming characteristics, headwater variability, and debris and bedload movement. The following sections describe the basic design considerations and limitations.

9.2 Step-Pool Ladders

As the name implies, step-pool ladders create a series of pools with flow control devices between each adjacent pool that limit the difference in elevation so that fish are able to pass easily from pool to pool up the ladder. The pools are designed to dissipate the energy of flow entering from the pool above, creating an area where fish can rest before using burst speed or leaping ability to ascend to the next higher level.

Several basic designs for step-pool ladders have been developed in response to specific site and operating conditions that are typically encountered. Three types of step-pool ladders described further in this section are the pool and weir ladder, the Ice Harbor ladder, and the vertical slot ladder. Each has certain features that may be more or less suitable for a given site, depending on the hydrology and hydraulics of the site and the site topography. In addition, different species of fish move through fishways in different ways. Some species prefer to leap over each hydraulic drop while others tend to prefer submerged pathways. A fishway that forces fish to use a migration technique they are not suited to will often cause delayed passage.

9.2.1 Pool and Weir

Pool and weir ladders consist of a series of pools with the primary hydraulic control provided by sharp-crested overflow weirs between each pool. The weir frequently includes a notch to ensure minimum overflow depths under low flow conditions, and an orifice is often placed at the base of the weir to provide a passage route for non-leaping swimmers (Figure 9.1). A principal limitation of this design is the relatively narrow range of operating flow. The minimum recommended depth of flow over the weir is 3 inches, which can be especially difficult to maintain when the weir is also equipped with an orifice.

While both the effective volume and the kinetic energy of the entering flow typically increase along with increased flow rate, the kinetic energy increases more dramatically, reaching a point where the effective volume of the pool will no longer dissipate enough energy to provide effective fish passage conditions.

Figure 9.1. Pool and weir ladder.

The transition from plunging flow to streaming flow is determined primarily by the relationship of the weir crest to the water surface of the pool downstream of the weir. Plunging flow occurs when the downstream water surface is below the crest of the weir, which is also referred to as the “free-discharge” weir flow condition. Streaming flow occurs when the downstream water surface is higher than the weir crest, which is also referred to as the “submerged” weir flow condition. For fish passage, plunging flow is required for dissipation of kinetic energy. In the streaming flow condition the kinetic energy of the flow entering each pool tends to pass over the weir crests as a continuous surface jet, defeating the purpose of the pools as resting areas. Plunging flow will occur at lower flow rates, transitioning to streaming flow as flow rates increase, and the water surfaces of the pools begin to submerge the weirs.

9.2.2 Ice Harbor

The Ice Harbor ladder configuration (Figure 9.2) was developed specifically for the ladders at Ice Harbor Dam on the Snake River in Washington State. The design was developed in response to the need for a pool and weir type ladder that could operate effectively with a greater slope than is normally feasible.

Figure 9.2. Ice Harbor fishway (courtesy of U.S. Army Corps of Engineers).

The design is an adaptation of the pool and weir concept, where each weir has two overflow sections located adjacent to the walls and a baffle section in the center that does not overflow. The baffle section is constructed with flow stabilizers that extend in the upstream direction. Submerged orifices are provided directly below the overflow sections of the weir. Size of the ladder pools and geometry of the various weir elements was developed specifically by the US Army Corps of Engineers to maximize pool stability at a slope of 10 percent. The two ladders at Ice Harbor dam were designed to operate with a flow of about 70 cfs each. An adaptation of the design suited for smaller flows is the half Ice Harbor ladder, which is half of the full Ice Harbor ladder cut along the centerline. Although the design optimizes flow stability, the feasible range of operating flow is limited and a relatively constant forebay elevation must be maintained.

9.2.3 Vertical Slot

Instead of overflow weirs, flow in a vertical slot ladder is controlled by a narrow full depth opening between each pool (Figure 9.3). Width of the slot may vary, but is typically 1 to 1.25 feet. The advantage of vertical slots is that they can maintain favorable passage conditions over a much wider range of flow rates and tailwater or forebay water surface fluctuation. Energy is dissipated in each pool by the jet mixing with water in the pool. As the flow rate increases, the pool depths increase but the difference in elevation between the water surfaces in adjacent pools remains approximately constant. For this reason, this type of ladder is said to be self-regulating. Dimensions and configuration of the vertical slot and pool are critical to stability of the flow. Design of this type of ladder should conform to the dimensions of proven installations.

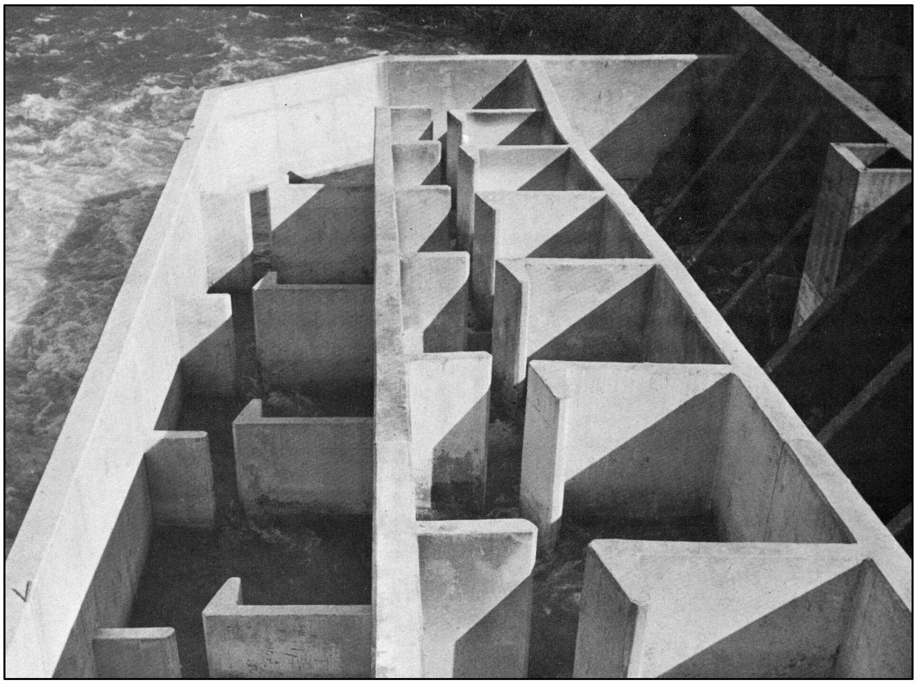


Figure 9.3. Vertical slot ladder (courtesy of U.S. Army Corps of Engineers).

The vertical slot concept is not suited to all species. Species that require overflow weirs to trigger a leaping response or that must orient to sidewalls may exhibit significantly delayed passage behavior in a vertical slot ladder. Another potential drawback of the design is a comparatively poor ability to pass debris due to the flow constriction presented by the slots.

9.3 Roughened Channels

In basic physical terms, the difficulty associated with steep slopes is an excess of energy. Due to the difference in elevation through the project area, water at the upstream end has potential energy. That potential energy is converted to kinetic energy as the water flows downhill to the lower elevation at the downstream end of the project. If the slope is steep, the potential energy represented by the overall elevation difference is converted to kinetic energy over a short distance, resulting in greater flow energy along the way compared to a shallower slope. Since the ability of fish to move upstream against the flow is limited, energy must be dissipated sufficiently to suit the swimming abilities of the fish that need to pass.

For the step-pool type ladders previously described, energy dissipation occurs at discrete locations along the way at the flow control structures that define each pool. An alternative concept is to increase the continuous dissipation of energy along the channel by increasing the roughness of the channel itself, thereby increasing the resistance to flow. A steep channel that is smooth will flow very rapidly, whereas flow in a rough channel with the same slope will be slowed down by the friction and turbulence induced by the roughness.

The concepts of roughened channels must be applied carefully in practice. Although turbulence effectively dissipates energy and thereby helps to decrease the average flow velocity, excessive turbulence itself can become a barrier to fish passage when the flow becomes so chaotic that fish can no longer orient to the required direction of travel.

9.3.1 Denil

The Denil fishway is an artificial roughened flume design that has been widely used throughout the world. Denil fishways are typically installed with a 17 to 20 percent slope and have been employed successfully at slopes up to 25 percent. The fishway itself consists of a relatively narrow flume with U-shaped baffles installed at short intervals (Figure 9.4). A wide range of flows are possible depending on fishway size, slope, and water depth requirements, but the fishway must be carefully engineered to provide the required passage conditions. Variation of the forebay water surface elevation must be limited to a range of approximately 1 m. The maximum feasible length of individual fishway segments is typically 9 m. Longer runs can be accommodated by installing individual segments of fishway with resting pools between segments where fish can recover before attempting the next climb. Denil fishways have been constructed using plywood, steel, aluminum, and concrete.

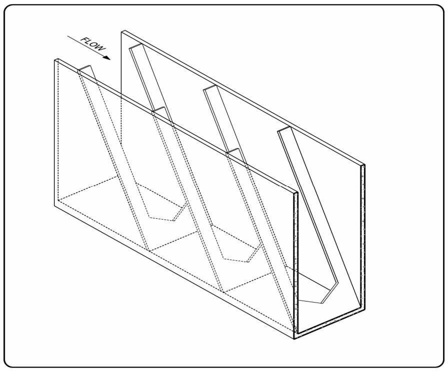


Figure 9.4. Denil fishway.

Denil fishways typically require a high degree of operational supervision and maintenance. The fishway must be kept completely free of debris to avoid altering the flow characteristics of the baffles, which would affect fish passage conditions.

9.3.2 Engineered Stream Channel

Constructed channel fishways are intended to replicate steep natural channels in much the same way as the Streambed Simulation design approach described in Chapter 5. Such channels have been constructed using either a series of control sills or rough rock linings. The use of control sills is a common method of revising a channel profile and is described in detail in Chapter 8.

For the rough rock lining approach, boulder-size roughness elements are placed in a pattern to optimize roughness as well as fish, flood flow, and debris passage. The boulders can be embedded into a cobble and gravel streambed for slopes up to about 5%, or anchored into a concrete channel subgrade for slopes up to about 8% (Bates 1992). There are no standard empirical methods for predicting fish passage through these fishways. Generally, they are designed to be stable for high structural design flows, and average velocities are used to predict fish passage conditions.

9.4 Hybrid Fishways

9.4.1 Pool and Chute

The pool and chute fishway was developed as an alternative to pool and weir ladders to permit operation over a wider range of stream flows. Instead of the simple horizontal crest of typical weirs, pool and chute weirs are vee-shaped overall with a low flow notch set into the apex of the vee. At low flow, the fishway performs as a pool and weir fishway with the flow plunging and dissipating in each pool. At high flow, a streaming flow condition exists down the center of the fishway where the bulk of the flow passes, but plunging flow and good fish passage conditions are be maintained at the edges of the pools.

Pool and chute fishways may be used where the total drop is less than about six feet. The recommended general configuration of the pool and chute fishway is based on observations of a number of pool and chute fishways (WDFW 2000). Recommended slope of the weir crest is 4H:1V. The high design flow for adult salmon should just fill the vee to the top of the sloped weir crest. At the design flow for juvenile salmon passage the water surface should be about three feet horizontally from the top of the sloped weir crest. The outer areas then remain as holding areas and passage corridors. The overall width of the fishway should be designed to provide these flow configurations relative to the design flows of the site. Recommended notch dimensions are width and depth equal to 15 and 8 percent of the fishway width respectively (Figure 9.8). It is suspected that the notch width could be as wide as necessary to provide additional flow capacity, but this has not been tested.

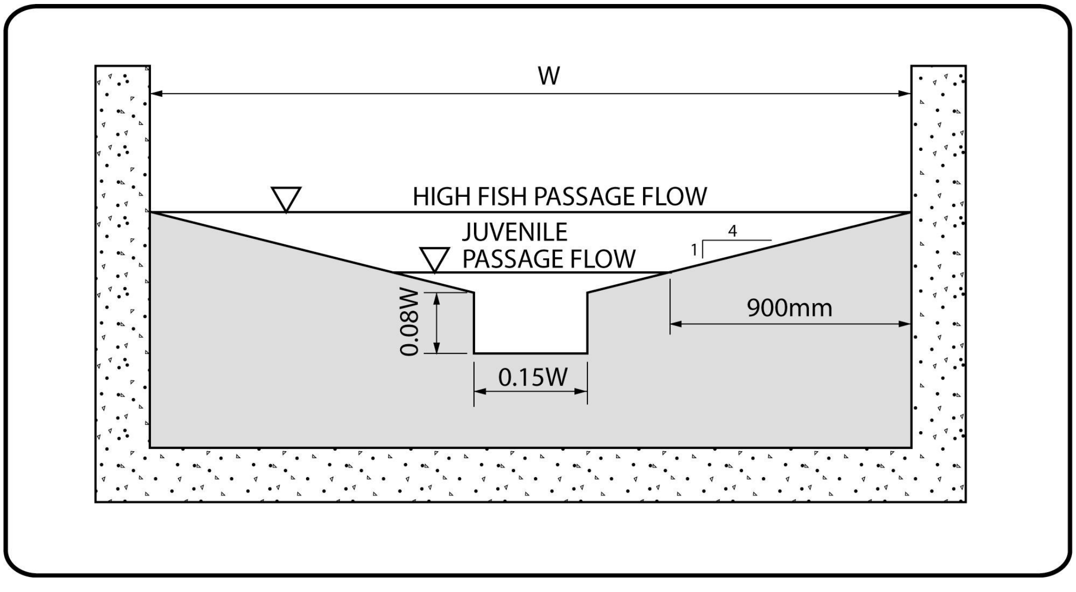


Figure 9.5. Pool and chute fishway section.

Model studies of pool and chute fishways have indicated that the streaming flow regime for the high fish passage design flow may not be achieved with fishway slopes greater than about 12 percent. Fishway slopes for high fish passage design flows greater than about 92 cfs may need to be even less. Specific design criteria for this type of fishway are still evolving as experience with them under various conditions is acquired.

CHAPTER 10

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10 REFERENCES

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APPENDIX A

GLOSSARY

APPENDIX A

GLOSSARY

Active Channel Stage: The active channel stage 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 3-2).

Aggradation: The geologic process by which a streambed is raised in elevation by the deposition of additional material transported from upstream (Opposite of degradation).

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.

Armor: A surface streambed and bank layer of course grained sediments that are rarely transported. This layer protects the underlying sediments from erosion and transport, while creating enough roughness to prevent channel down-cutting.

Backwater: Stream water, obstructed by some downstream hydraulic control, is slowed or stopped from flowing at its normal, open-channel flow condition.

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 and increases flow depth 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. (Figures 3-2).

Bed Roughness: The unevenness of streambed material (i.e. gravel, cobbles) that contributes resistance to stream flow. The degree of roughness is commonly expressed using Manning's roughness coefficient (see Equation 2 in Chapter 5, *Hydraulic Design Option*).

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.

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.

Cascade: A series of small, vertical drops within a channel. They can be natural or man-made.

CFS: Cubic feet per second.

Channel-bed width: For the purpose of culvert design, the channel-bed width is defined as the width of the bankfull channel. The bankfull channel is defined as the stage when water just begins to overflow into the active floodplain. Determining bankfull width requires the presence of a floodplain or a bench; however, many channels have neither. In those cases, bankfull channel must be determined using features that do not depend on a floodplain, such as those used in the description of active channel and ordinary high water (see Chapter 4, *No-Slope Design Option* and Appendix F, *Summary Forms for Fish-Passage Design Data* for more information*)*. Refer to Appendix H, *Measuring Channel-Bed Width* for details and information on how to measure channel-bed width.

Clast: A fragment of rock.

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 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.

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).

Debris: Material distributed along and within a channel or its floodplain either by natural processes or human influences. Includes gravel, cobble, rubble and boulder-sized sediments, as well as trees and other organic accumulation scattered about by either natural processes or human influences.

Degradation: The removal of streambed materials caused by the erosional force of water flow that results in a lowering of the bed elevation throughout a reach (Opposite of *aggradation.*)

Deposition: The settlement of material onto the channel-bed surface or floodplain.

Dewater: To remove water from an area.

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.

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.

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

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.

Fork Length: The length of a fish measured from the most anterior part of the head to the deepest point of the notch in the tail fin.

Freshet: A rapid, temporary rise in stream flow caused by snow melt or rain.

Geomorphology: The study of physical features associated with landscapes and their evolution. Includes factors such as; stream gradient, elevation, parent material, stream size, valley bottom width and others.

Grade Stabilization or Grade Control: Stabilization of the streambed surface elevation to protect against degradation. Grade stabilization usually consists of a natural or man-made hard point in the channel that holds a set elevation.

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

Gradient: The slope of a stream-channel bed or water surface, expressed as a percentage of the drop in elevation divided by the distance in which the drop is measured.

Headcut: The erosion of the channel bed, progressing in an upstream direction, creating an incised channel. Generally recognized as small, vertical drops or waterfalls, or abnormally over-steepened channel segments.

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).

Incised channel: A stream channel that has deepened and narrowed, becoming disconnected from its floodplain.

Incision: The resulting change in channel cross section from the process of degradation.

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

Inlet: Upstream entrance to a culvert.

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.

Mitigation: Actions taken to avoid or compensate for the impacts to habitat resulting from man’s activities (WAC 220-110-050).

Ordinary High Water Mark (OHW 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.

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

Outlet: Downstream opening of a culvert.

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.

Reach: A section of a stream having similar physical and biological characteristics.

Recurrence Interval: Also referred to as flood frequency, or return period. It is the average time interval between actual occurrences 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.

Regrade: The channel's process of stabilization usually caused by new or extreme conditions. See headcut and degradation.

Riffle Crest: See "tailwater control".

Riffle: A reach of stream in which the water flow is rapid and usually more shallow that the reaches above and below. Natural streams often consist of a succession of pools and riffles.

Riparian Area: The area adjacent to flowing water (e.g., rivers, perennial or intermittent streams, seeps, or springs) that contains elements of both aquatic and terrestrial ecosystems, which mutually influence each other.

Riprap: Large, durable materials (usually fractured rocks; sometimes broken concrete, etc.) used to protect a stream bank or lake shore from erosion; also refers to the materials used for this purpose.

Rise: The maximum, vertical, open dimension of a culvert; equal to the diameter in a round culvert and the height in a rectangular culvert.

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.

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

Scour: The process of removing material from the bed or banks of a channel through the erosive action of flowing water.

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.

Shear Strength: The characteristic of soil, rock and root structure that resists the sliding of one material against another.

Shear Stress: A measure of the erosive force acting on and parallel to the flow of water. It is expressed as force per unit area (lb/ft2). In a channel, shear stress is created by water flowing parallel to the boundaries of the channel; bank shear is a combined function of the flow magnitude and duration, as well as the shape of the bend and channel cross section.

Slope Ratio: The ratio of the proposed culvert bed slope to the upstream water-surface slope.

Slope: Vertical change with respect to horizontal distance within the channel (*see gradient*). Refer to Appendix H for information on how to measure slope.

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.

Substrate: Mineral and organic material that forms the bed of a stream.

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

Tailout: The downstream end of a pool where the bed surface gradually rises and the water depth increases. It may vary in length, but usually occurs immediately upstream of a riffle.

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.

Toe: The base area of a streambank, usually consisting of the bottom margin of vegetated bank and that portion of bank that is submerged during low flow.

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.

Width Ratio: The ratio of the proposed culvert-bed width to the upstream channel bankfull width.

APPENDIX B

CDFG CULVERT CRITERIA FOR FISH PASSAGE

STATE OF CALIFORNIA
RESOURCES AGENCY
DEPARTMENT OF FISH AND GAME

CULVERT CRITERIA FOR FISH PASSAGE

May 2002

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

Contents

1. Introduction

The following criteria have been adopted by the California Department of Fish and Game (CDFG) 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 CDFG 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, additional criteria have been added for two new design options that are based on the principles of ecological connectivity. The two additional design methods are the
Active Channel Option and the **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 Marine Fisheries Service, Southwest Region (NMFS-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.

Variances from these criteria, including the use of other design methodologies for fish passage, may be granted with the written approval of the Department of Fish and Game. At a minimum, the rationale for the variance must be described and justified in the request. Evaluation and monitoring may be required as a condition of any variance, to ensure that the requested variance does not result in a reduced level of protection for the aquatic resources.

2. Bridges, Culverts, and Low Water Crossings

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: 1) the degree of constriction the crossing has on the stream channel; 2) the degree to which the streambed is allowed to adjust vertically; 3) the length of stream channel impacted by the crossing, and; 4) 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.

3. 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 Marine Fisheries Service (for projects in marine and anadromous waters) and the U.S. 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 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 91709	(909) 597-9823.

Table 1

4. 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 2.

Allowable Design Options			
Fish Passage Requirement	**Active Channel Design Option (Section 5) or Stream Simulation Design Option (Section 6)**	**Hydraulic Design Option For Upstream Fish Passage (Section 7)**	**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 2

5. Active Channel Design Option

The Active Channel Design Option 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 streambed 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%
- Short culvert length (less than 100 feet)
- Passage required for all fish

Culvert Setting & Dimensions - Figure 1

- **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% slope).

- **Embedment -** The bottom of the culvert shall be buried into the streambed not less than 20% of the culvert height at the outlet and not more than 40% of the culvert height at the inlet. Embedment does not apply to bottomless culverts.

See Section 8 for additional considerations, conditions, and restrictions for all designs options.

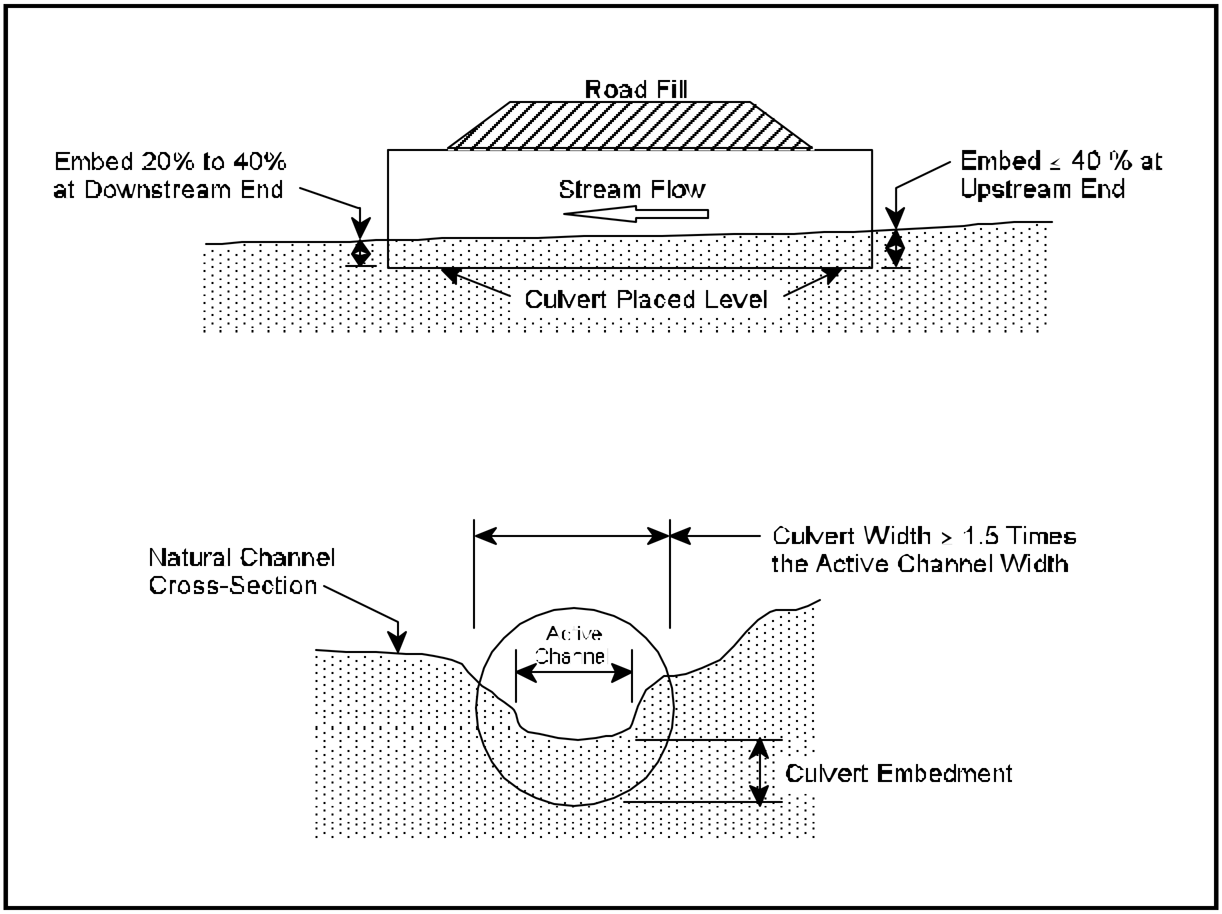

Figure 1 - Active Channel Design Option

6. Stream Simulation Design Option

The Stream Simulation Design Option 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%
- Moderate to long culvert length (greater than 100 feet)
- Passage required for all fish
- Ecological connectivity desired

Culvert Setting & Dimensions - Figure 2

- **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%.

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

- **Substrate Configuration and Stability**

    - Culverts with slopes greater than 3% 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 7.

    - Smooth walled culverts with slopes greater than 3% 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 the stream bed material.

See Section 8 for additional considerations, conditions, and restrictions for all designs options.

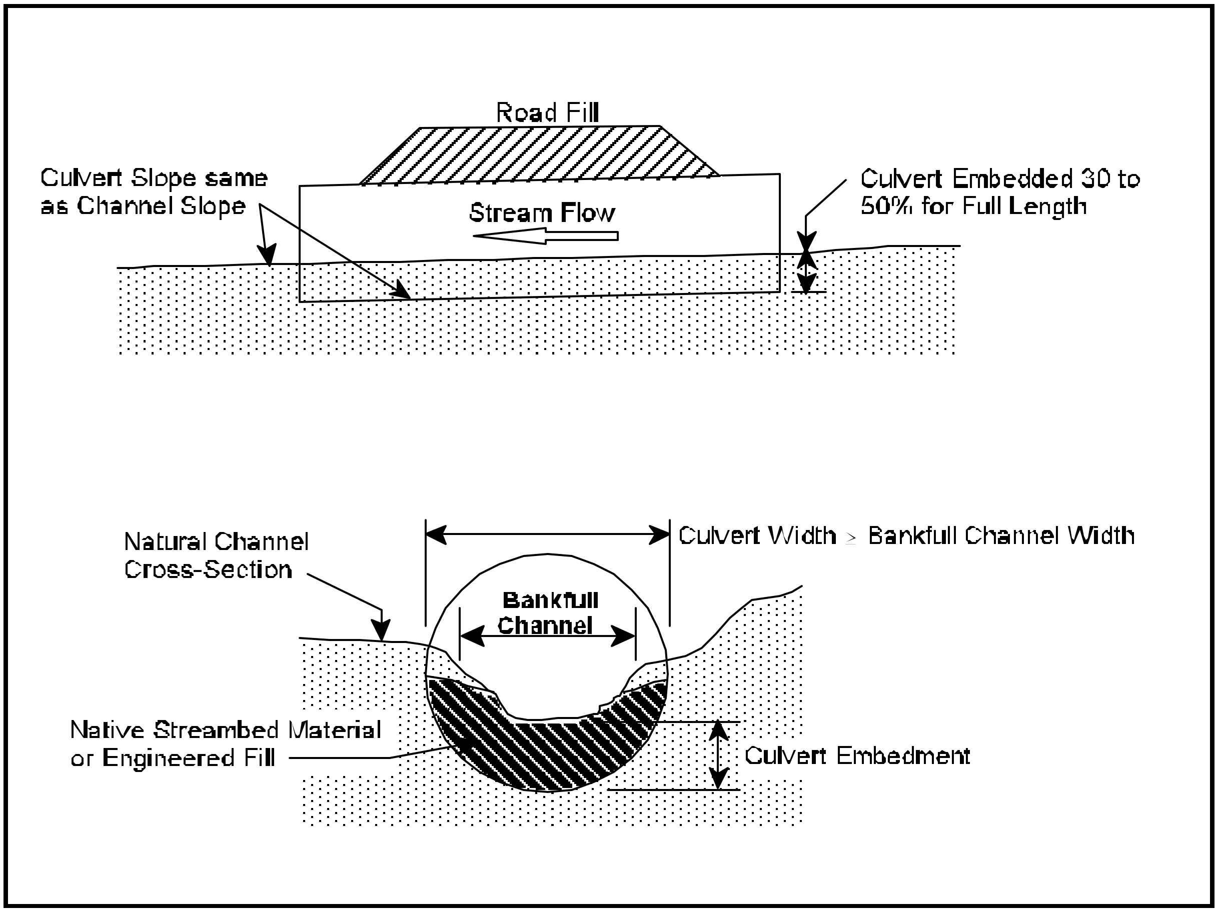

Figure 2 - Stream Simulation Design Option

7. 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 and, therefore, 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%)
- 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 3. If flow duration data is not available the values shown for Percentage of 2-yr 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-yr 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 3

- **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 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 4

Hydraulics

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

Maximum Average Water Velocity and Minimum Depth of Flow

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 5

Culvert Length vs Maximum Average Water Velocity for Adult Salmonids		
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 6

- **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, it's magnitude should be evaluated for both high design flow and low design flow and shall not exceed the values shown in Table 7. If a hydraulic drop occurs at the culvert outlet, a jump pool of at least 2 feet in depth shall be provided.

Maximum Drop at Culvert Outlet	
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 7

- **Hydraulic Controls -** Hydraulic controls (e.g. boulder weirs, log sills, etc.) 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 and Weirs -** Baffles or weirs 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 turbulent 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%.

- **Embedment** - Where physically possible, the bottom of the culvert shall be buried into the streambed a minimum of 20% 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.

See Section 8 for additional considerations, conditions, and restrictions for all designs options.

8. Considerations, Conditions, and Restrictions for All Designs 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-yr 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-yr peak flood and shall not be greater than 50% of the culvert height or diameter above the top of the culvert inlet for the 100-yr peak flood.

- **Oversizing for Debris** - In some cases, is 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-yr 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.

9. 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 the 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 or adding additional culverts. However, in many cases, fish passage can be significantly improved for some species and 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 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.

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 on 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 the channel downstream of the culvert outlet to provide backwater through the culvert or to reduce an excessive hydraulic drop at a culvert outlet. The maximum drop at the culvert outlet shall not exceed the values in Table 7.

  - **Upstream Channel -** Control weirs can be used in the channel upstream of a culvert inlet to re-grade the bed slope and improve fish exit conditions.

  - **Hydraulic Drop -** The individual hydraulic drop across a single control weir shall not exceed the values in Table 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 can not 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 a culvert outlet. Fishways require specialized site specific design for each installation.

10. Select References and Internet Web Sites

Baker, C.O. and F.E. Votapka. 1990. *Fish Passage Through Culverts.* Federal Highways Administration & USDA Forest Service. FHWA-FL-90-006. (Available from USDA Forest Service publications, San Dimas Laboratory, CA)

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 Marine Fisheries Service, 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.
U.S.D.A. Forest Service. 1999. *Fish Xing. Version 2.2*. Six Rivers National Forest Watershed Interactions Team, Eureka, CA.
www.stream.fs.fed.us/fishxing/

USDA Forest Service Water-Road Interaction Technology Series Documents
www.stream.fs.fed.us/water-road/index.html

Washington Department of Fish and Wildlife Fish Passage Technical Assistance
www.wa.gov/wdfw/hab/engineer/habeng.htm

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

11. Select Definitions

The following definitions are provided for clarification of the terms used in this document and the context in which they are used. They are not necessarily definitions as established by case or statutory law, or definitions used for other purposes.

Active Channel: 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 point at which the cleanly scoured substrate of the stream ends and terrestrial vegetation begins.

Anadromous Fish: A group of fish that migrate from the ocean into fresh water to breed. Includes salmon and steelhead, as well as many other fish.

Bankfull Channel: The channel defined by the bankfull discharge, which is the discharge that fills a stable alluvial channel up to the elevation of the active floodplain. Identification of the bankfull channel should be based on the determination of the minimum channel width to depth ratio determined from cross sectional measurements of stable channel reaches up and downstream of the proposed culvert location.

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.

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

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

Culvert Inlet: The upstream 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.

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.

Flow Duration (a.k.a. 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 migratory 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 Controls: Weirs, constructed primarily of rock 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).

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.

Recurrence Interval: Also referred to as flood frequency, or return period; it is the average time interval between actual occurrences of a hydrological event of a given or greater magnitude. A flood event with a 2 year recurrence interval has a 50% chance of occurring in any given year.

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

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

Weirs: A small dam that causes water to back up behind it and flow over or through it. Often has a notch used to control or regulate flows over it.

APPENDIX C

NOAA GUIDELINES FOR SALMONID PASSAGE AT STREAM CROSSINGS

National Marine Fisheries Service
Southwest Region

GUIDELINES FOR SALMONID PASSAGE AT STREAM CROSSINGS

1.0 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 Marine Fisheries Service, Southwest Region (NMFS-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 U.S. 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 NMFS 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 (CDFG). 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 U.S. 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.

2.0 PREFERRED ALTERNATIVES AND CROSSINGS

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

1. *Nothing* - Road realignment to avoid crossing the stream
2. *Bridge* - spanning the stream to allow for long term dynamic channel stabilty
3. *Streambed simulation strategies* - bottomless arch, embedded culvert design, or ford
4. *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
5. *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.

3.0 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 (CDFG, 2001). It is intended to apply to new and replacement culverts where fish passage is legally mandated or important.

3.1 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% in natural slope or for culvert lengths greater than 100 feet. Structures for this design method are typical 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% slope).
- Embedment - The bottom of the culvert shall be buried into the streambed not less than 20% of the culvert height at the outlet and not more than 40% of the culvert height at the inlet.

3.2 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%.
- Embedment - The bottom of the culvert shall be buried into the streambed not less than 30% and not more than 50% of the culvert height. For bottomless culverts the footings or foundation should be designed for the largest anticipated scour depth.

3.3 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%.

$ Embedment - Where physically possible, the bottom of the culvert shall be buried into the streambed a minimum of 20% 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 Fish Passage Design Flow** - The high design flow 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% annual exceedance. If flow duration data or methods necessary to compute them are not available then 50% 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% annual exceedance flow.

$ **Low Fish Passage Design Flow** - 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 the 50% annual exceedance flow or 3 cfs, whichever is greater, should be used for adults and the 95% 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

Minimum Water Depth at the Low Fish Passage Design Flow - For non-embedded culverts, minimum water depth shall be twelve 12 inches for adult steelhead and salmon, and six 6 inches for juvenile salmon.

Juvenile Upstream Passage - Hydraulic design for juvenile upstream passage should based on representative flows in which juveniles typically migrate. Recent research (NMFS, 2001, in progress) indicates that providing for juvenile salmon up to the 10% 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.

3.4 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.

3.5 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 stream bed 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.

4.0 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 NMFS or CDFG 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 substituted 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 can not 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 NMFS or CDFG 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.

5.0 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 light sources shall not exceed 75 feet.

The NMFS and the CDFG set in-stream 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 NMFS or CDFG. 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 NMFS and CDFG 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 NMFS or CDFG 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.

6.0 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:

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

NMFS and/or CDFG 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

NMFS 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.

8.0 DEFINITIONS

These definitions apply to terms used in this document. Meanings may differ when used in another context and are not legal unless otherwise noted. Definitions were shortened, paraphrased or adapted to fit regional conditions and for ease of understanding.

Active Channel: A waterway of perceptible extent that periodically or continuously contains moving water. It has definite bed and banks which serve to confine the water and includes stream channels, secondary channels, and braided channels. It is often determined by the "ordinary high water mark" which means that line on the shore established by the fluctuations of water and indicated by physical characteristics such as clear, natural line impressed on the bank, shelving, changes in the character of soil, destruction of terrestrial vegetation, the presence of litter and debris, or other appropriate means that consider the characteristics of the surrounding areas.

Bankfull: The point on a streambank at which overflow into the floodplain begins. The floodplain is a relatively flat area adjacent to the channel constructed by the stream and overflowed by the stream at a recurrence interval of about one to two years. If the floodplain is absent or poorly defined, other indicators may identify bankfull. These include the height of depositional features, a change in vegetation, slope or topographic breaks along the bank, a change in the particle size of bank material, undercuts in the bank, and stain lines or the lower extent of lichens and moss on boulders. Field determination of bankfull should be calibrated to known stream flows or to regional relationships between bankfull flow and watershed drainage area.

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.

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

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.

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.

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

Flow Duration Curve: A cumulative frequency curve that shows the percentage of time that specified discharges are equaled or exceeded. Flow duration curves are usually based on daily streamflow and describe the flow characteristics of a stream throughout a range of discharges without regard to the sequence of occurrence. If years of data are plotted the annual exceedance flows can be determined.

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.

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.

Section 10 and 404 Regulatory Programs: The principal federal regulatory programs, carried out by the U.S. 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 U.S. 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.

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.

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Internet Resources:

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

National Marine Fisheries Service 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/fishxing/

USDA Forest Service Water-Road Interaction Technology Series Documents
http://www.stream.fs.fed.us/water-road/index.html

British Columbia Forest Practices Code Stream Crossing Guidebook for Fish Streams
http://www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/stream/str-toc.htm

Please direct questions regarding this material to:

National Marine Fisheries Service
Hydraulic Engineering Staff
777 Sonoma Avenue, Suite 325
Santa Rosa, CA 95404

Phone: (707) 575-6050
Fax: (707) 578-3425

Email: nmfs.swr.fishpassage@noaa.gov

APPENDIX D

CALTRANS FISH PASSAGE DESIGN FORMS

FORM 1

EXISTING DATA AND INFORMATION SUMMARY

EXISTING DATA AND INFORMATION SUMMARY FORM 1

Project Information		Computed:	Date:
		Checked:	Date:
Stream Name:	County:	Route:	Postmile:

Proposed Project Type	☐ New Culvert	☐ New Bridge
	☐ Replacement Culvert	☐ Replacement Bridge
	☐ Retrofit Culvert	☐ Retrofit Bridge
	☐ Proposed Culvert Length= ft	☐ Proposed Bridge Length= ft
	☐ Other	☐ Other

Design Species/Life Stage	☐ All Species	Source: Contact: Date:
	☐ Adult Anadromous Salmonids	
	☐ Adult Non-Anadromous Salmonids	
	☐ Juvenile Salmonids	
	☐ Native Non-Salmonids	
	☐ Non-Native Species	

Collect Existing Data

Included in Caltrans Culvert Inventory	☐ Yes	☐ No
As-Built Drawings	☐ Yes	☐ No
Assessor’s Parcel Map	☐ Yes	☐ No
Previous Studies Performed: (i.e. FEMA Flood Insurance Studies, Army Corps of Engineering Studies, Other)		
Hydrology Analysis	☐ Yes	☐ No
Hydraulics Analysis	☐ Yes	☐ No
Floodplain Mapping	☐ Yes	☐ No
Other Studies Types Available: (i.e. Watershed Management Plans, Stream Restoration Plans, Other)	☐ Yes	☐ No
Existing Land Use Map	☐ Yes	☐ No
Proposed Land Use Map	☐ Yes	☐ No
Precipitation Gage Data	☐ Yes	☐ No
Stream Flow Gage Data	☐ Yes	☐ No

EXISTING DATA AND INFORMATION SUMMARY

Topographic Mapping: (i.e. USGS Topographic Quadrangle, DEM Data, LIDAR Data, Other)	☐ Yes	☐ No
District Hydraulics Library	☐ Yes	☐ No

Obtain Access Permission

Will Project study limits extend beyond Caltrans R/W? ☐ Yes ☐ No

If yes, obtain right-of-entry.

Contact Report Index Attached ☐ Yes ☐ No

Existing Information Index Attached ☐ Yes ☐ No

CONTACT REPORT INDEX

Project Information

Computed:

Date:

Checked:

Date:

Stream Name:

County:

Route:

Postmile:

Date of Contact	Person Contacted	Subject Discussed

EXISTING INFORMATION INDEX

Project Information		Computed:	Date:
		Checked:	Date:
Stream Name:	County:	Route:	Postmile:

Report Date	Report Name and Source

FORM 2

SITE VISIT SUMMARY

SITE VISIT SUMMARY FORM 2

Project Information		Computed:	Date:
		Checked:	Date:
Stream Name:	County:	Route:	Postmile:

Obtain Physical Characteristics of Existing Culvert

Confined Spaces

Is the culvert height 5 ft or greater? ☐ Yes ☐ No

Can you stand up in the culvert? ☐ Yes ☐ No

Can you see all the way through the culvert? ☐ Yes ☐ No

Can you feel a breeze through the culvert? ☐ Yes ☐ No

If answer is “No” to any of the above questions, do not enter the culvert without confined spaces equipment for surveying.

Inlet Characteristics

Inlet Type	☐ Projecting	☐ Headwall	☐ Wingwall	
	☐ Flared end section	☐ Segment connection		
Inlet Condition	☐ Channel scour	☐ Excessive deposition	☐ Debris accumulation	☐ None applicable
Inlet Apron	☐ Channel scour	☐ Excessive deposition	☐ Debris accumulation	☐ None applicable

Skew Angle: º

Upstream Invert Elevation: ft (NGVD 29 or NAVD 88)

Barrel Characteristics

Diameter: in	Fill height above culvert: ft
Height/Rise: ft	Length: ft
Width/Span: ft	Number of barrels:

Culvert Type	☐ Arch	☐ Box	☐ Circular
	☐ Pipe-Arch	☐ Elliptical	
Culvert Material	☐ HDPE	☐ Steel Plate Pipe	☐ Concrete Pipe
	☐ Spiral Rib / Corrugated Metal Pipe		
Barrel Condition	☐ Corrosion	☐ Debris accumulation	☐ Structural damage
	☐ Abrasion	☐ Bedload accumulation	☐ None applicable

SITE VISIT SUMMARY FORM 2

Horizontal alignment breaks: ft

Vertical alignment breaks: ft

Outlet Characteristics

Outlet Type
☐ Projecting ☐ Headwall ☐ Wingwall
☐ Flared end section ☐ Segment connection

Outlet Condition
☐ Scour hole ☐ Backwatered ☐ Debris accumulation ☐ None applicable
☐ Perched
Outlet elevation drop: ft
Outlet drop condition:
Scour hole depth: ft

Outlet Apron
☐ Channel scour ☐ Excessive deposition ☐ Debris Accumulation ☐ None Applicable

Skew Angle: º

Downstream Invert Elevation: ft (NGVD 29 or NAVD 88)

Obtain Physical Characteristics of Existing Bridge

Elevation of high chord (top of road): ft

Elevation of low chord: ft

Channel Lining
☐ No lining ☐ Concrete ☐ Rock ☐ Other

Skew Angle: º

Bridge width (length): ft

Pier Characteristics (if applicable) ☐

Number of Piers:

Upstream cross-section starting station: ft

Pier Width: ft

Downstream cross-section starting station: ft

Pier Centerline Spacing: ft

Pier Shape
☐ Square nose and tail ☐ Semi-circular nose and tail ☐ 90° triangular nose and tail
☐ Twin-cylinder piers with connecting diaphragm ☐ Twin-cylinder piers without connecting diaphragm ☐ Ten pile trestle bent

Pier Condition
☐ Scour ☐ Corrosion ☐ Debris accumulation

Skew angle º

Channel Characteristics

Hydraulic Structure Roughness Coefficients

(Source: Caltrans Highway Design Manual Table 864.3A)		**(Source: HEC-RAS User's Manual)**	
Type of Structure	**n- value**	**Type of Structure**	**n- value (normal)**

Linned Channels:		**Corrugated Metal:**	
Portland Cement Concrete	0.014	Subdrain	0.019
Air Blown Mortar (troweled)	0.012	Storm drain	0.024
Air Blown Mortar (untroweled)	0.016	**Wood:**	
Air Blown Mortar (roughened)	0.025	Stave	0.012
Asphalt Concrete	0.018	Laminated, treated	0.017
Sacked Concrete	0.025	**Brickwork:**	
Pavement and Gutters:		Glazed	0.013
Portland Cement Concrete	0.015	Lined with cement mortar	0.015
Asphault Concrete	0.016		
Depressed Medians:			
Earth (without growth)	0.040		
Earth (with growth)	0.050		
Gravel	0.055		

Recommended Permissible Velocities for Unlined Channels (Source: Caltrans Highway Design Manual, Table 862.2)

Type of Material in Excavation Section	Intermittent Flow (f/s)	Sustained Flow (f/s)
Fine Sand (Noncolloidal)	2.6	2.6
Sandy Loam (Noncolloidal)	2.6	2.6
Silt Loam (Noncolloidal)	3.0	3.0
Fine Loam	3.6	3.6
Volcanic Ash	3.9	3.6
Fine Gravel	3.9	3.6
Stiff Clay (Colloidal)	4.9	3.9
Graded Material (Noncolloidal)		
Loam to Gravel	6.6	4.9
Silt to Gravel	6.9	5.6
Gravel	7.5	5.9

Coarse Gravel	7.9	6.6
Gravel to Cobbles (Under 150mm)	8.8	6.9
Gravel and Cobbles Over 200mm)	9.8	7.9
Flow Estimation cfs	☐ Supercritical flow	☐ Subcritical flow

Channel Cross-Section Schematic	Channel depth = ft
Average Active Channel Width Take at least five channel width measurments to determine the active channel width. The active channel stage or ordinary high water level is the elevation delineating the hightest water level that has been maintained for a sufficient period of time to leave evidence on the landscape.	Average Active Channel Width = ft

1) ft	2) ft	3) ft	4) ft	5) ft

Boundary Conditions The normal depth option (slope area method) can only be used as a downstream boundary condition for an open-ended reach. Is normal depth appropriate? If no, what is the known starting water surface elevation?	Upstream	slope ft/ft
	Downstream	slope ft/ft
	Known starting water surface elevation Source:	ft

General Considerations

Identify Physical Restrictions	☐ Right-of-way	☐ Utility conflict	☐ Vegetation
	☐ Man-made features	☐ Natural features	☐ Other

Cross-Section Sketches Attached ☐ Yes ☐ No

Site Photograph Documentation Attached ☐ Yes ☐ No

Channel / Overbank Manning’s n-value Calculation Attached ☐ Yes ☐ No

Field Notes Attached ☐ Yes ☐ No

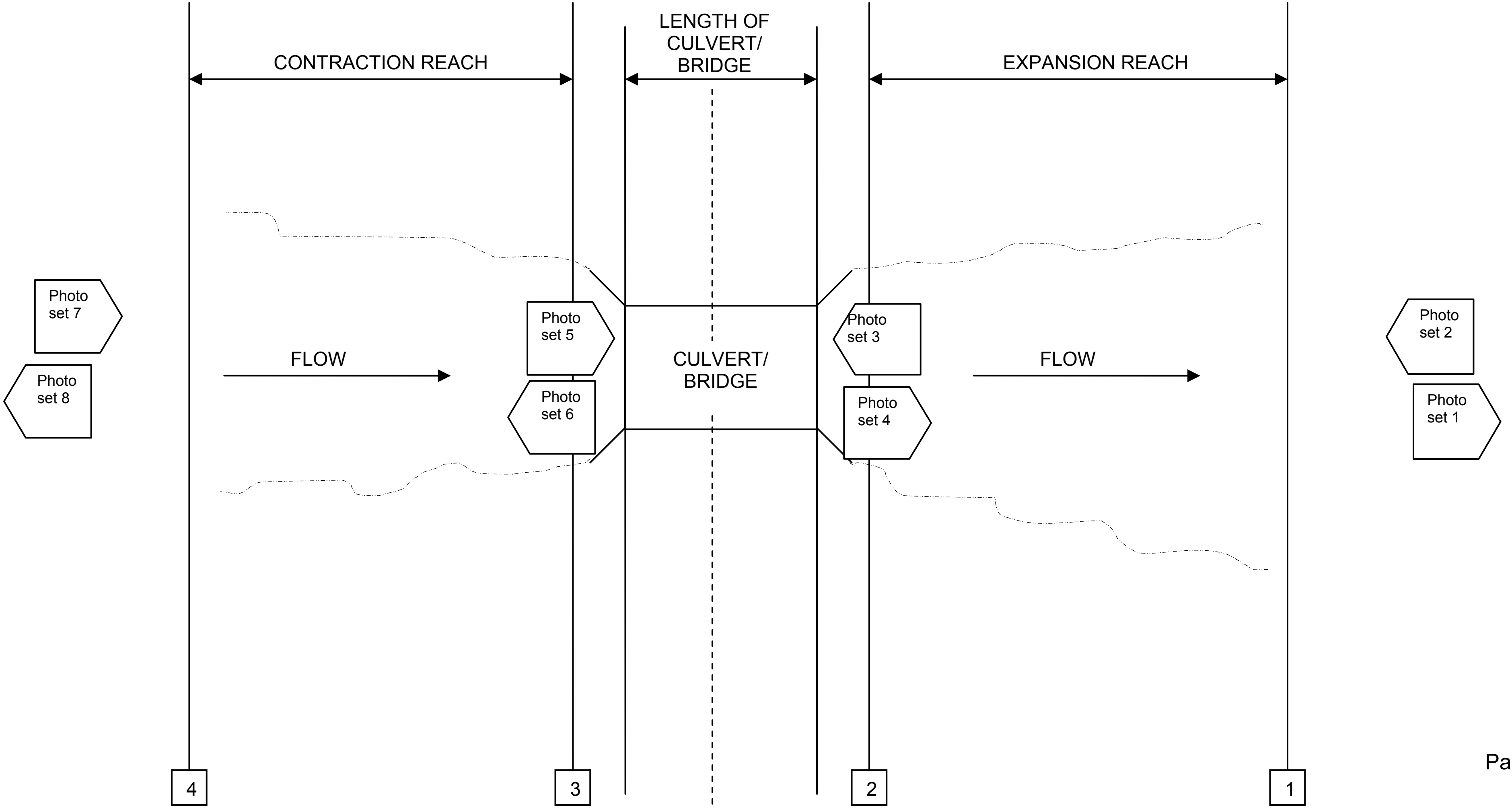
CROSS-SECTION SKETCH

Upstream face of structure:

Downstream face of structure:

SITE PHOTOGRAPH DOCUMENTATION

Project Information				Computed:		Date:	
				Checked:		Date:	
Stream Name:		County:		Route:		Postmile:	
Crossing Type	☐ Culvert		☐ Bridge		☐ Other Type/Comments		
Distance From:	X-sec. 1 to X-sec. 2: ft		X-sec. 2 to DS face of structure ft		US face of structure to X-Sec. 3 ft	X-sec. 3 to X-sec. 4 ft	
Distance From:	Photo Sets 1 & 2 to DS face of structure ft		Photo Sets 3 & 4 to DS face of structure ft		Photo Sets 5 & 6 to US face of structure ft	Photo Sets 7 & 8 to US face of structure ft	
Length of Culvert/Bridge:	ft						



SITE PHOTOGRAPH DOCUMENTATION

Photo Descriptions:

Photo Set 1	
Photo Set 2	
Photo Set 3	
Photo Set 4	
Photo Set 5	
Photo Set 6	
Photo Set 7	
Photo Set 8	

Manning's n Computation - Overbank

Project Information

Computed:

Date:

Checked:

Date:

Stream Name:

County:

Route:

Postmile:

Aerial Picture Attached:

Photographs (#'s and locations)

Is roughness uniform throughout the reach? ________

Note: If not, n-value should be assigned for the AVERAGE condition of the reach

Is roughness uniformly distributed along the cross section? ________

Is a division between the channel and floodplain necessary? ________

Calculation of n-value:

n = (nb + n1 + n2 + n3 + n4)m

where:

	Description of Range
nb = base n value for surface	*median size between 1" and 2.5"=0.028 to 0.035, between 2.5" and 10"=0.030 to 0.050*
n1 = surface irregularity factor	*smooth = 0 up to severe at 0.020*
n2 = cross section variation factor	*gradual = 0 up to alternating frequently at 0.015*
n3 = obstructions factor	*assumed to equal 0*
n4 = vegetation factor	*small = 0.002 to very large (average depth of flow is less than 1/2 height of vegetation) at 0.100*
m = sinuosity/meandering factor	*equals 0 for floodplains*

Base n value for surface

nb: Sand channel? ________ if yes, median size of bed material? ________

nb =

median size (in)	nb
0.008	0.012
0.012	0.017
0.016	0.020
0.020	0.022
0.024	0.023
0.031	0.025
0.039	0.026

All other channels:

median size (in)	nb
.04 to .08	0.026 to 0.035
1 to 2.5	0.028 to 0.035
2.5 to 10	0.030 to 0.050
>10	0.040 to 0.070

Notes:

nb = ________

Surface Irregularity

n1:	Smooth	Compares to the smoothest, flattest floodplain in a given bed material.	if yes, n1 = 0
	Minor	Is the floodplain slightly irregular in shape. A few rises and dips or sloughs may be more visible on the floodplain.	if yes, n1 = 0.001 - 0.005
	Moderate	Has more rises and dips. Sloughs and hummocks may occur.	if yes, n1 = 0.006 - 0.010
	Severe	Floodplain very irregular in shape. Many rises and dips or sloughs are visible.	if yes, n1 = 0.011 - 0.020

n1 = ________

Notes:

Manning's n Computation - Overbank

Cross Section Variation Factor

n2 = 0.000

Notes: Not applicable to floodplains.

Obstructions factor

n3:

Negligible	Does the stream have a few scattered obstructions that occupy < 5% of the cross-sectional area?	if yes, n3 = 0.000 - 0.004
Minor	Obstructions occupy < 15% of the cross-sectional area and the spacing between obstructions is such that the sphere of influence doesn't extend to other obstructions?	if yes, n3 = 0.005 - 0.015
Appreciable	Obstructions occupy 15% - 50% of the cross-sectional area and the spacing between obstructions is small enough to be additive?	if yes, n3 = 0.020 - 0.030

n3 = ______

Notes:

Vegetation factor

n4:

Small	Does the channel have dense growth of flexible turf grass or weed growth where the flow is at least 2 times the height of the vegetation; tree seedlings of willows, cottonwoods, etc where the average depth of flow is at least three times the height of the vegetation?	if yes, n4 = 0.002 - 0.010
Medium	Does the channel have turf grass where the average depth of flow is 1-2 times the height of the vegetation; moderately stemmy grass, weeds or tree seedlings growing where the flow is 2-3 times the height of vegetation? Brushy, moderately dense vegetation, similar to 1-2 year old willow trees in dormant season.	if yes, n4 = 0.010 - 0.025
Large	Does the channel where the average. depth of flow is equal to the height of the vegetation; 8 to 10 year old. willows, cottonwoods intergrown with weeds and brush; where the R = 1.97 ft or bushy willows of 1 year old are in the channel bottom, where R =2.00 ft?	if yes, n4 = 0.025 -0.050
Very large	Does the channel have turf grass growing where the average depth of flow < 1/2 the height of the vegetation; bushy willows about 1 year old. with weeds intergrown on side slopes; dense cattails in channel bottom; trees intergrown with weeds and brush?	if yes, n4 = 0.050 - 0.100
Extreme	Does the channel have dense bushy willow, mesquite, and salt cedar (full foliage), or heavy stand of timber, few down trees, depth of reaching branches?	if yes, n4 = 0.100 - 0.200

n4 = ______

Notes:

Sinuosity/meandering factor

m = 1.00

Notes: Not applicable to floodplains.

Manning's n - Overbank **n =**

FORM 3

GUIDANCE OF SELECTION FISH PASSAGE DESIGN OPTION

GUIDANCE ON SELECTION OF FISH PASSAGE DESIGN OPTION FORM 3

Project Information		Computed:	Date:
		Checked:	Date:
Stream Name:	County:	Route:	Postmile:

Design Species/ Life Stage	☐	All Species
	☐	Adult Anadromous Salmonids
	☐	Adult Non-Anadromous Salmonids
	☐	Juvenile Salmonids
	☐	Native Non-Salmonids
	☐	Non-Native Species

☐ **NMFS Active Channel Design Option -** The NMFS Active Channel Design Option 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 streambed 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 with stream hydraulic charagcteristics within the culvert are intended to mimic the stream conditions upstream and downstream of the crossing. However, hydraulic analyses for traffic safety, hydraulic impacts, and scour are required.

Criteria for choosing option:

☐ New and replacement culvert/bridge installations

☐ Passage required for all species

☐ Proposed culver/bridge length less than 100 feet

☐ Channel slope less than 3%

☐ **CA Fish & Game Low-Slope Design Option –** The CA Fish & Game Low-Slope Design Option is a modification and replacement of the Active Channel Design Option as presented in Part XII: Fish Passage And Implementation (April 2009) addition to *the California Salmonid Stream Habitat Restoration Manual*. It 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 streambed 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 with stream hydraulic charagcteristics within the culvert are intended to mimic the stream conditions upstream and downstream of the crossing. However, hydraulic analyses for traffic safety, hydraulic impacts, and scour are required.

Criteria for choosing option:

☐ New and replacement culvert/bridge installations

☐ Passage required for all species

☐ Proposed culver/bridge length less than 75 feet

☐ Channel slope less than 1%

☐ **Hydraulic Design Option -** The Hydraulic Design Option is a design process that matches the hydraulic performance of a culvert with the swimming ablitities of a target species and age class of fish. This method targets distinct species of fish and, therefore, does not account for ecosystem requirments of non-target species.

Criteria for choosing option:

GUIDANCE ON SELECTION OF FISH PASSAGE DESIGN OPTION FORM 3

☐ New and replacement culvert/bridge installations (If retrofit installation, see Baffle or Rock Weir Design Options)

☐ Target species identified for passage

☐ Low to moderate channel slopes (less than 3%)

☐ Active channel design or stream simulation design options are not physically feasible

Retrofit Culvert/Bridge Installations

☐ **Baffle Design Option -** The Baffle Design Option is a Hydraulic Design process that is intended to increase flow depth, or to add roughness elements as a measure to reduce flow velocity within the culvert/bridge structure. Determination of the high and low fish passage design flows, water velocity, and water depth is required for this option.

- ☐ Retrofit culvert/bridge installation
- ☐ Little bedload material movement
- ☐ Existing culvert/bridge is structurally sound
- ☐ Target species identified for passage
- ☐ Low to moderate channel slopes
- ☐ Active channel design or stream simulation design options are not physically feasible

☐ **Rock Weir Design Option -** The Rock Weir Design Option is a Hydraulic Design process that is intended to increase flow depth, or add roughness elements as a measure to reduce flow velocity, or to increase the channel slope downstream of the culvert/bridge. Determination of the high and low fish passage design flows, water velocity, and water depth is required for this option.

- ☐ Retrofit culvert/bridge installations
- ☐ Perched condition at outlet
- ☐ Steep slope at inlet
- ☐ Target species identified for passage
- ☐ Active channel design or stream simulation design options are not physically feasible

☐ **Stream Simulation Design Option -** The Stream Simulation Design Option 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.

Criteria for choosing option:

☐ New and replacement culvert/bridge installations

☐ Passage required for all species

☐ Culvert/bridge length greater than 100 feet

GUIDANCE ON SELECTION OF FISH PASSAGE DESIGN OPTION FORM 3

☐ Channel width should be less than 20 feet

☐ Minimum culvert/bridge width no less than 6 feet

☐ Culvert/bridge slope does not greatly exceed slope of natural channel, slopes of 6 % or less

☐ Narrow stream valleys

Selected Design Option:

Basis for Selection:

Seek Agency Approval: ☐ Yes ☐ No

FORM 4

GUIDANCE ON METHODOLOGY FOR HYDROLOGIC ANALYSIS

GUIDANCE ON METHODOLOGY FOR HYDROLOGIC ANALYSIS [1, 2] FORM 4

Project Information		Computed:	Date:
		Checked:	Date:
Stream Name:	County:	Route:	Postmile:

Summary of Methods for Estimating Peak Design Discharges for Use in Hydraulic Analysis

Ungaged Streams

☐ **Regional Regression[3, 4]**

Data Requirements	Limitations	Guidance
▪ Drainage area ▪ Mean annual precipitation ▪ Altitude index	▪ Peak discharge value for flow under natural conditions unaffected by urban development and little or no regulation by lakes or reservoirs ▪ Ungaged channel	The most recently published USGS report for estimating peak discharges may be used. The user should exercise caution to ensure that the reports are used only for the conditions and locations for which they are recommended.

Rainfall-Runoff Models

☐ **NRCS (TR 55)[5]**

Data Requirements	Limitations	Guidance
▪ 24-hour Rainfall ▪ Rainfall distribution ▪ Runoff curve number ▪ Concentration time ▪ Drainage area	▪ Small or midsize catchment (<8 km^2) ▪ Maximum of 10 subwatersheds ▪ Concentration time range from 0.1-10 hour (tabular hydrograph method limit <2 hour) ▪ Runoff is overland and channel flow ▪ Simplified channel routing ▪ Negligible channel storage	TR-55 focuses on small urban and urbanizing watersheds.

☐ **HEC-1/HEC-HMS[6, 7] (SCS Dimnesionless, Snyder Unit, Clark Unit Hydrographs)**

Data Requirements	Limitations	Guidance
▪ Watershed/subbasin parameters ▪ Precipitation depth, duration, frequency, and distribution ▪ Precipitation losses ▪ Unit hydrograph parameters ▪ Streamflow routing and diversion parameters	▪ Simulations are limited to a single storm event ▪ Streamflow routing is performed by hydrologic routing methods and is therefore not appropriate for unsteady state routing conditions.	Can be used for watersheds which are: small or large, simple or complex, and developed or undeveloped.

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[1] Caltrans Highway Design Manual, Chapter 810 Hydrology, Topic 819 Estimating Design Discharge
[2] FEMA Guidelines and Specifications, Appendix C, Section C.1
[3] USGS Water-Resources Investigation 77-21 (Magnitude and Frequency of Floods in California)
[4] USGS Open-File Report 93-419 (Methods for Estimating Magnitude and Frequency of floods in the Southwestern United States)
[5] United States Department of Agriculture, Natural Resources Conservation Service, Urban Hydrology for Small Watersheds Technical Release 55, June 1986. ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf
[6] HEC-1 User's Manual
[7] HEC-HMS User's Manual
[8] Bulletin 17B

GUIDANCE ON METHODOLOGY FOR HYDROLOGIC ANALYSIS[1, 2]

FORM 4

GAGED STREAMS

☐ **Statistical Methods[8]**

Data Requirements	Limitations	Guidance
▪ 10 or more years of gaged flood records	▪ Gage data is usually only available for midsized and large catchments ▪ Appropriate station and/or generalized skew coefficient relationship applied	For watersheds with less than 50 years of record, compare with results of appropriate USGS regional regression equations. For watersheds with less than 25 years of record, compare with results of appropriate USGS regional regresssion equations and/or HEC-1/HEC-HMS model results.

☐ **Basin Transfer of Gage Data**

Data Requirements	Limitations	Guidance
▪ Discharge and area for gaged watershed ▪ Area for ungaged watershed	▪ Similar hydrologic characteristics ▪ Channel storage	Must obtain approval of transfer technique from hydraulics engineer prior to use.

☐ **Fish Passage Flows**

▪ Streamflow hydrograph ▪ Flow duration curve		Lower and upper fish passage flows define the range of flows a culvert should contain suitable conditions for fish passage.

Selected Hydrologic Method:

Basis for Selection:

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[1] Caltrans Highway Design Manual, Chapter 810 Hydrology, Topic 819 Estimating Design Discharge

[2] FEMA Guidelines and Specifications, Appendix C, Section C.1

[3] USGS Water-Resources Investigation 77-21 (Magnitude and Frequency of Floods in California)

[4] USGS Open-File Report 93-419 (Methods for Estimating Magnitude and Frequency of floods in the Southwestern United States)

[5] United States Department of Agriculture, Natural Resources Conservation Service, Urban Hydrology for Small Watersheds Technical Release 55, June 1986. ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf

[6] HEC-1 User's Manual

[7] HEC-HMS User's Manual

[8] Bulletin 17B

GUIDANCE ON METHODOLOGY FOR HYDROLOGIC ANALYSIS [1, 2] FORM 4

Verify Reasonableness and Recommended Peak Discharges

Source	**50% Annual Probability (2-Year Flood Event) (cfs)**	**10% Annual Probability (10-Year Flood Event) (cfs)**	**4% Annual Probability (25-Year Flood Event) (cfs)**	**2% Annual Probability (50-Year Flood Event) (cfs)**	**1% Annual Probability (100-Year Flood Event) (cfs)**	**High Fish Passage Design Flow (cfs)**	**Low Fish Passage Design Flow (cfs)**
Effective Study Peak Discharges							
Recommended Peak Discharges							

Hydrologic Analysis Index Attached ☐ Yes ☐ No

Hydrologic Analysis Calculations Attached ☐ Yes ☐ No

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[1] Caltrans Highway Design Manual, Chapter 810 Hydrology, Topic 819 Estimating Design Discharge

[2] FEMA Guidelines and Specifications, Appendix C, Section C.1

[3] USGS Water-Resources Investigation 77-21 (Magnitude and Frequency of Floods in California)

[4] USGS Open-File Report 93-419 (Methods for Estimating Magnitude and Frequency of floods in the Southwestern United States)

[5] United States Department of Agriculture, Natural Resources Conservation Service, Urban Hydrology for Small Watersheds Technical Release 55, June 1986. ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf

[6] HEC-1 User's Manual

[7] HEC-HMS User's Manual

[8] Bulletin 17B

HYDROLOGIC ANALYSES INDEX

FORM 4

Project Information	Computed:	Date:
	Checked:	Date:

Stream Name:	County:	Route:	Postmile:

Flooding Source/Stream Name	Hydrologic Method/Model Used	Method/Model Analysis Date	Exhibit No.	
			Paper Copy	Electronic Copy

FORM 6A

NMFS ACTIVE CHANNEL DESIGN OPTION

FISH PASSAGE: NMFS ACTIVE CHANNEL DESIGN OPTION FORM 6A

Project Information	Computed:	Date:
	Checked:	Date:

Stream Name:	County:	Route:	Postmile:

Hydrology Results - Peak Discharge Values

2% Annual Probability (50-Year Flood Event)	cfs	1% Annual Probability (100-Year Flood Event)	cfs

Establish Culvert Setting and Dimensions

Culvert Width - The minimum culvert width shall be equal to, or greater than, 1.5 times the average active channel width.

Average Active Channel Width = ft	Average Active Channel Width X 1.5 = ft	Culvert Width = ft

Culvert Length - Must be less than 100 feet.

Culvert Length ft

Culvert Embedment - The bottom of the culvert shall be buried into the streambed 20% to 40% of culvert height at the outlet, and not more than 40% of the culvert height at the inlet.

Upstream Embedment = ft (≤40% of culvert rise)

Downstream Embedment = ft (≥20% to ≤40% of culvert rise)

Culvert Slope - The culvert shall be placed level (0% slope).

Upstream invert elevation = ft	Downstream invert elevation = ft

Summarize Proposed Culvert Physical Characterstics

Inlet Characteristics

Inlet Type	☐ Projecting	☐ Headwall	☐ Wingwall
	☐ Flared end section	☐ Segment connection	☐ Skew Angle: º

Barrel Characteristics

Diameter: in	Fill height above culvert: ft
Height/Rise: - ft	Number of barrels:
Width/Span: - ft	

FISH PASSAGE: NMFS ACTIVE CHANNEL DESIGN OPTION FORM 6A

Culvert Type	☐ Arch ☐ Pipe-Arch	☐ Box ☐ Elliptical	☐ Circular
Culvert Material	☐ HDPE ☐ Spiral Rib / Corrugated Metal Pipe	☐ Steel Plate Pipe	☐ Concrete Pipe

Horizontal alignment breaks: - ft

Vertical alignment breaks: - ft

Outlet Characteristics

Outlet Type	☐ Projecting ☐ Flared end section	☐ Headwall ☐ Segment connection	☐ Wingwall Skew Angle: º

Develop and run Hydraulic Models to compute water surface elevations, flow depths, and channel velocities for the 50- and 100-year peak or design discharges reflecting existing and project conditions.

Maximum Allowable Inlet Water Surface Elevation

Shall not be greater than 50% of the culvert height or diameter above the top of the culvert inlet for the 100-Year peak flood, and without objectionable backwater.	Allowable (maximum) WSEL: ft

Allowable Hydraulic Impacts

Is the crossing located within a floodplain as designated by the Federal Emergency Management Agency or another responsible state or local agency?
☐ Yes ☐ No

If yes, establish allowable hydraulic impacts and hydraulic design requirements with the appropriate agency. Attach results.

Will the project result in the increase capacity of an existing crossing? ☐ Yes ☐ No

If yes, will it significantly increase downstream peak flows due to the reduced upstream attenuation? ☐ Yes ☐ No

If yes, consult District Hydraulics. Further analysis may be needed.

Velocity Summary – Proposed Conditions maximum culvert velocities at inlet, barrel, and outlet transition for the peak or design discharge:

Culvert Velocity	Design Flow Velocity (ft/s)
Culvert Inlet Velocity (evaluated at x-section immediately located upstream of culvert)	
Culvert Barrel Velocity (evaluated through Culvert Output in HEC-RAS)	
Culvert Outlet Velocity(evaluated at x-section immediately located downstream of culvert)	

Do the velocities exceed the permissible scour velocities? ☐ Yes ☐ No

If yes, revise design to reduce velocities and rerun hydraulic analyses to verfiy, or design erosion protection.

Proposed Plan and Profile Drawing Attached ☐ Yes ☐ No

Hydraulic Analysis Index Sheet Attached ☐ Yes ☐ No

FORM 6A1

CA FISH & GAME LOW-SLOPE DESIGN OPTION

FISH PASSAGE: CA FISH & GAME LOW-SLOPE DESIGN OPTION FORM 6A1

Project Information

Computed:

Date:

Checked:

Date:

Stream Name:

County:

Route:

Postmile:

Hydrology Results - Peak Discharge Values

2% Annual Probability (50-Year Flood Event)	cfs	1% Annual Probability (100-Year Flood Event)	cfs

Establish Culvert Setting and Dimensions

Culvert Width - The minimum culvert width shall be equal to, or greater than, 1.25 times the average bankfull width.

Average Bankfull Width = ft

Average Backfill Width X 1.25 = ft

Culvert Width = ft

Culvert Length - Must be less than 75 feet.

Culvert Length ft

Culvert Embedment - The bottom of the culvert shall be buried into the streambed 20% to 40% of culvert rise throughout.

Upstream Embedment = ft

Downstream Embedment = ft

Culvert Slope - The culvert shall be placed at the natural stream slope.

Upstream invert elevation = ft

Downstream invert elevation = ft

Summarize Proposed Culvert Physical Characterstics

Inlet Characteristics

Inlet Type

☐ Projecting

☐ Headwall

☐ Wingwall

☐ Flared end section

☐ Segment connection

☐ Skew Angle: º

Barrel Characteristics

Diameter: in

Fill height above culvert: ft

Height/Rise: - ft

Number of barrels:

Width/Span: - ft

FISH PASSAGE: CA FISH & GAME LOW-SLOPE DESIGN OPTION FORM 6A1

Culvert Type	☐ Arch ☐ Pipe-Arch	☐ Box ☐ Elliptical	☐ Circular
Culvert Material	☐ HDPE ☐ Spiral Rib / Corrugated Metal Pipe	☐ Steel Plate Pipe	☐ Concrete Pipe

Horizontal alignment breaks: - ft

Vertical alignment breaks: - ft

Outlet Characteristics

Outlet Type	☐ Projecting ☐ Flared end section	☐ Headwall ☐ Segment connection	☐ Wingwall Skew Angle: º

Develop and run Hydraulic Models to compute water surface elevations, flow depths, and channel velocities for the 50- and 100-year peak or design discharges reflecting existing and project conditions.

Maximum Allowable Inlet Water Surface Elevation

Shall not be greater than 50% of the culvert height or diameter above the top of the culvert inlet for the 100-Year peak flood, and without objectionable backwater.	Allowable (maximum) WSEL: ft

Allowable Hydraulic Impacts

Is the crossing located within a floodplain as designated by the Federal Emergency Management Agency or another responsible state or local agency?
☐ Yes ☐ No

If yes, establish allowable hydraulic impacts and hydraulic design requirements with the appropriate agency. Attach results.

Will the project result in the increase capacity of an existing crossing? ☐ Yes ☐ No

If yes, will it significantly increase downstream peak flows due to the reduced upstream attenuation? ☐ Yes ☐ No

If yes, consult District Hydraulics. Further analysis may be needed.

Velocity Summary – Proposed Conditions maximum culvert velocities at inlet, barrel, and outlet transition for the peak or design discharge:

Culvert Velocity	**Design Flow Velocity (ft/s)**
Culvert Inlet Velocity (evaluated at x-section immediately located upstream of culvert)	
Culvert Barrel Velocity (evaluated through Culvert Output in HEC-RAS)	
Culvert Outlet Velocity(evaluated at x-section immediately located downstream of culvert)	

Do the velocities exceed the permissible scour velocities? ☐ Yes ☐ No

If yes, revise design to reduce velocities and rerun hydraulic analyses to verfiy, or design erosion protection.

Proposed Plan and Profile Drawing Attached ☐ Yes ☐ No

Hydraulic Analysis Index Sheet Attached ☐ Yes ☐ No

FORM 6B

HYDRAULIC DESIGN OPTION

FISH PASSAGE: HYDRAULIC DESIGN OPTION FORM 6B

Project Information		Computed:	Date:
		Checked:	Date:
Stream Name:	County:	Route:	Postmile:

General Considerations

Hydraulic controls (e.g. boulders weirs, log sills, etc.) 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, and control erosion of the streambed and banks.

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

The following **Adverse 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. Crossing 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 turbulent conditions, and Abrubt changes in water surface elevation in inlet and outlet.

Hydrology Results - Peak Discharge Values

50% Annual Probability (2-Year Flood Event)	cfs	10% Annual Probability (10-Year Flood Event)	cfs
2% Annual Probability (50-Year Flood Event)	cfs	1% Annual Probability (100-Year Flood Event)	cfs
High Fish Passage Design Flow	cfs	Low Fish Passage Design Flow	cfs

Estabilsh Proposed Culvert Settings and Dimensions

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

Proposed Culvert Width: ft

Culvert Embedment - Where physically possible, the bottom of the culvert shall be buried into the streambed a minimum of 20% 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.

Upstream Embedment: ft (≥ 1 foot)

Downstream Embedment: ft (≥ 20% of culvert rise and ≥ 1 foot)

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%.

Upstream invert elevation: ft (NGVD 29 or NAVD 88)	Downstream invert elevation: ft (NGVD 29 or NAVD 88)

Summarize Proposed Culvert Physical Characterstics

Inlet Characteristics

Inlet Type	☐ Projecting	☐ Headwall	☐ Wingwall
	☐ Flared end section	☐ Segment connection	☐ Skew Angle: º

FISH PASSAGE: HYDRAULIC DESIGN OPTION FORM 6B

Barrel Characteristics

Diameter: in	Fill height above culvert: ft
Height/Rise: ft	Length: ft
Width/Span: ft	Number of barrels:

Culvert Type	☐ Arch ☐ Pipe-Arch	☐ Box ☐ Elliptical	☐ Circular
Culvert Material	☐ HDPE ☐ Spiral Rib / Corrugated Metal Pipe	☐ Steel Plate Pipe	☐ Concrete Pipe

Horizontal alignment breaks: ft	Vertical alignment breaks: ft

Outlet Characteristics

Outlet Type	☐ Projecting ☐ Flared end section	☐ Headwall ☐ Segment connection	☐ Wingwall Skew Angle: º

Summarize Proposed Bridge Physical Characterstics

Bridge Physical Characteristics

Elevation of high chord (top of road): ft	Elevation of low chord: ft

Channel Lining	☐ No lining	☐ Concrete	☐ Rock	☐ Other

Skew Angle: º	Bridge width (length): ft

Pier Characteristics (if applicable) ☐

Number of Piers: ft	Upstream cross-section starting station: ft
Pier Width: ft	Downstream cross-section starting station: ft
Pier Centerline Spacing: ft	Skew angle: º

Pier Shape	☐ Square nose and tail ☐ Twin-cylinder piers with connecting diaphragm	☐ Semi-circular nose and tail ☐ Twin-cylinder piers without connecting diaphragm	☐ 90° triangular nose and tail ☐ Ten pile trestle bent

Establish High Design Flow for Fish Passage - Depending on species, develop high design flows:

Species/Life Stage	Percent Annual Exceedance Flow	Percentage of 2-Yr Recurrence Interval Flow	Design Flows (cfs)
☐ 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%	

Establish Low Design Flow for Fish Passage - Depending on species, develop low design flows:

Species/Life Stage	**Percent Annual Exceedance Flow**	**Alternate Minimum Flow (cfs)**	**Design 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	

Establish Maximum Average Water Velocity and Minimum Flow Depth in Culvert (At high design flow) - Depending on culvert length and/or species, select Maximum Average Water Veolcity and Minimum Flow Depth.

Species/Life Stage	**Maximum Average Water Velocity at High Fish Design Flow (ft/sec)**	**Minimum Flow Depth at Low Fish Design Flow (ft)**
☐ Adult Anadromous Salmonids	6 (Culvert length <60 ft)	1.0
	5 (Culvert length 60-100 ft)	
	4 (Culvert length 100-200 ft)	
	3 (Culvert length 200-300 ft)	
	2 (Culvert length >300 ft)	
☐ Adult Non-Anadromous Salmonids	4 (Culvert length <60 ft)	0.67
	4 (Culvert length 60-100 ft)	
	3 (Culvert length 100-200 ft)	
	2 (Culvert length 200-300 ft)	
	2 (Culvert length >300 ft)	
☐ 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	

Establish 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, it's magnitude should be evaluated for both high design flow and low design flow and shall not exceed the values shown below. If a hydraulic drop occurs at the culvert outlet, a jump pool of at least 2 feet in depth shall be provided.

Species/Life Stage	**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	

Maximum Allowable Inlet Water Surface Elevation

Culvert ☐

A culvert is required to pass the 10-year peak discharge without causing pressure flow in the culvert,	Allowable WSEL: ft
And shall not be greater than 50% of the culvert height or diameter above the top of the culvert inlet for the 100-Year peak flood.	Allowable WSEL: ft

Bridge ☐

A bridge is required to pass the 50-year peak discharge with freeboard, vertical clearance between the lowest structural member and the water surface elevation,	Allowable WSEL: ft
While passing the 100-year peak or design discharge under low chord of the bridge.	Allowable WSEL: ft

Establish Allowable Hydraulic Impacts

Is the crossing located within a floodplain as designated by the Federal Emergency Management Agency or another responsible state or local agency?
☐ Yes ☐ No

If yes, establish allowable hydraulic imacts and hydraulic design requirements with the appropriate agency. Attach results.

Will the project result in the increase capacity of an existing crossing? ☐ Yes ☐ No

If yes, will it significantly increase downstream peak flows due to the reduced upstream attenuation? ☐ Yes ☐ No

If yes, consult District Hydraulics. Further analysis may be needed.

Will the project result in a reduction in flow area for the 100-year peak discharge? ☐ Yes ☐ No

If yes, establish the allowable increase in upstream water surface elevation and establish how far upstream the increased water surface may extend.

Develop and run Hydraulic Models to compute water surface elevations, flow depths, and channel velocities fo the low fish passage design flow, the high fish passage design flow and for the 2-, 10-, 50-, and 100-year peak or design discharges reflecting existing and project conditions.
☐ Yes ☐ No

Evaluate computed water surface elevations, flow depths, and channel velocities: ☐ Yes ☐ No

Maximum average velocity in culvert at high fish design flow: ft/s

Does the velocity exceed the maximum allowable for the culvert length and design species? ☐ Yes ☐ No

If yes, modify design to comply and rerun hydraulic anaylses to verify.

Minimum flow depth in culvert at low fish design flow: ft

Does the depth equal or not exceed the mimimum allowable for the culvert length and design species? ☐ Yes ☐ No

If yes, modify design to comply and rerun hydraulic anaylses to verify.

Drop between the water surface elevation in the culvert and the outlet channel for:

High Fish Passage Flow: ft

Low Fish Passage Flow: ft

Does the drop between the water surface in the culvert and the outlet channel at high or low design fish flows exceed the maximum allowable for the design species? ☐ Yes ☐ No

If yes, modify design to avoid a drop if possible. If a drop is unavoidable modify design to meet criteria and provide a jump pool at least two feet in depth. Rerun hydraulic analyses to verfiy.

Water Surface elevation at inlet for the 10-year peak discharge:

Does the water surface elevation exceed the allowable? ☐ Yes ☐ No

If yes, modify design to comply and rerun hydraulic analyses to verify.

Maximum Culvert and Channel velocities at inlet and outlet transition for the peak or design discharge:

Range of velocities for Inlet transition:	ft/s	to	ft/s
Range of velocities for Culvert portion:	ft/s	to	ft/s
Range of velocities for Outlet Transition:	ft/s	to	ft/s

Do the velocities exceed the permissible scour velocities? ☐ Yes ☐ No

If yes, revise design to reduce velocities and rerun hydraulic analyses to verify, or design erosion protection.

Comparison between existing and project future condition water surface elevations for the 10-Year and 100-Year peak flow:

Cross-Section	**10-Yr WSEL**	**10-Yr WSEL**	**WSEL Difference**	**100-Year WSEL**	**100-Year WSEL**	**WSEL Difference**
	Existing	**Future**	**(ft)**	**Existing**	**Future**	**(ft)**

FISH PASSAGE: HYDRAULIC DESIGN OPTION **FORM 6B**

	Conditions (ft)	Conditions (ft)		Conditions (ft)	Conditions (ft)	
1						
2						
3						
4						

If WSELs increase, does the increase exceed the maximum elevation? ☐ Yes ☐ No

Maximum elevation: ft

If yes, revise the design and rerun hydraulic analyses to verify.

If WSELs decrease, does it appear that the attenuation of peak flow will significally change? ☐ Yes ☐ No

If yes, evaluate to determine if downstream hydraulic impacts are significant and modify design as appropriate.

Proposed Plan and Profile Drawing Attached ☐ Yes ☐ No

Hydraulic Analysis Index Sheet Attached ☐ Yes ☐ No

FORM 6C

STREAM SIMULATION DESIGN OPTION

FISH PASSAGE: STREAM SIMULATION DESIGN OPTION FORM 6C

Project Information		Computed:	Date:
		Checked:	Date:
Stream Name:	County:	Route:	Postmile:

General Considerations

The **Stream Simulation** method strives to result in the same passage conditions within the culvert as those seen in the selected reference reach, to the extent practical. The Stream Simulation process includes these four steps: 1) Develop long profile and define the reference reach, 2) Establish proposed structure settings and dimensions, 3) Design bed material and shape, and 4) Check bed stability.

Hydrology Results - Peak Discharge Values

50% Annual Probability (2-Year Flood Event)	cfs	10% Annual Probability (10-Year Flood Event)	cfs
4% Annual Probability (25-Year Flood Event)	cfs	2% Annual Probability (50-Year Flood Event)	cfs
1% Annual Probability (100-Year Flood Event)	cfs		

Develop Long Profile and Define the Reference Reach

Attach channel profile sheet. ☐ Yes ☐ No

Identify reference reach on long profile with characteristics that will be appropriate for the replacement culvert. ☐ Yes ☐ No

Identify channel type and key features that vary depending on the bed mobility. ☐ Yes ☐ No

Identify location of bed material samples on profile. ☐ Yes ☐ No

Identify typical channel cross-sections. ☐ Yes ☐ No

Identify channel characteristics and processes on long profile. ☐ Yes ☐ No

Plot stream/culvert profile or range of profiles for consideration. ☐ Yes ☐ No

Illustrate the typical reference reach cross-section:

FISH PASSAGE: STREAM SIMULATION DESIGN OPTION FORM 6C

Bankfull Channel: The channel defined by the bankfull discharge, which is the discharge that fills a stable alluvial channel up to the elevation of the active floodplain. Identification of the bankfull channel should be based on the determination of the minimum channel width to depth ratio determined from cross sectional measurements of stable channel reaches upstream and downstream of the proposed culvert location.

Bankfull channel width = ft

Estabilsh Proposed Culvert Settings and Dimensions

Culvert Width: Culvert width is the width needed to span the bankfull channel. If permanent banklines are constructed of rock, adequate culvert width must be provided to span the bed plus the size of the rock on both banks. For an initial estimate of the minimum culvert width, add twice the diameter of the largest material in the bed to the bankfull width. A stability analysis might show that other bed material is needed.

Culvert Width = ft

Culvert Length: Culvert length must be greater than 100 feet

Culvert Length = ft

Culvert Embedment: A circular culvert embedded into the streambed no less than 30% but no more than 50% of its rise is a good practical guide.

Upstream embedment = ft	Downstream embedment = ft

Culvert Slope Culvert slope does not greatly exceed slope of natural channel, slopes of 6% or less

Upstream invert elevation = ft (NGVD 29 or NAVD 88)	Downstream invert elevation = ft (NGVD 29 or NAVD 88)

Summarize Proposed Culvert Physical Characterstics

Inlet Characteristics

Inlet Type	☐ Projecting	☐ Headwall	☐ Wingwall
	☐ Flared end section	☐ Segment connection	☐ Skew Angle: º

Barrel Characteristics

Diameter: in	Fill height above culvert: ft
Height/Rise: ft	Length: ft
Width/Span: ft	Number of barrels:

Culvert Type	☐ Arch	☐ Box	☐ Circular
	☐ Pipe-Arch	☐ Elliptical	

Culvert Material: ☐ HDPE ☐ Steel Plate Pipe ☐ Concrete Pipe ☐ Spiral Rib / Corrugated Metal Pipe

Horizontal alignment breaks: ft

Vertical alignment breaks: ft

Outlet Characteristics

Outlet Type: ☐ Projecting ☐ Headwall ☐ Wingwall ☐ Flared end section ☐ Segment connection Skew Angle: º

Summarize Proposed Bridge Physical Characterstics

Bridge Physical Characteristics

Elevation of high chord (top of road): ft (NGVD 29 or NAVD 88)

Elevation of low chord: ft (NGVD 29 or NAVD 88)

Channel Lining: ☐ No lining ☐ Concrete ☐ Rock ☐ Other

Pier Characteristics (if applicable) ☐

Number of Piers: ft

Upstream cross-section starting station: ft

Pier Width: ft

Downstream cross-section starting station: ft

Pier Centerline Spacing: ft

Skew angle: º

Pier Shape: ☐ Square nose and tail ☐ Semi-circular nose and tail ☐ 90° triangular nose and tail ☐ Twin-cylinder piers with connecting diaphragm ☐ Twin-cylinder piers without connecting diaphragm ☐ Ten pile trestle bent

Define Bed Material and Shape

Create reference grain-size distribution curve from reference reach material.

D_{16} = in. D_{50} = in. D_{84} = in.

Bed Stability/Mobility Analysis

Reference Reach:

FISH PASSAGE: STREAM SIMULATION DESIGN OPTION — FORM 6C

1. Choose bed stability/mobility method.

Modified Shields: ☐ Yes ☐ No

Critical Unit Discharge: ☐ Yes ☐ No

2. Pick a minimum of 5 flows between active channel and bankfull flows (or greater).

Q_a = cfs

Q_b = cfs

Q_c = cfs

Q_d = cfs

Q_e = cfs

3. Calculate driving force (τ_c or q) for each flow in Step 2.

$\tau_{c(a)}$ = psf OR $q_{(a)}$ = ft^2/s

$\tau_{c(b)}$ = psf OR $q_{(b)}$ = ft^2/s

$\tau_{c(c)}$ = psf OR $q_{(c)}$ = ft^2/s

$\tau_{c(d)}$ = psf OR $q_{(d)}$ = ft^2/s

$\tau_{c(e)}$ = psf OR $q_{(e)}$ = ft^2/s

4. Calculate critical shear stress or critical unit discharge to entrain D_{84} particle.

$\tau_{c\text{-}D84(a)}$ = psf OR $q_{c\text{-}D84}$ = ft^2/s

Is $\tau_{c\text{-}D84}$ or $q_{c\text{-}D84}$ > tc or q for any of the driving forces in Step 3? ☐ Yes ☐ No

If D_{84} is not mobile for any of the flows picked in Step 2, choose greater flow values. ☐

If all flows in Step 2 cause movement in D_{84} particle, choose lower flows until a flow is found where D_{84} particle is stable. ☐

5. Plot τ_c or q vs Q. From graph, find flow that corresponds to $\tau_{c\text{-}D84}$ or $q_{c\text{-}D84}$. This is the critical flow that will cause initial movement of D_{84} particle.

$Q_{critical}$ = cfs

Design Reach:

6. Choose a D_{84} particle size for the design stream simulation culvert or bridge bed that is within 25% of reference reach D_{84} diameter.

D_{84} = in.

FISH PASSAGE: STREAM SIMULATION DESIGN OPTION	FORM 6C

7. Shift reference reach gradation curve to match intial D_{84} particle size. From shifted gradation cuve determine corresponding D_{50} and D_{16}.	D_{50} = in.
	D_{16} = in.
8. Repeat Step 2.	Q_a = cfs
	Q_b = cfs
	Q_c = cfs
	Q_d = cfs
	Q_e = cfs
9. Repeat Step 3.	$\tau_{c(a)}$ = psf OR $q_{(a)}$ = ft^2/s
	$\tau_{c(b)}$ = psf OR $q_{(b)}$ = ft^2/s
	$\tau_{c(c)}$ = psf OR $q_{(c)}$ = ft^2/s
	$\tau_{c(d)}$ = psf OR $q_{(d)}$ = ft^2/s
	$\tau_{c(e)}$ = psf OR $q_{(e)}$ = ft^2/s

10. Repeat Step 4.

$\tau_{c\text{-}D84(a)}$ = psf OR $q_{c\text{-}D84}$ = ft^2/s

Is $\tau_{c\text{-}D84}$ or $q_{c\text{-}D84}$ > tc or q for any of the driving forces in Step 3? ☐ Yes ☐ No

If D_{84} is not mobile for any of the flows picked in Step 2, choose greater flow values. ☐

If all flows in Step 2 cause movement in D_{84} particle, choose lower flows until a flow is found where D_{84} particle is stable. ☐

11. Repeat Step 5.

$Q_{critical}$ = cfs

12. Compare $Q_{crtical}$ from reference reach and design reach.

Is Qcritical similar between the 2 reaches? ☐ Yes ☐ No

If no, adjust D_{84} particle size and re-shift gradation curve for design reach. ☐

If subsequent D_{84} diameter trial(s) for design reach exceeds D_{84} for reference reach by more than 25%, reevaluate culvert variables (diameter, slope, etc.) or bridge variables (length, height, etc.). ☐

13. Use Fuller-Thompson method to calculate D_8 and D_{16} particle sizes that will promote high density bed mix and low porosity.

D_8 (calculated) = in. D_{16} (calculated) = in.

D_8 (design curve) = in. D_{16} (design curve) = in.

If D_8 and/or D_{16} values from design curve are greater than calculated D_8 and/or D_{16} values, change design reach gradation curve to match calculated values. ☐

14. Determine stream simulation culvert or bridge bed minimum thickness.

Minimum thickness = 4 × D_{84} (design reach) = in.

Creek Feature Stability Analysis (ie. Rock bands, Boulder Clusters, Banklines)

1. Establish bed design flows	25-Year design storm or 50-Year design storm, Q = cfs
2. Determine average water velocity in culvert	Culvert inlet velocity, V_c = ft/s
	Culvert outlet velocity, V_c = ft/s
	Average culvert velocity, V_c = ft/s
3. Determine average field rock size diameter	Average field rock size diameter, D_{field} = ft
4. Select minimum stable diameter (D_{50}) corresponding to average culvert velocity	Minimum stable diameter, D_{50} = ft
5. Calculated Caltrans RSP Class rough diameter	Calculated Caltrans RSP Class rough diameter, D_{rsp} = ft

If minimum stable diameter is greater than average field rock size diameter, the average field rock size diameter must be increased.
If minimum stable diameter is less than the average field rock size diameter, select the corresponding RSP class rough diameter.

6. Selected Caltrans RSP Class	Selected Caltrans RSP Class =

Maximum Allowable Inlet Water Surface Elevation

Culvert ☐

A culvert is required to pass the 10-year peak discharge without causing pressure flow in the culvert,	Allowable WSEL: ft
And shall not be greater than 50% of the culvert height or diameter above the top of the culvert inlet for the 100-Year peak flood.	Allowable WSEL: ft

FISH PASSAGE: STREAM SIMULATION DESIGN OPTION FORM 6C

Bridge ☐

A bridge is required to pass the 50-year peak discharge with freeboard, vertical clearance between the lowest structural member and the water surface elevation,	Allowable WSEL: ft
While passing the 100-year peak or design discharge under low chord of bridge.	Allowable WSEL: ft

Establish Allowable Hydraulic Impacts

Is the crossing located within a floodplain as designated by the Federal Emergency Management Agency or another responsible state or local agency?
☐ Yes ☐ No

If yes, establish allowable hydraulic impacts and hydraulic design requirements with the appropriate agency. Attach results.

Will the project result in increase capacity of an existing crossing? ☐ Yes ☐ No

If yes, will it significantly increase downstream peak flows due to the reduced upstream attenuation? ☐ Yes ☐ No

If yes, consult District Hydraulics. Further analysis may be needed.

Will the project result in a reduction in flow area for the 100-year peak discharge? ☐ Yes ☐ No

If yes, establish the allowable increase in upstream water surface elevation and establish how far upstream the increased water surface may extend.

Develop and run Hydraulic Models to compute water surface elevations, flow depths, and channel velocities for the 2-, 10-, 50-, and 100-year peak or design discharges reflecting existing and project conditions. ☐ Yes ☐ No

Evaluate computed water surface elevations, flow depths, and channel velocities. ☐ Yes ☐ No

Water surface elevation at inlet for the 10-year peak discharge: ft

Does the water surface elevation exceed the allowable elevation? ☐ Yes ☐ No

If yes, modify design to comply and rerun hydraulic analyses to verfiy.

Maximum Culvert and Channel velocities at inlet and outlet transition for the peak or design discharge:

Range of velocities for Inlet transition:	**ft/s to ft/s**
Range of velocities for Culvert portion:	**ft/s to ft/s**
Range of velocities for Outlet Transition:	**ft/s to ft/s**

Do the velocities exceed the permissible scour velocities? ☐ Yes ☐ No

If yes, revise design to reduce velocities and rerun hydraulic analyses to verfiy, or design erosion protection.

Comparison between existing and project future condition water surface elevations for the 10-Year and 100-Year peak flow:

FISH PASSAGE: STREAM SIMULATION DESIGN OPTION FORM 6C

Cross-Section	10-Yr WSEL	10-Yr WSEL	Difference	100-Year WSEL	100-Year WSEL	Difference
	Existing Conditions (ft)	Future Conditions (ft)	(ft)	Existing Conditions (ft)	Future Conditions (ft)	(ft)
1						
2						
3						
4						

If WSELs increase, does the increase exceed the maximum elevation? ☐ Yes ☐ No

Maximum elevation: ft

If yes, revise the design and rerun hydraulic analyses to verify.

If WSELs decrease, does it appear that the attenuation of peak flow will significally change? ☐ Yes ☐ No

If yes, evaluate to determine if downstream hydraulic impacts are significant and modify design as appropriate.

Proposed Profile Drawing Attached ☐ Yes ☐ No

Hydraulic Analysis Index Sheet Attached ☐ Yes ☐ No

Bed Stability Analysis Calculations Attached ☐ Yes ☐ No

Grain-Size Distribution Curve Attached ☐ Yes ☐ No

FORM 6D

HYDRAULIC BAFFLE DESIGN OPTION

FISH PASSAGE: HYDRAULIC BAFFLE DESIGN OPTION FORM 6D

Project Information:		Computed:	Date:
		Checked:	Date:
Stream Name:	County:	Route:	Postmile:

General Considerations - Baffles shall be used in the design retrofitted culverts in order to meet the hydraulic design criteria.

Hydrology Results - Peak Discharge Values

2-Year Flood Event (50% Annual Probability)	- cfs	Low Fish Passage Design Flow	cfs
100-Year Flood Event (1% Annual Probability)	cfs	High Fish Passage Design Flow	cfs

Summarize Retrofitted Culvert Physical Characterstics

Inlet Characteristics - Retrofitted design to inlet: ☐ Yes ☐ No

Inlet Type	☐ Projecting	☐ Headwall	☐ Wingwall
	☐ Flared end section	☐ Segment connection	☐ Skew Angle: º

Barrel Characteristics - Retrofitted design to barrel: ☐ Yes ☐ No

Diameter:	in	Fill height above culvert:	ft
Height/Rise:	- ft	Length:	ft
Width/Span:	- ft	Number of barrels:	

Culvert Type	☐ Arch	☐ Box	☐ Circular
	☐ Pipe-Arch	☐ Elliptical	
Culvert Material	☐ HDPE	☐ Steel Plate Pipe	☐ Concrete Pipe
	☐ Spiral Rib / Corrugated Metal Pipe		

Horizontal alignment breaks:	- ft	Vertical alignment breaks:	- ft

Outlet Characteristics - Retrofitted design to outlet: ☐ Yes ☐ No

Outlet Type	☐ Projecting	☐ Headwall	☐ Wingwall
	☐ Flared end section	☐ Segment connection	Skew Angle: º

Proposed Baffle Settings and Dimensions

Baffle height:	ft	Baffle width:	ft
Baffle spacing (along longitudinal axis):	ft		

FISH PASSAGE: HYDRAULIC BAFFLE DESIGN OPTION FORM 6D

Selecting Weir Coefficient, C

1) Estimate the highest weir coefficient using the highest head for the previously calculated crest width (breadth of crest of weir) from the HEC-22 Broad Crested Weir Coefficient Table.	C = $ft^{0.5}/sec$
2) Run the proposed HEC-RAS model and find the average head (weir average depth) over a weir for the Low Fish Passage Flow from HEC-RAS results.	Weir Average Depth = ft
3) Given the average head (weir average depth) from the HEC-RAS results and the crest width (breadth of crest of weir), find a second weir coefficient from the HEC-22 Broad Crested Weir Coefficient Table.	C = $ft^{0.5}/sec$
4) Run the proposed HEC-RAS model with the second weir coefficient from Step C and find the average head (weir average depth) over a weir for the Low Fish Passage Flow from HEC-RAS results.	Weir Average Depth = ft
5) Given the average head (weir average depth) from the HEC-RAS results and the crest width (breadth of crest of weir), find a third weir coefficient from the HEC-22 Broad Crested Weir Coefficient Table.	C = $ft^{0.5}/sec$
6) Compare weir coefficient from Step C and Step E. If weir coefficients are close in value, then use Step E weir coefficient for remaining HEC-RAS modeling. If weir coefficients are not close in value, repeat Steps C-F until an appropriate weir coefficient is found.	Modeled broad-crested weir coefficient: $ft^{0.5}/sec$

Verify High Design Flow for Fish Passage - Depending on species, develop high design flows:

Species/Life Stage	Percent Annual Exceedance Flow	Percentage of 2-Yr Recurrence Interval Flow	Design Flows (cfs)
☐ 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%	

Verify Low Design Flow for Fish Passage - Depending on species, develop low design flows:

Species/Life Stage	Percent Annual Exceedance Flow	Alternate Minimum Flow (cfs)	Design 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	

FISH PASSAGE: HYDRAULIC BAFFLE DESIGN OPTION FORM 6D

Verify Maximum Average Water Velocity (at High Design Flow) and Minimum Flow Depth in Culvert (at Low Design Flow) Depending on culvert length and/or species, select Maximum Average Water Veolcity and Minimum Flow Depth.

Species/Life Stage	**Maximum Average Water Velocity at High Fish Design Flow (ft/sec)**	**Minimum Flow Depth at Low Fish Design Flow (ft)**
☐ Adult Anadromous Salmonids	6 (Culvert length <60 ft)	1.0
	5 (Culvert length 60-100 ft)	
	4 (Culvert length 100-200 ft)	
	3 (Culvert length 200-300 ft)	
	2 (Culvert length >300 ft)	
☐ Adult Non-Anadromous Salmonids	4 (Culvert length <60 ft)	0.67
	4 (Culvert length 60-100 ft)	
	3 (Culvert length 100-200 ft)	
	2 (Culvert length 200-300 ft)	
	2 (Culvert length >300 ft)	
☐ 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		

Verify 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, it's magnitude should be evaluated for both high design flow and low design flow and shall not exceed the values shown below. If a hydraulic drop occurs at the culvert outlet, a jump pool of at least 2 feet in depth shall be provided.

Species/Life Stage	**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	

Develop and run hydraulic models to compute water surface elevations, flow depths, and velocities for Low Fish Design Flow, High Fish Design Flow, and the 100-Year peak or design discharge reflecting existing and proposed conditions. Evaluate results.

Maximum average velocity in culvert at High Fish Design Flow: ft/s

Does the velocity exceed the maximum allowable for the culvert length and design species? ☐ Yes ☐ No

If yes, modify design to comply and rerun hydraulic anaylses to verify.

Minimum flow depth in culvert at Low Fish Design Flow: ft

Does the depth equal or not exceed the mimimum allowable for the culvert length and design species? ☐ Yes ☐ No

If yes, modify design to comply and rerun hydraulic anaylses to verify.

Depth impacts at 100-Year Flood Flow:

If water surface elevations increase, does the increase exceed the maximum elevation? ☐ Yes ☐ No Maximum elevation: HP= ft

If yes, revise the design and rerun hydraulic analyses to verify.

Allowable Hydraulic Impacts:

Is the crossing located within a floodplain as designated by the Federal Emergency Management Agency or another responsible state or local agency? ☐ Yes ☐ No

If yes, establish allowable hydraulic impacts and hydraulic design requirements with the appropriate agency. Attach results.

Will the project result in the decrease capacity of an existing crossing? ☐ Yes ☐ No

If yes, will it significantly increase upstream backwater effects due to the reduced upstream attenuation? ☐ Yes ☐ No

If yes, consult District Hydraulics. Further analysis may be needed.

Drop between the water surface elevation in the culvert and the outlet channel:

Low Fish Design Flow Drop Length: ft

Does the drop between the water surface in the culvert and the outlet channel at high or low design fish flows exceed the maximum allowable for the design species? ☐ Yes ☐ No

If yes, modify design to avoid a drop if possible. If a drop is unavoidable modify design to meet criteria and provide a jump pool at least two feet in depth. Rerun hydraulic analyses to verfiy.

Calculate Energy Dissipation Factor (EDF)

Water Density, γ = 62.4 lbm/ft^3	High Fish Flow, Q: cfs	Culvert Slope, S: ft/ft	X-sectional flow area in between baffles, A: ft^2

EDF = γQS / A : ft-lb/ft^3/s

Velocity Criteria Versus Design (High Fish Passage Flow)

FISH PASSAGE: HYDRAULIC BAFFLE DESIGN OPTION FORM 6D

Culvert Velocity	**Design Flow Velocity (ft/s)**	**Criteria Flow Velocity (ft/s)**
Culvert Inlet Velocity (evaluated at x-section immediately located upstream of culvert)		
Culvert Barrel Velocity (evaluated through Culvert Output in HEC-RAS)		
Culvert Outlet Velocity (evaluated at x-section immediately located downstream of culvert)		

Depth Criteria Versus Design (Low Fish Passage Flow)

Cross-Section	**Design Flow Depth (ft)**	**Criteria Flow Depth (ft)**

Proposed Plan and Profile Drawing Attached ☐ Yes ☐ No

Hydraulic Analysis Index Sheet Attached ☐ Yes ☐ No

FORM 6E

HYDRAULIC ROCK WEIR DESIGN OPTION

FISH PASSAGE: HYDRAULIC ROCK WEIR DESIGN OPTION — FORM 6E

Project Information		Computed:	Date:
		Checked:	Date:
Stream Name:	County:	Route:	Postmile:

General Considerations - Rock weirs shall be used in the design of retrofitted or new bridges and culverts in order to meet the hydraulic design criteria.

Hydrology Results - Peak Discharge Values

50% Annual Probability (2-Year Flood Event)	cfs	Low Fish Passage Design Flow	cfs
2% Annual Probability (50-Year Flood Event)	cfs	High Fish Passage Design Flow	cfs
1% Annual Probability (100-Year Flood Event)	cfs		

Summarize Retrofitted Culvert Physical Characterstics

Inlet Characteristics - Retrofitted design to inlet: ☐ Yes ☐ No

Inlet Type	☐ Projecting	☐ Headwall	☐ Wingwall
	☐ Flared end section	☐ Segment connection	☐ Skew Angle: º

Barrel Characteristics - Retrofitted design to barrel: ☐ Yes ☐ No

Diameter: in	Fill height above culvert: ft
Height/Rise: ft	Length: ft
Width/Span: ft	Number of barrels:

Culvert Type	☐ Arch	☐ Box	☐ Circular
	☐ Pipe-Arch	☐ Elliptical	
Culvert Material	☐ HDPE	☐ Steel Plate Pipe	☐ Concrete Pipe
	☐ Spiral Rib / Corrugated Metal Pipe		

Horizontal alignment breaks: ft	Vertical alignment breaks: ft

Outlet Characteristics - Retrofitted design to outlet: ☐ Yes ☐ No

Outlet Type	☐ Projecting	☐ Headwall	☐ Wingwall
	☐ Flared end section	☐ Segment connection	Skew Angle: º

FISH PASSAGE: HYDRAULIC ROCK WEIR DESIGN OPTION FORM 6E

Summarize Retrofitted Bridge Physical Characterstics

Bridge Physical Characteristics Retrofitted design to bridge structure: ☐ **Yes** ☐ **No**

Elevation of high chord (top of road): ft	Elevation of low chord: ft

Channel Lining ☐ No lining ☐ Concrete ☐ Rock ☐ Other

Skew Angle: - º	Bridge width (length): ft

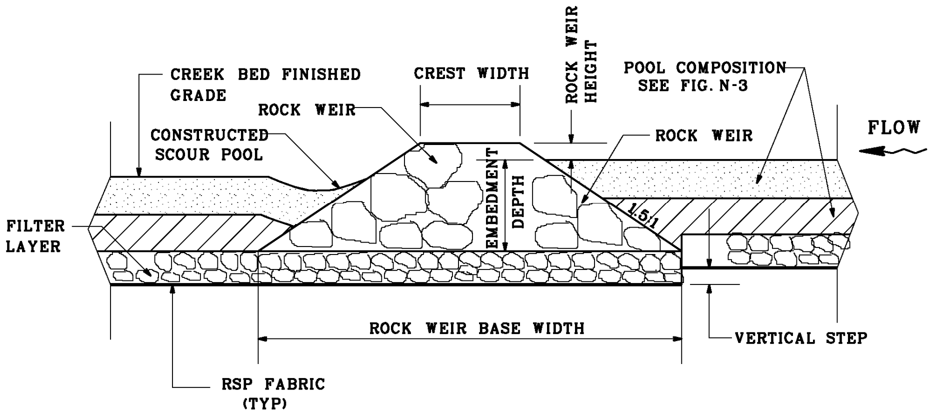
Pier Characteristics (if applicable) Retrofitted design to piers: ☐ Yes ☐ No

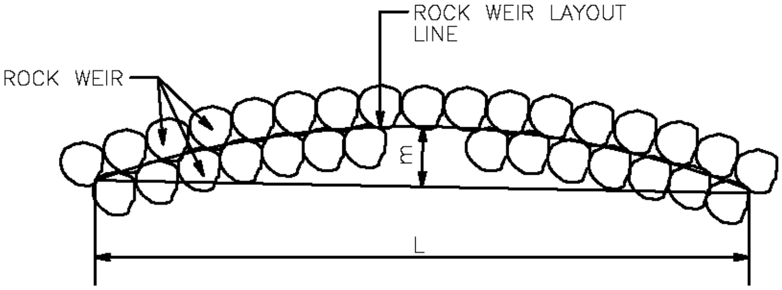
Number of Piers: ft	Upstream cross-section starting station: ft
Pier Width: ft	Downstream cross-section starting station: ft
Pier Centerline Spacing: ft	Skew angle: - º

Pier Shape	☐ Square nose and tail	☐ Semi-circular nose and tail	☐ 90° triangular nose and tail
	☐ Twin-cylinder piers with connecting diaphragm	☐ Twin-cylinder piers without connecting diaphragm	☐ Ten pile trestle bent

Determine Rock Weir Dimensions

Rock weir size (RSP class):	Embedment depth: ft
Crest width: ft	Height: ft
Side slope: 1.5:1	Rock weir plan view radius ft
	Rock weir base width ft





PLAN

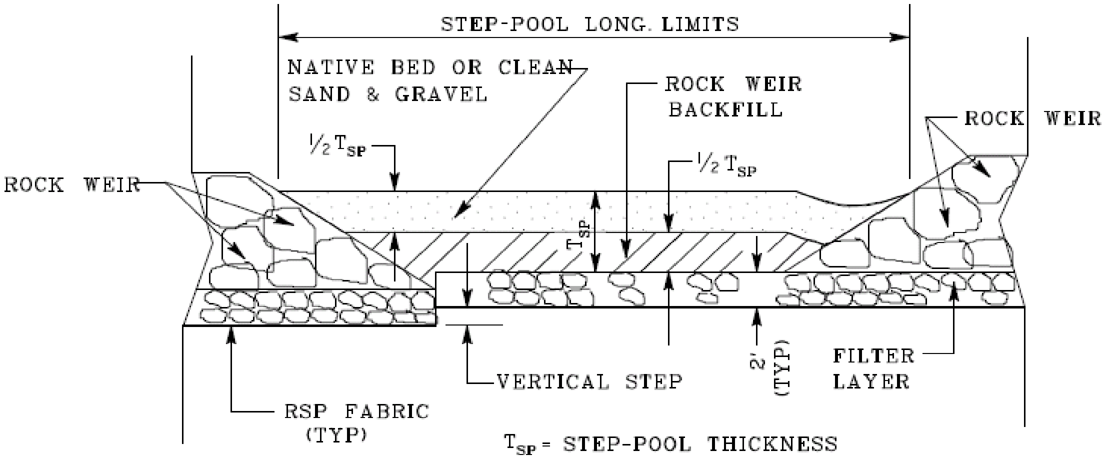
Determine Step-Pool Composition and Thickness

Tsp: ft

Rock weir backfill thickness (1/2 Tsp): ft

Native bed: ☐ Yes ☐ No Thickness (if applicable): ft

Clean sand and gravel: ☐ Yes ☐ No Thickness (if applicable): ft



Step Pool Profile

Design Bank and Toe Revetment

RSP revetment: ☐ Yes ☐ No

Combined RSP and vegetative revetment: ☐ Yes ☐ No

If yes, contact District Hydraulics Engineer and District Landscape Architect to coordinate design.

Parallel flow: ☐ Yes ☐ No If parallel flow, apply a 0.67 factor to design velocity.

Impinging flow: ☐ Yes ☐ No If impinging flow, apply 1.33 factor to design velocity.

Bank slope (α): °

Design velocity (Suggested 50-Yr max velocity): ft/s

SG = 2.65	R = 70°	W =

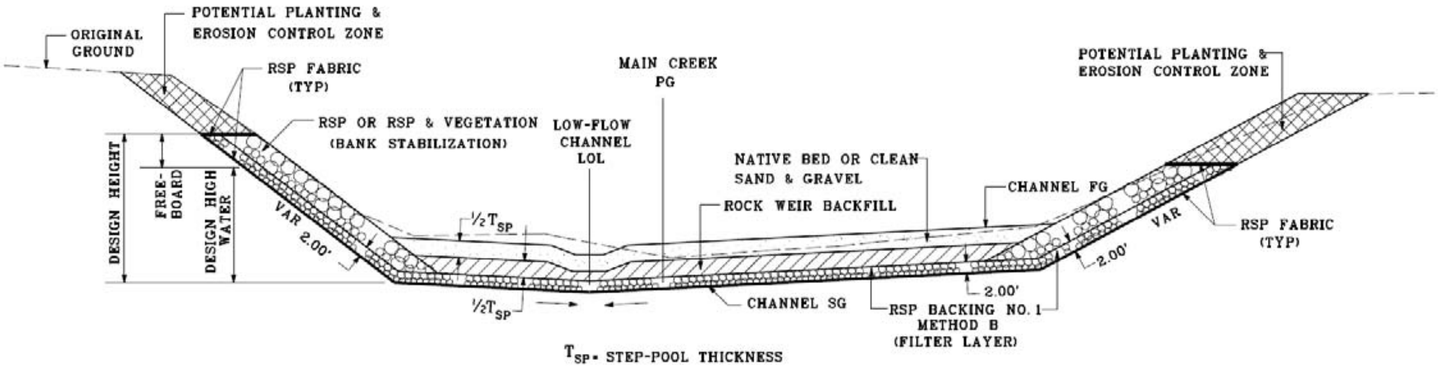
$$W = \frac{0.00002 \quad V^6 \quad SG}{(SG - 1)^3 \quad SIN^3 (r - a)}$$

Field contributing features (i.e. high water marks):

Freeboard: ft

Design height: ft

RSP class (outside layer):	RSP thickness: ft
RSP class (backing layer):	RSP thickness: ft
RSP class (inner layer):	RSP thickness: ft



Step Pool Cross Section

Determine Rock Weir Series Dimensions

Number of steps:	Number of step pools:
Number of rock weirs:	Spacing of rock weirs: ft
Height of rock weir: ft	Jump pool depth ft

Selecting Weir Coefficient, C

1) Estimate the highest weir coefficient using the highest head for the previously calculated crest width (breadth of crest of weir) from the HEC-22 Broad Crested Weir Coefficient Table.	C = $ft^{0.5}$/sec
2) Run the proposed HEC-RAS model and find the average head (weir average depth) over a weir for the Low Fish Passage Flow from HEC-RAS results.	Weir Average Depth = ft
3) Given the average head (weir average depth) from the HEC-RAS results and the crest width (breadth of crest of weir), find a second weir coefficient from the HEC-22 Broad Crested Weir Coefficient Table.	C = $ft^{0.5}$/sec
4) Run the proposed HEC-RAS model with the second weir coefficient from Step C and find the average head (weir average depth) over a weir for the Low Fish Passage Flow from HEC-RAS results.	Weir Average Depth = ft

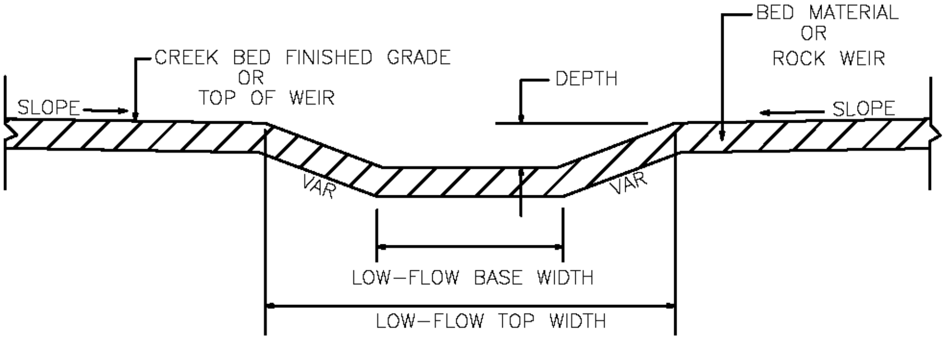
5) Given the average head (weir average depth) from the HEC-RAS results and the crest width (breadth of crest of weir), find a third weir coefficient from the HEC-22 Broad Crested Weir Coefficient Table.	C = $ft^{0.5}/sec$
6) Compare weir coefficient from Step C and Step E. If weir coefficients are close in value, then use Step E weir coefficient for remaining HEC-RAS modeling. If weir coefficients are not close in value, repeat Steps C-F until an appropriate weir coefficient is found.	Modeled broad-crested weir coefficient: $ft^{0.5}/sec$

Determine Rock Weir Low-Flow Notch/Channel Dimensions

Base Width: ft

Top Width: ft

Depth: ft



Low Flow Notch / Channel

Verify High Design Flow for Fish Passage - Depending on species, develop high design flows:

Species/Life Stage	Percent Annual Exceedance Flow	Percentage of 2-Yr Recurrence Interval Flow	Design Flows (cfs)
☐ Adult Anadromous Salmonids	1%	50%	
☐ Adult Non-Anadromous	5%	30%	
☐ Juvenile Salmonids	10%	10%	
☐ Native Non-Salmonids	5%	30%	
☐ Non-Native Species	10%	10%	

Verify Low Design Flow for Fish Passage - Depending on species, develop low design flows:

Species/Life Stage	Percent Annual Exceedance Flow	Alternate Minimum Flow (cfs)	Design Flow (cfs)
☐ Adult Anadromous Salmonids	50%	3	
☐ Adult Non-Anadromous	90%	2	
☐ Juvenile Salmonids	95%	1	
☐ Native Non-Salmonids	90%	1	
☐ Non-Native Species	90%	1	

FISH PASSAGE: HYDRAULIC ROCK WEIR DESIGN OPTION FORM 6E

Verify Maximum Average Water Velocity (at High Design Flow) and Minimum Flow Depth in Culvert (at Low Design Flow) Depending on culvert length and/or species, select Maximum Average Water Veolcity and Minimum Flow Depth.

Species/Life Stage	**Maximum Average Water Velocity at High Fish Design Flow (ft/sec)**	**Minimum Flow Depth at Low Fish Design Flow (ft)**
☐ Adult Anadromous Salmonids	6 (Culvert length <60 ft)	1.0
	5 (Culvert length 60-100 ft)	
	4 (Culvert length 100-200 ft)	
	3 (Culvert length 200-300 ft)	
	2 (Culvert length >300 ft)	
☐ Adult Non-Anadromous Salmonids	4 (Culvert length <60 ft)	0.67
	4 (Culvert length 60-100 ft)	
	3 (Culvert length 100-200 ft)	
	2 (Culvert length 200-300 ft)	
	2 (Culvert length >300 ft)	
☐ 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		

Verify 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, it's magnitude should be evaluated for both high design flow and low design flow and shall not exceed the values shown below. If a hydraulic drop occurs at the culvert outlet, a jump pool of at least 2 feet in depth shall be provided.

Species/Life Stage	**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	

Develop and run hydraulic models to compute water surface elevations, flow depths, and velocities for Low Fish Design Flow, High Fish Design Flow, and the 100-Year peak or design discharge reflecting existing and proposed conditions. Evaluate results.

Maximum average velocity in culvert at High Fish Design Flow: ft/s

Does the velocity exceed the maximum allowable for the culvert length and design species? ☐ Yes ☐ No

If yes, modify design to comply and rerun hydraulic anaylses to verify.

FISH PASSAGE: HYDRAULIC ROCK WEIR DESIGN OPTION FORM 6E

Minimum flow depth in culvert at Low Fish Design Flow: ft

Does the depth equal or not exceed the mimimum allowable for the culvert length and design species? ☐ Yes ☐ No

If yes, modify design to comply and rerun hydraulic anaylses to verify.

Depth impacts at 100-Year Flood Flow:

If water surface elevations increase, does the increase exceed the maximum elevation? ☐ Yes ☐ No Maximum elevation: ft

If maximum elevation is exceeded for bridge, check 50-Year water surface elevation and determine if freeboard exists. Consult Structures Hydraulics for freeboard validation.

Allowable Hydraulic Impacts:

Is the crossing located within a floodplain as designated by the Federal Emergency Management Agency or another responsible state or local agency? ☐ Yes ☐ No

If yes, establish allowable hydraulic impacts and hydraulic design requirements with the appropriate agency. Attach results.

Will the project result in the decrease capacity of an existing crossing? ☐ Yes ☐ No

If yes, will it significantly increase upstream backwater effects due to the reduced upstream attenuation? ☐ Yes ☐ No

If yes, consult District Hydraulics. Further analysis may be needed.

Drop between the water surface elevation in the culvert and the outlet channel:

Low Fish Design Flow Drop Length: ft

Does the drop between the water surface in the culvert and the outlet channel at high or low design fish flows exceed the maximum allowable for the design species? ☐ Yes ☐ No

If yes, modify design to avoid a drop if possible. If a drop is unavoidable modify design to meet criteria and provide a jump pool at least two feet in depth. Rerun hydraulic analyses to verfiy.

Velocity Criteria Versus Design (High Fish Passage Flow)

Bridge / **Culvert Velocity**	**Design Flow Velocity (ft/s)**	**Criteria Flow Velocity (ft/s)**
Culvert Inlet Velocity (evaluated at x-section immediately located upstream of culvert)		
Culvert Barrel Velocity (evaluated through Culvert Output in HEC-RAS)		
Culvert Outlet Velocity (evaluated at x-section immediately located downstream of culvert)		

FISH PASSAGE: HYDRAULIC ROCK WEIR DESIGN OPTION FORM 6E

Depth Criteria Versus Design (Low Fish Passage Flow)

Cross-Section	Design Flow Depth (ft)	Criteria Flow Depth (ft)

Proposed Plan and Profile Drawing Attached ☐ Yes ☐ No

Hydraulic Analysis Index Sheet Attached ☐ Yes ☐ No

APPENDIX E

FISH PASSAGE FLOWS

E Fish Passage Flows

E.1 Overview of Hydrologic Methods

This section presents three methods to calculate high and low design flows for road crossings where fish passage is a requirement. Design flows can be determined using the 1) USGS regional regression equations; 2) local stream gage data to estimate annual exceedance factors and 3) the Natural Resources Conservation Service (NRCS) Urban Hydrology for Small Watersheds Technical Release 55 (TR-55).

A general discussion on the hydrologic process is not presented in this section because numerous textbooks discuss the hydrologic process in detail. It is assumed that the traffic engineer has had at least one university level class covering hydrology and hydraulics. As a refresher, a good discussion on hydrology is presented in Chapter 810 of the Caltrans Highway Design Manual (HDM). The HDM should be readily available to all Caltrans engineers and it is highly recommended that Chapter 810 is read by the traffic engineer before beginning any hydrologic analysis.

Additional references required by the traffic engineer include:

- A hydrology text or manual that includes discussion on coefficients such as Manning’s roughness values.
- The Natural Resources Conservation Service, Urban Hydrology for Small Watersheds Technical Release 55 (TR-55). This document can be found at the U.S. Department of Agriculture’s website http://www.info.usda.gov/CED/
- Rantz, S.E., 1969, Mean annual precipitation in the California region: U.S. Geological Survey Open-File Map (Reprinted 1972, 1975).
- Miller, J.F., Frederick, R.H., and Tracey, R.J., 1973, Precipitation – Frequency Atlas of the Western United States, Volume XI – California, NOAA.

E.2 Selecting the Appropriate Method

In most instances, watershed characteristics control which hydrologic method is used for analysis. Contributing to the method selection is the available information for the watershed. For instance, it is unlikely that a stream gage would be located at or even near the stream crossing under consideration. Gage data is typically recorded on large streams where stream crossings have already been designed and constructed.

Table 1 below provides guidance on which method is appropriate to use based on the watershed characteristics and available information.

Table E-1. Guidance on use of methods.

Method	Assumptions	Data Needed
Exceedance**	▪ At least five years of recorded daily average flows, and preferably more than ten-years (do not need to be consecutive years) ▪ Drainage area less than 129.5 km² (50 mi²) (preferably less than 25.9 km² (10 mi²)) ▪ Unregulated flows (no upstream impoundment or water diversions)	▪ Gage Data from nearby stream ▪ Drainage area of both watersheds
Regional Regression*	▪ Catchment area limit varies by region ▪ Ungaged channel ▪ Basin not located on floor of Sacramento and San Joaquin Valleys ▪ Peak discharge value for flow under natural conditions unaffected by urban development and little or no regulation by lakes or reservoirs	▪ Drainage area ▪ Mean annual precipitation ▪ Altitude Index
TR-55*	▪ Small or midsize catchment (< 8 km² (< 3.1 mi²)) ▪ Concentration time range from 0.1 to 10-hour (tabular hydrograph method limit < 2 hour) ▪ Runoff is overland and channel flow ▪ Simplified channel routing ▪ Negligible channel storage	▪ 24-hour rainfall ▪ Rainfall distribution ▪ Runoff curve number ▪ Concentration time ▪ Drainage area

*Refer to the Caltrans Highway Design Manual for further information

**Refer to the California Salmonid Stream Habitat Restoration Manual for further information

In determining the high fish passage flows for design, if stream gage data is available, the exceedance flow method should be used to calculate a percent exceedance flow. Using Table 2 below, the percentages are listed for each fish species. If stream gage data is not available, then the recurrence intervals for the 2-year and 100-year flow should be calculated using either the regional regression or TR-55 methods and a percentage of the 2-year is used for high fish passage design flows.

Table E-2. High design flow for fish passage.

Species/Life Stage	Exceedance Flow	Percentage of 2-year Recurrence Interval
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%

In determining lower fish passage flow, again, if stream gage data is available, the exceedance flow method should be used to calculate a percent exceedance flow. If the exceedance flow is determined to be less than the Alternate Minimum Flow (shown in Table 3), then the alternate minimum flow should be used.

Table E-3. Low design flow for fish passage.

Species/Life Stage	Exceedance Flow	Alternative Minimum Flow	
		(ft^3/s)	(m^3/s)
Adult Anadromous Salmonids	50%	3	0.08
Adult Non-Anadromous Salmonids	90%	2	0.06
Juvenile Salmonids	95%	1	0.03
Native Non-Salmonids	90%	1	0.03
Non-Native Species	90%	1	0.03

The exceedance flow, regional regression, and TR-55 methods for determining flows are presented in detail in the following sections.

E.3 Exceedance Flow Rates using Gage Data

E.3.1 Method Description

The upper fish passage flow limit for adult anadromous salmonids is defined as the 1 percent exceedance flow (or the flow equaled to or exceeded 1 percent of the time). The lower fish passage flow equals the 50 percent exceedance flow. Figure 1 below shows a typical distribution of flow data and the exceedance intervals. These exceedance flows rates are not to be confused with calculating an exceedance flow probability which requires a statistical analysis using annual peak flows.

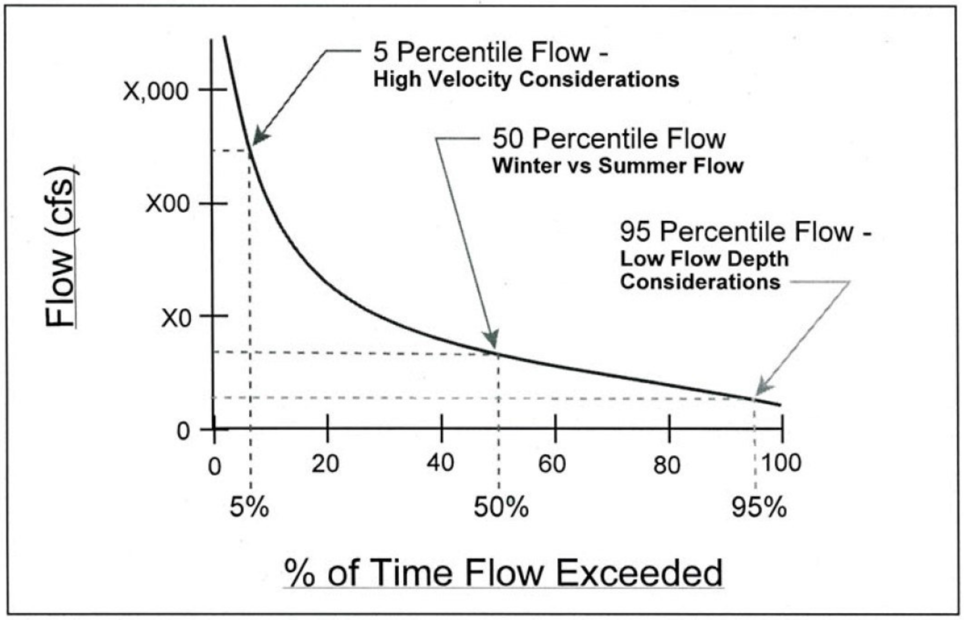


Figure E-1. Example of a flow duration curve.

Source: California Salmonid Stream Habitat Restoration Manual, 2003.

Identifying exceedance flows requires obtaining average daily stream flow data. If the stream flow rate is known based on gage data collected for that stream, then the crossing should be sized based on that data. Often times, a crossing is to be designed on a stream where gage data is not available. However, if a nearby stream has gage data and the stream where the crossing is to be designed has similar watershed characteristics, then the available gage data can be adjusted and used for design. The method presented below describes how to adjust nearby stream gage data to estimate the peak stream flow rate. The following method was abstracted from Section IX of the California Salmonid Stream Habitat Restoration Manual. For more information please reference the Manual.

1. Flow records for nearby streams should be acquired from the USGS and/or the California Department of Water Resources. The information must 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 (130 km^2), and preferably less than 10 square miles (26 km^2)
    - 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.
2. 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 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:

    $i_{50\%} = 0.50(n+1)$ $i_{1\%} = 0.01(n+1)$
3. Round values to the nearest whole number. The flows corresponding to those ranks are the 50 percent and 1 percent exceedance flows for the gaged stream.
4. To apply these flows to the ungaged stream, multiply the flows obtained in the above step, $Q_{50\%}$ and $Q_{1\%}$, by the ratio of the gaged 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.

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.

Other things to consider when using gage data includes:

- This method is limited in a number of ways, one of which is the fact that it only considers a narrow time frame in the life time of the stream crossing. For example, stream flow data may have only been collected during a drought. This would result in sizing a fish passage that is too small. Inversely, the fish passage could be sized too large if the gage data was taken during years of high rainfall.

- A second limitation of this method is the transfer of stream flow data from one watershed to another. Although the watersheds may be near each other, there will still be differences between the two. Cover, detention, soil type, slope, and even rainfall could vary between the two watersheds. Careful inspection of the two watersheds should be conducted to determine if it is reasonable to transfer the data.

E.3.2 Example Calculation – Exceedance Flow Rate Using Gage Data

For this example a stream is located in Santa Barbara County with a drainage area of 35.6 mi^2. There is no gage data available for this stream, but a nearby stream with similar watershed characteristics has gage data available. Data was collected by USGS gage number 11132500 for daily average streamflow between the dates of 10/01/1987 and 10/01/2002. This information was downloaded from the USGS website. There was a total of 5480 data points. The drainage area for this gage is 47.1 square miles.

There is more than ten years of recorded daily average flow available for a nearby stream, the drainage area of the stream of interest is less than 31 mi^2, and both streams have unregulated flow. Based on the criteria stated in Section 2, the exceedance flow rate method is most appropriate for this case.

The data was sorted from high to low. Each data point was assigned a rank; the highest value was assigned one and the lowest value was assigned 5480. The 50% and 1% exceedance values were determined using the following equations:

$$i_{50\%} = 0.50(5480+1)$$
$$i_{1\%} = 0.01(5480+1)$$

$$i_{50\%} = 2741$$
$$i_{1\%} = 55$$

Looking up these flow values in the ranked table yields:

Flow	Rank
1.8	2737
1.8	2738
1.8	2739
1.8	2740
1.8	2741
1.8	2742
1.8	2743

Flow	Rank
294	52
293	53
285	54
283	55
279	56
267	57
264	58

The corresponding flow rates at these rankings are:

$$Q_{50\%} = 1.8\text{cfs}$$

$$Q_{1\%} = 283\text{cfs}$$

These values need to be adjusted down based on the differences between the drainage areas:

$$Q_{50\%} = 1.8\text{cfs}\left(\frac{35.6\,\text{mi}^2}{47.1\,\text{mi}^2}\right)$$

$$Q_{1\%} = 283\text{cfs}\left(\frac{35.6\,\text{mi}^2}{47.1\,\text{mi}^2}\right)$$

$$\underline{\underline{Q_{50\%} = 1.4\,\text{cfs}}}$$

$$\underline{\underline{Q_{1\%} = 213.9\,\text{cfs}}}$$

E.4 Regional Regression Equations

E.4.1 Method Description

Regional Regression equations have been developed for the state of California to estimate the peak discharge for a watershed for recurrence intervals of 2, 5, 10, 25, 50, and 100 years. The state is divided into six hydrologic regions and each region has specifically derived equations unique to that region. A map showing the different regions is shown in Figure 2. The parameters for the equations include drainage area (A), in square miles; mean annual precipitation (P), in inches; and an altitude index (H), which is the average altitudes in thousands of feet at the points along the main channel at 10 percent, and 85 percent of the distances from the site to the divide (USGS 1993).

Area and altitude index are determined from a topographic map, and mean annual precipitation is determined from a map in Rantz (1969). The USGS provides non-proprietary software that may be used to calculate the flows using the regression equations. The software is available at their website, www.usgs.gov, and is called the National Flood Frequency Program (NFF). The following equations are used to calculate the design flow rates for the six hydrologic regions in California.

Digital base from U.S. Geological Survey 1:2,000,000, 1970

Albers equal-area projection based on standard parallels 29.5 and 45.5 degrees

Figure E-2. Flood-frequency region map for California.

Source: http://water.usgs.ca.gov/software/nff- manual/ca/index.html

North Coast Region

$$Q_2 = 3.52A^{0.90}P^{0.89}H^{-0.47}$$
$$Q_5 = 5.04A^{0.89}P^{0.91}H^{-0.35}$$
$$Q_{10} = 6.21A^{0.88}P^{0.93}H^{-0.27}$$
$$Q_{25} = 7.64A^{0.87}P^{0.94}H^{-0.17}$$
$$Q_{50} = 8.57A^{0.87}P^{0.96}H^{-0.08}$$
$$Q_{100} = 9.23A^{0.87}P^{0.97}$$

In the North Coast region, use a minimum value of 1.0 for the altitude index (H).

Northeast Region

$$Q_2 = 22A^{0.40}$$
$$Q_5 = 46A^{0.45}$$
$$Q_{10} = 61A^{0.49}$$
$$Q_{25} = 84A^{0.54}$$
$$Q_{50} = 103A^{0.57}$$
$$Q_{100} = 125A^{0.59}$$

Maximum drainage basin is 40 km^2 for the Northeast region.

Sierra Region

$$Q_2 = 0.24A^{0.88}P^{1.58}H^{-0.80}$$
$$Q_5 = 1.20A^{0.82}P^{1.37}H^{-0.64}$$
$$Q_{10} = 2.63A^{0.80}P^{1.25}H^{-0.58}$$
$$Q_{25} = 6.55A^{0.79}P^{1.12}H^{-0.52}$$
$$Q_{50} = 10.4A^{0.89}P^{1.03}H^{-0.41}$$
$$Q_{100} = 15.7A^{0.77}P^{1.02}H^{-0.43}$$

Central Coast Region

$$Q_2 = 0.0061A^{0.92}P^{2.54}H^{-1.10}$$
$$Q_5 = 0.118A^{0.91}P^{1.95}H^{-0.79}$$
$$Q_{10} = 0.583A^{0.90}P^{1.61}H^{-0.64}$$
$$Q_{25} = 2.91A^{0.89}P^{1.26}H^{-0.50}$$
$$Q_{50} = 8.20A^{0.89}P^{1.03}H^{-0.41}$$
$$Q_{100} = 19.7A^{0.88}P^{0.84}H^{-0.33}$$

South Coast Region

$$Q_2 = 0.14A^{0.72}P^{1.62}$$
$$Q_5 = 0.40A^{0.77}P^{1.69}$$
$$Q_{10} = 0.63A^{0.79}P^{1.75}$$
$$Q_{25} = 1.10A^{0.81}P^{1.81}$$
$$Q_{50} = 1.50A^{0.82}P^{1.85}$$
$$Q_{100} = 1.95A^{0.83}P^{1.87}$$

South Lahontan-Colorado Desert Region

$$Q_2 = 7.3A^{0.30}$$
$$Q_5 = 53A^{0.44}$$
$$Q_{10} = 150A^{0.53}$$
$$Q_{25} = 410A^{0.63}$$
$$Q_{50} = 700A^{0.68}$$
$$Q_{100} = 1080A^{0.71}$$

Maximum drainage basin is 40 km^2 for the South Lahontan-Colorado Desert regions.

Where:

A = Drainage area, mi^2

P = Precipitation, inches

H = altitude index

Other things to consider when using the Regional Regression equations include:

- Ground conditions play a significant role in the peak flow rate of a stream. Bare ground with little infiltration and a steep slope will result in a higher peak flow rate because water will reach the point of interest faster than the same area that has lush ground cover, absorbent soils, and a flat slope.
- Drainage area and altitude index are easily calculated from a topographic map. Mean annual precipitation, on the other hand, is a general estimate for an area and not specific to a particular watershed. Rainfall amounts collected at various gages throughout a region are extrapolated over that region to get isohyets, or lines of equal rainfall. Mean annual precipitation for a region is based on these isohyets that are drawn from information collected over a number of years. A number of publications can be consulted for further discussion on the derivation and applicability of mean annual precipitation.
- Inherent in the regression equations are errors of estimate. According to the USGS, the standard error of estimate for the California regression equations ranges from 60 to 100 percent.
- Regression equations should be used when little is known about the watershed. If sufficient information about the watershed is available, use of the other methods described in this section is recommended for analysis.
- For more information of the development and use of regression equations refer to the U.S. Geological Survey Water-Resources Investigations Report 94-4002.

E.4.2 Example Calculation - Regional Regression Method

Lower fish passage flows are for the 50% exceedance probability values, which is equivalent to a 2 year recurrence interval. The 1% exceedance probability is equivalent to a 100-year event. For this example, a stream is located in Humboldt County which is in the North Coast hydrologic region according to the regional regression map (Shown on page X). The stream is not located on the floor of the Sacramento and San Joaquin Valleys and there is no gage data available. This stream fits the regional regression method well based on criteria listed in the table in Section 4. The 2-year and 100-year recurrence interval regression equations for this region are:

$$Q_2 = 3.52A^{0.90}P^{0.89}H^{-0.47}$$
$$Q_{100} = 9.23A^{0.87}P^{0.97}$$

The watershed characteristics for the area are as follows:

Drainage Area (A) = 248 miles

2-Year, 24-hour Rainfall (P_2) = 4 in
100-Year, 24-hour Rainfall (P_{100}) = 8 in
Source: NOAA Atals

Average elevation at 10 percent = 125 feet
Source: Topographic map

Average elevation at 85 percent = 210 feet

Altitude Index H = 125+210/2 = 167.5 feet = 0.1675 thousands feet

Plugging in the drainage area and the appropriate precipitation into the equation results in:

$$Q_2 = 3.52\left(248\text{ mi}^2\right)^{0.90}(4\ \text{ in})^{0.89}(0.1675)^{-0.47}$$
$$Q_{100} = 9.23\left(248\text{ mi}^2\right)^{0.87}(8\text{ in})^{0.97}$$

$$\underline{\underline{Q_2 = 4{,}000\text{ cfs}}}$$
$$\underline{\underline{Q_{100} = 8{,}402\text{ cfs}}}$$

E.5 TR-55 Method

E.5.1 Method Description

The TR-55 method presents simplified procedures for estimating runoff and peak discharges in small watersheds. The method is geared towards estimating runoff in urban and urbanizing watersheds; however, the procedures apply to any small watershed in which certain limitations are met.

The method begins with the assumption that rainfall is uniformly imposed on the watershed over a specified time distribution. TR-55 includes four regional rainfall time distributions for a 24-hour period. The rainfall distributions were designed to contain the intensity of any duration of rainfall for the frequency of the event chosen.

Mass rainfall is converted to mass runoff by using a runoff curve number (CN). CN is based on soils, interception, and surface storage. Runoff is then transformed into a hydrograph by using unit hydrograph theory and routing procedures that depend on runoff travel time through segments of the watershed (TR-55 1986).

Three steps are performed to calculate the peak discharge of a drainage area. The three steps are to calculate the Q in inches, calculate the time of concentration in hours, and then calculate the peak discharge. The three steps are described in the following sub-sections.

The TR-55 method is used for a single hydrologically homogenous watershed. If the watershed is heterogeneous, made up of several homogenous subareas, then the TR-55 publication should be consulted. TR-55 also addresses how to use detention basins to reduce the peak flow rate of an urbanizing watershed.

E.5.2 SCS Runoff Curve Number

The SCS runoff equation, which calculates Q in inches, is

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

Where Q equals runoff (in), P equals rainfall (in), S equals potential maximum retention after runoff begins (in), and I_a equals initial abstraction (in).

Initial abstraction is all losses before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. Through studies of many small agricultural watersheds, I_a was found to be approximated by the following empirical equation:

$$I_a = 0.2S$$

Combing these two equations results in the following equation:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

S is related to the soil and cover conditions of the watershed through the CN. CN has a range of 0 to 100, and S is related to CN by:

$$S = \frac{1000}{CN} - 10$$

Figure 3 and Table 4 solve the above equations for a range of CNs and rainfall.

Parameters used to determine CN include hydrologic soil group (HSG), cover type, treatment, hydrologic condition, antecedent runoff condition (ARC), and whether the runoff passes over an impervious area directly connected to a drainage system (connected) or spread over a pervious area before connecting to a drainage system (unconnected) area before entering the drainage system. These parameters must be determined through investigation of the drainage area. Figure 4 is used to determine which figure or table to use in choosing a CN. Tables 5 through 8 assume impervious areas that are directly connected. The following sub-sections describe each parameter used to determine CNs and how to modify them for urban conditions.

E.5.3 Hydrologic Soil Groups (HSG)

Soils are classified into four HSG's (A, B, C, and D) according to their minimum infiltration rate. The soils of interest may be identified from a soil report, which can be obtained from local NRCS offices or soil and water conservation district offices.

E.5.4 Cover Type

Cover can be determined by field reconnaissance, aerial photography, and land use maps. Tables 5 through 8 addresses most cover types, such as vegetation, bare soil, and impervious surfaces.

E.5.5 Treatment

Treatment is a cover type modifier to describe the management of cultivated agricultural lands as seen in Table 6.

E.5.6 Hydrologic Condition

Hydrologic condition relates to the density of plant and residue cover on sample areas. Good hydrologic condition indicates that the soil usually has a low runoff potential. Some factors to consider in estimating the effect of cover on infiltration and runoff are (a) canopy or density of lawns, crops, or other vegetative areas; (b) amount of year round cover; (c) amount of grass close-seeded legumes in rotations; (d) percent of residue cover; and (e) degree of surface roughness.

E.5.7 Antecedent Runoff Condition (ARC)

ARC is an attempt to account for the variation in CN at a site from storm to storm. The CN's in Tables 5 through 8 are for average ARC, which is used primarily for design applications.

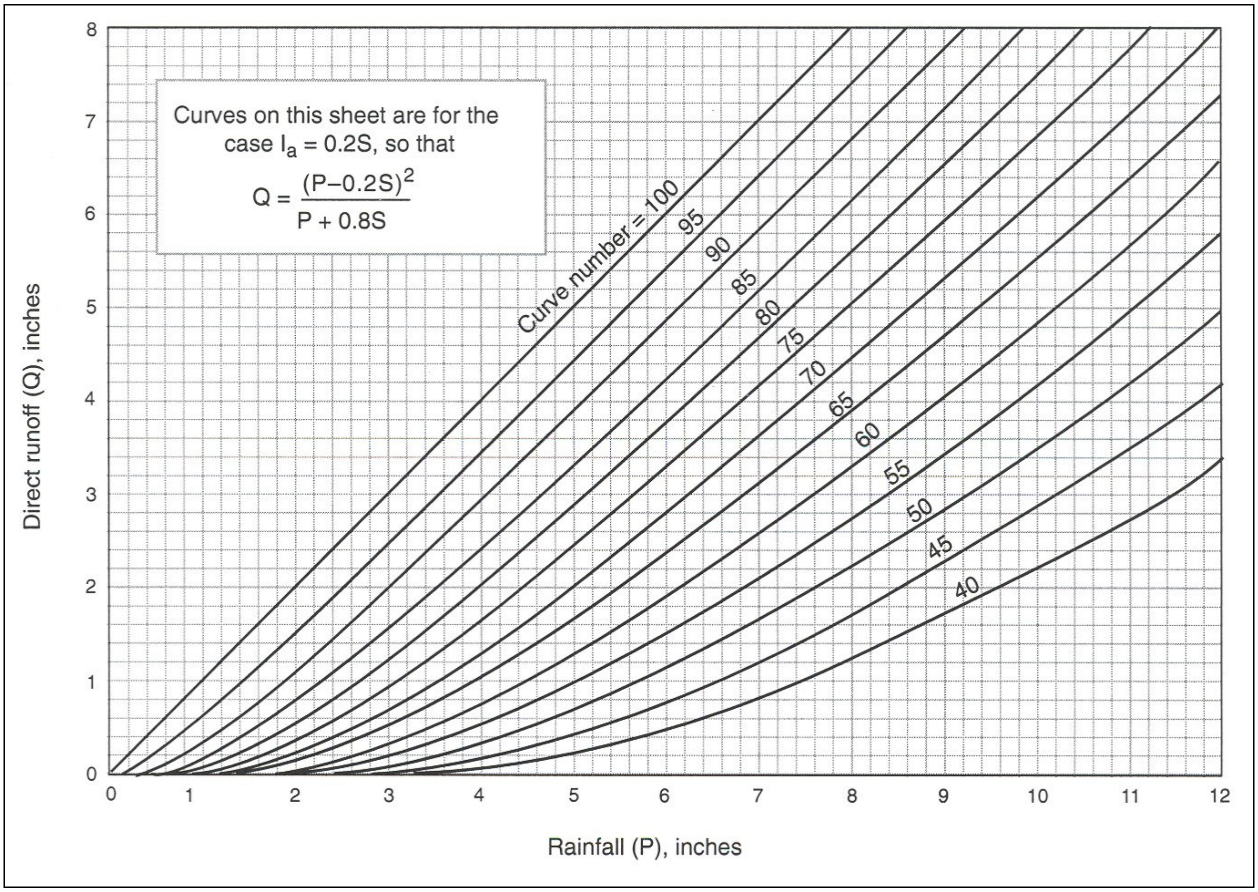
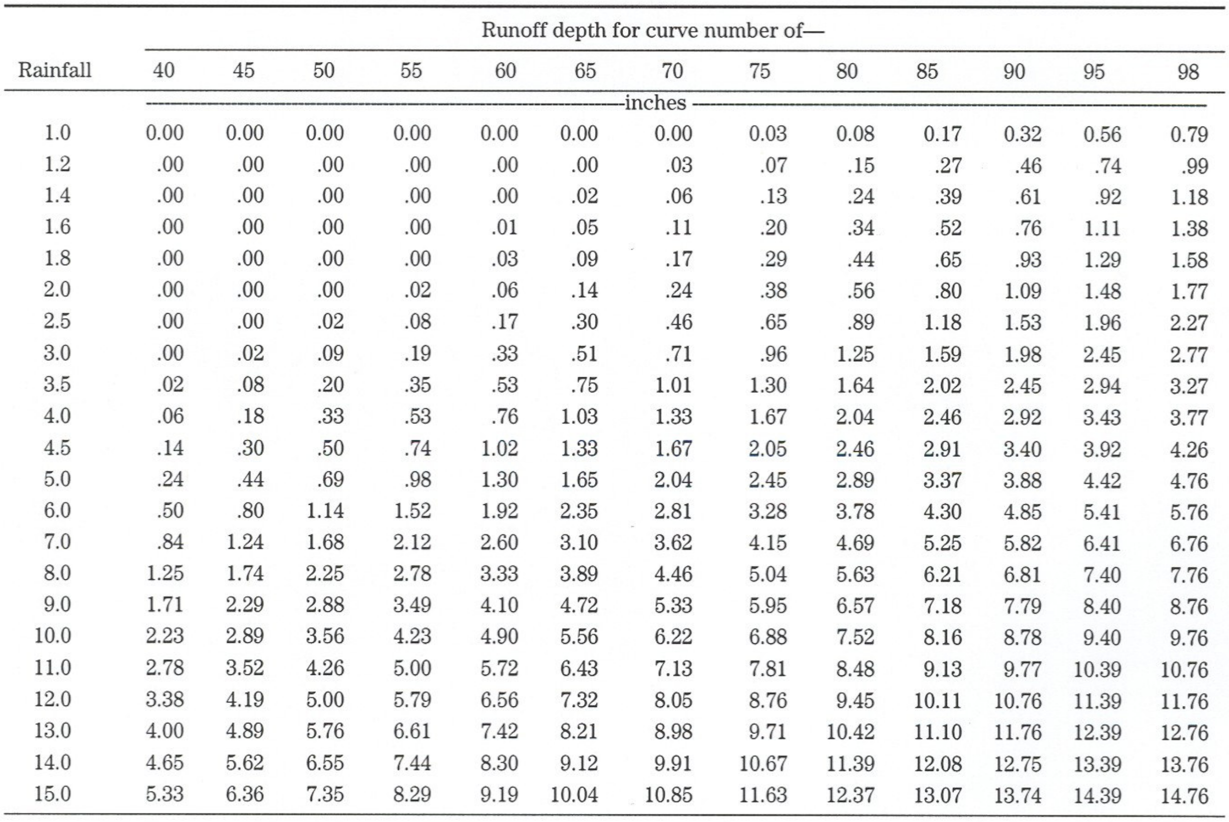


Figure E-3. Solution of runoff equation.

Source: TR-55, 1986.

Table E-4. Runoff depth for selected CNs and rainfall amounts.

Source: TR-55, 1986.



	Runoff depth for curve number of—												
Rainfall	40	45	50	55	60	65	70	75	80	85	90	95	98
	inches												
1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.17	0.32	0.56	0.79
1.2	.00	.00	.00	.00	.00	.00	.03	.07	.15	.27	.46	.74	.99
1.4	.00	.00	.00	.00	.00	.02	.06	.13	.24	.39	.61	.92	1.18
1.6	.00	.00	.00	.00	.01	.05	.11	.20	.34	.52	.76	1.11	1.38
1.8	.00	.00	.00	.00	.03	.09	.17	.29	.44	.65	.93	1.29	1.58
2.0	.00	.00	.00	.02	.06	.14	.24	.38	.56	.80	1.09	1.48	1.77
2.5	.00	.00	.02	.08	.17	.30	.46	.65	.89	1.18	1.53	1.96	2.27
3.0	.00	.02	.09	.19	.33	.51	.71	.96	1.25	1.59	1.98	2.45	2.77
3.5	.02	.08	.20	.35	.53	.75	1.01	1.30	1.64	2.02	2.45	2.94	3.27
4.0	.06	.18	.33	.53	.76	1.03	1.33	1.67	2.04	2.46	2.92	3.43	3.77
4.5	.14	.30	.50	.74	1.02	1.33	1.67	2.05	2.46	2.91	3.40	3.92	4.26
5.0	.24	.44	.69	.98	1.30	1.65	2.04	2.45	2.89	3.37	3.88	4.42	4.76
6.0	.50	.80	1.14	1.52	1.92	2.35	2.81	3.28	3.78	4.30	4.85	5.41	5.76
7.0	.84	1.24	1.68	2.12	2.60	3.10	3.62	4.15	4.69	5.25	5.82	6.41	6.76
8.0	1.25	1.74	2.25	2.78	3.33	3.89	4.46	5.04	5.63	6.21	6.81	7.40	7.76
9.0	1.71	2.29	2.88	3.49	4.10	4.72	5.33	5.95	6.57	7.18	7.79	8.40	8.76
10.0	2.23	2.89	3.56	4.23	4.90	5.56	6.22	6.88	7.52	8.16	8.78	9.40	9.76
11.0	2.78	3.52	4.26	5.00	5.72	6.43	7.13	7.81	8.48	9.13	9.77	10.39	10.76
12.0	3.38	4.19	5.00	5.79	6.56	7.32	8.05	8.76	9.45	10.11	10.76	11.39	11.76
13.0	4.00	4.89	5.76	6.61	7.42	8.21	8.98	9.71	10.42	11.10	11.76	12.39	12.76
14.0	4.65	5.62	6.55	7.44	8.30	9.12	9.91	10.67	11.39	12.08	12.75	13.39	13.76
15.0	5.33	6.36	7.35	8.29	9.19	10.04	10.85	11.63	12.37	13.07	13.74	14.39	14.76

[1/] Interpolate the values shown to obtain runoff depths for CN's or rainfall amounts not shown.

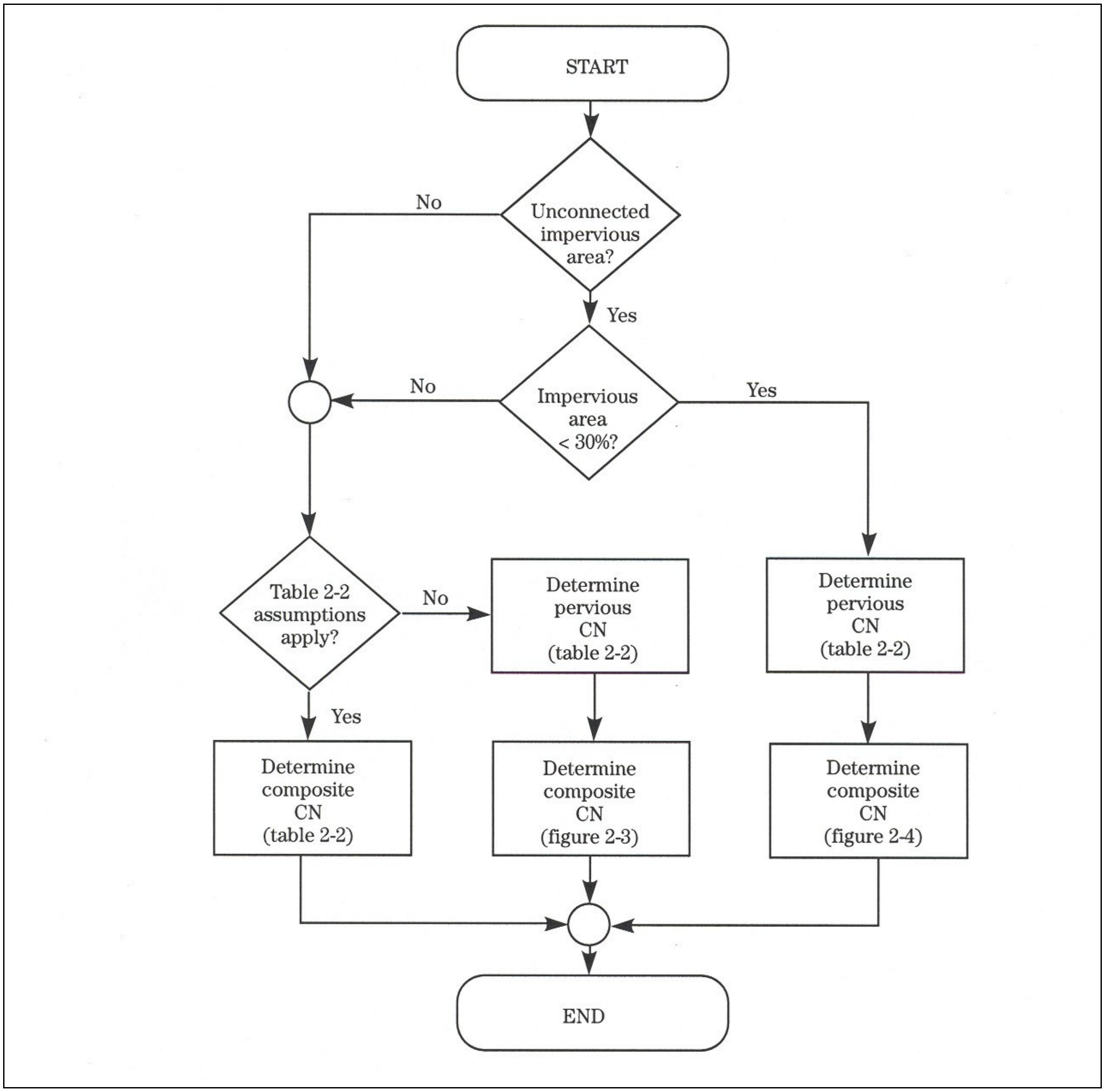
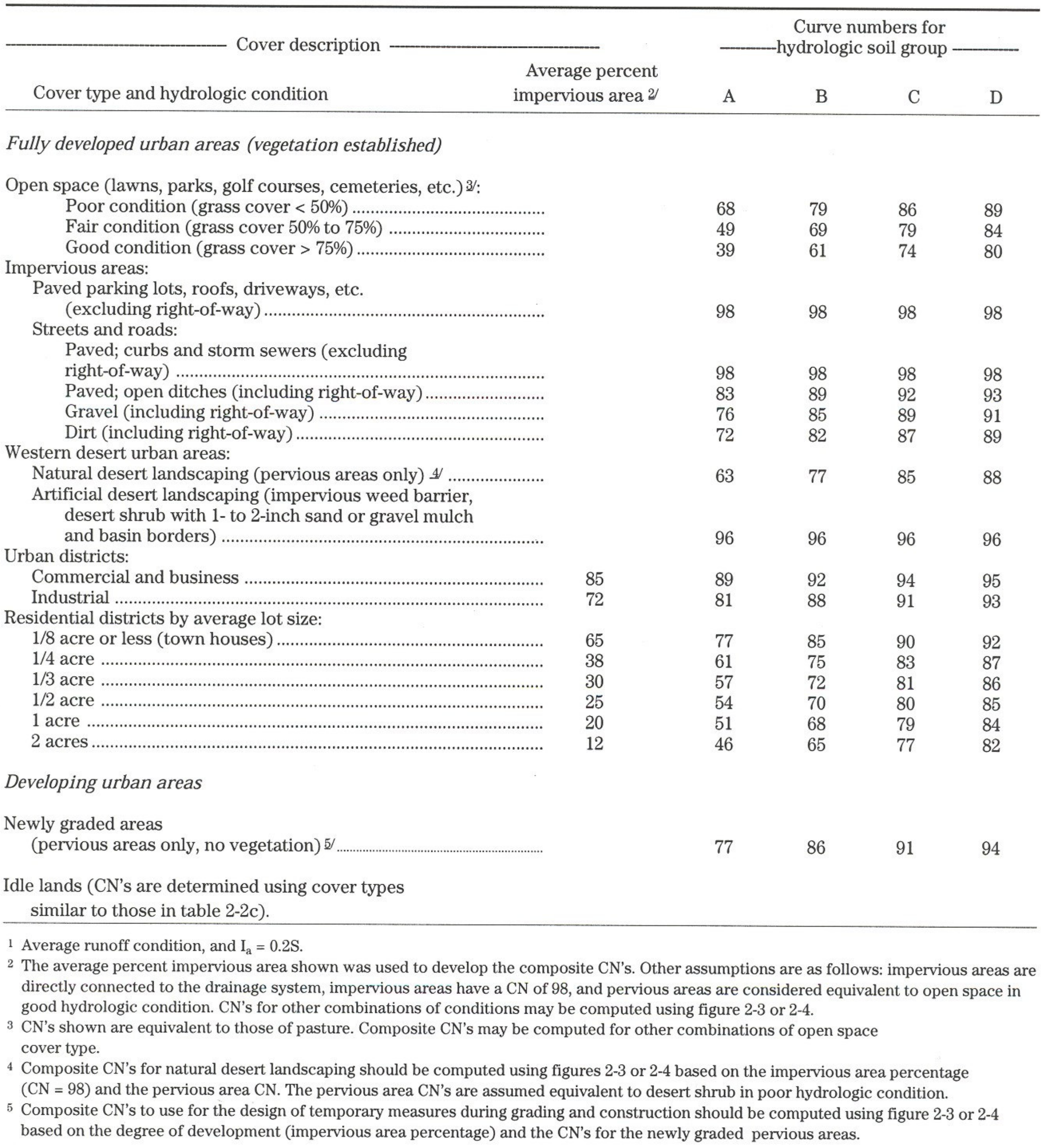


Figure E-4. Flow chart for selecting the appropriate figure or table for determining runoff curve numbers.

Source: TR-55, 1986.

Table E-5. Runoff curve numbers for urban areas.

Source: TR-55, 1986.



Cover description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	Average percent impervious area [2]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) [3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation) [5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

---

[1] Average runoff condition, and $I_a = 0.2S$.

[2] The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.

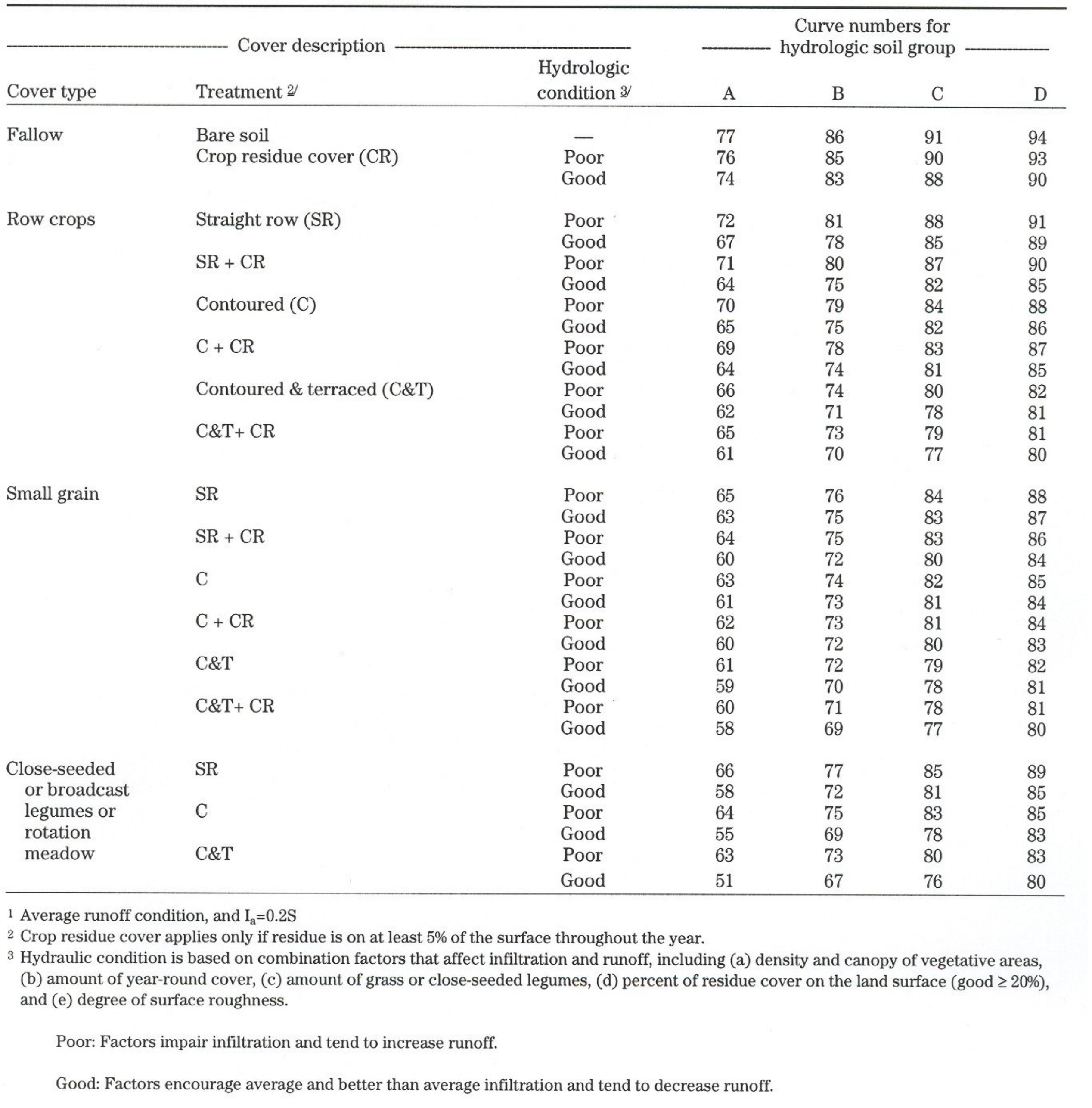
[3] CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.

[4] Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.

[5] Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4 based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

Table E-6.Runoff curve numbers for cultivated agricultural lands.

Source: TR-55, 1986.



Cover description			Curve numbers for hydrologic soil group			
Cover type	Treatment [2]	Hydrologic condition [3]	A	B	C	D
Fallow	Bare soil	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T+ CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T+ CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80

[1] Average runoff condition, and I_a=0.2S

[2] Crop residue cover applies only if residue is on at least 5% of the surface throughout the year.

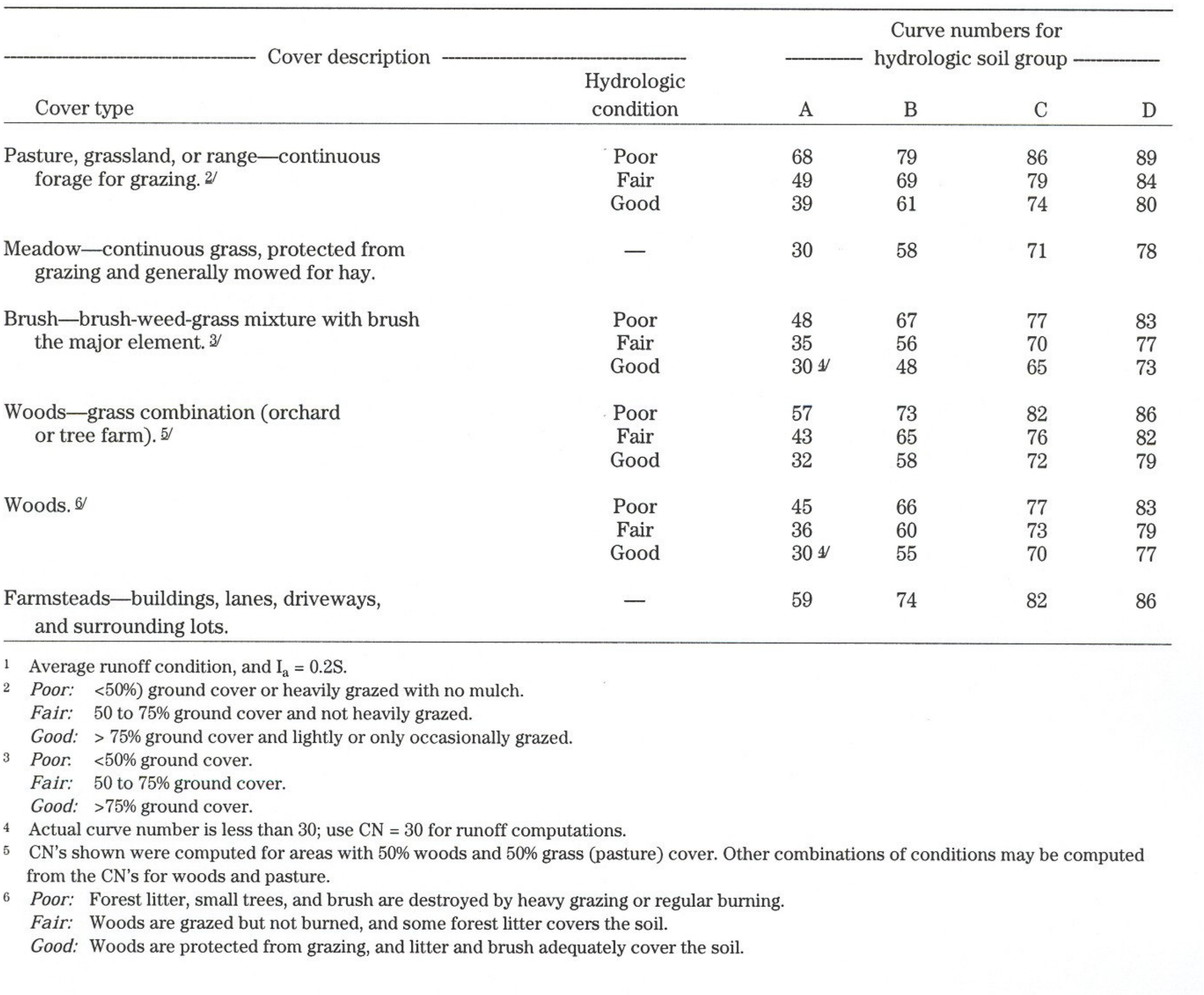
[3] Hydraulic condition is based on combination factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes, (d) percent of residue cover on the land surface (good ≥ 20%), and (e) degree of surface roughness.

Poor: Factors impair infiltration and tend to increase runoff.

Good: Factors encourage average and better than average infiltration and tend to decrease runoff.

Table E-7. Runoff curve numbers for other agricultural lands.

Source: TR-55, 1986.



Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range—continuous forage for grazing. [2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element. [3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30 [4]	48	65	73
Woods—grass combination (orchard or tree farm). [5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods. [6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30 [4]	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

[1] Average runoff condition, and $I_a = 0.2S$.

[2] *Poor:* <50%) ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: > 75% ground cover and lightly or only occasionally grazed.

[3] *Poor:* <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.

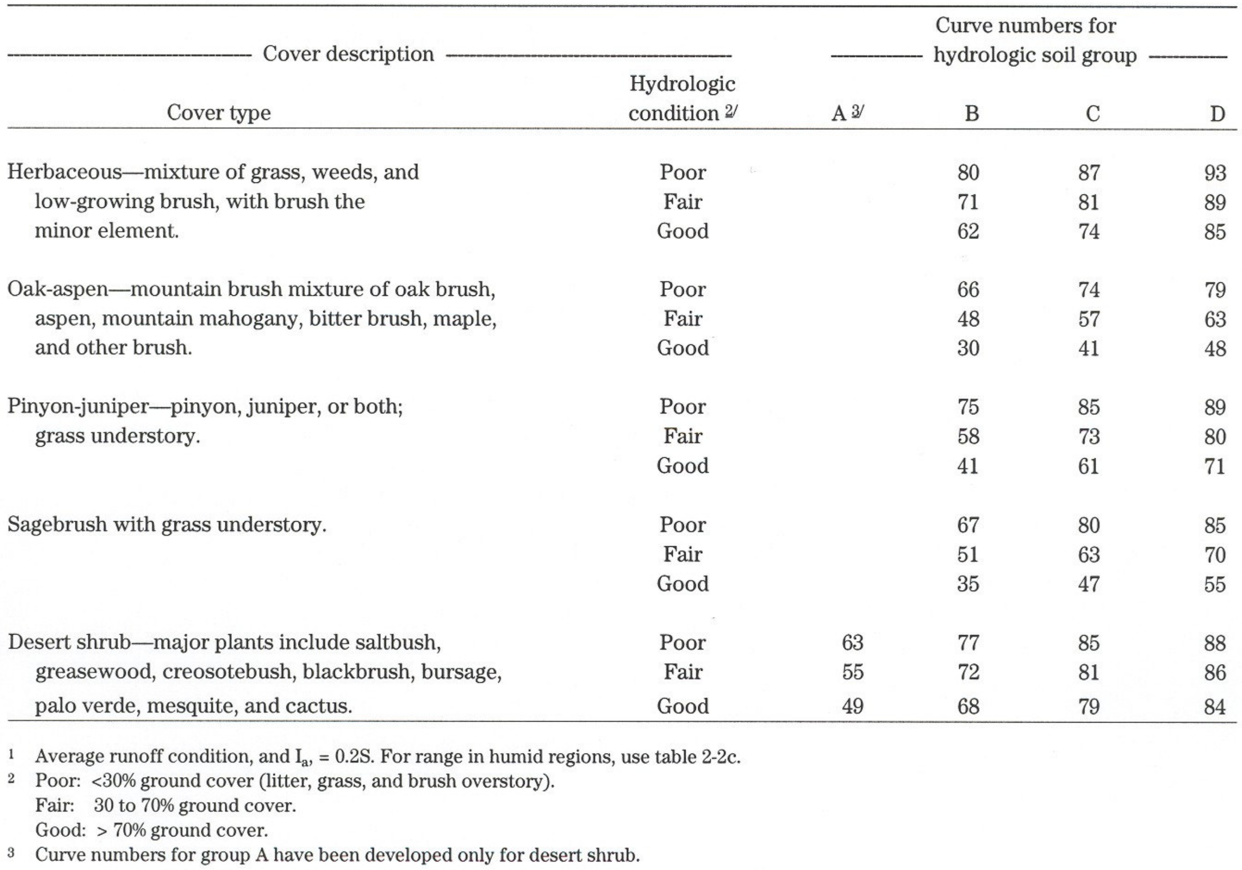
[4] Actual curve number is less than 30; use CN = 30 for runoff computations.

[5] CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

[6] *Poor:* Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

Table E-8. Runoff curve numbers for arid and semiarid rangelands.

Source: TR-55, 1986.



Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition [2]	A [3]	B	C	D
Herbaceous—mixture of grass, weeds, and low-growing brush, with brush the minor element.	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen—mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush.	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Pinyon-juniper—pinyon, juniper, or both; grass understory.	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sagebrush with grass understory.	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub—major plants include saltbush, greasewood, creosotebush, blackbrush, bursage, palo verde, mesquite, and cactus.	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

[1] Average runoff condition, and I_a, = 0.2S. For range in humid regions, use table 2-2c.

[2] Poor: <30% ground cover (litter, grass, and brush overstory).
Fair: 30 to 70% ground cover.
Good: > 70% ground cover.

[3] Curve numbers for group A have been developed only for desert shrub.

E.5.8 Urban Impervious Area Modifications

Several factors, such as the percentage of impervious area and the means of conveying runoff from impervious areas to the drainage system, should be considered in computing CN for urban areas.

An impervious area is considered connected if runoff from it flows directly into the drainage system or if runoff occurs as shallow flow over a pervious area then into a drainage system. Runoff from unconnected impervious areas is spread over a pervious area as sheet flow. Urban CN's were developed for typical land use relationships based on specific assumed percentages of impervious area.

For connected areas, urban CNs (Table 5) were developed for various land use relationships based on an assumed percentage of impervious area.

To determine CN when all or part of the impervious area is not directly connected to the drainage system, (1) use Figure 5 if total impervious area is less than 30 percent or (2) use Figure 6 if the total impervious area is equal to or greater than 30 percent, because the absorptive capacity of the remaining pervious areas will not significantly affect runoff.

E.5.9 Time of Concentration and Travel Time

Travel time (T_t) is the time it takes water to travel from one location to another in a watershed. Time of concentration (T_c) is the time it takes water to travel from the hydraulically most distant point of the watershed to the point of interest. Factors that affect travel T_t and T_c are surface roughness, channel shape, flow patterns and slope.

Travel time, T_t is the ratio of flow length to flow velocity:

$$T_t = \frac{L}{3600V}$$

Where T_t equals the travel time (hr), L equals the flow length (ft), V equals the average velocity (ft/s), and 3600 if the conversion from seconds to hours.

Sheet flow occurs over land before water collects in streams. TR-55 uses the Mannings's kinematic solution to compute T_t for sheet flow of less than 300 feet.

$$T_t = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5} s^{0.4}}$$

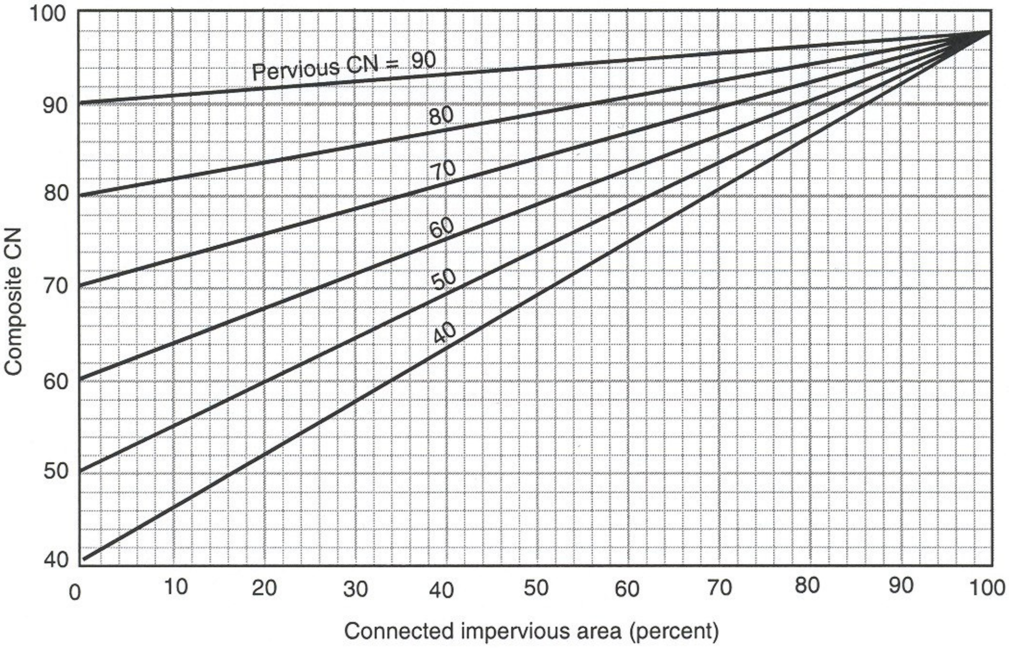


Figure E-5. Composite CN with connected impervious area.
Source: TR-55, 1986.

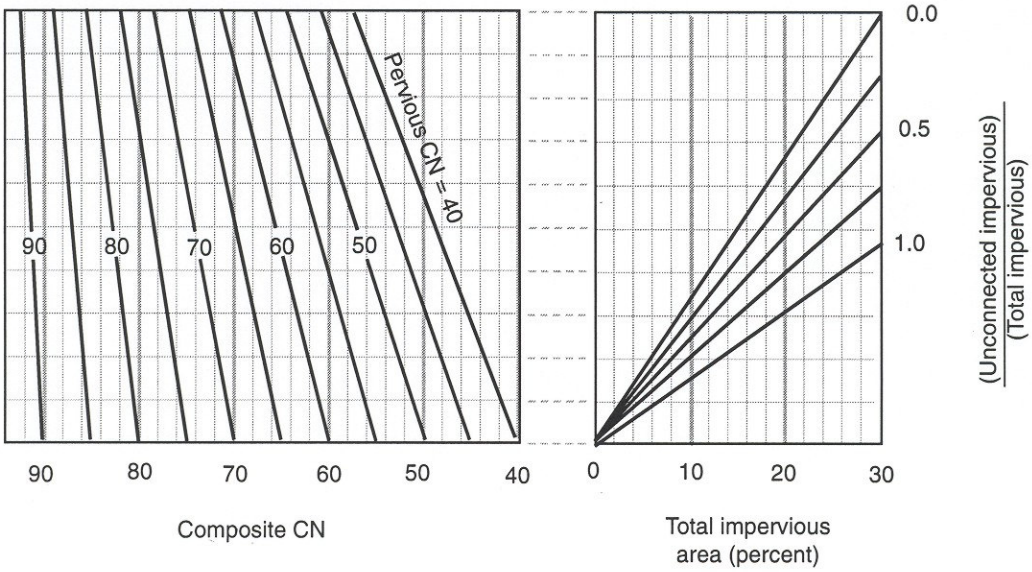
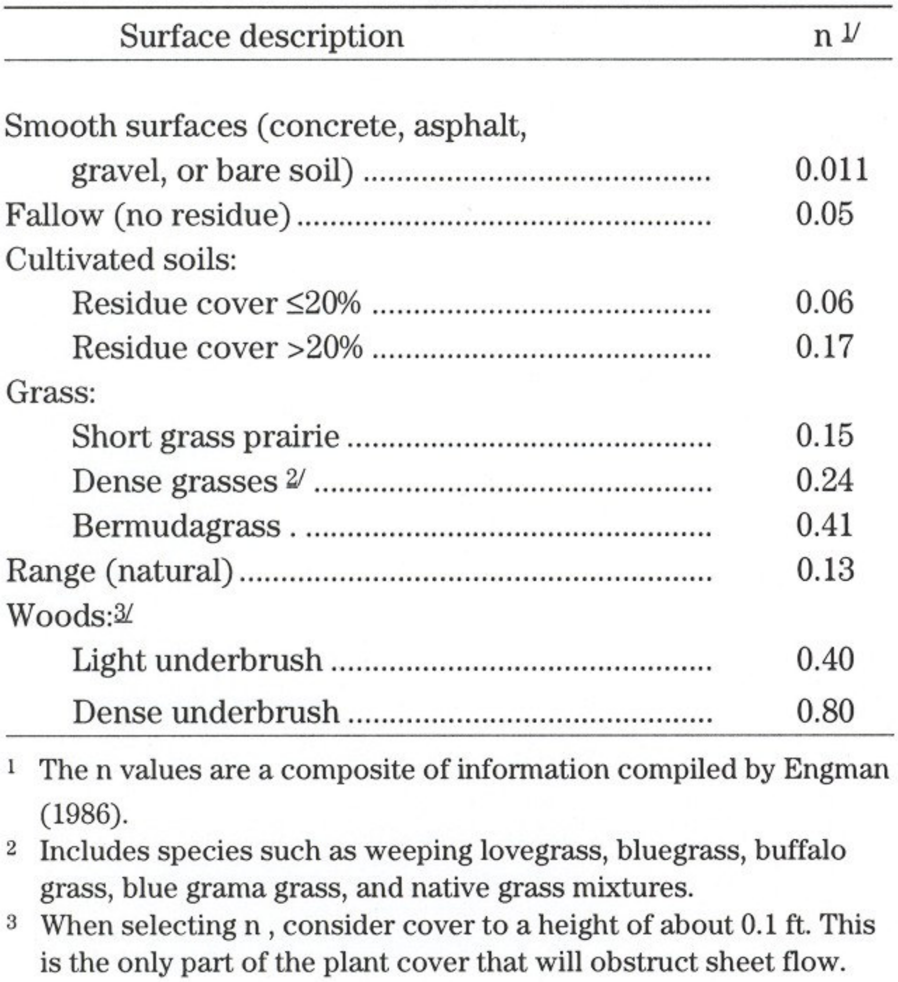


Figure E-6. Composite CN with unconnected impervious areas and total impervious area less than 30%.
Source: TR-55, 1986.

Where T_t equals travel time (hr), n equals Manning's roughness coefficient, L equals the flow length, P_2 equals 2-year, 24-hour rainfall (in), and s equals slope of hydraulic grade line (land slope, ft/ft). Table 9 provides Manning's n coefficients for shallow depths of about 0.1 foot.

Table E-9. Roughness coefficients (Manning's n) for sheet flow.

Source: TR-55, 1986.



Surface description	n[1]
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover ≤20%	0.06
Residue cover >20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses[2]	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods:[3]	
Light underbrush	0.40
Dense underbrush	0.80

[1] The n values are a composite of information compiled by Engman (1986).

[2] Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.

[3] When selecting n , consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

After a maximum of 300 feet, sheet flow usually becomes shallow concentrated flow. The average velocity for this flow can be determined from Figure 7, in which the average velocity is a function of watercourse slope and type of channel. This velocity can be used to estimate travel time for the shallow concentrated flow segment.

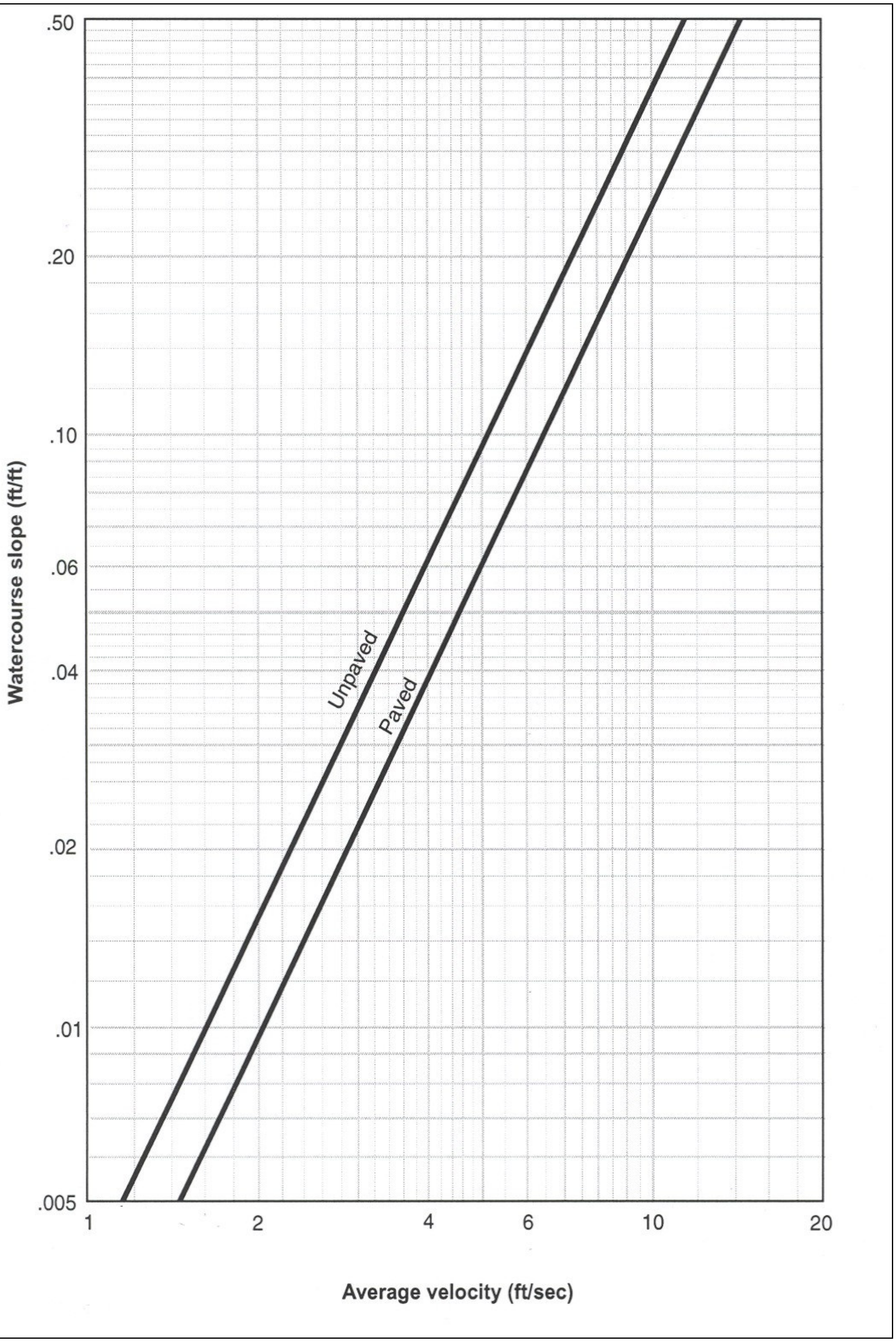

.50
.20
.10
.06
.04
.02
.01
.005
Watercourse slope (ft/ft)
Unpaved
Paved
1
2
4
6
10
20
Average velocity (ft/sec)

Figure E-7. Average velocities for estimating travel time for shallow concentrated flow.
Source: TR-55, 1986.

The Manning's equation can be used to estimate average flow velocity in open channels. Average velocity is usually determined for bank-full elevation.

$$V = \frac{1.49r^{2/3}s^{1/2}}{n}$$

Where V equals average velocity (ft/s), r equals hydraulic radius (ft) and is equal to a/p_w, a equals to cross-sectional flow area (ft^2), p_w equals wetted perimeter (ft), s equals slope of the hydraulic grade line (channel slope ft/ft), and n equals Manning's roughness coefficient for open channel flow.

Travel time through lakes and reservoirs is small and can be assumed to equal zero.

E.5.10 Graphical Peak Discharge

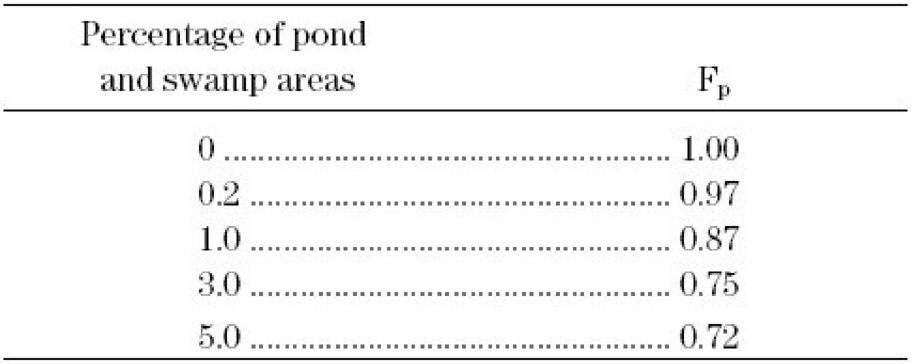
Peak discharge is calculated using the following equation:

$$q_p = q_u A_m Q F_p$$

Where q_p equals peak discharge (cfs), q_u equals unit peak discharge in cubic feet of discharge per second per square mile of watershed per inch of runoff (csm/in), A_m equals drainage area (mi^2), Q equals runoff (in), and F_p equals pond and swamp adjustment factor. If pond and swamp areas are spread throughout the watershed and are not considered in the T_c computation, an adjustment for pond and swamp areas is also needed.

For the selected frequency, the 24-hour rainfall (P) is obtained from the Precipitation-Frequency Atlas from NOAA. A_m and Q have already been calculated in previous sections. The pond and swamp adjustment factor is obtained from Table 10 (rounded to the nearest table value).

Table E-10. Adjustment factor (Fp) for pond and swamp areas that are spread throughout the watershed
Source: TR-55, 1986.



Percentage of pond and swamp areas	F_p
0	1.00
0.2	0.97
1.0	0.87
3.0	0.75
5.0	0.72

The remaining value to calculate is q_u. Rainfall patterns in California have been categorized to have three separate distributions as shown in Figure 8. The three types of rainfall distribution are Type I, Ia, II or III. The corresponding Figures (Figures 9 through 12) must be used to calculate q_u depending on the location of the stream. The CN is used to calculate the initial abstraction (I_a) and the ratio of the initial abstraction and precipitation (I_a/P) value is calculated. This ratio, in combination with the time of concentration, is used to calculate q_u.

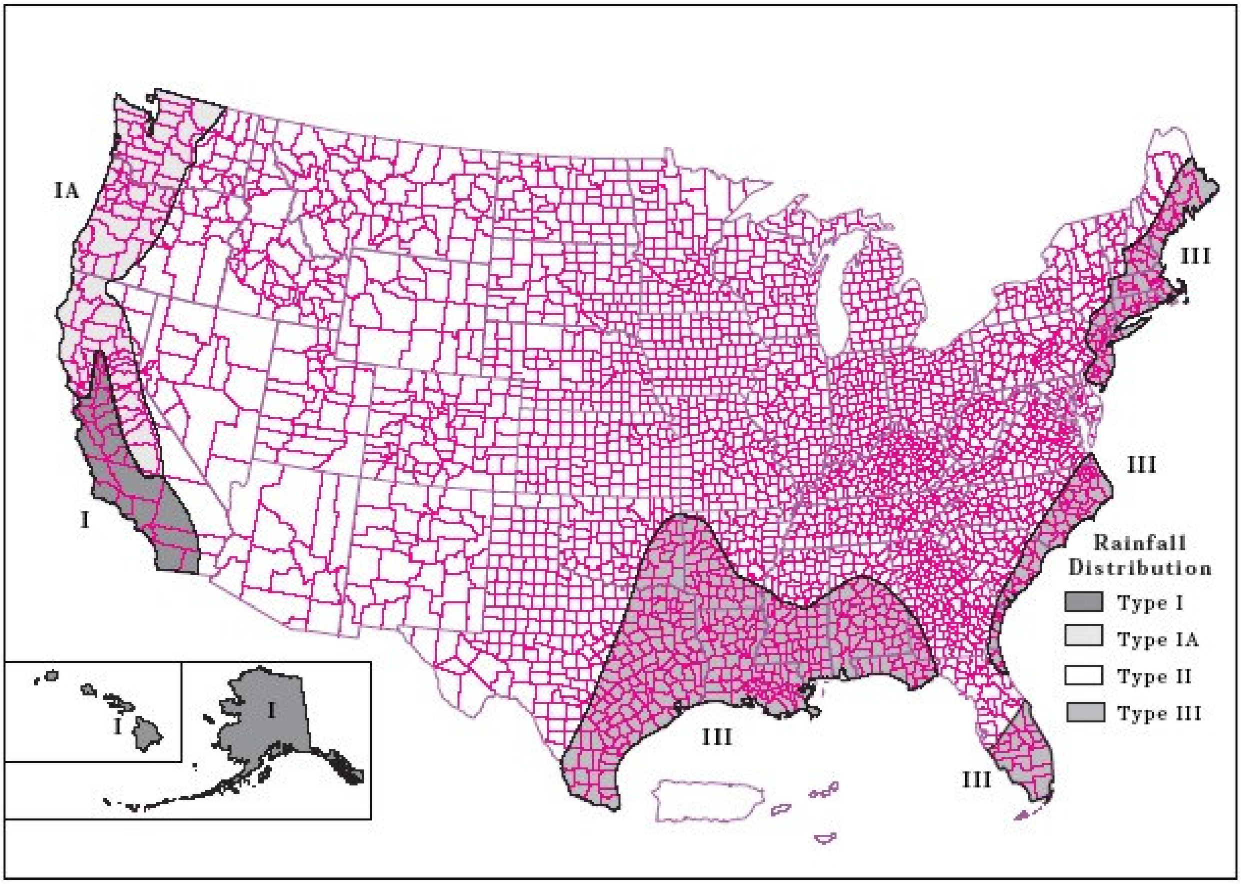


Figure E-8. Approximate geographic boundaries for NRCS (SCS) rainfall distributions.
Source: TR-55, 1986.

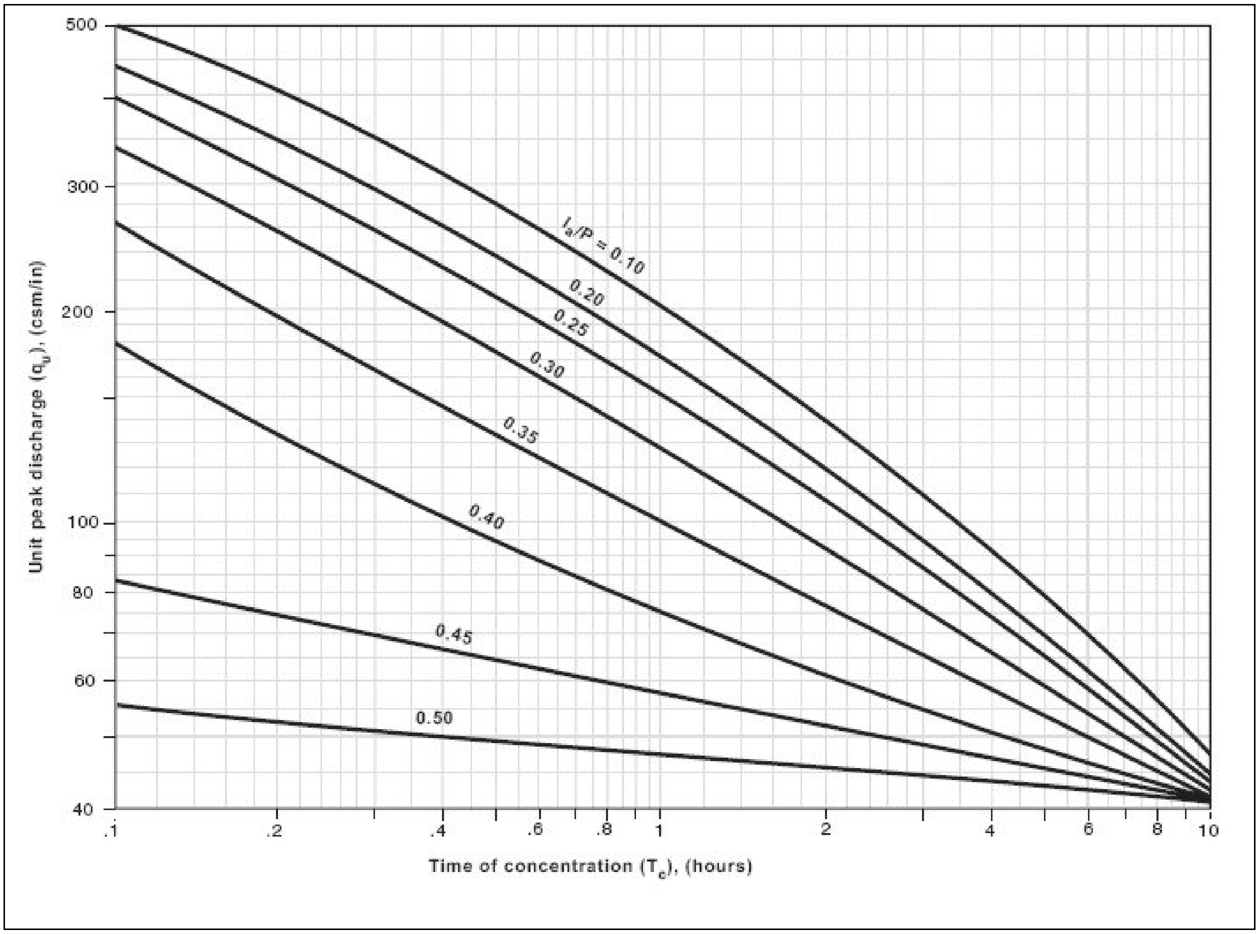


Figure E-9. Unit peak discharge (qu) for NRCS (SCS) type I rainfall distribution.
Source: TR-55, 1986.

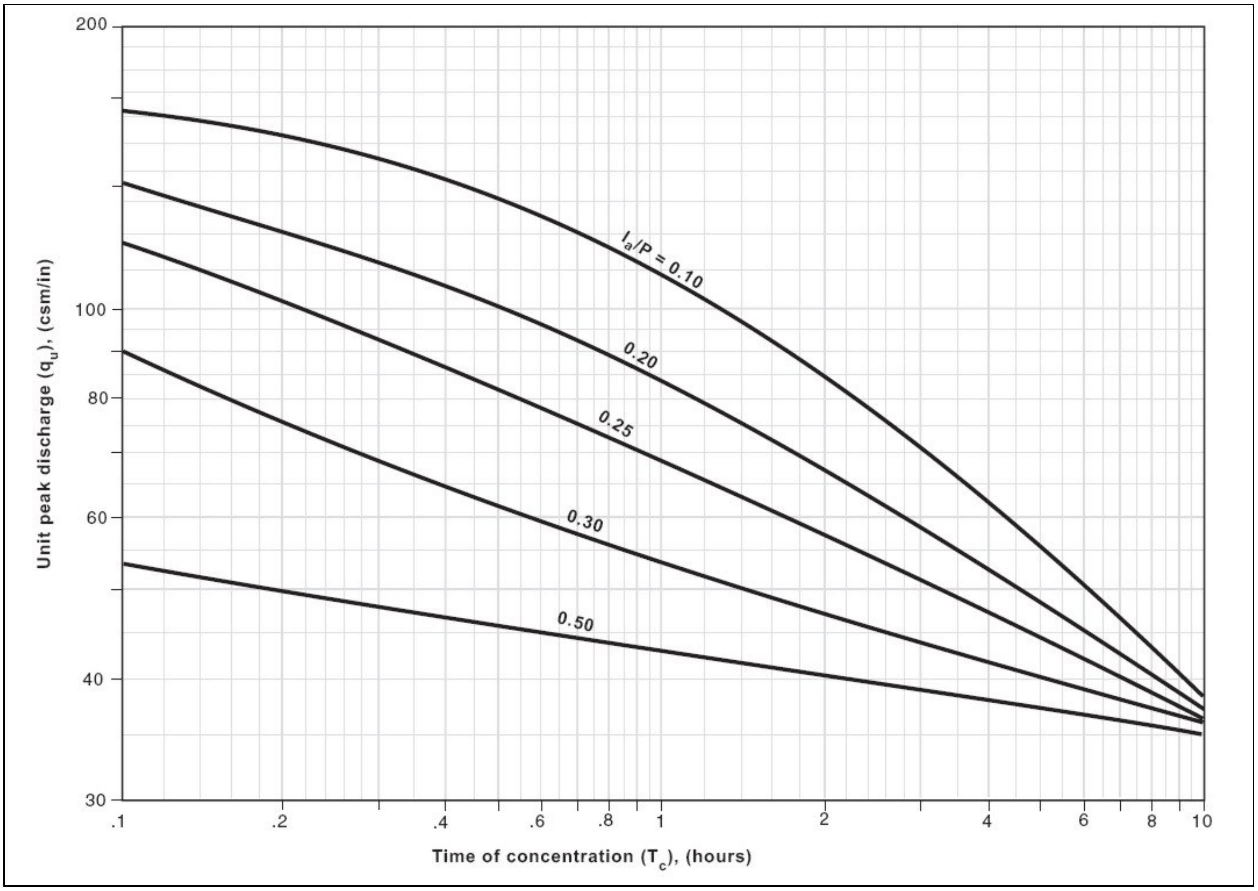


Figure E-10. Unit peak discharge (qu) for NRCS (SCS) type IA rainfall distribution.
Source: TR-55, 1986.

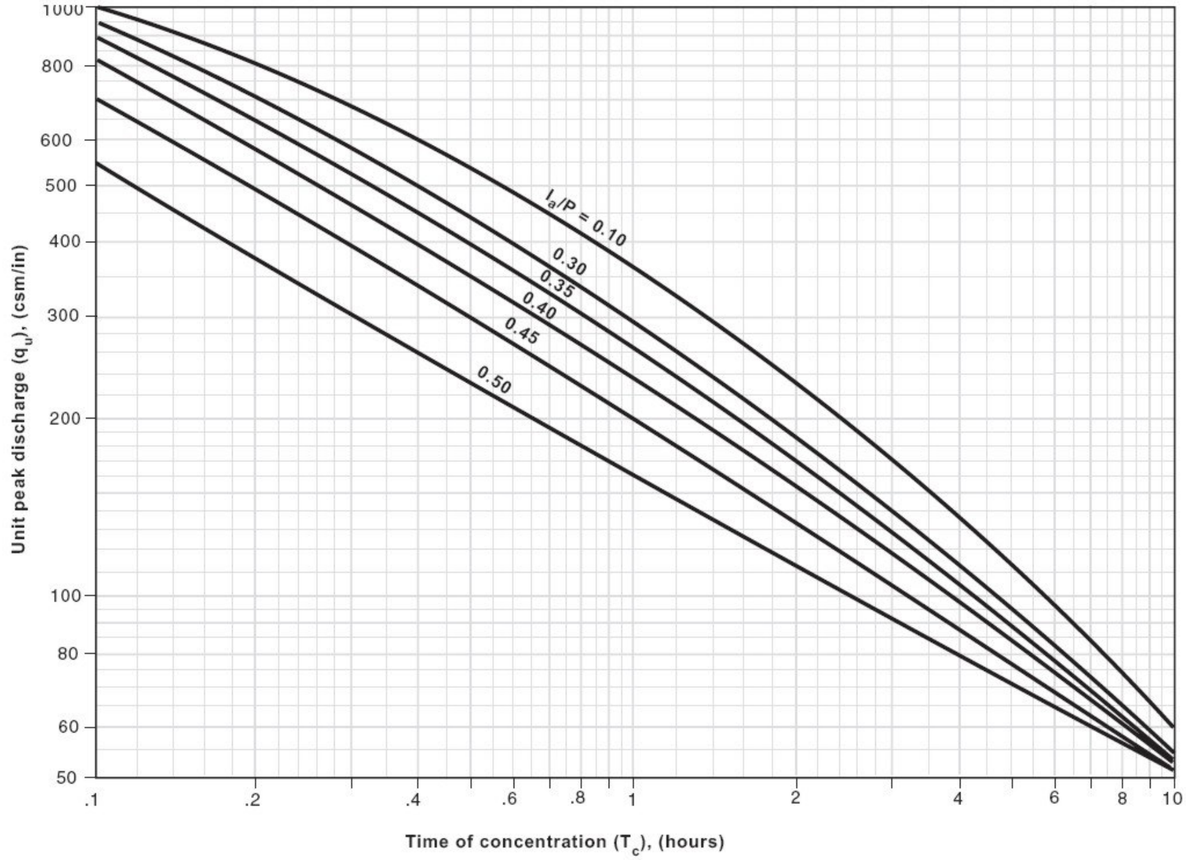


Figure E-11. Unit peak discharge (qu) for NRCS (SCS) type II rainfall distribution.
Source: TR-55, 1986.

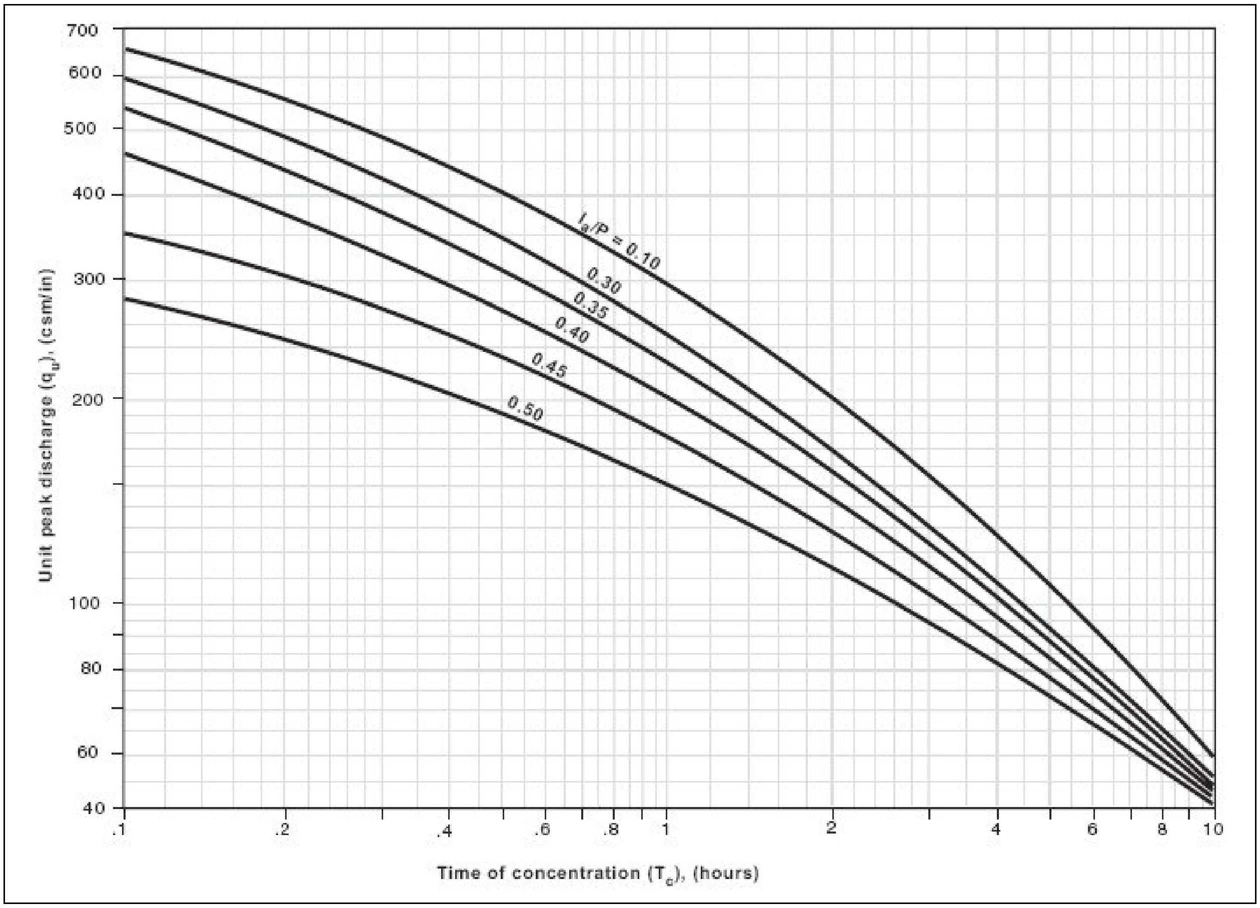


Figure E-12. Unit peak discharge (qu) for NRCS (SCS) type III rainfall distribution.
Source: TR-55, 1986.

Of the three methods, the TR-55 method is the most desirable if the designer has access to the required information. However there are some limitations to this method.

- The initial abstraction number is dependent upon the situation. It has been generalized with as 0.2S based on data from agricultural watersheds. This approximation can be especially important depending on the amount of urbanization of a watershed. Impervious areas increase with greater urbanization and therefore infiltration decreases. This should be considered when determining initial abstraction.
- Runoff from snowmelt or rain on frozen ground cannot be estimated using these procedures.
- The CN procedure is less accurate when runoff is less than 0.5 inch. As a check, another procedure to calculate runoff should be used.
- The SCS runoff procedure applies to direct surface runoff and does not consider ground water.
- When the weighted CN is less than 40, use another method to determine runoff.
- If water travels through sewer pipelines, the travel time through the pipe should be calculated with an appropriate pipe flow equation, such as Manning's equation for pipe flow.
- For further limitations refer to the TR-55 publication.

E.5.11 Example Calculations - TR-55 Method

For this method the example the watershed has the following characteristics:

- Stream is located in San Luis Obispo County
- Drainage Area = 2.95 mi2

CN Calculation

Cover is sagebrush with grass understory, fair
Grass is considered short prairie grass
Soil type - 20% of area is Serpentano (Type B), 80% of area is Lombard (Type C).

To calculate a CN, we use Table 8 - Runoff curve numbers for arid and semiarid rangelands. Because the hydrologic soil group is a mix of two types, we must calculate a composite CN. The CN for sagebrush with grass understory, fair and Serpentano (Type B) is 51. The CN for sagebrush with grass understory, fair and Lombard (Type C) is 63. The composite CN is then:

$$CN = 0.2(51) + 0.8(63) = 60.6$$

Potential Maximum Retention After Runoff (S)

$$S = \frac{1000}{CN} = \frac{1000}{60.6} - 10 = 6.5\,\text{in}$$

Initial Abstraction (I_a)

$$I_a = 0.2S = 0.2(6.5) = 1.3\,\text{in}$$

Runoff (Q)

Mean Annual Precipitation (P) = 8 in
2-Year, 24-hour Rainfall (P_2) = 4 in
100-Year, 24-hour Rainfall (P_{100}) = 8 in

$$Q_{2yr} = \frac{(P-0.2S)^2}{(P+0.8S)} = \frac{(4-0.2(6.5))^2}{(4+0.8(6.5))} = \frac{7.29}{9.2} = 0.79\text{in}$$

$$Q_{100yr} = \frac{(P-0.2S)^2}{(P+0.8S)} = \frac{(8-0.2(6.5))^2}{(8+0.8(6.5))} = \frac{44.9}{13.2} = 3.4\text{in}$$

Travel Time

Channel distance to outlet = 8000 ft
Average channel velocity = 1.3 ft/s

$$T_t = \frac{L}{3600V} = \frac{8000}{3600(1.3)} = 1.7\text{hr}$$

Peak Discharge (q_p)

2yr: $\frac{I_a}{P} = \frac{1.3}{4} = 0.325$

100yr: $\frac{I_a}{P} = \frac{1.3}{8} = 0.16\text{hr}$

From Figure 9 using Type I rainfall distribution using T_t and I_a/P:

2yr: q_u = 95 csm/in

100yr: q_u = 140 csm/in

2yr: $q_p = q_u A_m Q F_p = 95(2.95)(0.79)(1) = \underline{\underline{221\text{cfs}}}$

100yr: $q_p = q_u A_m Q F_p = 140(2.95)(3.4)(1) = \underline{\underline{1404\text{cfs}}}$

APPENDIX F

HYDRAULICS OF BAFFLES

F. HYDRAULICS OF BAFLES

F.1 Baffled Culvert Research Overview

During the period from Summer 2004 through Fall 2008, Humboldt State University (HSU) conducted baffled culvert research, requested and funded by Caltrans, with goals of quantifying impacts on hydraulic capacity and identifying appropriate design and analysis methods. This research was led by Professor Margaret Lang and concentrated on the changes in culvert hydraulic performance under higher flow conditions due to the addition of baffles. Prior to the HSU research effort, analyzing and modeling culverts retrofitted with baffles under high/flood flows have been somewhat crude. This shortfall justified the need for research in hopes of increasing accuracy in analysis and possibly reducing the amount of conservatism that has typically been applied to the design of baffles in culvert rehabilitation.

Previously, research performed by others such as Rajaratnam and Katopodis, focused on baffled culvert performance during lower flows when fish would be migrating through a culvert. Under these lower flow conditions, the individual baffles operate as weirs where water plunges over a baffle into the pool between two successive baffles. When flows are higher and baffles are fully overtopped, water streams over them and they become a roughness element inside a culvert and no longer act as weirs (See Figure F.1). As flow depth increases above a baffle, their roughness influence on the culvert hydraulics decreases. In addition, culvert hydraulics are affected by spacing, height and configuration of baffles. This higher flow condition was examined at baffled culvert sites in the field, recreated and analyzed in the laboratory, and modeled using computer software by the HSU research team.

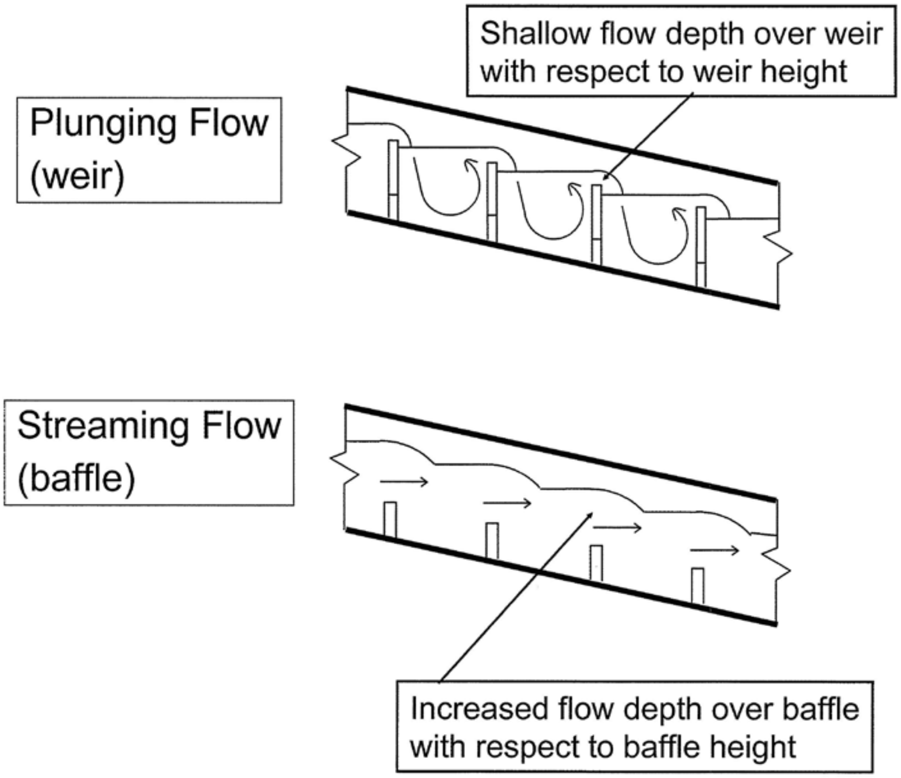


Figure F.1 Plunging Flow vs. Streaming Flow

At seven field sites located within reasonable proximity to HSU, flow depth and peak discharge were measured for varying culvert types and baffle configurations. See Table F.1 for the summary of field sites and baffled culvert descriptions. The flow depth measurement was done by painting vertical lines with clay at intervals along the length of the culvert, where portions of the clay lines would wash away as water moved through the culverts creating high water marks. After a large or significant storm, the HSU research team would measure the height from the invert of the culvert to the bottom of each clay line. This measurement was the flow-depth in the culvert for a storm event at a particular location inside the culvert. The collection of the measured heights for all of the clay lines established a water surface profile through the culvert.

Culvert Type	Stream Name/ Site Location	Retrofit Type	Size (D or H x W)	Length	Culvert Slope
CMP	Chadd Creek HUM101, PM 40.12	Wooden weirs	9. 5 ft	592 ft	3.7%
RCP	Clarks Creek DN199, PM 2.59	Offset baffles	8 ft x 8 ft	76 ft	1.8%
CMP	Griffin Creek DN199, PM 31.31	Corner Baffles	12 ft	406 ft	1.2%
CMP	John Hatt Creek MEN 128, PM 39.95	Corner Baffles	5.5 ft	171 ft	3.0%
ARCH	Luffenholtz Creek HUM101, PM99.03	Vortex Weirs	14 ft x 14 ft	300 ft – US segment 100 ft – DS segment	4.7% 0.2%
CMP	Palmer Creek HUM 101, PM62.22	Corner Baffles	7.5 ft	426 ft – US segment 60 ft – DS segment	0.9% 1.8%
ARCH	Peacock Creek Tan Oak Drive	Vortex Weirs	10 radius arch over weirs	120 ft	6.7%

Table F.1 Baffled Culvert Field Sites

Once a water surface profile was generated for a culvert with baffles, these profiles were typically recreated using HEC-RAS or HY-8 software by using a measured or calculated peak flow and varying Mannings Roughness (n-value). As predicted, an n-value found to recreate a water surface profile from the field would increase with lower flow-depths and decrease with higher flow-depths. The higher the flow-depth above baffles, the less influence the baffles have on the roughness element inside a culvert, and the lower an n-value will be as flow-depth increases. For this phenomenon to occur, flows must be large enough to overtop the baffle so that streaming flow controls. This changing n-value according to flow-depth above a baffle inside a culvert is an effective roughness value (n_{eff}), which will be discussed in more detail later in this Appendix.

In the HSU hydraulics laboratory, scaled models of the seven field sites, as well as additional baffle configurations, were developed in a tilting flume. Scaling of the lab models considered geometric and kinematic similitude, where Froude number was used for the latter. The lab experiments quantified the effective roughness results found in the field for scaled, measured or calibrated flows. In addition, lab experiments were used to analyze effects of baffles on headwater depth and sediment transport, and extend empirical design parameters from past research by Rajaratnam and Katopodis.

As mentioned previously, Rajaratnam and Katopodis conducted research with baffles in circular culverts mainly for lower flows, but they also executed experiments for baffled culverts operating up to 80% flow capacity. Through this research, a relationship between dimensionless discharge (Q*) and dimensionless depth (y_o/D) were derived.

$$\text{Circular Culverts: } Q_* = \frac{Q}{\sqrt{gS_oD^5}} = C\left(\frac{y_o}{D}\right)^a$$

Through the HSU study, it was found that the dimensionless discharge equation could be modified for box culverts. This modified equation is expressed below:

$$\text{Box Culverts: } Q_* = \frac{Q}{\sqrt{gS_oW^5}} = C\left(\frac{y_o}{z_{\max}}\right)^a$$

Where:

C & a = Experimental design parameters

D = Circular culvert diameter

W = Box culvert width

z_{max} = Maximum baffle height

y_o = Flow depth

S_o = Culvert slope

Q = Actual discharge

G = Gravity

The HSU team built upon the Rajaratnam and Katopodis past research and determined C and a values for several baffle configurations through their flume experiments. The benefit of the equations above is that the C and a values determined from the scaled experiments apply directly to geometrically similar full-scale baffled culverts without having to use factors or other equations to relate scaled lab results to full-scale field design.

In the analysis/design of baffled culverts, the dimensionless discharge equation will be most used in the form below to solve for flow depth (y_o):

$$\text{Circular Culverts: } y_o = D\left[\frac{Q}{C\sqrt{gS_oD^5}}\right]^{1/a}$$

Or

$$\text{Box Culverts: } y_o = W\left[\frac{Q}{C\sqrt{gS_oW^5}}\right]^{1/a}$$

At the HSU lab, C and a values were determined for box culverts with many combinations of high, medium, or low height baffles and close, intermediate, and far-spaced baffles. The box culvert was the main shape of focus for developing experimental parameters in the determination of effective roughness, partly because it is commonly found in the field. It was also the main focus due to its typical wide cross section and smooth surface that can be poor in creating fish friendly environments that ideally have high depth and low velocity. As for circular culverts, the most common culvert shape, the C and a values were developed in the lab for corner baffles. This type of baffle retrofit type is most widely recommended for circular culverts by the resource agencies (i.e. CA Fish & Game, etc).

The configuration and corresponding C and a values are summarized in Table F.2, which are suggested baffle configurations for Caltrans projects. Also, see Figures F.2, F.3, F.4, and F.5 for plan view and box/circular cross-sectional views.

Culvert Shape	Retrofit Type	Baffle Height (ft)	Baffle Spacing (ft)	Wall Angle in Plan View (Degrees)	C	a
Box	High Height, Close-Spaced, Full Span, Top Angled Baffle	$z_{min} = 0.132W$ $z_{max} = 0.202W$	0.5W	60	0.122	1.85
Box	Medium Height, Close-Spaced, Full Span, Top Angled Baffle	$z_{min} = 0.092W$ $z_{max} = 0.158W$	0.5W	60	0.123	1.70
Box	Low Height, Close-Spaced, Full Span, Top Angled Baffle	$z_{min} = 0.050W$ $z_{max} = 0.112W$	0.5W	60	0.113	1.64
Box	High Height, Intermediate-Spaced, Full Span, Top Angled Baffle	$z_{min} = 0.132W$ $z_{max} = 0.202W$	0.75W	60	0.139	1.82
Box	Medium Height, Intermediate-Spaced, Full Span, Top Angled Baffle	$z_{min} = 0.092W$ $z_{max} = 0.158W$	0.75W	60	0.125	1.82
Box	Low Height, Intermediate-Spaced, Full Span, Top Angled Baffle	$z_{min} = 0.050W$ $z_{max} = 0.112W$	0.75W	60	0.119	1.68
Box	High Height, Far-Spaced, Full Span, Top Angled Baffle	$z_{min} = 0.132W$ $z_{max} = 0.202W$	W	60	0.169	1.79
Box	Medium Height, Far-Spaced, Full Span, Top Angled Baffle	$z_{min} = 0.092W$ $z_{max} = 0.158W$	W	60	0.166	1.73
Box	Low Height, Far-Spaced, Full Span, Top Angled Baffle	$z_{min} = 0.050W$ $z_{max} = 0.112W$	W	60	0.180	1.64
Circular	Corner Baffle	$z = 0.10D$ $z_{max} = 0.13D$	0.5D	90	7.81	2.63

W = Box Culvert Width D = Circular Culvert Diameter

Table F.2 Experimental "C" and "a" Parameters

In Table F.2, baffle recommendations for arch culverts are not addressed. Contact HQ Hydraulics for arch culvert potential baffle configuration and analysis methods.

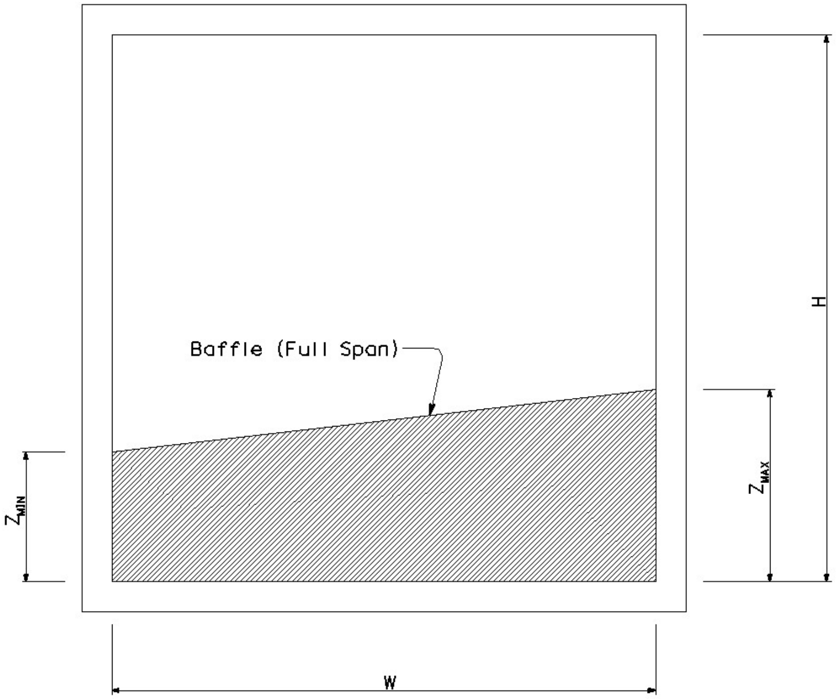


Figure F.2 Top-Angled Baffle Cross Section For Box Culverts

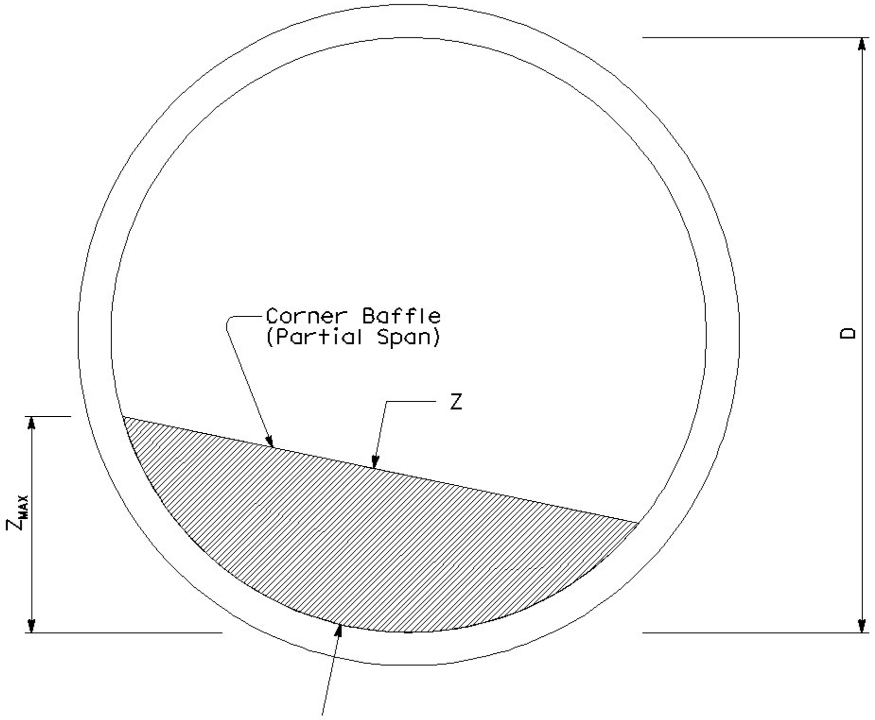


Figure F.3 Corner Baffle Cross Section For Circular Culverts

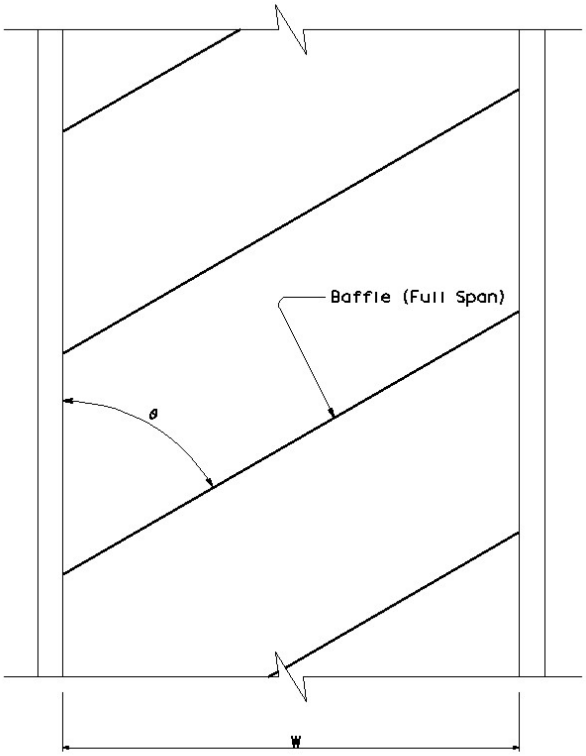


Figure F.4 Top-Angled Baffle (Full-Spanning) Plan View

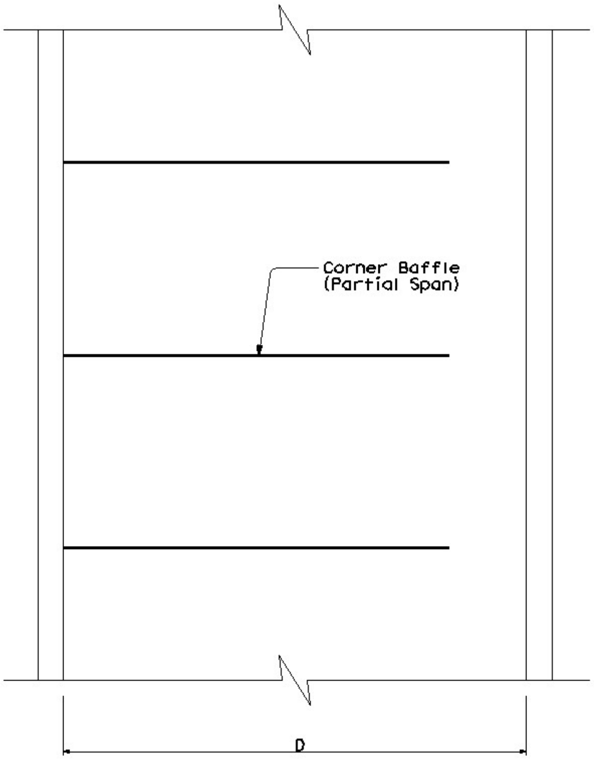


Figure F.5 Corner Baffle (Partial Spanning) Plan View

From collecting data at existing field sites, performing scaled model testing, and developing computer models using software, effects of baffles on culvert performance during larger flows were determined. Based on this research, recommendations for minimizing headwater changes and sediment accumulation in culverts have been made. In addition, a method for analyzing baffled culvert hydraulics under larger flows was developed through the calculation of effective roughness. In sections following this research overview, application of the research results will be presented.

F.2 Baffle Configuration, Height, and Spacing

As seen in Figure F.4, the suggested baffles for box culverts are to be constructed at a 60-degree angle with the culvert wall in plan view. From flume experiments at HSU, large wall angles (90-degrees) provide a more blunt projection to the flow projecting to the flow promoting increased flow resistance and higher headwater, as well as increased average culvert flow depths. Smaller wall angles, as low as 30-degrees, create lower average flow depths inside a culvert and lower headwater. The smaller wall angles also produce higher velocities.

From solely a fish passage perspective, higher flow depths and subsequent lower velocities are attractive. When viewing the culvert strictly as a water conveyance structure, higher depths in the culvert, higher headwater, and low velocity mean reduced capacity and function. The compromise from the two perspectives (fish conveyance vs. water conveyance) is to have a reasonable increase in headwater and flow depth with decreased velocity so that fish can pass through a culvert without inundating capacity. This compromise is the suggested 60-degree culvert wall and baffle in plan view.

In the corner baffle configuration for circular culverts seen in Figure F.5, a 90-degree wall angle is the recommendation, if not an informal standard. This configuration is widely accepted by agencies, such as CA Fish & Game and NMFS. The corner baffle partially spans a culvert and provides wall roughness with a minimal potential for debris catchment. Even though the 90-degree wall angle is blunt, its effect on increasing headwater and flow depth is less given its partial span and steep top angle. With this stated, the corner baffle will still promote reasonable passage of adult and juvenile fish with the benefit of minimal changes to culvert capacity.

As for the slope on the top of both box and circular culvert baffles, this slope will provide smoother changes in water surface and less turbulence in the pools between baffles compared to a baffle with constant height. Similar to the reasoning behind placing baffles in an angled orientation in plan view, the sloped baffles in cross section will provide increased flow depth and decreased velocity without harshly affecting culvert flow depth and headwater.

In addition to baffle configuration, spacing and height (z_{max}) of baffles play a significant role in their ability to improve culvert fish passage without adversely affecting a culvert's ability to convey water. The design baffle height and corresponding spacing combination can vary to achieve acceptable depth and velocity, which means that multiple solutions or combinations can exist for a given site. The combination with the lowest height and maximum spacing that will achieve appropriate depth and velocity should be first consideration since it will have the least effect on culvert headwater, capacity, and sediment transport.

The majority of existing culverts that require baffle retrofits have steep slopes and operate under inlet control, which means that the placement or location of the most upstream baffle can greatly affect the headwater elevation. From the scaled model testing at HSU, the headwater depths in inlet control culverts were higher when the most upstream baffles were close to the culvert inlet. In general, the optimum distance having the least affect on headwater between the most upstream baffle and the culvert inlet is 0.5W to 1.4W for box culverts or 0.5D to 1.4D for circular culverts. For Caltrans projects, it is recommended to place the most upstream baffle at 1.0W or 1.0D downstream of the culvert inlet with the lowest possible baffle height (z_{max}) so that headwater impact is minimized.

Through the HSU scaled model testing with introduced sediment, it was found that the lowest possible height (z_{max}) used in conjunction with the largest spacing yielded the least amount of sediment trapping in a baffled culvert. As seen in the field and in the flume, sediment typically builds up the most between the upstream baffle and the inlet, and sediment slowly fills in the downstream pools between baffles. The problem with sediment trapping in the downstream pools is that the baffles will no longer function, and the culvert barrel roughness will subsequently decrease creating shallow depths and high velocities. When baffles are far-spaced having low height, the accumulation of sediment in the downstream pools was fairly insignificant. Therefore, it is recommended that the lowest height (z_{max}) of baffle be used in conjunction with the greatest spacing to avoid significant sediment accumulation while maintaining proper depth and velocity for fish passage.

In order to determine a preliminary (first trial) baffle height and spacing combination, see Figure F.6 and associated equations. In Figure F.6, a pool between two baffles is shown inside an existing culvert. A line representing level water surface has been drawn from the top of the upstream side of the downstream baffle to the downstream side of the upstream baffle. By using the equations below, a trial baffle height ($h_1 = z_{max}$) can be assumed and a corresponding baffle spacing can be calculated based on the CDFG and NMFS minimum pool depth (h_3), or baffle spacing can be assumed and a corresponding baffle height ($h_1 = z_{max}$) can be calculated. Again, this combination of baffle height and spacing is preliminary. After using the method below, it must be verified that proper fish passage depths and velocities have been met through the low and high fish passage modeling procedure outlined in Section F.4 and F.6 or F.7. Also, energy dissipation factor (EDF) criteria and procedure must be met and followed in Section F.5.

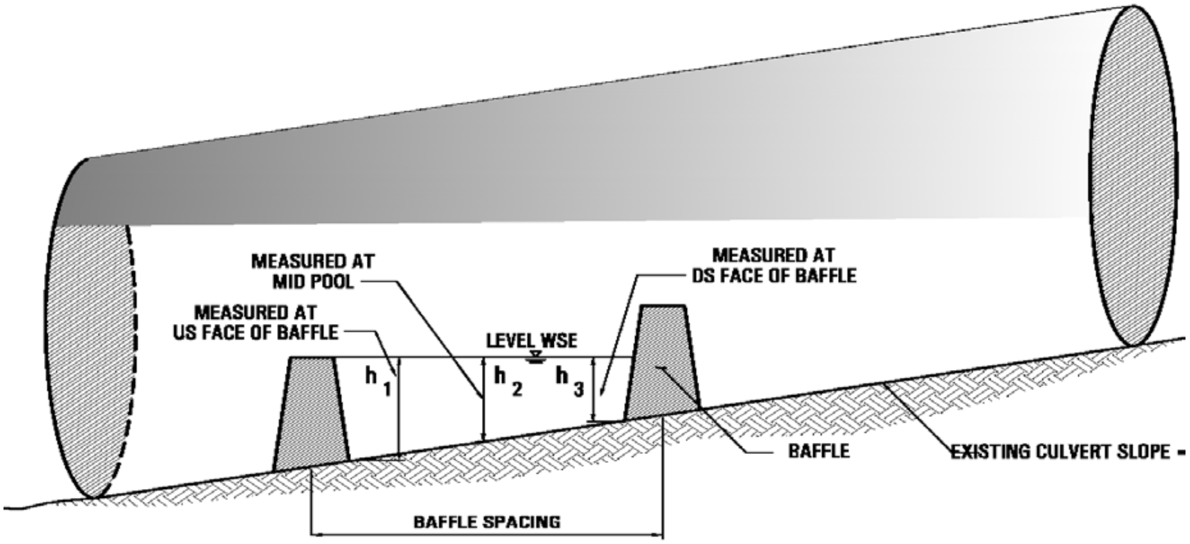


Figure F.6 Baffle Height and Spacing Diagram

Assume h_1 & Solve For:

$$\text{Baffle Spacing} = (h_1-h_3)/S_o$$

Assume Baffle Spacing & Solve For:

$$h_1 = [(\text{Baffle Spacing})\ (S_o)]+h_3$$

$$h_2 = [(\text{Baffle Spacing}/2)]\ (S_o)$$

Where:

h_1 = z_{max} = Maximum baffle height

h_2 = Depth at pool mid-point

h_3 = Minimum pool depth according to design lifestage & species (CDFG/NMFS Criteria)

S_o = Existing culvert slope

In determining a final baffle height and spacing combination, consideration should be given to be close to one of the retrofit types from Table F.2, especially when using the effective roughness method for modeling higher flows. See Section F.3 for discussion of effective roughness determination and Section F.6 for discussion of modeling accuracy using effective roughness.

F.3 Calculation of Baffled Culvert Effective Roughness (Streaming Flow)

Step 1: Calculate high fish passage flow and flood flows of interest (i.e. Q_{25}, Q_{50}, Q_{100}) using appropriate hydrologic methods.

Step 2: Use one of the equations below to calculate y_o for each flow in consideration. See Table F.2 for C and a values. Contact HQ Hydraulics for direction with arch culverts.

$$\text{Circular Culverts:}\quad y_o = D\left[\frac{Q}{C\sqrt{gS_oD^5}}\right]^{1/a}$$

Or

$$\text{Box Culverts:}\quad y_o = W\left[\frac{Q}{C\sqrt{gS_oW^5}}\right]^{1/a}$$

Where:

C & a = Experimental design parameters (See Table F.2)

D = Circular culvert diameter

W = Box culvert width

z_{max} = Maximum baffle height

y_o = Flow depth

S_o = Culvert slope

Q = Actual discharge

G = Gravity

For corner baffle retrofits in circular culverts, y_o must be equal to or greater than $0.75z_{max}$ for streaming flow to occur. For box culverts, y_o must be equal to or greater than $1.1z_{max}$ to demonstrate streaming flow condition. When calculated y_o is less than or equal to 0.8H (H = Culvert Height), use the calculated y_o to determine effective roughness. In cases where y_o is greater than 0.8H, use $y_o = 0.8H$ in calculating effective roughness values in Step 3.

Step 3: Solve the rearranged Mannings equation below using y_o from Step 2 to determine A_w and R (Hydraulic Radius).

$$n_{eff} = 1.486(R)^{2/3}(S)^{1/2}(v)^{-1}$$

Where:

n_{eff} = Effective roughness

R = Hydraulic Radius (ft) = A_{wet}/P_{wet}

v = Velocity (ft/s) = Q/A_{wet}

A_{wet} = Wetted Area (ft^2) considering y_o

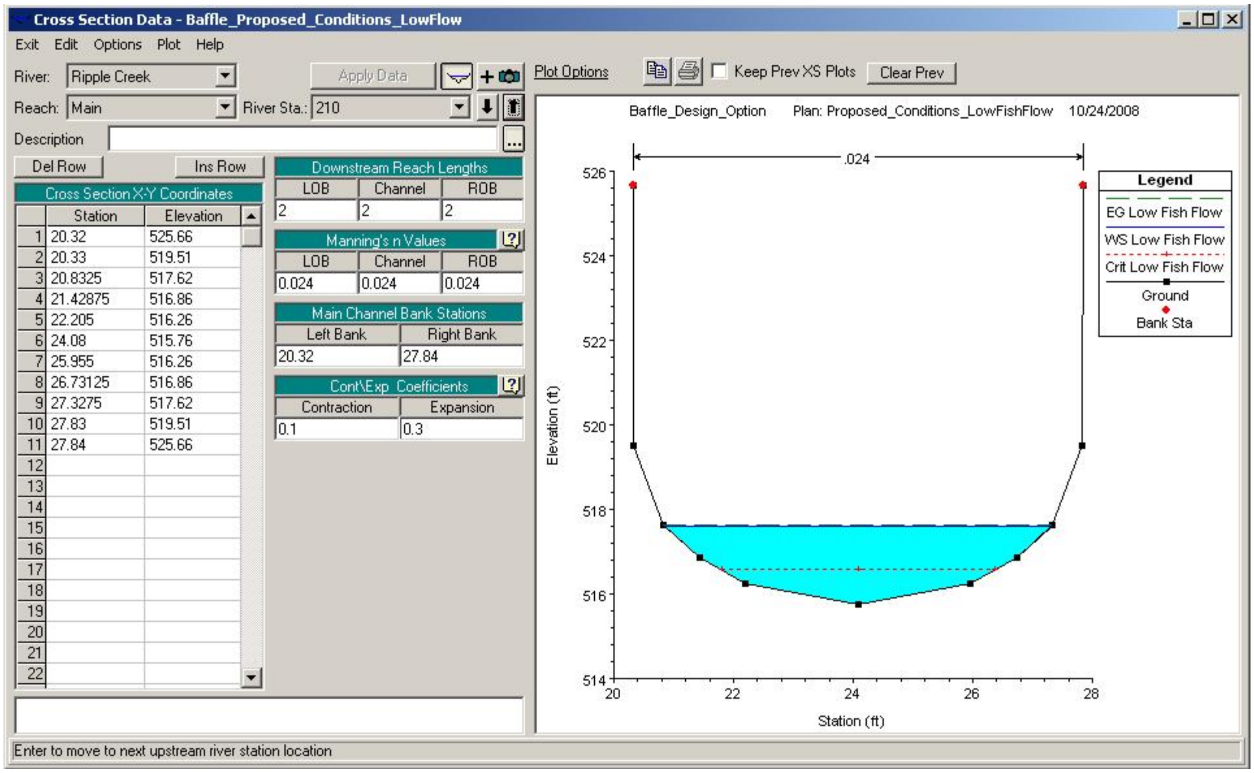
P_{wet} = Wetted Perimeter (ft) considering y_o

This n_{eff} value is the roughness inside a baffled culvert for a given flow. A new effective roughness must be calculated for each flow of interest because it changes as flow depth over a baffle changes. As flow depth increases, the influence of the baffles on overall culvert roughness decreases.

F.4 Baffled Culvert Modeling (Low Fish Passage Flow Condition)

In order to perform modeling of a baffled culvert for low fish passage flow, HEC-RAS software should be used. As discussed previously, the baffles act as weirs during low flows with water accumulating behind and plunging over a baffle.

HEC-RAS has the capability of modeling a series of in-line weirs in a channel, but they cannot be placed inside a culvert. The alternative or work-around for this situation is to consider the culvert an open channel, and create channel cross sections in the shape of the culvert. Because flow will be low without the possibility of filling a culvert and developing into pressure flow, a culvert under this condition is simply an open channel shaped like a culvert. With open channel cross sections created in HEC-RAS, in-line weirs can be placed at required locations. Since this strategy should only be used during lower flow conditions, the depth in a cross section will be low as well. This means that only the bottom half of the culvert shape is needed as input for the HEC-RAS channel section (i.e. semi-circle, semi-box, semi-arch). See Figure F.7 for a semi-circle example, where the circular portion of the culvert was input using chords.



Cross Section Data - Baffle_Proposed_Conditions_LowFlow

River: Ripple Creek

Reach: Main

River Sta.: 210

Description

Cross Section X-Y Coordinates

	Station	Elevation
1	20.32	525.66
2	20.33	519.51
3	20.8325	517.62
4	21.42875	516.86
5	22.205	516.26
6	24.08	515.76
7	25.955	516.26
8	26.73125	516.86
9	27.3275	517.62
10	27.83	519.51
11	27.84	525.66
12		
13		
14		
15		
16		
17		
18		
19		
20		
21		
22		

Downstream Reach Lengths

LOB	Channel	ROB
2	2	2

Manning's n Values

LOB	Channel	ROB
0.024	0.024	0.024

Main Channel Bank Stations

Left Bank	Right Bank
20.32	27.84

Cont\Exp Coefficients

Contraction	Expansion
0.1	0.3

Enter to move to next upstream river station location

Baffle_Design_Option Plan: Proposed_Conditions_LowFishFlow 10/24/2008

Figure F.7 HEC-RAS Semi-Circular Cross Section

Another limitation to the in-line weir function in HEC-RAS is the weir (baffle) plan view orientation, which can only be placed and analyzed normal (90 degrees) to the channel cross section. See Figure F.8 for baffle plan view. For the suggested 60-degree full-span baffle in box culverts, they would have to be input perpendicular to the channel (culvert).

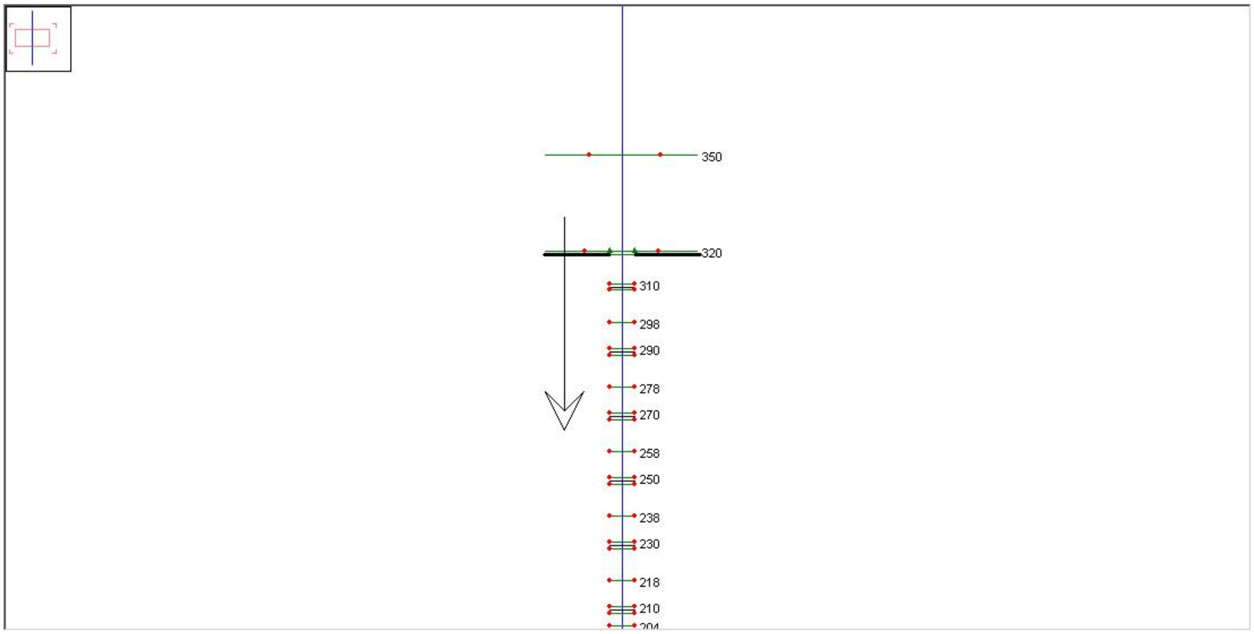
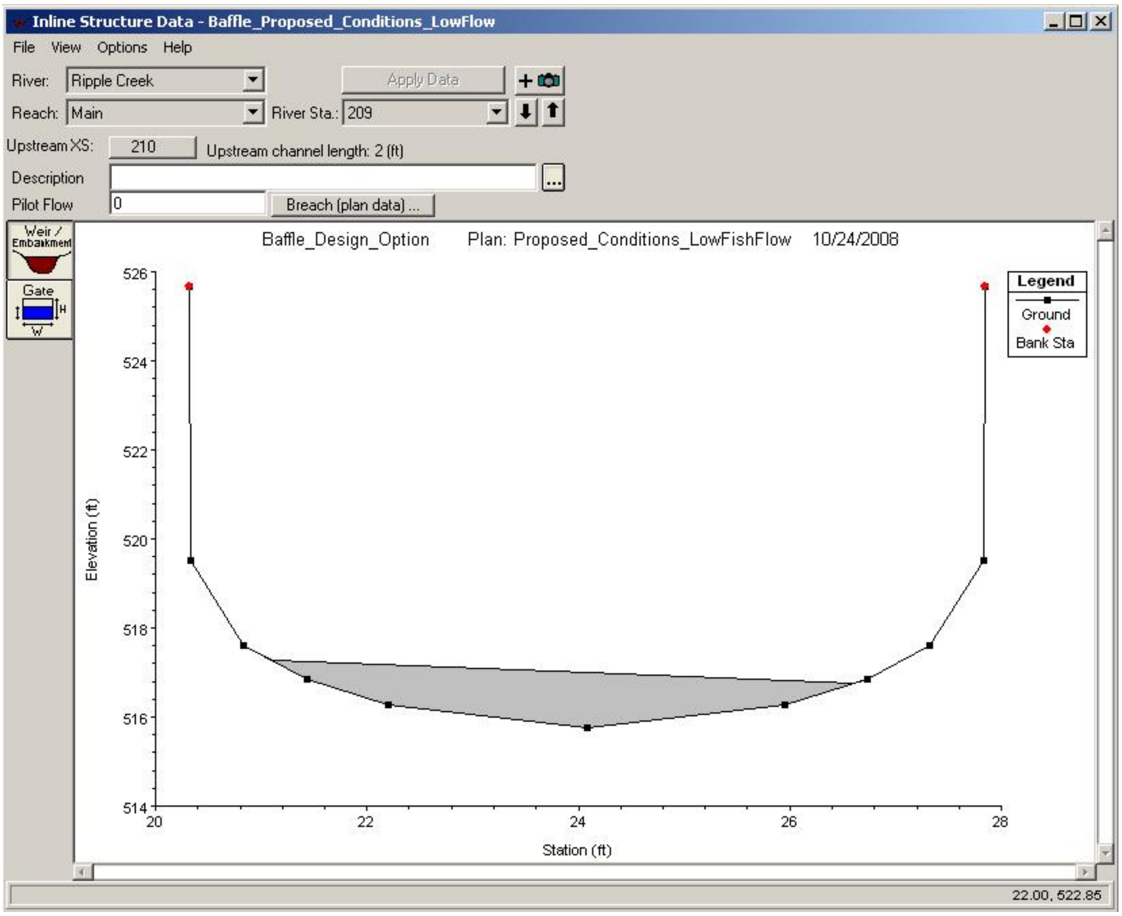


Figure F.8 Baffles In Plan View (HEC-RAS)

Fortunately in cross section view, the baffles can have an actual depiction in HEC-RAS with features such as a sloping top. Baffle shapes in cross section are entered through section coordinates similar to a channel cross section. See Figure F.9 for a baffle cross section from HEC-RAS. In addition to entering cross-sectional geometry, a weir coefficient must be given. The process for determining this weir coefficient is in Section F.5.



Inline Structure Data - Baffle_Proposed_Conditions_LowFlow

River: Ripple Creek

Reach: Main

River Sta.: 209

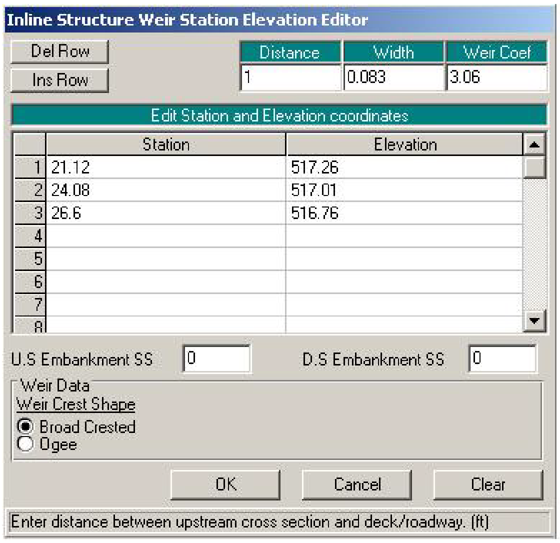
Upstream XS: 210

Upstream channel length: 2 (ft)

Description:

Pilot Flow: 0

Baffle_Design_Option Plan: Proposed_Conditions_LowFishFlow 10/24/2008



Inline Structure Weir Station Elevation Editor

Distance	Width	Weir Coef
1	0.083	3.06

Edit Station and Elevation coordinates

	Station	Elevation
1	21.12	517.26
2	24.08	517.01
3	26.6	516.76
4		
5		
6		
7		
8		

U.S Embankment SS: 0

D.S Embankment SS: 0

Weir Data

Weir Crest Shape

● Broad Crested

○ Ogee

Enter distance between upstream cross section and deck/roadway. (ft)

Figure F.9 Corner Baffle In Cross Section (HEC-RAS)

Once the cross sections representing the culvert and the “regular” stream cross sections have been entered, as well as the in-line weirs representing baffles, HEC-RAS can be executed for the low fish passage flow. Flow-depth can be checked at appropriate cross sections and compared to CA Fish & Game and NMFS criteria. In order to develop an accurate water surface profile, it is recommended that at least three cross sections be created between weirs (baffles): one cross section immediately downstream of a weir (baffle), one cross section at the mid-point of the pool between weirs (baffles), and one cross section just upstream of a weir (baffle). The most critical cross section, which will have the lowest depth, is the one immediately downstream of a weir (baffle) within the plunge pool. Depth at this cross section especially, as well as the other cross sections, should meet minimum design criteria.

F.5 Determination of Weir Coefficient

By following the iterative procedure below that uses Table F-3 from HEC-22, a weir coefficient can be determined for use in modeling a baffled culvert during the low fish passage condition. When metal baffles are used, such as typical corner baffles, its thickness (breadth of crest of weir) is less than 1 inch. In Table F.3, the smallest thickness is 0.5 feet. For cases like this where baffle thickness (breadth of crest of weir) is thin, it is recommended to use weir coefficients associated with 0.5 feet according to the Head found in HEC-RAS. Thin metal baffles are technically operating as sharp-crested weirs, but HEC-RAS will only recognize broad-crested weirs and use these equations. The amount of error in using broad crested weir equations for sharp-crested weirs is not great, and will yield a conservative solution. For other baffle materials, such as concrete, their thickness is typically 0.5 feet or greater and will qualify as broad-crested weirs.

Step A: Estimate the highest weir coefficient using the highest head for the previously calculated crest width (breadth of crest of weir) from Table F.3 Broad Crested Weir Coefficient.

Step B: Run the proposed HEC-RAS model and find the average head (weir average depth) over a baffle for the Low Fish Passage Flow from HEC-RAS results.

Step C: Given the average head (weir average depth) from the HEC-RAS results and the crest width (breadth of crest of weir), find a second weir coefficient from Table F.3 Broad Crested Weir Coefficient.

Step D: Run the proposed HEC-RAS model with the second weir coefficient from Step C and find the average head (weir average depth) over a baffle for the Low Fish Passage Flow from HEC-RAS results.

Step E: Given the average head (weir average depth) from the HEC-RAS results and the crest width (breadth of crest of weir), find a third weir coefficient from Table F.3 Broad Crested Weir Coefficient.

Step F**:** Compare weir coefficient from Step C and Step E. If weir coefficients are close in value, then use Step E weir coefficient for remaining HEC-RAS modeling. If weir coefficients are not close in value, repeat Steps C-F until an appropriate weir coefficient is found.

Head (ft)	Breadth of Crest of Weir (ft)										
	0.50	0.75	1.00	1.50	2.00	2.50	3.00	4.00	5.00	10.00	15.00
0.2	2.80	2.75	2.69	2.62	2.54	2.48	2.44	2.38	2.34	2.49	2.68
0.4	2.92	2.80	2.72	2.64	2.61	2.60	2.58	2.54	2.50	2.56	2.70
0.6	3.08	2.89	2.75	2.64	2.61	2.60	2.68	2.69	2.70	2.70	2.70
0.8	3.30	3.04	2.85	2.68	5.60	2.60	2.678	2.68	2.68	2.69	2.64
1.0	3.32	3.14	2.98	2.75	2.66	2.64	2.65	2.67	2.68	2.68	2.63
1.2	3.32	3.20	3.08	2.86	2.70	2.65	2.64	2.67	2.66	2.69	2.64
1.4	3.32	3.26	3.20	2.92	2.77	2.68	2.64	2.65	2.65	2.67	2.64
1.6	3.32	3.29	3.28	3.07	2.89	2.75	2.68	2.66	2.65	2.64	2.63
1.8	3.32	3.32	3.31	3.07	2.88	2.74	2.68	2.66	2.65	2.64	2.63
2.0	3.32	3.31	3.30	3.03	2.85	2.76	2.72	2.68	2.65	2.64	2.63
2.5	3.32	3.32	3.31	3.28	3.07	2.89	2.81	2.72	2.67	2.64	2.63
3.0	3.32	3.32	3.32	3.32	3.20	3.05	2.92	2.73	2.66	2.64	2.63
3.5	3.32	3.32	3.32	3.32	3.32	3.19	2.97	2.76	2.68	2.64	2.63
4.0	3.32	3.32	3.32	3.32	3.32	3.32	3.07	2.79	2.70	2.64	2.63
4.5	3.32	3.32	3.32	3.32	3.32	3.32	3.32	2.88	2.74	2.64	2.63
5.0	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.07	2.79	2.64	2.63
5.5	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32	2.88	2.64	2.63

Table F.3 Broad Crested Weir Coefficient

F.6 Baffled Culvert Modeling Using Effective Roughness (Higher Flows)

The simplest procedure for modeling a baffled culvert under higher flows is through the use of effective roughness (n_{eff}). Unlike the low fish passage flow condition, water can fill the culvert and possibly operate under pressure flow. Because of this possibility, it is essential to use the culvert routine in HEC-RAS. As mentioned in Section F.4, baffles cannot be analyzed in a culvert within HEC-RAS, as well as other culvert software. Through calculation of effective roughness under different flows and corresponding depths, the roughness influence of the baffles, as water streams over them, can be properly depicted. This means that other Caltrans recommended software (HY-8 and Haestad CulvertMaster) can also be used to model baffled culverts by changing the culvert roughness for each scenario.

When using the procedures to calculate effective roughness in Section F.3, culvert shape and retrofit type (baffle height, spacing, and configuration) must be considered in selecting the experimental values developed from the HSU study. The goal in choosing the design baffle retrofit type is to be as close to a type identified in Table F.2 as possible. Because the equations developed from the research are empirical, the greater difference in design retrofit type or culvert shape from the ones in Table F.2, the less accurate modeling results may be. In other words, the closer the design and suggested height/spacing combination are to each other, the more accurate the modeling results. Given the limitations of the alternative method for modeling high fish passage and flood flows in Section F.7 commonly used in the fish passage design community, the effective roughness method may be the better choice even when the design baffle height/spacing combination is not that close to the combination developed from the research study.

After running HEC-RAS using the effective roughness method, an average culvert velocity can be found for a high fish passage flow and compared to the CDFG and NMFS criteria for compliance. Also, culvert capacity can be reviewed by checking culvert flow depth and headwater under appropriate flood flows.

If the effective roughness method for analyzing culvert hydraulics under higher flows is not used, see Section F.7 for an alternative method.

F.7 Alternative Baffled Culvert Modeling (Higher Flows)

When the effective roughness method for determining baffled culvert roughness under higher flows cannot be used, the following alternative method is suggested. This method is based on an HSU study from 2004 funded by NMFS where roughness coefficients (n-values) were measured at three baffled culvert sites from seven observations.

For a range of (y/z_{max}) ratio, where y = flow depth and z_{max} =baffle height, a range of corresponding culvert n-values were determined by HSU in their 2004 study. Based on field data, measured n-values ranged from 0.107 to 0.039 and y/z_{max} ratios ranged from 0.6 to 1.95. The 0.107 n-value was considered an outlier for $y/z_{max} = 1.3$ by HSU and was discarded. The next highest measured n-value was 0.076.

For baffled culvert modeling purposes of any type, shape, or material, a baffled culvert n-value of 0.076 can be used for $y/z_{max} = 0.6$ or lower. When y/z_{max} is 1.95 or higher, use n-value equal to 0.039. In order to determine n-values for a y/z_{max} ratio between 0.6 and 1.95, perform linear interpolation to find an n-value between 0.076 and 0.039. As previously discussed, the higher the flow depth above a baffle, the less influence on culvert roughness it has, yielding a lower n-value.

Before an n-value can be selected, the baffle height (z_{max}) must have been previously determined and flow depth (y) must be calculated. It is recommended to use the low fish passage flow HEC-RAS model, where in-line weirs have been entered as baffles in channel cross sections having the culvert shape, to determine the average flow depth (y) in the pools between baffles using the higher flow of interest. Depending on the magnitude of the higher flow, it may be necessary to vertically extend the walls of the channel sections mimicking a culvert or enter the majority of the culvert shape (excluding the culvert top) within the HEC-RAS model geometry. After determining the baffled culvert n-value, the culvert can be modeled in HEC-RAS, HY-8, or Haestad CulvertMaster.

In the NMFS funded study, HSU did not distinguish the independent effects or influence on n-values from baffle type and configuration, nor culvert shape and material. This is a limitation to the method, but its use will provide conservative modeling results. Limitations in predicting baffled culvert n-values are common and accepted in fish passage professional practice where conservatism is applied. The HSU alternative method is considered reasonable, as well as conservative in professional practice, and is similar to the Washington Department of Fish & Wildlife general n-value recommendations observed from baffled culvert sites in Washington State.

Because the latest HSU study (2008) considers influences of culvert shape, as well as baffle configuration and spacing, the effective roughness method is the choice for modeling higher flows in baffled culverts. With the consideration of these influences, the analysis results more accurately depict actual water surface profiles and capacity. Using the alternative method, results are typically more conservative, which may not be warranted. If the effective roughness method is found to be inapplicable at a site, it is better to be more conservative than less by using the alternative method. While this alternative method could technically be used for low fish passage flow modeling as well as high flow modeling, the low flow method discussed in Section F.4 is preferred having more accuracy.

F.8 Energy Dissipation Factor

In the pool between baffles, turbulence is created as energy is dissipated. This turbulence can be defined or measured by an Energy Dissipation Factor (EDF) having ft-lb/ft^3/sec units. When turbulence is too high, it can be an impediment for fish passage. On the contrary, if turbulence is too low, sediment can be deposited and fill the pools rendering the baffles inoperable. Based on field observation and monitoring under different flows, it is recommended that EDF should be 3 to 5 for baffled culvert systems so that sediment can be transported without an exceptional amount of turbulence.

The following equation is used to calculate EDF:

$$\mathrm{EDF} = \frac{\gamma Q S_o}{A_{wet}}$$

Where:

EDF = Energy Dissipation Factor (ft-lb/ft^3/sec)

γ = Unit weight of water (62.4 lb/ft^3)

S_o = Existing culvert slope (ft/ft)

A_{wet} = Wetted cross-sectional flow area (ft^2) between baffles under high fish Passage flow, use y_o (Section F.3) as flow depth in A_{wet} calculation.

NOTE: If y_o from the effective roughness calculation cannot be used, run the low fish passage flow HEC-RAS model recommended in Section F.4 using the high passage flow. From the HEC-RAS results, use the “Flow Area” at the pool mid-point cross section between baffles as the A_{wet} component.

APPENDIX G

BAFFLE SAMPLE CALCULATIONS AND STRUCTURAL DETAILS

G.1 Concrete Baffle Sample Calculations

	Job No.	No.
Project	Computed KD	Date 06/01/06
Subject	Checked	Date
Task Concrete Baffle Design	Sheet	Of

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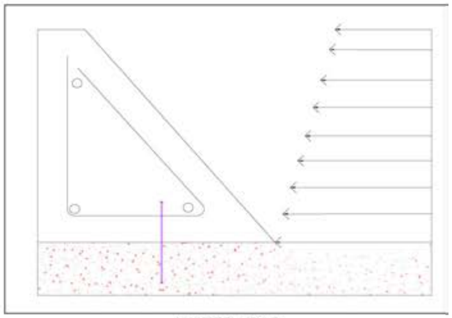
CONCRETE BAFFLE DESIGN

Assume Baffle is 5' Below WSE and 2.0' in Height
Assume 1 Foot Section

Commentary:
The following highlighted terms are inputs determined in the fielc

f'c =	2500	psi
fy =	60000	psi
phi =	0.9	
Baffle Height	2	FT
Baffle Depth	0.4	FT
Assumed Baffle Section	1	FT
Water Density	62.4	LB/FT^3
Distance From WSE to Top of Baffle	5	FT
Load at Top of Baffle	312	LB/FT
Distance From WSE to Bot of Baffle	7.5	FT
Load at Bottom of Baffle	468	LB/FT
Water Velocity	5	FT/S
Gravity	32.2	(lbm*ft)/(lbf*sec^2)



WATER LOAD

Reference: USACE EC 1110-2-6058, Stability Analysis of Concrete Structures

Assumptions: Use Westergaard equation (1933) to estimate hydrodynamic earthquake loading in stilling basin

Resultant Hydrodynamic Force P_E acts $0.4h_w$ above bottom of basin

=> See Figures 4-3 for wall geometry, pressures and forces

Equation for Hydrodynamic Force due to water above ground level (p. 4-5)

$$P_E = (7/12)\ k_h\ {}_w\, h_w^2$$

Where -

P_E = Hydrodynamic force per unit length
${}_w$ = Unit weight of water
k_h = Horizontal seismic coefficient
h_w = Depth of water in basin

Earthquake Loading -

k_h = 0.07 g

Water Surface:

h_w = 7.5 ft.
${}_w$= 62.4 cfs

Results -

Hydrodynamic Resultant -

			Location of Point Load (distance from base of wall) -		Moment (M_h) (kip-ft)
P_E =	**137**	lbs	@	3 ft	-0.41
H=	137	lbs			-0.41

Pressure at bottom of basin -

p_E = **27.3** psf

Hydrodynamic Force Due to Velocity of Water -

$$\boxed{F \qquad A v^2}$$

			Location of Point Load (distance from base of wall) -		Moment (M_v) (kip-ft)
P_E =	**97**	lbs	@	1 ft	-0.10
H=	97	lbs			-0.10

Commentary:
Hydrodynamic Force Due to Water Velocity can usually be ignored, due to the magnitude compared to the hydrostatic force.

Job No.	No.

Project	Computed KD	Date 06/01/06
Subject	Checked	Date
Task Concrete Baffle Design	Sheet	Of

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Maximum Moment From Uniform Load = $\boxed{M_{un} \quad \frac{wl^2}{2}}$ 624 lb-ft

Maximum Moment From Triangular Load = $\boxed{M_T \quad \frac{wl}{3}}$ 104 lb-ft

Service Dead Load Factor 1.2
Combined Service Moment (Mv+M_h + M_T + M_{un}) 1481 LB-FT

Cover = 3 INCHES
d (Depth - Cover) = 1.8 INCHES
jd (0.875*d) = 1.575 INCHES

Determine Area of Required Steel $\boxed{A_S \quad \frac{M_U}{f_Y jd}}$ 0.21 in^2

Check Minimum Reinforcement
(UBC-97 SEC. 1910.5.1) $\boxed{A_{SMin} \quad \frac{3\sqrt{f'c}}{f_Y} b_w d}$ 0.05 in^2

$\boxed{A_{SMin} \quad \frac{200}{f_Y} b_w d}$ 0.072 in^2

Use **0.21 in^2**

2 - #4 Bars Adequate As = 0.40 in^2

Commentary:
1 - #4 Bar is adequate, an additional safety factor of 2 was used in order to account for any field uncertainties (i.e. excessive debris). Therefore, 2 - #4 bars are appropriate.

Check Shear

Phi 0.85
Service Dead Load Factor = 1.2
Maximum Shear From Uniform Load (WL)= 624 LB

Maximum Shear From Triangular Load (W) = 156 LB

Maximum Shear From Dynamic Load (Wh) = 137 LB

Maximum Shear From Water Velocity (Wv) = 97 LB

Total Shear = 1216.0733 LB

Shear Capacity
(UBC-97 SEC 1911.3.1.1) $\boxed{V_u \quad 2 \sqrt{f'c}db}$ 1836.00 LB

Job No.	No.

Project	Computed KD	Date 06/01/06
Subject	Checked	Date
Task Concrete Baffle Design	Sheet	Of

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Concrete Strength Adequate for Shear
USE #4 STIRRUP AT 12" OC TO BE CONSERVATIVE

Commentary:
ACI equations show that concrete strength is adequate for the applied shear forces. In order to account for any field uncertainties (i.e. excessive debris) stirrups can be placed at 12, 18, or 24 inches o.c.

ANCHORAGE TO CONCRETE: ANCHOR BOLT DESIGN (UBC - SECTION 1923)

Note: Blue numbers are input.

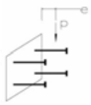
f_{ut} = 60,000 psi Min specified tensile strength of anchor, Assume 60ksi for A307 bolts or A108 stud
d_b = 0.50 in
A_b = 0.20 in^2
No. of Bolts = 1
Bolt Pattern = 1 x2
L_{emb} = 4.5 in Embeded length of anchors
L= 24 in Distance between anchor bolts

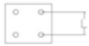
Commentary:
Based upon above loads, the loading on the bolt is minimal, and the diameter of the bolt can be small. The controlling factor, as can be seen from the table below, will be the concrete strength.

A_p= 90.0 in^2 Effective area of the projection of an assumed concrete failure surface, $2L>L_{emb}$. For $2L<L_{emb}$, need input.
(Shear)= 0.65 Strength reduction factor
f'c= 2500 psi
= 1 Normal weight concrete,0.75 for all lightweight conc., 0.85 for sand-lightweight conc.
d_e = 2 in Edge distance from the anchor axis to the free edge
Load Factor: 1.4 DL See 1909.2 for details
1.7 LL
Multiplier= 2 2, if special inspection is not provided, 1.3 if it is provided
Multiplier= 3 Anchors are embedded in tension zone of a member, 3 if special inspection is not provided, 2 if it is provided
NT T,Anchors are embedded in tension zone of a member;NT, not in tension zone
L G,Edge distance is greater than 10 diameters;L,less than 10 diameters away
P_{DL}= 2432.147 lb P_{LL}= 0 lb/bolt Pu= 6810 lb
e= 0.5 in Mu= 3405.0052 lb-in
Pu= 6810 lb/bolt Vu= 142 lb/bolt

Design strength in tension: (Min of the following)

$\boxed{P_{ss} \quad 0.9A_b f_{ut}}$ $\boxed{P_c \quad 4A_p\sqrt{f'_c}}$



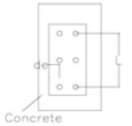


Design strength in shear: (Min of the following)

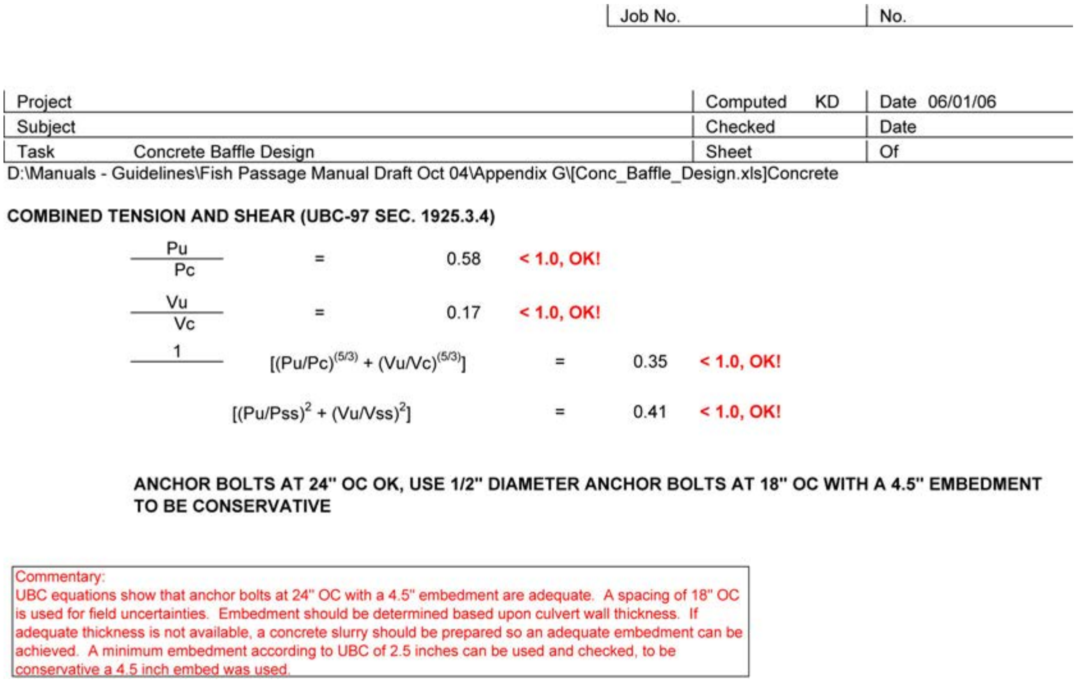
$\boxed{V_{ss} \quad 0.75A_b f_{ut}}$

$\boxed{Vc \quad 800A_b \sqrt{f'_c}}$ Where loaded toward an edge greater than 10 diameters away

$\boxed{V_c \quad 2 \quad {}_e^2 \sqrt{f'_c}}$ Where loaded toward an edge less than 10 diameters away



Bolt		BOLT STRENGTH		CONCRETE STRENGTH			
Diam. (in.)	Area (in^2)	Tension	Shear	Tension		Shear	
d_b	A_b	Pss (lb)	Vss (lb)	Pc (lb)	Pc (lb)	Vc (lb)	Vc (lb)
1/2	0.20	10603	8836	11696	17994	817	1257
3/4	0.44	23856	19880	11696	17994	817	1257
1	0.79	42412	35343	11696	17994	817	1257
1 1/4	1.23	66268	55223	11696	17994	817	1257
1 1/2	1.77	95426	79522	11696	17994	817	1257
1 3/4	2.41	129885	108238	11696	17994	817	1257
2	3.14	169646	141372	11696	17994	817	1257



	Job No.	No.
Project	Computed KD	Date 06/01/06
Subject	Checked	Date
Task Concrete Baffle Design	Sheet	Of

D:\Manuals - Guidelines\Fish Passage Manual Draft Oct 04\Appendix G\[Conc_Baffle_Design.xls]Concrete

COMBINED TENSION AND SHEAR (UBC-97 SEC. 1925.3.4)

$$\frac{Pu}{Pc} = 0.58$$ **< 1.0, OK!**

$$\frac{Vu}{Vc} = 0.17$$ **< 1.0, OK!**

$$\frac{1}{\quad} \quad [(Pu/Pc)^{(5/3)} + (Vu/Vc)^{(5/3)}] = 0.35$$ **< 1.0, OK!**

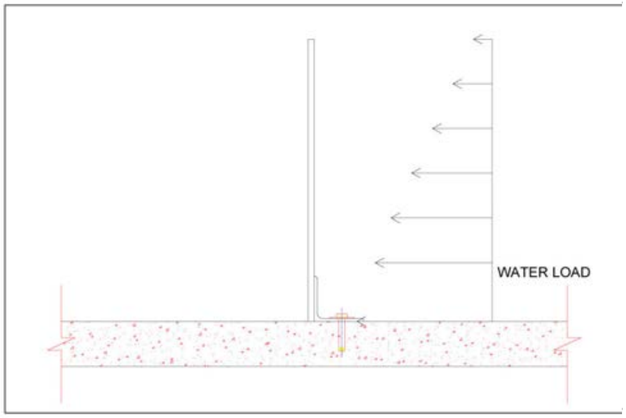
$$[(Pu/Pss)^{2} + (Vu/Vss)^{2}] = 0.41$$ **< 1.0, OK!**

ANCHOR BOLTS AT 24" OC OK, USE 1/2" DIAMETER ANCHOR BOLTS AT 18" OC WITH A 4.5" EMBEDMENT TO BE CONSERVATIVE

Commentary:
UBC equations show that anchor bolts at 24" OC with a 4.5" embedment are adequate. A spacing of 18" OC is used for field uncertainties. Embedment should be determined based upon culvert wall thickness. If adequate thickness is not available, a concrete slurry should be prepared so an adequate embedment can be achieved. A minimum embedment according to UBC of 2.5 inches can be used and checked, to be conservative a 4.5 inch embed was used.

G.2 Metal Baffle Sample Calculations

Metal Baffle Design



Forces Acting on Angle and Weld

Shear Force Pu = 6810 lb

Moment = 3405.005 lb-in

Commentary:
Forces come from previous page.

Determine Length of Required Weld

Throad of Weld W = 3/16 in

Electrode = E70XX

Fw = 31.5 ksi

Weld Strength = $\boxed{0.707 * W * F_w}$ 4.18 k/in

Total Required Length = 1.63 inches

Try 4x4x1/4 Angle Welded on all Edges to Baffle

Commentary:
The length of weld will not govern the size of the angle. The determining factor will be the size of the bolt being used along with the tearout. The angle needs to be large enough to support the bolt.

Check Connection Angle and Bolt Tearout

Diameter of Bolt d = 0.5 in

Area of Bolt Ab = 0.20 sq in

Hole Diameter = 0.625 in

Gross Area of Angle Ag = 1.94 sq in

Thickness of Angle t = 0.25 in

Edge Distance D = 1.75 in

Fy = 36 ksi

Fu = 58 ksi

Fv = 48 ksi

Phi (Shear) = 0.75

Bolt Shear Capacity = $\boxed{F_v A_b}$ 7.07 kips > 6.81 kips OK
(AISC Table J3.2)

Phi (Bearing) = 0.75

Dist from edge of hole to edge of angle Lc = 3.75 in

Angle Thickness t = 0.25 in

Tearout Capacity = $\boxed{1.2 L_c t F_u}$ 48.94 kips > 6.81 kips OK
(RCSC EQ LRFD 4.3)

Tearout Capacity Max = $\boxed{2.4 d t F_u}$ 13.05 kips > 6.81 kips OK
(RCSC EQ LRFD 4.3)

Shear on Gross Area = 0.4Fy = 14.4 ksi

Stress = Applied Load/Ag = 3.51 ksi < 14.4 ksi OK

Shear on Net Area = 0.3Fu = 17.4 ksi

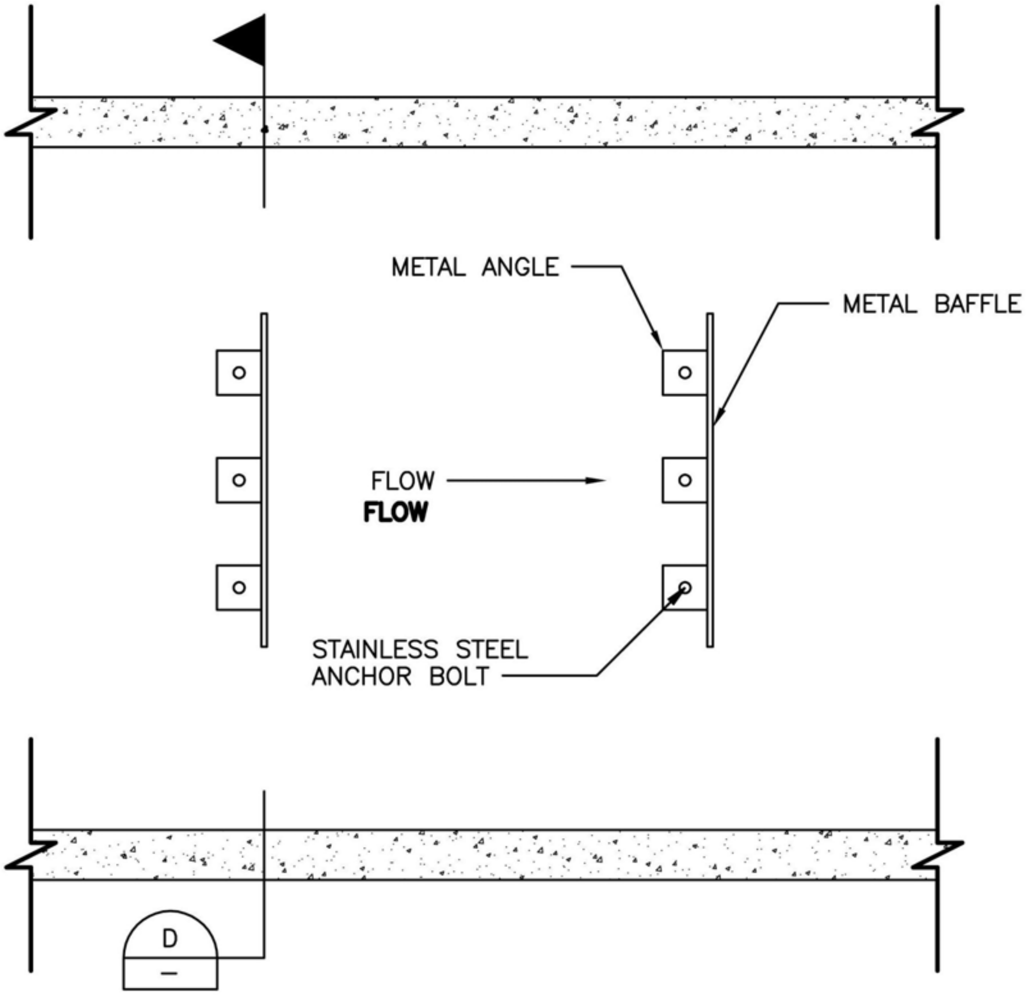
Net Area = Ag - Hole Diameter = 1.63 sq in

Stress = Applied Load/An = 4.17 ksi < 17.40 ksi OK

Use 4x4x1/4 Angle with 1/2" Diameter Bolts Embedded 4-1/2"

Commentary:
Embedment was determined from the previous sheet. Above calculations show that a 1/2 inch bolt is sufficient.

G.3 Metal Baffle for Reinforced Concrete Circular Culverts (Details)



PLAN VIEW

NTS

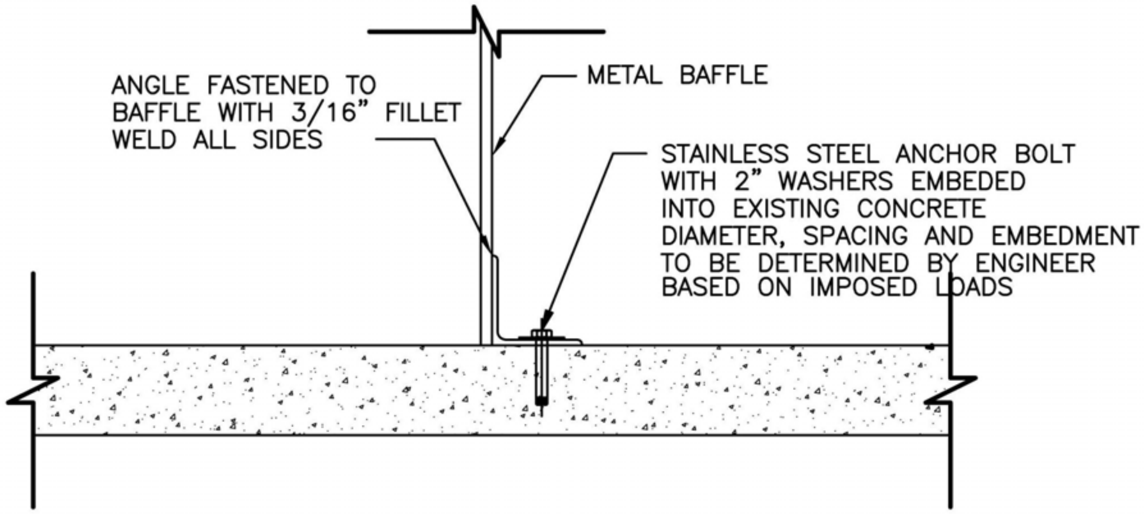
NOTES: 1. NUMBER OF CONNECTION ANGELS AND THICKNESS OF BAFFLE TO BE DETERMINED BY ENGINEER BASED ON IMPOSED LOADS

NTS
06938–38713

**METAL BAFFLE FOR REINFORCED
CONCRETE CIRCULAR CULVERTS**

Date
05/06

Sheet
1



CONNECTION DETAIL

NTS

C
–

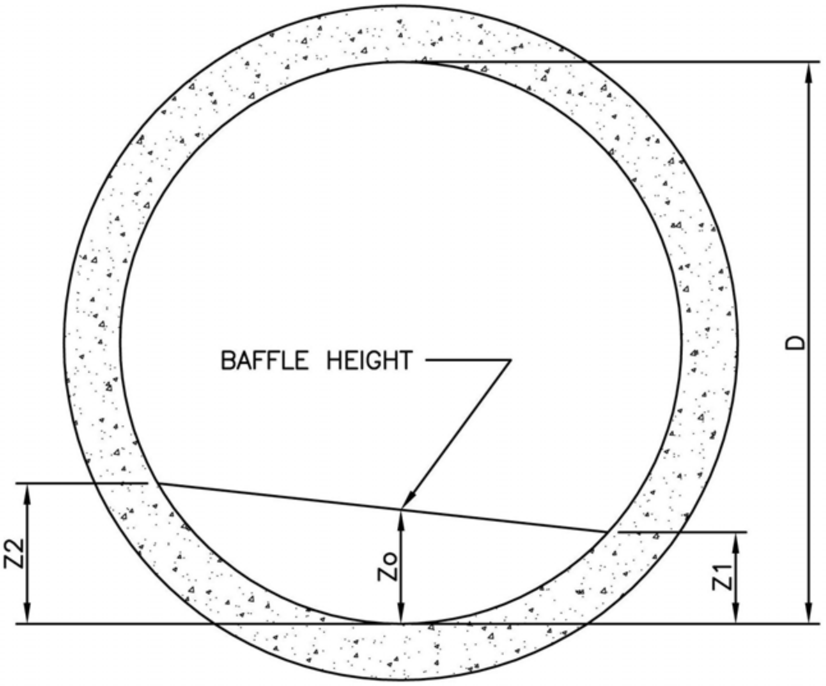
NOTES: 1. SIZE OF THE ANGLE TO BE DETERMINED BY THE ENGINEER BASED ON IMPOSED LOADS

NTS
06938–38713

METAL BAFFLE FOR REINFORCED CONCRETE CIRCULAR CULVERTS

Date
05/06

Sheet
1



BAFFLE HEIGHT		
Zo	Z1	Zo
6”	3”	9”
9”	6”	12”
12”	9”	15”

SECTION D

NTS

NOTES: 1. SEE DETAIL C FOR CONNECTION DETAILS

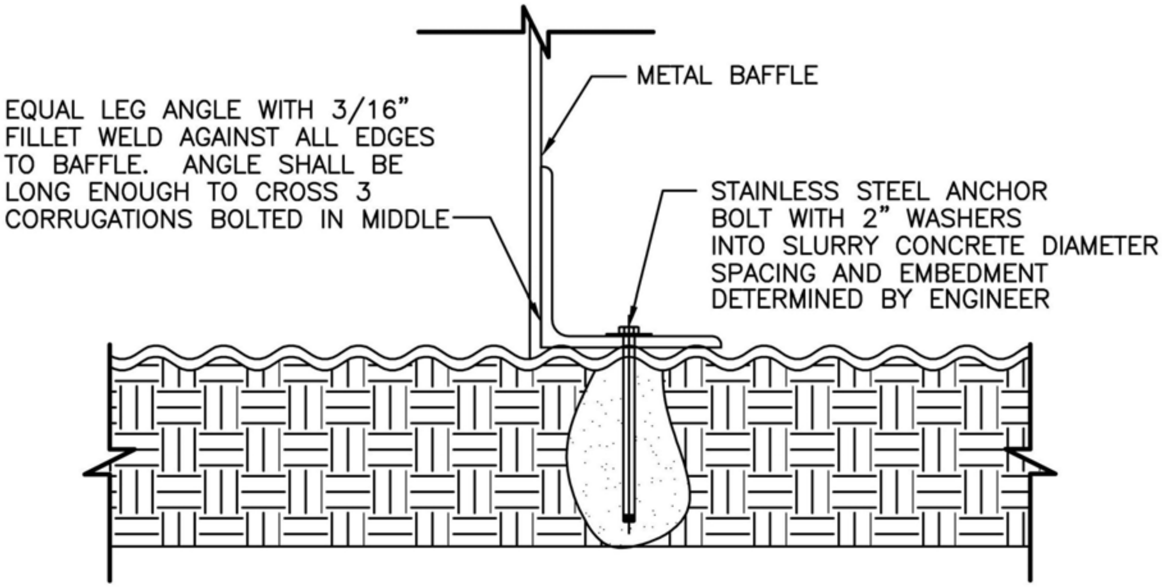
NTS
06938–38713

METAL BAFFLE FOR REINFORCED CONCRETE CIRCULAR CULVERTS

Date
05/06

Sheet
1

G.4 Metal Baffle for Corrugated Metals Circular Culverts (Details)



CONNECTION DETAIL

NTS

E

–

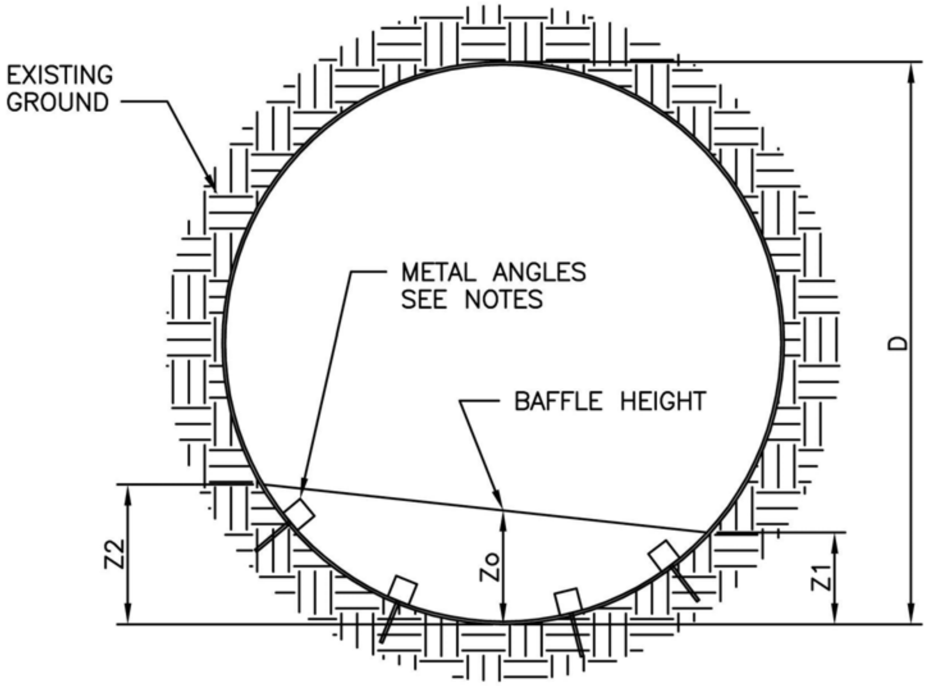
NTS

06938–38713

METAL BAFFLE FOR CORRUGATED METAL CIRCULAR CULVERTS

Date
05/06

Sheet
1



BAFFLE HEIGHT		
Zo	Z1	Zo
6”	3”	9”
9”	6”	12”
12”	9”	15”

NOTES:
1. FASTEN ANGLES TO BAFFLE, 3/16” FILLET WELD ALL SIDES
2. BOTTOM ANGLE LEG TO BE LONG ENOUGH TO CROSS 3 CORRUGATIONS
3. ANGLES TO BE SPACED EVERY 18 INCHES ALONG CIRCUMFERENCE
4. SEE DETAIL E FOR CONNECTION

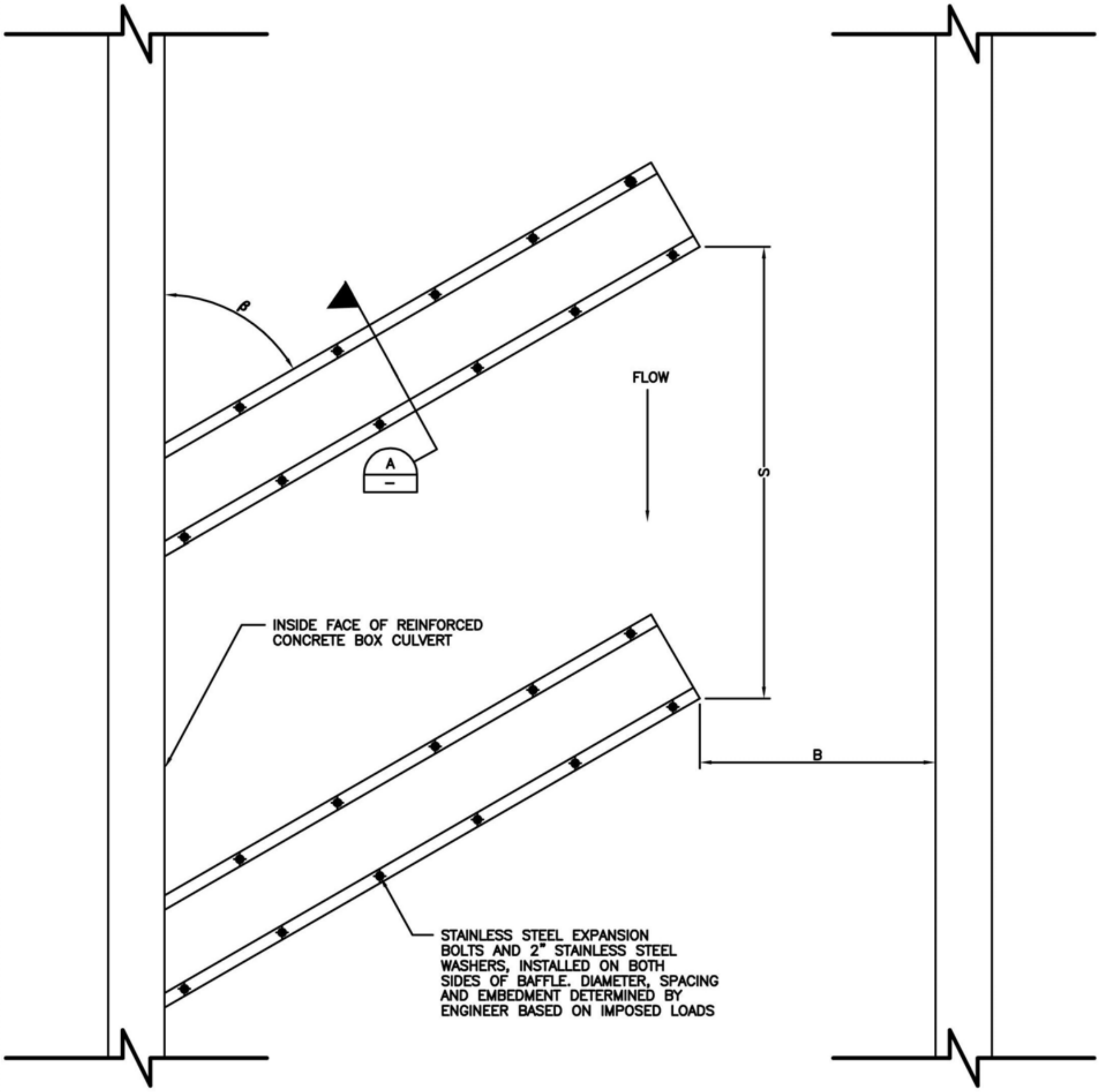
NTS
06938–38713

METAL BAFFLE FOR CORRUGATED METAL CIRCULAR CULVERTS

Date
05/06

Sheet
1

G.5 Metal Baffle for Reinforced Concrete Box Culverts (Details)



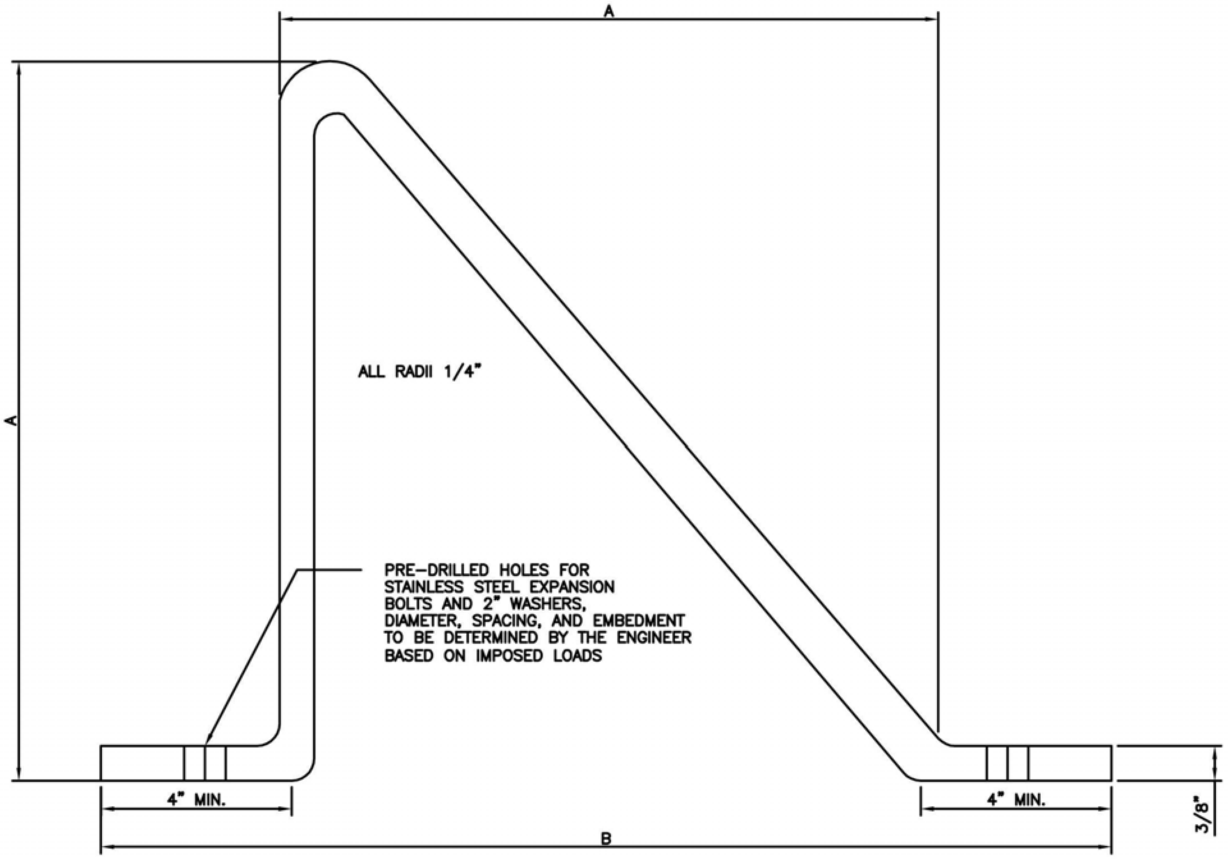
NOTES: 1. SEE ACCOMPANYING TEXT FOR GUIDANCE ON DIMENSIONS AND SPACING (S AND B) ALONG WITH BAFFLE ANGLE (β)

NTS
06938–38713

METAL BAFFLE FOR REINFORCED CONCRETE BOX CULVERTS

Date
05/06

Sheet
1



SECTION A

NTS

A
–

NOTES:
1. METAL BAFFLE MATERIAL SHALL BE FORMED FROM FLAT SHEET STOCK
2. INSTALL BAFFLE WITH VERTICAL LEG ON DOWNSTREAM SIDE
3. EMBED BOLTS INTO EXISTING CONCRETE WITH MINIMUM DEPTH AS CALCULATED BY ENGINEER

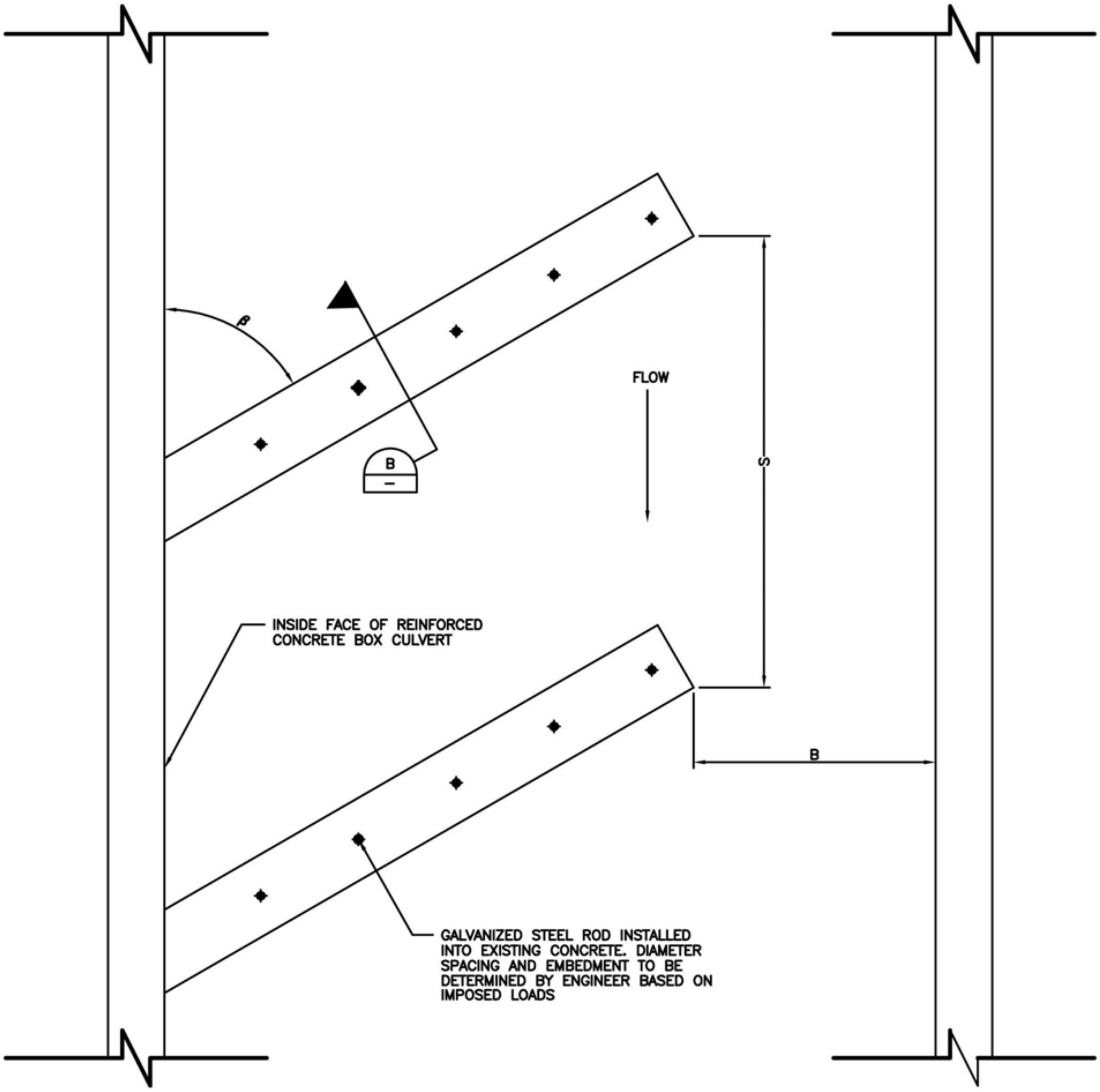
NTS
06938–38713

METAL BAFFLE FOR REINFORCED CONCRETE BOX CULVERTS

Date
05/06

Sheet
1

G.6 Concrete Baffle for Reinforced Concrete Box Culverts (Details)



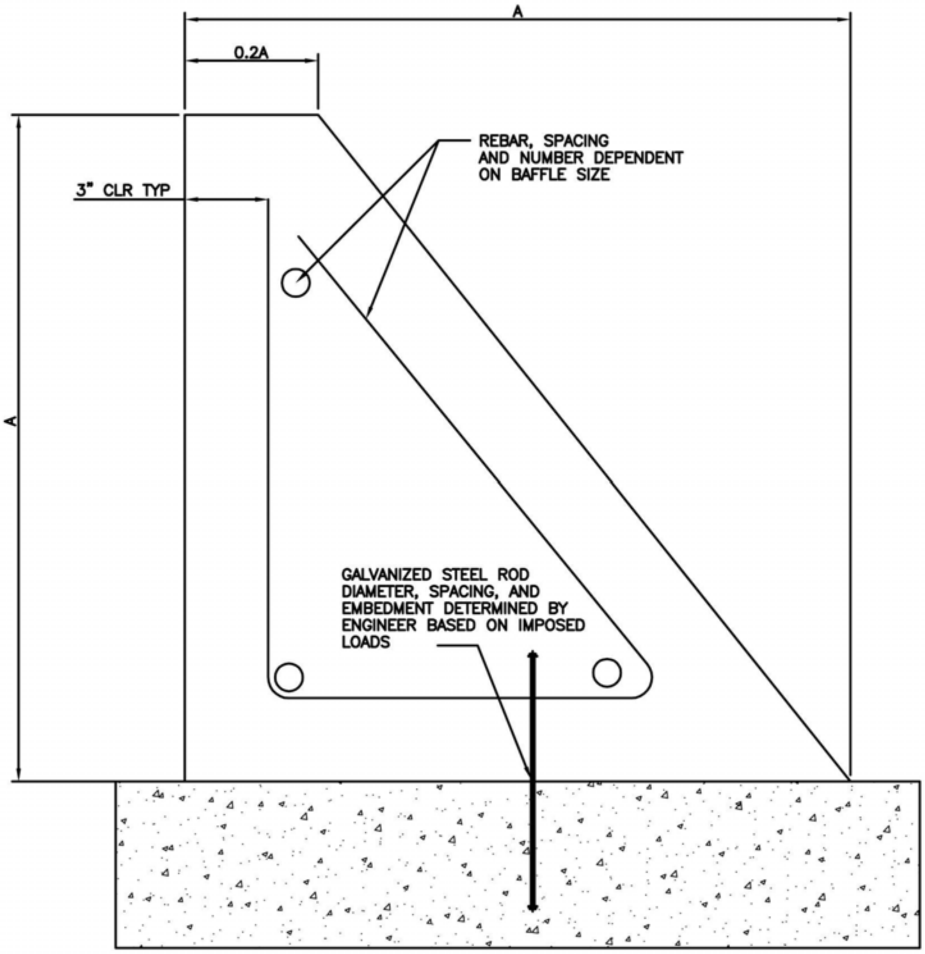
NOTES: 1. SEE ACCOMPANYING TEXT FOR GUIDANCE ON DIMENSIONS AND SPACING (S AND B) ALONG WITH BAFFLE ANGLE (β)

NTS
06938–38713

CONCRETE BAFFLE FOR REINFORCED CONCRETE BOX CULVERTS

Date
05/06

Sheet
1



SECTION B
NTS

B
–

NOTES:
1. CONCRETE SHALL HAVE A MINIMUM 28–DAY COMPRESSIVE STRENGTH OF 3000 PSI AND SHALL CONFORM TO SECTIONS 1903 AND 1905 OF THE UBC
2. INSTALL BAFFLE WITH VERTICAL LEG ON DOWNSTREAM SIDE
3. REBARS CAN BE SUBSTITUTED WITH EQUIVALENT DIAMETER THREADED STEEL ROD. REBAR SHALL BE GRADE 60 MINIMUM WITH EQUAL EMBEDMENT.

NTS
06938–38713

CONCRETE BAFFLE FOR REINFORCED CONCRETE BOX CULVERTS

Date
05/06

Sheet
1

APPENDIX H

DESIGN EXAMPLE - ACTIVE CHANNEL DESIGN OPTION

Active Channel Design
(Culvert Replacement)

Problem Statement

Within the City limits of Folsom in Sacramento County, Route 888 has been plagued with head-on/cross-over collisions, and has poor level of service due to highway capacity issues. In order to improve level of service and reduce traffic accidents, a 5-mile stretch of Route 888 will be widened from two to four lanes and separated by a median barrier. Due to the widening of the highway, existing culverts must be lengthened or replaced depending on field and hydraulic conditions.

One of the existing culverts that must be addressed in the design process is at Blue Creek. The existing culvert diameter is 48 inches and is 30 feet in length. Over time, the corrugated metal pipe has abraded from transported sand cobble bed load to a point where most of the culvert bottom is missing.

Blue Creek supports various native non-salmonids and non-native fish species in its corridor, therefore fish passage must be considered as an aspect of design. Given the poor structural condition of the existing culvert and this need to provide fish passage, the culvert should be replaced instead of attempting to rehabilitate it through various culvert liners or baffles.

NOTE: Route 888 and Blue Creek are fictitious and created for the purpose of presenting a design example for this fish-passage training guidance.

Form 1 - Existing Data and Information Summary

Form 1 provides a list of suggested data references that would be beneficial to collect before the beginning of design process.

For this particular example, an assessor's parcel map, USGS topographic quadrangle map, hydrology analysis, hydraulics analysis, floodplain mapping from an effective FEMA flood insurance study, and a proposed land use map was available for reference. As for site access, the field investigations cannot be done within Caltrans right-of-way; therefore, right-of-entry will be required.

The USGS topographic quadrangle data was downloaded from the USGS website, www.usgs.gov.

The FEMA Map Service Center, http://msc.fema.gov/, was accessed to determine if a previous hydrologic study, hydraulic study, and/or floodplain mapping had been performed. For Blue Creek, an effective detailed study had been conducted. Floodplain mapping, water surface elevation profiles, and floodway data table were created because of the study.

The City's engineering department was able to provide a proposed land use and assessors parcel map for the project study area. The proposed land use map provided 2015 land use conditions.

California Department of Water Resources (CDEC, http://cdec.water.ca.gov/), was searched for precipitation and stream flow gage data. Unfortunately, no stream flow gages were located on Blue Creek or precipitation gages located in close vicinity.

EXISTING DATA AND INFORMATION SUMMARY — FORM 1

Project Information Route 888 4-Lane		Computed: EKB	Date: 5/1/06
		Checked: JJL	Date: 5/2/06
Stream Name: Blue Creek	County: Sacramento	Route: 888	Postmile: 67.2

Proposed Project Type	☐ New Culvert	☐ New Bridge
	☒ Replacement Culvert	☐ Replacement Bridge
	☐ Retrofit Culvert	☐ Retrofit Bridge
	☐ Proposed Culvert Length= 68.0 ft	☐ Proposed Bridge Length= ft
	☐ Other	☐ Other

Design Species/Life Stage	☒ All Species	Source: St. of CA Contact: Dept. of Fish & Game Date: Bill Hook 916-361-9322
	☐ Adult Anadromous Salmonids	
	☐ Adult Non-Anadromous Salmonids	
	☐ Juvenile Salmonids	
	☐ Native Non-Salmonids	
	☐ Non-Native Species	

Collect Existing Data

Included in Caltrans Culvert Inventory	☐ Yes	☒ No
As-Built Drawings	☐ Yes	☒ No
Assessor's Parcel Map	☒ Yes	☐ No
Previous Studies Performed: (i.e. FEMA Flood Insurance Studies, Army Corps of Engineering Studies, Other)		
Hydrology Analysis	☒ Yes	☐ No
Hydraulics Analysis	☒ Yes	☐ No
Floodplain Mapping	☒ Yes	☐ No
Other Studies Types Available: (i.e. Watershed Management Plans, Stream Restoration Plans, Other)	☐ Yes	☒ No
Existing Land Use Map	☐ Yes	☒ No
Proposed Land Use Map	☒ Yes	☐ No
Precipitation Gage Data	☐ Yes	☒ No
Stream Flow Gage Data	☐ Yes	☒ No

Topographic Mapping:
(i.e. [✓ USGS Topographic Quadrangle], DEM Data, LIDAR Data, Other) ☒ Yes ☐ No

District Hydraulics Library ☐ Yes ☒ No

Obtain Access Permission

Will Project study limits extend beyond Caltrans R/W? ☒ Yes ☐ No

If yes, obtain right-of-entry.

Contact Report Index Attached ☒ Yes ☐ No

Existing Information Index Attached ☒ Yes ☐ No

CONTACT REPORT INDEX

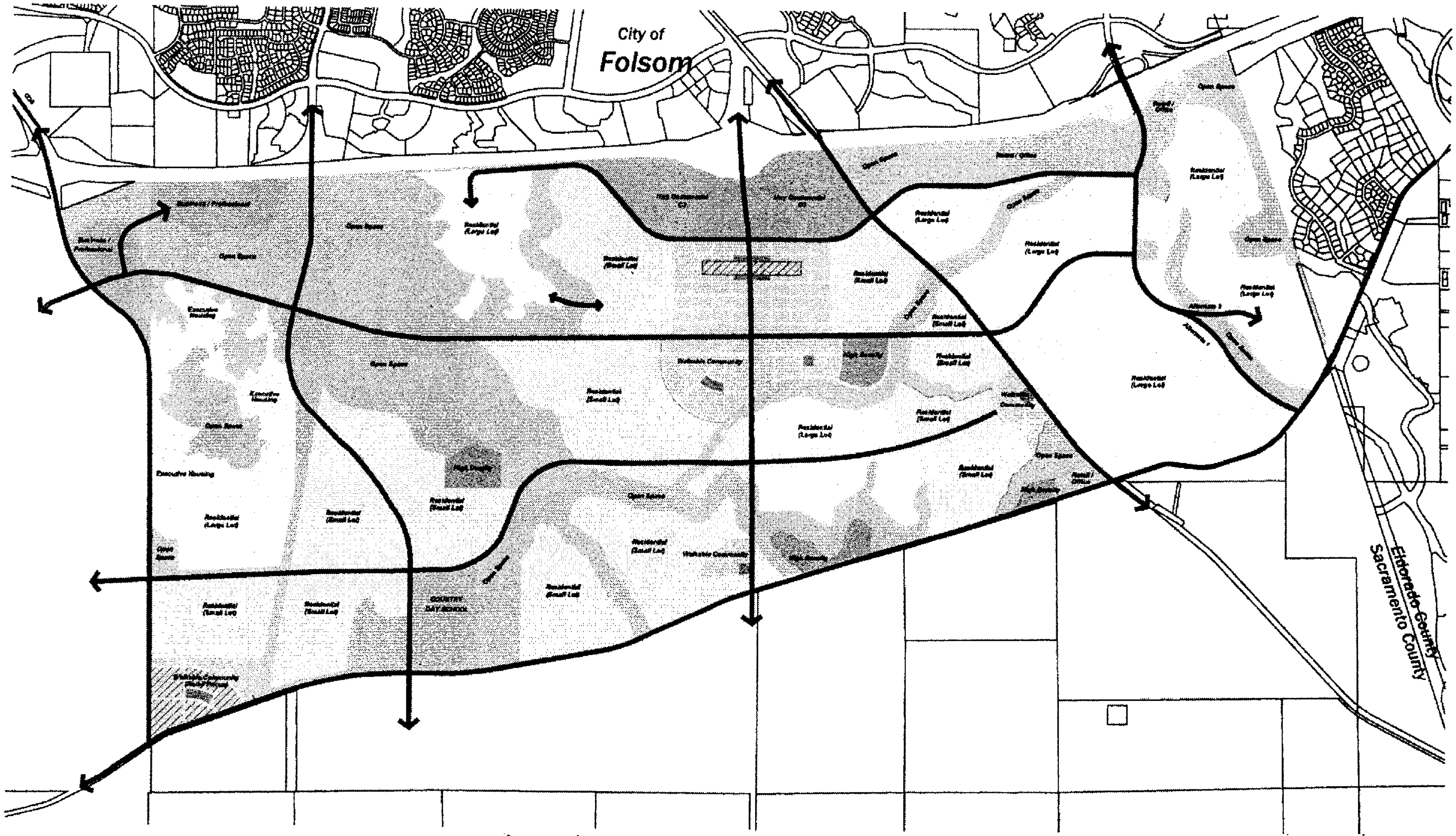
Project Information Route 888 4-lane		Computed: EKB	Date: 5/1/06
		Checked: JJL	Date: 5/2/06
Stream Name: Blue Creek	County: Sacramento	Route: 888	Postmile: 67.2

Date of Contact	Person Contacted	Subject Discussed
4/16/06	Joe Brown, City of Folsom 916-983-1010	Requested historical flow data
4/22/06	Bill Hook, St. of CA Dept. of Fish + Game 916-361-9322	Requested design species information

EXISTING INFORMATION INDEX

Project Information Route 888 4-lane		Computed: EKB	Date: 5/1/06
		Checked: JJL	Date: 5/2/06
Stream Name: Blue Creek	County: Sacramento	Route: 888	Postmile: 67.2

Report Date	Report Name and Source
5/05	Proposed Annexation Concept Plan
	City of Folsom Sphere of Influence
9/30/92	FEMA - FIS Study - City of Folsom, CA
	Sacramento County
4/25/06	California Dept of Water Resources (CDEC)
	CDEC Station Locator
2004	County of Sacramento, Department of
	Water Resources - LIDAR



Legend

- Proposed Minor Roadways
- ━ Proposed Arterial / Collector
- ▒ Business / Professional
- ▒ Retail / Office
- ▒ Highway Commercial
- ▒ Open Space
- ▒ School
- ░ Residential (Small Lot)
- ▓ Residential (Large Lot)
- □ Executive Housing
- ▓ High Density Residential
- ░ Walkable Community
- ▨ Walkable Community - Mixed
- ▓ Public - Quasi Public

Folsom Sphere of Influence Area
Land Use Summary

	Acres	Density	Range of Product	Total Dwelling Units
Executive Housing	110	3 du/ac	2-4 du/ac	330
Large Lot	590	4-5	2-6	2360 - 2950
Small Lot	900	6-9	6-12	5400 - 8100
High Density	50	20	18-22	1000
Walkable Community	150	15	13-22	2250
Total Residential	1800			11340 - 14630
Highway Commercial	100			
Business / Professional	70			
Retail / Office	125			
Public / Quasi Public	10			
School / Park	297			
Open Space	1076			
Major Roads	107			
Total	3584			

Note: School and park site locations and exact land use categories to be determined during the precise planning stage.

Proposed Annexation Concept Plan

City of Folsom Sphere of Influence

Sacramento County, California

California Department of Water Resources Division of Flood Management

Current River Conditions | Snowpack Status | River Stages/Flows | Reservoir Data/Reports | Satellite Images | Station Information
Data Query Tools | Precipitation/Snow | River/Tide Forecasts | Water Supply | Weather Forecasts | Text Reports

---

CDEC Station Locator - Stations near AMERICAN R AT FOLSOM *(AMF)*

AMERICAN R AT FOLSOM *(AMF)* is located at latitude 38.683, longitude -121.183.

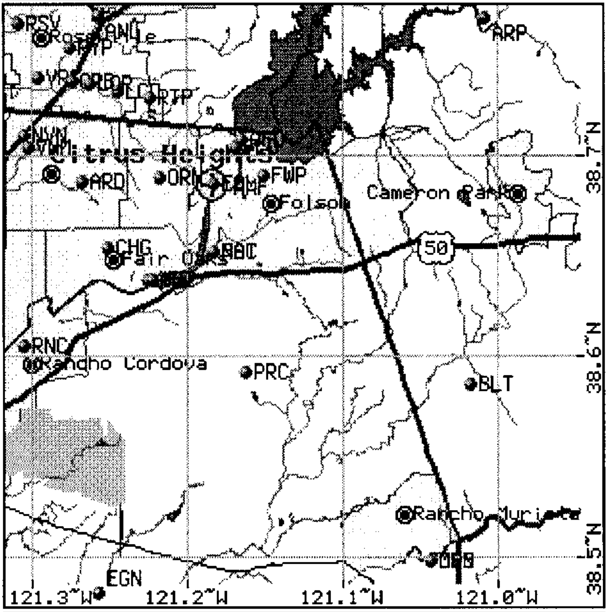
Map Level

Get All Stations

Search

NW | NORTH | NE

WEST



EAST

SW | SOUTH | SE

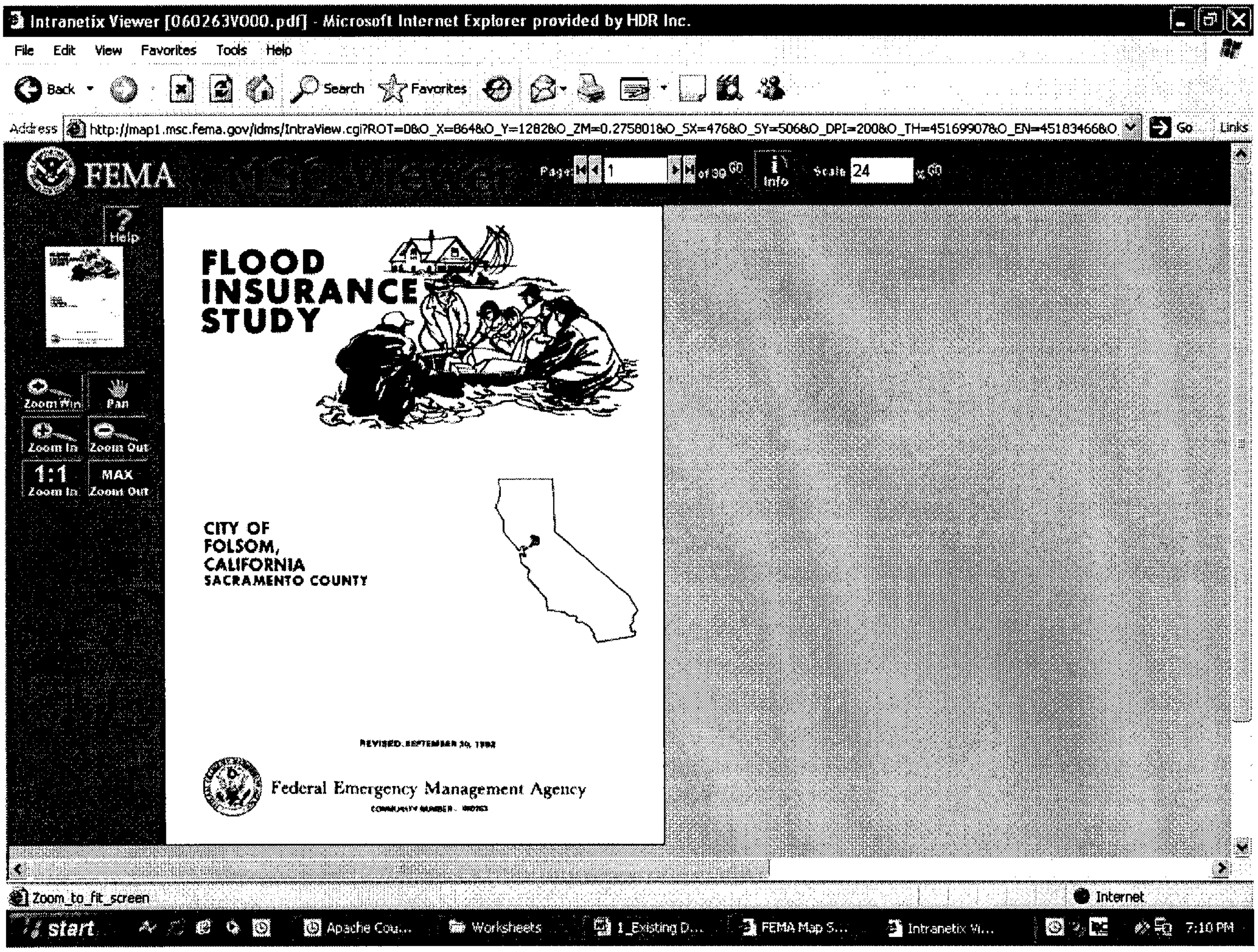
Click On Dot For Station Information Or Select Sensor

Scale 1:328424 0 2 4 6 8 10 mi / 0 5 10 15 20 km
*average--true scale depends on monitor resolution

Station:

All stations in the area:

AFD - AMERICAN R BELOW FOLSOM DAM
AFO - AMERICAN RIVER AT FAIR OAKS
AHZ - AMERICAN R AT HAZEL AVE BRIDGE
AMF - AMERICAN R AT FOLSOM
ANL - ANTELOPE CREEK AT LANDFILL
ARD - ARCADE CREEK AT SUNRISE BLVD
ARP - SO FRK AMERICAN R NR PILOT HILL
BLT - BEN BOLT
CHG - CHICAGO
CRB - CIRBY CREEK - TINA WAY
CSN - COSUMNES R AT MICHIGAN BAR
EGN - COSUMNES RIVER AT EAGLES NEST ROAD
FLD - FOLSOM DAM
FOL - FOLSOM LAKE
FSC - FOLSOM SOUTH CANAL
FWP - FOLSOM WATER TREATMENT PLANT
LCO - LINDA CREEK AT CHAMPION OAKS
LOR - LINDA CREEK AT OAK RIDGE ROAD
MHB - COSUMNES RIVER



FLOOD INSURANCE STUDY

CITY OF
FOLSOM,
CALIFORNIA
SACRAMENTO COUNTY

REVISED: SEPTEMBER 30, 1982

Federal Emergency Management Agency
COMMUNITY NUMBER - 060263

Form 2 - Site Visit Summary

Form 2 captures the existing conditions of the hydraulic structure including channel and structure roughness values. By completing the Site Visit Summary form, the drainage designer will have all necessary parameters required to complete any of the fish passage design options.

For this particular example, the corrugated metal pipe culvert is slightly projecting from the surrounding fill on both the inlet and outlet. The existing culvert slope matched the surrounding channel invert slope of 0.5%.

Manning's n-values were calculated for the channel and left and right overbanks. For this project site, the left and right overbanks displayed the similar roughness characteristics; therefore, the same Manning's n-value was used for both the left and right overbanks.

The active channel width was measured by looking for the active channel stage or ordinary high water level, which is the elevation delineating the highest water level that has been maintained for a sufficient period to leave evidence on the landscape. Evidence shown included bank elevation at which cleanly scoured substrate of the stream ends and terrestrial vegetation began, 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. Five channel width measurements were measured and averaged to determine the active channel width. The best measurement sites are located above the crossing in a channel reach visually beyond any influence the crossing may have on channel width. If it had not been possible to measure active channel width above the crossing, downstream measurements could have been taken beyond the influence of the crossing. An average of these measurements should account for natural variations in channel width.

In addition, flow in the creek at the time of the field visit was determined from appropriate measurements. The flow was calculated by measuring a velocity and depth, calculating wetted area from a field developed creek cross section, and dividing velocity by wetted area to achieve flow according to the continuity of flow equation. By placing a small leaf in the creek and timing its travel over a set length, a velocity was determined. In order to find a representative velocity for the creek, this operation was performed three times, where the leaf was placed near the left bank, near the right bank, and around the center of the creek. The velocity corresponding to each leaf placement was added together and averaged to find a representative velocity.

Finally, the flow regime for the creek was estimated in the field by tossing a small rock in the center of the creek and noting the propagation of the ripples. When ripples propagate upstream, the flow regime is subcritical, while supercritical flow is denoted by downstream ripple propagation.

SITE VISIT SUMMARY

FORM 2

Project Information Route 888 4-lane		Computed: EKB	Date: 5/3/06
		Checked: JJL	Date: 5/5/06
Stream Name: Blue Creek	County: Sacramento	Route: 888	Postmile: 67.2

Obtain Physical Characteristics of Existing Culvert

Confined Spaces

Is the culvert height 5 ft or greater?	☐ Yes ☒ No
Can you stand up in the culvert?	☐ Yes ☒ No
Can you see all the way through the culvert?	☒ Yes ☐ No
Can you feel a breeze through the culvert?	☒ Yes ☐ No

If answer is "No" to any of the above questions, do not enter the culvert without confined spaces equipment for surveying.

Inlet Characteristics

Inlet Type	☒ Projecting	☐ Headwall	☐ Wingwall	
	☐ Flared end section	☐ Segment connection		
Inlet Condition	☒ Channel scour	☐ Excessive deposition	☐ Debris accumulation	☐ None applicable
Inlet Apron	☐ Channel scour	☐ Excessive deposition	☐ Debris accumulation	☒ None applicable

Skew Angle: NONE °

Upstream Invert Elevation: 320.96 ft ([✓ NGVD 29] or NAVD 88)

Barrel Characteristics

Diameter: 48 in	Fill height above culvert: 9.54 ft
Height/Rise: – ft	Length: 30 ft
Width/Span: – ft	Number of barrels: 1

Culvert Type	☐ Arch	☐ Box	☒ Circular
	☐ Pipe-Arch	☐ Elliptical	
Culvert Material	☐ HDPE	☐ Steel Plate Pipe	☐ Concrete Pipe
	☒ Spiral Rib / Corrugated Metal Pipe		
Barrel Condition	☐ Corrosion	☐ Debris accumulation	☐ Structural damage
	☒ Abrasion	☐ Bedload accumulation	☐ None applicable

SITE VISIT SUMMARY FORM 2

Horizontal alignment breaks: NONE ft

Vertical alignment breaks: NONE ft

Outlet Characteristics

Outlet Type: ☒ Projecting ☐ Headwall ☐ Wingwall ☐ Flared end section ☐ Segment connection

Outlet Condition: ☐ Scour hole ☐ Backwatered ☐ Debris accumulation ☒ None applicable

☐ Perched

Outlet elevation drop: NONE ft

Outlet drop condition: Sandy-small rocks

Scour hole depth: NONE ft

Outlet Apron: ☐ Channel scour ☐ Excessive deposition ☐ Debris Accumulation ☒ None Applicable

Skew Angle: °

Downstream Invert Elevation: 320.80 ft ([✓ NGVD 29] or NAVD 88)

Bridge Physical Characteristics N/A

Elevation of high chord (top of road): ft

Elevation of low chord: ft

Channel Lining: ☐ No lining ☐ Concrete ☐ Rock ☐ Other

Skew Angle: °

Bridge width (length): ft

Pier Characteristics (if applicable) ☐ N/A

Number of Piers: ft

Upstream cross-section starting station: ft

Pier Width: ft

Downstream cross-section starting station: ft

Pier Centerline Spacing: ft

Pier Shape: ☐ Square nose and tail ☐ Semi-circular nose and tail ☐ 90° triangular nose and tail ☐ Twin-cylinder piers with connecting diaphragm ☐ Twin-cylinder piers without connecting diaphragm ☐ Ten pile trestle bent

Pier Condition: ☐ Scour ☐ Corrosion ☐ Debris accumulation

Skew angle °

Channel Characteristics

Hydraulic Structure Roughness Coefficients

(Source: Caltrans Highway Design Manual Table 864.3A)		**(Source: HEC-RAS User's Manual)**	
Type of Structure	**n- value**	**Type of Structure**	**n- value (normal)**

SITE VISIT SUMMARY FORM 2

Linned Channels:		**Corrugated Metal:**	
Portland Cement Concrete	0.014	Subdrain	0.019
Air Blown Mortar (troweled)	0.012	[✓ Storm drain]	[✓ 0.024]
Air Blown Mortar (untroweled)	0.016	**Wood:**	
Air Blown Mortar (roughened)	0.025	Stave	0.012
Asphalt Concrete	0.018	Laminated, treated	0.017
Sacked Concrete	0.025	**Brickwork:**	
Pavement and Gutters:		Glazed	0.013
Portland Cement Concrete	0.015	Lined with cement mortar	0.015
Asphault Concrete	0.016		
Depressed Medians:			
Earth (without growth)	0.040		
Earth (with growth)	0.050		
Gravel	0.055		

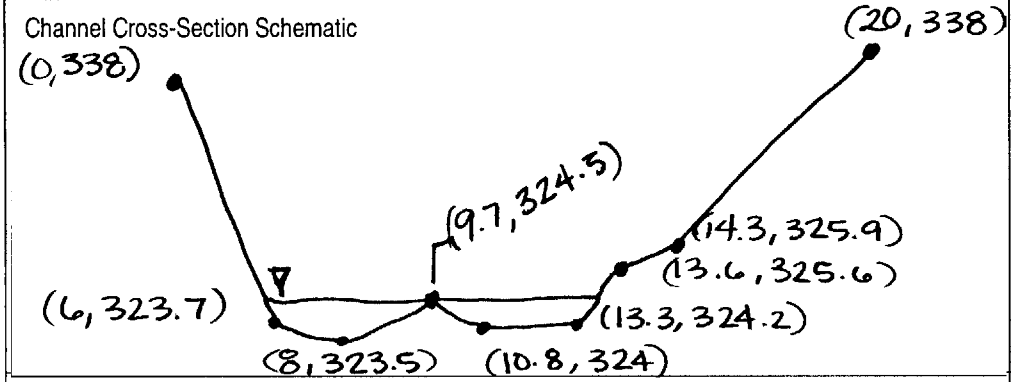
Recommended Permissible Velocities for Unlined Channels (Source: Caltrans Highway Design Manual, Table 862.2)

Type of Material in Excavation Section	Intermittent Flow (f/s)	Sustained Flow (f/s)
Fine Sand (Noncolloidal)	2.6	2.6
Sandy Loam (Noncolloidal)	2.6	2.6
Silt Loam (Noncolloidal)	3.0	3.0
Fine Loam	3.6	3.6
Volcanic Ash	3.9	3.6
Fine Gravel	3.9	3.6
Stiff Clay (Colloidal)	4.9	3.9
Graded Material (Noncolloidal)		
Loam to Gravel	6.6	4.9
Silt to Gravel	[✓ 6.9]	[✓ 5.6]
Gravel	7.5	5.9

SITE VISIT SUMMARY — FORM 2

Coarse Gravel	7.9	6.6
Gravel to Cobbles (Under 150mm)	8.8	6.9
Gravel and Cobbles Over 200mm)	9.8	7.9
Flow Estimation 5 cfs	☐ Supercritical flow	☑ Subcritical flow

Channel Cross-Section Schematic



Channel depth = 0.94 ft

Average Active Channel Width
Take at least five channel width measurments to determine the active channel width. The active channel stage or ordinary high water level is the elevation delineating the hightest water level that has been maintained for a sufficient period of time to leave evidence on the landscape.

Average Active Channel Width = 5.3 ft

1) 5.8 ft	2) 3.0 ft	3) 6.2 ft	4) 5.4 ft	5) 6.1 ft

Boundary Conditions
The normal depth option (slope area method) can only be used as a downstream boundary condition for an open-ended reach. Is normal depth appropriate? If no, what is the known starting water surface elevation? yes

Upstream Normal depth	slope 0.005 ft/ft
Downstream Normal depth	slope 0.005 ft/ft
Known starting water surface elevation Source:	— ft

General Considerations

Identify Physical restrictions

☐ Right-of-way ☐ Utility conflict ☐ Vegetation

☑ Man-made features ☐ Natural features ☐ Other

↳ Cylindical concrete structure pinches channel @ DS

Cross-Section Sketches Attached ☒ Yes ☐ No

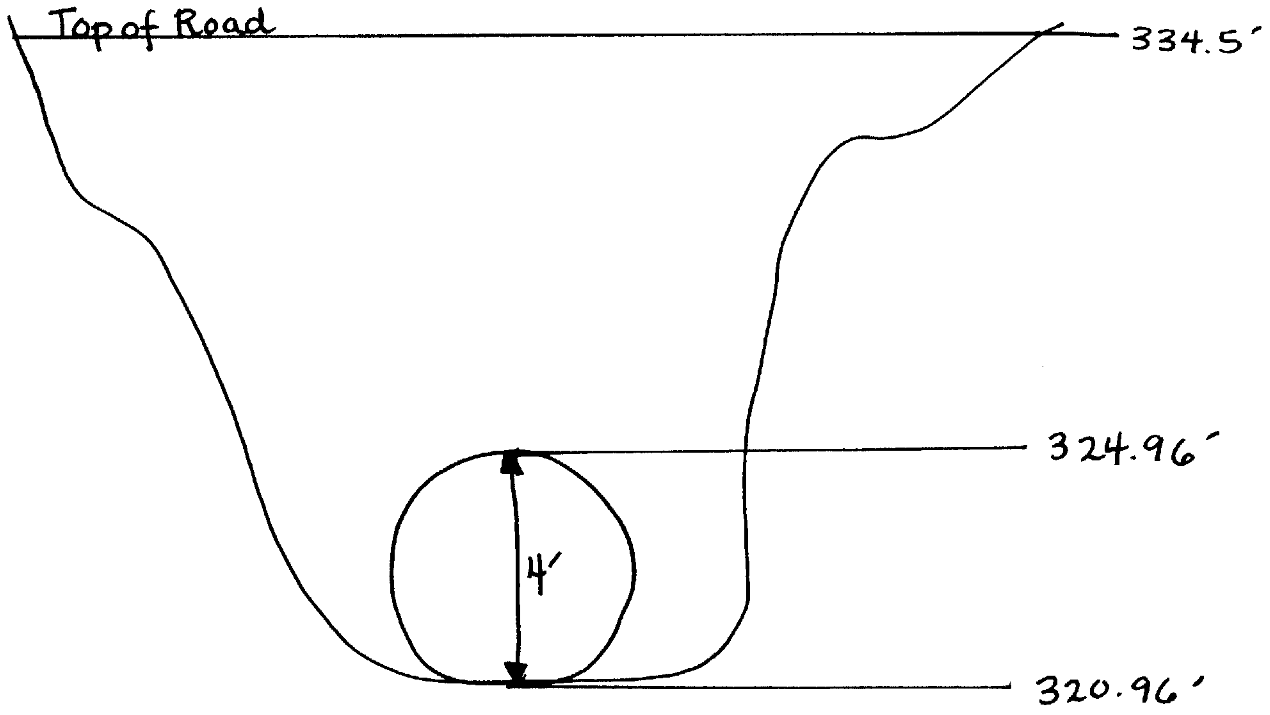
Site Photograph Documentation Attached ☒ Yes ☐ No

Channel / Overbank Manning's n-value Calculation Attached ☒ Yes ☐ No

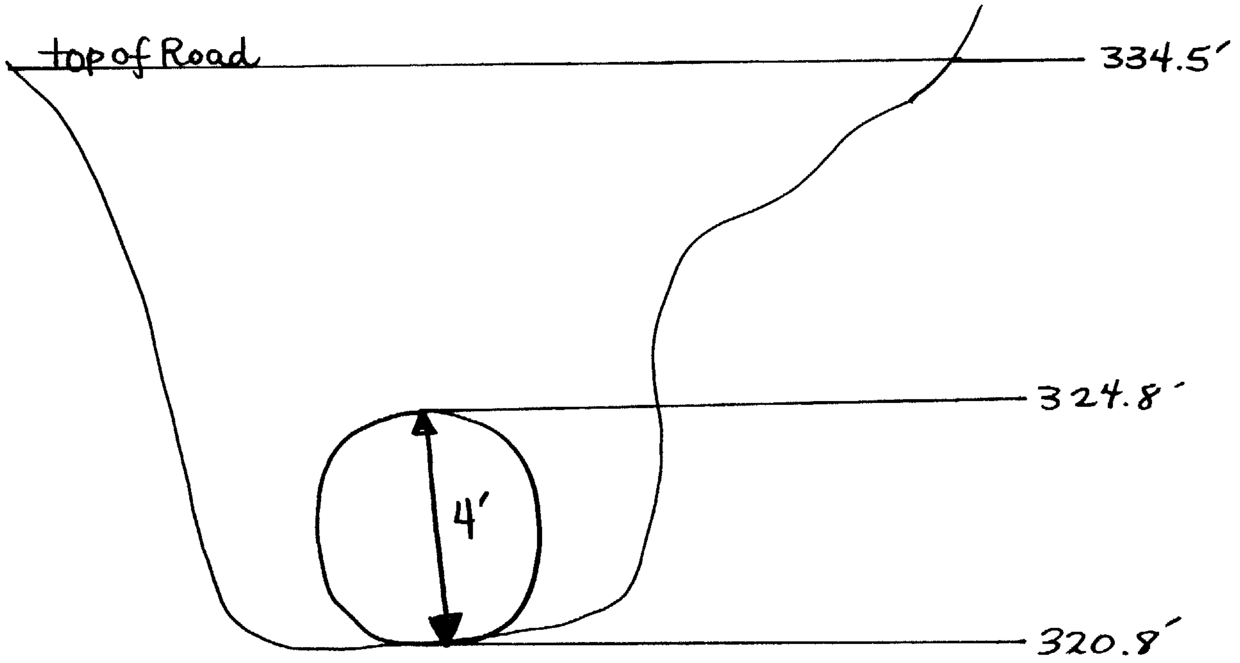
Field Notes Attached ☒ Yes ☐ No

Cross-Section Sketch

Upstream face of structure:



Downstream face of structure:



SITE PHOTOGRAPH DOCUMENTATION

Project Information Route 888 4-Lane

Computed: EKB Date: 5/3/06

Checked: JJL Date: 5/4/06

Stream Name Blue Creek

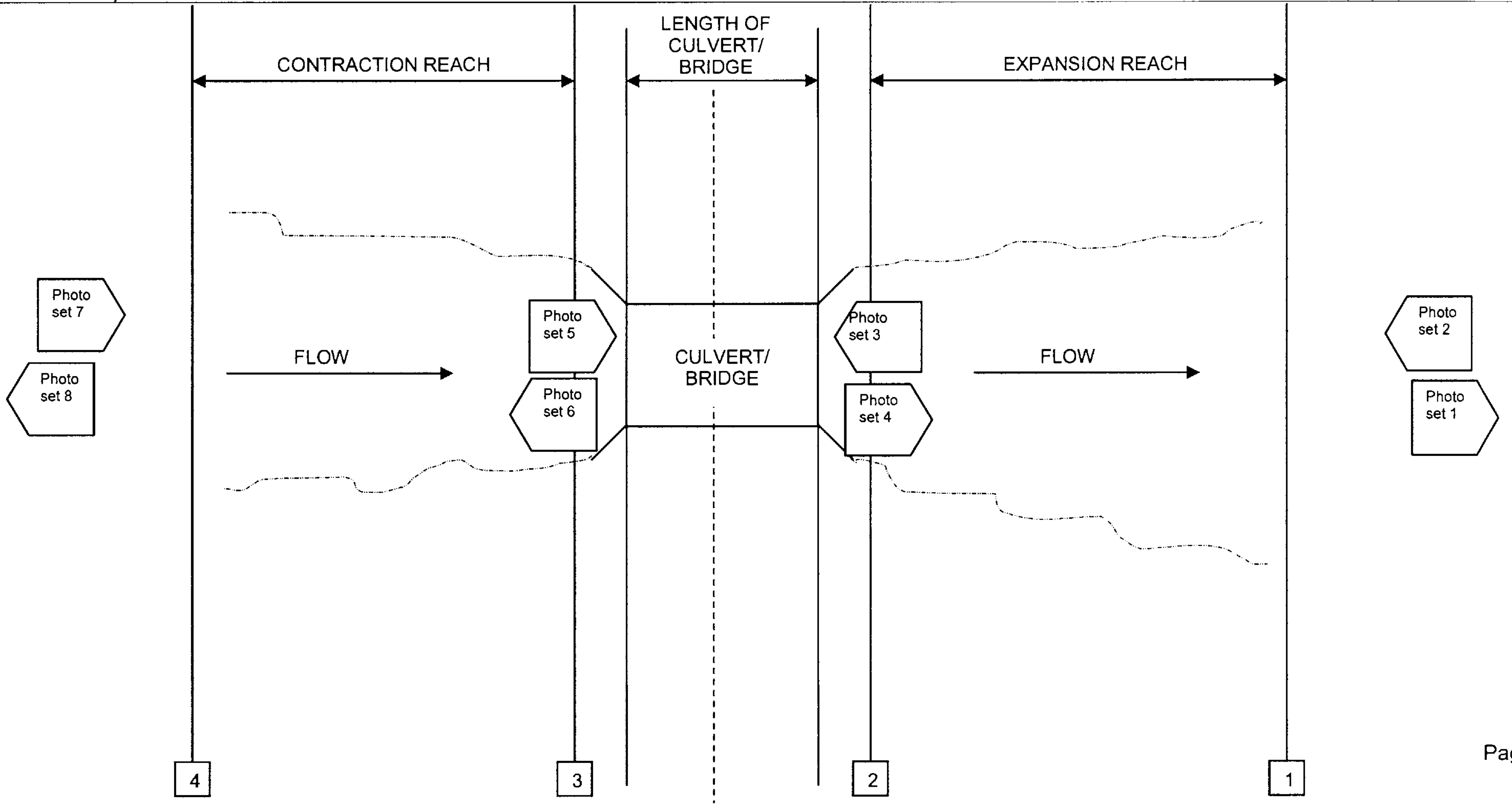
City/County Folsom/Sacramento

Road 888

Postmile 67.2

Crossing Type ☒ Culvert ☐ Bridge ☐ Other Type/Comments

Distance From:	X-sec. 1 to X-sec. 2: 20 ft	X-sec. 2 to DS face of culvert 8 ft	US face of culvert to X-Sec. 3 2 ft	X-sec. 3 to X-sec. 4 40 ft
Distance From:	Photo Sets 1 & 2 to DS face of culvert 105 ft	Photo Sets 3 & 4 to DS face of culvert 5 ft	Photo Sets 5 & 6 to US face of culvert 6 ft	Photo Sets 7 & 8 to US face of culvert 103 ft
Length of Culvert/Bridge:	ft			



SITE PHOTOGRAPH DOCUMENTATION

Photo Descriptions:

Photo Set 1	2. JPG	Looking US of culvert inlet
Photo Set 2	15.JPG	Looking DS at culvert inlet
Photo Set 3	1a.JPG	Looking DS at inlet of culvert. NOTE: culvert Projecting out of fill
Photo Set 4	17.JPG	Looking US of culvert inlet
Photo Set 5	16JPG	Looking US at culvert outlet
Photo Set 6	25.JPG	Looking DS of culvert outlet NOTE: Concrete structure in channel
Photo Set 7	4. JPG	Looking US at culvert outlet
Photo Set 8	10. JPG	Looking DS of culvert outlet

Looking upstream of Culvert Inlet

Looking downstream at Culvert Inlet

Looking downstream at inlet of Culvert

Looking upstream of Culvert Inlet

Looking upstream at Culvert Outlet

Looking downstream of Culvert Outlet

Looking upstream at Culvert Outlet

Looking downstream of Culvert Outlet

Manning's n Computation Summary

Project Information Route 888 4-Lane		Computed: EKB	Date: 5/3/06
		Checked: JJL	Date: 5/4/06
Stream Name: Blue Creek	County: Sacramento	Route: 888	Postmile: 67.2

Aerial Picture Attached: Yes

Photographs (#'s and locations) See individual Channel & OB Worksheets

Summary of n-Values:

Reach	Left Overbank	Main Channel	Right Overbank
	0.058	0.049	0.058

Notes:

Manning's n Computation - Main Channel

Project Information

Route 888 4-Lane

Computed: EKB
Date: 5/3/06
Checked: JJL
Date: 5/4/06

Stream Name: Blue Creek
County: Sacramento
Route: 888
Postmile: 67.2

Aerial Picture Attached: 1a, 1b, 2, 3, 4

Photographs (#'s and locations) 1a-culvert inlet facing DS, 1b-culvert outlet facing US
2-facing US @ culvert inlet
3-facing DS from culvert outlet
4-facing US @ culvert outlet

Is roughness uniform throughout the reach? NO

Note: If not, n-value should be assigned for the AVERAGE condition of the reach

Is roughness uniformly distributed along the cross section? NO

Is a division between the channel and floodplain necessary? yes

Calculation of n-value:
n = (nb + n1 + n2 + n3 + n4)m

where:

	Description of Range
nb = base n value for surface	*median size btwn 1" and 2.5"=0.028 to 0.035, btwn 2.5" and 10"=0.030 to 0.050*
n1 = surface irregularity factor	*smooth = 0 up to severe at 0.020*
n2 = cross section variation factor	*gradual = 0 up to alternating frequently at 0.015*
n3 = obstructions factor	*negligible = 0 up to severe (over 50% of cross section) at 0.05*
n4 = vegetation factor	*small = 0.002 to very large (average depth of flow is less than 1/2 height of vegetation) at 0.100*
m = sinuosity/meandering factor	*minor = 1.0, appreciable = 1.15, Severe = 1.30*

Base n value for surface

nb: Sand channel? NO if yes, median size of bed material? ________

nb =

median size (in)	nb
0.008	0.012
0.012	0.017
0.016	0.020
0.020	0.022
0.024	0.023
0.031	0.025
0.039	0.026

All other channels:

median size (in)	nb
→ .04 to .08	0.026 to 0.035
1 to 2.5	0.028 to 0.035
2.5 to 10	0.030 to 0.050
>10	0.040 to 0.070

Notes: Channel bottom consists of small rocks and soils. At downstream culvert exit Finer soil sediment has accumulated. See Photos 1a and 1b

nb = 0.026

Manning's n Computation - Main Channel

Surface Irregularity

n1:	Smooth	Is channel smooth? NO	if yes, n1 = 0
	Minor	Is channel in good condition with slightly eroded or scoured side slopes?	if yes, n1 = 0.001 - 0.005
	Moderate	Is channel a dredged channel having moderate to considerable bed roughness and moderately sloughed or eroded side slopes in rock?	[✓ if yes, n1 = 0.006 - 0.010]
	Severe	Is channel badly sloughed, scalloped banks or badly eroded or sloughed sides or jagged and irregular surface?	if yes, n1 = 0.011 - 0.020

Notes: Channel bottom has many elevation drops. All less than 1.0ft (see photo 2)

n1 = 0.006

Cross Section Variation Factor

n2:	Gradual	Does the size and shape of the channel cross section change gradually?	if yes, n2 = 0.000
	Alternately occasionally	Does the cross section alternate to large to small, *occasionally* or does the main flow *occasionally* shift from side to side?	[✓ if yes, n2 = 0.001 - 0.005]
	Alternately frequently	Does the cross section alternate to large to small, *frequently* or does the main flow *frequently* shift from side to side?	if yes, n2 = 0.010 - 0.015

n2 = 0.005

Notes: The wetted X-section area does alternate a bit from side-to-side. (see photo 2)

Obstructions factor

n3:	Negligible	Does the stream have a few scattered obstructions that occupy < 5% of the cross-sectional area?	if yes, n3 = 0.000 - 0.004
	Minor	Obstructions occupy < 15% of the cross-sectional area and the spacing between obstructions is such that the sphere of influence doesn't extend to other obstructions?	if yes, n3 = 0.005 - 0.015
	Appreciable	Obstructions occupy 15% - 50% of the cross-sectional area and the spacing between obstructions is small enough to be additive?	if yes, n3 = 0.020 - 0.030
	Severe	Obstructions occupy more than 50% of the cross-sectional area or the spacing between obstructions causes turbulence?	if yes, n3 = 0.040 - 0.050

n3 = 0.004

Notes: There are few bolders that partially obstruct flow however, not a major concern. On the DS side of the culvert there is a large circular concrete structure that pinches the channel. (see photo 3)

Manning's n Computation - Main Channel

Vegetation factor

n4:

	Small	Does the channel have dense growth of flexible turf grass or weed growth where the flow is at least 2 times the height of the vegetation; tree seedlings of willows, cottonwoods, etc? →	if yes, n4 = 0.002 - 0.010
	Medium	Does the channel have turf grass where the average depth of flow is 1 to 2 times the height of the vegetation; moderately stemmy grass, weeds or tree seedlings growing where the flow is 2 to 3 times the height of the vegetation?	if yes, n4 = 0.010 - 0.025
	Large	Does the channel where the average depth of flow is equal to the height of the vegetation; 8 to 10 years-old willows or cottonwoods intergrown with weeds and brush; where the hydraulic radius exceeds 0.6 m (1.97 ft) or bushy willows about 1 year old intergrown with some weeds along side slopes, and no significant vegetation exists along the channel bottom, where the hydraulic radius is greater than 0.61m (2.0 ft).	if yes, n4 = 0.025 -0.050
	Very large	Does the channel have turf grass growing where the average depth of flow < 1/2 the height of the vegetation; bushy willows about 1 year old. with weeds intergrown on side slopes; dense cattails in channel bottom; trees intergrown with weeds and brush?	if yes, n4 = 0.050 - 0.100

n4 = 0.008

Notes: Due to the rocky/gravel channel bottom. Very little vegetation IS able to grow directly in the channel. (see photo 4)

Sinuosity/meandering factor

m	Minor	Ratio of the channel length to valley length in 1.0 to 1.2	if yes, m = 1.00
	Appreciable	Ratio of the channel length to valley length in 1.2 to 1.5	if yes, m = 1.15
	Severe	Ratio of the channel length to valley length > 1.5	if yes, m = 1.30

m = 1.0

Notes: NOT an ISSUE

Manning's n - Main Channel n = 0.049

Manning's n Computation - Overbank

Project Information Route 888 4-lane		Computed: EKB	Date: 5/3/06
		Checked: JJL	Date: 5/4/06
Stream Name: Blue Creek	County: Sacramento	Route: 888	Postmile: 67.2

Aerial Picture Attached: See channel photos

Photographs (#'s and locations)

Is roughness uniform throughout the reach? NO

Note: If not, n-value should be assigned for the AVERAGE condition of the reach

Is roughness uniformly distributed along the cross section? NO

Is a division between the channel and floodplain necessary? yes

Calculation of n-value:

n = (nb + n1 + n2 + n3 + n4)m

where:

	Description of Range
nb = base n value for surface	*median size between 1" and 2.5"=0.028 to 0.035, between 2.5" and 10"=0.030 to 0.050*
n1 = surface irregularity factor	*smooth = 0 up to severe at 0.020*
n2 = cross section variation factor	*gradual = 0 up to alternating frequently at 0.015*
n3 = obstructions factor	*assumed to equal 0*
n4 = vegetation factor	*small = 0.002 to very large (average depth of flow is less than 1/2 height of vegetation) at 0.100*
m = sinuosity/meandering factor	*equals 0 for floodplains*

Base n value for surface

nb: Sand channel? ________ if yes, median size of bed material? ________

nb =

median size (in)	nb
0.008	0.012
0.012	0.017
0.016	0.020
0.020	0.022
0.024	0.023
0.031	0.025
0.039	0.026

All other channels:

median size (in)	nb
→ .04 to .08	0.026 to 0.035
1 to 2.5	0.028 to 0.035
2.5 to 10	0.030 to 0.050
>10	0.040 to 0.070

Notes:

nb = 0.026

Surface Irregularity

n1:	Smooth	Compares to the smoothest, flattest floodplain in a given bed material.	if yes, n1 = 0
	Minor	Is the floodplain slightly irregular in shape. A few rises and dips or sloughs may be more visible on the floodplain.	→ if yes, n1 = 0.001 - 0.005
	Moderate	Has more rises and dips. Sloughs and hummocks may occur.	if yes, n1 = 0.006 - 0.010
	Severe	Floodplain very irregular in shape. Many rises and dips or sloughs are visible.	if yes, n1 = 0.011 - 0.020

n1 = 0.003

Notes:

Manning's n Computation - Overbank

Cross Section Variation Factor

n2 = 0.000

Notes: Not applicable to floodplains.

Obstructions factor

n3:

Negligible	Does the stream have a few scattered obstructions that occupy < 5% of the cross-sectional area?	if yes, n3 = 0.000 - 0.004
Minor	Obstructions occupy < 15% of the cross-sectional area and the spacing between obstructions is such that the sphere of influence doesn't extend to other obstructions? →	if yes, n3 = 0.005 - 0.015
Appreciable	Obstructions occupy 15% - 50% of the cross-sectional area and the spacing between obstructions is small enough to be additive?	if yes, n3 = 0.020 - 0.030

n3 = 0.005

Notes:

Vegetation factor

n4:

Small	Does the channel have dense growth of flexible turf grass or weed growth where the flow is at least 2 times the height of the vegetation; tree seedlings of willows, cottonwoods, etc where the average depth of flow is at least three times the height of the vegetation?	if yes, n4 = 0.002 - 0.010
Medium	Does the channel have turf grass where the average depth of flow is 1-2 times the height of the vegetation; moderately stemmy grass, weeds or tree seedlings growing where the flow is 2-3 times the height of vegetation? Brushy, moderately dense vegetation, similar to 1-2 year old willow trees in dormant season. →	if yes, n4 = 0.010 - 0.025
Large	Does the channel where the average. depth of flow is equal to the height of the vegetation; 8 to 10 year old. willows, cottonwoods intergrown with weeds and brush; where the R = 1.97 ft or bushy willows of 1 year old are in the channel bottom, where R =2.00 ft?	if yes, n4 = 0.025 -0.050
Very large	Does the channel have turf grass growing where the average depth of flow < 1/2 the height of the vegetation; bushy willows about 1 year old. with weeds intergrown on side slopes; dense cattails in channel bottom; trees intergrown with weeds and brush?	if yes, n4 = 0.050 - 0.100
Extreme	Does the channel have dense bushy willow, mesquite, and salt cedar (full foliage), or heavy stand of timber, few down trees, depth of reaching branches?	if yes, n4 = 0.100 - 0.200

n4 = 0.024

Notes: Much denser vegetation is present on over banks than within channel

Sinuosity/meandering factor

m = 1.00

Notes: Not applicable to floodplains.

Manning's n - Overbank n = 0.058

Form 3 - Guidance on Selection of Fish Passage Design Option

Form 3 summarizes requirements for each design option in order for the designer to select the appropriate fish-passage design option.

Because specific target species and their swimming abilities are not known for this project, which is needed when using the Hydraulic Design strategy, only the Stream Simulation and Active Channel strategies are initially viable. By using either of these design options, passage can be satisfied for all fish, both are suitable design options for culvert replacement, and both options can be used for the proposed culvert slope of 0.5%

For Blue Creek, the 68-foot proposed culvert length controls the choice of design option. When designing a fish passage culvert, its length must be greater than 100 feet for the Stream Simulation option. Therefore, the Active Channel design option is the best strategy for fish-passage design at Blue Creek.

Given the new, larger diameter culvert and its potential to convey higher flow more effectively, District Hydraulics must be consulted so that any negative impacts to downstream properties or facilities can be assessed prior to final design.

GUIDANCE ON SELECTION OF FISH PASSAGE DESIGN OPTION FORM 3

Project Information Route 888 4-Lane		Computed: EKB	Date: 5/3/06
		Checked: JJL	Date: 5/4/06
Stream Name:	County:	Route: 888	Postmile: 67.2

Design Species/ Life Stage	☒	All Species
	☐	Adult Anadromous Salmonids
	☐	Adult Non-Anadromous Salmonids
	☐	Juvenile Salmonids
	☐	Native Non-Salmonids
	☐	Non-Native Species

☒ **Active Channel Design Option -** The Active Channel Design Option 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 streambed 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 with stream hydraulic charagcteristics within the culvert are intended to mimic the stream conditions upstream and downstream of the crossing. However, hydraulic analyses for traffic safety, hydraulic impacts, and scour are required.

Criteria for choosing option:

☒ New and replacement culvert/bridge installations

☒ Passage required for all species

☒ Proposed culver/bridge length less than 100 feet

☒ Channel slope less than 3%

☐ **Hydraulic Design Option -** The Hydraulic Design Option is a design process that matches the hydraulic performance of a culvert with the swimming ablitities of a target species and age class of fish. This method targets distinct species of fish and, therefore, does not account for ecosystem requirments of non-target species.

Criteria for choosing option:

☒ New and replacement culvert/bridge installations (If retrofit installation, see Baffle or Rock Weir Design Options)

☐ Target species identified for passage

☒ Low to moderate channel slopes (less than 3%)

☐ Active channel design or stream simulation design options are not physically feasible

Retrofit Culvert/Bridge Installations

☐ **Baffle Design Option -** The Baffle Design Option is a Hydrualic Design process that is intended to increase flow depth, or to add roughness elements as a measure to reduce flow velocity within the culvert/bridge structure. Determination of the high and low fish passage design flows, water velocity, and water depth is required for this option.

☐ Retrofit culvert/bridge installation

☐ Little bedload material movement

GUIDANCE ON SELECTION OF FISH PASSAGE DESIGN OPTION FORM 3

- ☐ Existing culvert/bridge is structurally sound
- ☐ Target species identified for passage
- ☐ Low to moderate channel slopes
- ☐ Active channel design or stream simulation design options are not physically feasible

☐ **Rock Weir Design Option -** The Rock Weir Design Option is a Hydraulic Design process that is intended to increase flow depth, or add roughness elements as a measure to reduce flow velocity, or to increase the channel slope downstream of the culvert/bridge. Determination of the high and low fish passage design flows, water velocity, and water depth is required for this option.

- ☐ Retrofit culvert/bridge installations
- ☐ Perched condition at outlet
- ☐ Steep slope at inlet
- ☐ Target species identified for passage
- ☐ Active channel design or stream simulation design options are not physically feasible

☐ **Stream Simulation Design Option -** The Stream Simulation Design Option 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.

Criteria for choosing option:

- ☒ New and replacement culvert/bridge installations
- ☒ Passage required for all species
- ☐ Culvert/bridge length greater than 100 feet
- ☒ Channel width should be less than 20 feet
- ☐ Minimum culvert/bridge width no less than 6 feet
- ☐ Culvert/bridge slope does not greatly exceed slope of natural channel, slopes of 6 % or less
- ☐ Narrow stream valleys

Selected Design Option: Active Channel Design

Basis for Selection:
- Replacement culvert
- all species required to pass
- Proposed culvert length is 68ft < 100ft
- Channel slope is 0.5%

Seek Agency Approval: ☐ Yes ☒ No

Form 4 - Guidance on Methodology for Hydrologic Analysis

Form 4 summarizes methods for estimating peak design discharges that will be used in a hydraulic analysis. Data requirements, limitations, and guidance are provided to assist in the hydrologic method selection.

For this particular example, all data requirements needed to calculate peak discharges by regional regression equations were readily available. These peak discharges were compared to the effective Flood Insurance Study; however, the new peak discharges were calculated completely independent of the effective study.

GUIDANCE ON METHODOLOGY FOR HYDROLOGIC ANALYSIS [1,2] FORM 4

Project Information
Route 888 4-lane

Computed: EKB
Date: 5/4/06
Checked: JJL
Date: 5/5/06

Stream Name: Blue Creek
County: Sacramento
Route: 888
Postmile: 67.2

Summary of Methods for Estimating Peak Design Discharges for Use in Hydraulic Analysis

Ungaged Streams

☒ **Regional Regression**[3,4]

Data Requirements	Limitations	Guidance
▪ Drainage area ▪ Mean annual precipitation ▪ Altitude index	▪ Peak discharge value for flow under natural conditions unaffected by urban development and little or no regulation by lakes or reservoirs ▪ Ungaged channel	The most recently published USGS report for estimating peak discharges may be used. The user should exercise caution to ensure that the reports are used only for the conditions and locations for which they are recommended.

Rainfall-Runoff Models

☐ **NRCS (TR 55)**[5]

Data Requirements	Limitations	Guidance
▪ 24-hour Rainfall ▪ Rainfall distribution ▪ Runoff curve number ▪ Concentration time ▪ Drainage area	▪ Small or midsize catchment (<8 km^2) ▪ Maximum of 10 subwatersheds ▪ Concentration time range from 0.1-10 hour (tabular hydrograph method limit <2 hour) ▪ Runoff is overland and channel flow ▪ Simplified channel routing ▪ Negligible channel storage	TR-55 focuses on small urban and urbanizing watersheds.

☐ **HEC-1/HEC-HMS**[6,7] **(SCS Dimnesionless, Snyder Unit, Clark Unit Hydrographs)**

Data Requirements	Limitations	Guidance
▪ Watershed/subbasin parameters ▪ Precipitation depth, duration, frequency, and distribution ▪ Precipitation losses ▪ Unit hydrograph parameters ▪ Streamflow routing and diversion parameters	▪ Simulations are limited to a single storm event ▪ Streamflow routing is performed by hydrologic routing methods and is therefore not appropriate for unsteady state routing conditions.	Can be used for watersheds which are: small or large, simple or complex, and developed or undeveloped.

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[1] Caltrans Highway Design Manual, Chapter 810 Hydrology, Topic 819 Estimating Design Discharge

[2] FEMA Guidelines and Specifications, Appendix C, Section C.1

[3] USGS Water-Resources Investigation 77-21 (Magnitude and Frequency of Floods in California)

[4] USGS Open-File Report 93-419 (Methods for Estimating Magnitude and Frequency of floods in the Southwestern United States)

[5] United States Department of Agriculture, Natural Resources Conservation Service, Urban Hydrology for Small Watersheds Technical Release 55, June 1986. ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf

[6] HEC-1 User's Manual

[7] HEC-HMS User's Manual

[8] Bulletin 17B

GUIDANCE ON METHODOLOGY FOR HYDROLOGIC ANALYSIS[1,2] FORM 4

GAGED STREAMS

☐ **Statistical Methods**[8]

Data Requirements	Limitations	Guidance
▪ 10 or more years of gaged flood records	▪ Gage data is usually only available for midsized and large catchments ▪ Appropriate station and/or generalized skew coefficient relationship applied	For watersheds with less than 50 years of record, compare with results of appropriate USGS regional regression equations. For watersheds with less than 25 years of record, compare with results of appropriate USGS regional regresssion equations and/or HEC-1/HEC-HMS model results.

☐ **Basin Transfer of Gage Data**

Data Requirements	Limitations	Guidance
▪ Discharge and area for gaged watershed ▪ Area for ungaged watershed	▪ Similar hydrologic characteristics ▪ Channel storage	Must obtain approval of transfer technique from hydraulics engineer prior to use.

☐ **Fish Passage Flows**

▪ Streamflow hydrograph ▪ Flow duration curve		Lower and upper fish passage flows define the range of flows a culvert should contain suitable conditions for fish passage.

Selected Hydrologic Method: Regional Regression

Basis for Selection:

Peak discharges calculated seem reasonable and appropriate for a subbasin of 0.53 mi² drainage area

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[1] Caltrans Highway Design Manual, Chapter 810 Hydrology, Topic 819 Estimating Design Discharge

[2] FEMA Guidelines and Specifications, Appendix C, Section C.1

[3] USGS Water-Resources Investigation 77-21 (Magnitude and Frequency of Floods in California)

[4] USGS Open-File Report 93-419 (Methods for Estimating Magnitude and Frequency of floods in the Southwestern United States)

[5] United States Department of Agriculture, Natural Resources Conservation Service, Urban Hydrology for Small Watersheds Technical Release 55, June 1986. ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf

[6] HEC-1 User's Manual

[7] HEC-HMS User's Manual

[8] Bulletin 17B

GUIDANCE ON METHODOLOGY FOR HYDROLOGIC ANALYSIS [1, 2] FORM 4

Verify Reasonableness and Recommended Flows

Source	50% Annual Probability (2-Year Flood Event) (cfs)	10% Annual Probability (10-Year Flood Event) (cfs)	2% Annual Probability (50-Year Flood Event) (cfs)	1% Annual Probability (100-Year Flood Event) (cfs)	High Fish Passage Design Flow (cfs)	Low Fish Passage Design Flow (cfs)
Effective Study Peak Discharges	22	100	203	252	N/A	N/A
Recommended Peak Discharges	30	106	222	284	N/A	N/A

Hydrologic Analysis Index Attached ☒ Yes ☐ No

Hydrologic Analysis Calculations Attached ☒ Yes ☐ No

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[1] Caltrans Highway Design Manual, Chapter 810 Hydrology, Topic 819 Estimating Design Discharge
[2] FEMA Guidelines and Specifications, Appendix C, Section C.1
[3] USGS Water-Resources Investigation 77-21 (Magnitude and Frequency of Floods in California)
[4] USGS Open-File Report 93-419 (Methods for Estimating Magnitude and Frequency of floods in the Southwestern United States)
[5] United States Department of Agriculture, Natural Resources Conservation Service, Urban Hydrology for Small Watersheds Technical Release 55, June 1986. ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf
[6] HEC-1 User's Manual
[7] HEC-HMS User's Manual
[8] Bulletin 17B

HYDROLOGIC ANALYSES INDEX

FORM 4

Project Information Route 888 4-Lane	Computed: EKB Checked: JJL	Date: 5/4/06 Date: 5/5/06	
Stream Name: Blue Creek	County: Sacramento	Route: 888	Postmile: 67.2

Flooding Source/Stream Name	Hydrologic Method/Model Used	Method/Model Analysis Date	Exhibit No.	
			Paper Copy	Electronic Copy
Blue Creek	Regional Regression	Site Located in Sierra Region, CA	1	-
↳ source:	Nationwide summary of USGS Regional Regression Equations for Estimating Magnitude + Frequency of Floods for Ungaged Sites, 1993.			

Regional Regression Computation Summary

Project Information:	Route 888 4-Lane			Computed:	EKB	Date:	5/4/2006
				Checked:	JJL	Date:	5/5/2006
Stream Name:	Blue Creek	County:	City of Folsom Sacramento County	Route:	888	Postmile:	67.2

Calculations:

-Site Located in Sierra Region

A, Drainage Area = 0.53 mi^2
P, Mean Annual Precipitation = 17 inches
H, Altitude Index = 0.317 thousands of feet

Regional Regression Equations

Q2 = 0.24A^0.88P^1.58H^-0.80
Q2 = 30 cfs

Q5 = 1.20A^0.82P^1.37H^-0.64
Q5 = 72 cfs

Q10 = 2.63A^0.80P^1.25H^-0.58
Q10 = 106 cfs

Q25 = 6.55A^0.79P^1.12H^-0.52
Q25 = 172 cfs

Q50 = 10.4A^0.78P^1.06H^-0.48
Q50 = 222 cfs

Q100 = 15.7A^0.77P^1.02H^-0.43
Q100 = 284 cfs

The following documentation was taken from:

U.S. Geological Survey Water-Resources Investigations Report 94-4002:
Nationwide summary of U.S. Geological Survey regional regression equations for estimating magnitude and frequency of floods for ungaged sites, 1993

CALIFORNIA

STATEWIDE RURAL

Summary

California is divided into six hydrologic regions (fig. 1). The regression equations developed for these regions are for estimating peak discharges (QT) having recurrence intervals T that range from 2 to 100 years. The explanatory basin variables used in the equations are drainage area (A), in square miles; mean annual precipitation (P), in inches; and an altitude index (H), which is the average of altitudes in thousands of feet at points along the main channel at 10 percent, and 85 percent of the distances from the site to the divide. The variables A and H may be measured from topographic maps. Mean annual precipitation (P) is determined from a map in Rantz (1969). The regression equations were developed from peak-discharge records of 10 years or longer, available as of 1975, at more than 700 gaging stations throughout the State. The regression equations are applicable to unregulated streams but are not applicable to some parts of the State (see fig. 1). The standard errors of estimate for the regression equations for various recurrence intervals and regions range from 60 to over 100 percent. The report by Waananen and Crippen (1977) includes an approximate procedure for increasing a rural discharge to account for the effect of urban development. The influences of fire and other basin changes on flood magnitudes are also discussed.

Procedure

Topographic maps, the hydrologic regions map (fig. 1), the mean annual precipitation from Rantz (1969), and the following equations are used to estimate the needed peak discharges QT, in cubic feet per second, having selected recurrence intervals T.

North Coast Region

$Q2 = 3.52\ A^{0.90}\ P^{0.89}\ H^{-0.47}$
$Q5 = 5.04\ A^{0.89}\ P^{0.91}\ H^{-0.35}$
$Q10 = 6.21\ A^{0.88}\ P^{0.93}\ H^{-0.27}$
$Q25 = 7.64\ A^{0.87}\ P^{0.94}\ H^{-0.17}$
$Q50 = 8.57\ A^{0.87}\ P^{0.96}\ H^{-0.08}$
$Q100 = 9.23\ A^{0.87}\ P^{0.97}$

Northeast Region

$Q2 = 22\ A^{0.40}$
$Q5 = 46\ A^{0.45}$
$Q10 = 61\ A^{0.49}$
$Q25 = 84\ A^{0.54}$
$Q50 = 103\ A^{0.57}$
$Q100 = 125\ A^{0.59}$

Sierra Region

$Q2 = 0.24\ A^{0.88}\ P^{1.58}\ H^{-0.80}$
$Q5 = 1.20\ A^{0.82}\ P^{1.37}\ H^{-0.64}$
$Q10 = 2.63\ A^{0.80}\ P^{1.25}\ H^{-0.58}$
$Q25 = 6.55\ A^{0.79}\ P^{1.12}\ H^{-0.52}$
$Q50 = 10.4\ A^{0.78}\ P^{1.06}\ H^{-0.48}$
$Q100 = 15.7\ A^{0.77}\ P^{1.02}\ H^{-0.43}$

Central Coast Region

$Q2 = 0.0061\ A^{0.92}\ P^{2.54}\ H^{-1.10}$
$Q5 = 0.118\ A^{0.91}\ P^{1.95}\ H^{-0.79}$
$Q10 = 0.583\ A^{0.90}\ P^{1.61}\ H^{-0.64}$
$Q25 = 2.91\ A^{0.89}\ P^{1.26}\ H^{-0.50}$
$Q50 = 8.20\ A^{0.89}\ P^{1.03}\ H^{-0.41}$
$Q100 = 19.7\ A^{0.88}\ P^{0.84}\ H^{-0.33}$

South Coast Region

$Q2 = 0.14\ A^{0.72}\ P^{1.62}$
$Q5 = 0.40\ A^{0.77}\ P^{1.69}$
$Q10 = 0.63\ A^{0.79}\ P^{1.75}$
$Q25 = 1.10\ A^{0.81}\ P^{1.81}$
$Q50 = 1.50\ A^{0.82}\ P^{1.85}$
$Q100 = 1.95\ A^{0.83}\ P^{1.87}$

South Lahontan-Colorado Desert Region

$Q2 = 7.3A^{0.30}$
$Q5 = 53A^{0.44}$
$Q10 = 150A^{0.53}$
$Q25 = 410A^{0.63}$
$Q50 = 700A^{0.68}$
$Q100 = 1080A^{0.71}$

In the North Coast region, use a minimum value of 1.0 for the altitude index (H). Equations are defined only for basins of 25 mi^2 or less in the Northeast and South Lahontan-Colorado Desert regions.

Reference

Waananen, A.O., and Crippen, J.R., 1977, Magnitude and frequency of floods in California: U.S. Geological Survey Water-Resources Investigations Report 77-21, 96 p.

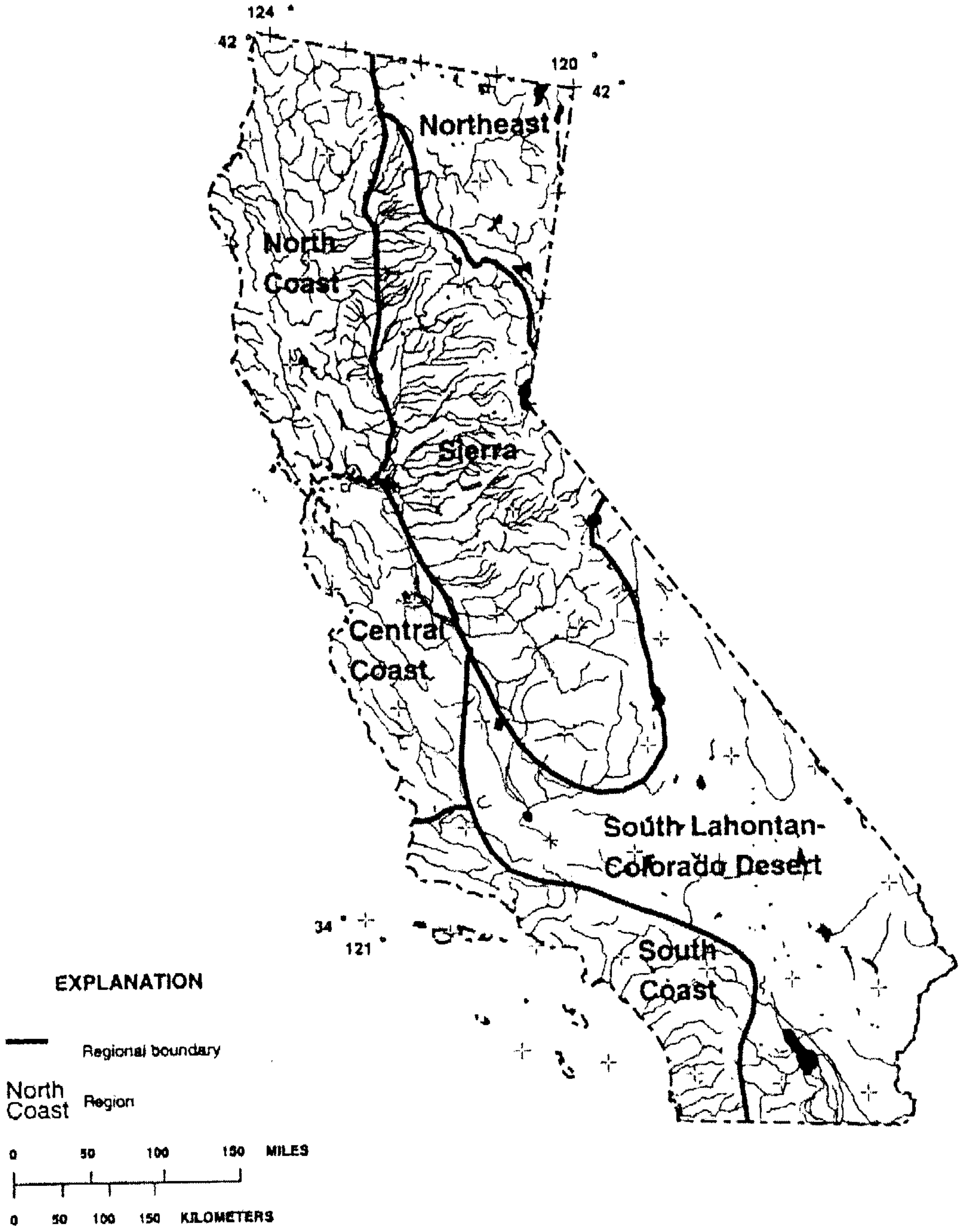
Additional Reference

Rantz, S.E., 1969, Mean annual precipitation in the California region: U.S. Geological Survey Open-File Map (Reprinted 1972, 1975).

Figure 1. Flood-frequency region map for California. (PostScript file of Figure 1.)

Back to NFF main page

USGS Surface-Water Software Page



Digital base from U.S. Geological Survey 1:2,000,000 , 1970
Albers equal-area projection based on standard parallels 29.5 and 45.5 degrees

Figure 1. Flood-frequency region map for California.

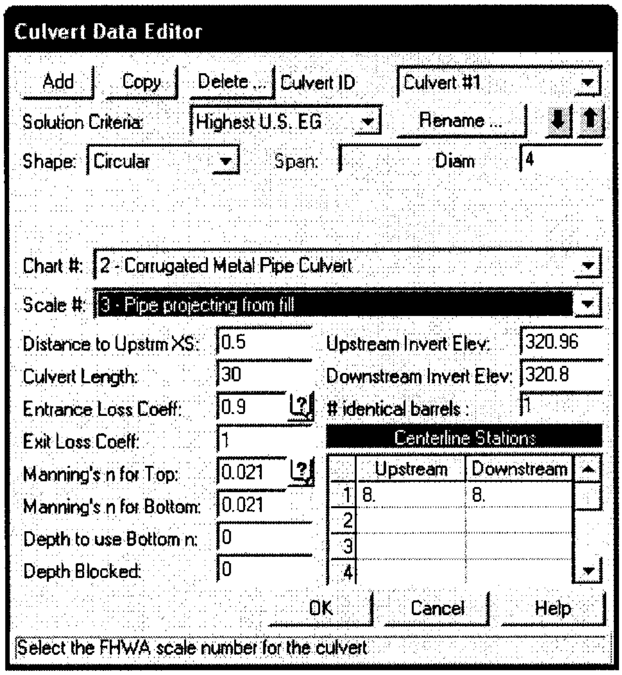
Form 5 - Guidance on Methodology for Hydraulic Analysis

Form 5 summarizes the acceptable methods available for hydraulic analysis. The modeling methods include FHWA Design Charts, HY8 - Culvert Analysis, and HEC-2/HEC-RAS.

For this particular example, HEC-RAS was used to model existing and proposed conditions. HEC-RAS easily allowed a quick comparison between existing and proposed water surface elevations and velocities.

The HEC-RAS model consists of two plans: existing geometry and proposed geometry conditions. Both plans use the same peak discharges estimated by regional regression analysis.

The existing culvert geometry was modeled using the Culvert Data Editor. The existing culvert parameters that had been measured and captured in Form 2 - Site Visit Summary, were entered into the Culvert Data Editor in HEC-RAS.



Culvert ID: Culvert #1

Solution Criteria: Highest U.S. EG

Shape: Circular

Span:

Diam: 4

Chart #: 2 - Corrugated Metal Pipe Culvert

Scale #: 3 - Pipe projecting from fill

Distance to Upstrm XS: 0.5

Culvert Length: 30

Entrance Loss Coeff: 0.9

Exit Loss Coeff: 1

Manning's n for Top: 0.021

Manning's n for Bottom: 0.021

Depth to use Bottom n: 0

Depth Blocked: 0

Upstream Invert Elev: 320.96

Downstream Invert Elev: 320.8

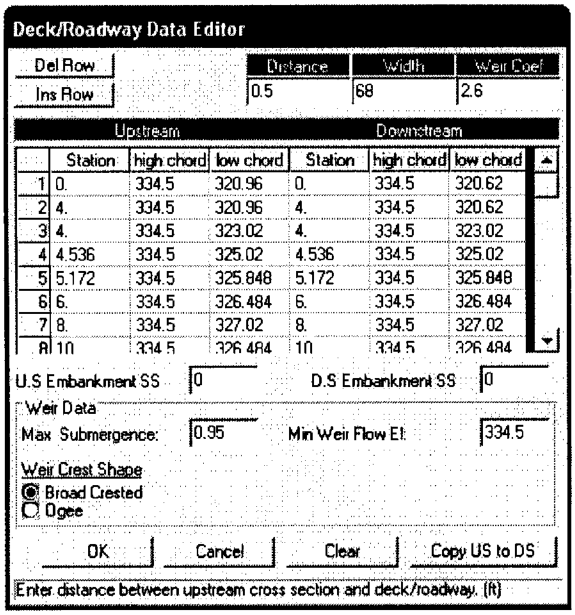
\# identical barrels: 1

Centerline Stations

	Upstream	Downstream
1	8.	8.
2		
3		
4		

Select the FHWA scale number for the culvert

The proposed culvert geometry was modeled using the Deck/Roadway Data Editor. The proposed culvert geometry could not be modeled using the standard Culvert Data Editor due to the different embedment depths at the culvert inlet and outlet. Instead, the proposed culvert geometry was modeled by manually entering the low chord elevations into the Deck/Roadway Data Editor.


Deck/Roadway Data Editor

Distance	Width	Weir Coef
0.5	68	2.6

	Upstream			Downstream		
	Station	high chord	low chord	Station	high chord	low chord
1	0.	334.5	320.96	0.	334.5	320.62
2	4.	334.5	320.96	4.	334.5	320.62
3	4.	334.5	323.02	4.	334.5	323.02
4	4.536	334.5	325.02	4.536	334.5	325.02
5	5.172	334.5	325.848	5.172	334.5	325.848
6	6.	334.5	326.484	6.	334.5	326.484
7	8.	334.5	327.02	8.	334.5	327.02
8	10	334.5	326.484	10	334.5	326.484

U.S Embankment SS: 0
D.S Embankment SS: 0

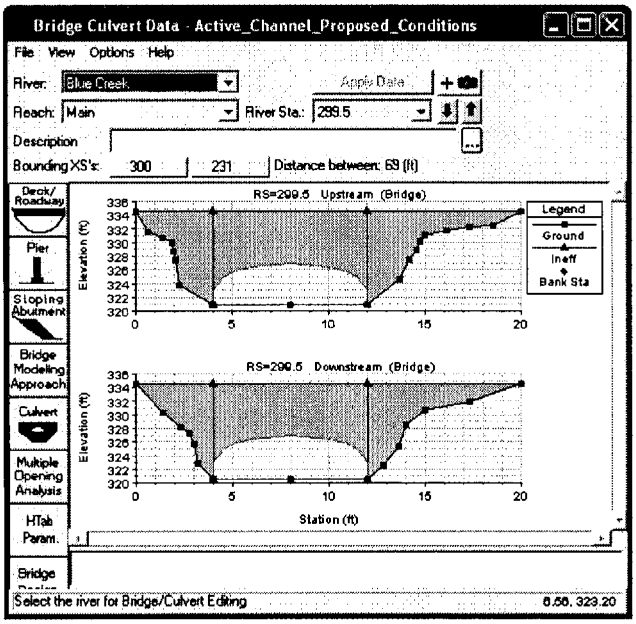
Weir Data

Max Submergence: 0.95
Min Weir Flow El: 334.5

Weir Crest Shape

● Broad Crested
○ Ogee

Enter distance between upstream cross section and deck/roadway. (ft)


Bridge Culvert Data - Active_Channel_Propused_Conditions

River: Blue Creek
Reach: Main
River Sta.: 299.5
Description
Bounding XS's: 300 231 Distance between: 69 (ft)

Select the river for Bridge/Culvert Editing
6.56, 323.20

GUIDANCE ON METHODOLOGY FOR HYDRAULIC ANALYSIS — FORM 5

Project Information Route 888 4-Lane		Computed: EKB	Date: 5/6/06
		Checked: JJL	Date: 5/7/06
Stream Name: Blue Creek	County: Sacramento	Route: 888	Postmile: 67.2

Summary of Methods for Hydraulic Analysis

☐ **FHWA Design Charts**

☐ **HY8 - Culvert Analysis or other HDS-5 Based Software**

☒ **HEC-2 / HEC-RAS**

☐ **Fish Xing (Pre-design assessment or post-design assessment when applicable)**

Is the hydraulic model used to create the effective FIRM available? ☐ Yes ☒ No
If yes, update and use this model for the hydraulic model.

Selected Method: HEC-RAS

Basis for Selection:

- X-section geometry for upstream and downstream available
- Steady flow Modeling

Verify Reasonableness and Recommended Flows ☒ Yes ☐ No

Hydraulic Analyses Index Attached ☒ Yes ☐ No

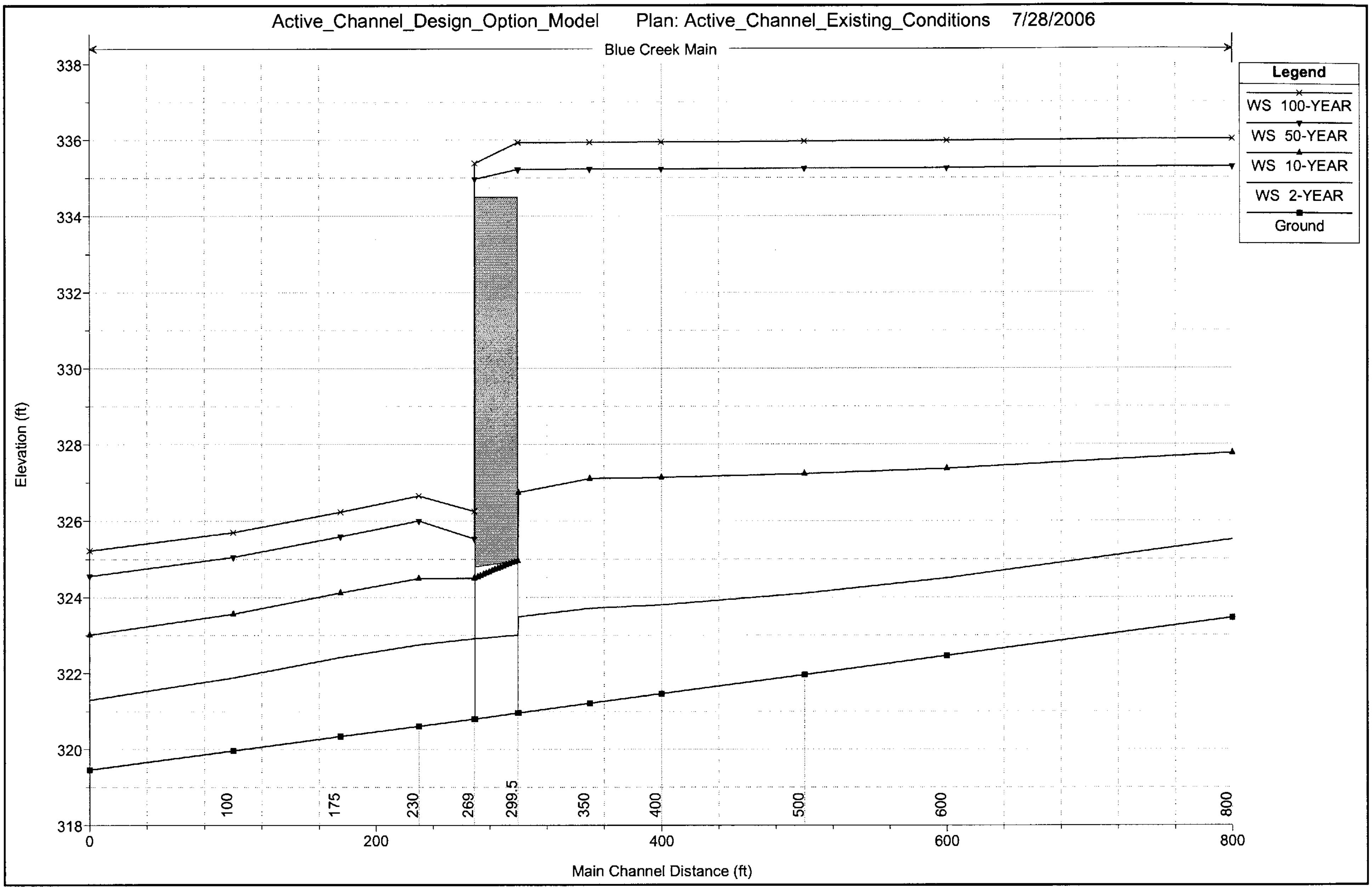
Hydraulic Analysis Calculation Attached ☒ Yes ☐ No

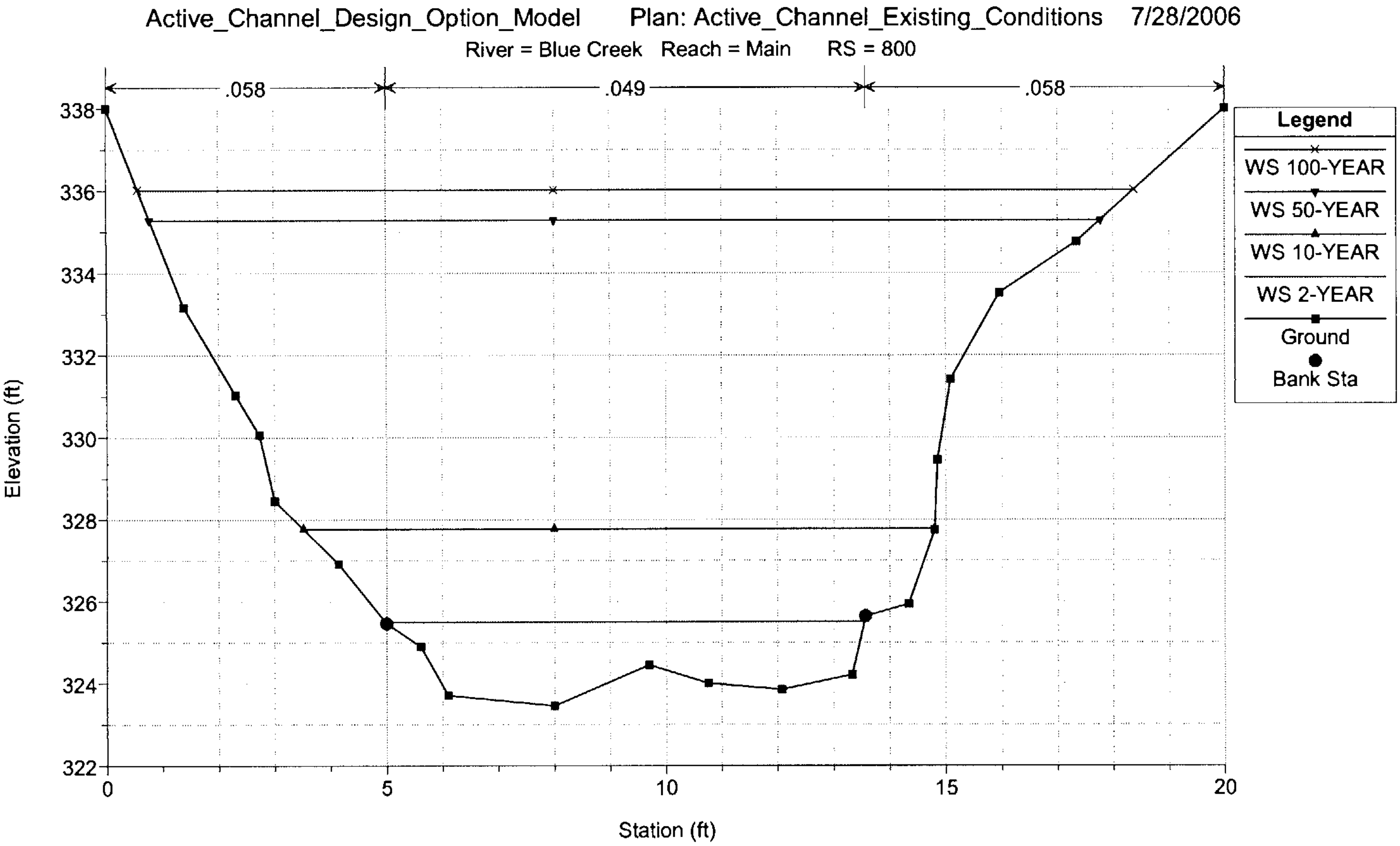
HYDRAULIC ANALYSES INDEX

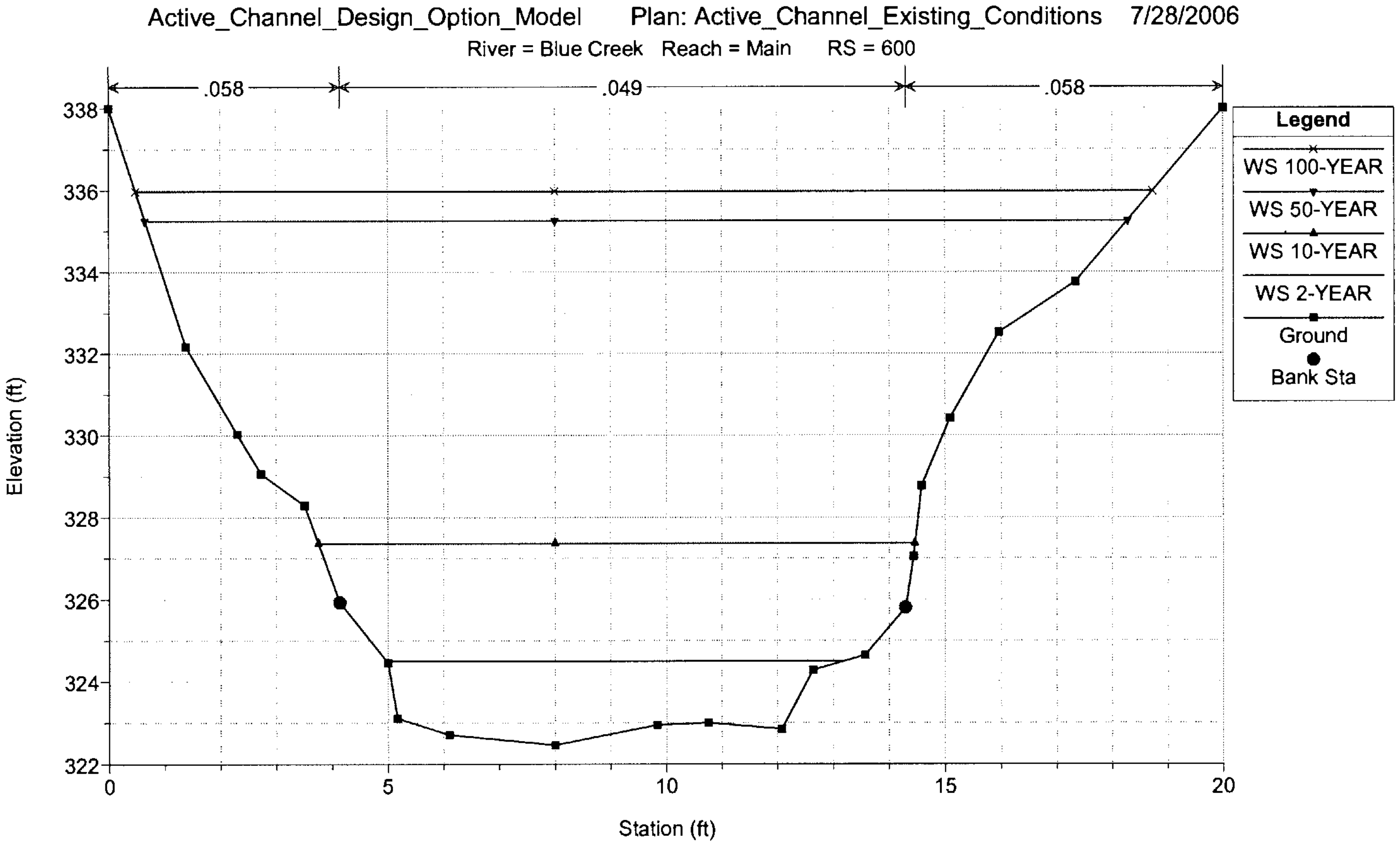
FORM 5

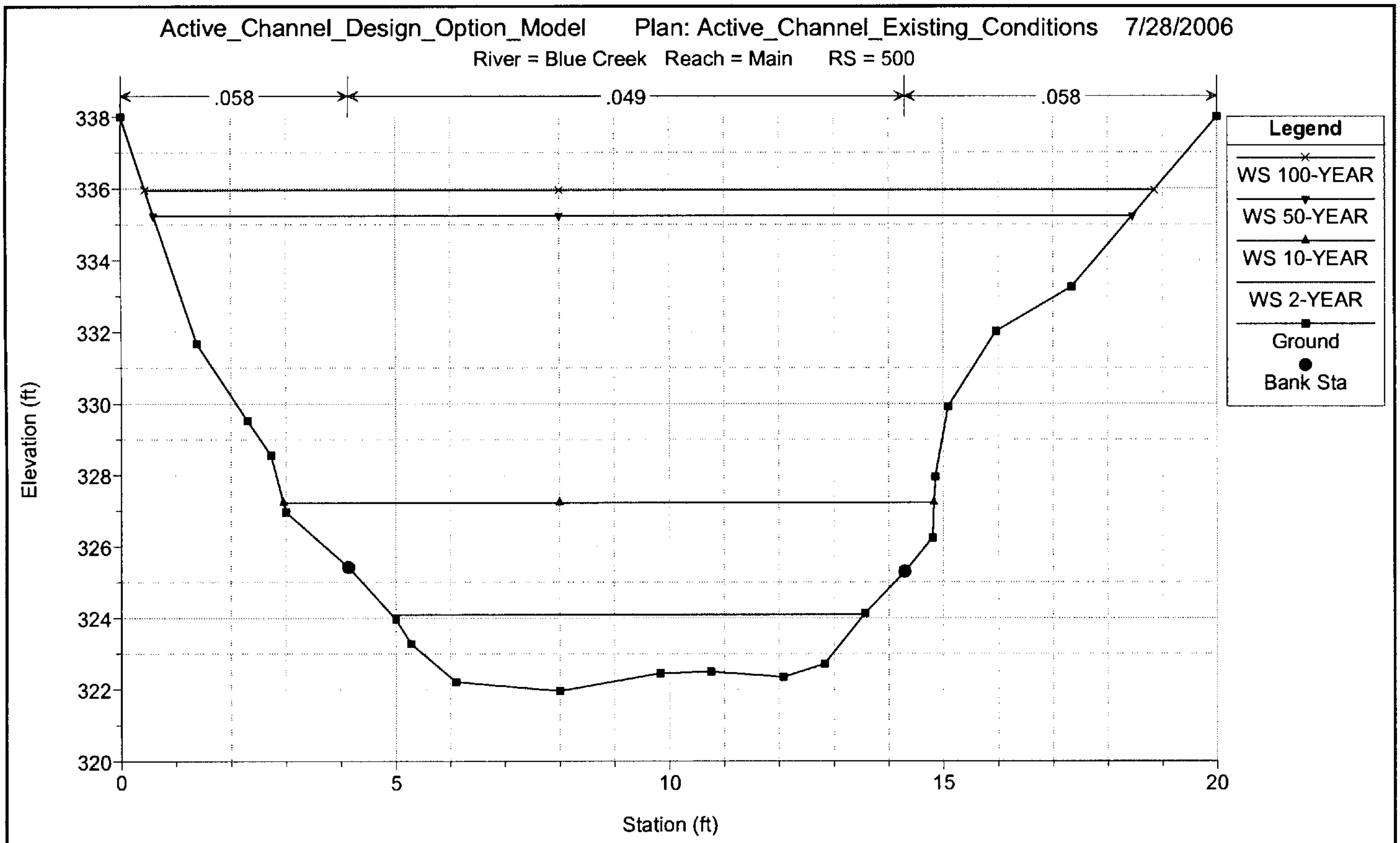
Project Information Route 888 4-lane		Computed: EKB	Date: 5/6/06
		Checked: JJL	Date: 5/7/06
Stream Name: Blue Creek	County: Sacramento	Route 888	Postmile 67.2

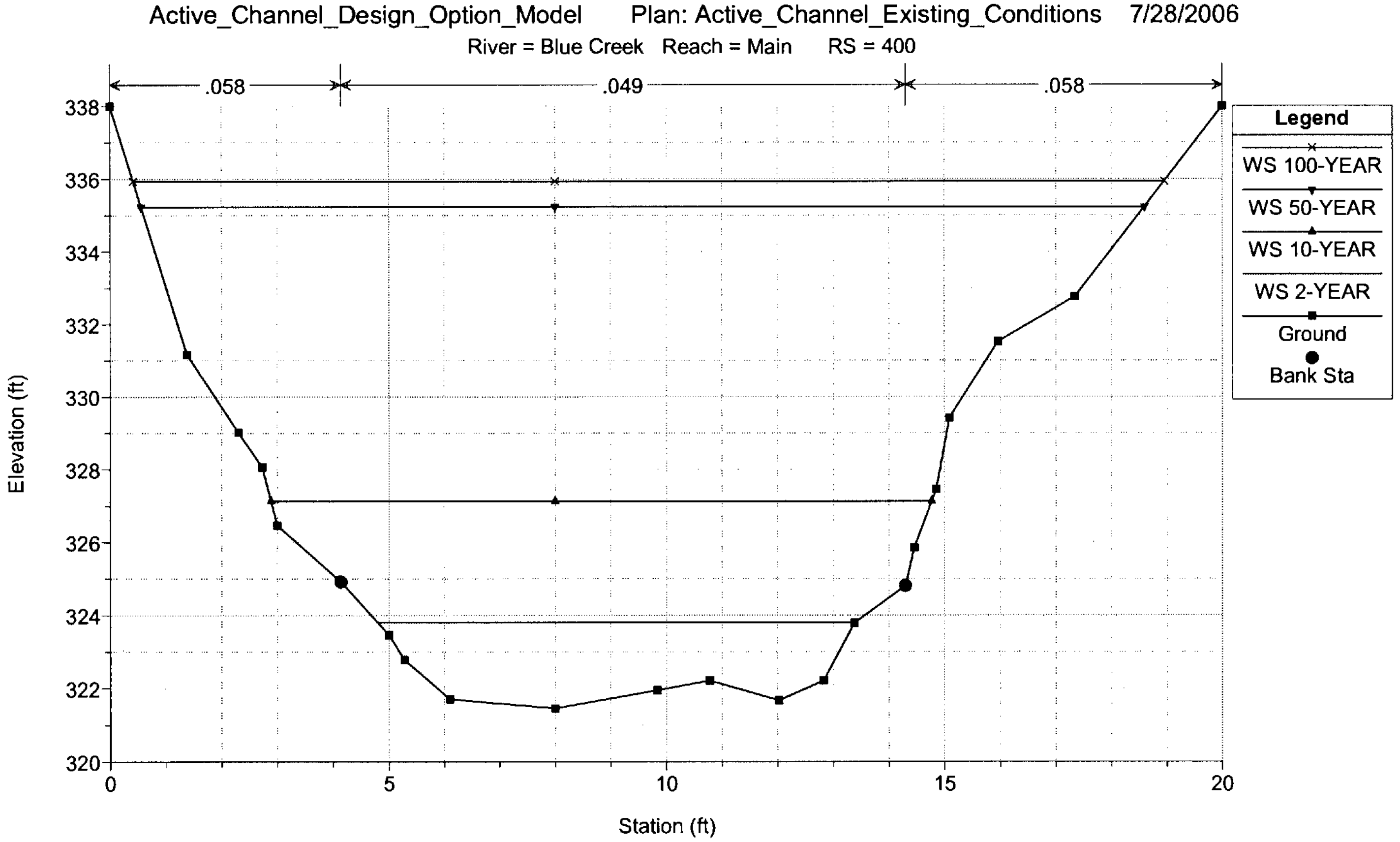
Flooding Source/Stream Name	Hydraulic Method/Model Used	Method/Model Analysis Date	Exhibit No.	
			Paper Copy	Electronic Copy
Blue Creek	HEC-RAS	5/6/06	1	
	→ Existing	conditions model		.p01 .g01
				.f01
	→ Proposed	Conditions model		.p02 .g02
				.f02

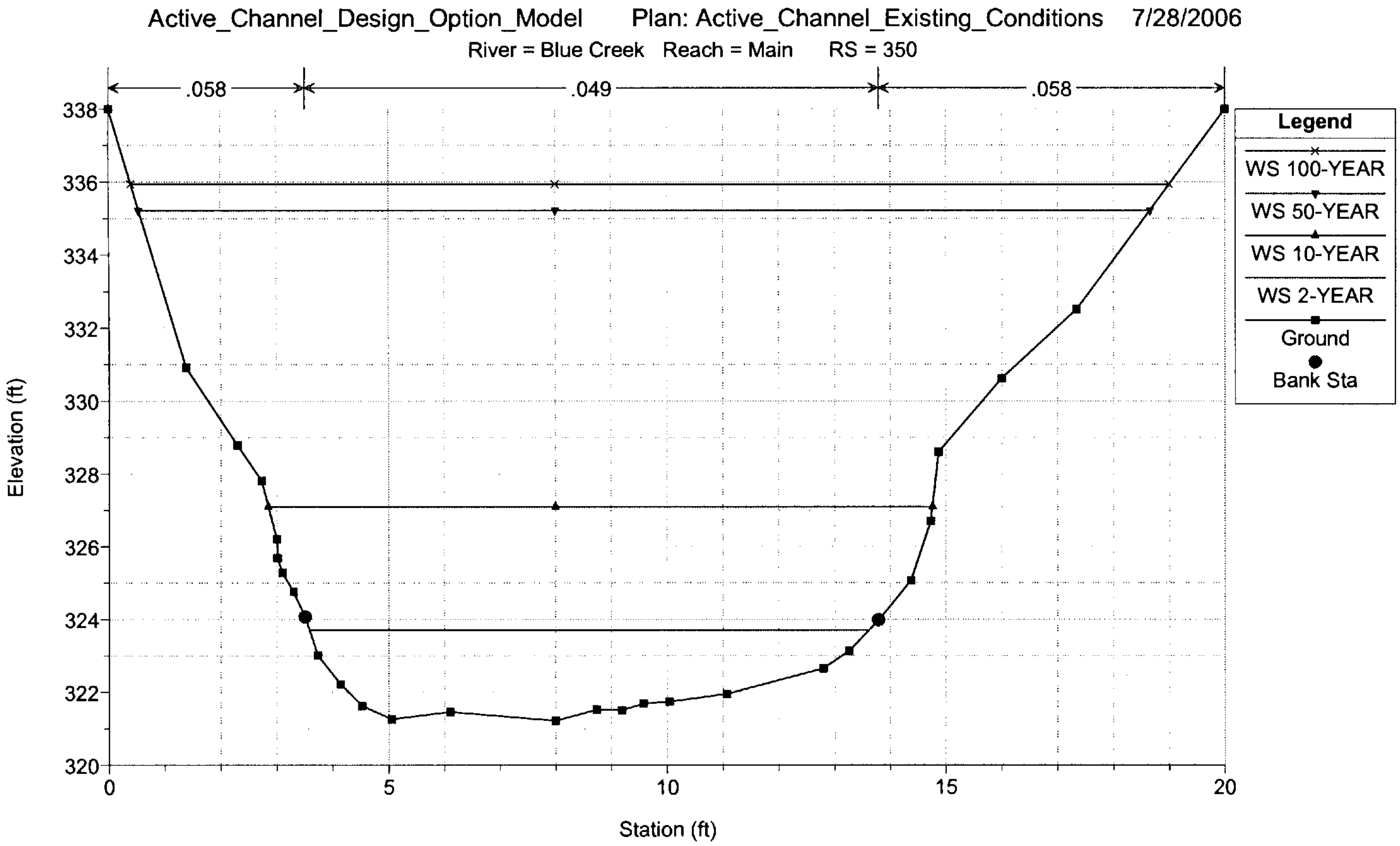

Active_Channel_Design_Option_Model Plan: Active_Channel_Existing_Conditions 7/28/2006
Blue Creek Main
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
Ground
Elevation (ft)
338
336
334
332
330
328
326
324
322
320
318
100
175
230
269
299.5
350
400
500
600
800
0
200
400
600
800
Main Channel Distance (ft)

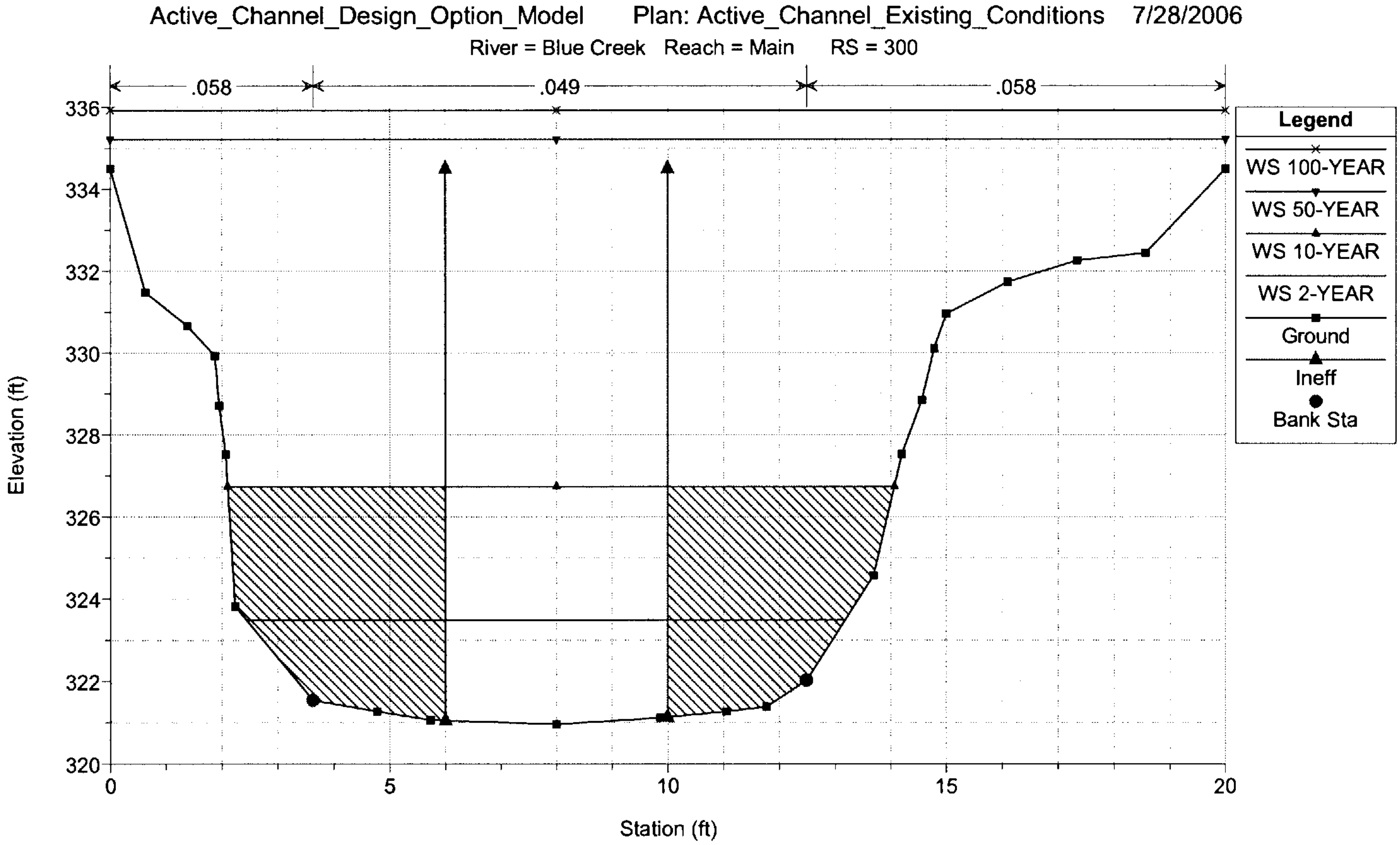

Active_Channel_Design_Option_Model Plan: Active_Channel_Existing_Conditions 7/28/2006
River = Blue Creek Reach = Main RS = 800
.058
.049
.058
Elevation (ft)
338
336
334
332
330
328
326
324
322
0
5
10
15
20
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
Ground
Bank Sta

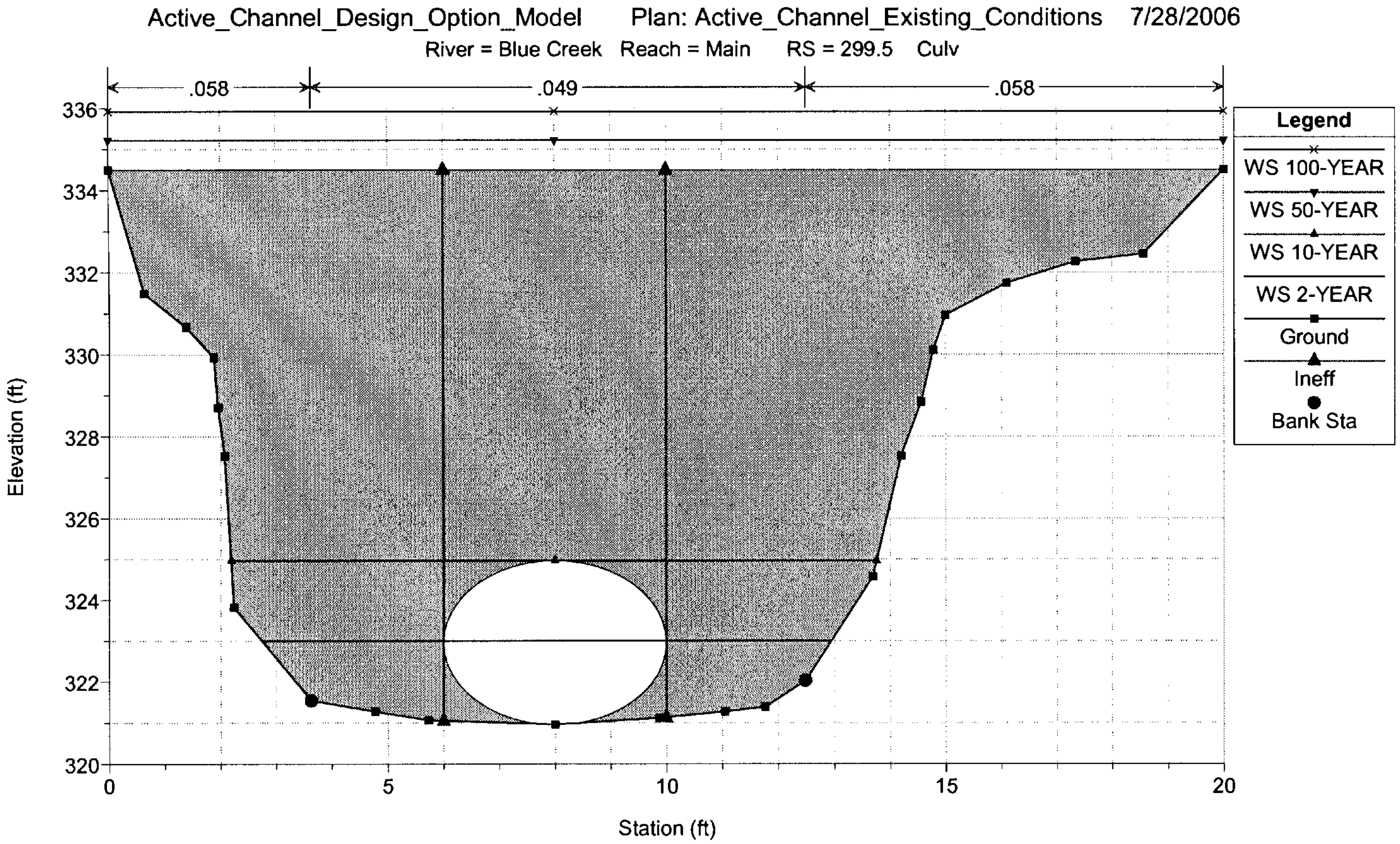

Active_Channel_Design_Option_Model Plan: Active_Channel_Existing_Conditions 7/28/2006
River = Blue Creek Reach = Main RS = 600
.058
.049
.058
Elevation (ft)
338
336
334
332
330
328
326
324
322
0
5
10
15
20
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
Ground
Bank Sta

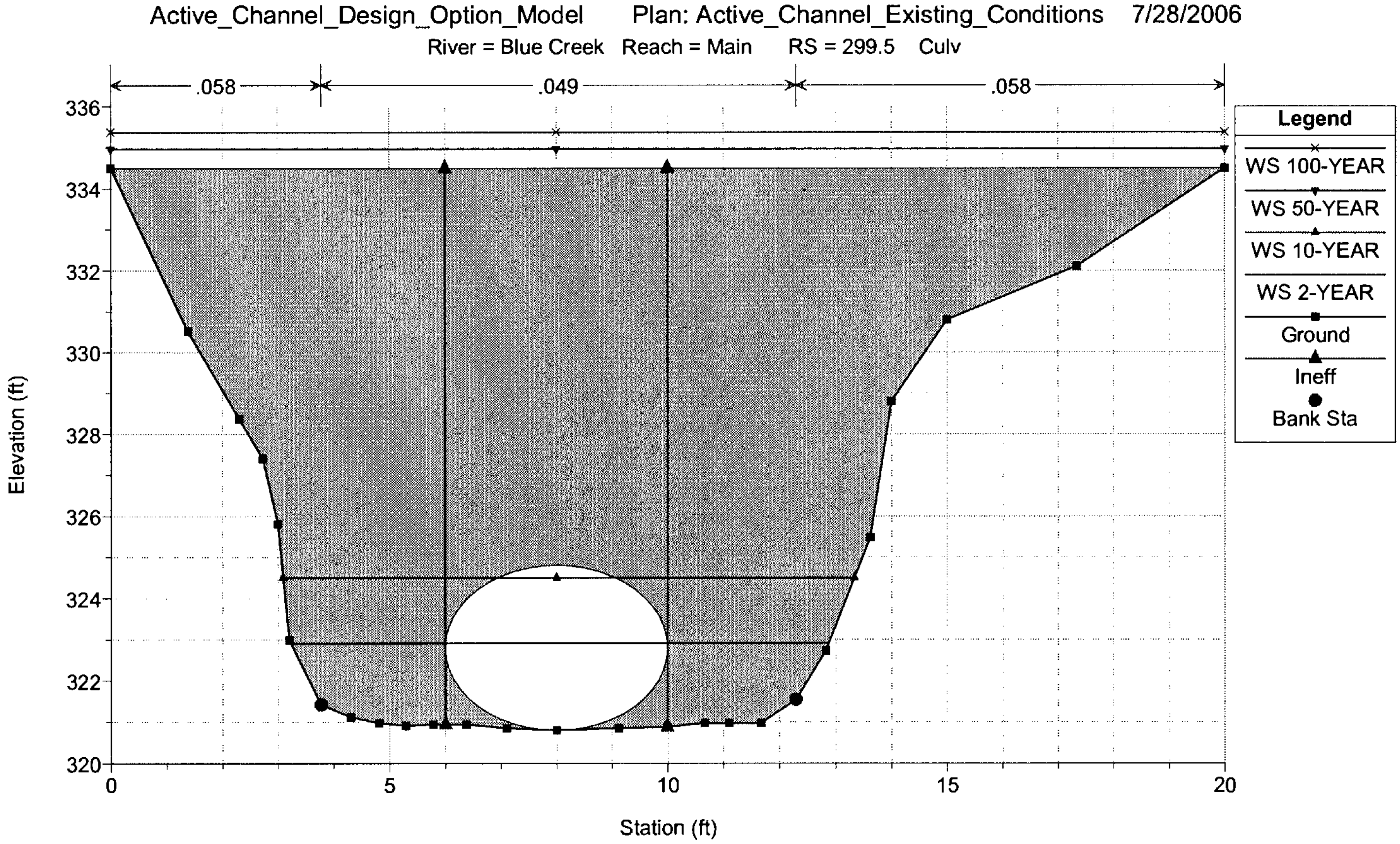

Active_Channel_Design_Option_Model Plan: Active_Channel_Existing_Conditions 7/28/2006
River = Blue Creek Reach = Main RS = 500
.058
.049
.058
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
Ground
Bank Sta
Elevation (ft)
338
336
334
332
330
328
326
324
322
320
0
5
10
15
20
Station (ft)

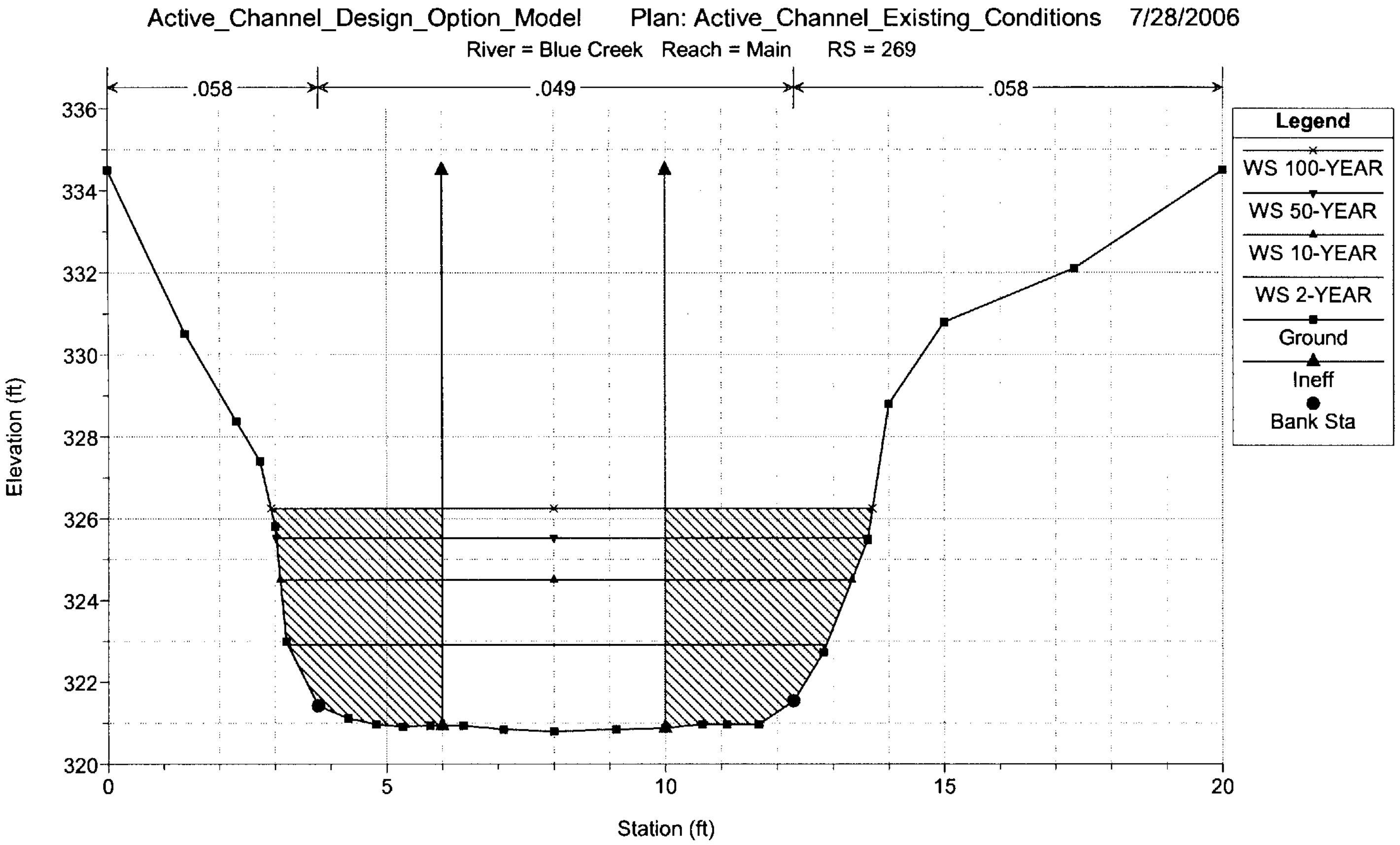

Active_Channel_Design_Option_Model Plan: Active_Channel_Existing_Conditions 7/28/2006
River = Blue Creek Reach = Main RS = 400
.058
.049
.058
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
Ground
Bank Sta
Elevation (ft)
338
336
334
332
330
328
326
324
322
320
0
5
10
15
20
Station (ft)

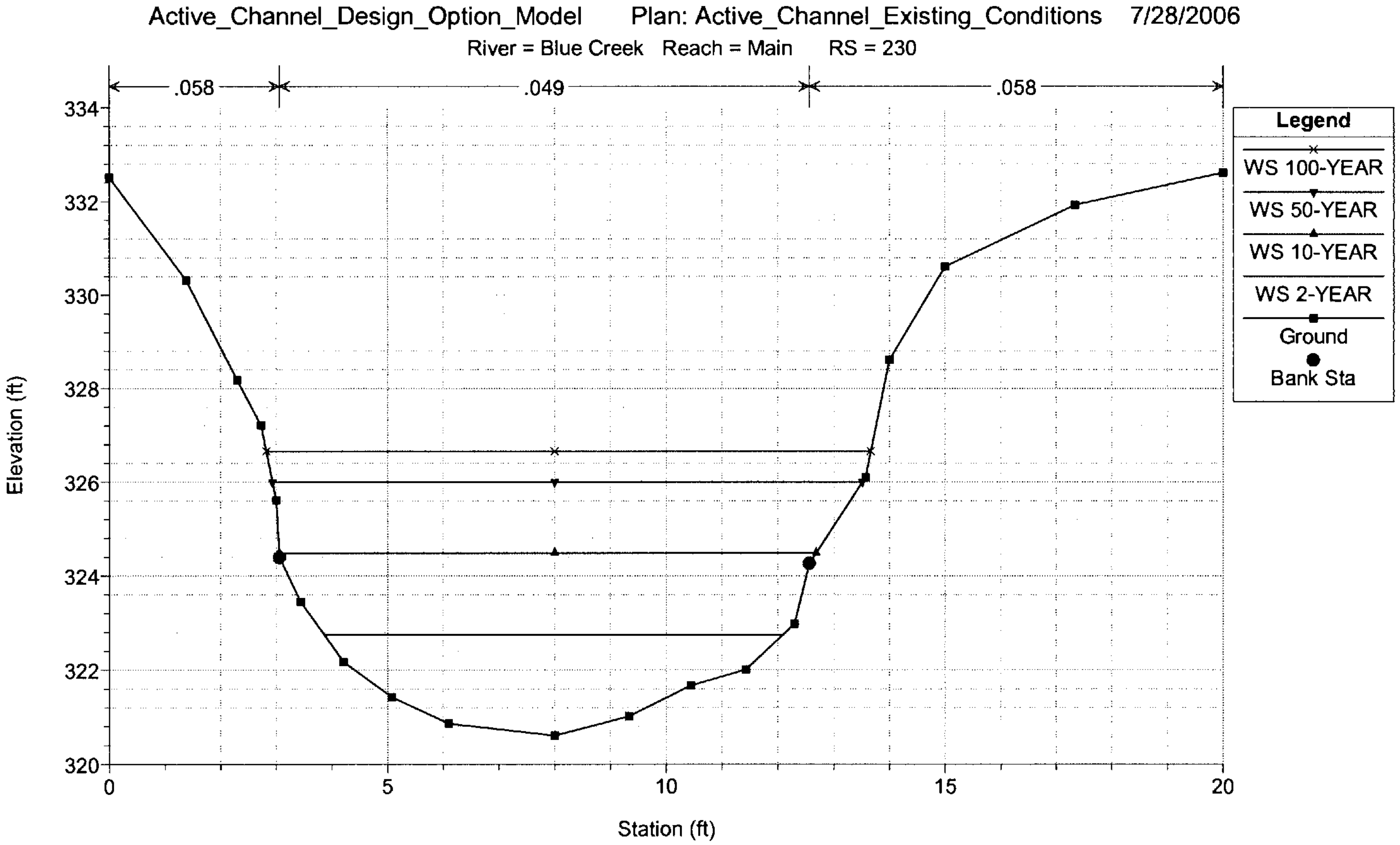

Active_Channel_Design_Option_Model Plan: Active_Channel_Existing_Conditions 7/28/2006
River = Blue Creek Reach = Main RS = 350
.058
.049
.058
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
Ground
Bank Sta
Elevation (ft)
338
336
334
332
330
328
326
324
322
320
0
5
10
15
20
Station (ft)

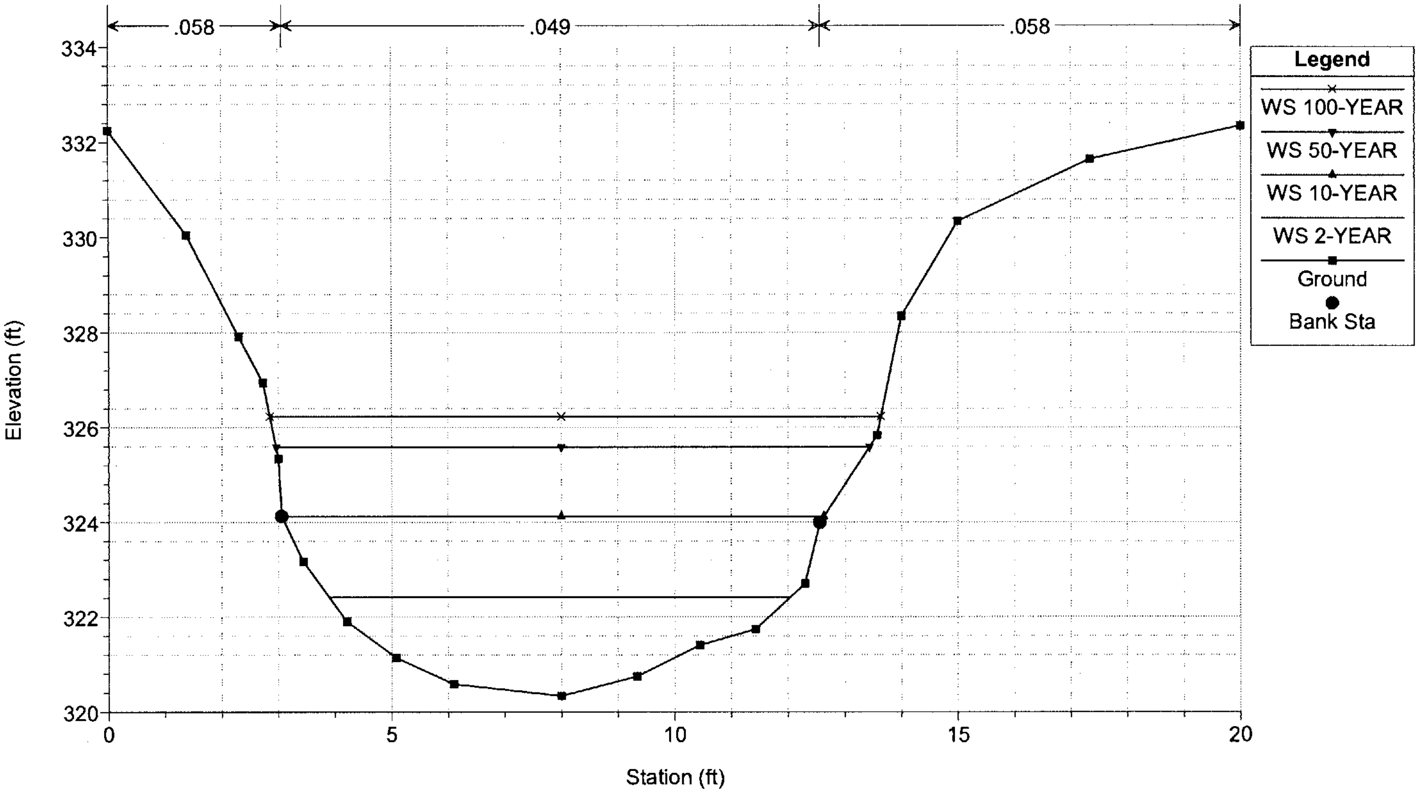

Active_Channel_Design_Option_Model Plan: Active_Channel_Existing_Conditions 7/28/2006
River = Blue Creek Reach = Main RS = 300
.058
.049
.058
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
Ground
Ineff
Bank Sta
Elevation (ft)
336
334
332
330
328
326
324
322
320
0
5
10
15
20
Station (ft)

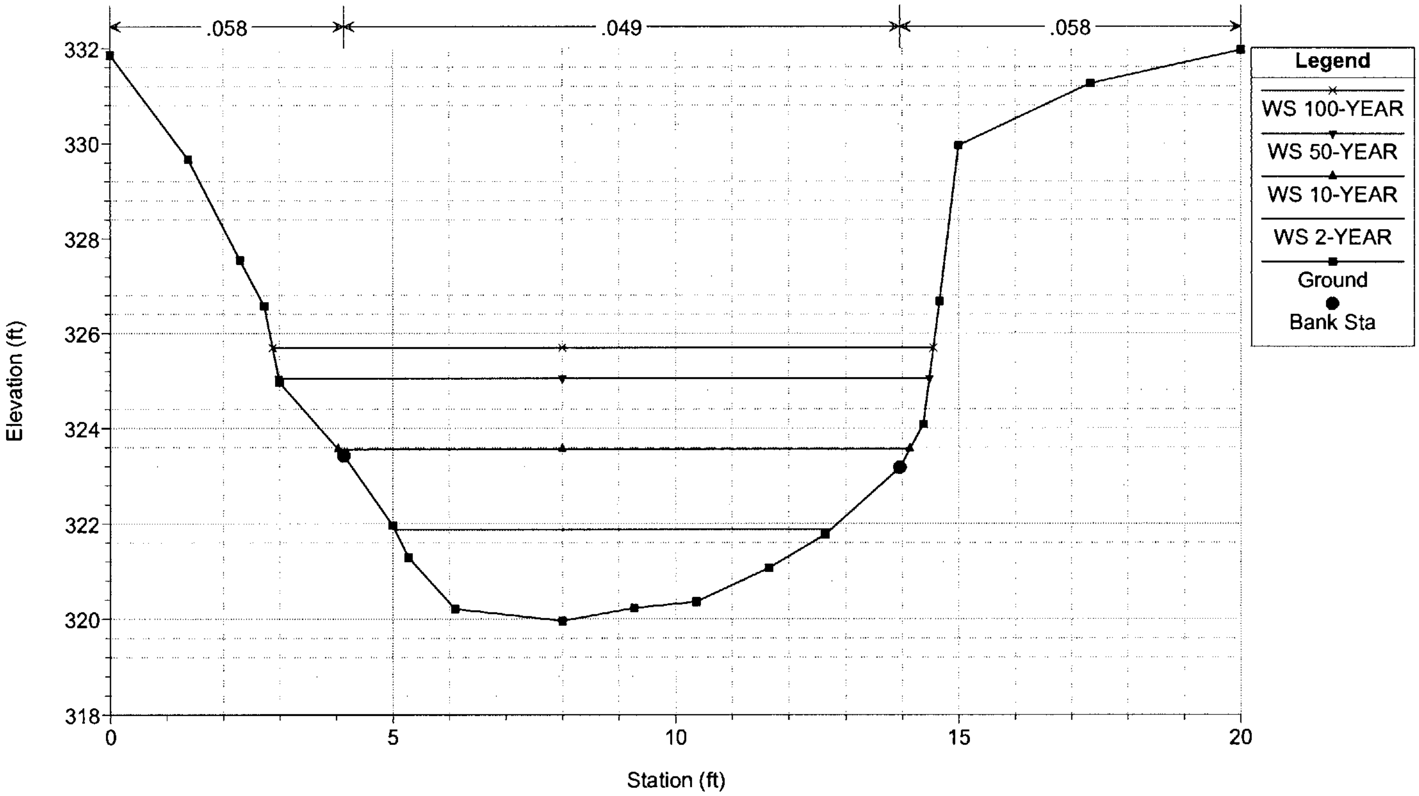

Active_Channel_Design_Option_Model Plan: Active_Channel_Existing_Conditions 7/28/2006
River = Blue Creek Reach = Main RS = 299.5 Culv
.058
.049
.058
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
Ground
Ineff
Bank Sta
Elevation (ft)
336
334
332
330
328
326
324
322
320
0
5
10
15
20
Station (ft)

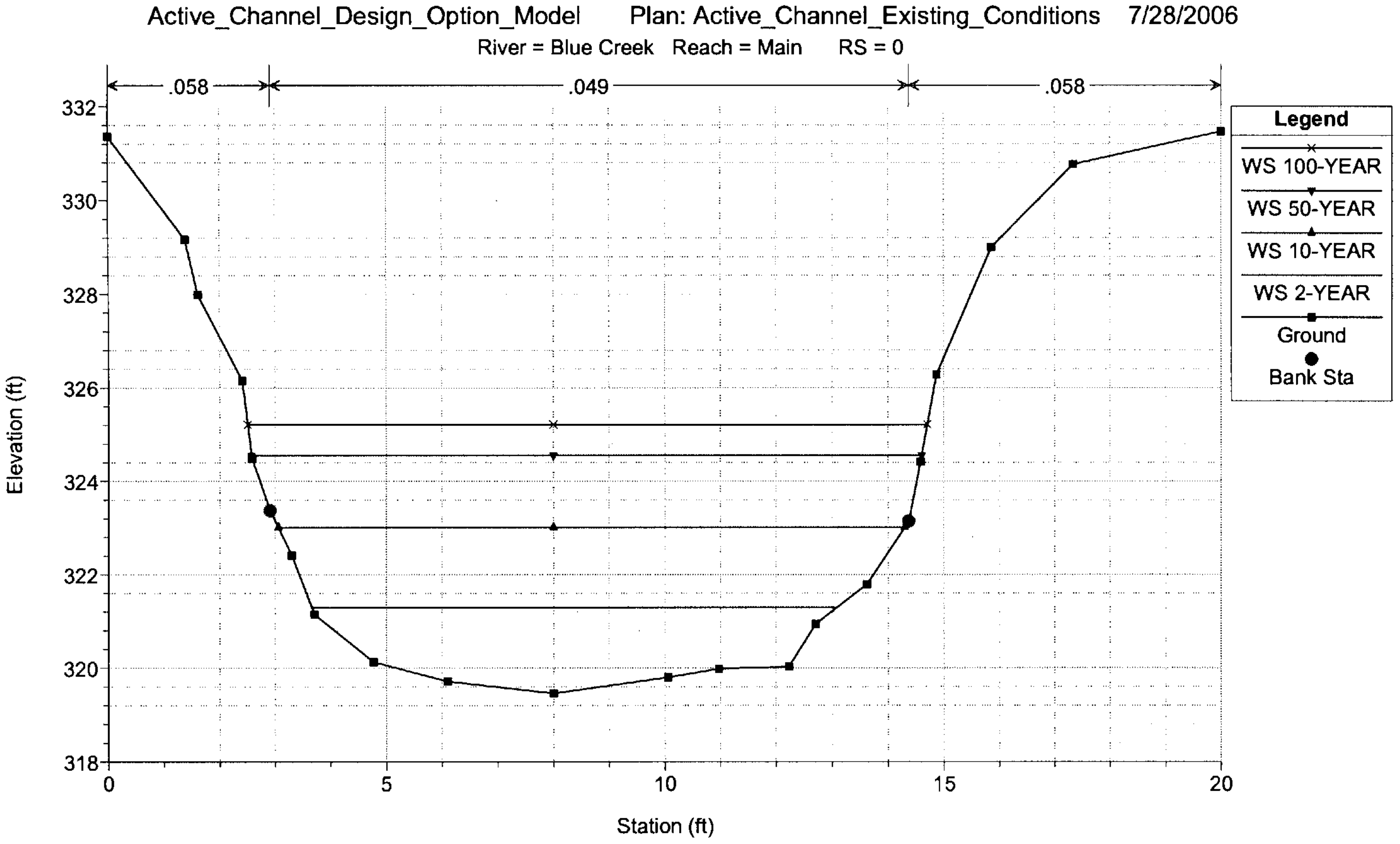

Active_Channel_Design_Option_Model Plan: Active_Channel_Existing_Conditions 7/28/2006
River = Blue Creek Reach = Main RS = 299.5 Culv
.058
.049
.058
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
Ground
Ineff
Bank Sta
Elevation (ft)
336
334
332
330
328
326
324
322
320
0
5
10
15
20
Station (ft)


Active_Channel_Design_Option_Model Plan: Active_Channel_Existing_Conditions 7/28/2006
River = Blue Creek Reach = Main RS = 269
.058
.049
.058
Elevation (ft)
336
334
332
330
328
326
324
322
320
0
5
10
15
20
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
Ground
Ineff
Bank Sta


Active_Channel_Design_Option_Model Plan: Active_Channel_Existing_Conditions 7/28/2006
River = Blue Creek Reach = Main RS = 230
.058
.049
.058
Elevation (ft)
334
332
330
328
326
324
322
320
0
5
10
15
20
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
Ground
Bank Sta


Active_Channel_Design_Option_Model Plan: Active_Channel_Existing_Conditions 7/28/2006
River = Blue Creek Reach = Main RS = 175


Active_Channel_Design_Option_Model Plan: Active_Channel_Existing_Conditions 7/28/2006
River = Blue Creek Reach = Main RS = 100


Active_Channel_Design_Option_Model Plan: Active_Channel_Existing_Conditions 7/28/2006
River = Blue Creek Reach = Main RS = 0
.058
.049
.058
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
Ground
Bank Sta
Elevation (ft)
332
330
328
326
324
322
320
318
0
5
10
15
20
Station (ft)

HEC-RAS Plan: Existing Conditions River: Blue Creek

River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Water Depth (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
0	2-YEAR	30	319.46	321.3	1.84	320.56	321.39	0.00501	2.38	12.59	9.43	0.36
0	10-YEAR	106	319.46	323.01	3.55	321.55	323.2	0.005003	3.48	30.43	11.24	0.37
0	50-YEAR	222	319.46	324.55	5.09	322.55	324.88	0.005004	4.61	48.45	12.03	0.4
0	100-YEAR	284	319.46	325.22	5.76	323	325.62	0.005005	5.09	56.5	12.2	0.41
100	2-YEAR	30	319.96	321.88	1.92		322.01	0.007684	2.89	10.38	7.71	0.44
100	10-YEAR	106	319.96	323.56	3.6		323.83	0.00751	4.17	25.45	10.1	0.46
100	50-YEAR	222	319.96	325.05	5.09		325.52	0.007114	5.5	41.64	11.49	0.48
100	100-YEAR	284	319.96	325.7	5.74		326.26	0.007048	6.04	49.14	11.67	0.49
175	2-YEAR	30	320.34	322.42	2.08		322.53	0.006232	2.68	11.21	8.15	0.4
175	10-YEAR	106	320.34	324.12	3.78		324.37	0.006817	4.01	26.47	9.57	0.42
175	50-YEAR	222	320.34	325.59	5.25		326.05	0.00723	5.47	41.18	10.48	0.47
175	100-YEAR	284	320.34	326.23	5.89		326.8	0.00736	6.06	48.02	10.79	0.48
230	2-YEAR	30	320.61	322.75	2.14		322.85	0.005507	2.56	11.7	8.23	0.38
230	10-YEAR	106	320.61	324.49	3.88		324.72	0.006061	3.87	27.42	9.63	0.4
230	50-YEAR	222	320.61	326	5.39		326.43	0.006497	5.3	42.62	10.58	0.45
230	100-YEAR	284	320.61	326.65	6.04	324.64	327.19	0.006646	5.88	49.63	10.84	0.46
269	2-YEAR	30	320.8	322.91	2.11	322.06	323.12	0.00554	3.65	8.23	9.66	0.45
269	10-YEAR	106	320.8	324.5	3.7	323.65	325.32	0.01029	7.27	14.57	10.25	0.67
269	50-YEAR	222	320.8	325.53	4.73	325.43	327.72	0.019696	11.88	18.69	10.61	0.97
269	100-YEAR	284	320.8	326.25	5.45	326.25	328.94	0.020024	13.17	21.56	10.78	1
299.5		Culvert										
300	2-YEAR	30	320.96	323.49	2.53	322.22	323.64	0.003021	3.04	9.87	10.74	0.34
300	10-YEAR	106	320.96	326.74	5.78	323.82	327.08	0.002292	4.63	22.87	11.96	0.34
300	50-YEAR	222	320.96	335.22	14.26	325.59	335.25	0.000084	1.58	189.64	20	0.07
300	100-YEAR	284	320.96	335.93	14.97	326.41	335.98	0.000115	1.91	203.75	20	0.09
350	2-YEAR	30	321.21	323.71	2.5		323.75	0.001604	1.6	18.73	10.04	0.21
350	10-YEAR	106	321.21	327.1	5.89		327.16	0.000634	1.96	56.63	11.91	0.15
350	50-YEAR	222	321.21	335.23	14.02		335.26	0.000107	1.51	177.93	18.12	0.07
350	100-YEAR	284	321.21	335.93	14.72		335.98	0.000146	1.82	190.93	18.6	0.09
400	2-YEAR	30	321.46	323.8	2.34		323.86	0.002694	1.94	15.46	8.59	0.25
400	10-YEAR	106	321.46	327.13	5.67		327.2	0.000969	2.17	50.6	11.89	0.17
400	50-YEAR	222	321.46	335.23	13.77		335.27	0.000135	1.57	169.54	18.03	0.08
400	100-YEAR	284	321.46	335.94	14.48		335.99	0.000183	1.89	182.52	18.54	0.09
500	2-YEAR	30	321.96	324.1	2.14		324.17	0.00353	2.15	13.96	8.63	0.3
500	10-YEAR	106	321.96	327.23	5.27		327.31	0.001227	2.34	46.71	11.87	0.2
500	50-YEAR	222	321.96	335.24	13.28		335.28	0.00015	1.63	161.92	17.85	0.08
500	100-YEAR	284	321.96	335.96	14		336.01	0.0002	1.96	174.86	18.41	0.1
600	2-YEAR	30	322.46	324.5	2.04		324.59	0.004884	2.38	12.63	8.24	0.34
600	10-YEAR	106	322.46	327.36	4.9		327.47	0.001804	2.61	40.95	10.71	0.23
600	50-YEAR	222	322.46	335.26	12.8		335.3	0.000184	1.73	150.47	17.63	0.09
600	100-YEAR	284	322.46	335.97	13.51		336.04	0.000244	2.07	163.36	18.25	0.1
800	2-YEAR	30	323.46	325.51	2.05	324.7	325.6	0.005295	2.39	12.54	8.58	0.35
800	10-YEAR	106	323.46	327.77	4.31	325.72	327.92	0.00278	3.21	35.49	11.29	0.29
800	50-YEAR	222	323.46	335.29	11.83	326.81	335.35	0.000257	2.04	136.92	17	0.11
800	100-YEAR	284	323.46	336.02	12.56	327.29	336.1	0.000335	2.42	149.59	17.81	0.12

Plan: Existing Blue Creek Main RS: 299.5 Culv Group: Culvert #1 Profile: 2-YEAR

Q Culv Group (cfs)	30.00	Culv Full Len (ft)	
# Barrels	1	Culv Vel US (ft/s)	4.63
Q Barrel (cfs)	30.00	Culv Vel DS (ft/s)	4.45
E.G. US. (ft)	323.64	Culv Inv El Up (ft)	320.96
W.S. US. (ft)	323.49	Culv Inv El Dn (ft)	320.80
E.G. DS (ft)	323.12	Culv Frctn Ls (ft)	0.12
W.S. DS (ft)	322.91	Culv Exit Loss (ft)	0.10
Delta EG (ft)	0.52	Culv Entr Loss (ft)	0.30
Delta WS (ft)	0.58	Q Weir (cfs)	
E.G. IC (ft)	323.36	Weir Sta Lft (ft)	
E.G. OC (ft)	323.64	Weir Sta Rgt (ft)	
Culvert Control	Outlet	Weir Submerg	
Culv WS Inlet (ft)	323.01	Weir Max Depth (ft)	
Culv WS Outlet (ft)	322.91	Weir Avg Depth (ft)	
Culv Nml Depth (ft)	1.91	Weir Flow Area (sq ft)	
Culv Crt Depth (ft)	1.62	Min El Weir Flow (ft)	334.51

Plan: Existing Blue Creek Main RS: 299.5 Culv Group: Culvert #1 Profile: 10-YEAR

Q Culv Group (cfs)	106.00	Culv Full Len (ft)	1.95
# Barrels	1	Culv Vel US (ft/s)	8.44
Q Barrel (cfs)	106.00	Culv Vel DS (ft/s)	8.73
E.G. US. (ft)	327.08	Culv Inv El Up (ft)	320.96
W.S. US. (ft)	326.74	Culv Inv El Dn (ft)	320.80
E.G. DS (ft)	325.32	Culv Frctn Ls (ft)	0.40
W.S. DS (ft)	324.50	Culv Exit Loss (ft)	0.36
Delta EG (ft)	1.75	Culv Entr Loss (ft)	0.99
Delta WS (ft)	2.24	Q Weir (cfs)	
E.G. IC (ft)	327.04	Weir Sta Lft (ft)	
E.G. OC (ft)	327.08	Weir Sta Rgt (ft)	
Culvert Control	Outlet	Weir Submerg	
Culv WS Inlet (ft)	324.96	Weir Max Depth (ft)	
Culv WS Outlet (ft)	324.50	Weir Avg Depth (ft)	
Culv Nml Depth (ft)	4.00	Weir Flow Area (sq ft)	
Culv Crt Depth (ft)	3.12	Min El Weir Flow (ft)	334.51

Errors Warnings and Notes

Note:	The normal depth exceeds the height of the culvert. The program assumes that the normal
	depth is equal to the height of the culvert.

Plan: Existing Blue Creek Main RS: 299.5 Culv Group: Culvert #1 Profile: 50-YEAR

Q Culv Group (cfs)	186.22	Culv Full Len (ft)	
# Barrels	1	Culv Vel US (ft/s)	14.82
Q Barrel (cfs)	186.22	Culv Vel DS (ft/s)	20.43
E.G. US. (ft)	335.25	Culv Inv El Up (ft)	320.96
W.S. US. (ft)	335.22	Culv Inv El Dn (ft)	320.80
E.G. DS (ft)	327.72	Culv Frctn Ls (ft)	2.18
W.S. DS (ft)	325.53	Culv Exit Loss (ft)	2.28
Delta EG (ft)	7.53	Culv Entr Loss (ft)	3.07
Delta WS (ft)	9.69	Q Weir (cfs)	35.78
E.G. IC (ft)	335.25	Weir Sta Lft (ft)	0.00
E.G. OC (ft)	333.33	Weir Sta Rgt (ft)	20.00
Culvert Control	Inlet	Weir Submerg	0.00
Culv WS Inlet (ft)	324.96	Weir Max Depth (ft)	0.78
Culv WS Outlet (ft)	323.52	Weir Avg Depth (ft)	0.78
Culv Nml Depth (ft)	4.00	Weir Flow Area (sq ft)	15.59
Culv Crt Depth (ft)	4.00	Min El Weir Flow (ft)	334.51

Errors Warnings and Notes

Warning:	The flow through the culvert is supercritical. However, since there is flow over the road (weir flow), the program cannot determine if the downstream cross section should be subcritical or supercritical. The program used the downstream subcritical answer, even though it may not be valid.
Warning:	During the supercritical analysis, the program could not converge on a supercritical answer in the downstream cross section. The program used the solution with the least error.
Note:	The normal depth exceeds the height of the culvert. The program assumes that the normal depth is equal to the height of the culvert.
Note:	Culvert critical depth exceeds the height of the culvert.
Note:	The flow in the culvert is entirely supercritical.

Plan: Existing Blue Creek Main RS: 299.5 Culv Group: Culvert #1 Profile: 100-YEAR

Q Culv Group (cfs)	191.68	Culv Full Len (ft)	30.00
# Barrels	1	Culv Vel US (ft/s)	15.25
Q Barrel (cfs)	191.68	Culv Vel DS (ft/s)	15.25
E.G. US. (ft)	335.98	Culv Inv El Up (ft)	320.96
W.S. US. (ft)	335.93	Culv Inv El Dn (ft)	320.80
E.G. DS (ft)	328.94	Culv Frctn Ls (ft)	2.86
W.S. DS (ft)	326.25	Culv Exit Loss (ft)	0.92
Delta EG (ft)	7.03	Culv Entr Loss (ft)	3.25
Delta WS (ft)	9.68	Q Weir (cfs)	92.32
E.G. IC (ft)	335.98	Weir Sta Lft (ft)	0.00
E.G. OC (ft)	335.80	Weir Sta Rgt (ft)	20.00
Culvert Control	Inlet	Weir Submerg	0.00
Culv WS Inlet (ft)	324.96	Weir Max Depth (ft)	1.47
Culv WS Outlet (ft)	324.80	Weir Avg Depth (ft)	1.47
Culv Nml Depth (ft)	4.00	Weir Flow Area (sq ft)	29.32
Culv Crt Depth (ft)	4.00	Min El Weir Flow (ft)	334.51

Errors Warnings and Notes

Note:	The normal depth exceeds the height of the culvert. The program assumes that the normal
	depth is equal to the height of the culvert.
Note:	Culvert critical depth exceeds the height of the culvert.
Note:	During the supercritical calculations a hydraulic jump occurred inside of the culvert.

Form 6A - Active Channel Design Option

Form 6A provides guidance to correctly select the active channel width while satisfying traffic safety, hydraulic impacts and scour concerns.

For this particular example, the average active channel width was measured at 5.3 feet. The culvert width is required to be 1.5 times the average active channel width; therefore, the proposed culvert width is 8 feet in diameter. By placing the culvert at the required 0% slope, the culvert inlet and outlet was embedded meeting the required embedment depth requirements. Although no specific species, depth, or velocity criteria had to be met, hydraulic analyses for hydraulic impacts and scour were satisfied.

FISH PASSAGE: ACTIVE CHANNEL DESIGN OPTION — FORM 6A

Project Information Route 888 4-Lane		Computed: EKB	Date: 5/6/06
		Checked: JJL	Date: 5/8/06
Stream Name: Blue Creek	County: Sacramento	Route: 888	Postmile: 67.2

Hydrology Results - Peak Discharge Values

50% Annual Probability (2-Year Flood Event)	30 cfs	10% Annual Probability (10-Year Flood Event)	106 cfs
2% Annual Probability (50-Year Flood Event)	222 cfs	1% Annual Probability (100-Year Flood Event)	284 cfs

Establish Culvert Setting and Dimensions

Culvert Width - The minimum culvert width shall be equal to, or greater than, 1.5 times the average active channel width.

Average Active Channel Width = 5.3 ft	Average Active Channel Width 5.3 X 1.5 = 7.95 ft	Culvert Width = 8.0 ft

Culvert Length - Must be less than 100 feet.

Culvert Length = 68 ft

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

Upstream Embedment = 1.94 ft (≤ then 40% of culvert rise) 24% of Culvert rise

Downstream Embedment = 1.60 ft (≥ 20% of culvert rise) 20% of Culvert rise

Culvert Slope - The culvert shall be placed level (0% slope).

Upstream invert elevation = 319.02 ft	Downstream invert elevation = 319.02 ft

Summarize Proposed Culvert Physical Characterstics

Inlet Characteristics

Inlet Type	☐ Projecting	☒ Headwall	☐ Wingwall
	☐ Flared end section	☐ Segment connection	☐ Skew Angle: °

Barrel Characteristics

Diameter: 96 in	Fill height above culvert: ~7.5 ft
Height/Rise: — ft	Length: 68 ft

FISH PASSAGE: ACTIVE CHANNEL DESIGN OPTION

FORM 6A

Width/Span:	— ft	Number of barrels:	1
Culvert Type	☐ Arch ☐ Pipe-Arch	☐ Box ☐ Elliptical	☒ Circular
Culvert Material	☐ HDPE ☐ Spiral Rib / Corrugated Metal Pipe	☐ Steel Plate Pipe	☒ Concrete Pipe
Horizontal alignment breaks:	NONE ft	Vertical alignment breaks:	NONE ft

Outlet Characteristics

Outlet Type	☐ Projecting ☐ Flared end section	☒ Headwall ☐ Segment connection	☐ Wingwall Skew Angle: °

Summarize Proposed Bridge Physical Characterstics N/A

Bridge Physical Characteristics

Elevation of high chord (top of road):	ft	Elevation of low chord:	ft
Channel Lining	☐ No lining	☐ Concrete	☐ Rock	Channel Lining
Skew Angle:	°	Bridge width (length):	ft

Pier Characteristics (if applicable) ☐

Number of Piers:	ft	Upstream cross-section starting station:	ft
Pier Width:	ft	Downstream cross-section starting station:	ft
Pier Centerline Spacing:	ft	Skew angle:	°
Pier Shape	☐ Square nose and tail ☐ Twin-cylinder piers with connecting diaphragm	☐ Semi-circular nose and tail ☐ Twin-cylinder piers without connecting diaphragm	☐ 90° triangular nose and tail ☐ Ten pile trestle bent

Maximum Allowable Inlet Water Surface Elevation

Culvert

A culvert is required to pass the 10-year peak discharge without causing pressure flow in the culvert,	Allowable WSEL: 327.02 ft
And shall not be greater than 50% of the culvert height or diameter above the top of the culvert inlet for the 100-Year peak flood.	Allowable WSEL: 331.02 ft

FISH PASSAGE: ACTIVE CHANNEL DESIGN OPTION — FORM 6A

Bridge N/A

A bridge is required to pass the 50-year peak discharge with freeboard, vertical clearance between the lowest structural member and the water surface elevation,	Allowable WSEL: ft
While passing the 100-year peak or design discharge under low chord of bridge.	Allowable WSEL: ft

Establish Allowable Hydraulic Impacts

Is the crossing located within a floodplain as designated by the Federal Emergency Management Agency or another responsible state or local agency?
☐ Yes ☒ No

If yes, establish allowable hydraulic impacts and hydraulic design requirements with the appropriate agency. Attach results.

Will the project result in the increase capacity of an existing crossing? ☐ Yes ☒ No

If yes, will it significantly increase downstream peak flows due to the reduced upstream attenuation? ☐ Yes ☒ No

If yes, consult District Hydraulics. Further analysis may be needed.

Will the project result in a reduction in flow area for the 100-year peak discharge? ☐ Yes ☒ No

If yes, establish the allowable increase in upstream water surface elevation and establish how far upstream the increased water surface may extend.

Develop and run Hydraulic Models to compute water surface elevations, flow depths, and channel velocities for the 2-, 10-, 50-, and 100-year peak or design discharges reflecting existing and project conditions. ☒ Yes ☐ No

Evaluate computed water surface elevations, flow depths, and channel velocities. ☒ Yes ☐ No

Water surface elevation at inlet for the 10-year peak discharge: 327.02 **ft**

Does the water surface elevation exceed the allowable elevation? ☐ Yes ☒ No

If yes, modify design to comply and rerun hydraulic analyses to verfiy.

Maximum Culvert and Channel velocities at inlet and outlet transition for the peak or design discharge: 100-Yr

Range of velocities for Inlet transition:	5.09	ft/s	to	—	ft/s
Range of velocities for Culvert portion:	5.45	ft/s	to	5.60	ft/s
Range of velocities for Outlet Transition:	6.02	ft/s	to	—	ft/s

Do the velocities exceed the permissible scour velocities? ☐ Yes ☒ No

If yes, revise design to reduce velocities and rerun hydraulic analyses to verfiy, or design erosion protection.

Comparison between existing and project future condition water surface elevations for the 10-Year and 100-Year peak flow:

Cross-Section	10-Yr WSEL	10-Yr WSEL	Difference	100-Year WSEL	100-Year WSEL	Difference
	Existing	Future	(ft)	Existing	Future	(ft)

FISH PASSAGE: ACTIVE CHANNEL DESIGN OPTION FORM 6A

	Conditions (ft)	Conditions (ft)		Conditions (ft)	Conditions (ft)	
1 230/175	324.49	324.12	-0.37	326.65	326.23	-0.42
2 269/231	324.50	324.40	-0.10	326.25	326.52	+0.27
3 300/300	326.74	324.75	-1.99	335.93	327.94	-7.99
4 350/350	327.10	324.90	-2.20	335.93	328.18	-7.75

If WSELs increase, does the increase exceed the maximum elevation? ☐ Yes ☒ No

Maximum elevation: ft

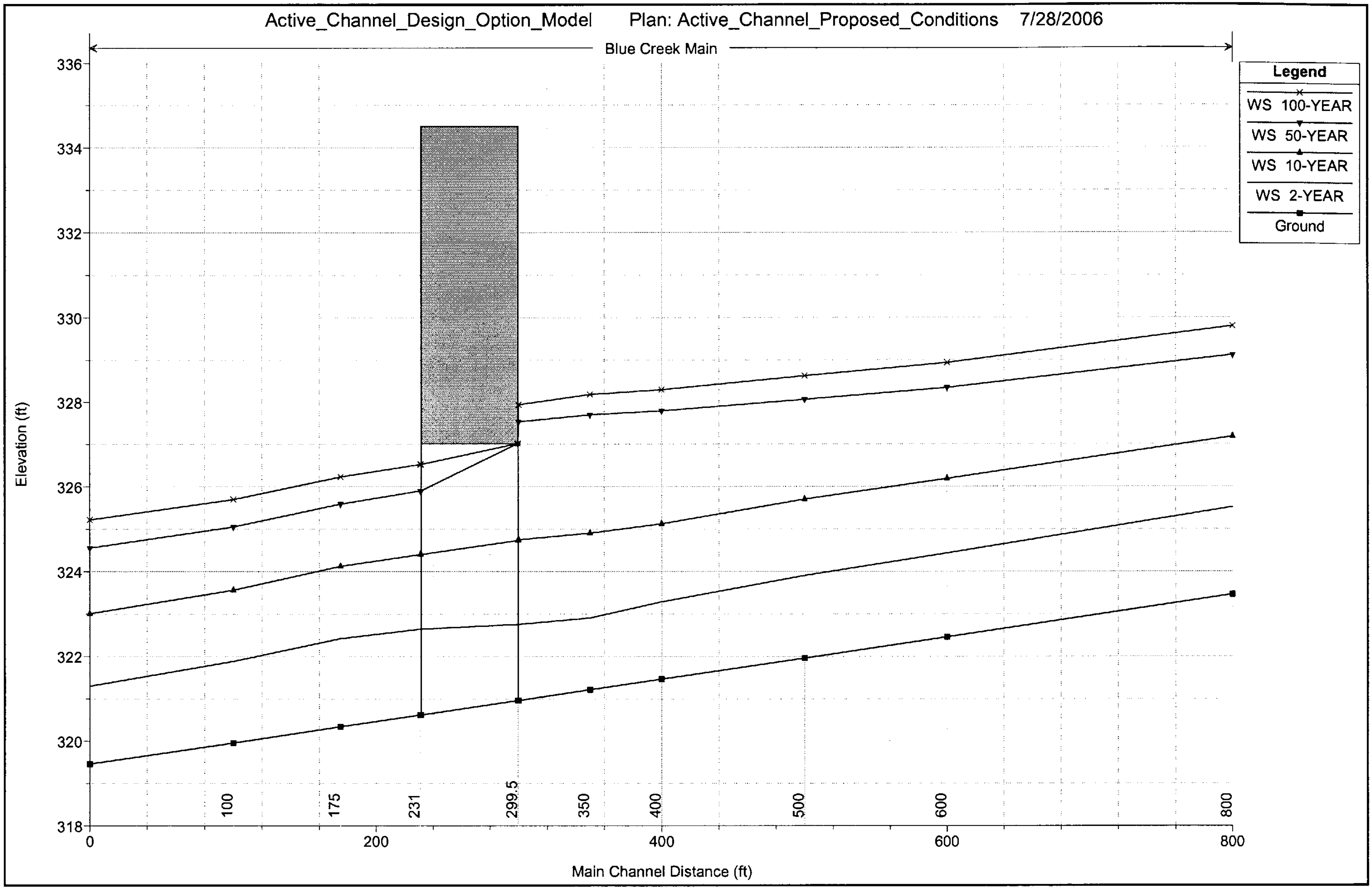
If yes, revise the design and rerun hydraulic analyses to verify.

If WSELs decrease, does it appear that the attenuation of peak flow will significally change? ☐ Yes ☒ No

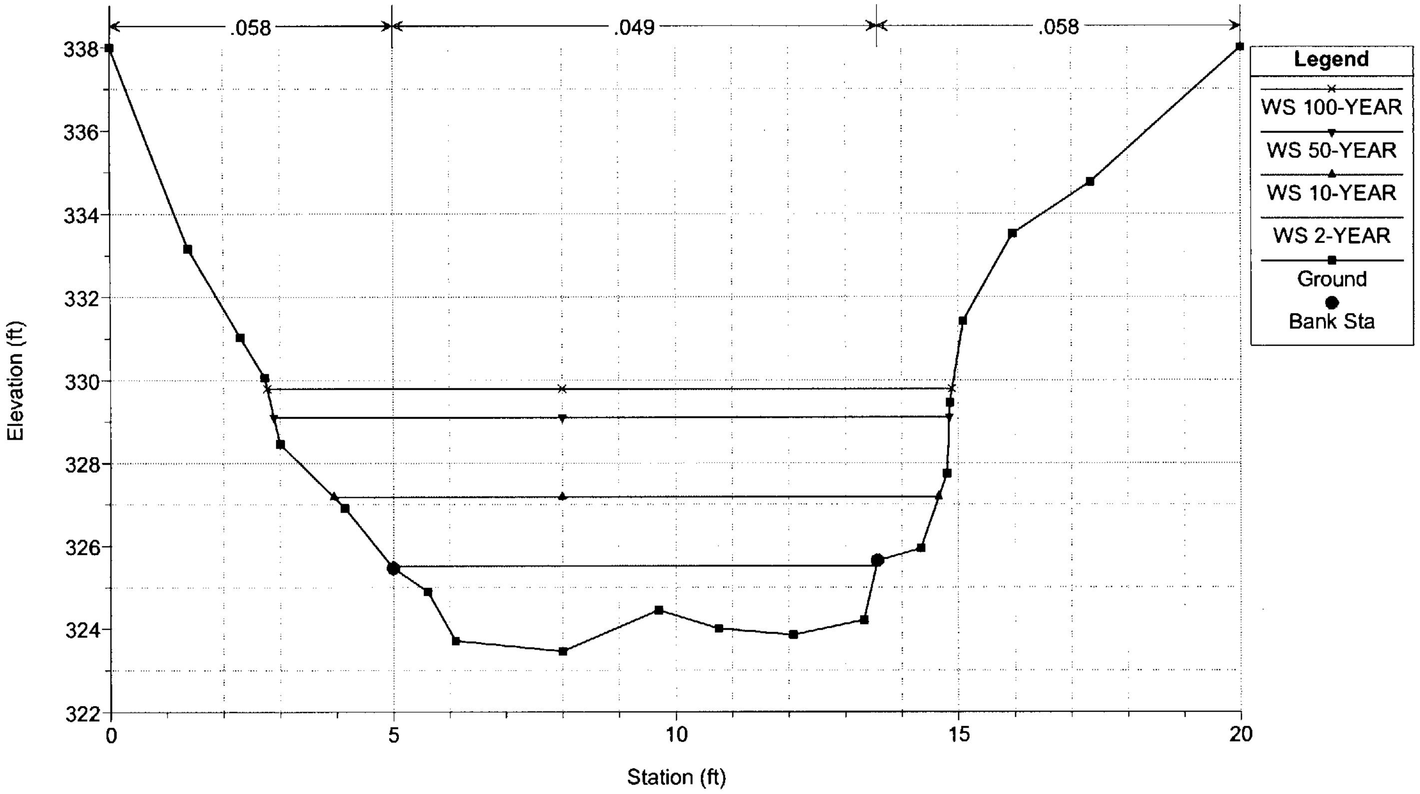
If yes, evaluate to determine if downstream hydraulic impacts are significant and modify design as appropriate.

Proposed Plan and Profile Drawing Attached ☒ Yes ☐ No

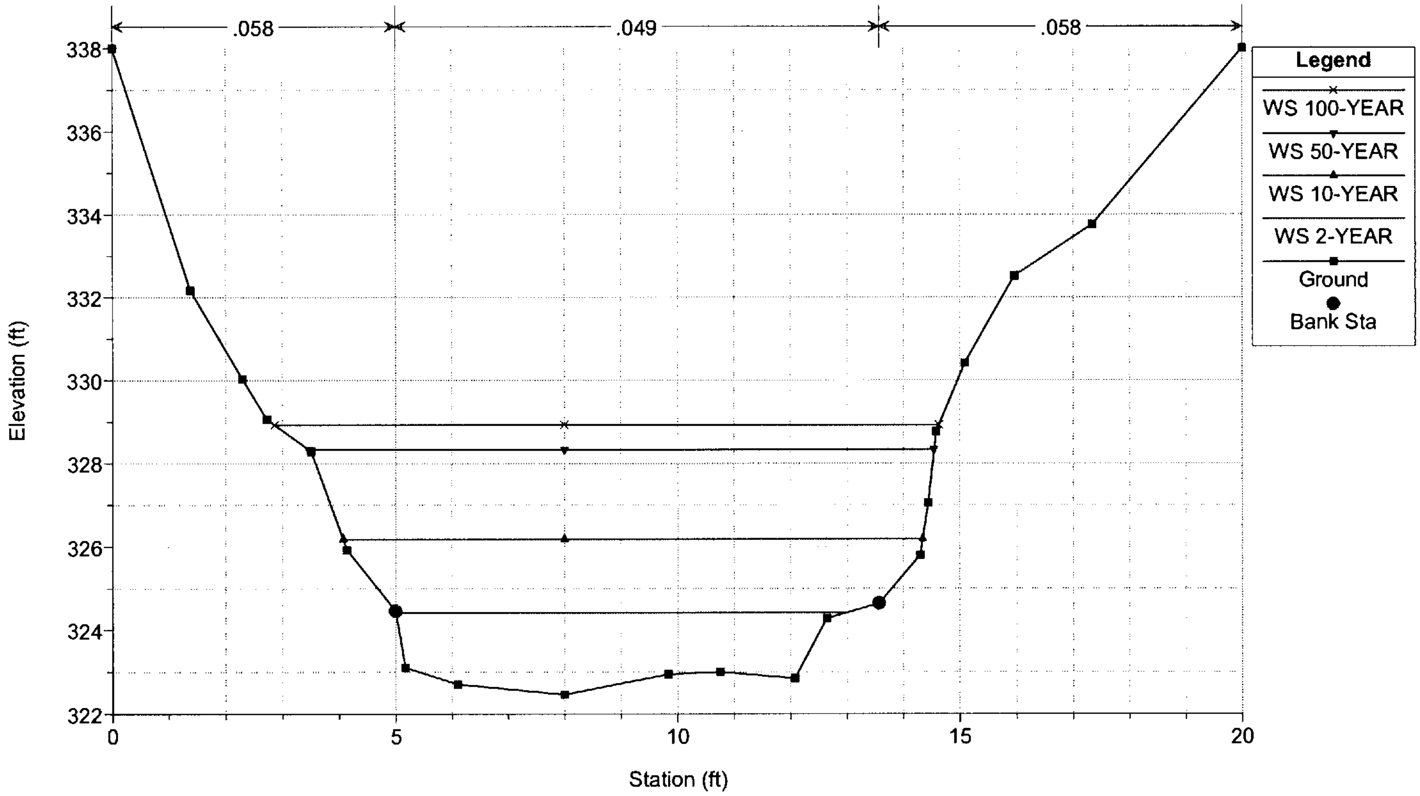
Hydraulic Analysis Index Sheet Attached ☒ Yes ☐ No



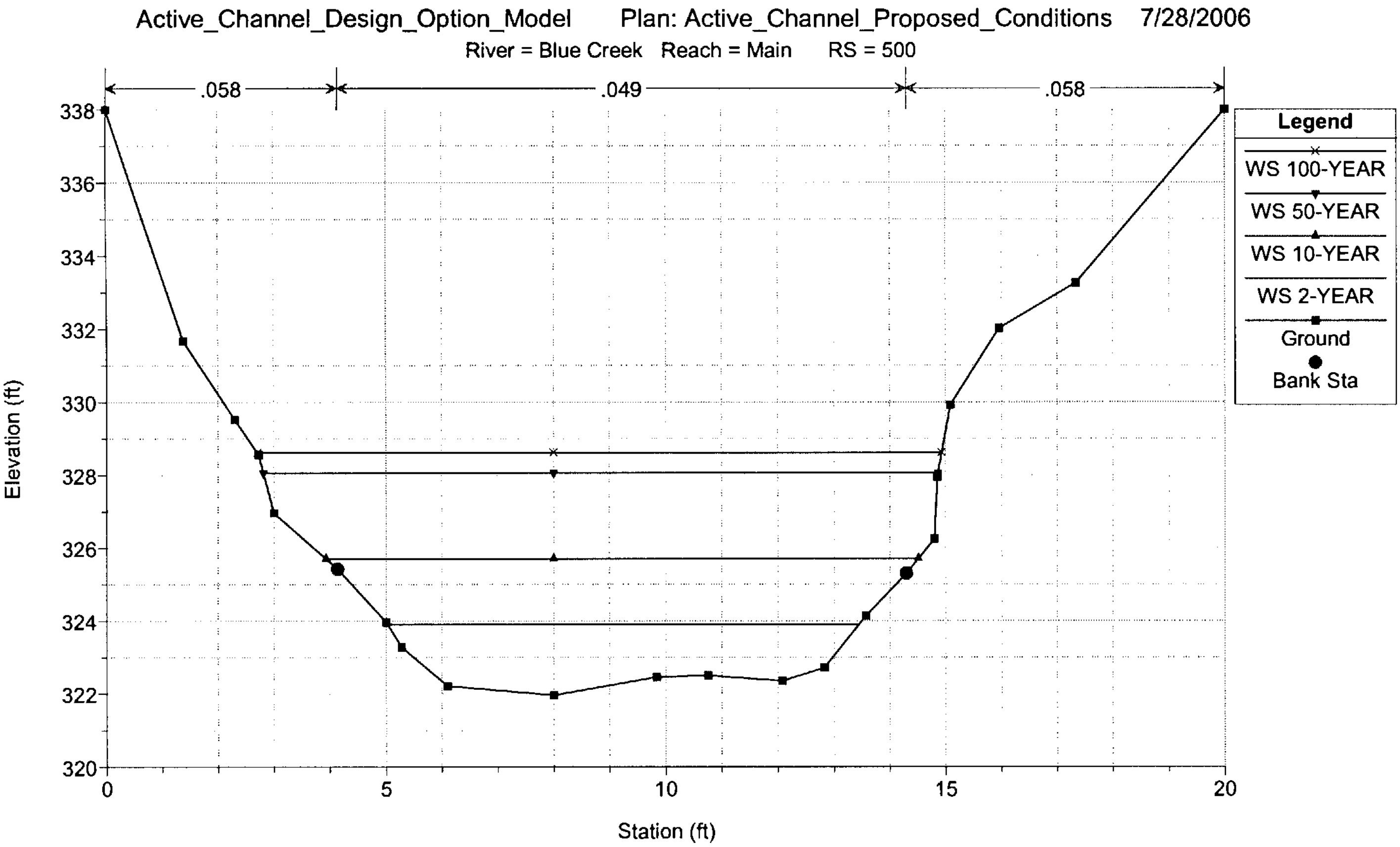
Active_Channel_Design_Option_Model Plan: Active_Channel_Proposed_Conditions 7/28/2006
Blue Creek Main
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
Ground
Elevation (ft)
336
334
332
330
328
326
324
322
320
318
100
175
231
299.5
350
400
500
600
800
0
200
400
600
800
Main Channel Distance (ft)

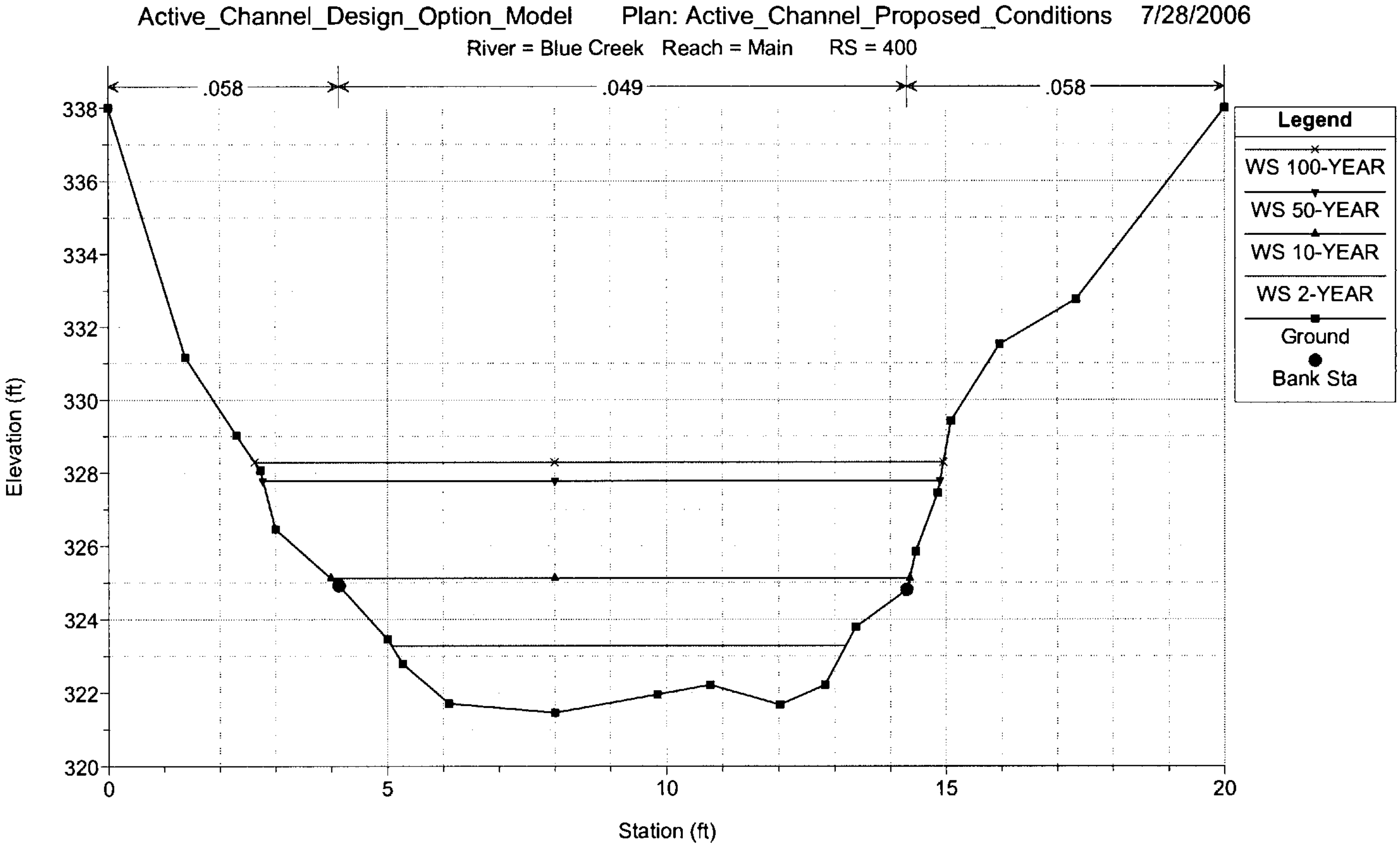


Active_Channel_Design_Option_Model Plan: Active_Channel_Proposed_Conditions 7/28/2006
River = Blue Creek Reach = Main RS = 800



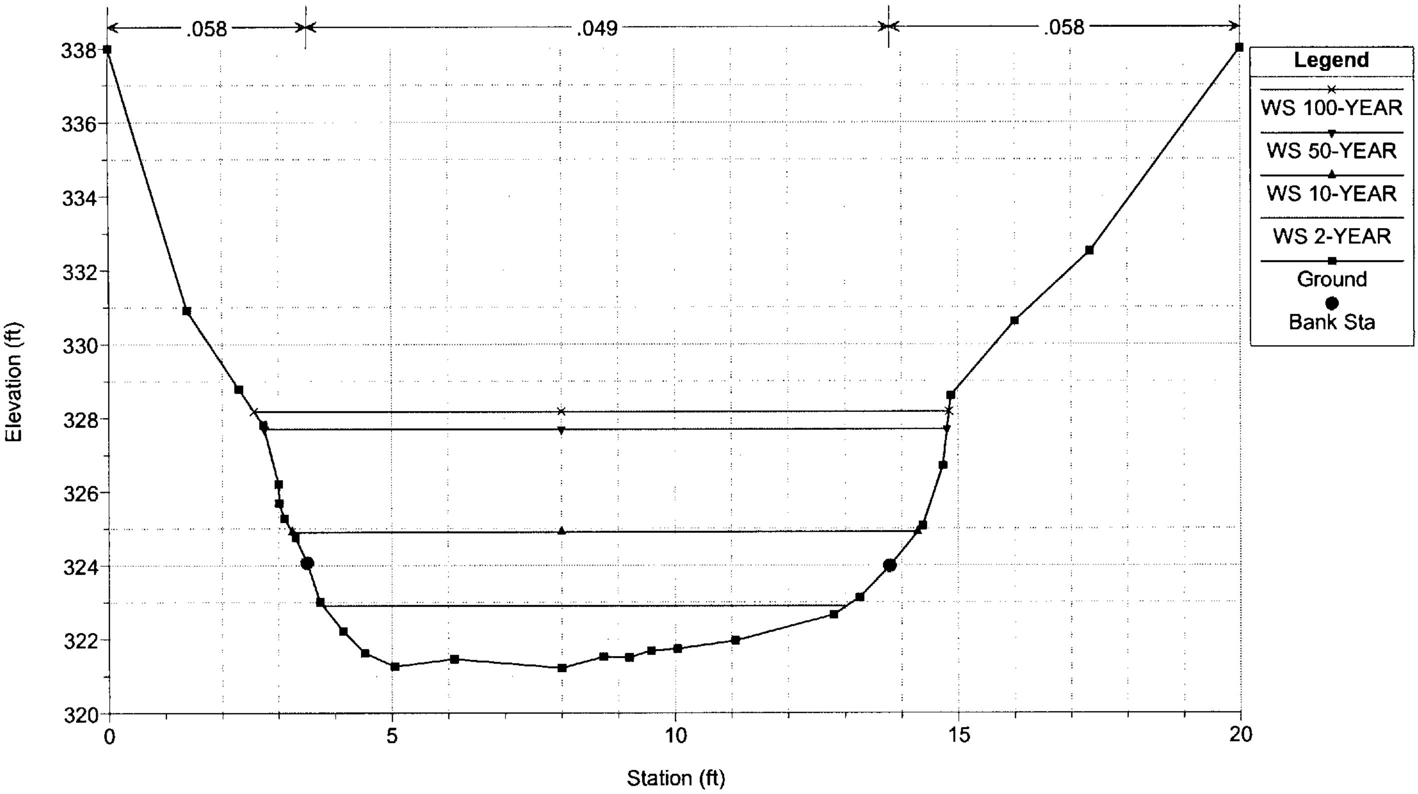
Active_Channel_Design_Option_Model Plan: Active_Channel_Proposed_Conditions 7/28/2006
River = Blue Creek Reach = Main RS = 600


Active_Channel_Design_Option_Model Plan: Active_Channel_Proposed_Conditions 7/28/2006
River = Blue Creek Reach = Main RS = 500


Active_Channel_Design_Option_Model Plan: Active_Channel_Proposed_Conditions 7/28/2006
River = Blue Creek Reach = Main RS = 400

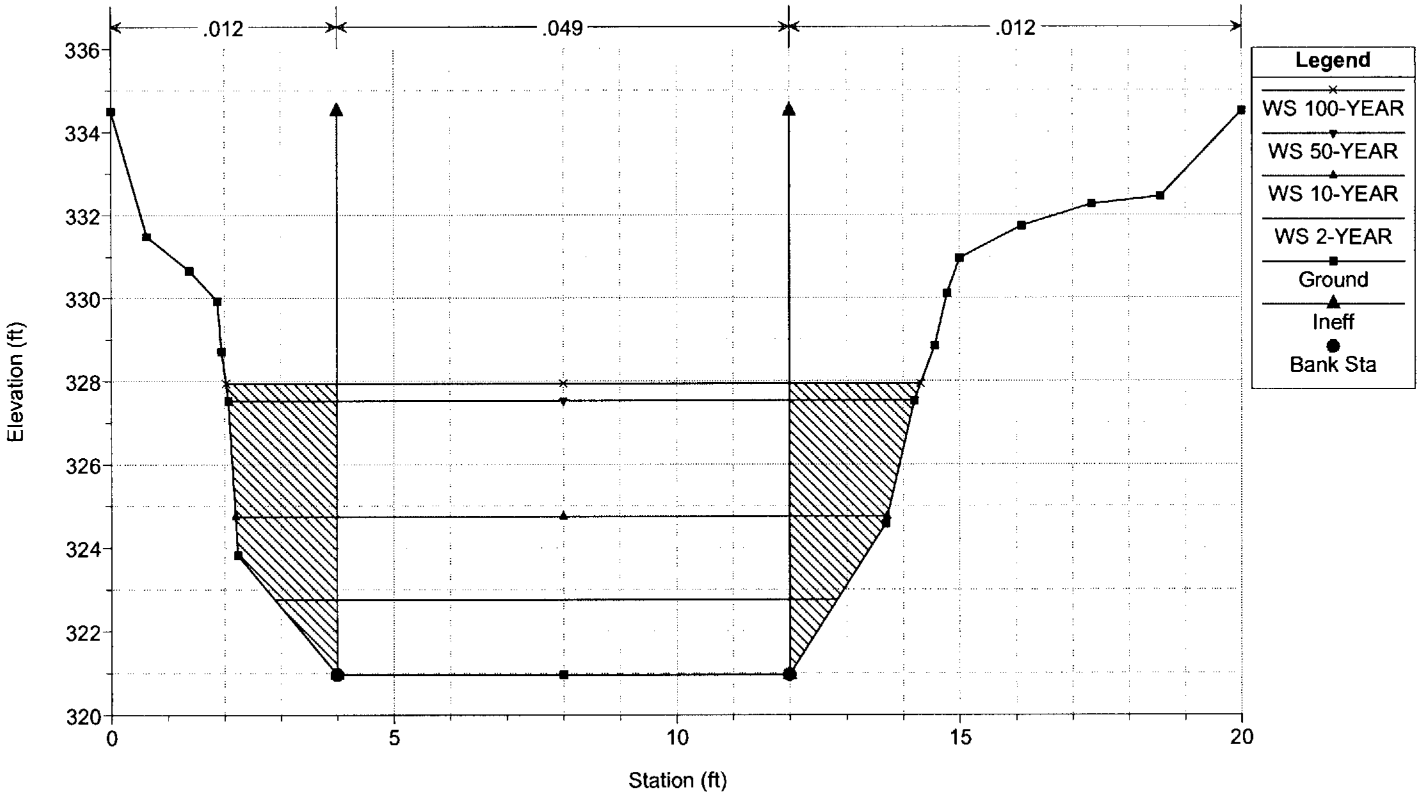
Active_Channel_Design_Option_Model Plan: Active_Channel_Proposed_Conditions 7/28/2006

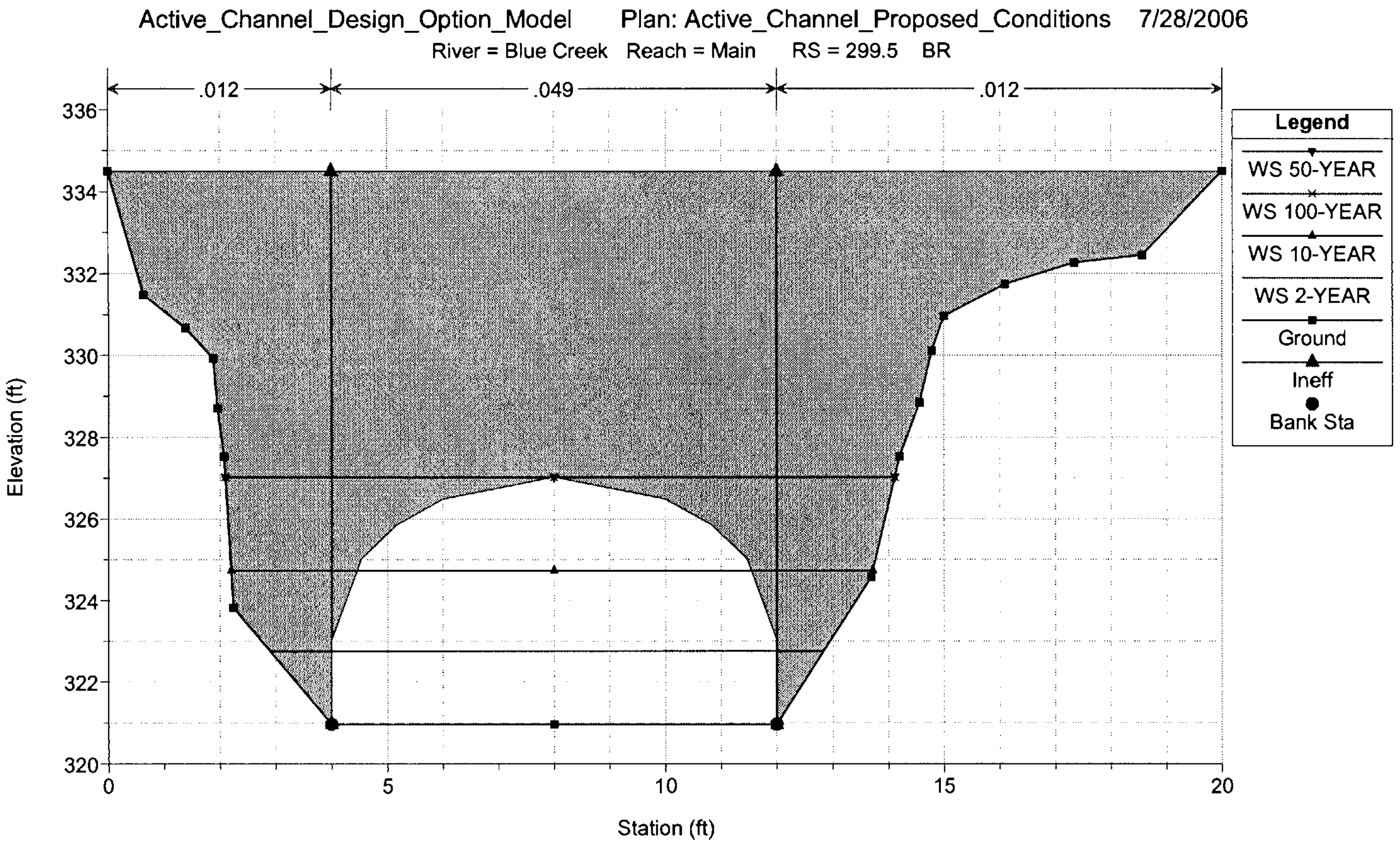
River = Blue Creek Reach = Main RS = 350



Active_Channel_Design_Option_Model Plan: Active_Channel_Proposed_Conditions 7/28/2006

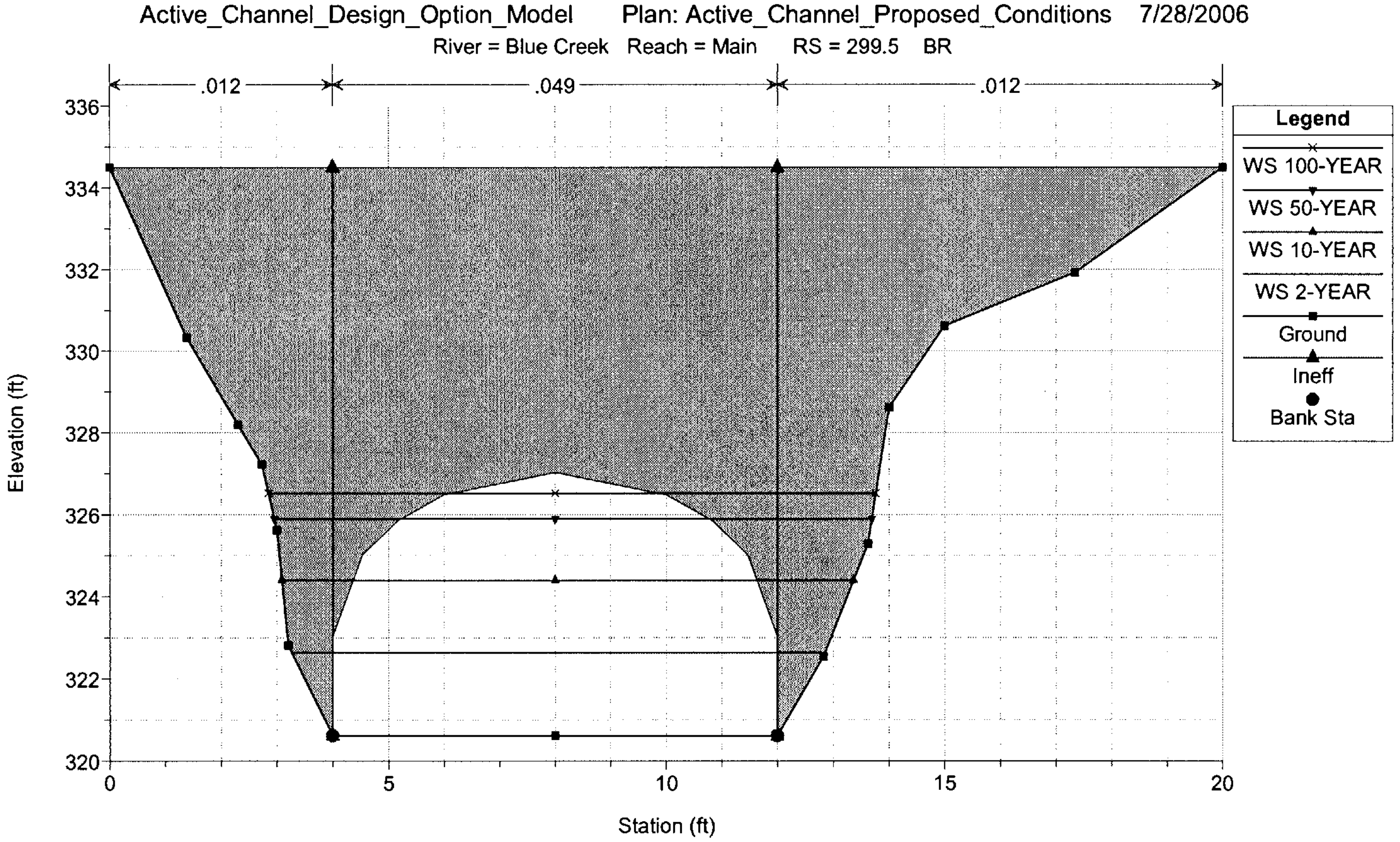
River = Blue Creek Reach = Main RS = 300





Active_Channel_Design_Option_Model Plan: Active_Channel_Proposed_Conditions 7/28/2006

River = Blue Creek Reach = Main RS = 299.5 BR

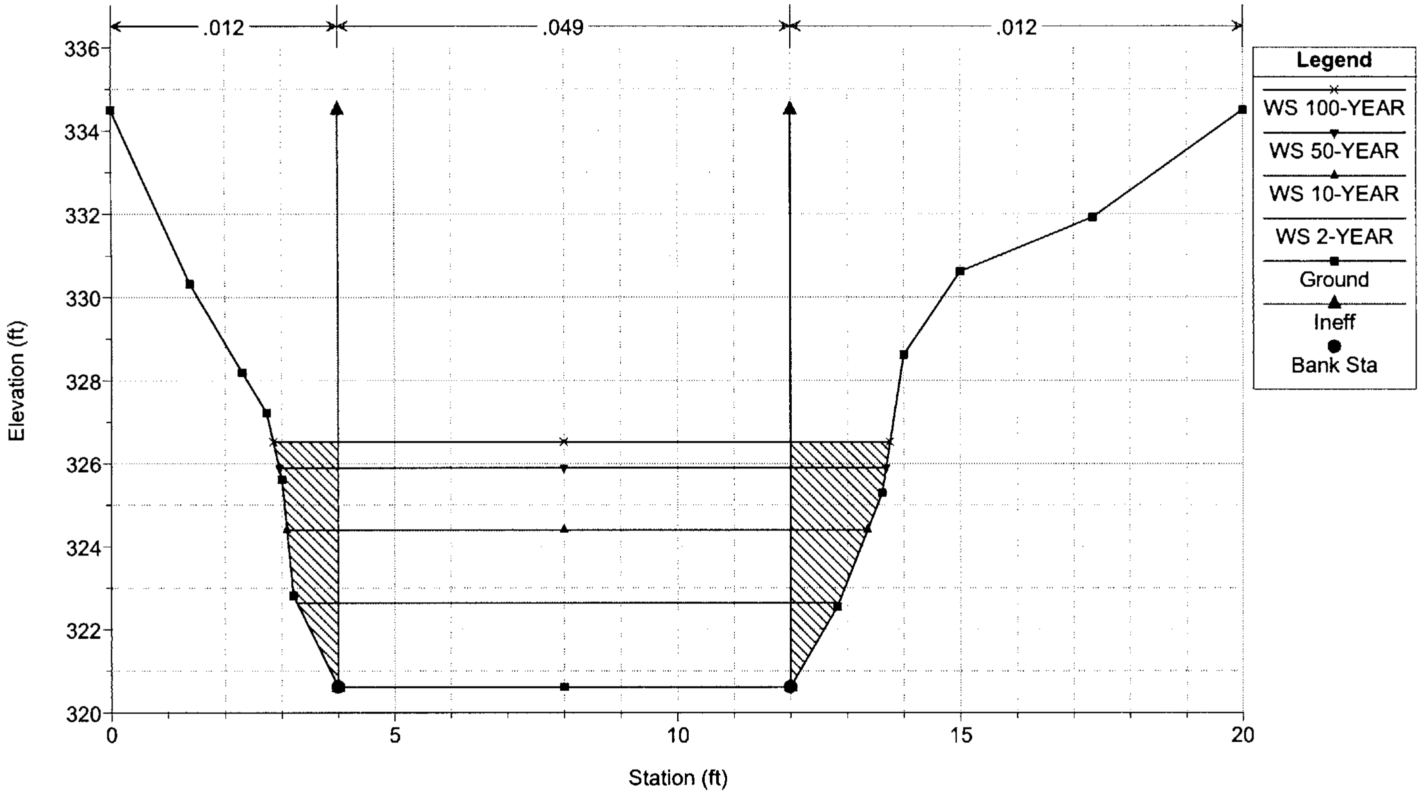


Active_Channel_Design_Option_Model Plan: Active_Channel_Proposed_Conditions 7/28/2006

River = Blue Creek Reach = Main RS = 299.5 BR

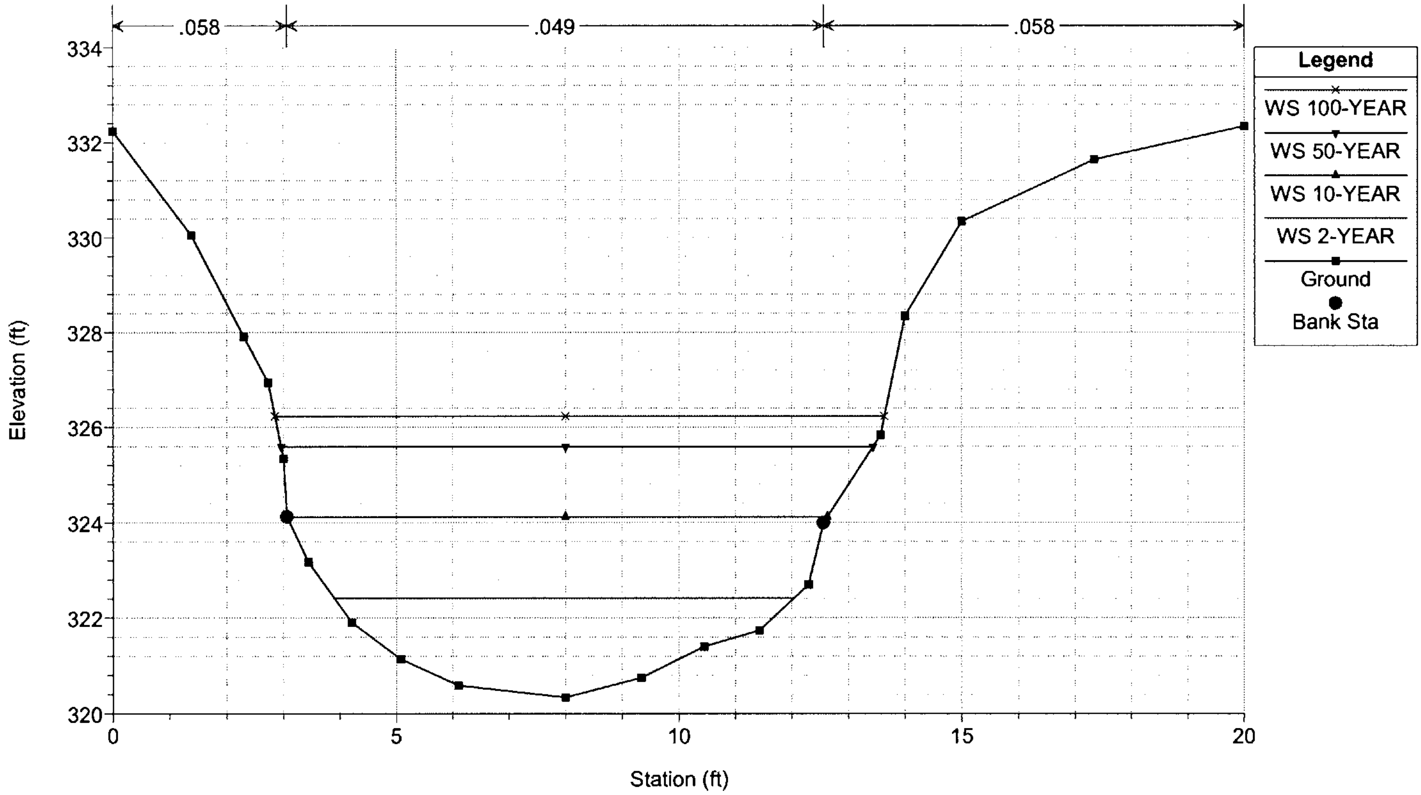
Active_Channel_Design_Option_Model Plan: Active_Channel_Proposed_Conditions 7/28/2006

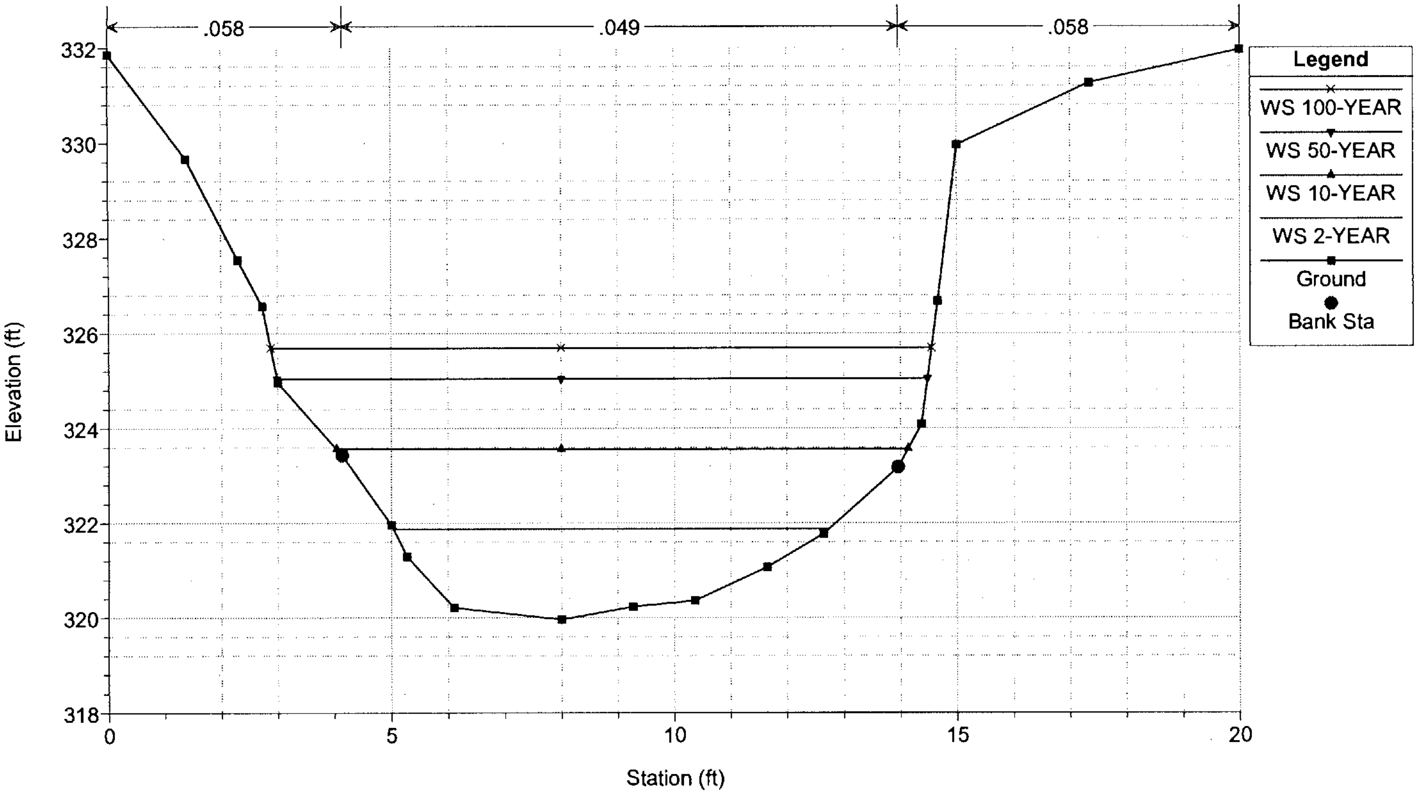
River = Blue Creek Reach = Main RS = 231



Active_Channel_Design_Option_Model Plan: Active_Channel_Proposed_Conditions 7/28/2006

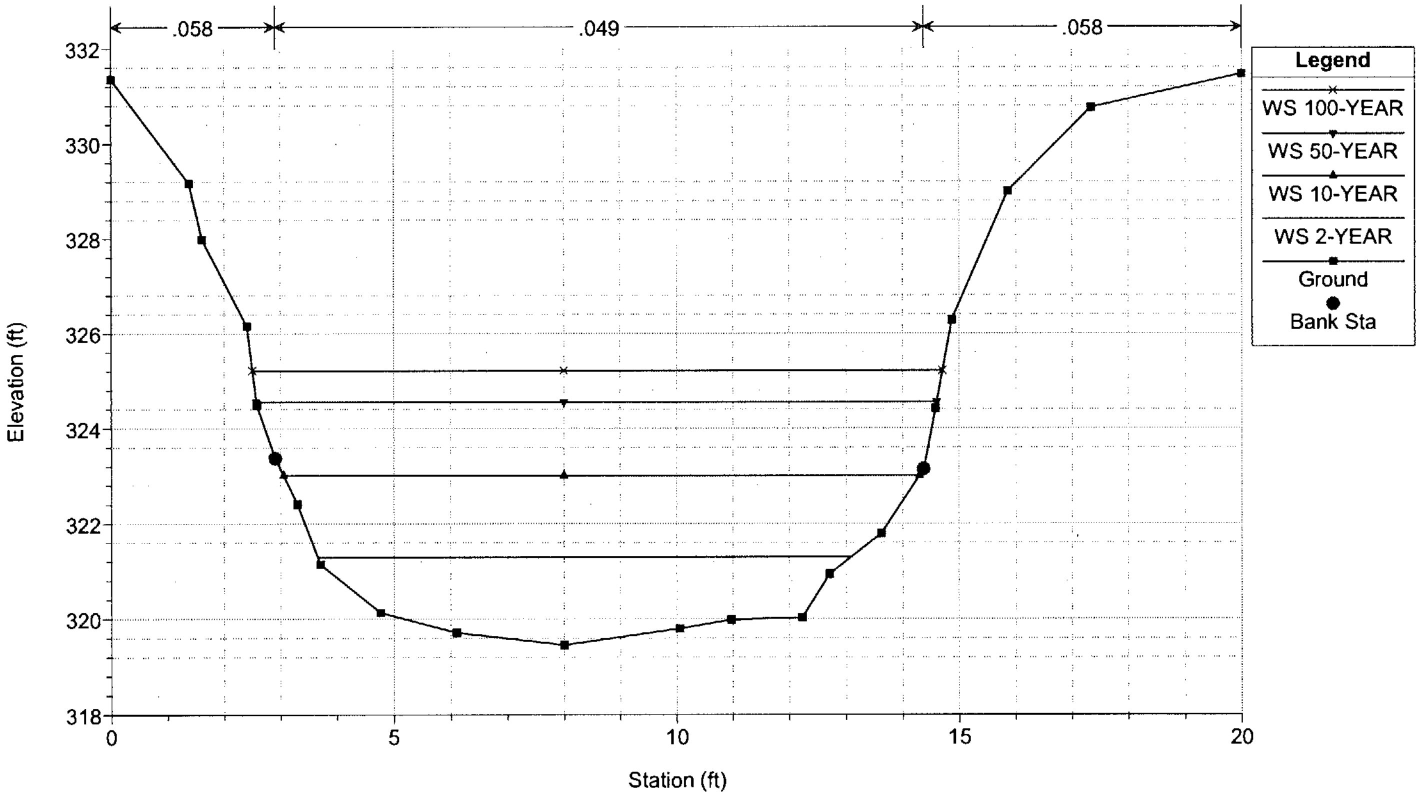
River = Blue Creek Reach = Main RS = 175





Active_Channel_Design_Option_Model Plan: Active_Channel_Proposed_Conditions 7/28/2006

River = Blue Creek Reach = Main RS = 100



Active_Channel_Design_Option_Model Plan: Active_Channel_Proposed_Conditions 7/28/2006

River = Blue Creek Reach = Main RS = 0

HEC-RAS Plan: Proposed Conditions River: Blue Creek

River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Water Depth (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
0	2-YEAR	30	319.46	321.3	1.84	320.56	321.39	0.00501	2.38	12.59	9.43	0.36
0	10-YEAR	106	319.46	323.01	3.55	321.55	323.2	0.005003	3.48	30.43	11.24	0.37
0	50-YEAR	222	319.46	324.55	5.09	322.55	324.88	0.005004	4.61	48.45	12.03	0.4
0	100-YEAR	284	319.46	325.22	5.76	323	325.62	0.005005	5.09	56.5	12.2	0.41
100	2-YEAR	30	319.96	321.88	1.92		322.01	0.007684	2.89	10.38	7.71	0.44
100	10-YEAR	106	319.96	323.56	3.6		323.83	0.007519	4.17	25.44	10.1	0.46
100	50-YEAR	222	319.96	325.05	5.09		325.52	0.007114	5.5	41.64	11.49	0.48
100	100-YEAR	284	319.96	325.7	5.74		326.26	0.007048	6.04	49.14	11.67	0.49
175	2-YEAR	30	320.34	322.42	2.08		322.53	0.006232	2.68	11.21	8.15	0.4
175	10-YEAR	106	320.34	324.12	3.78		324.37	0.006819	4.01	26.46	9.57	0.42
175	50-YEAR	222	320.34	325.59	5.25		326.05	0.00723	5.47	41.18	10.48	0.47
175	100-YEAR	284	320.34	326.23	5.89		326.8	0.00736	6.06	48.02	10.79	0.48
231	2-YEAR	30	320.62	322.64	2.02	321.38	322.7	0.00146	1.85	16.18	9.6	0.23
231	10-YEAR	106	320.62	324.4	3.78	322.37	324.59	0.002267	3.5	30.25	10.28	0.32
231	50-YEAR	222	320.62	325.9	5.28	323.5	326.33	0.003274	5.26	42.21	10.74	0.4
231	100-YEAR	284	320.62	326.52	5.9	324.02	327.08	0.00369	6.02	47.21	10.91	0.44
299.5		Bridge										
300	2-YEAR	30	320.96	322.76	1.8	321.72	322.83	0.002165	2.09	14.38	9.95	0.27
300	10-YEAR	106	320.96	324.75	3.79	322.72	324.94	0.002256	3.5	30.29	11.52	0.32
300	50-YEAR	222	320.96	327.53	6.57	323.84	327.81	0.001576	4.22	52.56	12.13	0.29
300	100-YEAR	284	320.96	327.94	6.98	324.36	328.34	0.002113	5.09	55.8	12.28	0.34
350	2-YEAR	30	321.21	322.91	1.7		323.03	0.007823	2.75	10.92	9.27	0.45
350	10-YEAR	106	321.21	324.9	3.69		325.09	0.00403	3.42	31.25	11.04	0.35
350	50-YEAR	222	321.21	327.7	6.49		327.9	0.001931	3.67	63.77	12.05	0.27
350	100-YEAR	284	321.21	328.18	6.97		328.46	0.002415	4.33	69.61	12.27	0.3
400	2-YEAR	30	321.46	323.28	1.82		323.4	0.007005	2.7	11.12	8.13	0.41
400	10-YEAR	106	321.46	325.12	3.66		325.34	0.00613	3.78	28.05	10.36	0.4
400	50-YEAR	222	321.46	327.78	6.32		328.03	0.00274	3.97	58.48	12.11	0.3
400	100-YEAR	284	321.46	328.29	6.83		328.62	0.003316	4.63	64.62	12.32	0.34
500	2-YEAR	30	321.96	323.9	1.94		324	0.005119	2.44	12.28	8.42	0.36
500	10-YEAR	106	321.96	325.7	3.74		325.91	0.005163	3.62	29.34	10.58	0.38
500	50-YEAR	222	321.96	328.06	6.1		328.32	0.002993	4.11	56.64	12.05	0.32
500	100-YEAR	284	321.96	328.62	6.66		328.96	0.003472	4.73	63.41	12.23	0.35
600	2-YEAR	30	322.46	324.43	1.97		324.53	0.005521	2.49	12.05	8.03	0.36
600	10-YEAR	106	322.46	326.19	3.73		326.42	0.004873	3.86	28.62	10.27	0.38
600	50-YEAR	222	322.46	328.34	5.88		328.67	0.003632	4.71	51.54	11.08	0.36
600	100-YEAR	284	322.46	328.93	6.47		329.37	0.004133	5.4	58.33	11.77	0.39
800	2-YEAR	30	323.46	325.51	2.05	324.7	325.6	0.005238	2.39	12.58	8.58	0.35
800	10-YEAR	106	323.46	327.18	3.72	325.72	327.41	0.005042	3.85	29	10.71	0.38
800	50-YEAR	222	323.46	329.11	5.65	326.8	329.45	0.004194	4.83	51.15	11.95	0.38
800	100-YEAR	284	323.46	329.79	6.33	327.29	330.22	0.004423	5.4	59.4	12.12	0.4

Plan: Proposed   Blue Creek   Main RS: 299.5   Profile: 2-YEAR

E.G. US. (ft)	322.83	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	322.76	E.G. Elev (ft)	322.82	322.70
Q Total (cfs)	30.00	W.S. Elev (ft)	322.76	322.64
Q Bridge (cfs)	30.00	Crit W.S. (ft)	321.72	321.38
Q Weir (cfs)		Max Chl Dpth (ft)	1.80	2.02
Weir Sta Lft (ft)		Vel Total (ft/s)	2.09	1.85
Weir Sta Rgt (ft)		Flow Area (sq ft)	14.37	16.19
Weir Submerg		Froude # Chl	0.27	0.23
Weir Max Depth (ft)		Specif Force (cu ft)	14.85	18.11
Min El Weir Flow (ft)	334.51	Hydr Depth (ft)	1.80	2.02
Min El Prs (ft)	327.02	W.P. Total (ft)	8.00	8.00
Delta EG (ft)	0.13	Conv. Total (cfs)	644.1	785.6
Delta WS (ft)	0.11	Top Width (ft)	8.00	8.00
BR Open Area (sq ft)	40.76	Frctn Loss (ft)	0.12	0.00
BR Open Vel (ft/s)	2.09	C & E Loss (ft)	0.01	0.00
Coef of Q		Shear Total (lb/sq ft)	0.24	0.18
Br Sel Method	Energy only	Power Total (lb/ft s)	0.51	0.34

Errors Warnings and Notes

Note:	Multiple critical depths were found at this location. The critical depth with the lowest, valid,
	energy was used.
Note:	Multiple critical depths were found at this location. The critical depth with the lowest, valid,
	energy was used.

Plan: Proposed   Blue Creek   Main RS: 299.5   Profile: 10-YEAR

E.G. US. (ft)	324.94	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	324.75	E.G. Elev (ft)	324.93	324.60
Q Total (cfs)	106.00	W.S. Elev (ft)	324.73	324.40
Q Bridge (cfs)	106.00	Crit W.S. (ft)	322.72	322.37
Q Weir (cfs)		Max Chl Dpth (ft)	3.77	3.78
Weir Sta Lft (ft)		Vel Total (ft/s)	3.61	3.57
Weir Sta Rgt (ft)		Flow Area (sq ft)	29.37	29.73
Weir Submerg		Froude # Chl	0.33	0.32
Weir Max Depth (ft)		Specif Force (cu ft)	68.26	68.64
Min El Weir Flow (ft)	334.51	Hydr Depth (ft)	4.15	4.09
Min El Prs (ft)	327.02	W.P. Total (ft)	13.60	13.26
Delta EG (ft)	0.34	Conv. Total (cfs)	1488.2	1544.3
Delta WS (ft)	0.35	Top Width (ft)	7.08	7.26
BR Open Area (sq ft)	40.76	Frctn Loss (ft)	0.33	0.00
BR Open Vel (ft/s)	3.61	C & E Loss (ft)	0.00	0.00
Coef of Q		Shear Total (lb/sq ft)	0.68	0.66
Br Sel Method	Energy only	Power Total (lb/ft s)	2.47	2.35

Errors Warnings and Notes

Note:	Multiple critical depths were found at this location. The critical depth with the lowest, valid,
	energy was used.
Warning:	The conveyance ratio (upstream conveyance divided by downstream conveyance) is less than
	0.7 or greater than 1.4. This may indicate the need for additional cross sections.
Note:	Multiple critical depths were found at this location. The critical depth with the lowest, valid,
	energy was used.

Plan: Proposed   Blue Creek   Main RS: 299.5   Profile: 50-YEAR

E.G. US. (ft)	327.81	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	327.53	E.G. Elev (ft)	327.81	326.33
Q Total (cfs)	222.00	W.S. Elev (ft)	327.02	325.90
Q Bridge (cfs)	222.00	Crit W.S. (ft)	323.81	323.47
Q Weir (cfs)		Max Chl Dpth (ft)	6.06	5.28
Weir Sta Lft (ft)		Vel Total (ft/s)	5.45	5.60
Weir Sta Rgt (ft)		Flow Area (sq ft)	40.76	39.61
Weir Submerg		Froude # Chl	0.39	0.43
Weir Max Depth (ft)		Specif Force (cu ft)	176.98	147.77
Min El Weir Flow (ft)	334.51	Hydr Depth (ft)		7.16
Min El Prs (ft)	327.02	W.P. Total (ft)	22.52	16.79
Delta EG (ft)	1.48	Conv. Total (cfs)	1835.8	2128.7
Delta WS (ft)	1.63	Top Width (ft)		5.53
BR Open Area (sq ft)	40.76	Frctn Loss (ft)		
BR Open Vel (ft/s)	5.45	C & E Loss (ft)		
Coef of Q		Shear Total (lb/sq ft)	1.65	1.60
Br Sel Method	Press Only	Power Total (lb/ft s)	9.00	8.98

Errors Warnings and Notes

Note:	The downstream water surface is below the minimum elevation for pressure flow. The sluice
	gate equations were used for pressure flow.
Note:	Multiple critical depths were found at this location. The critical depth with the lowest, valid,
	energy was used.
Note:	Multiple critical depths were found at this location. The critical depth with the lowest, valid,
	energy was used.

Plan: Proposed   Blue Creek   Main RS: 299.5   Profile: 100-YEAR

E.G. US. (ft)	328.34	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	327.94	E.G. Elev (ft)	328.34	327.08
Q Total (cfs)	284.00	W.S. Elev (ft)	327.02	326.52
Q Bridge (cfs)	284.00	Crit W.S. (ft)	324.31	323.98
Q Weir (cfs)		Max Chl Dpth (ft)	6.06	5.90
Weir Sta Lft (ft)		Vel Total (ft/s)	6.97	6.67
Weir Sta Rgt (ft)		Flow Area (sq ft)	40.76	42.55
Weir Submerg		Froude # Chl	0.50	0.48
Weir Max Depth (ft)		Specif Force (cu ft)	200.88	193.72
Min El Weir Flow (ft)	334.51	Hydr Depth (ft)		11.44
Min El Prs (ft)	327.02	W.P. Total (ft)	22.52	19.01
Delta EG (ft)	1.25	Conv. Total (cfs)	1835.8	2208.4
Delta WS (ft)	1.41	Top Width (ft)		3.72
BR Open Area (sq ft)	40.76	Frctn Loss (ft)		
BR Open Vel (ft/s)	6.97	C & E Loss (ft)		
Coef of Q		Shear Total (lb/sq ft)	2.70	2.31
Br Sel Method	Press Only	Power Total (lb/ft s)	18.84	15.43

Errors Warnings and Notes

Note:	The downstream water surface is below the minimum elevation for pressure flow. The sluice gate equations were used for pressure flow.
Note:	Multiple critical depths were found at this location. The critical depth with the lowest, valid, energy was used.
Note:	Multiple critical depths were found at this location. The critical depth with the lowest, valid, energy was used.

Summary Statement

The initial goals of this replacement culvert design project included designing a safer roadway, designing a structurally sound culvert, passing the 100-Year storm event, creating a friendly fish passage design for all species, preventing hydraulic design threats downstream, and meeting permissible scour velocities. Specifically for fish passage, all criteria for the Active Channel Design Option were successfully met by following the process laid out within the forms. An overview of the steps include researching existing data and available information, collecting all required parameters at the site, selecting the best fish passage design option for the site, completing the hydrology and efficiently brainstorming and completing the hydraulic modeling, and finally meeting all requirements of the Active Channel Design Option.

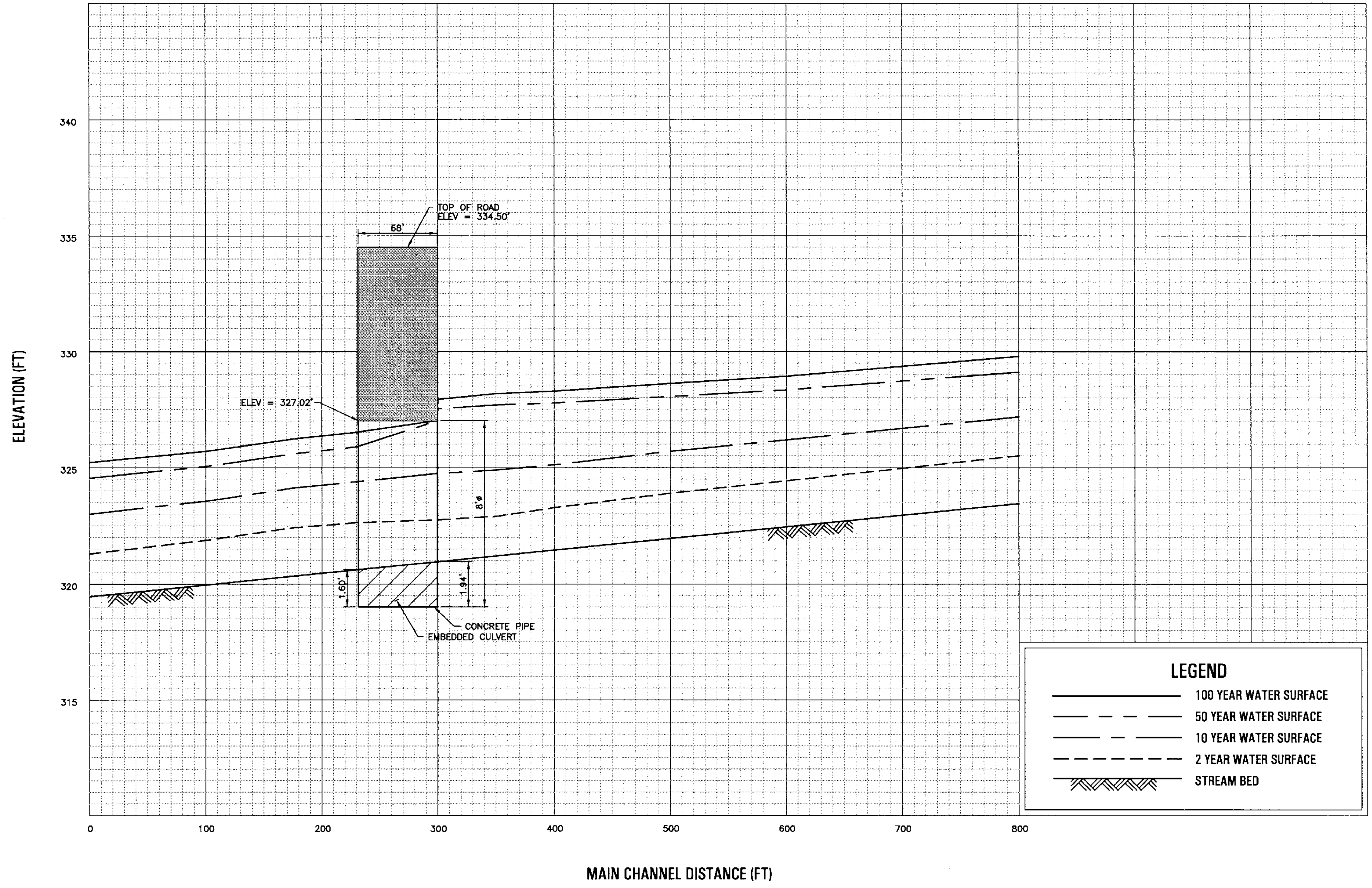
As found in the problem statement, the goal was providing cross drainage for Rose Creek that met hydraulic standards in the Caltrans Hydraulic Design Manual, as well as fish standards in the California Department of Fish and Game Culvert Criteria and the NOAA Fisheries Guidelines for Salmonid Passage at Stream Crossings.

Summary Data Table 1: Culvert Velocities

Geometry Condition and Flood Event	Permissible Velocity for Sustained (2-Year Event) /Intermittent (100-Year Event) Flows in Unlined Channels (ft/s)	Upstream Velocity in Culvert (ft/s)	Downstream Velocity in Culvert (ft/s)
Existing Conditions 2-Year Event / 100-Year Event	5.60 / 6.90	4.63 / 15.25	4.45 / 15.25
Proposed Conditions 2-Year Event / 100-Year Event	5.60 / 6.90	2.09 / 6.97	1.85 / 6.67

Summary Data Table 2: Culvert Depths

Geometry Condition	Flood Event	Water Depth inside Culvert at Inlet (ft)	Water Depth inside Culvert at Outlet (ft)
Existing Conditions	50% Annual Probability (2-Year Event)	2.05	2.11
	10% Annual Probability (10-Year Event)	4.00	3.70
	2% Annual Probability (50-Year Event)	4.00	2.72
	1% Annual Probability (100-Year Event)	4.00	4.00
Proposed Conditions	50% Annual Probability (2-Year Event)	1.80	2.02
	10% Annual Probability (10-Year Event)	3.77	3.78
	2% Annual Probability (50-Year Event)	6.06	5.28
	1% Annual Probability (100-Year Event)	6.06	5.90



P:/06938/38713 TO7 Fish Passage/5.0 Project Data/AutoCAD/General Details/Active-Change-blue-creek.DWG
08-03-06 AJACKSON 12:01:30

Issue No.	Description	Date	Drwn.	Chkd.	Resp. Engr.	Proj. Mgr.

BAR LENGTH ON ORIGINAL DRAWING EQUALS ONE INCH. ADJUST SCALE ACCORDINGLY.

Project Manager: LEF
Designed: EKB
Designed:
Checked: JJL
Drawn: AJ

Route 888 4 Lane
at Blue Creek

ACTIVE CHANNEL DESIGN
PROPOSED CONDITIONS

Date:
Scale: 1" = 100'
Project No.: 06938-38713
File Name: Active-Change-blue-creek.DWG
Drawing No.: 1
Issue:

APPENDIX I

DESIGN EXAMPLE - HYDRAULIC DESIGN OPTION

Hydraulic Design Option
(Culvert Replacement)

Problem Statement

In the County of Del Norte, a rehabilitation project has been initiated for a 3-mile segment of Route 777, which will include outside shoulder widening. Because shoulder widening is involved in the project, existing culverts must be lengthened or replaced depending on field and hydraulic conditions.

Within the project limits, Rose Creek is conveyed under Route 777 by a 70-foot long 8-foot diameter corrugated metal pipe culvert with a headwall at both its entrance and outlet. In close proximity to this culvert, a 54-inch diameter high-pressure gas main runs parallel with the culvert and is located 7 feet right of the Rose Creek culvert centerline.

Currently in Rose Creek, adult anadromous salmonids are prevented from traveling upstream of the Route 777 culvert due to its high velocity. High velocities through the culvert had been observed and noted in a previous fish-passage assessment.

In addition to the existing culvert being a fish barrier, it has questionable hydraulic capacity, as well as perforations in its invert. Based on past Maintenance records, the culvert and roadway have been overtopped twice in the past ten years. As for the perforations in the culvert invert, the metal has obviously corroded and is in need of attention as well.

As a part of the design for this rehabilitation project, a solution must be found for the culvert conveying flows from Rose Creek that addresses structural integrity, hydraulic capacity, and fish-passage performance.

NOTE: Route 777 and Rose Creek are fictitious and created for the purpose of presenting a design example for this fish-passage training guidance.

Form 1-Existing Data and Information Summary

Form 1 provides a list of suggested data references that would be beneficial to collect before the beginning of design process.

For this particular example, USGS topographic quadrangle map, DEM data, as-built drawings, target fish species and life stage data, and stream flow gage data was available for reference.

The USGS topographic quadrangle data and DEM data was downloaded from the USGS website, www.usgs.gov.

The FEMA Map Service Center, http://msc.fema.gov/, was accessed to determine if a previous hydrologic study, hydraulic study, and/or floodplain mapping had been performed. For Rose Creek, no previous detailed or approximate studies had been performed; therefore, no effective data was available for reference.

The County's engineering department was able to provide as-built drawings for the stream crossing and fish species and life stage data.

California Department of Water Resources (CDEC, http://cdec.water.ca.gov/), was searched for precipitation and stream flow gage data. Recording flow gages are located on Blue Creek.

As for site access status, the field investigations can be done within Caltrans Right-of - Way, therefore rights-of-entry will not be required.

EXISTING DATA AND INFORMATION SUMMARY FORM 1

Project Information Road Widening Route 777		Computed: EKB	Date: 2/6/06
		Checked: JJL	Date: 2/7/06
Stream Name: Rose Creek	County: Del Norte, CA	Route: 777	Postmile: 6.15

Proposed Project Type	☐ New Culvert	☐ New Bridge
	☒ Replacement Culvert	☐ Replacement Bridge
	☐ Retrofit Culvert	☐ Retrofit Bridge
	☐ Proposed Culvert Length= 86 ft	☐ Proposed Bridge Length= ft
	☐ Other	☐ Other

Design Species/Life Stage	☐ All Species	Source: State of CA Contact: Dept. of Fish & Game Date: Bill Hook 1-422-351-9322 contacted on: 1/22/06
	☒ Adult Anadromous Salmonids	
	☐ Adult Non-Anadromous Salmonids	
	☐ Juvenile Salmonids	
	☐ Native Non-Salmonids	
	☐ Non-Native Species	

Collect Existing Data

Included in Caltrans Culvert Inventory	☐ Yes	☒ No
As-Built Drawings AS-built date Sept 1981	☒ Yes	☐ No
Assessor's Parcel Map	☐ Yes	☒ No
Previous Studies Performed: (i.e. FEMA Flood Insurance Studies, Army Corps of Engineering Studies, Other)		
Hydrology Analysis	☐ Yes	☒ No
Hydraulics Analysis	☐ Yes	☒ No
Floodplain Mapping	☐ Yes	☒ No
Other Studies Types Available: (i.e. Watershed Management Plans, Stream Restoration Plans, Other)	☐ Yes	☒ No
Existing Land Use Map	☐ Yes	☒ No
Proposed Land Use Map	☐ Yes	☒ No
Precipitation Gage Data	☐ Yes	☒ No
Stream Flow Gage Data	☒ Yes	☐ No

EXISTING DATA AND INFORMATION SUMMARY FORM 1

Topographic Mapping:
(i.e. USGS Topographic Quadrangle, DEM Data, LIDAR Data, Other) Quad Name: Hiouchi (1:24K) ☒ Yes ☐ No

District Hydraulics Library ☐ Yes ☒ No

Obtain Access Permission

Will Project study limits extend beyond Caltrans R/W? ☐ Yes ☒ No

If yes, obtain right-of-entry.

Contact Report Index Attached ☒ Yes ☐ No

Existing Information Index Attached ☒ Yes ☐ No

CONTACT REPORT INDEX

Project Information Road Widening Route 777

Computed: EKB

Date: 2/6/06

Checked: JJL

Date: 2/7/06

Stream Name: Rose Creek

County: Del Norte, CA

Route: 777

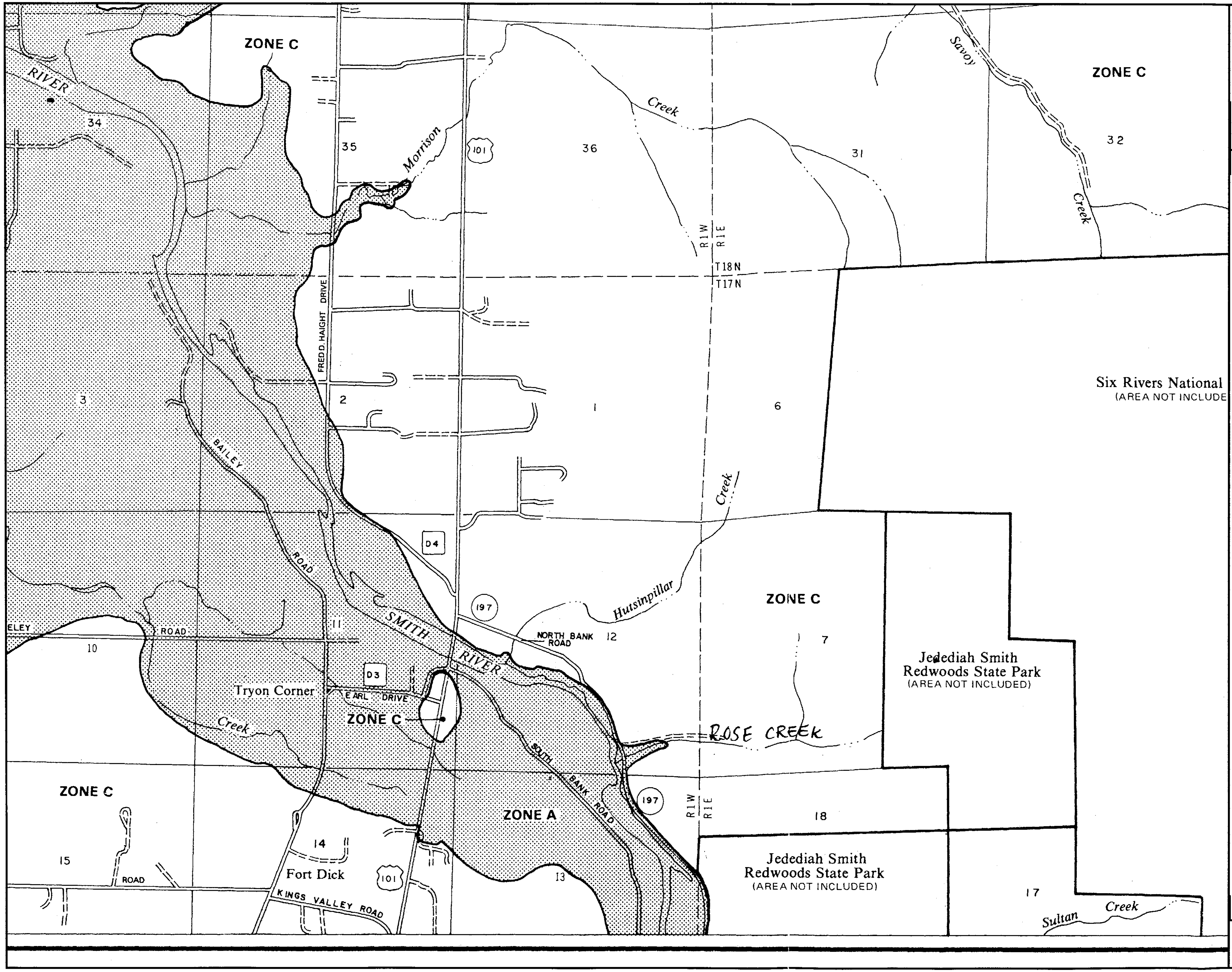
Postmile: 6.15

Date of Contact	Person Contacted	Subject Discussed
1/22/06	Bill Hook 422-351-9322	Adult Anadromous Salmonids

EXISTING INFORMATION INDEX

Project Information Road Widening Route 777		Computed: EKB	Date: 2/6/06
		Checked: JJL	Date: 2/7/06
Stream Name: Rose Creek	County: Del Norte, CA	Route: 777	Postmile: 6.15

Report Date	Report Name and Source
2/6/06	California Dept. of Water Resources (CDEC)
	Station Locator



APPROXIMATE SCALE
2000 0 2000 FEET

NATIONAL FLOOD INSURANCE PROGRAM

FIRM
FLOOD INSURANCE RATE MAP
DEL NORTE COUNTY, CALIFORNIA
UNINCORPORATED AREA

PANEL 25 OF 325
(SEE MAP INDEX FOR PANELS NOT PRINTED)

COMMUNITY-PANEL NUMBER
065025 0025 B

EFFECTIVE DATE:
JANUARY 24, 1983

Federal Emergency Management Agency

Form 2- Site Visit Summary

Form 2 captures the existing conditions of the hydraulic structure including channel and structure roughness values. By completing the Site Visit Summary form, the drainage designer will have all necessary parameters required to complete any of the fish passage design options.

At the Rose Creek site, various culvert and creek properties were investigated, such as layout configuration, roughness, velocity, and flow regime.

As mentioned above, it was noted in the field, as well as the As-Built plans, that a headwall/endwall exists at the culvert inlet and outlet. Also, the existing culvert lies at a 0% slope, which certainly creates hydraulic capacity issues.

For the creek, roughness characteristics of the main channel, the left overbank channel, and the right overbank channel were also investigated and ultimately Manning's n-values were estimated. Based on field observation, the left and right overbank channels were found to have the same n-values in the vicinity of the culvert crossing and the project study area.

In addition, flow in the creek at the time of the field visit was determined from appropriate measurements. The flow was calculated by measuring a velocity and depth, calculating wetted area from a field developed creek cross section, and dividing velocity by wetted area to achieve flow according to the continuity of flow equation. By placing a small leaf in the creek and timing its travel over a set length, a velocity was determined. In order to find a representative velocity for the creek, this operation was performed three times, where the leaf was placed near the left bank, near the right bank, and around the center of the creek. The velocity corresponding to each leaf placement was added together and averaged to find a representative velocity.

Finally, the flow regime for the creek was estimated in the field by tossing a small rock in the center of the creek and noting the propagation of the ripples. When ripples propagate upstream, the flow regime is subcritical, while supercritical flow is denoted by downstream ripple propagation.

SITE VISIT SUMMARY FORM 2

Project Information Road Widening Route 777		Computed: EKB	Date: 2/15/06
		Checked: JJL	Date: 2/16/06
Stream Name: Rose Creek	County: Del Norte, CA	Route: 777	Postmile: 6.15

Obtain Physical Characteristics of Existing Culvert

Confined Spaces

Is the culvert height 5 ft or greater?	☒ Yes ☐ No
Can you stand up in the culvert?	☒ Yes ☐ No
Can you see all the way through the culvert?	☒ Yes ☐ No
Can you feel a breeze through the culvert?	☒ Yes ☐ No

If answer is “No” to any of the above questions, do not enter the culvert without confined spaces equipment for surveying.

Inlet Characteristics

Inlet Type	☐ Projecting	☒ Headwall	☐ Wingwall	
	☐ Flared end section	☐ Segment connection		
Inlet Condition	☐ Channel scour	☐ Excessive deposition	☐ Debris accumulation	☒ None applicable
Inlet Apron	☐ Channel scour	☐ Excessive deposition	☐ Debris accumulation	☒ None applicable

Skew Angle: NONE °	Upstream Invert Elevation: 681.1 ft ([✓ NGVD 29] or NAVD 88)

Barrel Characteristics

Diameter: 8.0 in	Fill height above culvert: 8.9 ft
Height/Rise: ft	Length: 70.0 ft
Width/Span: ft	Number of barrels:

Culvert Type	☐ Arch	☐ Box	☒ Circular
	☐ Pipe-Arch	☐ Elliptical	
Culvert Material	☐ HDPE	☐ Steel Plate Pipe	☐ Concrete Pipe
	☒ Spiral Rib / Corrugated Metal Pipe		
Barrel Condition	☒ Corrosion	☐ Debris accumulation	☐ Structural damage
	☐ Abrasion	☐ Bedload accumulation	☐ None applicable

Horizontal alignment breaks: NONE ft

Vertical alignment breaks: NONE ft

Outlet Characteristics

Outlet Type: ☐ Projecting ☒ Headwall ☐ Wingwall ☐ Flared end section ☐ Segment connection

Outlet Condition: ☐ Scour hole ☐ Backwatered ☐ Debris accumulation ☐ None applicable

☐ Perched

Outlet elevation drop: ft

Outlet drop condition: Freefall onto rocks

Scour hole depth: ft

Outlet Apron: ☐ Channel scour ☐ Excessive deposition ☐ Debris Accumulation ☒ None Applicable

Skew Angle: NONE °

Downstream Invert Elevation: 680.7 ft (NGVD 29 or NAVD 88)

Bridge Physical Characteristics N/A

Elevation of high chord (top of road): ft

Elevation of low chord: ft

Channel Lining: ☐ No lining ☐ Concrete ☐ Rock ☐ Other

Skew Angle: °

Bridge width (length): ft

Pier Characteristics (if applicable) ☐ N/A

Number of Piers: ft

Upstream cross-section starting station: ft

Pier Width: ft

Downstream cross-section starting station: ft

Pier Centerline Spacing: ft

Pier Shape: ☐ Square nose and tail ☐ Semi-circular nose and tail ☐ 90° triangular nose and tail ☐ Twin-cylinder piers with connecting diaphragm ☐ Twin-cylinder piers without connecting diaphragm ☐ Ten pile trestle bent

Pier Condition: ☐ Scour ☐ Corrosion ☐ Debris accumulation

Skew angle °

Channel Characteristics

Hydraulic Structure Roughness Coefficients

(Source: Caltrans Highway Design Manual Table 864.3A)		(Source: HEC-RAS User's Manual)	
Type of Structure	n- value	Type of Structure	n- value (normal)

Linned Channels:		**Corrugated Metal:**	
Portland Cement Concrete	0.014	Subdrain	0.019
Air Blown Mortar (troweled)	0.012	[✓ Storm Drain]	[✓ 0.024]
Air Blown Mortar (untroweled)	0.016	**Wood:**	
Air Blown Mortar (roughened)	0.025	Stave	0.012
Asphalt Concrete	0.018	Laminated, treated	0.017
Sacked Concrete	0.025	**Brickwork:**	
Pavement and Gutters:		Glazed	0.013
Portland Cement Concrete	0.015	Lined with cement mortar	0.015
Asphault Concrete	0.016		
Depressed Medians:			
Earth (without growth)	0.040		
Earth (with growth)	0.050		
Gravel	0.055		

Recommended Permissible Velocities for Unlined Channels (Source: Caltrans Highway Design Manual, Table 862.2)

Type of Material in Excavation Section	Intermittent Flow (f/s)	Sustained Flow (f/s)
Fine Sand (Noncolloidal)	2.6	2.6
Sandy Loam (Noncolloidal)	2.6	2.6
Silt Loam (Noncolloidal)	3.0	3.0
Fine Loam	3.6	3.6
Volcanic Ash	3.9	3.6
Fine Gravel	3.9	3.6
Stiff Clay (Colloidal)	4.9	3.9
Graded Material (Noncolloidal)		
Loam to Gravel	6.6	4.9
Silt to Gravel	6.9	5.6
Gravel	7.5	5.9

SITE VISIT SUMMARY FORM 2

Coarse Gravel	7.9	6.6
Gravel to Cobbles (Under 150mm)	8.8	6.9
Gravel and Cobbles Over 200mm)	9.8	7.9
Flow Estimation 30 cfs	☐ Supercritical flow	☒ Subcritical flow

Channel Cross-Section Schematic	Channel depth = ft

Average Active Channel Width

Take at least five channel width measurements to determine the active channel width. The active channel stage or ordinary high water level is the elevation delineating the hightest water level that has been maintained for a sufficient period of time to leave evidence on the landscape.

Average Active Channel Width = 23.2 ft

1) 23.1 ft	2) 23.5 ft	3) 23.1 ft	4) 23.2 ft	5) 23.2 ft

Boundary Conditions

The normal depth option (slope area method) can only be used as a downstream boundary condition for an open-ended reach. Is normal depth appropriate? If no, what is the known starting water surface elevation? yes

Upstream	slope ft/ft
Downstream Normal Depth	slope 0.01 ft/ft
Known starting water surface elevation Source:	ft

General Considerations

Identify Physical restrictions

☐ Right-of-way ☒ Utility conflict ☐ Vegetation

☐ Man-made features ☐ Natural features ☐ Other

Cross-Section Sketches Attached ☒ Yes ☐ No

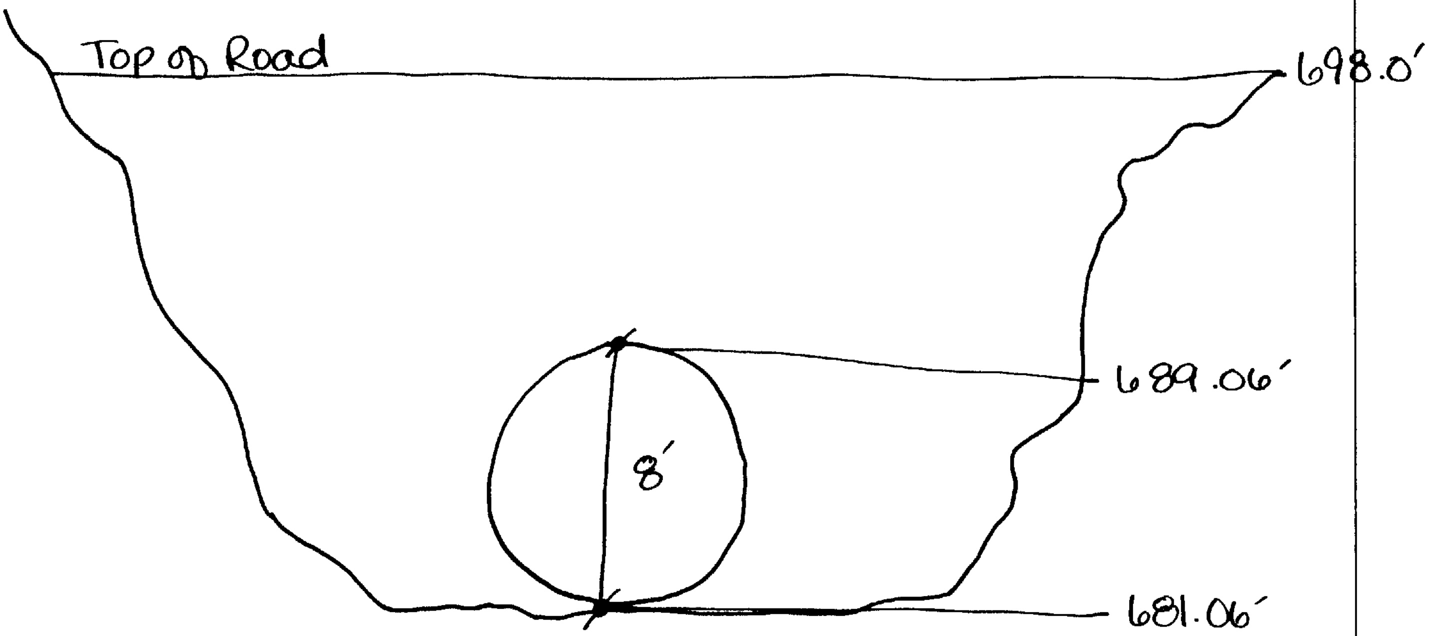
Site Photograph Documentation Attached ☒ Yes ☐ No

Channel / Overbank Manning's n-value Calculation Attached ☒ Yes ☐ No

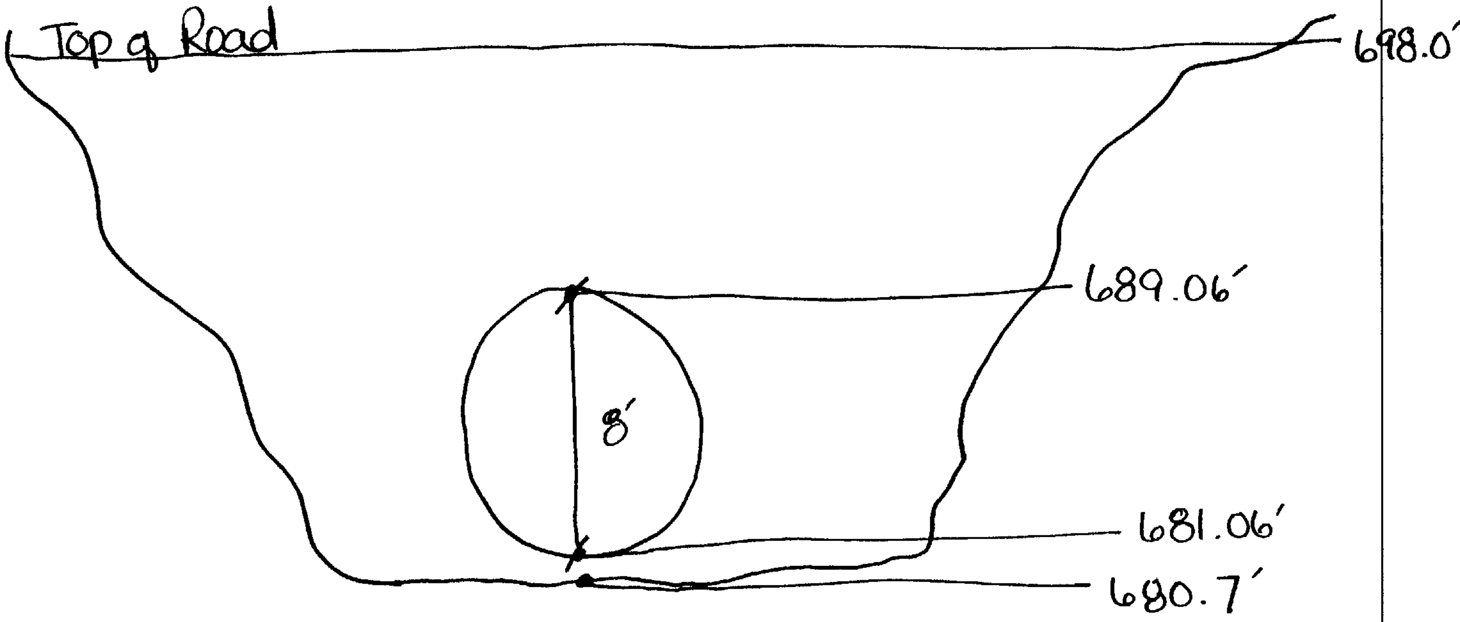
Field Notes Attached ☒ Yes ☐ No

Cross-Section Sketch

Upstream face of structure:



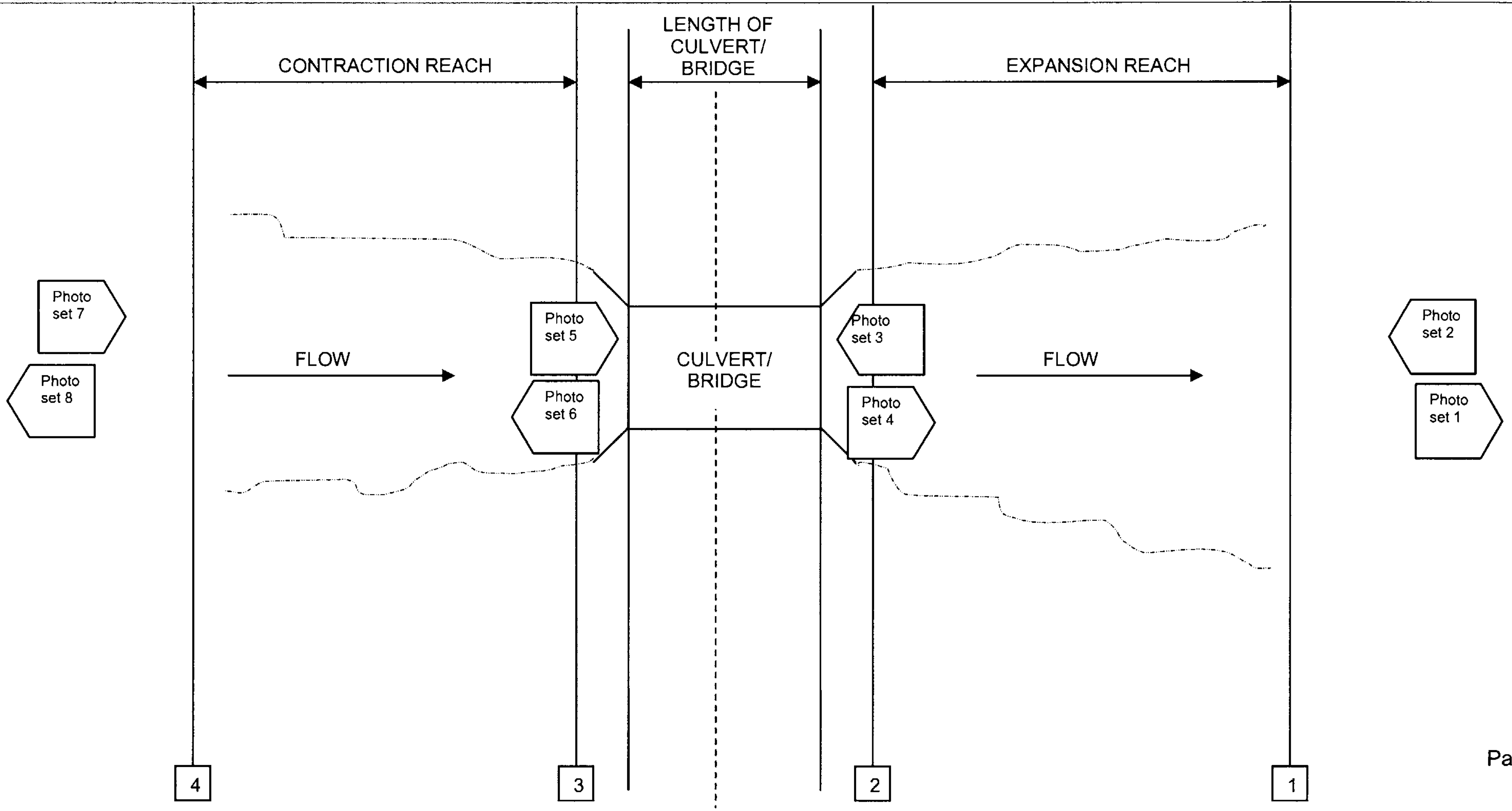
Downstream face of structure:



Rocky conditions
@ outlet

SITE PHOTOGRAPH DOCUMENTATION

Project Information	Road Widening Route 777		Computed: EKB Checked: JJL	Date: 2/15/06 Date: 2/16/06
Stream Name Rose Creek	City/County Del Norte, CA		Road 777	Postmile 6.15
Crossing Type	☒ Culvert	☐ Bridge	☐ Other Type/Comments	
Distance From:	X-sec. 1 to X-sec. 2: 88 ft	X-sec. 2 to DS face of culvert 2 ft	US face of culvert to X-Sec. 3 2 ft	X-sec. 3 to X-sec. 4 58 ft
Distance From:	Photo Sets 1 & 2 to DS face of culvert 60 ft	Photo Sets 3 & 4 to DS face of culvert 10 ft	Photo Sets 5 & 6 to US face of culvert 15 ft	Photo Sets 7 & 8 to US face of culvert 80 ft
Length of Culvert/Bridge:	70.0' ft			



SITE PHOTOGRAPH DOCUMENTATION

Photo Descriptions:

Photo Set 1	upstream channel
Photo Set 2	
Photo Set 3	looking DS @ culvert inlet
Photo Set 4	
Photo Set 5	looking US @ culvert outlet
Photo Set 6	
Photo Set 7	
Photo Set 8	looking DS away from culvert outlet

Culvert Inlet

Culvert Outlet

Looking Downstream of Culvert Outlet

2002 8 5

Looking Upstream from Culvert Inlet

2002 8 5

Manning's n Computation Summary

Project Information
Road Widening Route 777

Computed: EKB
Date: 2/15/06
Checked: QJL
Date: 2/16/06

Stream Name: Rose Creek
County: Del Norte
Route: 777
Postmile: 6.15

Aerial Picture Attached: NONE

Photographs (#'s and locations) # 1, 2, 3, 4

Summary of n-Values:

Reach	**Left Overbank**	**Main Channel**	**Right Overbank**
	0.054	0.0485	0.054

Notes:

Manning's n Computation - Main Channel

Project Information Road Widening Route 777		Computed: EKB	Date: 2/15/06
		Checked: JJL	Date: 2/16/06
Stream Name: Rose Creek	County: Del Norte, CA	Route: 777	Postmile: 6.15
Aerial Picture Attached: NONE			
Photographs (#'s and locations) # 1, 2, 3, 4			

Is roughness uniform throughout the reach? NO

Note: If not, n-value should be assigned for the AVERAGE condition of the reach

Is roughness uniformly distributed along the cross section? NO

Is a division between the channel and floodplain necessary? Yes

Calculation of n-value:

n = (nb + n1 + n2 + n3 + n4)m

where:	Description of Range
nb = base n value for surface	*median size btwn 1" and 2.5"=0.028 to 0.035, btwn 2.5" and 10"=0.030 to 0.050*
n1 = surface irregularity factor	*smooth = 0 up to severe at 0.020*
n2 = cross section variation factor	*gradual = 0 up to alternating frequently at 0.015*
n3 = obstructions factor	*negligible = 0 up to severe (over 50% of cross section) at 0.05*
n4 = vegetation factor	*small = 0.002 to very large (average depth of flow is less than 1/2 height of vegetation) at 0.100*
m = sinuosity/meandering factor	*minor = 1.0, appreciable = 1.15, Severe = 1.30*

Base n value for surface

nb: Sand channel? ________ if yes, median size of bed material? ________

nb =

median size (in)	nb
0.008	0.012
0.012	0.017
0.016	0.020
0.020	0.022
0.024	0.023
0.031	0.025
0.039	0.026

All other channels:

median size (in)	nb
.04 to .08	0.026 to 0.035
1 to 2.5	0.028 to 0.035
[✓ 2.5 to 10]	0.030 to 0.050
>10	0.040 to 0.070

Notes:

Main Channel consists of small rocks

nb = 0.040

Manning's n Computation - Main Channel

Surface Irregularity

n1:	Smooth	Is channel smooth? ________	if yes, n1 = 0
	Minor	Is channel in good condition with slightly eroded or scoured side slopes?	[✓ if yes, n1 = 0.001 - 0.005]
	Moderate	Is channel a dredged channel having moderate to considerable bed roughness and moderately sloughed or eroded side slopes in rock?	if yes, n1 = 0.006 - 0.010
	Severe	Is channel badly sloughed, scalloped banks or badly eroded or sloughed sides or jagged and irregular surface?	if yes, n1 = 0.011 - 0.020

n1 = 0.0025

Notes: Gradual elevation changes

Cross Section Variation Factor

n2:	Gradual	Does the size and shape of the channel cross section change gradually?	if yes, n2 = 0.000
	Alternately occasionally	Does the cross section alternate to large to small, *occasionally* or does the main flow *occasionally* shift from side to side?	[✓ if yes, n2 = 0.001 - 0.005]
	Alternately frequently	Does the cross section alternate to large to small, *frequently* or does the main flow *frequently* shift from side to side?	if yes, n2 = 0.010 - 0.015

n2 = 0.002

Notes: The main channel x-section width is slightly pinched around bends

Obstructions factor

n3:	Negligible	Does the stream have a few scattered obstructions that occupy < 5% of the cross-sectional area?	[✓ if yes, n3 = 0.000 - 0.004]
	Minor	Obstructions occupy < 15% of the cross-sectional area and the spacing between obstructions is such that the sphere of influence doesn't extend to other obstructions?	if yes, n3 = 0.005 - 0.015
	Appreciable	Obstructions occupy 15% - 50% of the cross-sectional area and the spacing between obstructions is small enough to be additive?	if yes, n3 = 0.020 - 0.030
	Severe	Obstructions occupy more than 50% of the cross-sectional area or the spacing between obstructions causes turbulence?	if yes, n3 = 0.040 - 0.050

n3 = 0.002

Notes:

A few larger rocks are present within the channel

Manning's n Computation - Main Channel

Vegetation factor

n4:

Small	Does the channel have dense growth of flexible turf grass or weed growth where the flow is at least 2 times the height of the vegetation; tree seedlings of willows, cottonwoods, etc?	→ yes, n4 = 0.002 - 0.010
Medium	Does the channel have turf grass where the average depth of flow is 1 to 2 times the height of the vegetation; moderately stemmy grass, weeds or tree seedlings growing where the flow is 2 to 3 times the height of the vegetation?	if yes, n4 = 0.010 - 0.025
Large	Does the channel where the average depth of flow is equal to the height of the vegetation; 8 to 10 years-old willows or cottonwoods intergrown with weeds and brush; where the hydraulic radius exceeds1.97 ft or bushy willows about 1 year old intergrown with some weeds along side slopes, and no significant vegetation exists along the channel bottom, where the hydraulic radius is greater than 2.0 ft.	if yes, n4 = 0.025 -0.050
Very large	Does the channel have turf grass growing where the average depth of flow < 1/2 the height of the vegetation; bushy willows about 1 year old. with weeds intergrown on side slopes; dense cattails in channel bottom; trees intergrown with weeds and brush?	if yes, n4 = 0.050 - 0.100

n4 = 0.002

Notes: Little vegetation is present in the main channel. Some vegetation has grown up around the culvert inlet

Sinuosity/meandering factor

m	Minor	Ratio of the channel length to valley length in 1.0 to 1.2	→ if yes, m = 1.00
	Appreciable	Ratio of the channel length to valley length in 1.2 to 1.5	if yes, m = 1.15
	Severe	Ratio of the channel length to valley length > 1.5	if yes, m = 1.30

m = 1.0

Notes:

The stream centerline meanders very little. Not an issue

Manning's n - Main Channel n = 0.0485

Manning's n Computation - Overbank

Project Information Road Widening Route 777		Computed: EKB	Date: 2/15/06
		Checked: JJL	Date: 2/16/06
Stream Name: Rose Creek	County: Del Norte, CA	Route: 777	Postmile: 6.15
Aerial Picture Attached:			
Photographs (#'s and locations) #1, 2, 3, 4			

Is roughness uniform throughout the reach? NO

Note: If not, n-value should be assigned for the AVERAGE condition of the reach

Is roughness uniformly distributed along the cross section? NO - Left & Right banks are displaying the same characteristics

Is a division between the channel and floodplain necessary? yes

Calculation of n-value:

n = (nb + n1 + n2 + n3 + n4)m

where:	Description of Range
nb = base n value for surface	*median size between 1" and 2.5"=0.028 to 0.035, between 2.5" and 10"=0.030 to 0.050*
n1 = surface irregularity factor	*smooth = 0 up to severe at 0.020*
n2 = cross section variation factor	*gradual = 0 up to alternating frequently at 0.015*
n3 = obstructions factor	*assumed to equal 0*
n4 = vegetation factor	*small = 0.002 to very large (average depth of flow is less than 1/2 height of vegetation) at 0.100*
m = sinuosity/meandering factor	*equals 0 for floodplains*

Base n value for surface

nb: Sand channel? ________ if yes, median size of bed material? ________

nb =

median size (in)	nb
0.008	0.012
0.012	0.017
0.016	0.020
0.020	0.022
0.024	0.023
0.031	0.025
0.039	0.026

All other channels:

median size (in)	nb
.04 to .08	0.026 to 0.035
→ 1 to 2.5	0.028 to 0.035
2.5 to 10	0.030 to 0.050
>10	0.040 to 0.070

Notes: Smaller rocks held by firm soil

nb = 0.028

Surface Irregularity

n1:	Smooth	Compares to the smoothest, flattest floodplain in a given bed material.	if yes, n1 = 0
	Minor	Is the floodplain slightly irregular in shape. A few rises and dips or sloughs may be more visible on the floodplain.	→ if yes, n1 = 0.001 - 0.005
	Moderate	Has more rises and dips. Sloughs and hummocks may occur.	if yes, n1 = 0.006 - 0.010
	Severe	Floodplain very irregular in shape. Many rises and dips or sloughs are visible.	if yes, n1 = 0.011 - 0.020

n1 = 0.003

Notes: Slightly steep slopes

Manning's n Computation - Overbank

Cross Section Variation Factor

n2 = 0.000

Notes: Not applicable to floodplains.

Obstructions factor

n3:

Negligible	Does the stream have a few scattered obstructions that occupy < 5% of the cross-sectional area?	if yes, n3 = 0.000 - 0.004
Minor	Obstructions occupy < 15% of the cross-sectional area and the spacing between obstructions is such that the sphere of influence doesn't extend to other obstructions?	[✓ if yes, n3 = 0.005 - 0.015]
Appreciable	Obstructions occupy 15% - 50% of the cross-sectional area and the spacing between obstructions is small enough to be additive?	if yes, n3 = 0.020 - 0.030

n3 = 0.005

Notes: Large bouldurs present in overbanks
very minimal obstruction

Vegetation factor

n4:

Small	Does the channel have dense growth of flexible turf grass or weed growth where the flow is at least 2 times the height of the vegetation; tree seedlings of willows, cottonwoods, etc where the average depth of flow is at least three times the height of the vegetation?	if yes, n4 = 0.002 - 0.010
Medium	Does the channel have turf grass where the average depth of flow is 1-2 times the height of the vegetation; moderately stemmy grass, weeds or tree seedlings growing where the flow is 2-3 times the height of vegetation? Brushy, moderately dense vegetation, similar to 1-2 year old willow trees in dormant season.	[✓ if yes, n4 = 0.010 - 0.025]
Large	Does the channel where the average. depth of flow is equal to the height of the vegetation; 8 to 10 year old. willows, cottonwoods intergrown with weeds and brush; where the R = 1.97 ft or bushy willows of 1 year old are in the channel bottom, where R =2.00 ft?	if yes, n4 = 0.025 -0.050
Very large	Does the channel have turf grass growing where the average depth of flow < 1/2 the height of the vegetation; bushy willows about 1 year old. with weeds intergrown on side slopes; dense cattails in channel bottom; trees intergrown with weeds and brush?	if yes, n4 = 0.050 - 0.100
Extreme	Does the channel have dense bushy willow, mesquite, and salt cedar (full foliage), or heavy stand of timber, few down trees, depth of reaching branches?	if yes, n4 = 0.100 - 0.200

n4 = 0.018

Notes: Low bush vegetation present
trees present with small diameter trunks

Sinuosity/meandering factor

m = 1.00

Notes: Not applicable to floodplains.

Manning's n - Overbank n = 0.054

Form 3- Guidance on Selection of Fish Passage Design Option

This form summarizes all requirements for each design option in order for the designer to select the appropriate fish-passage design option.

Because the existing culvert has hydraulic capacity issues, structural deficiencies (perforated invert), as well as a velocity barrier to fish passage, culvert rehabilitation is not an option and it must be replaced. In replacing the culvert, special attention must be given to the existing high-pressure gas line that runs roughly parallel and is offset by approximately 7 feet from the culvert centerline on its inlet side.

Initially both the Active Channel and Stream Simulation design options could be viable strategies for the Rose Creek culvert, but each would yield a large culvert size and most likely encroach on the high-pressure gas line. If either one of these options were used, the new culvert would have to span at least 1.5 times the active channel or span the bankfull channel, which would be a much larger culvert than the existing culvert.

Since the target species/life stage (adult anadromous salmonids) are known for this project and the replacement culvert slope will be less than 3%, the Hydraulic Design option is another possibility. While more time and effort is required in the analysis/design phase of the project, this method is advantageous in that it will yield smaller diameter culverts and reduced impacts during construction. Unlike the Active Channel and Stream Simulation options, the engineer must show that velocity and depth meet CDFG and NOAA Fisheries guidelines under site-specific low and high fish passage flow conditions.

Because of the possible utility conflict at Rose Creek, the smallest diameter culvert that will properly convey flood flows and allow fish movement is most important. Ultimately, this is the overriding reason for choosing the Hydraulic Design option over other strategies. By avoiding utility conflict and difficult relocation, it is worth the additional analysis and design effort.

Given the new, larger diameter culvert and its potential to convey higher flow more efficiently, District Hydraulics must be consulted so that any negative impacts to downstream properties or facilities can be assessed prior to final design.

GUIDANCE ON SELECTION OF FISH PASSAGE DESIGN OPTION FORM 3

Project Information Road Widening Route 777		Computed: EKB	Date: 2/17/06
		Checked: JJL	Date: 2/18/06
Stream Name: Rose Creek	County: Del Norte, CA	Route: 777	Postmile: 6.15

Design Species/ Life Stage	☐	All Species
	☒	Adult Anadromous Salmonids
	☐	Adult Non-Anadromous Salmonids
	☐	Juvenile Salmonids
	☐	Native Non-Salmonids
	☐	Non-Native Species

☐ **Active Channel Design Option -** The Active Channel Design Option 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 streambed 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 with stream hydraulic charagcteristics within the culvert are intended to mimic the stream conditions upstream and downstream of the crossing. However, hydraulic analyses for traffic safety, hydraulic impacts, and scour are required.

Criteria for choosing option:

☒ New and replacement culvert/bridge installations

☐ Passage required for all species

☒ Proposed culver/bridge length less than 100 feet

☒ Channel slope less than 3%

☒ **Hydraulic Design Option** - The Hydraulic Design Option is a design process that matches the hydraulic performance of a culvert with the swimming ablitities of a target species and age class of fish. This method targets distinct species of fish and, therefore, does not account for ecosystem requirments of non-target species.

Criteria for choosing option:

☑ New and replacement culvert/bridge installations (If retrofit installation, see Baffle or Rock Weir Design Options)

☒ Target species identified for passage

☒ Low to moderate channel slopes (less than 3%)

☒ Active channel design or stream simulation design options are not physically feasible

Retrofit Culvert/Bridge Installations

☐ **Baffle Design Option -** The Baffle Design Option is a Hydrualic Design process that is intended to increase flow depth, or to add roughness elements as a measure to reduce flow velocity within the culvert/bridge structure. Determination of the high and low fish passage design flows, water velocity, and water depth is required for this option.

☐ Retrofit culvert/bridge installation

☐ Little bedload material movement

GUIDANCE ON SELECTION OF FISH PASSAGE DESIGN OPTION FORM 3

☐ Existing culvert/bridge is structurally sound

☐ Target species identified for passage

☐ Low to moderate channel slopes

☐ Active channel design or stream simulation design options are not physically feasible

☐ **Rock Weir Design Option -** The Rock Weir Design Option is a Hydraulic Design process that is intended to increase flow depth, or add roughness elements as a measure to reduce flow velocity, or to increase the channel slope downstream of the culvert/bridge. Determination of the high and low fish passage design flows, water velocity, and water depth is required for this option.

☐ Retrofit culvert/bridge installations

☐ Perched condition at outlet

☐ Steep slope at inlet

☐ Target species identified for passage

☐ Active channel design or stream simulation design options are not physically feasible

☐ **Stream Simulation Design Option -** The Stream Simulation Design Option 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.

Criteria for choosing option:

☒ New and replacement culvert/bridge installations

☐ Passage required for all species

☐ Culvert/bridge length greater than 100 feet

☒ Channel width should be less than 20 feet

☒ Minimum culvert/bridge width no less than 6 feet

☒ Culvert/bridge slope does not greatly exceed slope of natural channel, slopes of 6 % or less

☐ Narrow stream valleys

Selected Design Option: Hydraulic Design Option

Basis for Selection: Adult Anadromous Salmonid criteria must be met

Seek Agency Approval: ☒ Yes ☐ No

Form 4- Guidance on Methodology for Hydrologic Analysis

Form 4 summarizes methods for estimating peak design discharges that will be used in a hydraulic analysis. Data requirements, limitations, and guidance are provided to assist in the hydrologic method selection.

For this particular example, all data requirements needed to calculate peak discharges by regional regression equations were readily available.

Stream flow data was also available allowing a stream flow hydrograph and stream duration curve to be created. Upper and lower fish passage flows were calculated.

GUIDANCE ON METHODOLOGY FOR HYDROLOGIC ANALYSIS[1, 2] FORM 4

Project Information Road Widening Route 777		Computed: EKB	Date: 2/22/06
		Checked: JJL	Date: 2/23/06
Stream Name: Rose Creek	County: Del Norte, CA	Route: 777	Postmile: 6.15

Summary of Methods for Estimating Peak Design Discharges for Use in Hydraulic Analysis

Ungaged Streams

☒ **Regional Regression**[3, 4]

Data Requirements	Limitations	Guidance
▪ Drainage area ▪ Mean annual precipitation ▪ Altitude index	▪ Peak discharge value for flow under natural conditions unaffected by urban development and little or no regulation by lakes or reservoirs ▪ Ungaged channel	The most recently published USGS report for estimating peak discharges may be used. The user should exercise caution to ensure that the reports are used only for the conditions and locations for which they are recommended.

Rainfall-Runoff Models

☐ **NRCS (TR 55)**[5]

Data Requirements	Limitations	Guidance
▪ 24-hour Rainfall ▪ Rainfall distribution ▪ Runoff curve number ▪ Concentration time ▪ Drainage area	▪ Small or midsize catchment (<8 km^2) ▪ Maximum of 10 subwatersheds ▪ Concentration time range from 0.1-10 hour (tabular hydrograph method limit <2 hour) ▪ Runoff is overland and channel flow ▪ Simplified channel routing ▪ Negligible channel storage	TR-55 focuses on small urban and urbanizing watersheds.

☐ **HEC-1/HEC-HMS**[6, 7] **(SCS Dimnesionless, Snyder Unit, Clark Unit Hydrographs)**

Data Requirements	Limitations	Guidance
▪ Watershed/subbasin parameters ▪ Precipitation depth, duration, frequency, and distribution ▪ Precipitation losses ▪ Unit hydrograph parameters ▪ Streamflow routing and diversion parameters	▪ Simulations are limited to a single storm event ▪ Streamflow routing is performed by hydrologic routing methods and is therefore not appropriate for unsteady state routing conditions.	Can be used for watersheds which are: small or large, simple or complex, and developed or undeveloped.

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[1] Caltrans Highway Design Manual, Chapter 810 Hydrology, Topic 819 Estimating Design Discharge

[2] FEMA Guidelines and Specifications, Appendix C, Section C.1

[3] USGS Water-Resources Investigation 77-21 (Magnitude and Frequency of Floods in California)

[4] USGS Open-File Report 93-419 (Methods for Estimating Magnitude and Frequency of floods in the Southwestern United States)

[5] United States Department of Agriculture, Natural Resources Conservation Service, Urban Hydrology for Small Watersheds Technical Release 55, June 1986. ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf

[6] HEC-1 User's Manual

[7] HEC-HMS User's Manual

[8] Bulletin 17B

GUIDANCE ON METHODOLOGY FOR HYDROLOGIC ANALYSIS [1, 2] FORM 4

GAGED STREAMS

☐ **Statistical Methods**[8]

Data Requirements	Limitations	Guidance
▪ 10 or more years of gaged flood records	▪ Gage data is usually only available for midsized and large catchments ▪ Appropriate station and/or generalized skew coefficient relationship applied	For watersheds with less than 50 years of record, compare with results of appropriate USGS regional regression equations. For watersheds with less than 25 years of record, compare with results of appropriate USGS regional regresssion equations and/or HEC-1/HEC-HMS model results.

☐ **Basin Transfer of Gage Data**

Data Requirements	Limitations	Guidance
▪ Discharge and area for gaged watershed ▪ Area for ungaged watershed	▪ Similar hydrologic characteristics ▪ Channel storage	Must obtain approval of transfer technique from hydraulics engineer prior to use.

☒ **Fish Passage Flows**

▪ ~~Streamflow hydrograph~~ ▪ [✓ Flow duration curve]		Lower and upper fish passage flows define the range of flows a culvert should contain suitable conditions for fish passage.

Selected Hydrologic Method: Regional Regression + Fish Passage Flows

Basis for Selection:

Must meet Adult Anadromous Salmonid depth + velocity criteria

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[1] Caltrans Highway Design Manual, Chapter 810 Hydrology, Topic 819 Estimating Design Discharge

[2] FEMA Guidelines and Specifications, Appendix C, Section C.1

[3] USGS Water-Resources Investigation 77-21 (Magnitude and Frequency of Floods in California)

[4] USGS Open-File Report 93-419 (Methods for Estimating Magnitude and Frequency of floods in the Southwestern United States)

[5] United States Department of Agriculture, Natural Resources Conservation Service, Urban Hydrology for Small Watersheds Technical Release 55, June 1986. ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf

[6] HEC-1 User's Manual

[7] HEC-HMS User's Manual

[8] Bulletin 17B

GUIDANCE ON METHODOLOGY FOR HYDROLOGIC ANALYSIS [1, 2] FORM 4

Verify Reasonableness and Recommended Peak Discharges

Source	**50% Annual Probability (2-Year Flood Event) (cfs)**	**10% Annual Probability (10-Year Flood Event) (cfs)**	**2% Annual Probability (50-Year Flood Event) (cfs)**	**1% Annual Probability (100-Year Flood Event) (cfs)**	**High Fish Passage Design Flow (cfs)**	**Low Fish Passage Design Flow (cfs)**
Effective Study Peak Discharges	N/A	N/A	N/A	N/A	N/A	N/A
Recommended Peak Discharges	245	510	800	900	146	18

Hydrologic Analysis Index Attached ☒ Yes ☐ No

Hydrologic Analysis Calculations Attached ☒ Yes ☐ No

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[1] Caltrans Highway Design Manual, Chapter 810 Hydrology, Topic 819 Estimating Design Discharge

[2] FEMA Guidelines and Specifications, Appendix C, Section C.1

[3] USGS Water-Resources Investigation 77-21 (Magnitude and Frequency of Floods in California)

[4] USGS Open-File Report 93-419 (Methods for Estimating Magnitude and Frequency of floods in the Southwestern United States)

[5] United States Department of Agriculture, Natural Resources Conservation Service, Urban Hydrology for Small Watersheds Technical Release 55, June 1986. ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf

[6] HEC-1 User's Manual

[7] HEC-HMS User's Manual

[8] Bulletin 17B

HYDROLOGIC ANALYSES INDEX

FORM 4

Project Information Road Widening Route 777

Computed: EKB

Date: 2/22/06

Checked: JJL

Date: 2/23/06

Stream Name: Rose Creek

County: Del Norte, CA

Route: 777

Postmile: 6.15

Flooding Source/Stream Name	Hydrologic Method/Model Used	Method/Model Analysis Date	Exhibit No.	
			Paper Copy	Electronic Copy
Rose Creek	Regional Regression >	Sierra Region	1	–
Rose Creek	Upper + Lower Fish Passage Flow		–	1

Regional Regression Computation Summary

Project Information:	Route 777 Road Widening			Computed:	EKB	Date:	2/22/2006
				Checked:	JJL	Date:	2/23/2006
Stream Name:	Rose Creek	County:	Del Norte	Route:	777	Postmile:	6.15

Calculations:

-Site Located in North Coast Region

A, Drainage Area = 1.48 mi^2
P, Mean Annual Precipitation = 79 inches
H, Altitude Index = 1 thousands of feet

Regional Regression Equations

Q2 =3.52A^0.90P^0.89H^-0.47
Q2 = 245 cfs

Q10 =6.21A^0.88P^0.93H^-0.27
Q10 = 510 cfs

Q50 = 8.57A^0.87P^0.96H^-0.08
Q50 = 800 cfs

Q100 = 9.23A^0.87P^0.97
Q100 = 900 cfs

The following documentation was taken from:

U.S. Geological Survey Water-Resources Investigations Report 94-4002:
Nationwide summary of U.S. Geological Survey regional regression equations for estimating magnitude and frequency of floods for ungaged sites, 1993

CALIFORNIA

STATEWIDE RURAL

Summary

California is divided into six hydrologic regions (fig. 1). The regression equations developed for these regions are for estimating peak discharges (QT) having recurrence intervals T that range from 2 to 100 years. The explanatory basin variables used in the equations are drainage area (A), in square miles; mean annual precipitation (P), in inches; and an altitude index (H), which is the average of altitudes in thousands of feet at points along the main channel at 10 percent, and 85 percent of the distances from the site to the divide. The variables A and H may be measured from topographic maps. Mean annual precipitation (P) is determined from a map in Rantz (1969). The regression equations were developed from peak-discharge records of 10 years or longer, available as of 1975, at more than 700 gaging stations throughout the State. The regression equations are applicable to unregulated streams but are not applicable to some parts of the State (see fig. 1). The standard errors of estimate for the regression equations for various recurrence intervals and regions range from 60 to over 100 percent. The report by Waananen and Crippen (1977) includes an approximate procedure for increasing a rural discharge to account for the effect of urban development. The influences of fire and other basin changes on flood magnitudes are also discussed.

Procedure

Topographic maps, the hydrologic regions map (fig. 1), the mean annual precipitation from Rantz (1969), and the following equations are used to estimate the needed peak discharges QT, in cubic feet per second, having selected recurrence intervals T.

North Coast Region

$Q2 = 3.52 A^{0.90} P^{0.89} H^{-0.47}$
$Q5 = 5.04 A^{0.89} P^{0.91} H^{-0.35}$
$Q10 = 6.21 A^{0.88} P^{0.93} H^{-0.27}$
$Q25 = 7.64 A^{0.87} P^{0.94} H^{-0.17}$
$Q50 = 8.57 A^{0.87} P^{0.96} H^{-0.08}$
$Q100 = 9.23 A^{0.87} P^{0.97}$

Northeast Region

$Q2 = 22 A^{0.40}$
$Q5 = 46 A^{0.45}$
$Q10 = 61 A^{0.49}$
$Q25 = 84 A^{0.54}$
$Q50 = 103 A^{0.57}$
$Q100 = 125 A^{0.59}$

Sierra Region

$Q2 = 0.24 A^{0.88} P^{1.58} H^{-0.80}$
$Q5 = 1.20 A^{0.82} P^{1.37} H^{-0.64}$
$Q10 = 2.63 A^{0.80} P^{1.25} H^{-0.58}$
$Q25 = 6.55 A^{0.79} P^{1.12} H^{-0.52}$
$Q50 = 10.4 A^{0.78} P^{1.06} H^{-0.48}$
$Q100 = 15.7 A^{0.77} P^{1.02} H^{-0.43}$

Central Coast Region

$Q2 = 0.0061 A^{0.92} P^{2.54} H^{-1.10}$
$Q5 = 0.118 A^{0.91} P^{1.95} H^{-0.79}$
$Q10 = 0.583 A^{0.90} P^{1.61} H^{-0.64}$
$Q25 = 2.91 A^{0.89} P^{1.26} H^{-0.50}$
$Q50 = 8.20 A^{0.89} P^{1.03} H^{-0.41}$
$Q100 = 19.7 A^{0.88} P^{0.84} H^{-0.33}$

South Coast Region

$Q2 = 0.14 A^{0.72} P^{1.62}$
$Q5 = 0.40 A^{0.77} P^{1.69}$
$Q10 = 0.63 A^{0.79} P^{1.75}$
$Q25 = 1.10 A^{0.81} P^{1.81}$
$Q50 = 1.50 A^{0.82} P^{1.85}$
$Q100 = 1.95 A^{0.83} P^{1.87}$

South Lahontan-Colorado Desert Region

$Q2 = 7.3A^{0.30}$
$Q5 = 53A^{0.44}$
$Q10 = 150A^{0.53}$
$Q25 = 410A^{0.63}$
$Q50 = 700A^{0.68}$
$Q100 = 1080A^{0.71}$

In the North Coast region, use a minimum value of 1.0 for the altitude index (H). Equations are defined only for basins of 25 mi² or less in the Northeast and South Lahontan-Colorado Desert regions.

Reference

Waananen, A.O., and Crippen, J.R., 1977, Magnitude and frequency of floods in California: U.S. Geological Survey Water-Resources Investigations Report 77-21, 96 p.

Additional Reference

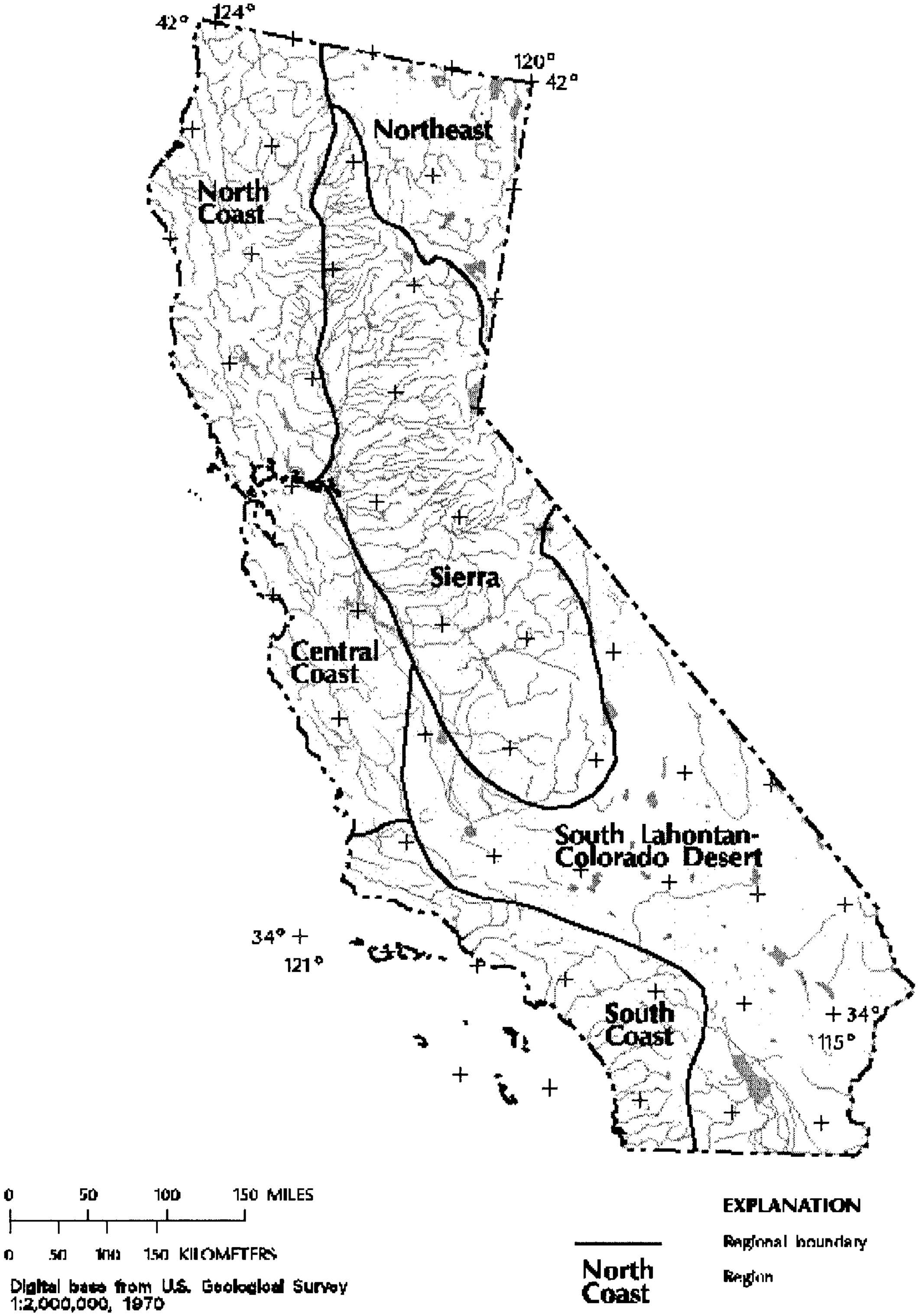
Rantz, S.E., 1969, Mean annual precipitation in the California region: U.S. Geological Survey Open-File Map (Reprinted 1972, 1975).

Figure 1. Flood-frequency region map for California. (PostScript file of Figure 1.)

Back to NFF main page

USGS Surface-Water Software Page

U.S. Geological Survey
National Flood Frequency Program
Water-Resources Investigations Report 94-4002

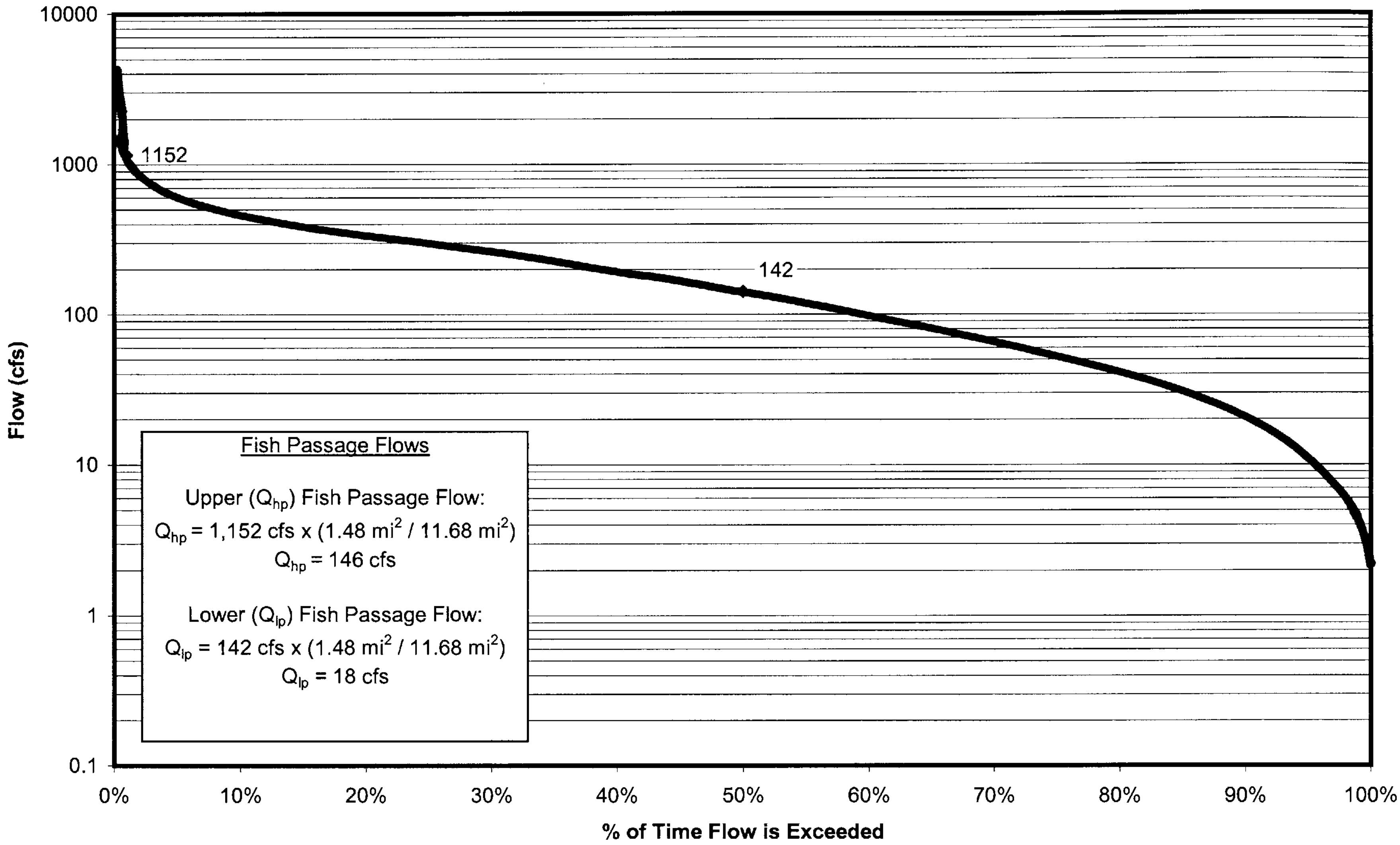


Digital base from U.S. Geological Survey 1:2,000,000, 1970

Albers equal-area projection based on standard parallels 29.5 and 45.5 degrees

Figure 1. Flood-frequency region map for California.

Flow Duration Curve



Fish Passage Flows

Upper (Q_{hp}) Fish Passage Flow:

Q_{hp} = 1,152 cfs x (1.48 mi^2 / 11.68 mi^2)

Q_{hp} = 146 cfs

Lower (Q_{lp}) Fish Passage Flow:

Q_{lp} = 142 cfs x (1.48 mi^2 / 11.68 mi^2)

Q_{lp} = 18 cfs

Form 5 - Guidance on Methodology for Hydraulic Analysis

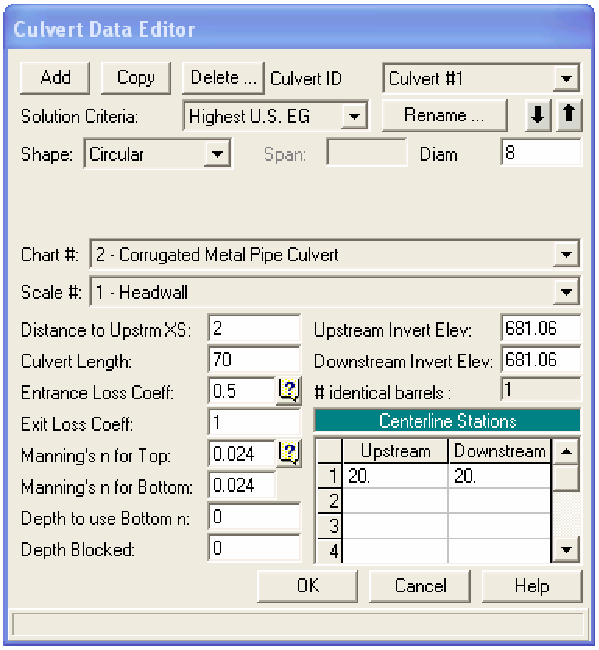
Form 5 summarizes the acceptable methods available for hydraulic analysis. The modeling methods include FHWA Design Charts, HY8 - Culvert Analysis, HEC-2/HEC-RAS, and Fish Xing (only for pre/post-design assessment).

For this particular example, HEC-RAS was used to model existing and proposed conditions. HEC-RAS easily allowed a quick comparison between existing and proposed water surface elevations and velocities. Fish Xing software was also used to assess the post-design condition.

The HEC-RAS model consists of two plans: existing geometry and proposed geometry conditions. Both plans use the same peak discharges estimated by regional regression analysis and the flow hydrograph and stream duration curve.

The existing culvert geometry was modeled using the Culvert Data Editor. The existing culvert parameters that had been measured and captured in Form 2 - Site Visit Summary, were entered into the Culvert Data Editor within HEC-RAS.

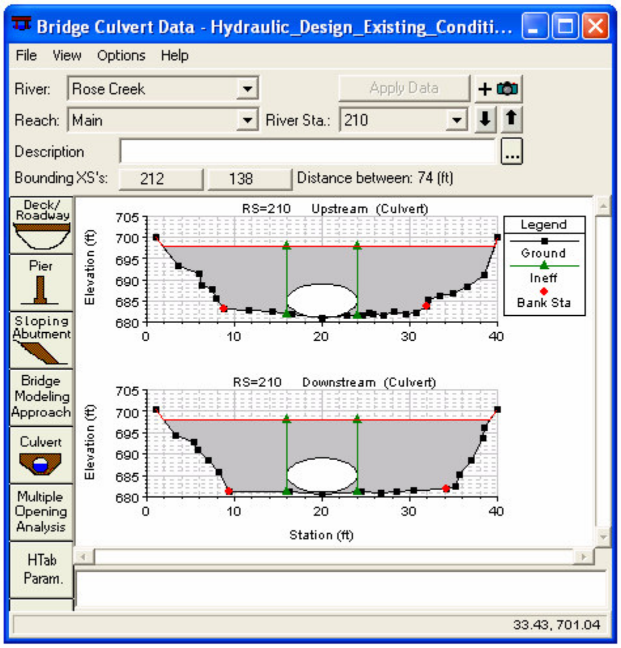
The Culvert Data Editor and Bridge Culvert Data windows are captured below.



Culvert ID: Culvert #1
Solution Criteria: Highest U.S. EG
Shape: Circular
Diam: 8
Chart #: 2 - Corrugated Metal Pipe Culvert
Scale #: 1 - Headwall
Distance to Upstrm XS: 2
Culvert Length: 70
Entrance Loss Coeff: 0.5
Exit Loss Coeff: 1
Manning's n for Top: 0.024
Manning's n for Bottom: 0.024
Depth to use Bottom n: 0
Depth Blocked: 0
Upstream Invert Elev: 681.06
Downstream Invert Elev: 681.06
identical barrels : 1

Centerline Stations

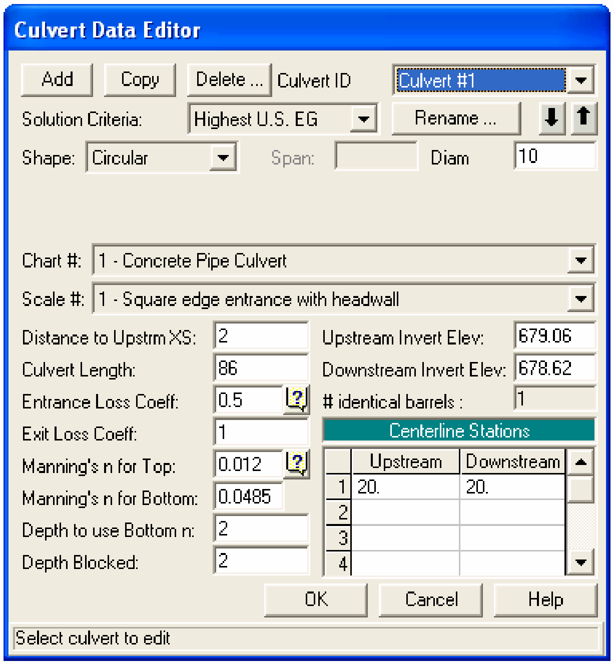
	Upstream	Downstream
1	20.	20.
2		
3		
4		



River: Rose Creek
Reach: Main
River Sta.: 210
Description:
Bounding XS's: 212 138 Distance between: 74 (ft)

The proposed culvert geometry was also modeled using the Culvert Data Editor in HEC-RAS. Since the culvert embedment is a constant depth throughout the culvert, the culvert embedment was modeled by blocking the appropriate depth out of the bottom of the culvert using the “depth blocked” function.

The Culvert Data Editor and Bridge Culvert Data windows are captured below.

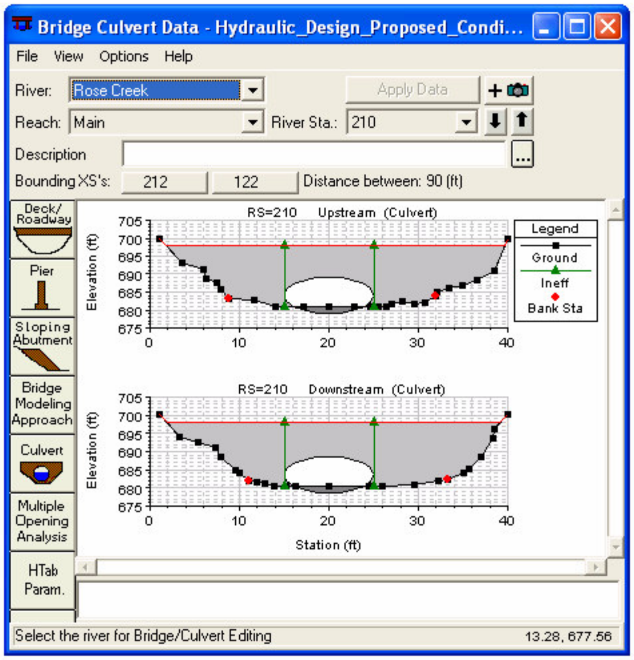


Culvert ID: Culvert #1
Solution Criteria: Highest U.S. EG
Shape: Circular
Span:
Diam: 10
Chart #: 1 - Concrete Pipe Culvert
Scale #: 1 - Square edge entrance with headwall
Distance to Upstrm XS: 2
Culvert Length: 86
Entrance Loss Coeff: 0.5
Exit Loss Coeff: 1
Manning's n for Top: 0.012
Manning's n for Bottom: 0.0485
Depth to use Bottom n: 2
Depth Blocked: 2
Upstream Invert Elev: 679.06
Downstream Invert Elev: 678.62
identical barrels : 1

Centerline Stations

	Upstream	Downstream
1	20.	20.
2		
3		
4		

Select culvert to edit



River: Rose Creek
Reach: Main
River Sta.: 210
Description:
Bounding XS's: 212 122 Distance between: 90 (ft)

Select the river for Bridge/Culvert Editing 13.28, 677.56

GUIDANCE ON METHODOLOGY FOR HYDRAULIC ANALYSIS

FORM 5

Project Information Road Widening Route 777

Computed: EKB Date: 2/22/06

Checked: JJL Date: 2/23/06

Stream Name: Rose Creek

County: Del Norte

Route: 777

Postmile: 6.15

Summary of Methods for Hydraulic Analysis

☐ **FHWA Design Charts**

☐ **HY8 - Culvert Analysis or other HDS-5 Based Software**

☒ **HEC-[✓ 2 / HEC-RAS]**

☒ **Fish Xing (Pre-design assessment [✓ or post-design assessment] when applicable)**

Is the hydraulic model used to create the effective FIRM available? ☐ Yes ☒ No

If yes, update and use this model for the hydraulic model.

Selected Method: HEC-RAS and Fish Xing

Basis for Selection:

HEC-RAS - upstream and downstream channel geometry available

- model as steady state flow

- peak discharges available

Fish Xing -

for post design assessment

Verify Reasonableness and Recommended Flows ☒ Yes ☐ No

Hydraulic Analyses Index Attached ☒ Yes ☐ No

Hydraulic Analysis Calculation Attached ☒ Yes ☐ No

HYDRAULIC ANALYSES INDEX

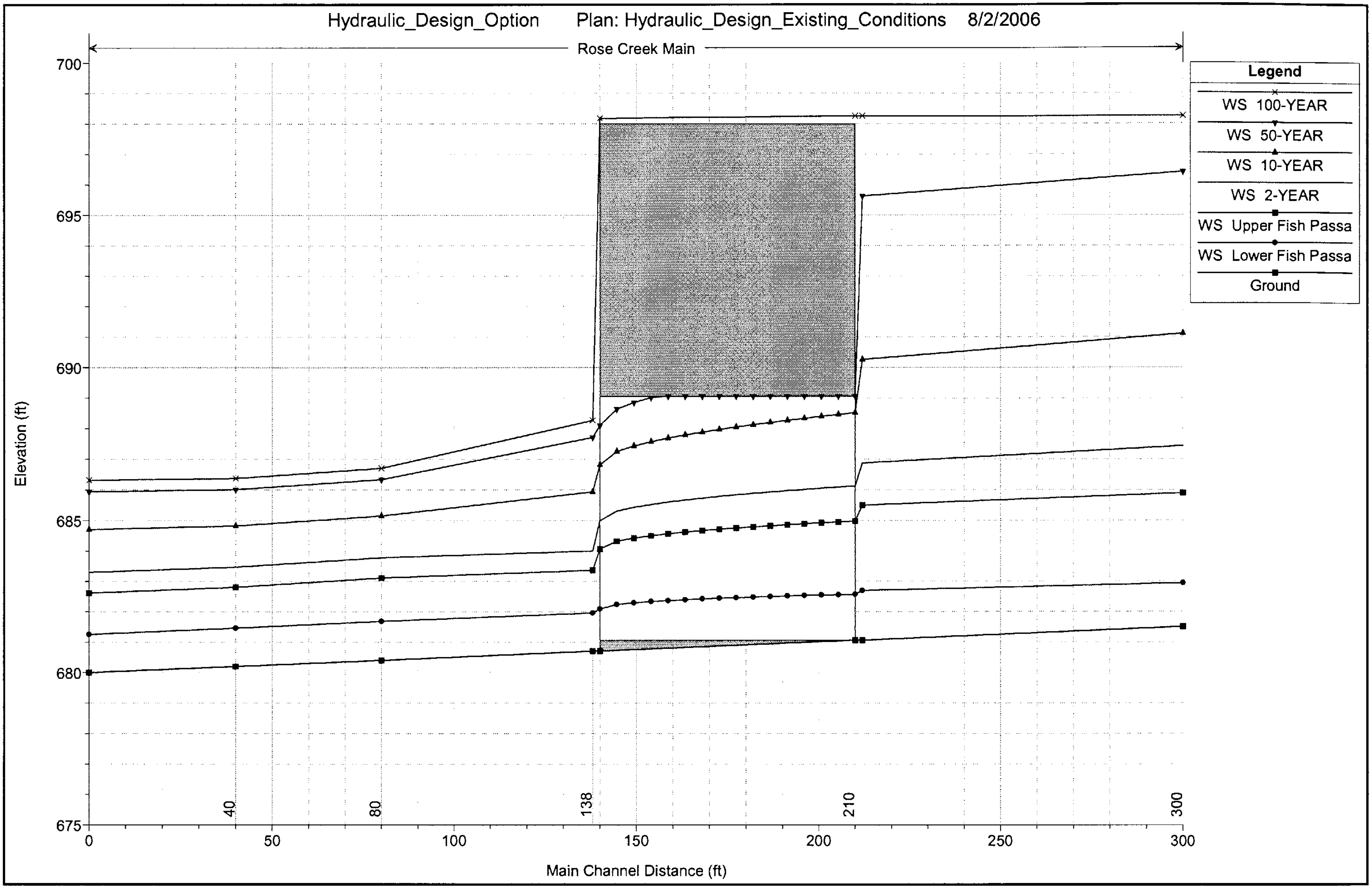
FORM 5

Project Information
Road Widening Route 777

Computed: EKB
Date: 2/22/06
Checked: JJL
Date: 2/23/06

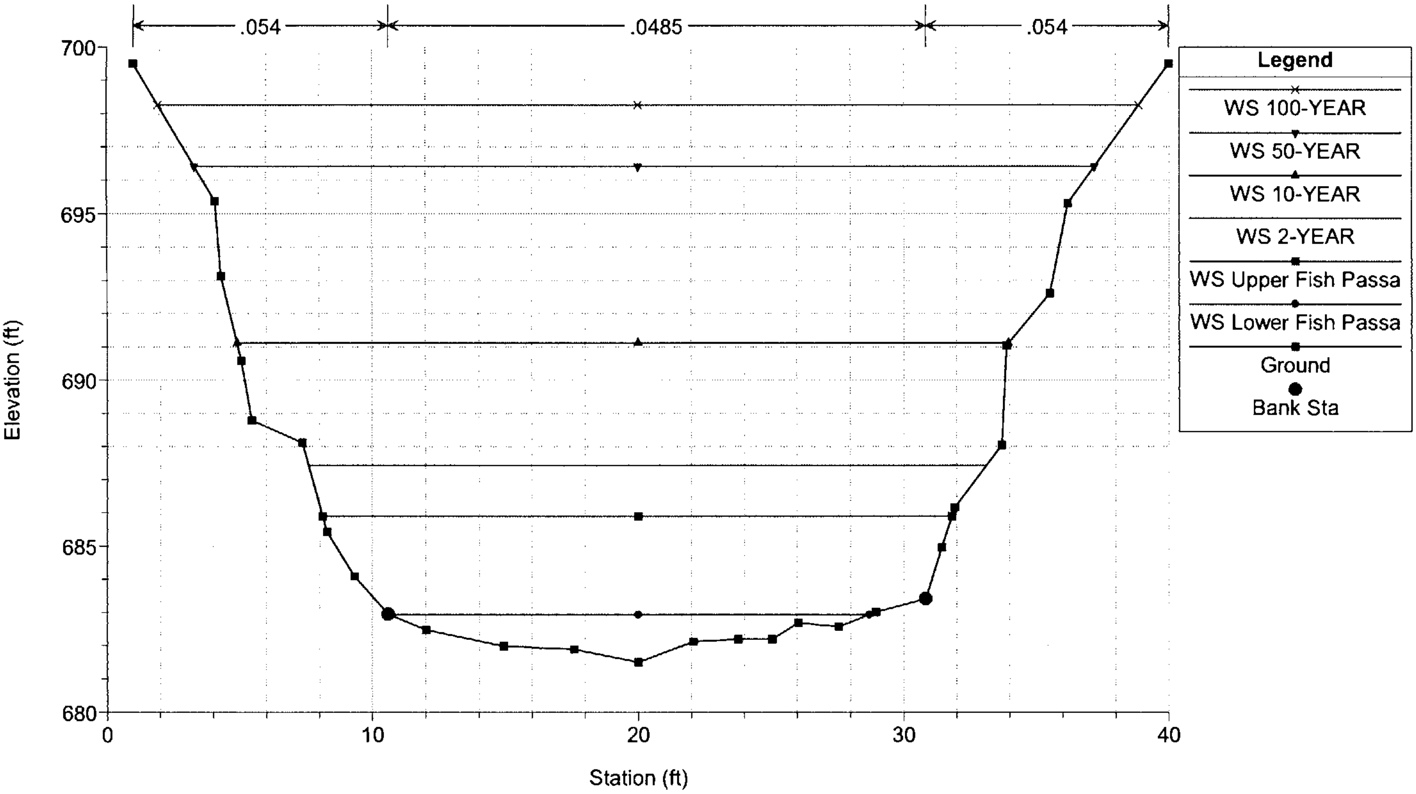
Stream Name: Rose Creek
County: Del Norte
Route: 777
Postmile: 6.5

Flooding Source/Stream Name	Hydraulic Method/Model Used	Method/Model Analysis Date	Exhibit No.	
			Paper Copy	Electronic Copy
Rose Creek	HEC-RAS	Existing/2/23/06	/	.p01 .g01 .f01
	HEC-RAS	Proposed 2/23/06	/	.p02 .g02 .f01
Rose Creek	FISH XING	Post-Design assessment	/	Rose Creek Culvert @ Route 777.xng


Hydraulic_Design_Option Plan: Hydraulic_Design_Existing_Conditions 8/2/2006
Rose Creek Main
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS Upper Fish Passa
WS Lower Fish Passa
Ground
Elevation (ft)
700
695
690
685
680
675
40
80
138
210
300
0
50
100
150
200
250
300
Main Channel Distance (ft)

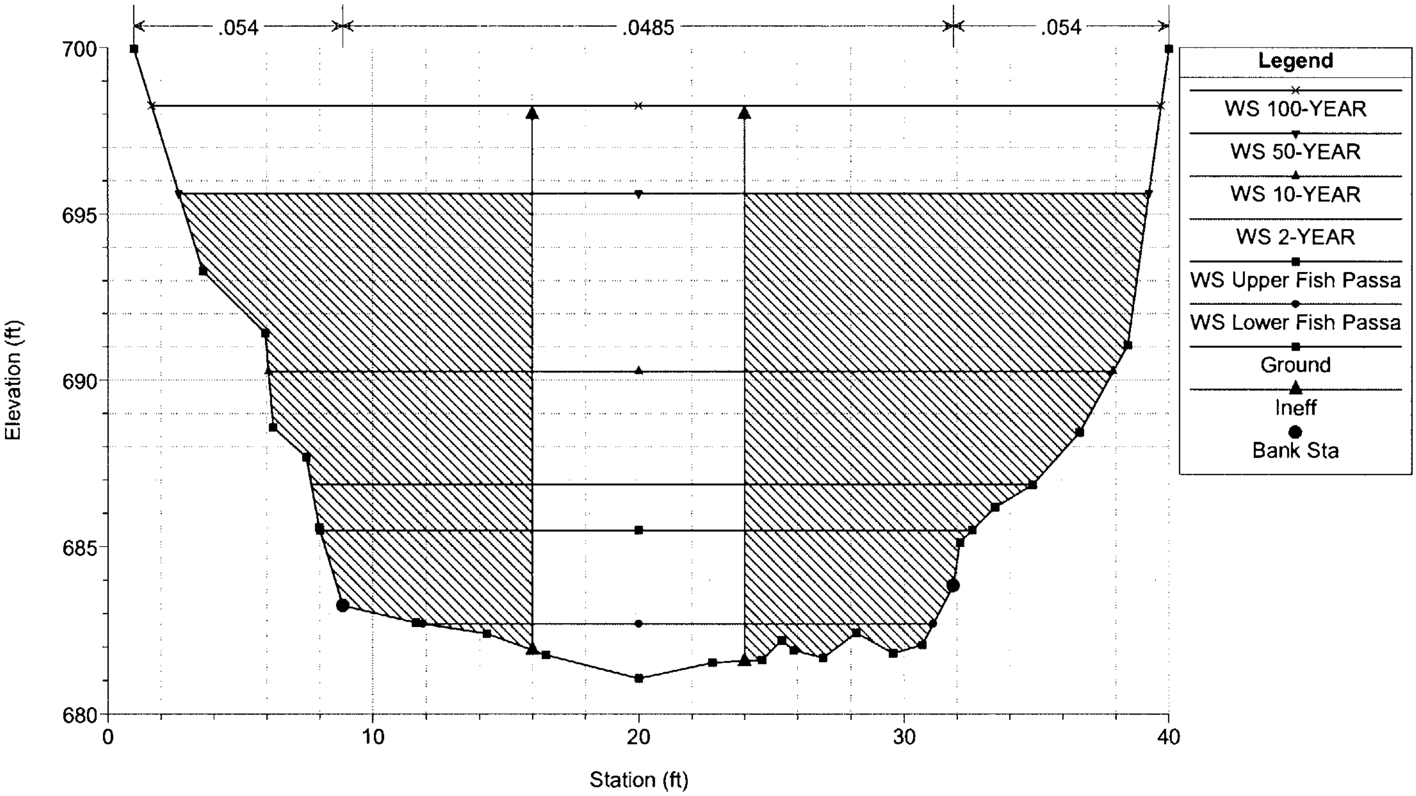
Hydraulic_Design_Option   Plan: Hydraulic_Design_Existing_Conditions   8/2/2006

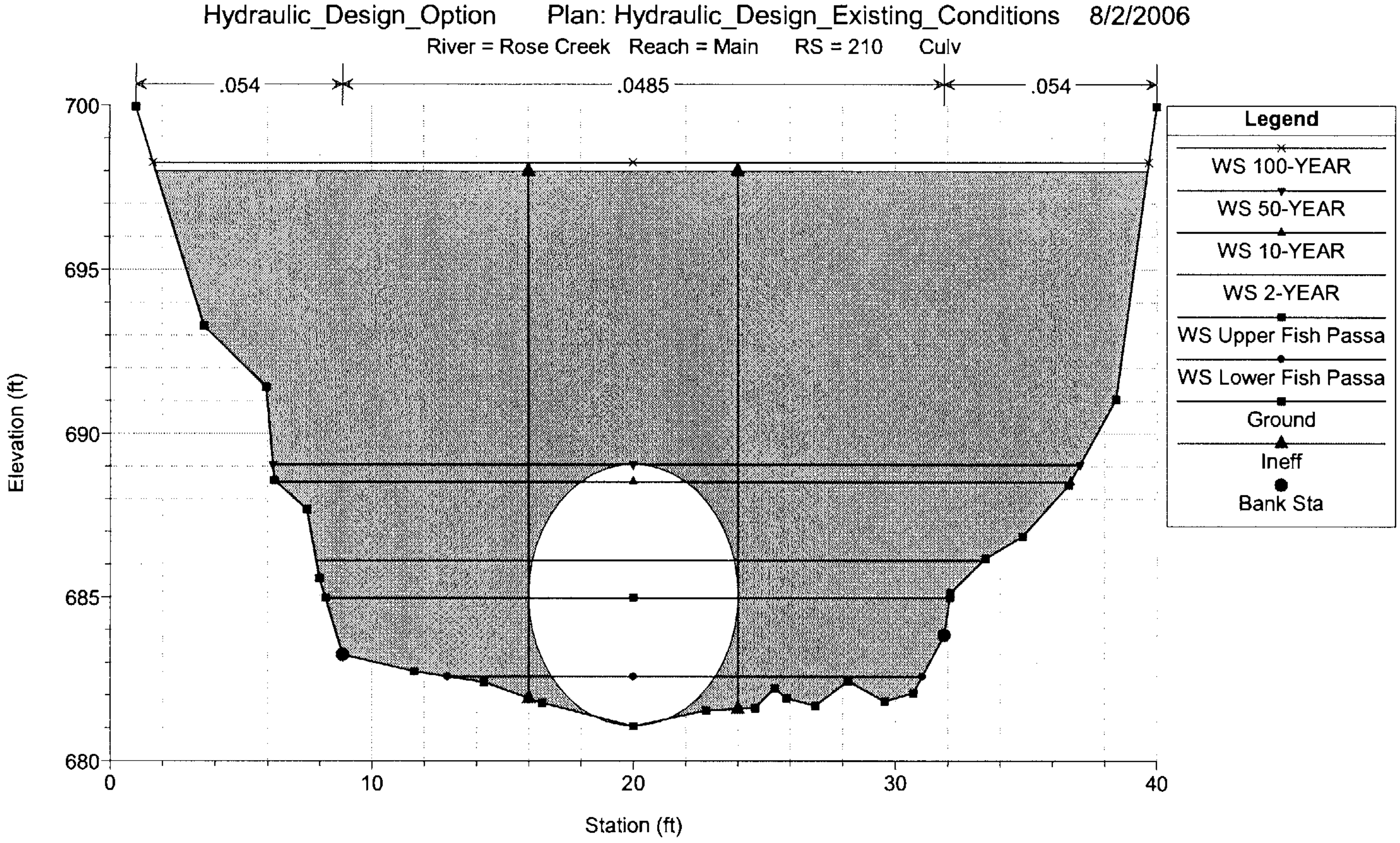
River = Rose Creek   Reach = Main   RS = 300

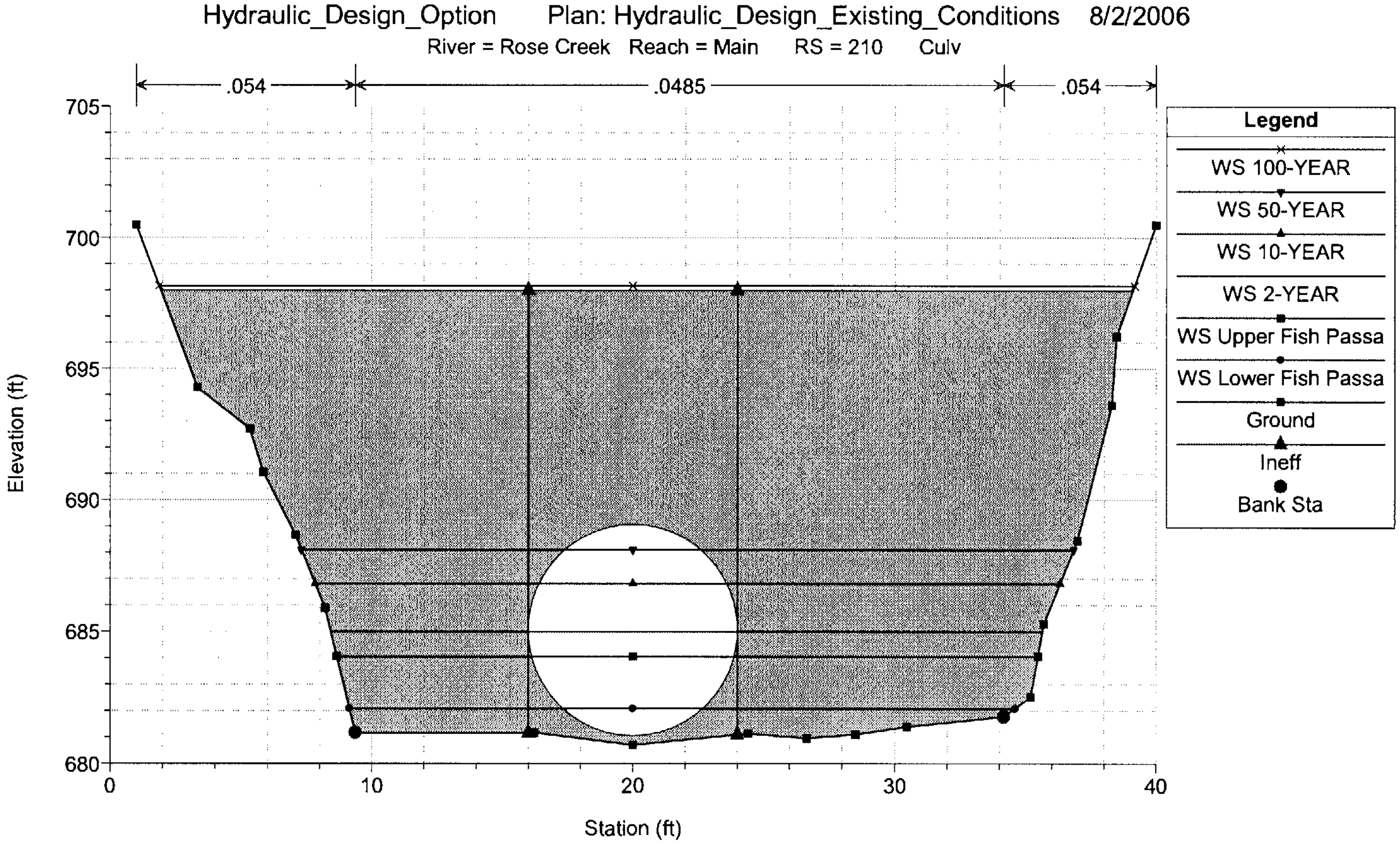


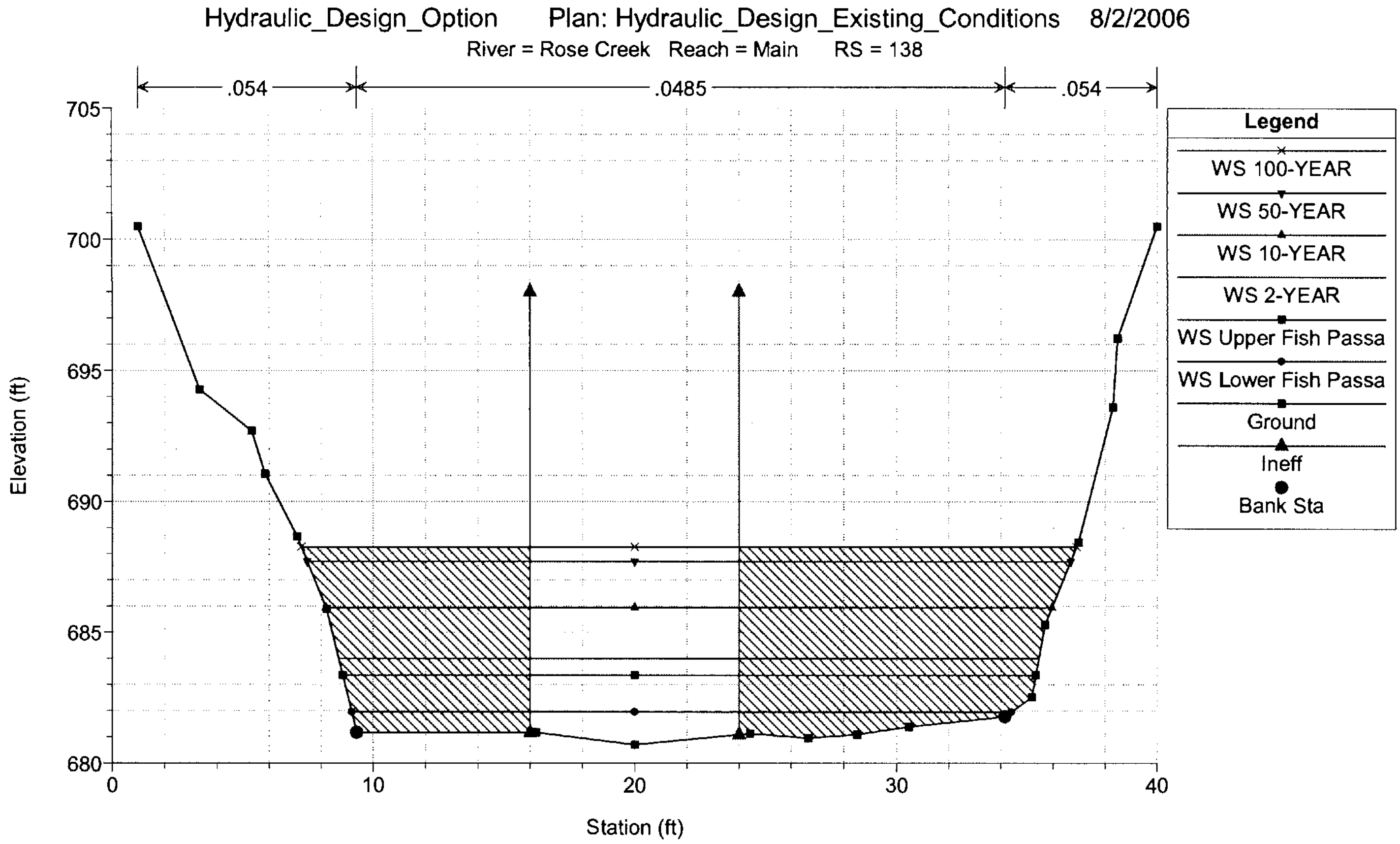
Hydraulic_Design_Option   Plan: Hydraulic_Design_Existing_Conditions   8/2/2006

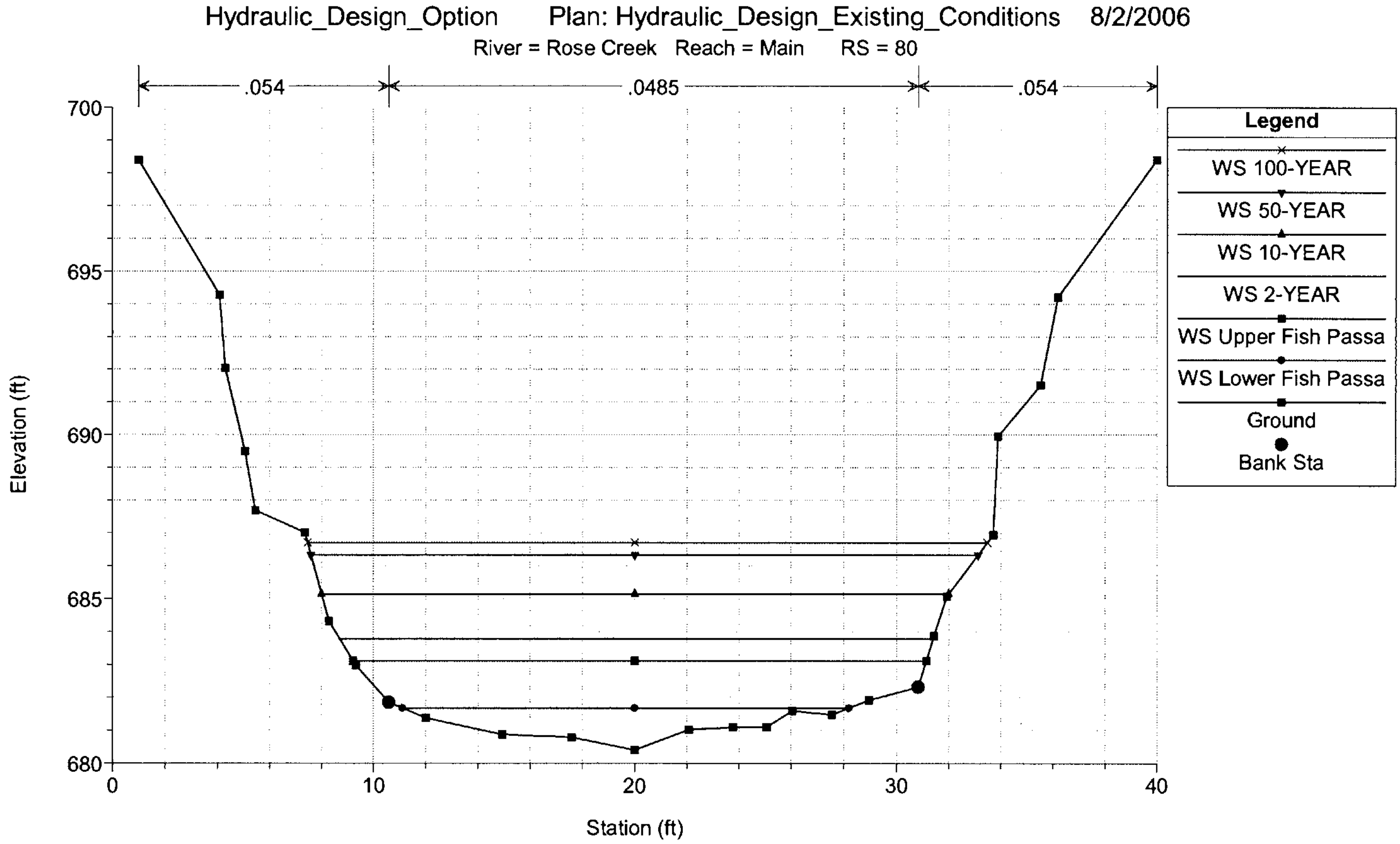
River = Rose Creek   Reach = Main   RS = 212

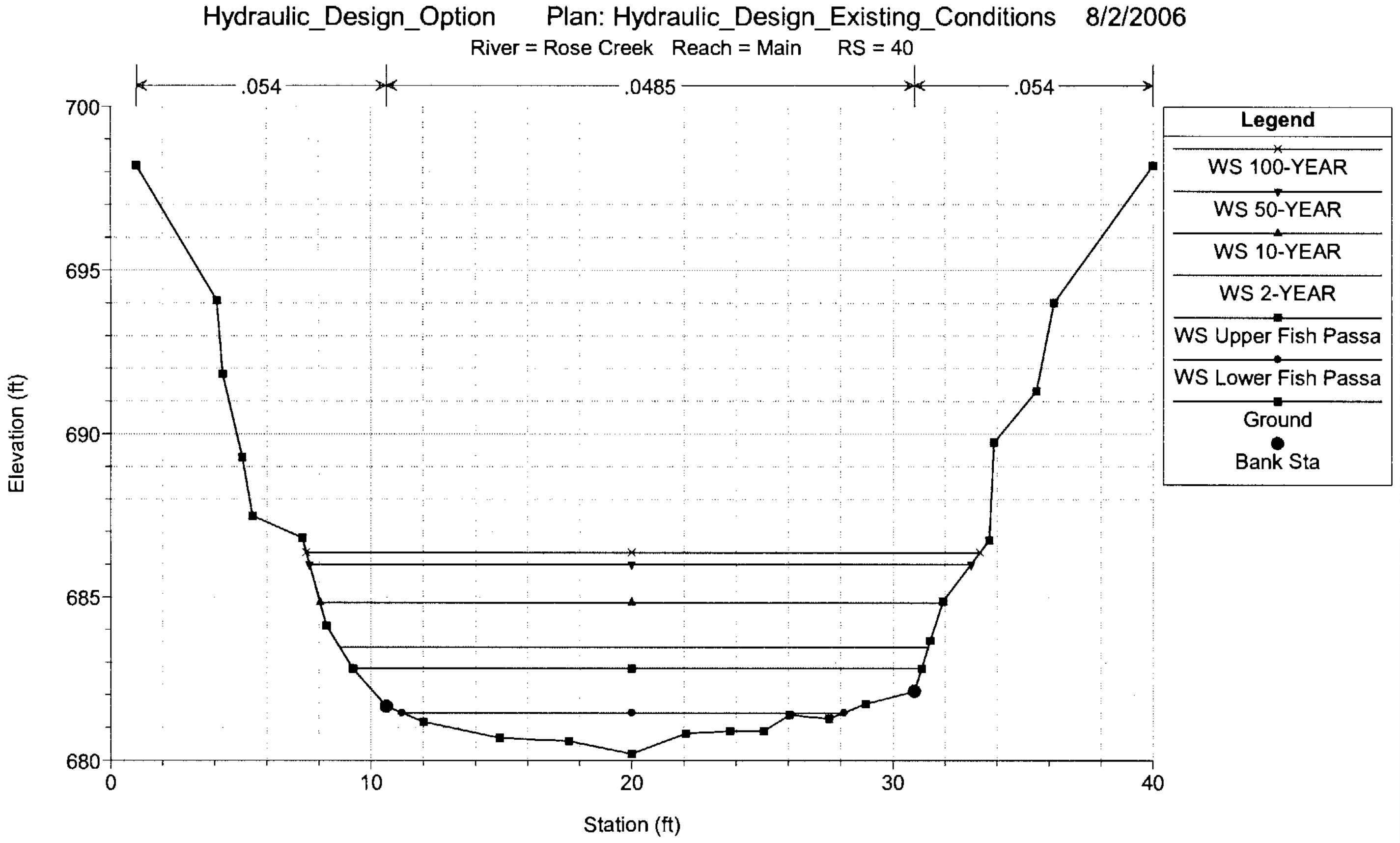


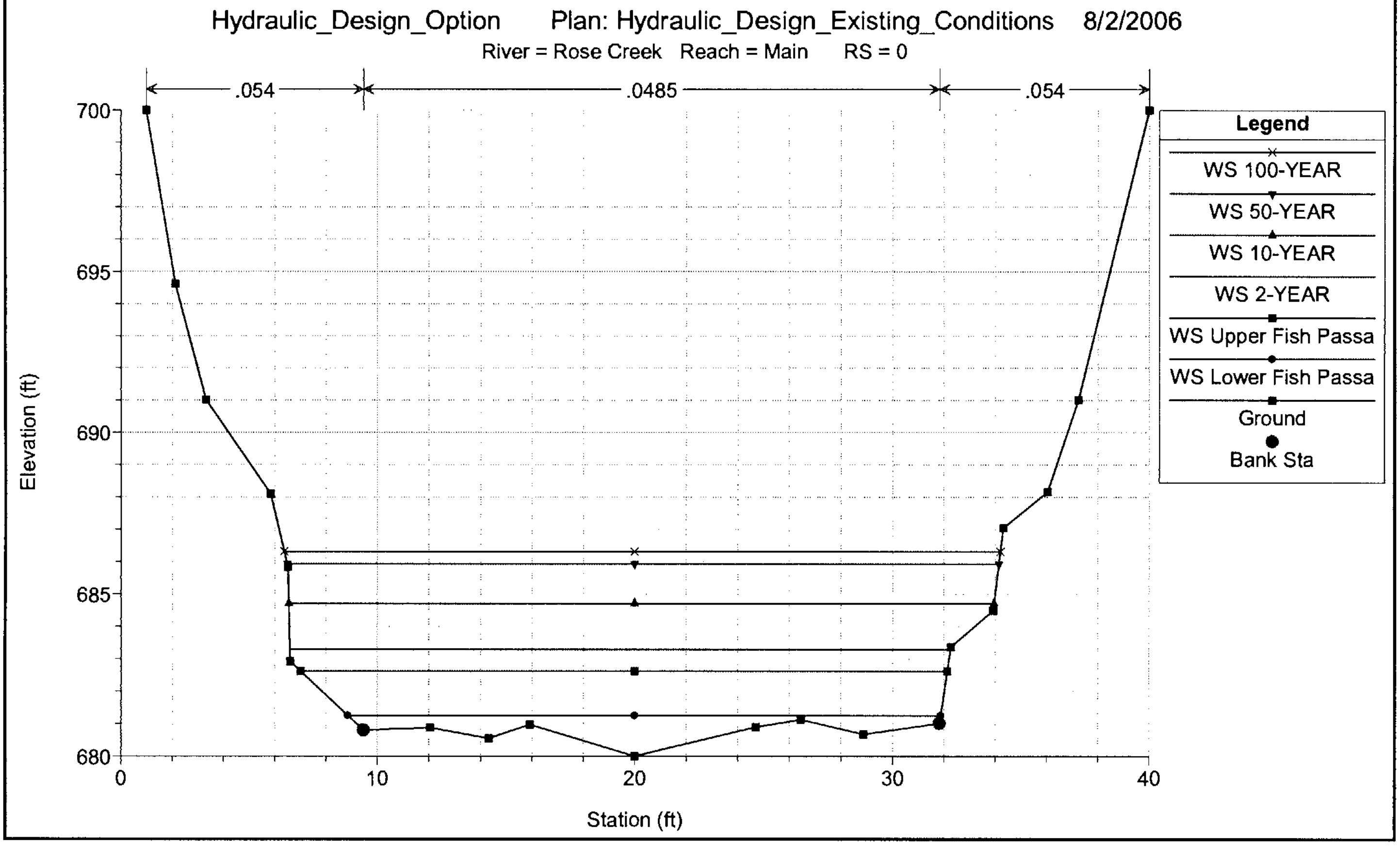

Hydraulic_Design_Option Plan: Hydraulic_Design_Existing_Conditions 8/2/2006
River = Rose Creek Reach = Main RS = 210 Culv


Hydraulic_Design_Option Plan: Hydraulic_Design_Existing_Conditions 8/2/2006
River = Rose Creek Reach = Main RS = 210 Culv


Hydraulic_Design_Option Plan: Hydraulic_Design_Existing_Conditions 8/2/2006
River = Rose Creek Reach = Main RS = 138
.054
.0485
.054
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS Upper Fish Passa
WS Lower Fish Passa
Ground
Ineff
Bank Sta
Elevation (ft)
705
700
695
690
685
680
0
10
20
30
40
Station (ft)


Hydraulic_Design_Option Plan: Hydraulic_Design_Existing_Conditions 8/2/2006
River = Rose Creek Reach = Main RS = 80
.054
.0485
.054
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS Upper Fish Passa
WS Lower Fish Passa
Ground
Bank Sta
Elevation (ft)
700
695
690
685
680
0
10
20
30
40
Station (ft)


Hydraulic_Design_Option Plan: Hydraulic_Design_Existing_Conditions 8/2/2006
River = Rose Creek Reach = Main RS = 40
.054
.0485
.054
700
695
690
685
680
Elevation (ft)
0
10
20
30
40
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS Upper Fish Passa
WS Lower Fish Passa
Ground
Bank Sta


Hydraulic_Design_Option Plan: Hydraulic_Design_Existing_Conditions 8/2/2006
River = Rose Creek Reach = Main RS = 0
.054
.0485
.054
700
695
690
685
680
Elevation (ft)
0
10
20
30
40
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS Upper Fish Passa
WS Lower Fish Passa
Ground
Bank Sta

HEC-RAS Plan: Existing Conditions River: Rose Creek

River Sta	Profile	Q Total	Min Ch El	W.S. Elev	W. Depth	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
		(cfs)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
0	2-YEAR	245	680	683.3	3.3	682.22	683.55	0.005	4.06	62.87	25.67	0.44
0	10-YEAR	510	680	684.71	4.71	683.18	685.15	0.005001	5.41	100.33	27.4	0.48
0	50-YEAR	800	680	685.93	5.93	684.02	686.55	0.005	6.46	134.01	27.65	0.5
0	100-YEAR	900	680	686.31	6.31	684.28	686.99	0.005002	6.77	144.51	27.83	0.5
0	Upper Fish Passage	146	680	682.62	2.62	681.78	682.78	0.005001	3.31	45.43	25.12	0.42
0	Lower Fish Passage	18	680	681.25	1.25	680.95	681.28	0.005002	1.45	12.53	23.02	0.34
40	2-YEAR	245	680.2	683.47	3.27		683.82	0.007482	4.79	52.51	22.58	0.54
40	10-YEAR	510	680.2	684.83	4.63		685.44	0.007396	6.37	84.07	23.87	0.57
40	50-YEAR	800	680.2	686	5.8		686.86	0.007306	7.56	113.08	25.36	0.59
40	100-YEAR	900	680.2	686.37	6.17		687.31	0.007265	7.9	122.45	25.84	0.6
40	Upper Fish Passage	146	680.2	682.81	2.61		683.05	0.00753	3.92	37.86	21.81	0.51
40	Lower Fish Passage	18	680.2	681.46	1.26		681.5	0.005839	1.69	10.64	16.95	0.38
80	2-YEAR	245	680.4	683.78	3.38		684.1	0.006451	4.58	55.03	22.7	0.5
80	10-YEAR	510	680.4	685.15	4.75		685.72	0.006641	6.16	87.03	24	0.55
80	50-YEAR	800	680.4	686.33	5.93		687.15	0.006695	7.36	116.38	25.53	0.57
80	100-YEAR	900	680.4	686.7	6.3		687.59	0.006693	7.71	125.83	26.01	0.58
80	Upper Fish Passage	146	680.4	683.11	2.71		683.32	0.006272	3.7	40.09	21.93	0.47
80	Lower Fish Passage	18	680.4	681.68	1.28		681.72	0.00521	1.63	11.05	17.1	0.36
138	2-YEAR	245	680.7	684	3.3	684	685.54	0.023656	9.94	24.65	26.8	1
138	10-YEAR	510	680.7	685.94	5.24	685.94	688.45	0.020231	12.71	40.11	27.78	1
138	50-YEAR	800	680.7	687.71	7.01	687.71	691.08	0.018144	14.73	54.3	29.22	1
138	100-YEAR	900	680.7	688.26	7.56	688.26	691.91	0.017673	15.32	58.73	29.68	1
138	Upper Fish Passage	146	680.7	683.36	2.66	683.11	684.23	0.01827	7.48	19.53	26.52	0.84
138	Lower Fish Passage	18	680.7	681.96	1.26	681.46	682.03	0.004864	2.18	8.27	25.24	0.38
210		Culvert										
212	2-YEAR	245	681.06	686.88	5.82	684.49	687.37	0.003566	5.61	43.67	27.21	0.42
212	10-YEAR	510	681.06	690.26	9.2	686.43	691.06	0.003099	7.21	70.71	31.83	0.43
212	50-YEAR	800	681.06	695.63	14.57	688.2	696.4	0.001566	7.04	113.69	36.57	0.33
212	100-YEAR	900	681.06	698.25	17.19	688.75	698.32	0.000133	2.15	500.57	38.04	0.09
212	Upper Fish Passage	146	681.06	685.5	4.44	683.59	685.81	0.003349	4.48	32.61	24.56	0.39
212	Lower Fish Passage	18	681.06	682.7	1.64	681.96	682.74	0.002432	1.76	10.22	19.22	0.27
300	2-YEAR	245	681.5	687.44	5.94		687.52	0.000625	2.25	116.53	25.54	0.17
300	10-YEAR	510	681.5	691.11	9.61		691.21	0.00042	2.64	219.01	29.05	0.16
300	50-YEAR	800	681.5	696.42	14.92		696.5	0.000201	2.5	385.9	33.89	0.12
300	100-YEAR	900	681.5	698.25	16.75		698.34	0.000165	2.46	450.92	36.93	0.11
300	Upper Fish Passage	146	681.5	685.9	4.4		685.95	0.000747	1.94	78.61	23.69	0.18
300	Lower Fish Passage	18	681.5	682.94	1.44		682.97	0.002614	1.29	13.91	18.1	0.26

Plan: Existing   Rose Creek   Main RS: 210 Culv Group: Culvert #1   Profile: Lower Fish Passa

Q Culv Group (cfs)	18.00	Culv Full Len (ft)	
# Barrels	1	Culv Vel US (ft/s)	2.73
Q Barrel (cfs)	18.00	Culv Vel DS (ft/s)	4.77
E.G. US. (ft)	682.75	Culv Inv El Up (ft)	681.06
W.S. US. (ft)	682.70	Culv Inv El Dn (ft)	681.06
E.G. DS (ft)	682.03	Culv Frctn Ls (ft)	0.25
W.S. DS (ft)	681.96	Culv Exit Loss (ft)	0.41
Delta EG (ft)	0.72	Culv Entr Loss (ft)	0.06
Delta WS (ft)	0.74	Q Weir (cfs)	
E.G. IC (ft)	682.44	Weir Sta Lft (ft)	
E.G. OC (ft)	682.75	Weir Sta Rgt (ft)	
Culvert Control	Outlet	Weir Submerg	
Culv WS Inlet (ft)	682.57	Weir Max Depth (ft)	
Culv WS Outlet (ft)	682.09	Weir Avg Depth (ft)	
Culv Nml Depth (ft)		Weir Flow Area (sq ft)	
Culv Crt Depth (ft)	1.03	Min El Weir Flow (ft)	698.01

Plan: Existing Rose Creek Main RS: 210 Culv Group: Culvert #1 Profile: Upper Fish Passa

Q Culv Group (cfs)	146.00	Culv Full Len (ft)	
# Barrels	1	Culv Vel US (ft/s)	5.97
Q Barrel (cfs)	146.00	Culv Vel DS (ft/s)	8.47
E.G. US. (ft)	685.81	Culv Inv El Up (ft)	681.06
W.S. US. (ft)	685.50	Culv Inv El Dn (ft)	681.06
E.G. DS (ft)	684.23	Culv Frctn Ls (ft)	0.35
W.S. DS (ft)	683.36	Culv Exit Loss (ft)	0.95
Delta EG (ft)	1.58	Culv Entr Loss (ft)	0.28
Delta WS (ft)	2.13	Q Weir (cfs)	
E.G. IC (ft)	685.24	Weir Sta Lft (ft)	
E.G. OC (ft)	685.81	Weir Sta Rgt (ft)	
Culvert Control	Outlet	Weir Submerg	
Culv WS Inlet (ft)	684.98	Weir Max Depth (ft)	
Culv WS Outlet (ft)	684.06	Weir Avg Depth (ft)	
Culv Nml Depth (ft)		Weir Flow Area (sq ft)	
Culv Crt Depth (ft)	3.00	Min El Weir Flow (ft)	698.01

Plan: Existing Rose Creek Main RS: 210 Culv Group: Culvert #1 Profile: 2-YEAR

Q Culv Group (cfs)	245.00	Culv Full Len (ft)	
# Barrels	1	Culv Vel US (ft/s)	7.31
Q Barrel (cfs)	245.00	Culv Vel DS (ft/s)	9.95
E.G. US. (ft)	687.37	Culv Inv El Up (ft)	681.06
W.S. US. (ft)	686.88	Culv Inv El Dn (ft)	681.06
E.G. DS (ft)	685.54	Culv Frctn Ls (ft)	0.42
W.S. DS (ft)	684.00	Culv Exit Loss (ft)	1.00
Delta EG (ft)	1.83	Culv Entr Loss (ft)	0.41
Delta WS (ft)	2.87	Q Weir (cfs)	
E.G. IC (ft)	686.72	Weir Sta Lft (ft)	
E.G. OC (ft)	687.37	Weir Sta Rgt (ft)	
Culvert Control	Outlet	Weir Submerg	
Culv WS Inlet (ft)	686.12	Weir Max Depth (ft)	
Culv WS Outlet (ft)	685.00	Weir Avg Depth (ft)	
Culv Nml Depth (ft)		Weir Flow Area (sq ft)	
Culv Crt Depth (ft)	3.94	Min El Weir Flow (ft)	698.01

Plan: Existing Rose Creek Main RS: 210 Culv Group: Culvert #1 Profile: 10-YEAR

Q Culv Group (cfs)	510.00	Culv Full Len (ft)	
# Barrels	1	Culv Vel US (ft/s)	10.45
Q Barrel (cfs)	510.00	Culv Vel DS (ft/s)	13.17
E.G. US. (ft)	691.07	Culv Inv El Up (ft)	681.06
W.S. US. (ft)	690.26	Culv Inv El Dn (ft)	681.06
E.G. DS (ft)	688.45	Culv Frctn Ls (ft)	0.71
W.S. DS (ft)	685.94	Culv Exit Loss (ft)	1.06
Delta EG (ft)	2.62	Culv Entr Loss (ft)	0.85
Delta WS (ft)	4.32	Q Weir (cfs)	
E.G. IC (ft)	690.34	Weir Sta Lft (ft)	
E.G. OC (ft)	691.07	Weir Sta Rgt (ft)	
Culvert Control	Outlet	Weir Submerg	
Culv WS Inlet (ft)	688.52	Weir Max Depth (ft)	
Culv WS Outlet (ft)	686.82	Weir Avg Depth (ft)	
Culv Nml Depth (ft)		Weir Flow Area (sq ft)	
Culv Crt Depth (ft)	5.76	Min El Weir Flow (ft)	698.01

Plan: Existing Rose Creek Main RS: 210 Culv Group: Culvert #1 Profile: 50-YEAR

Q Culv Group (cfs)	800.00	Culv Full Len (ft)	54.86
# Barrels	1	Culv Vel US (ft/s)	15.92
Q Barrel (cfs)	800.00	Culv Vel DS (ft/s)	17.06
E.G. US. (ft)	696.40	Culv Inv El Up (ft)	681.06
W.S. US. (ft)	695.63	Culv Inv El Dn (ft)	681.06
E.G. DS (ft)	691.08	Culv Frctn Ls (ft)	1.80
W.S. DS (ft)	687.71	Culv Exit Loss (ft)	1.55
Delta EG (ft)	5.32	Culv Entr Loss (ft)	1.97
Delta WS (ft)	7.92	Q Weir (cfs)	
E.G. IC (ft)	696.18	Weir Sta Lft (ft)	
E.G. OC (ft)	696.40	Weir Sta Rgt (ft)	
Culvert Control	Outlet	Weir Submerg	
Culv WS Inlet (ft)	689.06	Weir Max Depth (ft)	
Culv WS Outlet (ft)	688.11	Weir Avg Depth (ft)	
Culv Nml Depth (ft)		Weir Flow Area (sq ft)	
Culv Crt Depth (ft)	7.05	Min El Weir Flow (ft)	698.01

Plan: Existing   Rose Creek   Main RS: 210   Culv Group: Culvert #1   Profile: 100-YEAR

Q Culv Group (cfs)	884.26	Culv Full Len (ft)	61.38
# Barrels	1	Culv Vel US (ft/s)	17.59
Q Barrel (cfs)	884.26	Culv Vel DS (ft/s)	18.41
E.G. US. (ft)	698.31	Culv Inv El Up (ft)	681.06
W.S. US. (ft)	698.25	Culv Inv El Dn (ft)	681.06
E.G. DS (ft)	691.91	Culv Frctn Ls (ft)	2.30
W.S. DS (ft)	688.26	Culv Exit Loss (ft)	1.70
Delta EG (ft)	6.40	Culv Entr Loss (ft)	2.40
Delta WS (ft)	9.99	Q Weir (cfs)	15.74
E.G. IC (ft)	698.31	Weir Sta Lft (ft)	1.65
E.G. OC (ft)	698.28	Weir Sta Rgt (ft)	39.71
Culvert Control	Inlet	Weir Submerg	0.00
Culv WS Inlet (ft)	689.06	Weir Max Depth (ft)	0.29
Culv WS Outlet (ft)	688.34	Weir Avg Depth (ft)	0.29
Culv Nml Depth (ft)		Weir Flow Area (sq ft)	11.17
Culv Crt Depth (ft)	7.28	Min El Weir Flow (ft)	698.01

Errors Warnings and Notes

Note:	During supercritical analysis, the culvert direct step method went to critical depth. The program
	then assumed critical depth at the outlet.
Note:	During the supercritical calculations a hydraulic jump occurred inside of the culvert.

Form 6B - Hydraulic Design Option

Form 6B provides guidance to correctly design a culvert that meets specific fish passage design criteria, while also considering hydraulic impacts and scour concerns.

For this particular example, the culvert design had to satisfy the upper and lower fish passage design requirements for depth and velocity. For the adult anadromous salmonids the maximum average velocity at high fish design flow was 5 ft/sec. This had to be satisfied while meeting a minimum flow depth at the low fish design flow of 1 foot. Hydraulic analyses for hydraulic impacts and scour were also satisfied.

FISH PASSAGE: HYDRAULIC DESIGN OPTION FORM 6B

Project Information Road Widening Route 777		Computed: EKB	Date: 2/26/06
		Checked: JJL	Date: 2/27/06
Stream Name: Rose Creek	County: Del Norte	Route: 777	Postmile: 6.15

General Considerations

Hydraulic controls (e.g. boulders weirs, log sills, etc.) 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, and control erosion of the streambed and banks.

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

The following **Adverse 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. Crossing 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 turbulent conditions, and Abrubt changes in water surface elevation in inlet and outlet.

Hydrology Results - Peak Discharge Values

50% Annual Probability (2-Year Flood Event)	245 cfs	10% Annual Probability (10-Year Flood Event)	510 cfs
2% Annual Probability (50-Year Flood Event)	800 cfs	1% Annual Probability (100-Year Flood Event)	900 cfs
High Fish Passage Design Flow	146 cfs	Low Fish Passage Design Flow	18 cfs

Estabilsh Proposed Culvert Setting and Dimensions

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

Proposed Culvert Width: 10.0 ft

Culvert Embedment - Where physically possible, the bottom of the culvert shall be buried into the streambed a minimum of 20% 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.

Upstream Embedment: 2.0 ft (≥ 1 foot)

Downstream Embedment: 2.0 ft (≥ 20% of culvert rise and ≥ 1 foot)

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%.

Upstream invert elevation: 681.06 ft ([✓ NGVD 29] or NAVD 88)

Downstream invert elevation: 680.59 ft ([✓ NGVD 29] or NAVD 88)

Summarize Proposed Culvert Physical Characterstics

Inlet Characteristics

Inlet Type	☐ Projecting	☒ Headwall	☐ Wingwall
	☐ Flared end section	☐ Segment connection	☐ Skew Angle: °

FISH PASSAGE: HYDRAULIC DESIGN OPTION FORM 6B

Barrel Characteristics

Diameter: 120 in	Fill height above culvert: approx. 9.0 ft
Height/Rise: — ft	Length: 86 ft
Width/Span: — ft	Number of barrels: 1

Culvert Type	☐ Arch	☐ Box	☒ Circular
	☐ Pipe-Arch	☐ Elliptical	
Culvert Material	☐ HDPE	☐ Steel Plate Pipe	☒ Concrete Pipe
	☐ Spiral Rib / Corrugated Metal Pipe		

Horizontal alignment breaks: NONE ft	Vertical alignment breaks: NONE ft

Outlet Characteristics

Outlet Type	☐ Projecting	☒ Headwall	☐ Wingwall
	☐ Flared end section	☐ Segment connection	Skew Angle: °

Bridge Physical Characteristics N/A

Elevation of high chord (top of road): ft	Elevation of low chord: ft

Channel Lining	☐ No lining	☐ Concrete	☐ Rock	☐ Other

Skew Angle: °	Bridge width (length): ft

Pier Characteristics (if applicable) ☐ N/A

Number of Piers: ft	Upstream cross-section starting station: ft
Pier Width: ft	Downstream cross-section starting station: ft
Pier Centerline Spacing: ft	Skew angle: °

Pier Shape	☐ Square nose and tail	☐ Semi-circular nose and tail	☐ 90° triangular nose and tail
	☐ Twin-cylinder piers with connecting diaphragm	☐ Twin-cylinder piers without connecting diaphragm	☐ Ten pile trestle bent

Establish High Design Flow for Fish Passage - Depending on species, develop high design flows:

Species/Life Stage	Percent Annual Exceedance Flow	Percentage of 2-Yr Recurrence Interval Flow	Design Flows (cfs)
☒ Adult Anadromous Salmonids	1%	50%	146
☐ Adult Non-Anadromous Salmonids	5%	30%	

☐ Juvenile Salmonids	10%	10%	
☐ Native Non-Salmonids	5%	30%	
☐ Non-Native Species	10%	10%	

Establish Low Design Flow for Fish Passage - Depending on species, develop low design flows:

Species/Life Stage	Percent Annual Exceedance Flow	Alternate Minimum Flow (cfs)	Design Flow (cfs)
☒ Adult Anadromous Salmonids	50%	3	18
☐ Adult Non-Anadromous Salmonids	90%	2	
☐ Juvenile Salmonids	95%	1	
☐ Native Non-Salmonids	90%	1	
☐ Non-Native Species	90%	1	

Establish Maximum Average Water Velocity and Minimum Flow Depth in Culvert (At high design flow) - Depending on culvert length and/or species, select Maximum Average Water Veolcity and Minimum Flow Depth.

Species/Life Stage	Maximum Average Water Velocity at High Fish Design Flow (ft/sec)	Minimum Flow Depth at Low Fish Design Flow (ft)
☒ Adult Anadromous Salmonids	6 (Culvert length <60 ft)	[✓ 1.0]
	[✓ 5 (Culvert length 60-100 ft)]	
	4 (Culvert length 100-200 ft)	
	3 (Culvert length 200-300 ft)	
	2 (Culvert length >300 ft)	
☐ Adult Non-Anadromous Salmonids	4 (Culvert length <60 ft)	0.67
	4 (Culvert length 60-100 ft)	
	3 (Culvert length 100-200 ft)	
	2 (Culvert length 200-300 ft)	
	2 (Culvert length >300 ft)	
☐ 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	

Establish 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, it's magnitude should be evaluated for both high design flow and low design flow and shall not exceed the values shown below. If a hydraulic drop occurs at the culvert outlet, a jump pool of at least 2 feet in depth shall be provided.

Species/Life Stage	**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	

Maximum Allowable Inlet Water Surface Elevation

Culvert ☒

A culvert is required to pass the 10-year peak discharge without causing pressure flow in the culvert,	Allowable WSEL: 689.06 ft
And shall not be greater than 50% of the culvert height or diameter above the top of the culvert inlet for the 100-Year peak flood.	Allowable WSEL: 694.06 ft

Bridge ☐ N/A

A bridge is required to pass the 50-year peak discharge with freeboard, vertical clearance between the lowest structural member and the water surface elevation,	Allowable WSEL: ft
While passing the 100-year peak or design discharge under low chord of the bridge.	Allowable WSEL: ft

Establish Allowable Hydraulic Impacts

Is the crossing located within a floodplain as designated by the Federal Emergency Management Agency or another responsible state or local agency?
☐ Yes ☒ No

If yes, establish allowable hydraulic imacts and hydraulic design requirements with the appropriate agency. Attach results.

Will the project result in the increase capacity of an existing crossing? ☒ Yes ☐ No

If yes, will it significantly increase downstream peak flows due to the reduced upstream attenuation? ☐ Yes ☒ No

If yes, consult District Hydraulics. Further analysis may be needed.

FISH PASSAGE: HYDRAULIC DESIGN OPTION FORM 6B

Will the project result in a reduction in flow area for the 100-year peak discharge? ☐ Yes ☒ No

If yes, establish the allowable increase in upstream water surface elevation and establish how far upstream the increased water surface may extend.

Develop and run Hydraulic Models to compute water surface elevations, flow depths, and channel velocities fo the low fish passage design flow, the high fish passage design flow and for the 2-, 10-, 50-, and 100-year peak or design discharges reflecting existing and project conditions.
☒ Yes ☐ No

Evaluate computed water surface elevations, flow depths, and channel velocities: ☒ Yes ☐ No

Maximum average velocity in culvert at high fish design flow: 5 ft/s

Does the velocity exceed the maximum allowable for the culvert length and design species? ☐ Yes ☒ No

If yes, modify design to comply and rerun hydraulic anaylses to verify.

Minimum flow depth in culvert at low fish design flow: 1 ft

Does the depth equal or not exceed the mimimum allowable for the culvert length and design species? ☐ Yes ☒ No

If yes, modify design to comply and rerun hydraulic anaylses to verify.

Drop between the water surface elevation in the culvert and the outlet channel for:

High Fish Passage Flow: NONE ft

Low Fish Passage Flow: NONE ft

Does the drop between the water surface in the culvert and the outlet channel at high or low design fish flows exceed the maximum allowable for the design species? ☐ Yes ☒ No

If yes, modify design to avoid a drop if possible. If a drop is unavoidable modify design to meet criteria and provide a jump pool at least two feet in depth. Rerun hydraulic analyses to verfiy.

Water Surface elevation at inlet for the 10-year peak discharge:

Does the water surface elevation exceed the allowable? ☐ Yes ☒ No

If yes, modify design to comply and rerun hydraulic analyses to verify.

Maximum Culvert and Channel velocities at inlet and outlet transition for the peak or design discharge: high fish passage flows

Range of velocities for Inlet transition:	4.43	ft/s	to		ft/s
Range of velocities for Culvert portion:	5.25	ft/s	to	5.88	ft/s
Range of velocities for Outlet Transition:	5.46	ft/s	to		ft/s

Do the velocities exceed the permissible scour velocities? ☐ Yes ☒ No

If yes, revise design to reduce velocities and rerun hydraulic analyses to verify, or design erosion protection.

Comparison between existing and project future condition water surface elevations for the 10-Year and 100-Year peak flow:

Cross-Section	10-Yr WSEL	10-Yr WSEL	WSEL Difference	100-Year WSEL	100-Year WSEL	WSEL Difference

FISH PASSAGE: HYDRAULIC DESIGN OPTION FORM 6B

	Existing Conditions (ft)	Future Conditions (ft)	(ft)	Existing Conditions (ft)	Future Conditions (ft)	(ft)
1 80/80	685.15	685.15	0.0	686.70	686.70	0.0
2 138/122	685.94	684.94	- 1.0	688.26	686.93	- 1.33
3 212/212	690.26	688.11	-2.15	698.25	692.49	- 5.76
4 300/300	691.11	688.97	-2.14	698.25	693.44	- 4.81

If WSELs increase, does the increase exceed the maximum elevation? ☐ Yes ☒ No

Maximum elevation: Top of road deck 698.0 ft

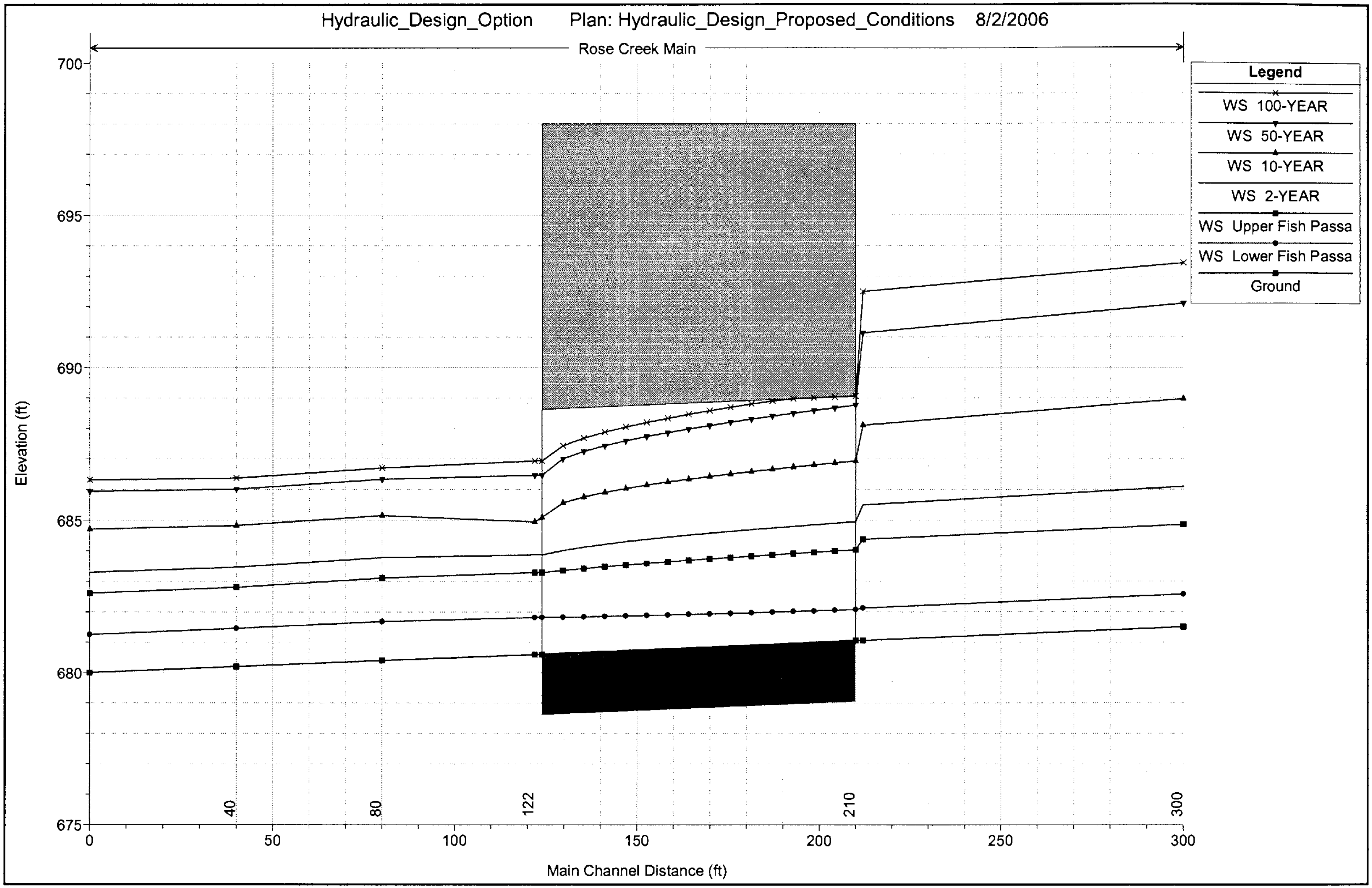
If yes, revise the design and rerun hydraulic analyses to verify.

If WSELs decrease, does it appear that the attenuation of peak flow will significally change? ☐ Yes ☒ No

If yes, evaluate to determine if downstream hydraulic impacts are significant and modify design as appropriate.

Proposed Plan and Profile Drawing Attached ☒ Yes ☐ No

Hydraulic Analysis Index Sheet Attached ☒ Yes ☐ No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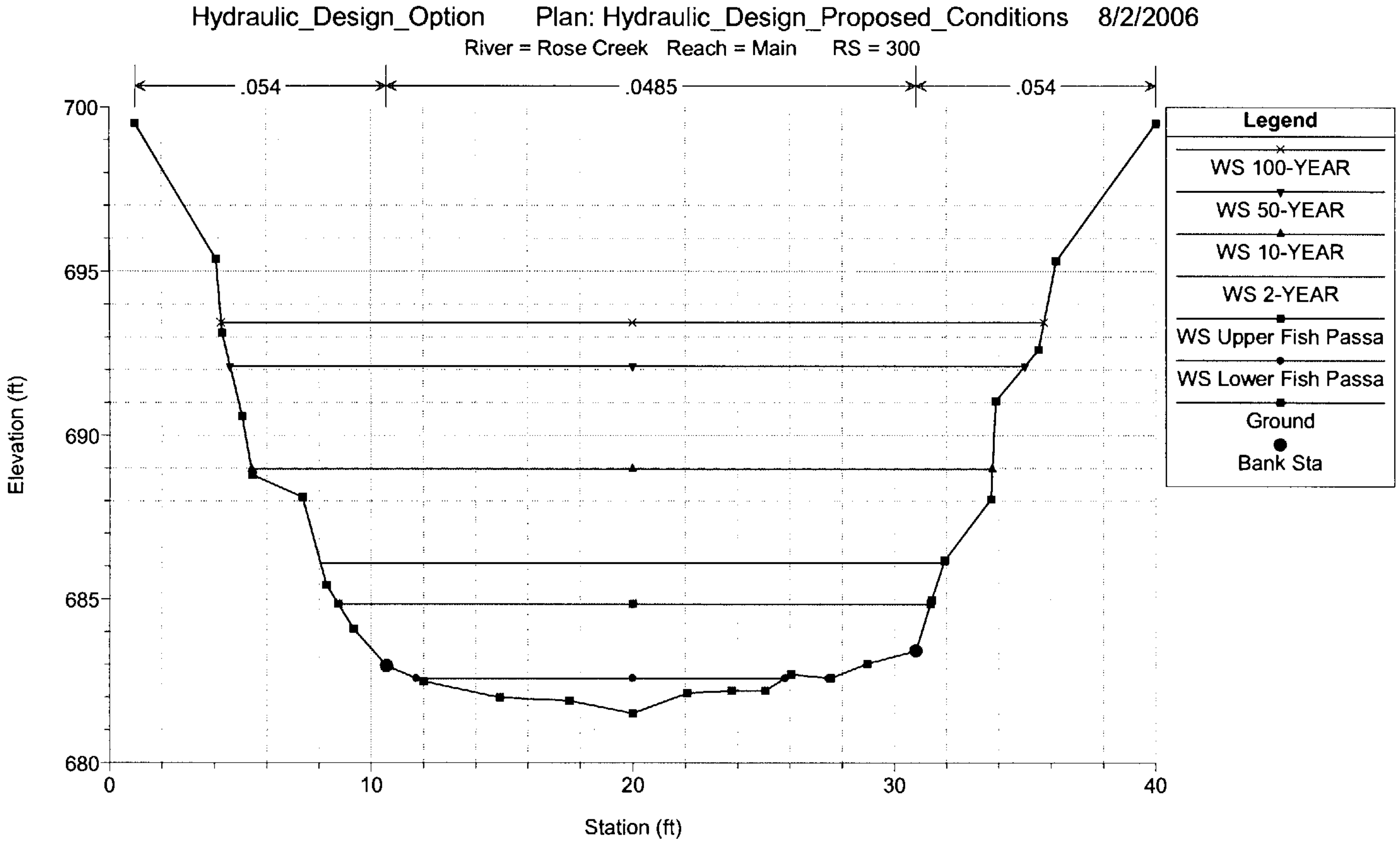
Rose Creek Main
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS Upper Fish Passa
WS Lower Fish Passa
Ground
Elevation (ft)
700
695
690
685
680
675
40
80
122
210
300
0
50
100
150
200
250
300
Main Channel Distance (ft)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.054
.0485
.054
Elevation (ft)
700
695
690
685
680
Station (ft)
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10
20
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Legend
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WS 50-YEAR
WS 10-YEAR
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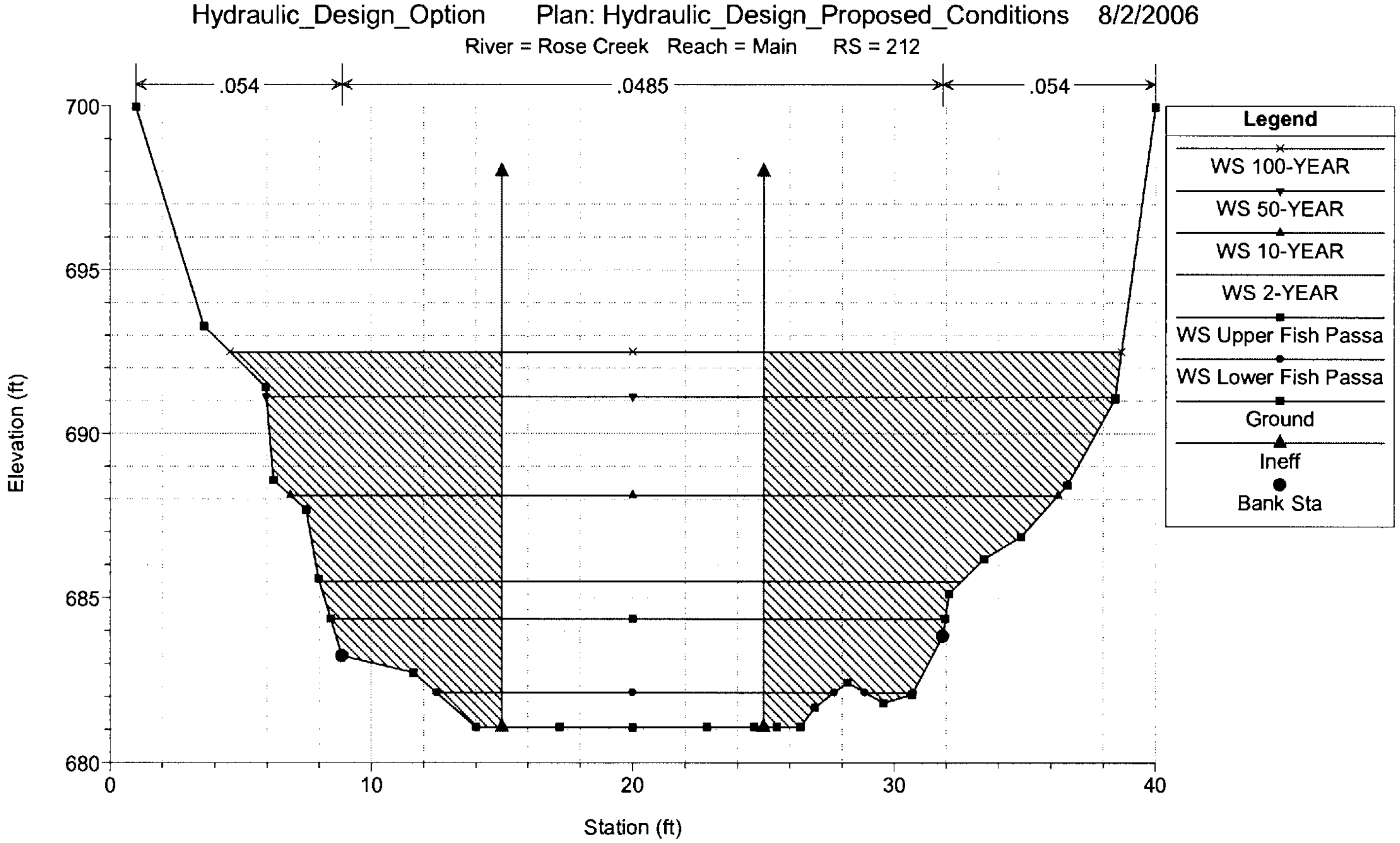
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Station (ft)
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WS 100-YEAR
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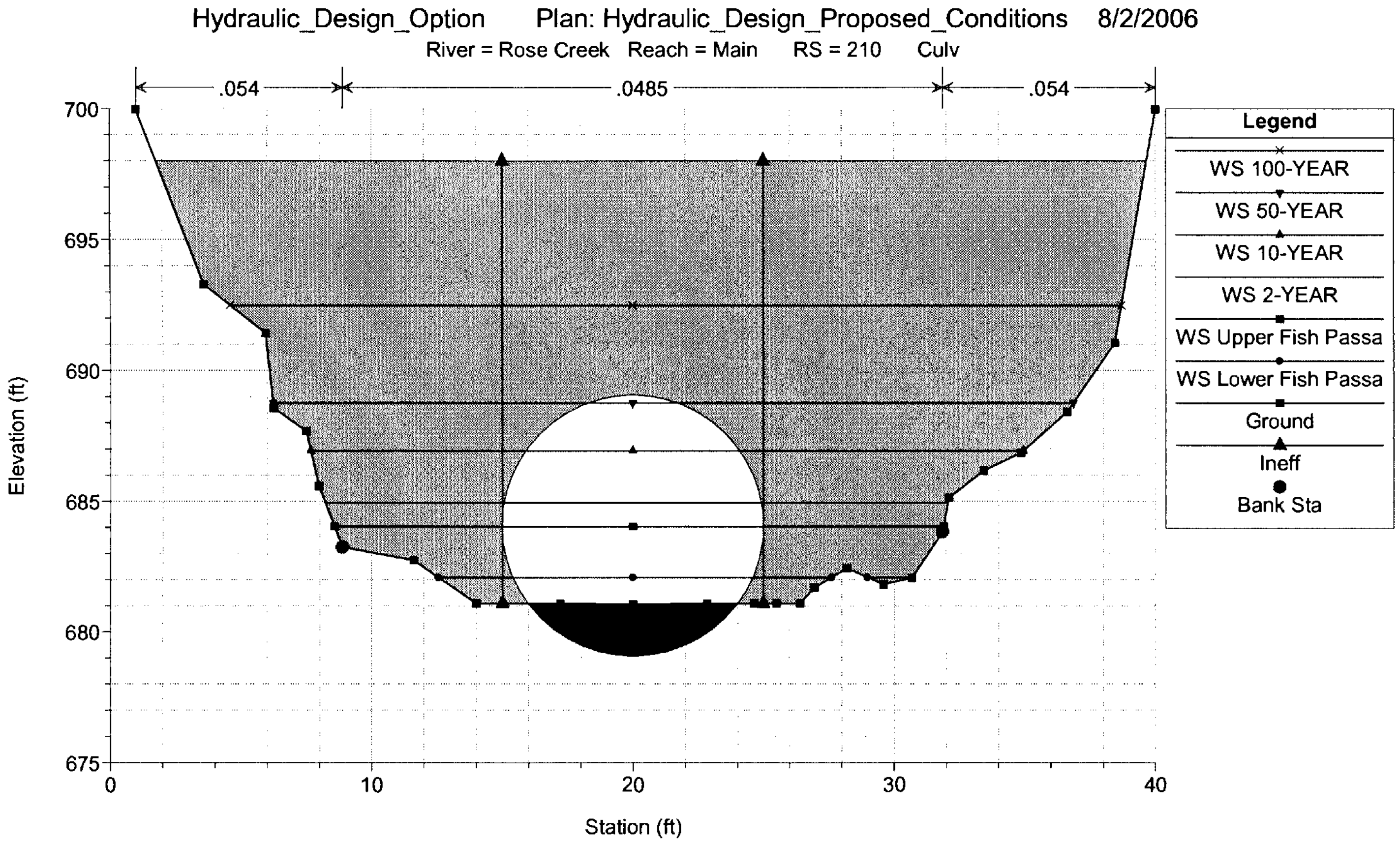
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Elevation (ft)
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685
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Station (ft)
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WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS Upper Fish Passa
WS Lower Fish Passa
Ground
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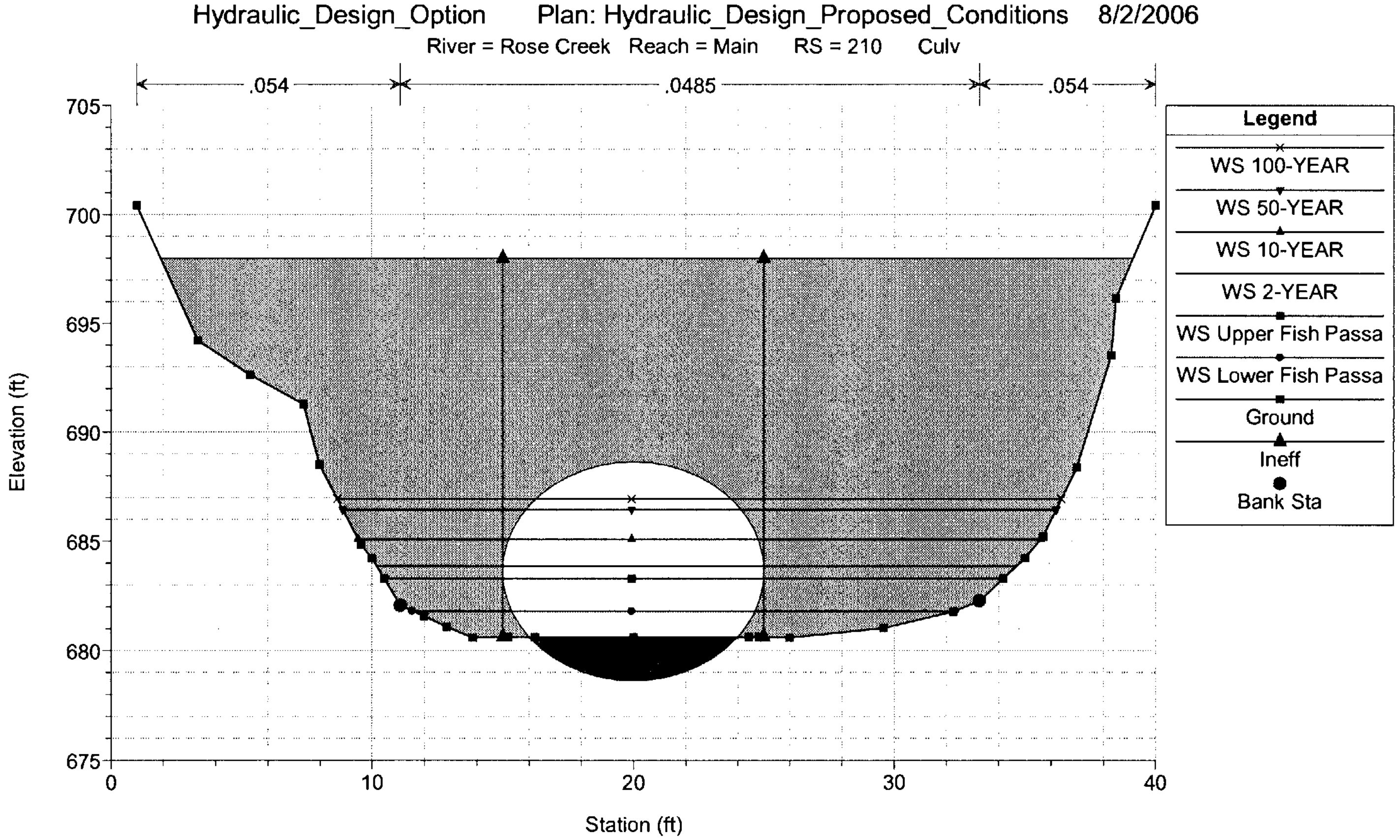
Bank Sta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Elevation (ft)
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690
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Station (ft)
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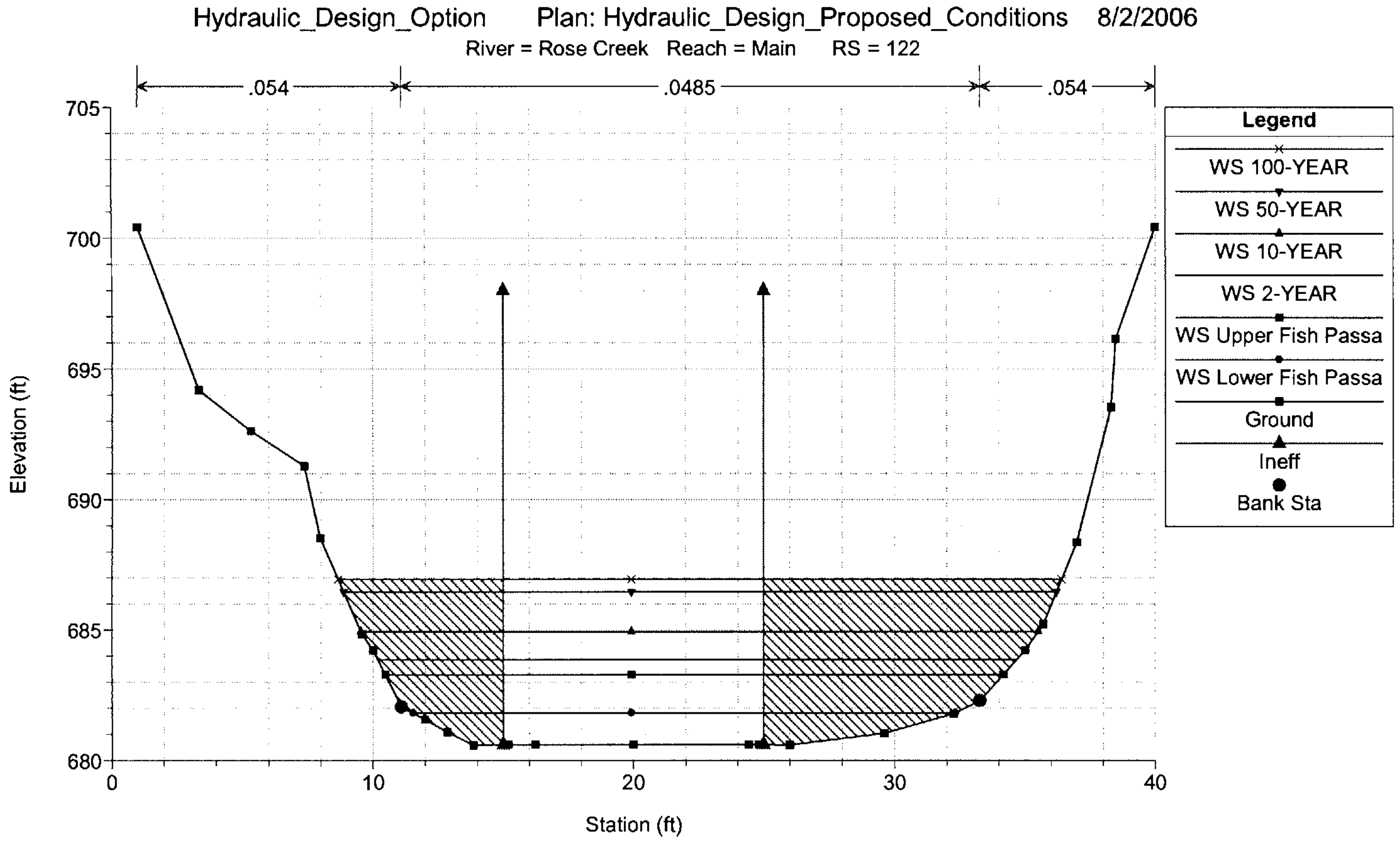

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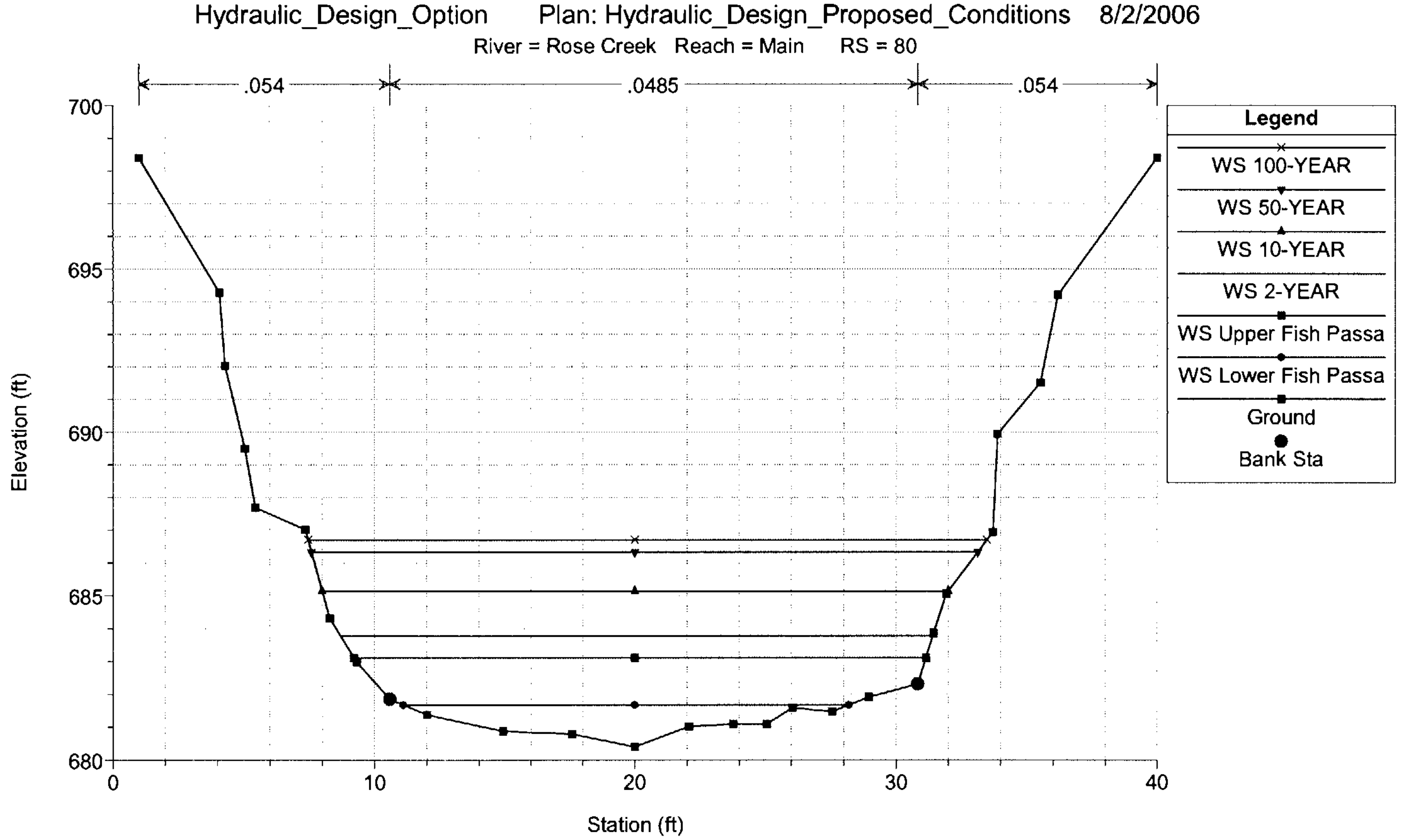

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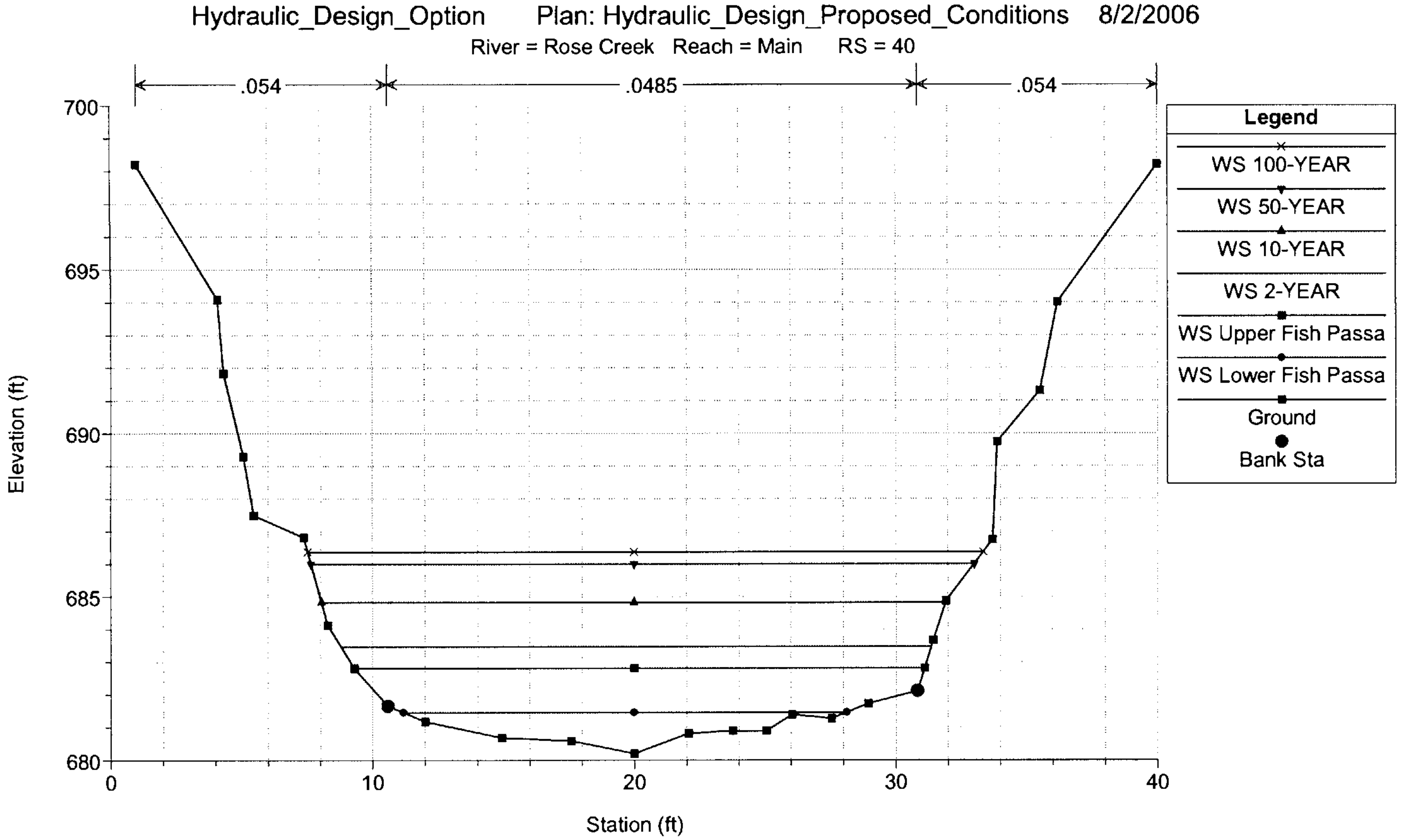
River = Rose Creek Reach = Main RS = 80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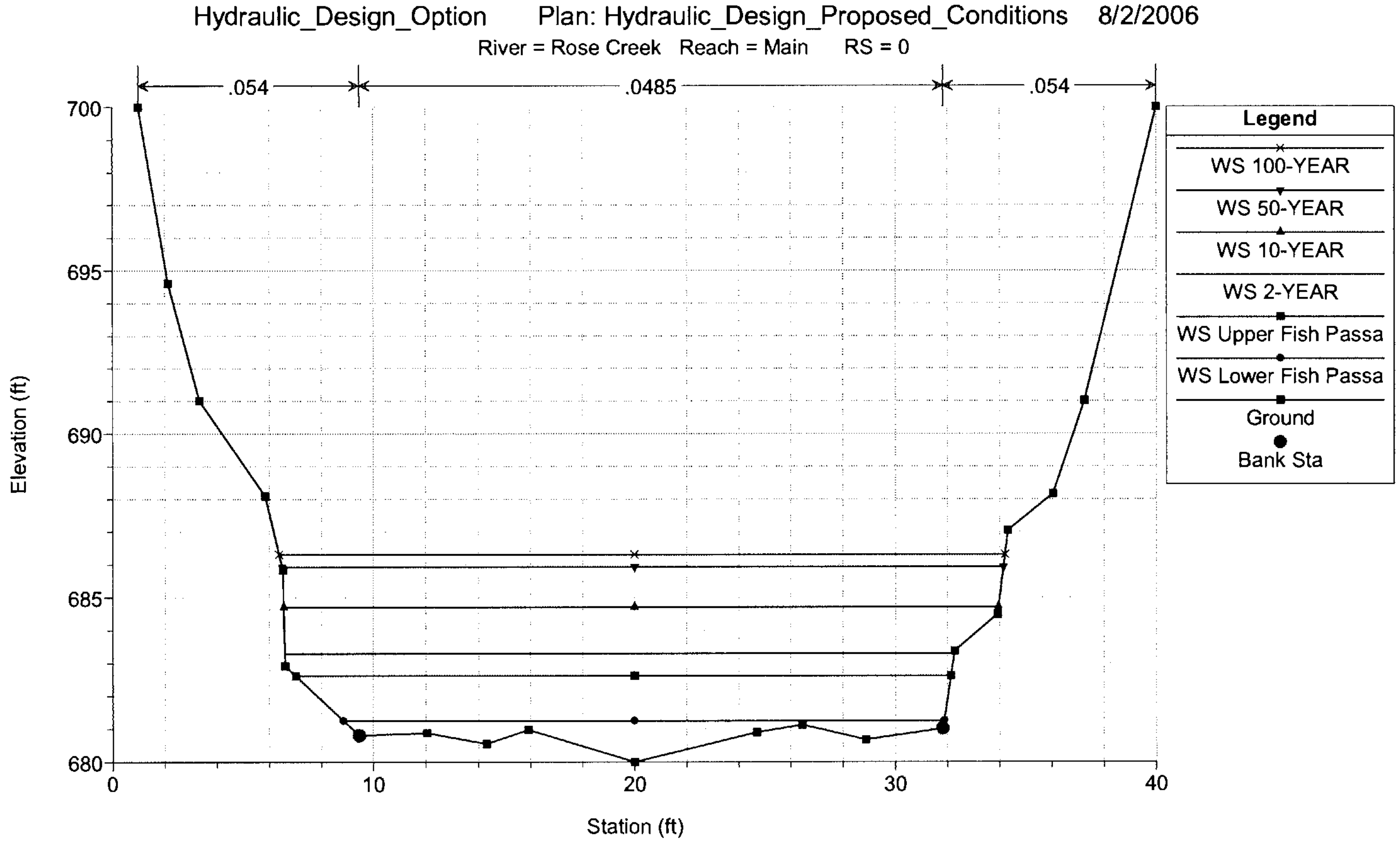
.0485
.054
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS Upper Fish Passa
WS Lower Fish Passa
Ground
Bank Sta
Elevation (ft)
700
695
690
685
680
0
10
20
30
40
Station (ft)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.054
.0485
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Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS Upper Fish Passa
WS Lower Fish Passa
Ground
Bank Sta
Elevation (ft)
700
695
690
685
680
0
10
20
30
40
Station (ft)

HEC-RAS Plan: Proposed Conditions River: Rose Creek

River Sta	Profile	Q Total	Min Ch El	W.S. Elev	W. Depth	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
		(cfs)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
0	2-YEAR	245	680	683.3	3.3	682.22	683.55	0.005	4.06	62.87	25.67	0.44
0	10-YEAR	510	680	684.71	4.71	683.18	685.15	0.005001	5.41	100.33	27.4	0.48
0	50-YEAR	800	680	685.93	5.93	684.02	686.55	0.005	6.46	134.01	27.65	0.5
0	100-YEAR	900	680	686.31	6.31	684.28	686.99	0.005002	6.77	144.51	27.83	0.5
0	Upper Fish	146	680	682.62	2.62	681.78	682.78	0.005001	3.31	45.43	25.12	0.42
0	Lower Fish	18	680	681.25	1.25	680.95	681.28	0.005002	1.45	12.53	23.02	0.34
40	2-YEAR	245	680.2	683.47	3.27		683.82	0.007482	4.79	52.51	22.58	0.54
40	10-YEAR	510	680.2	684.83	4.63		685.44	0.007396	6.37	84.07	23.87	0.57
40	50-YEAR	800	680.2	686	5.8		686.86	0.007304	7.56	113.09	25.37	0.59
40	100-YEAR	900	680.2	686.37	6.17		687.31	0.007265	7.9	122.45	25.84	0.6
40	Upper Fish	146	680.2	682.81	2.61		683.05	0.007528	3.92	37.87	21.81	0.51
40	Lower Fish	18	680.2	681.46	1.26		681.5	0.005839	1.69	10.64	16.95	0.38
80	2-YEAR	245	680.4	683.78	3.38		684.1	0.006451	4.58	55.03	22.7	0.5
80	10-YEAR	510	680.4	685.15	4.75	683.86	685.72	0.006641	6.16	87.03	24	0.55
80	50-YEAR	800	680.4	686.33	5.93	684.79	687.15	0.006694	7.36	116.38	25.53	0.57
80	100-YEAR	900	680.4	686.7	6.3	685.07	687.59	0.006693	7.71	125.83	26.01	0.58
80	Upper Fish	146	680.4	683.11	2.71		683.32	0.006271	3.7	40.09	21.93	0.47
80	Lower Fish	18	680.4	681.68	1.28		681.72	0.00521	1.63	11.05	17.1	0.36
122	2-YEAR	245	680.59	683.87	3.28	683.28	684.75	0.012591	7.54	32.49	24.51	0.74
122	10-YEAR	510	680.59	684.94	4.35	684.94	687.1	0.021057	11.8	43.23	25.99	1
122	50-YEAR	800	680.59	686.46	5.87	686.46	689.37	0.018962	13.69	58.44	27.35	1
122	100-YEAR	900	680.59	686.93	6.34	686.93	690.09	0.01856	14.26	63.13	27.74	1
122	Upper Fish	146	680.59	683.29	2.7	682.5	683.76	0.008575	5.46	26.72	23.71	0.59
122	Lower Fish	18	680.59	681.81	1.22	681.09	681.85	0.001917	1.51	11.93	20.8	0.24
210		Culvert										
212	2-YEAR	245	681.06	685.5	4.44	683.73	685.97	0.00451	5.54	44.21	24.56	0.46
212	10-YEAR	510	681.06	688.11	7.05	685.39	688.92	0.004158	7.25	70.33	29.38	0.48
212	50-YEAR	800	681.06	691.13	10.07	686.89	692.11	0.003105	7.95	100.57	32.49	0.44
212	100-YEAR	900	681.06	692.49	11.43	687.4	693.46	0.002575	7.88	114.17	34.11	0.41
212	Upper Fish	146	681.06	684.37	3.31	682.96	684.67	0.004273	4.43	32.93	23.52	0.43
212	Lower Fish	18	681.06	682.13	1.07	681.54	682.17	0.002895	1.71	10.54	17.07	0.29
300	2-YEAR	245	681.5	686.1	4.6	683.93	686.24	0.001753	3.08	83.36	23.84	0.28
300	10-YEAR	510	681.5	688.97	7.47	684.96	689.16	0.001112	3.57	157.55	28.34	0.24
300	50-YEAR	800	681.5	692.11	10.61	685.89	692.31	0.000713	3.7	248.64	30.39	0.21
300	100-YEAR	900	681.5	693.44	11.94	686.17	693.63	0.000579	3.62	289.95	31.46	0.19
300	Upper Fish	146	681.5	684.85	3.35	683.45	684.97	0.002387	2.76	54.31	22.67	0.3
300	Lower Fish	18	681.5	682.58	1.08	682.37	682.66	0.013035	2.31	7.78	14.19	0.55

Plan: Proposed Rose Creek Main RS: 210 Culv Group: Culvert #1 Profile: Lower Fish Passa

Q Culv Group (cfs)	18.00	Culv Full Len (ft)	
# Barrels	1	Culv Vel US (ft/s)	2.05
Q Barrel (cfs)	18.00	Culv Vel DS (ft/s)	1.73
E.G. US. (ft)	682.17	Culv Inv El Up (ft)	679.06
W.S. US. (ft)	682.13	Culv Inv El Dn (ft)	678.62
E.G. DS (ft)	681.85	Culv Frctn Ls (ft)	0.28
W.S. DS (ft)	681.81	Culv Exit Loss (ft)	0.01
Delta EG (ft)	0.33	Culv Entr Loss (ft)	0.03
Delta WS (ft)	0.32	Q Weir (cfs)	
E.G. IC (ft)	681.83	Weir Sta Lft (ft)	
E.G. OC (ft)	682.17	Weir Sta Rgt (ft)	
Culvert Control	Outlet	Weir Submerg	
Culv WS Inlet (ft)	682.08	Weir Max Depth (ft)	
Culv WS Outlet (ft)	681.81	Weir Avg Depth (ft)	
Culv Nml Depth (ft)	2.95	Weir Flow Area (sq ft)	
Culv Crt Depth (ft)	2.53	Min El Weir Flow (ft)	698.01

Plan: Proposed   Rose Creek   Main RS: 210 Culv Group: Culvert #1   Profile: Upper Fish Passa

Q Culv Group (cfs)	146.00	Culv Full Len (ft)	
# Barrels	1	Culv Vel US (ft/s)	5.25
Q Barrel (cfs)	146.00	Culv Vel DS (ft/s)	5.88
E.G. US. (ft)	684.67	Culv Inv El Up (ft)	679.06
W.S. US. (ft)	684.37	Culv Inv El Dn (ft)	678.62
E.G. DS (ft)	683.76	Culv Frctn Ls (ft)	0.63
W.S. DS (ft)	683.29	Culv Exit Loss (ft)	0.07
Delta EG (ft)	0.92	Culv Entr Loss (ft)	0.21
Delta WS (ft)	1.08	Q Weir (cfs)	
E.G. IC (ft)	684.09	Weir Sta Lft (ft)	
E.G. OC (ft)	684.67	Weir Sta Rgt (ft)	
Culvert Control	Outlet	Weir Submerg	
Culv WS Inlet (ft)	684.03	Weir Max Depth (ft)	
Culv WS Outlet (ft)	683.29	Weir Avg Depth (ft)	
Culv Nml Depth (ft)	5.16	Weir Flow Area (sq ft)	
Culv Crt Depth (ft)	4.05	Min El Weir Flow (ft)	698.01

Plan: Proposed   Rose Creek   Main RS: 210 Culv Group: Culvert #1   Profile: 2-YEAR

Q Culv Group (cfs)	245.00	Culv Full Len (ft)	
# Barrels	1	Culv Vel US (ft/s)	6.64
Q Barrel (cfs)	245.00	Culv Vel DS (ft/s)	8.01
E.G. US. (ft)	685.97	Culv Inv El Up (ft)	679.06
W.S. US. (ft)	685.50	Culv Inv El Dn (ft)	678.62
E.G. DS (ft)	684.75	Culv Frctn Ls (ft)	0.76
W.S. DS (ft)	683.87	Culv Exit Loss (ft)	0.11
Delta EG (ft)	1.22	Culv Entr Loss (ft)	0.34
Delta WS (ft)	1.63	Q Weir (cfs)	
E.G. IC (ft)	685.34	Weir Sta Lft (ft)	
E.G. OC (ft)	685.97	Weir Sta Rgt (ft)	
Culvert Control	Outlet	Weir Submerg	
Culv WS Inlet (ft)	684.95	Weir Max Depth (ft)	
Culv WS Outlet (ft)	683.87	Weir Avg Depth (ft)	
Culv Nml Depth (ft)	6.31	Weir Flow Area (sq ft)	
Culv Crt Depth (ft)	4.84	Min El Weir Flow (ft)	698.01

Plan: Proposed Rose Creek Main RS: 210 Culv Group: Culvert #1 Profile: 10-YEAR

Q Culv Group (cfs)	510.00	Culv Full Len (ft)	
# Barrels	1	Culv Vel US (ft/s)	9.25
Q Barrel (cfs)	510.00	Culv Vel DS (ft/s)	11.98
E.G. US. (ft)	688.92	Culv Inv El Up (ft)	679.06
W.S. US. (ft)	688.11	Culv Inv El Dn (ft)	678.62
E.G. DS (ft)	687.10	Culv Frctn Ls (ft)	0.94
W.S. DS (ft)	684.94	Culv Exit Loss (ft)	0.21
Delta EG (ft)	1.82	Culv Entr Loss (ft)	0.66
Delta WS (ft)	3.16	Q Weir (cfs)	
E.G. IC (ft)	688.30	Weir Sta Lft (ft)	
E.G. OC (ft)	688.92	Weir Sta Rgt (ft)	
Culvert Control	Outlet	Weir Submerg	
Culv WS Inlet (ft)	686.93	Weir Max Depth (ft)	
Culv WS Outlet (ft)	685.09	Weir Avg Depth (ft)	
Culv Nml Depth (ft)	10.00	Weir Flow Area (sq ft)	
Culv Crt Depth (ft)	6.47	Min El Weir Flow (ft)	698.01

Errors Warnings and Notes

Note:	The normal depth exceeds the height of the culvert. The program assumes that the normal depth is equal to the height of the culvert.

Plan: Proposed   Rose Creek   Main RS: 210 Culv Group: Culvert #1 Profile: 50-YEAR

Q Culv Group (cfs)	800.00	Culv Full Len (ft)	
# Barrels	1	Culv Vel US (ft/s)	12.00
Q Barrel (cfs)	800.00	Culv Vel DS (ft/s)	14.57
E.G. US. (ft)	692.11	Culv Inv El Up (ft)	679.06
W.S. US. (ft)	691.13	Culv Inv El Dn (ft)	678.62
E.G. DS (ft)	689.37	Culv Frctn Ls (ft)	1.24
W.S. DS (ft)	686.46	Culv Exit Loss (ft)	0.39
Delta EG (ft)	2.74	Culv Entr Loss (ft)	1.12
Delta WS (ft)	4.67	Q Weir (cfs)	
E.G. IC (ft)	692.01	Weir Sta Lft (ft)	
E.G. OC (ft)	692.11	Weir Sta Rgt (ft)	
Culvert Control	Outlet	Weir Submerg	
Culv WS Inlet (ft)	688.76	Weir Max Depth (ft)	
Culv WS Outlet (ft)	686.46	Weir Avg Depth (ft)	
Culv Nml Depth (ft)	10.00	Weir Flow Area (sq ft)	
Culv Crt Depth (ft)	7.82	Min El Weir Flow (ft)	698.01

Errors Warnings and Notes

Note:	The normal depth exceeds the height of the culvert. The program assumes that the normal
	depth is equal to the height of the culvert.

Plan: Proposed   Rose Creek   Main RS: 210   Culv Group: Culvert #1   Profile: 100-YEAR

Q Culv Group (cfs)	900.00	Culv Full Len (ft)	21.08
# Barrels	1	Culv Vel US (ft/s)	13.36
Q Barrel (cfs)	900.00	Culv Vel DS (ft/s)	15.36
E.G. US. (ft)	693.46	Culv Inv El Up (ft)	679.06
W.S. US. (ft)	692.49	Culv Inv El Dn (ft)	678.62
E.G. DS (ft)	690.09	Culv Frctn Ls (ft)	1.47
W.S. DS (ft)	686.93	Culv Exit Loss (ft)	0.51
Delta EG (ft)	3.37	Culv Entr Loss (ft)	1.39
Delta WS (ft)	5.56	Q Weir (cfs)	
E.G. IC (ft)	693.51	Weir Sta Lft (ft)	
E.G. OC (ft)	693.46	Weir Sta Rgt (ft)	
Culvert Control	Outlet	Weir Submerg	
Culv WS Inlet (ft)	689.06	Weir Max Depth (ft)	
Culv WS Outlet (ft)	686.93	Weir Avg Depth (ft)	
Culv Nml Depth (ft)	10.00	Weir Flow Area (sq ft)	
Culv Crt Depth (ft)	8.21	Min El Weir Flow (ft)	698.01

Errors Warnings and Notes

Note:	The normal depth exceeds the height of the culvert. The program assumes that the normal depth is equal to the height of the culvert.
Note:	During supercritical analysis, the culvert direct step method went to critical depth. The program then assumed critical depth at the outlet.
Note:	During the supercritical calculations a hydraulic jump occurred inside of the culvert.
Note:	The culvert inlet is submerged and the culvert flows full over part or all of its length. Therefore, the culvert inlet equations are not valid and the supercritical result has been discarded. The outlet answer will be used.

Culvert Report for Rose Creek Culvert @ Route 777

Project: Hydraulic Design Rose Creek

Culvert Location Information

Road: Route 777
Mile Post: 6.15
Stream Name: Rose Creek
Length of Historical Upstream Habitat: 3000

Biological Data

Species: Adult Coho
Fish Length: 610 mm
Minimum Water Depth: 1 ft
Migration Period: August to January
Prolonged Swimming Speed: 6 ft/s
Prolonged Time to Exhaustion: 30 min
Burst Swimming Speed: 11.9 ft/s
Burst Time to Exhaustion: 5 s
Jumping Speed: 14 ft/s
Velocity Reduction Factors:
  Inlet: 1.00
  Barrel: 1.00
  Outlet: 1.00

Culvert Installation Data

Culvert Type: 120 in Circular
Construction: Concrete
Installation: Sunken
Countersunk Depth: 2 ft
Culvert Length: 86 ft
Culvert Slope: 0.51%
Culvert Roughness Coefficient: 0.012
Natural Bottom Roughness Coefficient: 0.045
Inlet Invert Elevation: 679.06 ft
Outlet Invert Elevation: 678.62 ft
Inlet Headloss Coefficient (Ke): 1

Design Flows

Low Passage Flow: 18 cfs
High Passage Flow: 146 cfs

Table 1. Uniform Flow Calculations.

Discharge (cfs)	Velocity (ft/s)	Normal Depth (ft)	Critical Depth (ft)	Outlet Velocity (ft/s)	Tailwater Depth (ft)	Pool Depth (ft)	Min Rqd. Leap Velocity (ft/s)	Vert. Leap Distance (ft)	Comments
0.00	0.00	0.00	0.00	0.00	1.78	0.00			
0.42	0.51	0.10	0.04	0.02	2.32	0.54	0.00	0.00	Depth
1.34	0.82	0.20	0.10	0.06	2.57	0.79	0.00	0.00	Depth
2.68	1.09	0.30	0.15	0.10	2.76	0.98	0.00	0.00	Depth
4.39	1.32	0.40	0.21	0.16	2.95	1.17	0.00	0.00	Depth
6.45	1.55	0.50	0.27	0.22	3.12	1.34	0.00	0.00	Depth
8.86	1.76	0.60	0.33	0.29	3.28	1.50	0.00	0.00	Depth
11.60	1.96	0.70	0.40	0.36	3.44	1.66	0.00	0.00	Depth
14.66	2.15	0.80	0.46	0.43	3.60	1.82	0.00	0.00	Depth
18.00	2.33	0.90	0.53	0.51	3.75	1.97	0.00	0.00	LPF; Depth
18.04	2.34	0.90	0.53	0.51	3.75	1.97	0.00	0.00	Depth
21.74	2.52	1.00	0.60	0.59	3.89	2.11	0.00	0.00	
25.75	2.69	1.10	0.67	0.67	4.04	2.26	0.00	0.00	
30.06	2.87	1.20	0.74	0.75	4.19	2.41	0.00	0.00	
34.67	3.04	1.30	0.81	0.84	4.34	2.56	0.00	0.00	
39.57	3.20	1.40	0.89	0.93	4.49	2.71	0.00	0.00	
44.77	3.36	1.50	0.96	1.01	4.64	2.86	0.00	0.00	
50.25	3.52	1.60	1.04	1.10	4.79	3.01	0.00	0.00	
56.01	3.68	1.70	1.11	1.19	4.95	3.17	0.00	0.00	
62.05	3.83	1.80	1.19	1.28	5.10	3.32	0.00	0.00	
68.36	3.98	1.90	1.26	1.37	5.26	3.48	0.00	0.00	
74.94	4.13	2.00	1.34	1.46	5.41	3.63	0.00	0.00	
81.77	4.27	2.10	1.42	1.55	5.57	3.79	0.00	0.00	
88.86	4.42	2.20	1.50	1.65	5.73	3.95	0.00	0.00	
96.20	4.56	2.30	1.57	1.74	5.89	4.11	0.00	0.00	
103.79	4.70	2.40	1.65	1.84	6.05	4.27	0.00	0.00	
111.61	4.83	2.50	1.73	1.93	6.21	4.43	0.00	0.00	
119.66	4.97	2.60	1.81	2.03	6.36	4.58	0.00	0.00	
127.93	5.10	2.70	1.89	2.13	6.53	4.75	0.00	0.00	
136.43	5.23	2.80	1.97	2.23	6.69	4.91	0.00	0.00	
145.13	5.36	2.90	2.04	2.33	6.85	5.07	0.00	0.00	
146.00	5.37	2.91	2.05	2.34	6.87	5.09	0.00	0.00	HPF
154.04	5.48	3.00	2.12	2.43	7.01	5.23	0.00	0.00	
163.14	5.61	3.10	2.20	2.54	7.18	5.40	0.00	0.00	
172.43	5.73	3.20	2.28	2.65	7.34	5.56	0.00	0.00	
181.90	5.85	3.30	2.36	2.76	7.50	5.72	0.00	0.00	
191.55	5.97	3.40	2.44	2.88	7.66	5.88	0.00	0.00	Vel
201.35	6.09	3.50	2.51	3.00	7.82	6.04	0.00	0.00	Vel
211.32	6.20	3.60	2.59	3.14	7.98	6.20	0.00	0.00	Vel
221.43	6.31	3.70	2.67	3.29	8.14	6.36	0.00	0.00	Vel
231.68	6.43	3.80	2.74	3.44	8.30	6.52	0.00	0.00	Vel
242.05	6.54	3.90	2.82	3.59	8.46	6.68	0.00	0.00	Vel
252.55	6.64	4.00	2.90	3.75	8.64	6.86	0.00	0.00	Vel

Comment Codes:
LPF - Low Passage Flow
HPF - High Passage Flow
Depth - Insufficient Depth

Vel - Excessive Velocity
Leap - Excessive Leap
Pool - Shallow Leap Pool

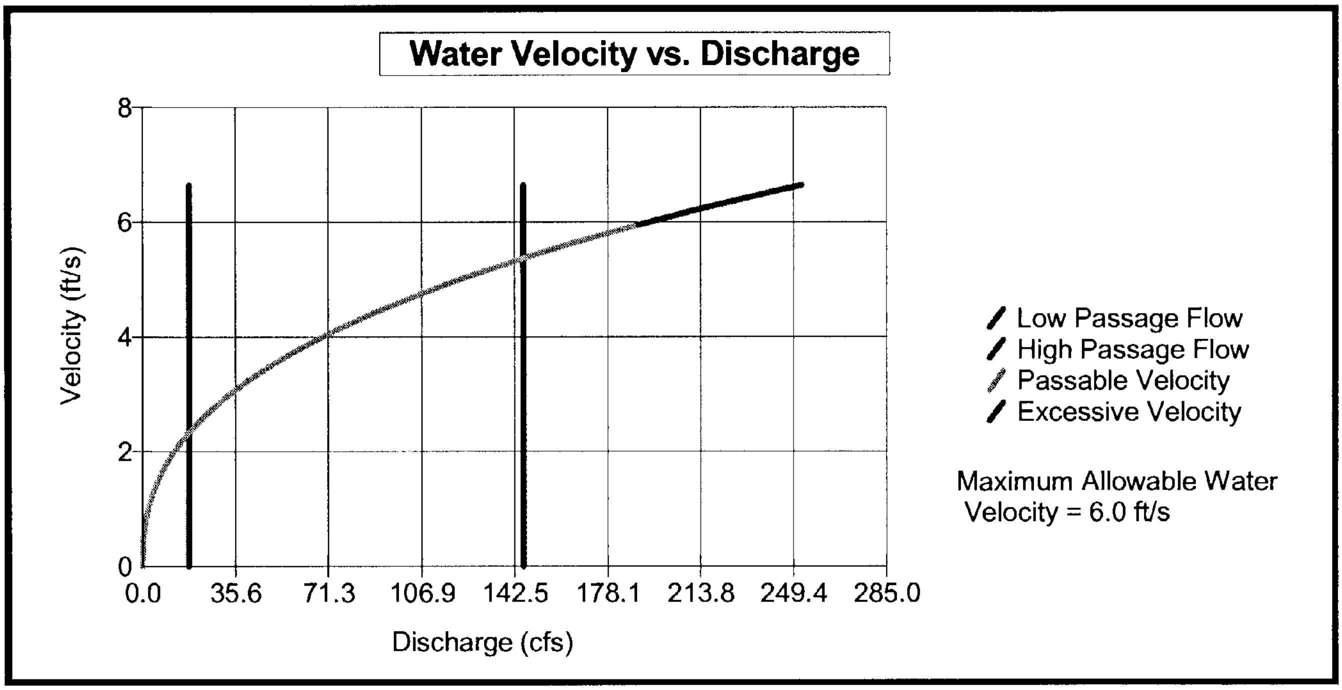


Figure 1. Velocity at Uniform Flow

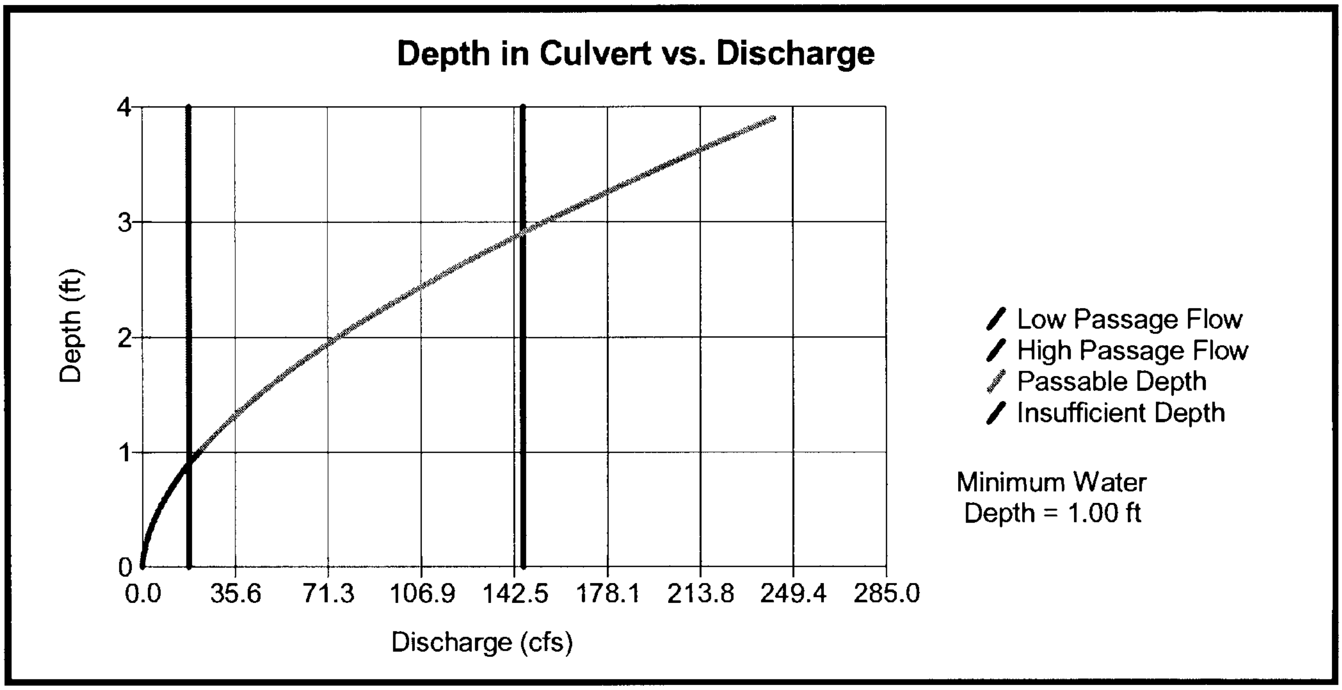


Figure 2. Depth at Uniform Flow

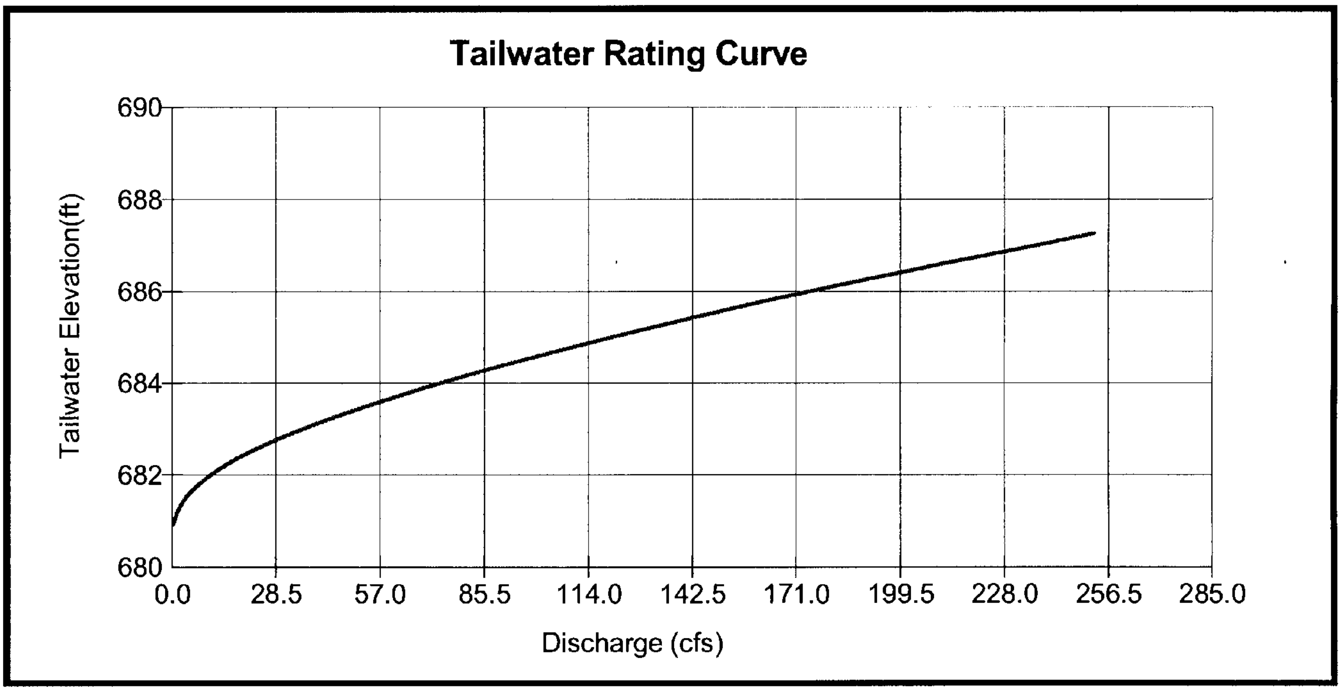


Figure 3. Tailwater Rating Curve at Uniform Flow

Table 2. Gradually Varied Flow Calculations for 18 cfs.

Q = 18.0 cfs				
Dist Down Culvert (ft)	Depth (ft)	Velocity (ft/s)	Curve	Swim Mode
0	3.30	0.00	Inlet	
3	3.29	0.82	M1	Prolonged
6	3.31	0.58	M1	Prolonged
10	3.33	0.57	M1	Prolonged
14	3.35	0.57	M1	Prolonged
18	3.38	0.57	M1	Prolonged
22	3.40	0.56	M1	Prolonged
26	3.42	0.56	M1	Prolonged
30	3.44	0.55	M1	Prolonged
34	3.46	0.55	M1	Prolonged
38	3.48	0.55	M1	Prolonged
42	3.51	0.54	M1	Prolonged
46	3.53	0.54	M1	Prolonged
50	3.55	0.54	M1	Prolonged
54	3.57	0.53	M1	Prolonged
58	3.59	0.53	M1	Prolonged
62	3.62	0.53	M1	Prolonged
66	3.64	0.52	M1	Prolonged
70	3.66	0.52	M1	Prolonged
74	3.68	0.52	M1	Prolonged
78	3.70	0.51	M1	Prolonged
82	3.72	0.51	M1	Prolonged
86	3.75	0.51	M1	Prolonged

Table 3. Gradually Varied Flow Specifications for 18 cfs.

	18.0 cfs
Normal Depth (ft)	0.90
Critical Depth (ft)	0.53
Headwater Depth (ft)	3.30
Inlet Velocity (ft/s)	0.82
Tailwater Depth (ft)	3.75
Burst Swim Time (s)	0.00
Prolonged Swim Time (min	0.26
Barrier Code	NONE

Barrier Codes

NONE - No Barrier

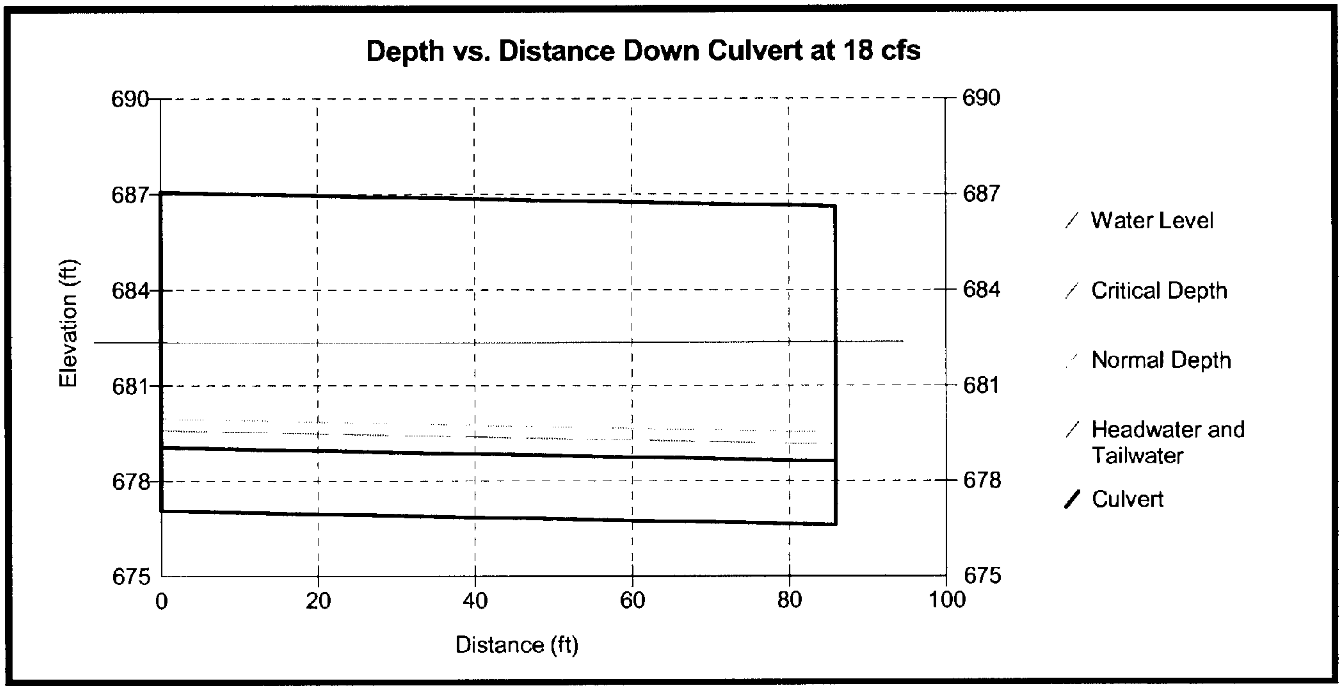


Figure 4. Water Surface Profile at 18 cfs

Table 4. Gradually Varied Flow Calculations for 82 cfs.

Q = 82.0 cfs				
Dist Down Culvert (ft)	Depth (ft)	Velocity (ft/s)	Curve	Swim Mode
0	5.27	0.00	Inlet	
3	5.18	2.36	M1	Prolonged
6	5.20	1.66	M1	Prolonged
10	5.21	1.66	M1	Prolonged
14	5.23	1.65	M1	Prolonged
18	5.25	1.65	M1	Prolonged
22	5.27	1.64	M1	Prolonged
26	5.29	1.63	M1	Prolonged
30	5.31	1.63	M1	Prolonged
34	5.33	1.62	M1	Prolonged
38	5.35	1.62	M1	Prolonged
42	5.37	1.61	M1	Prolonged
46	5.39	1.61	M1	Prolonged
50	5.41	1.60	M1	Prolonged
54	5.42	1.60	M1	Prolonged
58	5.44	1.59	M1	Prolonged
62	5.46	1.59	M1	Prolonged
66	5.48	1.58	M1	Prolonged
70	5.50	1.58	M1	Prolonged
74	5.52	1.57	M1	Prolonged
78	5.54	1.57	M1	Prolonged
82	5.56	1.56	M1	Prolonged
86	5.58	1.56	M1	Prolonged

Table 5. Gradually Varied Flow Specifications for 82 cfs.

	82.0 cfs
Normal Depth (ft)	2.10
Critical Depth (ft)	1.42
Headwater Depth (ft)	5.27
Inlet Velocity (ft/s)	2.36
Tailwater Depth (ft)	5.58
Burst Swim Time (s)	0.00
Prolonged Swim Time (min	0.33
Barrier Code	NONE

Barrier Codes

NONE - No Barrier

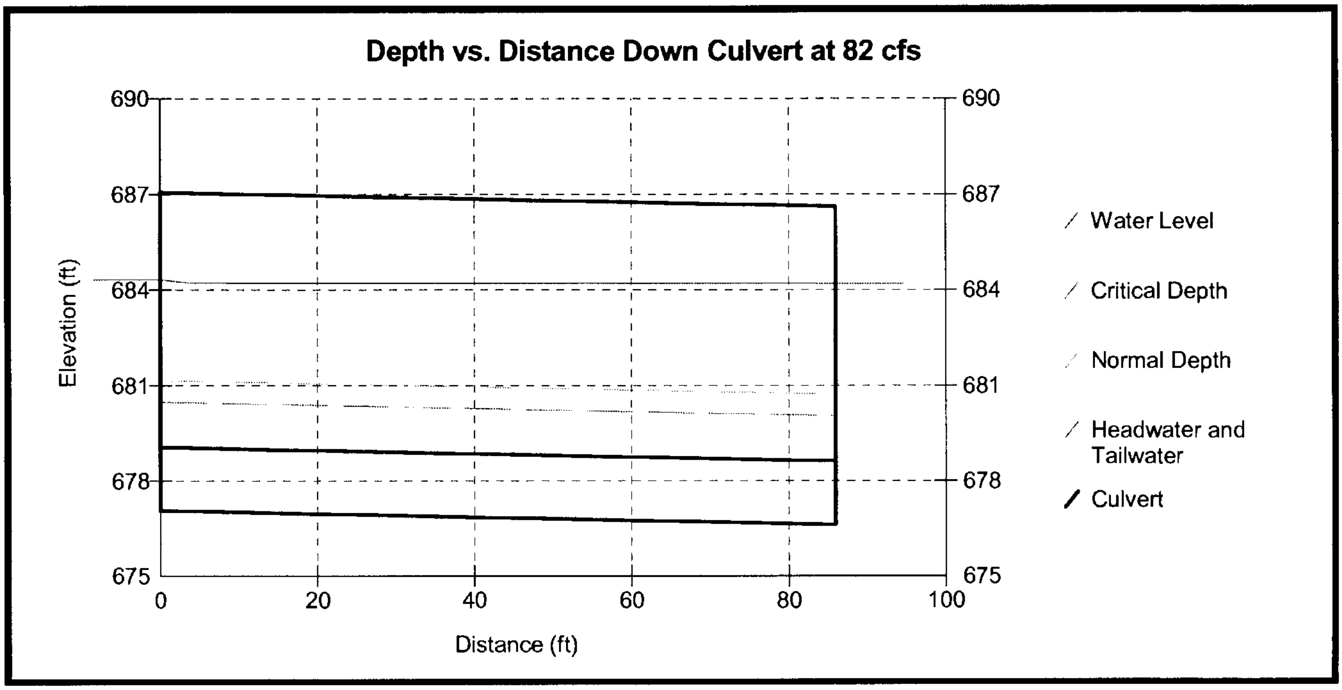


Figure 5. Water Surface Profile at 82 cfs

Table 6. Gradually Varied Flow Calculations for 146 cfs.

Q = 146.0 cfs				
Dist Down Culvert (ft)	Depth (ft)	Velocity (ft/s)	Curve	Swim Mode
0	6.58	0.00	Inlet	
3	6.40	3.49	M1	Prolonged
6	6.41	2.46	M1	Prolonged
10	6.44	2.45	M1	Prolonged
14	6.46	2.45	M1	Prolonged
18	6.48	2.44	M1	Prolonged
22	6.50	2.43	M1	Prolonged
26	6.53	2.43	M1	Prolonged
30	6.55	2.42	M1	Prolonged
34	6.57	2.41	M1	Prolonged
38	6.60	2.41	M1	Prolonged
42	6.62	2.40	M1	Prolonged
46	6.64	2.40	M1	Prolonged
50	6.66	2.39	M1	Prolonged
54	6.69	2.38	M1	Prolonged
58	6.71	2.38	M1	Prolonged
62	6.73	2.37	M1	Prolonged
66	6.76	2.37	M1	Prolonged
70	6.78	2.36	M1	Prolonged
74	6.80	2.35	M1	Prolonged
78	6.82	2.35	M1	Prolonged
82	6.85	2.34	M1	Prolonged
86	6.87	2.34	M1	Prolonged

Table 7. Gradually Varied Flow Specifications for 146 cfs.

	146.0 cfs
Normal Depth (ft)	2.91
Critical Depth (ft)	2.05
Headwater Depth (ft)	6.58
Inlet Velocity (ft/s)	3.49
Tailwater Depth (ft)	6.87
Burst Swim Time (s)	0.00
Prolonged Swim Time (min	0.40
Barrier Code	NONE

Barrier Codes

NONE - No Barrier

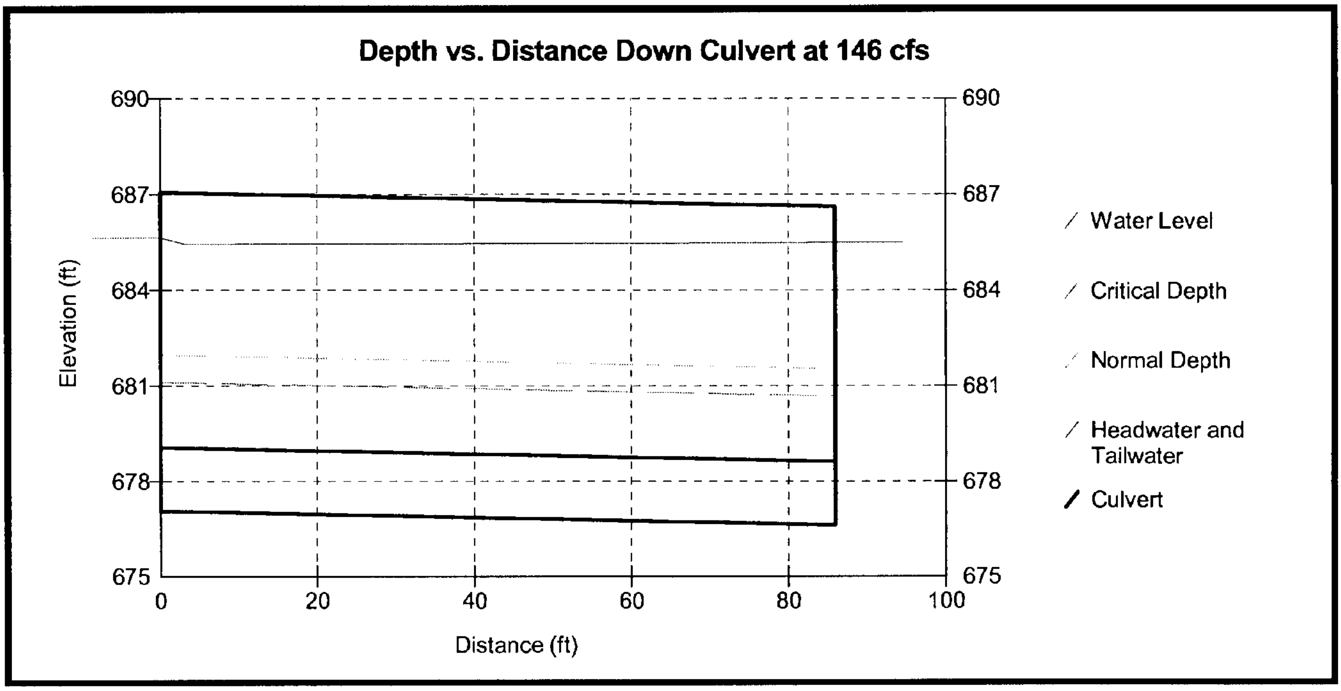


Figure 6. Water Surface Profile at 146 cfs

Tailwater Information

Channel Bottom Slope: 0.051%
Outlet-Pool Bottom Elevation: 680.4 ft
Manning's Roughness Downstream of Tailwater: 0.0485

Table 8. Tailwater Cross Section Data.

Obs. No.	Station (ft)	Elevation (ft)
1	5.06	689.49
2	5.45	687.69
3	7.36	687.01
4	8.29	684.32
5	9.32	682.98
6	10.60	681.85
7	12.01	681.38
8	14.93	680.88
9	17.59	680.79
10	20.00	680.40
11	22.08	681.02
12	23.77	681.10
13	25.06	681.10
14	26.04	681.59
15	27.55	681.47
16	28.96	681.92
17	30.83	682.31
18	31.44	683.86
19	31.93	685.07
20	33.70	686.94
21	33.88	689.94
22	35.52	691.51

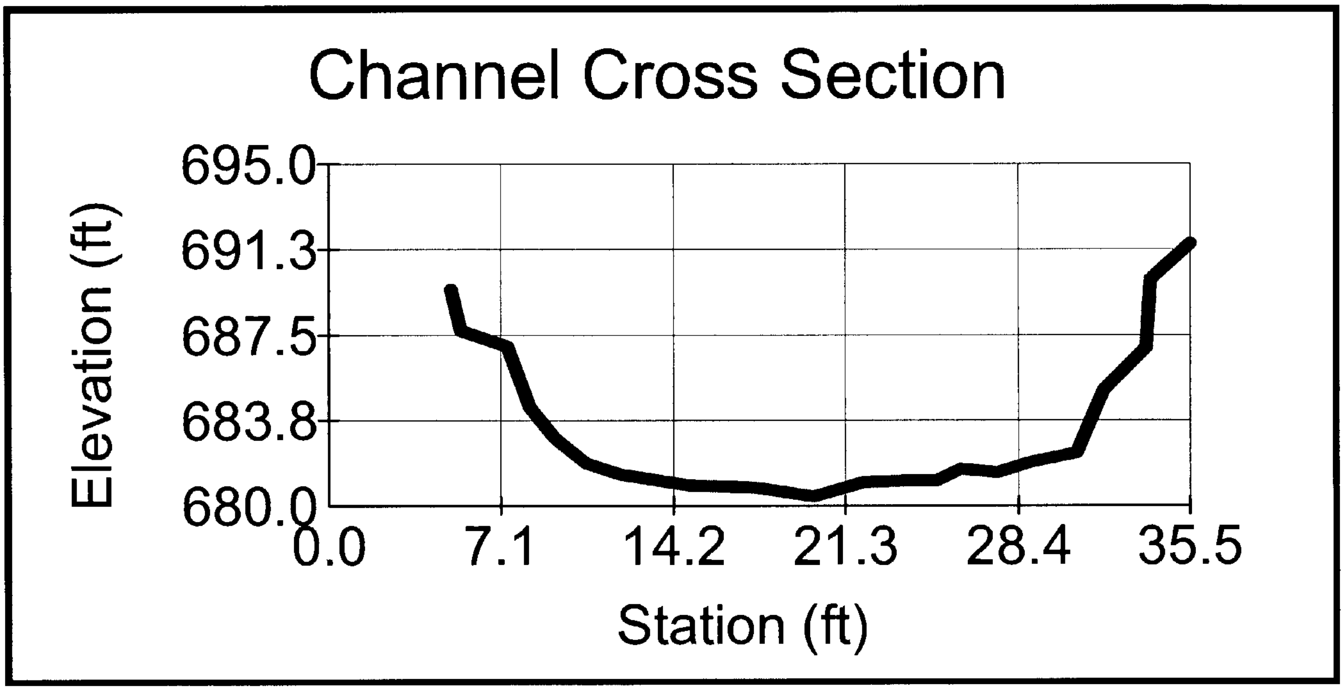


Figure 7. Channel Cross Section at Tailwater Crest.

Table 9. Tailwater Rating Table Information.

Discharge (cfs)	Tailwater Elevation (ft)	Wetted Perimeter (ft)	Cross-Sect. Area (sq. ft)
0.0	680.4	0.00	0.00
0.0	680.5	0.98	0.05
0.0	680.6	1.95	0.19
0.1	680.7	2.93	0.43
0.2	680.8	4.14	0.76
0.3	680.9	6.97	1.33
0.6	681.0	7.91	2.06
0.9	681.1	10.27	2.94
1.4	681.2	12.37	4.12
2.0	681.3	13.19	5.38
2.9	681.4	13.95	6.72
3.7	681.5	14.97	8.12
4.6	681.6	16.95	9.69
5.9	681.7	17.60	11.38
7.3	681.8	18.24	13.14
8.9	681.9	18.80	14.95
10.6	682.0	19.41	16.81
12.4	682.1	20.05	18.73
14.3	682.2	20.70	20.71
16.4	682.3	21.34	22.75
18.8	682.4	21.63	24.83
21.4	682.5	21.89	26.93
24.1	682.6	22.15	29.04
26.9	682.7	22.41	31.17
29.8	682.8	22.67	33.31
32.8	682.9	22.93	35.47
36.0	683.0	23.18	37.64
39.3	683.1	23.41	39.83
42.7	683.2	23.65	42.02
46.2	683.3	23.88	44.23
49.8	683.4	24.11	46.45
53.5	683.5	24.35	48.68
57.3	683.6	24.58	50.93
61.2	683.7	24.81	53.18
65.2	683.8	25.05	55.45
69.3	683.9	25.28	57.73
73.4	684.0	25.52	60.02
77.7	684.1	25.75	62.32
82.1	684.2	25.98	64.63
86.6	684.3	26.22	66.96
91.2	684.4	26.44	69.30
95.8	684.5	26.65	71.64
100.6	684.6	26.86	73.99
105.4	684.7	27.08	76.35
110.4	684.8	27.29	78.71
115.4	684.9	27.50	81.09
120.4	685.0	27.72	83.47
125.6	685.1	27.94	85.86

Discharge (cfs)	Tailwater Elevation (ft)	Wetted Perimeter (ft)	Cross-Sect. Area (sq. ft)
130.7	685.2	28.18	88.26
135.9	685.3	28.43	90.67
141.2	685.4	28.67	93.10
146.6	685.5	28.91	95.54
152.1	685.6	29.16	97.99
157.7	685.7	29.40	100.45
163.3	685.8	29.64	102.93
169.0	685.9	29.89	105.42
174.8	686.0	30.13	107.92
180.7	686.1	30.38	110.44
186.6	686.2	30.62	112.97
192.7	686.3	30.86	115.51
198.8	686.4	31.11	118.07
205.0	686.5	31.35	120.64
211.2	686.6	31.59	123.22
217.6	686.7	31.84	125.81
224.0	686.8	32.08	128.42
230.5	686.9	32.32	131.04
237.2	687.0	32.54	133.67
243.2	687.1	32.92	136.32
249.2	687.2	33.32	138.99
255.3	687.3	33.72	141.69
261.5	687.4	34.12	144.43
267.8	687.5	34.52	147.19
274.2	687.6	34.91	149.98
280.8	687.7	35.29	152.79
288.4	687.8	35.50	155.62
296.1	687.9	35.70	158.46
303.8	688.0	35.90	161.30
311.6	688.1	36.10	164.13
319.5	688.2	36.31	166.98
327.4	688.3	36.51	169.82
335.4	688.4	36.71	172.67
343.4	688.5	36.91	175.52
351.4	688.6	37.12	178.37
359.6	688.7	37.32	181.23
367.7	688.8	37.52	184.09
376.0	688.9	37.72	186.95
384.2	689.0	37.93	189.81
392.6	689.1	38.13	192.68
400.9	689.2	38.33	195.55
409.4	689.3	38.53	198.42
417.8	689.4	38.74	201.30
425.5	689.5	38.92	203.89

Summary Statement

The initial goals of this replacement culvert design project included widening the roadway, designing a structurally sound culvert, passing the 100-Year storm event, creating a friendly fish passage design for adult anadromous salmonids, preventing hydraulic design threats downstream, meeting permissible scour velocities in the channel, and meeting species-specific depth and velocity criteria.

Specifically for fish passage, all criteria for the Hydraulic Design Option were successfully met by following the process laid out within the forms. An overview of the steps include researching existing data and available information, collecting all required parameters at the site, selecting the best fish passage design option for the project site, completing the hydrology and efficiently brainstorming and completing the hydraulic modeling, and finally meeting all requirements of the Hydraulic Design Option.

As found in the problem statement, the goal was providing cross drainage for Rose Creek that met hydraulic standards in the Caltrans Hydraulic Design Manual, as well as fish standards in the California Department of Fish and Game Culvert Criteria and the NOAA Fisheries Guidelines for Salmonid Passage at Stream Crossings.

Three different hydraulic analysis software programs were used to compute culvert velocities. Those software programs include HEC-RAS and Fish Xing. Results from the three separate analyses are shown below in Summary Data Table 1 and 2.

Summary Data Table1: Culvert Velocities

	Maximum Average Water Velocity at High Fish Design Flow for Adult Anadromous Salmonids (ft/s)	High Fish Design Downstream Velocity in Culvert (ft/s)	High Fish Design Upstream Velocity in Culvert (ft/s)	High Fish Design Average Water Velocity in Culvert (ft/s)
Existing Conditions (HEC-RAS)	5.00	8.47	5.97	7.22
Proposed Conditions (HEC-RAS)	5.00	5.88	5.25	5.57
Proposed Conditions (Fish Xing)	5.00	3.49	2.34	2.92

Summary Data Table 2: Culvert Depths

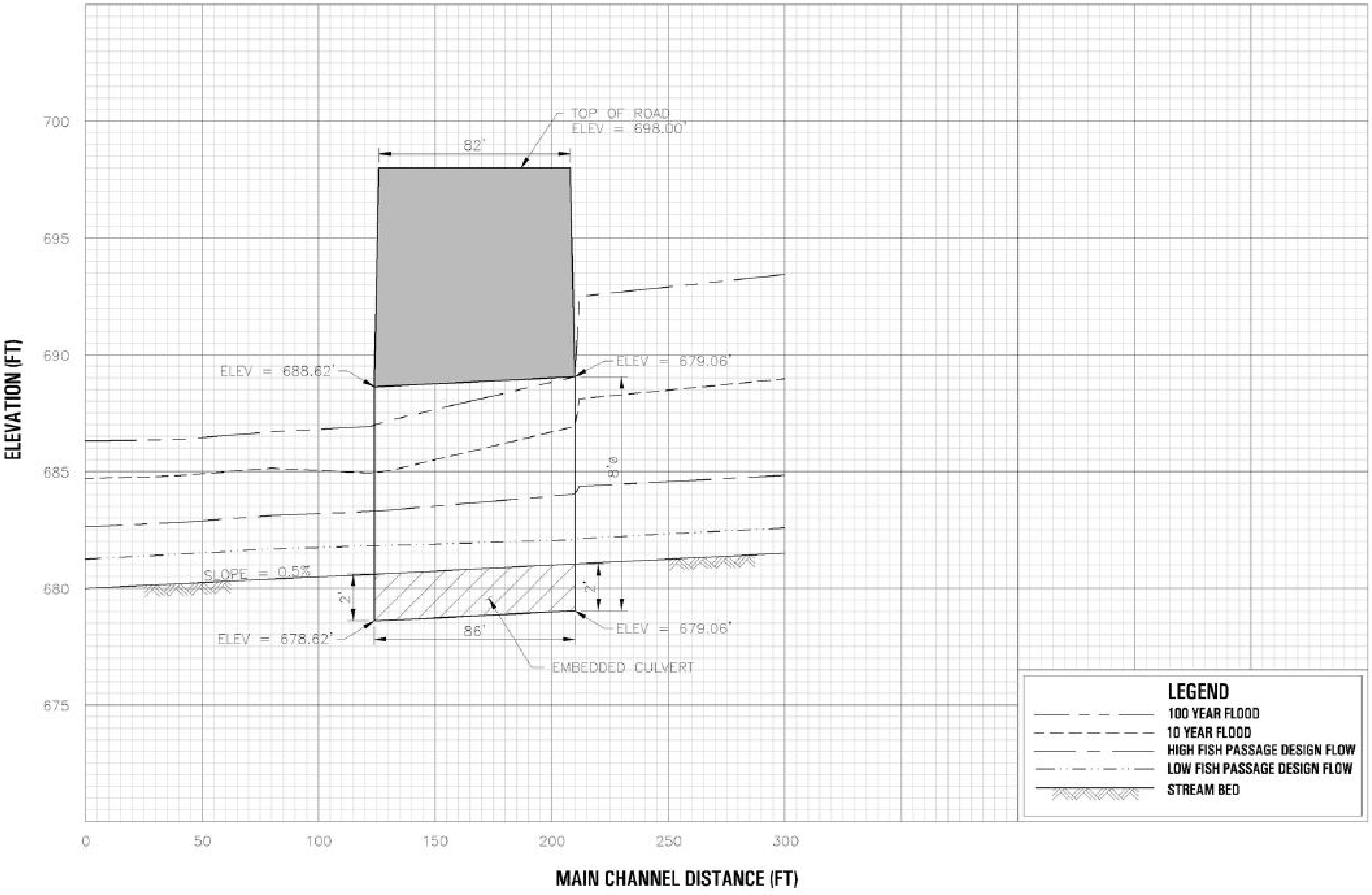
	Minimum Flow Depth at Low Fish Design Flow (ft)	Water Depth inside Culvert at Inlet (ft)	Water Depth inside Culvert at Outlet (ft)
Existing Conditions (HEC-RAS)	1.00	1.51	1.50
Proposed Conditions (HEC-RAS)	1.00	1.02	1.22
Proposed Conditions (Fish Xing)	1.00	3.75	3.75

Although the proposed conditions velocities slightly exceed the maximum average water velocity, the County's engineering team felt that the proposed velocities were acceptable due to the high-pressure gas main constraining the channel geometry. It is recommended that a limiting value for acceptable outlet velocity be defined as it relates to site-specific conditions, such as the natural stream velocity occurring during a specific flood event. Had there been the possibility for severe bank erosion, this proposed condition would have not been acceptable.

Slight variation of velocities and depths were calculated using the Fish Xing software and HEC-RAS.

The Fish Xing software provided the lowest velocity and highest depth results. For High Fish Passage Design flows, no barriers were found within the culvert. Only a prolonged swim mode through the entire culvert was required. Fish Xing only considers the tailwater channel cross-section, while the other programs consider at least two cross-sections for calculations. Channel velocities and depths using Fish Xing may not be accurately represented due to the limited channel information required for Fish Xing calculations.

HEC-RAS results were considered the most accurate and were used to determine the acceptability of the proposed culvert design. HEC-RAS calculates results reflecting the upstream and downstream channel geometry in addition to the culvert.



P:/06938/38713 TO7 Fish Passage/5.0 Project Data/AutoCAD/General Details/Hydraulic-design-Rose-Creek.DWG
08-29-06 AJACKSON 11:38:14

Issue No.	Description	Date	Drwn.	Chkd.	Resp. Engr.	Proj. Mgr.

Project Manager
LEF

Designed
EKB

Designed

Checked
JJL

Drawn
AJ

**Road Widening Route 777
at Rose Creek**

**HYDRAULIC DESIGN
PROPOSED CONDITIONS**

Date

Scale HORIZ: 1" = 50'
VERT: 1" = 5'

Project No. 06938-38713

File Name Hydraulic-design-Rose-Creek.DWG

Drawing No. 1

Issue

APPENDIX J

DESIGN EXAMPLE - HYDRAULIC DESIGN OPTION (REHABILITATE CULVERT WITH BAFFLE)

Hydraulic Design Option
(Baffles)

Problem Statement

At Ripple Creek in Mendocino County crossing Route 555, adult Coho salmon are unable to move through the existing 8-foot diameter x 8-foot length culvert. From past monitoring, Coho salmon have been sighted congregated just below this culvert during normal migration periods, which has triggered this site as a high priority for CA Fish & Game and NOAA Fisheries. After using Fish Xing software to analyze existing conditions and identify barriers to fish movement, low depths and high velocities were found inside this culvert.

The existing culvert is in good condition. The only problem is some localized scour on the banks of the creek near the culvert inlet. Within the project scope, Maintenance Design will provide rock slope protection on the creek banks and bed to control future scour and protect the culvert facility. Other than this scour issue, the culvert is free of structural damage from abrasion or excessive debris loading. Also, the existing culvert is believed to have more than adequate hydraulic capacity, and again is not subjected to heavy or damaging bedloads.

In order to improve fish passage through the Ripple Creek culvert and protect the culvert inlet, Caltrans District Maintenance Design will dedicate Minor B funds, and apply to CA Fish & Game for a matching grant. The design and construction management of this cooperative project will be performed by Caltrans.

NOTE: Route 555 and Ripple Creek are fictitious and created for presenting a design example for this fish-passage training guidance.

Form 1-Existing Data and Information Summary

Form 1 provides a list of suggested data references that would be beneficial to collect before the beginning of the design process.

For this particular example, USGS topographic quadrangle map, DEM data, as-built drawings, target fish species and life stage data, and stream flow gage data was available for reference.

The USGS topographic quadrangle data and DEM data was downloaded from the USGS website, www.usgs.gov.

The FEMA Map Service Center, http://msc.fema.gov/, was accessed to determine if a previous hydrologic study, hydraulic study, and floodplain mapping had been performed. For Ripple Creek, no previous detailed or approximate studies had been performed; therefore, no effective data was available for reference.

As-built drawings were found in District Hydraulics archives. CA Fish and Game provided target species and life stage data for Ripple Creek.

California Department of Water Resources (CDEC, http://cdec.water.ca.gov/), was searched for precipitation and stream flow gage data. Unfortunately, no recording stream flow gages are located on Ripple Creek; however, an adjacent watershed with similar basin characteristics has recording data that will be appropriate for basin transfer. The adjacent watershed gage data was downloaded off of CDEC's website.

As for site access status, the field investigations can be done within Caltrans Right-of-Way, therefore, rights-of-entry will not be required.

EXISTING DATA AND INFORMATION SUMMARY FORM 1

Project Information Fish Passage Improvement Route 555		Computed: EKB	Date: 7-1-06
		Checked: LEF	Date: 7-2-06
Stream Name: Ripple Creek	County: Mendocino	Route: 555	Postmile: 20.2

Proposed Project Type	☐ New Culvert	☐ New Bridge
	☐ Replacement Culvert	☐ Replacement Bridge
	☒ Retrofit Culvert	☐ Retrofit Bridge
	☒ Proposed Culvert Length= 60 ft	☐ Proposed Bridge Length= ft
	☐ Other	☐ Other

Design Species/Life Stage	☐ All Species	Source: John Bait Contact: NOAA Fisheries Date: contacted on 6/25/06 1-678-555-3322
	☒ Adult Anadromous Salmonids – adult coho salmon	
	☐ Adult Non-Anadromous Salmonids	
	☐ Juvenile Salmonids	
	☐ Native Non-Salmonids	
	☐ Non-Native Species	

Collect Existing Data

Included in Caltrans Culvert Inventory	☐ Yes	☒ No
As-Built Drawings	☒ Yes	☐ No
Assessor's Parcel Map	☐ Yes	☒ No
Previous Studies Performed: (i.e. FEMA Flood Insurance Studies, Army Corps of Engineering Studies, Other)		
Hydrology Analysis	☐ Yes	☒ No
Hydraulics Analysis	☐ Yes	☒ No
Floodplain Mapping	☐ Yes	☒ No
Other Studies Types Available: (i.e. Watershed Management Plans, Stream Restoration Plans, Other)	☐ Yes	☒ No
Existing Land Use Map	☐ Yes	☒ No
Proposed Land Use Map	☐ Yes	☒ No
Precipitation Gage Data	☐ Yes	☒ No
Stream Flow Gage Data	☒ Yes	☐ No

EXISTING DATA AND INFORMATION SUMMARY FORM 1

Topographic Mapping: ☒ Yes ☐ No
(i.e. [✓ USGS Topographic Quadrangle], [✓ DEM Data], LIDAR Data, Other)

District Hydraulics Library ☐ Yes ☒ No

Obtain Access Permission

Will Project study limits extend beyond Caltrans R/W? ☐ Yes ☒ No

If yes, obtain right-of-entry.

Contact Report Index Attached ☒ Yes ☐ No

Existing Information Index Attached ☒ Yes ☐ No

CONTACT REPORT INDEX

Project Information Fish Passage Improvement - Route 555		Computed: EKB	Date: 7/1/06
		Checked: LEF	Date: 7/2/06
Stream Name: Ripple Creek	County: Mendocino	Route: 555	Postmile: 20.2

Date of Contact	Person Contacted	Subject Discussed
6/25/06	John Bait @ NOAA	Coho Salmon design
	Fisheries	Species data
	678-555-3322	

EXISTING INFORMATION INDEX

Project Information

Fish Passage Improvement - Route 555

Computed: EKB

Date: 7/1/06

Checked: LEF

Date: 7/2/06

Stream Name: Ripple Creek

County: Mendocino

Route: 555

Postmile: 20.2

Report Date	Report Name and Source
8/1982	As-builts drawings for culvert
5/20/2006	Stream Flow gage data downloaded from CDEC
6/22/2006	USGS Topographical Map

Form 2- Site Visit Summary

Form 2 captures the existing conditions of the hydraulic structure including channel and structure roughness values. By completing the Site Visit Summary form, the drainage designer will have all necessary parameters required to complete any of the fish passage design options.

At the Ripple Creek site, various culvert and creek properties were investigated. These include layout configuration, roughness, velocity, and flow regime.

As mentioned above, it was noted in the field, as well as the As-Built plans that a headwall/endwall exists at the culvert inlet and outlet. Also, the existing culvert lies at a 2% slope matching the upstream and downstream channel invert.

For the creek, roughness characteristics of the main channel, the left overbank channel, and the right overbank channel were also investigated and ultimately Manning's n-values were estimated. Based on field observation, the left and right overbank channels were found to have the same n-values in the vicinity of the culvert crossing and the project study area.

Flow in the creek at the time of the field visit was determined from appropriate measurements. The flow was calculated by measuring a velocity and depth, calculating wetted area from a field developed creek cross-section, and dividing velocity by wetted area to achieve flow according to the continuity of flow equation. By placing a small leaf in the creek and timing its travel over a set length, a velocity was determined. In order to find a representative velocity for the creek, this operation was performed three times, where the leaf was placed near the left bank, near the right bank, and around the center of the creek. The velocity corresponding to each leaf placement was added together and averaged to find a representative velocity.

Finally, the flow regime for the creek was estimated in the field by tossing a small rock in the center of the creek and noting the propagation of the ripples. When ripples propagate upstream, the flow regime is subcritical, while supercritical flow is denoted by downstream ripple propagation. For Ripple Creek, subcritical flow was occurring upstream and downstream of the culvert.

SITE VISIT SUMMARY

FORM 2

Project Information Fish Passage Improvement Route 555	Computed: EKB	Date: 7-7-06
	Checked: LEF	Date: 7-8-06

Stream Name: Ripple Creek	County: Mendocino	Route: 555	Postmile: 20.2

Obtain Physical Characteristics of Existing Culvert

Confined Spaces

Is the culvert height 5 ft or greater?	☒ Yes ☐ No
Can you stand up in the culvert?	☒ Yes ☐ No
Can you see all the way through the culvert?	☒ Yes ☐ No
Can you feel a breeze through the culvert?	☒ Yes ☐ No

If answer is "No" to any of the above questions, do not enter the culvert without confined spaces equipment for surveying.

Inlet Characteristics

Inlet Type	☐ Projecting	☒ Headwall	☐ Wingwall	
	☐ Flared end section	☐ Segment connection		
Inlet Condition	☒ Channel scour	☐ Excessive deposition	☐ Debris accumulation	☐ None applicable
Inlet Apron	☒ Channel scour	☐ Excessive deposition	☐ Debris accumulation	☐ None applicable

Skew Angle: None °	Upstream Invert Elevation: 516.2 ft (NGVD 29 or [✓ NAVD 88])

Barrel Characteristics

Diameter: — in	Fill height above culvert: 12 ft
Height/Rise: 8 ft	Length: 60 ft
Width/Span: 8 ft	Number of barrels: 1

Culvert Type	☐ Arch	☒ Box	☐ Circular
	☐ Pipe-Arch	☐ Elliptical	
Culvert Material	☐ HDPE	☐ Steel Plate Pipe	☒ Concrete Pipe
	☐ Spiral Rib / Corrugated Metal Pipe		
Barrel Condition	☐ Corrosion	☐ Debris accumulation	☐ Structural damage
	☐ Abrasion	☐ Bedload accumulation	☒ None applicable

SITE VISIT SUMMARY FORM 2

Horizontal alignment breaks: NONE ft

Vertical alignment breaks: NONE ft

Outlet Characteristics

Outlet Type: ☐ Projecting ☒ Headwall ☐ Wingwall ☐ Flared end section ☐ Segment connection

Outlet Condition: ☐ Scour hole ☐ Backwatered ☐ Debris accumulation ☒ None applicable

☐ Perched

Outlet elevation drop: ft

Outlet drop condition:

Scour hole depth: ft

Outlet Apron: ☐ Channel scour ☐ Excessive deposition ☐ Debris Accumulation ☒ None Applicable

Skew Angle: NONE °

Downstream Invert Elevation: 514.96 ft (NGVD 29 or [✓ NAVD 88])

Bridge Physical Characteristics N/A

Elevation of high chord (top of road): ft

Elevation of low chord: ft

Channel Lining: ☐ No lining ☐ Concrete ☐ Rock ☐ Other

Skew Angle: °

Bridge width (length): ft

Pier Characteristics (if applicable) ☐ N/A

Number of Piers: ft

Upstream cross-section starting station: ft

Pier Width: ft

Downstream cross-section starting station: ft

Pier Centerline Spacing: ft

Pier Shape: ☐ Square nose and tail ☐ Semi-circular nose and tail ☐ 90° triangular nose and tail ☐ Twin-cylinder piers with connecting diaphragm ☐ Twin-cylinder piers without connecting diaphragm ☐ Ten pile trestle bent

Pier Condition: ☐ Scour ☐ Corrosion ☐ Debris accumulation

Skew angle °

Channel Characteristics

Hydraulic Structure Roughness Coefficients

(Source: Caltrans Highway Design Manual Table 864.3A)		(Source: HEC-RAS User's Manual)	
Type of Structure	**n- value**	**Type of Structure**	**n- value (normal)**

Linned Channels:		**Corrugated Metal:**	
Portland Cement Concrete	0.014	Subdrain	0.019
Air Blown Mortar (troweled)	[✓ 0.012]	Storm drain	0.024
Air Blown Mortar (untroweled)	0.016	**Wood:**	
Air Blown Mortar (roughened)	0.025	Stave	0.012
Asphalt Concrete	0.018	Laminated, treated	0.017
Sacked Concrete	0.025	**Brickwork:**	
Pavement and Gutters:		Glazed	0.013
Portland Cement Concrete	0.015	Lined with cement mortar	0.015
Asphault Concrete	0.016		
Depressed Medians:			
Earth (without growth)	0.040		
Earth (with growth)	0.050		
Gravel	0.055		

Recommended Permissible Velocities for Unlined Channels (Source: Caltrans Highway Design Manual, Table 862.2)

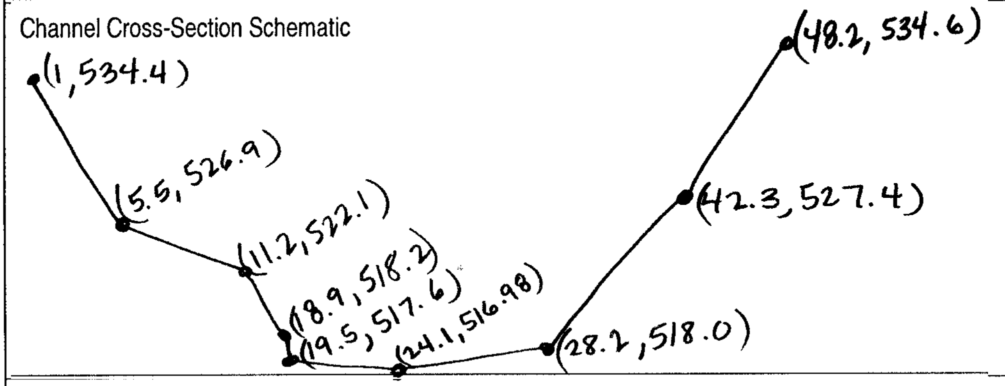
Type of Material in Excavation Section	Intermittent Flow (f/s)	Sustained Flow (f/s)
Fine Sand (Noncolloidal)	2.6	2.6
Sandy Loam (Noncolloidal)	2.6	2.6
Silt Loam (Noncolloidal)	3.0	3.0
Fine Loam	3.6	3.6
Volcanic Ash	3.9	3.6
Fine Gravel	3.9	3.6
Stiff Clay (Colloidal)	4.9	3.9
Graded Material (Noncolloidal)		
Loam to Gravel	6.6	4.9
Silt to Gravel	6.9	5.6
Gravel	7.5	5.9

SITE VISIT SUMMARY FORM 2

Coarse Gravel	7.9	6.6
Gravel to Cobbles (Under 150mm)	[✓ 8.8]	[✓ 6.9]
Gravel and Cobbles Over 200mm)	9.8	7.9

Flow Estimation 5 cfs ☐ Supercritical flow ☒ Subcritical flow

Channel Cross-Section Schematic



Channel depth = 0.5 ft

Average Active Channel Width
Take at least five channel width measurments to determine the active channel width. The active channel stage or ordinary high water level is the elevation delineating the hightest water level that has been maintained for a sufficient period of time to leave evidence on the landscape.

Average Active Channel Width = 8.3 ft

1) 6.2 ft	2) 4.9 ft	3) 10.2 ft	4) 12.1 ft	5) 8.0 ft

Boundary Conditions
The normal depth option (slope area method) can only be used as a downstream boundary condition for an open-ended reach. Is normal depth appropriate? If no, what is the known starting water surface elevation? Yes

Upstream NORMAL DEPTH slope 0.02 ft/ft

Downstream NORMAL DEPTH slope 0.02 ft/ft

Known starting water surface elevation Source: —— ft

General Considerations

Identify Physical restrictions

☐ Right-of-way ☐ Utility conflict ☐ Vegetation

☐ Man-made features ☐ Natural features ☐ Other

Cross-Section Sketches Attached ☒ Yes ☐ No

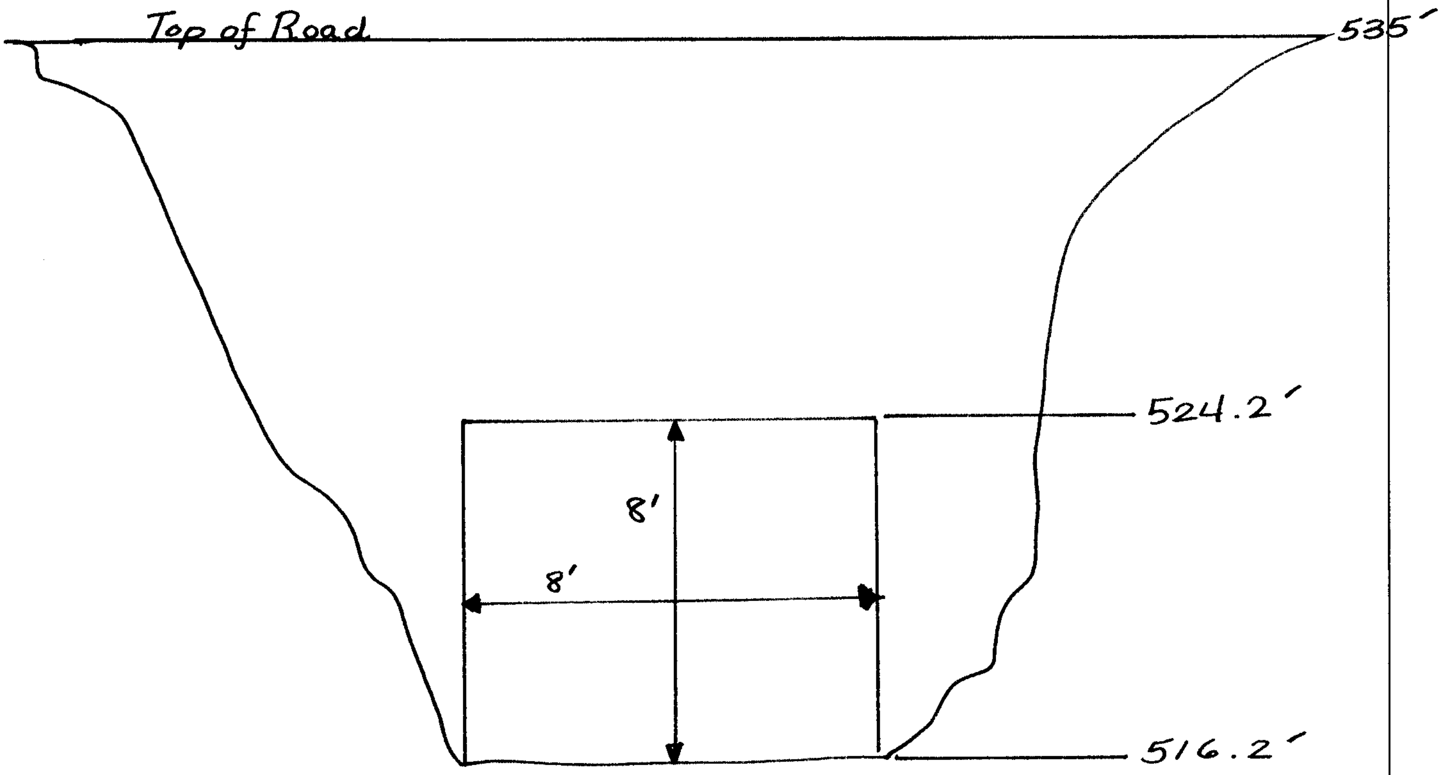
Site Photograph Documentation Attached ☒ Yes ☐ No

Channel / Overbank Manning's n-value Calculation Attached ☒ Yes ☐ No

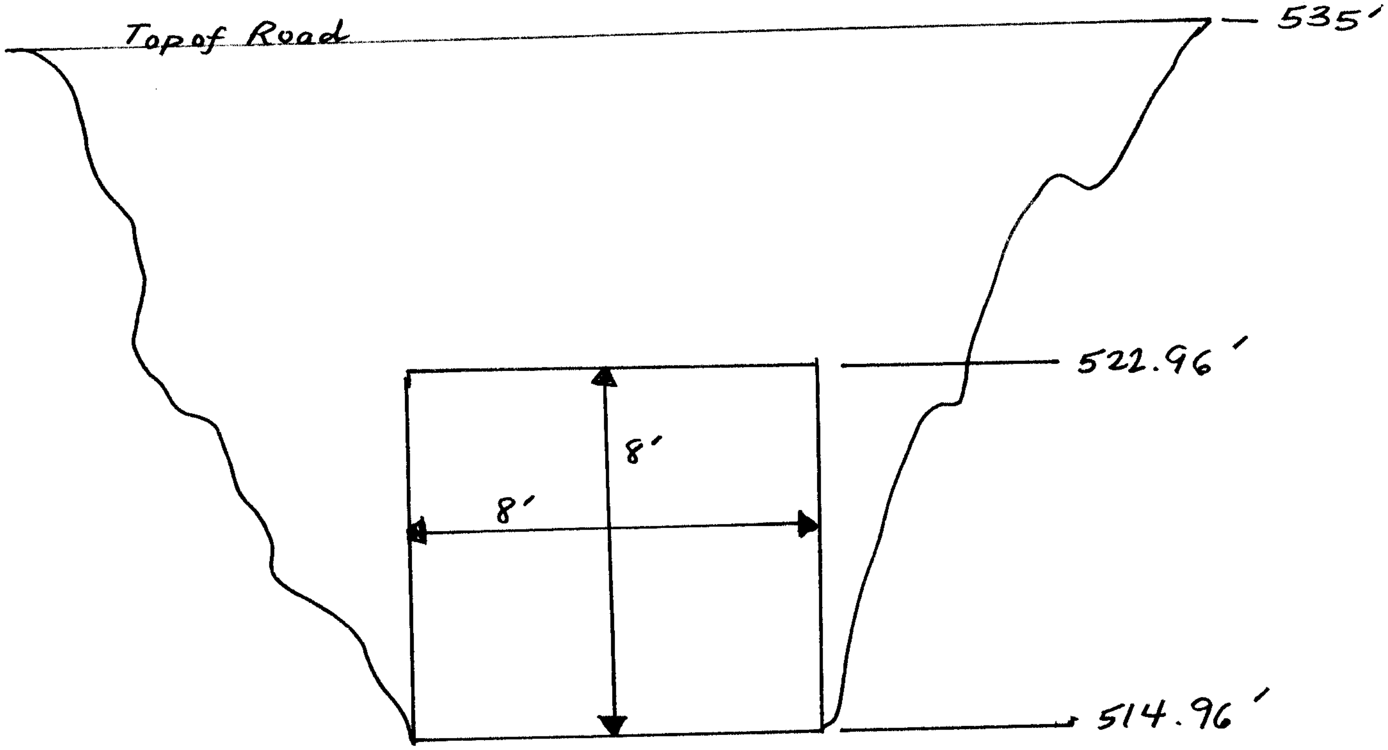
Field Notes Attached ☒ Yes ☐ No

Cross-Section Sketch

Upstream face of structure:



Downstream face of structure:



SITE PHOTOGRAPH DOCUMENTATION

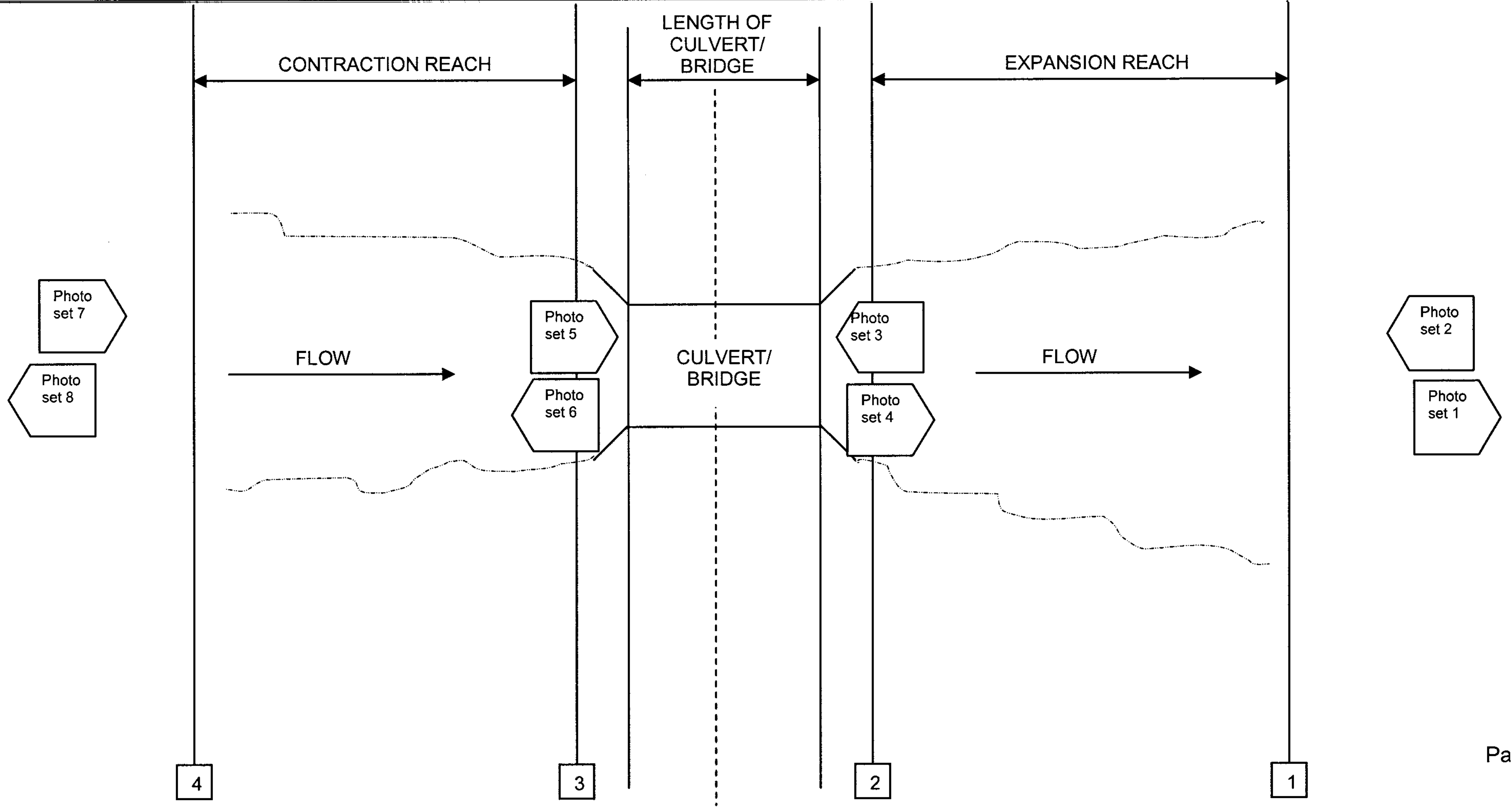
Project Information
Fish Passage Improvement Route 555

Computed: EKB
Date: 7/7/06
Checked: LEF
Date: 7/8/06

Stream Name Ripple Creek
City/County Mendocino
Road 555
Postmile 20.2

Crossing Type ☒ Culvert ☐ Bridge ☐ Other Type/Comments

Distance From:	X-sec. 1 to X-sec. 2: 28 ft	X-sec. 2 to DS face of culvert 1 ft	US face of culvert to X-Sec. 3 1 ft	X-sec. 3 to X-sec. 4 40 ft
Distance From:	Photo Sets 1 & 2 to DS face of culvert 100 ft	Photo Sets 3 & 4 to DS face of culvert 10 ft	Photo Sets 5 & 6 to US face of culvert 12 ft	Photo Sets 7 & 8 to US face of culvert 60 ft
Length of Culvert/Bridge:	ft			



SITE PHOTOGRAPH DOCUMENTATION

Photo Descriptions:

Photo Set 1	Looking at Downstream Channel
Photo Set 2	—
Photo Set 3	Looking at Culvert outlet
Photo Set 4	—
Photo Set 5	Looking at Culvert Inlet
Photo Set 6	Looking at Upstream channel
Photo Set 7	—
Photo Set 8	—

Downstream channel

Culver Outlet

Culvert Inlet

Upstream channel

Downstream channel

Culvert Outlet

Manning's n Computation Summary

Project Information Fish Passage Improvement - Route 555		Computed: EKB	Date: 7/7/06
		Checked: LEF	Date: 7/8/06
Stream Name: Ripple Creek	County: Mendocino	Route: 555	Postmile: 20.2

Aerial Picture Attached: NONE

Photographs (#'s and locations) #1, 3, 5, 6

Summary of n-Values:

Reach	Left Overbank	Main Channel	Right Overbank
	0.054	0.048	0.054

Notes:

- Rockslope protection added for proposed conditions at inlet. $n=0.040$
- concrete culvert box $n=0.012$

Manning's n Computation - Main Channel

Project Information Fish Passage Improvement Route 555		Computed: EKB	Date: 7/7/06
		Checked: LEF	Date: 7/8/06
Stream Name: Ripple Creek	County: Mendocino	Route: 555	Postmile: 20.2
Aerial Picture Attached: NONE			
Photographs (#'s and locations) # 1, 3, 5, 6			

Is roughness uniform throughout the reach? NO

Note: If not, n-value should be assigned for the AVERAGE condition of the reach

Is roughness uniformly distributed along the cross section? NO

Is a division between the channel and floodplain necessary? yes

Calculation of n-value:

n = (nb + n1 + n2 + n3 + n4)m

where:

	Description of Range
nb = base n value for surface	*median size btwn 1" and 2.5"=0.028 to 0.035, btwn 2.5" and 10"=0.030 to 0.050*
n1 = surface irregularity factor	*smooth = 0 up to severe at 0.020*
n2 = cross section variation factor	*gradual = 0 up to alternating frequently at 0.015*
n3 = obstructions factor	*negligible = 0 up to severe (over 50% of cross section) at 0.05*
n4 = vegetation factor	*small = 0.002 to very large (average depth of flow is less than 1/2 height of vegetation) at 0.100*
m = sinuosity/meandering factor	*minor = 1.0, appreciable = 1.15, Severe = 1.30*

Base n value for surface

nb: Sand channel? NO if yes, median size of bed material? ________

nb =

median size (in)	nb
0.008	0.012
0.012	0.017
0.016	0.020
0.020	0.022
0.024	0.023
0.031	0.025
0.039	0.026

All other channels:

median size (in)	nb
→ .04 to .08	0.026 to 0.035
1 to 2.5	0.028 to 0.035
2.5 to 10	0.030 to 0.050
>10	0.040 to 0.070

Notes: Small rock and dirt natural channel

nb = 0.026

Manning's n Computation - Main Channel

Surface Irregularity

n1:	Smooth	Is channel smooth? ____________	if yes, n1 = 0
	Minor	Is channel in good condition with slightly eroded or scoured side slopes?	[✓ if yes, n1 = 0.001 - 0.005]
	Moderate	Is channel a dredged channel having moderate to considerable bed roughness and moderately sloughed or eroded side slopes in rock?	if yes, n1 = 0.006 - 0.010
	Severe	Is channel badly sloughed, scalloped banks or badly eroded or sloughed sides or jagged and irregular surface?	if yes, n1 = 0.011 - 0.020

Notes: slight eroding of channel. more around Culvert inlet

n1 = 0.005

Cross Section Variation Factor

n2:	Gradual	Does the size and shape of the channel cross section change gradually?	if yes, n2 = 0.000
	Alternately occasionally	Does the cross section alternate to large to small, *occasionally* or does the main flow *occasionally* shift from side to side?	[✓ if yes, n2 = 0.001 - 0.005]
	Alternately frequently	Does the cross section alternate to large to small, *frequently* or does the main flow *frequently* shift from side to side?	if yes, n2 = 0.010 - 0.015

n2 = 0.003

Notes: occasion shift of flow from left bank to right bank

Obstructions factor

n3:	Negligible	Does the stream have a few scattered obstructions that occupy < 5% of the cross-sectional area?	[✓ if yes, n3 = 0.000 - 0.004]
	Minor	Obstructions occupy < 15% of the cross-sectional area and the spacing between obstructions is such that the sphere of influence doesn't extend to other obstructions?	if yes, n3 = 0.005 - 0.015
	Appreciable	Obstructions occupy 15% - 50% of the cross-sectional area and the spacing between obstructions is small enough to be additive?	if yes, n3 = 0.020 - 0.030
	Severe	Obstructions occupy more than 50% of the cross-sectional area or the spacing between obstructions causes turbulence?	if yes, n3 = 0.040 - 0.050

n3 = 0.004

Notes: NO large obstructions in channel

Manning's n Computation - Main Channel

Vegetation factor

n4:			
	Small	Does the channel have dense growth of flexible turf grass or weed growth where the flow is at least 2 times the height of the vegetation; tree seedlings of willows, cottonwoods, etc?	if yes, n4 = 0.002 - 0.010
	Medium	Does the channel have turf grass where the average depth of flow is 1 to 2 times the height of the vegetation; moderately stemmy grass, weeds or tree seedlings growing where the flow is 2 to 3 times the height of the vegetation? →	if yes, n4 = 0.010 - 0.025
	Large	Does the channel where the average depth of flow is equal to the height of the vegetation; 8 to 10 years-old willows or cottonwoods intergrown with weeds and brush; where the hydraulic radius exceeds1.97 ft or bushy willows about 1 year old intergrown with some weeds along side slopes, and no significant vegetation exists along the channel bottom, where the hydraulic radius is greater than 2.0 ft.	if yes, n4 = 0.025 -0.050
	Very large	Does the channel have turf grass growing where the average depth of flow < 1/2 the height of the vegetation; bushy willows about 1 year old. with weeds intergrown on side slopes; dense cattails in channel bottom; trees intergrown with weeds and brush?	if yes, n4 = 0.050 - 0.100

n4 = 0.010

Notes: Leafy-Low vegetation

Sinuosity/meandering factor

m	Minor	Ratio of the channel length to valley length in 1.0 to 1.2	if yes, m = 1.00
	Appreciable	Ratio of the channel length to valley length in 1.2 to 1.5	if yes, m = 1.15
	Severe	Ratio of the channel length to valley length > 1.5	if yes, m = 1.30

m = 1.00

Notes:

Manning's n - Main Channel n = 0.048

Manning's n Computation - Overbank

Project Information Fish Passage Improvement - Route 555		Computed: EKB	Date: 7/7/06
		Checked: LEF	Date: 7/8/06
Stream Name: Ripple Creek	County: Mendocino	Route: 555	Postmile: 20.2

Aerial Picture Attached: NONE

Photographs (#'s and locations) #1, 3, 5, 6

Is roughness uniform throughout the reach? NO

Note: If not, n-value should be assigned for the AVERAGE condition of the reach

Is roughness uniformly distributed along the cross section? NO

Is a division between the channel and floodplain necessary? yes

Calculation of n-value:

n = (nb + n1 + n2 + n3 + n4)m

where:	Description of Range
nb = base n value for surface	*median size between 1" and 2.5"=0.028 to 0.035, between 2.5" and 10"=0.030 to 0.050*
n1 = surface irregularity factor	*smooth = 0 up to severe at 0.020*
n2 = cross section variation factor	*gradual = 0 up to alternating frequently at 0.015*
n3 = obstructions factor	*assumed to equal 0*
n4 = vegetation factor	*small = 0.002 to very large (average depth of flow is less than 1/2 height of vegetation) at 0.100*
m = sinuosity/meandering factor	*equals 0 for floodplains*

Base n value for surface

nb: Sand channel? NO if yes, median size of bed material? ________

nb =

median size (in)	nb
0.008	0.012
0.012	0.017
0.016	0.020
0.020	0.022
0.024	0.023
0.031	0.025
0.039	0.026

All other channels:

median size (in)	nb
→ .04 to .08	0.026 to 0.035
1 to 2.5	0.028 to 0.035
2.5 to 10	0.030 to 0.050
>10	0.040 to 0.070

Notes: Overbanks consist of small rocks and dirt

nb = 0.026

Surface Irregularity

n1:	Smooth	Compares to the smoothest, flattest floodplain in a given bed material.	if yes, n1 = 0
	Minor	Is the floodplain slightly irregular in shape. A few rises and dips or sloughs may be more visible on the floodplain.	→ if yes, n1 = 0.001 - 0.005
	Moderate	Has more rises and dips. Sloughs and hummocks may occur.	if yes, n1 = 0.006 - 0.010
	Severe	Floodplain very irregular in shape. Many rises and dips or sloughs are visible.	if yes, n1 = 0.011 - 0.020

n1 = 0.005

Notes: Slight eroding of overbanks

Manning's n Computation - Overbank

Cross Section Variation Factor

n2 = 0.000

Notes: Not applicable to floodplains.

Obstructions factor

n3:	Negligible	Does the stream have a few scattered obstructions that occupy < 5% of the cross-sectional area?	if yes, n3 = 0.000 - 0.004
	Minor	Obstructions occupy < 15% of the cross-sectional area and the spacing between obstructions is such that the sphere of influence doesn't extend to other obstructions? →	if yes, n3 = 0.005 - 0.015
	Appreciable	Obstructions occupy 15% - 50% of the cross-sectional area and the spacing between obstructions is small enough to be additive?	if yes, n3 = 0.020 - 0.030

n3 = 0.005

Notes: large boulders present in overbank area

Vegetation factor

n4:			
	Small	Does the channel have dense growth of flexible turf grass or weed growth where the flow is at least 2 times the height of the vegetation; tree seedlings of willows, cottonwoods, etc where the average depth of flow is at least three times the height of the vegetation?	if yes, n4 = 0.002 - 0.010
	Medium	Does the channel have turf grass where the average depth of flow is 1-2 times the height of the vegetation; moderately stemmy grass, weeds or tree seedlings growing where the flow is 2-3 times the height of vegetation? Brushy, moderately dense vegetation, similar to 1-2 year old willow trees in dormant season. →	if yes, n4 = 0.010 - 0.025
	Large	Does the channel where the average. depth of flow is equal to the height of the vegetation; 8 to 10 year old. willows, cottonwoods intergrown with weeds and brush; where the R = 1.97 ft or bushy willows of 1 year old are in the channel bottom, where R =2.00 ft?	if yes, n4 = 0.025 -0.050
	Very large	Does the channel have turf grass growing where the average depth of flow < 1/2 the height of the vegetation; bushy willows about 1 year old. with weeds intergrown on side slopes; dense cattails in channel bottom; trees intergrown with weeds and brush?	if yes, n4 = 0.050 - 0.100
	Extreme	Does the channel have dense bushy willow, mesquite, and salt cedar (full foliage), or heavy stand of timber, few down trees, depth of reaching branches?	if yes, n4 = 0.100 - 0.200

n4 = 0.018

Notes: Leafy vegetation, low to ground ~ 5ft tall

Sinuosity/meandering factor

m = 1.00

Notes: Not applicable to floodplains.

Manning's n - Overbank n = 0.054

Form 3- Guidance on Selection of Fish Passage Design Option

This form summarizes requirements for each design option in order for the designer to select the appropriate fish-passage design option.

Since the existing culvert is in good structural and hydraulic condition, it should be rehabilitated instead of replaced to allow for adult, Coho salmon migration. By rehabilitation, the Caltrans portion of the project cost can be funded through a Minor B, and of course fewer impacts to the stream and habitat are probable during construction.

The best method of rehabilitation is to construct baffles inside the culvert. This would qualify as a Hydraulic Design option, and velocity/depth requirements will have to be addressed. As identified in the CA Fish & Game *Culvert Criteria for Fish Passage*, the velocity/depth criteria should be the goal for improvement, not the required threshold. With this statement in mind, the design engineer must still make reasonable effort to meet the velocity/depth requirements through the culvert baffling.

GUIDANCE ON SELECTION OF FISH PASSAGE DESIGN OPTION FORM 3

Project Information Fish Passage Improvement Route 555		Computed: EKB	Date: 7/10/06
		Checked: LEF	Date: 7/11/06
Stream Name: Ripple Creek	County: Mendocino	Route: 555	Postmile: 20.2

Design Species/ Life Stage	☐	All Species
	☒	Adult Anadromous Salmonids
	☐	Adult Non-Anadromous Salmonids
	☐	Juvenile Salmonids
	☐	Native Non-Salmonids
	☐	Non-Native Species

☐ **Active Channel Design Option -** The Active Channel Design Option 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 streambed 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 with stream hydraulic charagcteristics within the culvert are intended to mimic the stream conditions upstream and downstream of the crossing. However, hydraulic analyses for traffic safety, hydraulic impacts, and scour are required.

Criteria for choosing option:

☐ New and replacement culvert/bridge installations

☐ Passage required for all species

☒ Proposed culver/bridge length less than 100 feet

☒ Channel slope less than 3%

☒ **Hydraulic Design Option** - The Hydraulic Design Option is a design process that matches the hydraulic performance of a culvert with the swimming ablitities of a target species and age class of fish. This method targets distinct species of fish and, therefore, does not account for ecosystem requirments of non-target species.

Criteria for choosing option:

☐ New and replacement culvert/bridge installations (If retrofit installation, see Baffle or Rock Weir Design Options)

☒ Target species identified for passage

☒ Low to moderate channel slopes (less than 3%)

☒ Active channel design or stream simulation design options are not physically feasible

Retrofit Culvert/Bridge Installations

☒ **Baffle Design Option -** The Baffle Design Option is a Hydrualic Design process that is intended to increase flow depth, or to add roughness elements as a measure to reduce flow velocity within the culvert/bridge structure. Determination of the high and low fish passage design flows, water velocity, and water depth is required for this option.

☒ Retrofit culvert/bridge installation

☒ Little bedload material movement

GUIDANCE ON SELECTION OF FISH PASSAGE DESIGN OPTION FORM 3

☒ Existing culvert/bridge is structurally sound

☒ Target species identified for passage

☒ Low to moderate channel slopes

☒ Active channel design or stream simulation design options are not physically feasible

☐ **Rock Weir Design Option -** The Rock Weir Design Option is a Hydraulic Design process that is intended to increase flow depth, or add roughness elements as a measure to reduce flow velocity, or to increase the channel slope downstream of the culvert/bridge. Determination of the high and low fish passage design flows, water velocity, and water depth is required for this option.

☐ Retrofit culvert/bridge installations

☐ Perched condition at outlet

☐ Steep slope at inlet

☒ Target species identified for passage

☒ Active channel design or stream simulation design options are not physically feasible

☐ **Stream Simulation Design Option -** The Stream Simulation Design Option 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.

Criteria for choosing option:

☐ New and replacement culvert/bridge installations

☐ Passage required for all species

☐ Culvert/bridge length greater than 100 feet

☒ Channel width should be less than 20 feet

☒ Minimum culvert/bridge width no less than 6 feet

☒ Culvert/bridge slope does not greatly exceed slope of natural channel, slopes of 6 % or less

☐ Narrow stream valleys

Selected Design Option: Hydraulic Baffle Design Option

Basis for Selection:
- Retrofit Culvert
- target species identified: coho salmon
- need to increase depth w/in Culvert
- need to decrease velocities W/in Culvert

Seek Agency Approval: ☐ Yes ☒ No

Form 4- Guidance on Methodology for Hydrologic Analysis

Form 4 summarizes methods for estimating peak design discharges that will be used in a hydraulic analysis. Data requirements, limitations, and guidance are provided to assist in the hydrologic method selection.

For this particular example, all data requirements needed to calculate peak discharges by regional regression equations were readily available.

Stream flow data was also available allowing a stream flow hydrograph and stream duration curve to be created. Upper and lower fish passage flows were calculated.

GUIDANCE ON METHODOLOGY FOR HYDROLOGIC ANALYSIS [1, 2] FORM 4

Project Information Fish Passage Improvement - Route 555		Computed: EKB	Date: 7/11/06
		Checked: LEF	Date: 7/12/06
Stream Name: Ripple Creek	County: Mendocino	Route: 555	Postmile: 20.2

Summary of Methods for Estimating Peak Design Discharges for Use in Hydraulic Analysis

Ungaged Streams

☒ **Regional Regression**[3, 4]

Data Requirements	Limitations	Guidance
▪ Drainage area ▪ Mean annual precipitation ▪ Altitude index	▪ Peak discharge value for flow under natural conditions unaffected by urban development and little or no regulation by lakes or reservoirs ▪ Ungaged channel	The most recently published USGS report for estimating peak discharges may be used. The user should exercise caution to ensure that the reports are used only for the conditions and locations for which they are recommended.

Rainfall-Runoff Models

☐ **NRCS (TR 55)**[5]

Data Requirements	Limitations	Guidance
▪ 24-hour Rainfall ▪ Rainfall distribution ▪ Runoff curve number ▪ Concentration time ▪ Drainage area	▪ Small or midsize catchment (<8 km^2) ▪ Maximum of 10 subwatersheds ▪ Concentration time range from 0.1-10 hour (tabular hydrograph method limit <2 hour) ▪ Runoff is overland and channel flow ▪ Simplified channel routing ▪ Negligible channel storage	TR-55 focuses on small urban and urbanizing watersheds.

☐ **HEC-1/HEC-HMS**[6, 7] **(SCS Dimnesionless, Snyder Unit, Clark Unit Hydrographs)**

Data Requirements	Limitations	Guidance
▪ Watershed/subbasin parameters ▪ Precipitation depth, duration, frequency, and distribution ▪ Precipitation losses ▪ Unit hydrograph parameters ▪ Streamflow routing and diversion parameters	▪ Simulations are limited to a single storm event ▪ Streamflow routing is performed by hydrologic routing methods and is therefore not appropriate for unsteady state routing conditions.	Can be used for watersheds which are: small or large, simple or complex, and developed or undeveloped.

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[1] Caltrans Highway Design Manual, Chapter 810 Hydrology, Topic 819 Estimating Design Discharge

[2] FEMA Guidelines and Specifications, Appendix C, Section C.1

[3] USGS Water-Resources Investigation 77-21 (Magnitude and Frequency of Floods in California)

[4] USGS Open-File Report 93-419 (Methods for Estimating Magnitude and Frequency of floods in the Southwestern United States)

[5] United States Department of Agriculture, Natural Resources Conservation Service, Urban Hydrology for Small Watersheds Technical Release 55, June 1986. ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf

[6] HEC-1 User's Manual

[7] HEC-HMS User's Manual

[8] Bulletin 17B

GUIDANCE ON METHODOLOGY FOR HYDROLOGIC ANALYSIS [1, 2] FORM 4

GAGED STREAMS

☐ **Statistical Methods**[8]

Data Requirements	Limitations	Guidance
▪ 10 or more years of gaged flood records	▪ Gage data is usually only available for midsized and large catchments ▪ Appropriate station and/or generalized skew coefficient relationship applied	For watersheds with less than 50 years of record, compare with results of appropriate USGS regional regression equations. For watersheds with less than 25 years of record, compare with results of appropriate USGS regional regresssion equations and/or HEC-1/HEC-HMS model results.

☐ **Basin Transfer of Gage Data**

Data Requirements	Limitations	Guidance
▪ Discharge and area for gaged watershed ▪ Area for ungaged watershed	▪ Similar hydrologic characteristics ▪ Channel storage	Must obtain approval of transfer technique from hydraulics engineer prior to use.

☒ **Fish Passage Flows**

▪ Streamflow hydrograph ▪ Flow duration curve		Lower and upper fish passage flows define the range of flows a culvert should contain suitable conditions for fish passage.

Selected Hydrologic Method: Regional Regression & Fish Passage Flows

Basis for Selection:

- Data available for Regional Regression analysis
- Required to meet adult anadromous Salmonid depth and velocities

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[1] Caltrans Highway Design Manual, Chapter 810 Hydrology, Topic 819 Estimating Design Discharge
[2] FEMA Guidelines and Specifications, Appendix C, Section C.1
[3] USGS Water-Resources Investigation 77-21 (Magnitude and Frequency of Floods in California)
[4] USGS Open-File Report 93-419 (Methods for Estimating Magnitude and Frequency of floods in the Southwestern United States)
[5] United States Department of Agriculture, Natural Resources Conservation Service, Urban Hydrology for Small Watersheds Technical Release 55, June 1986. ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf
[6] HEC-1 User's Manual
[7] HEC-HMS User's Manual
[8] Bulletin 17B

GUIDANCE ON METHODOLOGY FOR HYDROLOGIC ANALYSIS [1, 2] FORM 4

Verify Reasonableness and Recommended Peak Discharges

Source	50% Annual Probability (2-Year Flood Event) (cfs)	10% Annual Probability (10-Year Flood Event) (cfs)	2% Annual Probability (50-Year Flood Event) (cfs)	1% Annual Probability (100-Year Flood Event) (cfs)	High Fish Passage Design Flow (cfs)	Low Fish Passage Design Flow (cfs)
Effective Study Peak Discharges	N/A	N/A	N/A	N/A	N/A	N/A
Recommended Peak Discharges	161	337	528	593	81	20

Hydrologic Analysis Index Attached ☒ Yes ☐ No

Hydrologic Analysis Calculations Attached ☒ Yes ☐ No

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[1] Caltrans Highway Design Manual, Chapter 810 Hydrology, Topic 819 Estimating Design Discharge
[2] FEMA Guidelines and Specifications, Appendix C, Section C.1
[3] USGS Water-Resources Investigation 77-21 (Magnitude and Frequency of Floods in California)
[4] USGS Open-File Report 93-419 (Methods for Estimating Magnitude and Frequency of floods in the Southwestern United States)
[5] United States Department of Agriculture, Natural Resources Conservation Service, Urban Hydrology for Small Watersheds Technical Release 55, June 1986. ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf
[6] HEC-1 User's Manual
[7] HEC-HMS User's Manual
[8] Bulletin 17B

HYDROLOGIC ANALYSES INDEX FORM 4

Project Information Fish Passage Improvement - Route 555		Computed: EKB	Date: 7/11/06
		Checked: LEF	Date: 7/12/06
Stream Name: Ripple Creek	County: Mendocino	Route: 555	Postmile: 20.2

Flooding Source/Stream Name	Hydrologic Method/Model Used	Method/Model Analysis Date	Exhibit No.	
			Paper Copy	Electronic Copy
Ripple Creek	USGS-Regional Regression	North Coast Region	1	—
Ripple Creek	Upper and Lower Fish Passage Flows	Flow Duration Curve	—	1

Regional Regression Computation Summary

Project Information:	Fish Passage Improvement - Route 555	Computed:	EKB	Date:	6/31/2006
		Checked:	JJL	Date:	7/1/2006
Stream Name: Ripple Creek	County: Mendocino	Route:	555	Postmile:	20.2

Calculations:

-Site Located in North Coast Region

A, Drainage Area =	1.05 mi^2
P, Mean Annual Precipitation =	70 inches
H, Altitude Index =	1 thousands of feet

Regional Regression Equations

Q2 =3.52A^0.90P^0.89H^-0.47
Q2 = 161 cfs

Q10 =6.21A^0.88P^0.93H^-0.27
Q10 = 337 cfs

Q50 = 8.57A^0.87P^0.96H^-0.08
Q50 = 528 cfs

Q100 = 9.23A^0.87P^0.97
Q100 = 593 cfs

The following documentation was taken from:

U.S. Geological Survey Water-Resources Investigations Report 94-4002:
Nationwide summary of U.S. Geological Survey regional regression equations for estimating magnitude and frequency of floods for ungaged sites, 1993

CALIFORNIA

STATEWIDE RURAL

Summary

California is divided into six hydrologic regions (fig. 1). The regression equations developed for these regions are for estimating peak discharges (QT) having recurrence intervals T that range from 2 to 100 years. The explanatory basin variables used in the equations are drainage area (A), in square miles; mean annual precipitation (P), in inches; and an altitude index (H), which is the average of altitudes in thousands of feet at points along the main channel at 10 percent, and 85 percent of the distances from the site to the divide. The variables A and H may be measured from topographic maps. Mean annual precipitation (P) is determined from a map in Rantz (1969). The regression equations were developed from peak-discharge records of 10 years or longer, available as of 1975, at more than 700 gaging stations throughout the State. The regression equations are applicable to unregulated streams but are not applicable to some parts of the State (see fig. 1). The standard errors of estimate for the regression equations for various recurrence intervals and regions range from 60 to over 100 percent. The report by Waananen and Crippen (1977) includes an approximate procedure for increasing a rural discharge to account for the effect of urban development. The influences of fire and other basin changes on flood magnitudes are also discussed.

Procedure

Topographic maps, the hydrologic regions map (fig. 1), the mean annual precipitation from Rantz (1969), and the following equations are used to estimate the needed peak discharges QT, in cubic feet per second, having selected recurrence intervals T.

North Coast Region

$Q2 = 3.52 A^{0.90} P^{0.89} H^{-0.47}$
$Q5 = 5.04 A^{0.89} P^{0.91} H^{-0.35}$
$Q10 = 6.21 A^{0.88} P^{0.93} H^{-0.27}$
$Q25 = 7.64 A^{0.87} P^{0.94} H^{-0.17}$
$Q50 = 8.57 A^{0.87} P^{0.96} H^{-0.08}$
$Q100 = 9.23 A^{0.87} P^{0.97}$

Northeast Region

$Q2 = 22 A^{0.40}$
$Q5 = 46 A^{0.45}$
$Q10 = 61 A^{0.49}$
$Q25 = 84 A^{0.54}$
$Q50 = 103 A^{0.57}$
$Q100 = 125 A^{0.59}$

Sierra Region

$Q2 = 0.24 A^{0.88} P^{1.58} H^{-0.80}$
$Q5 = 1.20 A^{0.82} P^{1.37} H^{-0.64}$
$Q10 = 2.63 A^{0.80} P^{1.25} H^{-0.58}$
$Q25 = 6.55 A^{0.79} P^{1.12} H^{-0.52}$
$Q50 = 10.4 A^{0.78} P^{1.06} H^{-0.48}$
$Q100 = 15.7 A^{0.77} P^{1.02} H^{-0.43}$

Central Coast Region

$Q2 = 0.0061 A^{0.92} P^{2.54} H^{-1.10}$
$Q5 = 0.118 A^{0.91} P^{1.95} H^{-0.79}$
$Q10 = 0.583 A^{0.90} P^{1.61} H^{-0.64}$
$Q25 = 2.91 A^{0.89} P^{1.26} H^{-0.50}$
$Q50 = 8.20 A^{0.89} P^{1.03} H^{-0.41}$
$Q100 = 19.7 A^{0.88} P^{0.84} H^{-0.33}$

South Coast Region

$Q2 = 0.14 A^{0.72} P^{1.62}$
$Q5 = 0.40 A^{0.77} P^{1.69}$
$Q10 = 0.63 A^{0.79} P^{1.75}$
$Q25 = 1.10 A^{0.81} P^{1.81}$
$Q50 = 1.50 A^{0.82} P^{1.85}$
$Q100 = 1.95 A^{0.83} P^{1.87}$

South Lahontan-Colorado Desert Region

$Q2 = 7.3A^{0.30}$
$Q5 = 53A^{0.44}$
$Q10 = 150A^{0.53}$
$Q25 = 410A^{0.63}$
$Q50 = 700A^{0.68}$
$Q100 = 1080A^{0.71}$

In the North Coast region, use a minimum value of 1.0 for the altitude index (H). Equations are defined only for basins of 25 mi² or less in the Northeast and South Lahontan-Colorado Desert regions.

Reference

Waananen, A.O., and Crippen, J.R., 1977, Magnitude and frequency of floods in California: U.S. Geological Survey Water-Resources Investigations Report 77-21, 96 p.

Additional Reference

Rantz, S.E., 1969, Mean annual precipitation in the California region: U.S. Geological Survey Open-File Map (Reprinted 1972, 1975).

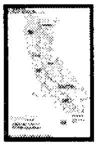
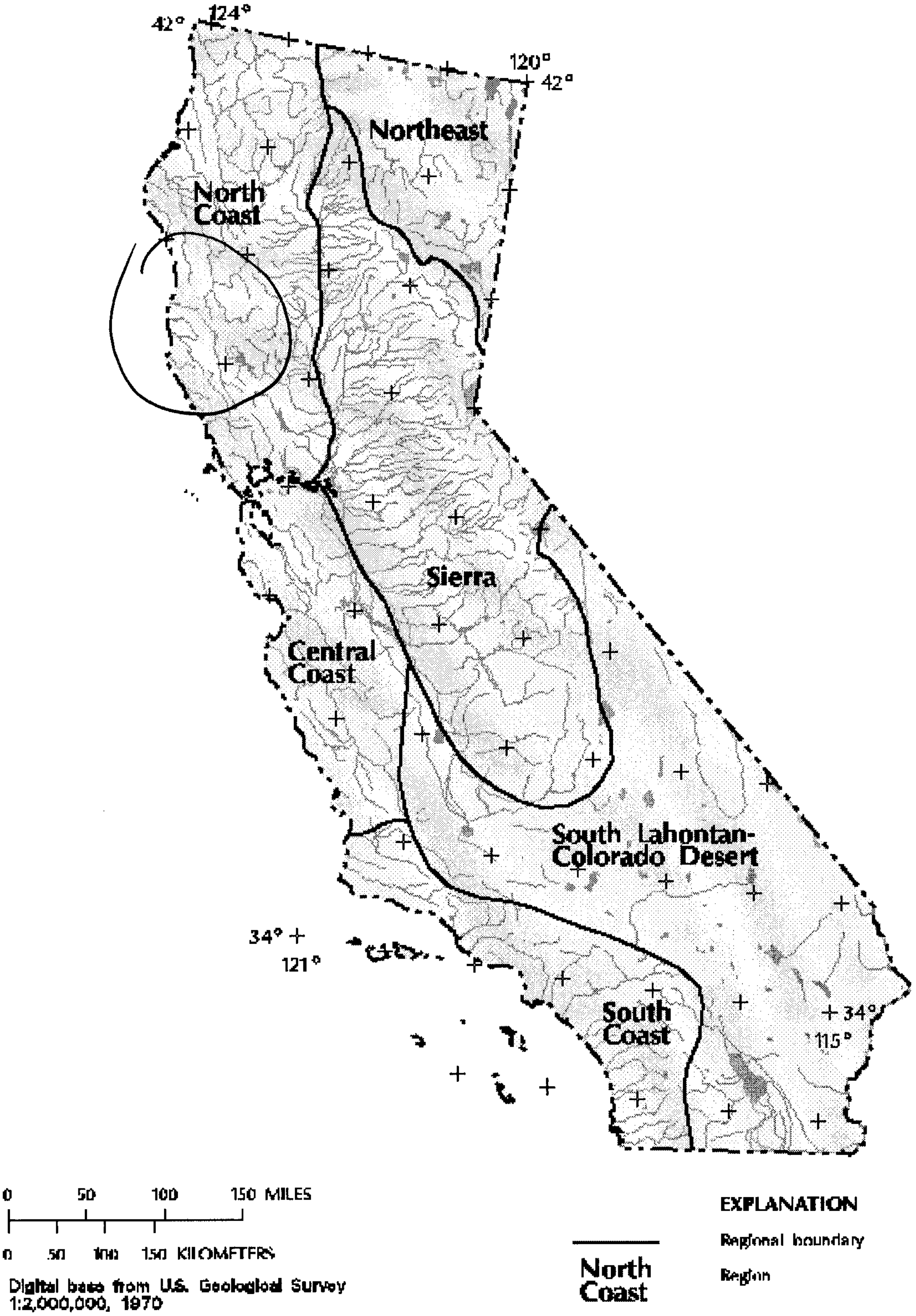


Figure 1. Flood-frequency region map for California. (PostScript file of Figure 1.)

Back to NFF main page

USGS Surface-Water Software Page

U.S. Geological Survey
National Flood Frequency Program
Water-Resources Investigations Report 94-4002

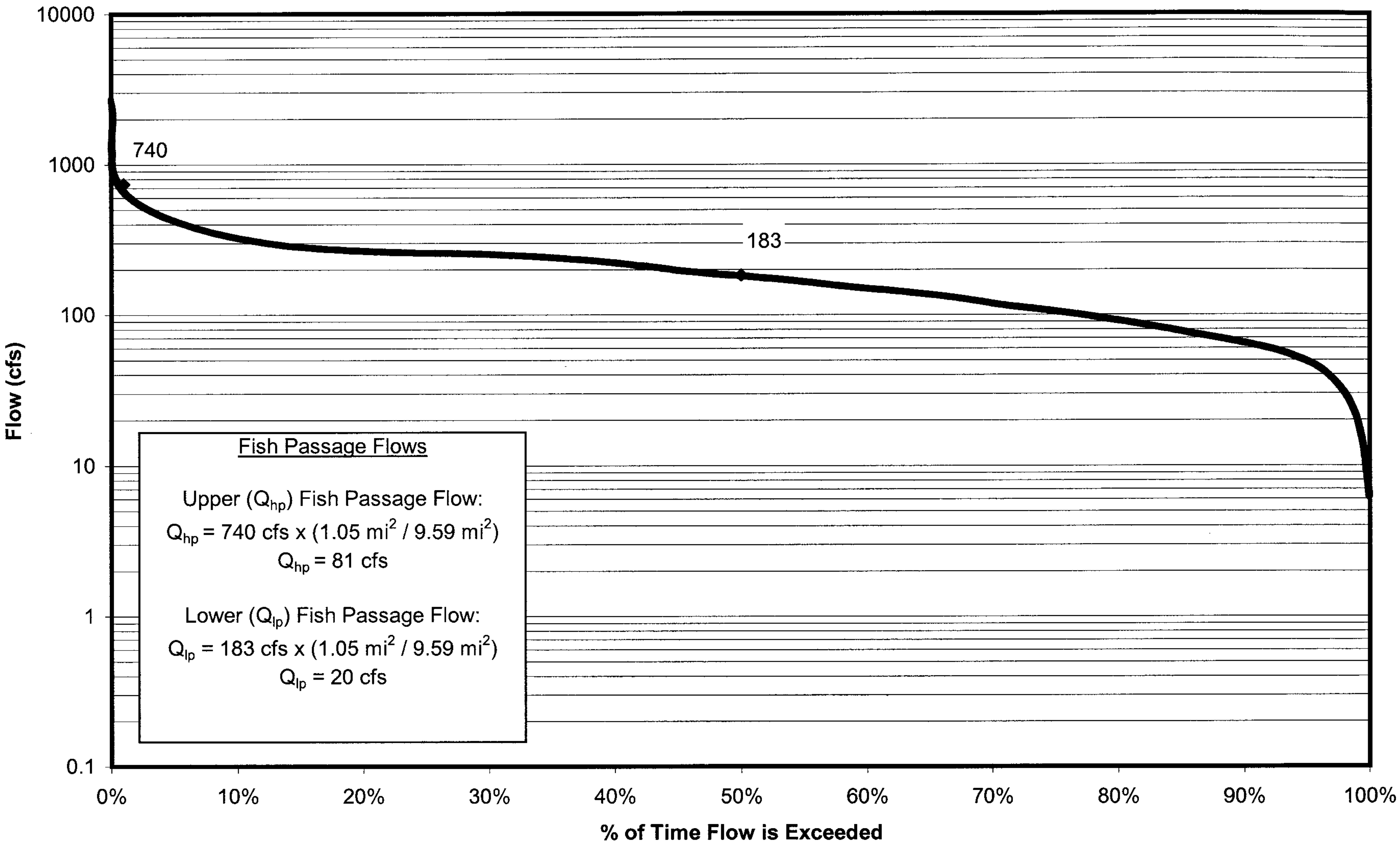


Digital base from U.S. Geological Survey
1:2,000,000, 1970

Albers equal-area projection based on
standard parallels 29.5 and 45.5 degrees

Figure 1. Flood-frequency region map for California.

Ripple Creek - Flow Duration Curve



Fish Passage Flows

Upper (Q_{hp}) Fish Passage Flow:

Q_{hp} = 740 cfs x (1.05 mi^2 / 9.59 mi^2)

Q_{hp} = 81 cfs

Lower (Q_{lp}) Fish Passage Flow:

Q_{lp} = 183 cfs x (1.05 mi^2 / 9.59 mi^2)

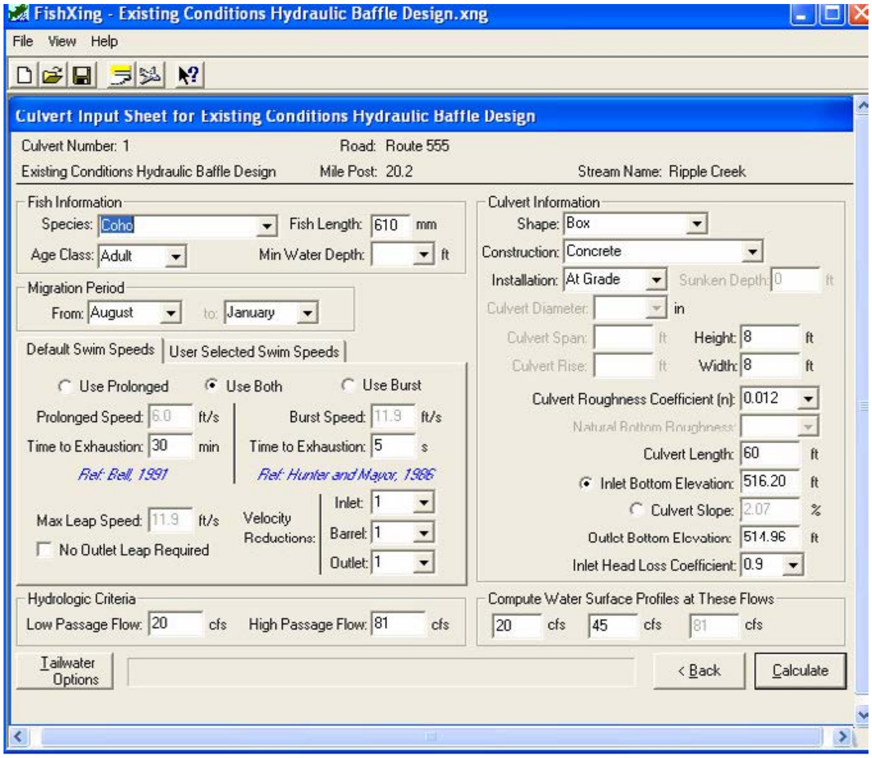
Q_{lp} = 20 cfs

Form 5 - Guidance on Methodology for Hydraulic Analysis

Form 5 summarizes the acceptable methods available for hydraulic analysis. The modeling methods include FHWA Design Charts, HY8 - Culvert Analysis, and HEC-2/HEC-RAS, and Fish Xing for pre or post design assessment.

For this particular example, Fish Xing and HEC-RAS were used to model existing conditions, and HEC-RAS was used to model proposed conditions. Fish Xing was not used to model proposed conditions because it presently cannot analyze baffles in the culvert. HEC-RAS easily allowed a quick comparison between existing and proposed water surface elevations and velocities.

Again, Fish Xing software was used to analyze existing conditions for Ripple Creek. Biological, existing culvert parameters and the tailwater cross section were entered into the Culvert Input sheet shown below.



Culvert Input Sheet for Existing Conditions Hydraulic Baffle Design

Culvert Number: 1
Road: Route 555
Existing Conditions Hydraulic Baffle Design
Mile Post: 20.2
Stream Name: Ripple Creek

Fish Information
Species: Coho
Fish Length: 610 mm
Age Class: Adult
Min Water Depth: ft

Migration Period
From: August to: January

Default Swim Speeds | User Selected Swim Speeds
○ Use Prolonged ● Use Both ○ Use Burst
Prolonged Speed: 6.0 ft/s
Time to Exhaustion: 30 min
Ref: Bell, 1991
Burst Speed: 11.9 ft/s
Time to Exhaustion: 5 s
Ref: Hunter and Mayor, 1986
Max Leap Speed: 11.9 ft/s
☐ No Outlet Leap Required
Velocity Reductions: Inlet: 1 Barrel: 1 Outlet: 1

Culvert Information
Shape: Box
Construction: Concrete
Installation: At Grade
Sunken Depth: 0 ft
Culvert Diameter: in
Culvert Span: ft
Height: 8 ft
Culvert Rise: ft
Width: 8 ft
Culvert Roughness Coefficient (n): 0.012
Natural Bottom Roughness:
Culvert Length: 60 ft
● Inlet Bottom Elevation: 516.20 ft
○ Culvert Slope: 2.07 %
Outlet Bottom Elevation: 514.96 ft
Inlet Head Loss Coefficient: 0.9

Hydrologic Criteria
Low Passage Flow: 20 cfs
High Passage Flow: 81 cfs

Compute Water Surface Profiles at These Flows
20 cfs 45 cfs 81 cfs

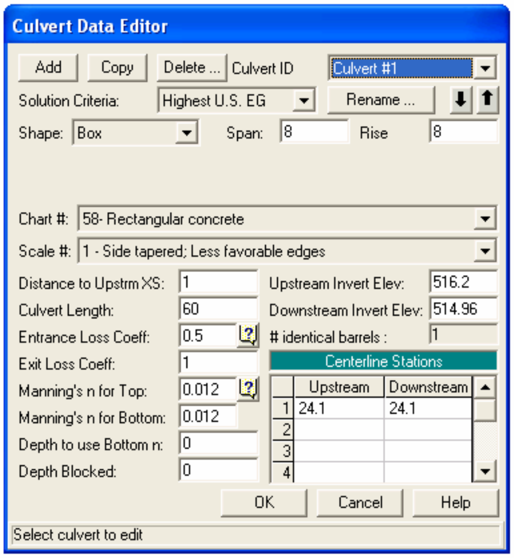
The HEC-RAS model consisted of three plans: Existing, Proposed Low Flow, and Proposed High Flow geometry conditions. Different geometry models for the low flows and high flows were considered as a necessary measure to accurately capture the correct water behavior for the different peak discharges.

For the low flows, which include the Low and High Fish Passage Design Flows, 2-Year, and the 10-Year Flood Event, the channel geometry was modeled as an open rectangular channel (8’x8’) with three inline structures representing the baffles within the culvert.

For the high flows, which include the 50-Year and 100-Year Flood Event, the culvert and baffles were modeled by allowing flow only through the notch and the 6'x 8' area above the inline structure through the culvert structure. At high flows, the baffle structures within the culvert are flooded out and do not provide control over the culvert velocities and depths. The Manning's n values also decrease due to the flooded out conditions. The Manning's n-values were selected by calibrating the Proposed High Flow, 2-Year flood event water surface elevations, against the Proposed Low Flow, 2-Year water surface elevation upstream and downstream of the culvert until the water surface elevation matched.

All HEC-RAS plans use the same peak discharges estimated by regional regression analysis and the flow hydrograph and stream duration curve.

The existing conditions culvert geometry was modeled using the Culvert Data Editor. The existing culvert parameters that had been measured and captured in Form 2 - Site Visit Summary, were entered into the Culvert Data Editor within HEC-RAS. The Culvert Data Editor and Bridge Culvert Data windows are captured below.

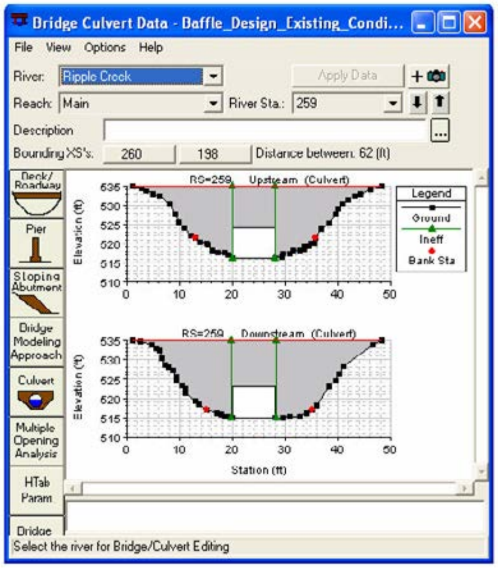


Culvert ID: Culvert #1
Solution Criteria: Highest U.S. EG
Shape: Box
Span: 8
Rise: 8
Chart #: 58- Rectangular concrete
Scale #: 1 - Side tapered; Less favorable edges
Distance to Upstrm XS: 1
Culvert Length: 60
Entrance Loss Coeff: 0.5
Exit Loss Coeff: 1
Manning's n for Top: 0.012
Manning's n for Bottom: 0.012
Depth to use Bottom n: 0
Depth Blocked: 0
Upstream Invert Elev: 516.2
Downstream Invert Elev: 514.96
identical barrels : 1

Centerline Stations

	Upstream	Downstream
1	24.1	24.1
2		
3		
4		

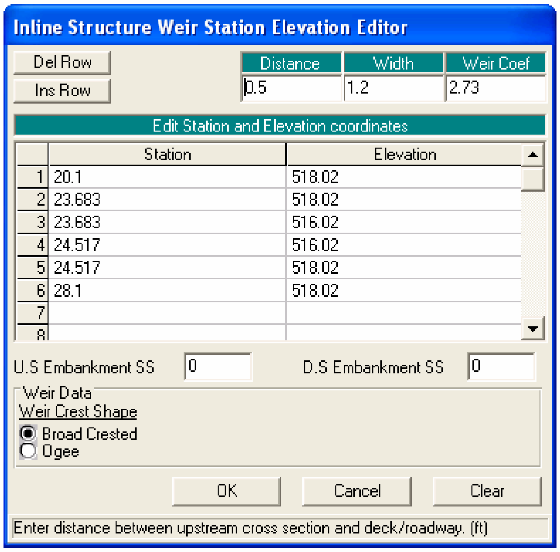
Select culvert to edit



River: Ripple Creek
Reach: Main
River Sta.: 259
Description
Bounding XS's: 260 198 Distance between: 62 (ft)

Select the river for Bridge/Culvert Editing

The proposed conditions for low flows geometry were modeled using the Inline Structure Weir Station Elevation Editor in HEC-RAS. Proposed dimensions of the weir were selected and entered into the culvert to determine proposed water surface behaviors for low flows. The Inline Structure Weir Station Elevation Editor and Inline Structure Data windows are captured below.



Inline Structure Weir Station Elevation Editor

Distance	Width	Weir Coef
0.5	1.2	2.73

Edit Station and Elevation coordinates

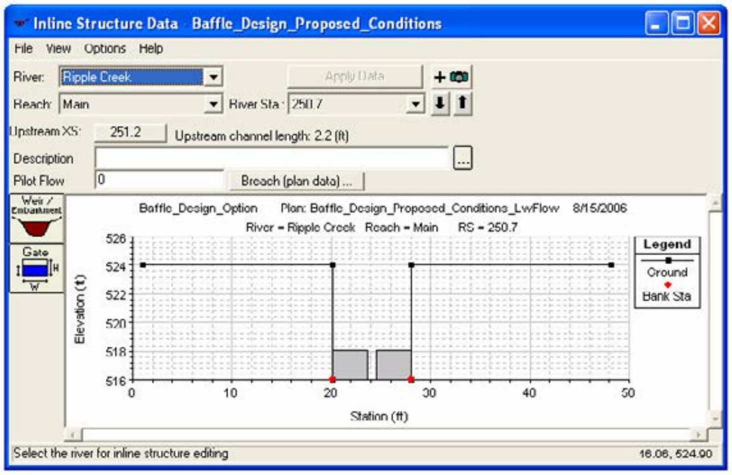
	Station	Elevation
1	20.1	518.02
2	23.683	518.02
3	23.683	516.02
4	24.517	516.02
5	24.517	518.02
6	28.1	518.02
7		
8		

U.S Embankment SS: 0
D.S Embankment SS: 0

Weir Data

Weir Crest Shape
● Broad Crested
○ Ogee

Enter distance between upstream cross section and deck/roadway. (ft)



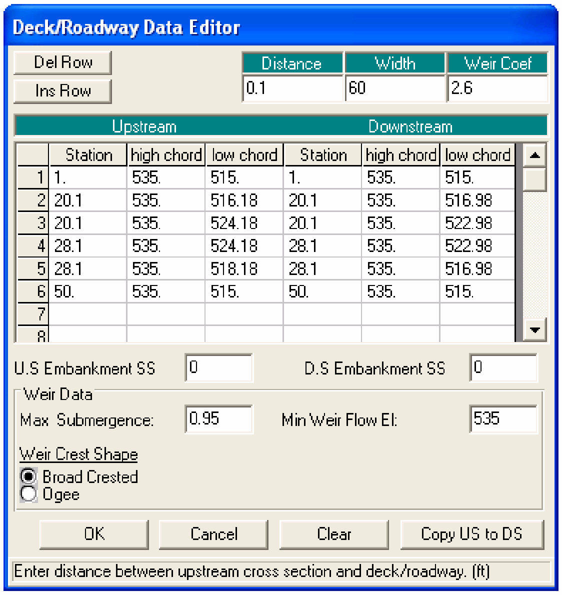
Inline Structure Data Baffle_Design_Proposed_Conditions

River: Ripple Creek
Reach: Main
River Sta.: 250.7
Upstream XS: 251.2
Upstream channel length: 2.2 (ft)
Description:
Pilot Flow: 0

Select the river for inline structure editing

16.06, 524.90

The proposed conditions for high flows geometry were modeled using the Deck/Roadway Data Editor in HEC-RAS. Culvert geometry for high flows was entered into the Deck/Roadway Data Editor to determine proposed water surface behaviors for high flows. The Deck/Roadway Data Editor and Bridge Culvert Data windows are captured below.



Deck/Roadway Data Editor

Distance	Width	Weir Coef
0.1	60	2.6

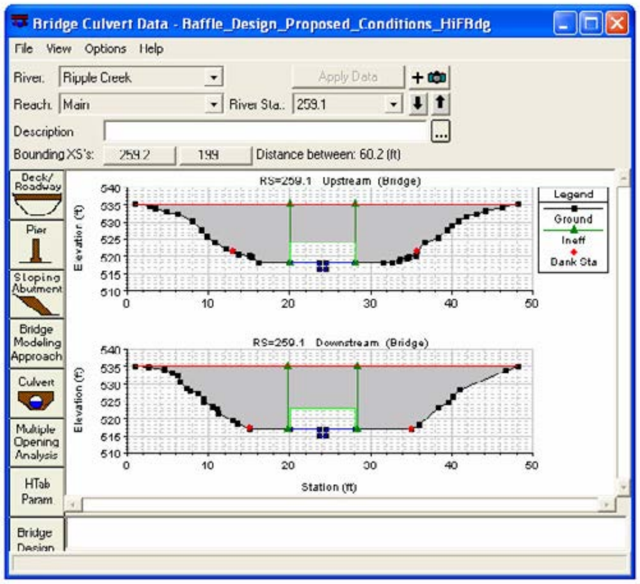
	Upstream			Downstream		
	Station	high chord	low chord	Station	high chord	low chord
1	1.	535.	515.	1.	535.	515.
2	20.1	535.	516.18	20.1	535.	516.98
3	20.1	535.	524.18	20.1	535.	522.98
4	28.1	535.	524.18	28.1	535.	522.98
5	28.1	535.	518.18	28.1	535.	516.98
6	50.	535.	515.	50.	535.	515.
7						
8						

U.S Embankment SS: 0
D.S Embankment SS: 0

Weir Data
Max Submergence: 0.95
Min Weir Flow El: 535

Weir Crest Shape
● Broad Crested
○ Ogee

Enter distance between upstream cross section and deck/roadway. (ft)



Bridge Culvert Data - Baffle_Design_Proposed_Conditions_HiFBdg

River: Ripple Creek
Reach: Main
River Sta.: 259.1
Description:
Bounding XS's: 259.2 199
Distance between: 60.2 (ft)

Hand Calculations to determine notch velocity and depth at the three weirs were also performed using the broad-crested weir equation located in Hydraulic Engineering Circular 22, *Urban Drainage Design Manual.*

GUIDANCE ON METHODOLOGY FOR HYDRAULIC ANALYSIS FORM 5

Project Information Fish Passage Improvement Route-555		Computed: EKB	Date: 7/15/06
		Checked: LEF	Date: 7/16/06
Stream Name: Ripple Creek	County: Mendocino	Route: 555	Postmile: 20.2

Summary of Methods for Hydraulic Analysis

☐ **FHWA Design Charts**

☐ **HY8 - Culvert Analysis or other HDS-5 Based Software**

☒ **HEC-2 / HEC-RAS**

☒ **Fish Xing ([✓ Pre-design assessment] or post-design assessment when applicable)**

Is the hydraulic model used to create the effective FIRM available? ☐ Yes ☒ No
If yes, update and use this model for the hydraulic model.

Selected Method: HEC - RAS

Basis for Selection: HEC-RAS-

Ability to model inline structures with different weir geometry

Fish Xing -

Pre-design assessment

Verify Reasonableness and Recommended Flows ☒ Yes ☐ No

Hydraulic Analyses Index Attached ☒ Yes ☐ No

Hydraulic Analysis Calculation Attached ☒ Yes ☐ No

HYDRAULIC ANALYSES INDEX

FORM 5

Project Information

Fish Passage Improvement - Route 555

Computed: EKB

Date: 7/15/06

Checked: LEF

Date: 7/16/06

Stream Name: Ripple Creek

County: Mendocino

Route: 555

Postmile: 20.2

Flooding Source/Stream Name	Hydraulic Method/Model Used	Method/Model Analysis Date	Exhibit No.	
			Paper Copy	Electronic Copy
Ripple Creek	HEC-RAS	Existing Conditions	/	.p07 .g06 .f01
Ripple Creek	HEC-RAS	Proposed Conditions Low Flow Analysis	/	.p02 .g02 .f01
Ripple Creek	HEC-RAS	Proposed Conditions High Flow Analysis	/	.p05 .g05 .f01
Ripple Creek	FISH XING	Existing - Conditions Hydraulic Baffle Design	/	pre-design assessment

Culvert Report for Existing Conditions Hydraulic Baffle Design

Project: Existing_Conditions_Hydraulic_Baffle_Design

Culvert Location Information
Road: Route 555
Mile Post: 20.2
Stream Name: Ripple Creek
Length of Historical Upstream Habitat: 3000 ft

Biological Data
Species: Adult Coho
Fish Length: 610 mm
Minimum Water Depth: 1 ft
Migration Period: August to January
Prolonged Swimming Speed: 6 ft/s
Prolonged Time to Exhaustion: 30 min
Burst Swimming Speed: 11.9 ft/s
Burst Time to Exhaustion: 5 s
Jumping Speed: 11.9 ft/s
Velocity Reduction Factors:
  Inlet: 1.00
  Barrel: 1.00
  Outlet: 1.00

Culvert Installation Data
Culvert Type: 8 X 8 ft Box
Construction: Concrete
Installation: At Grade
Culvert Length: 60 ft
Culvert Slope: 2.07%
Culvert Roughness Coefficient: 0.012
Inlet Invert Elevation: 516.2 ft
Outlet Invert Elevation: 514.96 ft
Inlet Headloss Coefficient (Ke): 0.9

Design Flows
Low Passage Flow: 20 cfs
High Passage Flow: 81 cfs

Table 1. Uniform Flow Calculations.

Discharge (cfs)	Velocity (ft/s)	Normal Depth (ft)	Critical Depth (ft)	Outlet Velocity (ft/s)	Tailwater Depth (ft)	Pool Depth (ft)	Min Rqd. Leap Velocity (ft/s)	Vert. Leap Distance (ft)	Comments
0.00	0.00	0.00	0.00	0.00	-0.56	0.00			
3.03	3.78	0.10	0.16	3.78	-0.11	0.45	5.21	0.21	Depth; Pool
9.45	5.91	0.20	0.35	5.91	0.13	0.69	0.00	0.00	Depth
18.29	7.62	0.30	0.55	7.02	0.33	0.89	0.00	0.00	Depth; Vel
20.00	7.89	0.32	0.58	7.05	0.35	0.91	0.00	0.00	LPF; Depth; Vel
29.10	9.09	0.40	0.74	7.37	0.49	1.05	0.00	0.00	Depth; Vel
41.58	10.40	0.50	0.94	7.89	0.66	1.22	0.00	0.00	Depth; Vel
55.53	11.57	0.60	1.14	8.49	0.82	1.38	0.00	0.00	Depth; Vel
70.77	12.64	0.70	1.34	9.09	0.97	1.53	0.00	0.00	Depth; Vel
81.00	13.27	0.76	1.47	9.46	1.07	1.63	0.00	0.00	HPF, Depth; Vel
87.18	13.62	0.80	1.55	9.67	1.13	1.69	0.00	0.00	Depth; Vel
104.64	14.53	0.90	1.74	10.24	1.28	1.84	0.00	0.00	Depth; Vel
123.06	15.38	1.00	1.94	10.79	1.43	1.99	0.00	0.00	Vel
142.36	16.18	1.10	2.14	11.33	1.57	2.13	0.00	0.00	Vel

Comment Codes:

LPF - Low Passage Flow
HPF - High Passage Flow
Depth - Insufficient Depth
Vel - Excessive Velocity
Leap - Excessive Leap
Pool - Shallow Leap Pool

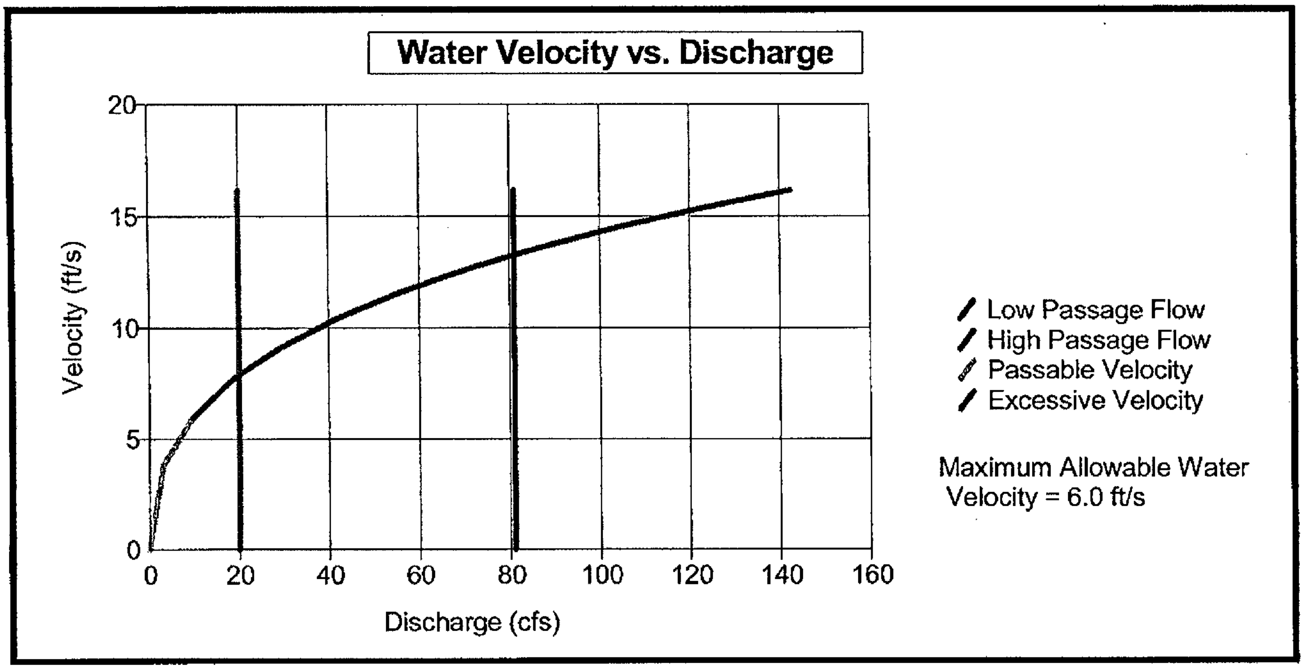


Figure 1. Velocity at Uniform Flow

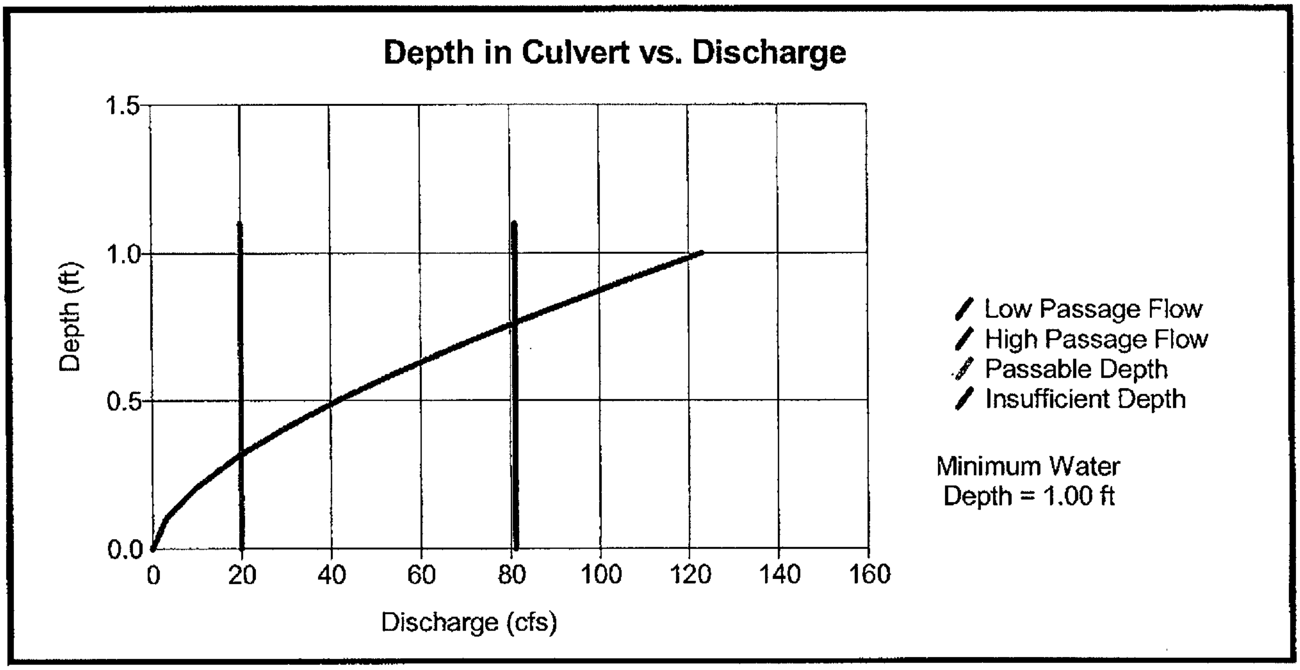


Figure 2. Depth at Uniform Flow

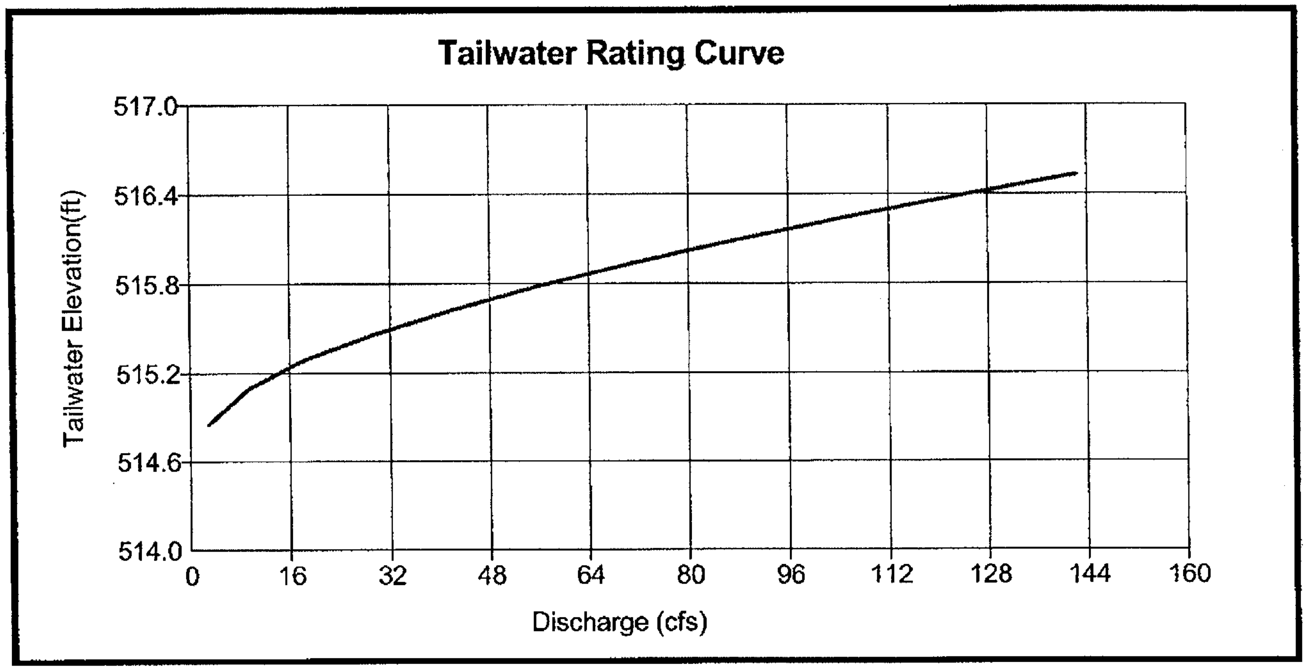


Figure 3. Tailwater Rating Curve at Uniform Flow

Table 2. Gradually Varied Flow Calculations for 20 cfs.

Q = 20.0 cfs				
Dist Down Culvert (ft)	Depth (ft)	Velocity (ft/s)	Curve	Swim Mode
0	1.13	0.00	Inlet	
3	0.58	5.95	S2	NA
5	0.48	5.22	S2	NA
8	0.44	5.70	S2	NA
11	0.41	6.06	S2	NA
14	0.40	6.32	S2	NA
17	0.38	6.54	S2	NA
20	0.37	6.72	S2	NA
23	0.36	6.86	S2	NA
26	0.36	6.99	S2	NA
29	0.35	7.11	S2	NA
32	0.35	7.20	S2	NA
35	0.34	7.28	S2	NA
38	0.34	7.35	S2	NA
41	0.34	7.42	S2	Exhausted
44	0.33	7.48	S2	Burst
47	0.33	7.52	S2	Burst
50	0.33	7.56	S2	Burst
53	0.33	7.59	S2	Burst
56	0.33	7.63	S2	Burst
60	0.33	7.68	S2	Burst

Table 3. Gradually Varied Flow Specifications for 20 cfs.

	20.0 cfs
Normal Depth (ft)	0.32
Critical Depth (ft)	0.58
Headwater Depth (ft)	1.13
Inlet Velocity (ft/s)	5.95
Tailwater Depth (ft)	0.35
Burst Swim Time (s)	5.00
Prolonged Swim Time (min	0.00
Barrier Code	Depth; EB

Barrier Codes

Depth - Too shallow for substantial distance

EB - Fish exhausted at burst speed

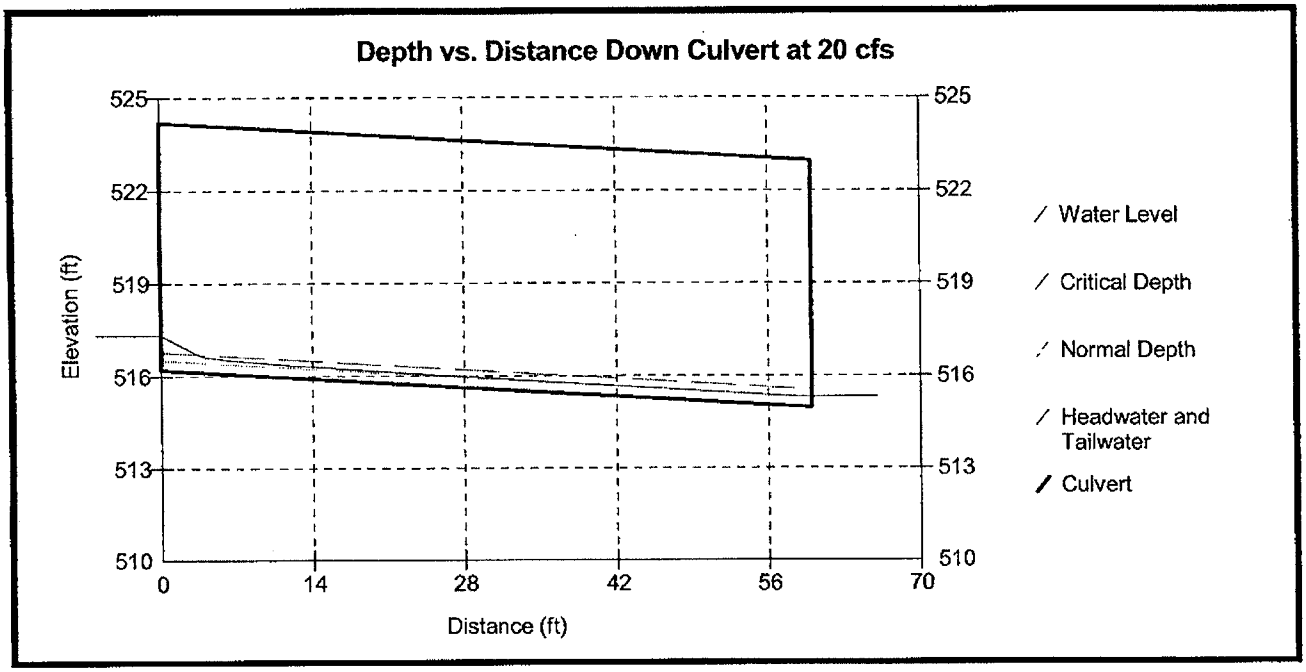


Figure 4. Water Surface Profile at 20 cfs

Table 4. Gradually Varied Flow Calculations for 45 cfs.

Q = 45.0 cfs				
Dist Down Culvert (ft)	Depth (ft)	Velocity (ft/s)	Curve	Swim Mode
0	1.94	0.00	Inlet	
3	0.99	7.80	S2	NA
5	0.85	6.60	S2	NA
8	0.79	7.11	S2	NA
11	0.75	7.47	S2	NA
14	0.72	7.76	S2	NA
17	0.70	8.00	S2	NA
20	0.68	8.22	S2	NA
23	0.67	8.41	S2	NA
26	0.65	8.59	S2	NA
29	0.64	8.74	S2	NA
32	0.63	8.88	S2	NA
35	0.62	9.01	S2	NA
38	0.62	9.13	S2	NA
41	0.61	9.24	S2	NA
44	0.60	9.34	S2	NA
47	0.60	9.43	S2	NA
50	0.59	9.51	S2	Exhausted
53	0.59	9.60	S2	Burst
56	0.58	9.67	S2	Burst
60	0.58	9.76	S2	Burst

Table 5. Gradually Varied Flow Specifications for 45 cfs.

	45.0 cfs
Normal Depth (ft)	0.53
Critical Depth (ft)	0.99
Headwater Depth (ft)	1.94
Inlet Velocity (ft/s)	7.80
Tailwater Depth (ft)	0.70
Burst Swim Time (s)	5.00
Prolonged Swim Time (min	0.00
Barrier Code	Depth; EB

Barrier Codes

Depth - Too shallow for substantial distance

EB - Fish exhausted at burst speed

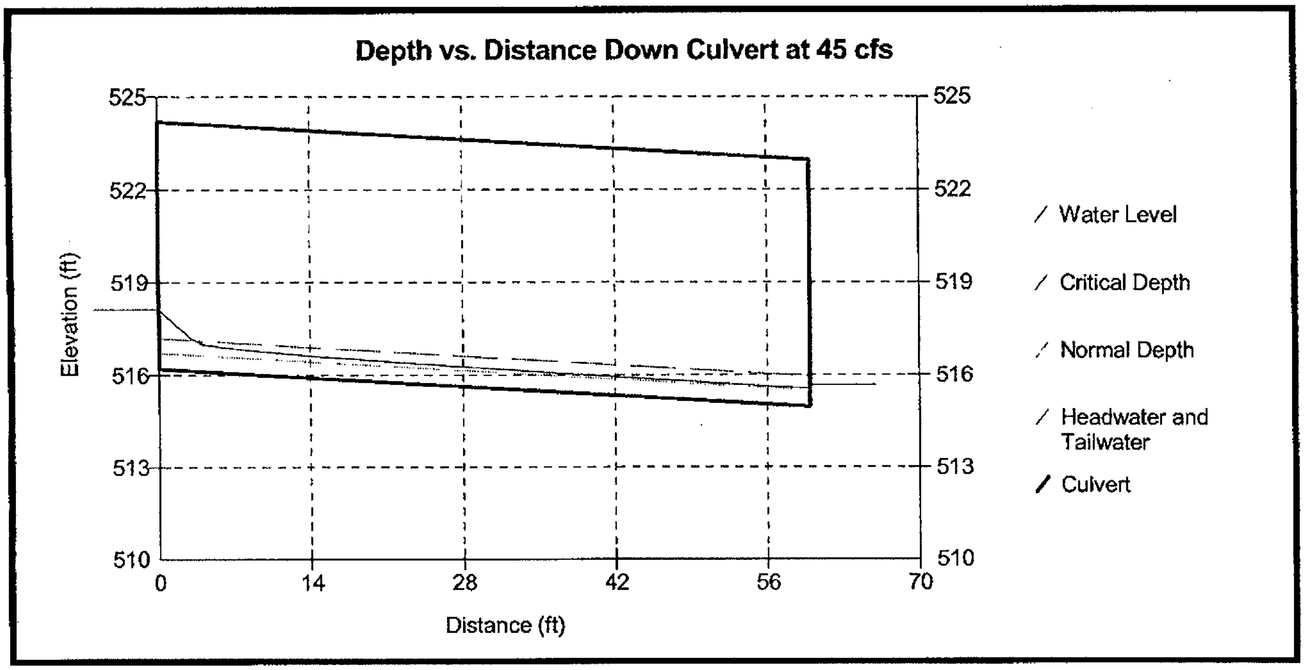


Figure 5. Water Surface Profile at 45 cfs

Table 6. Gradually Varied Flow Calculations for 81 cfs.

Q = 81.0 cfs				
Dist Down Culvert (ft)	Depth (ft)	Velocity (ft/s)	Curve	Swim Mode
0	2.87	0.00	Inlet	
3	1.47	9.49	S2	NA
5	1.29	7.84	S2	NA
8	1.21	8.34	S2	NA
11	1.16	8.71	S2	NA
14	1.12	9.01	S2	NA
17	1.09	9.27	S2	NA
20	1.07	9.50	S2	NA
23	1.04	9.71	S2	NA
26	1.02	9.90	S2	NA
29	1.00	10.08	S2	NA
32	0.99	10.25	S2	NA
35	0.97	10.40	S2	NA
38	0.96	10.54	S2	NA
41	0.95	10.67	S2	NA
44	0.94	10.79	S2	NA
47	0.93	10.91	S2	NA
50	0.92	11.02	S2	NA
53	0.91	11.11	S2	NA
56	0.90	11.21	S2	NA
60	0.89	11.33	S2	Exhausted

Table 7. Gradually Varied Flow Specifications for 81 cfs.

	81.0 cfs
Normal Depth (ft)	0.76
Critical Depth (ft)	1.47
Headwater Depth (ft)	2.87
Inlet Velocity (ft/s)	9.49
Tailwater Depth (ft)	1.07
Burst Swim Time (s)	5.00
Prolonged Swim Time (min	0.00
Barrier Code	EB

Barrier Codes

EB - Fish exhausted at burst speed*

*Culvert may be a barrier due to depth

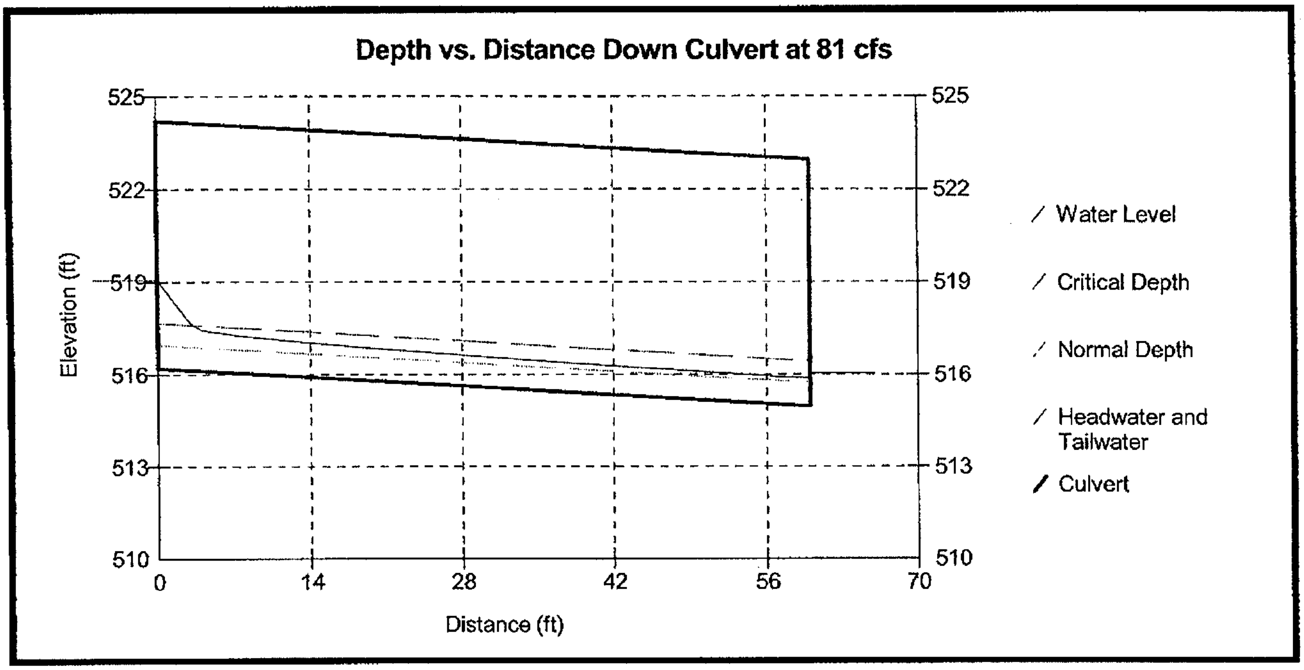


Figure 6. Water Surface Profile at 81 cfs

Tailwater Information

Channel Bottom Slope: 2%
Outlet-Pool Bottom Elevation: 514.4 ft
Manning's Roughness Downstream of Tailwater: 0.048

Table 8. Tailwater Cross Section Data.

Obs. No.	Station (ft)	Elevation (ft)
1	12.36	519.33
2	15.64	515.18
3	17.91	514.86
4	20.85	514.71
5	21.00	514.50
6	21.30	514.61
7	22.27	514.52
8	22.65	514.40
9	23.10	514.52
10	23.39	514.44
11	23.69	514.48
12	24.07	514.40
13	24.47	514.59
14	25.06	514.67
15	25.47	514.74
16	26.10	514.53
17	26.91	514.93
18	27.73	515.18
19	28.69	515.05
20	29.82	515.57
21	31.15	516.61
22	32.79	517.65

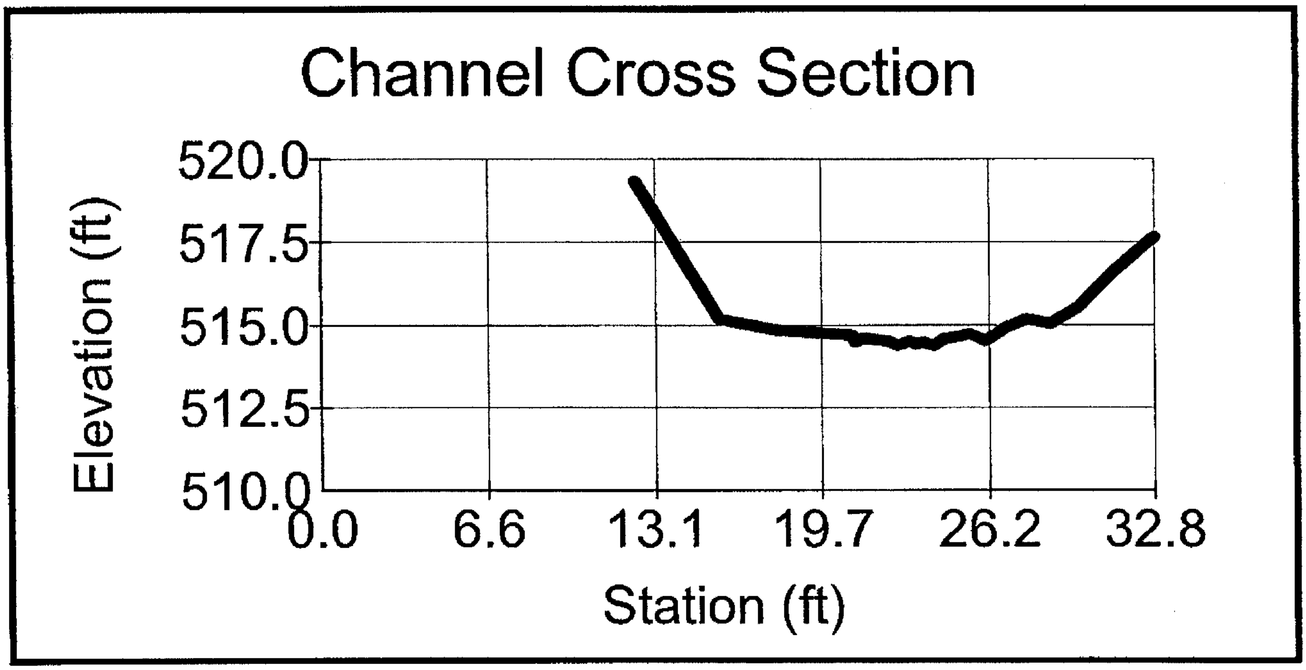
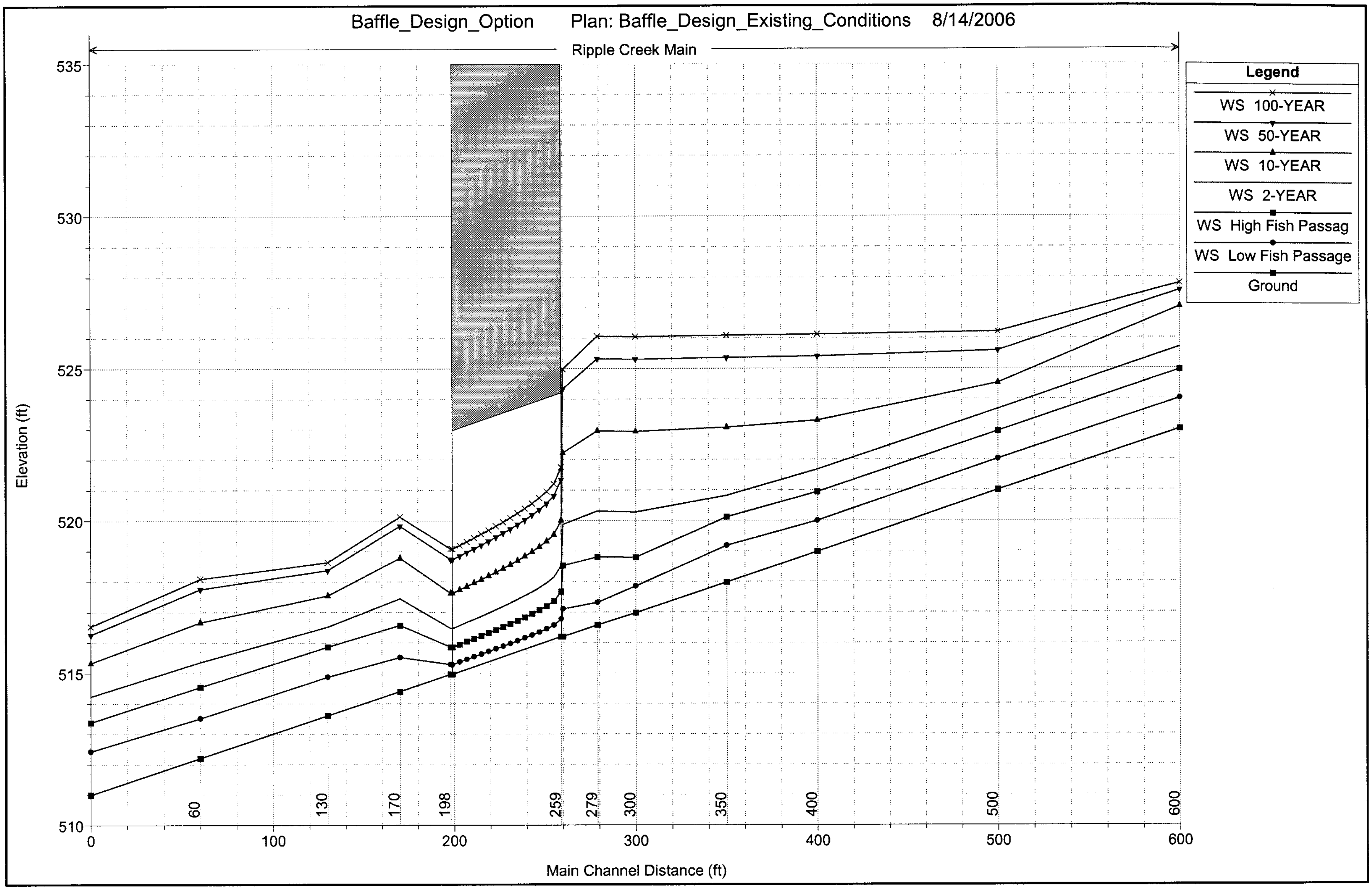
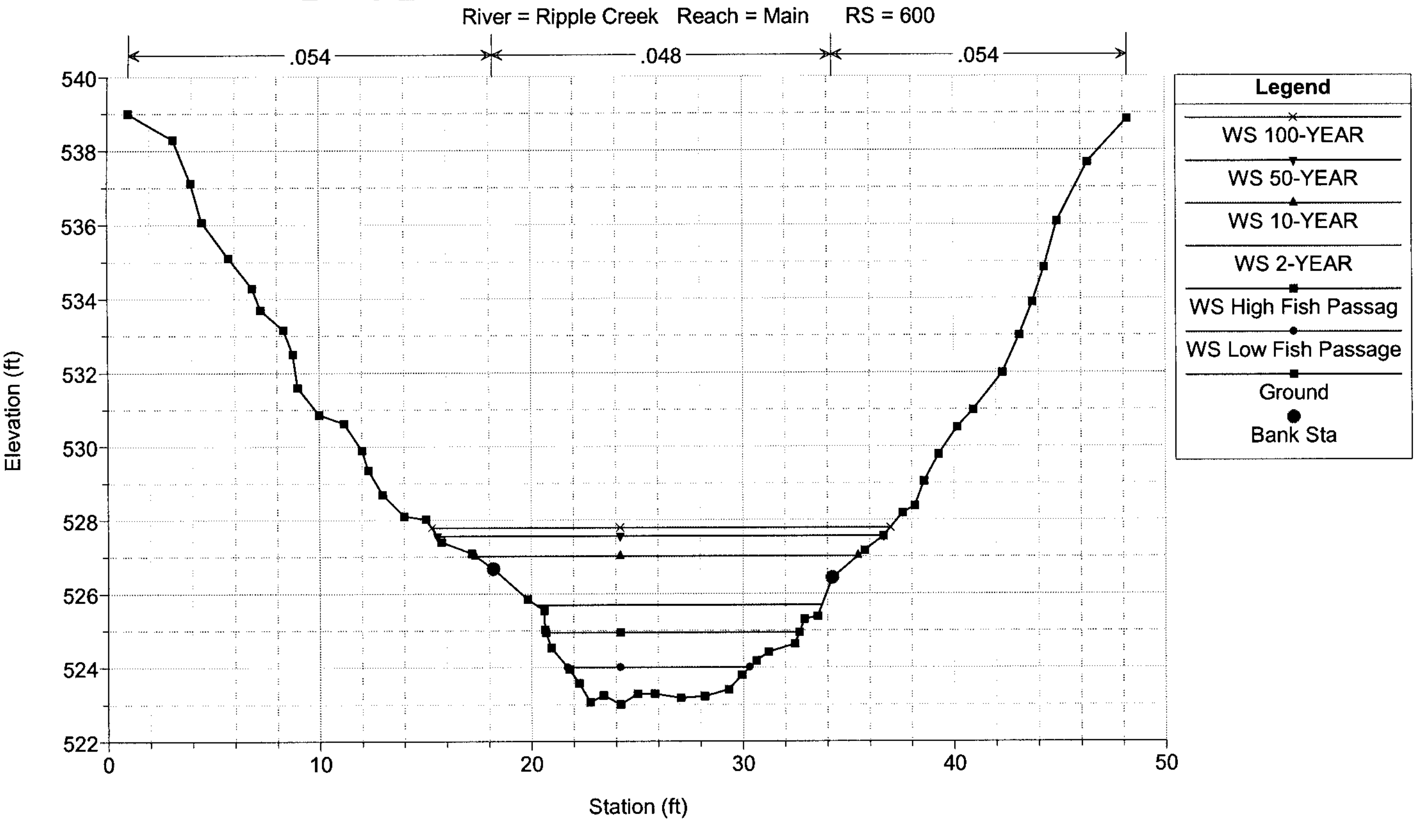


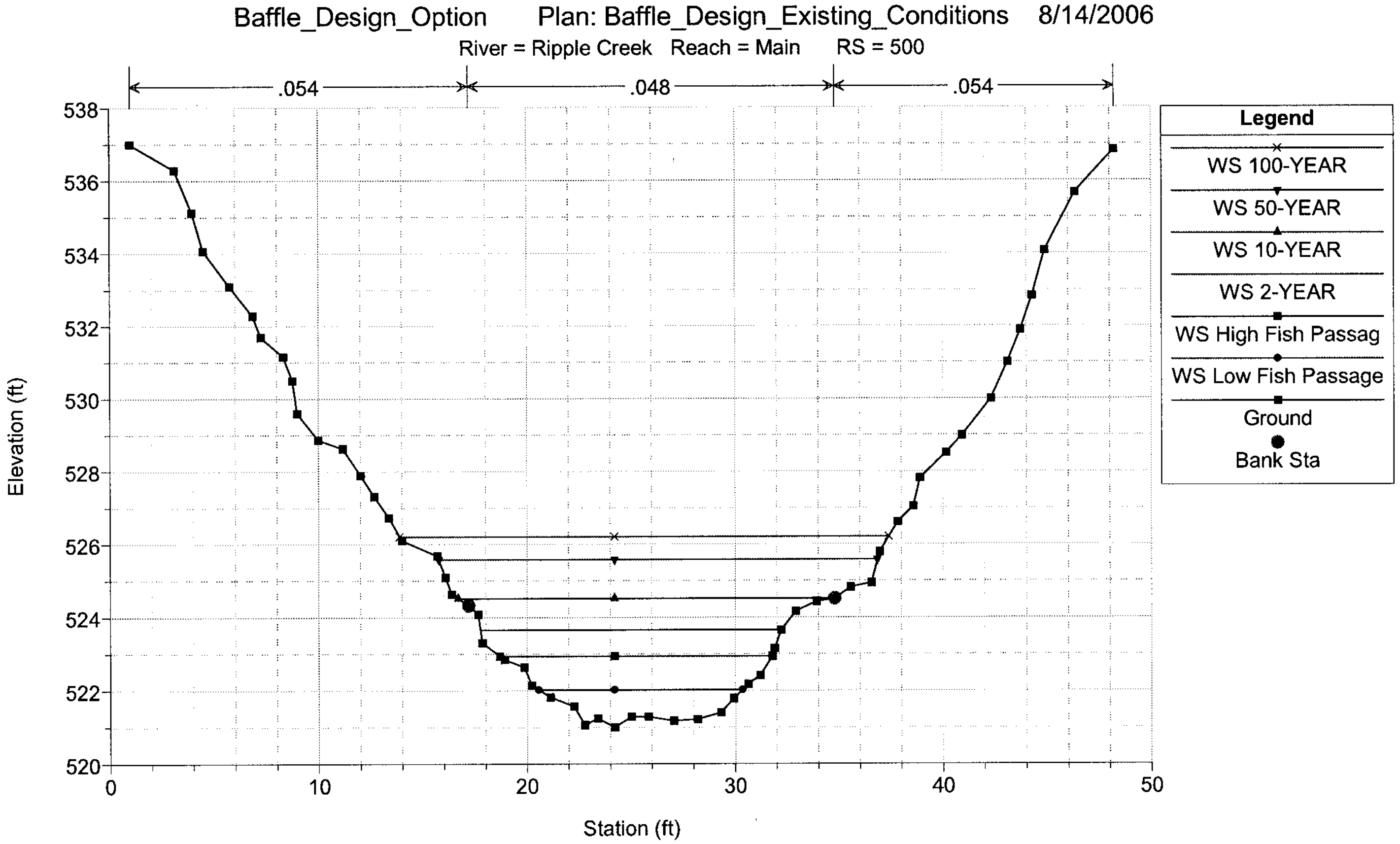
Figure 7. Channel Cross Section at Tailwater Crest.

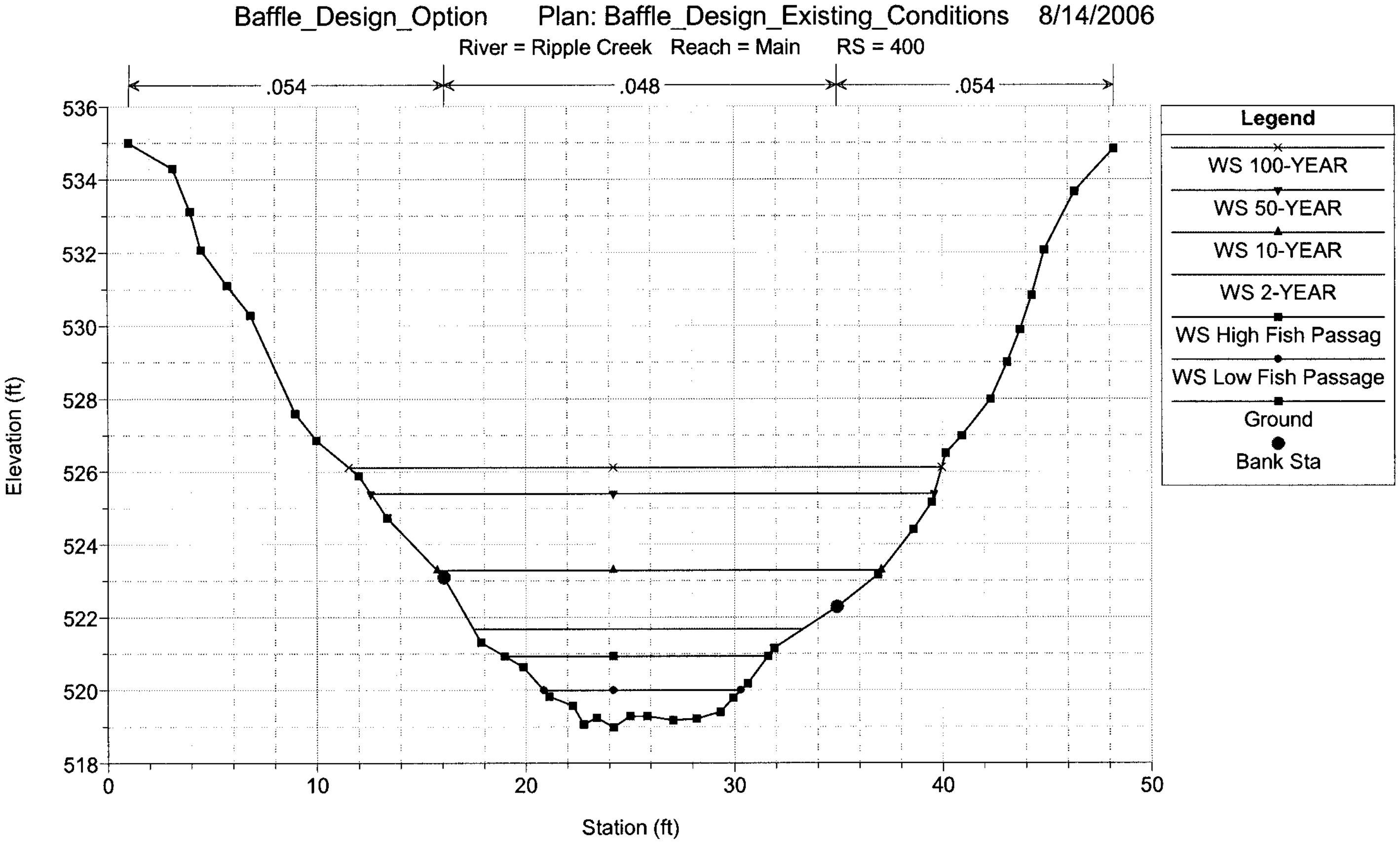
Table 9. Tailwater Rating Table Information.

Discharge (cfs)	Tailwater Elevation (ft)	Wetted Perimeter (ft)	Cross-Sect. Area (sq. ft)
0.0	514.4	0.00	0.00
0.0	514.5	1.87	0.09
0.3	514.6	4.03	0.36
1.0	514.7	5.53	0.82
2.1	514.8	7.90	1.46
3.9	514.9	9.59	2.32
6.6	515.0	10.62	3.29
9.7	515.1	12.17	4.37
13.6	515.2	13.88	5.64
19.1	515.3	14.24	7.00
25.3	515.4	14.61	8.38
32.3	515.5	14.98	9.80
40.0	515.6	15.32	11.24
48.5	515.7	15.61	12.70
57.6	515.8	15.90	14.19
67.3	515.9	16.19	15.70
77.7	516.0	16.48	17.22
88.6	516.1	16.77	18.77
100.1	516.2	17.06	20.34
112.2	516.3	17.35	21.93
124.9	516.4	17.64	23.54
138.2	516.5	17.93	25.17
152.0	516.6	18.22	26.82
166.2	516.7	18.53	28.50
181.0	516.8	18.84	30.19
196.3	516.9	19.16	31.91
212.2	517.0	19.47	33.66
228.7	517.1	19.79	35.43
245.7	517.2	20.10	37.22
263.3	517.3	20.41	39.03
281.4	517.4	20.73	40.87
300.1	517.5	21.04	42.74
319.3	517.6	21.36	44.62
329.1	517.7	21.51	45.58


Baffle_Design_Option Plan: Baffle_Design_Existing_Conditions 8/14/2006
Ripple Creek Main
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Passag
WS Low Fish Passage
Ground
Elevation (ft)
535
530
525
520
515
510
Main Channel Distance (ft)
0
100
200
300
400
500
600
60
130
170
198
259
279
300
350
400
500
600

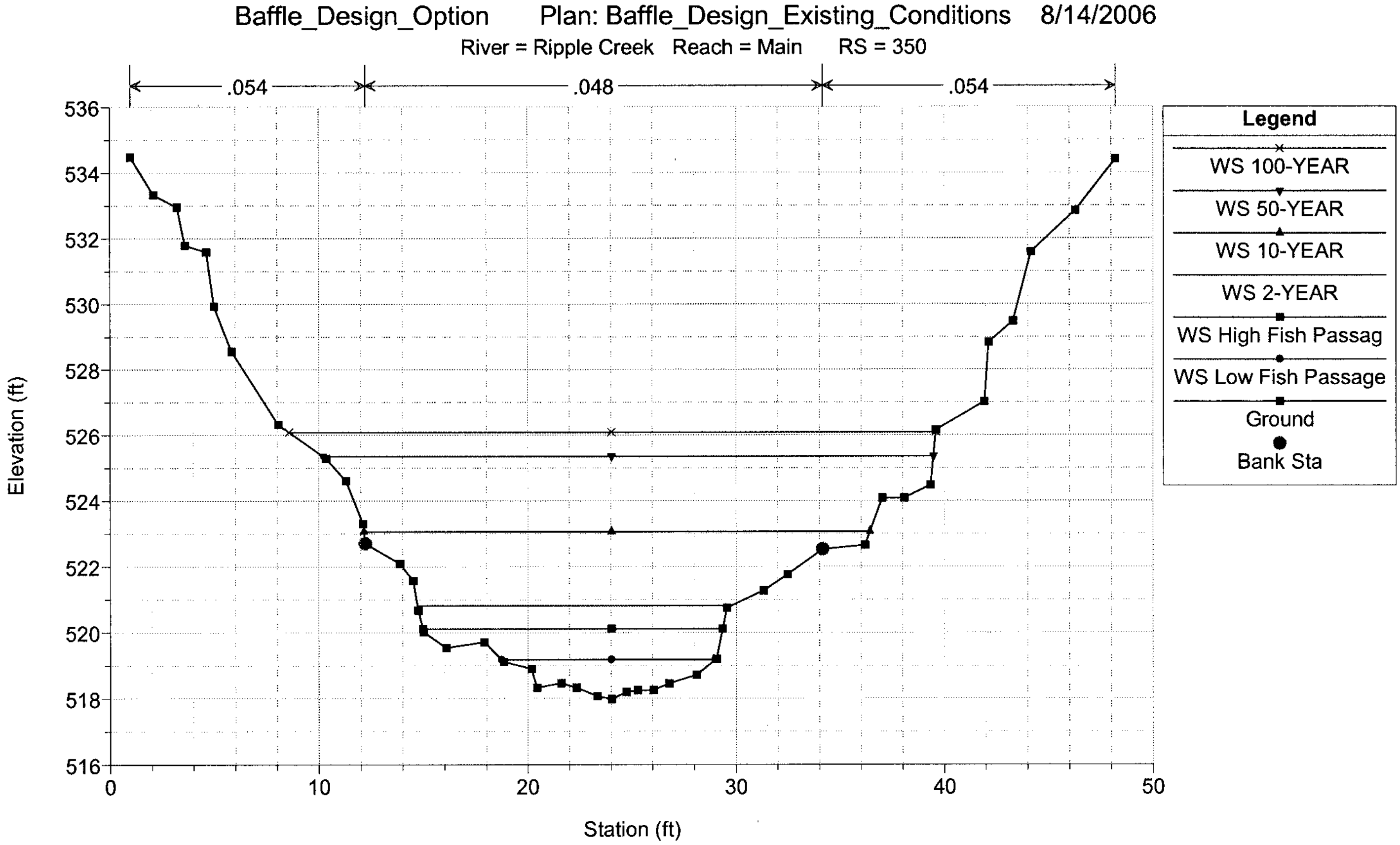

Baffle_Design_Option
Plan: Baffle_Design_Existing_Conditions
8/14/2006
River = Ripple Creek Reach = Main RS = 600
.054
.048
.054
540
538
536
534
532
530
528
526
524
522
Elevation (ft)
0
10
20
30
40
50
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Passag
WS Low Fish Passage
Ground
Bank Sta


Baffle_Design_Option
Plan: Baffle_Design_Existing_Conditions
8/14/2006
River = Ripple Creek Reach = Main RS = 500
.054
.048
.054
538
536
534
532
530
528
526
524
522
520
Elevation (ft)
0
10
20
30
40
50
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Passag
WS Low Fish Passage
Ground
Bank Sta



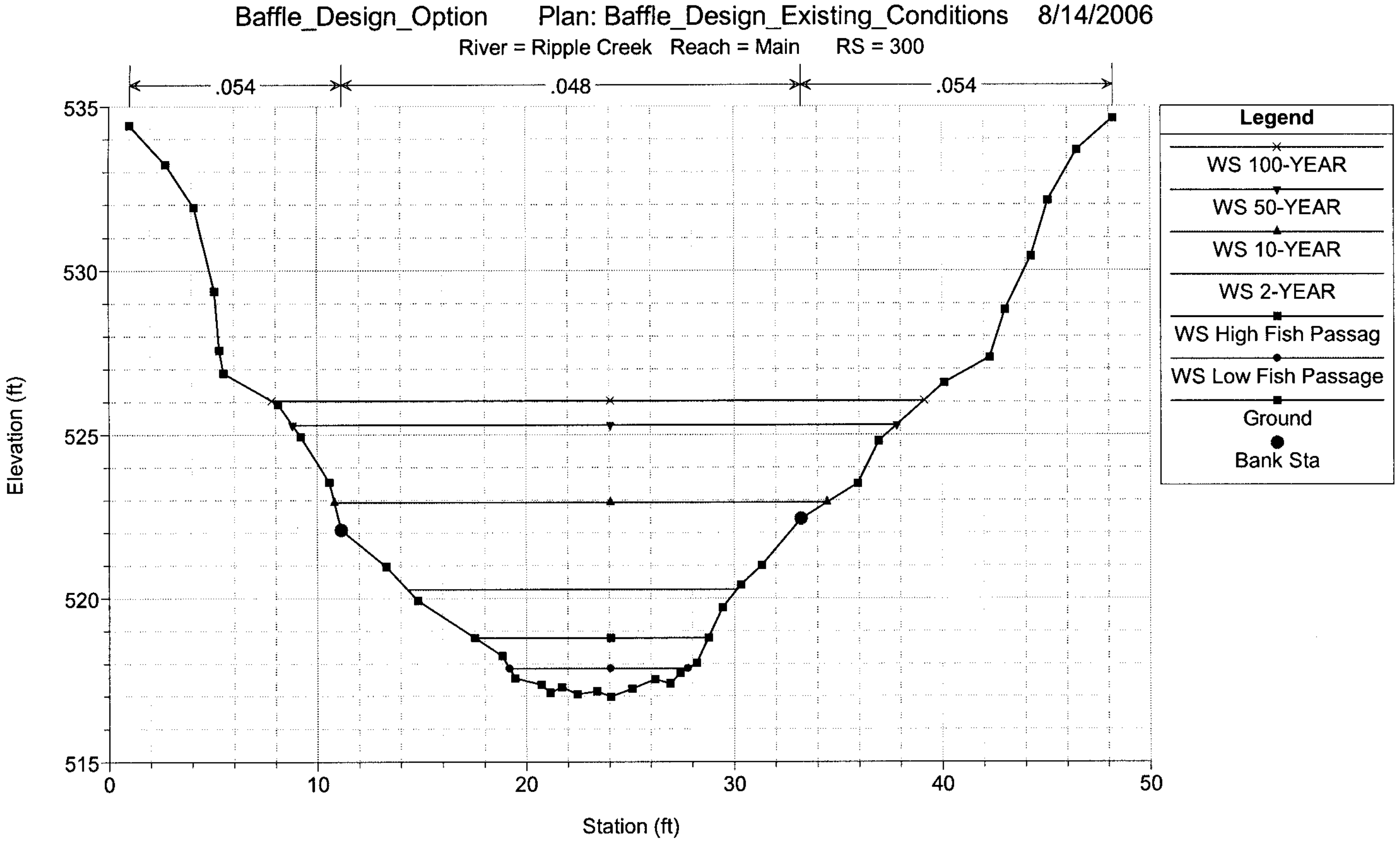
Baffle_Design_Option Plan: Baffle_Design_Existing_Conditions 8/14/2006

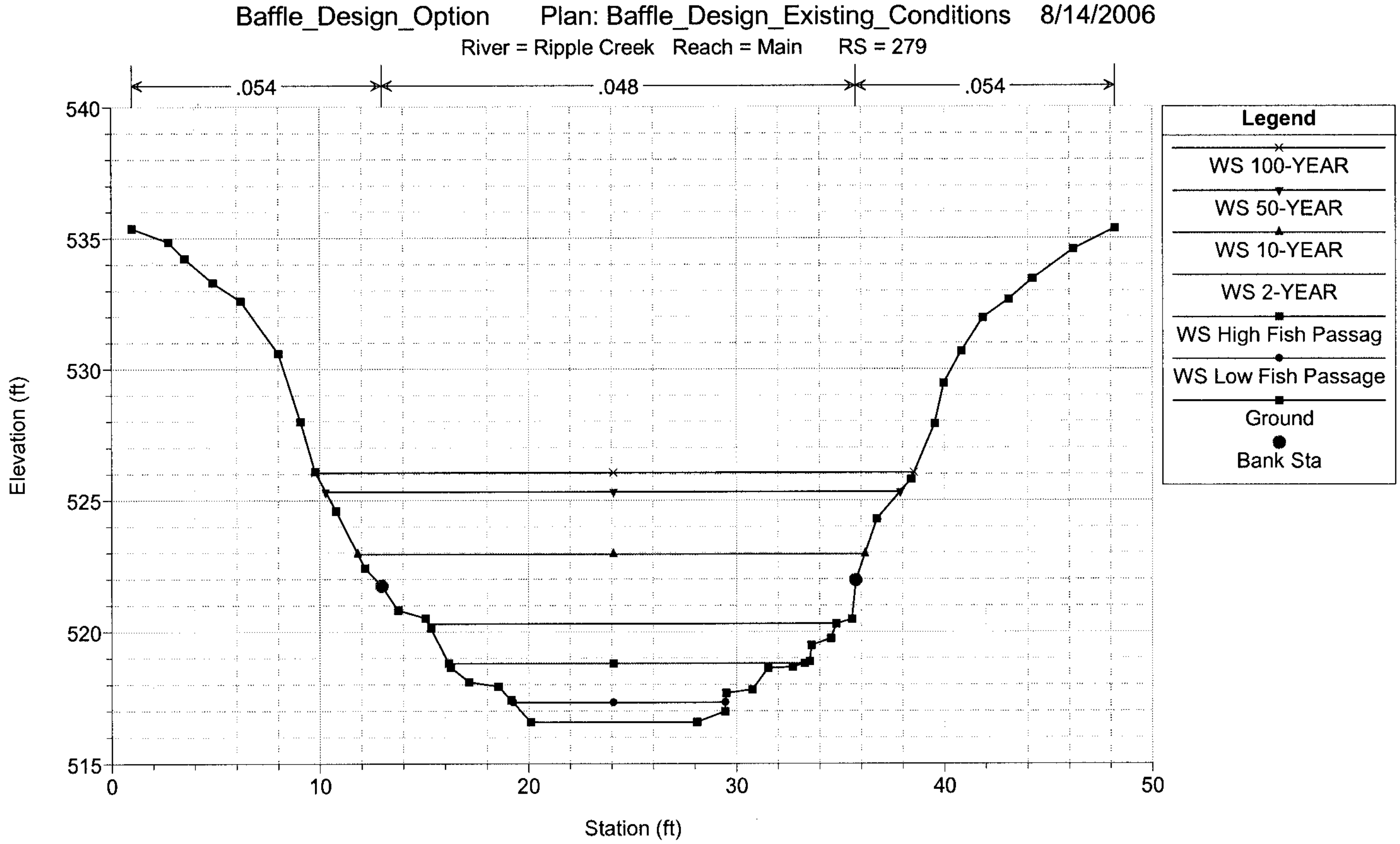
River = Ripple Creek Reach = Main RS = 400

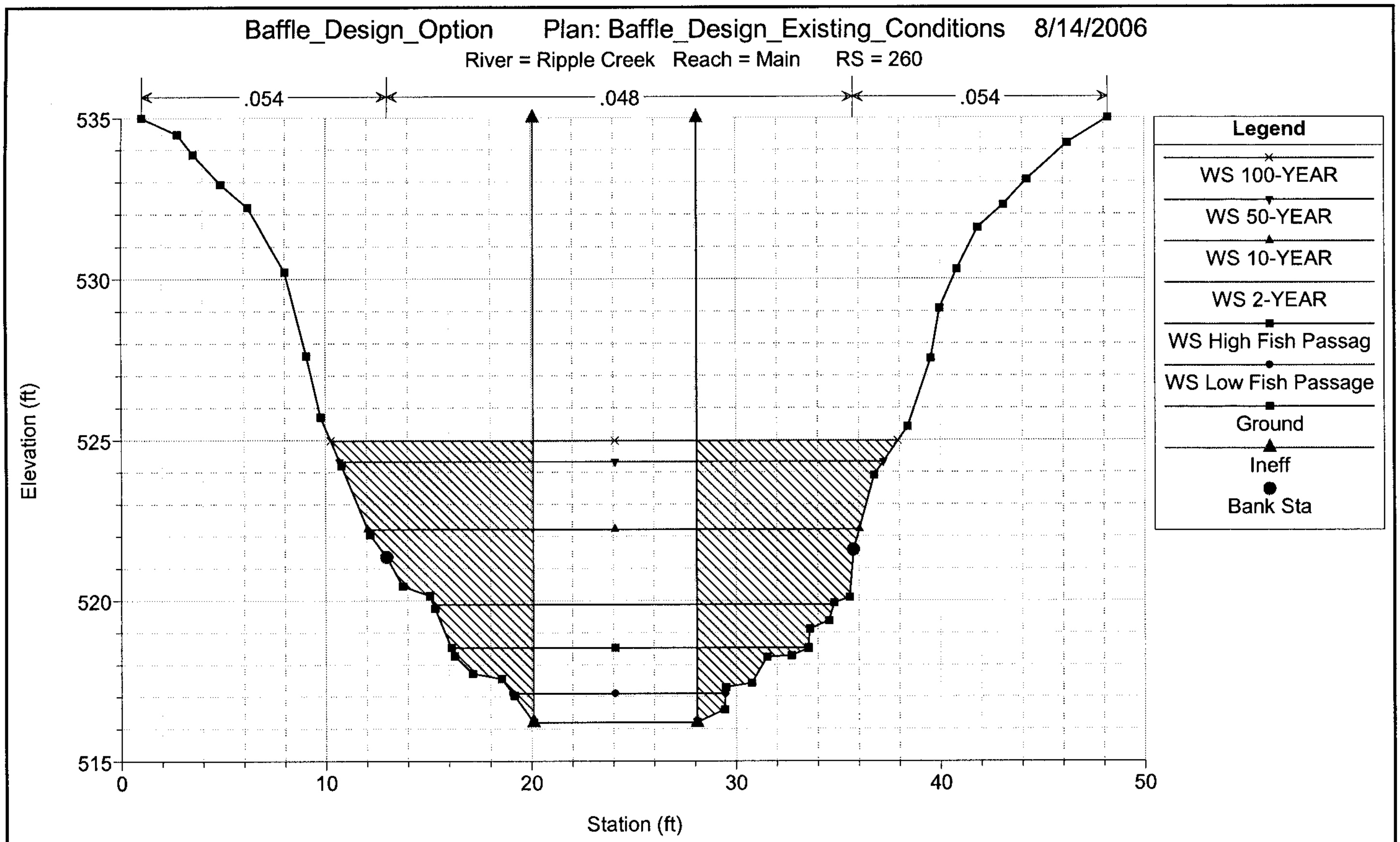


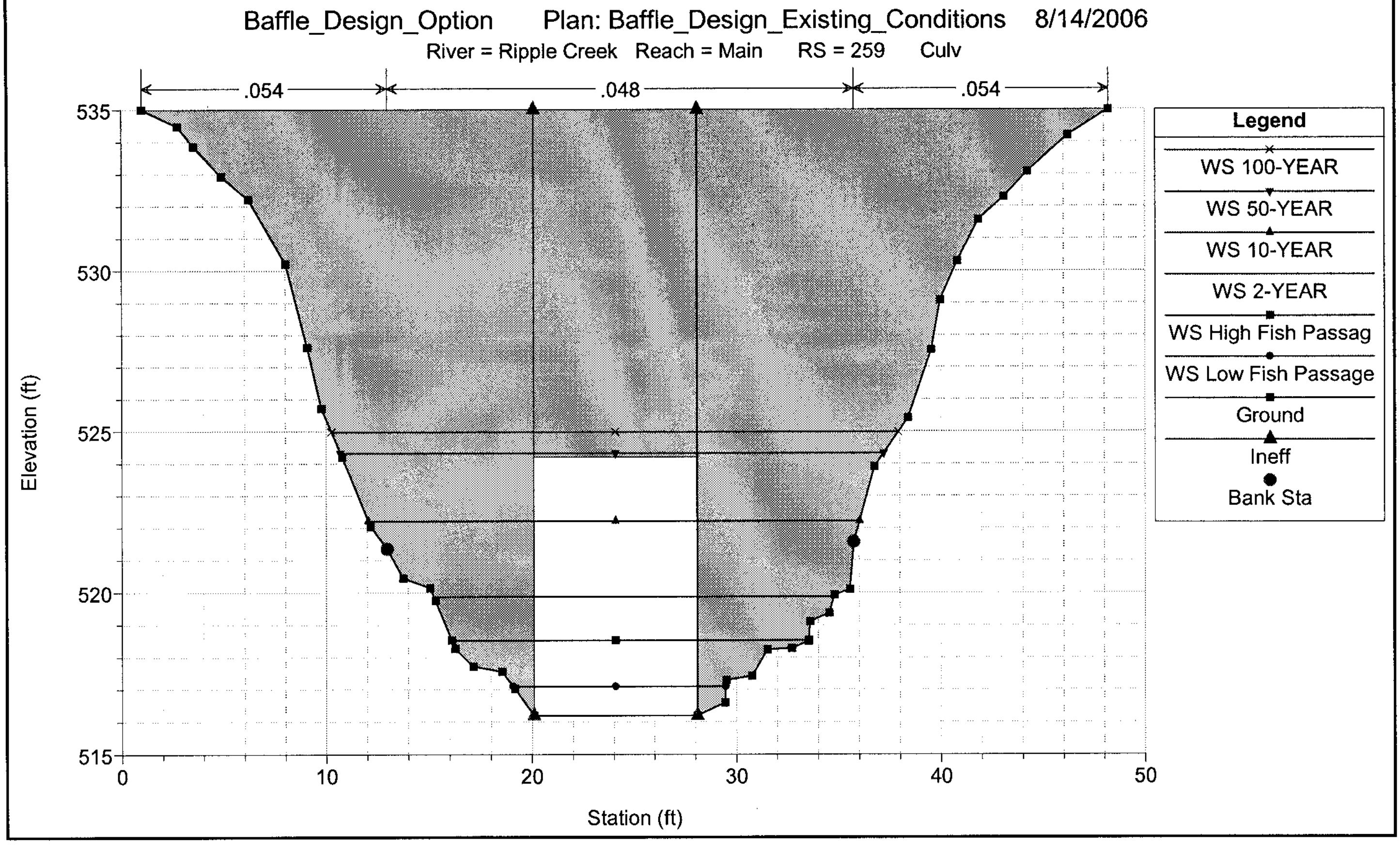
Baffle_Design_Option Plan: Baffle_Design_Existing_Conditions 8/14/2006

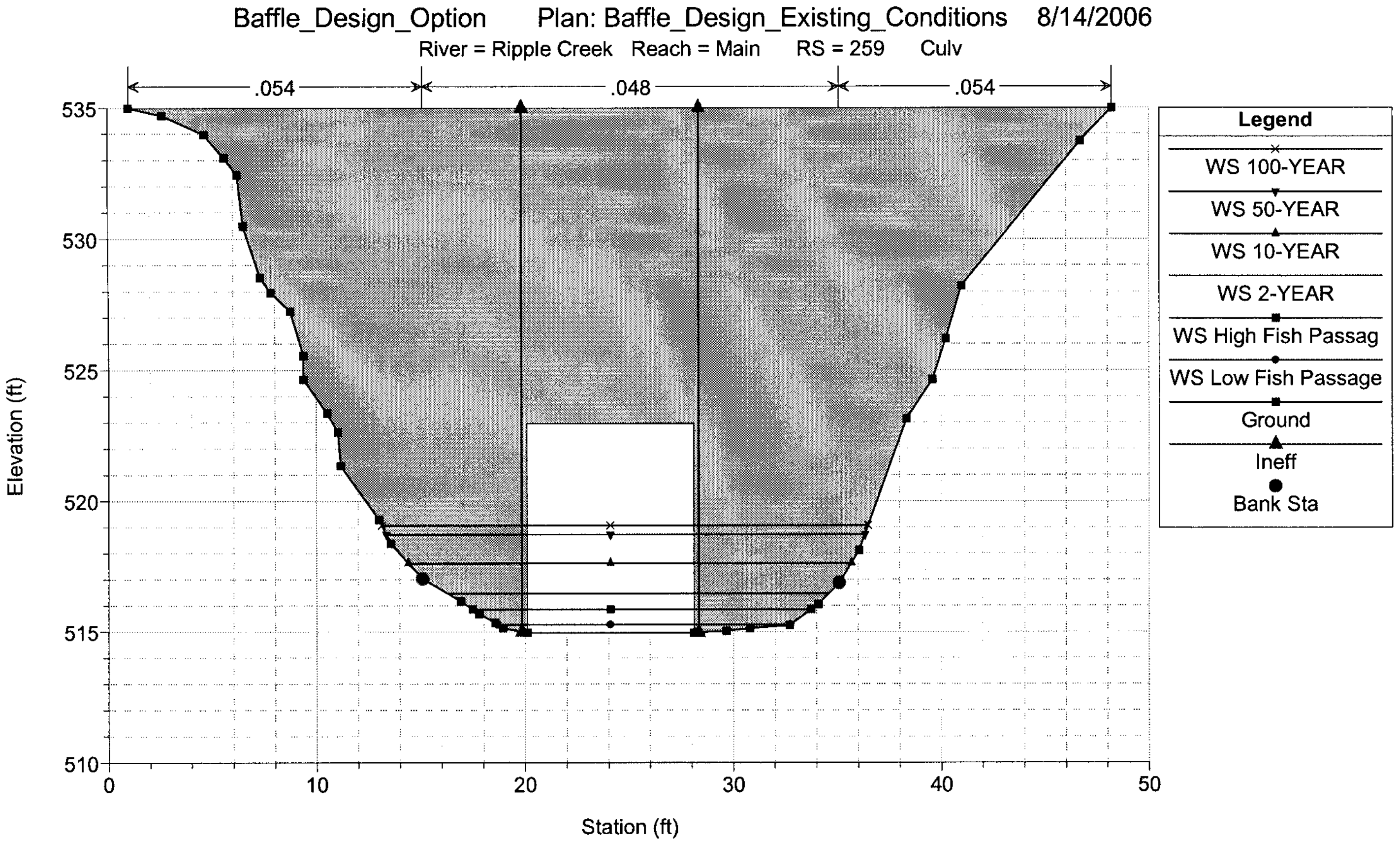
River = Ripple Creek Reach = Main RS = 350

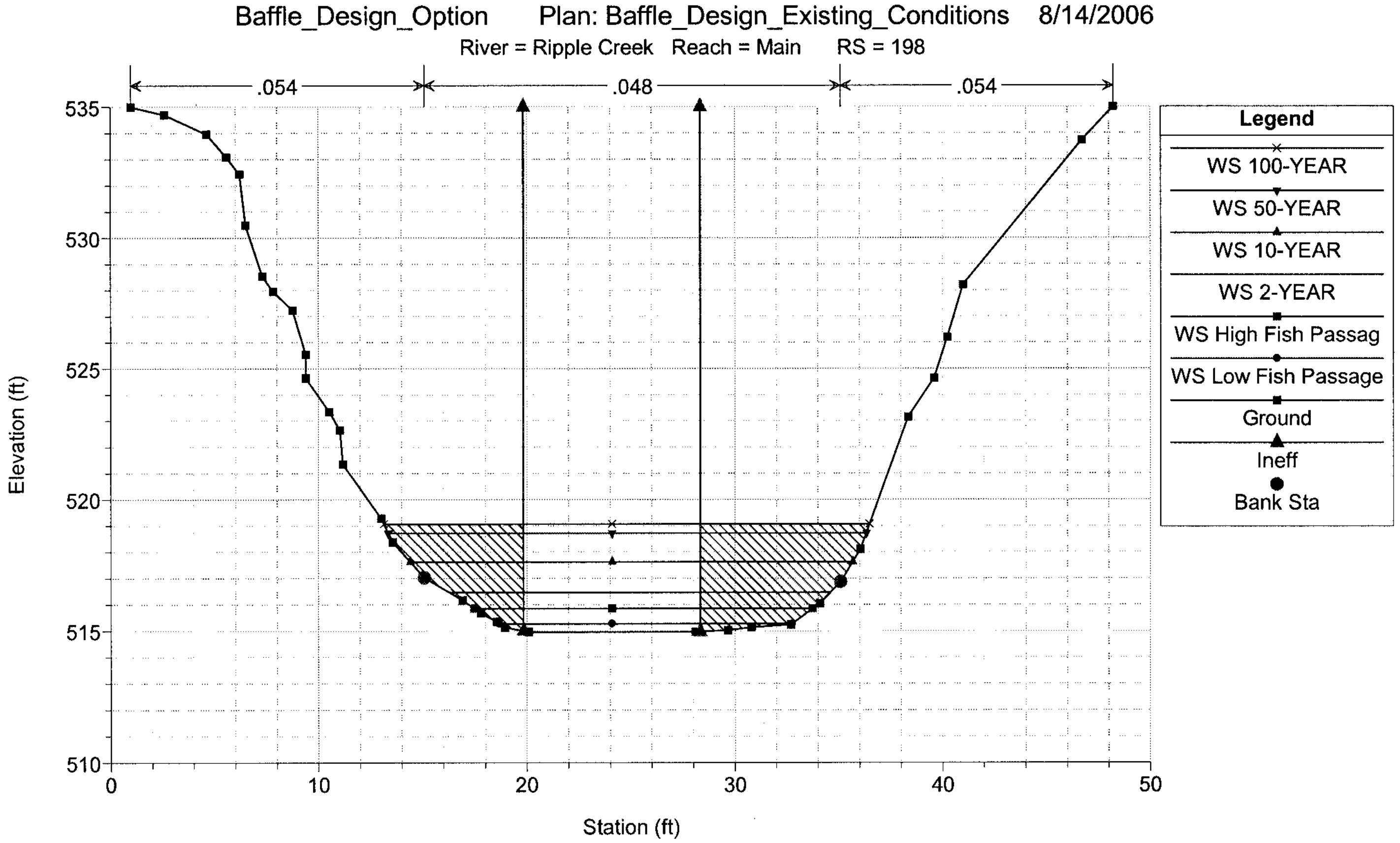

Baffle_Design_Option Plan: Baffle_Design_Existing_Conditions 8/14/2006
River = Ripple Creek Reach = Main RS = 300
.054
.048
.054
Elevation (ft)
535
530
525
520
515
0
10
20
30
40
50
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Passag
WS Low Fish Passage
Ground
Bank Sta

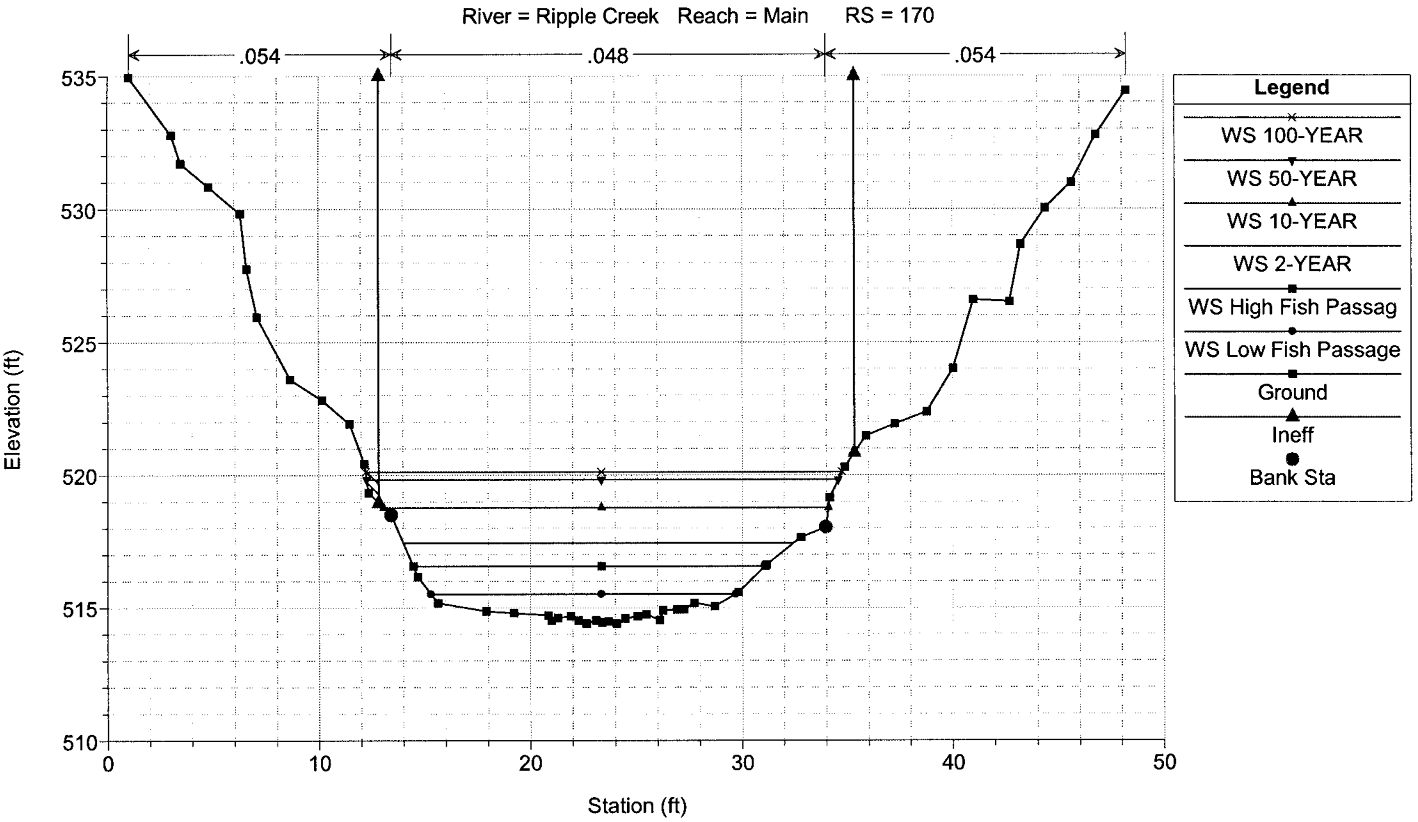

Baffle_Design_Option Plan: Baffle_Design_Existing_Conditions 8/14/2006
River = Ripple Creek Reach = Main RS = 279
.054
.048
.054
Elevation (ft)
540
535
530
525
520
515
0
10
20
30
40
50
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Passag
WS Low Fish Passage
Ground
Bank Sta

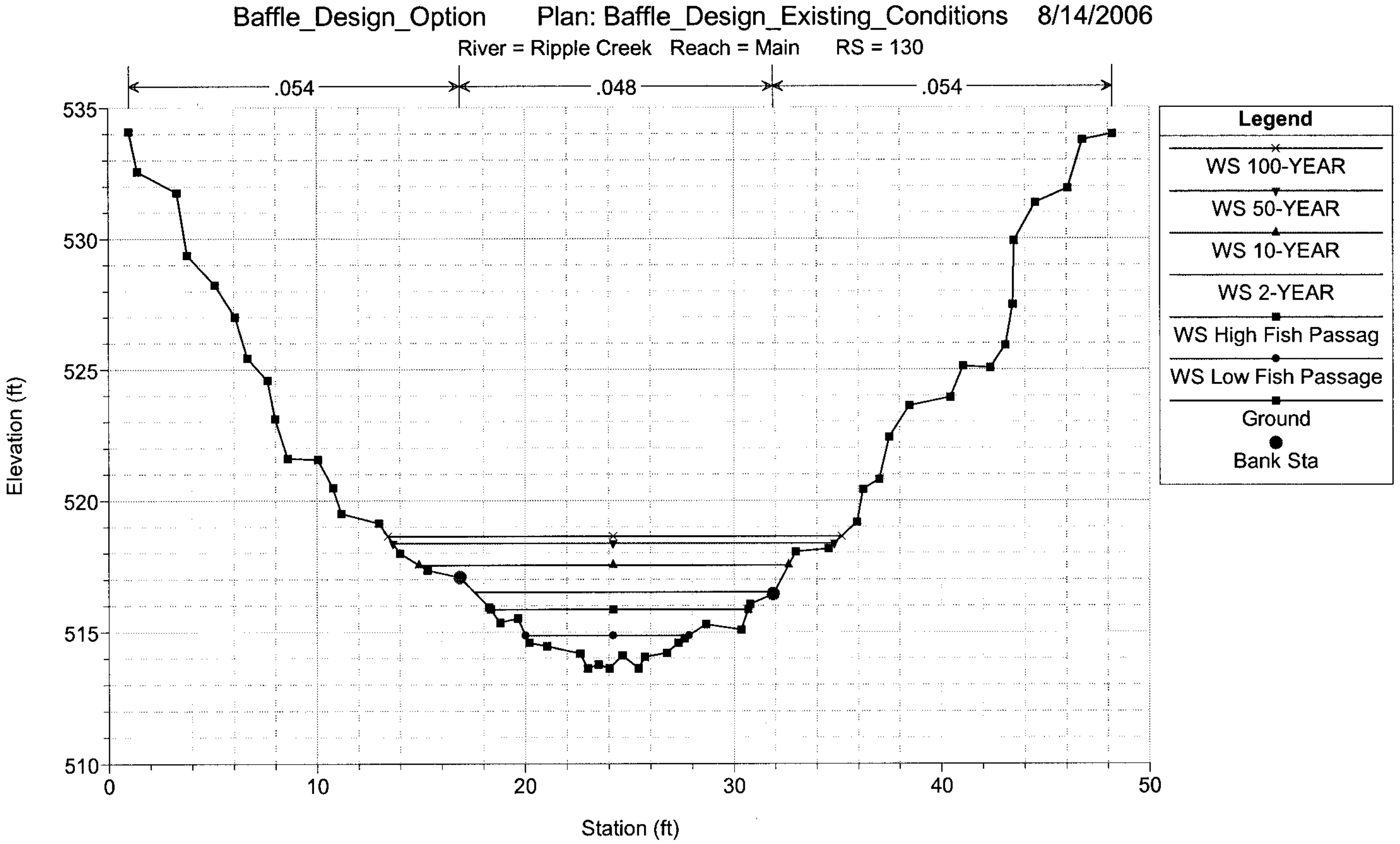

Baffle_Design_Option Plan: Baffle_Design_Existing_Conditions 8/14/2006
River = Ripple Creek Reach = Main RS = 260
.054
.048
.054
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Passag
WS Low Fish Passage
Ground
Ineff
Bank Sta
Elevation (ft)
535
530
525
520
515
0
10
20
30
40
50
Station (ft)

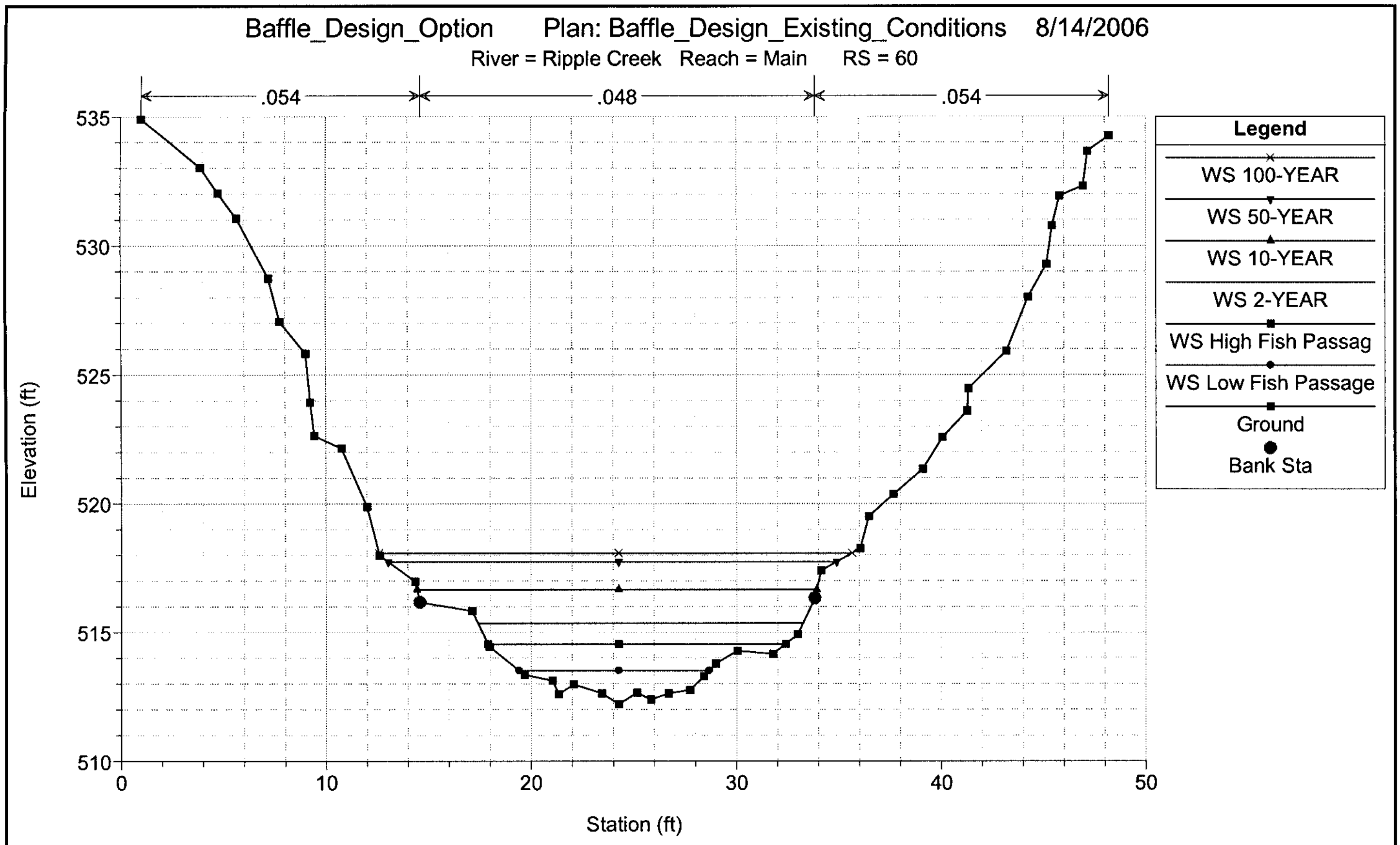

Baffle_Design_Option Plan: Baffle_Design_Existing_Conditions 8/14/2006
River = Ripple Creek Reach = Main RS = 259 Culv
.054
.048
.054
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Passag
WS Low Fish Passage
Ground
Ineff
Bank Sta
Elevation (ft)
535
530
525
520
515
0
10
20
30
40
50
Station (ft)


Baffle_Design_Option Plan: Baffle_Design_Existing_Conditions 8/14/2006
River = Ripple Creek Reach = Main RS = 259 Culv
.054
.048
.054
535
530
525
520
515
510
Elevation (ft)
0
10
20
30
40
50
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Passag
WS Low Fish Passage
Ground
Ineff
Bank Sta


Baffle_Design_Option Plan: Baffle_Design_Existing_Conditions 8/14/2006
River = Ripple Creek Reach = Main RS = 198
.054
.048
.054
535
530
525
520
515
510
Elevation (ft)
0
10
20
30
40
50
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Passag
WS Low Fish Passage
Ground
Ineff
Bank Sta

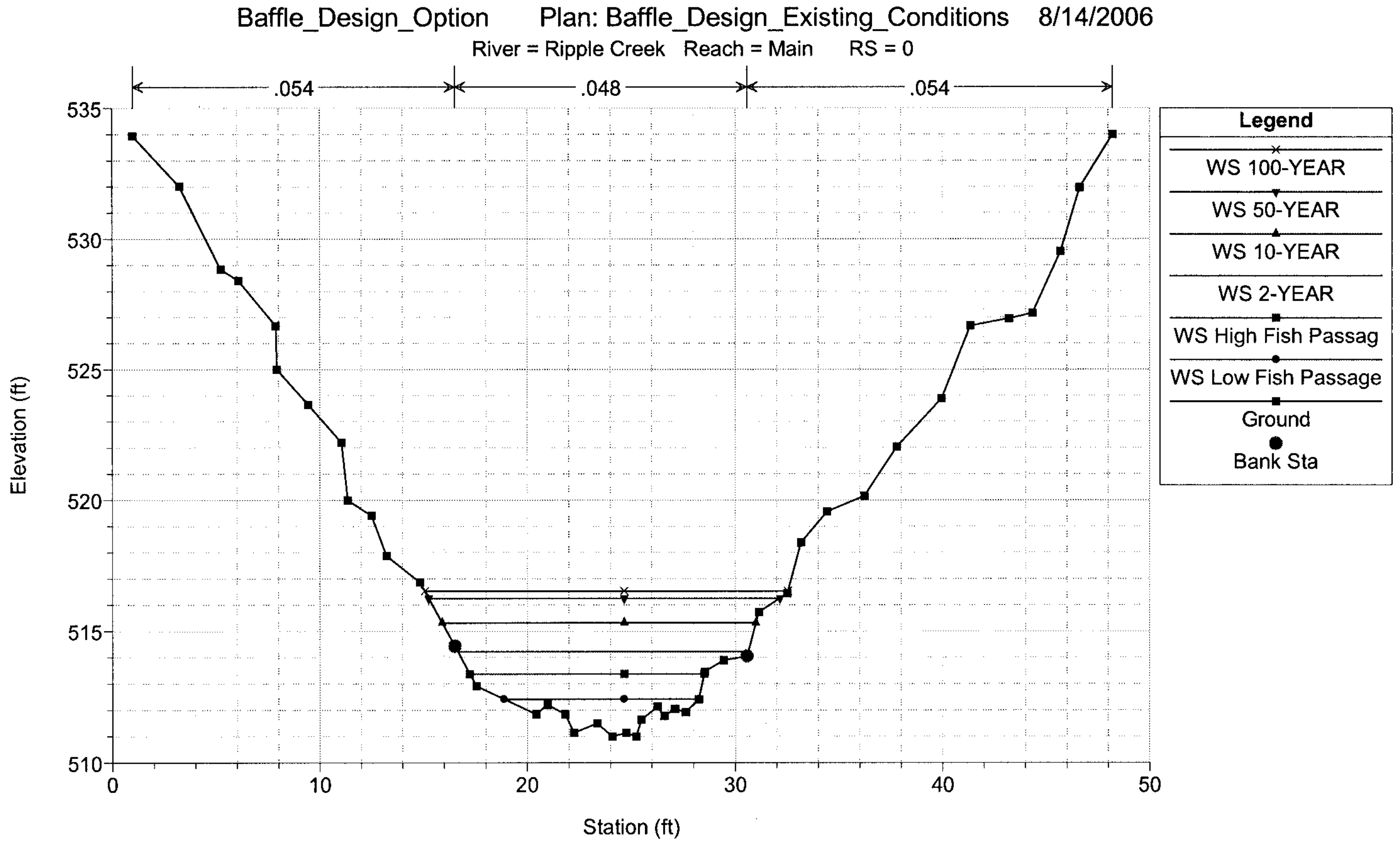

Baffle_Design_Option Plan: Baffle_Design_Existing_Conditions 8/14/2006
River = Ripple Creek Reach = Main RS = 170
.054
.048
.054
Elevation (ft)
535
530
525
520
515
510
0
10
20
30
40
50
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Passag
WS Low Fish Passage
Ground
Ineff
Bank Sta


Baffle_Design_Option Plan: Baffle_Design_Existing_Conditions 8/14/2006
River = Ripple Creek Reach = Main RS = 130
.054
.048
.054
Elevation (ft)
535
530
525
520
515
510
0
10
20
30
40
50
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Passag
WS Low Fish Passage
Ground
Bank Sta



Baffle_Design_Option Plan: Baffle_Design_Existing_Conditions 8/14/2006

River = Ripple Creek Reach = Main RS = 60



Baffle_Design_Option Plan: Baffle_Design_Existing_Conditions 8/14/2006

River = Ripple Creek Reach = Main RS = 0

Plan: Existing Ripple Creek Main RS: 259 Culv Group: Culvert #1 Profile: Low Fish Passage

Q Culv Group (cfs)	20.00	Culv Full Len (ft)	
# Barrels	1	Culv Vel US (ft/s)	4.32
Q Barrel (cfs)	20.00	Culv Vel DS (ft/s)	7.91
E.G. US. (ft)	517.23	Culv Inv El Up (ft)	516.20
W.S. US. (ft)	517.10	Culv Inv El Dn (ft)	514.96
E.G. DS (ft)	515.89	Culv Frctn Ls (ft)	0.82
W.S. DS (ft)	515.75	Culv Exit Loss (ft)	0.36
Delta EG (ft)	1.34	Culv Entr Loss (ft)	0.16
Delta WS (ft)	1.35	Q Weir (cfs)	
E.G. IC (ft)	517.23	Weir Sta Lft (ft)	
E.G. OC (ft)	517.21	Weir Sta Rgt (ft)	
Culvert Control	Inlet	Weir Submerg	
Culv WS Inlet (ft)	516.78	Weir Max Depth (ft)	
Culv WS Outlet (ft)	515.28	Weir Avg Depth (ft)	
Culv Nml Depth (ft)	0.32	Weir Flow Area (sq ft)	
Culv Crt Depth (ft)	0.58	Min El Weir Flow (ft)	548.20

Errors Warnings and Notes

Note:	Multiple critical depths were found at this location. The critical depth with the lowest, valid,
	energy was used.
Note:	During supercritical analysis, the culvert direct step method went to normal depth. The program
	then assumed normal depth at the outlet.
Note:	The flow in the culvert is entirely supercritical.

Plan: Existing Ripple Creek Main RS: 259 Culv Group: Culvert #1 Profile: High Fish Passag

Q Culv Group (cfs)	81.00	Culv Full Len (ft)	
# Barrels	1	Culv Vel US (ft/s)	6.88
Q Barrel (cfs)	81.00	Culv Vel DS (ft/s)	11.39
E.G. US. (ft)	518.82	Culv Inv El Up (ft)	516.20
W.S. US. (ft)	518.53	Culv Inv El Dn (ft)	514.96
E.G. DS (ft)	517.15	Culv Frctn Ls (ft)	0.54
W.S. DS (ft)	516.66	Culv Exit Loss (ft)	0.71
Delta EG (ft)	1.67	Culv Entr Loss (ft)	0.41
Delta WS (ft)	1.86	Q Weir (cfs)	
E.G. IC (ft)	518.82	Weir Sta Lft (ft)	
E.G. OC (ft)	518.77	Weir Sta Rgt (ft)	
Culvert Control	Inlet	Weir Submerg	
Culv WS Inlet (ft)	517.67	Weir Max Depth (ft)	
Culv WS Outlet (ft)	515.85	Weir Avg Depth (ft)	
Culv Nml Depth (ft)	0.76	Weir Flow Area (sq ft)	
Culv Crt Depth (ft)	1.47	Min El Weir Flow (ft)	548.20

Errors Warnings and Notes

Note:	Multiple critical depths were found at this location. The critical depth with the lowest, valid,
	energy was used.
Note:	The flow in the culvert is entirely supercritical.

Plan: Existing Ripple Creek Main RS: 259 Culv Group: Culvert #1 Profile: 2-YEAR

Q Culv Group (cfs)	161.00	Culv Full Len (ft)	
# Barrels	1	Culv Vel US (ft/s)	8.65
Q Barrel (cfs)	161.00	Culv Vel DS (ft/s)	13.37
E.G. US. (ft)	520.34	Culv Inv El Up (ft)	516.20
W.S. US. (ft)	519.88	Culv Inv El Dn (ft)	514.96
E.G. DS (ft)	518.33	Culv Frctn Ls (ft)	0.45
W.S. DS (ft)	517.37	Culv Exit Loss (ft)	0.91
Delta EG (ft)	2.01	Culv Entr Loss (ft)	0.65
Delta WS (ft)	2.51	Q Weir (cfs)	
E.G. IC (ft)	520.34	Weir Sta Lft (ft)	
E.G. OC (ft)	520.27	Weir Sta Rgt (ft)	
Culvert Control	Inlet	Weir Submerg	
Culv WS Inlet (ft)	518.53	Weir Max Depth (ft)	
Culv WS Outlet (ft)	516.47	Weir Avg Depth (ft)	
Culv Nml Depth (ft)	1.20	Weir Flow Area (sq ft)	
Culv Crt Depth (ft)	2.33	Min El Weir Flow (ft)	548.20

Errors Warnings and Notes

Note:	Multiple critical depths were found at this location. The critical depth with the lowest, valid,
	energy was used.
Note:	The flow in the culvert is entirely supercritical.

Plan: Existing Ripple Creek Main RS: 259 Culv Group: Culvert #1 Profile: 10-YEAR

Q Culv Group (cfs)	337.00	Culv Full Len (ft)	
# Barrels	1	Culv Vel US (ft/s)	11.07
Q Barrel (cfs)	337.00	Culv Vel DS (ft/s)	15.82
E.G. US. (ft)	522.98	Culv Inv El Up (ft)	516.20
W.S. US. (ft)	522.22	Culv Inv El Dn (ft)	514.96
E.G. DS (ft)	520.44	Culv Frctn Ls (ft)	0.40
W.S. DS (ft)	518.62	Culv Exit Loss (ft)	1.07
Delta EG (ft)	2.54	Culv Entr Loss (ft)	1.07
Delta WS (ft)	3.60	Q Weir (cfs)	
E.G. IC (ft)	522.98	Weir Sta Lft (ft)	
E.G. OC (ft)	522.86	Weir Sta Rgt (ft)	
Culvert Control	Inlet	Weir Submerg	
Culv WS Inlet (ft)	520.01	Weir Max Depth (ft)	
Culv WS Outlet (ft)	517.62	Weir Avg Depth (ft)	
Culv Nml Depth (ft)	1.97	Weir Flow Area (sq ft)	
Culv Crt Depth (ft)	3.81	Min El Weir Flow (ft)	548.20

Errors Warnings and Notes

Note:	Multiple critical depths were found at this location. The critical depth with the lowest, valid,
	energy was used.
Note:	The flow in the culvert is entirely supercritical.

Plan: Existing Ripple Creek Main RS: 259 Culv Group: Culvert #1 Profile: 50-YEAR

Q Culv Group (cfs)	528.00	Culv Full Len (ft)	
# Barrels	1	Culv Vel US (ft/s)	12.86
Q Barrel (cfs)	528.00	Culv Vel DS (ft/s)	17.56
E.G. US. (ft)	525.35	Culv Inv El Up (ft)	516.20
W.S. US. (ft)	524.32	Culv Inv El Dn (ft)	514.96
E.G. DS (ft)	522.36	Culv Frctn Ls (ft)	0.39
W.S. DS (ft)	519.90	Culv Exit Loss (ft)	1.15
Delta EG (ft)	2.99	Culv Entr Loss (ft)	1.45
Delta WS (ft)	4.42	Q Weir (cfs)	
E.G. IC (ft)	525.35	Weir Sta Lft (ft)	
E.G. OC (ft)	525.18	Weir Sta Rgt (ft)	
Culvert Control	Inlet	Weir Submerg	
Culv WS Inlet (ft)	521.33	Weir Max Depth (ft)	
Culv WS Outlet (ft)	518.72	Weir Avg Depth (ft)	
Culv Nml Depth (ft)	2.70	Weir Flow Area (sq ft)	
Culv Crt Depth (ft)	5.13	Min El Weir Flow (ft)	548.20

Errors Warnings and Notes

Note:	Multiple critical depths were found at this location. The critical depth with the lowest, valid,
	energy was used.
Note:	The flow in the culvert is entirely supercritical.

Plan: Existing Ripple Creek Main RS: 259 Culv Group: Culvert #1 Profile: 100-YEAR

Q Culv Group (cfs)	593.00	Culv Full Len (ft)	
# Barrels	1	Culv Vel US (ft/s)	13.36
Q Barrel (cfs)	593.00	Culv Vel DS (ft/s)	18.04
E.G. US. (ft)	526.09	Culv Inv El Up (ft)	516.20
W.S. US. (ft)	524.98	Culv Inv El Dn (ft)	514.96
E.G. DS (ft)	522.95	Culv Frctn Ls (ft)	0.40
W.S. DS (ft)	520.27	Culv Exit Loss (ft)	1.17
Delta EG (ft)	3.13	Culv Entr Loss (ft)	1.57
Delta WS (ft)	4.70	Q Weir (cfs)	
E.G. IC (ft)	526.09	Weir Sta Lft (ft)	
E.G. OC (ft)	525.91	Weir Sta Rgt (ft)	
Culvert Control	Inlet	Weir Submerg	
Culv WS Inlet (ft)	521.75	Weir Max Depth (ft)	
Culv WS Outlet (ft)	519.07	Weir Avg Depth (ft)	
Culv Nml Depth (ft)	2.93	Weir Flow Area (sq ft)	
Culv Crt Depth (ft)	5.55	Min El Weir Flow (ft)	548.20

Errors Warnings and Notes

Note:	Multiple critical depths were found at this location. The critical depth with the lowest, valid,
	energy was used.
Note:	The flow in the culvert is entirely supercritical.

HEC-RAS Plan: Existing River: Ripple Creek Reach: Main

Reach	River Sta	Profile	Q Total	W.S. Elev	Min Ch El	Diff	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)		(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main	0	2-YEAR	161.00	514.23	510.99	3.24	513.78	514.77	0.020033	5.89	27.34	13.97	0.74
Main	0	10-YEAR	337.00	515.33	510.99	4.34	514.90	516.29	0.020006	7.86	43.32	15.10	0.79
Main	0	50-YEAR	528.00	516.25	510.99	5.26	515.82	517.61	0.020037	9.39	57.92	16.90	0.83
Main	0	100-YEAR	593.00	516.53	510.99	5.54	516.13	518.01	0.020027	9.81	62.69	17.47	0.84
Main	0	High Fish Passag	81.00	513.38	510.99	2.39	513.04	513.74	0.020013	4.86	16.68	11.28	0.70
Main	0	Low Fish Passage	20.00	512.42	510.99	1.43	512.21	512.56	0.020003	3.05	6.56	9.37	0.64
Main	60	2-YEAR	161.00	515.36	512.20	3.16		515.77	0.013983	5.19	31.03	15.84	0.65
Main	60	10-YEAR	337.00	516.66	512.20	4.46		517.26	0.012608	6.22	54.22	19.47	0.65
Main	60	50-YEAR	528.00	517.75	512.20	5.55	516.70	518.51	0.010382	7.02	76.25	21.87	0.63
Main	60	100-YEAR	593.00	518.08	512.20	5.88	516.94	518.89	0.009872	7.23	83.84	23.07	0.62
Main	60	High Fish Passag	81.00	514.54	512.20	2.34		514.84	0.016443	4.35	18.62	14.50	0.68
Main	60	Low Fish Passage	20.00	513.51	512.20	1.31		513.65	0.016352	2.97	6.73	9.25	0.61
Main	130	2-YEAR	161.00	516.52	513.61	2.91	516.34	517.18	0.027371	6.50	24.77	14.41	0.87
Main	130	10-YEAR	337.00	517.54	513.61	3.93	517.42	518.63	0.025773	8.39	40.90	17.74	0.91
Main	130	50-YEAR	528.00	518.37	513.61	4.76	518.37	519.83	0.024512	9.81	56.85	21.19	0.93
Main	130	100-YEAR	593.00	518.63	513.61	5.02	518.63	520.17	0.023750	10.13	62.50	21.78	0.92
Main	130	High Fish Passag	81.00	515.86	513.61	2.25		516.26	0.024455	5.07	15.96	12.34	0.79
Main	130	Low Fish Passage	20.00	514.87	513.61	1.26		515.07	0.025172	3.56	5.63	7.82	0.74
Main	170	2-YEAR	161.00	517.44	514.40	3.04	516.41	517.68	0.006248	3.86	41.68	18.47	0.45
Main	170	10-YEAR	337.00	518.77	514.40	4.37	517.37	519.15	0.006288	4.94	68.25	21.04	0.48
Main	170	50-YEAR	528.00	519.82	514.40	5.42	518.18	520.36	0.006132	5.87	90.76	22.31	0.49
Main	170	100-YEAR	593.00	520.12	514.40	5.72	518.42	520.71	0.006206	6.16	97.20	22.54	0.50
Main	170	High Fish Passag	81.00	516.57	514.40	2.17	515.83	516.72	0.006143	3.08	26.30	16.63	0.43
Main	170	Low Fish Passage	20.00	515.52	514.40	1.12	515.20	515.58	0.007501	2.01	9.94	14.40	0.43
Main	198	2-YEAR	161.00	516.47	514.96	1.51	517.20	518.92	0.095296	12.56	12.82	18.35	0.50
Main	198	10-YEAR	337.00	517.63	514.96	2.67	518.62	521.06	0.062527	14.88	22.65	21.28	0.50
Main	198	50-YEAR	528.00	518.72	514.96	3.76	519.90	522.96	0.048667	16.51	31.97	22.98	0.50
Main	198	100-YEAR	593.00	519.07	514.96	4.11	520.27	523.54	0.045675	16.97	34.94	23.35	0.50
Main	198	High Fish Passag	81.00	515.85	514.96	0.89	516.38	517.63	0.139068	10.69	7.58	16.28	0.50
Main	198	Low Fish Passage	20.00	515.28	514.96	0.32	515.52	516.13	0.262353	7.39	2.71	14.08	0.51
Main	259		Culvert										
Main	260	2-YEAR	161.00	519.88	516.20	3.68	518.53	520.34	0.005505	5.47	29.42	19.54	0.50
Main	260	10-YEAR	337.00	522.22	516.20	6.02	520.01	522.98	0.004665	7.00	48.16	23.98	0.50
Main	260	50-YEAR	528.00	524.32	516.20	8.12	521.34	525.35	0.004219	8.13	64.98	26.52	0.50
Main	260	100-YEAR	593.00	524.98	516.20	8.78	521.75	526.08	0.004111	8.45	70.22	27.67	0.50
Main	260	High Fish Passag	81.00	518.53	516.20	2.33	517.68	518.82	0.006420	4.35	18.60	17.44	0.50
Main	260	Low Fish Passage	20.00	517.10	516.20	0.90	516.78	517.22	0.009186	2.77	7.22	10.41	0.51
Main	279	2-YEAR	161.00	520.31	516.58	3.73		520.45	0.002965	2.97	54.28	19.66	0.31
Main	279	10-YEAR	337.00	522.95	516.58	6.37		523.09	0.001462	2.98	113.88	24.36	0.24
Main	279	50-YEAR	528.00	525.32	516.58	8.74		525.47	0.000955	3.12	174.94	27.60	0.20
Main	279	100-YEAR	593.00	526.06	516.58	9.48		526.21	0.000864	3.17	195.78	28.75	0.20
Main	279	High Fish Passag	81.00	518.81	516.58	2.23		518.95	0.006128	3.04	26.64	17.11	0.43
Main	279	Low Fish Passage	20.00	517.32	516.58	0.74	517.12	517.45	0.015594	2.87	6.96	10.21	0.61
Main	300	2-YEAR	161.00	520.27	516.98	3.29		520.62	0.009986	4.73	34.07	15.86	0.57
Main	300	10-YEAR	337.00	522.93	516.98	5.95		523.16	0.003099	3.90	86.89	23.64	0.35
Main	300	50-YEAR	528.00	525.30	516.98	8.32		525.51	0.001494	3.71	149.54	29.01	0.26
Main	300	100-YEAR	593.00	526.04	516.98	9.06		526.25	0.001272	3.69	171.84	31.33	0.25
Main	300	High Fish Passag	81.00	518.79	516.98	1.81	518.71	519.31	0.030243	5.81	13.94	11.24	0.92
Main	300	Low Fish Passage	20.00	517.85	516.98	0.87	517.85	518.13	0.045260	4.25	4.71	8.59	1.01
Main	350	2-YEAR	161.00	520.81	517.98	2.83		521.29	0.016456	5.53	29.10	15.08	0.70
Main	350	10-YEAR	337.00	523.06	517.98	5.08		523.40	0.005848	4.68	72.71	24.27	0.46
Main	350	50-YEAR	528.00	525.36	517.98	7.38		525.62	0.002285	4.18	133.91	29.28	0.31
Main	350	100-YEAR	593.00	526.09	517.98	8.11		526.34	0.001857	4.09	155.98	31.01	0.29
Main	350	High Fish Passag	81.00	520.11	517.98	2.13	519.77	520.40	0.015676	4.31	18.80	14.39	0.66
Main	350	Low Fish Passage	20.00	519.18	517.98	1.20		519.30	0.013709	2.76	7.26	10.29	0.58
Main	400	2-YEAR	161.00	521.68	518.98	2.70		522.23	0.020453	5.95	27.04	15.82	0.80
Main	400	10-YEAR	337.00	523.29	518.98	4.31		523.84	0.010162	5.99	57.12	21.29	0.61
Main	400	50-YEAR	528.00	525.40	518.98	6.42		525.81	0.003804	5.24	108.59	27.01	0.41
Main	400	100-YEAR	593.00	526.12	518.98	7.14		526.49	0.002980	5.06	128.39	28.42	0.37
Main	400	High Fish Passag	81.00	520.93	518.98	1.95		521.31	0.020182	4.94	16.40	12.63	0.76
Main	400	Low Fish Passage	20.00	519.99	518.98	1.01	519.84	520.16	0.021500	3.27	6.12	9.44	0.71
Main	500	2-YEAR	161.00	523.66	521.00	2.66		524.21	0.019361	5.99	26.88	14.47	0.77
Main	500	10-YEAR	337.00	524.52	521.00	3.52	524.47	525.61	0.029050	8.38	40.28	18.14	0.98
Main	500	50-YEAR	528.00	525.58	521.00	4.58	525.30	526.78	0.019417	8.83	61.64	21.09	0.85

HEC-RAS Plan: Existing   River: Ripple Creek   Reach: Main (Continued)

Reach	River Sta	Profile	Q Total	W.S. Elev	Min Ch El	Diff	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)		(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main	500	100-YEAR	593.00	526.21	521.00	5.21	525.55	527.24	0.013523	8.26	75.56	23.51	0.73
Main	500	High Fish Passag	81.00	522.94	521.00	1.94		523.30	0.019505	4.82	16.80	13.09	0.75
Main	500	Low Fish Passage	20.00	522.02	521.00	1.02		522.17	0.019069	3.11	6.43	9.79	0.68
Main	600	2-YEAR	161.00	525.69	523.00	2.69	525.42	526.32	0.022544	6.37	25.28	13.53	0.82
Main	600	10-YEAR	337.00	527.02	523.00	4.02	526.56	527.87	0.017753	7.40	45.93	18.09	0.78
Main	600	50-YEAR	528.00	527.57	523.00	4.57	527.50	528.99	0.023751	9.63	56.69	21.11	0.92
Main	600	100-YEAR	593.00	527.79	523.00	4.79	527.79	529.34	0.023818	10.07	61.52	21.70	0.93
Main	600	High Fish Passag	81.00	524.95	523.00	1.95	524.73	525.35	0.021430	5.10	15.89	11.99	0.78
Main	600	Low Fish Passage	20.00	524.00	523.00	1.00	523.84	524.18	0.021037	3.35	5.97	8.61	0.71

Form 6D - Baffle Design Option

Form 6D provides guidance to correctly design a culvert that meets specific fish passage design criteria, while also considering hydraulic impacts and scour concerns.

For this particular example, the culvert design tried to satisfy the upper and lower fish passage design requirements for depth and velocity. For the adult anadromous salmonids the suggested maximum average velocity at high fish design flow is 5 ft/sec. Velocities had to be satisfied while meeting a minimum flow depth at the low fish design flow of 1 foot at the inlet and outlet of the culvert, while creating resting pools 2 feet in depth between each baffle. Hydraulic analyses for hydraulic impacts and scour were also satisfied.

For proposed conditions at the culvert inlet, velocities and depths were acceptable per the Hydraulic Design Fish Passage requirements.

For proposed conditions through the culvert barrel, the average velocity over the baffles was 2.5 ft/s while 6.8 ft/s velocity was calculated through the notch in the baffle. An increase in velocity through the notch was expected due to the quick decrease of cross-sectional area through the baffle. The 6.8 ft/s velocity through the culvert was deemed acceptable for this particular type of notched baffle design. Higher velocities would have caused greater concern and a redesign would have been necessary.

For proposed conditions at the culvert outlet, velocities and depths were significantly improved from existing conditions and were very close to meeting the 5 ft/s acceptable velocity and 1 foot depth.

Baffle height and spacing was determined by selecting a design that most easily satisfied velocity and depth requirements while keeping the structure dimensions in mind. A baffle spacing of 25 ft was used for the 8 ft x 8 ft, 60 ft long box culvert. Three baffles were installed into the box culvert, one located at the outlet of the culvert, and two installed in the middle of the culvert at the 25 ft spacing.

The weir coefficient of 2.73 $\mathrm{ft}^{0.5}/\mathrm{s}$ was determined as appropriate for this specific baffle design. The weir coefficient selection processed is outlined below.

Step 1: Estimate the highest possible weir coefficient for the particular design.

For this example, the proposed breadth of crest of weir 1.2 ft, therefore, the highest possible weir coefficient for a broad-crested or sharp-crested weir is 3.32 $\mathrm{ft}^{0.5}/\mathrm{s}$. (See Hydraulic Engineering Circular 22, *Urban Drainage Design Manual*, pages 8-24 and 8-28). The highest weir coefficient is then entered into the HEC-RAS model and run.

Step 2: Check range of head over baffle in hydraulic model. Does the Low Fish Passage Design depths equal or not exceed the minimum allowable depth per design species? If yes, breath of crest of weir or allowable head is inappropriate for design. Design must be modified and rerun. If no, determine type of weir.

Step 3: Determine type of weir. When the breadth of crest of weir is greater than 0.47 times the head, it is classified as a broad-crested weir.

For this example, the breadth of crest of weir was 1.2 feet. The head from the model results ran with a weir coefficient of 3.32 $ft^{0.5}/s$, equaled 0.51 ft. Since the breadth of crest of weir was greater than the head times 0.47, the weir is classified as a broad-crested weir.

Step 4: Select a more appropriate broad-crested weir coefficient from Table 8-1 from Hydraulic Engineering Circular 22, *Urban Drainage Design Manual.* The weir coefficient is then entered again into the HEC-RAS model and run.

For this example, 2.73 $ft^{0.5}/s$ was selected as a more appropriate broad-crested weir coefficient.

Step 5: Check range of head over baffle in hydraulic model. Does the Low Fish Passage Design depths equal or not exceed the minimum allowable depth per design species? If yes, calculation error occurred in Step 2.

For this example, the average head increase was less than 0.1 feet. Another iteration of weir coefficient selection was unnecessary due to no change in the coefficient value. A weir coefficient value of 2.73 $ft^{0.5}/s$ was used for the HEC-RAS model.

FISH PASSAGE: HYDRAULIC BAFFLE DESIGN OPTION FORM 6D

Project Information Fish Passage Improvement - Route 555		Computed: EKB Checked: LEF	Date: 7/18/06 Date: 7/19/06
Stream Name: Ripple Creek	County: Mendocino	Route: 555	Postmile: 20.2

General Considerations

Baffles shall be used in the design retrofitted culverts or bridges in order to meet the hydraulic design criteria.

Hydrology Results - Peak Discharge Values

50% Annual Probability (2-Year Flood Event)	161	cfs	10% Annual Probability (10-Year Flood Event)	337	cfs
2% Annual Probability (50-Year Flood Event)	528	cfs	1% Annual Probability (100-Year Flood Event)	593	cfs
High Fish Passage Design Flow	81	cfs	Low Fish Passage Design Flow	20	cfs

Selecting Weir Coefficient, C

1) Estimate highest possible weir coefficient for design.[1]

Initial estimate of weir coefficient, C 3.32 $ft^{0.5}/sec$

2) Check range of head over baffle in hydraulic model.

Does the Low Fish Passage Design depths equal or not exceed the minimum allowable depth per design species? ☐ Yes ☒ No

If yes, breath of crest of weir or allowable head is inappropriate for design. Modify design to comply and re-run hydraulic anaylses to verify.

Does the High Fish Passage Design velocities over the weir and through the notch exceed the minimum allowable velocities per design species?
☐ Yes ☒ No

If yes, breath of crest of weir or allowable head is inappropriate for design. Modify design to comply and re-run hydraulic anaylses to verify.

If no for both questions above, determine type of weir.

3) Determine type of weir.

When the thickness of the crest of a weir is more than 0.47 times the head, it is classified as a broad-crested weir.[2]

Baffle/Weir width: 1.2 ft	Head: 0.51 ft	Head x 0.47 = 0.24 ft
☒ Broad crested weir	☐ Sharp crested weir	☐ Other

4) Select a more appropriate weir for particular type of weir, C:

Establish range of reasonable C coefficients in accordance with Hydraulic Engineering Circular 22 ☒ Yes ☐ No

5) Check range of head over baffle in hydraulic model.

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[1] Hydraulic Engineering Circular 22, *Urban Drainage Design Manual,* Chapter 8 (www.fhwa.dot.gov)

[2] Gupta, Ram S., *Hydrology and Hydraulic Systems,* Chapter 6.

FISH PASSAGE: HYDRAULIC BAFFLE DESIGN OPTION FORM 6D

Does the Low Fish Passage Design depths equal or not exceed the minimum allowable depth per design species? ☐ Yes ☒ No

If yes, modify design to comply and rerun hydraulic anaylses to verify.

Does the High Fish Passage Design velocities over the baffle and through the notch exceed the minimum allowable velocities per design species?
☐ Yes ☒ No

If yes, modify design to comply and rerun hydraulic anaylses to verify.

Proposed Baffle Settings and Dimensions

Baffle height:	2.0	ft	Baffle width:	1.2	ft
Baffle spacing (along longitudinal axis):	25	ft	Weir coefficient:	2.73	$ft^{0.5}$/sec

Summarize Retrofitted Culvert Physical Characterstics

Inlet Characteristics - Retrofitted design to inlet: ☐ Yes ☒ No

Inlet Type	☐ Projecting	☐ Headwall	☐ Wingwall
	☐ Flared end section	☐ Segment connection	☐ Skew Angle: °

Barrel Characteristics - Retrofitted design to barrel: ☐ Yes ☒ No

Diameter:	in	Fill height above culvert:	ft
Height/Rise:	ft	Length:	ft
Width/Span:	ft	Number of barrels:	

Culvert Type	☐ Arch	☐ Box	☐ Circular
	☐ Pipe-Arch	☐ Elliptical	
Culvert Material	☐ HDPE	☐ Steel Plate Pipe	☐ Concrete Pipe
	☐ Spiral Rib / Corrugated Metal Pipe		

Horizontal alignment breaks:	ft	Vertical alignment breaks:	ft

Outlet Characteristics - Retrofitted design to outlet: ☐ Yes ☒ No

Outlet Type	☐ Projecting	☐ Headwall	☐ Wingwall
	☐ Flared end section	☐ Segment connection	Skew Angle: °

Summarize Retrofitted Bridge Physical Characterstics N/A

Bridge Physical Characteristics **Retrofitted design to bridge structure:** ☐ Yes ☐ No

FISH PASSAGE: HYDRAULIC BAFFLE DESIGN OPTION FORM 6D

Elevation of high chord (top of road): ft | Elevation of low chord: ft

Channel Lining ☐ No lining ☐ Concrete ☐ Rock ☐ Other

Skew Angle: ° | Bridge width (length): ft

Pier Characteristics (if applicable) Retrofitted design to piers: ☐ Yes ☐ No N/A

Number of Piers: ft | Upstream cross-section starting station: ft

Pier Width: ft | Downstream cross-section starting station: ft

Pier Centerline Spacing: ft | Skew angle: °

Pier Shape
☐ Square nose and tail ☐ Semi-circular nose and tail ☐ 90° triangular nose and tail
☐ Twin-cylinder piers with connecting diaphragm ☐ Twin-cylinder piers without connecting diaphragm ☐ Ten pile trestle bent

Establish High Design Flow for Fish Passage - Depending on species, develop high design flows:

Species/Life Stage	**Percent Annual Exceedance Flow**	**Percentage of 2-Yr Recurrence Interval Flow**	**Design Flows (cfs)**
☒ Adult Anadromous Salmonids	[✓ 1%]	50%	81
☐ Adult Non-Anadromous Salmonids	5%	30%	
☐ Juvenile Salmonids	10%	10%	
☐ Native Non-Salmonids	5%	30%	
☐ Non-Native Species	10%	10%	

Establish Low Design Flow for Fish Passage - Depending on species, develop low design flows:

Species/Life Stage	**Percent Annual Exceedance Flow**	**Alternate Minimum Flow (cfs)**	**Design Flow (cfs)**
☒ Adult Anadromous Salmonids	[✓ 50%]	3	20
☐ Adult Non-Anadromous Salmonids	90%	2	
☐ Juvenile Salmonids	95%	1	
☐ Native Non-Salmonids	90%	1	
☐ Non-Native Species	90%	1	

Establish Maximum Average Water Velocity and Minimum Flow Depth in Culvert (At high design flow) - Depending on culvert length and/or species, select Maximum Average Water Veolcity and Minimum Flow Depth.

Species/Life Stage	**Maximum Average Water Velocity at High Fish Design Flow (ft/sec)**	**Minimum Flow Depth at Low Fish Design Flow (ft)**

☒ Adult Anadromous Salmonids	6 (Culvert length <60 ft)	[✓ 1.0]
	[✓ 5 (Culvert length 60-100 ft)]	
	4 (Culvert length 100-200 ft)	
	3 (Culvert length 200-300 ft)	
	2 (Culvert length >300 ft)	
☐ Adult Non-Anadromous Salmonids	4 (Culvert length <60 ft)	0.67
	4 (Culvert length 60-100 ft)	
	3 (Culvert length 100-200 ft)	
	2 (Culvert length 200-300 ft)	
	2 (Culvert length >300 ft)	
☐ 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		

Establish 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, it's magnitude should be evaluated for both high design flow and low design flow and shall not exceed the values shown below. If a hydraulic drop occurs at the culvert outlet a jump pool of at least 2 feet in depth shall be provided.

Species/Life Stage	**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	

Maximum Allowable Inlet Water Surface Elevation

Culvert ☒

A culvert is required to pass the 10-year peak	Allowable WSEL: 524.18 ft

discharge without causing pressure flow in the culvert,	
And shall not be greater than 50% of the culvert height or diameter above the top of the culvert inlet for the 100-Year peak flood.	Allowable WSEL: 529.59 ft

Bridge ☐ N/A

A bridge is required to pass the 50-year peak discharge with freeboard, vertical clearance between the lowest structural member and the water surface elevation,	Allowable WSEL: ft
While passing the 100-year peak or design discharge under low chord of the bridge.	Allowable WSEL: ft

Establish Allowable Hydraulic Impacts

Is the crossing located within a floodplain as designated by the Federal Emergency Management Agency or another responsible state or local agency? ☐ Yes ☒ No

If yes, establish allowable hydraulic imacts and hydraulic design requirements with the appropriate agency. Attach results.

Will the project result in the increase capacity of an existing crossing? ☐ Yes ☒ No

If yes, will it significantly increase downstream peak flows due to the reduced upstream attenuation? ☐ Yes ☒ No

If yes, consult District Hydraulics. Further analysis may be needed.

Will the project result in a reduction in flow area for the 100-year peak discharge? ☐ Yes ☒ No

If yes, establish the allowable increase in upstream water surface elevation and establish how far upstream the increased water surface may extend.

Develop and run Hydraulic Models to compute water surface elevations, flow depths, and channel velocities fo the low fish passage design flow, the high fish passage design flow and for the 2-, 10-, 50-, and 100-year peak or design discharges reflecting existing and project conditions.
☒ Yes ☐ No

Evaluate computed water surface elevations, flow depths, and channel velocities: ☒ Yes ☐ No

Maximum average velocity in culvert at high fish design flow: 5 ft/s

Does the velocity exceed the maximum allowable for the culvert length and design species? ☐ Yes ☒ No

If yes, modify design to comply and rerun hydraulic anaylses to verify.

Minimum flow depth in culvert at low fish design flow: 2ft depth for resting pools ft

Does the depth equal or not exceed the mimimum allowable for the culvert length and design species? ☐ Yes ☒ No

If yes, modify design to comply and rerun hydraulic anaylses to verify.

Drop between the water surface elevation in the culvert and the outlet channel for: due to 2' height of baffle

FISH PASSAGE: HYDRAULIC BAFFLE DESIGN OPTION FORM 6D

High Fish Passage Flow: 2.42 ft

Low Fish Passage Flow: 1.91 ft

Does the drop between the water surface in the culvert and the outlet channel at high or low design fish flows exceed the maximum allowable for the design species? ☐ Yes ☒ No Notch in Weir

If yes, modify design to avoid a drop if possible. If a drop is unavoidable modify design to meet criteria and provide a jump pool at least two feet in depth. Rerun hydraulic analyses to verfiy.

Water Surface elevation at inlet for the 10-year peak discharge: 524.02 ft

Does the water surface elevation exceed the allowable? ☐ Yes ☒ No

If yes, modify design to comply and rerun hydraulic analyses to verify.

Maximum Culvert and Channel velocities at inlet and outlet transition for the peak or design discharge: High Fish Passage Flows

Range of velocities for Inlet transition:	2.50	ft/s	to		ft/s
Range of velocities for Culvert portion:	2.50 over baffle	ft/s	to	6.8 through notch	ft/s
Range of velocities for Outlet Transition:	5.60	ft/s	to		ft/s

Do the velocities exceed the permissible scour velocities? ☐ Yes ☒ No

If yes, revise design to reduce velocities and rerun hydraulic analyses to verify, or design erosion protection.

Comparison between existing and project future condition water surface elevations for the 10-Year and 100-Year peak flow:

Cross-Section	10-Yr WSEL	10-Yr WSEL	WSEL Difference	100-Year WSEL	100-Year WSEL	WSEL Difference
	Existing Conditions (ft)	Future Conditions (ft)	(ft)	Existing Conditions (ft)	Future Conditions (ft)	(ft)
1 170	518.77	518.77	0.00	520.12	516.96	-3.16
2 198	517.63	518.62	+0.99	519.07	521.21	+2.14
3 260/259	522.22	523.56	+1.34	524.98	523.57	-1.41
4 279	522.95	524.02	+1.07	526.06	526.44	+0.38

If WSELs increase, does the increase exceed the maximum elevation? ☐ Yes ☒ No

Maximum elevation: 535 ft

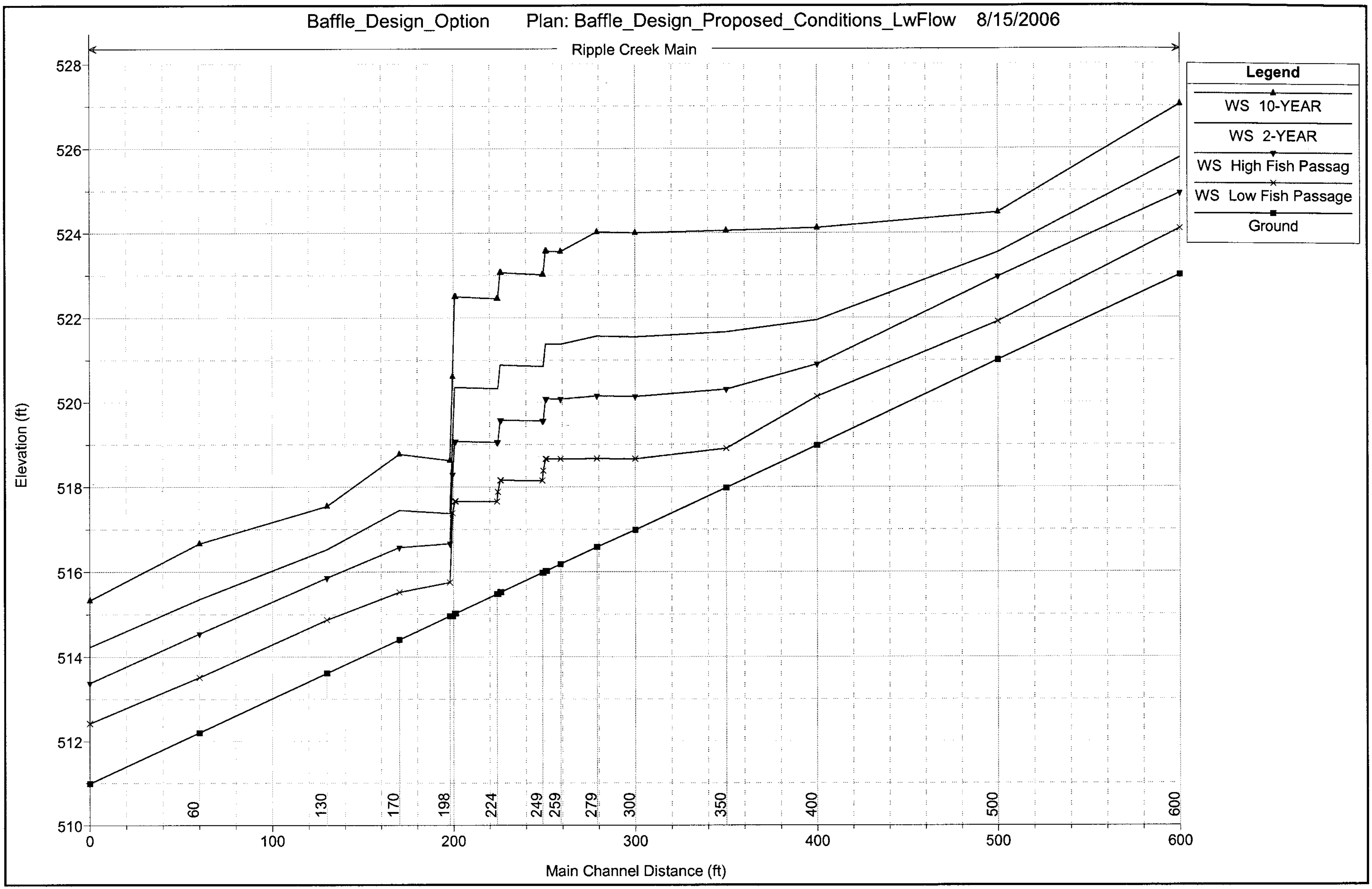
If yes, revise the design and rerun hydraulic analyses to verify.

If WSELs decrease, does it appear that the attenuation of peak flow will significally change? ☐ Yes ☒ No

If yes, evaluate to determine if downstream hydraulic impacts are significant and modify design as appropriate.

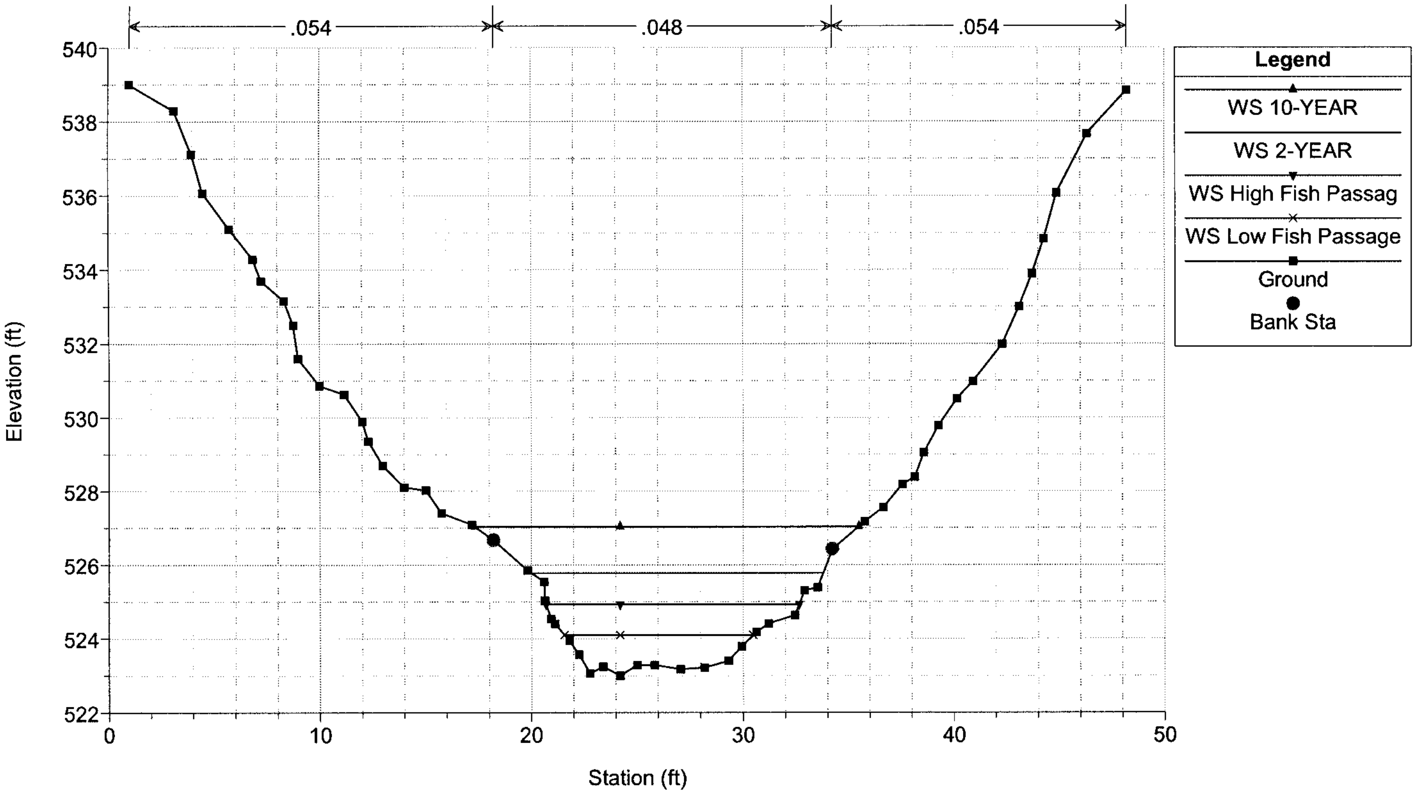
Proposed Plan and Profile Drawing Attached ☒ Yes ☐ No

Hydraulic Analysis Index Sheet Attached ☒ Yes ☐ No


Baffle_Design_Option Plan: Baffle_Design_Proposed_Conditions_LwFlow 8/15/2006
Ripple Creek Main
Legend
WS 10-YEAR
WS 2-YEAR
WS High Fish Passag
WS Low Fish Passage
Ground
Elevation (ft)
528
526
524
522
520
518
516
514
512
510
60
130
170
198
224
249
259
279
300
350
400
500
600
0
100
200
300
400
500
600
Main Channel Distance (ft)

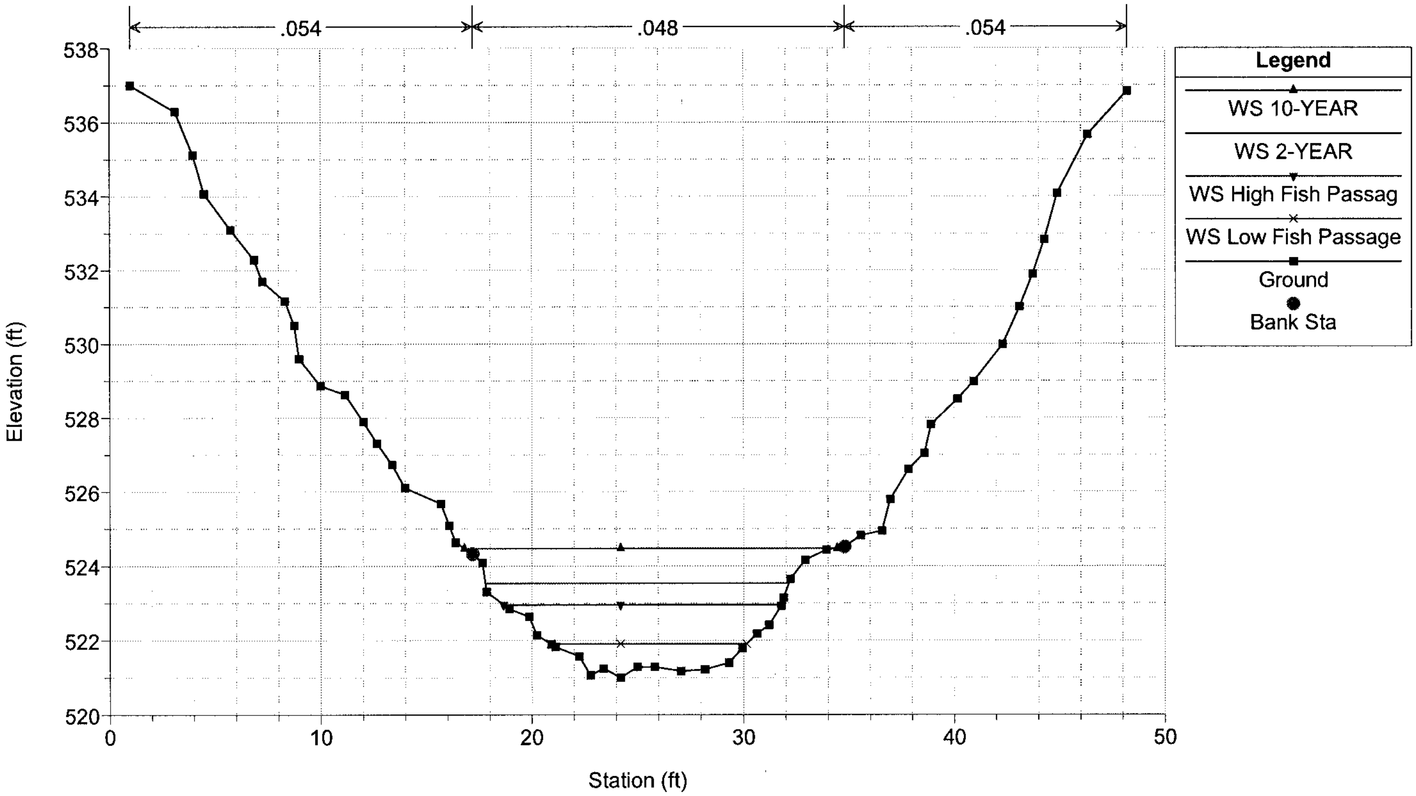
Baffle_Design_Option   Plan: Baffle_Design_Proposed_Conditions_LwFlow   8/15/2006

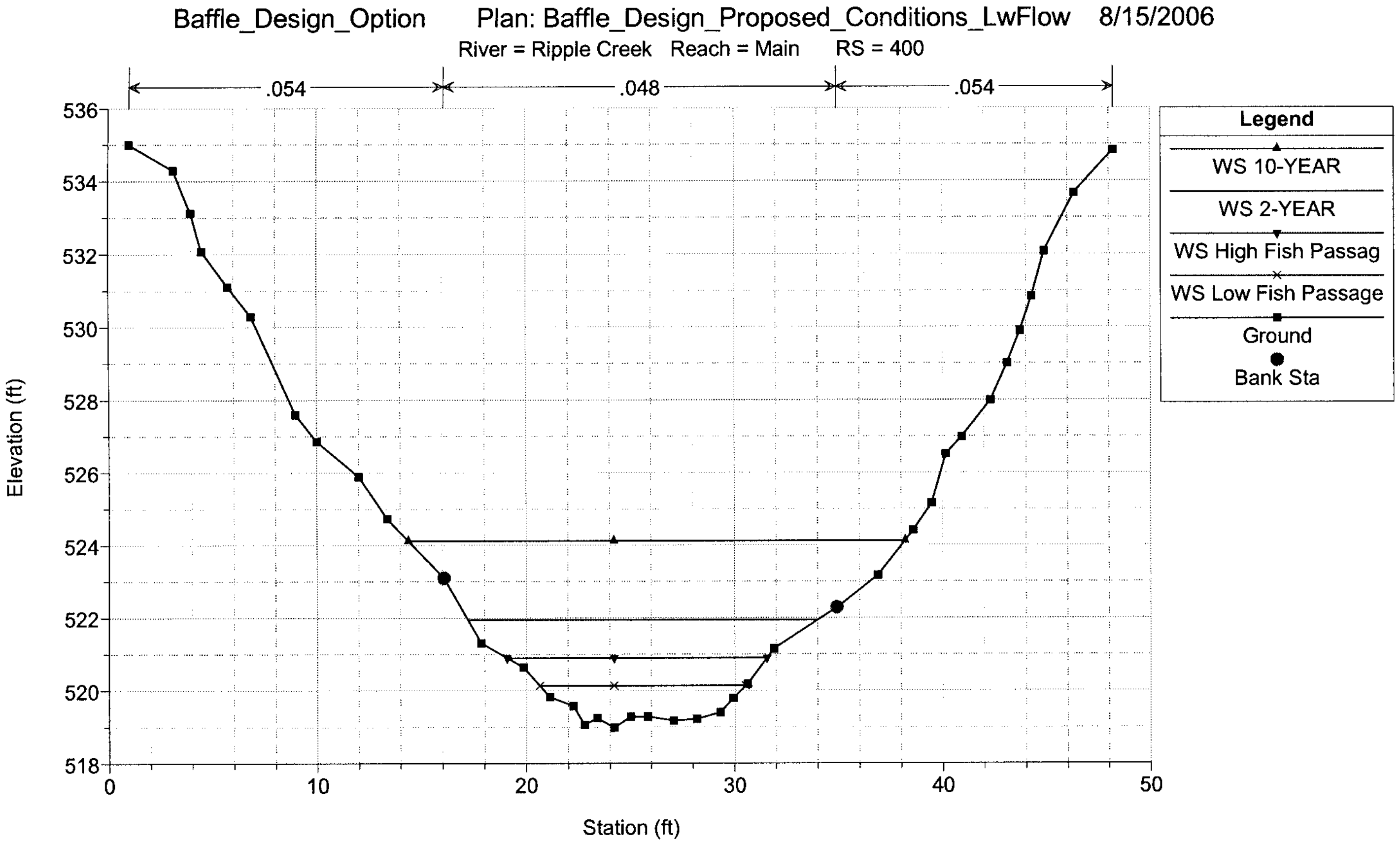
River = Ripple Creek   Reach = Main   RS = 600

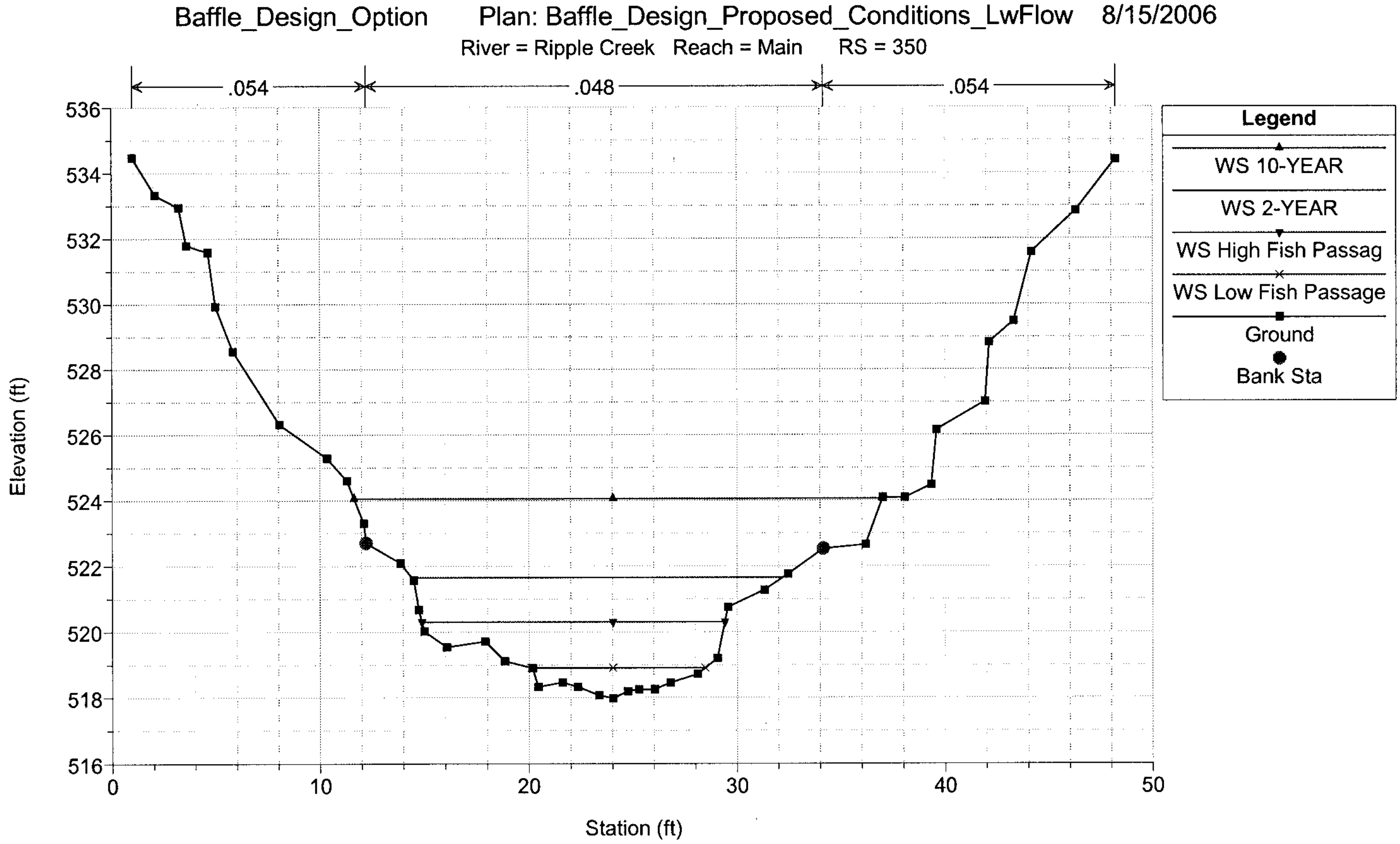


Baffle_Design_Option   Plan: Baffle_Design_Proposed_Conditions_LwFlow   8/15/2006

River = Ripple Creek   Reach = Main   RS = 500

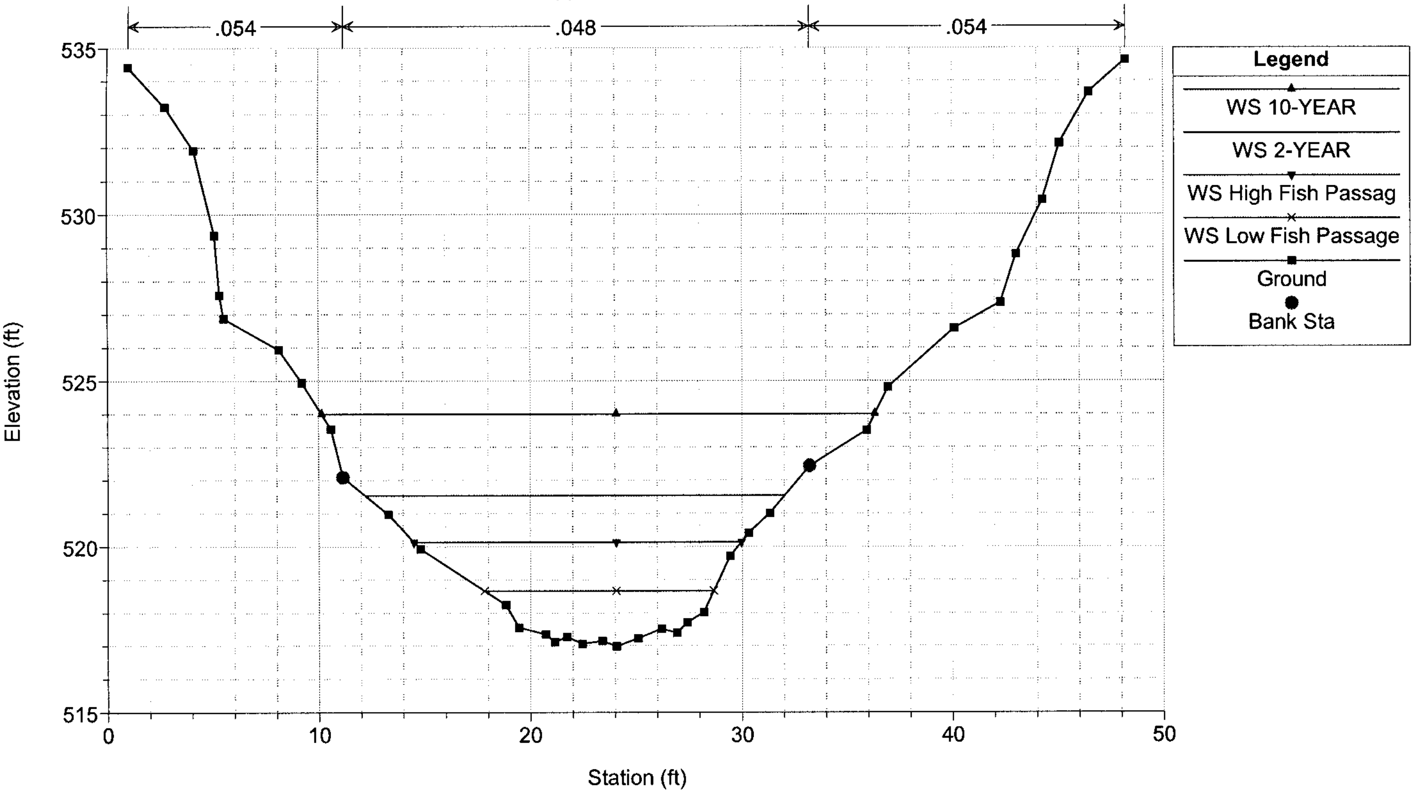



Baffle_Design_Option Plan: Baffle_Design_Proposed_Conditions_LwFlow 8/15/2006
River = Ripple Creek Reach = Main RS = 400


Baffle_Design_Option Plan: Baffle_Design_Proposed_Conditions_LwFlow 8/15/2006
River = Ripple Creek Reach = Main RS = 350

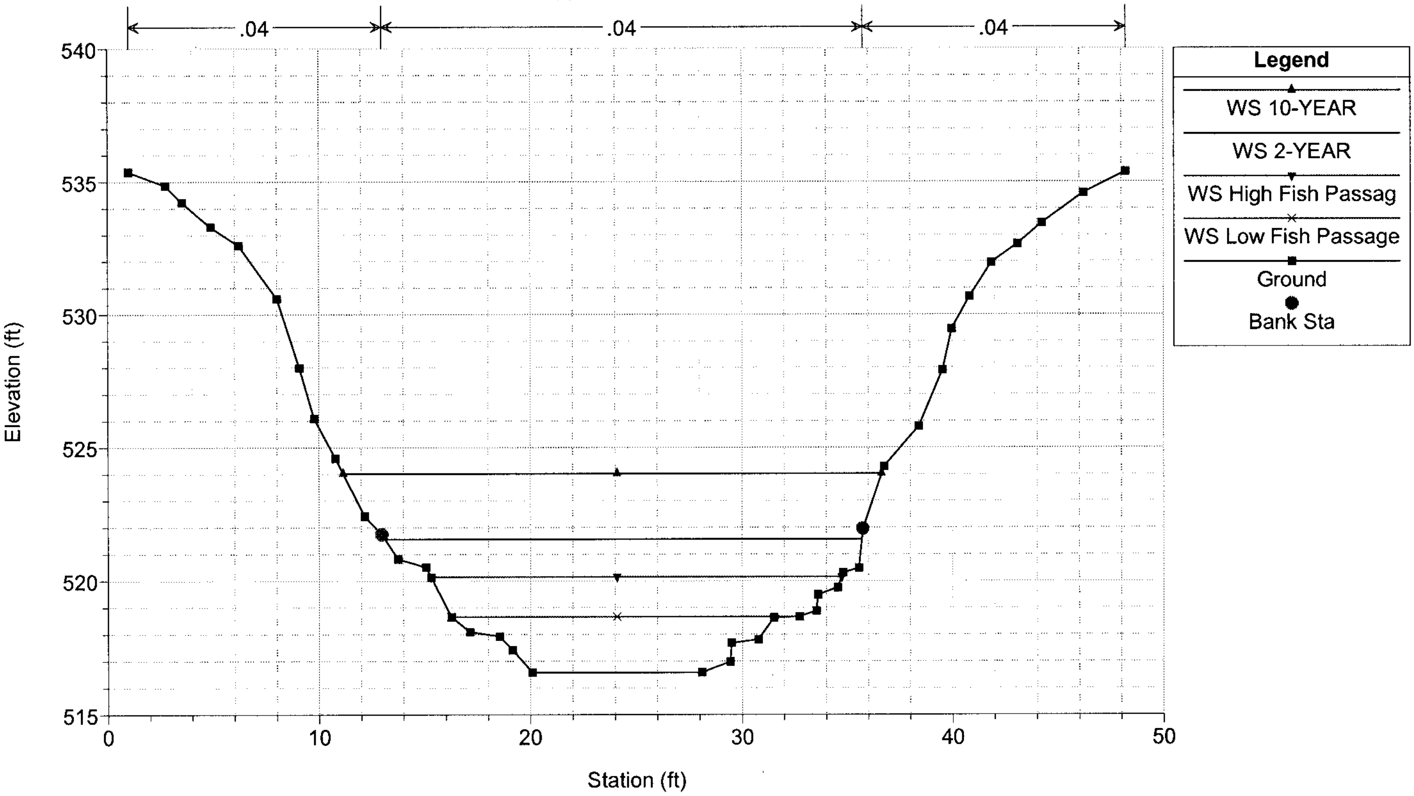
Baffle_Design_Option Plan: Baffle_Design_Proposed_Conditions_LwFlow 8/15/2006

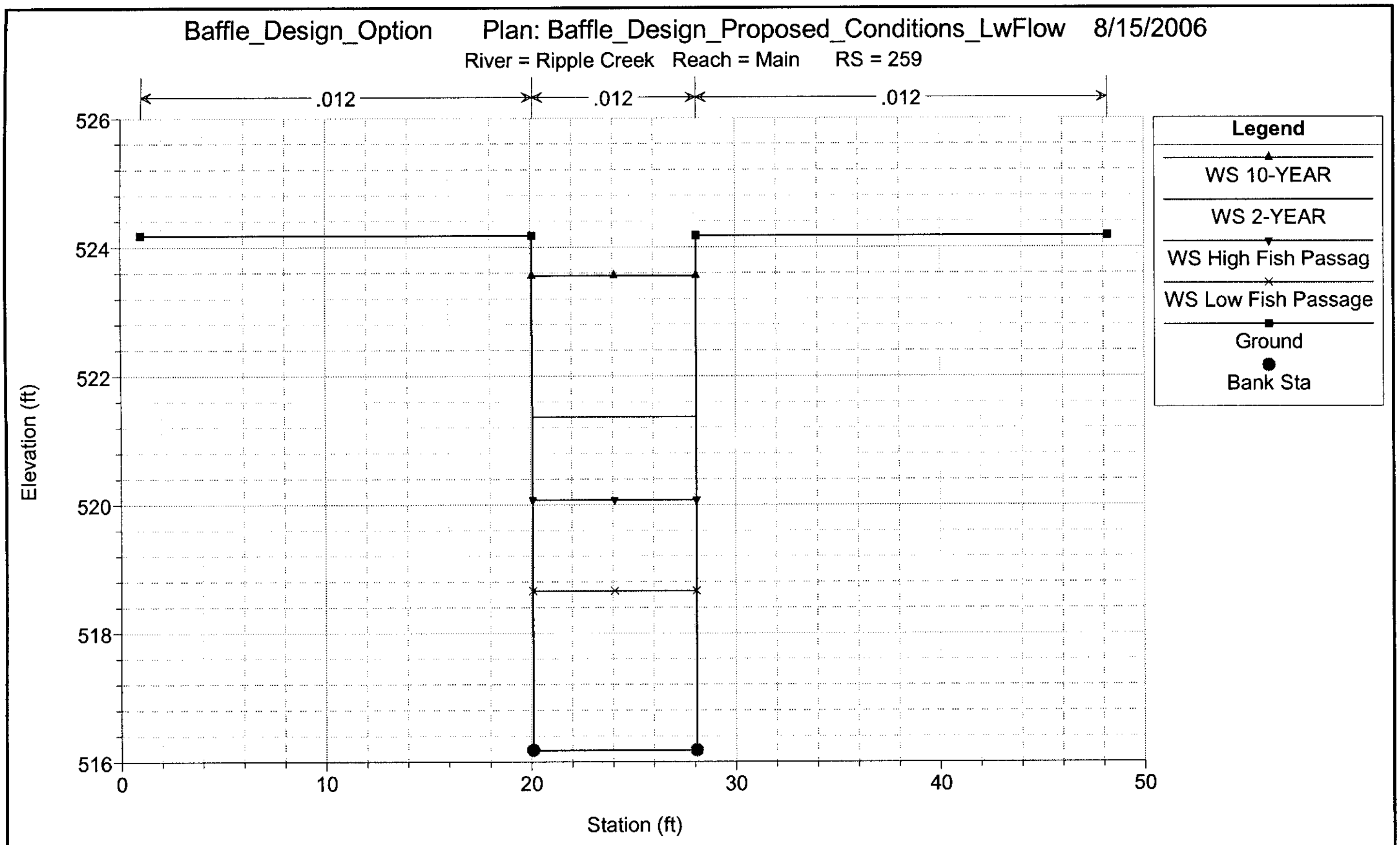
River = Ripple Creek Reach = Main RS = 300



Baffle_Design_Option Plan: Baffle_Design_Proposed_Conditions_LwFlow 8/15/2006

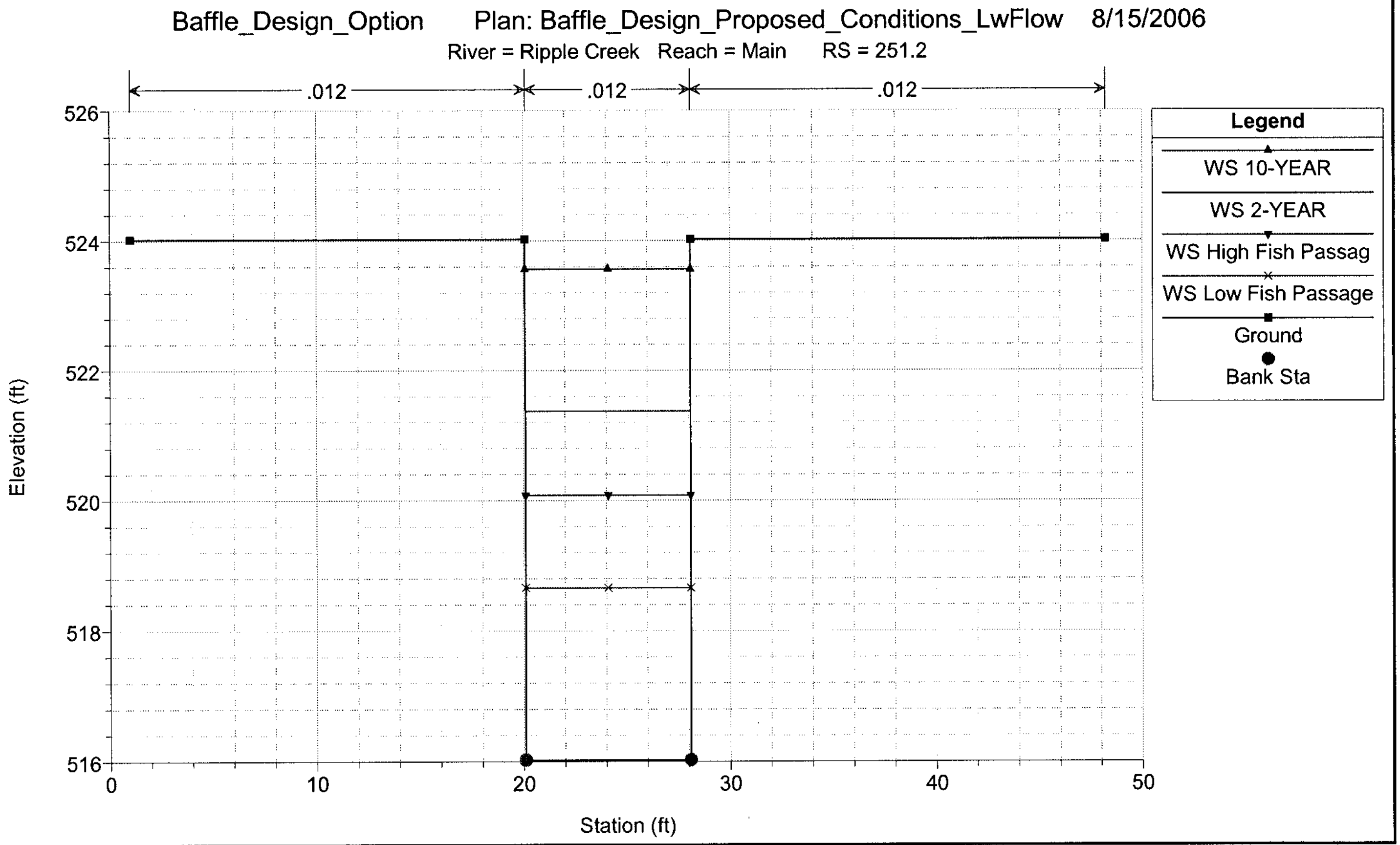
River = Ripple Creek Reach = Main RS = 279





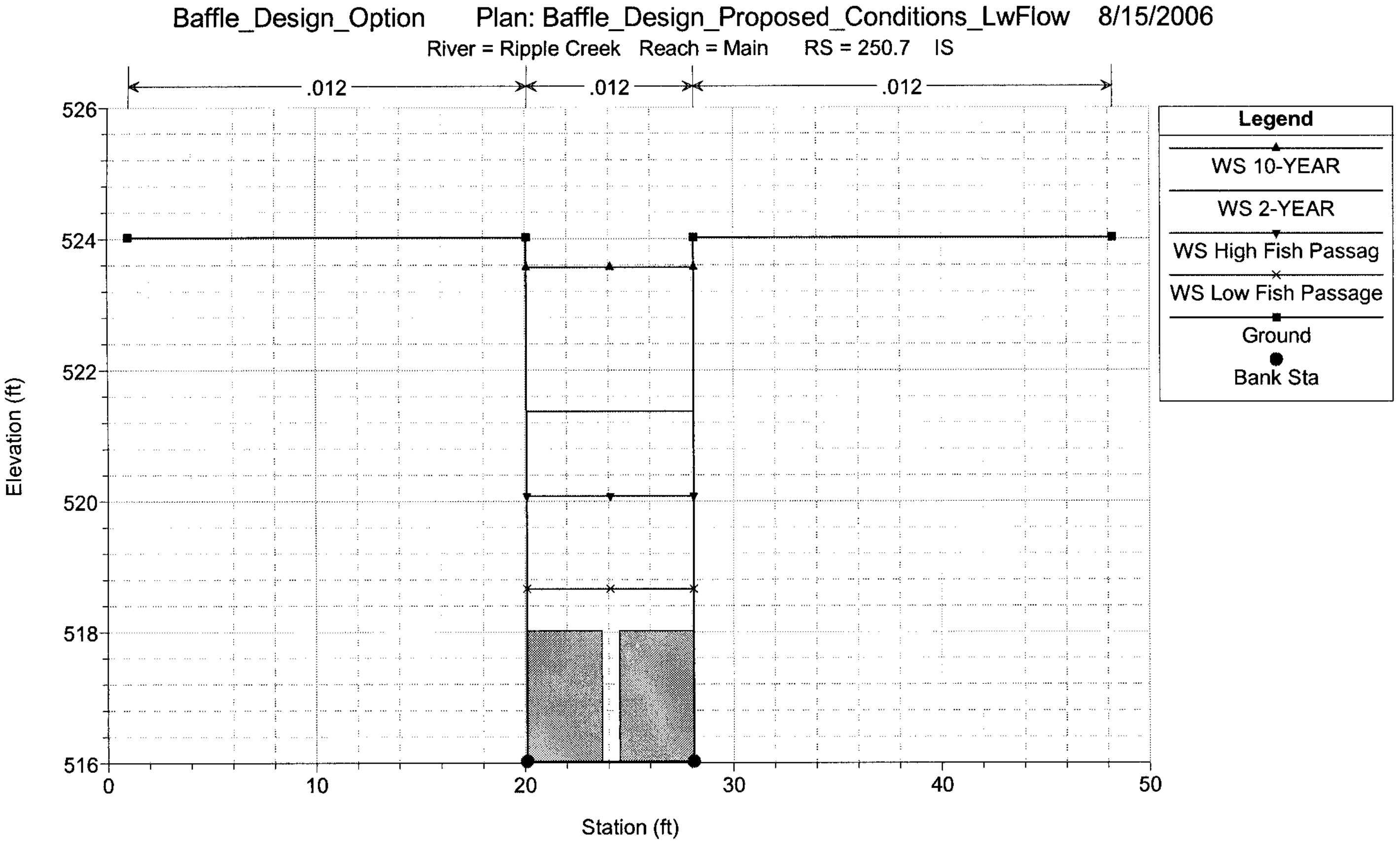
Baffle_Design_Option Plan: Baffle_Design_Proposed_Conditions_LwFlow 8/15/2006

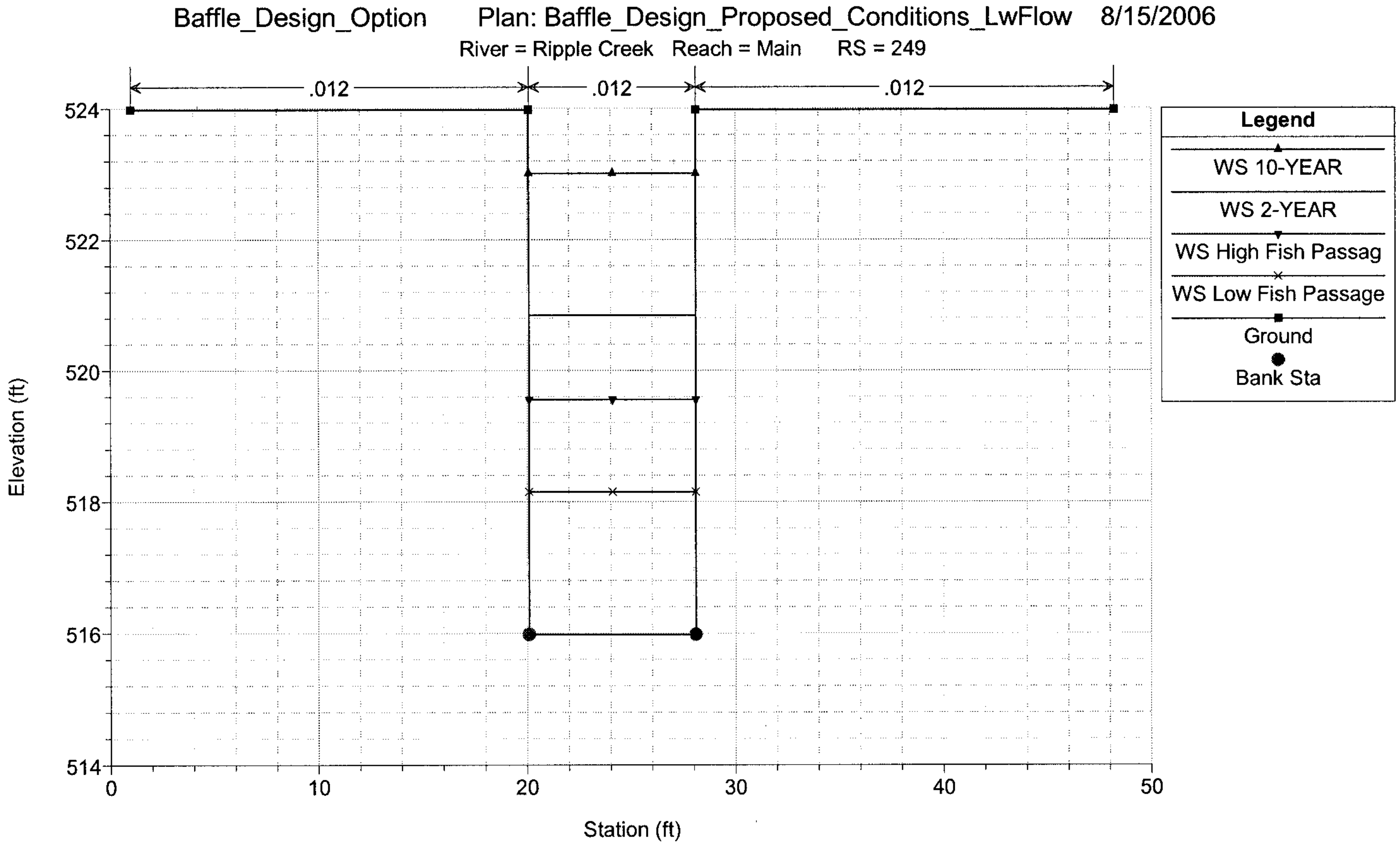
River = Ripple Creek Reach = Main RS = 259

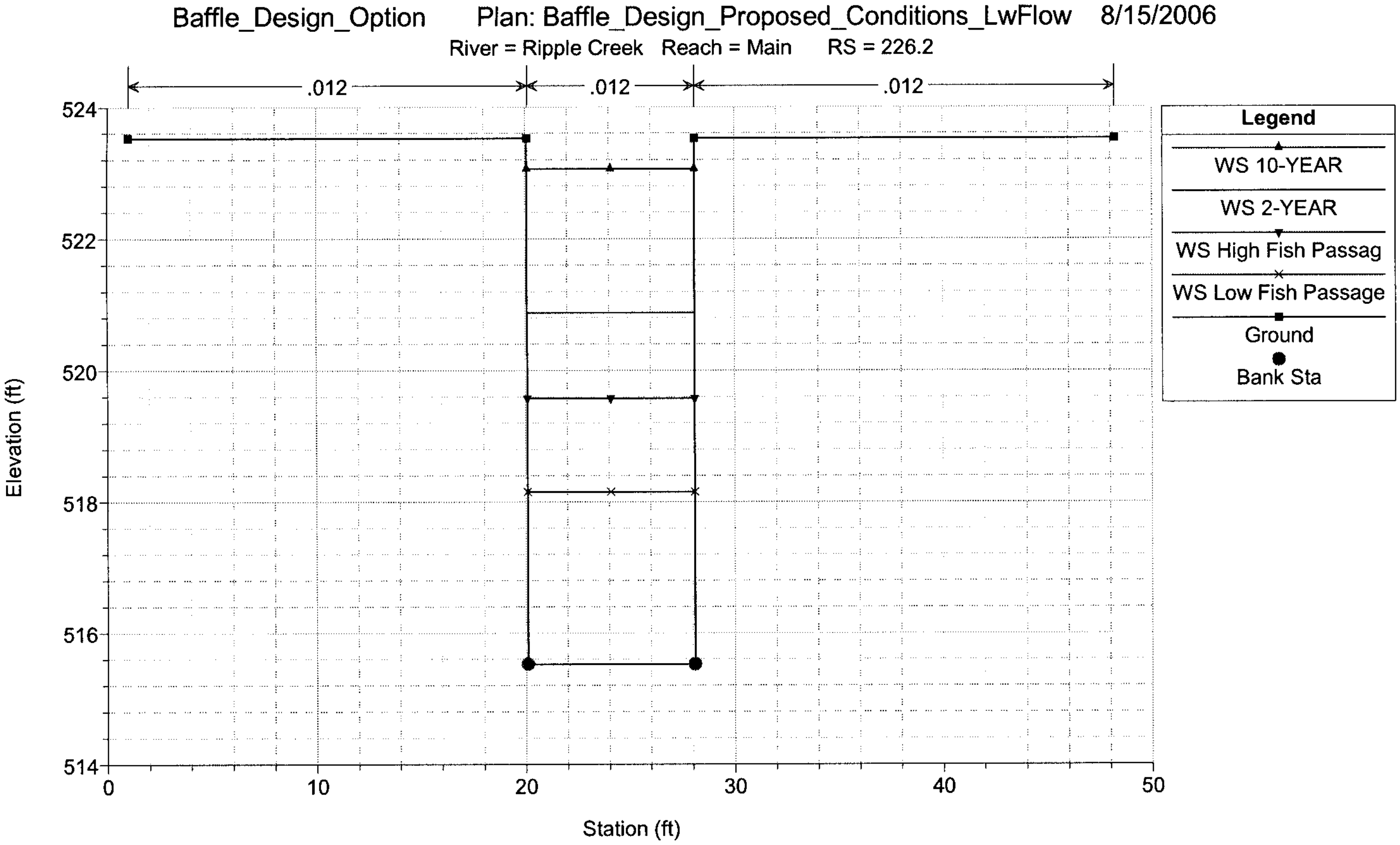


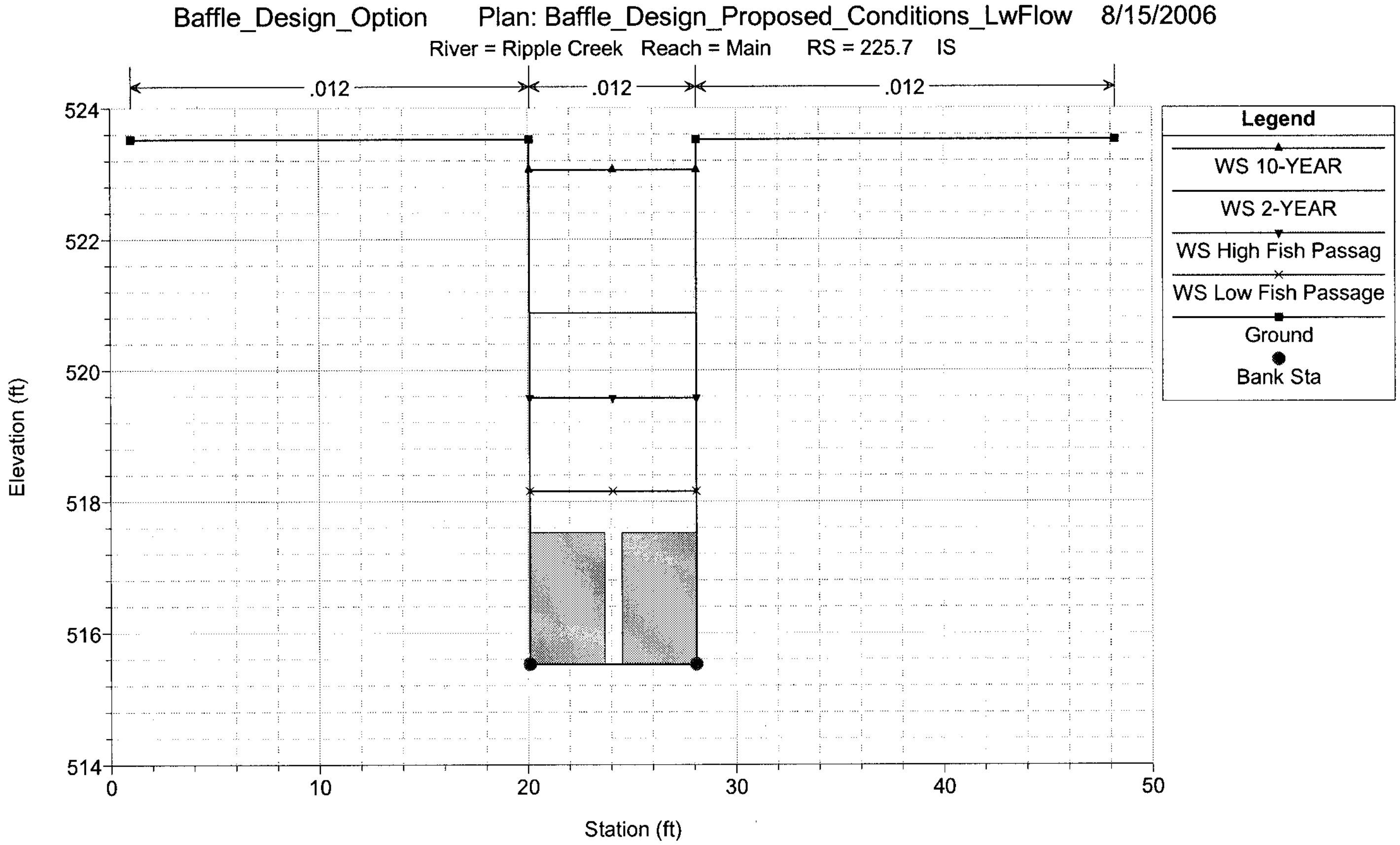
Baffle_Design_Option Plan: Baffle_Design_Proposed_Conditions_LwFlow 8/15/2006

River = Ripple Creek Reach = Main RS = 251.2

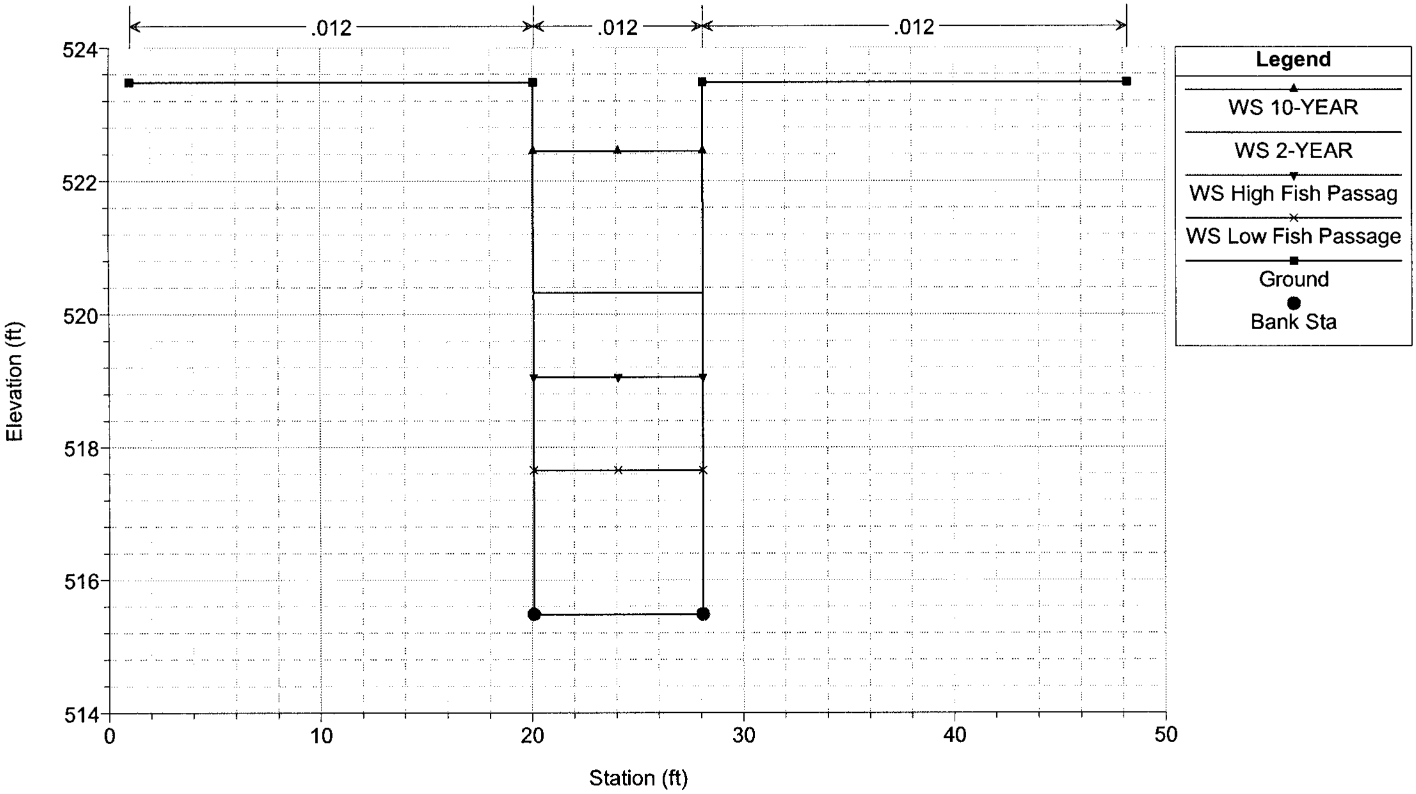

Baffle_Design_Option Plan: Baffle_Design_Proposed_Conditions_LwFlow 8/15/2006
River = Ripple Creek Reach = Main RS = 250.7 IS
.012
.012
.012
526
524
522
520
518
516
Elevation (ft)
0
10
20
30
40
50
Station (ft)
Legend
WS 10-YEAR
WS 2-YEAR
WS High Fish Passag
WS Low Fish Passage
Ground
Bank Sta


Baffle_Design_Option Plan: Baffle_Design_Proposed_Conditions_LwFlow 8/15/2006
River = Ripple Creek Reach = Main RS = 249
.012
.012
.012
524
522
520
518
516
514
Elevation (ft)
0
10
20
30
40
50
Station (ft)
Legend
WS 10-YEAR
WS 2-YEAR
WS High Fish Passag
WS Low Fish Passage
Ground
Bank Sta

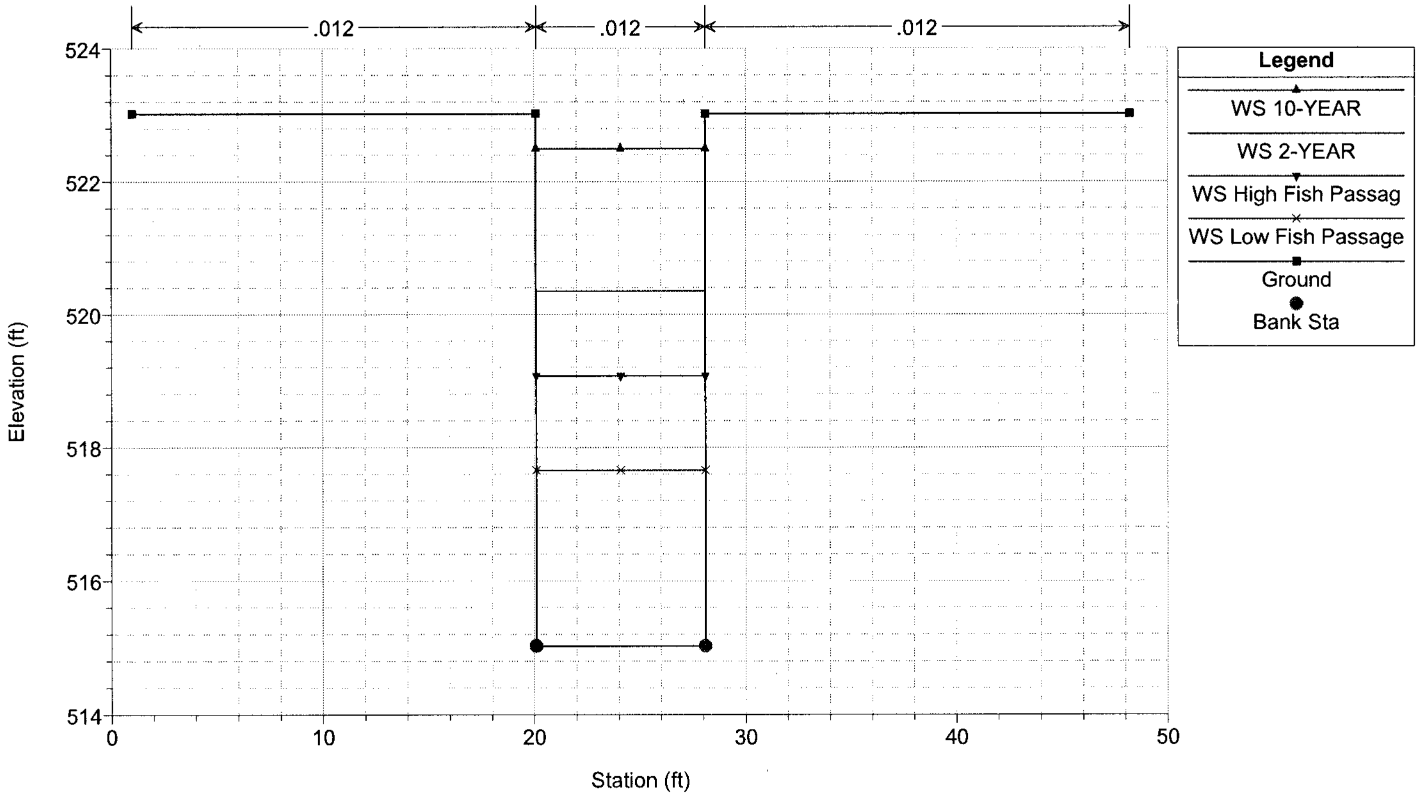

Baffle_Design_Option
Plan: Baffle_Design_Proposed_Conditions_LwFlow
8/15/2006
River = Ripple Creek
Reach = Main
RS = 226.2
.012
.012
.012
Legend
WS 10-YEAR
WS 2-YEAR
WS High Fish Passag
WS Low Fish Passage
Ground
Bank Sta
Elevation (ft)
524
522
520
518
516
514
0
10
20
30
40
50
Station (ft)

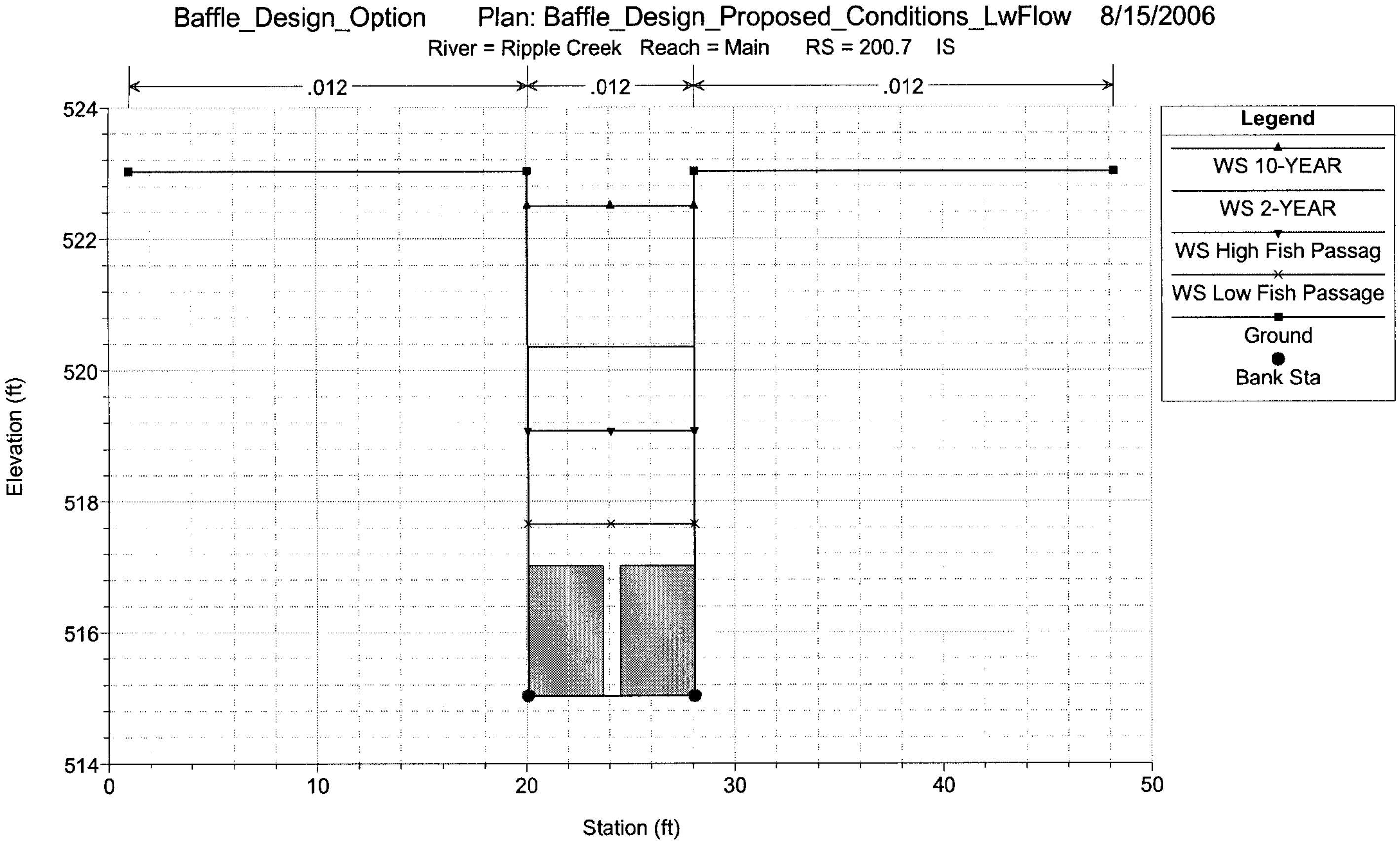

Baffle_Design_Option
Plan: Baffle_Design_Proposed_Conditions_LwFlow
8/15/2006
River = Ripple Creek
Reach = Main
RS = 225.7
IS
.012
.012
.012
Legend
WS 10-YEAR
WS 2-YEAR
WS High Fish Passag
WS Low Fish Passage
Ground
Bank Sta
Elevation (ft)
524
522
520
518
516
514
0
10
20
30
40
50
Station (ft)

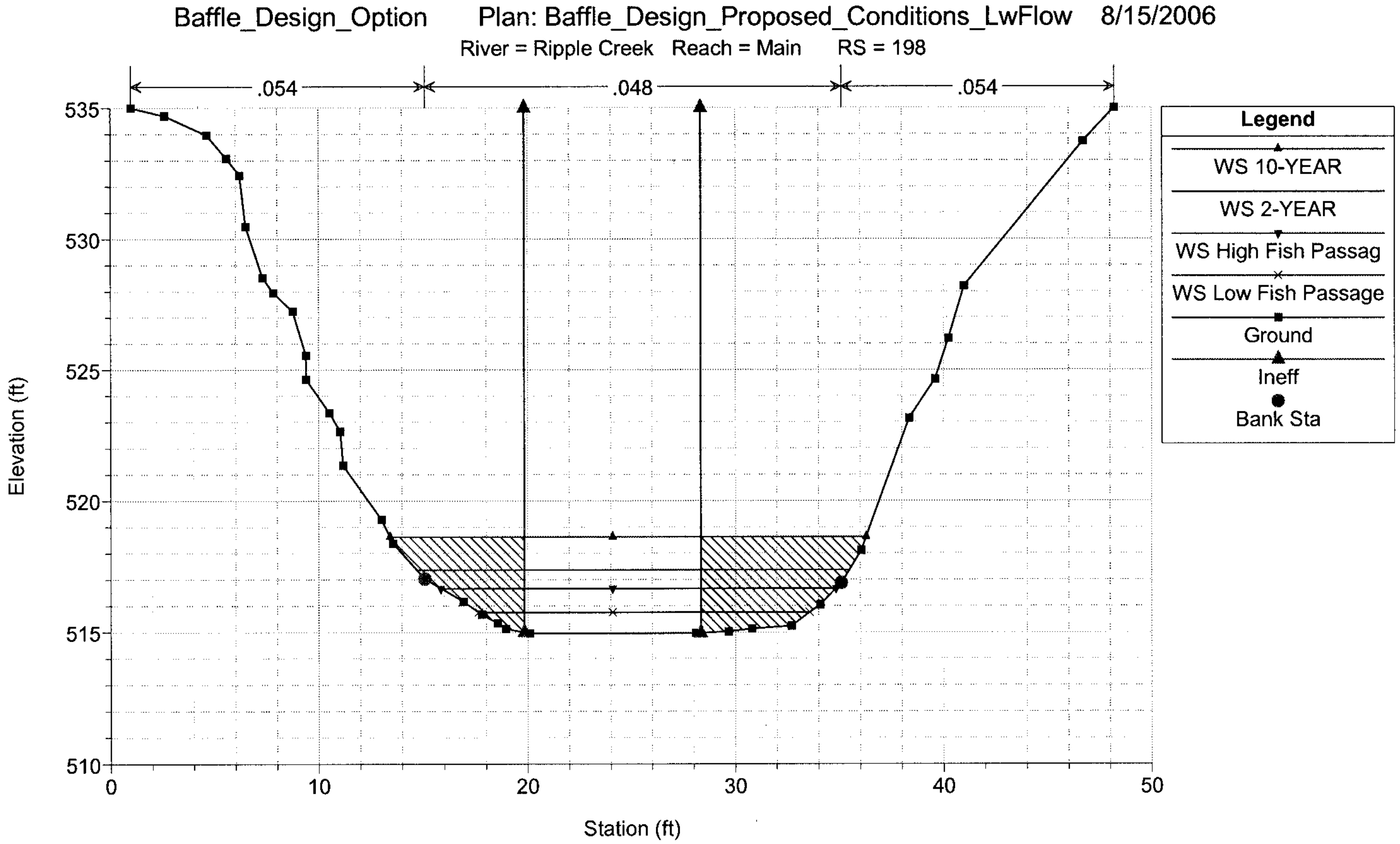
Baffle_Design_Option Plan: Baffle_Design_Proposed_Conditions_LwFlow 8/15/2006
River = Ripple Creek Reach = Main RS = 224

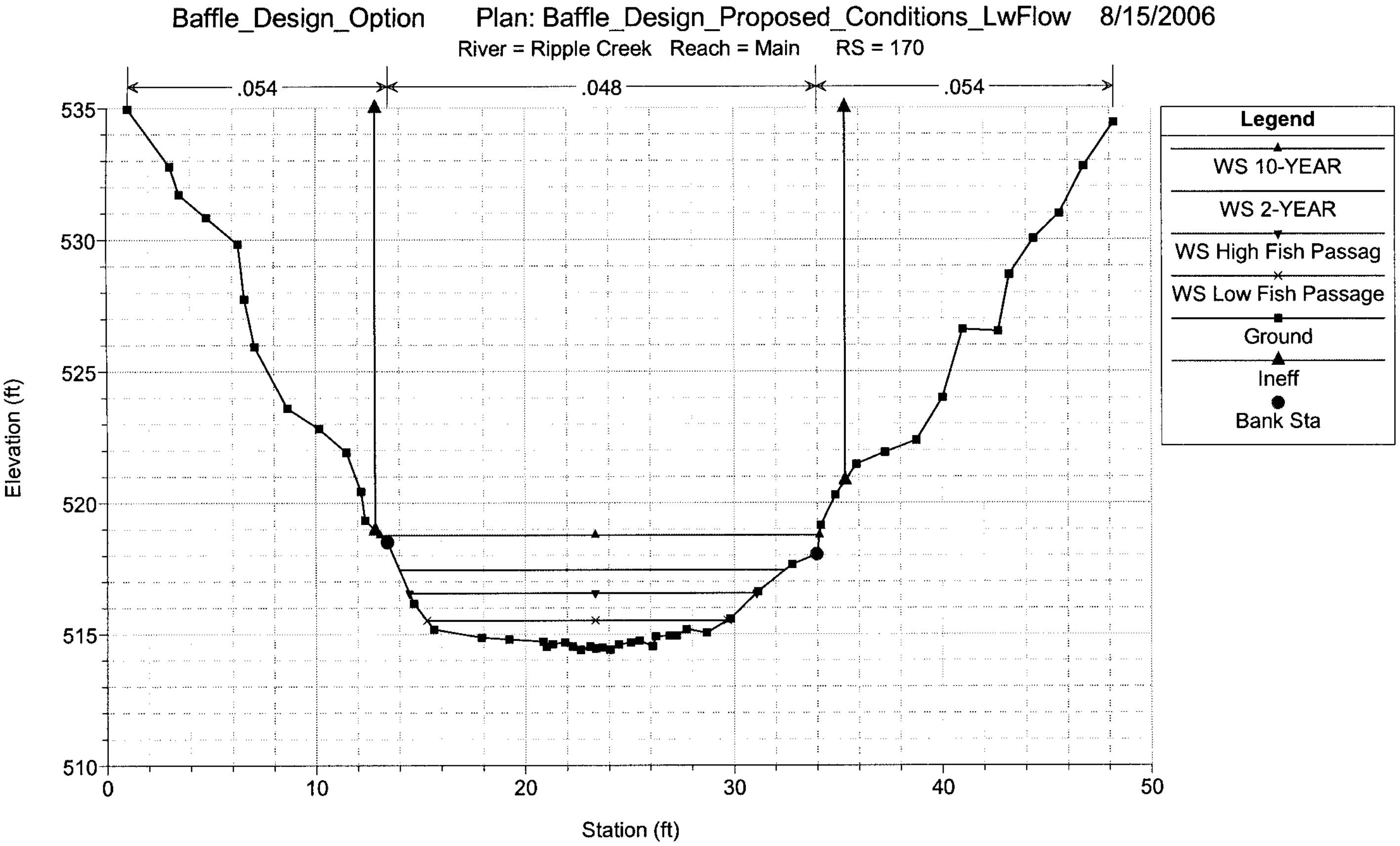


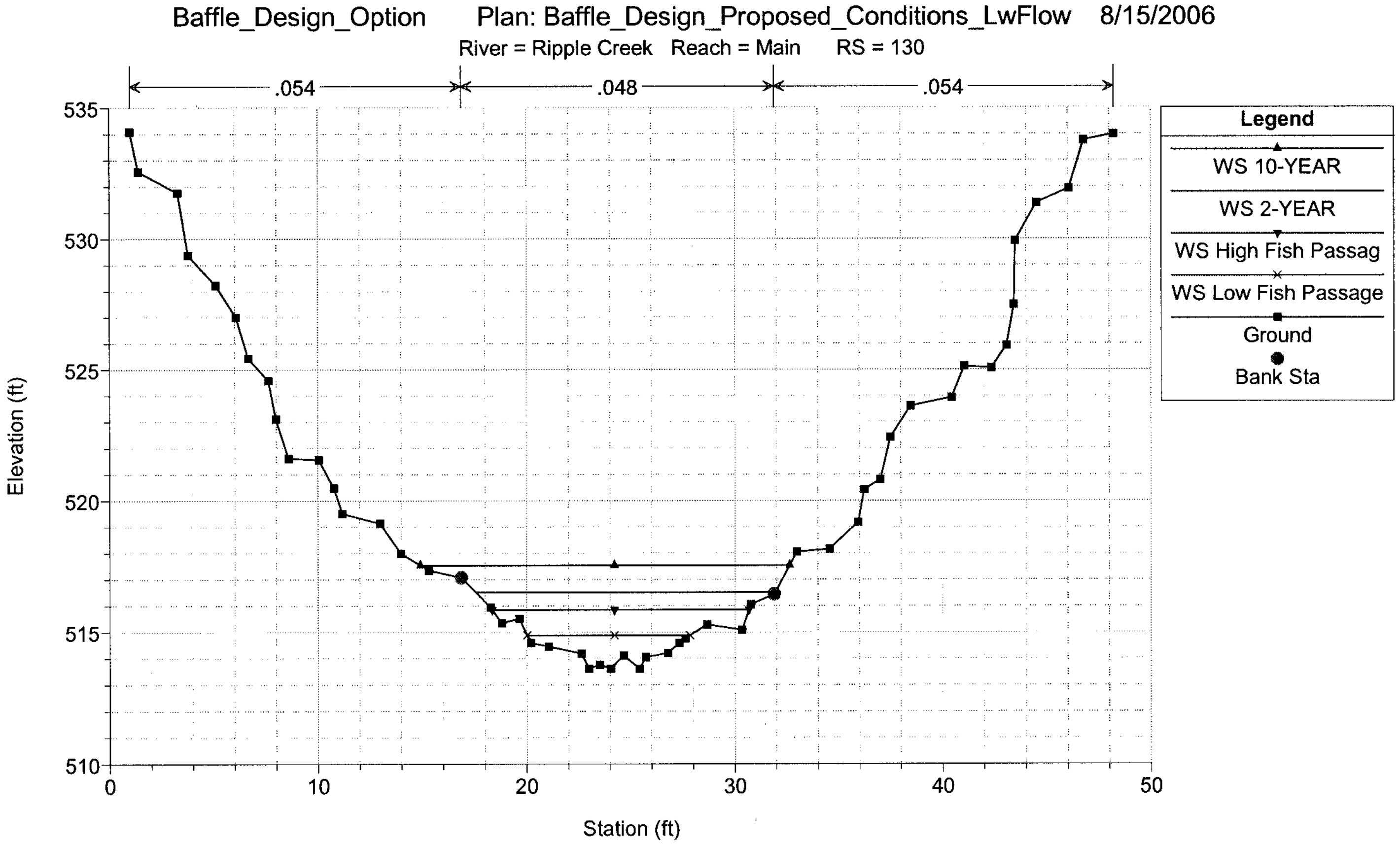
Baffle_Design_Option Plan: Baffle_Design_Proposed_Conditions_LwFlow 8/15/2006
River = Ripple Creek Reach = Main RS = 201.2

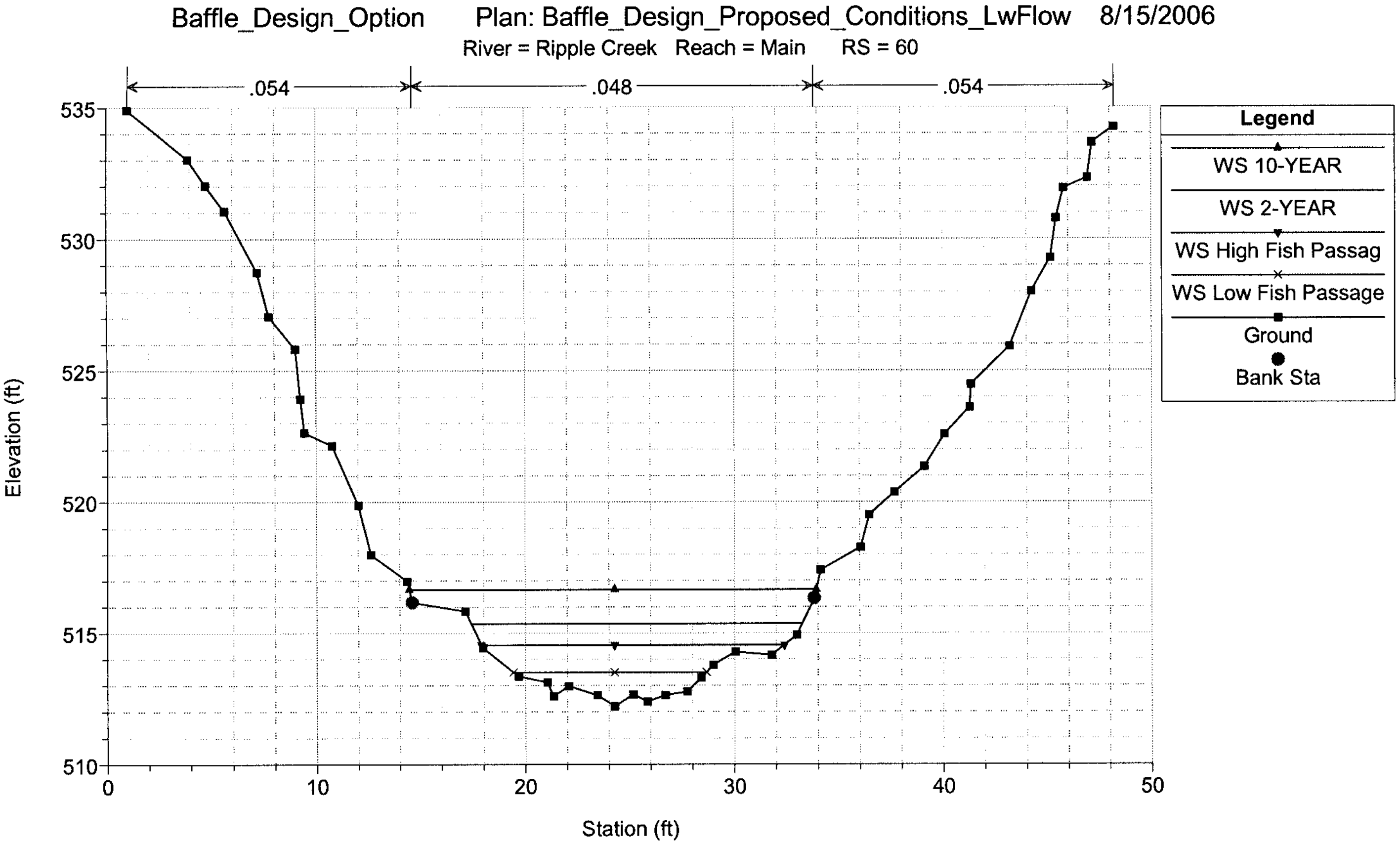



Baffle_Design_Option
Plan: Baffle_Design_Proposed_Conditions_LwFlow
8/15/2006
River = Ripple Creek Reach = Main RS = 200.7 IS
.012
.012
.012
524
522
520
518
516
514
Elevation (ft)
0
10
20
30
40
50
Station (ft)
Legend
WS 10-YEAR
WS 2-YEAR
WS High Fish Passag
WS Low Fish Passage
Ground
Bank Sta

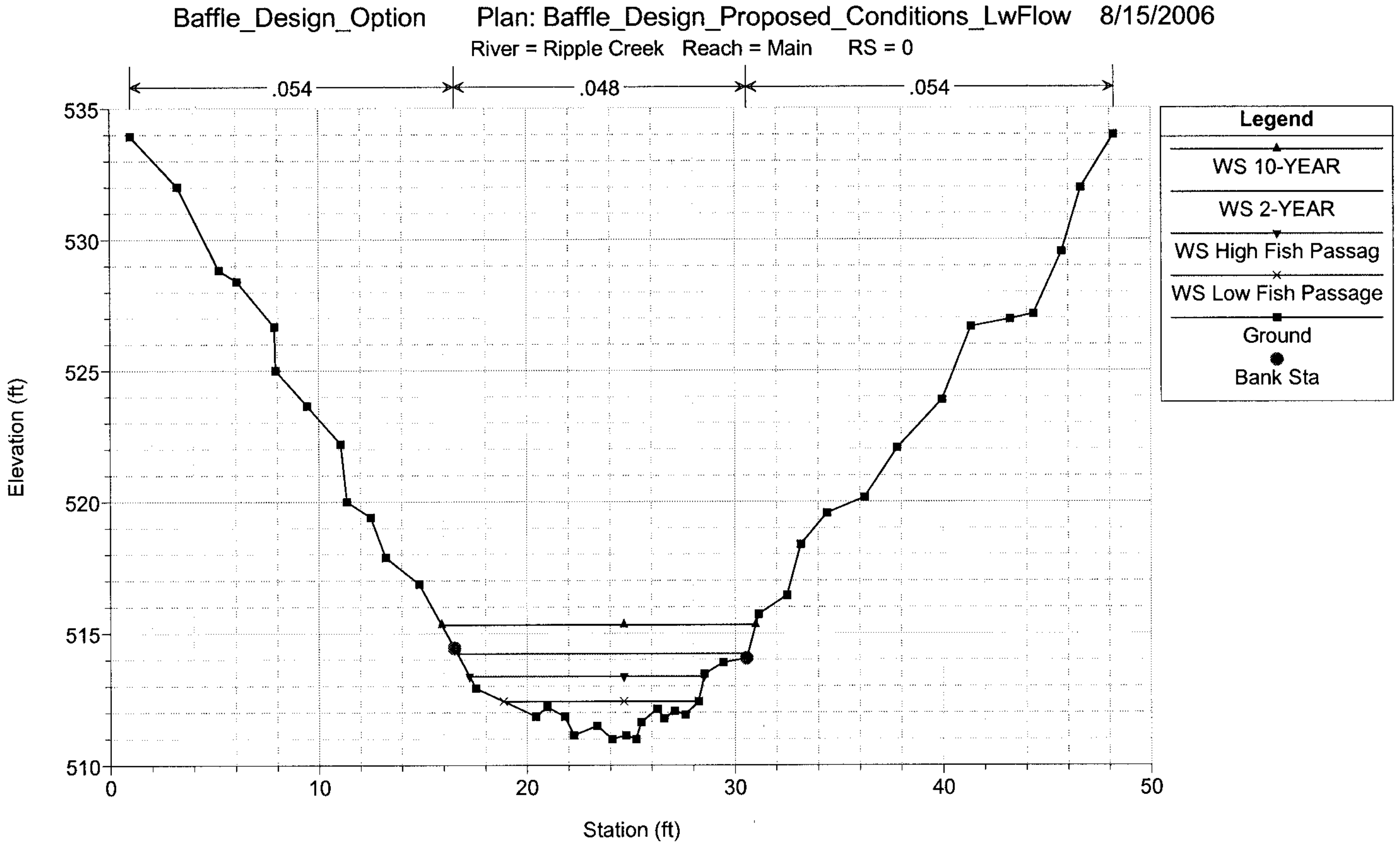

Baffle_Design_Option
Plan: Baffle_Design_Proposed_Conditions_LwFlow
8/15/2006
River = Ripple Creek Reach = Main RS = 198
.054
.048
.054
535
530
525
520
515
510
Elevation (ft)
0
10
20
30
40
50
Station (ft)
Legend
WS 10-YEAR
WS 2-YEAR
WS High Fish Passag
WS Low Fish Passage
Ground
Ineff
Bank Sta


Baffle_Design_Option Plan: Baffle_Design_Proposed_Conditions_LwFlow 8/15/2006
River = Ripple Creek Reach = Main RS = 170
.054
.048
.054
Elevation (ft)
535
530
525
520
515
510
0
10
20
30
40
50
Station (ft)
Legend
WS 10-YEAR
WS 2-YEAR
WS High Fish Passag
WS Low Fish Passage
Ground
Ineff
Bank Sta


Baffle_Design_Option Plan: Baffle_Design_Proposed_Conditions_LwFlow 8/15/2006
River = Ripple Creek Reach = Main RS = 130
.054
.048
.054
Elevation (ft)
535
530
525
520
515
510
0
10
20
30
40
50
Station (ft)
Legend
WS 10-YEAR
WS 2-YEAR
WS High Fish Passag
WS Low Fish Passage
Ground
Bank Sta


Baffle_Design_Option   Plan: Baffle_Design_Proposed_Conditions_LwFlow   8/15/2006

River = Ripple Creek   Reach = Main   RS = 60


Baffle_Design_Option   Plan: Baffle_Design_Proposed_Conditions_LwFlow   8/15/2006

River = Ripple Creek   Reach = Main   RS = 0

Plan: Proposed LwQ Ripple Creek Main RS: 250.7 Inl Struct: Profile: High Fish Passag

E.G. Elev (ft)	520.17	Q Gates (cfs)	
W.S. Elev (ft)	520.08	Q Gate Group (cfs)	
Q Total (cfs)	81.00	Gate Open Ht (ft)	337.29
Q Weir (cfs)	81.00	Gate #Open	337
Weir Flow Area (sq ft)	18.93	Gate Area (sq ft)	
Weir Sta Lft (ft)	20.09	Gate Submerg	
Weir Sta Rgt (ft)	28.11	Gate Invert (ft)	0.00
Weir Max Depth (ft)	4.15		
Weir Avg Depth (ft)	2.36		
Weir Submerg	0.75		
Min El Weir Flow (ft)	516.03		
Wr Top Wdth (ft)	8.01		

Plan: Proposed LwQ Ripple Creek Main RS: 250.7 Inl Struct: Profile: Low Fish Passage

E.G. Elev (ft)	518.67	Q Gates (cfs)	
W.S. Elev (ft)	518.66	Q Gate Group (cfs)	
Q Total (cfs)	20.00	Gate Open Ht (ft)	528.02
Q Weir (cfs)	20.00	Gate #Open	528
Weir Flow Area (sq ft)	6.91	Gate Area (sq ft)	
Weir Sta Lft (ft)	20.10	Gate Submerg	
Weir Sta Rgt (ft)	28.10	Gate Invert (ft)	0.00
Weir Max Depth (ft)	2.65		
Weir Avg Depth (ft)	0.86		
Weir Submerg	0.49		
Min El Weir Flow (ft)	516.03		
Wr Top Wdth (ft)	8.01		

Plan: Proposed LwQ Ripple Creek Main RS: 225.7 Inl Struct: Profile: High Fish Passag

E.G. Elev (ft)	519.67	Q Gates (cfs)	
W.S. Elev (ft)	519.58	Q Gate Group (cfs)	
Q Total (cfs)	81.00	Gate Open Ht (ft)	337.29
Q Weir (cfs)	81.00	Gate #Open	337
Weir Flow Area (sq ft)	18.92	Gate Area (sq ft)	
Weir Sta Lft (ft)	20.09	Gate Submerg	
Weir Sta Rgt (ft)	28.11	Gate Invert (ft)	0.00
Weir Max Depth (ft)	4.15		
Weir Avg Depth (ft)	2.36		
Weir Submerg	0.75		
Min El Weir Flow (ft)	515.53		
Wr Top Wdth (ft)	8.01		

Plan: Proposed LwQ   Ripple Creek   Main RS: 225.7   Inl Struct: Profile: Low Fish Passage

E.G. Elev (ft)	518.17	Q Gates (cfs)	
W.S. Elev (ft)	518.15	Q Gate Group (cfs)	
Q Total (cfs)	20.00	Gate Open Ht (ft)	528.02
Q Weir (cfs)	20.00	Gate #Open	528
Weir Flow Area (sq ft)	6.85	Gate Area (sq ft)	
Weir Sta Lft (ft)	20.10	Gate Submerg	
Weir Sta Rgt (ft)	28.10	Gate Invert (ft)	0.00
Weir Max Depth (ft)	2.64		
Weir Avg Depth (ft)	0.86		
Weir Submerg	0.50		
Min El Weir Flow (ft)	515.53		
Wr Top Wdth (ft)	8.01		

Plan: Proposed LwQ   Ripple Creek   Main RS: 200.7   Inl Struct: Profile: High Fish Passag

E.G. Elev (ft)	519.17	Q Gates (cfs)	
W.S. Elev (ft)	519.08	Q Gate Group (cfs)	
Q Total (cfs)	81.00	Gate Open Ht (ft)	337.29
Q Weir (cfs)	81.00	Gate #Open	337
Weir Flow Area (sq ft)	18.91	Gate Area (sq ft)	
Weir Sta Lft (ft)	20.09	Gate Submerg	
Weir Sta Rgt (ft)	28.11	Gate Invert (ft)	0.00
Weir Max Depth (ft)	4.15		
Weir Avg Depth (ft)	2.36		
Weir Submerg	0.09		
Min El Weir Flow (ft)	515.03		
Wr Top Wdth (ft)	8.01		

Plan: Proposed LwQ   Ripple Creek   Main RS: 200.7   Inl Struct: Profile: Low Fish Passage

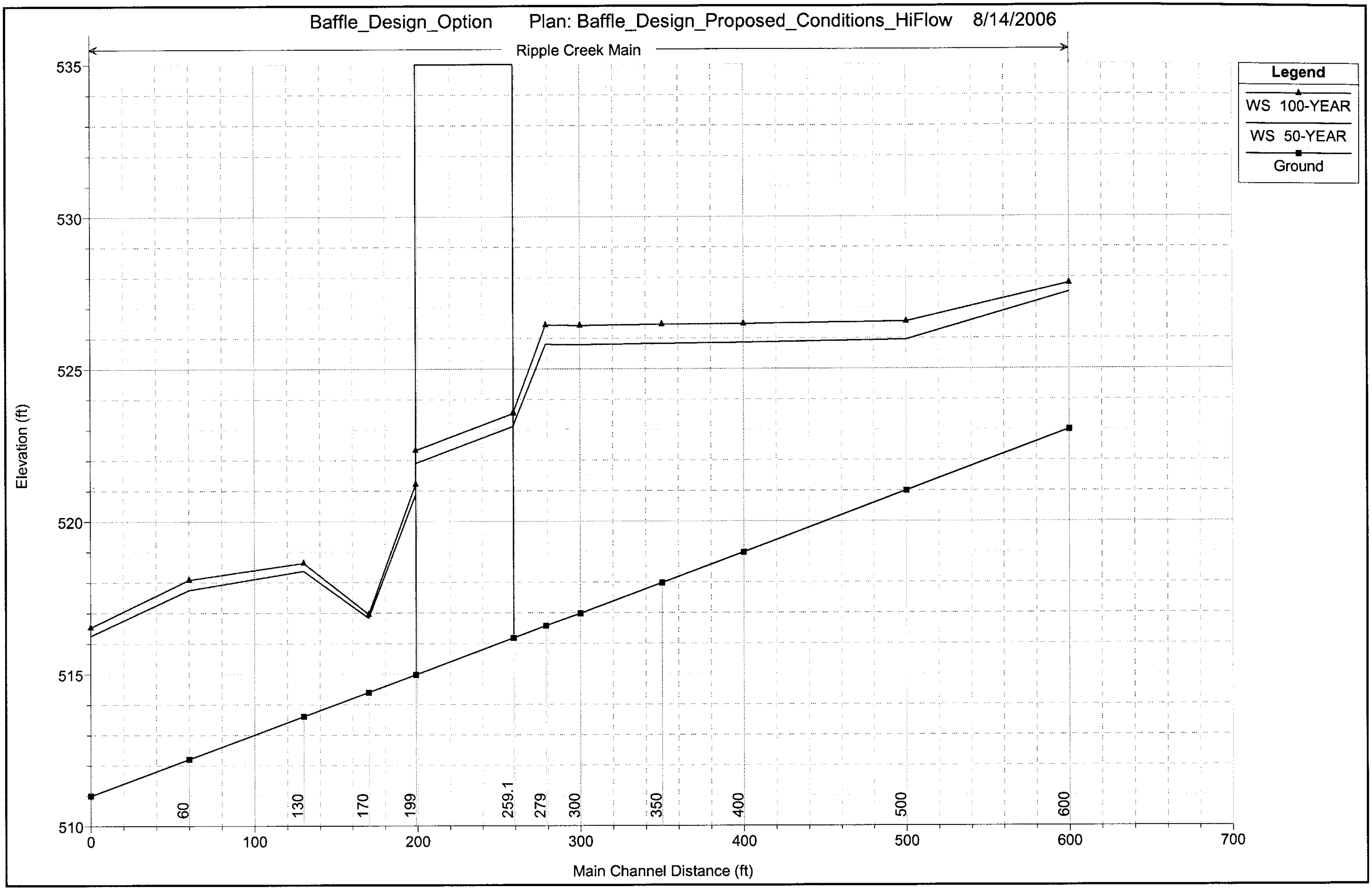
E.G. Elev (ft)	517.67	Q Gates (cfs)	
W.S. Elev (ft)	517.66	Q Gate Group (cfs)	
Q Total (cfs)	20.00	Gate Open Ht (ft)	528.02
Q Weir (cfs)	20.00	Gate #Open	528
Weir Flow Area (sq ft)	6.88	Gate Area (sq ft)	
Weir Sta Lft (ft)	20.10	Gate Submerg	
Weir Sta Rgt (ft)	28.10	Gate Invert (ft)	0.00
Weir Max Depth (ft)	2.65		
Weir Avg Depth (ft)	0.86		
Weir Submerg	0.13		
Min El Weir Flow (ft)	515.03		
Wr Top Wdth (ft)	8.01		

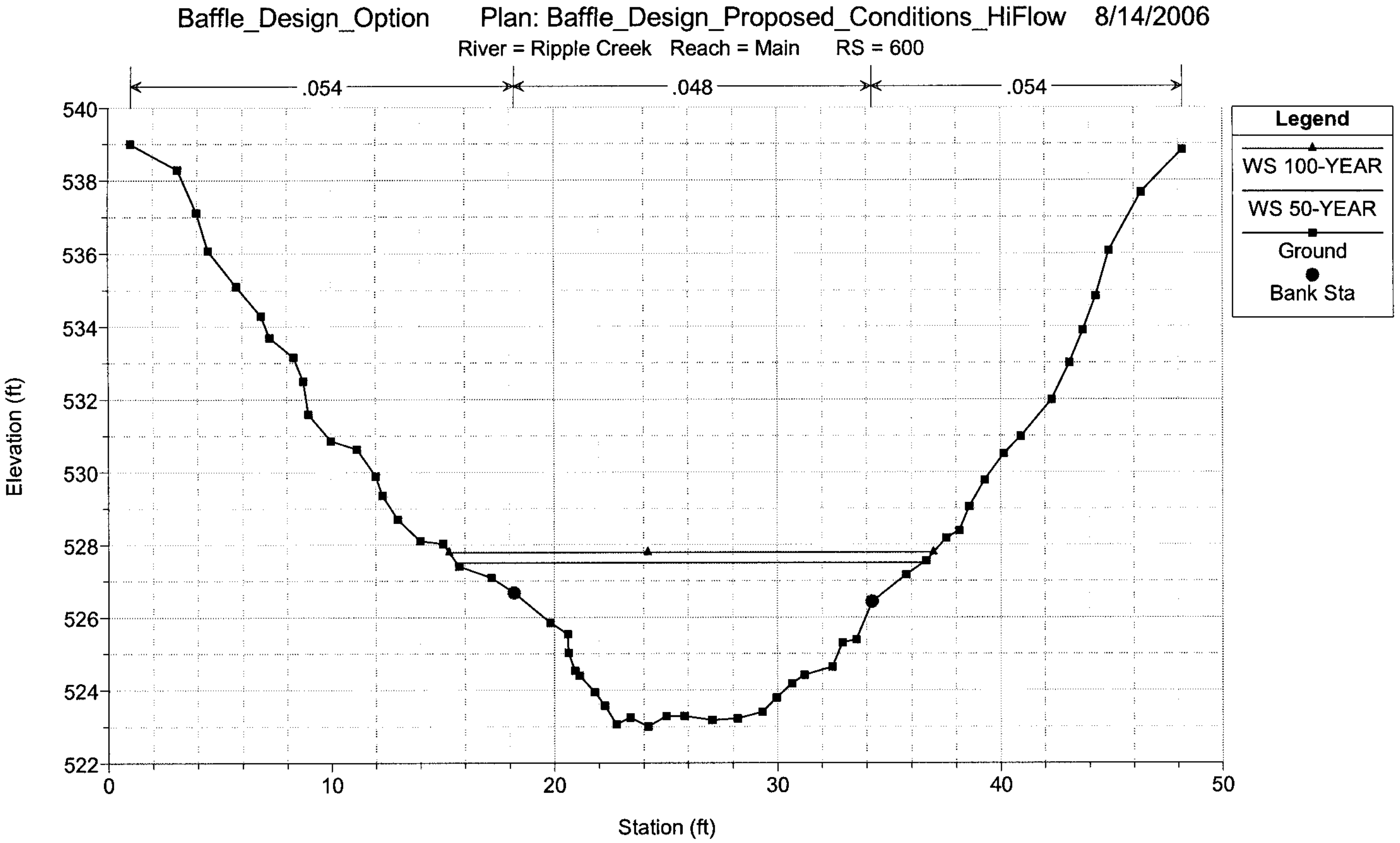
HEC-RAS Plan: Proposed LwQ River: Ripple Creek Reach: Main

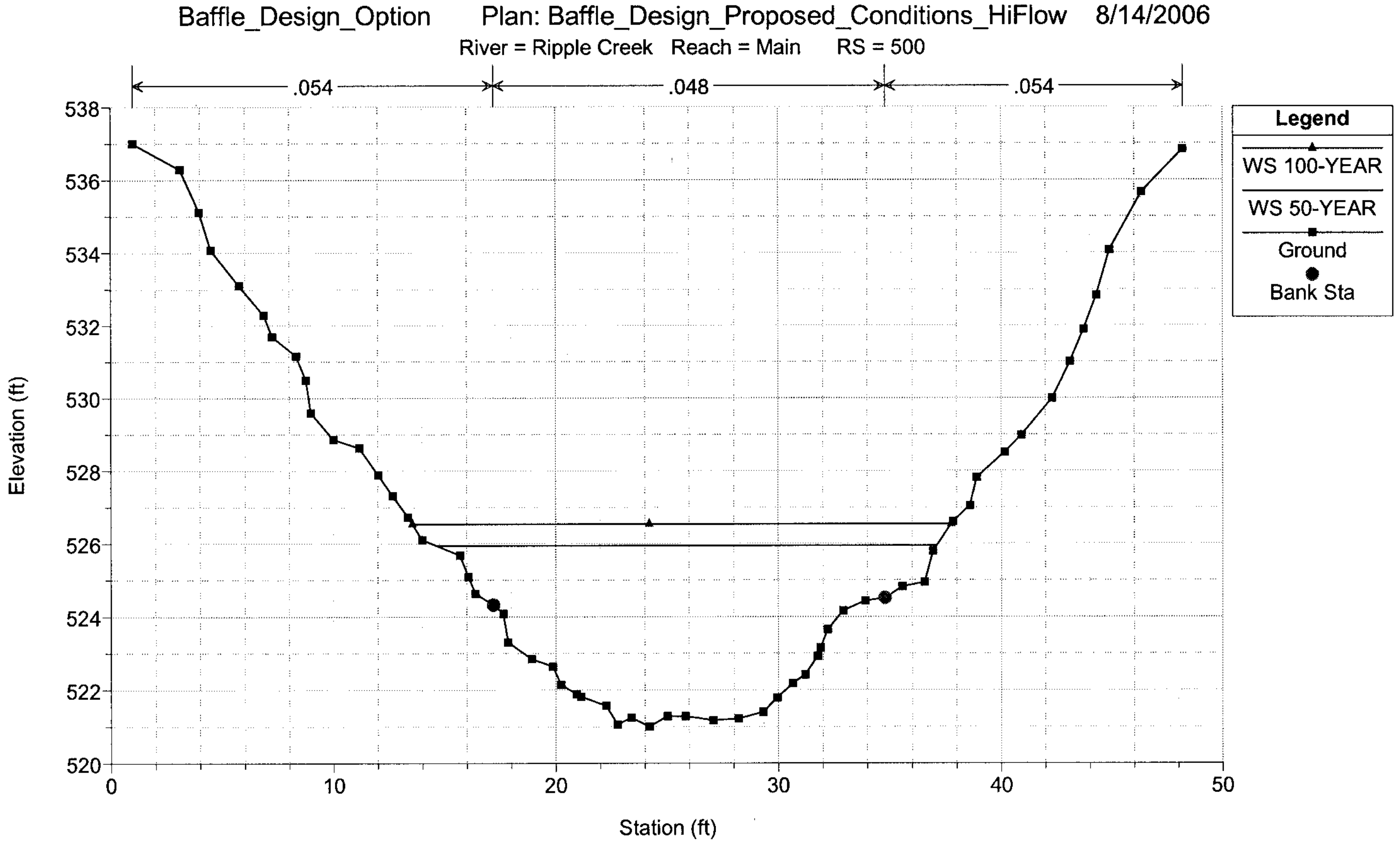
Reach	River Sta	Profile	Q Total	W.S. Elev	Min Ch El	Diff	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)		(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main	0	2-YEAR	161.00	514.23	510.99	3.24	513.78	514.77	0.020033	5.89	27.34	13.97	0.74
Main	0	10-YEAR	337.00	515.33	510.99	4.34	514.90	516.29	0.020006	7.86	43.32	15.10	0.79
Main	0	High Fish Passag	81.00	513.38	510.99	2.39	513.04	513.74	0.020013	4.86	16.68	11.28	0.70
Main	0	Low Fish Passage	20.00	512.42	510.99	1.43	512.21	512.56	0.020003	3.05	6.56	9.37	0.64
Main	60	2-YEAR	161.00	515.36	512.20	3.16		515.77	0.013983	5.19	31.03	15.84	0.65
Main	60	10-YEAR	337.00	516.66	512.20	4.46		517.26	0.012596	6.22	54.23	19.47	0.65
Main	60	High Fish Passag	81.00	514.54	512.20	2.34		514.84	0.016443	4.35	18.62	14.50	0.68
Main	60	Low Fish Passage	20.00	513.51	512.20	1.31		513.65	0.016573	2.99	6.70	9.24	0.62
Main	130	2-YEAR	161.00	516.52	513.61	2.91	516.34	517.18	0.027371	6.50	24.77	14.41	0.87
Main	130	10-YEAR	337.00	517.54	513.61	3.93	517.42	518.63	0.025777	8.39	40.90	17.74	0.91
Main	130	High Fish Passag	81.00	515.86	513.61	2.25		516.26	0.024455	5.07	15.96	12.34	0.79
Main	130	Low Fish Passage	20.00	514.87	513.61	1.26		515.07	0.025102	3.55	5.63	7.82	0.74
Main	170	2-YEAR	161.00	517.44	514.40	3.04	516.41	517.68	0.006248	3.86	41.68	18.47	0.45
Main	170	10-YEAR	337.00	518.77	514.40	4.37	517.37	519.15	0.006288	4.94	68.25	21.04	0.48
Main	170	High Fish Passag	81.00	516.57	514.40	2.17	515.83	516.72	0.006143	3.08	26.30	16.63	0.43
Main	170	Low Fish Passage	20.00	515.52	514.40	1.12	515.20	515.58	0.007507	2.01	9.94	14.40	0.43
Main	198	2-YEAR	161.00	517.37	514.96	2.41	517.20	518.33	0.020016	7.87	20.47	20.79	0.89
Main	198	10-YEAR	337.00	518.62	514.96	3.66	518.62	520.44	0.021673	10.83	31.13	22.87	1.00
Main	198	High Fish Passag	81.00	516.66	514.96	1.70	516.38	517.15	0.016131	5.60	14.46	19.00	0.76
Main	198	Low Fish Passage	20.00	515.75	514.96	0.79	515.52	515.89	0.012702	2.98	6.71	15.92	0.59
Main	200.7		Inl Struct										
Main	201.2	2-YEAR	161.00	520.35	515.02	5.33	517.34	520.58	0.000100	3.78	42.68	8.01	0.29
Main	201.2	10-YEAR	337.00	522.50	515.02	7.48	518.82	522.99	0.000142	5.64	59.84	8.02	0.36
Main	201.2	High Fish Passag	81.00	519.08	515.02	4.06	516.49	519.17	0.000063	2.50	32.43	8.01	0.22
Main	201.2	Low Fish Passage	20.00	517.66	515.02	2.64	515.60	517.67	0.000016	0.95	21.08	8.01	0.10
Main	224	2-YEAR	161.00	520.32	515.48	4.84		520.59	0.000137	4.15	38.79	8.01	0.33
Main	224	10-YEAR	337.00	522.45	515.48	6.97		523.01	0.000179	6.05	55.80	8.02	0.40
Main	224	High Fish Passag	81.00	519.06	515.48	3.58		519.18	0.000095	2.83	28.64	8.01	0.26
Main	224	Low Fish Passage	20.00	517.65	515.48	2.17		517.67	0.000031	1.15	17.39	8.01	0.14
Main	225.7		Inl Struct										
Main	226.2	2-YEAR	161.00	520.88	515.52	5.36	517.84	521.10	0.000098	3.76	42.87	8.01	0.29
Main	226.2	10-YEAR	337.00	523.06	515.52	7.54	519.32	523.55	0.000138	5.59	60.37	8.02	0.36
Main	226.2	High Fish Passag	81.00	519.58	515.52	4.06	516.99	519.67	0.000063	2.50	32.45	8.01	0.22
Main	226.2	Low Fish Passage	20.00	518.15	515.52	2.63	516.10	518.17	0.000016	0.95	21.04	8.01	0.10
Main	249	2-YEAR	161.00	520.85	515.98	4.87		521.11	0.000135	4.13	38.98	8.01	0.33
Main	249	10-YEAR	337.00	523.01	515.98	7.03		523.57	0.000174	5.99	56.34	8.02	0.40
Main	249	High Fish Passag	81.00	519.56	515.98	3.58		519.68	0.000095	2.83	28.66	8.01	0.26
Main	249	Low Fish Passage	20.00	518.15	515.98	2.17		518.17	0.000031	1.15	17.36	8.01	0.14
Main	250.7		Inl Struct										
Main	251.2	2-YEAR	161.00	521.38	516.02	5.36	518.34	521.60	0.000099	3.76	42.85	8.01	0.29
Main	251.2	10-YEAR	337.00	523.57	516.02	7.55	519.82	524.05	0.000137	5.58	60.43	8.02	0.36
Main	251.2	High Fish Passag	81.00	520.08	516.02	4.06	517.49	520.17	0.000063	2.50	32.45	8.01	0.22
Main	251.2	Low Fish Passage	20.00	518.66	516.02	2.64	516.60	518.67	0.000016	0.95	21.10	8.01	0.10
Main	259	2-YEAR	161.00	521.37	516.18	5.19		521.60	0.000109	3.88	41.55	8.01	0.30
Main	259	10-YEAR	337.00	523.56	516.18	7.38		524.06	0.000148	5.71	59.09	8.02	0.37
Main	259	High Fish Passag	81.00	520.07	516.18	3.89		520.18	0.000072	2.60	31.18	8.01	0.23
Main	259	Low Fish Passage	20.00	518.66	516.18	2.48		518.68	0.000020	1.01	19.84	8.01	0.11
Main	279	2-YEAR	161.00	521.56	516.58	4.98		521.62	0.000674	1.98	81.31	22.57	0.18
Main	279	10-YEAR	337.00	524.02	516.58	7.44		524.11	0.000525	2.44	140.52	25.51	0.18
Main	279	High Fish Passag	81.00	520.15	516.58	3.57		520.19	0.000623	1.59	51.09	19.43	0.17
Main	279	Low Fish Passage	20.00	518.67	516.58	2.09		518.68	0.000338	0.83	24.21	16.48	0.12
Main	300	2-YEAR	161.00	521.54	516.98	4.56		521.67	0.002493	2.84	56.73	19.87	0.30
Main	300	10-YEAR	337.00	524.00	516.98	7.02		524.14	0.001358	3.03	113.85	26.18	0.24
Main	300	High Fish Passag	81.00	520.13	516.98	3.15		520.23	0.003045	2.54	31.88	15.48	0.31
Main	300	Low Fish Passage	20.00	518.66	516.98	1.68	517.85	518.70	0.002500	1.60	12.52	10.83	0.26
Main	350	2-YEAR	161.00	521.66	517.98	3.68		521.88	0.005667	3.74	43.09	17.87	0.42
Main	350	10-YEAR	337.00	524.05	517.98	6.07		524.25	0.002365	3.55	97.29	25.36	0.30
Main	350	High Fish Passag	81.00	520.30	517.98	2.32		520.52	0.010203	3.75	21.60	14.53	0.54
Main	350	Low Fish Passage	20.00	518.91	517.98	0.93	518.91	519.19	0.045275	4.28	4.67	8.36	1.01

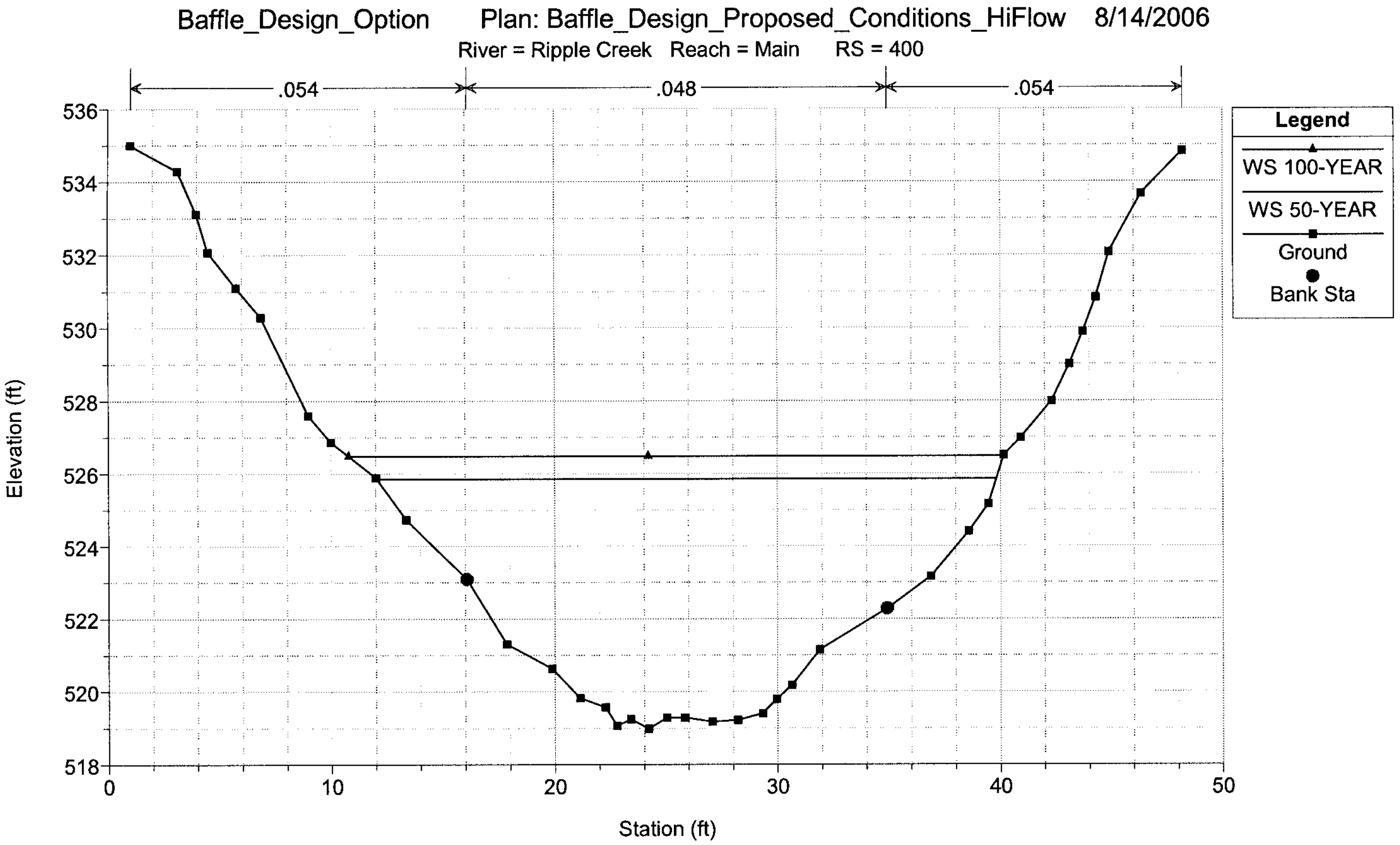
HEC-RAS Plan: Proposed LwQ River: Ripple Creek Reach: Main (Continued)

Reach	River Sta	Profile	Q Total	W.S. Elev	Min Ch El	Diff	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)		(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main	400	2-YEAR	161.00	521.94	518.98	2.96		522.35	0.013519	5.13	31.41	16.80	0.66
Main	400	10-YEAR	337.00	524.12	518.98	5.14		524.44	0.004354	4.62	75.79	23.80	0.42
Main	400	High Fish Passag	81.00	520.90	518.98	1.92		521.30	0.021778	5.08	15.94	12.48	0.79
Main	400	Low Fish Passage	20.00	520.13	518.98	1.15		520.24	0.011824	2.67	7.48	9.90	0.54
Main	500	2-YEAR	161.00	523.53	521.00	2.53	523.34	524.17	0.023777	6.41	25.10	14.35	0.85
Main	500	10-YEAR	337.00	524.48	521.00	3.48	524.47	525.61	0.030104	8.53	39.55	17.65	0.99
Main	500	High Fish Passag	81.00	522.96	521.00	1.96		523.31	0.018552	4.74	17.09	13.15	0.73
Main	500	Low Fish Passage	20.00	521.91	521.00	0.91	521.85	522.13	0.033253	3.76	5.32	9.26	0.87
Main	600	2-YEAR	161.00	525.78	523.00	2.78	525.43	526.35	0.019958	6.09	26.44	13.80	0.78
Main	600	10-YEAR	337.00	527.04	523.00	4.04	526.56	527.88	0.017319	7.35	46.31	18.19	0.77
Main	600	High Fish Passag	81.00	524.93	523.00	1.93	524.73	525.35	0.022138	5.15	15.72	11.97	0.79
Main	600	Low Fish Passage	20.00	524.10	523.00	1.10	523.84	524.23	0.014520	2.95	6.77	8.91	0.60


Baffle_Design_Option Plan: Baffle_Design_Proposed_Conditions_HiFlow 8/14/2006
Ripple Creek Main
Legend
WS 100-YEAR
WS 50-YEAR
Ground
Elevation (ft)
535
530
525
520
515
510
60
130
170
199
259.1
279
300
350
400
500
600
0
100
200
300
400
500
600
700
Main Channel Distance (ft)

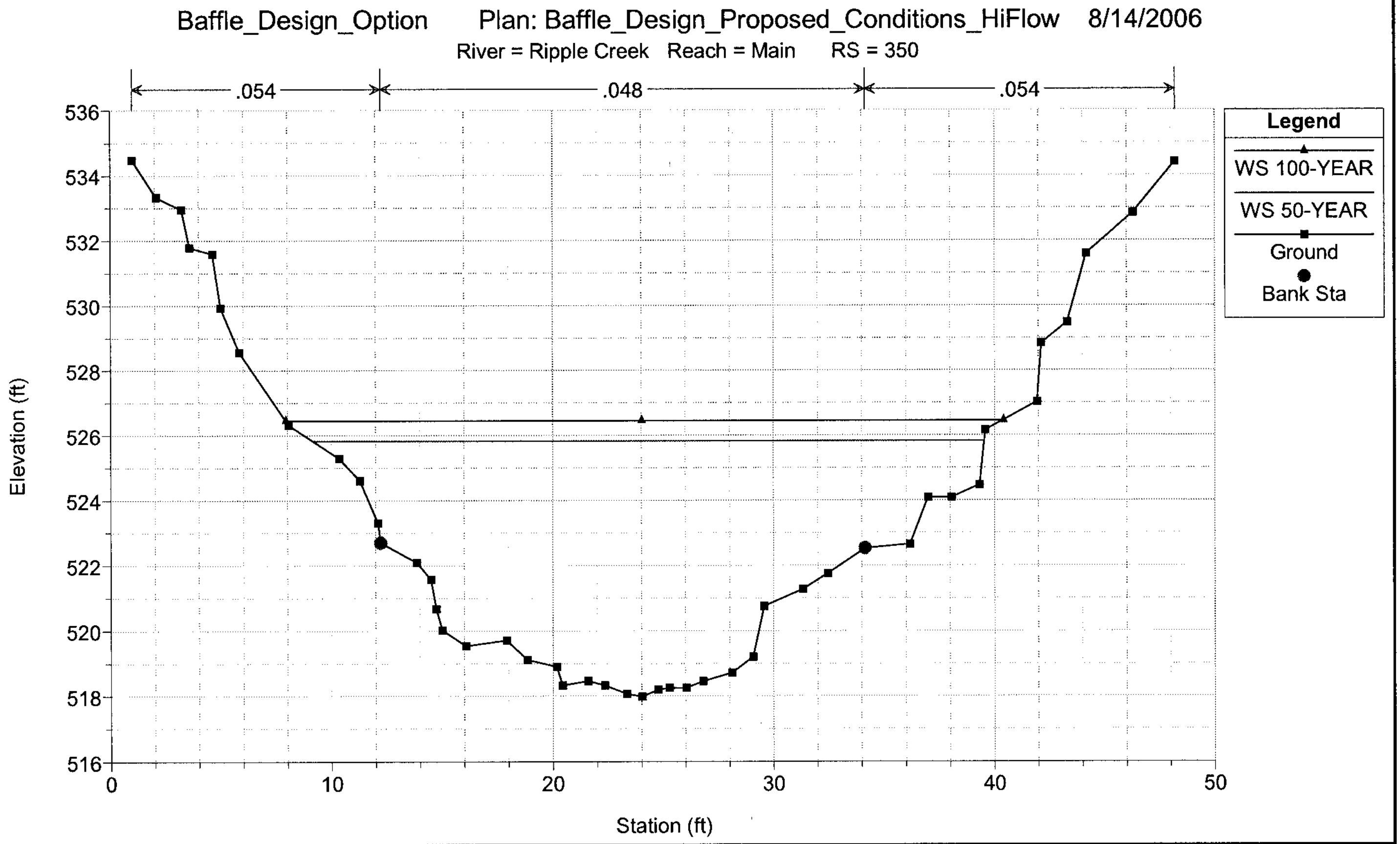

Baffle_Design_Option Plan: Baffle_Design_Proposed_Conditions_HiFlow 8/14/2006
River = Ripple Creek Reach = Main RS = 600
.054
.048
.054
Legend
WS 100-YEAR
WS 50-YEAR
Ground
Bank Sta
Elevation (ft)
540
538
536
534
532
530
528
526
524
522
Station (ft)
0
10
20
30
40
50


Baffle_Design_Option Plan: Baffle_Design_Proposed_Conditions_HiFlow 8/14/2006
River = Ripple Creek Reach = Main RS = 500
.054
.048
.054
Legend
WS 100-YEAR
WS 50-YEAR
Ground
Bank Sta
Elevation (ft)
538
536
534
532
530
528
526
524
522
520
Station (ft)
0
10
20
30
40
50



Baffle_Design_Option Plan: Baffle_Design_Proposed_Conditions_HiFlow 8/14/2006

River = Ripple Creek Reach = Main RS = 400

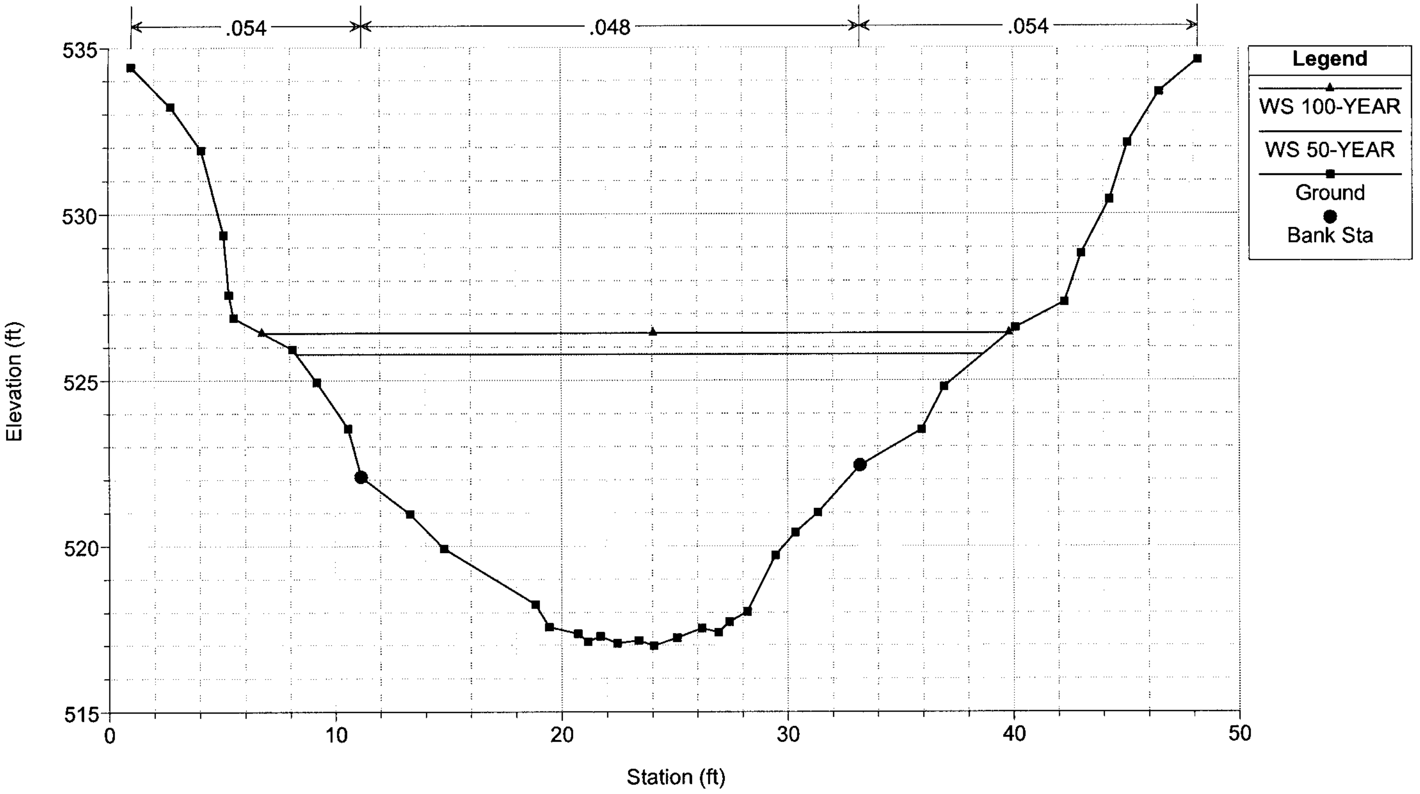


Baffle_Design_Option Plan: Baffle_Design_Proposed_Conditions_HiFlow 8/14/2006

River = Ripple Creek Reach = Main RS = 350

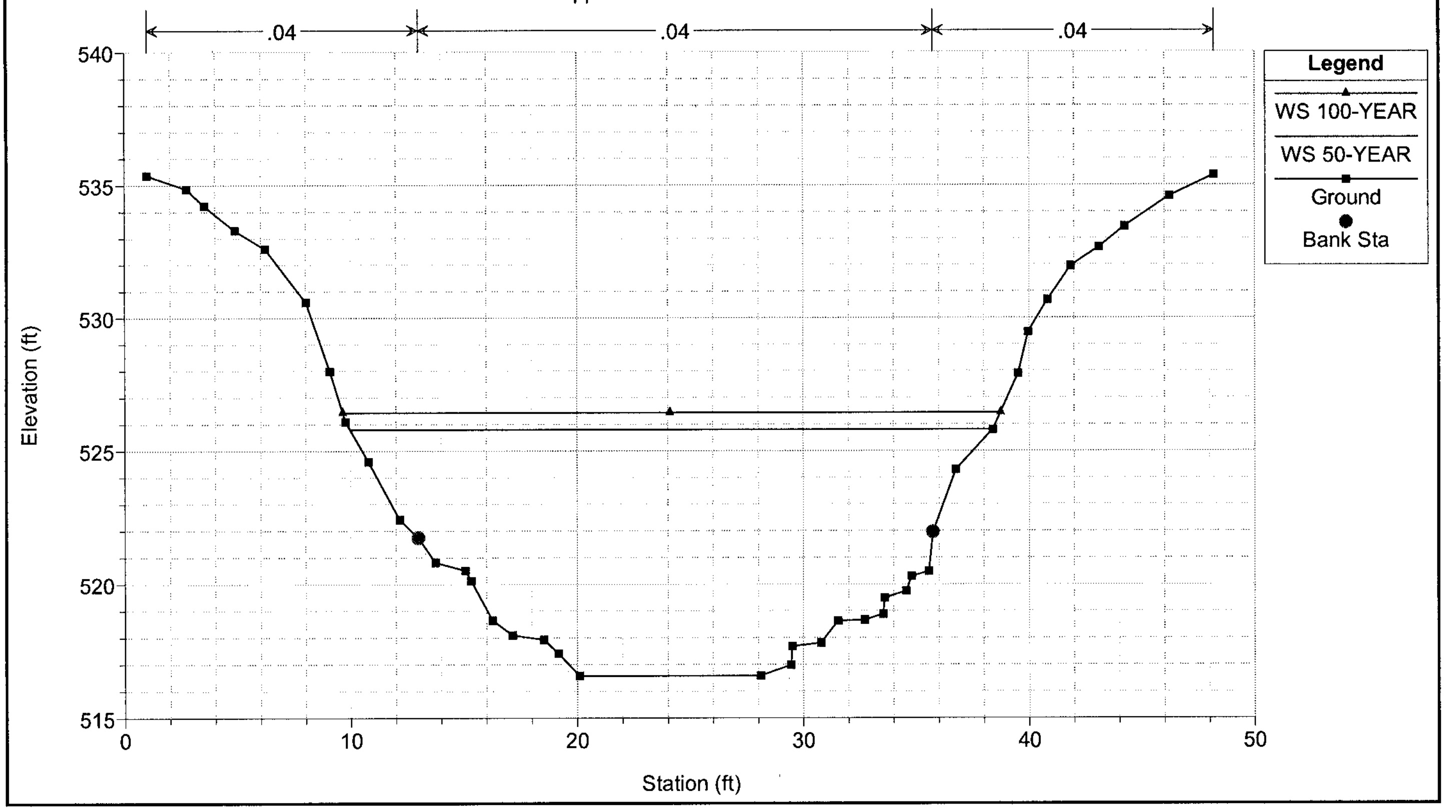
Baffle_Design_Option Plan: Baffle_Design_Proposed_Conditions_HiFlow 8/14/2006

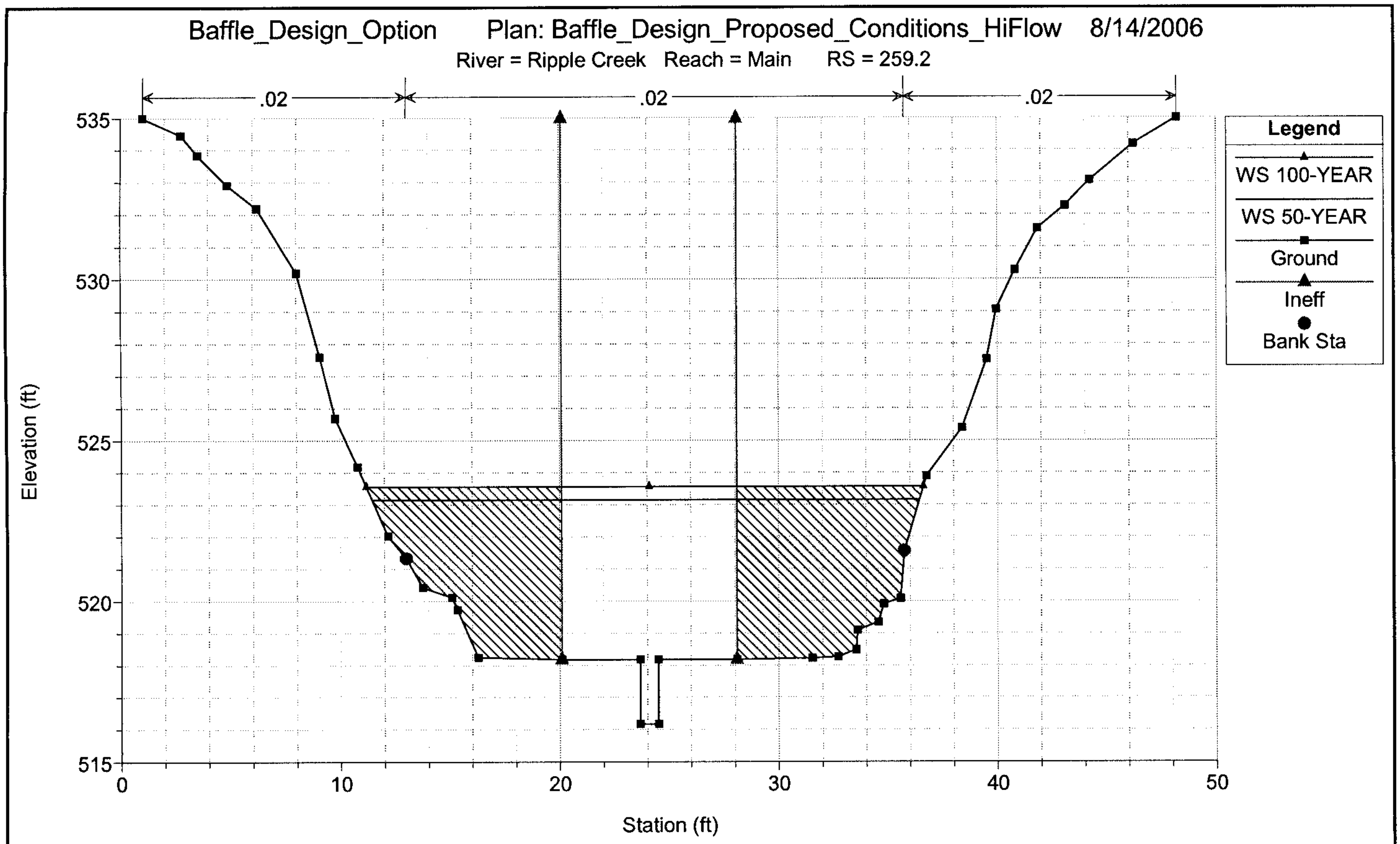
River = Ripple Creek Reach = Main RS = 300



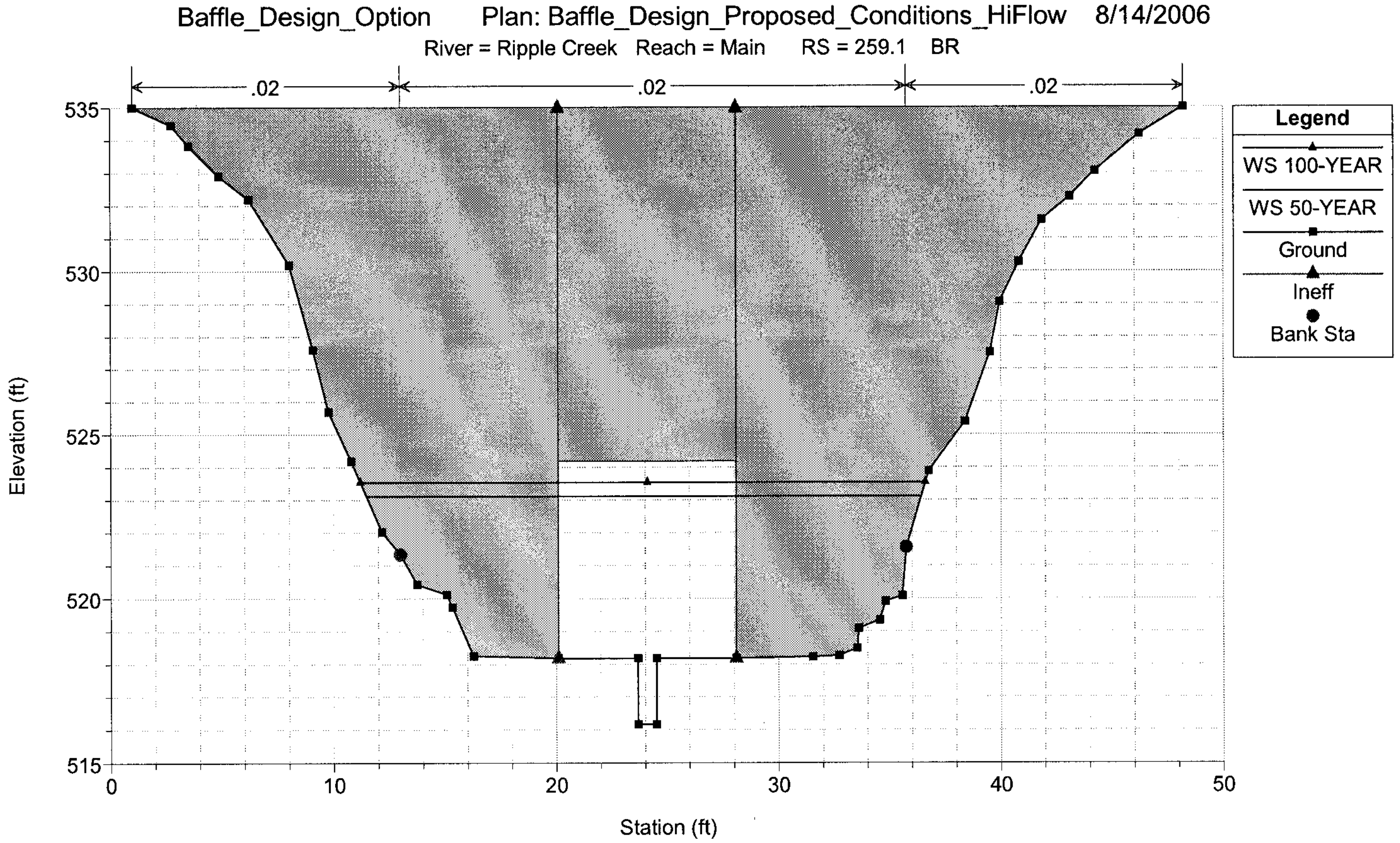
Baffle_Design_Option Plan: Baffle_Design_Proposed_Conditions_HiFlow 8/14/2006

River = Ripple Creek Reach = Main RS = 279

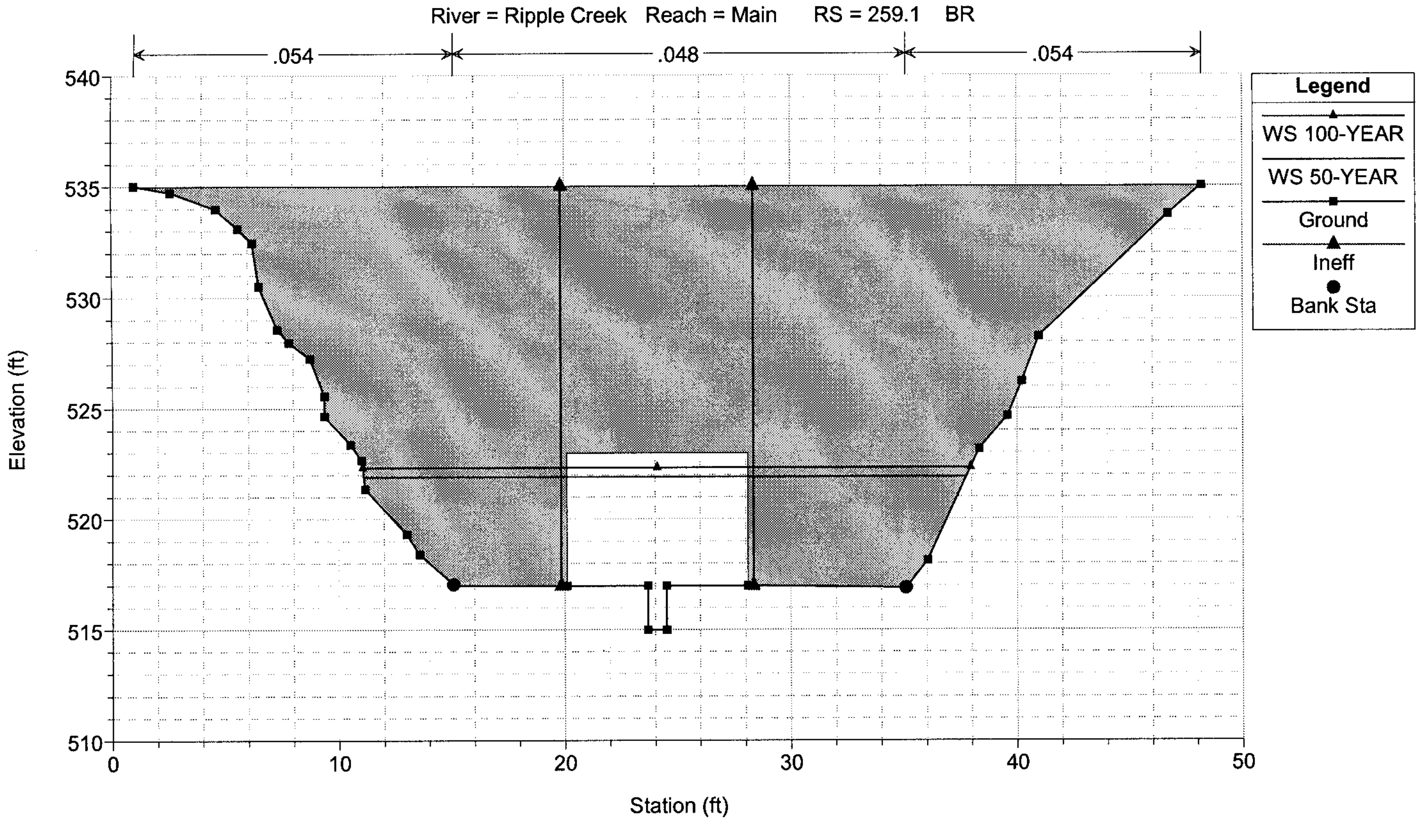


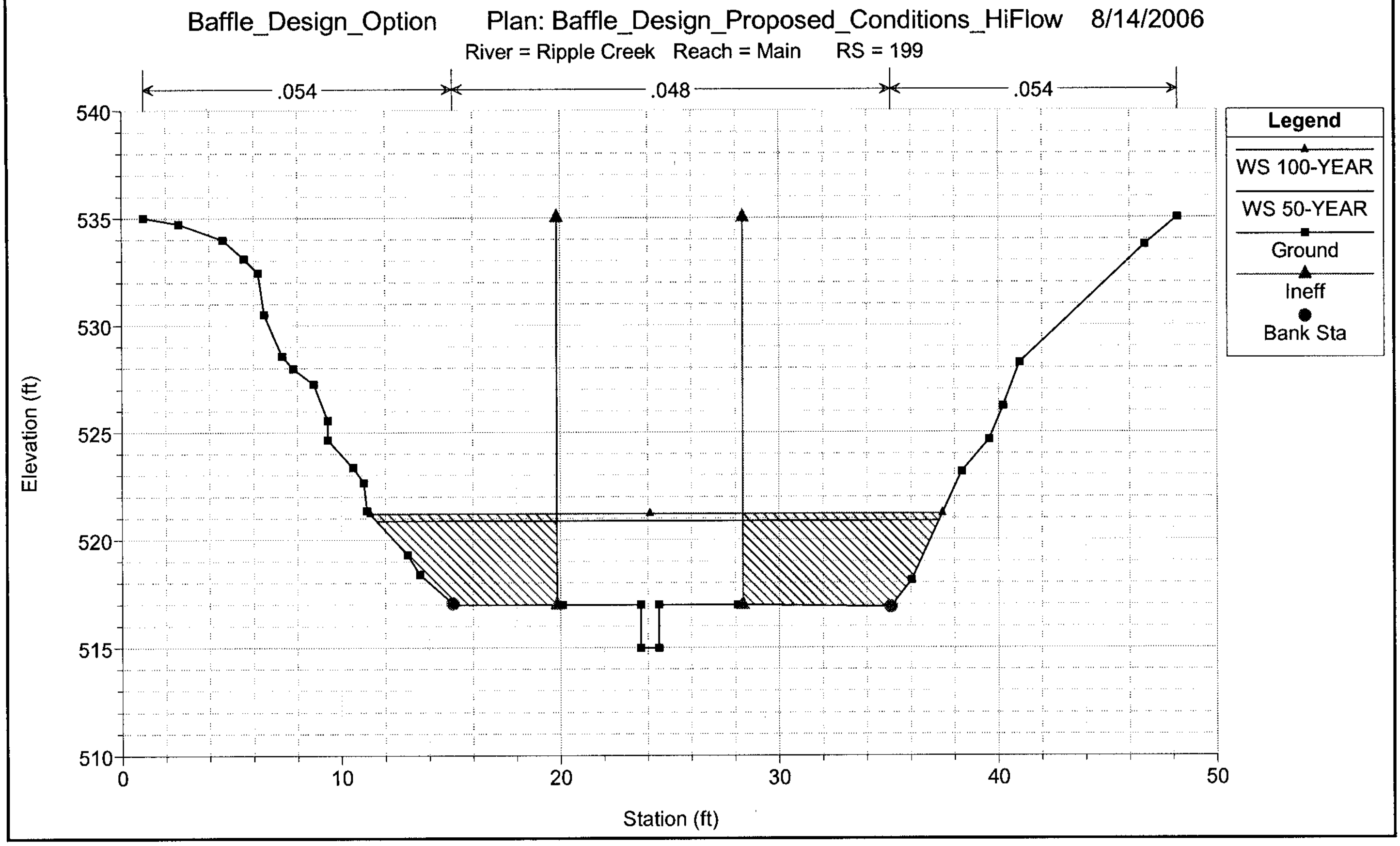


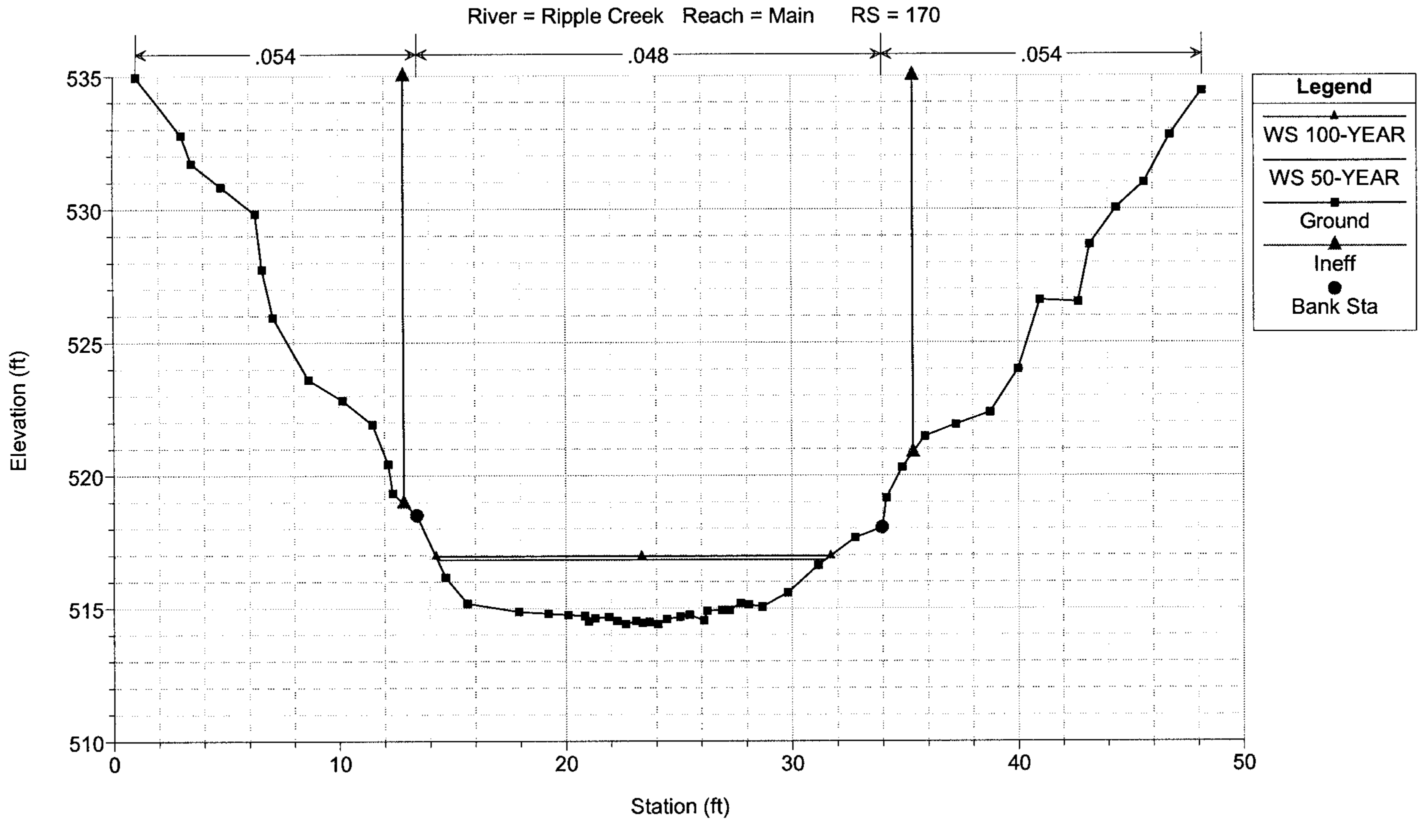
Baffle_Design_Option Plan: Baffle_Design_Proposed_Conditions_HiFlow 8/14/2006
River = Ripple Creek Reach = Main RS = 259.2

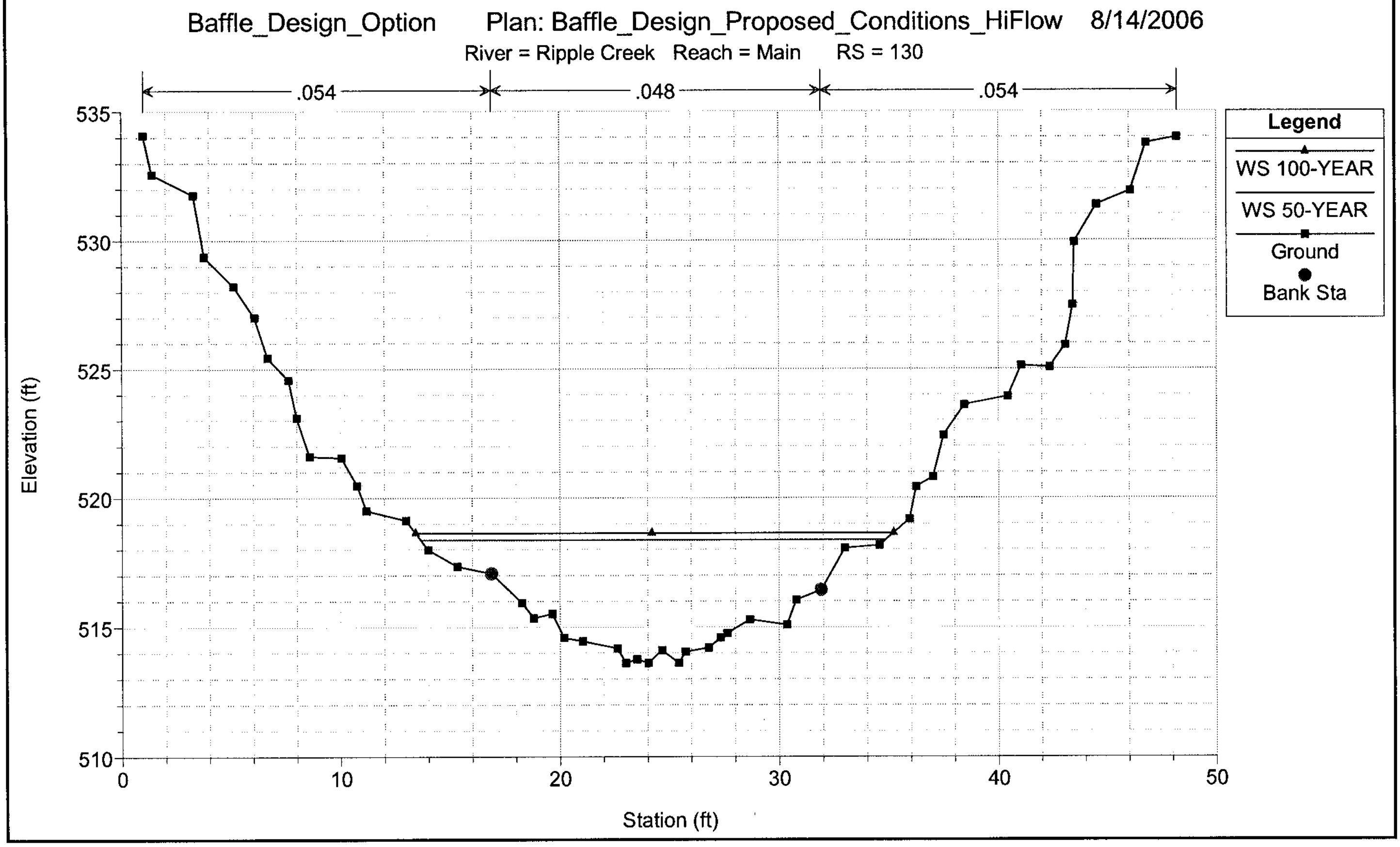


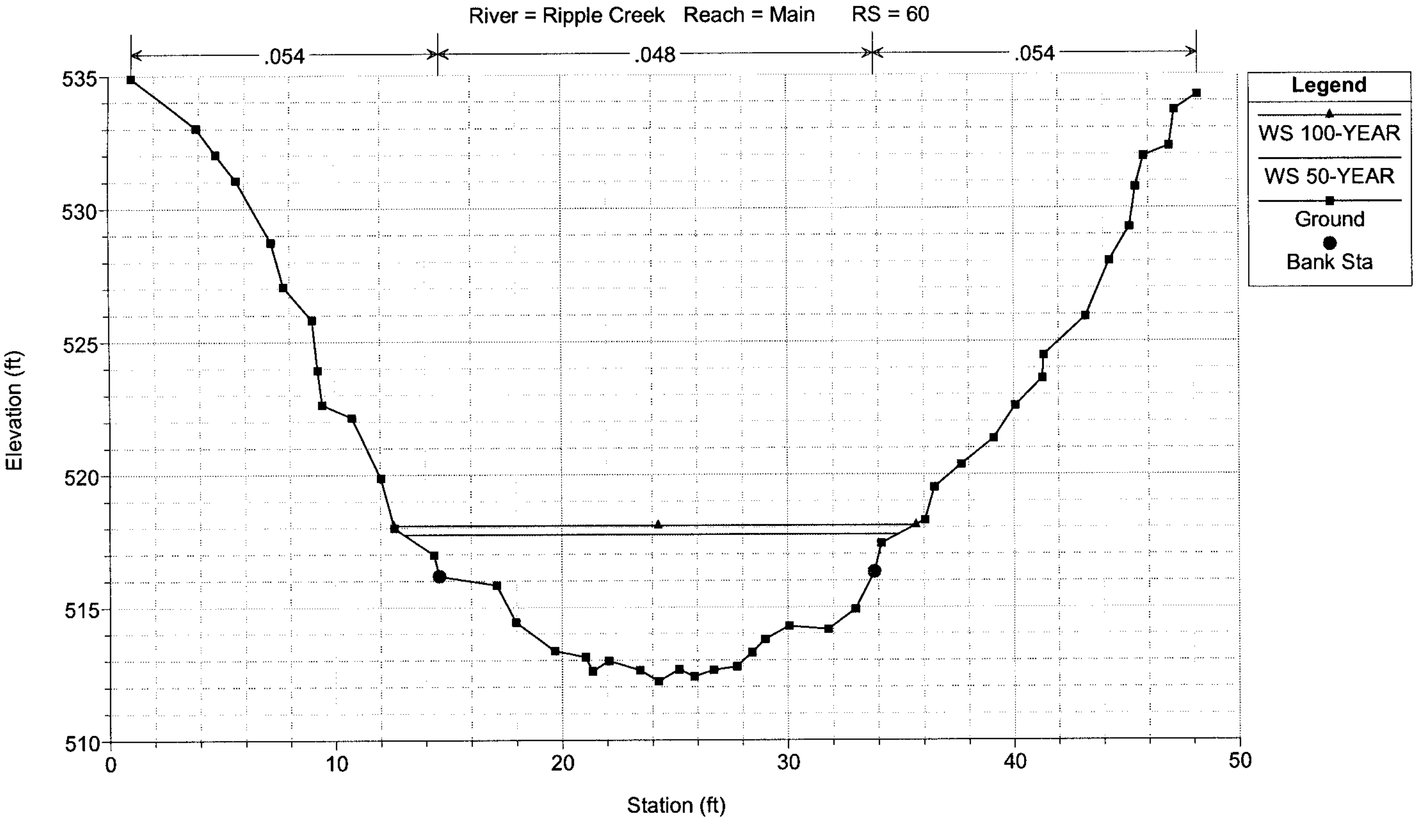
Baffle_Design_Option Plan: Baffle_Design_Proposed_Conditions_HiFlow 8/14/2006
River = Ripple Creek Reach = Main RS = 259.1 BR


Baffle_Design_Option Plan: Baffle_Design_Proposed_Conditions_HiFlow 8/14/2006
River = Ripple Creek Reach = Main RS = 259.1 BR


Baffle_Design_Option Plan: Baffle_Design_Proposed_Conditions_HiFlow 8/14/2006
River = Ripple Creek Reach = Main RS = 199

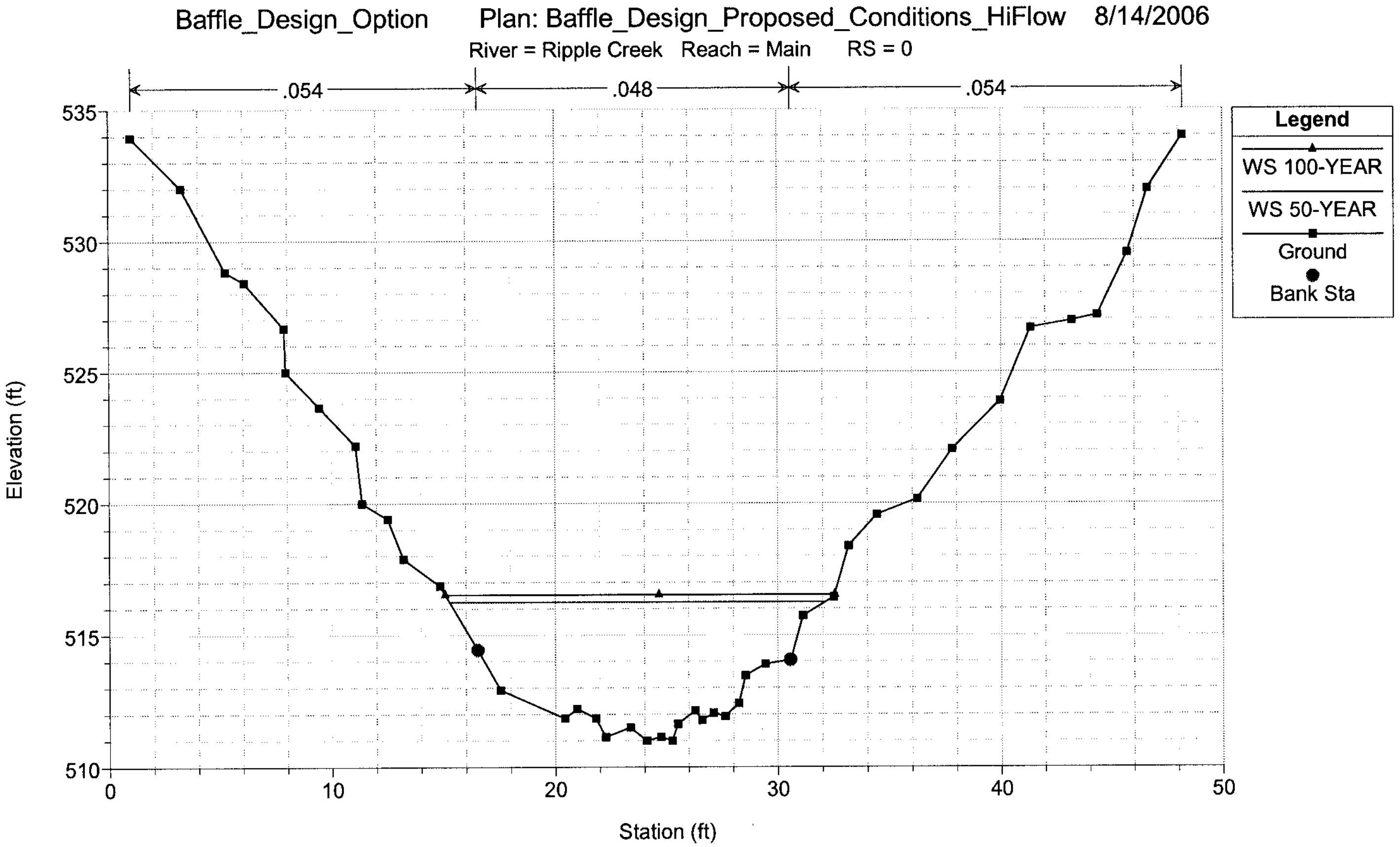

Baffle_Design_Option Plan: Baffle_Design_Proposed_Conditions_HiFlow 8/14/2006
River = Ripple Creek Reach = Main RS = 170
.054
.048
.054
Legend
WS 100-YEAR
WS 50-YEAR
Ground
Ineff
Bank Sta
Elevation (ft)
535
530
525
520
515
510
0
10
20
30
40
50
Station (ft)


Baffle_Design_Option Plan: Baffle_Design_Proposed_Conditions_HiFlow 8/14/2006
River = Ripple Creek Reach = Main RS = 130
.054
.048
.054
Legend
WS 100-YEAR
WS 50-YEAR
Ground
Bank Sta
Elevation (ft)
535
530
525
520
515
510
0
10
20
30
40
50
Station (ft)



Baffle_Design_Option Plan: Baffle_Design_Proposed_Conditions_HiFlow 8/14/2006

River = Ripple Creek Reach = Main RS = 60



Baffle_Design_Option Plan: Baffle_Design_Proposed_Conditions_HiFlow 8/14/2006

River = Ripple Creek Reach = Main RS = 0

HEC-RAS Plan: Proposed HiQ River: Ripple Creek Reach: Main

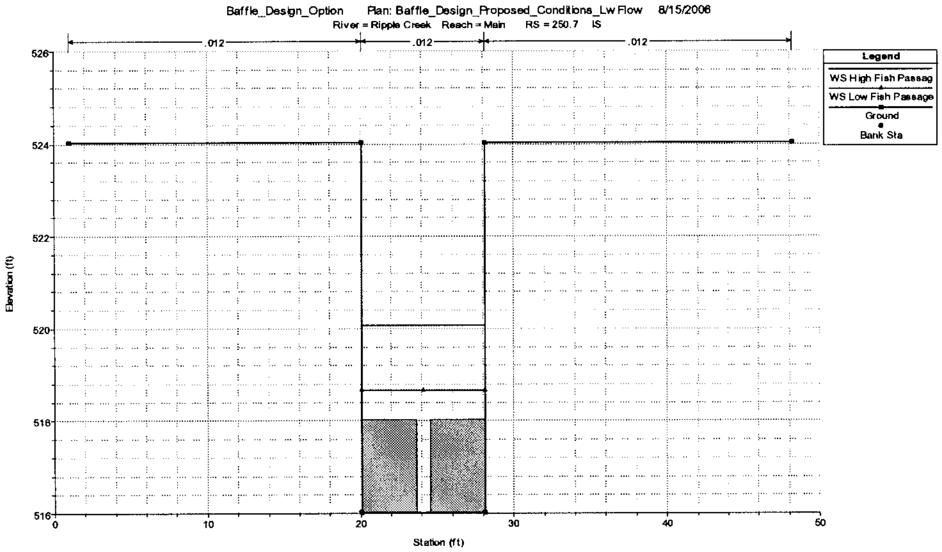
Reach	River Sta	Profile	Q Total	W.S. Elev	Min Ch El	Diff	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)		(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main	0	50-YEAR	528.00	516.25	510.99	5.26	515.82	517.61	0.020037	9.39	57.92	16.90	0.83
Main	0	100-YEAR	593.00	516.53	510.99	5.54	516.13	518.01	0.020027	9.81	62.69	17.47	0.84
Main	60	50-YEAR	528.00	517.75	512.20	5.55	516.70	518.51	0.010381	7.02	76.25	21.87	0.63
Main	60	100-YEAR	593.00	518.08	512.20	5.88	516.94	518.89	0.009872	7.23	83.84	23.07	0.62
Main	130	50-YEAR	528.00	518.37	513.61	4.76	518.37	519.83	0.024512	9.81	56.85	21.19	0.93
Main	130	100-YEAR	593.00	518.63	513.61	5.02	518.63	520.17	0.023750	10.13	62.50	21.78	0.92
Main	170	50-YEAR	528.00	516.83	514.40	2.43	518.18	521.41	0.164079	17.18	30.74	17.17	2.26
Main	170	100-YEAR	593.00	516.96	514.40	2.56	518.42	521.99	0.168783	18.00	32.94	17.44	2.31
Main	199	50-YEAR	528.00	520.88	514.98	5.90	521.69	524.44	0.060925	15.14	34.87	25.71	1.32
Main	199	100-YEAR	593.00	521.21	514.98	6.23	522.12	525.06	0.059482	15.75	37.66	26.15	1.32
Main	259.1		Bridge										
Main	259.2	50-YEAR	528.00	523.15	516.18	6.97	523.11	525.67	0.005636	12.74	41.44	25.00	0.99
Main	259.2	100-YEAR	593.00	523.57	516.18	7.39	523.51	526.29	0.005495	13.25	44.77	25.45	0.99
Main	279	50-YEAR	528.00	525.81	516.58	9.23		525.94	0.000529	2.91	188.61	28.45	0.18
Main	279	100-YEAR	593.00	526.44	516.58	9.86		526.57	0.000509	3.01	206.76	29.10	0.18
Main	300	50-YEAR	528.00	525.79	516.98	8.81		525.97	0.001149	3.42	164.01	30.41	0.23
Main	300	100-YEAR	593.00	526.42	516.98	9.44		526.60	0.001055	3.48	184.00	33.04	0.23
Main	350	50-YEAR	528.00	525.83	517.98	7.85		526.05	0.001710	3.81	148.05	30.40	0.27
Main	350	100-YEAR	593.00	526.46	517.98	8.48		526.68	0.001519	3.84	167.70	32.49	0.26
Main	400	50-YEAR	528.00	525.86	518.98	6.88		526.19	0.002785	4.75	121.13	27.78	0.36
Main	400	100-YEAR	593.00	526.48	518.98	7.50		526.80	0.002393	4.72	138.83	29.36	0.34
Main	500	50-YEAR	528.00	525.95	521.00	4.95	525.30	526.91	0.013553	7.91	69.62	22.52	0.72
Main	500	100-YEAR	593.00	526.54	521.00	5.54	525.55	527.40	0.010187	7.56	83.42	24.19	0.64
Main	600	50-YEAR	528.00	527.50	523.00	4.50	527.50	528.99	0.025353	9.83	55.39	20.90	0.95
Main	600	100-YEAR	593.00	527.79	523.00	4.79	527.79	529.34	0.023816	10.07	61.52	21.70	0.93

Velocity and Depth Hand Calculations Through Baffles

Project Information: Fish Passage Improvement Route 555			Computed: EKB		Date: 7/18/2006
			Checked: JJL		Date: 7/19/2006
Stream Name:	Ripple Creek	County: Mendocino	Route: 555		Postmile: 20.2

Calculations:

Baffle Structure = 250.7 IS


Baffle_Design_Option Plan: Baffle_Design_Proposed_Conditions_Lw Flow 8/15/2006
River = Ripple Creek Reach = Main RS = 250.7 IS

Broad Crested Weir Q = CLH^1.5

<u>Low Fish Passage Design Flow = 20 cfs</u>

Knowns:

C = 2.73 ft^0.5/sec
Length of weir = 3.583 ft
WSE_LowFlow = 518.66 ft
Top of Weir Elevation = 518.02 ft
Head = 0.64 ft

Q_Baffle = 5.0 cfs
Q_Total_Baffle = 10.02 cfs

Q_Notch = Q_Total - Q_Total_Baffle = 20 cfs - 10 cfs
Q_Notch = 10 cfs

A_Notch = Base*Height = 0.83 ft * 2.64 ft
A_Notch = 2.19 ft^2

V_Notch = Flow / Area = 10 cfs / 2.19 ft^2
V_Notch = 4.56 ft/sec

<u>High Fish Passage Design Flow = 81 cfs</u>

Knowns:

C = 2.73 ft^0.5/sec
Length of weir = 3.583 ft
WSE_HighFlow = 520.08 ft
Top of Weir Elevation = 518.02 ft
Head = 2.06 ft

Q_Baffle = 28.92 cfs
Q_Total_Baffle = 57.84 cfs

Q_Notch = Q_Total - Q_Total_Baffle = 81 cfs - 57.84 cfs
Q_Notch = 23.16 cfs

A_Notch = Base*Height = 0.83 ft * 4.06 ft
A_Notch = 3.37 ft^2

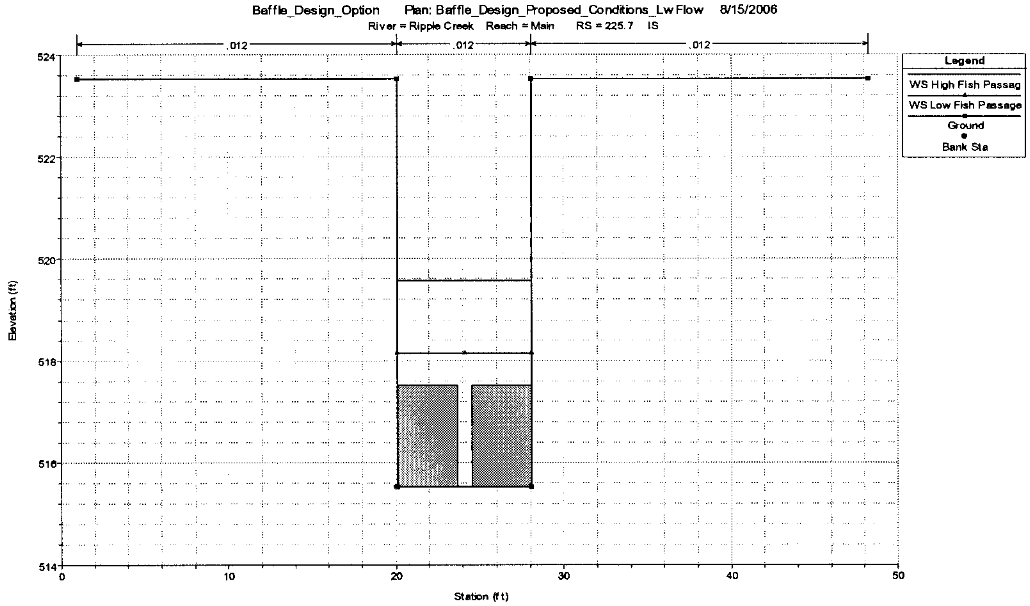
V_Notch = Flow / Area = 23.16 cfs / 3.37 ft^2
V_Notch = 6.87 ft/sec

Velocity and Depth Hand Calculations Through Baffles

Project Information:				Computed:	EKB	Date:	7/18/2006
Fish Passage Improvement Route 555				Checked:	JJL	Date:	7/19/2006
Stream Name:	Ripple Creek	County:	Mendocino	Route:	555	Postmile:	20.2

Calculations:

Baffle Structure = 225.7 IS



Broad Crested Weir Q = CLH^1.5

Low Fish Passage Design Flow = 20 cfs

Knowns:

C =	2.73	ft^0.5/sec
Length of weir =	3.583	ft
WSE_LowFlow =	518.15	ft
Top of Weir Elevation =	517.52	ft
Head =	0.63	ft

Q_Baffle = 4.9 cfs
Q_Total_Baffle = 9.78 cfs

Q_Notch = Q_Total - Q_Total_Baffle = 20 cfs - 9.78 cfs
Q_Notch = 10 cfs

A_Notch = Base*Height = 0.83 ft * 2.63 ft
A_Notch = 2.18 ft^2

V_Notch = Flow / Area = 10.22 cfs / 2.18 ft^2
V_Notch = 4.68 ft/sec

High Fish Passage Design Flow = 81 cfs

Knowns:

C =	2.73	ft^0.5/sec
Length of weir =	3.583	ft
WSE_HighFlow =	519.58	ft
Top of Weir Elevation =	517.52	ft
Head =	2.06	ft

Q_Baffle = 28.92 cfs
Q_Total_Baffle = 57.84 cfs

Q_Notch = Q_Total - Q_Total_Baffle = 81 cfs - 57.83 cfs
Q_Notch = 23.17 cfs

A_Notch = Base*Height = 0.83 ft * 4.06 ft
A_Notch = 3.37 ft^2

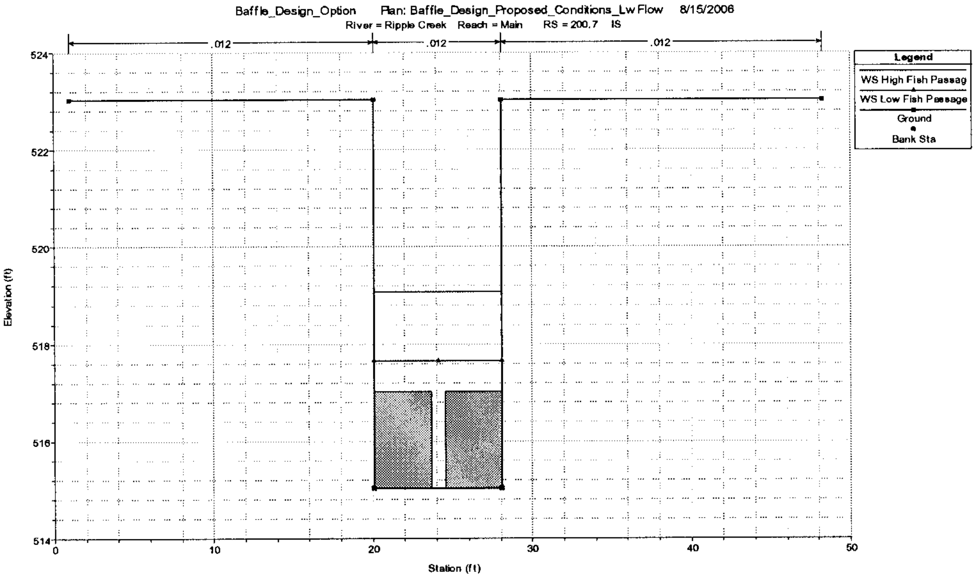
V_Notch = Flow / Area = 23.17 cfs / 3.37 ft^2
V_Notch = 6.88 ft/sec

Velocity and Depth Hand Calculations Through Baffles

Project Information: Fish Passage Improvement Route 555				Computed:	EKB	Date:	7/18/2006
				Checked:	JJL	Date:	7/19/2006
Stream Name:	Ripple Creek	County:	Mendocino	Route:	555	Postmile:	20.2

Calculations:

Baffle Structure = 200.7 IS



Broad Crested Weir Q = CLH^1.5

Low Fish Passage Design Flow = 20 cfs

Knowns:

C =	2.73	ft^0.5/sec
Length of weir =	3.583	ft
WSE_LowFlow =	517.66	ft
Top of Weir Elevation =	517.02	ft
Head =	0.64	ft

Q_Baffle = 5.0 cfs
Q_Total_Baffle = 10.02 cfs

Q_Notch = Q_Total - Q_Total_Baffle = 20 cfs - 10.02 cfs
Q_Notch = 9.98 cfs

A_Notch = Base*Height = 0.83 ft * 2.64 ft
A_Notch = 2.19 ft^2

V_Notch = Flow / Area = 9.98 cfs / 2.19 ft^2
V_Notch = 4.55 ft/sec

High Fish Passage Design Flow = 81 cfs

Knowns:

C =	2.73	ft^0.5/sec
Length of weir =	3.583	ft
WSE_HighFlow =	519.08	ft
Top of Weir Elevation =	517.02	ft
Head =	2.06	ft

Q_Baffle = 28.92 cfs
Q_Total_Baffle = 57.84 cfs

Q_Notch = Q_Total - Q_Total_Baffle = 81 cfs - 57.84 cfs
Q_Notch = 23.17 cfs

A_Notch = Base*Height = 0.83 ft * 4.06 ft
A_Notch = 3.37 ft^2

V_Notch = Flow / Area = 23.17 cfs / 3.37 ft^2
V_Notch = 6.88 ft/sec

Summary Statement

The initial goals of this retrofit culvert design project included providing fish passage through the 60-foot long culvert for the adult Coho salmon while adding some rock slope protection at the culvert inlet. Retrofitting the culvert with three two feet tall baffles allowed the velocities to decrease and depths increase. Resting pools two feet in depth were also created for the Coho salmon.

Specifically for fish passage, criteria for the Hydraulic Baffle Design Option were successfully met by following the process laid out within the forms. An overview of the steps include researching existing data and available information, collecting all required parameters at the site, selecting the best fish passage design option for the site, completing the hydrology and efficiently brainstorming and completing the hydraulic modeling, and finally meeting requirements of the Hydraulic Baffle Design Option.

Culvert velocities and depths calculated from Fish Xing and HEC-RAS are summarized in Table 1 and 2 below. Existing conditions modeled in both software programs identified problematic velocities and lack of depth in the culvert. The results of the proposed conditions concluded that installing hydraulic baffles through the culvert significantly improved the fish passage conditions.

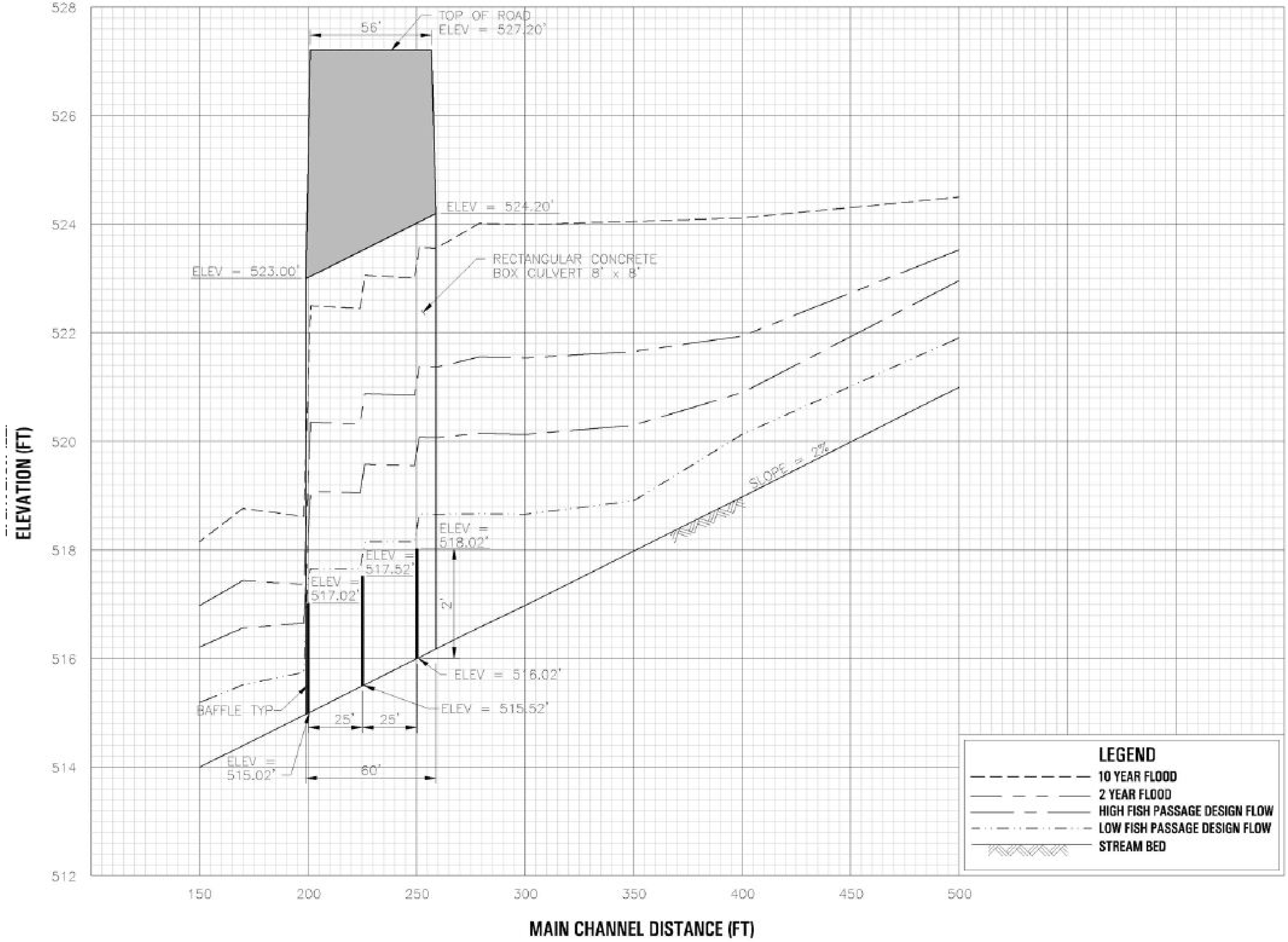
As found in the problem statement, the goal was providing fish passage for Ripple Creek that met hydraulic standards in the Caltrans Hydraulic Design Manual, as well as fish standards in the California Department of Fish and Game Culvert Criteria and the NOAA Fisheries Guidelines for Salmonid Passage at Stream Crossings.

Summary Data Table 1: Culvert Velocities

	Maximum Average Water Velocity at High Fish Design Flow for Adult Anadromous Salmonids (ft/s)	High Fish Design Outlet Velocity (ft/s)	High Fish Design Inlet Velocity (ft/s)	High Fish Design Average Barrel Velocity (ft/s)
Existing Conditions (Fish Xing)	5.00	11.33	9.47	10.05
Existing Conditions (HEC-RAS)	5.00	10.70	4.37	9.14
Proposed Conditions (HEC-RAS)	5.00	5.60	2.50	2.50 (over baffle) 6.80 (through notch)

Summary Data Table 2: Culvert Depths

	Minimum Low Fish Passage Design Depth (ft)	Low Fish Passage Design Outlet Depth (ft)	Low Fish Passage Design Inlet Depth (ft)
Existing Conditions (Fish Xing)	1.00	0.32	0.32
Existing Conditions (HEC-RAS)	1.00	0.89	1.47
Proposed Conditions (HEC-RAS)	1.00	1.70	3.89



P:/06938/38713 TO7 Fish Passage/5.0 Project Data/AutoCAD/General Details/Baffle-Design-Improvement.DWG
08-29-06 AJACKSON 11:41:21

Issue No. | Description | Date | Drwn. | Chkd. | Resp. Engr. | Proj. Mgr.

Project Manager LEF
Designed EKB
Designed
Checked JJL
Drawn AJ

FISH PASSAGE IMPROVEMENT
ROUTE 555

BAFFLE DESIGN

PROPOSED CONDITIONS

Date
Scale HORIZ: 1" = 50'
VERT: 1" = 2'
Project No. 06938-38713
File Name Baffle-Design-Improvement.DWG
Drawing No. **1**
Issue

APPENDIX K

DESIGN EXAMPLE - HYDRAULIC DESIGN OPTION (REHABILITATE STRUCTURE WITH ROCK WEIR)

Hydraulic Design Option
(Rock Weir)

Problem Statement

In Ventura County, the Stoney Creek Bridge on Route 444 is to be widened as a part of a traffic safety project that will consist of a curve correction and shoulder widening. The existing bridge abutments are protected by reinforced concrete placed on the creek banks and bed. This lining has been damaged over time and must be addressed in the bridge widening aspect of this project. Instead of "replacing-in-kind," a more environmentally friendly combination of rock slope protection (RSP) and planting will be used to protect the abutments.

At the downstream end of the existing concrete-lined apron, a 5-foot deep scour hole has developed and continues to deepen. Because of this excessive drop, adult steelhead are inhibited in their migration upstream. Therefore, a solution must be found that will work in conjunction with the planned RSP and planting, and will prevent future scour while encourage the steelhead to move upstream.

NOTE: Route 444 and Stoney Creek are fictitious and created for the purpose of presenting a design example for this fish-passage training guidance.

Form 1-Existing Data and Information Summary

Form 1 provides a list of suggested data references that would be beneficial to collect before the beginning of the design process.

For this particular example, USGS topographic quadrangle map, as-built drawings, target fish species and life stage data, and stream flow gage data was available for reference.

The USGS topographic quadrangle data and DEM data was downloaded from the USGS website, www.usgs.gov.

The FEMA Map Service Center, http://msc.fema.gov/, was accessed to determine if a previous hydrologic study, hydraulic study, and floodplain mapping had been performed. For Stoney Creek, no previous detailed or approximate studies had been performed; therefore, no effective data was available for reference.

As-built drawings were found in District Hydraulics archives. CA Fish and Game provided target species and life stage data for Stoney Creek.

California Department of Water Resources (CDEC, http://cdec.water.ca.gov/), was searched for precipitation and stream flow gage data. Unfortunately, no recording stream flow gages are located on Stoney Creek; however, an adjacent watershed with similar basin characteristics has recording data that will be appropriate for basin transfer. The adjacent watershed gage data was downloaded off of CDEC's website.

As for site access status, the field investigations can be done within Caltrans Right-of -Way, therefore, rights-of-entry will not be required.

EXISTING DATA AND INFORMATION SUMMARY

FORM 1

Project Information Stoney Creek Bridge Widening - Route 444		Computed: EKB	Date: 6/10/06
		Checked: LEF	Date: 6/11/06
Stream Name: Stoney Creek	County: Ventura	Route: 444	Postmile: 15.3

Proposed Project Type	☐ New Culvert	☐ New Bridge
	☐ Replacement Culvert	☐ Replacement Bridge
	☐ Retrofit Culvert	☒ Retrofit Bridge
	☐ Proposed Culvert Length= ft	☒ Proposed Bridge Length= 80 ft
	☐ Other	☐ Other

Design Species/Life Stage	☐ All Species	Source: Contact: Date: John Bait NOAA Fisheries Contacted on 5/11/06 1-678-555-3322
	☒ Adult Anadromous Salmonids adult steelhead	
	☐ Adult Non-Anadromous Salmonids	
	☐ Juvenile Salmonids	
	☐ Native Non-Salmonids	
	☐ Non-Native Species	

Collect Existing Data

Included in Caltrans Culvert Inventory	☐ Yes	☒ No
As-Built Drawings	☒ Yes	☐ No
Assessor's Parcel Map	☐ Yes	☒ No
Previous Studies Performed: (i.e. FEMA Flood Insurance Studies, Army Corps of Engineering Studies, Other)		
Hydrology Analysis	☐ Yes	☒ No
Hydraulics Analysis	☐ Yes	☒ No
Floodplain Mapping	☐ Yes	☒ No
Other Studies Types Available: (i.e. Watershed Management Plans, Stream Restoration Plans, Other)	☐ Yes	☒ No
Existing Land Use Map	☐ Yes	☒ No
Proposed Land Use Map	☐ Yes	☒ No
Precipitation Gage Data	☐ Yes	☒ No
Stream Flow Gage Data	☒ Yes	☐ No

EXISTING DATA AND INFORMATION SUMMARY

FORM 1

Topographic Mapping: (i.e. USGS Topographic Quadrangle, DEM Data, LIDAR Data, Other)	☒	Yes	☐	No
District Hydraulics Library	☐	Yes	☒	No

Obtain Access Permission

Will Project study limits extend beyond Caltrans R/W? ☐ Yes ☒ No

If yes, obtain right-of-entry.

Contact Report Index Attached ☒ Yes ☐ No

Existing Information Index Attached ☒ Yes ☐ No

CONTACT REPORT INDEX

Project Information
Stoney Creek Bridge Widening - Route 444

Computed: EKB Date: 6/10/06

Checked: LEF Date: 6/11/06

Stream Name: Stoney Creek County: Ventura

Route: 444 Postmile: 15.3

Date of Contact	Person Contacted	Subject Discussed
5/11/06	John Bait @ NOAA Fisheries	Adult steelhead species data

EXISTING INFORMATION INDEX

Project Information

StoneyCreek Bridge Widening - Route 444

Computed: EKB

Date: 6/10/06

Checked: LEF

Date: 6/11/06

Stream Name: Stoney Creek

County: Ventura

Route: 444

Postmile: 15.3

Report Date	Report Name and Source
6/1995	As-built drawings - Stoney Creek Bridge
5/25/06	stream flow gage data downloaded from CDEC
5/26/06	USGS Topographical map downloaded from USGS

Form 2- Site Visit Summary

Form 2 captures the existing conditions of the hydraulic structure including channel and structure roughness values. By completing the Site Visit Summary form, the drainage designer will have all necessary parameters required to complete any of the fish passage design options.

At the Stoney Creek site, various bridge and creek properties were investigated. These include layout configuration, roughness, velocity, and flow regime.

As mentioned above, it was noted in the field, as well as the As-Built plans that a bridge with two circular piers exists.

For the creek, roughness characteristics of the main channel, the left overbank channel, and the right overbank channel were also investigated and ultimately Manning's n-values were estimated. Based on field observation, the left and right overbank channels were found to have the same n-values in the vicinity of the culvert crossing and the project study area.

Flow in the creek at the time of the field visit was determined from appropriate measurements. The flow was calculated by measuring a velocity and depth, calculating wetted area from a field developed creek cross-section, and dividing velocity by wetted area to achieve flow according to the continuity of flow equation. By placing a small leaf in the creek and timing its travel over a set length, a velocity was determined. In order to find a representative velocity for the creek, this operation was performed three times, where the leaf was placed near the left bank, near the right bank, and around the center of the creek. The velocity corresponding to each leaf placement was added together and averaged to find a representative velocity.

Finally, the flow regime for the creek was estimated in the field by tossing a small rock in the center of the creek and noting the propagation of the ripples. When ripples propagate upstream, the flow regime is subcritical, while supercritical flow is denoted by downstream ripple propagation. For Stoney Creek, subcritical flow was occurring upstream and downstream of the culvert.

SITE VISIT SUMMARY

FORM 2

Project Information Stoney Creek Bridge Widening - Route 444		Computed: EKB	Date: 6/12/06
		Checked: LEF	Date: 6/13/06
Stream Name: Storey Creek	County: Ventura	Route: 444	Postmile: 15.3

Obtain Physical Characteristics of Existing Culvert N/A

Confined Spaces

Is the culvert height 5 ft or greater? ☐ Yes ☐ No

Can you stand up in the culvert? ☐ Yes ☐ No

Can you see all the way through the culvert? ☐ Yes ☐ No

Can you feel a breeze through the culvert? ☐ Yes ☐ No

If answer is "No" to any of the above questions, do not enter the culvert without confined spaces equipment for surveying.

Inlet Characteristics

Inlet Type	☐ Projecting ☐ Headwall ☐ Wingwall ☐ Flared end section ☐ Segment connection
Inlet Condition	☐ Channel scour ☐ Excessive deposition ☐ Debris accumulation ☐ None applicable
Inlet Apron	☐ Channel scour ☐ Excessive deposition ☐ Debris accumulation ☐ None applicable

Skew Angle: °	Upstream Invert Elevation: ft (NGVD 29 or NAVD 88)

Barrel Characteristics

Diameter: in	Fill height above culvert: ft
Height/Rise: ft	Length: ft
Width/Span: ft	Number of barrels:

Culvert Type	☐ Arch ☐ Box ☐ Circular ☐ Pipe-Arch ☐ Elliptical
Culvert Material	☐ HDPE ☐ Steel Plate Pipe ☐ Concrete Pipe ☐ Spiral Rib / Corrugated Metal Pipe
Barrel Condition	☐ Corrosion ☐ Debris accumulation ☐ Structural damage ☐ Abrasion ☐ Bedload accumulation ☐ None applicable

SITE VISIT SUMMARY

FORM 2

Horizontal alignment breaks: ft	Vertical alignment breaks: ft

Outlet Characteristics

Outlet Type	☐ Projecting	☐ Headwall	☐ Wingwall	
	☐ Flared end section	☐ Segment connection		
Outlet Condition	☐ Scour hole	☐ Backwatered	☐ Debris accumulation	☐ None applicable
	☐ Perched	Outlet elevation drop: ft		
		Outlet drop condition:		
		Scour hole depth: ft		
Outlet Apron	☐ Channel scour	☐ Excessive deposition	☐ Debris Accumulation	☐ None Applicable

Skew Angle: °	Downstream Invert Elevation: ft (NGVD 29 or NAVD 88)

Obtain Physical Characteristics of Existing Bridge

Elevation of high chord (top of road): 129.37 ft		Elevation of low chord: 121.37 ft		
Channel Lining	☐ No lining	☒ Concrete	☐ Rock	☐ Other
Skew Angle: NONE °		Bridge width (length): 68 ft		

Pier Characteristics (if applicable) ☒

Number of Piers: 2	Upstream cross-section starting station: 995 ft
Pier Width: 6 ft to 4 ft ft	Downstream cross-section starting station: 925 ft
Pier Centerline Spacing: 50 ft	

Pier Shape	☐ Square nose and tail	☒ Semi-circular nose and tail	☐ 90° triangular nose and tail
	☐ Twin-cylinder piers with connecting diaphragm	☐ Twin-cylinder piers without connecting diaphragm	☐ Ten pile trestle bent
Pier Condition	☐ Scour	☐ Corrosion	☐ Debris accumulation
Skew angle	NONE °		

Channel Characteristics

Hydraulic Structure Roughness Coefficients

(Source: Caltrans Highway Design Manual Table 864.3A)		(Source: HEC-RAS User's Manual)	
Type of Structure	**n- value**	**Type of Structure**	**n- value (normal)**

SITE VISIT SUMMARY

FORM 2

Linned Channels:		**Corrugated Metal:**	
Portland Cement Concrete	0.014	Subdrain	0.019
Air Blown Mortar (troweled)	[✓ 0.012]	Storm drain	0.024
Air Blown Mortar (untroweled)	0.016	**Wood:**	
Air Blown Mortar (roughened)	0.025	Stave	0.012
Asphalt Concrete	0.018	Laminated, treated	0.017
Sacked Concrete	0.025	**Brickwork:**	
Pavement and Gutters:		Glazed	0.013
Portland Cement Concrete	0.015	Lined with cement mortar	0.015
Asphault Concrete	0.016		
Depressed Medians:			
Earth (without growth)	0.040		
Earth (with growth)	0.050		
Gravel	0.055		

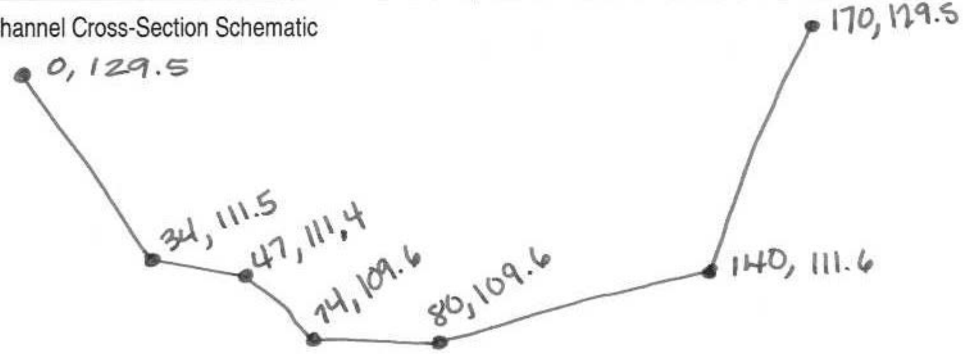
Recommended Permissible Velocities for Unlined Channels (Source: Caltrans Highway Design Manual, Table 862.2)

Type of Material in Excavation Section	Intermittent Flow (f/s)	Sustained Flow (f/s)
Fine Sand (Noncolloidal)	2.6	2.6
Sandy Loam (Noncolloidal)	2.6	2.6
Silt Loam (Noncolloidal)	3.0	3.0
Fine Loam	3.6	3.6
Volcanic Ash	3.9	3.6
Fine Gravel	3.9	3.6
Stiff Clay (Colloidal)	4.9	3.9
Graded Material (Noncolloidal)		
Loam to Gravel	6.6	4.9
Silt to Gravel	6.9	5.6
Gravel	[✓ 7.5]	[✓ 5.9]

SITE VISIT SUMMARY FORM 2

Coarse Gravel	7.9	6.6
Gravel to Cobbles (Under 150mm)	8.8	6.9
Gravel and Cobbles Over 200mm)	9.8	7.9
Flow Estimation 10 cfs	☐ Supercritical flow	☒ Subcritical flow

Channel Cross-Section Schematic



Channel depth = 0.5 ft

Average Active Channel Width
Take at least five channel width measurments to determine the active channel width. The active channel stage or ordinary high water level is the elevation delineating the hightest water level that has been maintained for a sufficient period of time to leave evidence on the landscape.

Average Active Channel Width = 92.4 ft

1) 107.2 ft	2) 109.5 ft	3) 72.5 ft	4) 80.1 ft	5) 92.8 ft

Boundary Conditions The normal depth option (slope area method) can only be used as a downstream boundary condition for an open-ended reach. Is normal depth appropriate? If no, what is the known starting water surface elevation? yes	Upstream normal depth	slope 0.007 ft/ft
	Downstream normal depth	slope 0.007 ft/ft
	Known starting water surface elevation Source:	— ft

General Considerations

Identify Physical restrictions	☐ Right-of-way	☐ Utility conflict	☐ Vegetation
	☐ Man-made features	☐ Natural features	☐ Other

Cross-Section Sketches Attached ☒ Yes ☐ No

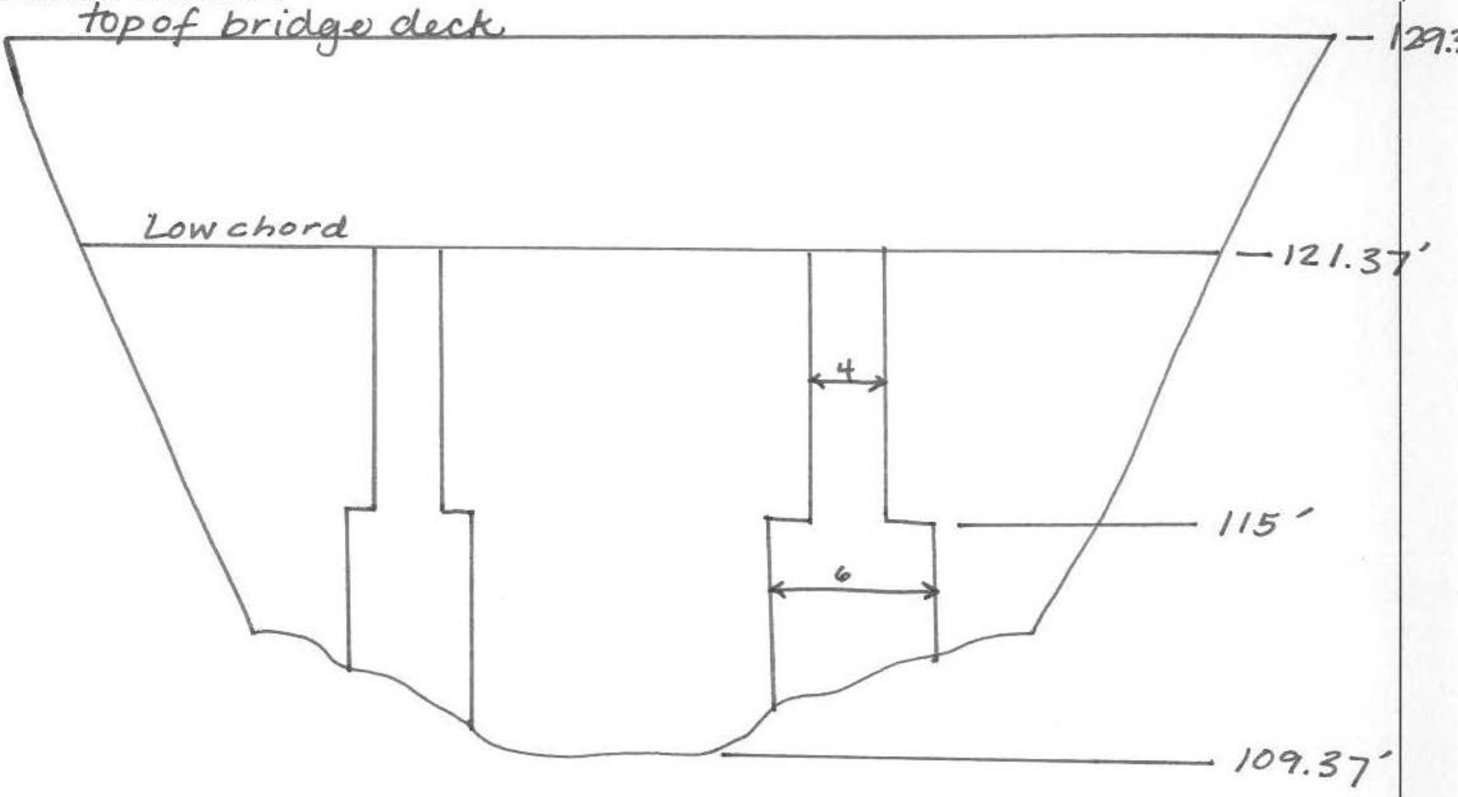
Site Photograph Documentation Attached ☒ Yes ☐ No

Channel / Overbank Manning's n-value Calculation Attached ☒ Yes ☐ No

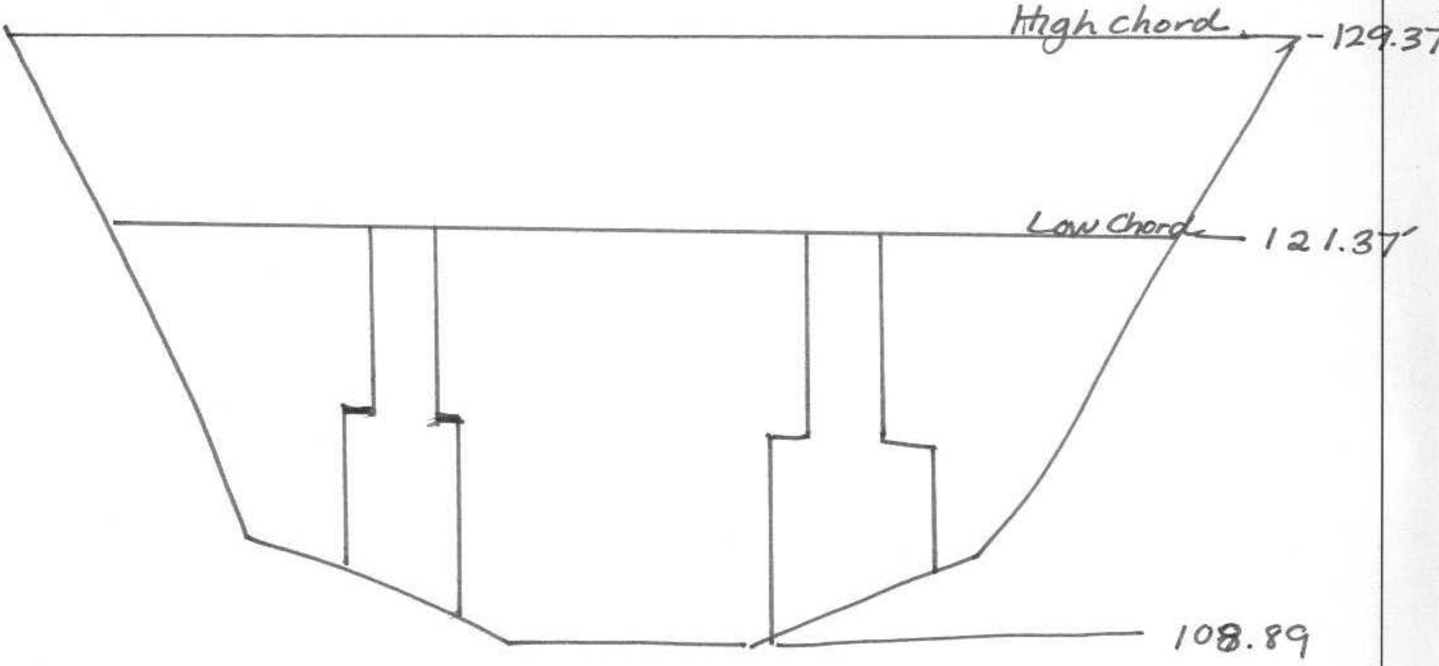
Field Notes Attached ☒ Yes ☐ No

CROSS-SECTION SKETCH

Upstream face of structure:



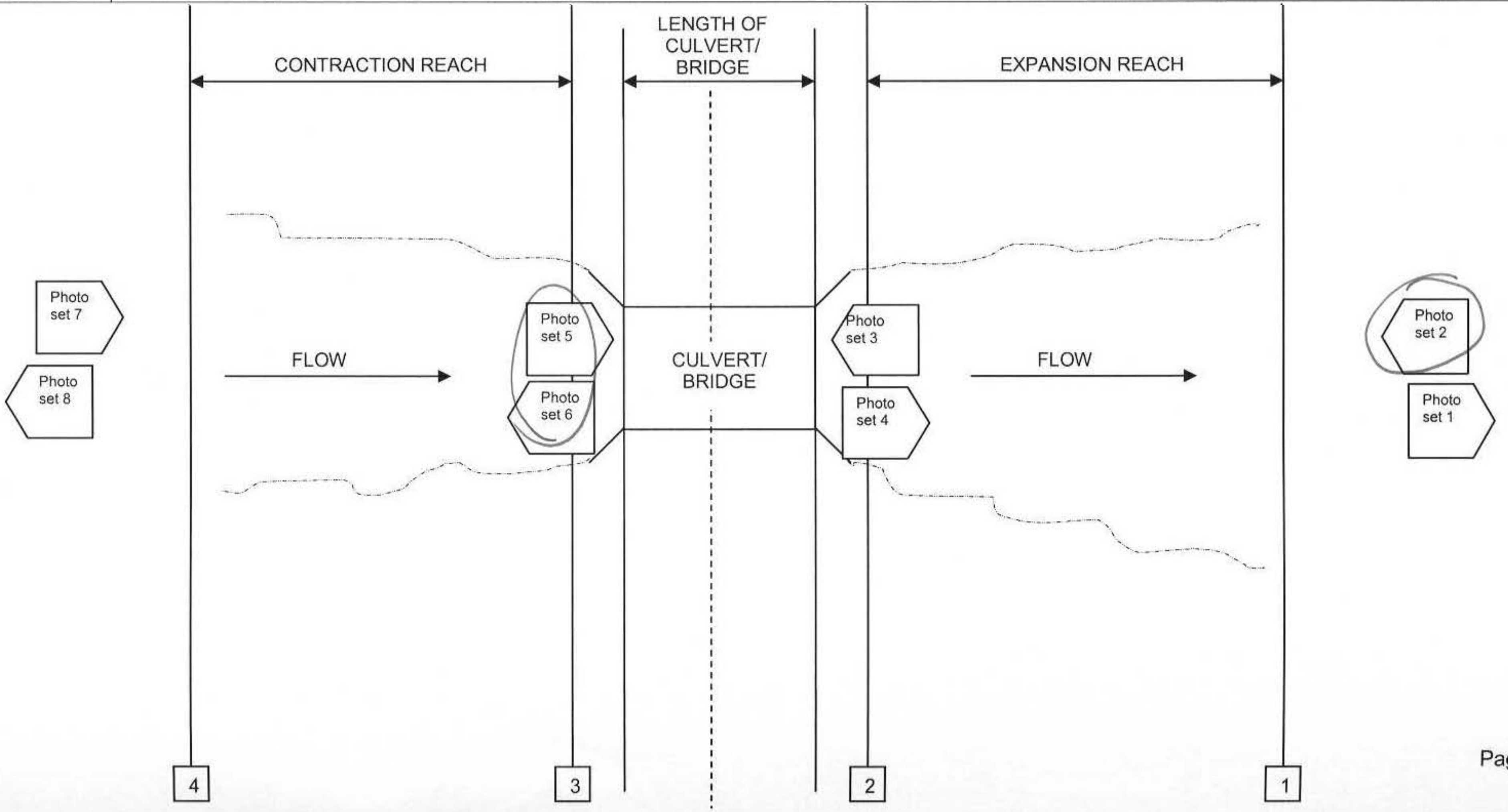
Downstream face of structure:



SITE PHOTOGRAPH DOCUMENTATION

Project Information Stoney Creek Bridge Widening Route 444				Computed:	EKB	Date: 6/12/06	
				Checked:	LEF	Date: 6/13/06	
Stream Name	Stoney Creek	County	Ventura	Road	444	Postmile	15.3
Crossing Type	☐ Culvert	☒ Bridge		☐ Other Type/Comments			

Distance From:	X-sec. 1 to X-sec. 2:	25	ft	X-sec. 2 to DS face of structure	1	ft	US face of structure to X-Sec. 3	1	ft	X-sec. 3 to X-sec. 4	25	ft
Distance From:	Photo Sets 1 & 2 to DS face of structure	100	ft	Photo Sets 3 & 4 to DS face of structure	20	ft	Photo Sets 5 & 6 to US face of structure	22	ft	Photo Sets 7 & 8 to US face of structure	110	ft
Length of Culvert/Bridge:					68	ft						



SITE PHOTOGRAPH DOCUMENTATION

Photo Descriptions:

Photo Set 1	—
Photo Set 2	Looking at upstream face of stoney Creek Bridge
Photo Set 3	—
Photo Set 4	—
Photo Set 5	Looking at concrete apron DS of bridge
Photo Set 6	—
Photo Set 7	—
Photo Set 8	—

Stoney Creek Bridge

Concrete Apron

Manning's n Computation Summary

Project Information

Stoney Creek Bridge Widening

Computed: EKB

Date: 6/12/06

Checked: LEF

Date: 6/13/06

Stream Name: Stoney Creek

County: Ventura

Route: 444

Postmile: 15.3

Aerial Picture Attached: None available

Photographs (#'s and locations) StoneyCrkBridge.jpg , concrete apron.jpg

Summary of n-Values:

Reach	**Left Overbank**	**Main Channel**	**Right Overbank**
	0.040	0.035	0.040

Notes:

- Concrete apron present in existing conditions $n = 0.012$

- Rock slope protection added for proposed conditions. $n = 0.040$

Manning's n Computation - Main Channel

Project Information Stoney Creek Bridge Widening		Computed: EKB	Date: 6/12/06
		Checked: LEF	Date: 6/13/06
Stream Name: Stoney Creek	County: Ventura	Route: 444	Postmile: 15.3

Aerial Picture Attached: NONE AVAILABLE

Photographs (#'s and locations) stoneycreekbridge.jpg, concreteapron.jpg

Is roughness uniform throughout the reach? NO

Note: If not, n-value should be assigned for the AVERAGE condition of the reach

Is roughness uniformly distributed along the cross section? NO

Is a division between the channel and floodplain necessary? yes

Calculation of n-value:

$n = (nb + n1 + n2 + n3 + n4)m$

where:	Description of Range
nb = base n value for surface	*median size btwn 1" and 2.5"=0.028 to 0.035, btwn 2.5" and 10"=0.030 to 0.050*
n1 = surface irregularity factor	*smooth = 0 up to severe at 0.020*
n2 = cross section variation factor	*gradual = 0 up to alternating frequently at 0.015*
n3 = obstructions factor	*negligible = 0 up to severe (over 50% of cross section) at 0.05*
n4 = vegetation factor	*small = 0.002 to very large (average depth of flow is less than 1/2 height of vegetation) at 0.100*
m = sinuosity/meandering factor	*minor = 1.0, appreciable = 1.15, Severe = 1.30*

Base n value for surface

nb: Sand channel? NO if yes, median size of bed material? ________

nb =

median size (in)	nb
0.008	0.012
0.012	0.017
0.016	0.020
0.020	0.022
0.024	0.023
0.031	0.025
0.039	0.026

All other channels:

	median size (in)	nb
→	.04 to .08	0.026 to 0.035
	1 to 2.5	0.028 to 0.035
	2.5 to 10	0.030 to 0.050
	>10	0.040 to 0.070

Notes: Small rocks

nb = 0.026

Manning's n Computation - Main Channel

Surface Irregularity

n1:	Smooth	Is channel smooth? NO	if yes, n1 = 0
	Minor	Is channel in good condition with slightly eroded or scoured side slopes?	→ if yes, n1 = 0.001 - 0.005
	Moderate	Is channel a dredged channel having moderate to considerable bed roughness and moderately sloughed or eroded side slopes in rock?	if yes, n1 = 0.006 - 0.010
	Severe	Is channel badly sloughed, scalloped banks or badly eroded or sloughed sides or jagged and irregular surface?	if yes, n1 = 0.011 - 0.020

Notes: Erosion occurring around concrete apron

n1 = 0.001

Cross Section Variation Factor

n2:	Gradual	Does the size and shape of the channel cross section change gradually?	if yes, n2 = 0.000
	Alternately occasionally	Does the cross section alternate to large to small, *occasionally* or does the main flow *occasionally* shift from side to side?	→ if yes, n2 = 0.001 - 0.005
	Alternately frequently	Does the cross section alternate to large to small, *frequently* or does the main flow *frequently* shift from side to side?	if yes, n2 = 0.010 - 0.015

n2 = 0.001

Notes: Occasional shift of flow from left bank to right bank

Obstructions factor

n3:	Negligible	Does the stream have a few scattered obstructions that occupy < 5% of the cross-sectional area?	→ if yes, n3 = 0.000 - 0.004
	Minor	Obstructions occupy < 15% of the cross-sectional area and the spacing between obstructions is such that the sphere of influence doesn't extend to other obstructions?	if yes, n3 = 0.005 - 0.015
	Appreciable	Obstructions occupy 15% - 50% of the cross-sectional area and the spacing between obstructions is small enough to be additive?	if yes, n3 = 0.020 - 0.030
	Severe	Obstructions occupy more than 50% of the cross-sectional area or the spacing between obstructions causes turbulence?	if yes, n3 = 0.040 - 0.050

n3 = 0.000

Notes: No obstructions in channel

Manning's n Computation - Main Channel

Vegetation factor

n4:			
	Small	Does the channel have dense growth of flexible turf grass or weed growth where the flow is at least 2 times the height of the vegetation; tree seedlings of willows, cottonwoods, etc? →	if yes, n4 = 0.002 - 0.010
	Medium	Does the channel have turf grass where the average depth of flow is 1 to 2 times the height of the vegetation; moderately stemmy grass, weeds or tree seedlings growing where the flow is 2 to 3 times the height of the vegetation?	if yes, n4 = 0.010 - 0.025
	Large	Does the channel where the average depth of flow is equal to the height of the vegetation; 8 to 10 years-old willows or cottonwoods intergrown with weeds and brush; where the hydraulic radius exceeds1.97 ft or bushy willows about 1 year old intergrown with some weeds along side slopes, and no significant vegetation exists along the channel bottom, where the hydraulic radius is greater than 2.0 ft.	if yes, n4 = 0.025 -0.050
	Very large	Does the channel have turf grass growing where the average depth of flow < 1/2 the height of the vegetation; bushy willows about 1 year old. with weeds intergrown on side slopes; dense cattails in channel bottom; trees intergrown with weeds and brush?	if yes, n4 = 0.050 - 0.100

n4 = 0.002

Notes: grasses channel

Sinuosity/meandering factor

m	Minor	Ratio of the channel length to valley length in 1.0 to 1.2	if yes, m = 1.00
	Appreciable	Ratio of the channel length to valley length in 1.2 to 1.5	if yes, m = 1.15
	Severe	Ratio of the channel length to valley length > 1.5	if yes, m = 1.30

m = 1.00

Notes:

Manning's n - Main Channel n = 0.030

Manning's n Computation - Overbank

Project Information
Stoney Creek Bridge Widening
Computed: EKB
Date: 6/12/06
Checked: LEF
Date: 6/13/06
Stream Name: Stoney Creek
County: Ventura
Route: 444
Postmile: 15.3
Aerial Picture Attached: none available
Photographs (#'s and locations) stoneycreekbridge.jpg , concreteapron.jpg
Is roughness uniform throughout the reach? NO

Note: If not, n-value should be assigned for the AVERAGE condition of the reach

Is roughness uniformly distributed along the cross section? NO
Is a division between the channel and floodplain necessary? yes

Calculation of n-value:
n = (nb + n1 + n2 + n3 + n4)m

where:	Description of Range
nb = base n value for surface	*median size between 1" and 2.5"=0.028 to 0.035, between 2.5" and 10"=0.030 to 0.050*
n1 = surface irregularity factor	*smooth = 0 up to severe at 0.020*
n2 = cross section variation factor	*gradual = 0 up to alternating frequently at 0.015*
n3 = obstructions factor	*assumed to equal 0*
n4 = vegetation factor	*small = 0.002 to very large (average depth of flow is less than 1/2 height of vegetation) at 0.100*
m = sinuosity/meandering factor	*equals 0 for floodplains*

Base n value for surface

nb: Sand channel? NO if yes, median size of bed material? ______

nb =

median size (in)	nb
0.008	0.012
0.012	0.017
0.016	0.020
0.020	0.022
0.024	0.023
0.031	0.025
0.039	0.026

All other channels:

median size (in)	nb
.04 to .08	0.026 to 0.035
1 to 2.5	0.028 to 0.035
2.5 to 10	0.030 to 0.050
>10	0.040 to 0.070

Notes: Overbanks consist of smaller sized rocks

nb = 0.030

Surface Irregularity

n1:	Smooth	Compares to the smoothest, flattest floodplain in a given bed material.	if yes, n1 = 0
	Minor	Is the floodplain slightly irregular in shape. A few rises and dips or sloughs may be more visible on the floodplain.	if yes, n1 = 0.001 - 0.005
	Moderate	Has more rises and dips. Sloughs and hummocks may occur.	if yes, n1 = 0.006 - 0.010
	Severe	Floodplain very irregular in shape. Many rises and dips or sloughs are visible.	if yes, n1 = 0.011 - 0.020

n1 = 0.002

Notes: Slight erosion of overbanks

Manning's n Computation - Overbank

Cross Section Variation Factor

n2 = 0.000

Notes: Not applicable to floodplains.

Obstructions factor

n3:	Negligible	Does the stream have a few scattered obstructions that occupy < 5% of the cross-sectional area?	if yes, n3 = 0.000 - 0.004
	Minor	Obstructions occupy < 15% of the cross-sectional area and the spacing between obstructions is such that the sphere of influence doesn't extend to other obstructions?	if yes, n3 = 0.005 - 0.015
	Appreciable	Obstructions occupy 15% - 50% of the cross-sectional area and the spacing between obstructions is small enough to be additive?	if yes, n3 = 0.020 - 0.030

n3 = 0.002

Notes: Few large boulders

Vegetation factor

n4:	Small	Does the channel have dense growth of flexible turf grass or weed growth where the flow is at least 2 times the height of the vegetation; tree seedlings of willows, cottonwoods, etc where the average depth of flow is at least three times the height of the vegetation?	[✓ if yes, n4 = 0.002 - 0.010]
	Medium	Does the channel have turf grass where the average depth of flow is 1-2 times the height of the vegetation; moderately stemmy grass, weeds or tree seedlings growing where the flow is 2-3 times the height of vegetation? Brushy, moderately dense vegetation, similar to 1-2 year old willow trees in dormant season.	if yes, n4 = 0.010 - 0.025
	Large	Does the channel where the average. depth of flow is equal to the height of the vegetation; 8 to 10 year old. willows, cottonwoods intergrown with weeds and brush; where the R = 1.97 ft or bushy willows of 1 year old are in the channel bottom, where R =2.00 ft?	if yes, n4 = 0.025 -0.050
	Very large	Does the channel have turf grass growing where the average depth of flow < 1/2 the height of the vegetation; bushy willows about 1 year old. with weeds intergrown on side slopes; dense cattails in channel bottom; trees intergrown with weeds and brush?	if yes, n4 = 0.050 - 0.100
	Extreme	Does the channel have dense bushy willow, mesquite, and salt cedar (full foliage), or heavy stand of timber, few down trees, depth of reaching branches?	if yes, n4 = 0.100 - 0.200

n4 = 0.006

Notes: Leafy vegetation, leaves low to ground < 5ft tall

Sinuosity/meandering factor

m = 1.00

Notes: Not applicable to floodplains.

Manning's n - Overbank n = 0.040

Form 3- Guidance on Selection of Fish Passage Design Option

This form summarizes requirements for each design option in order for the designer to select the appropriate fish-passage design option.

The best solution to the fish-passage problem is to construct gradient-control rock weirs for the downstream channel in order to soften the existing, excessive hydraulic drop at the deep scour hole. The rock weirs can be anchored into the proposed RSP abutment protection, which will aid in the stability of the weirs.

Because the rock weirs are categorized as a retrofit strategy under the Hydraulic Design option, velocity and depth calculations using the low and high fish-passage flows must be performed and adult anadromous salmonid criteria must be analyzed. As identified in the CA Fish & Game *Culvert Criteria for Fish Passage*, the velocity/depth criteria should be the goal for improvement, not the required threshold. It must be noted, the design engineer must still make reasonable effort in meeting the criteria through the installation of gradient-control rock weirs.

GUIDANCE ON SELECTION OF FISH PASSAGE DESIGN OPTION

FORM 3

Project Information Stoney Creek Bridge Widening Route 444		Computed: EKB	Date: 6/15/06
		Checked: LEF	Date: 6/16/06
Stream Name: Stoney Creek	County: Ventura	Route: 444	Postmile: 15.3

Design Species/ Life Stage	☐	All Species
	☒	Adult Anadromous Salmonids
	☐	Adult Non-Anadromous Salmonids
	☐	Juvenile Salmonids
	☐	Native Non-Salmonids
	☐	Non-Native Species

☐ **Active Channel Design Option -** The Active Channel Design Option 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 streambed 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 with stream hydraulic charagcteristics within the culvert are intended to mimic the stream conditions upstream and downstream of the crossing. However, hydraulic analyses for traffic safety, hydraulic impacts, and scour are required.

Criteria for choosing option:

☐ New and replacement culvert/bridge installations

☐ Passage required for all species

☒ Proposed culver/bridge length less than 100 feet

☒ Channel slope less than 3%

☒ **Hydraulic Design Option** - The Hydraulic Design Option is a design process that matches the hydraulic performance of a culvert with the swimming ablitities of a target species and age class of fish. This method targets distinct species of fish and, therefore, does not account for ecosystem requirments of non-target species.

Criteria for choosing option:

☐ New and replacement culvert/bridge installations (If retrofit installation, see Baffle or Rock Weir Design Options)

☒ Target species identified for passage

☒ Low to moderate channel slopes (less than 3%)

☒ Active channel design or stream simulation design options are not physically feasible

Retrofit Culvert/Bridge Installations

☐ **Baffle Design Option -** The Baffle Design Option is a Hydrualic Design process that is intended to increase flow depth, or to add roughness elements as a measure to reduce flow velocity within the culvert/bridge structure. Determination of the high and low fish passage design flows, water velocity, and water depth is required for this option.

☒ Retrofit culvert/bridge installation

☒ Little bedload material movement

GUIDANCE ON SELECTION OF FISH PASSAGE DESIGN OPTION **FORM 3**

☒ Existing culvert/bridge is structurally sound

☒ Target species identified for passage

☒ Low to moderate channel slopes

☒ Active channel design or stream simulation design options are not physically feasible

☒ **Rock Weir Design Option -** The Rock Weir Design Option is a Hydraulic Design process that is intended to increase flow depth, or add roughness elements as a measure to reduce flow velocity, or to increase the channel slope downstream of the culvert/bridge. Determination of the high and low fish passage design flows, water velocity, and water depth is required for this option.

☒ Retrofit culvert/bridge installations

☒ Perched condition at outlet ✱

☒ Steep slope at inlet

☒ Target species identified for passage

☒ Active channel design or stream simulation design options are not physically feasible

☐ **Stream Simulation Design Option -** The Stream Simulation Design Option 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.

Criteria for choosing option:

☐ New and replacement culvert/bridge installations

☐ Passage required for all species

☐ Culvert/bridge length greater than 100 feet

☐ Channel width should be less than 20 feet

☒ Minimum culvert/bridge width no less than 6 feet

☒ Culvert/bridge slope does not greatly exceed slope of natural channel, slopes of 6 % or less

☐ Narrow stream valleys

Selected Design Option: Hydraulic Rock Weir Design Option

Basis for Selection: – main reason: perched condition at outlet
channel invert must be built back up to
similar original elevation and slope

Seek Agency Approval: ☐ Yes ☒ No

Form 4- Guidance on Methodology for Hydrologic Analysis

Form 4 summarizes methods for estimating peak design discharges that will be used in a hydraulic analysis. Data requirements, limitations, and guidance are provided to assist in the hydrologic method selection.

For this particular example, all data requirements needed to calculate peak discharges by regional regression equations were readily available.

Although no recording stream flow gages were located on Stoney Creek; an adjacent watershed with similar basin characteristics has recording data that was appropriate for basin transfer. A stream flow hydrograph and a stream duration curve were created allowing upper and lower fish passage flows to be calculated.

GUIDANCE ON METHODOLOGY FOR HYDROLOGIC ANALYSIS [1, 2] FORM 4

Project Information Stoney Creek Bridge Widening-Route 444		Computed: EKB	Date: 6/15/06
		Checked: LEF	Date: 6/16/06
Stream Name: Stoney Creek	County: Ventura	Route: 444	Postmile: 15.3

Summary of Methods for Estimating Peak Design Discharges for Use in Hydraulic Analysis

Ungaged Streams

☒ **Regional Regression**[3, 4]

Data Requirements	Limitations	Guidance
▪ Drainage area ▪ Mean annual precipitation ▪ Altitude index	▪ Peak discharge value for flow under natural conditions unaffected by urban development and little or no regulation by lakes or reservoirs ▪ Ungaged channel	The most recently published USGS report for estimating peak discharges may be used. The user should exercise caution to ensure that the reports are used only for the conditions and locations for which they are recommended.

Rainfall-Runoff Models

☐ **NRCS (TR 55)**[5]

Data Requirements	Limitations	Guidance
▪ 24-hour Rainfall ▪ Rainfall distribution ▪ Runoff curve number ▪ Concentration time ▪ Drainage area	▪ Small or midsize catchment (<8 km^2) ▪ Maximum of 10 subwatersheds ▪ Concentration time range from 0.1-10 hour (tabular hydrograph method limit <2 hour) ▪ Runoff is overland and channel flow ▪ Simplified channel routing ▪ Negligible channel storage	TR-55 focuses on small urban and urbanizing watersheds.

☐ **HEC-1/HEC-HMS**[6, 7] **(SCS Dimnesionless, Snyder Unit, Clark Unit Hydrographs)**

Data Requirements	Limitations	Guidance
▪ Watershed/subbasin parameters ▪ Precipitation depth, duration, frequency, and distribution ▪ Precipitation losses ▪ Unit hydrograph parameters ▪ Streamflow routing and diversion parameters	▪ Simulations are limited to a single storm event ▪ Streamflow routing is performed by hydrologic routing methods and is therefore not appropriate for unsteady state routing conditions.	Can be used for watersheds which are: small or large, simple or complex, and developed or undeveloped.

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[1] Caltrans Highway Design Manual, Chapter 810 Hydrology, Topic 819 Estimating Design Discharge

[2] FEMA Guidelines and Specifications, Appendix C, Section C.1

[3] USGS Water-Resources Investigation 77-21 (Magnitude and Frequency of Floods in California)

[4] USGS Open-File Report 93-419 (Methods for Estimating Magnitude and Frequency of floods in the Southwestern United States)

[5] United States Department of Agriculture, Natural Resources Conservation Service, Urban Hydrology for Small Watersheds Technical Release 55, June 1986. ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf

[6] HEC-1 User's Manual

[7] HEC-HMS User's Manual

[8] Bulletin 17B

GUIDANCE ON METHODOLOGY FOR HYDROLOGIC ANALYSIS [1, 2] FORM 4

GAGED STREAMS

☐ **Statistical Methods**[8]

Data Requirements	Limitations	Guidance
▪ 10 or more years of gaged flood records	▪ Gage data is usually only available for midsized and large catchments ▪ Appropriate station and/or generalized skew coefficient relationship applied	For watersheds with less than 50 years of record, compare with results of appropriate USGS regional regression equations. For watersheds with less than 25 years of record, compare with results of appropriate USGS regional regresssion equations and/or HEC-1/HEC-HMS model results.

☐ **Basin Transfer of Gage Data**

Data Requirements	Limitations	Guidance
▪ Discharge and area for gaged watershed ▪ Area for ungaged watershed	▪ Similar hydrologic characteristics ▪ Channel storage	Must obtain approval of transfer technique from hydraulics engineer prior to use.

☒ **Fish Passage Flows**

▪ Streamflow hydrograph ▪ Flow duration curve		Lower and upper fish passage flows define the range of flows a culvert should contain suitable conditions for fish passage.

Selected Hydrologic Method: Regional Regression Eqns. & Fish Passage Flows

Basis for Selection:

- Data available for Regional Regression analysis
- Required to meet adult anadromous salmonid depths and velocities

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[1] Caltrans Highway Design Manual, Chapter 810 Hydrology, Topic 819 Estimating Design Discharge

[2] FEMA Guidelines and Specifications, Appendix C, Section C.1

[3] USGS Water-Resources Investigation 77-21 (Magnitude and Frequency of Floods in California)

[4] USGS Open-File Report 93-419 (Methods for Estimating Magnitude and Frequency of floods in the Southwestern United States)

[5] United States Department of Agriculture, Natural Resources Conservation Service, Urban Hydrology for Small Watersheds Technical Release 55, June 1986. ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf

[6] HEC-1 User's Manual

[7] HEC-HMS User's Manual

[8] Bulletin 17B

GUIDANCE ON METHODOLOGY FOR HYDROLOGIC ANALYSIS [1, 2] FORM 4

Verify Reasonableness and Recommended Peak Discharges

Source	50% Annual Probability (2-Year Flood Event) (cfs)	10% Annual Probability (10-Year Flood Event) (cfs)	2% Annual Probability (50-Year Flood Event) (cfs)	1% Annual Probability (100-Year Flood Event) (cfs)	High Fish Passage Design Flow (cfs)	Low Fish Passage Design Flow (cfs)
Effective Study Peak Discharges	N/A	N/A	N/A	N/A	N/A	N/A
Recommended Peak Discharges	155	1252	4460	6336	78	50

Hydrologic Analysis Index Attached ☒ Yes ☐ No

Hydrologic Analysis Calculations Attached ☒ Yes ☐ No

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[1] Caltrans Highway Design Manual, Chapter 810 Hydrology, Topic 819 Estimating Design Discharge

[2] FEMA Guidelines and Specifications, Appendix C, Section C.1

[3] USGS Water-Resources Investigation 77-21 (Magnitude and Frequency of Floods in California)

[4] USGS Open-File Report 93-419 (Methods for Estimating Magnitude and Frequency of floods in the Southwestern United States)

[5] United States Department of Agriculture, Natural Resources Conservation Service, Urban Hydrology for Small Watersheds Technical Release 55, June 1986. ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf

[6] HEC-1 User's Manual

[7] HEC-HMS User's Manual

[8] Bulletin 17B

HYDROLOGIC ANALYSES INDEX

FORM 4

Project Information Stoney Creek Bridge Widening		Computed: EKB	Date: 6/15/06
		Checked: LEF	Date: 6/16/06
Stream Name: Stoney Creek	County: Ventura	Route: 444	Postmile: 15.3

Flooding Source/Stream Name	Hydrologic Method/Model Used	Method/Model Analysis Date	Exhibit No.	
			Paper Copy	Electronic Copy
Stoney Creek	USGS-Regional Regression	Central Coast	/	—
Stoney Creek	Upper and lower Fish Passage Flows	Flow Duration Curve	—	/

Regional Regression Computation Summary

Project Information:	Stoney Creek Bridge Widening - Route 444			Computed:	EKB	Date:	6/31/2006
				Checked:	LEF	Date:	7/1/2006
Stream Name:	Stoney Creek	County:	Ventura	Route:	444	Postmile:	15.3

Calculations:

-Site Located in South Coast Region

A, Drainage Area = 8 mi^2
P, Mean Annual Precipitation = 30 inches

Regional Regression Equations

Q2 = 0.14A^0.72P^1.62
Q2 = 155 cfs

Q10 = 0.63A^0.79P^1.75
Q10 = 1252 cfs

Q50 = 1.50A^0.82P^1.85
Q50 = 4460 cfs

Q100 = 1.95A^0.83P^1.87
Q100 = 6336 cfs

The following documentation was taken from:

U.S. Geological Survey Water-Resources Investigations Report 94-4002:
Nationwide summary of U.S. Geological Survey regional regression equations for estimating magnitude and frequency of floods for ungaged sites, 1993

CALIFORNIA

STATEWIDE RURAL

Summary

California is divided into six hydrologic regions (fig. 1). The regression equations developed for these regions are for estimating peak discharges (QT) having recurrence intervals T that range from 2 to 100 years. The explanatory basin variables used in the equations are drainage area (A), in square miles; mean annual precipitation (P), in inches; and an altitude index (H), which is the average of altitudes in thousands of feet at points along the main channel at 10 percent, and 85 percent of the distances from the site to the divide. The variables A and H may be measured from topographic maps. Mean annual precipitation (P) is determined from a map in Rantz (1969). The regression equations were developed from peak-discharge records of 10 years or longer, available as of 1975, at more than 700 gaging stations throughout the State. The regression equations are applicable to unregulated streams but are not applicable to some parts of the State (see fig. 1). The standard errors of estimate for the regression equations for various recurrence intervals and regions range from 60 to over 100 percent. The report by Waananen and Crippen (1977) includes an approximate procedure for increasing a rural discharge to account for the effect of urban development. The influences of fire and other basin changes on flood magnitudes are also discussed.

Procedure

Topographic maps, the hydrologic regions map (fig. 1), the mean annual precipitation from Rantz (1969), and the following equations are used to estimate the needed peak discharges QT, in cubic feet per second, having selected recurrence intervals T.

North Coast Region

$Q2 = 3.52\ A^{0.90}\ P^{0.89}\ H^{-0.47}$
$Q5 = 5.04\ A^{0.89}\ P^{0.91}\ H^{-0.35}$
$Q10 = 6.21\ A^{0.88}\ P^{0.93}\ H^{-0.27}$
$Q25 = 7.64\ A^{0.87}\ P^{0.94}\ H^{-0.17}$
$Q50 = 8.57\ A^{0.87}\ P^{0.96}\ H^{-0.08}$
$Q100 = 9.23\ A^{0.87}\ P^{0.97}$

Northeast Region

$Q2 = 22\ A^{0.40}$
$Q5 = 46\ A^{0.45}$
$Q10 = 61\ A^{0.49}$
$Q25 = 84\ A^{0.54}$
$Q50 = 103\ A^{0.57}$
$Q100 = 125\ A^{0.59}$

Sierra Region

$Q2 = 0.24\ A^{0.88}\ P^{1.58}\ H^{-0.80}$
$Q5 = 1.20\ A^{0.82}\ P^{1.37}\ H^{-0.64}$
$Q10 = 2.63\ A^{0.80}\ P^{1.25}\ H^{-0.58}$
$Q25 = 6.55\ A^{0.79}\ P^{1.12}\ H^{-0.52}$
$Q50 = 10.4\ A^{0.78}\ P^{1.06}\ H^{-0.48}$
$Q100 = 15.7\ A^{0.77}\ P^{1.02}\ H^{-0.43}$

Central Coast Region

$Q2 = 0.0061\ A^{0.92}\ P^{2.54}\ H^{-1.10}$
$Q5 = 0.118\ A^{0.91}\ P^{1.95}\ H^{-0.79}$
$Q10 = 0.583\ A^{0.90}\ P^{1.61}\ H^{-0.64}$
$Q25 = 2.91\ A^{0.89}\ P^{1.26}\ H^{-0.50}$
$Q50 = 8.20\ A^{0.89}\ P^{1.03}\ H^{-0.41}$
$Q100 = 19.7\ A^{0.88}\ P^{0.84}\ H^{-0.33}$

South Coast Region

$Q2 = 0.14\ A^{0.72}\ P^{1.62}$
$Q5 = 0.40\ A^{0.77}\ P^{1.69}$
$Q10 = 0.63\ A^{0.79}\ P^{1.75}$
$Q25 = 1.10\ A^{0.81}\ P^{1.81}$
$Q50 = 1.50\ A^{0.82}\ P^{1.85}$
$Q100 = 1.95\ A^{0.83}\ P^{1.87}$

South Lahontan-Colorado Desert Region

$Q2 = 7.3A^{0.30}$
$Q5 = 53A^{0.44}$
$Q10 = 150A^{0.53}$
$Q25 = 410A^{0.63}$
$Q50 = 700A^{0.68}$
$Q100 = 1080A^{0.71}$

In the North Coast region, use a minimum value of 1.0 for the altitude index (H). Equations are defined only for basins of 25 mi^2 or less in the Northeast and South Lahontan-Colorado Desert regions.

Reference

Waananen, A.O., and Crippen, J.R., 1977, Magnitude and frequency of floods in California: U.S. Geological Survey Water-Resources Investigations Report 77-21, 96 p.

Additional Reference

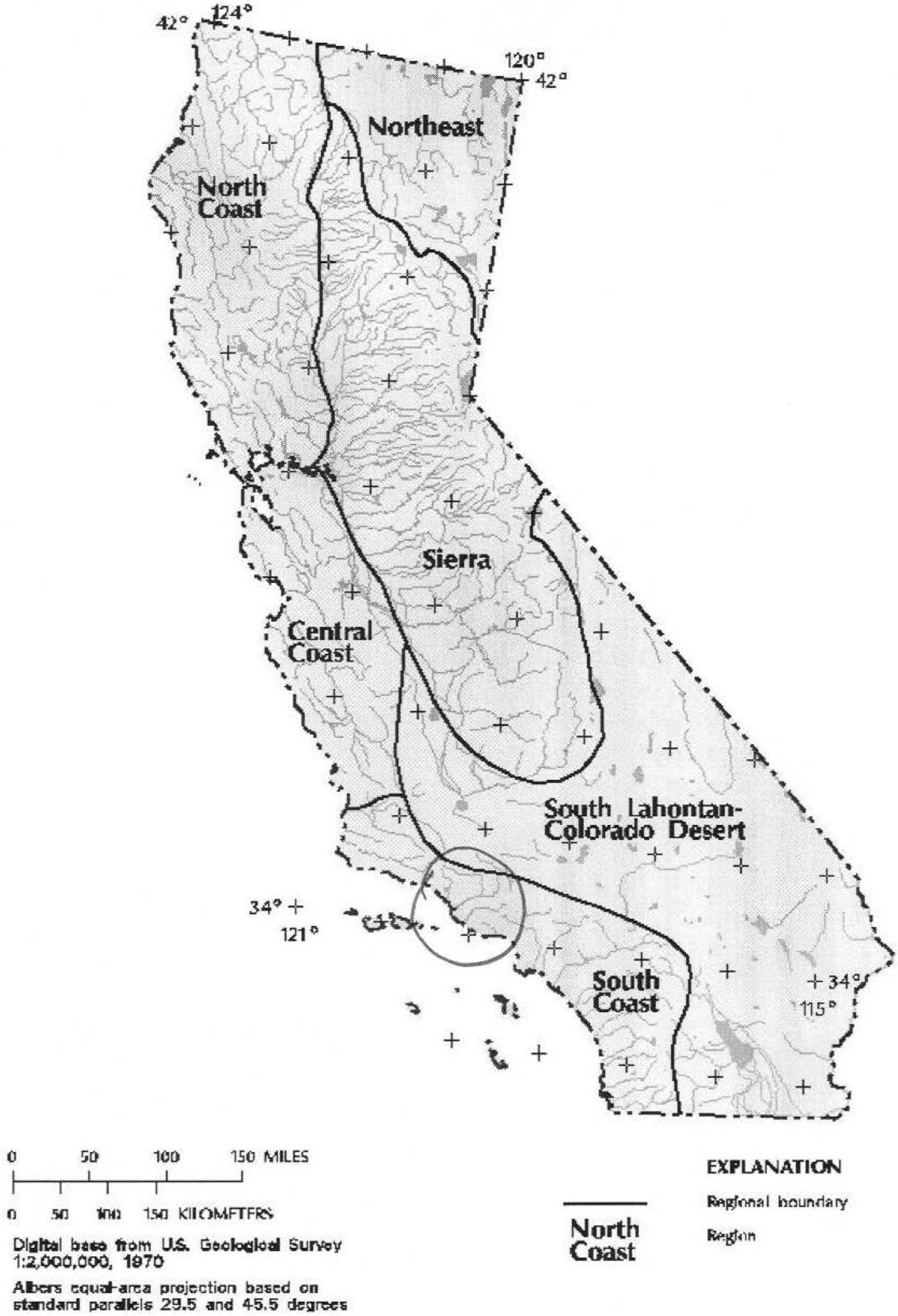
Rantz, S.E., 1969, Mean annual precipitation in the California region: U.S. Geological Survey Open-File Map (Reprinted 1972, 1975).

Figure 1. Flood-frequency region map for California. (PostScript file of Figure 1.)

Back to NFF main page

USGS Surface-Water Software Page

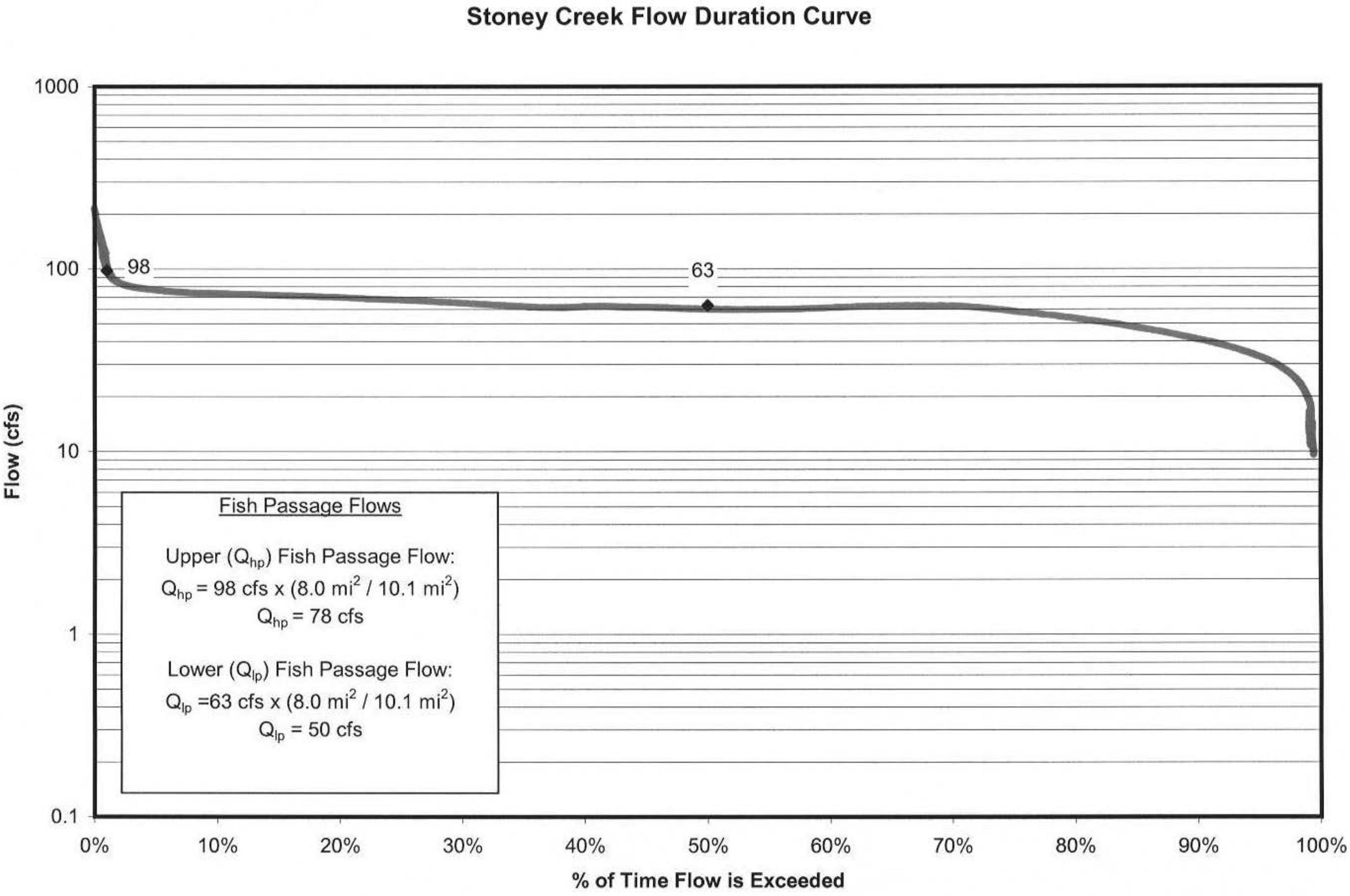
U.S. Geological Survey
National Flood Frequency Program
Water-Resources Investigations Report 94-4002



Digital base from U.S. Geological Survey
1:2,000,000, 1970

Albers equal-area projection based on
standard parallels 29.5 and 45.5 degrees

Figure 1. Flood-frequency region map for California.



Fish Passage Flows

Upper (Q_{hp}) Fish Passage Flow:
Q_{hp} = 98 cfs x (8.0 mi^2 / 10.1 mi^2)
Q_{hp} = 78 cfs

Lower (Q_{lp}) Fish Passage Flow:
Q_{lp} =63 cfs x (8.0 mi^2 / 10.1 mi^2)
Q_{lp} = 50 cfs

Form 5 - Guidance on Methodology for Hydraulic Analysis

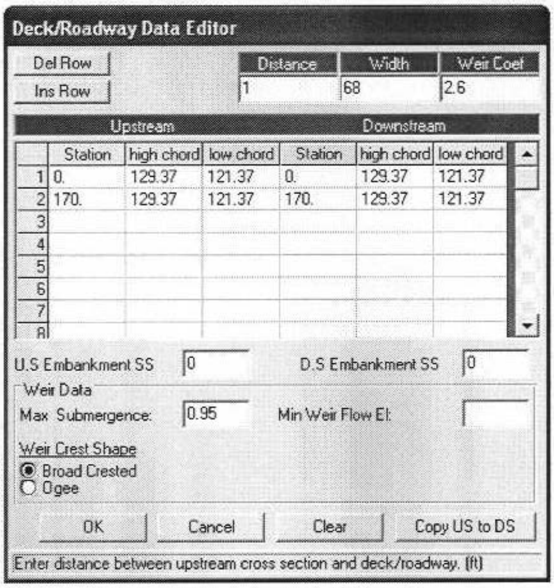
Form 5 summarizes the acceptable methods available for hydraulic analysis. The modeling methods include FHWA Design Charts, HY8 - Culvert Analysis, and HEC-2/HEC-RAS.

For this particular example, HEC-RAS was used to model existing and proposed conditions. HEC-RAS easily allowed a quick comparison between existing and proposed water surface elevations and velocities.

The HEC-RAS model consisted of two plans: existing conditions and proposed conditions.

Both HEC-RAS plans use the same peak discharges estimated by regional regression analysis and the flow hydrograph and stream duration curve.

The existing conditions bridge geometry was modeled using the Deck/Roadway Data Editor. The existing bridge parameters that had been measured and captured in Form 2 - Site Visit Summary, were entered into the Deck/Roadway Data Editor and Pier Data Editor within HEC-RAS. The Deck/Roadway Data Editor and Bridge Culvert Data windows are captured below.


Deck/Roadway Data Editor

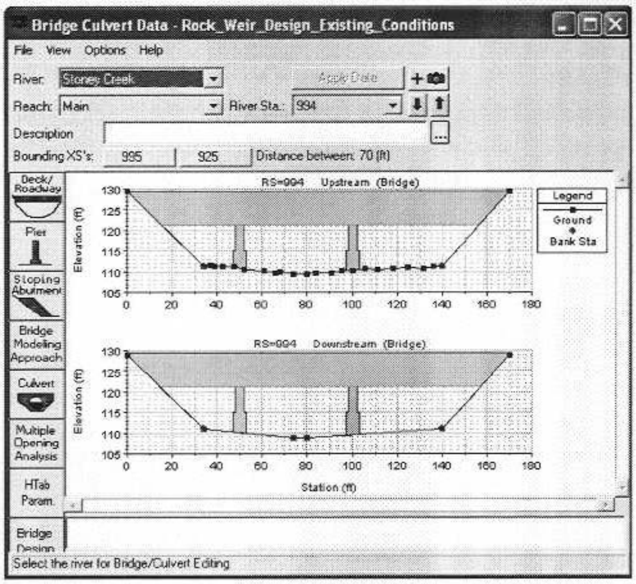
Distance	Width	Weir Coef
1	68	2.6

	Upstream			Downstream		
	Station	high chord	low chord	Station	high chord	low chord
1	0.	129.37	121.37	0.	129.37	121.37
2	170.	129.37	121.37	170.	129.37	121.37
3						
4						
5						
6						
7						
8						

U.S Embankment SS: 0
D.S Embankment SS: 0

Weir Data
Max Submergence: 0.95
Min Weir Flow El:
Weir Crest Shape
● Broad Crested
○ Ogee

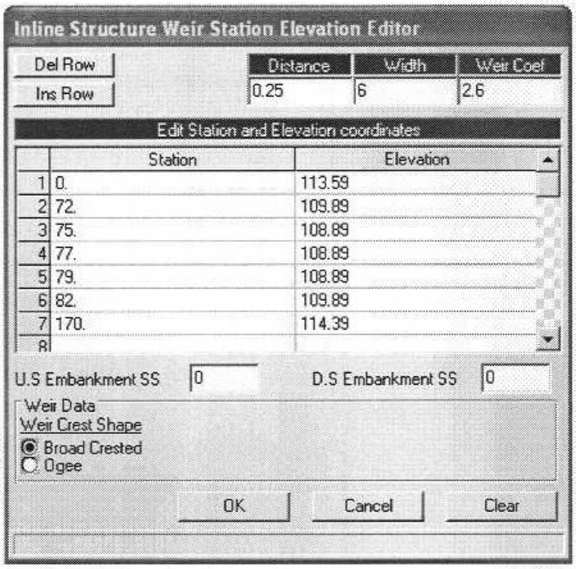
Enter distance between upstream cross section and deck/roadway. (ft)


Bridge Culvert Data - Rock_Weir_Design_Existing_Conditions

River: Stoney Creek
Reach: Main
River Sta.: 994
Description:
Bounding XS's: 995 925 Distance between: 70 (ft)

Select the river for Bridge/Culvert Editing

The proposed conditions bridge geometry was also modeled using the Deck/Roadway Data Editor. The retrofitted bridge parameters were entered into the Deck/Roadway Data Editor and Pier Data Editor within HEC-RAS. Proposed dimensions of the weir were selected and entered into the Inline Structure Weir Station Elevation Editor to determine proposed water surface behaviors for low flows. The Inline Structure Weir Station Elevation Editor and Inline Structure Data windows are captured below.



Distance	Width	Weir Coef
0.25	6	2.6

	Station	Elevation
1	0.	113.59
2	72.	109.89
3	75.	108.89
4	77.	108.89
5	79.	108.89
6	82.	109.89
7	170.	114.39
8		

U.S Embankment SS: 0

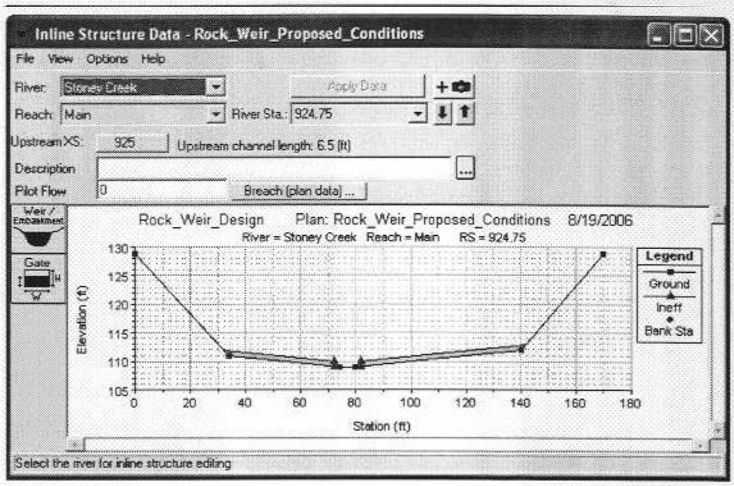
D.S Embankment SS: 0

Weir Data

Weir Crest Shape

● Broad Crested

○ Ogee



River: Stoney Creek

Reach: Main

River Sta.: 924.75

Upstream XS: 925

Upstream channel length: 6.5 (ft)

Description:

Pilot Flow: 0

Select the river for inline structure editing

GUIDANCE ON METHODOLOGY FOR HYDRAULIC ANALYSIS — FORM 5

Project Information Stoney Creek Bridge Widening		Computed: EKB	Date: 6/31/06
		Checked: LEF	Date: 7/1/06
Stream Name: Stoney Creek	County: Ventura	Route: 444	Postmile: 15.3

Summary of Methods for Hydraulic Analysis

☐ **FHWA Design Charts**

☐ **HY8 - Culvert Analysis or other HDS-5 Based Software**

☒ **HEC-2 / HEC-RAS**

☐ **Fish Xing (Pre-design assessment or post-design assessment when applicable)**

Is the hydraulic model used to create the effective FIRM available? ☐ Yes ☒ No
If yes, update and use this model for the hydraulic model.

Selected Method: HEC-RAS

Basis for Selection:

Ability to model multiple incline Structures

Verify Reasonableness and Recommended Flows ☒ Yes ☐ No

Hydraulic Analyses Index Attached ☒ Yes ☐ No

Hydraulic Analysis Calculation Attached ☒ Yes ☐ No

HYDRAULIC ANALYSES INDEX

FORM 5

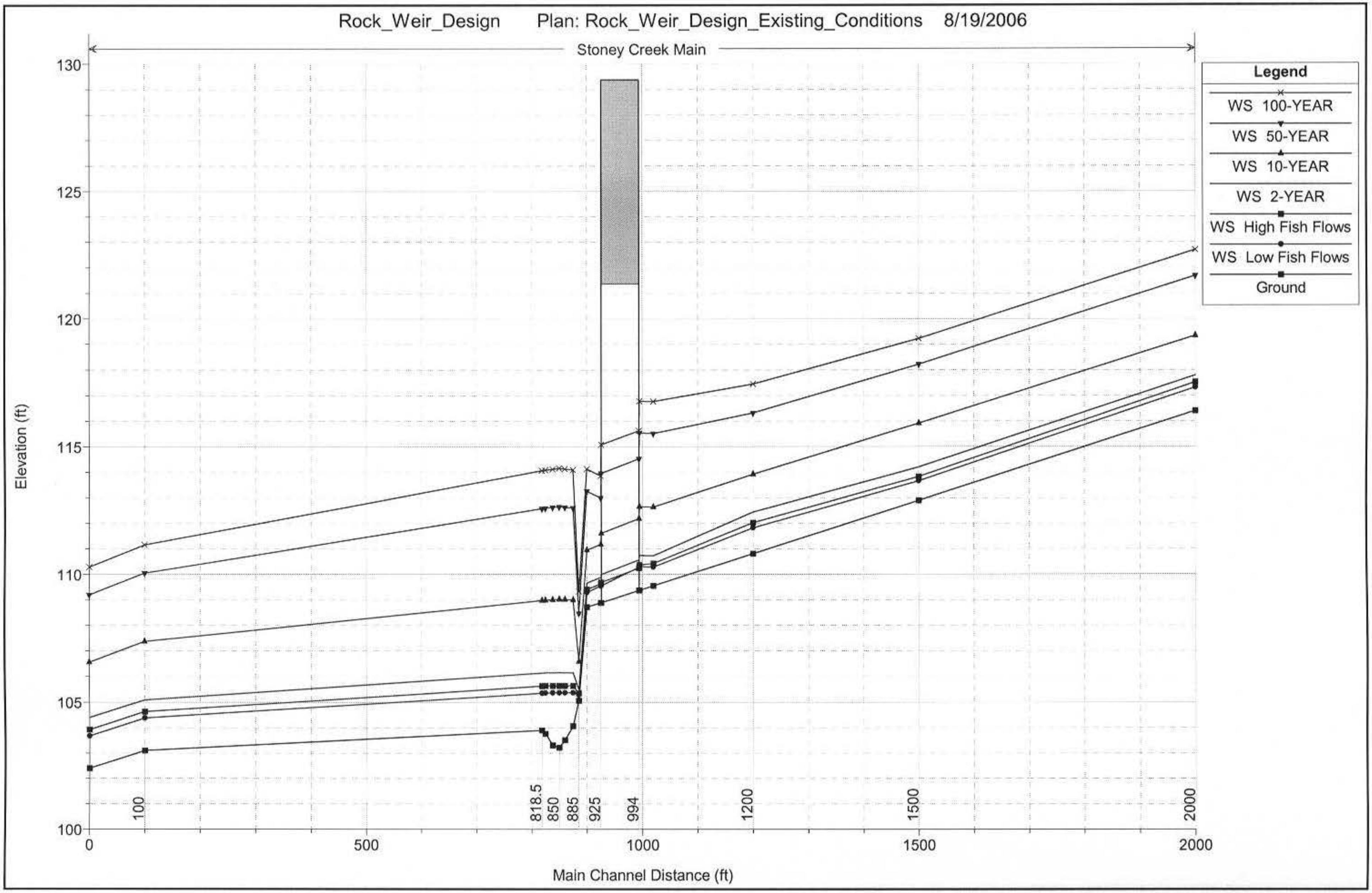
Project Information

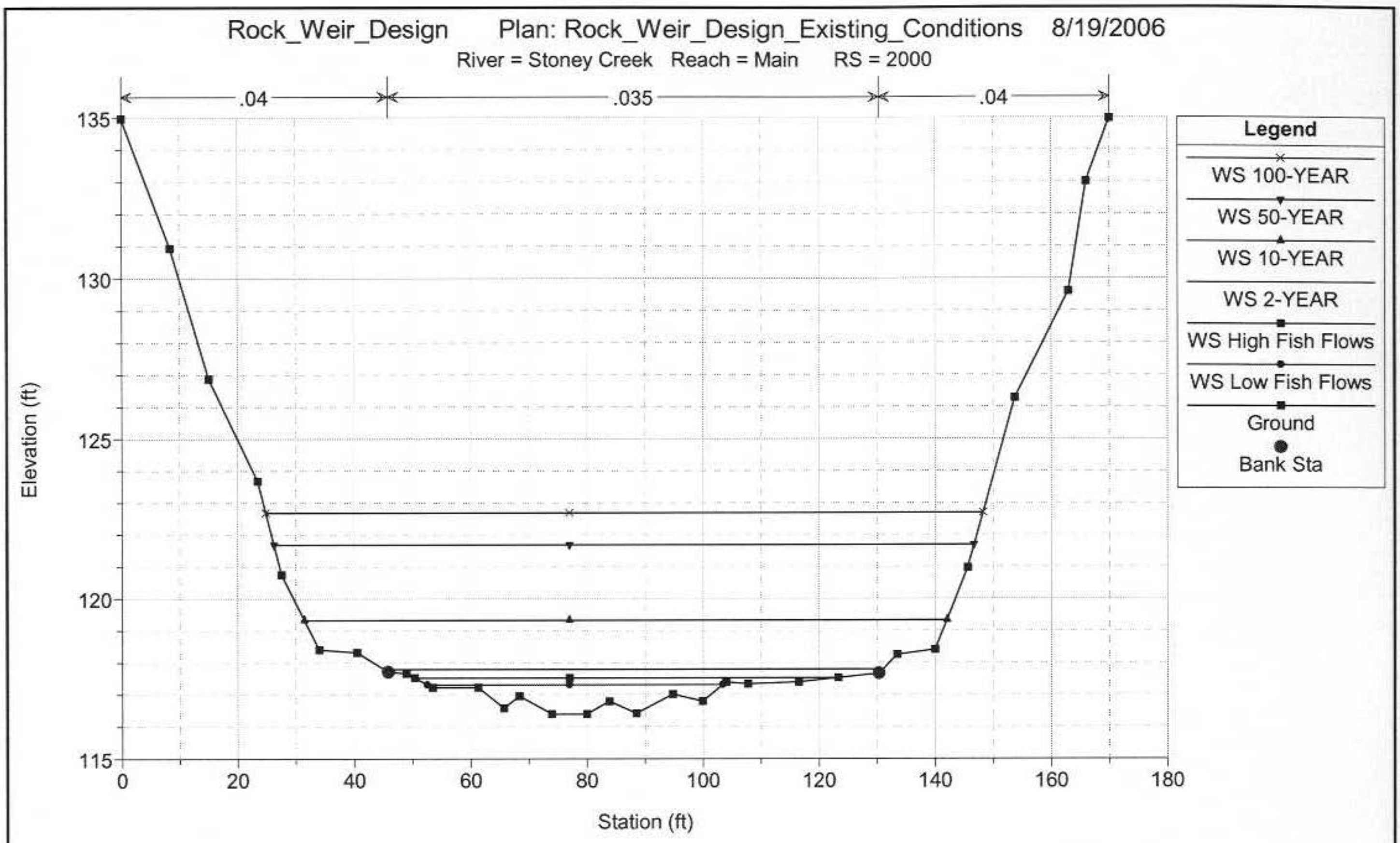
Stoney Creek Bridge Widening

Computed: EKB
Date: 7/5/06
Checked: LEF
Date: 7/6/06

Stream Name: Stoney Creek
County: Ventura
Route 444
Postmile 15.3

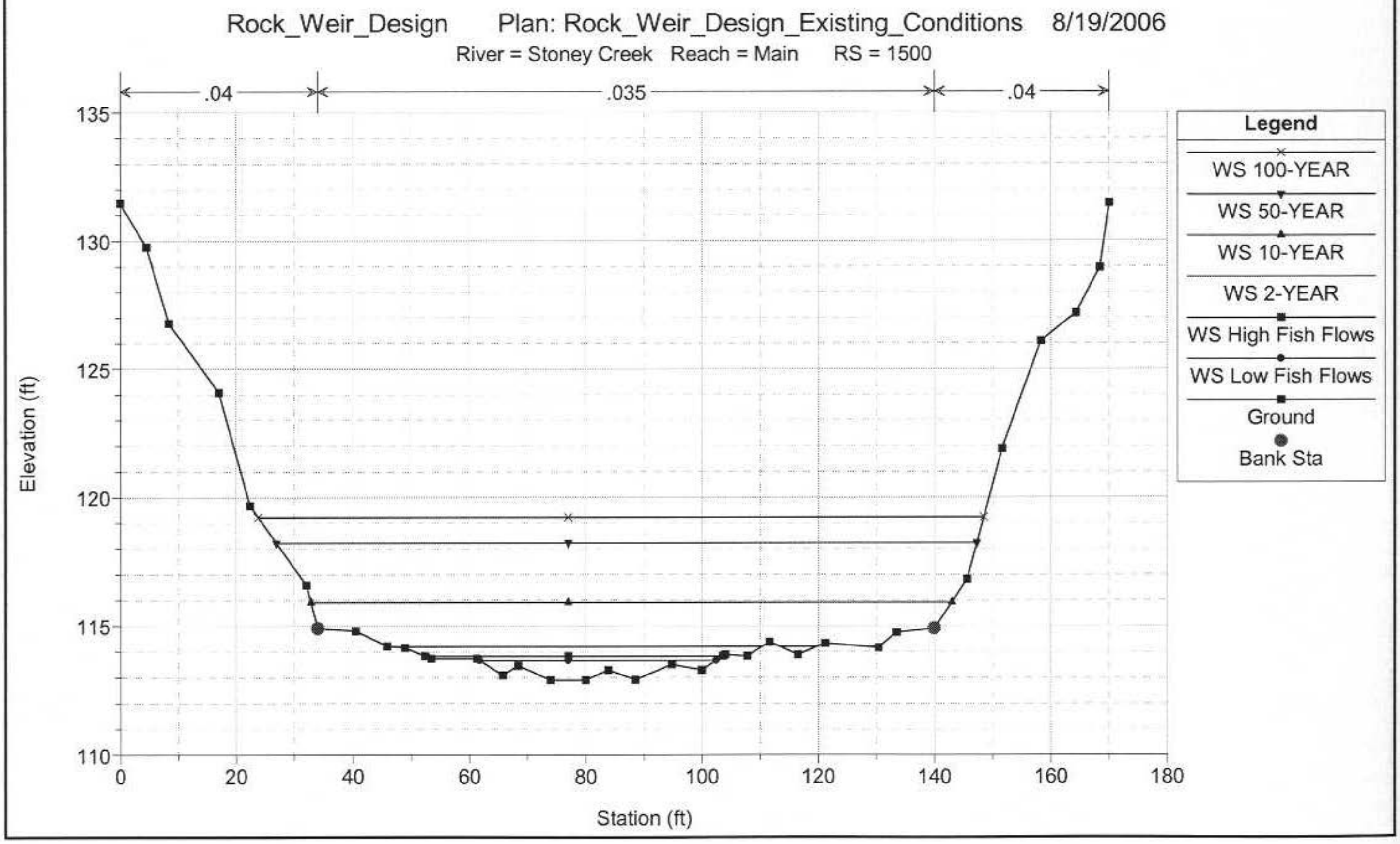
Flooding Source/Stream Name	Hydraulic Method/Model Used	Method/Model Analysis Date	Exhibit No.	
			Paper Copy	Electronic Copy
Stoney Creek	HEC-RAS	Existing Conditions	-	.p03 .g02 .f01
Stoney Creek	HEC-RAS	Proposed conditions	-	.p01 .g01 .f01


Rock_Weir_Design
Plan: Rock_Weir_Design_Existing_Conditions
8/19/2006
Stoney Creek Main
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Elevation (ft)
130
125
120
115
110
105
100
Main Channel Distance (ft)
0
500
1000
1500
2000
100
818.5
850
885
925
994
1200
1500
2000



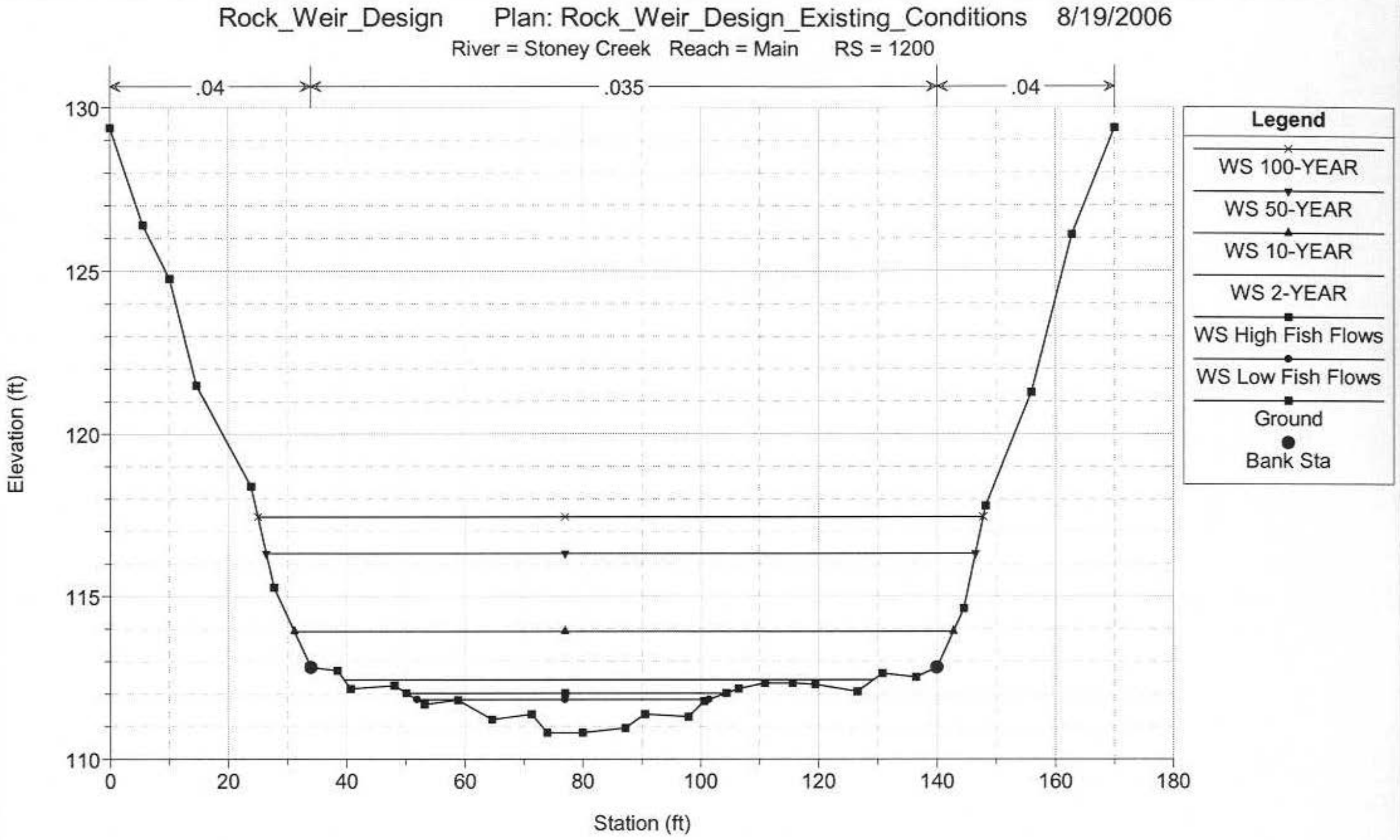
Rock_Weir_Design Plan: Rock_Weir_Design_Existing_Conditions 8/19/2006

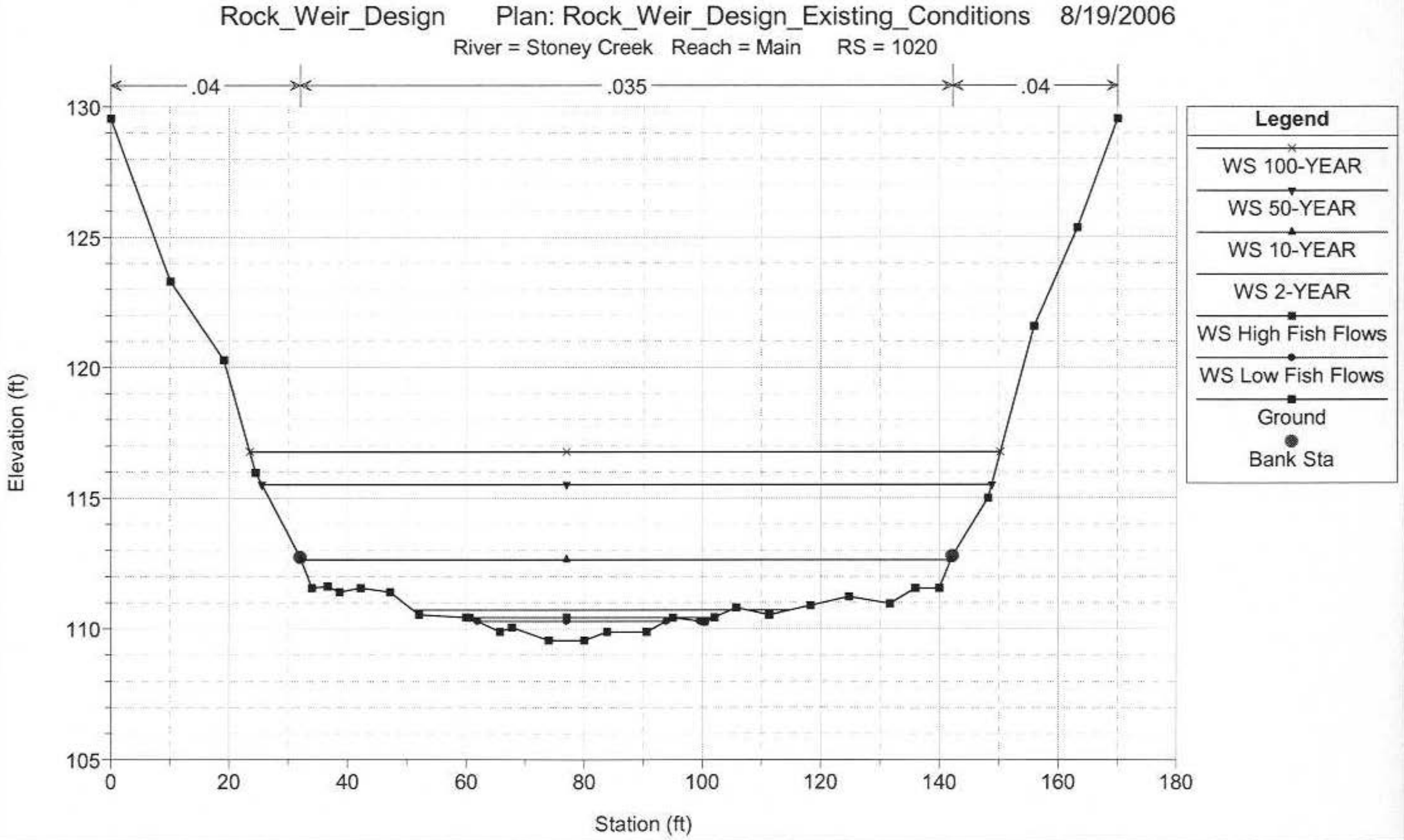
River = Stoney Creek Reach = Main RS = 2000

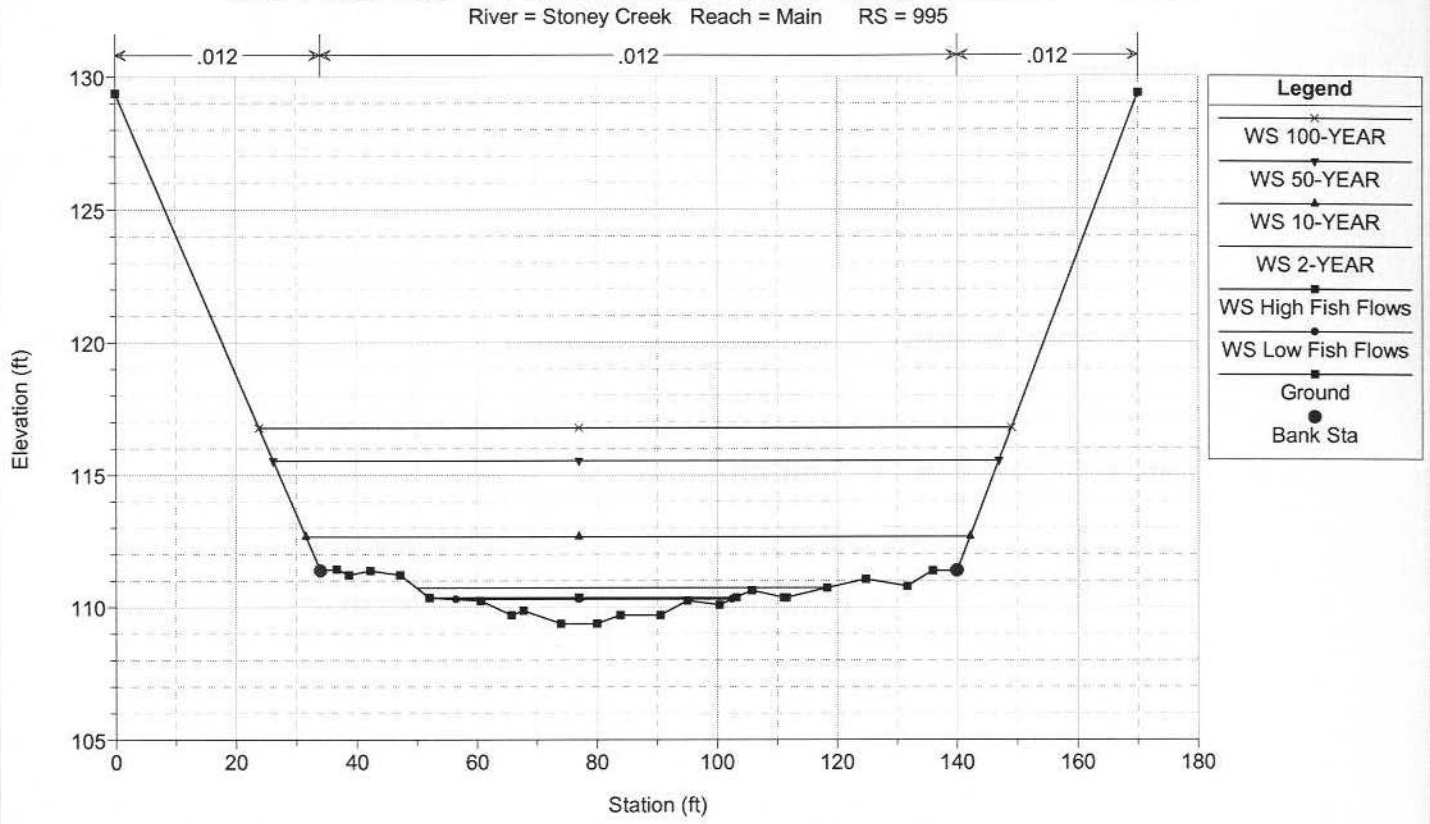


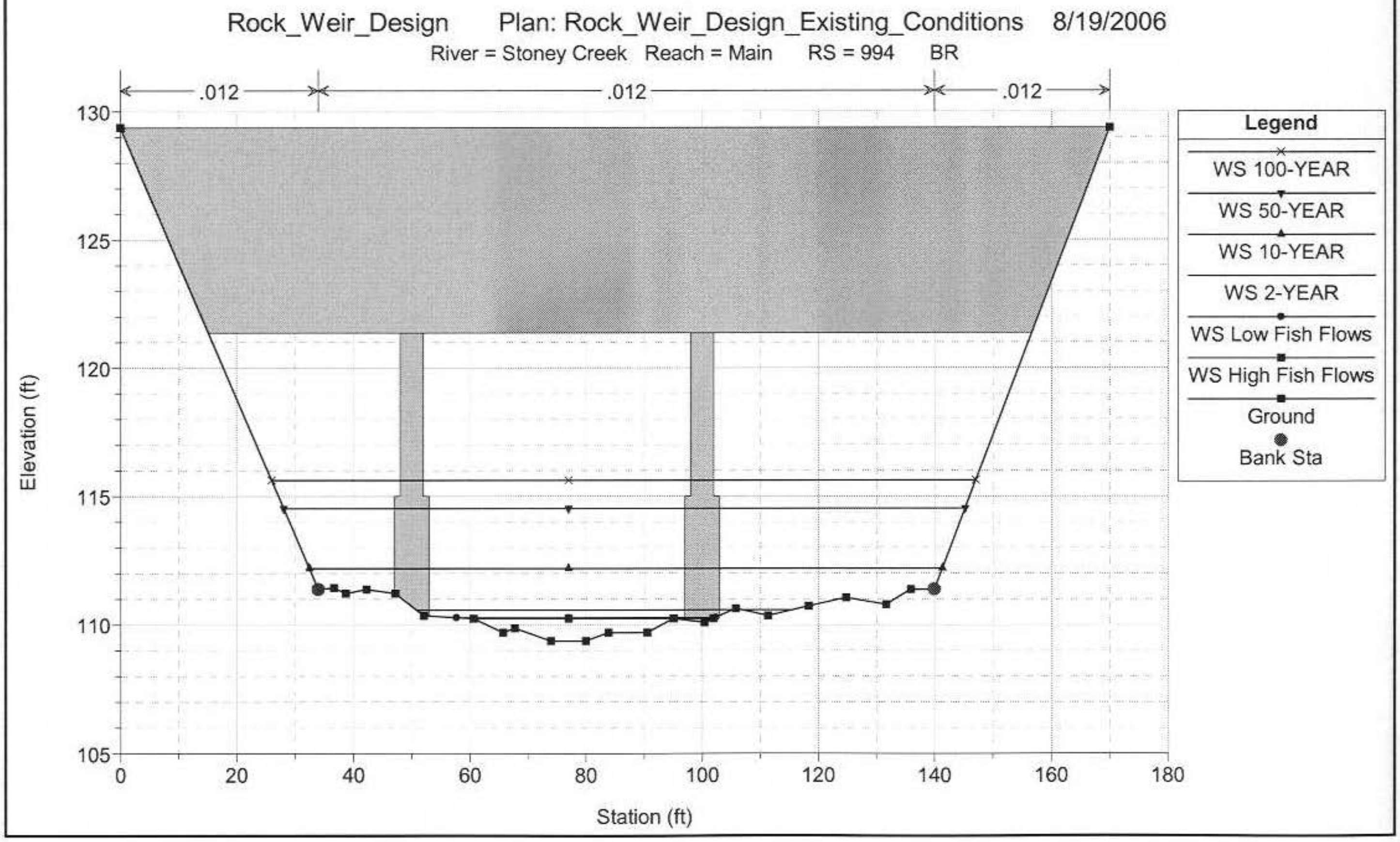
Rock_Weir_Design Plan: Rock_Weir_Design_Existing_Conditions 8/19/2006

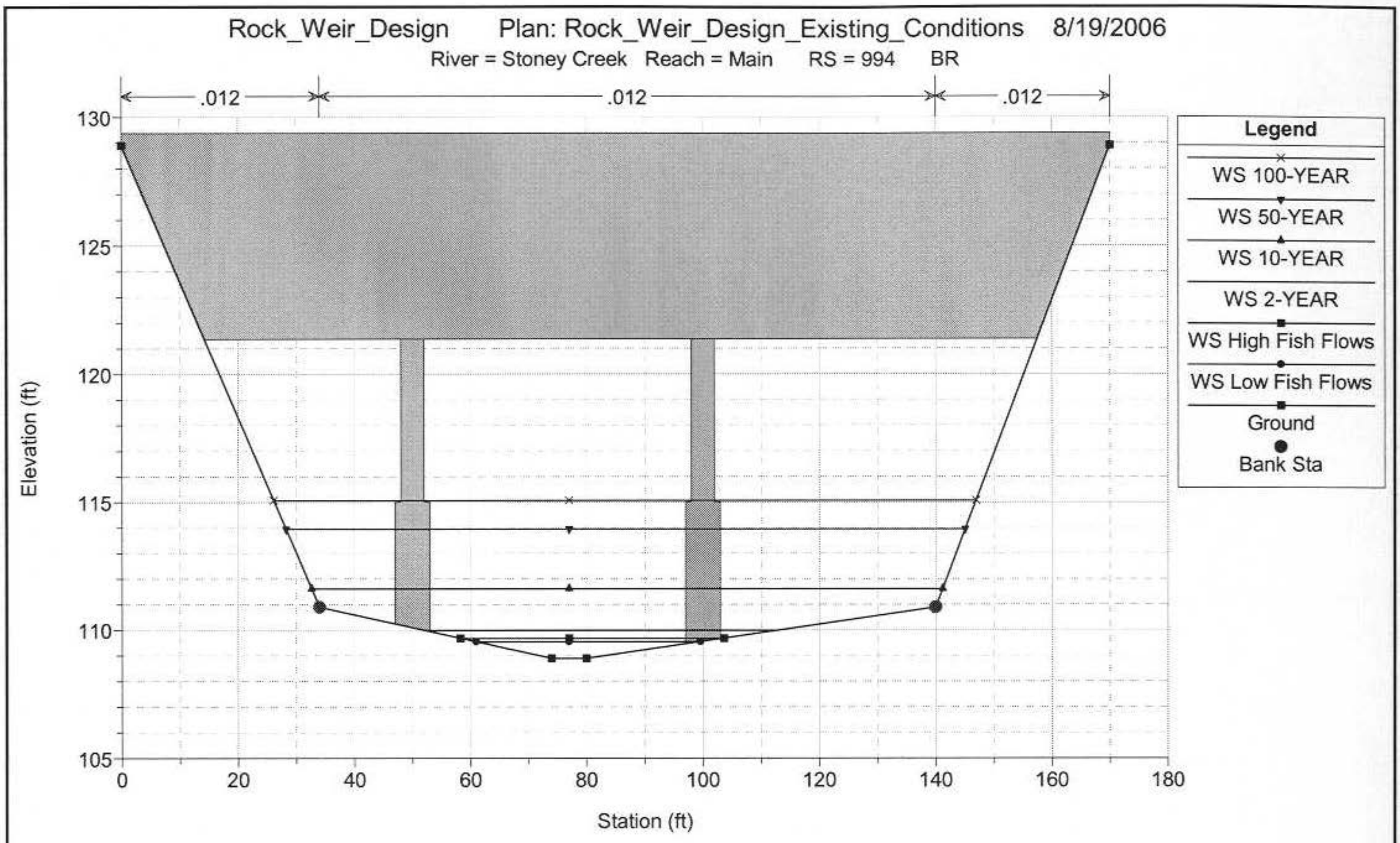
River = Stoney Creek Reach = Main RS = 1500

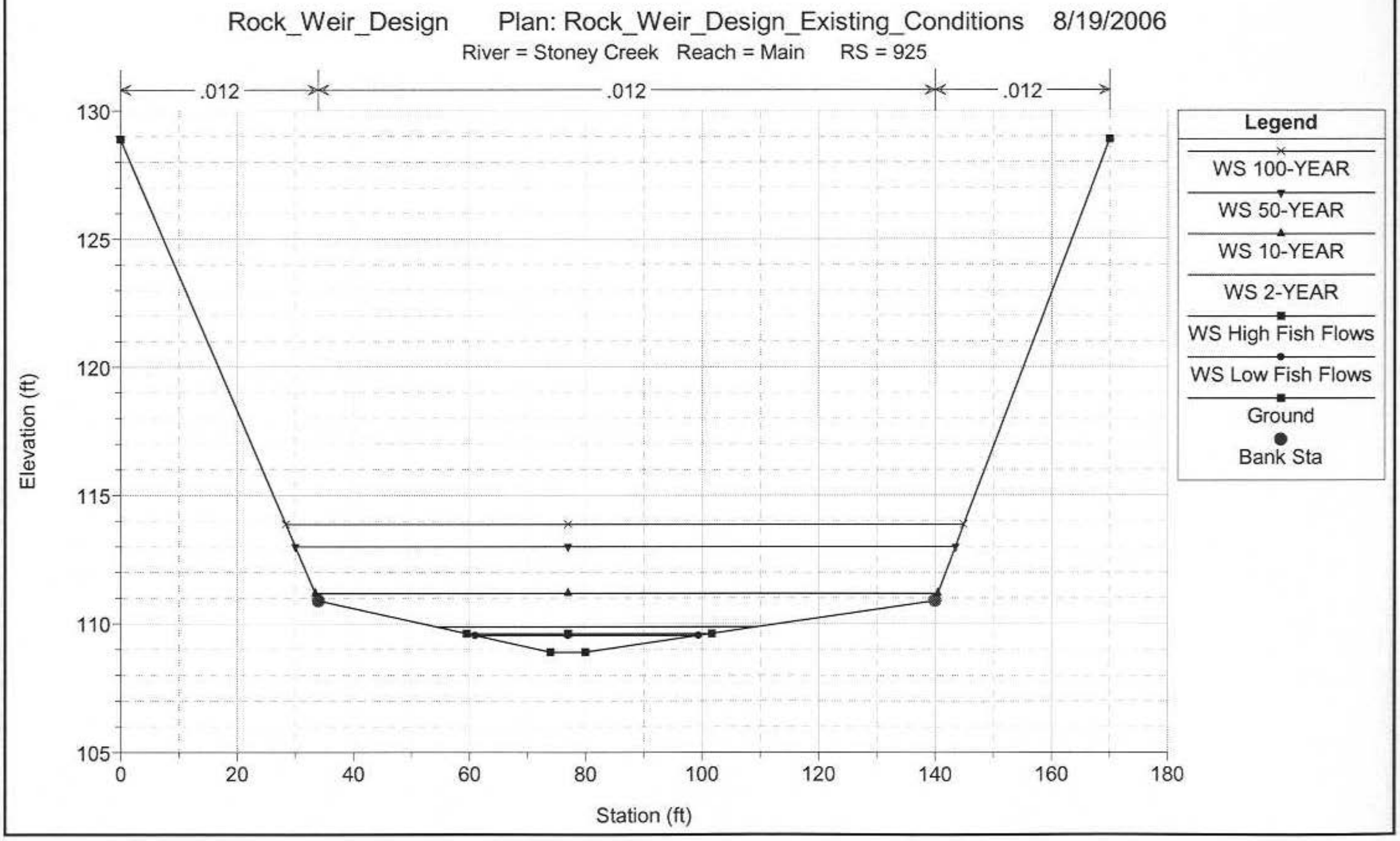

Rock_Weir_Design Plan: Rock_Weir_Design_Existing_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 1200
.04
.035
.04
Elevation (ft)
130
125
120
115
110
Station (ft)
0
20
40
60
80
100
120
140
160
180
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Bank Sta

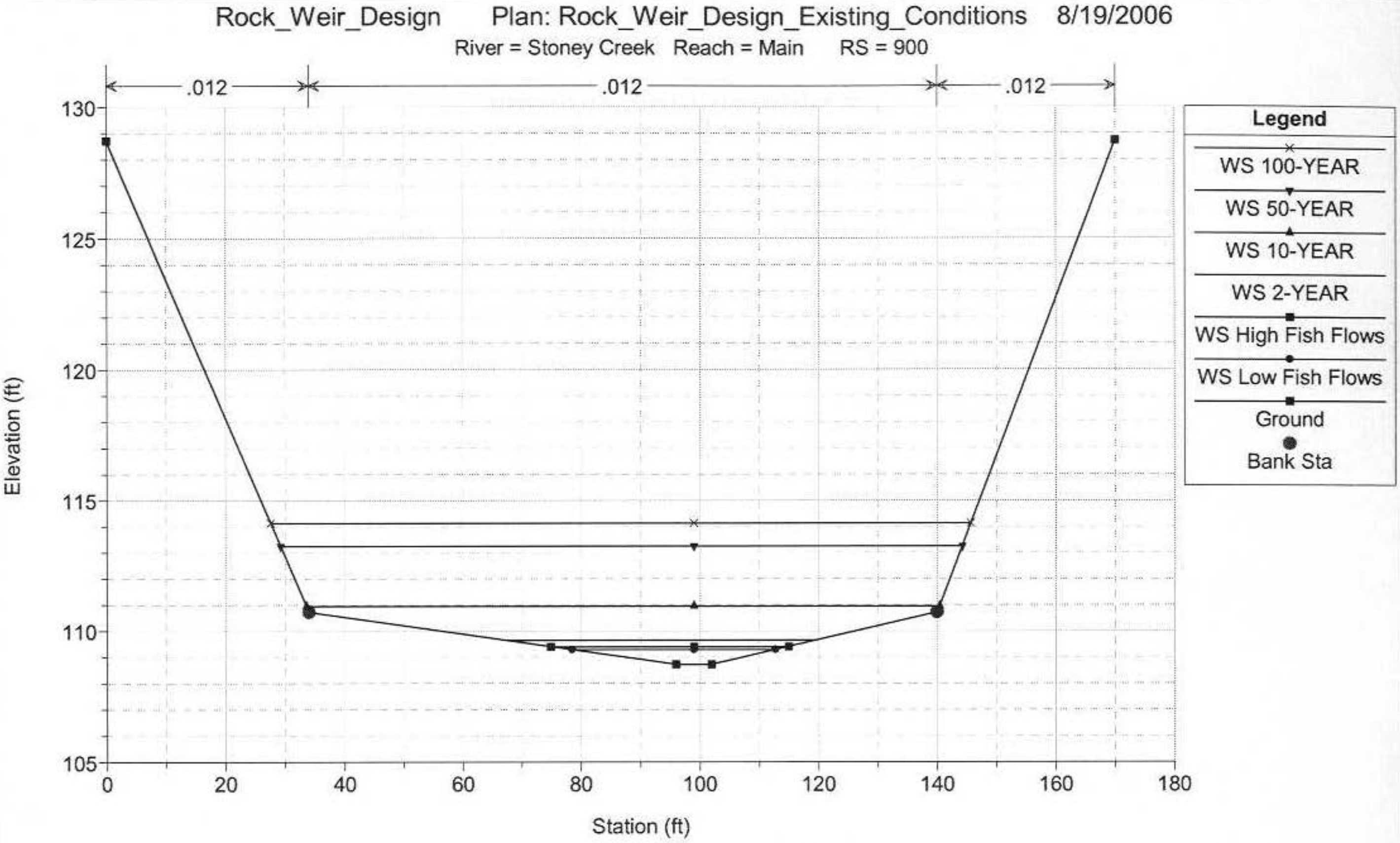

Rock_Weir_Design Plan: Rock_Weir_Design_Existing_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 1020
.04
.035
.04
Elevation (ft)
130
125
120
115
110
105
Station (ft)
0
20
40
60
80
100
120
140
160
180
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Bank Sta


Rock_Weir_Design Plan: Rock_Weir_Design_Existing_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 995
.012
.012
.012
Elevation (ft)
130
125
120
115
110
105
0
20
40
60
80
100
120
140
160
180
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Bank Sta


Rock_Weir_Design Plan: Rock_Weir_Design_Existing_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 994 BR
.012
.012
.012
Elevation (ft)
130
125
120
115
110
105
0
20
40
60
80
100
120
140
160
180
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS Low Fish Flows
WS High Fish Flows
Ground
Bank Sta

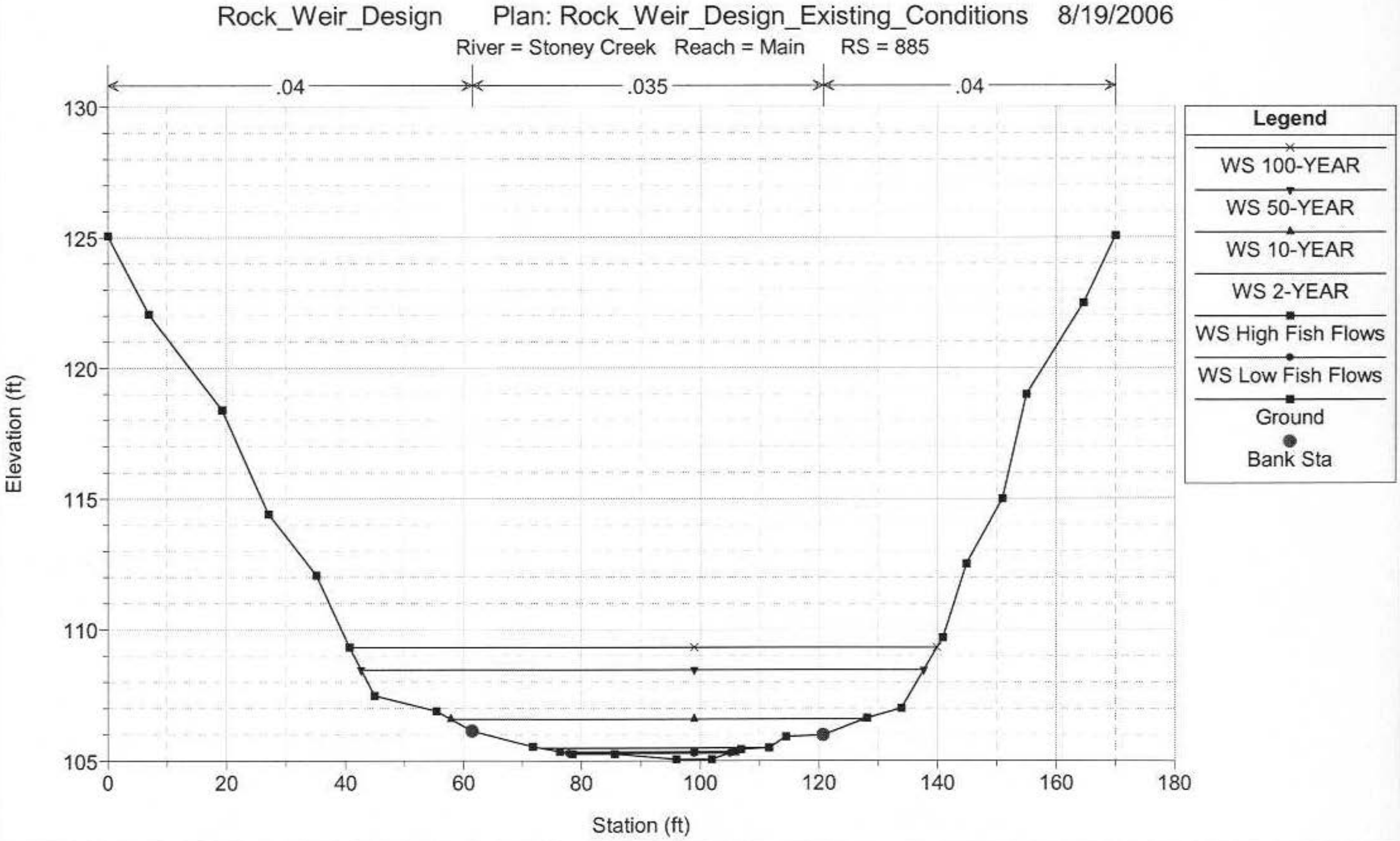

Rock_Weir_Design Plan: Rock_Weir_Design_Existing_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 994 BR
.012
.012
.012
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Bank Sta
Elevation (ft)
130
125
120
115
110
105
Station (ft)
0
20
40
60
80
100
120
140
160
180


Rock_Weir_Design Plan: Rock_Weir_Design_Existing_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 925
.012
.012
.012
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Bank Sta
Elevation (ft)
130
125
120
115
110
105
Station (ft)
0
20
40
60
80
100
120
140
160
180



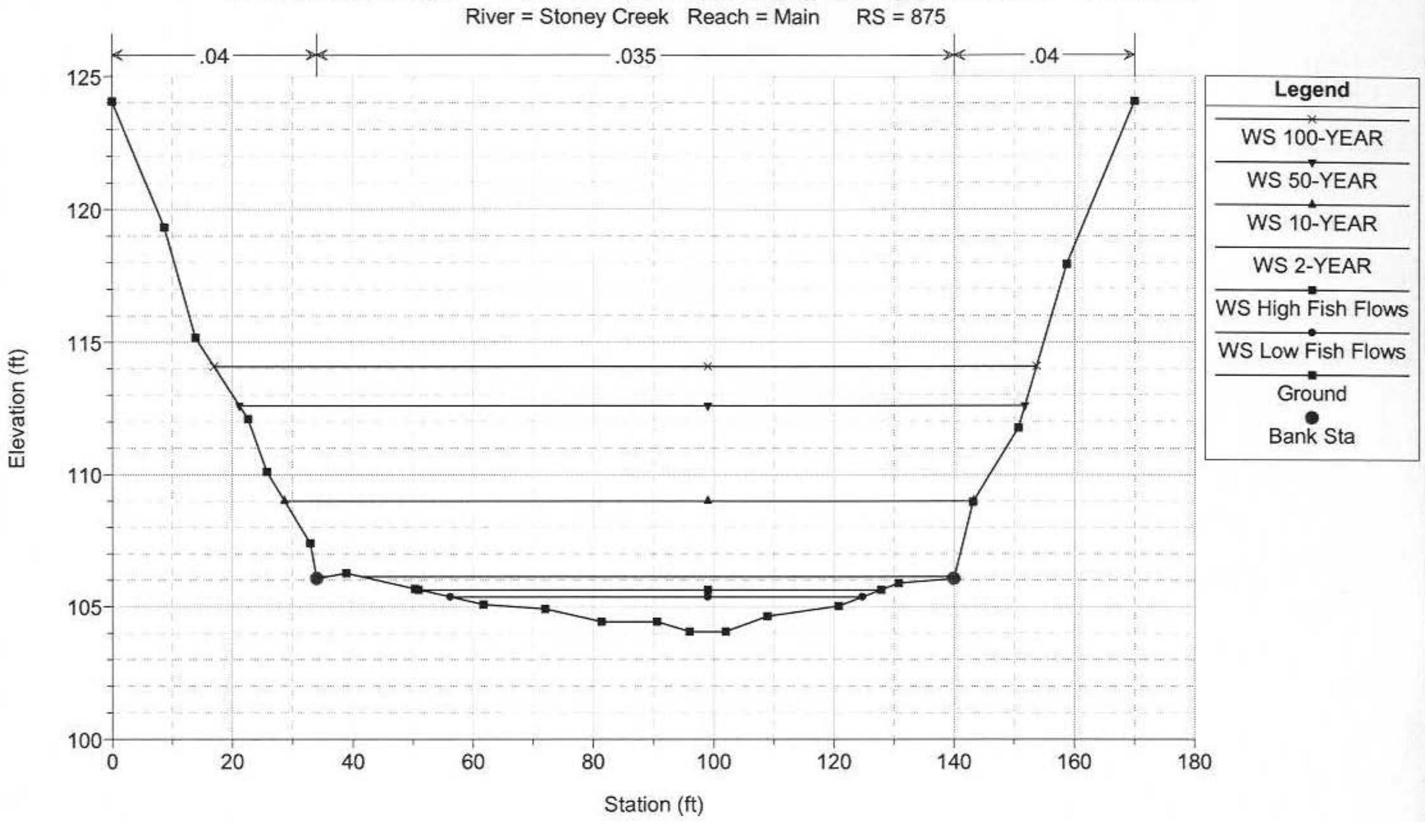
Rock_Weir_Design Plan: Rock_Weir_Design_Existing_Conditions 8/19/2006

River = Stoney Creek Reach = Main RS = 900



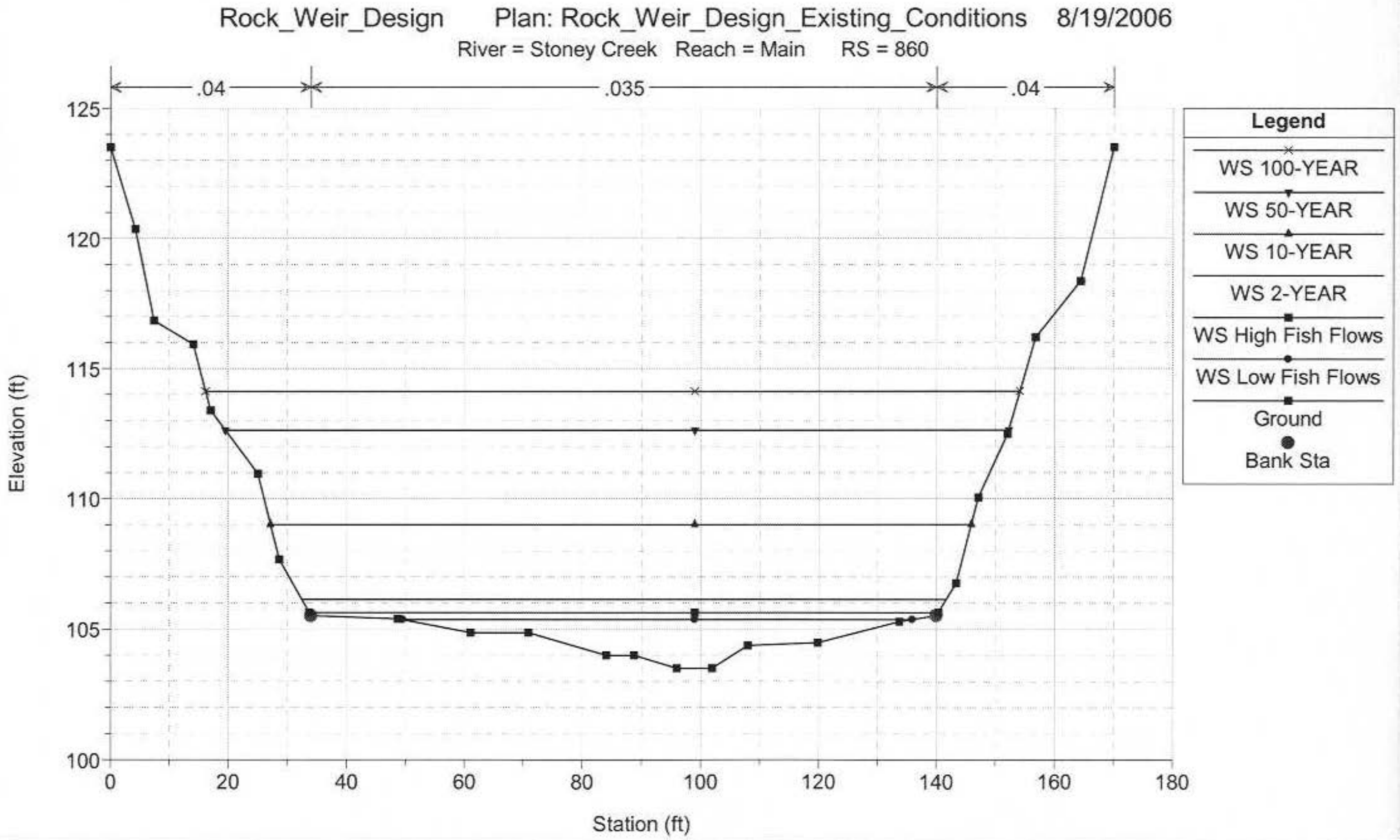
Rock_Weir_Design Plan: Rock_Weir_Design_Existing_Conditions 8/19/2006

River = Stoney Creek Reach = Main RS = 885



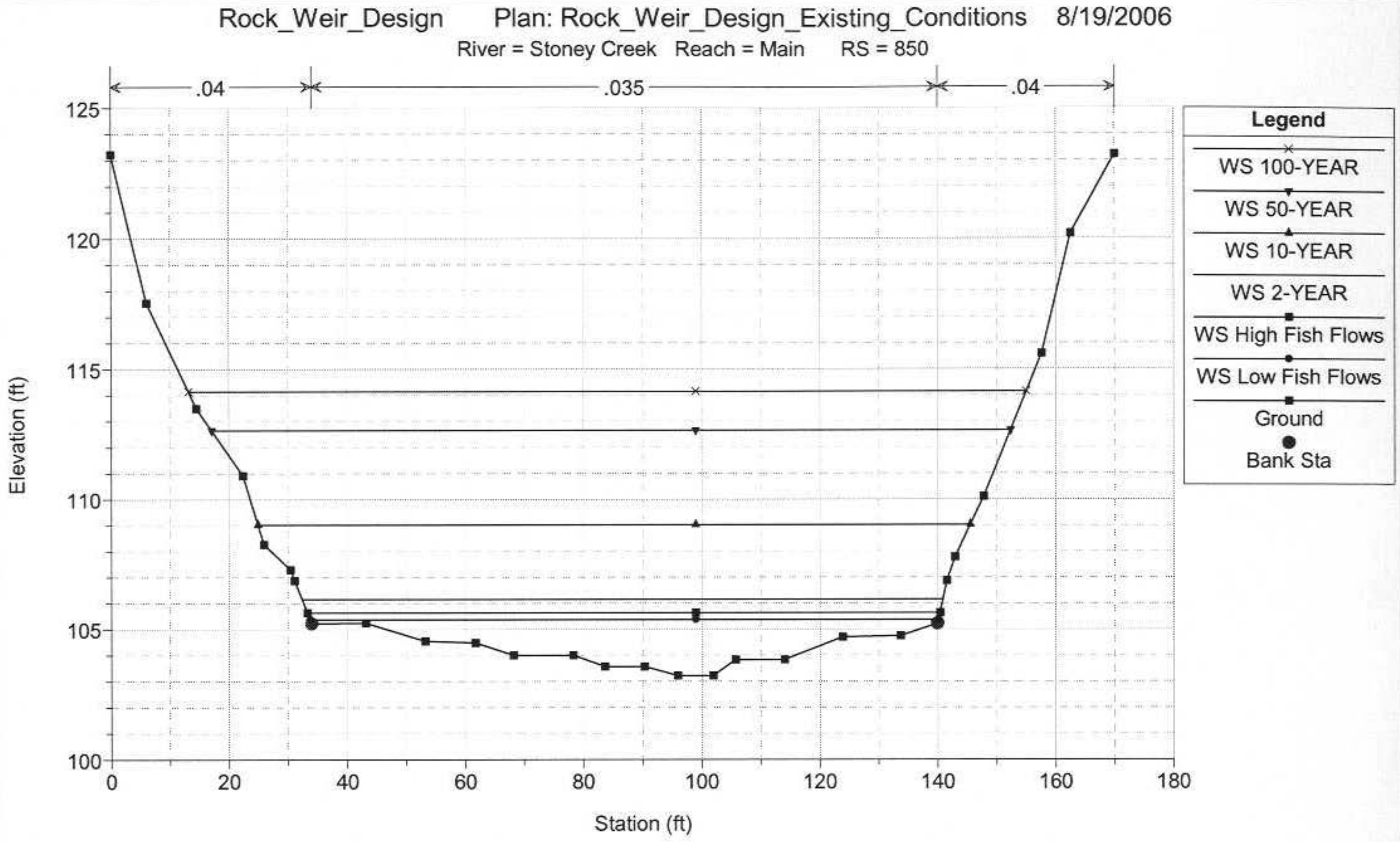
Rock_Weir_Design Plan: Rock_Weir_Design_Existing_Conditions 8/19/2006

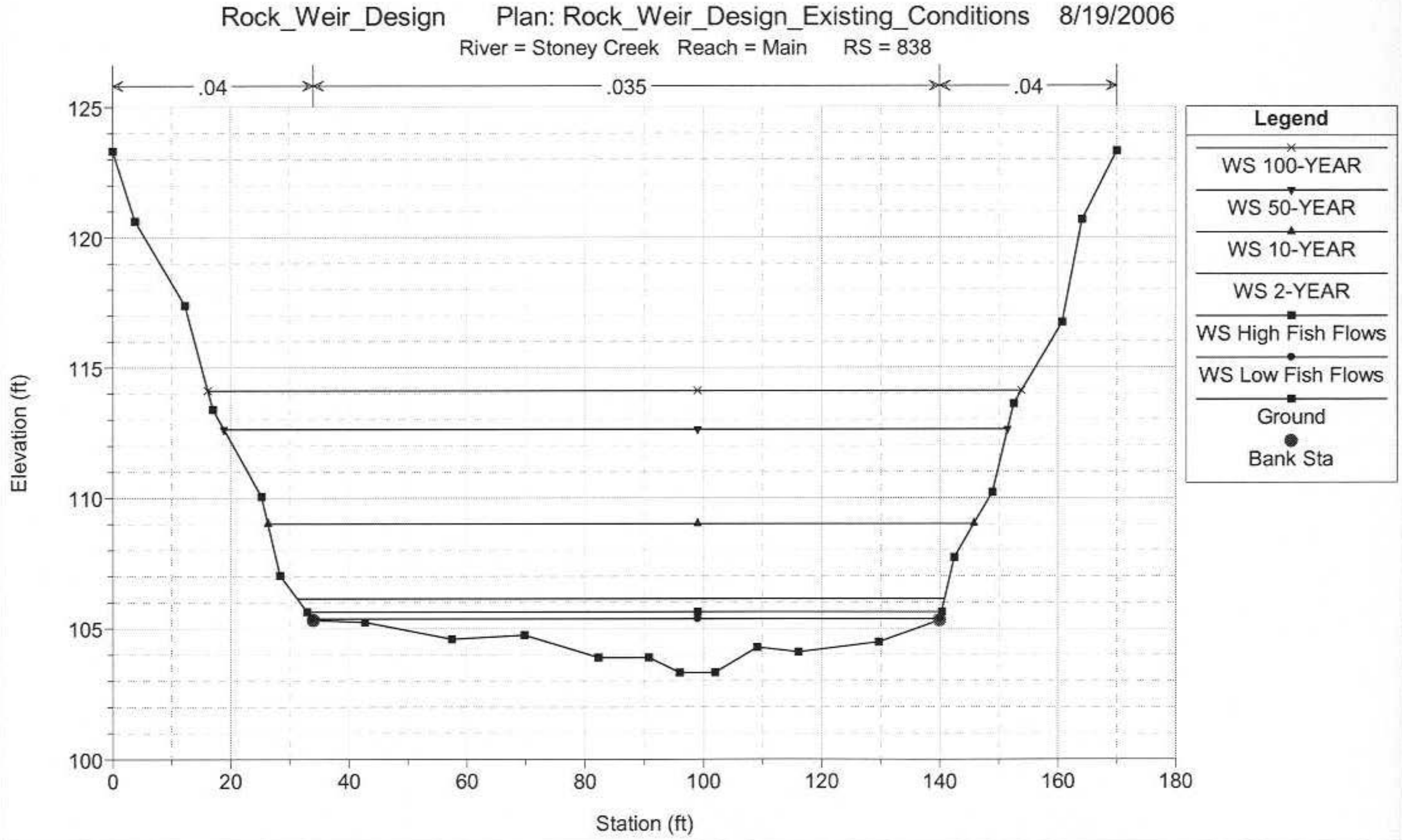
River = Stoney Creek Reach = Main RS = 875

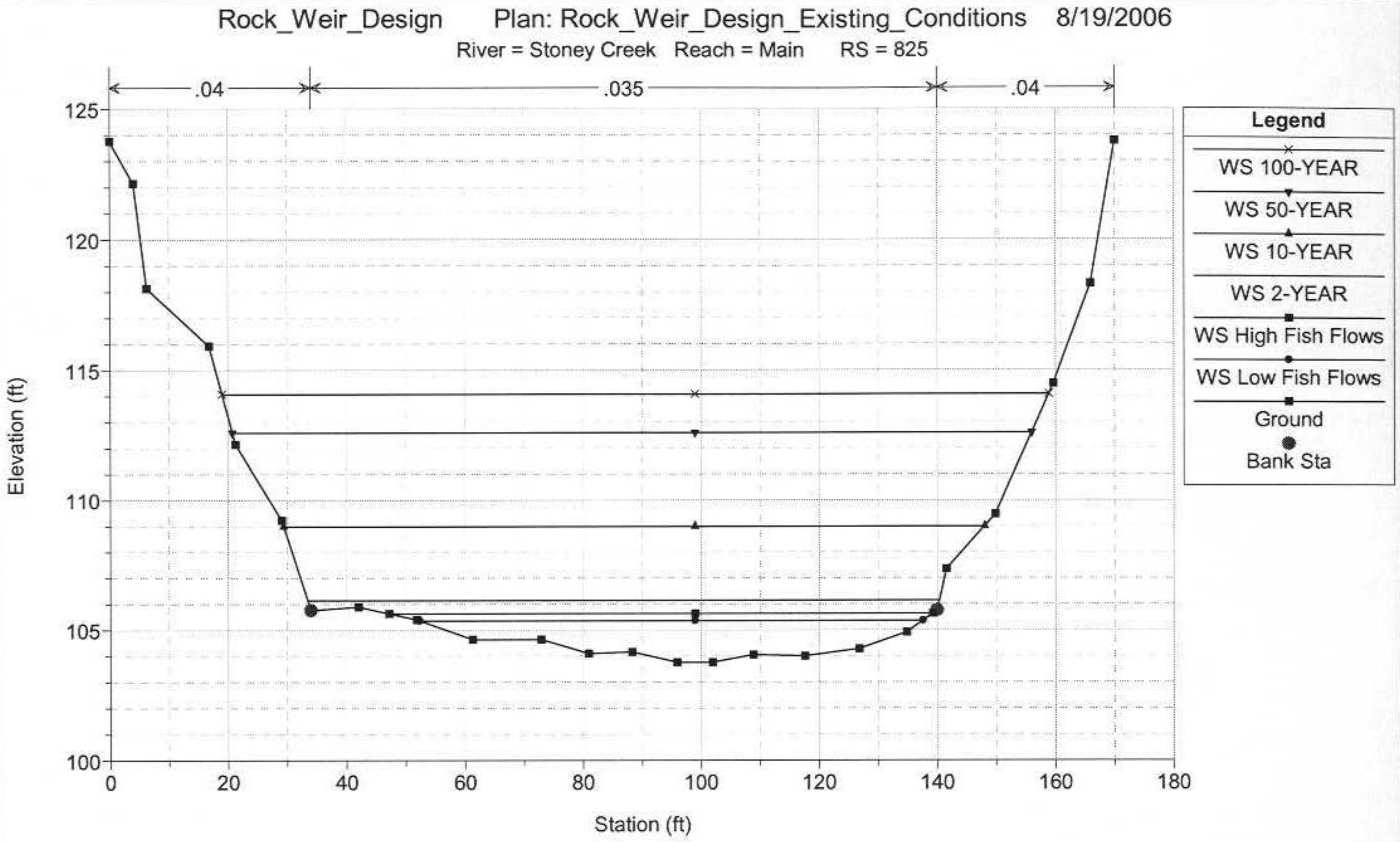


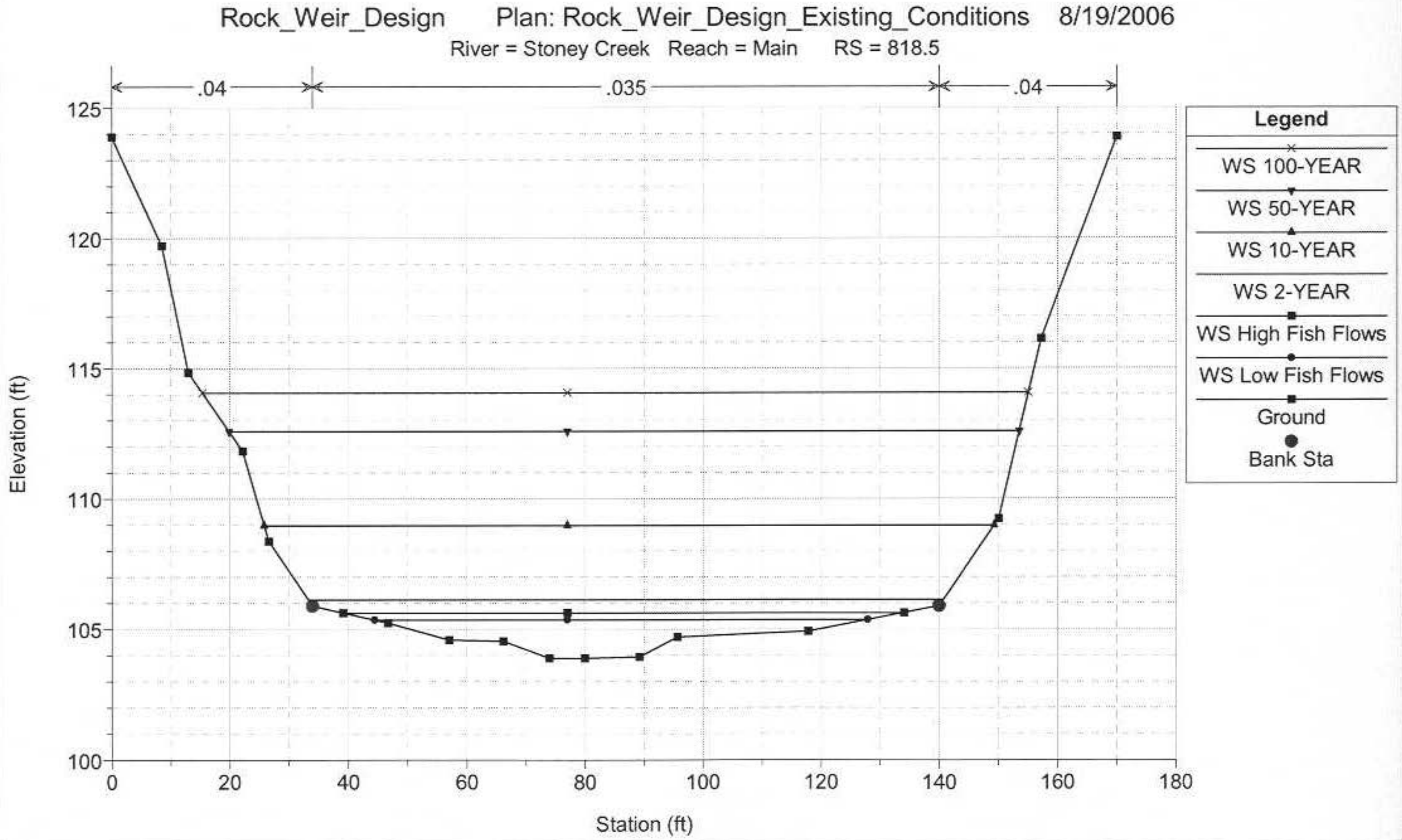
Rock_Weir_Design Plan: Rock_Weir_Design_Existing_Conditions 8/19/2006

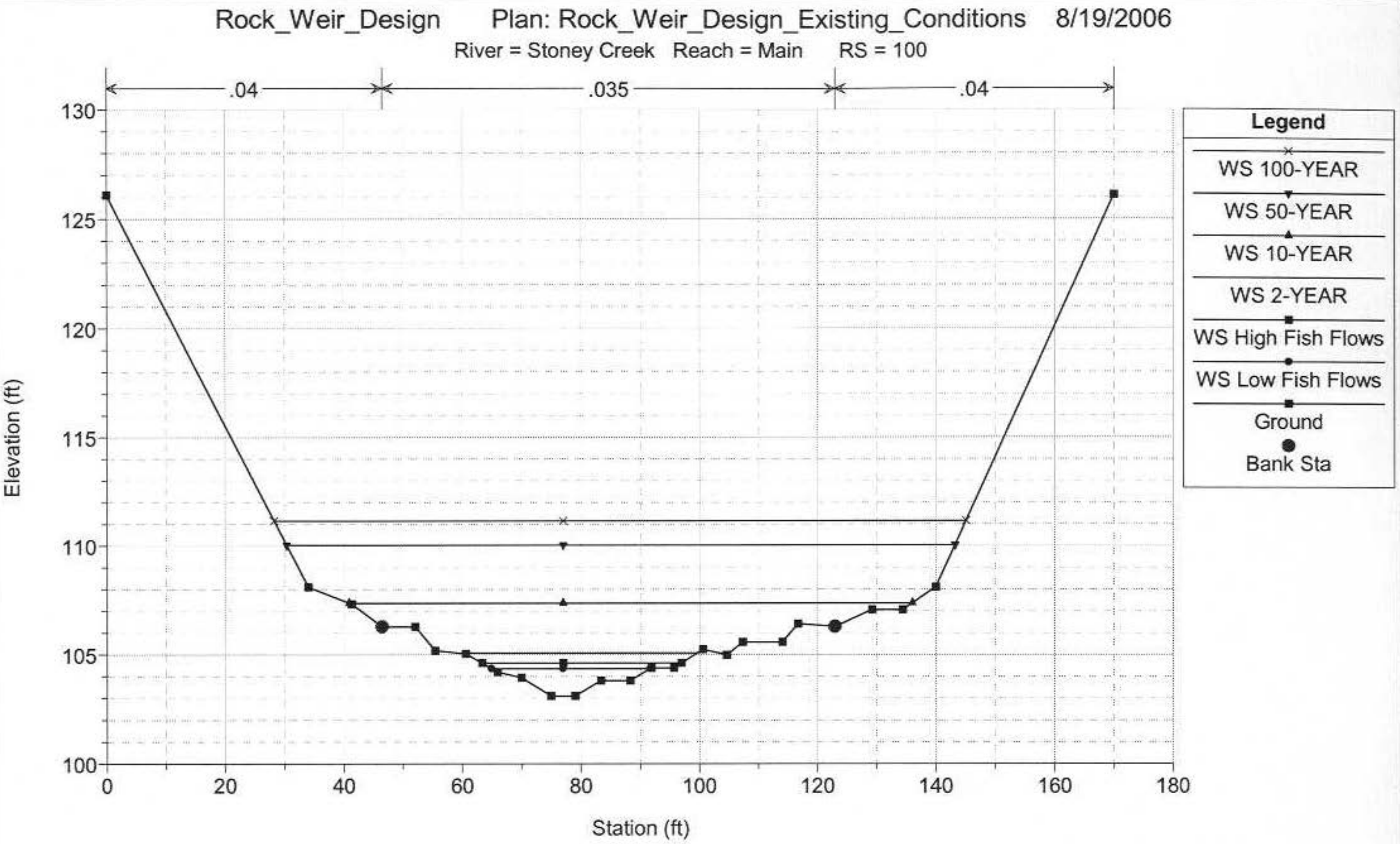
River = Stoney Creek Reach = Main RS = 860

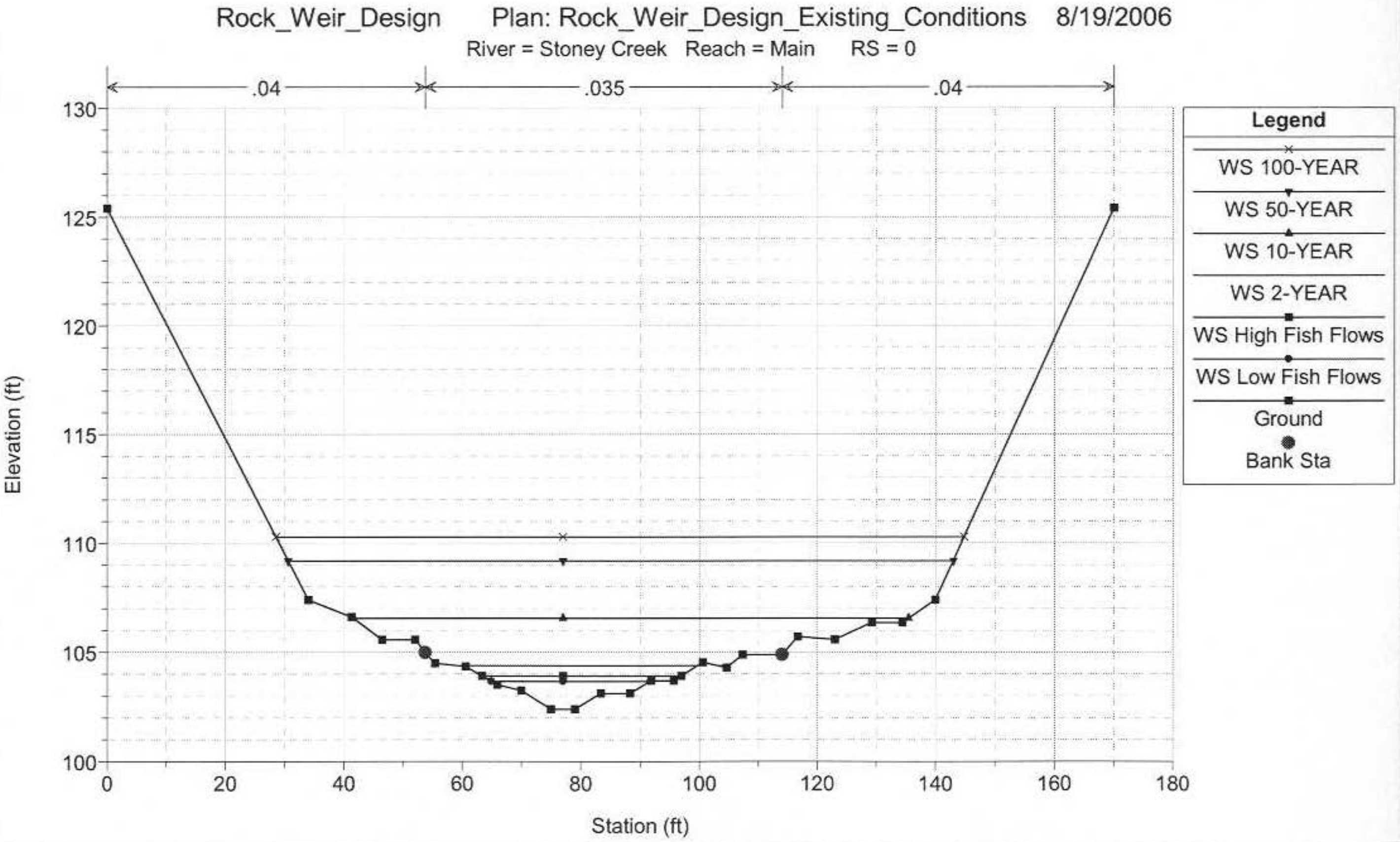

Rock_Weir_Design Plan: Rock_Weir_Design_Existing_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 850
.04
.035
.04
Elevation (ft)
125
120
115
110
105
100
Station (ft)
0
20
40
60
80
100
120
140
160
180
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Bank Sta


Rock_Weir_Design Plan: Rock_Weir_Design_Existing_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 838
.04
.035
.04
Elevation (ft)
125
120
115
110
105
100
Station (ft)
0
20
40
60
80
100
120
140
160
180
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Bank Sta


Rock_Weir_Design
Plan: Rock_Weir_Design_Existing_Conditions
8/19/2006
River = Stoney Creek Reach = Main RS = 825
.04
.035
.04
Elevation (ft)
125
120
115
110
105
100
Station (ft)
0
20
40
60
80
100
120
140
160
180
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Bank Sta


Rock_Weir_Design
Plan: Rock_Weir_Design_Existing_Conditions
8/19/2006
River = Stoney Creek Reach = Main RS = 818.5
.04
.035
.04
Elevation (ft)
125
120
115
110
105
100
Station (ft)
0
20
40
60
80
100
120
140
160
180
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Bank Sta


Rock_Weir_Design Plan: Rock_Weir_Design_Existing_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 100
.04
.035
.04
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Bank Sta
Elevation (ft)
100
105
110
115
120
125
130
Station (ft)
0
20
40
60
80
100
120
140
160
180


Rock_Weir_Design Plan: Rock_Weir_Design_Existing_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 0
.04
.035
.04
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Bank Sta
Elevation (ft)
100
105
110
115
120
125
130
Station (ft)
0
20
40
60
80
100
120
140
160
180

HEC-RAS Plan Existing River Stoney Creek Reach Main

Reach	River Sta	Profile	Q Total	W.S. Elev	Min Ch El	Diff	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)		(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main	0	2-YEAR	155.00	104.39	102.40	1.99	104.02	104.59	0.007010	3.58	43.28	42.49	0.63
Main	0	10-YEAR	1252.00	106.56	102.40	4.16	106.19	107.30	0.007005	7.04	193.34	93.81	0.74
Main	0	50-YEAR	4460.00	109.19	102.40	6.79	108.84	110.80	0.007005	10.94	472.68	112.37	0.83
Main	0	100-YEAR	6336.00	110.28	102.40	7.88	109.87	112.30	0.007014	12.36	597.68	116.26	0.85
Main	0	High Fish Flows	78.00	103.92	102.40	1.52	103.62	104.06	0.007005	2.99	26.11	33.64	0.60
Main	0	Low Fish Flows	50.00	103.67	102.40	1.27	103.43	103.79	0.007000	2.74	18.27	26.80	0.58
Main	100	2-YEAR	155.00	105.09	103.10	1.99		105.29	0.007001	3.58	43.33	42.55	0.62
Main	100	10-YEAR	1252.00	107.37	103.10	4.27		107.99	0.006550	6.36	203.38	95.13	0.70
Main	100	50-YEAR	4460.00	110.04	103.10	6.94		111.47	0.006190	9.98	489.65	112.91	0.77
Main	100	100-YEAR	6336.00	111.15	103.10	8.05		112.97	0.006188	11.36	617.38	116.86	0.80
Main	100	High Fish Flows	78.00	104.62	103.10	1.52		104.76	0.006974	2.98	26.15	33.66	0.60
Main	100	Low Fish Flows	50.00	104.37	103.10	1.27		104.49	0.007043	2.74	18.23	26.78	0.59
Main	818.5	2-YEAR	155.00	106.13	103.89	2.24		106.15	0.000468	1.11	140.31	107.44	0.17
Main	818.5	10-YEAR	1252.00	108.98	103.89	5.09		109.09	0.000629	2.76	470.01	123.45	0.24
Main	818.5	50-YEAR	4460.00	112.58	103.89	8.69		112.96	0.000928	5.07	932.39	133.65	0.32
Main	818.5	100-YEAR	6336.00	114.06	103.89	10.17		114.59	0.001024	5.98	1135.00	139.68	0.35
Main	818.5	High Fish Flows	78.00	105.63	103.89	1.74		105.64	0.000481	0.89	88.09	94.83	0.16
Main	818.5	Low Fish Flows	50.00	105.36	103.89	1.47		105.36	0.000483	0.78	64.02	83.44	0.16
Main	825	2-YEAR	155.00	106.14	103.76	2.38		106.15	0.000277	0.94	164.31	106.91	0.13
Main	825	10-YEAR	1252.00	108.99	103.76	5.23		109.10	0.000543	2.65	482.69	118.59	0.22
Main	825	50-YEAR	4460.00	112.59	103.76	8.83		112.97	0.000872	5.01	942.20	135.25	0.31
Main	825	100-YEAR	6336.00	114.08	103.76	10.32		114.60	0.000968	5.91	1146.72	139.93	0.34
Main	825	High Fish Flows	78.00	105.63	103.76	1.87		105.64	0.000203	0.69	112.79	92.01	0.11
Main	825	Low Fish Flows	50.00	105.36	103.76	1.60		105.37	0.000167	0.56	88.86	85.23	0.10
Main	838	2-YEAR	155.00	106.14	103.31	2.83		106.16	0.000186	0.84	186.14	109.57	0.11
Main	838	10-YEAR	1252.00	109.01	103.31	5.70		109.10	0.000454	2.50	514.38	119.45	0.21
Main	838	50-YEAR	4460.00	112.63	103.31	9.32		112.98	0.000790	4.86	971.02	132.60	0.30
Main	838	100-YEAR	6336.00	114.12	103.31	10.81		114.61	0.000895	5.78	1172.04	137.70	0.33
Main	838	High Fish Flows	78.00	105.64	103.31	2.33		105.64	0.000149	0.60	131.08	107.40	0.09
Main	838	Low Fish Flows	50.00	105.37	103.31	2.06		105.37	0.000140	0.49	102.07	106.24	0.09
Main	850	2-YEAR	155.00	106.15	103.22	2.93		106.16	0.000140	0.77	202.30	108.52	0.10
Main	850	10-YEAR	1252.00	109.02	103.22	5.80		109.11	0.000409	2.43	529.85	120.59	0.20
Main	850	50-YEAR	4460.00	112.65	103.22	9.43		112.99	0.000739	4.76	992.37	135.27	0.29
Main	850	100-YEAR	6336.00	114.15	103.22	10.93		114.62	0.000841	5.67	1199.74	141.87	0.32
Main	850	High Fish Flows	78.00	105.64	103.22	2.42		105.64	0.000101	0.53	147.46	107.14	0.08
Main	850	Low Fish Flows	50.00	105.37	103.22	2.15		105.37	0.000086	0.42	118.43	106.40	0.07
Main	860	2-YEAR	155.00	106.15	103.51	2.64		106.16	0.000320	0.99	158.01	109.29	0.14
Main	860	10-YEAR	1252.00	109.01	103.51	5.50		109.12	0.000547	2.64	487.35	118.78	0.22
Main	860	50-YEAR	4460.00	112.63	103.51	9.12		113.01	0.000881	5.02	938.21	132.76	0.31
Main	860	100-YEAR	6336.00	114.12	103.51	10.61		114.64	0.000979	5.93	1140.51	137.98	0.34
Main	860	High Fish Flows	78.00	105.64	103.51	2.13		105.65	0.000330	0.76	103.16	106.66	0.14
Main	860	Low Fish Flows	50.00	105.37	103.51	1.86		105.37	0.000286	0.66	75.93	86.38	0.12
Main	875	2-YEAR	155.00	106.14	104.06	2.08	105.18	106.17	0.000937	1.39	111.61	101.04	0.23
Main	875	10-YEAR	1252.00	109.00	104.06	4.94	106.72	109.14	0.000811	3.00	424.68	114.59	0.27
Main	875	50-YEAR	4460.00	112.61	104.06	8.55	108.88	113.04	0.001097	5.39	869.00	130.66	0.35
Main	875	100-YEAR	6336.00	114.09	104.06	10.03	109.89	114.68	0.001184	6.31	1067.28	136.81	0.37
Main	875	High Fish Flows	78.00	105.64	104.06	1.58	104.91	105.66	0.000885	1.16	67.46	76.95	0.22
Main	875	Low Fish Flows	50.00	105.37	104.06	1.31	104.76	105.38	0.000988	1.05	47.74	68.58	0.22
Main	885	2-YEAR	155.00	105.49	105.06	0.43	106.04	109.53	0.923831	16.12	9.61	38.69	5.70
Main	885	10-YEAR	1252.00	106.59	105.06	1.53	107.79	111.70	0.156007	18.27	70.48	69.91	3.02
Main	885	50-YEAR	4460.00	108.47	105.06	3.41	110.27	114.82	0.057875	21.31	233.73	95.04	2.16
Main	885	100-YEAR	6336.00	109.33	105.06	4.27	111.38	116.26	0.046280	22.52	317.19	99.23	2.02
Main	885	High Fish Flows	78.00	105.35	105.06	0.29	105.75	109.15	1.448057	15.63	4.99	29.50	6.69
Main	885	Low Fish Flows	50.00	105.29	105.06	0.23	105.62	108.95	2.211689	15.35	3.26	27.17	7.81
Main	900	2-YEAR	155.00	109.65	108.72	0.93	109.79	110.15	0.005025	5.67	27.34	52.63	1.39
Main	900	10-YEAR	1252.00	110.95	108.72	2.23	111.28	112.26	0.003945	9.19	136.33	106.81	1.43
Main	900	50-YEAR	4460.00	113.25	108.72	4.53	113.45	115.31	0.001587	11.56	391.98	115.01	1.08
Main	900	100-YEAR	6336.00	114.13	108.72	5.41	114.45	116.76	0.001527	13.11	493.96	118.13	1.09
Main	900	High Fish Flows	78.00	109.40	108.72	0.68	109.51	109.79	0.005628	4.97	15.69	40.07	1.40
Main	900	Low Fish Flows	50.00	109.29	108.72	0.57	109.37	109.58	0.005470	4.39	11.39	34.27	1.34
Main	925	2-YEAR	155.00	109.88	108.89	0.99	109.96	110.28	0.003813	5.11	30.31	55.38	1.22
Main	925	10-YEAR	1252.00	111.17	108.89	2.28	111.45	112.38	0.003431	8.81	142.20	107.01	1.34

HEC-RAS Plan: Existing River: Stoney Creek Reach: Main (Continued)

Reach	River Sta	Profile	Q Total	W.S. Elev	Min Ch El	Diff	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)		(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main	925	50-YEAR	4460.00	112.99	108.89	4.10	113.62	115.67	0.002447	13.18	342.74	113.48	1.31
Main	925	100-YEAR	6336.00	113.86	108.89	4.97	114.62	117.12	0.002175	14.60	442.19	116.55	1.28
Main	925	High Fish Flows	78.00	109.61	108.89	0.72	109.68	109.92	0.004221	4.46	17.47	42.23	1.22
Main	925	Low Fish Flows	50.00	109.54	108.89	0.65	109.54	109.73	0.002914	3.47	14.40	38.42	1.00
Main	994		Bridge										
Main	995	2-YEAR	155.00	110.74	109.37	1.37	110.54	110.90	0.001086	3.22	48.20	68.71	0.68
Main	995	10-YEAR	1252.00	112.66	109.37	3.29	112.05	113.09	0.000612	5.24	240.70	110.59	0.62
Main	995	50-YEAR	4460.00	115.53	109.37	6.16	114.20	116.51	0.000475	8.00	573.09	120.81	0.62
Main	995	100-YEAR	6336.00	116.78	109.37	7.41	115.18	118.01	0.000454	9.04	725.90	125.22	0.63
Main	995	High Fish Flows	78.00	110.36	109.37	0.99	110.25	110.51	0.001641	3.10	25.14	51.54	0.78
Main	995	Low Fish Flows	50.00	110.29	109.37	0.92	110.07	110.37	0.000924	2.29	21.85	46.00	0.59
Main	1020	2-YEAR	155.00	110.73	109.55	1.18	110.73	111.02	0.021959	4.35	35.64	61.84	1.01
Main	1020	10-YEAR	1252.00	112.64	109.55	3.09		113.15	0.007360	5.73	218.41	109.73	0.72
Main	1020	50-YEAR	4460.00	115.51	109.55	5.96		116.55	0.004626	8.23	553.66	123.22	0.66
Main	1020	100-YEAR	6336.00	116.76	109.55	7.21		118.05	0.004260	9.20	710.17	126.73	0.66
Main	1020	High Fish Flows	78.00	110.43	109.55	0.88	110.43	110.67	0.023288	3.92	19.89	42.12	1.01
Main	1020	Low Fish Flows	50.00	110.28	109.55	0.73	110.25	110.47	0.019899	3.45	14.50	33.09	0.92
Main	1200	2-YEAR	155.00	112.44	110.81	1.63	111.95	112.52	0.004240	2.29	67.77	89.79	0.46
Main	1200	10-YEAR	1252.00	113.92	110.81	3.11		114.41	0.006645	5.64	224.14	111.58	0.69
Main	1200	50-YEAR	4460.00	116.32	110.81	5.51		117.58	0.006260	9.12	504.01	120.05	0.76
Main	1200	100-YEAR	6336.00	117.45	110.81	6.64		119.04	0.005862	10.25	641.35	122.76	0.76
Main	1200	High Fish Flows	78.00	112.02	110.81	1.21		112.09	0.003896	2.07	37.65	54.27	0.44
Main	1200	Low Fish Flows	50.00	111.83	110.81	1.02		111.88	0.004071	1.82	27.44	49.56	0.43
Main	1500	2-YEAR	155.00	114.20	112.90	1.30	113.98	114.35	0.009245	3.14	49.40	73.02	0.67
Main	1500	10-YEAR	1252.00	115.92	112.90	3.02		116.42	0.006786	5.67	222.06	110.17	0.69
Main	1500	50-YEAR	4460.00	118.23	112.90	5.33		119.57	0.006859	9.39	488.16	120.38	0.79
Main	1500	100-YEAR	6336.00	119.23	112.90	6.33		120.98	0.006833	10.76	611.15	124.72	0.82
Main	1500	High Fish Flows	78.00	113.83	112.90	0.93	113.67	113.96	0.011294	2.92	26.74	51.20	0.71
Main	1500	Low Fish Flows	50.00	113.66	112.90	0.76	113.55	113.77	0.010799	2.64	18.94	40.73	0.68
Main	2000	2-YEAR	155.00	117.79	116.40	1.39	117.50	117.89	0.005586	2.55	60.96	85.94	0.53
Main	2000	10-YEAR	1252.00	119.33	116.40	2.93	118.96	119.88	0.007044	6.12	217.42	110.59	0.72
Main	2000	50-YEAR	4460.00	121.68	116.40	5.28	121.16	123.07	0.007085	9.88	490.44	120.47	0.81
Main	2000	100-YEAR	6336.00	122.69	116.40	6.29	122.15	124.48	0.007109	11.29	613.23	123.43	0.84
Main	2000	High Fish Flows	78.00	117.52	116.40	1.12	117.17	117.58	0.005010	1.99	39.27	72.87	0.48
Main	2000	Low Fish Flows	50.00	117.31	116.40	0.91	117.05	117.37	0.005131	1.93	25.88	50.90	0.48

Plan: Existing   Stoney Creek   Main RS: 994   Profile: High Fish Flows

E.G. US. (ft)	110.51	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	110.36	E.G. Elev (ft)	110.50	109.93
Q Total (cfs)	78.00	W.S. Elev (ft)	110.24	109.68
Q Bridge (cfs)	78.00	Crit W.S. (ft)	110.24	109.68
Q Weir (cfs)		Max Chl Dpth (ft)	0.87	0.79
Weir Sta Lft (ft)		Vel Total (ft/s)	4.12	3.99
Weir Sta Rgt (ft)		Flow Area (sq ft)	18.92	19.53
Weir Submerg		Froude # Chl	1.01	1.00
Weir Max Depth (ft)		Specif Force (cu ft)	16.11	15.56
Min El Weir Flow (ft)	129.38	Hydr Depth (ft)	0.52	0.50
Min El Prs (ft)	121.37	W.P. Total (ft)	36.38	39.68
Delta EG (ft)	0.59	Conv. Total (cfs)	1514.6	1507.6
Delta WS (ft)	0.75	Top Width (ft)	36.22	39.41
BR Open Area (sq ft)	1233.04	Frctn Loss (ft)		
BR Open Vel (ft/s)	4.12	C & E Loss (ft)		
Coef of Q		Shear Total (lb/sq ft)	0.09	0.08
Br Sel Method	Momentum	Power Total (lb/ft s)	0.35	0.33

Errors Warnings and Notes

Warning:	The water surface upstream of the bridge computed by the Yarnell method was below critical
	depth. The Yarnell solution has been disregarded.
Note:	Yarnell answer is not valid if the water surface is above the low chord or if there is weir flow.
	The Yarnell answer has been disregarded.
Note:	The momentum method has computed a class B profile.

Plan: Existing   Stoney Creek   Main RS: 994   Profile: Low Fish Flows

E.G. US. (ft)	110.37	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	110.29	E.G. Elev (ft)	110.37	109.73
Q Total (cfs)	50.00	W.S. Elev (ft)	110.28	109.54
Q Bridge (cfs)	50.00	Crit W.S. (ft)	110.07	109.53
Q Weir (cfs)		Max Chl Dpth (ft)	0.91	0.65
Weir Sta Lft (ft)		Vel Total (ft/s)	2.44	3.45
Weir Sta Rgt (ft)		Flow Area (sq ft)	20.46	14.48
Weir Submerg		Froude # Chl	0.60	0.96
Weir Max Depth (ft)		Specif Force (cu ft)	10.72	8.96
Min El Weir Flow (ft)	129.38	Hydr Depth (ft)	0.52	0.40
Min El Prs (ft)	121.37	W.P. Total (ft)	39.49	36.18
Delta EG (ft)	0.65	Conv. Total (cfs)	1633.8	973.4
Delta WS (ft)	0.75	Top Width (ft)	39.29	36.07
BR Open Area (sq ft)	1233.04	Frctn Loss (ft)		
BR Open Vel (ft/s)	3.45	C & E Loss (ft)		
Coef of Q		Shear Total (lb/sq ft)	0.03	0.07
Br Sel Method	Momentum	Power Total (lb/ft s)	0.07	0.23

Errors Warnings and Notes

Warning:	The water surface upstream of the bridge computed by the Yarnell method was below critical

Errors Warnings and Notes (Continued)

	depth. The Yarnell solution has been disregarded.
Note:	Yarnell answer is not valid if the water surface is above the low chord or if there is weir flow.
	The Yarnell answer has been disregarded.

Form 6E - Hydraulic Rock Weir Design Option

Form 6E provides a guidance to correctly design a structure that meets specific fish passage design criteria, while also considering hydraulic impacts and scour concerns.

The main goal of the rock weir design process is to satisfy State and Federal requirements for velocity and depth during upper and lower fish-passage flow events. For adult steelhead, the target lifestage and species, the suggested maximum average velocity is 4 feet/second during high fish-passage flows given the project reach length of around 150 feet. When low fish-passage flows occur, a minimum 1-foot flow depth should be maintained within the step-pools, but a minimum 2-foot depth should be provided within the "jump" pool at the base of each weir.

ROCK WEIR SIZING

The top or cap layer of rock within a rock weir will directly resist active forces of drag, lift, and buoyancy while subjected to flowing water in a creek. These individual rocks will resist the active forces through their weight and friction with the streambed and/or adjacent rocks.

Because a rock weir must resist these active forces in order to remain stable, the rock for a rock weir will be sized by the most conservative of three methods: Field Inspection, Rock Slope Protection (RSP) Revetment Design, and Boulder Cluster design. In other words, the largest rock yielded from one of these methods will be recommended for construction.

Field Inspection Method

While walking in the upstream and downstream reaches of the creek, in reference to the existing bridge, the largest rocks in the stream were measured that appeared to be immobile during overtopping flows. Some simple stability indicators to locate on or around boulders are salt and silt stains, moss and lichen growth, and bar/terrace development. For Stoney Creek, rough diameters of various boulder-size rocks were found by measuring at least two of three principle axes (long, short, and middle). The approximate or rough diameters were determined by averaging these measurements. From the Stoney Creek field investigation, rough diameters varied between 18 and 27 inches, which would be classified as a ¼ to ½ Ton Caltrans RSP material class according to the following table consistent with the *California Bank and Shore Rock Slope Protection Design Report (CA RSP report):*

Caltrans RSP CLASS	ROUGH D_{50} (FEET)
Cobble	0.66
Backing No. 1	0.95
Light	1.32
¼ Ton	1.79
½ Ton	2.26
1 Ton	2.85
2 Ton	3.59
4 Ton	4.50
8 Ton	5.70

Table 6E-1 Caltrans RSP Class Rough Diameter

RSP Revetment Design Method

When using this method, a rock weir is analyzed as a revetment following the procedures outlined in the *CA RSP Report*. The minimum weight of rock that will resist forces from flowing water and remain stable is calculated based on a factored velocity, rock angle of repose, and rock specific gravity.

Because the *CA RSP Report* equation is being applied to the sizing of a rock weir rather than an RSP revetment, certain modifications can be made. For instance, the angle of repose of the stacked/placed rock can be simplified for rock weir analysis. When stacking or placing rock to build a weir, the steepest repose angle, recommended by the *CA RSP Report,* will be used to reduce rock quantity, as well as improve constructability. Basically, the flatter the rock weir side slope, the wider its base width will be (See Figure 6E-2), and the greater potential that individual weirs within a series will intersect or conflict with each other. It would be difficult to construct the weirs to the proper dimensions and tolerances if the rocks are all merged together. This would compromise the function of the weir, in addition to complicating the construction process. So, it is advantageous to have the steepest slope feasible for rock placement to avoid these problems.

In contrast, the rock for a revetment is controlled by the natural slope of the banks and will change at each project site, whereas the rock within a weir can placed at the same angle of repose in all cases with only minor influence from each site condition. Given 1:1.5 as the recommended slope for rock weir placement for all cases, the angle of repose will be 36.3 degrees. Therefore, a modified version of the *CA RSP Report* equation can be expressed as follows:

$$W= (0.00002\ V^6\ SG) / ((SG-1)^3\ (0.207))$$

Where, W= minimum rock mass (pounds)

*$V= 1.33\ V_{AVG}$ (ft/s)

SG= rock specific gravity

*In RSP revetment design, the velocity term is factored to consider parallel or impinging flow conditions. For parallel flow, the average stream velocity is multiplied by a 0.67 factor, while a 1.33 factor is applied to average stream velocity for impinging flow conditions.

For in-stream weirs, flow will be impinging on the weir in all cases and a 1.33 factor is applied to increase average stream velocity as applied in the *CA RSP Report*. Basically, the velocity vector from the stream flow will act directly on a weir in a perpendicular direction, and it will be also be subjected to secondary currents providing higher than average velocities. The average stream velocity should correspond with a 50-year flow at a minimum for rock weir sizing.

For this design example: $W= (0.00002 (15.37)^6 (2.65) / ((2.65-1)^3 (0.207))$

Where, $V= 1.33 (11.56)= 15.37$ ft/s

$SG= 2.65$

<u>W= 750 pounds</u>

The calculated weight (W) will correspond to an RSP material class, which is summarized in Table 6E-2. For example, W= 1000 pounds corresponds to a ½ Ton RSP class, W= 2000 pounds corresponds to a 1-Ton weight class, etc. When sizing rock weirs, ½ -Ton RSP is the lightest rock to be used to ensure conservatism due to adapting design methods that were not developed specifically for rock weir analysis.

In using the above equation for this design example, an average velocity was chosen from the HEC-RAS model of the existing condition that is upstream of the existing scour at the base of concrete apron. This chosen velocity corresponds to Q_{50}, which is the minimum deign flow to be used for rock weir sizing.

RSP CLASS	WEIGHT (pounds)
Backing No. 1	75
Light	200
¼ Ton	500
½ Ton	1000
1 Ton	2000
2 Ton	4000
4 Ton	8000

Table 6E-2 RSP Class Weights

As shown above, the calculated W is in between the **¼ Ton and ½ Ton RSP classes**. This is the same result as found using the Field Inspection method.

Boulder Cluster Design Method

This simplistic approach uses a table containing minimum boulder diameters and their associated critical shear stress (τ_c) and critical velocity (v_c) assuming a rock/boulder angle of repose equal to 42 degrees (approximately 1:1.8) and rock specific gravity equal to 2.65. The τ_c and v_c values were determined considering drag, lift, and buoyancy forces acting on the rocks/boulders. For the minimum diameter given in the following table, the rock/boulder will be stable during turbulent flow with it fully immersed. In other words, incipient motion will occur for a given rock/boulder diameter when stream velocities are higher than the critical velocity shown in Table 6E-3.

GENERIC ROCK CLASS	**MIN. DIA ((inches)**	**τ_c (lb/sf)**	**v_c (ft/s)**
Very Large Boulder	>80	37.4	25
Large Boulder	>40	18.7	19
Medium Boulder	>20	9.3	14
Small Boulder	>10	4.7	10
Large Cobble	>5	2.3	7
Small Cobble	>2.5	1.1	5

Table 6E-3 Boulder Cluster Design Method- Minimum Rock Diameter

The average stream velocity, v_{50}= 11.56 feet/second, was used to interpolate a minimum rock diameter of 13.75 inches, which is between a small and medium size boulder. According to Table 6E-1 and the *CA RSP Report*, this 13.75-inch diameter boulder would be classified as RSP Light having a weight of 200 pounds.

As mentioned previously, the most conservative of the three rock sizing methods will control in recommending the rock size for a weir. The Field Inspection and RSP Revetment Design Methods yielded similar results of ¼ to ½ Ton RSP, while RSP Light was found from the Boulder Cluster Design Method. Because ½ Ton RSP is the minimum class, the high end of the range will be chosen.

Therefore, **Use ½ Ton RSP**

ROCK WEIR EMBEDMENT

The depth or embedment of the rock weir is dependent upon the estimated scour potential for the site. An exact method for determining scour depth at a rock weir does not exist, but it can be estimated by one of two methods: Field Inspection/Topographic Survey and Toe-Scour Estimate Equation.

Field Inspection/Topographic Survey Method

The most significant evidence of scour was found through preliminary field investigations at the base of the existing concrete apron and verified through topographic survey data. As supported by field measurements and survey data, the scour hole depth measured 5 feet.

Because scour depths typically are not observed during the peak of a significant storm when flow and sediment movement would be at their highest, a safety factor of 1.2 is applied to observed scour depths. As flow decreases on the descending limb of a hydrograph, suspended sediment begins to deposit. This means that scour holes found in the field during clear weather conditions are smaller than during peaks of storm events.

In order to account for this condition, the observed 5-foot scour depth is multiplied by 1.2, which gives a **6-foot potential scour depth** that could be used in determining rock weir embedment depth for this design example.

Toe-Scour Estimate Method

For this method, scour depth will be calculated considering the rock weir as a stabilized bendway. Similar to a bendway section of channel, the vortex-shaped rock weir will be subjected to secondary currents, which cause higher velocities and shear stresses. These conditions will trigger greater scour around a rock weir, as well as changes in sediment transport and supply.

The toe-scour equation is empirical and was developed by synthesizing laboratory and field data. The scour depth calculation is dependent upon mean channel depth and water surface width upstream of a bend or weir, in addition to centerline bend radius and maximum water depth in bend.

Within the scour depth calculation, two ratios are incorporated. The first ratio is the centerline bend radius divided by the water surface width upstream of a bend or weir (R_c/W), while the second ration is this same water surface width divided by the mean channel depth upstream of a bend or weir. (W/D_{mnc}). Since the equation is empirical, limits apply to its use, more specifically to the R_c/W and W/D_{mnc} ratios. Based on the range of field and laboratory data sets, R_c/W is limited from 1.5 to 10 and W/D_{mnc} limited from 20 to 125. In other words, when W/D_{mnc} is calculated to be less than 20, a value of 20 must be used. Conversely, a value of 125 must be used when W/D_{mnc} is calculated to be above 125.

As for the R_c/W ratio, it is of course dependent upon the centerline bend radius. Because the toe-scour equation is being adapted to apply to rock weir design in straight and bending channel sections, 1.5 will be used as the default value. By using 1.5 for all cases, calculated potential scour depths will be conservative.

Finally, the equations used in estimating scour depth in this method are:

$$\text{SCOUR DEPTH}= D_{mxb} - D_{mnc}$$

Where, D_{mxb}= maximum water depth at weir (feet)

D_{mnc}= mean channel depth upstream of weir (feet)

D_{mxb}= 1.14 D_{mnc} (1.72 + (0.0084 W/D_{mnc}))

For this design example, the W and W/D_{mnc} values were taken from the HEC-RAS model of the existing condition and are 120 feet and 5.41 feet respectively. These values correspond to the 50-year storm flow.

D_{mxb}= 1.14 (5.41) (1.72 + (0.0084 120/5.41))

D_{mxb}= 11.76 feet

SCOUR DEPTH= (11.76) – (5.41)

SCOUR DEPTH= 6.35 feet

The toe-scour estimate equation yields a slightly higher scour depth than the factored field inspection/topographic survey method (6.35>6.00). The more conservative value is chosen as the design scour depth, but rounded to a more even 6.5 feet

Use 6.5-foot rock weir embedment depth

Therefore, the ½ Ton rock weir will extend down to a depth of 6.5 feet below the channel bed finished grade surface. The height of rock weir above the channel bed will be determined during the hydraulics analysis.

The total height of the rock weir, equal to the height above channel bed plus the embedment depth, must be equal to or greater than the recommended RSP class thickness recommended by the *CA RSP Report* displayed in Table 6E-4.

RSP CLASS	MINIMUM THICKNESS (FEET)
½ Ton	3.40
1 Ton	4.30
2 Ton	5.40
4 Ton	6.80
8 Ton	8.50

Table 6E-4 Minimum RSP Class Thickness

The minimum thickness for a ½-Ton RSP layer is 3.4 feet, compared to the 6.5-foot embedment depth calculated previously. The 6.5-foot depth is greater than the minimum required and is acceptable. After the height of the weir is determined through hydraulics analysis, which is measured above the channel bed, the total rock weir thickness is of course greater than the required minimum of 3.4 feet. If the embedment depth plus the rock weir height had been less, the minimum RSP layer thickness would control.

Below the rock weir, a 1.8-foot (or 2-foot) layer of Backing No. 1 RSP underlain by RSP Fabric is needed to provide filtration beneath all rock weirs. This filter layer will prevent soil movement and loss of fines from piping, and ultimately improve rock weir stability.

See Figure 6E-2 for embedment depth, rock weir height, and filter layer illustrations.

ROCK WEIR GEOMETRY

The components of rock weir geometry include crest width, side slope ratio, and plan-view radius. As mentioned previously, the side slope ratio will be 1:1.5 for all rock weirs, but the crest width and plan-view radius must be calculated. The crest width is simply expressed below, where D_{50} is associated with the rock weir RSP class.

CREST WIDTH= 2 (Rock Weir D_{50})

For this example: D_{50}= 2.26 feet

CREST WIDTH= 5.52 feet

Use CREST WIDTH= 6.00 feet

The other rock weir geometry element to consider is the vortex (arc), plan-view shape. See Figure 6E-1. The mid-chord offset of the arc is equal to 3 times D_{50} of the rock weir RSP class. The chord length will equal the distance between the left and right toes of slope. After determining the mid-chord offset and chord length, the radius of the arc can be determined with the equation below:

$$R= (L^2/8\ m) + (m/2)$$

Where, R= rock weir radius (feet)

L= chord length (feet)

m= mid-chord offset= 3 D_{50} (feet)

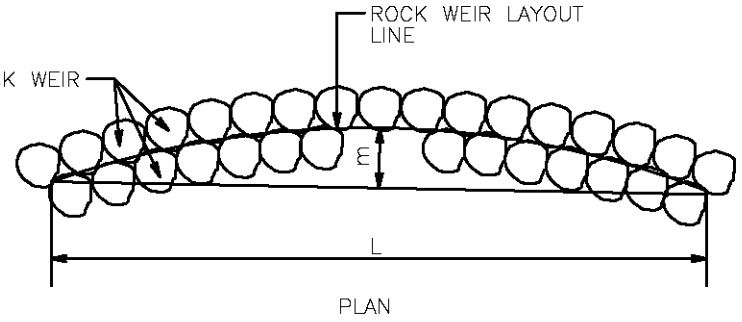


Figure 6E-1 Rock Weir Layout

For this example, $R= ((100)^2)/8\ (6.6)) / (6.6/2)$

R= 232.47 feet

Use R= 232 feet

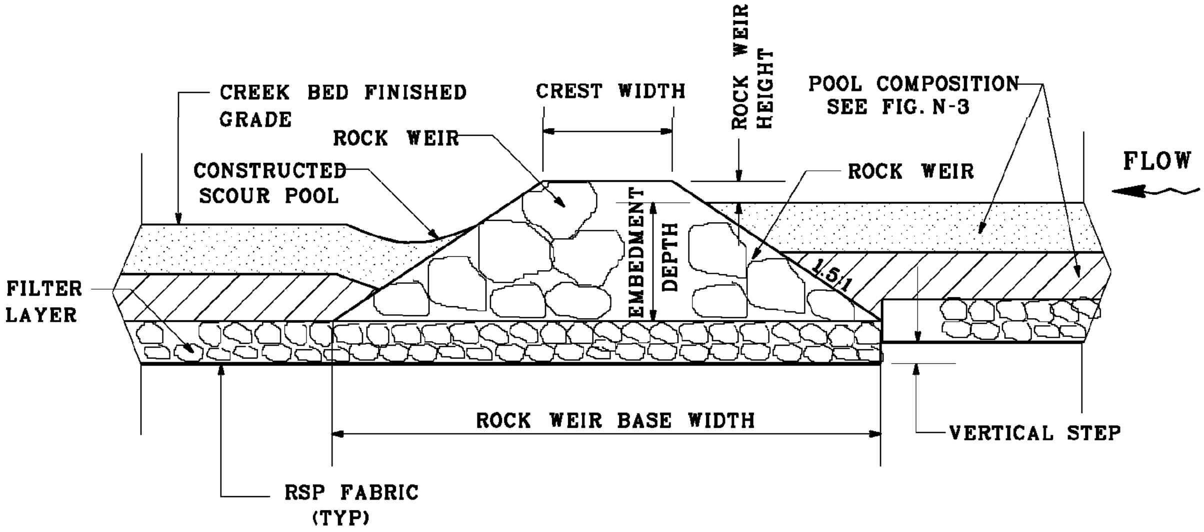


Figure 6E-2 Rock Weir Profile

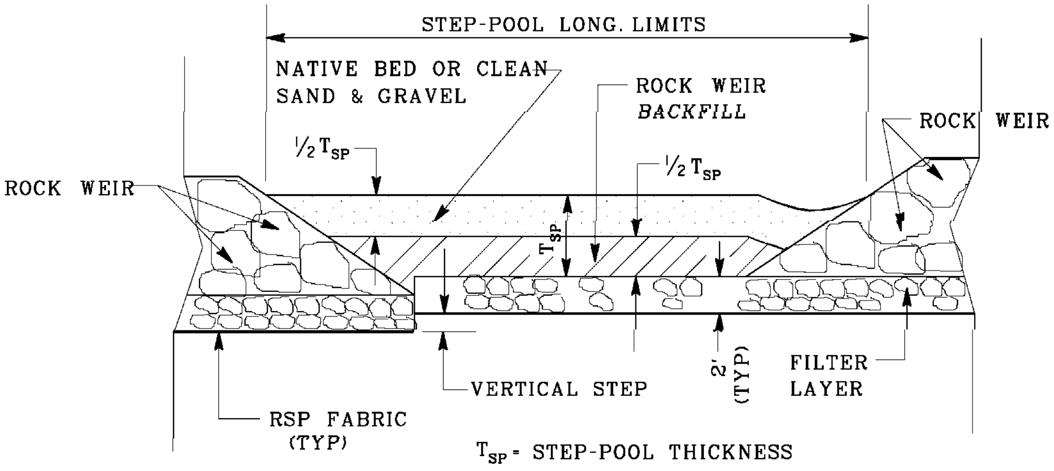


Figure 6E-3 Step-Pool Profile

Step-Pool Composition

The portion of the creek between rock weirs is the pool or step-pool, which has total thickness defined in Figure N-3 as Tsp. The total thickness is measured from the creek bed finished grade to the top of the filter layer. Tsp dimensions will vary for each project depending on rock weir embedment depth and vertical step height within the pools.

As also seen in Figure N-3, the step-pool is composed of two layers of equal thickness. The top layer is either native bed material or clean sand and gravel, and these materials do not require compaction during placement. The function of the top layer is to support habitat and to allow the development of various micro-pools that will promote resting areas for fish as they move through the rock weir/step-pool system. The top layer in the step-pool can move and scour without threatening the stability of the weirs.

During construction, the top 1-feet to 3-feet of the excavated creek bed can be stockpiled on site and later placed or returned to the creek as the step-pool top layer according to specified dimensions. If the excavated material is deemed unsuitable, clean sand and gravel can be imported and placed. The following is a recommended gradation for clean sand and gravel:

Table 6E-5 Clean Sand and Gravel Gradation

Seive Size	Percentage Passing
1”	100
¾”	60-90
No. 4	25-60
No. 30	0-20

For the bottom layer of the step-pool, a rock weir backfill is recommended that has cohesive properties and well-compacted (roughly 90%), somewhat similar to structure backfill. The purpose of this rock weir backfill is to provide stability of the weir at its base, as well as aid in scour resistance. The properties of the recommended rock weir backfill are as follows:

Table 6E-6 Rock Weir Backfill Properties

Minimum Sand Equivalent	50
Maximum Aggregate Size	3”
Maximum Plasticity Index	20
Minimum Plasticity Index	12

At the downstream end of a rock weir within the step-pool, a scour pool should be constructed. This scour pool will encourage fish to rest before jumping over the rock weir and continuing their journey. As stated previously, a 2-foot flow depth shall be provided at the downstream end of a rock weir. Even though a scour pool will form naturally over time as flow plunges over a weir, the constructed scour pool will provide immediate benefit after construction.

For recommended “Place Native Creek Ned Material” and “Rock Weir Backfill” non-standard special provisions, see Appendix O.

For this design example, the embedment depth is equal to 6.5 feet and the vertical step is 1.0 foot. The **Tsp** value is the difference between these two values and is equal to **5.5 feet**. The Tsp will be divided evenly for a 2-layer pool composition.

Given the average gradation results from random samples taken in the creek bed, the **native material** will be used as the top or cap layer in the step-pool instead of importing clean sand and gravel. The results below show a fairly uniform graded material varying from 3” cobble down to fine aggregate passing a No, 200 sieve. For this project, the “Place Native Creek Bed Material” special provision will specify that the top 2 feet of the excavated creek bed will be stockpiled and oater placed as the step-pool cap layer. The stockpiles material will be placed at a **2.25-foot thickness** without compaction.

Table 6E-7 Existing Creek Bed Gradation

Seive Size	Percent Passing
3 ½”	100
3”	97
2 ½”	87
2”	79
1 ½”	66
1”	51
¾”	44
½”	34
3/8”	29
No. 4	19
No. 8	13
No. 30	4
No. 200	1

As for the bottom layer of the step-pool, rock weir backfill will be shown on the plans and placed at **2.25-foot thickness** with a 90% compaction rate.

Therefore, the step-pool will be composed of a 2.25-foot thick top layer of native bed material and an equally thick bottom layer of well-compacted rock weir backfill.

Bank and Toe Stabilization

Because of energy losses caused by rock weirs, turbulent backwaters can be created, especially during over topping and flanking conditions. The banks and toes are vulnerable to scour under these conditions, and they must be stabilized through rock slope protection (RSP) or a combination of RSP and vegetation where appropriate.

The Caltrans Standard for bank and tow protection design is in the *Highway Design Manual (HDM)*, Chapter 870 Channel and Shore Protection-Erosion Control. According to Topic 873 Design Concepts, a suggested RSP design event is the 50-year or 2%-probability storm. Given the flow associated with a 50-year storm, average stream velocity and water surface level are calculated to determine rock size and design high water on the bank (design high water + freeboard = design height). As also stated in Topic 873, the design height estimation should, in addition, take into account other factors, such as historic high water marks, size and nature of debris, as well as construction costs. Basically, engineering judgment must be exercised in adjusting the RSP height up or down from the calculated 50-year average flow depth, but freeboard must be considered as well.

If the combined RSP and vegetative revetment is desired, the decision for determining the minimum RSP height and design velocity is at the discretion of the District Hydraulics Engineer. The District Landscape Architect must be consulted in determining the proper plants and grasses to be specified for each project. For all projects, the toe of a bank, which is highly susceptible to scour, must be stabilized with RSP to 3 feet above the toe at a minimum. See Figure 6E-4 for a typical step-pool cross section showing pool composition and bank protection.

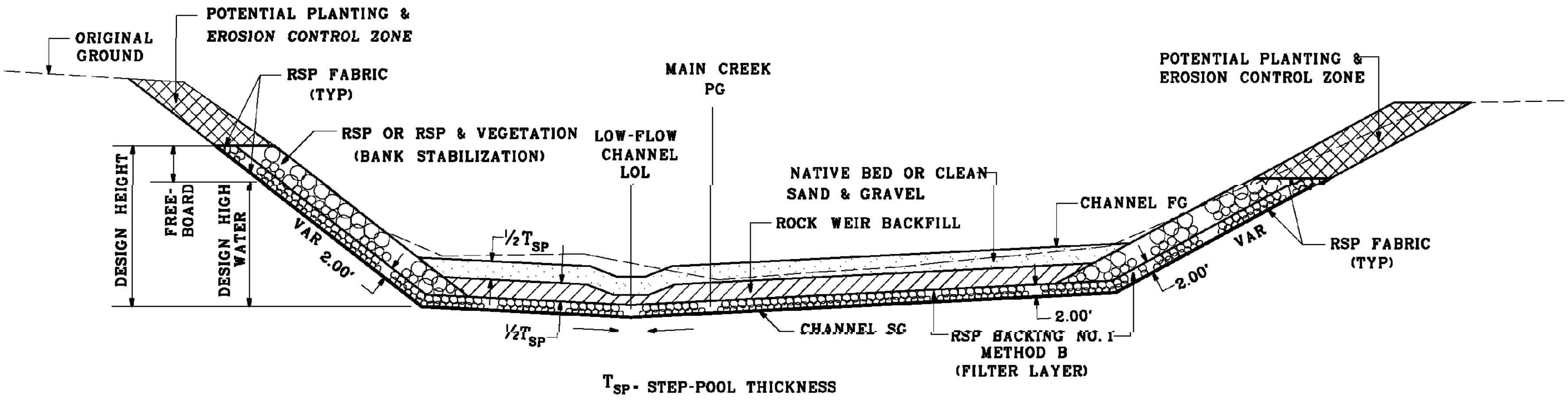


Figure 6E-4 Step-Pool Cross Section

For the Stoney Creek site, the rock weirs are located in a tangent reach. From Chapter 870 of the *HDM*, the stream protection for flexible revetments will be used, which is based in the *CA RSP Report* previously mentioned. At this location, high water marks are not evident, but residential development is very close to the banks of the creek. Because of property damage risk, the 50-year storm design flow will be used to determine rock size and design height. The equation for calculating rock size is as follows:

$$W = \frac{0.00002V^6 Sg_r \csc^3(B - \propto)}{(sg_r - 1)^3}$$

Where Sg_r = specific gravity of stones (generally 2.65 is used)

$\propto$ = angle of face slope from horizontal

B = 70° from broken rock (constant)

W(lbs) = weight for minimum stable stone

V(fps) = *average stream velocity (parallel flow to bank)

Or

= 4/3 average stream velocity (impinging flow to bank)

*For flow parallel to bank, use average stream velocity and eliminate 2/3 factor found in *HDM* Chapter 870. Full average velocity should be used to account for increased turbulence created by rock weirs.

As found in the ground survey data and the HEC-RAS model, the two inputs to solve for W are average bank slope and 50-year average stream velocity. The bank slope is approximately 2:1, which translates to $\propto = 26.6°$; while the 50-year velocity equals 11.56 fps. Because the flow will be parallel to the stream bank, this velocity is used without applying a factor.

$$W = \frac{0.00002(11.56)^6(2.65)CSC^3(70° - 26.6°)}{(2.65 - 1)^3}$$

<u>W = 87 lbs</u>

As seen in Table 873.3A from the *HDM*, the corresponding RSP class is **¼-ton**, which will be placed over the RSP Backing filter layer shown in Figure 6E-4. The thickness of the ¼-ton RSP is 3.3 feet and provided in Table 873.3C.

As stated earlier, risk of residential property damage is a factor in the design of the bank revetment, so design high water will be conservative based on the 50-year storm. Using the HEC-RAS, Proposed Condition results, an average flow depth is 8.27 feet. This value will be rounded to **8.5 feet** and used as the **design high water depth**.

Because the project is in a tangent reach of the creek, which means that the banks will not be subjected to flow super elevation, so the freeboard will be determined considering increased flow depths caused by physical objects being transported in the stream.

Because the rock weirs are in-stream, in-line structures, they will very likely catch various types of natural debris (i.e. tree, plants) and/or urban trash. Once again, the HEC-RAS Proposed Condition model was reviewed, and the effects of the rock weirs on the 50-year water surface were noted. From the model, the rock weirs on the 50-year water surface were noted. From the model, the rock weirs create an average increase of 1.91 feet to the water surface. Of course, this increase is intended in order to provide better depth for fish. The assumption is made that the head losses from the potential debris could cause an increase in flow depth equal to this additional head created by the lock weirs. Therefore, the **freeboard** is conservatively set at **2 feet**.

For the revetment design height,

Design Height = Design High Water + Freeboard

= 8.5 feet + 2 feet

Design Height = 10.50 feet

BROAD CRESTED WEIR COEFFICIENT DETERMINATION

The weir coefficient of 2.65 ft $^{0.5}$/s was determined as appropriate for this specific rock broad crested weir design. The weir coefficient selection processed is outlined below.

Step 1**:** Estimate the highest possible weir coefficient for the broad crested design.

For this example, the proposed breadth of crest of weir is 6ft, therefore, the highest possible weir coefficient for a broad-crested is 2.832 ft$^{0.5}$/s. (See Hydraulic Engineering Circular 22, *Urban Drainage Design Manual*, pages 8-24 and 8-28). The highest weir coefficient is then entered into the HEC-RAS model and run.

Step 2: Check range of head over baffle in hydraulic model. Does the Low Fish Passage Design depths equal or not exceed the minimum allowable depth per design species? If yes, breath of crest of weir or allowable head is inappropriate for design. Design must be modified and rerun. If no, determine type of weir.

Step 3: Select a more appropriate broad-crested weir coefficient from Table 8-1 from Hydraulic Engineering Circular 22, *Urban Drainage Design Manual*. The weir coefficient is then entered again into the HEC-RAS model and run.

For this example, 2.65 ft$^{0.5}$/s was selected as a more appropriate broad-crested weir coefficient.

Step 4: Check range of head over baffle in hydraulic model. Does the Low Fish Passage Design depths equal or not exceed the minimum allowable depth per design species? If yes, calculation error occurred in Step 2.

ROCK WEIR SPACING, HEIGHT, AND LOW-FLOW NOTCH DIMENSIONS

Through an iterative hydraulics analysis, the spacing and height of the rock weirs, as well as the low-flow notch/channel dimensions are determined. These components are varied during the hydraulics modeling process until the velocity and depth requirements are satisfied as outlined in the CDFG *Culvert Criteria for Fish Passage* and the NOAA lifestage and species. For rock weir analysis, each weir will be treated as being broad-crested. The broad-crested weir coefficients can be found in Appendix F Hydraulics of Baffles. As stated at the beginning of this section, the suggested maximum average velocity is 4 ft/s during high fish-passage flow for adult steelhead given a project length of around 150 feet. When low fish-passage flow occurs, a minimum 1-foot flow depth should be maintained within the step-pools, but a minimum 2-foot depth must be provided within the "jump" pool at the base of each weir.

For a series of rock weirs, the minimum spacing is 25 feet. This is mainly governed by the construction process, where individual rock weirs could intersect and their physical definition could be lost if they are placed too close together. Instead of having a series of individual rock weirs, a larger pile or mass will develop without clear definition of each rock weir and the pools between them. If this occurs, the rock weirs and pools will not function properly for fish passage. This is why it is important that rock weirs are at least spaced at 25-foot intervals.

At each rock weir, a 0.5-foot to 1-foot (maximum) vertical step in the new stream profile is typically placed to minimize the longitudinal pool slope between weirs. The rock weir will dissipate the increase of energy at a step. With a flatter pool slope, the velocity and depth criteria are more easily achieved. The use of vertical steps is especially beneficial when dealing with significant elevation changes within the project limits, which would create steep pool slopes. The overall stream gradient can be softened by having up to 1-foot grade changes at each weir location, yet provide relatively flat pool slopes or smaller grade changes between weirs. For rock weir design, the pool slope can vary between 0% and 4%, but is ultimately controlled by the velocity and depth criteria.

As for rock weir height, its minimum is 6 inches. In the hydraulics analysis, special attention must be made to maximum drops stated in the State and Federal criteria. For all adult species, the maximum drop in water surface is 1 foot, while juvenile salmonids can only tolerate 6 inches. At the downstream base of each rock weir, a 2-foot jump pool should be provided for all species and lifestage. As can be seen in Figure 6E-2, the rock weir height is measured from the channel be finished grade to the top of the weir crest.

The minimum dimensions for the low-flow notch in a rock weir, or the low-flow channel in the pools between weirs, is a 6-inch depth, a 2-foot base width, and a 4-foot top width. Basically, the low-flow notch and channel dimensions will be consistent. As the name suggest, the function of the low-flow notch and channel is to provide minimum flow depths during low fish-passage flow. The top of a rock weir and the channel bed must have a 4% to 5% cross slope toward the low-flow notch/channel so that water will be concentrated and minimum depth is more easily attained. See Figure 6E-4 for cross sections of the low-flow notch and channel.

During construction, a rock weir is normally built in full without the notch in order to have proper placement and locking of rocks. After it is built, rock is removed to form the notch. Of course given the variable physical sizes of the individual rocks, the dimensions specified on the plans for a notch are somewhat approximate. Because of this situation, the D_{50} of the rock weir should also be considered in determining the dimensions of the low-flow notch. The cross-sectional dimensions of the notch cannot be less than D_{50}.

Another factor to consider in the design of the low-flow notch and channel is meandering and sinuosity of the notch and channel in plan view. By having this, channel length is increased and longitudinal slope is decreased, which further contributes to having adequate fish-passage depth and velocity especially in a steep slope environment. While a standard for the sinusoidal pattern does not exist, the engineer can use judgment in approximating a meandering low-flow channel around the creek centerline as shown in Figure 6E-3.

For this design example, several HEC-RAS runs were performed where rock weir height, spacing, and low-flow notch/channel dimensions were varied until a combination was found that met velocity and depth requirements. The final results are as follows, **rock weir height = 1 foot, rock weir spacing = 25 feet with 1-foot vertical profile steps at each weir, 0% pool slopes between weirs, and a low-flow notch/channel with a 1-foot depth, 4-foot base width, and a 10-foot top width.** See the HEC-RAS model results for the proposed condition, which used this data.

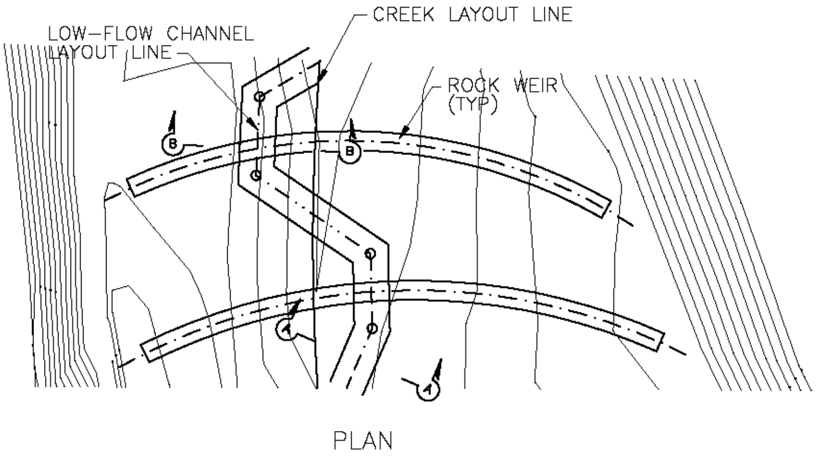


Figure 6E-5 Rock Weir and Low-Flow Notch/Channel Layout

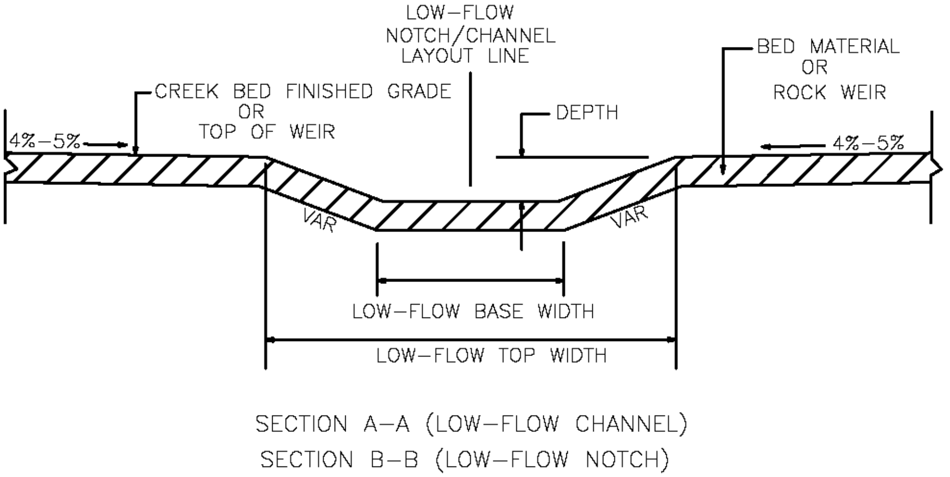


Figure 6E-6 Low-Flow Notch/Channel Cross Section

BROAD CRESTED WEIR COEFFICIENT DETERMINATION

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For this example, the proposed breadth of crest of weir is 6 ft, therefore, the highest possible weir coefficient for a broad-crested is 2.832 $ft^{0.5}/s$. (See Hydraulic Engineering Circular 22, *Urban Drainage Design Manual*, pages 8-24 and 8-28). The highest weir coefficient is then entered into the HEC-RAS model and run.

Step 2: Check range of head over baffle in hydraulic model. Does the Low Fish Passage Design depths equal or not exceed the minimum allowable depth per design species? If yes, breath of crest of weir or allowable head is inappropriate for design. Design must be modified and rerun. If no, determine type of weir.

Step 3: Select a more appropriate broad-crested weir coefficient from Table 8-1 from Hydraulic Engineering Circular 22, *Urban Drainage Design Manual.* The weir coefficient is then entered again into the HEC-RAS model and run.

For this example, 2.65 $ft^{0.5}/s$ was selected as a more appropriate broad-crested weir coefficient.

Step 4: Check range of head over baffle in hydraulic model. Does the Low Fish Passage Design depths equal or not exceed the minimum allowable depth per design species? If yes, calculation error occurred in Step 2.

FISH PASSAGE: HYDRAULIC ROCK WEIR DESIGN OPTION

FORM 6E

Project Information Stoney Creek Bridge Widening	Computed: EKB	Date: 7/6/06
	Checked: LEF	Date: 7/7/06
Stream Name: Stoney Creek County: Ventura	Route: 444	Postmile: 15.6

General Considerations

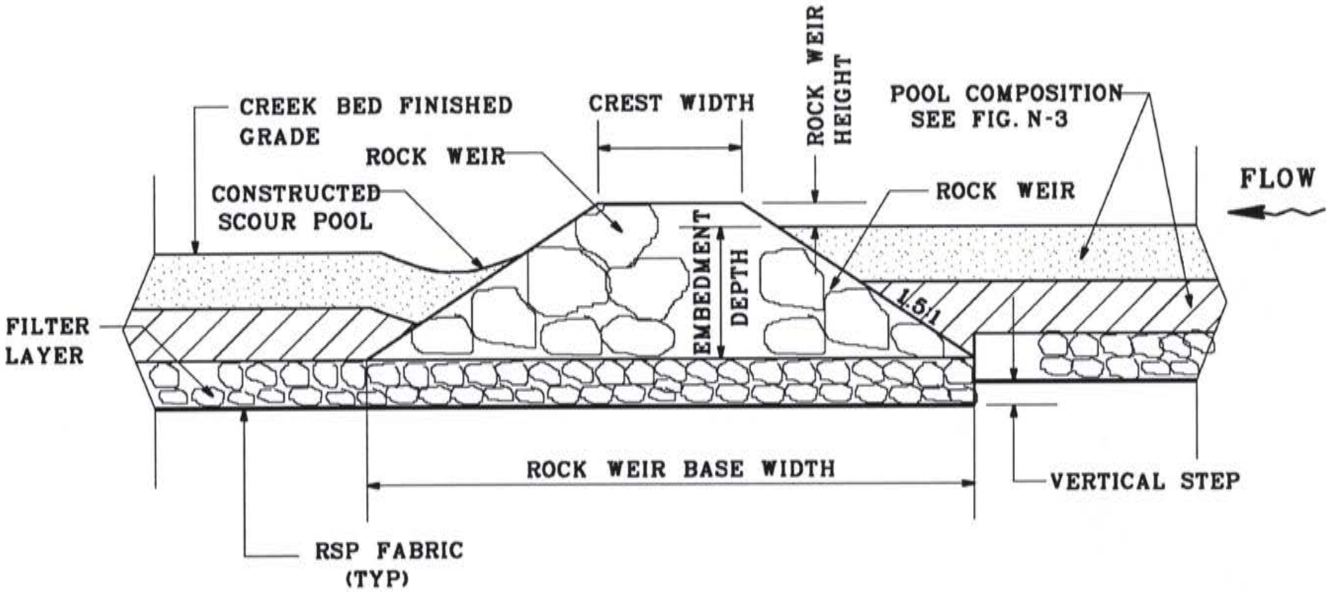
Rock weirs shall be used in the design of retrofitted culverts in order to meet the hydraulic design criteria.

Hydrology Results - Peak Discharge Values

50% Annual Probability (2-Year Flood Event)	155	cfs	10% Annual Probability (10-Year Flood Event)	1252	cfs
2% Annual Probability (50-Year Flood Event)	4460	cfs	1% Annual Probability (100-Year Flood Event)	6336	cfs
High Fish Passage Design Flow	78	cfs	Low Fish Passage Design Flow	50	cfs

Determine Rock Weir Dimensions

Rock size (RSP class):	1/2 ton		Embedment depth:	6.5	ft
Crest width:	6	ft	Height:	1	ft
Side slope:	1½:1		Base width:	28.5	ft
Spacing:	25	ft			



Rock Weir Profile

Determine Step-Pool Layers and Thickness

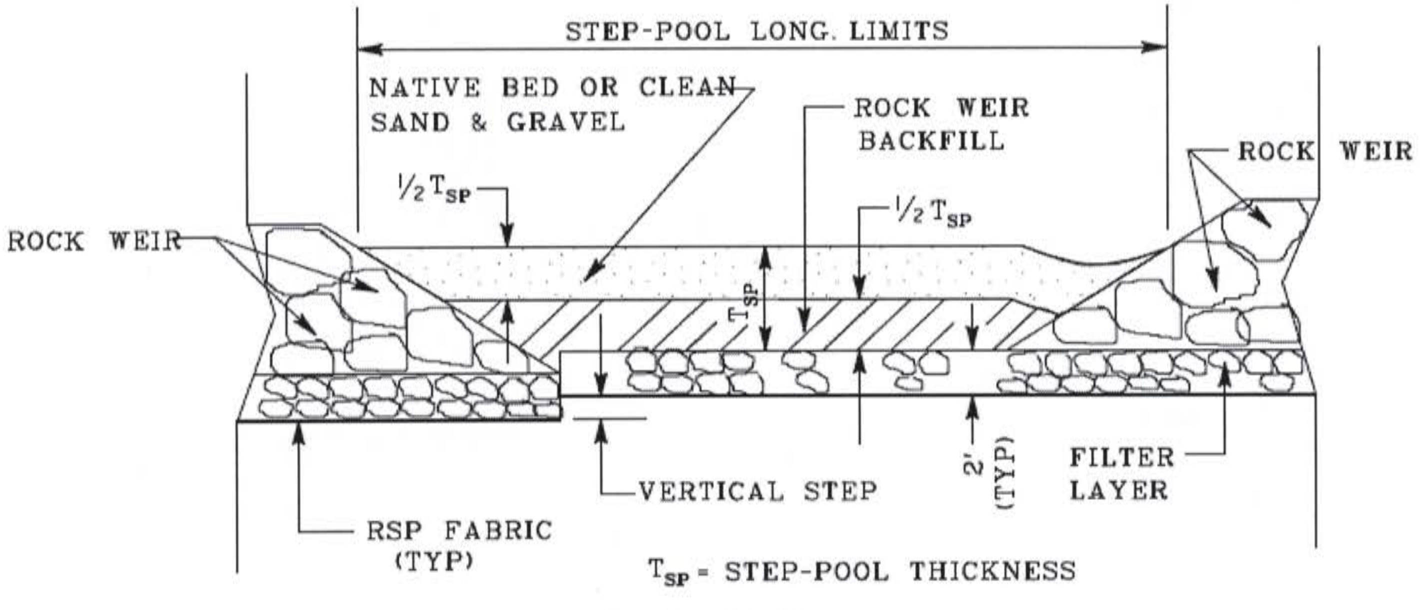
Tsp: 5.5 ft

Rock weir backfill thickness (1/2 Tsp): 2.25 ft

FISH PASSAGE: HYDRAULIC ROCK WEIR DESIGN OPTION FORM 6E

Native bed: ☒ Yes ☐ No Thickness (if applicable): 2.25 ft

Clean sand and gravel: ☐ Yes ☒ No Thickness (if applicable): N/A ft



Step Pool Profile

Design Bank Revetment

RSP revetment: ☒ Yes ☐ No

Combined RSP and vegetative revetment: ☐ Yes ☒ No

If yes, contact District Hydraulics Engineer and District Landscape Architect to coordinate design.

Parallel flow: ☒ Yes ☐ No

Impinging flow: ☐ Yes ☒ No

If yes, apply 1.33 factor to average stream velocity.

Bank slope (α): 26.6 (2:1) °

50-year average stream velocity: 11.56 ft/s

Design velocity: 11.56 ft

50-year flow depth: 8.5 ft

Field contributing features (i.e. high water marks): NONE

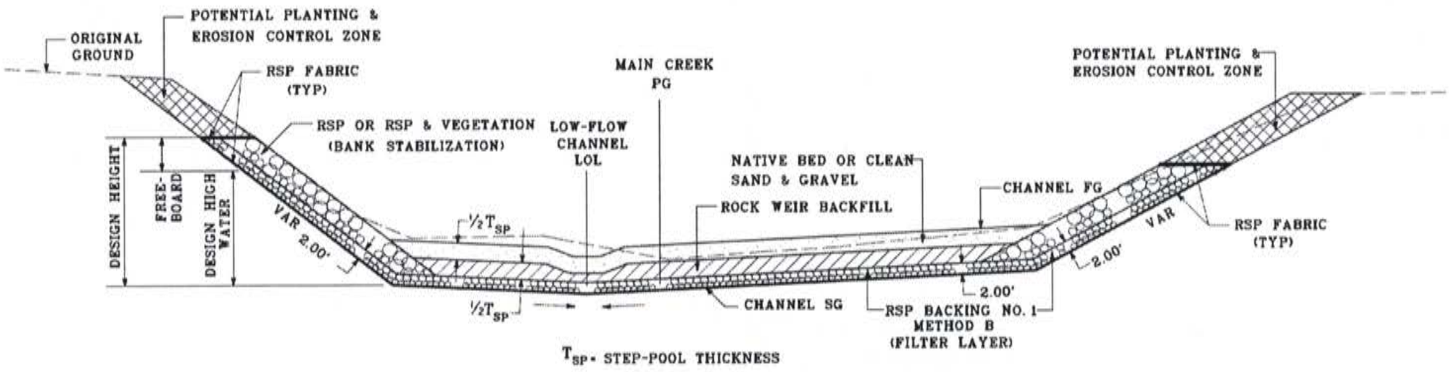
Freeboard: 2 ft

FISH PASSAGE: HYDRAULIC ROCK WEIR DESIGN OPTION FORM 6E

Design height: 10.5 ft

RSP class: 1/4 ton

RSP thickness: 3.3 ft



Step Pool Cross Section

Selecting Weir Coefficient, C

1) Estimate highest possible weir coefficient for broad crested weir design. [1]

Initial estimate of broad crested weir coefficient, C 2.832 $ft^{0.5}/sec$

2) Check range of head over baffle in hydraulic model.

Does the Low Fish Passage Design depths equal or not exceed the minimum allowable depth per design species? ☐ Yes ☒ No

If yes, breath of crest of weir or allowable head is inappropriate for design. Modify design to comply and re-run hydraulic anaylses to verify.

Does the High Fish Passage Design velocities over the weir and through the notch exceed the minimum allowable velocities per design species? ☐ Yes ☒ No

If yes, breath of crest of weir or allowable head is inappropriate for design. Modify design to comply and re-run hydraulic anaylses to verify.

If no for both questions above, select a more appropriate broad-crested weir coefficient, C.

3) Select a more appropriate broad-crested weir coefficient, C:

Establish range of reasonable C coefficients in accordance with Hydraulic Engineering Circular 22, Urban Drainage Design Manual ☒ Yes ☐ No

4) Check range of head over baffle in hydraulic model.

Does the Low Fish Passage Design depths equal or not exceed the minimum allowable depth per design species? ☐ Yes ☒ No

If yes, modify design to comply and rerun hydraulic anaylses to verify.

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[1] Hydraulic Engineering Circular 22, *Urban Drainage Design Manual*, Chapter 8 (www.fhwa.dot.gov)

FISH PASSAGE: HYDRAULIC ROCK WEIR DESIGN OPTION FORM 6E

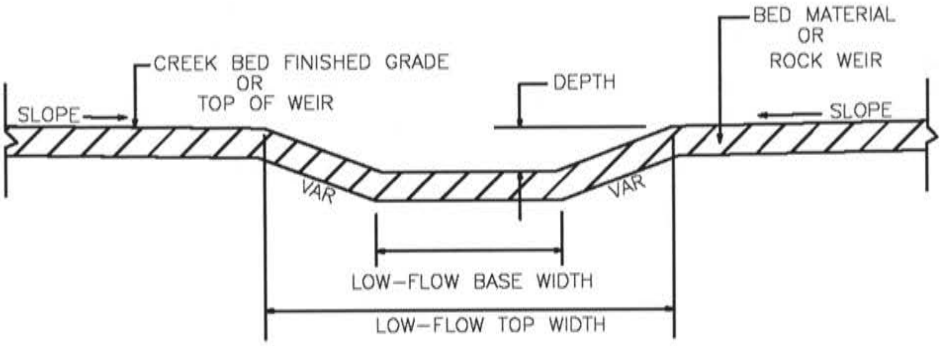
Does the High Fish Passage Design velocities over the baffle and through the notch exceed the minimum allowable velocities per design species?
☐ Yes ☒ No

If yes, modify design to comply and rerun hydraulic anaylses to verify.

Modeled broad-crested weir coefficient: 2.65 ft^0.5/sec

Determine Rock Weir Low-Flow Notch/Channel Dimensions

Base Width:	4 ft	Top Width:	10 ft
Depth:	1 ft		



Low Flow Notch / Channel

Summarize Retrofitted Culvert Physical Characterstics N/A

Inlet Characteristics - Retrofitted design to inlet: ☐ Yes ☐ No

Inlet Type	☐ Projecting	☐ Headwall	☐ Wingwall
	☐ Flared end section	☐ Segment connection	☐ Skew Angle: °

Barrel Characteristics - Retrofitted design to barrel: ☐ Yes ☐ No

Diameter:	in	Fill height above culvert:	ft
Height/Rise:	ft	Length:	ft
Width/Span:	ft	Number of barrels:	

Culvert Type	☐ Arch	☐ Box	☐ Circular
	☐ Pipe-Arch	☐ Elliptical	
Culvert Material	☐ HDPE	☐ Steel Plate Pipe	☐ Concrete Pipe
	☐ Spiral Rib / Corrugated Metal Pipe		

Horizontal alignment breaks:	ft	Vertical alignment breaks:	ft

FISH PASSAGE: HYDRAULIC ROCK WEIR DESIGN OPTION

FORM 6E

Outlet Characteristics - Retrofitted design to outlet: ☐ Yes ☐ No

Outlet Type	☐ Projecting	☐ Headwall	☐ Wingwall
	☐ Flared end section	☐ Segment connection	Skew Angle: °

Summarize Retrofitted Bridge Physical Characterstics

Bridge Physical Characteristics **Retrofitted design to bridge structure:** ☒ Yes ☐ No Bridge Widening

Elevation of high chord (top of road): 129.37 ft	Elevation of low chord: 121.37 ft

Channel Lining	☐ No lining	☒ Concrete	☐ Rock	☐ Other

Skew Angle: NONE °	Bridge width (length): ft

Pier Characteristics (if applicable) **Retrofitted design to piers:** ☐ Yes ☐ No

Number of Piers: ft	Upstream cross-section starting station: ft
Pier Width: ft	Downstream cross-section starting station: ft
Pier Centerline Spacing: ft	Skew angle: °

Pier Shape	☐ Square nose and tail	☐ Semi-circular nose and tail	☐ 90° triangular nose and tail
	☐ Twin-cylinder piers with connecting diaphragm	☐ Twin-cylinder piers without connecting diaphragm	☐ Ten pile trestle bent

Establish High Design Flow for Fish Passage - Depending on species, develop high design flows:

Species/Life Stage	**Percent Annual Exceedance Flow**	**Percentage of 2-Yr Recurrence Interval Flow**	**Design Flows (cfs)**
☒ Adult Anadromous Salmonids	[✓ 1%]	50%	78
☐ Adult Non-Anadromous Salmonids	5%	30%	
☐ Juvenile Salmonids	10%	10%	
☐ Native Non-Salmonids	5%	30%	
☐ Non-Native Species	10%	10%	

Establish Low Design Flow for Fish Passage - Depending on species, develop low design flows:

Species/Life Stage	**Percent Annual Exceedance Flow**	**Alternate Minimum Flow (cfs)**	**Design Flow (cfs)**
☒ Adult Anadromous Salmonids	[✓ 50%]	3	50
☐ Adult Non-Anadromous Salmonids	90%	2	
☐ Juvenile Salmonids	95%	1	

☐ Native Non-Salmonids	90%	1	
☐ Non-Native Species	90%	1	

Establish Maximum Average Water Velocity and Minimum Flow Depth in Culvert (At high design flow) - Depending on culvert length and/or species, select Maximum Average Water Veolcity and Minimum Flow Depth.

Species/Life Stage	Maximum Average Water Velocity at High Fish Design Flow (ft/sec)	Minimum Flow Depth at Low Fish Design Flow (ft)
☒ Adult Anadromous Salmonids	6 (Culvert length <60 ft)	[✓ 1.0]
	[✓ 5 (Culvert length 60-100 ft)]	
	4 (Culvert length 100-200 ft)	
	3 (Culvert length 200-300 ft)	
	2 (Culvert length >300 ft)	
☐ Adult Non-Anadromous Salmonids	4 (Culvert length <60 ft)	0.67
	4 (Culvert length 60-100 ft)	
	3 (Culvert length 100-200 ft)	
	2 (Culvert length 200-300 ft)	
	2 (Culvert length >300 ft)	
☐ 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		

Establish 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, it's magnitude should be evaluated for both high design flow and low design flow and shall not exceed the values shown below. If a hydraulic drop occurs at the culvert outlet, a jump pool of at least 2 feet in depth shall be provided.

Species/Life Stage	Maximum Drop (ft)
☒ Adult Anadromous Salmonids	[✓ 1]
☐ Adult Non-Anadromous Salmonids	1
☐ Juvenile Salmonids	0.5

FISH PASSAGE: HYDRAULIC ROCK WEIR DESIGN OPTION FORM 6E

☐ 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	

Maximum Allowable Inlet Water Surface Elevation

Culvert ☐ N/A

A culvert is required to pass the 10-year peak discharge without causing pressure flow in the culvert,	Allowable WSEL: ft
And shall not be greater than 50% of the culvert height or diameter above the top of the culvert inlet for the 100-Year peak flood.	Allowable WSEL: ft

Bridge ☒

A bridge is required to pass the 50-year peak discharge with freeboard, vertical clearance between the lowest structural member and the water surface elevation,	Allowable WSEL: 118.37 ft (2' of freeboard required)
While passing the 100-year peak or design discharge under low chord of the bridge.	Allowable WSEL: 121.37 ft

Establish Allowable Hydraulic Impacts

Is the crossing located within a floodplain as designated by the Federal Emergency Management Agency or another responsible state or local agency?
☐ Yes ☒ No

If yes, establish allowable hydraulic imacts and hydraulic design requirements with the appropriate agency. Attach results.

Will the project result in the increase capacity of an existing crossing? ☐ Yes ☒ No

If yes, will it significantly increase downstream peak flows due to the reduced upstream attenuation? ☐ Yes ☒ No

If yes, consult District Hydraulics. Further analysis may be needed.

Will the project result in a reduction in flow area for the 100-year peak discharge? ☐ Yes ☒ No

If yes, establish the allowable increase in upstream water surface elevation and establish how far upstream the increased water surface may extend.

Develop and run Hydraulic Models to compute water surface elevations, flow depths, and channel velocities fo the low fish passage design flow, the high fish passage design flow and for the 2-, 10-, 50-, and 100-year peak or design discharges reflecting existing and project conditions.
☒ Yes ☐ No

Evaluate computed water surface elevations, flow depths, and channel velocities: ☒ Yes ☐ No

Maximum average velocity in structure at high fish design flow: 5 ft/s

Does the velocity exceed the maximum allowable for the structure length and design species? ☐ Yes ☒ No

If yes, modify design to comply and rerun hydraulic anaylses to verify.

Minimum flow depth in structure at low fish design flow: 1 ft

Does the depth equal or not exceed the mimimum allowable for the structure length and design species? ☐ Yes ☒ No

If yes, modify design to comply and rerun hydraulic anaylses to verify.

Drop between the water surface elevation in the structure and the outlet channel for: N/A

High Fish Passage Flow: ft | Low Fish Passage Flow: ft

Does the drop between the water surface in the structure and the outlet channel at high or low design fish flows exceed the maximum allowable for the design species? ☐ Yes ☒ No

If yes, modify design to avoid a drop if possible. If a drop is unavoidable modify design to meet criteria and provide a jump pool at least two feet in depth. Rerun hydraulic analyses to verfiy.

Water Surface elevation at inlet for the 10-year peak discharge: N/A ft

Does the water surface elevation exceed the allowable? ☐ Yes ☐ No

If yes, modify design to comply and rerun hydraulic analyses to verify.

Maximum Structure and Channel velocities at inlet and outlet transition for the peak or design discharge: high fish passage flows

Range of velocities for Inlet transition:	1.0	ft/s	to	ft/s
Range of velocities for structure portion:	1.5	ft/s	to	ft/s
Range of velocities for Outlet Transition:	1.1	ft/s	to	ft/s

Do the velocities exceed the permissible scour velocities? ☐ Yes ☐ No

If yes, revise design to reduce velocities and rerun hydraulic analyses to verify, or design erosion protection.

Comparison between existing and project future condition water surface elevations for the 10-Year and 100-Year peak flow:

Cross-Section	10-Yr WSEL	10-Yr WSEL	WSEL Difference	100-Year WSEL	100-Year WSEL	WSEL Difference
	Existing Conditions (ft)	Future Conditions (ft)	(ft)	Existing Conditions (ft)	Future Conditions (ft)	(ft)
1 810	N/A	108.67	—	N/A	113.54	—
2 818.5	N/A	108.68	—	N/A	113.60	—
3 1007	112.66	113.95	+1.29	116.78	118.30	+1.52
4 1020	112.64	113.95	+1.31	116.78	118.31	+1.55

If WSELs increase, does the increase exceed the maximum elevation? ☐ Yes ☒ No | Maximum elevation: 121.37 ft

If yes, revise the design and rerun hydraulic analyses to verify.

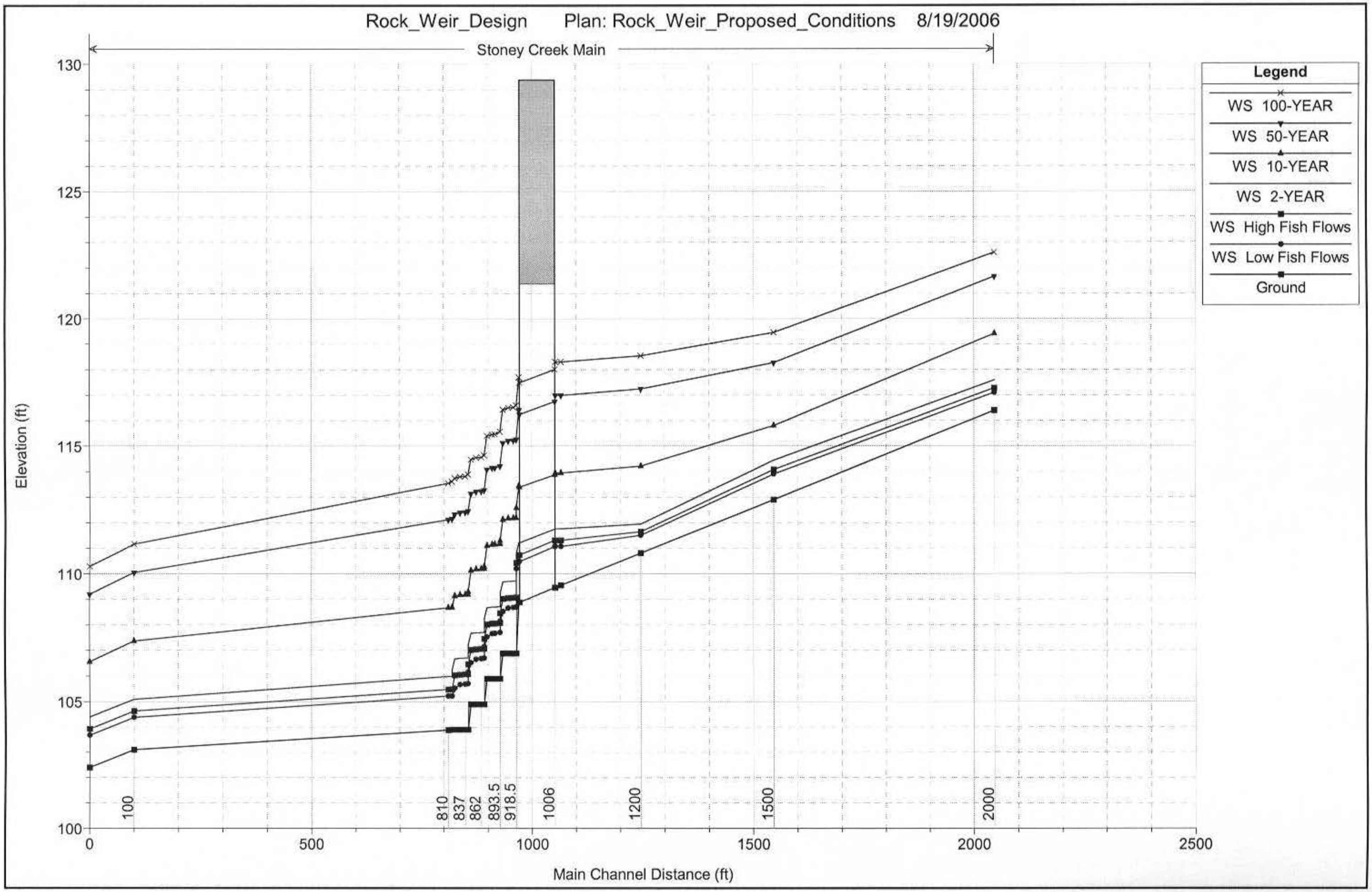
If WSELs decrease, does it appear that the attenuation of peak flow will significally change? ☐ Yes ☒ No

FISH PASSAGE: HYDRAULIC ROCK WEIR DESIGN OPTION FORM 6E

If yes, evaluate to determine if downstream hydraulic impacts are significant and modify design as appropriate.

Proposed Plan and Profile Drawing Attached ☒ Yes ☐ No

Hydraulic Analysis Index Sheet Attached ☒ Yes ☐ No

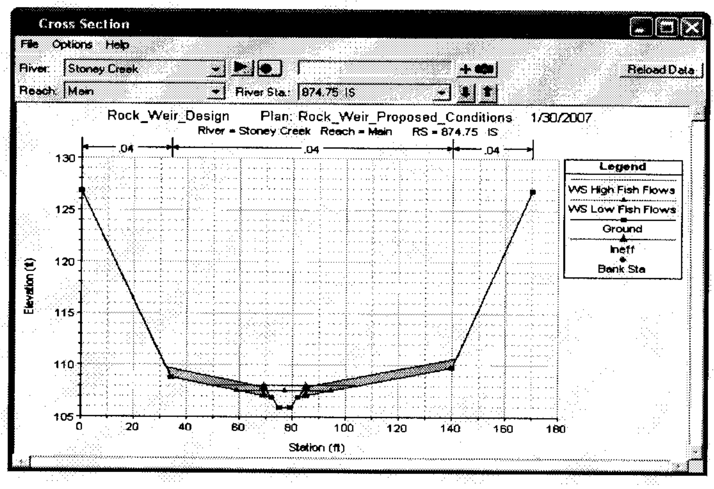

Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006
Stoney Creek Main
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Elevation (ft)
130
125
120
115
110
105
100
100
810
837
862
893.5
918.5
1006
1200
1500
2000
0
500
1000
1500
2000
2500
Main Channel Distance (ft)

Velocity and Depth Hand Calculations Through Weirs

Project Information: Stoney Creek Bridge Widening		Computed: EKB	Date: 7/6/2006
		Checked: LEF	Date: 7/7/2006
Stream Name: Stoney Creek	County: Ventura	Route: 444	Postmile: 15.6

Calculations:

Weir Structure = 874.75 IS



Cross Section

River: Stoney Creek

Reach: Main

River Sta.: 874.75 IS

Broad Crested Weir Q = CLH^1.5

Low Fish Passage Design Flow = 50 cfs

Knowns:

C =	2.65	ft^0.5/sec
Length of weir =	10	ft
WSE_LowFlow =	105.52	ft
Top of Weir Elevation =	105.89	ft
Head =	-0.37	ft

Q_Baffle = 0.0 cfs

Q_Total_Baffle = 0.00 cfs

Q_Notch = Q_Total - Q_Total_Baffle = 50 cfs - 0 cfs

Q_Notch = 50.00 cfs

A_Notch = Base*Height + (2)(1/2)*Base*Height = (4)(2) + (2)(1/2)(10)(2)

A_Notch = 28.00 ft^2

V_Notch = Flow / Area = 50 cfs / 28 ft^2

V_Notch = 1.79 ft/sec

High Fish Passage Design Flow = 78 cfs

Knowns:

C =	2.65	ft^0.5/sec
Length of weir =	10	ft
WSE_HighFlow =	106.02	ft
Top of Weir Elevation =	105.89	ft
Head =	0.13	ft

Q_Baffle = 1.24 cfs

Q_Total_Baffle = 2.48 cfs

Q_Notch = Q_Total - Q_Total_Baffle =78 cfs - 2.48 cfs

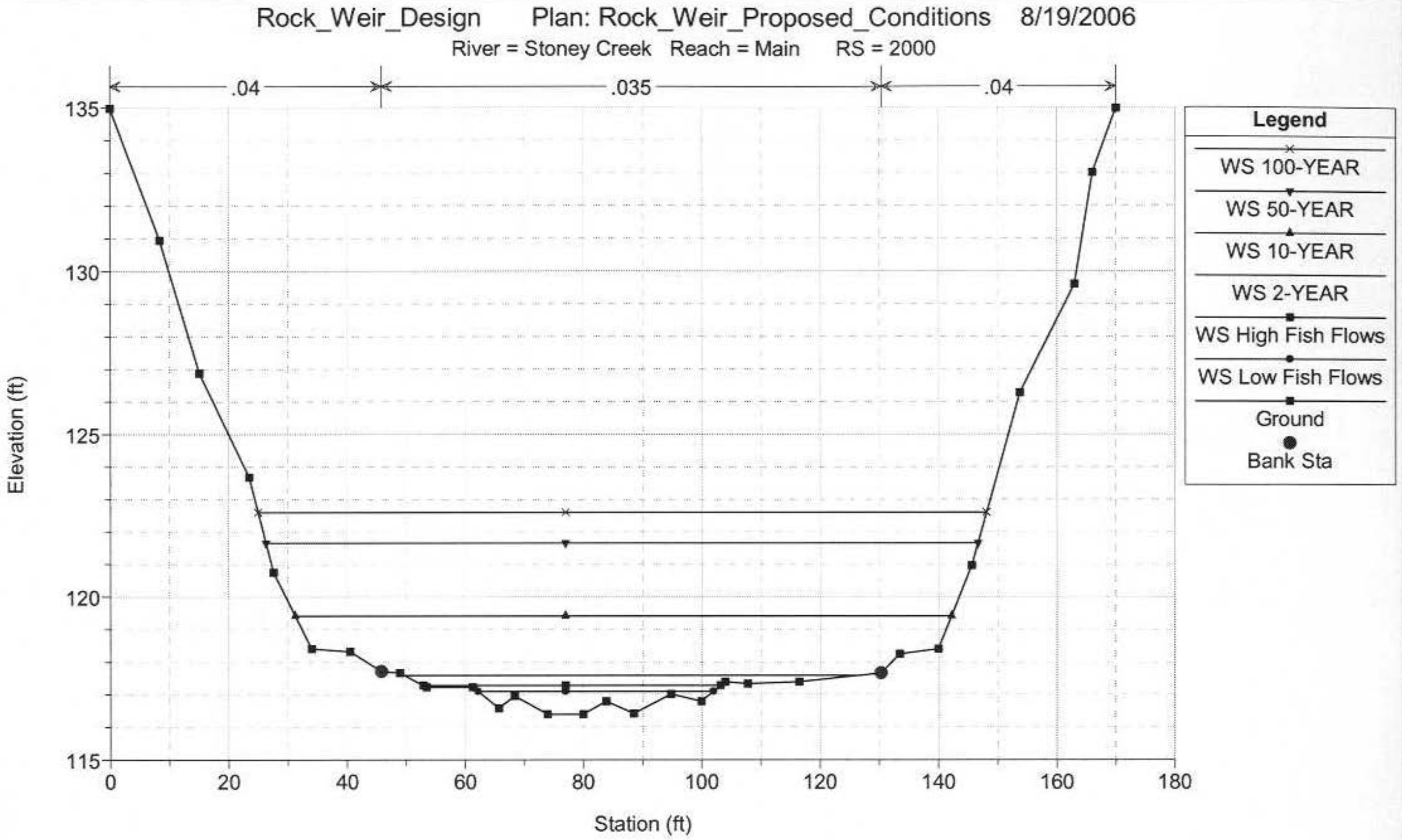
Q_Notch = 75.52 cfs

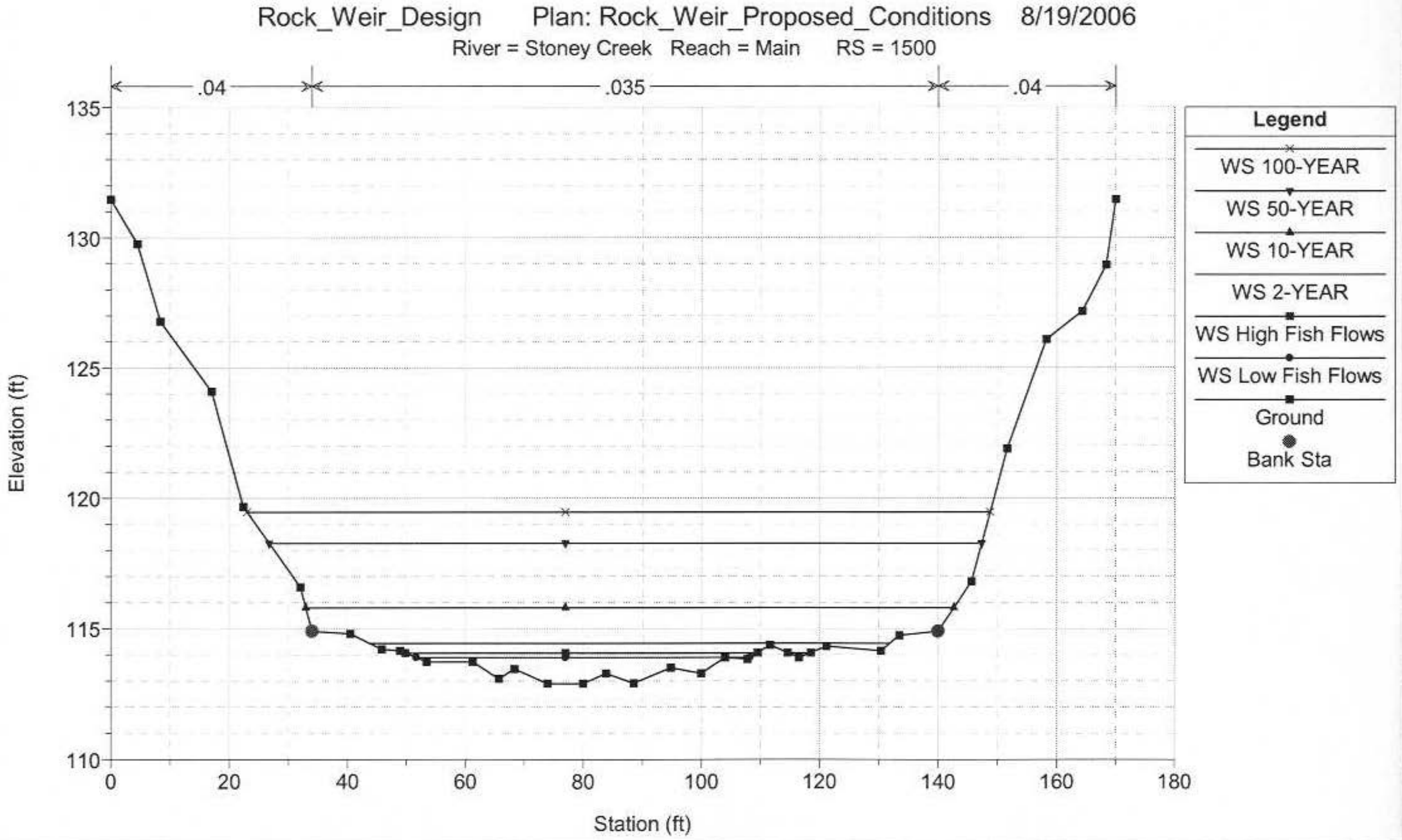
A_Notch = Base*Height + (2)(1/2)*Base*Height = (4)(2) + (2)(1/2)(10)(2)

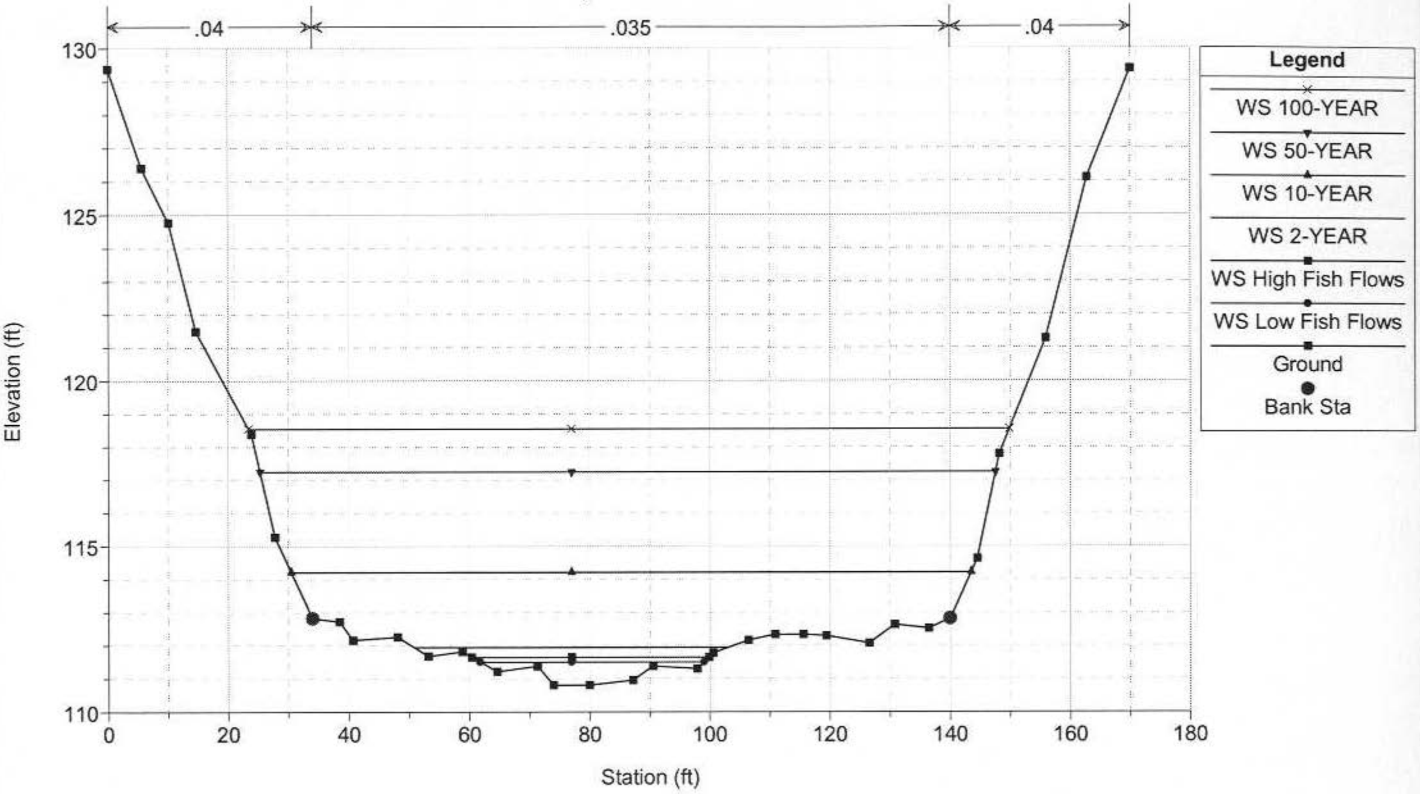
A_Notch = 28.00 ft^2

V_Notch = Flow / Area = 75.52 cfs / 28 ft^2

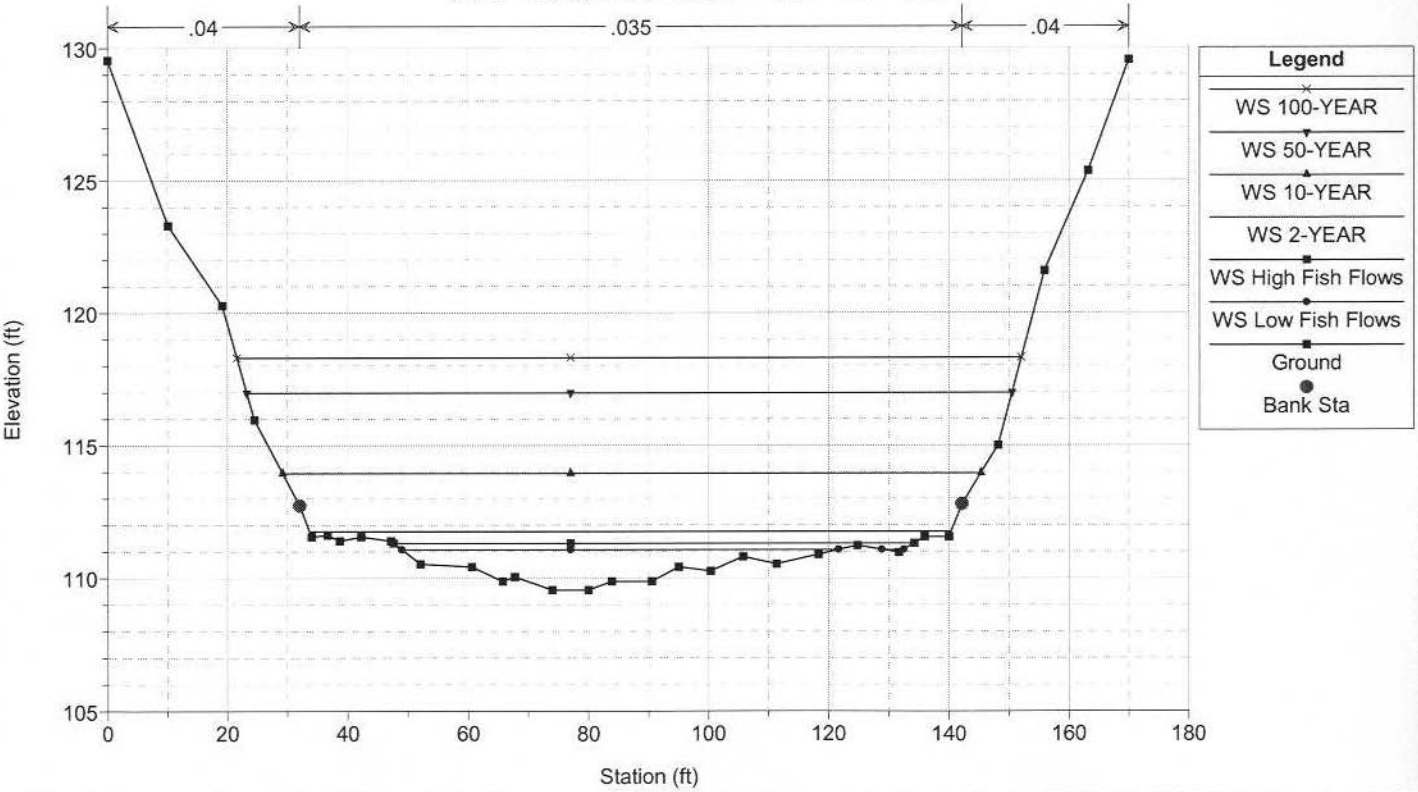
V_Notch = 2.70 ft/sec


Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 2000
.04
.035
.04
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Bank Sta
Elevation (ft)
135
130
125
120
115
0
20
40
60
80
100
120
140
160
180
Station (ft)

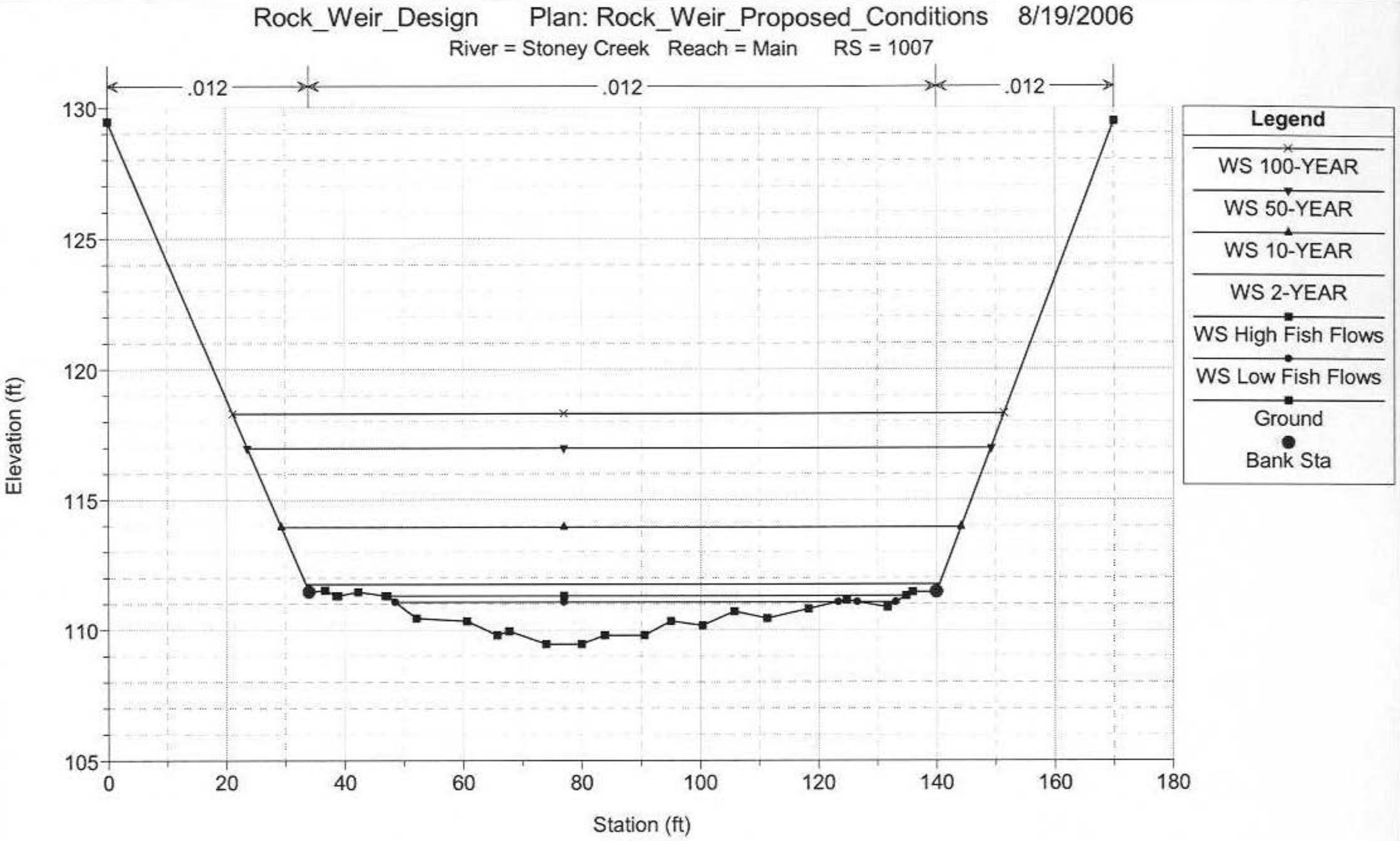

Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 1500
.04
.035
.04
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Bank Sta
Elevation (ft)
135
130
125
120
115
110
0
20
40
60
80
100
120
140
160
180
Station (ft)

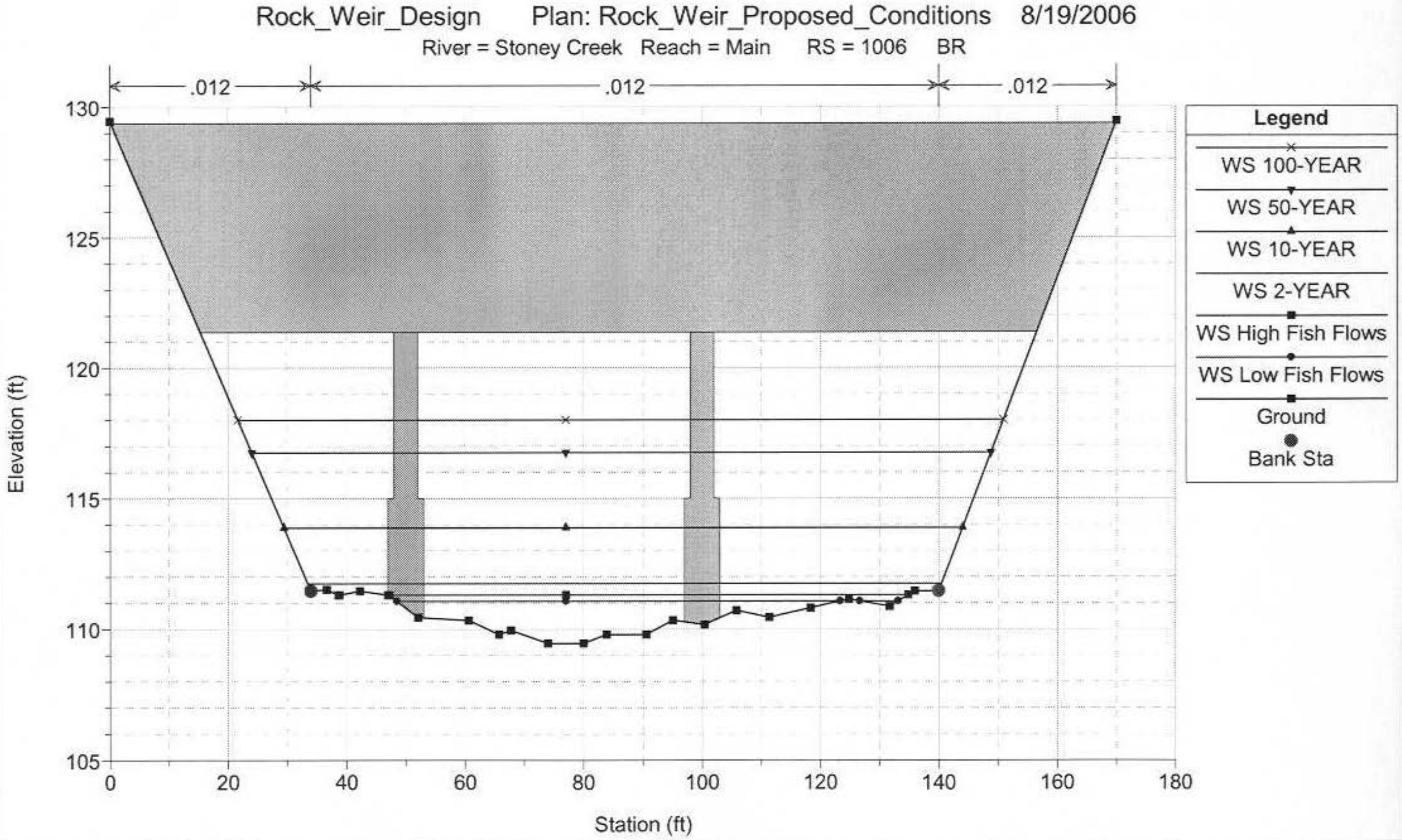


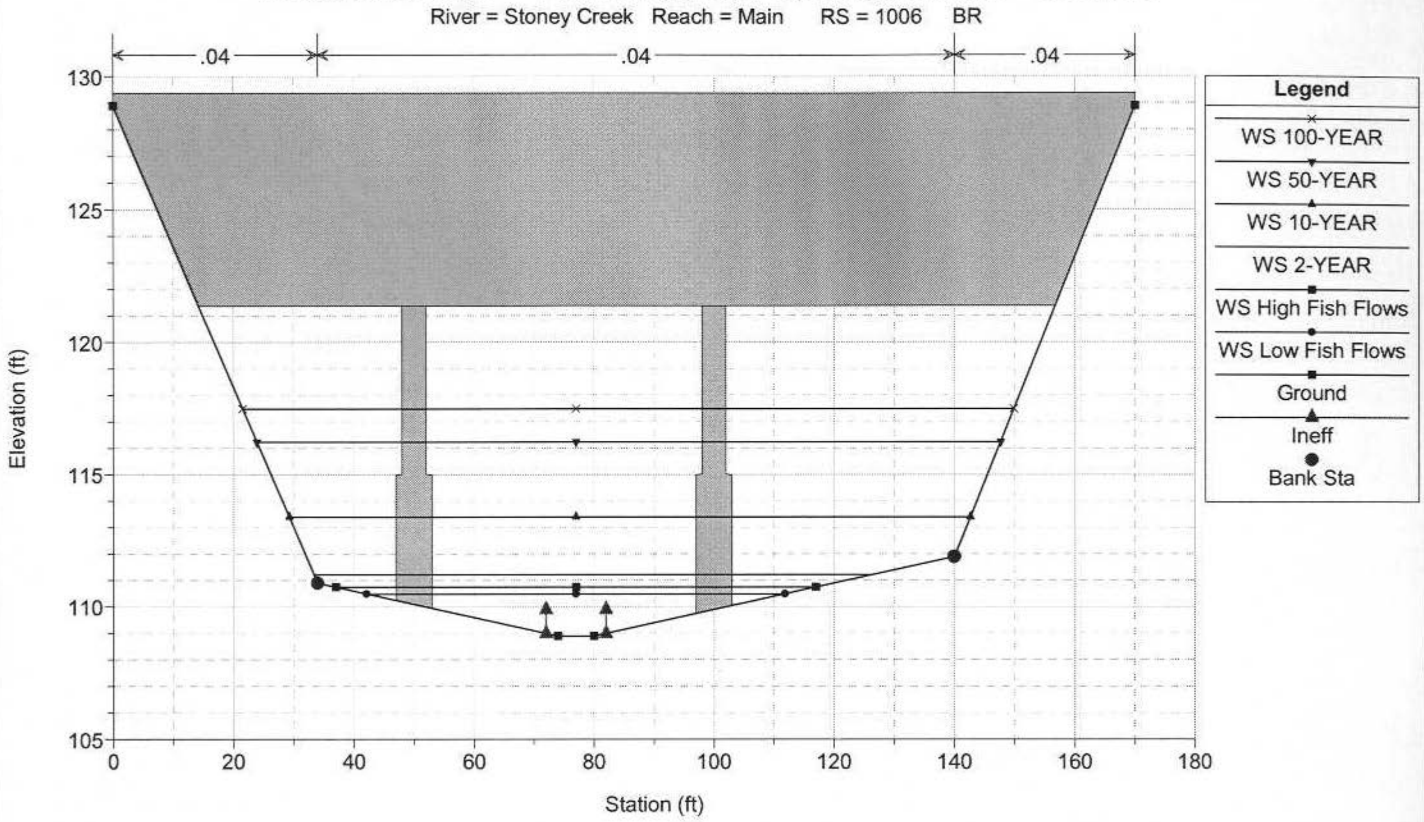
Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 1200

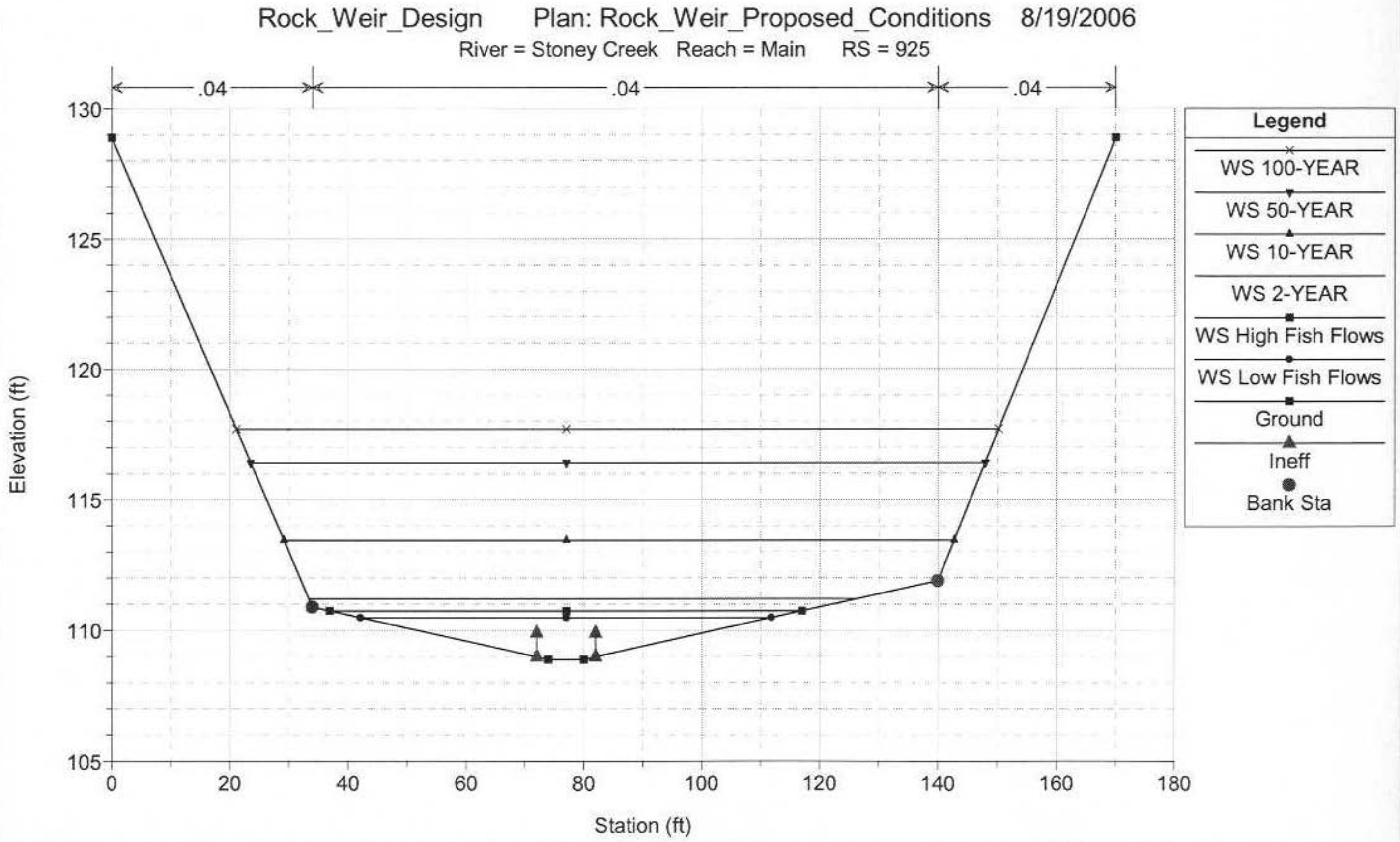


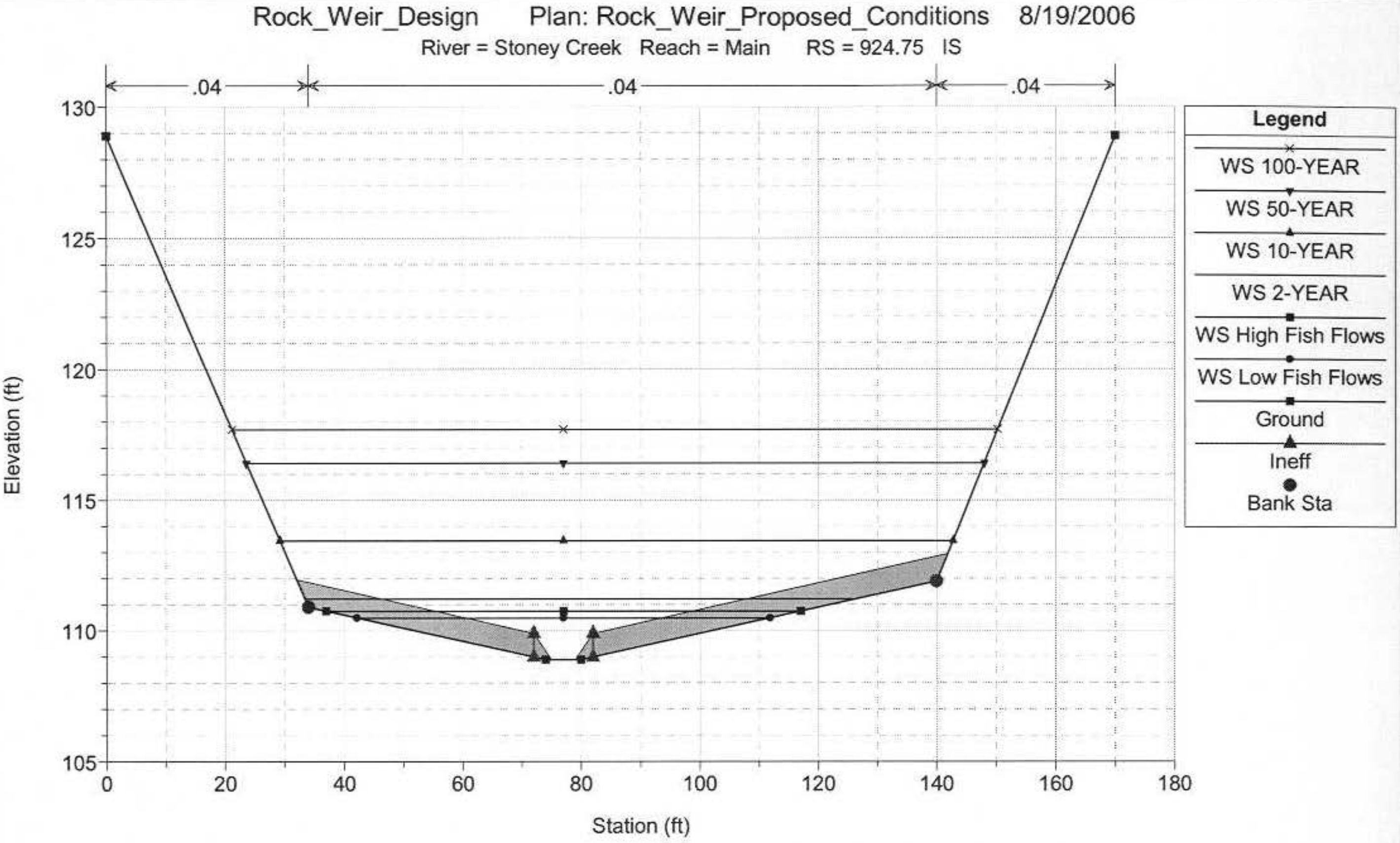
Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 1020


Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 1007
.012
.012
.012
Elevation (ft)
130
125
120
115
110
105
0
20
40
60
80
100
120
140
160
180
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Bank Sta


Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 1006 BR
.012
.012
.012
Elevation (ft)
130
125
120
115
110
105
0
20
40
60
80
100
120
140
160
180
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Bank Sta


Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 1006 BR
.04
.04
.04
Elevation (ft)
130
125
120
115
110
105
Station (ft)
0
20
40
60
80
100
120
140
160
180
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Ineff
Bank Sta


Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 925
.04
.04
.04
Elevation (ft)
130
125
120
115
110
105
Station (ft)
0
20
40
60
80
100
120
140
160
180
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Ineff
Bank Sta


Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 924.75 IS
.04
.04
.04
Elevation (ft)
130
125
120
115
110
105
Station (ft)
0
20
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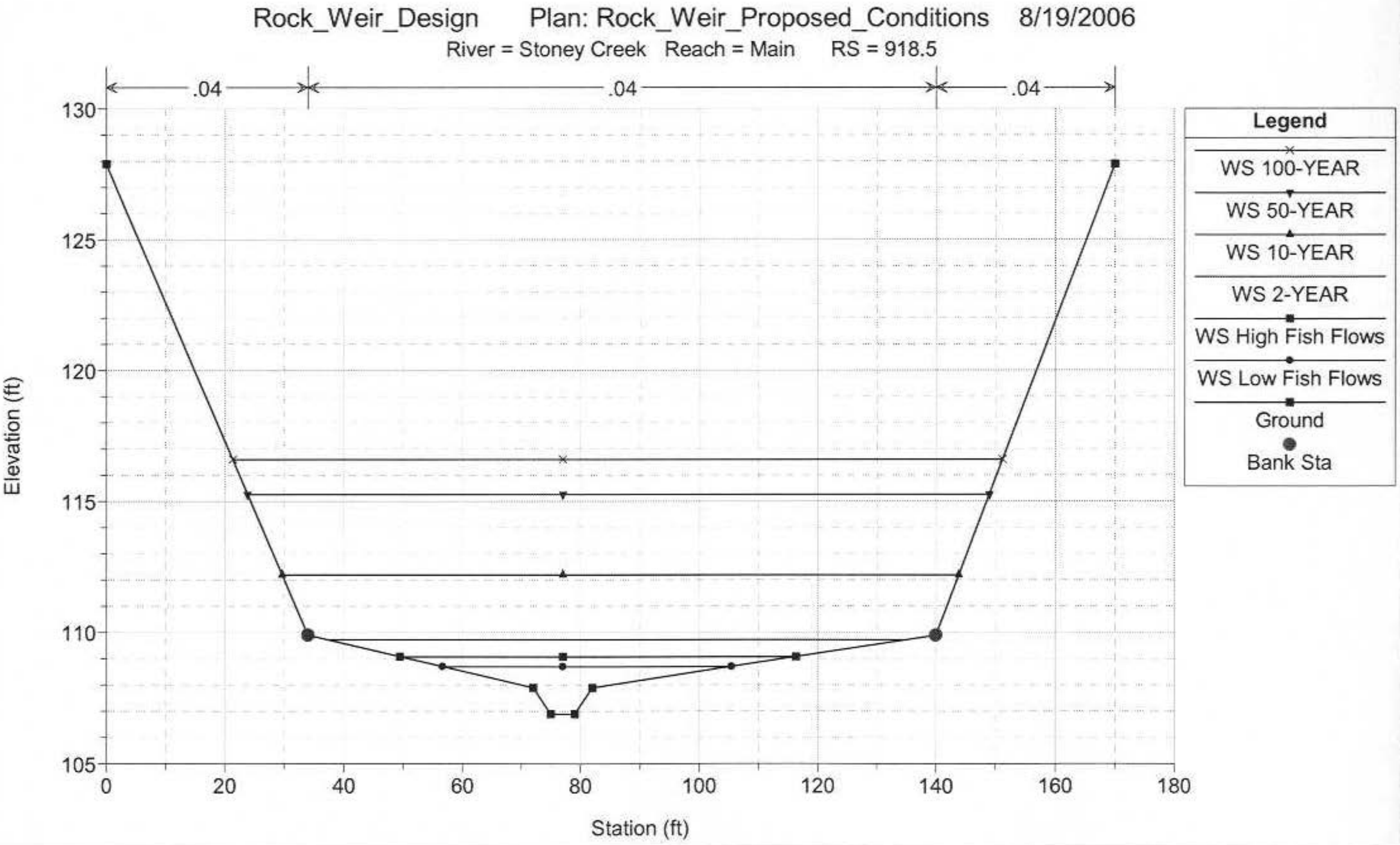
60
80
100
120
140
160
180
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Ineff
Bank Sta


Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 918.5
.04
.04
.04
Elevation (ft)
130
125
120
115
110
105
Station (ft)
0
20
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60
80
100
120
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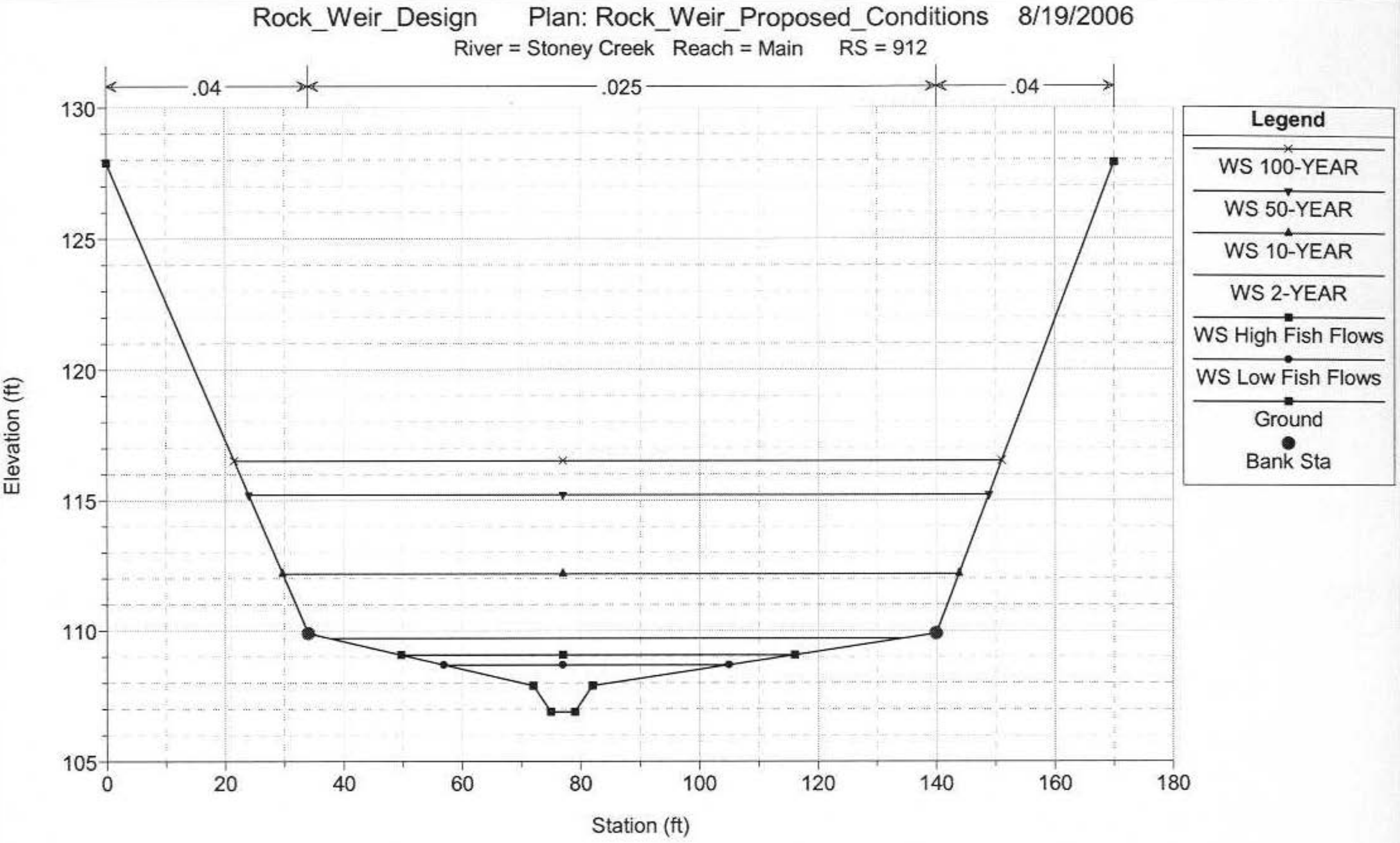
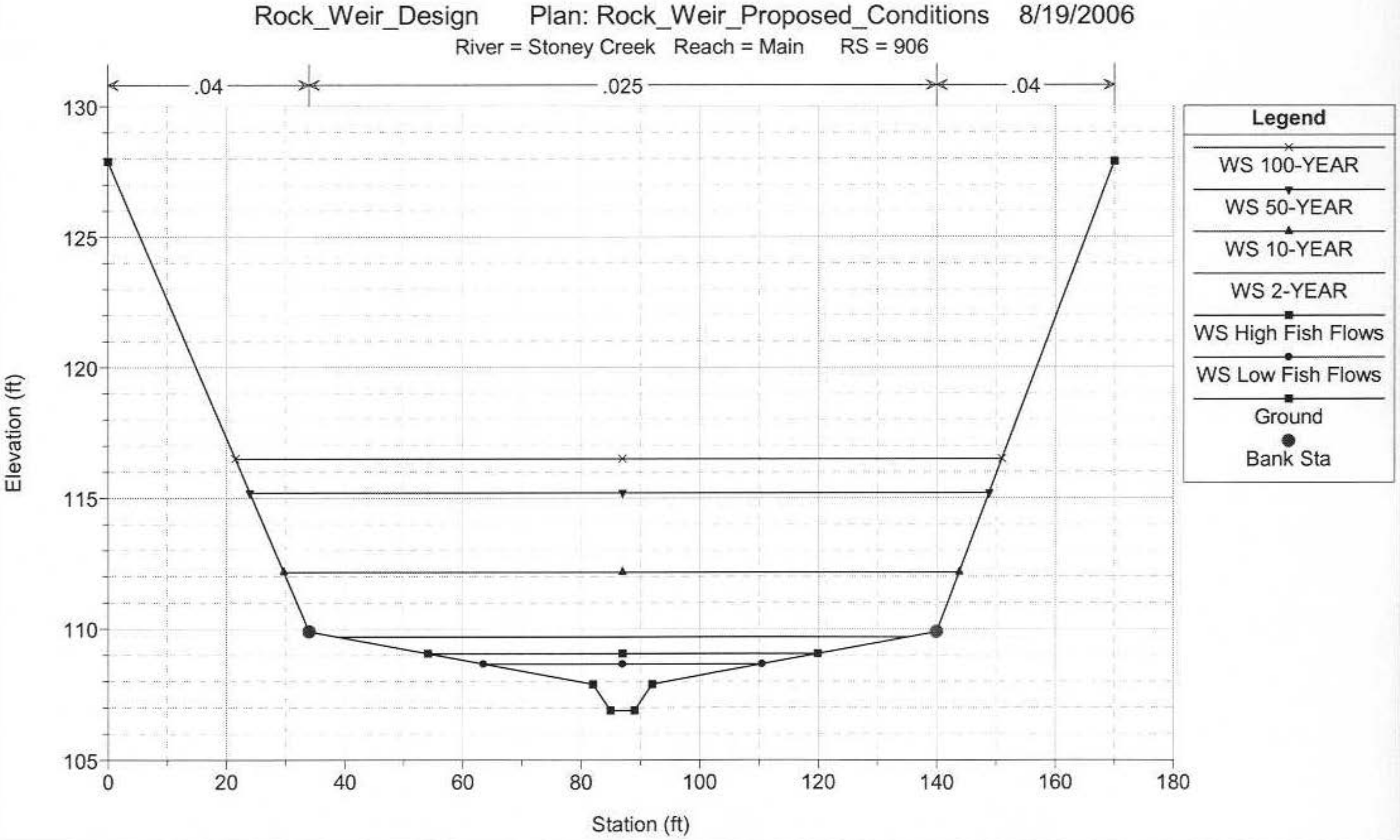
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Bank Sta



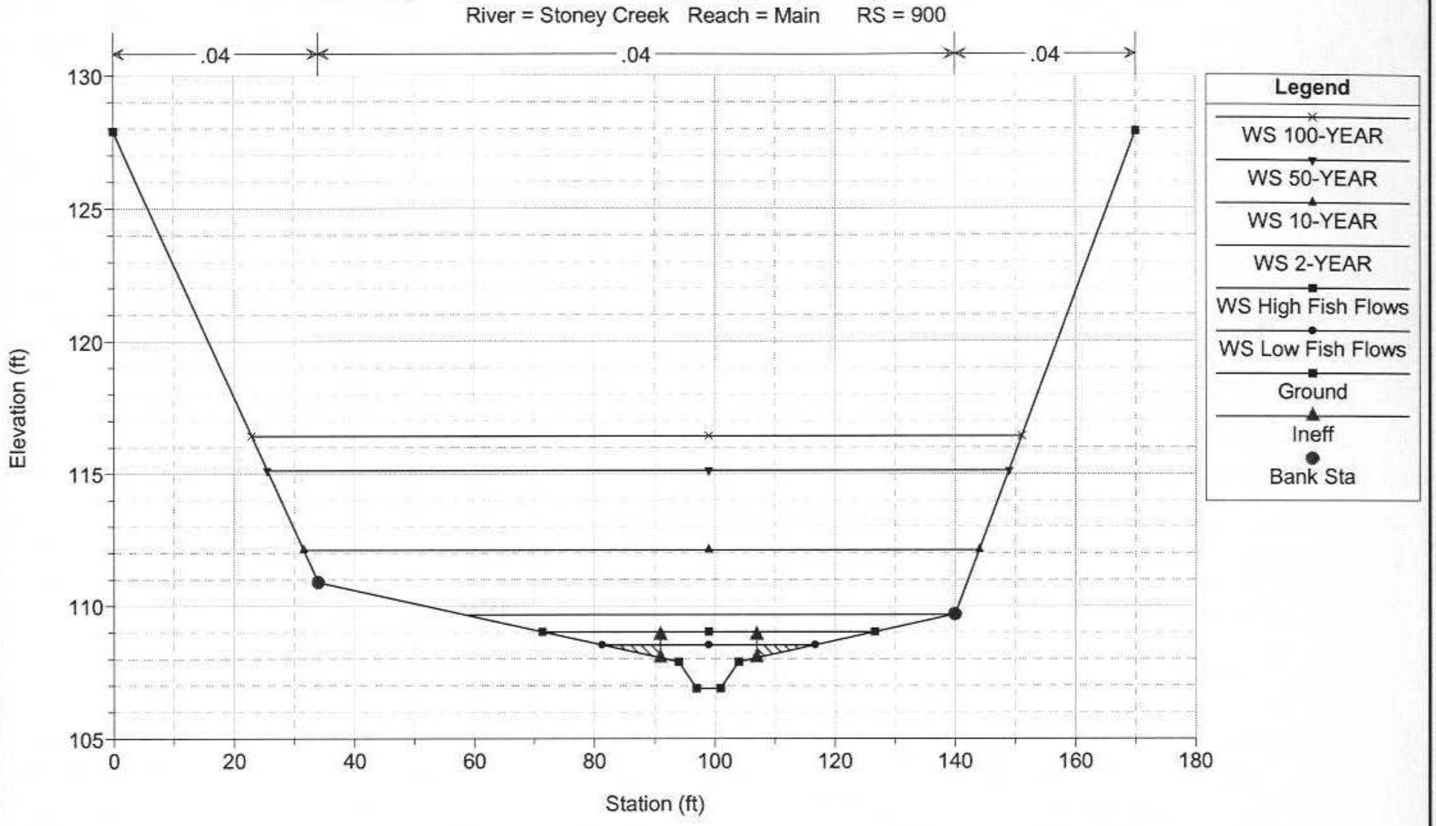
Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006

River = Stoney Creek Reach = Main RS = 912



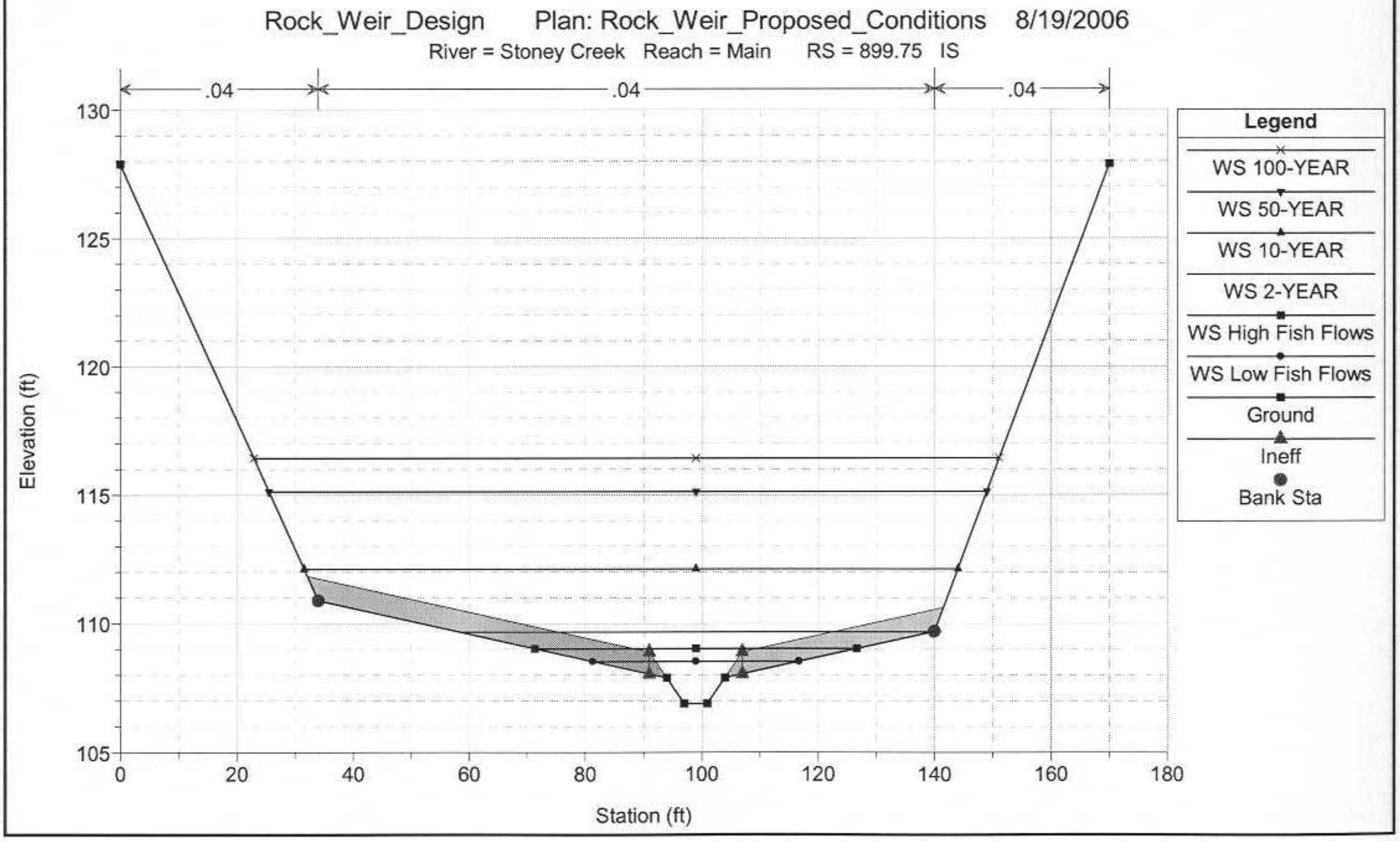
Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006

River = Stoney Creek Reach = Main RS = 906



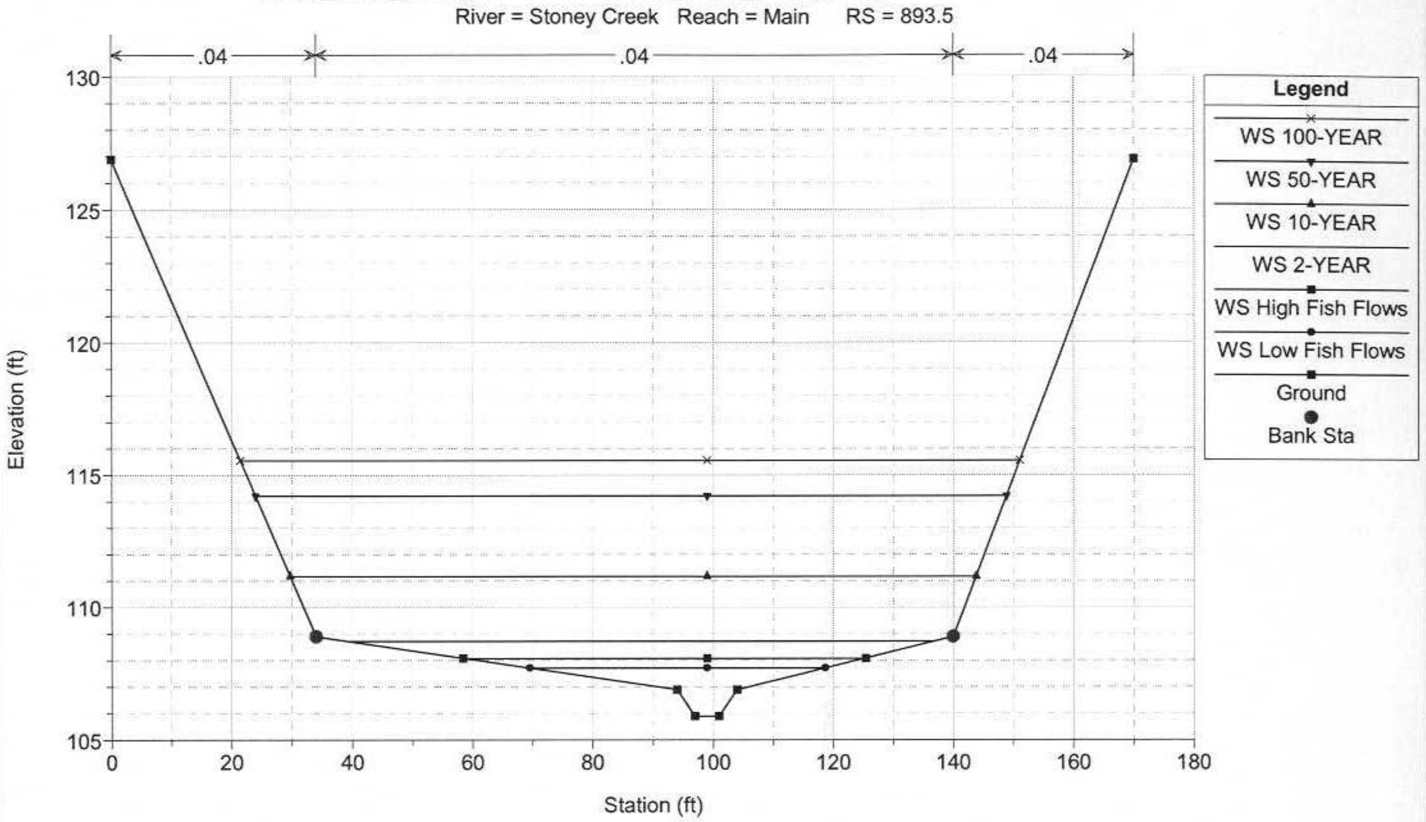
Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006

River = Stoney Creek Reach = Main RS = 900



Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006

River = Stoney Creek Reach = Main RS = 899.75 IS


Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 893.5
.04
.04
.04
Elevation (ft)
130
125
120
115
110
105
0
20
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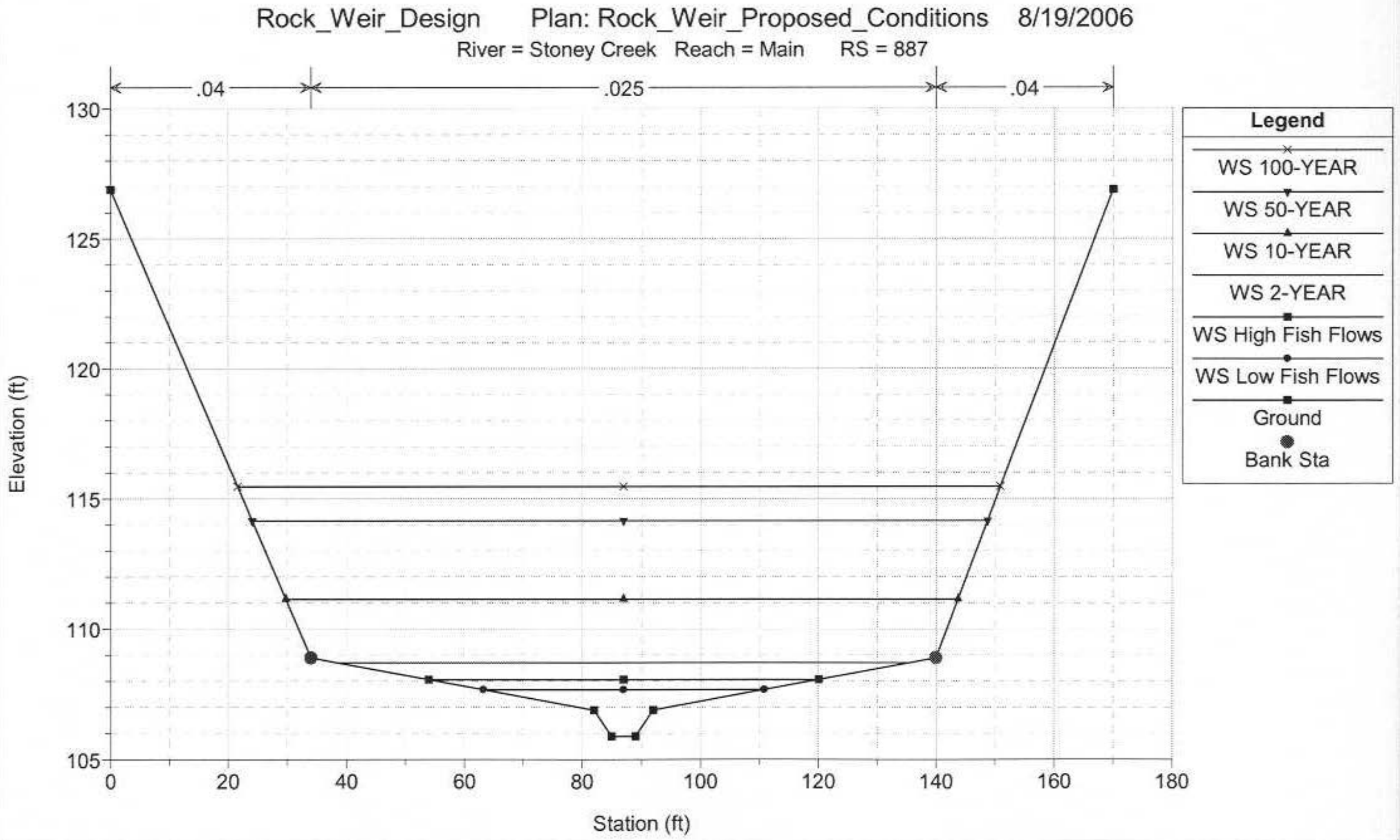
100
120
140
160
180
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Bank Sta


Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 887
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.025
.04
Elevation (ft)
130
125
120
115
110
105
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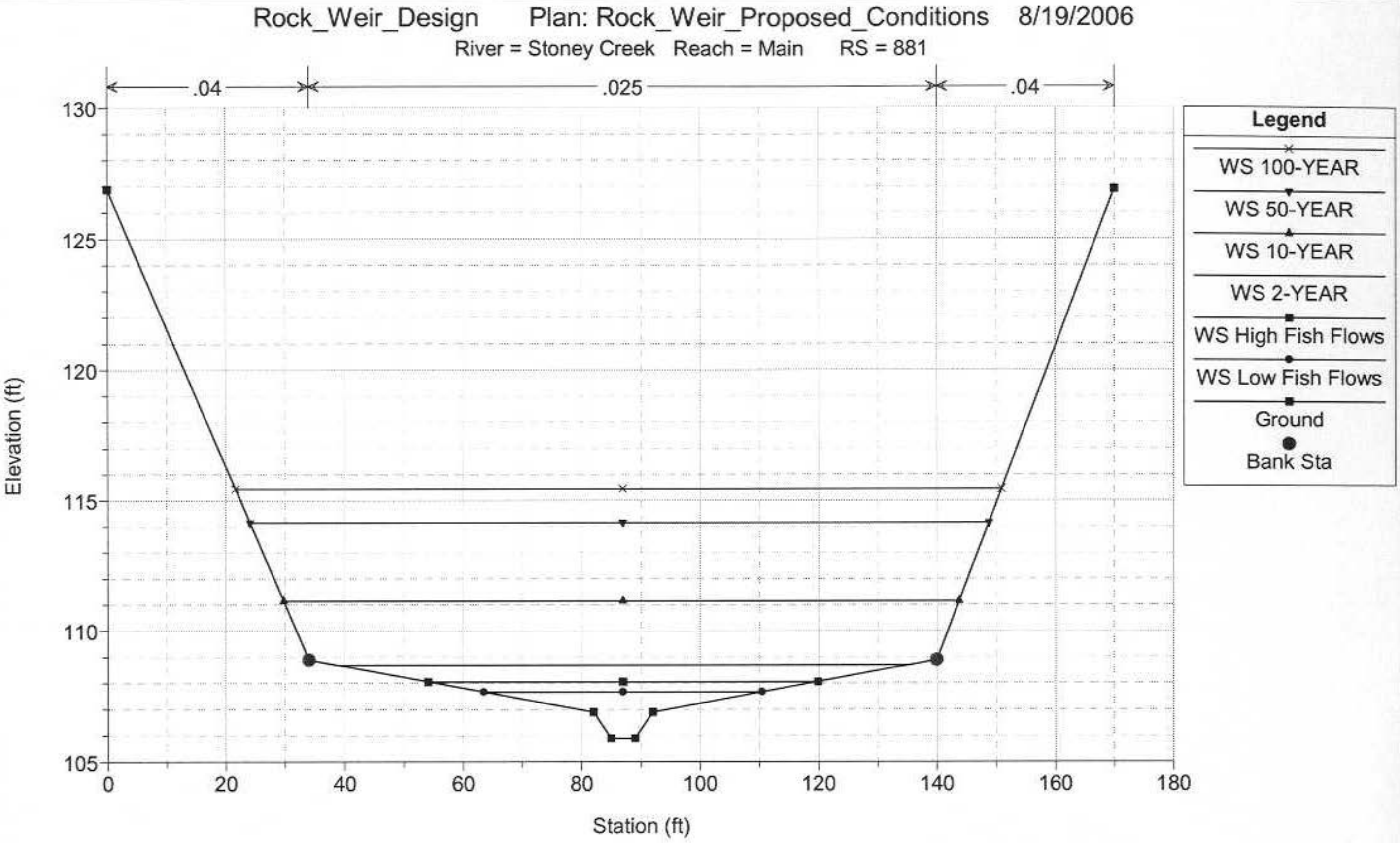
180
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Bank Sta


Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 881
.04
.025
.04
Elevation (ft)
130
125
120
115
110
105
Station (ft)
0
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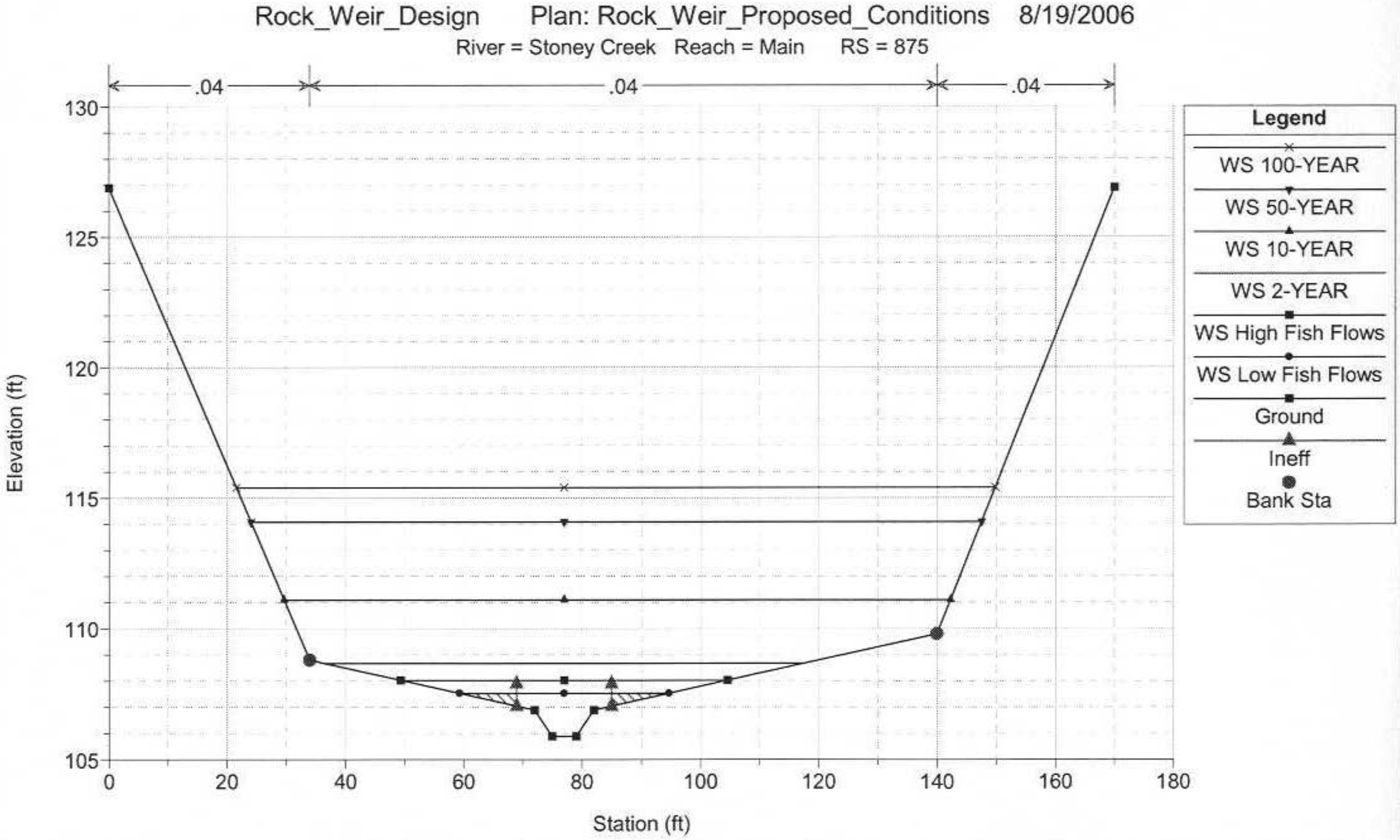
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Bank Sta


Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 875
.04
.04
.04
Elevation (ft)
130
125
120
115
110
105
Station (ft)
0
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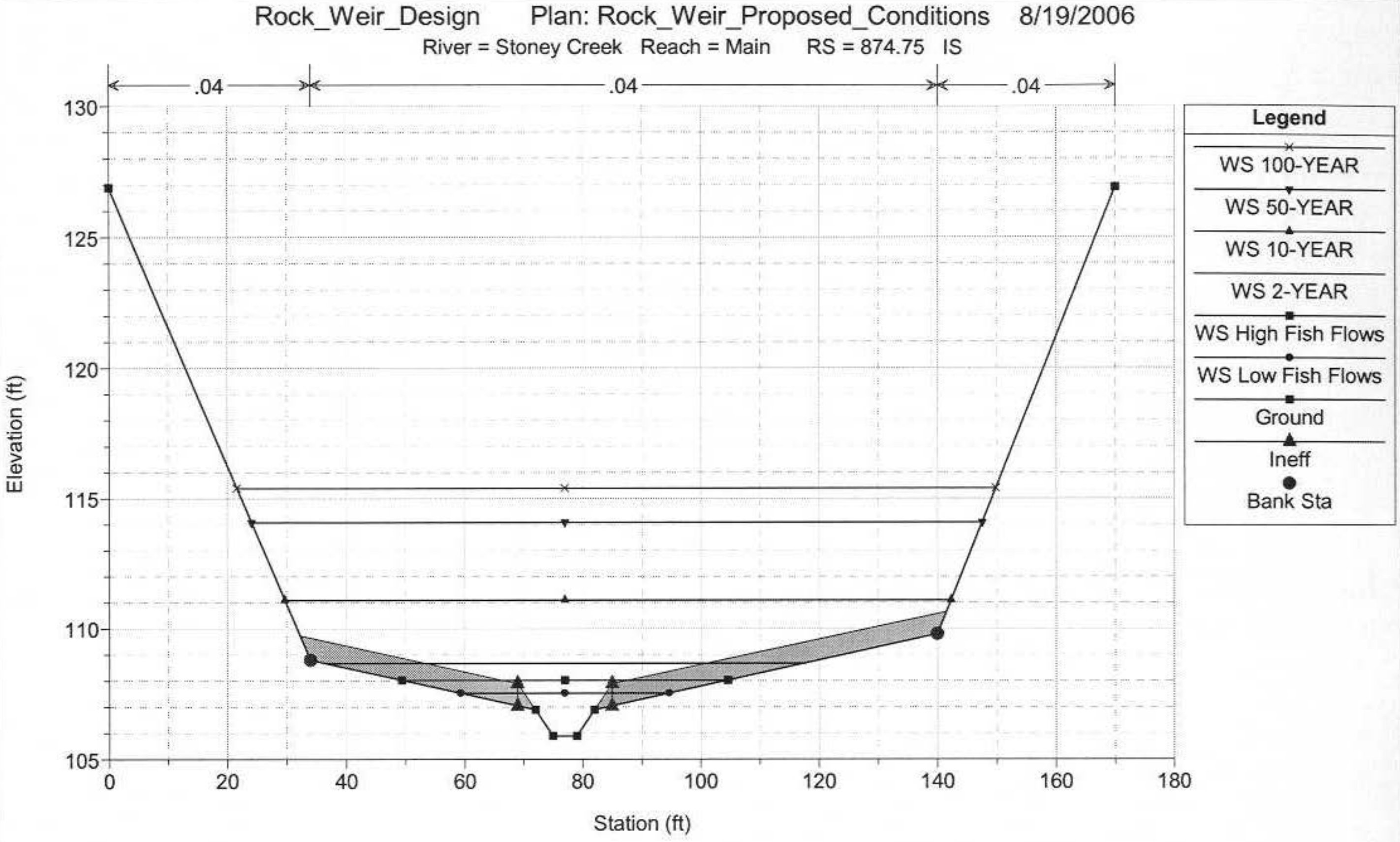
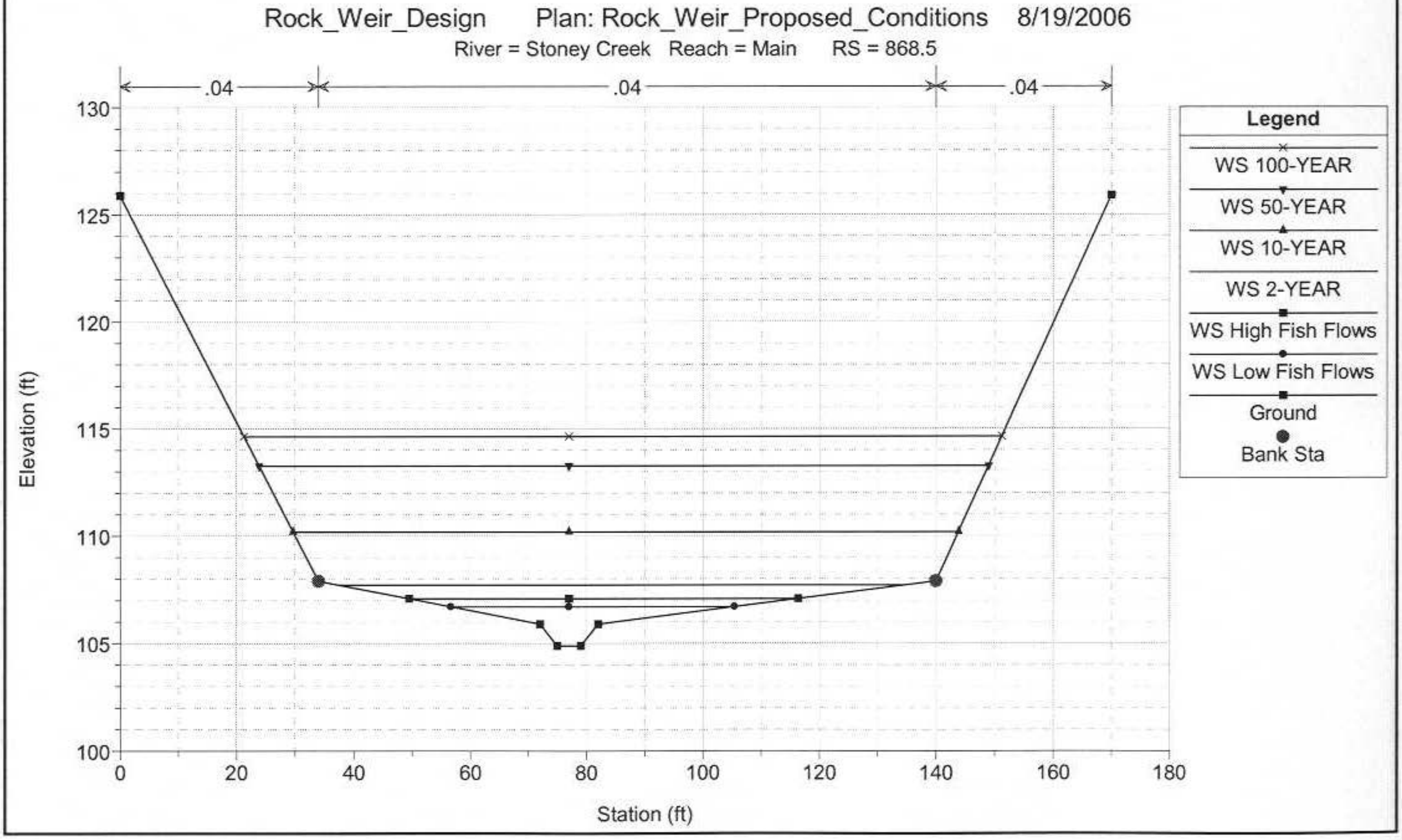
80
100
120
140
160
180
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Ineff
Bank Sta


Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 874.75 IS
.04
.04
.04
Elevation (ft)
130
125
120
115
110
105
0
20
40
60
80
100
120
140
160
180
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Ineff
Bank Sta


Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 868.5
.04
.04
.04
Elevation (ft)
130
125
120
115
110
105
100
0
20
40
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160
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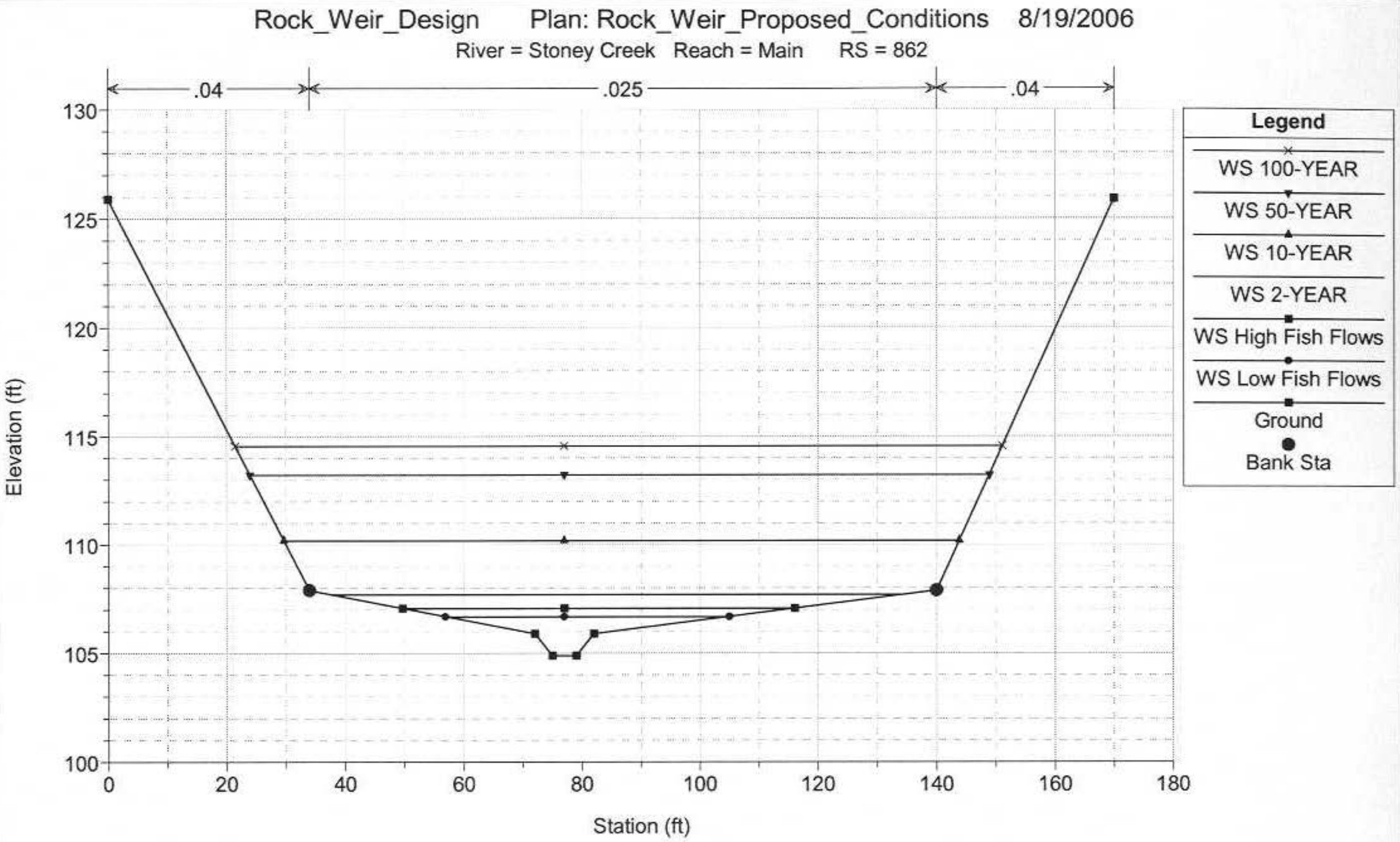
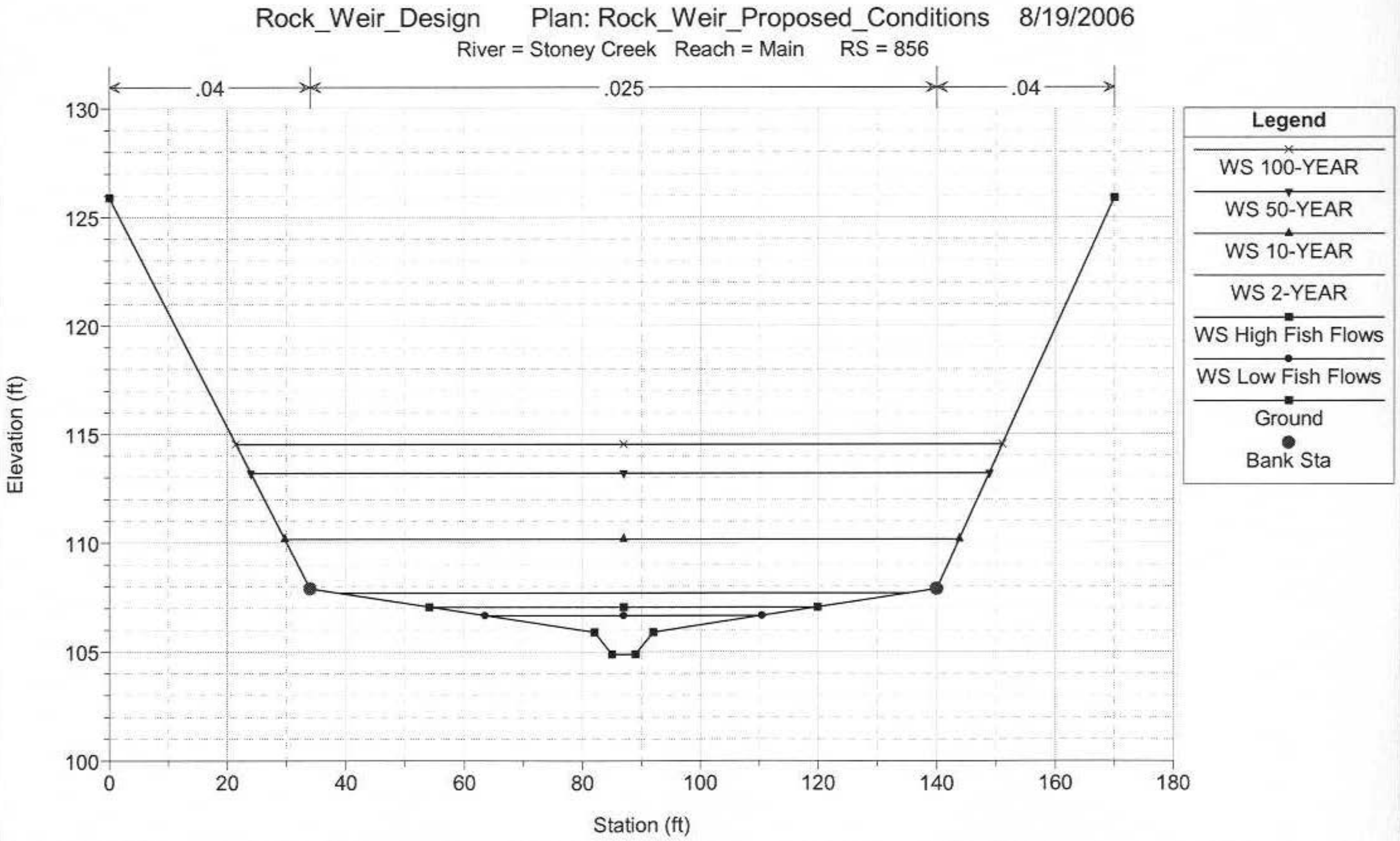
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Bank Sta



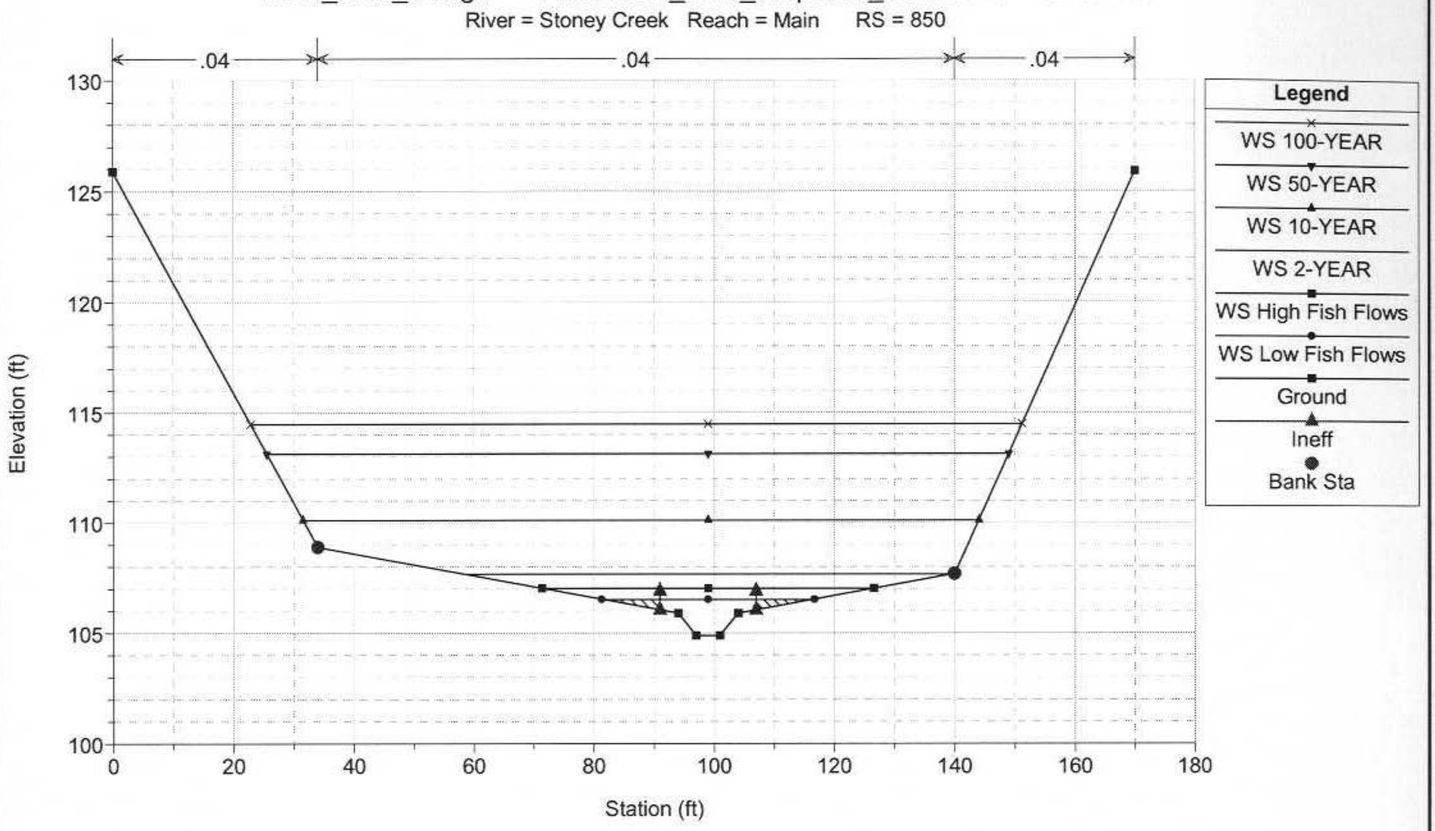
Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006

River = Stoney Creek Reach = Main RS = 862



Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006

River = Stoney Creek Reach = Main RS = 856


Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 850
.04
.04
.04
Elevation (ft)
130
125
120
115
110
105
100
Station (ft)
0
20
40
60
80
100
120
140
160
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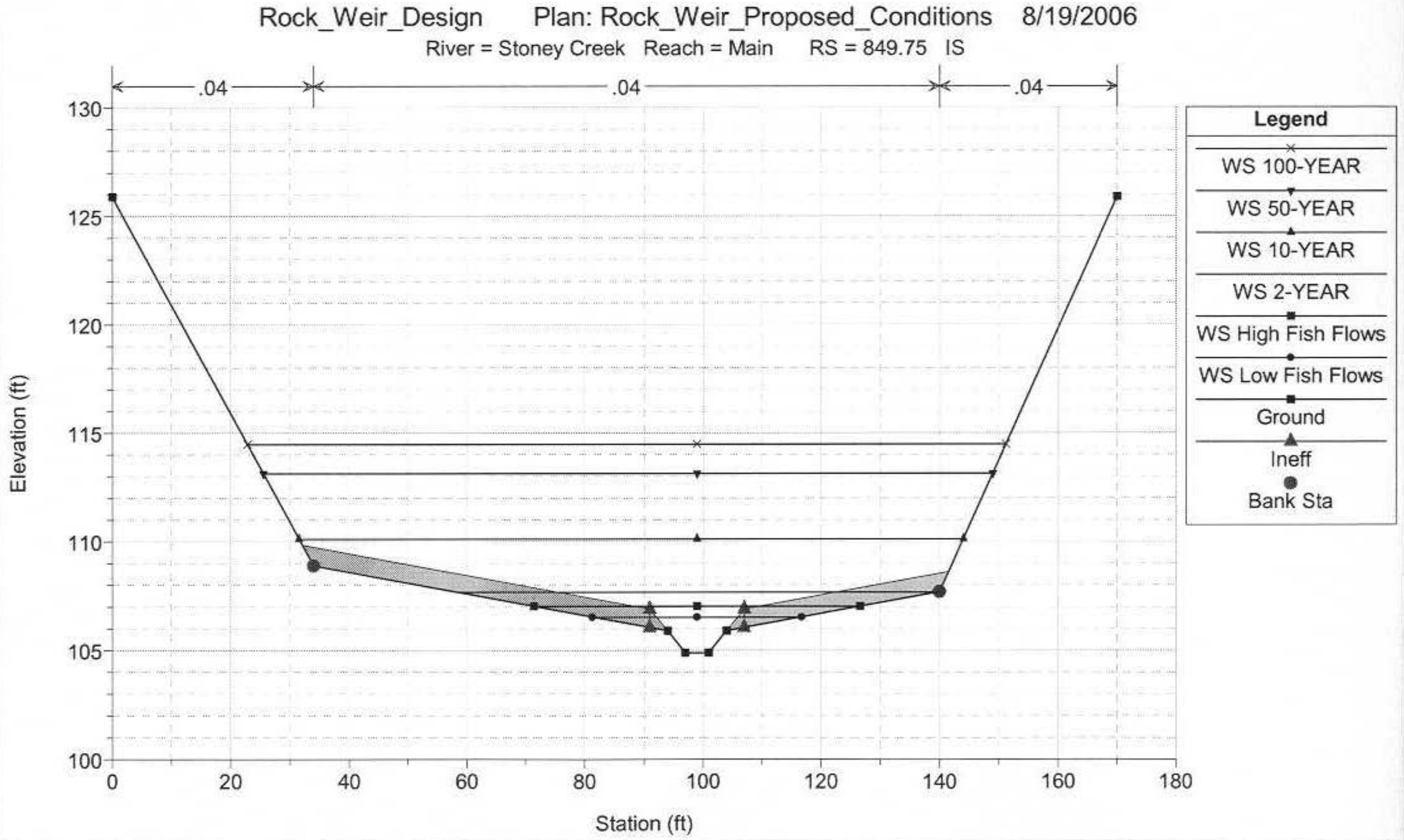
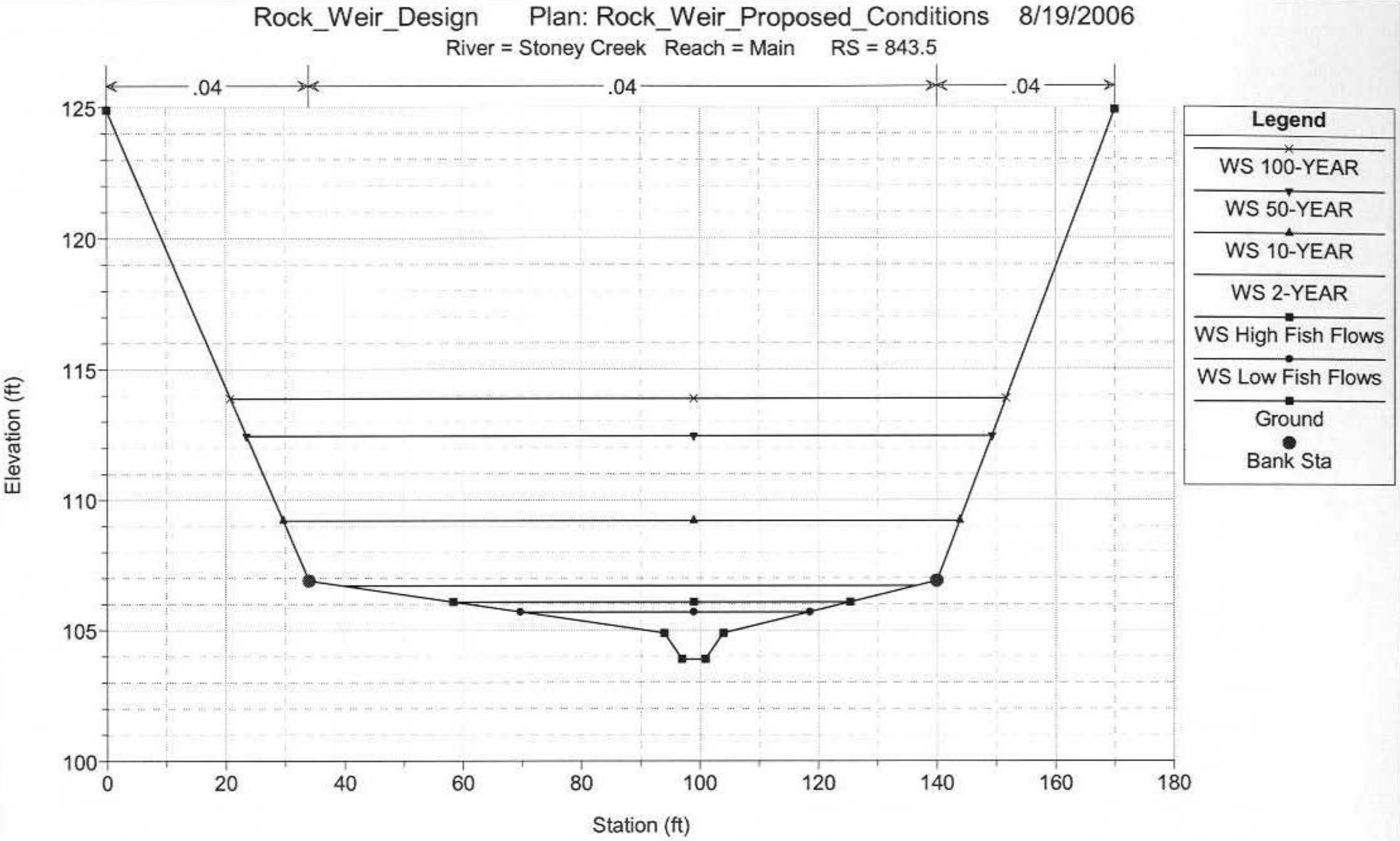
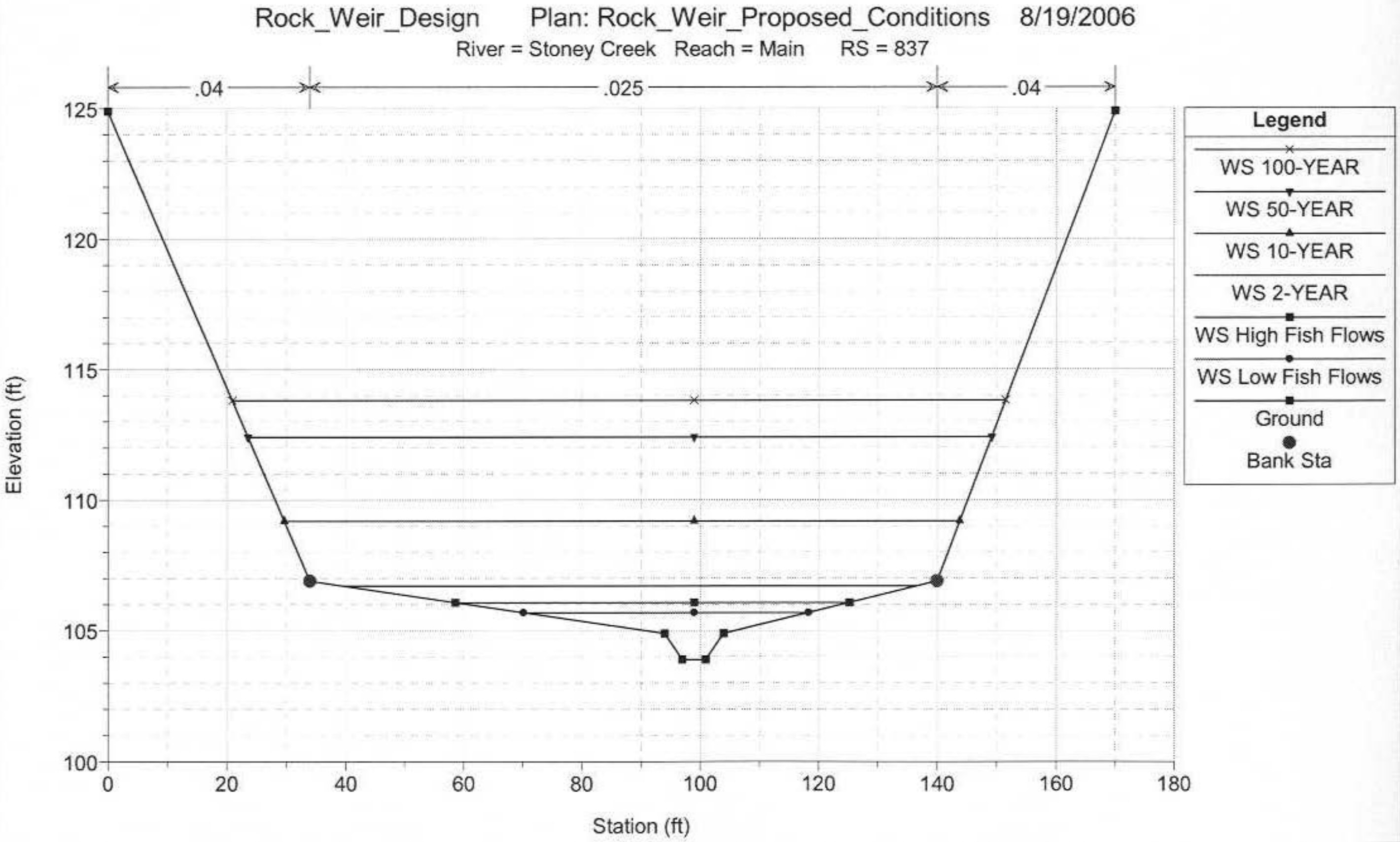
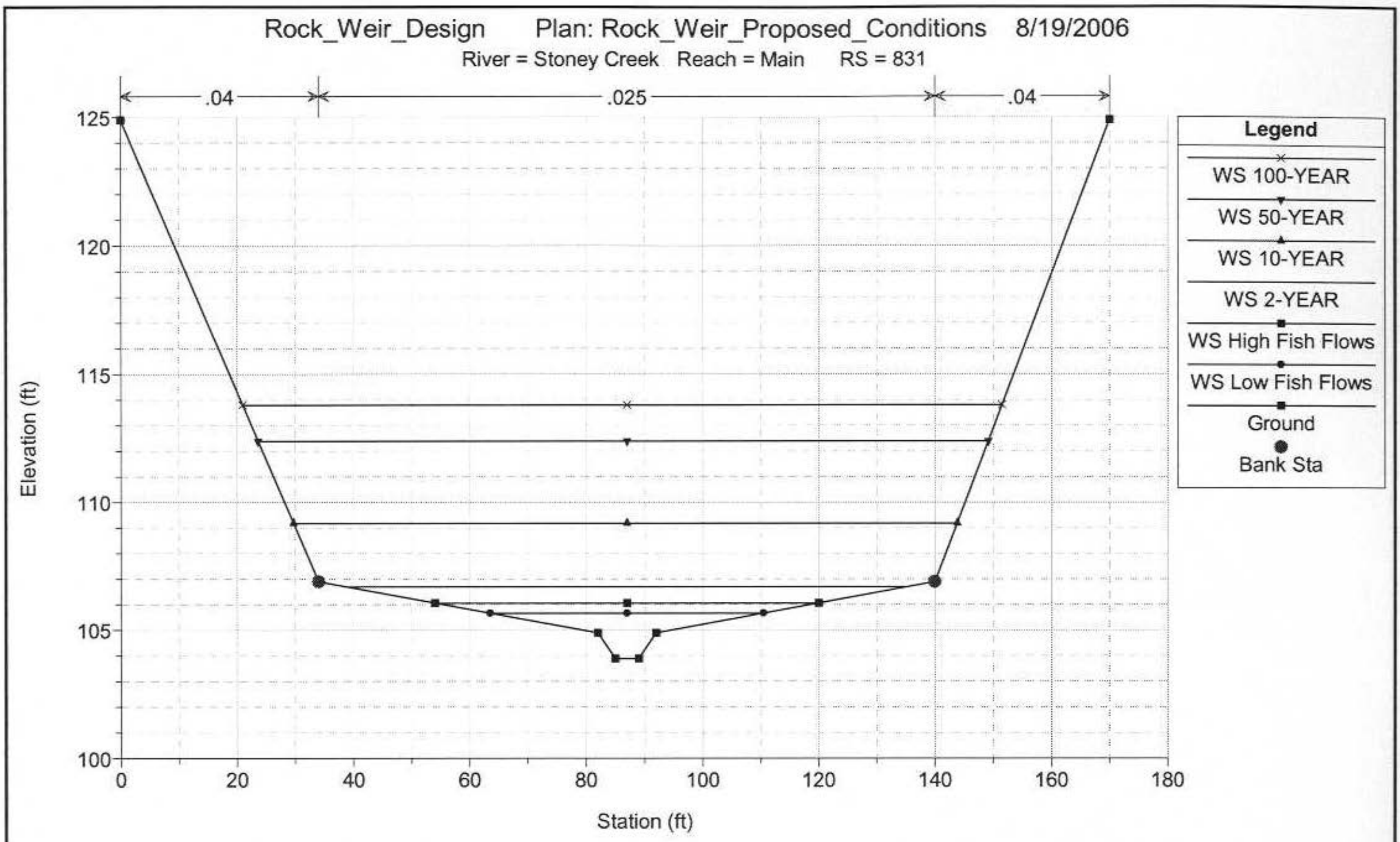
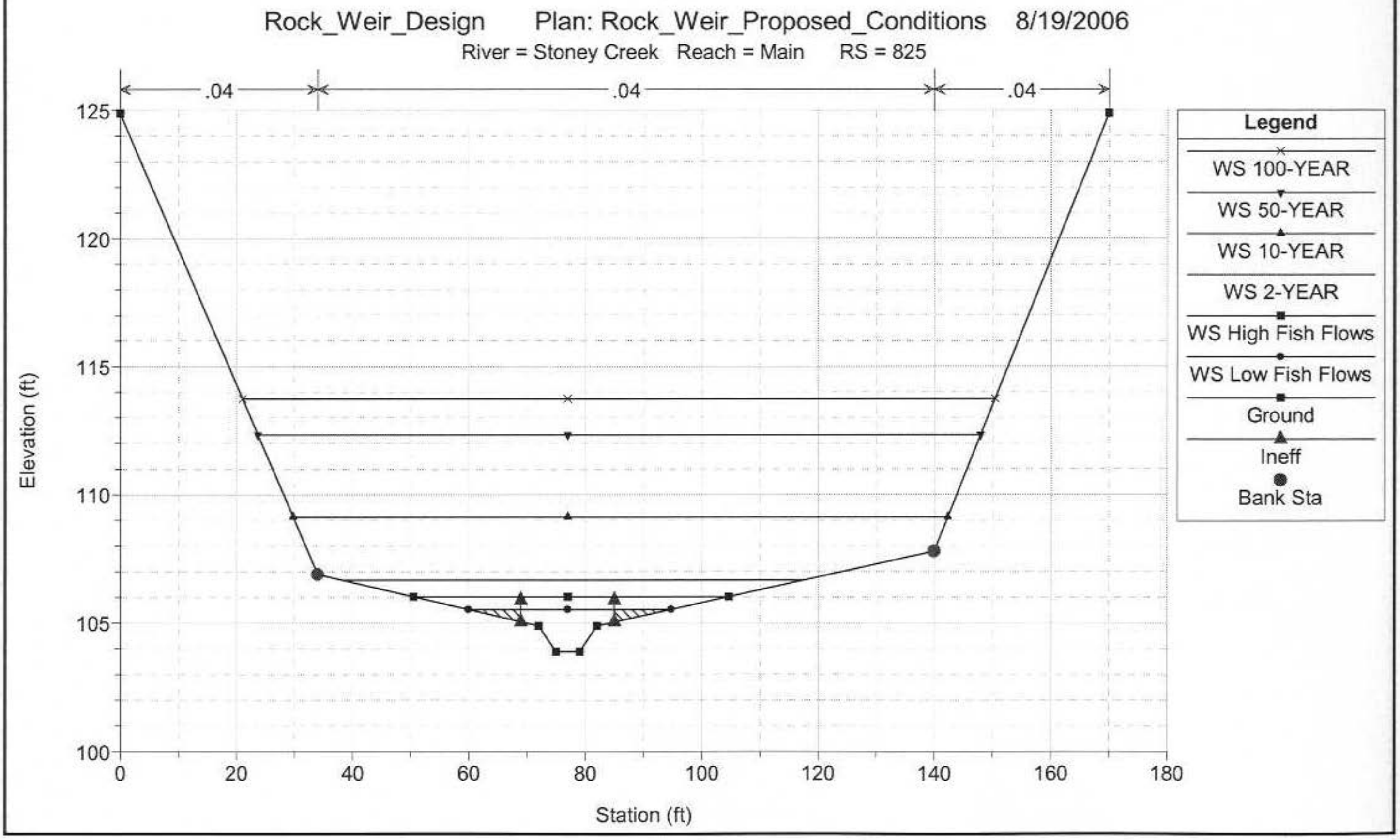
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Ineff
Bank Sta

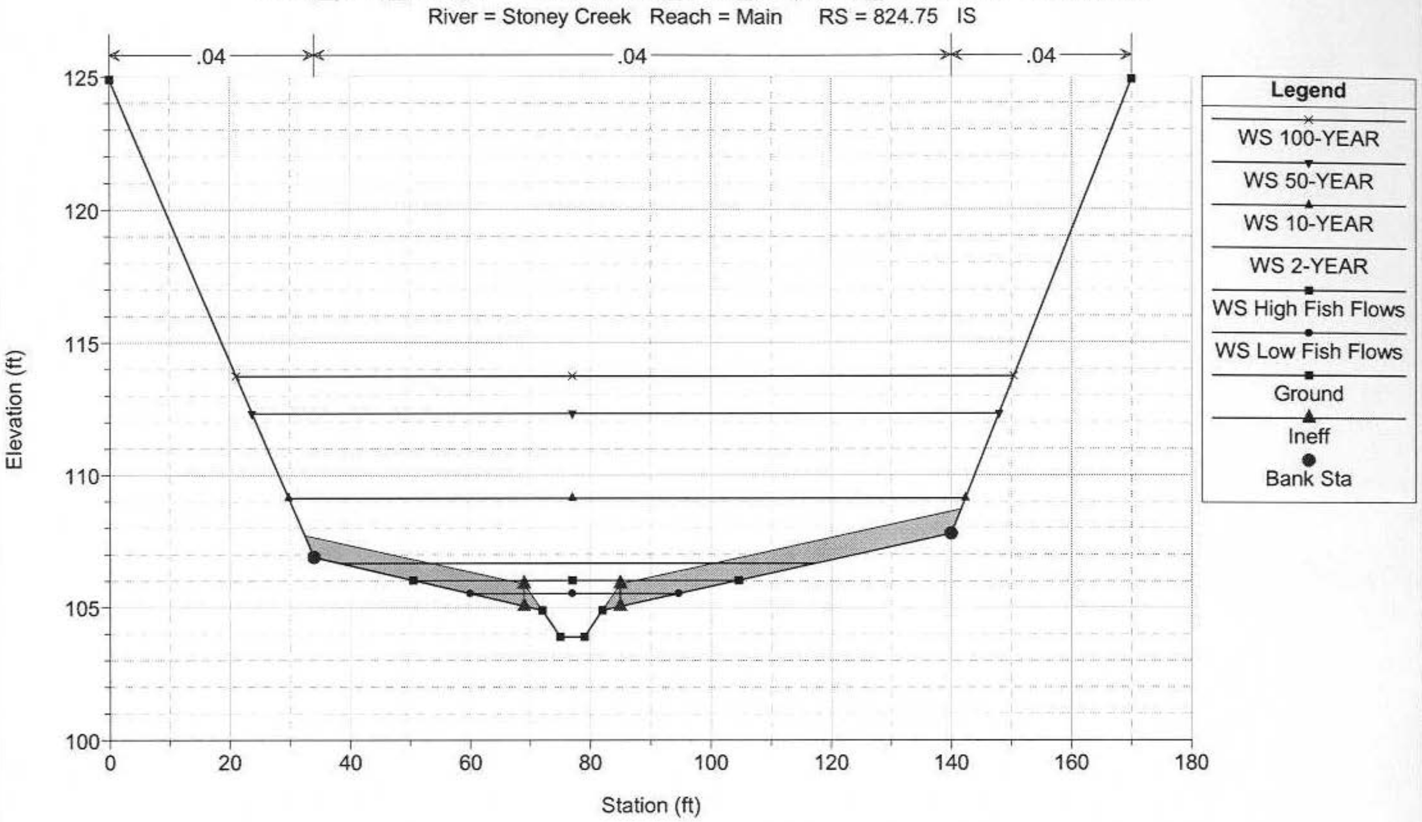

Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 849.75 IS
.04
.04
.04
Elevation (ft)
130
125
120
115
110
105
100
Station (ft)
0
20
40
60
80
100
120
140
160
180
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Ineff
Bank Sta

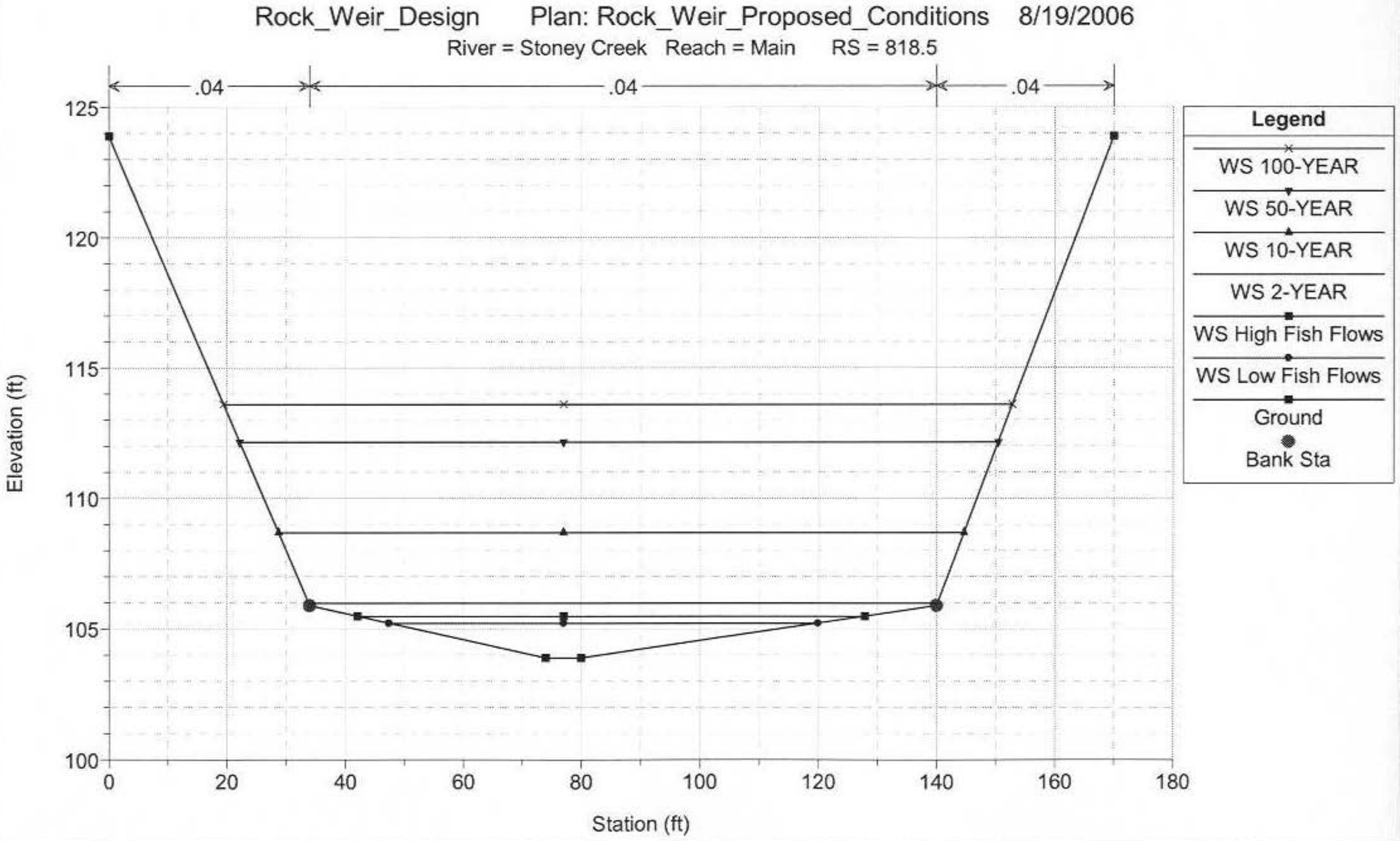

Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 843.5
.04
.04
.04
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Bank Sta
Elevation (ft)
125
120
115
110
105
100
0
20
40
60
80
100
120
140
160
180
Station (ft)


Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 837
.04
.025
.04
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Bank Sta
Elevation (ft)
125
120
115
110
105
100
0
20
40
60
80
100
120
140
160
180
Station (ft)

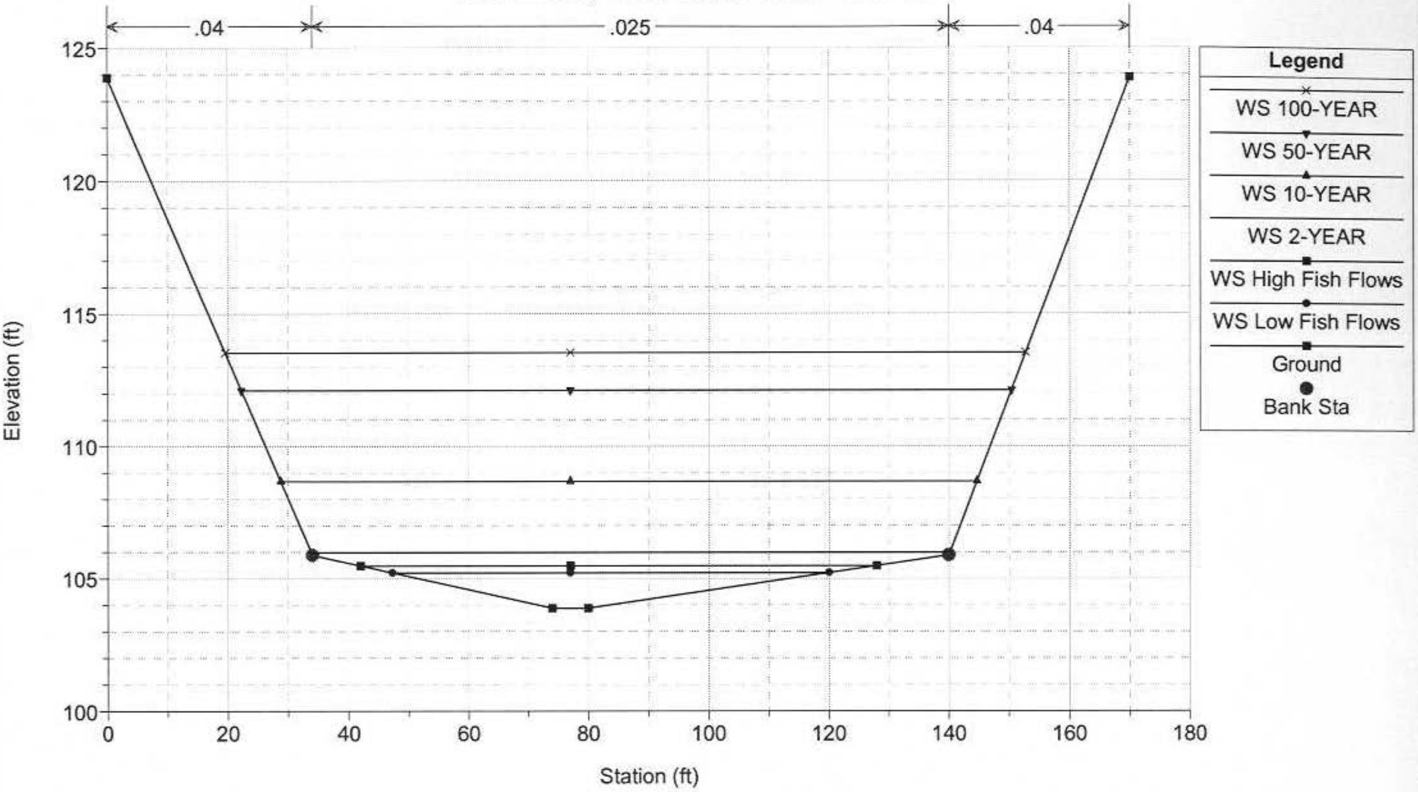

Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 831
.04
.025
.04
Elevation (ft)
125
120
115
110
105
100
Station (ft)
0
20
40
60
80
100
120
140
160
180
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Bank Sta


Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 825
.04
.04
.04
Elevation (ft)
125
120
115
110
105
100
Station (ft)
0
20
40
60
80
100
120
140
160
180
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Ineff
Bank Sta

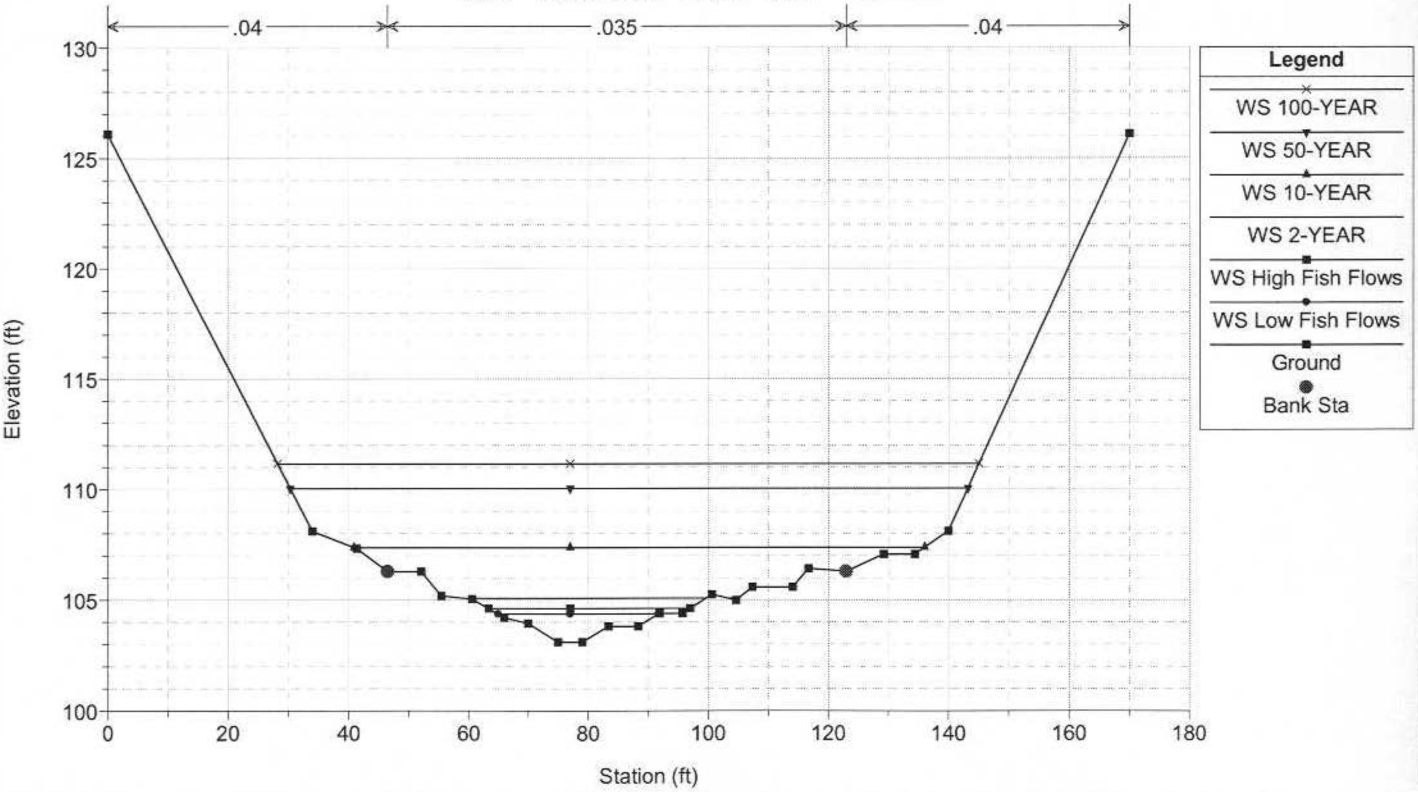

Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 824.75 IS
.04
.04
.04
Elevation (ft)
125
120
115
110
105
100
0
20
40
60
80
100
120
140
160
180
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Ineff
Bank Sta

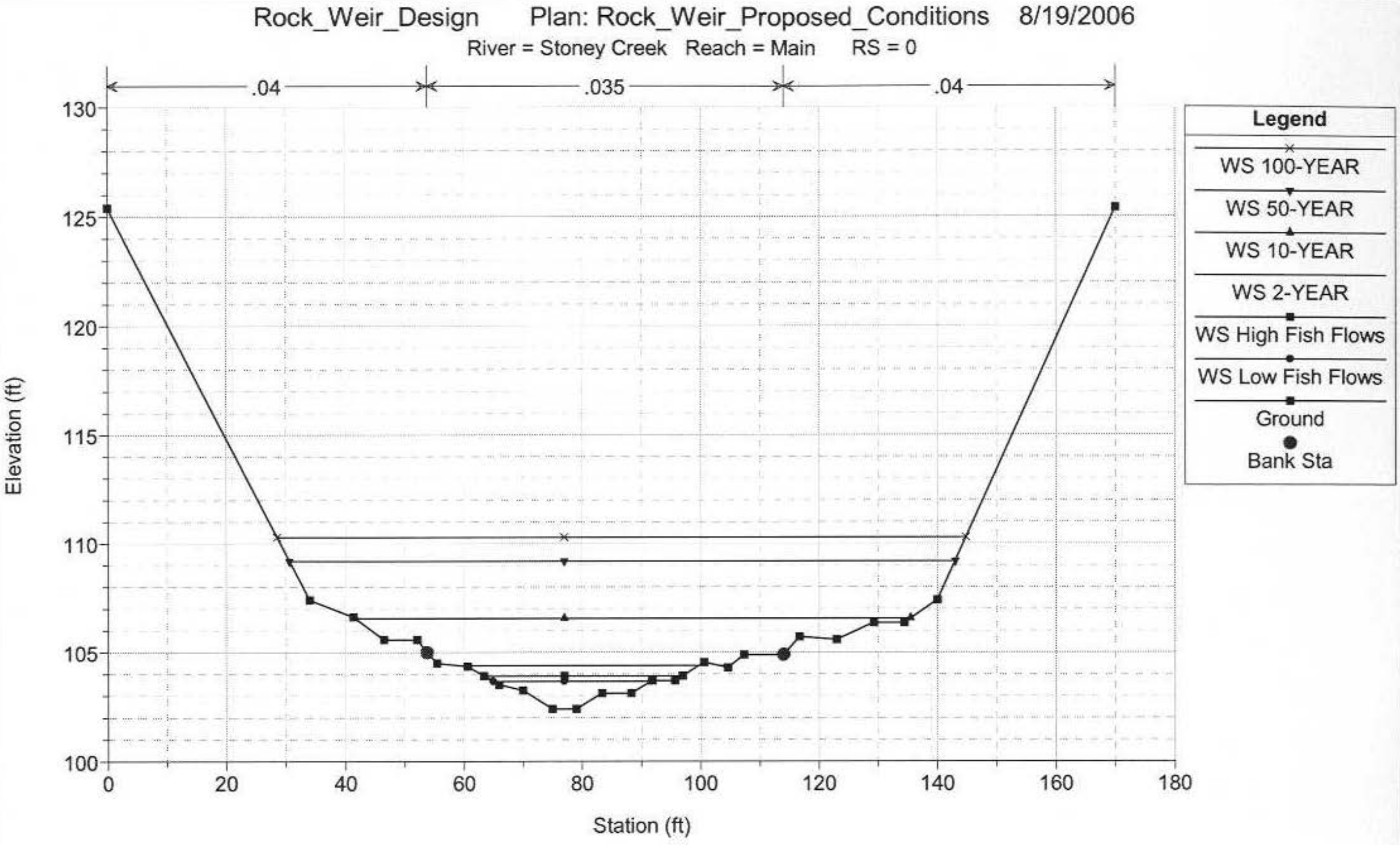

Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 818.5
.04
.04
.04
Elevation (ft)
125
120
115
110
105
100
0
20
40
60
80
100
120
140
160
180
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Bank Sta

Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 810



Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 100




Rock_Weir_Design Plan: Rock_Weir_Proposed_Conditions 8/19/2006
River = Stoney Creek Reach = Main RS = 0
.04
.035
.04
Elevation (ft)
130
125
120
115
110
105
100
Station (ft)
0
20
40
60
80
100
120
140
160
180
Legend
WS 100-YEAR
WS 50-YEAR
WS 10-YEAR
WS 2-YEAR
WS High Fish Flows
WS Low Fish Flows
Ground
Bank Sta

HEC-RAS Plan: Proposed River: Stoney Creek Reach: Main

Reach	River Sta	Profile	Q Total	W.S. Elev	Min Ch El	Diff	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)		(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main	0	2-YEAR	155.00	104.39	102.40	1.99	104.02	104.59	0.007010	3.58	43.28	42.49	0.63
Main	0	10-YEAR	1252.00	106.56	102.40	4.16	106.19	107.30	0.007005	7.04	193.34	93.81	0.74
Main	0	50-YEAR	4460.00	109.19	102.40	6.79	108.84	110.80	0.007005	10.94	472.68	112.37	0.83
Main	0	100-YEAR	6336.00	110.28	102.40	7.88	109.87	112.30	0.007014	12.36	597.68	116.26	0.85
Main	0	High Fish Flows	78.00	103.92	102.40	1.52	103.62	104.06	0.007005	2.99	26.11	33.64	0.60
Main	0	Low Fish Flows	50.00	103.67	102.40	1.27	103.43	103.79	0.007000	2.74	18.27	26.80	0.58
Main	100	2-YEAR	155.00	105.09	103.10	1.99		105.29	0.007001	3.58	43.33	42.55	0.62
Main	100	10-YEAR	1252.00	107.37	103.10	4.27		107.99	0.006554	6.36	203.34	95.13	0.70
Main	100	50-YEAR	4460.00	110.05	103.10	6.95		111.47	0.006181	9.98	489.91	112.92	0.77
Main	100	100-YEAR	6336.00	111.16	103.10	8.06		112.97	0.006173	11.35	617.88	116.88	0.79
Main	100	High Fish Flows	78.00	104.62	103.10	1.52		104.76	0.006991	2.99	26.13	33.65	0.60
Main	100	Low Fish Flows	50.00	104.37	103.10	1.27		104.49	0.007018	2.74	18.25	26.80	0.59
Main	810	2-YEAR	155.00	105.98	103.88	2.10		106.00	0.000374	1.27	122.53	106.35	0.21
Main	810	10-YEAR	1252.00	108.67	103.88	4.79		108.81	0.000434	3.04	421.86	115.93	0.27
Main	810	50-YEAR	4460.00	112.12	103.88	8.24		112.59	0.000629	5.61	842.46	128.18	0.37
Main	810	100-YEAR	6336.00	113.54	103.88	9.66		114.19	0.000692	6.62	1027.64	133.22	0.39
Main	810	High Fish Flows	78.00	105.48	103.88	1.60		105.50	0.000392	1.06	73.57	85.98	0.20
Main	810	Low Fish Flows	50.00	105.22	103.88	1.34		105.23	0.000395	0.95	52.58	72.76	0.20
Main	818.5	2-YEAR	155.00	105.98	103.89	2.09		106.01	0.000972	1.27	121.98	106.33	0.21
Main	818.5	10-YEAR	1252.00	108.68	103.89	4.79		108.82	0.001099	3.02	421.67	115.92	0.27
Main	818.5	50-YEAR	4460.00	112.15	103.89	8.26		112.61	0.001539	5.49	845.76	128.27	0.36
Main	818.5	100-YEAR	6336.00	113.60	103.89	9.71		114.21	0.001662	6.43	1034.60	133.40	0.38
Main	818.5	High Fish Flows	78.00	105.48	103.89	1.59		105.50	0.001019	1.07	73.15	85.74	0.20
Main	818.5	Low Fish Flows	50.00	105.22	103.89	1.33		105.23	0.001030	0.96	52.22	72.51	0.20
Main	824.75		Inl Struct										
Main	825	2-YEAR	155.00	106.67	103.89	2.78	105.89	106.72	0.002076	1.79	86.71	79.48	0.30
Main	825	10-YEAR	1252.00	109.13	103.89	5.24	107.58	109.34	0.002184	3.72	340.16	112.57	0.37
Main	825	50-YEAR	4460.00	112.33	103.89	8.44	109.78	112.95	0.002539	6.40	719.54	124.24	0.45
Main	825	100-YEAR	6336.00	113.75	103.89	9.86	110.77	114.56	0.002557	7.35	899.06	129.40	0.46
Main	825	High Fish Flows	78.00	106.02	103.89	2.13	105.38	106.07	0.003188	1.80	43.35	54.18	0.35
Main	825	Low Fish Flows	50.00	105.52	103.89	1.63	105.15	105.66	0.006322	3.00	16.69	34.74	0.52
Main	831	2-YEAR	155.00	106.70	103.89	2.81		106.73	0.000581	1.50	103.66	96.85	0.25
Main	831	10-YEAR	1252.00	109.18	103.89	5.29		109.36	0.000633	3.40	374.66	114.13	0.32
Main	831	50-YEAR	4460.00	112.39	103.89	8.50		112.97	0.000862	6.16	760.22	125.57	0.42
Main	831	100-YEAR	6336.00	113.80	103.89	9.91		114.58	0.000906	7.18	940.13	130.56	0.45
Main	831	High Fish Flows	78.00	106.06	103.89	2.17		106.09	0.000921	1.52	51.32	65.99	0.30
Main	831	Low Fish Flows	50.00	105.66	103.89	1.77		105.71	0.001625	1.73	28.96	46.99	0.39
Main	837	2-YEAR	155.00	106.71	103.89	2.82		106.74	0.000571	1.48	104.40	97.21	0.25
Main	837	10-YEAR	1252.00	109.19	103.89	5.30		109.36	0.000627	3.39	375.68	114.16	0.32
Main	837	50-YEAR	4460.00	112.41	103.89	8.52		112.98	0.000857	6.15	761.89	125.62	0.42
Main	837	100-YEAR	6336.00	113.81	103.89	9.92		114.59	0.000900	7.16	941.99	130.61	0.44
Main	837	High Fish Flows	78.00	106.07	103.89	2.18		106.10	0.000884	1.50	52.14	66.58	0.30
Main	837	Low Fish Flows	50.00	105.68	103.89	1.79		105.73	0.001485	1.67	30.02	48.06	0.37
Main	843.5	2-YEAR	155.00	106.71	103.89	2.82		106.75	0.001440	1.48	104.97	97.50	0.25
Main	843.5	10-YEAR	1252.00	109.19	103.89	5.30		109.37	0.001578	3.37	376.73	114.19	0.32
Main	843.5	50-YEAR	4460.00	112.45	103.89	8.56		113.00	0.002084	6.02	767.42	125.77	0.41
Main	843.5	100-YEAR	6336.00	113.88	103.89	9.99		114.61	0.002153	6.97	951.37	130.87	0.43
Main	843.5	High Fish Flows	78.00	106.08	103.89	2.19		106.11	0.002196	1.48	52.76	67.03	0.29
Main	843.5	Low Fish Flows	50.00	105.70	103.89	1.81		105.74	0.003564	1.62	30.80	48.84	0.36
Main	849.75		Inl Struct										
Main	850	2-YEAR	155.00	107.68	104.89	2.79	106.89	107.72	0.001991	1.75	88.66	81.44	0.30
Main	850	10-YEAR	1252.00	110.12	104.89	5.23	108.57	110.34	0.002196	3.73	339.65	112.47	0.37
Main	850	50-YEAR	4460.00	113.13	104.89	8.24	110.78	113.80	0.002835	6.62	694.75	123.46	0.47
Main	850	100-YEAR	6336.00	114.47	104.89	9.58	111.77	115.35	0.002896	7.64	863.65	128.35	0.49
Main	850	High Fish Flows	78.00	107.02	104.89	2.13	106.39	107.07	0.003144	1.78	43.86	55.22	0.35
Main	850	Low Fish Flows	50.00	106.52	104.89	1.63	106.15	106.66	0.006303	2.99	16.70	35.38	0.52
Main	856	2-YEAR	155.00	107.70	104.89	2.81		107.74	0.000578	1.49	103.87	96.95	0.25
Main	856	10-YEAR	1252.00	110.17	104.89	5.28		110.35	0.000634	3.41	374.36	114.12	0.32
Main	856	50-YEAR	4460.00	113.21	104.89	8.32		113.82	0.000949	6.35	736.98	124.91	0.44
Main	856	100-YEAR	6336.00	114.54	104.89	9.65		115.37	0.001012	7.42	906.69	129.65	0.47
Main	856	High Fish Flows	78.00	107.05	104.89	2.16		107.09	0.000933	1.53	51.07	65.81	0.31

HEC-RAS Plan: Proposed River: Stoney Creek Reach: Main (Continued)

Reach	River Sta	Profile	Q Total	W.S. Elev	Min Ch El	Diff	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)		(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main	856	Low Fish Flows	50.00	106.66	104.89	1.77		106.71	0.001626	1.73	28.95	46.98	0.39
Main	862	2-YEAR	155.00	107.71	104.89	2.82		107.74	0.000568	1.48	104.60	97.31	0.25
Main	862	10-YEAR	1252.00	110.18	104.89	5.29		110.36	0.000629	3.40	375.38	114.15	0.32
Main	862	50-YEAR	4460.00	113.22	104.89	8.33		113.83	0.000942	6.33	738.85	124.96	0.44
Main	862	100-YEAR	6336.00	114.56	104.89	9.67		115.39	0.001004	7.41	908.82	129.71	0.47
Main	862	High Fish Flows	78.00	107.07	104.89	2.18		107.10	0.000895	1.50	51.90	66.41	0.30
Main	862	Low Fish Flows	50.00	106.68	104.89	1.79		106.73	0.001486	1.67	30.01	48.06	0.37
Main	868.5	2-YEAR	155.00	107.71	104.89	2.82		107.75	0.001433	1.47	105.17	97.59	0.25
Main	868.5	10-YEAR	1252.00	110.19	104.89	5.30		110.37	0.001582	3.37	376.43	114.18	0.32
Main	868.5	50-YEAR	4460.00	113.27	104.89	8.38		113.85	0.002290	6.20	744.72	125.13	0.43
Main	868.5	100-YEAR	6336.00	114.64	104.89	9.75		115.41	0.002398	7.20	918.87	129.98	0.45
Main	868.5	High Fish Flows	78.00	107.07	104.89	2.18		107.11	0.002221	1.49	52.53	66.86	0.30
Main	868.5	Low Fish Flows	50.00	106.70	104.89	1.81		106.74	0.003566	1.62	30.80	48.83	0.36
Main	874.75		Inl Struct										
Main	875	2-YEAR	155.00	108.68	105.89	2.79	107.89	108.72	0.001990	1.75	88.68	81.45	0.30
Main	875	10-YEAR	1252.00	111.09	105.89	5.20	109.56	111.31	0.002220	3.74	338.61	112.61	0.37
Main	875	50-YEAR	4460.00	114.08	105.89	8.19	111.76	114.75	0.002887	6.66	690.99	123.45	0.47
Main	875	100-YEAR	6336.00	115.39	105.89	9.50	112.76	116.28	0.002976	7.70	856.44	128.23	0.50
Main	875	High Fish Flows	78.00	108.02	105.89	2.13	107.39	108.07	0.003145	1.78	43.85	55.21	0.35
Main	875	Low Fish Flows	50.00	107.52	105.89	1.63	107.15	107.66	0.006303	2.99	16.70	35.38	0.52
Main	881	2-YEAR	155.00	108.70	105.89	2.81		108.74	0.000578	1.49	103.89	96.96	0.25
Main	881	10-YEAR	1252.00	111.14	105.89	5.25		111.32	0.000656	3.44	370.56	114.00	0.33
Main	881	50-YEAR	4460.00	114.15	105.89	8.26		114.77	0.000981	6.41	729.35	124.69	0.45
Main	881	100-YEAR	6336.00	115.45	105.89	9.56		116.31	0.001052	7.51	895.21	129.33	0.48
Main	881	High Fish Flows	78.00	108.05	105.89	2.16		108.09	0.000933	1.53	51.06	65.80	0.31
Main	881	Low Fish Flows	50.00	107.66	105.89	1.77		107.71	0.001626	1.73	28.95	46.98	0.39
Main	887	2-YEAR	155.00	108.71	105.89	2.82		108.74	0.000572	1.49	104.27	97.15	0.25
Main	887	10-YEAR	1252.00	111.15	105.89	5.26		111.33	0.000652	3.43	371.10	114.02	0.33
Main	887	50-YEAR	4460.00	114.15	105.89	8.26		114.78	0.000976	6.40	730.34	124.72	0.45
Main	887	100-YEAR	6336.00	115.46	105.89	9.57		116.31	0.001048	7.50	896.36	129.37	0.48
Main	887	High Fish Flows	78.00	108.06	105.89	2.17		108.09	0.000913	1.51	51.49	66.11	0.30
Main	887	Low Fish Flows	50.00	107.67	105.89	1.78		107.72	0.001548	1.69	29.53	47.57	0.38
Main	893.5	2-YEAR	155.00	108.72	105.89	2.83		108.75	0.001427	1.47	105.31	97.66	0.25
Main	893.5	10-YEAR	1252.00	111.16	105.89	5.27		111.34	0.001632	3.41	372.82	114.07	0.32
Main	893.5	50-YEAR	4460.00	114.21	105.89	8.32		114.80	0.002360	6.26	737.61	124.93	0.43
Main	893.5	100-YEAR	6336.00	115.55	105.89	9.66		116.35	0.002487	7.28	908.14	129.69	0.46
Main	893.5	High Fish Flows	78.00	108.08	105.89	2.19		108.11	0.002208	1.48	52.65	66.95	0.29
Main	893.5	Low Fish Flows	50.00	107.70	105.89	1.81		107.74	0.003497	1.61	31.04	49.07	0.36
Main	899.75		Inl Struct										
Main	900	2-YEAR	155.00	109.68	106.89	2.79	108.89	109.72	0.001991	1.75	88.66	81.44	0.30
Main	900	10-YEAR	1252.00	112.12	106.89	5.23	110.57	112.33	0.002208	3.73	339.07	112.46	0.37
Main	900	50-YEAR	4460.00	115.12	106.89	8.23	112.78	115.79	0.002850	6.63	693.56	123.42	0.47
Main	900	100-YEAR	6336.00	116.43	106.89	9.54	113.77	117.32	0.002960	7.69	857.66	128.18	0.50
Main	900	High Fish Flows	78.00	109.02	106.89	2.13	108.39	109.07	0.003144	1.78	43.86	55.22	0.35
Main	900	Low Fish Flows	50.00	108.52	106.89	1.63	108.15	108.66	0.006303	2.99	16.70	35.38	0.52
Main	906	2-YEAR	155.00	109.70	106.89	2.81		109.74	0.000578	1.49	103.87	96.95	0.25
Main	906	10-YEAR	1252.00	112.17	106.89	5.28		112.35	0.000637	3.41	373.81	114.10	0.32
Main	906	50-YEAR	4460.00	115.20	106.89	8.31		115.81	0.000954	6.36	735.85	124.88	0.44
Main	906	100-YEAR	6336.00	116.50	106.89	9.61		117.34	0.001031	7.47	900.95	129.49	0.47
Main	906	High Fish Flows	78.00	109.05	106.89	2.16		109.09	0.000933	1.53	51.07	65.81	0.31
Main	906	Low Fish Flows	50.00	108.66	106.89	1.77		108.71	0.001626	1.73	28.95	46.98	0.39
Main	912	2-YEAR	155.00	109.71	106.89	2.82		109.74	0.000568	1.48	104.60	97.31	0.25
Main	912	10-YEAR	1252.00	112.18	106.89	5.29		112.36	0.000632	3.40	374.83	114.13	0.32
Main	912	50-YEAR	4460.00	115.21	106.89	8.32		115.83	0.000946	6.34	737.73	124.93	0.44
Main	912	100-YEAR	6336.00	116.51	106.89	9.62		117.35	0.001024	7.45	903.13	129.55	0.47
Main	912	High Fish Flows	78.00	109.07	106.89	2.18		109.10	0.000895	1.50	51.90	66.41	0.30
Main	912	Low Fish Flows	50.00	108.68	106.89	1.79		108.73	0.001486	1.67	30.01	48.06	0.37
Main	918.5	2-YEAR	155.00	109.71	106.89	2.82		109.75	0.001433	1.47	105.17	97.59	0.25
Main	918.5	10-YEAR	1252.00	112.19	106.89	5.30		112.36	0.001590	3.38	375.89	114.17	0.32
Main	918.5	50-YEAR	4460.00	115.26	106.89	8.37		115.84	0.002300	6.21	743.62	125.10	0.43

HEC-RAS Plan: Proposed River: Stoney Creek Reach: Main (Continued)

Reach	River Sta	Profile	Q Total	W.S. Elev	Min Ch El	Diff	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)		(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main	918.5	100-YEAR	6336.00	116.59	106.89	9.70		117.38	0.002444	7.24	913.32	129.83	0.46
Main	918.5	High Fish Flows	78.00	109.07	106.89	2.18		109.11	0.002221	1.48	52.53	66.86	0.30
Main	918.5	Low Fish Flows	50.00	108.70	106.89	1.81		108.74	0.003566	1.62	30.80	48.83	0.36
Main	924.75		Inl Struct										
Main	925	2-YEAR	155.00	111.22	108.89	2.33	110.05	111.24	0.000829	1.28	121.27	93.15	0.20
Main	925	10-YEAR	1252.00	113.44	108.89	4.55	111.73	113.63	0.001806	3.51	360.77	113.56	0.34
Main	925	50-YEAR	4460.00	116.41	108.89	7.52	113.92	117.04	0.002601	6.45	714.22	124.41	0.45
Main	925	100-YEAR	6336.00	117.70	108.89	8.81	114.91	118.55	0.002757	7.52	877.67	129.12	0.48
Main	925	High Fish Flows	78.00	110.74	108.89	1.85	109.89	110.76	0.000699	0.98	79.72	80.08	0.17
Main	925	Low Fish Flows	50.00	110.48	108.89	1.59	109.83	110.49	0.000603	0.83	60.38	69.76	0.16
Main	1006		Bridge										
Main	1007	2-YEAR	155.00	111.76	109.46	2.30	110.63	111.78	0.000066	1.17	132.68	107.06	0.18
Main	1007	10-YEAR	1252.00	113.95	109.46	4.49	112.13	114.12	0.000145	3.39	375.58	114.84	0.32
Main	1007	50-YEAR	4460.00	116.98	109.46	7.52	114.28	117.57	0.000211	6.24	740.77	125.64	0.43
Main	1007	100-YEAR	6336.00	118.30	109.46	8.84	115.28	119.10	0.000225	7.28	909.41	130.33	0.46
Main	1007	High Fish Flows	78.00	111.31	109.46	1.85	110.34	111.32	0.000054	0.90	86.97	88.32	0.16
Main	1007	Low Fish Flows	50.00	111.07	109.46	1.61	110.16	111.08	0.000049	0.75	66.31	81.42	0.15
Main	1020	2-YEAR	155.00	111.76	109.55	2.21	110.72	111.78	0.000731	1.26	123.08	106.71	0.21
Main	1020	10-YEAR	1252.00	113.95	109.55	4.40		114.13	0.001361	3.45	365.96	116.13	0.33
Main	1020	50-YEAR	4460.00	116.99	109.55	7.44		117.58	0.001864	6.24	738.81	127.28	0.44
Main	1020	100-YEAR	6336.00	118.31	109.55	8.76		119.10	0.001963	7.26	908.78	130.47	0.46
Main	1020	High Fish Flows	78.00	111.31	109.55	1.76	110.43	111.33	0.000609	0.99	79.17	86.58	0.18
Main	1020	Low Fish Flows	50.00	111.07	109.55	1.52	110.25	111.08	0.000555	0.84	59.27	76.27	0.17
Main	1200	2-YEAR	155.00	111.95	110.81	1.14	111.95	112.28	0.021392	4.61	33.65	52.48	1.01
Main	1200	10-YEAR	1252.00	114.21	110.81	3.40		114.59	0.004247	4.92	257.41	113.07	0.56
Main	1200	50-YEAR	4460.00	117.24	110.81	6.43		118.09	0.003300	7.50	616.10	122.27	0.57
Main	1200	100-YEAR	6336.00	118.55	110.81	7.74		119.64	0.003193	8.52	777.59	126.49	0.58
Main	1200	High Fish Flows	78.00	111.65	110.81	0.84	111.65	111.89	0.022858	4.00	19.51	39.52	1.00
Main	1200	Low Fish Flows	50.00	111.51	110.81	0.70	111.51	111.70	0.025489	3.54	14.14	37.37	1.01
Main	1500	2-YEAR	155.00	114.45	112.90	1.55		114.52	0.003712	2.21	70.05	88.17	0.44
Main	1500	10-YEAR	1252.00	115.81	112.90	2.91		116.36	0.008178	6.00	209.73	109.71	0.76
Main	1500	50-YEAR	4460.00	118.28	112.90	5.38		119.59	0.006588	9.28	494.44	120.60	0.78
Main	1500	100-YEAR	6336.00	119.46	112.90	6.56		121.06	0.005918	10.29	639.95	125.71	0.77
Main	1500	High Fish Flows	78.00	114.08	112.90	1.18	113.67	114.13	0.003590	1.90	41.12	63.61	0.42
Main	1500	Low Fish Flows	50.00	113.90	112.90	1.00		113.94	0.003460	1.64	30.42	56.75	0.40
Main	2000	2-YEAR	155.00	117.59	116.40	1.19	117.49	117.78	0.013920	3.47	44.69	77.32	0.80
Main	2000	10-YEAR	1252.00	119.41	116.40	3.01	118.96	119.92	0.006228	5.89	226.22	110.99	0.68
Main	2000	50-YEAR	4460.00	121.66	116.40	5.26	121.16	123.06	0.007212	9.94	487.66	120.41	0.82
Main	2000	100-YEAR	6336.00	122.60	116.40	6.20	122.15	124.46	0.007510	11.49	602.53	123.17	0.86
Main	2000	High Fish Flows	78.00	117.28	116.40	0.88	117.17	117.44	0.015566	3.24	24.11	50.30	0.82
Main	2000	Low Fish Flows	50.00	117.10	116.40	0.70	117.05	117.25	0.016780	3.04	16.46	39.89	0.83

Plan: Proposed Stoney Creek Main RS: 1006 Profile: High Fish Flows

E.G. US. (ft)	111.32	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	111.31	E.G. Elev (ft)	111.32	110.76
Q Total (cfs)	78.00	W.S. Elev (ft)	111.31	110.74
Q Bridge (cfs)	78.00	Crit W.S. (ft)	110.33	109.89
Q Weir (cfs)		Max Chl Dpth (ft)	1.85	1.85
Weir Sta Lft (ft)		Vel Total (ft/s)	1.01	1.11
Weir Sta Rgt (ft)		Flow Area (sq ft)	77.35	70.44
Weir Submerg		Froude # Chl	0.18	0.19
Weir Max Depth (ft)		Specif Force (cu ft)	52.53	51.57
Min El Weir Flow (ft)	129.38	Hydr Depth (ft)	1.02	1.04
Min El Prs (ft)	121.37	W.P. Total (ft)	78.98	71.01
Delta EG (ft)	0.57	Conv. Total (cfs)	9444.8	2602.7
Delta WS (ft)	0.57	Top Width (ft)	76.02	67.93
BR Open Area (sq ft)	1221.40	Frctn Loss (ft)		
BR Open Vel (ft/s)	1.11	C & E Loss (ft)		
Coef of Q		Shear Total (lb/sq ft)	0.00	0.06
Br Sel Method	Momentum	Power Total (lb/ft s)	0.00	0.06

Plan: Proposed Stoney Creek Main RS: 1006 Profile: Low Fish Flows

E.G. US. (ft)	111.08	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	111.07	E.G. Elev (ft)	111.08	110.50
Q Total (cfs)	50.00	W.S. Elev (ft)	111.07	110.48
Q Bridge (cfs)	50.00	Crit W.S. (ft)	110.16	109.83
Q Weir (cfs)		Max Chl Dpth (ft)	1.61	1.59
Weir Sta Lft (ft)		Vel Total (ft/s)	0.84	0.92
Weir Sta Rgt (ft)		Flow Area (sq ft)	59.51	54.34
Weir Submerg		Froude # Chl	0.16	0.17
Weir Max Depth (ft)		Specif Force (cu ft)	35.03	34.38
Min El Weir Flow (ft)	129.38	Hydr Depth (ft)	0.84	0.94
Min El Prs (ft)	121.37	W.P. Total (ft)	73.00	59.72
Delta EG (ft)	0.58	Conv. Total (cfs)	6431.6	1895.8
Delta WS (ft)	0.59	Top Width (ft)	70.77	57.68
BR Open Area (sq ft)	1221.40	Frctn Loss (ft)		
BR Open Vel (ft/s)	0.92	C & E Loss (ft)		
Coef of Q		Shear Total (lb/sq ft)	0.00	0.04
Br Sel Method	Momentum	Power Total (lb/ft s)	0.00	0.04

Errors Warnings and Notes

Note:	Multiple critical depths were found at this location. The critical depth with the lowest, valid, energy was used.

Plan: Proposed Stoney Creek Main RS: 924.75 Inl Struct: Profile: High Fish Flows

E.G. Elev (ft)	110.76	Q Gates (cfs)	
W.S. Elev (ft)	110.74	Q Gate Group (cfs)	0.00
Q Total (cfs)	78.00	Gate Open Ht (ft)	0.00
Q Weir (cfs)	78.00	Gate #Open	0
Weir Flow Area (sq ft)	30.33	Gate Area (sq ft)	0.00
Weir Sta Lft (ft)	55.13	Gate Submerg	
Weir Sta Rgt (ft)	98.95	Gate Invert (ft)	
Weir Max Depth (ft)	1.87		
Weir Avg Depth (ft)	0.69		
Weir Submerg	0.03		
Min El Weir Flow (ft)	108.90		
Wr Top Wdth (ft)	43.82		

Plan: Proposed Stoney Creek Main RS: 924.75 Inl Struct: Profile: Low Fish Flows

E.G. Elev (ft)	110.49	Q Gates (cfs)	
W.S. Elev (ft)	110.48	Q Gate Group (cfs)	0.00
Q Total (cfs)	50.00	Gate Open Ht (ft)	0.00
Q Weir (cfs)	50.00	Gate #Open	0
Weir Flow Area (sq ft)	20.18	Gate Area (sq ft)	0.00
Weir Sta Lft (ft)	60.24	Gate Submerg	
Weir Sta Rgt (ft)	93.82	Gate Invert (ft)	
Weir Max Depth (ft)	1.60		
Weir Avg Depth (ft)	0.60		
Weir Submerg	0.00		
Min El Weir Flow (ft)	108.90		
Wr Top Wdth (ft)	33.59		

Errors Warnings and Notes

Note:	Multiple critical depths were found at this location. The critical depth with the lowest, valid, energy was used.

Plan: Proposed Stoney Creek Main RS: 899.75 Inl Struct: Profile: High Fish Flows

E.G. Elev (ft)	109.07	Q Gates (cfs)	
W.S. Elev (ft)	109.02	Q Gate Group (cfs)	0.00
Q Total (cfs)	78.00	Gate Open Ht (ft)	0.00
Q Weir (cfs)	78.00	Gate #Open	0
Weir Flow Area (sq ft)	23.52	Gate Area (sq ft)	0.00
Weir Sta Lft (ft)	87.41	Gate Submerg	
Weir Sta Rgt (ft)	110.59	Gate Invert (ft)	
Weir Max Depth (ft)	2.18		
Weir Avg Depth (ft)	1.01		
Weir Submerg	0.42		
Min El Weir Flow (ft)	106.90		

Plan: Proposed Stoney Creek Main RS: 899.75 Inl Struct: Profile: High Fish Flows (Continued)

Wr Top Wdth (ft)	23.18		

Errors Warnings and Notes

Note:	Multiple critical depths were found at this location. The critical depth with the lowest, valid,
	energy was used.

Plan: Proposed Stoney Creek Main RS: 899.75 Inl Struct: Profile: Low Fish Flows

E.G. Elev (ft)	108.66	Q Gates (cfs)	
W.S. Elev (ft)	108.52	Q Gate Group (cfs)	0.00
Q Total (cfs)	50.00	Gate Open Ht (ft)	0.00
Q Weir (cfs)	50.00	Gate #Open	0
Weir Flow Area (sq ft)	16.53	Gate Area (sq ft)	0.00
Weir Sta Lft (ft)	91.68	Gate Submerg	
Weir Sta Rgt (ft)	106.32	Gate Invert (ft)	
Weir Max Depth (ft)	1.77		
Weir Avg Depth (ft)	1.13		
Weir Submerg	0.34		
Min El Weir Flow (ft)	106.90		
Wr Top Wdth (ft)	14.64		

Errors Warnings and Notes

Warning:	The inline structure solution failed to converge. The program used the solution with the least
	error.
Note:	Multiple critical depths were found at this location. The critical depth with the lowest, valid,
	energy was used.

Plan: Proposed Stoney Creek Main RS: 874.75 Inl Struct: Profile: High Fish Flows

E.G. Elev (ft)	108.07	Q Gates (cfs)	
W.S. Elev (ft)	108.02	Q Gate Group (cfs)	0.00
Q Total (cfs)	78.00	Gate Open Ht (ft)	0.00
Q Weir (cfs)	78.00	Gate #Open	0
Weir Flow Area (sq ft)	23.52	Gate Area (sq ft)	0.00
Weir Sta Lft (ft)	65.41	Gate Submerg	
Weir Sta Rgt (ft)	88.67	Gate Invert (ft)	
Weir Max Depth (ft)	2.18		
Weir Avg Depth (ft)	1.01		
Weir Submerg	0.42		
Min El Weir Flow (ft)	105.90		
Wr Top Wdth (ft)	23.26		

Errors Warnings and Notes

Note:	Multiple critical depths were found at this location. The critical depth with the lowest, valid,
	energy was used.

Plan: Proposed Stoney Creek Main RS: 874.75 Inl Struct: Profile: Low Fish Flows

E.G. Elev (ft)	107.66	Q Gates (cfs)	
W.S. Elev (ft)	107.52	Q Gate Group (cfs)	0.00
Q Total (cfs)	50.00	Gate Open Ht (ft)	0.00
Q Weir (cfs)	50.00	Gate #Open	0
Weir Flow Area (sq ft)	16.53	Gate Area (sq ft)	0.00
Weir Sta Lft (ft)	69.68	Gate Submerg	
Weir Sta Rgt (ft)	84.32	Gate Invert (ft)	
Weir Max Depth (ft)	1.77		
Weir Avg Depth (ft)	1.13		
Weir Submerg	0.33		
Min El Weir Flow (ft)	105.90		
Wr Top Wdth (ft)	14.64		

Errors Warnings and Notes

Warning:	The inline structure solution failed to converge. The program used the solution with the least
	error.
Note:	Multiple critical depths were found at this location. The critical depth with the lowest, valid,
	energy was used.

Plan: Proposed Stoney Creek Main RS: 849.75 Inl Struct: Profile: High Fish Flows

E.G. Elev (ft)	107.07	Q Gates (cfs)	
W.S. Elev (ft)	107.02	Q Gate Group (cfs)	0.00
Q Total (cfs)	78.00	Gate Open Ht (ft)	0.00
Q Weir (cfs)	78.00	Gate #Open	0
Weir Flow Area (sq ft)	23.52	Gate Area (sq ft)	0.00
Weir Sta Lft (ft)	87.41	Gate Submerg	
Weir Sta Rgt (ft)	110.59	Gate Invert (ft)	
Weir Max Depth (ft)	2.18		
Weir Avg Depth (ft)	1.01		
Weir Submerg	0.42		
Min El Weir Flow (ft)	104.90		
Wr Top Wdth (ft)	23.18		

Errors Warnings and Notes

Note:	Multiple critical depths were found at this location. The critical depth with the lowest, valid,
	energy was used.

Plan: Proposed Stoney Creek Main RS: 849.75 Inl Struct: Profile: Low Fish Flows

E.G. Elev (ft)	106.66	Q Gates (cfs)	
W.S. Elev (ft)	106.52	Q Gate Group (cfs)	0.00
Q Total (cfs)	50.00	Gate Open Ht (ft)	0.00
Q Weir (cfs)	50.00	Gate #Open	0
Weir Flow Area (sq ft)	16.53	Gate Area (sq ft)	0.00

Plan: Proposed Stoney Creek Main RS: 849.75 Inl Struct: Profile: Low Fish Flows (Continued)

Weir Sta Lft (ft)	91.68	Gate Submerg	
Weir Sta Rgt (ft)	106.32	Gate Invert (ft)	
Weir Max Depth (ft)	1.77		
Weir Avg Depth (ft)	1.13		
Weir Submerg	0.33		
Min El Weir Flow (ft)	104.90		
Wr Top Wdth (ft)	14.64		

Errors Warnings and Notes

Warning:	The inline structure solution failed to converge. The program used the solution with the least
	error.
Note:	Multiple critical depths were found at this location. The critical depth with the lowest, valid,
	energy was used.

Plan: Proposed Stoney Creek Main RS: 824.75 Inl Struct: Profile: High Fish Flows

E.G. Elev (ft)	106.07	Q Gates (cfs)	
W.S. Elev (ft)	106.02	Q Gate Group (cfs)	0.00
Q Total (cfs)	78.00	Gate Open Ht (ft)	0.00
Q Weir (cfs)	78.00	Gate #Open	0
Weir Flow Area (sq ft)	23.60	Gate Area (sq ft)	0.00
Weir Sta Lft (ft)	65.34	Gate Submerg	
Weir Sta Rgt (ft)	88.66	Gate Invert (ft)	
Weir Max Depth (ft)	2.18		
Weir Avg Depth (ft)	1.01		
Weir Submerg	0.62		
Min El Weir Flow (ft)	103.90		
Wr Top Wdth (ft)	23.32		

Errors Warnings and Notes

Note:	Multiple critical depths were found at this location. The critical depth with the lowest, valid,
	energy was used.

Plan: Proposed Stoney Creek Main RS: 824.75 Inl Struct: Profile: Low Fish Flows

E.G. Elev (ft)	105.66	Q Gates (cfs)	
W.S. Elev (ft)	105.52	Q Gate Group (cfs)	0.00
Q Total (cfs)	50.00	Gate Open Ht (ft)	0.00
Q Weir (cfs)	50.00	Gate #Open	0
Weir Flow Area (sq ft)	16.53	Gate Area (sq ft)	0.00
Weir Sta Lft (ft)	69.68	Gate Submerg	
Weir Sta Rgt (ft)	84.32	Gate Invert (ft)	
Weir Max Depth (ft)	1.77		
Weir Avg Depth (ft)	1.13		
Weir Submerg	0.66		

Plan: Proposed Stoney Creek Main RS: 824.75 Inl Struct: Profile: Low Fish Flows (Continued)

Min El Weir Flow (ft)	103.90		
Wr Top Wdth (ft)	14.64		

Errors Warnings and Notes

Warning:	The inline structure solution failed to converge. The program used the solution with the least error.
Note:	Multiple critical depths were found at this location. The critical depth with the lowest, valid, energy was used.

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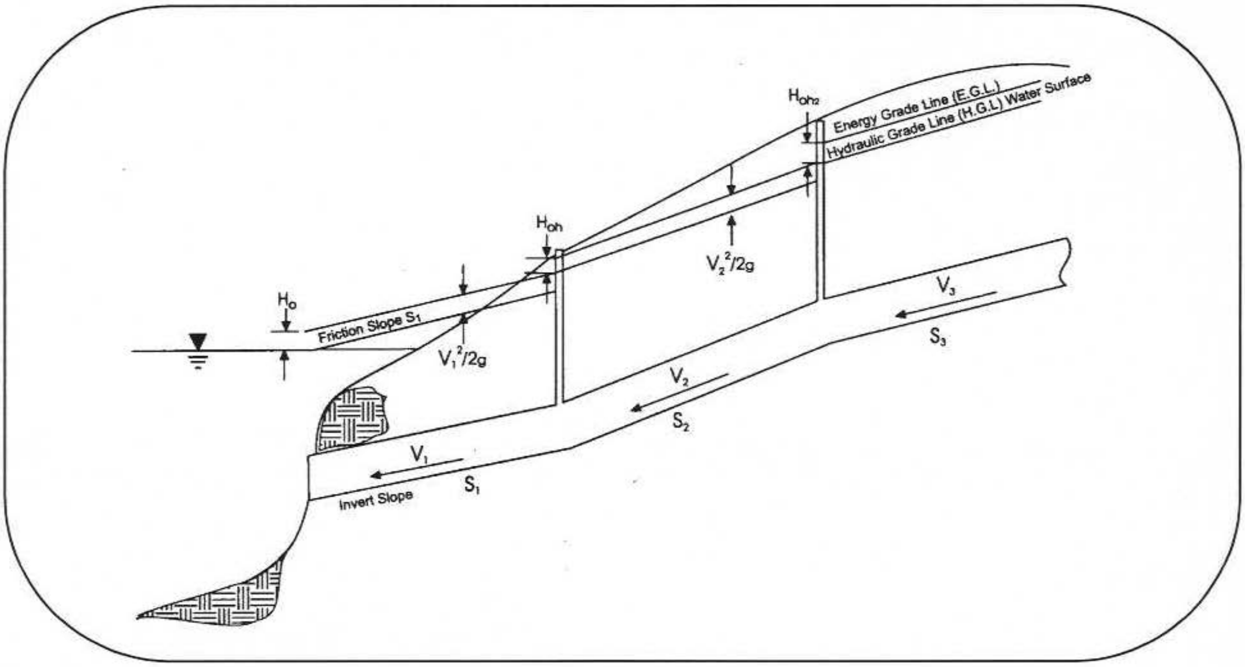
URBAN DRAINAGE DESIGN MANUAL



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Stage Discharge Tabulation for only orifice Flow

DEPTH		*STAGE*		*DISCHARGE*	
(meters)	*(feet)*	*(meters)*	*(feet)*	*(m^3/s)*	*(ft^3/s)*
0.00	0.0	10.0	32.8	0.000	0.00
0.20	0.7	10.2	33.5	0.017	0.61
0.40	1.3	10.4	34.1	0.027	0.93
0.60	2.0	10.6	34.8	0.034	1.20
0.80	2.6	10.8	35.4	0.040	1.39
1.00	3.3	11.0	36.1	0.045	1.59
1.20	3.9	11.2	36.7	0.050	1.74
1.40	4.6	11.4	37.4	0.054	1.89
1.60	5.2	11.6	38.0	0.058	2.02
1.80	5.9	11.8	38.7	0.062	2.16
2.00	6.6	12.0	39.4	0.065	2.29

8.4.4.2 Weirs

Relationships for sharp-crested, broad-crested, V-notch, and proportional weirs are provided in the following sections:

Sharp Crested Weirs

Typical sharp crested weirs are illustrated in figure 8-13. Equation 8-19 provides the discharge relationship for **sharp crested weirs** with no end contractions (illustrated in figure 8-13a).

$$Q = C_{scw} \, L \, H^{1.5} \qquad (8\text{-}19)$$

where:

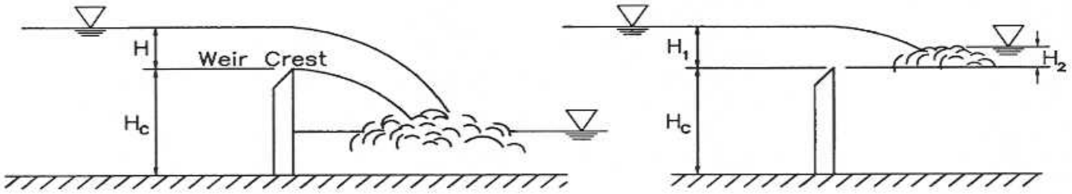
Q = discharge, m^3/s (ft^3/s)
L = horizontal weir length, m (ft)
H = head above weir crest excluding velocity head, m (ft)
C_{SCW} = 1.81 + 0.22 (H/H_c) [3.27 + 0.4 (H/H_c) in English units]

As indicated above, the value of the coefficient C_{SCW} is known to vary with the ratio H/H_c (see figure 8-13c for definition of terms). For values of the ratio H/H_c less than 0.3, a constant C_{SCW} of 1.84 (3.33 in english units) is often used.

Equation 8-20 provides the discharge equation for **sharp-crested weirs with end contractions** (illustrated in figure 8-13(b)). As indicated above, the value of the coefficient C_{scw} is known to vary with the ratio H/H_c (see figure 8-13c for definition of terms). For values of the ratio H/H_c less than 0.3, a constant C_{scw} of 1.84 (3.33 in English units) is often used.

$$Q = C_{SCW} \, (L - 0.2\, H) \, H^{1.5} \qquad (8\text{-}20)$$

a. No end contractions b. With end contractions



c. Section d. Section

Figure 8-13. Sharp crested weirs.

Sharp crested weirs will be effected by submergence when the tailwater rises above the weir crest elevation, as shown in figure 8-13(d). The result will be that the discharge over the weir will be reduced. The discharge equation for a **submerged sharp-crested weir** is:(49)

$$Q_s = Q_r\, (1 - (H_2/H_1)^{1.5})^{0.385} \qquad (8\text{-}21)$$

where:

Q_s = submerged Flow, m^3/s (ft^3/s)
Q_r = unsubmerged weir Flow from equation 8-19 or 8-20, m^3/s (ft^3/s)
H_1 = upstream head above crest, m (ft)
H_2 = downstream head above crest, m (ft)

Flow over the top edge of a riser pipe is typically treated as Flow over a sharp crested weir with no end constrictions. Equation 8-19 should be used for this case.

Example 8-6

Given: *A riser pipe as shown in figure 8-14 with the following characteristics:*

diameter (D) = 0.53 m (1.74 ft)
crest elevation = 10.8 m (35.4 ft)
weir height (H_c) = 0.8 m (2.6 ft)

Find: *Stage - discharge rating for the riser pipe between 10 m (32.8 ft) and 12.0 m (39.4 ft).*

The resulting stage - discharge relationship is summarized in the following table:

STAGE		*EFFECTIVE HEAD*		*ORIFICE FLOW*		*WEIR FLOW*	
(m)	*(ft)*	*(m)*	*(ft)*	*(m^3/s)*	*(ft^3/s)*	*(m^3/s)*	*(ft^3/s)*
10.0	*32.80*	*0.0*	*0.0*	*0.00*	*0.0*	*0.00*	*0.0*
10.8	*35.43*	*0.0*	*0.0*	*0.00*	*0.0*	*0.00*	*0.0*
10.9	*35.76*	*0.1*	*0.33*	*0.19*	*6.6*	*0.10**	*3.5**
11.0	*36.09*	*0.2*	*0.66*	*0.26**	*9.2**	*0.27*	*9.8*
11.2	*36.74*	*0.4*	*1.31*	*0.37**	*13.1**	*0.78*	*27.5*
11.4	*37.40*	*0.6*	*1.97*	*0.45**	*15.9**	*1.43*	*50.6*
11.6	*38.06*	*0.8*	*2.63*	*0.53**	*18.7**	*2.20*	*77.7*
11.8	*38.71*	*1.0*	*3.28*	*0.59**	*20.8**	*3.07*	*108.8*
12.0	*39.37*	*1.2*	*3.94*	*0.64**	*22.6**	*4.04*	*143.2*

**Designates controlling Flow.*

The Flow condition, orifice or weir, producing the lowest discharge for a given stage defines the controlling relationship. As illustrated in the above table, at a stage of 10.9 m (35.76 ft) weir Flow controls the discharge through the riser. However, at and above a stage of 11.0 m (36.09 ft), orifice Flow controls the discharge through the riser.

Broad-Crested Weir

The equation typically used for a broad-crested weir is:(49)

$$Q = C_{BCW}\ L\ H^{1.5} \tag{8-22}$$

where:

Q = discharge, m^3/s (ft^3/s)
$C_{BC\,W}$ = broad-crested weir coefficient, 1.35 - 1.83 (2.34 to 3.32)
L = broad-crested weir length, m (ft)
H = head above weir crest, m (ft)

If the upstream edge of a broad-crested weir is so rounded as to prevent contraction and if the slope of the crest is as great as the loss of head due to friction, Flow will pass through critical depth at the weir crest; this gives the maximum C value of 1.70. For sharp corners on the broad crested weir, a minimum value of 1.44 should be used. Additional information on C values as a function of weir crest breadth and head is given in table 8-1.

Table 8-1. SI Units - Broad-Crested Weir Coefficient C Values as a Function of Weir Crest.

Broad-Crested Weir Coefficient C Values as a Function of Weir Crest Breadth and Head (coefficient has units of $m^{0.5}/sec$).(1)

Head(2)	Breadth of Crest of Weir (m)														
(m)	0.15	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.25	1.50	2.00	3.00	4.00
0.10	1.59	1.56	1.50	1.47	1.45	1.43	1.42	1.41	1.40	1.39	1.37	1.35	1.36	1.40	1.45
0.15	1.65	1.60	1.51	1.48	1.45	1.44	1.44	1.44	1.45	1.45	1.44	1.43	1.44	1.45	1.47
0.20	1.73	1.66	1.54	1.49	1.46	1.44	1.44	1.45	1.47	1.48	1.48	1.49	1.49	1.49	1.48
0.30	1.83	1.77	1.64	1.56	1.50	1.47	1.46	1.46	1.46	1.47	1.47	1.48	1.48	1.48	1.46
0.40	1.83	1.80	1.74	1.65	1.57	1.52	1.49	1.47	1.46	1.46	1.47	1.47	1.47	1.48	1.47
0.50	1.83	1.82	1.81	1.74	1.67	1.60	1.55	1.51	1.48	1.48	1.47	1.46	1.46	1.46	1.45
0.60	1.83	1.83	1.82	1.73	1.65	1.58	1.54	1.46	1.31	1.34	1.48	1.46	1.46	1.46	1.45
0.70	1.83	1.83	1.83	1.78	1.72	1.65	1.60	1.53	1.44	1.45	1.49	1.47	1.47	1.46	1.45
0.80	1.83	1.83	1.83	1.82	1.79	1.72	1.66	1.60	1.57	1.55	1.50	1.47	1.47	1.46	1.45
0.90	1.83	1.83	1.83	1.83	1.81	1.76	1.71	1.66	1.61	1.58	1.50	1.47	1.47	1.46	1.45
1.00	1.83	1.83	1.83	1.83	1.82	1.81	1.76	1.70	1.64	1.60	1.51	1.48	1.47	1.46	1.45
1.10	1.83	1.83	1.83	1.83	1.83	1.83	1.80	1.75	1.66	1.62	1.52	1.49	1.47	1.46	1.45
1.20	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.79	1.70	1.65	1.53	1.49	1.48	1.46	1.45
1.30	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.82	1.77	1.71	1.56	1.51	1.49	1.46	1.45
1.40	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.77	1.60	1.52	1.50	1.46	1.45
1.50	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.79	1.66	1.55	1.51	1.46	1.45
1.60	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.81	1.74	1.58	1.53	1.46	1.45

(1) Modified from reference 49

(2) Measured at le **a** st 2.5 H_c upstream of the weir

Table 8-1. English Units - Broad-Crested Weir Coefficient C Values as a Function of Weir Crest.

Broad-Crested Weir Coefficient C Values as a Function of Weir Crest Breadth and Head (coefficient has units of $ft^{0.5}/sec$).(1)

Head(2)	Breadth of Crest of Weir (ft)										
(ft)	0.50	0.75	1.00	1.5	2.0	2.50	3.00	4.00	5.00	10.00	15.00
0.2	2.80	2.75	2.69	2.62	2.54	2.48	2.44	2.38	2.34	2.49	2.68
0.4	2.92	2.80	2.72	2.64	2.61	2.60	2.58	2.54	2.50	2.56	2.70
0.6	3.08	2.89	2.75	2.64	2.61	2.60	2.68	2.69	2.70	2.70	2.70
0.8	3.30	3.04	2.85	2.68	2.60	2.60	2.67	2.68	2.68	2.69	2.64
1.0	3.32	3.14	2.98	2.75	2.66	2.64	2.65	2.67	2.68	2.68	2.63
1.2	3.32	3.20	3.08	2.86	2.70	2.65	2.64	2.67	2.66	2.69	2.64
1.4	3.32	3.26	3.20	2.92	2.77	2.68	2.64	2.65	2.65	2.67	2.64
1.6	3.32	3.29	3.28	3.07	2.89	2.75	2.68	2.66	2.65	2.64	2.63
1.8	3.32	3.32	3.31	3.07	2.88	2.74	2.68	2.66	2.65	2.64	2.63
2.0	3.32	3.31	3.30	3.03	2.85	2.76	2.72	2.68	2.65	2.64	2.63
2.5	3.32	3.32	3.31	3.28	3.07	2.89	2.81	2.72	2.67	2.64	2.63
3.0	3.32	3.32	3.32	3.32	3.20	3.05	2.92	2.73	2.66	2.64	2.63
3.5	3.32	3.32	3.32	3.32	3.32	3.19	2.97	2.76	2.68	2.64	2.63
4.0	3.32	3.32	3.32	3.32	3.32	3.32	3.07	2.79	2.70	2.64	2.63
4.5	3.32	3.32	3.32	3.32	3.32	3.32	3.32	2.88	2.74	2.64	2.63
5.0	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.07	2.79	2.64	2.63
5.5	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32	2.88	2.64	2.63

(1) Table is taken from reference 49.

Summary Statement

The initial goals of this retrofit bridge design project included providing a safer roadway for motorists. Removing the scour hole at the downstream outlet of the bridge not only prevented a future bridge failure in the future, but also providing fish passage for the adult steelhead. Retrofitting the bridge outlet with five rock weirs allowed the channel invert elevation to rise back to its original slope while decreasing channel velocities and increasing channel depths. Resting pools two feet in depth were also created for the adult steelhead.

Specifically for fish passage, criteria for the Hydraulic Rock Weir Design Option were successfully met by following the process laid out within the forms. An overview of the steps include researching existing data and available information, collecting all required parameters at the site, selecting the best fish passage design option for the site, completing the hydrology and efficiently brainstorming and completing the hydraulic modeling, and finally meeting requirements of the Hydraulic Rock Weir Design Option.

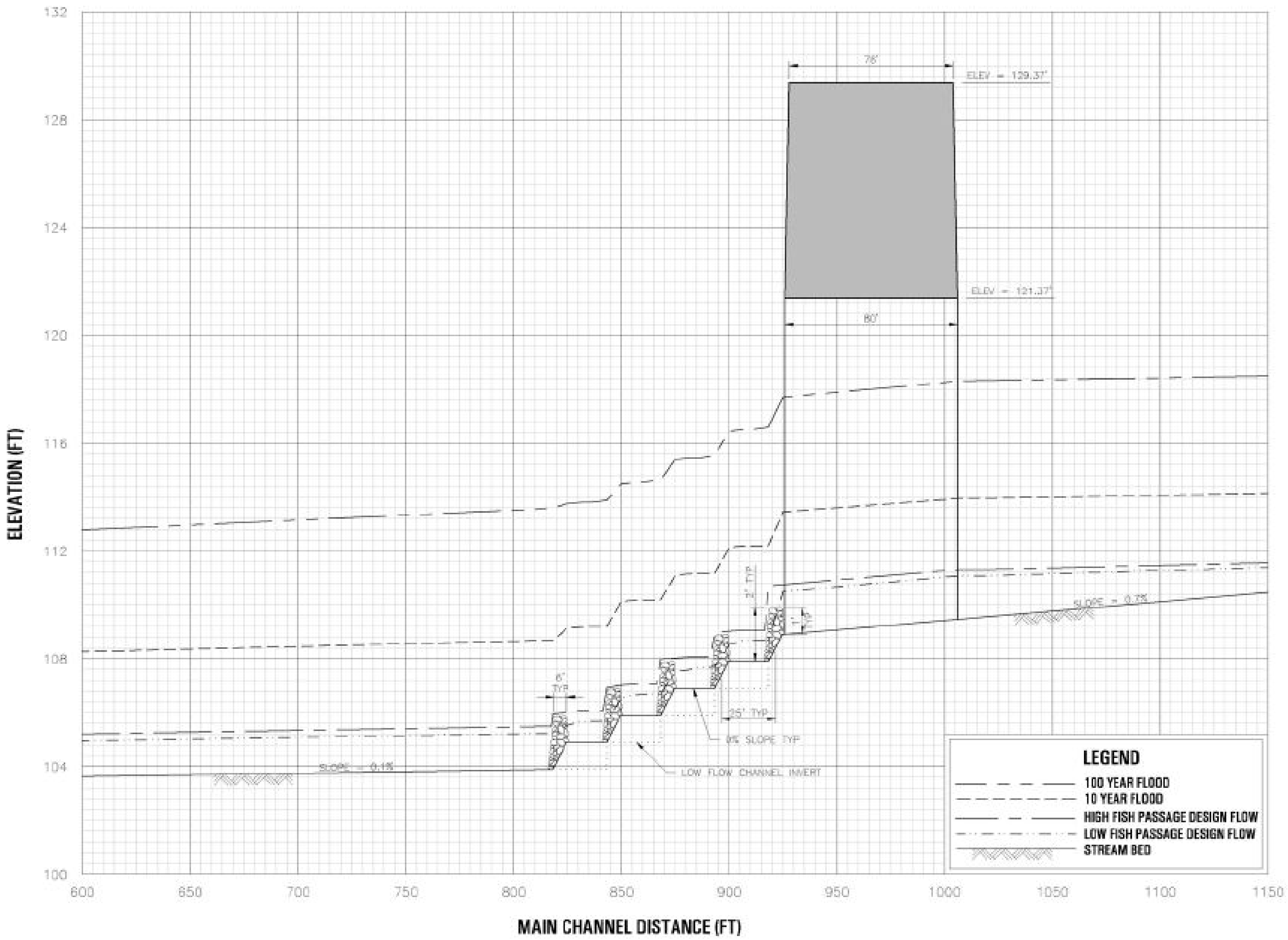
As found in the problem statement, the goal was providing fish passage for Stoney Creek that met hydraulic standards in the Caltrans Hydraulic Design Manual, as well as fish standards in the California Department of Fish and Game Culvert Criteria and the NOAA Fisheries Guidelines for Salmonid Passage at Stream Crossings.

Summary Data Table 1: Bridge Velocities

	Maximum Average Water Velocity at High Fish Design Flow for Adult Anadromous Salmonids (ft/s)	High Fish Design Outlet Velocity (ft/s)	High Fish Design Inlet Velocity (ft/s)	High Fish Design Average Barrel Velocity (ft/s)
Existing Conditions	5.00	3.1	4.5	4.1
Proposed Conditions	5.00	1.1	1.0	1.5

Summary Data Table 2: Bridge Depths

	Minimum Low Fish Passage Design Depth (ft)	Low Fish Passage Design Outlet Depth (ft)	Low Fish Passage Design Inlet Depth (ft)
Existing Conditions	1.00	0.65	0.91
Proposed Conditions	1.00	1.59	1.61



P:/06938/38713 TO7 Fish Passage/5.0 Project Data/AutoCAD/General Details/Rock-Weir-Prop-Design.DWG
08-29-06 AJACKSON 11:28:06

Issue No.	Description	Date	Drwn.	Chkd.	Resp. Engr.	Proj. Mgr.

Project Manager
LEF

Designed
EKB

Designed

Checked
JJL

Drawn
AJ

Stoney Creek Bridge - Route 444
at Stoney Creek

ROCK WEIR

PROPOSED CONDITIONS

Date

Scale HORIZ: 1" = 50'
VERT: 1" = 4'

Project No. 06938-38713

File Name Rock-Weir-Prop-Design.DWG

Drawing No. **1**

Issue

APPENDIX L

DESIGN EXAMPLE - STREAM SIMULATION DESIGN OPTION

With this October 2014 update, the process for design and analysis of the stream simulation culvert or bridge bed has changed. The new process is based on the U.S. Forest Service method. CA Fish & Wildlife recognizes the U.S. Forest Service method for bed mobility stability/mobility analysis, as well as the bed particle sizing and distribution.

See "Updated Method for Stream Simulation Culvert or Bridge Bed Material Sizing" at the bottom of this design example.

Stream Simulation Design Option

Problem Statement

In scenic Mono County, an existing 2-lane, 5-mile segment of Route 333 has a history of head-on collisions and is scheduled for widening to 4 lanes with a wide median to improve safety.

Within the project limits, Stormy Creek crosses Route 333 and is currently conveyed by a 6-foot diameter, 50-foot long, corrugated metal pipe. From visual inspection, the existing culvert is in reasonable structural condition, although Maintenance has expressed longevity concerns with this culvert given its 75-year age. As for hydraulic condition, Maintenance has also reported highway overtopping during a series of significant storms in January 1995. Therefore, hydraulic analysis of the existing condition is important in assessing the culvert's capacity during less frequent storm events (25-year, 50-year, and 100-year storms).

The Mono Lake Committee has been monitoring the Stormy Creek watershed for the past decade. In May 2004, stream restoration strategies were recommended in a report sponsored by the Mono Lake Committee, CalTrout, and the Sierra Club to improve ecological conditions within the watershed. The Route 333 culvert was identified as contributing to an ecologic disconnect between the lower and upper reaches of the stream. Also, identified in the report, brown and rainbow trout have been seen congregating at the outlet of the existing culvert. Based on the habitat and ecological problems, the stream restoration report calls for a replacement of the Route 333 culvert that will be fish-friendly, as well as providing a more seamless connection of the upstream and downstream reaches of the creek.

NOTE: Route 333 and Stormy Creek are fictitious and created for the purpose of presenting a design example for this fish-passage training guidance.

Form 1-Existing Data and Information Summary

Form 1 provides a list of suggested data references that would be beneficial to collect before the beginning of design process.

For this particular example, USGS topographic quadrangle map, and a stream restoration report from May of 2004 was available for reference

The USGS topographic quadrangle data and DEM data was downloaded from the USGS website, www.usgs.gov.

The FEMA Map Service Center, http://msc.fema.gov/, was accessed to determine if a previous hydrologic study, hydraulic study, and/or floodplain mapping had been performed. For Stormy Creek, no previous detailed or approximate studies had been performed; therefore, no effective data was available for reference.

The County's engineering department was able to provide a copy of the May 2004 stream restoration report sponsored by the Mono Lake Committee, CalTrout, and the Sierra Club.

As for site access, the field investigations cannot be done within Caltrans right-of-way; therefore, right-of-entry will be required.

EXISTING DATA AND INFORMATION SUMMARY

FORM 1

Project Information Route 333 4-Lane		Computed: EKB	Date: 8/1/06
		Checked: LEF	Date: 8/2/06
Stream Name: Stormy Creek	County: Mono	Route: 333	Postmile: 34.1

Proposed Project Type	☐ New Culvert	☐ New Bridge
	☒ Replacement Culvert	☐ Replacement Bridge
	☐ Retrofit Culvert	☐ Retrofit Bridge
	☒ Proposed Culvert Length= 140 ft	☐ Proposed Bridge Length= ft
	☐ Other	☐ Other

Design Species/Life Stage	☒ All Species	Source: Contact: Date: State of CA Dept of Fish & Game Bill Hook 1-422-351-9322 Contacted on 7/20/06
	☐ Adult Anadromous Salmonids	
	☐ Adult Non-Anadromous Salmonids	
	☐ Juvenile Salmonids	
	☐ Native Non-Salmonids	
	☐ Non-Native Species	

Collect Existing Data

Included in Caltrans Culvert Inventory	☐ Yes	☒ No
As-Built Drawings	☐ Yes	☒ No
Assessor's Parcel Map	☐ Yes	☒ No
Previous Studies Performed: (i.e. FEMA Flood Insurance Studies, Army Corps of Engineering Studies, Other)		
Hydrology Analysis	☐ Yes	☒ No
Hydraulics Analysis	☐ Yes	☒ No
Floodplain Mapping	☐ Yes	☒ No
Other Studies Types Available: (i.e. Watershed Management Plans, [✓ Stream Restoration Plans], Other)	☒ Yes	☐ No
Existing Land Use Map	☐ Yes	☒ No
Proposed Land Use Map	☐ Yes	☒ No
Precipitation Gage Data	☐ Yes	☒ No
Stream Flow Gage Data	☐ Yes	☒ No

EXISTING DATA AND INFORMATION SUMMARY FORM 1

Topographic Mapping: (i.e. [✓ USGS Topographic Quadrangle], [✓ DEM Data], LIDAR Data, Other)	☒ Yes	☐ No
District Hydraulics Library	☐ Yes	☒ No

Obtain Access Permission

Will Project study limits extend beyond Caltrans R/W? ☒ Yes ☐ No

If yes, obtain right-of-entry.

Contact Report Index Attached ☒ Yes ☐ No

Existing Information Index Attached ☒ Yes ☐ No

CONTACT REPORT INDEX

Project Information
Route 333 4-Lane

Computed: EKB
Date: 8/1/06
Checked: LEF
Date: 8/2/06

Stream Name: Stormy Creek
County: Mono
Route: 333
Postmile: 34.1

Date of Contact	Person Contacted	Subject Discussed
7/20/06	Bill Hook, St. of CA Dept of Fish & Game 422-351-9322	all species info

EXISTING INFORMATION INDEX

Project Information
Route 333 4-Lane

Computed: EKB
Date: 8/1/06
Checked: LEF
Date: 8/2/06

Stream Name: Stormy Creek
County: Mono
Route: 333
Postmile: 34.1

Report Date	Report Name and Source
5/2004	Stream Restoration Plan for Stormy Creek

Form 2- Site Visit Summary

Form 2 captures the existing conditions of the hydraulic structure including channel and structure roughness values. By completing the Site Visit Summary form, the drainage designer will have all necessary parameters required to complete any of the fish passage design options.

At the Stormy Creek site, various culvert and creek properties were investigated, such as layout configuration, roughness, velocity, and flow regime.

For the creek, roughness characteristics of the main channel, the left overbank channel, and the right overbank channel were also investigated and ultimately Manning's n-values were estimated. Based on field observation, the left and right overbank channels were found to have the same n-values in the vicinity of the culvert crossing and the project study area.

In addition, flow in the creek at the time of the field visit was determined from appropriate measurements. The flow was calculated by measuring a velocity and depth, calculating wetted area from a field developed creek cross section, and dividing velocity by wetted area to achieve flow according to the continuity of flow equation. By placing a small leaf in the creek and timing its travel over a set length, a velocity was determined. In order to find a representative velocity for the creek, this operation was performed three times, where the leaf was placed near the left bank, near the right bank, and around the center of the creek. The velocity corresponding to each leaf placement was added together and averaged to find a representative velocity.

Finally, the flow regime for the creek was estimated in the field by tossing a small rock in the center of the creek and noting the propagation of the ripples. When ripples propagate upstream, the flow regime is subcritical, while supercritical flow is denoted by downstream ripple propagation.

SITE VISIT SUMMARY

FORM 2

Project Information Route 333 6-Lane		Computed: EKB	Date: 8/11/06
		Checked: LEF	Date: 8/13/06
Stream Name: Stormy Creek	County: Mono	Route: 333	Postmile: 34.1

Obtain Physical Characteristics of Existing Culvert

Confined Spaces

Is the culvert height 5 ft or greater?	☒ Yes ☐ No
Can you stand up in the culvert?	☒ Yes ☐ No
Can you see all the way through the culvert?	☒ Yes ☐ No
Can you feel a breeze through the culvert?	☒ Yes ☐ No

If answer is "No" to any of the above questions, do not enter the culvert without confined spaces equipment for surveying.

Inlet Characteristics

Inlet Type	☐ Projecting	☒ Headwall	☐ Wingwall	
	☐ Flared end section	☐ Segment connection		
Inlet Condition	☐ Channel scour	☐ Excessive deposition	☐ Debris accumulation	☒ None applicable
Inlet Apron	☐ Channel scour	☐ Excessive deposition	☐ Debris accumulation	☒ None applicable

Skew Angle: none °	Upstream Invert Elevation: 7883.16 ft [✓ NGVD 29] or NAVD 88)

Barrel Characteristics

Diameter: 72 in	Fill height above culvert: approx. 11.0 ft
Height/Rise: — ft	Length: 50 ft
Width/Span: — ft	Number of barrels: 1

Culvert Type	☐ Arch	☐ Box	☒ Circular
	☐ Pipe-Arch	☐ Elliptical	
Culvert Material	☐ HDPE	☐ Steel Plate Pipe	☐ Concrete Pipe
	☒ Spiral Rib / Corrugated Metal Pipe		
Barrel Condition	☐ Corrosion	☐ Debris accumulation	☐ Structural damage
	☐ Abrasion	☐ Bedload accumulation	☒ None applicable

SITE VISIT SUMMARY FORM 2

Horizontal alignment breaks: NONE ft	Vertical alignment breaks: NONE ft

Outlet Characteristics

Outlet Type	☐ Projecting	☒ Headwall	☐ Wingwall	
	☐ Flared end section	☐ Segment connection		
Outlet Condition	☐ Scour hole	☐ Backwatered	☐ Debris accumulation	☒ None applicable
	☐ Perched	Outlet elevation drop: ft		
		Outlet drop condition:		
		Scour hole depth: ft		
Outlet Apron	☐ Channel scour	☐ Excessive deposition	☐ Debris Accumulation	☒ None Applicable

Skew Angle: NONE °	Downstream Invert Elevation: 7882.38 ft ([✓ NGVD 29] or NAVD 88)

Obtain Physical Characteristics of Existing Bridge N/A

Elevation of high chord (top of road): ft	Elevation of low chord: ft

Channel Lining	☐ No lining	☐ Concrete	☐ Rock	☐ Other

Skew Angle: °	Bridge width (length): ft

Pier Characteristics (if applicable) ☐

Number of Piers:	Upstream cross-section starting station: ft
Pier Width: ft	Downstream cross-section starting station: ft
Pier Centerline Spacing: ft	

Pier Shape	☐ Square nose and tail	☐ Semi-circular nose and tail	☐ 90° triangular nose and tail
	☐ Twin-cylinder piers with connecting diaphragm	☐ Twin-cylinder piers without connecting diaphragm	☐ Ten pile trestle bent
Pier Condition	☐ Scour	☐ Corrosion	☐ Debris accumulation
Skew angle	°		

Channel Characteristics

Hydraulic Structure Roughness Coefficients

(Source: Caltrans Highway Design Manual Table 864.3A)		(Source: HEC-RAS User's Manual)	
Type of Structure	**n- value**	**Type of Structure**	**n- value (normal)**

SITE VISIT SUMMARY

FORM 2

Linned Channels:		**Corrugated Metal:**	
Portland Cement Concrete	0.014	Subdrain	0.020 [✓ 0.019]
Air Blown Mortar (troweled)	0.012	Storm drain	[✓ 0.024]
Air Blown Mortar (untroweled)	0.016	**Wood:**	
Air Blown Mortar (roughened)	0.025	Stave	0.012
Asphalt Concrete	0.018	Laminated, treated	0.017
Sacked Concrete	0.025	**Brickwork:**	
Pavement and Gutters:		Glazed	0.013
Portland Cement Concrete	0.015	Lined with cement mortar	0.015
Asphault Concrete	0.016		
Depressed Medians:			
Earth (without growth)	0.040		
Earth (with growth)	0.050		
Gravel	0.055		

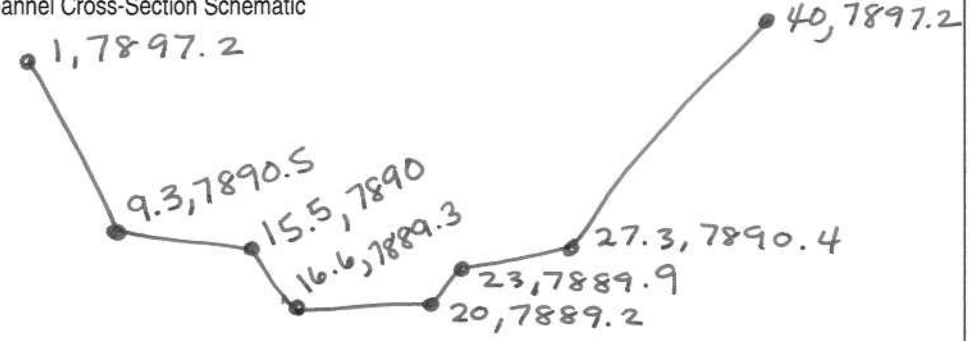
Recommended Permissible Velocities for Unlined Channels (Source: Caltrans Highway Design Manual, Table 862.2)

Type of Material in Excavation Section	Intermittent Flow (f/s)	Sustained Flow (f/s)
Fine Sand (Noncolloidal)	2.6	2.6
Sandy Loam (Noncolloidal)	2.6	2.6
Silt Loam (Noncolloidal)	3.0	3.0
Fine Loam	3.6	3.6
Volcanic Ash	3.9	3.6
Fine Gravel	3.9	3.6
Stiff Clay (Colloidal)	4.9	3.9
Graded Material (Noncolloidal)		
Loam to Gravel	6.6	4.9
Silt to Gravel	6.9	5.6
Gravel	7.5	5.9

SITE VISIT SUMMARY FORM 2

Coarse Gravel	[✓ 7.9]	6.6
Gravel to Cobbles (Under 150mm)	8.8	6.9
Gravel and Cobbles Over 200mm)	9.8	7.9
Flow Estimation 4 cfs	☐ Supercritical flow	☒ Subcritical flow

Channel Cross-Section Schematic



Channel depth = 0.64 ft

Average Active Channel Width
Take at least five channel width measurments to determine the active channel width. The active channel stage or ordinary high water level is the elevation delineating the hightest water level that has been maintained for a sufficient period of time to leave evidence on the landscape.

Average Active Channel Width = 16.6 ft

1) 16.2 ft	2) 18.9 ft	3) 13.6 ft	4) 17.5 ft	5) 16.8 ft

Boundary Conditions
The normal depth option (slope area method) can only be used as a downstream boundary condition for an open-ended reach. Is normal depth appropriate? If no, what is the known starting water surface elevation? yes Normal depth

Upstream Normal depth	slope 0.015 ft/ft
Downstream normal depth	slope 0.015 ft/ft
Known starting water surface elevation Source:	— ft

General Considerations

Identify Physical Restrictions	☐ Right-of-way	☐ Utility conflict	☐ Vegetation
	☐ Man-made features	☐ Natural features	☐ Other

Cross-Section Sketches Attached ☒ Yes ☐ No

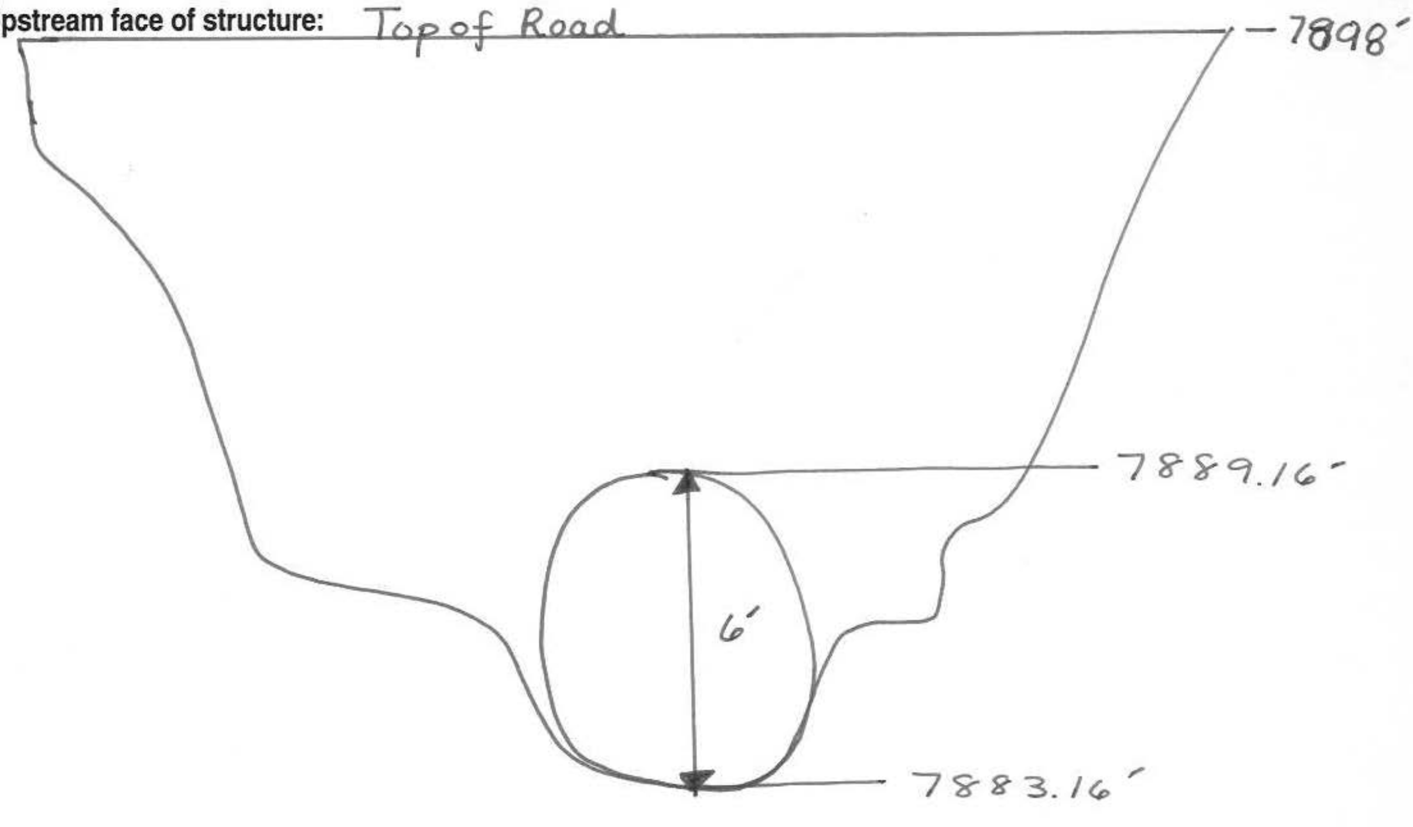
Site Photograph Documentation Attached ☒ Yes ☐ No

Channel / Overbank Manning's n-value Calculation Attached ☒ Yes ☐ No

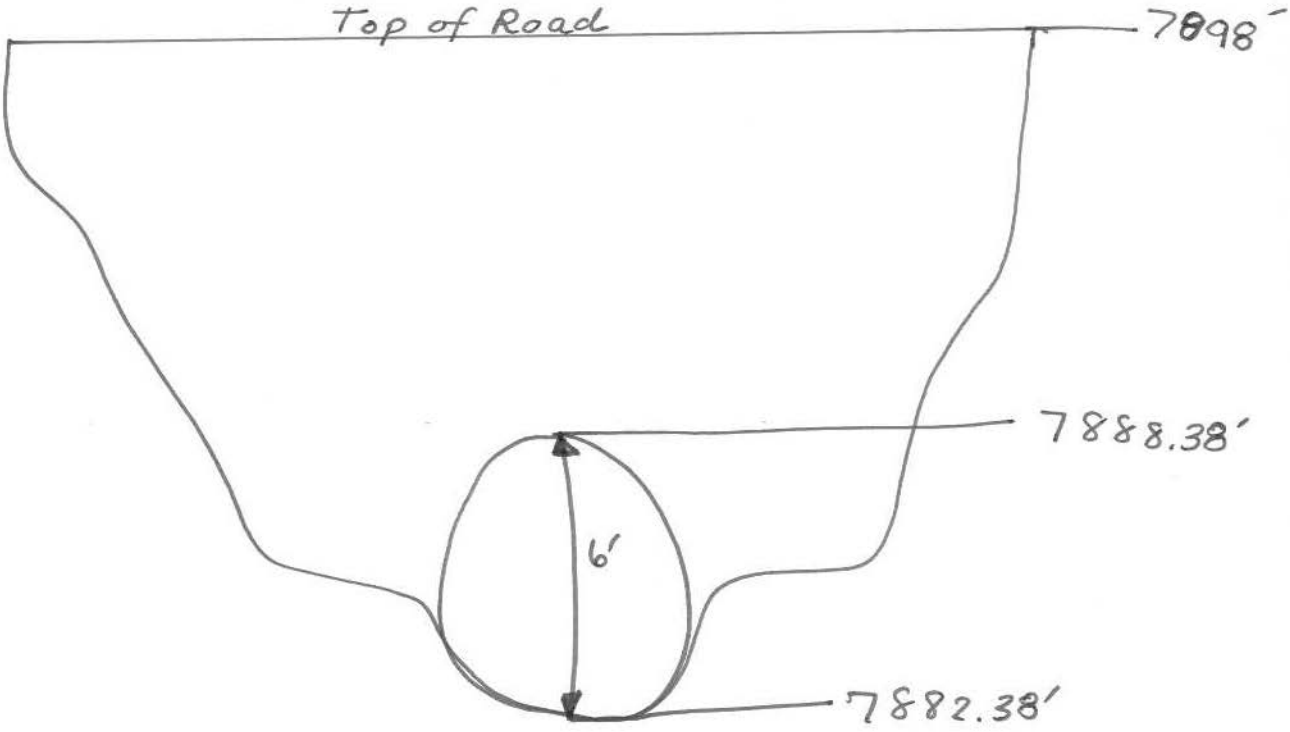
Field Notes Attached ☒ Yes ☐ No

CROSS-SECTION SKETCH

Upstream face of structure:



Downstream face of structure:



SITE PHOTOGRAPH DOCUMENTATION

Project Information Route 333 4-Lane

Computed: EKB Date: 8/11/06

Checked: LEF Date: 8/13/06

Stream Name: Stormy Creek

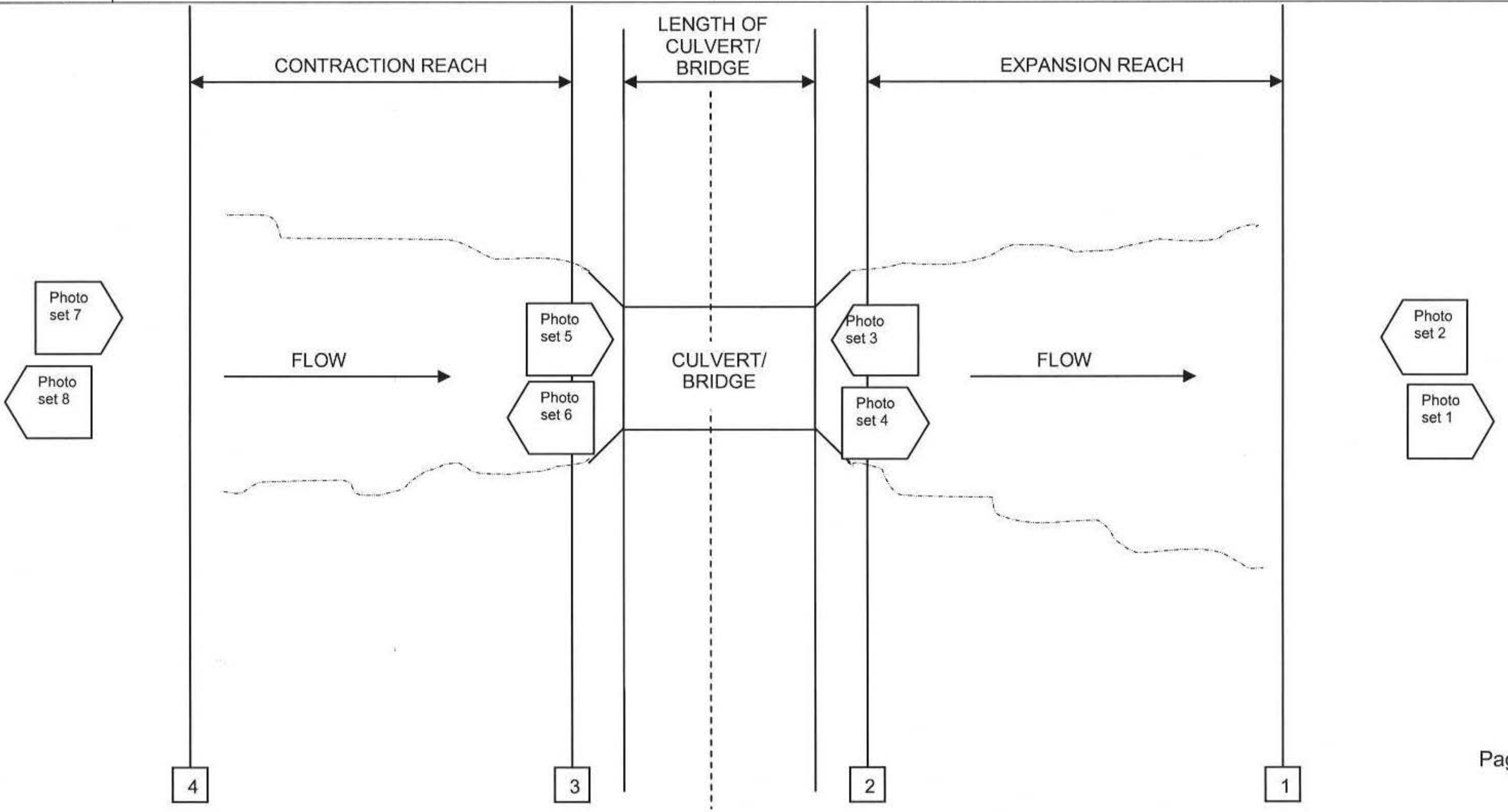
County: Mono

Route: 333

Postmile: 34.1

Crossing Type ☒ Culvert ☐ Bridge ☐ Other Type/Comments

Distance From:	X-sec. 1 to X-sec. 2: 100 ft	X-sec. 2 to DS face of structure / ft	US face of structure to X-Sec. 3 / ft	X-sec. 3 to X-sec. 4 200 ft
Distance From:	Photo Sets 1 & 2 to DS face of structure — ft	Photo Sets 3 & 4 to DS face of structure / ft	Photo Sets 5 & 6 to US face of structure — ft	Photo Sets 7 & 8 to US face of structure — ft
Length of Culvert/Bridge:	50 ft			



SITE PHOTOGRAPH DOCUMENTATION

Photo Descriptions:

Photo Set 1	—
Photo Set 2	—
Photo Set 3	Culvert outlet Looking upstream
Photo Set 4	—
Photo Set 5	—
Photo Set 6	—
Photo Set 7	—
Photo Set 8	—

Culvert outlet looking upstream

Manning's n Computation Summary

Project Information Route 333 4-Lane		Computed: EKB	Date: 8/11/06
		Checked: LEF	Date: 8/13/06
Stream Name: Stormy Creek	County: Mono	Route: 333	Postmile: 34.1

Aerial Picture Attached: none available

Photographs (#'s and locations) #1

Summary of n-Values:

Reach	Left Overbank	Main Channel	Right Overbank
	0.062	0.055	0.062

Notes:

Manning's n Computation - Main Channel

Project Information Route 333 4-Lane		Computed: EKB	Date: 8/11/06
		Checked: LEF	Date: 8/13/06
Stream Name: Stormy Creek	County: Mono	Route: 333	Postmile: 34.1

Aerial Picture Attached: none available

Photographs (#'s and locations) #1

Is roughness uniform throughout the reach? no

Note: If not, n-value should be assigned for the AVERAGE condition of the reach

Is roughness uniformly distributed along the cross section? no

Is a division between the channel and floodplain necessary? yes

Calculation of n-value:

$n = (nb + n1 + n2 + n3 + n4)m$

where:

	Description of Range
nb = base n value for surface	*median size btwn 1" and 2.5"=0.028 to 0.035, btwn 2.5" and 10"=0.030 to 0.050*
n1 = surface irregularity factor	*smooth = 0 up to severe at 0.020*
n2 = cross section variation factor	*gradual = 0 up to alternating frequently at 0.015*
n3 = obstructions factor	*negligible = 0 up to severe (over 50% of cross section) at 0.05*
n4 = vegetation factor	*small = 0.002 to very large (average depth of flow is less than 1/2 height of vegetation) at 0.100*
m = sinuosity/meandering factor	*minor = 1.0, appreciable = 1.15, Severe = 1.30*

Base n value for surface

nb: Sand channel? no if yes, median size of bed material? —

nb =

median size (in)	nb
0.008	0.012
0.012	0.017
0.016	0.020
0.020	0.022
0.024	0.023
0.031	0.025
0.039	0.026

All other channels:

median size (in)	nb
.04 to .08	0.026 to 0.035
→ 1 to 2.5	0.028 to 0.035
2.5 to 10	0.030 to 0.050
>10	0.040 to 0.070

Notes: Channel bottom - variation of rock and soil sizes

- soil samples were taken at reference reach site
- grain size distribution curve created

nb = 0.030

Manning's n Computation - Main Channel

Surface Irregularity

n1:	Smooth	Is channel smooth? no	if yes, n1 = 0
	Minor	Is channel in good condition with slightly eroded or scoured side slopes?	[✓ if yes, n1 = 0.001 - 0.005]
	Moderate	Is channel a dredged channel having moderate to considerable bed roughness and moderately sloughed or eroded side slopes in rock?	if yes, n1 = 0.006 - 0.010
	Severe	Is channel badly sloughed, scalloped banks or badly eroded or sloughed sides or jagged and irregular surface?	if yes, n1 = 0.011 - 0.020

Notes: Slight erosion occurring on channel side slopes

n1 = 0.004

Cross Section Variation Factor

n2:	Gradual	Does the size and shape of the channel cross section change gradually?	if yes, n2 = 0.000
	Alternately occasionally	Does the cross section alternate to large to small, *occasionally* or does the main flow *occasionally* shift from side to side?	[✓ if yes, n2 = 0.001 - 0.005]
	Alternately frequently	Does the cross section alternate to large to small, *frequently* or does the main flow *frequently* shift from side to side?	if yes, n2 = 0.010 - 0.015

n2 = 0.004

Notes: Main flow slightly shifts from side to side at lower flows

Obstructions factor

n3:	Negligible	Does the stream have a few scattered obstructions that occupy < 5% of the cross-sectional area?	[✓ if yes, n3 = 0.000 - 0.004]
	Minor	Obstructions occupy < 15% of the cross-sectional area and the spacing between obstructions is such that the sphere of influence doesn't extend to other obstructions?	if yes, n3 = 0.005 - 0.015
	Appreciable	Obstructions occupy 15% - 50% of the cross-sectional area and the spacing between obstructions is small enough to be additive?	if yes, n3 = 0.020 - 0.030
	Severe	Obstructions occupy more than 50% of the cross-sectional area or the spacing between obstructions causes turbulence?	if yes, n3 = 0.040 - 0.050

n3 = 0.002

Notes: Few Large boulders located in Channel

Manning's n Computation - Main Channel

Vegetation factor

n4:

Small	Does the channel have dense growth of flexible turf grass or weed growth where the flow is at least 2 times the height of the vegetation; tree seedlings of willows, cottonwoods, etc?	if yes, n4 = 0.002 - 0.010
Medium	Does the channel have turf grass where the average depth of flow is 1 to 2 times the height of the vegetation; moderately stemmy grass, weeds or tree seedlings growing where the flow is 2 to 3 times the height of the vegetation? →	if yes, n4 = 0.010 - 0.025
Large	Does the channel where the average depth of flow is equal to the height of the vegetation; 8 to 10 years-old willows or cottonwoods intergrown with weeds and brush; where the hydraulic radius exceeds1.97 ft or bushy willows about 1 year old intergrown with some weeds along side slopes, and no significant vegetation exists along the channel bottom, where the hydraulic radius is greater than 2.0 ft.	if yes, n4 = 0.025 -0.050
Very large	Does the channel have turf grass growing where the average depth of flow < 1/2 the height of the vegetation; bushy willows about 1 year old. with weeds intergrown on side slopes; dense cattails in channel bottom; trees intergrown with weeds and brush?	if yes, n4 = 0.050 - 0.100

n4 = 0.015

Notes: Medium seasonable vegetation present in main channel.

Sinuosity/meandering factor

m

Minor	Ratio of the channel length to valley length in 1.0 to 1.2	if yes, m = 1.00
Appreciable	Ratio of the channel length to valley length in 1.2 to 1.5	if yes, m = 1.15
Severe	Ratio of the channel length to valley length > 1.5	if yes, m = 1.30

m = 1.00

Notes: Not an issue

Manning's n - Main Channel **n =** 0.055

Manning's n Computation - Overbank

Project Information Ronde 333 4-Lane		Computed: EKB	Date: 8/11/06
		Checked: LEF	Date: 8/13/06
Stream Name: Stormy Creek	County: Mono	Route: 333	Postmile: 34.1

Aerial Picture Attached: none available

Photographs (#'s and locations) #1

Is roughness uniform throughout the reach? no

Note: If not, n-value should be assigned for the AVERAGE condition of the reach

Is roughness uniformly distributed along the cross section? no

Is a division between the channel and floodplain necessary? yes

Calculation of n-value:

n = (nb + n1 + n2 + n3 + n4)m

where:	Description of Range
nb = base n value for surface	*median size between 1" and 2.5"=0.028 to 0.035, between 2.5" and 10"=0.030 to 0.050*
n1 = surface irregularity factor	*smooth = 0 up to severe at 0.020*
n2 = cross section variation factor	*gradual = 0 up to alternating frequently at 0.015*
n3 = obstructions factor	*assumed to equal 0*
n4 = vegetation factor	*small = 0.002 to very large (average depth of flow is less than 1/2 height of vegetation) at 0.100*
m = sinuosity/meandering factor	*equals 0 for floodplains*

Base n value for surface

nb: Sand channel? no if yes, median size of bed material? —

nb =

median size (in)	nb
0.008	0.012
0.012	0.017
0.016	0.020
0.020	0.022
0.024	0.023
0.031	0.025
0.039	0.026

All other channels:

median size (in)	nb
.04 to .08	0.026 to 0.035
[✓ 1 to 2.5]	0.028 to 0.035
2.5 to 10	0.030 to 0.050
>10	0.040 to 0.070

Notes: same conditions found in main channel

nb = 0.030

Surface Irregularity

n1:	Smooth	Compares to the smoothest, flattest floodplain in a given bed material.	if yes, n1 = 0
	Minor	Is the floodplain slightly irregular in shape. A few rises and dips or sloughs may be more visible on the floodplain.	if yes, n1 = 0.001 - 0.005
	Moderate	Has more rises and dips. Sloughs and hummocks may occur.	[✓ if yes, n1 = 0.006 - 0.010]
	Severe	Floodplain very irregular in shape. Many rises and dips or sloughs are visible.	if yes, n1 = 0.011 - 0.020

n1 = 0.008

Notes: Floodplain has many rises and dips in elevation.

Manning's n Computation - Overbank

Cross Section Variation Factor

n2 = 0.000

Notes: Not applicable to floodplains.

Obstructions factor

n3:	Negligible	Does the stream have a few scattered obstructions that occupy < 5% of the cross-sectional area? →	if yes, n3 = 0.000 - 0.004
	Minor	Obstructions occupy < 15% of the cross-sectional area and the spacing between obstructions is such that the sphere of influence doesn't extend to other obstructions?	if yes, n3 = 0.005 - 0.015
	Appreciable	Obstructions occupy 15% - 50% of the cross-sectional area and the spacing between obstructions is small enough to be additive?	if yes, n3 = 0.020 - 0.030

n3 = 0.003

Notes: large boulders

Vegetation factor

n4:	Small	Does the channel have dense growth of flexible turf grass or weed growth where the flow is at least 2 times the height of the vegetation; tree seedlings of willows, cottonwoods, etc where the average depth of flow is at least three times the height of the vegetation?	if yes, n4 = 0.002 - 0.010
	Medium	Does the channel have turf grass where the average depth of flow is 1-2 times the height of the vegetation; moderately stemmy grass, weeds or tree seedlings growing where the flow is 2-3 times the height of vegetation? Brushy, moderately dense vegetation, similar to 1-2 year old willow trees in dormant season. →	if yes, n4 = 0.010 - 0.025
	Large	Does the channel where the average. depth of flow is equal to the height of the vegetation; 8 to 10 year old. willows, cottonwoods intergrown with weeds and brush; where the R = 1.97 ft or bushy willows of 1 year old are in the channel bottom, where R =2.00 ft?	if yes, n4 = 0.025 -0.050
	Very large	Does the channel have turf grass growing where the average depth of flow < 1/2 the height of the vegetation; bushy willows about 1 year old. with weeds intergrown on side slopes; dense cattails in channel bottom; trees intergrown with weeds and brush?	if yes, n4 = 0.050 - 0.100
	Extreme	Does the channel have dense bushy willow, mesquite, and salt cedar (full foliage), or heavy stand of timber, few down trees, depth of reaching branches?	if yes, n4 = 0.100 - 0.200

n4 = 0.021

Notes: Medium vegetation - both seasonal and year round

Sinuosity/meandering factor

m = 1.00

Notes: Not applicable to floodplains.

Manning's n - Overbank n = 0.062

Form 3- Guidance on Selection of Fish Passage Design Option

This form summarizes requirements for each design option in order for the designer to select the appropriate fish-passage design option.

Because all species of fish must be passed through the culvert conveying Stormy Creek and individual species swimming abilities are unknown, the Active Channel and Stream Simulation options are two viable strategies. Unlike the Hydraulic Design option, both of these options do not require fish swimming data and the development of low and high fish-passage flows, as well as their corresponding velocity and depth calculations.

Since the restoration of Stormy Creek is a high priority to environmental groups in Mono County, the Route 333 culvert has been identified as a contributor to the ecologic disconnect within the watershed, and the existing culvert is 75 years old with questionable hydraulic capacity, the culvert will be replaced instead of rehabilitated and extended.

Given the addition of two lanes and inside/outside shoulders, as well as the addition of a wide median, the new culvert will be 140 feet in length. This new length is greater than the 100-foot length limit stated in the Active Channel guidelines. Therefore, Stream Simulation is the best design option for Stormy Creek by strict definition.

This design option is also more attractive than the Active Channel based on the environmental sensitivity of the watershed and the need to satisfy local environmental groups in restoring the ecological connectivity within it. While both the Stream Simulation and Active Channel strategies attempt to mimic stream conditions through a culvert, the Stream Simulation design process is more detailed in performing this task. When designing a Stream Simulation culvert, a reference reach is selected and its substrate, cross-sectional, and channel formation properties are used in specifying the simulated bed through the culvert. As noted in the *CA Fish & Game Culvert Criteria,* the Active Channel method is a more simplified version of this process where a culvert is oversized and embedded into the channel to allow the formation of a stable streambed inside the culvert. In Active Channel design, the individual characteristics of the stream are not specifically mimicked inside a culvert.

Again, given the more robust Stream Simulation design process and goal of restoring ecological connectivity with the watershed, this is best fish-passage design option for Stormy Creek in addition to the culvert length requirement.

Because the new, larger diameter culvert and its potential to convey higher flow more effectively, District Hydraulics must be consulted so that any negative impacts to downstream properties or facilities can be assessed prior to final design.

GUIDANCE ON SELECTION OF FISH PASSAGE DESIGN OPTION FORM 3

Project Information Route 333 4-Lane		Computed: EKB	Date: 8/15/06
		Checked: LEF	Date: 8/17/06
Stream Name: Stormy Creek	County: Mono	Route: 333	Postmile: 34.1

Design Species/ Life Stage	☒	All Species
	☐	Adult Anadromous Salmonids
	☐	Adult Non-Anadromous Salmonids
	☐	Juvenile Salmonids
	☐	Native Non-Salmonids
	☐	Non-Native Species

☐ **Active Channel Design Option -** The Active Channel Design Option 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 streambed 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 with stream hydraulic charagcteristics within the culvert are intended to mimic the stream conditions upstream and downstream of the crossing. However, hydraulic analyses for traffic safety, hydraulic impacts, and scour are required.

Criteria for choosing option:

- ☒ New and replacement culvert/bridge installations
- ☒ Passage required for all species
- ☐ Proposed culver/bridge length less than 100 feet
- ☒ Channel slope less than 3%

☐ **Hydraulic Design Option** - The Hydraulic Design Option is a design process that matches the hydraulic performance of a culvert with the swimming ablitities of a target species and age class of fish. This method targets distinct species of fish and, therefore, does not account for ecosystem requirments of non-target species.

Criteria for choosing option:

- ☒ New and replacement culvert/bridge installations (If retrofit installation, see Baffle or Rock Weir Design Options)
- ☐ Target species identified for passage
- ☒ Low to moderate channel slopes (less than 3%)
- ☐ Active channel design or stream simulation design options are not physically feasible

Retrofit Culvert/Bridge Installations

☐ **Baffle Design Option -** The Baffle Design Option is a Hydrualic Design process that is intended to increase flow depth, or to add roughness elements as a measure to reduce flow velocity within the culvert/bridge structure. Determination of the high and low fish passage design flows, water velocity, and water depth is required for this option.

- ☐ Retrofit culvert/bridge installation
- ☐ Little bedload material movement

GUIDANCE ON SELECTION OF FISH PASSAGE DESIGN OPTION FORM 3

- ☐ Existing culvert/bridge is structurally sound
- ☐ Target species identified for passage
- ☐ Low to moderate channel slopes
- ☐ Active channel design or stream simulation design options are not physically feasible

☐ **Rock Weir Design Option -** The Rock Weir Design Option is a Hydraulic Design process that is intended to increase flow depth, or add roughness elements as a measure to reduce flow velocity, or to increase the channel slope downstream of the culvert/bridge. Determination of the high and low fish passage design flows, water velocity, and water depth is required for this option.

- ☐ Retrofit culvert/bridge installations
- ☐ Perched condition at outlet
- ☐ Steep slope at inlet
- ☐ Target species identified for passage
- ☐ Active channel design or stream simulation design options are not physically feasible

☒ **Stream Simulation Design Option -** The Stream Simulation Design Option 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.

Criteria for choosing option:

- ☒ New and replacement culvert/bridge installations
- ☒ Passage required for all species
- ☒ Culvert/bridge length greater than 100 feet
- ☒ Channel width should be less than 20 feet
- ☒ Minimum culvert/bridge width no less than 6 feet
- ☒ Culvert/bridge slope does not greatly exceed slope of natural channel, slopes of 6 % or less
- ☒ Narrow stream valleys

Selected Design Option: Stream Simulation Design Option

Basis for Selection: All criteria was met, emphasis on bed stability of the channel and within culvert

Seek Agency Approval: ☐ Yes ☒ No

Form 4- Guidance on Methodology for Hydrologic Analysis

Form 4 summarizes methods for estimating peak design discharges that will be used in a hydraulic analysis. Data requirements, limitations, and guidance are provided to assist in the hydrologic method selection.

For this particular example, all data requirements needed to calculate peak discharges by regional regression equations were readily available. Mono County is located in the South Lahontan-Colorado Region.

GUIDANCE ON METHODOLOGY FOR HYDROLOGIC ANALYSIS [1, 2] FORM 4

Project Information Route 333 4-Lane		Computed: EKB	Date: 8/19/06
		Checked: LEF	Date: 8/20/06
Stream Name: Stormy Creek	County: Mono	Route: 333	Postmile: 34.1

Summary of Methods for Estimating Peak Design Discharges for Use in Hydraulic Analysis

Ungaged Streams

☒ **Regional Regression**[3, 4]

Data Requirements	Limitations	Guidance
▪ Drainage area ▪ Mean annual precipitation ▪ Altitude index	▪ Peak discharge value for flow under natural conditions unaffected by urban development and little or no regulation by lakes or reservoirs ▪ Ungaged channel	The most recently published USGS report for estimating peak discharges may be used. The user should exercise caution to ensure that the reports are used only for the conditions and locations for which they are recommended.

Rainfall-Runoff Models

☐ **NRCS (TR 55)**[5]

Data Requirements	Limitations	Guidance
▪ 24-hour Rainfall ▪ Rainfall distribution ▪ Runoff curve number ▪ Concentration time ▪ Drainage area	▪ Small or midsize catchment (<8 km²) ▪ Maximum of 10 subwatersheds ▪ Concentration time range from 0.1-10 hour (tabular hydrograph method limit <2 hour) ▪ Runoff is overland and channel flow ▪ Simplified channel routing ▪ Negligible channel storage	TR-55 focuses on small urban and urbanizing watersheds.

☐ **HEC-1/HEC-HMS[6, 7] (SCS Dimnesionless, Snyder Unit, Clark Unit Hydrographs)**

Data Requirements	Limitations	Guidance
▪ Watershed/subbasin parameters ▪ Precipitation depth, duration, frequency, and distribution ▪ Precipitation losses ▪ Unit hydrograph parameters ▪ Streamflow routing and diversion parameters	▪ Simulations are limited to a single storm event ▪ Streamflow routing is performed by hydrologic routing methods and is therefore not appropriate for unsteady state routing conditions.	Can be used for watersheds which are: small or large, simple or complex, and developed or undeveloped.

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[1] Caltrans Highway Design Manual, Chapter 810 Hydrology, Topic 819 Estimating Design Discharge

[2] FEMA Guidelines and Specifications, Appendix C, Section C.1

[3] USGS Water-Resources Investigation 77-21 (Magnitude and Frequency of Floods in California)

[4] USGS Open-File Report 93-419 (Methods for Estimating Magnitude and Frequency of floods in the Southwestern United States)

[5] United States Department of Agriculture, Natural Resources Conservation Service, Urban Hydrology for Small Watersheds Technical Release 55, June 1986. ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf

[6] HEC-1 User's Manual

[7] HEC-HMS User's Manual

[8] Bulletin 17B

GUIDANCE ON METHODOLOGY FOR HYDROLOGIC ANALYSIS [1, 2] FORM 4

GAGED STREAMS

☐ **Statistical Methods**[8]

Data Requirements	Limitations	Guidance
10 or more years of gaged flood records	Gage data is usually only available for midsized and large catchments Appropriate station and/or generalized skew coefficient relationship applied	For watersheds with less than 50 years of record, compare with results of appropriate USGS regional regression equations. For watersheds with less than 25 years of record, compare with results of appropriate USGS regional regresssion equations and/or HEC-1/HEC-HMS model results.

☐ **Basin Transfer of Gage Data**

Data Requirements	Limitations	Guidance
Discharge and area for gaged watershed Area for ungaged watershed	Similar hydrologic characteristics Channel storage	Must obtain approval of transfer technique from hydraulics engineer prior to use.

☐ **Fish Passage Flows**

Streamflow hydrograph Flow duration curve		Lower and upper fish passage flows define the range of flows a culvert should contain suitable conditions for fish passage.

Selected Hydrologic Method: Regional Regression Analysis

Basis for Selection:

All parameters needed to calculate peak discharges using regional regression equations were readily available

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[1] Caltrans Highway Design Manual, Chapter 810 Hydrology, Topic 819 Estimating Design Discharge

[2] FEMA Guidelines and Specifications, Appendix C, Section C.1

[3] USGS Water-Resources Investigation 77-21 (Magnitude and Frequency of Floods in California)

[4] USGS Open-File Report 93-419 (Methods for Estimating Magnitude and Frequency of floods in the Southwestern United States)

[5] United States Department of Agriculture, Natural Resources Conservation Service, Urban Hydrology for Small Watersheds Technical Release 55, June 1986. ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf

[6] HEC-1 User's Manual

[7] HEC-HMS User's Manual

[8] Bulletin 17B

Verify Reasonableness and Recommended Peak Discharges

Source	50% Annual Probability (2-Year Flood Event) (cfs)	10% Annual Probability (10-Year Flood Event) (cfs)	4% Annual Probability (25-Year Flood Event) (cfs)	2% Annual Probability (50-Year Flood Event) (cfs)	1% Annual Probability (100-Year Flood Event) (cfs)	High Fish Passage Design Flow (cfs)	Low Fish Passage Design Flow (cfs)
Effective Study Peak Discharges	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Recommended Peak Discharges	7	47	342	516	880	N/A	N/A

Hydrologic Analysis Index Attached ☒ Yes ☐ No

Hydrologic Analysis Calculations Attached ☒ Yes ☐ No

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[1] Caltrans Highway Design Manual, Chapter 810 Hydrology, Topic 819 Estimating Design Discharge

[2] FEMA Guidelines and Specifications, Appendix C, Section C.1

[3] USGS Water-Resources Investigation 77-21 (Magnitude and Frequency of Floods in California)

[4] USGS Open-File Report 93-419 (Methods for Estimating Magnitude and Frequency of floods in the Southwestern United States)

[5] United States Department of Agriculture, Natural Resources Conservation Service, Urban Hydrology for Small Watersheds Technical Release 55, June 1986. ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf

[6] HEC-1 User's Manual

[7] HEC-HMS User's Manual

[8] Bulletin 17B

HYDROLOGIC ANALYSES INDEX

FORM 4

Project Information Route 333 4-Lane	Computed: EKB	Date: 8/19/06	
	Checked: LEF	Date: 8/20/06	
Stream Name: Stormy Creek	County: Mono	Route: 333	Postmile: 34.1

Flooding Source/Stream Name	Hydrologic Method/Model Used	Method/Model Analysis Date	Exhibit No.	
			Paper Copy	Electronic Copy
Stormy Creek	Regional Regression	Site Location: South Lahotan-Colorado Desert Region	/	—

↳ Source: National Summary of USGS Regional Regression Equations for Estimating Magnitude & Frequency of Floods for Ungaged sites, 1993.

Regional Regression Computation Summary

Project Information:	Route 333 4-Lane	Computed:	EKB	Date:	6/31/2006
		Checked:	LEF	Date:	7/1/2006
Stream Name: Stormy Creek	County: Mono	Route:	333	Postmile:	12.8

Calculations:

-Site Located in South Lahontan-Colorado Desert

A, Drainage Area = 0.75 mi^2

Regional Regression Equations

Q2 = 7.3A^0.30
Q2 = 7 cfs

Q10 = 53A^0.44
Q10 = 47 cfs

Q25 = 410A^0.63
Q25 = 342 cfs

Q50 = 700A^0.68
Q50 = 576 cfs

Q100 = 1080A^0.71
Q100 = 880 cfs

The following documentation was taken from:

U.S. Geological Survey Water-Resources Investigations Report 94-4002:
Nationwide summary of U.S. Geological Survey regional regression equations for estimating magnitude and frequency of floods for ungaged sites, 1993

CALIFORNIA

STATEWIDE RURAL

Summary

California is divided into six hydrologic regions (fig. 1). The regression equations developed for these regions are for estimating peak discharges (QT) having recurrence intervals T that range from 2 to 100 years. The explanatory basin variables used in the equations are drainage area (A), in square miles; mean annual precipitation (P), in inches; and an altitude index (H), which is the average of altitudes in thousands of feet at points along the main channel at 10 percent, and 85 percent of the distances from the site to the divide. The variables A and H may be measured from topographic maps. Mean annual precipitation (P) is determined from a map in Rantz (1969). The regression equations were developed from peak-discharge records of 10 years or longer, available as of 1975, at more than 700 gaging stations throughout the State. The regression equations are applicable to unregulated streams but are not applicable to some parts of the State (see fig. 1). The standard errors of estimate for the regression equations for various recurrence intervals and regions range from 60 to over 100 percent. The report by Waananen and Crippen (1977) includes an approximate procedure for increasing a rural discharge to account for the effect of urban development. The influences of fire and other basin changes on flood magnitudes are also discussed.

Procedure

Topographic maps, the hydrologic regions map (fig. 1), the mean annual precipitation from Rantz (1969), and the following equations are used to estimate the needed peak discharges QT, in cubic feet per second, having selected recurrence intervals T.

North Coast Region

$Q2 = 3.52 A^{0.90} P^{0.89} H^{-0.47}$
$Q5 = 5.04 A^{0.89} P^{0.91} H^{-0.35}$
$Q10 = 6.21 A^{0.88} P^{0.93} H^{-0.27}$
$Q25 = 7.64 A^{0.87} P^{0.94} H^{-0.17}$
$Q50 = 8.57 A^{0.87} P^{0.96} H^{-0.08}$
$Q100 = 9.23 A^{0.87} P^{0.97}$

Northeast Region

$Q2 = 22 A^{0.40}$
$Q5 = 46 A^{0.45}$
$Q10 = 61 A^{0.49}$
$Q25 = 84 A^{0.54}$
$Q50 = 103 A^{0.57}$
$Q100 = 125 A^{0.59}$

Sierra Region

$Q2 = 0.24 A^{0.88} P^{1.58} H^{-0.80}$
$Q5 = 1.20 A^{0.82} P^{1.37} H^{-0.64}$
$Q10 = 2.63 A^{0.80} P^{1.25} H^{-0.58}$
$Q25 = 6.55 A^{0.79} P^{1.12} H^{-0.52}$
$Q50 = 10.4 A^{0.78} P^{1.06} H^{-0.48}$
$Q100 = 15.7 A^{0.77} P^{1.02} H^{-0.43}$

Central Coast Region

$Q2 = 0.0061 A^{0.92} P^{2.54} H^{-1.10}$
$Q5 = 0.118 A^{0.91} P^{1.95} H^{-0.79}$
$Q10 = 0.583 A^{0.90} P^{1.61} H^{-0.64}$
$Q25 = 2.91 A^{0.89} P^{1.26} H^{-0.50}$
$Q50 = 8.20 A^{0.89} P^{1.03} H^{-0.41}$
$Q100 = 19.7 A^{0.88} P^{0.84} H^{-0.33}$

South Coast Region

$Q2 = 0.14 A^{0.72} P^{1.62}$
$Q5 = 0.40 A^{0.77} P^{1.69}$
$Q10 = 0.63 A^{0.79} P^{1.75}$
$Q25 = 1.10 A^{0.81} P^{1.81}$
$Q50 = 1.50 A^{0.82} P^{1.85}$
$Q100 = 1.95 A^{0.83} P^{1.87}$

South Lahontan-Colorado Desert Region

$$
\begin{aligned}
Q2 &= 7.3A^{0.30}\\
Q5 &= 53A^{0.44}\\
Q10 &= 150A^{0.53}\\
Q25 &= 410A^{0.63}\\
Q50 &= 700A^{0.68}\\
Q100 &= 1080A^{0.71}
\end{aligned}
$$

In the North Coast region, use a minimum value of 1.0 for the altitude index (H). Equations are defined only for basins of 25 mi² or less in the Northeast and South Lahontan-Colorado Desert regions.

Reference

Waananen, A.O., and Crippen, J.R., 1977, Magnitude and frequency of floods in California: U.S. Geological Survey Water-Resources Investigations Report 77-21, 96 p.

Additional Reference

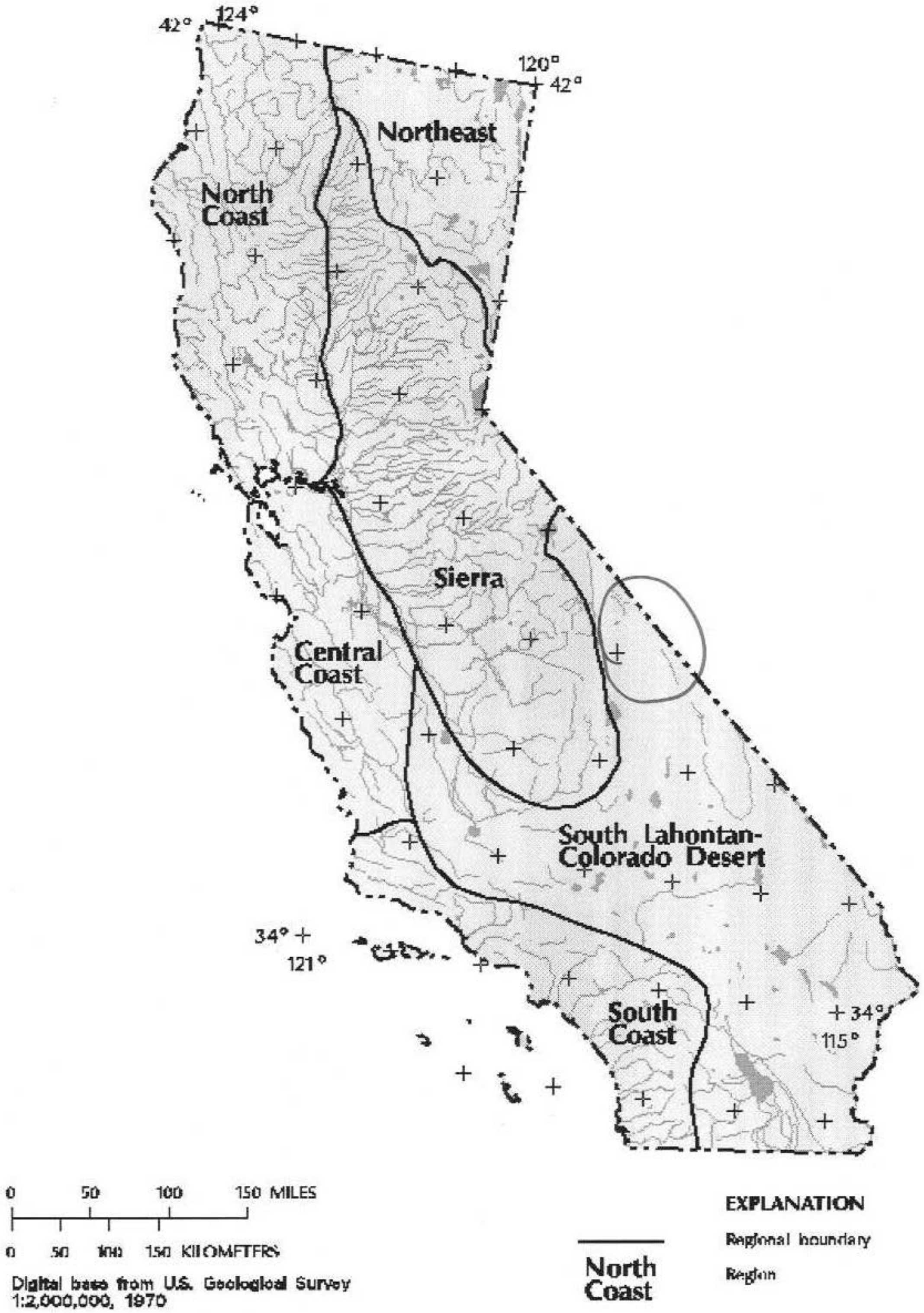
Rantz, S.E., 1969, Mean annual precipitation in the California region: U.S. Geological Survey Open-File Map (Reprinted 1972, 1975).

Figure 1. Flood-frequency region map for California. (PostScript file of Figure 1.)

Back to NFF main page

USGS Surface-Water Software Page

U.S. Geological Survey
National Flood Frequency Program
Water-Resources Investigations Report 94-4002



Digital base from U.S. Geological Survey 1:2,000,000, 1970

Albers equal-area projection based on standard parallels 29.5 and 45.5 degrees

Figure 1. Flood-frequency region map for California.

Form 5 - Guidance on Methodology for Hydraulic Analysis

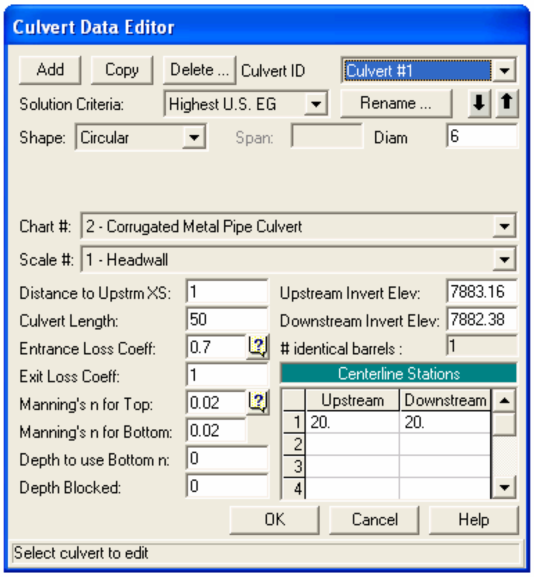
Form 5 summarizes the acceptable methods available for hydraulic analysis. The modeling methods include FHWA Design Charts, HY8 - Culvert Analysis, and HEC-2/HEC-RAS, and Fish Xing for pre- or post-design assessment.

For this particular example, HEC-RAS was used to model existing and proposed conditions. HEC-RAS easily allowed a quick comparison between existing and proposed water surface elevations and velocities.

The HEC-RAS model consists of two plans: existing geometry and proposed geometry conditions. Both plans use the same peak discharges estimated by regional regression analysis.

The existing culvert geometry was modeled using the Culvert Data Editor. The existing culvert parameters that had been measured and captured in Form 2 - Site Visit Summary, were entered into the Culvert Data Editor within HEC-RAS.

The Culvert Data Editor and Bridge Culvert Data windows are captured below.

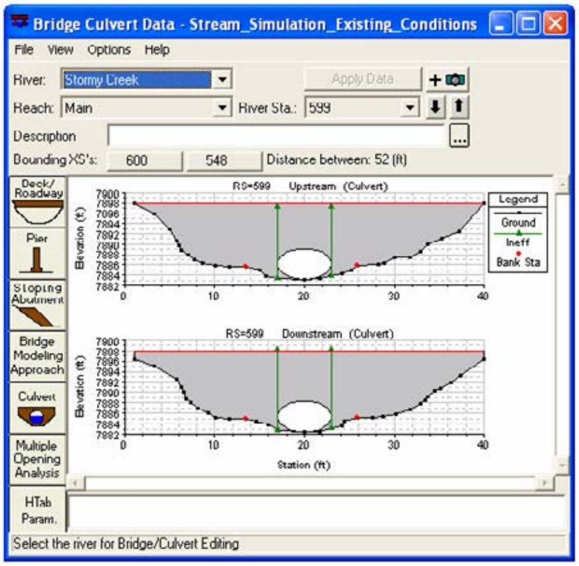


Culvert ID: Culvert #1
Solution Criteria: Highest U.S. EG
Shape: Circular
Span:
Diam: 6
Chart #: 2 - Corrugated Metal Pipe Culvert
Scale #: 1 - Headwall
Distance to Upstrm XS: 1
Culvert Length: 50
Entrance Loss Coeff: 0.7
Exit Loss Coeff: 1
Manning's n for Top: 0.02
Manning's n for Bottom: 0.02
Depth to use Bottom n: 0
Depth Blocked: 0
Upstream Invert Elev: 7883.16
Downstream Invert Elev: 7882.38
identical barrels : 1

Centerline Stations

	Upstream	Downstream
1	20.	20.
2		
3		
4		

Select culvert to edit

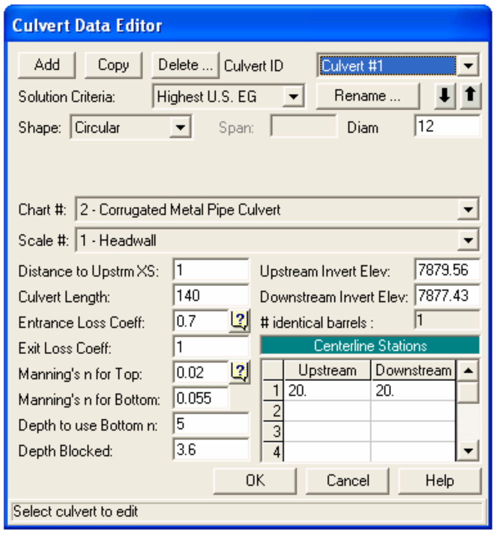


River: Stormy Creek
Reach: Main
River Sta.: 599
Description:
Bounding XS's: 600 548 Distance between: 52 (ft)

Select the river for Bridge/Culvert Editing

The proposed culvert geometry was also modeled using the Culvert Data Editor in HEC-RAS. The depth blocked feature and higher Manning's n-values for the culvert bottom was used to model the bed embedment.

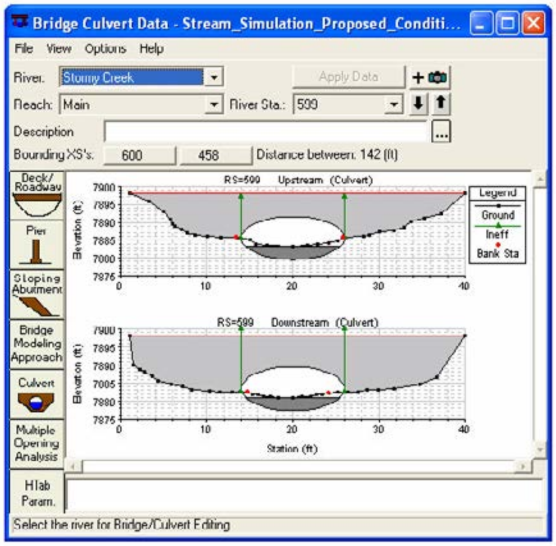
The Culvert Data Editor and Bridge Culvert Data windows are captured below.



Culvert ID: Culvert #1
Solution Criteria: Highest U.S. EG
Shape: Circular
Diam: 12
Chart #: 2 - Corrugated Metal Pipe Culvert
Scale #: 1 - Headwall
Distance to Upstrm XS: 1
Culvert Length: 140
Entrance Loss Coeff: 0.7
Exit Loss Coeff: 1
Manning's n for Top: 0.02
Manning's n for Bottom: 0.055
Depth to use Bottom n: 5
Depth Blocked: 3.6
Upstream Invert Elev: 7879.56
Downstream Invert Elev: 7877.43
identical barrels : 1

	Upstream	Downstream
1	20.	20.
2		
3		
4		

Select culvert to edit



River: Stormy Creek
Reach: Main
River Sta.: 599
Description:
Bounding XS's: 600 458 Distance between: 142 (ft)

Select the river for Bridge/Culvert Editing

GUIDANCE ON METHODOLOGY FOR HYDRAULIC ANALYSIS FORM 5

Project Information Route 333 4-Lane		Computed: EKB	Date: 8/22/06
		Checked: JJL	Date: 8/23/06
Stream Name: Stormy Creek	County: Mono	Route: 333	Postmile: 34.1

Summary of Methods for Hydraulic Analysis

☐ **FHWA Design Charts**

☐ **HY8 - Culvert Analysis or other HDS-5 Based Software**

☒ **HEC-2 / [✓ HEC-RAS]**

☐ **Fish Xing (Pre-design assessment or post-design assessment when applicable)**

Is the hydraulic model used to create the effective FIRM available? ☐ Yes ☒ No
If yes, update and use this model for the hydraulic model.

Selected Method: HEC-RAS

Basis for Selection:

- X-section geometry for upstream and downstream readily available
- Steady flow modeling

Verify Reasonableness and Recommended Flows ☒ Yes ☐ No

Hydraulic Analyses Index Attached ☒ Yes ☐ No

Hydraulic Analysis Calculation Attached ☒ Yes ☐ No

HYDRAULIC ANALYSES INDEX

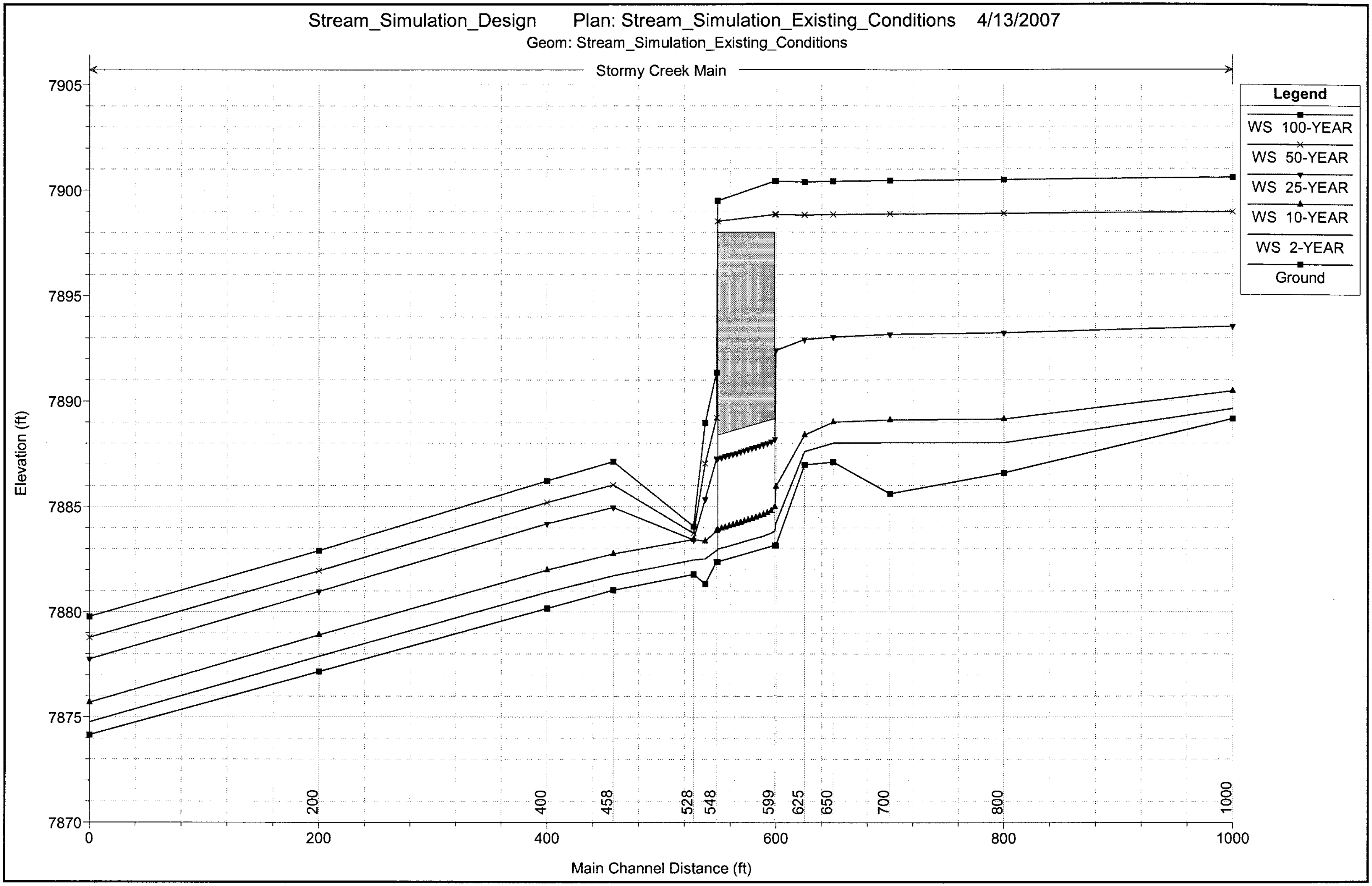
FORM 5

Project Information
Route 333 4-Lane

Computed: EKB Date: 8/22/06
Checked: LEF Date: 8/23/06

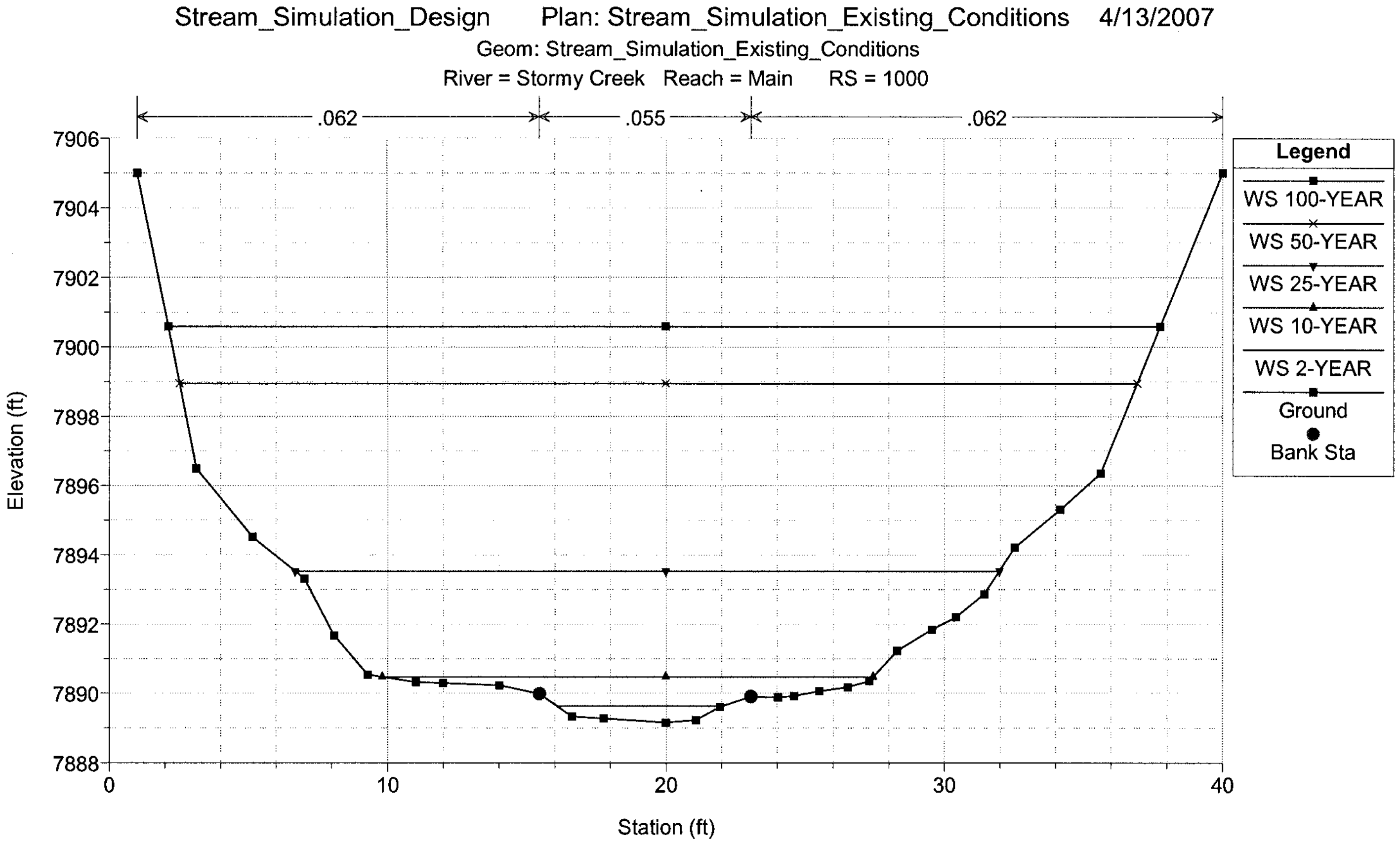
Stream Name: Stormy Creek County: Mono Route 333 Postmile 34.1

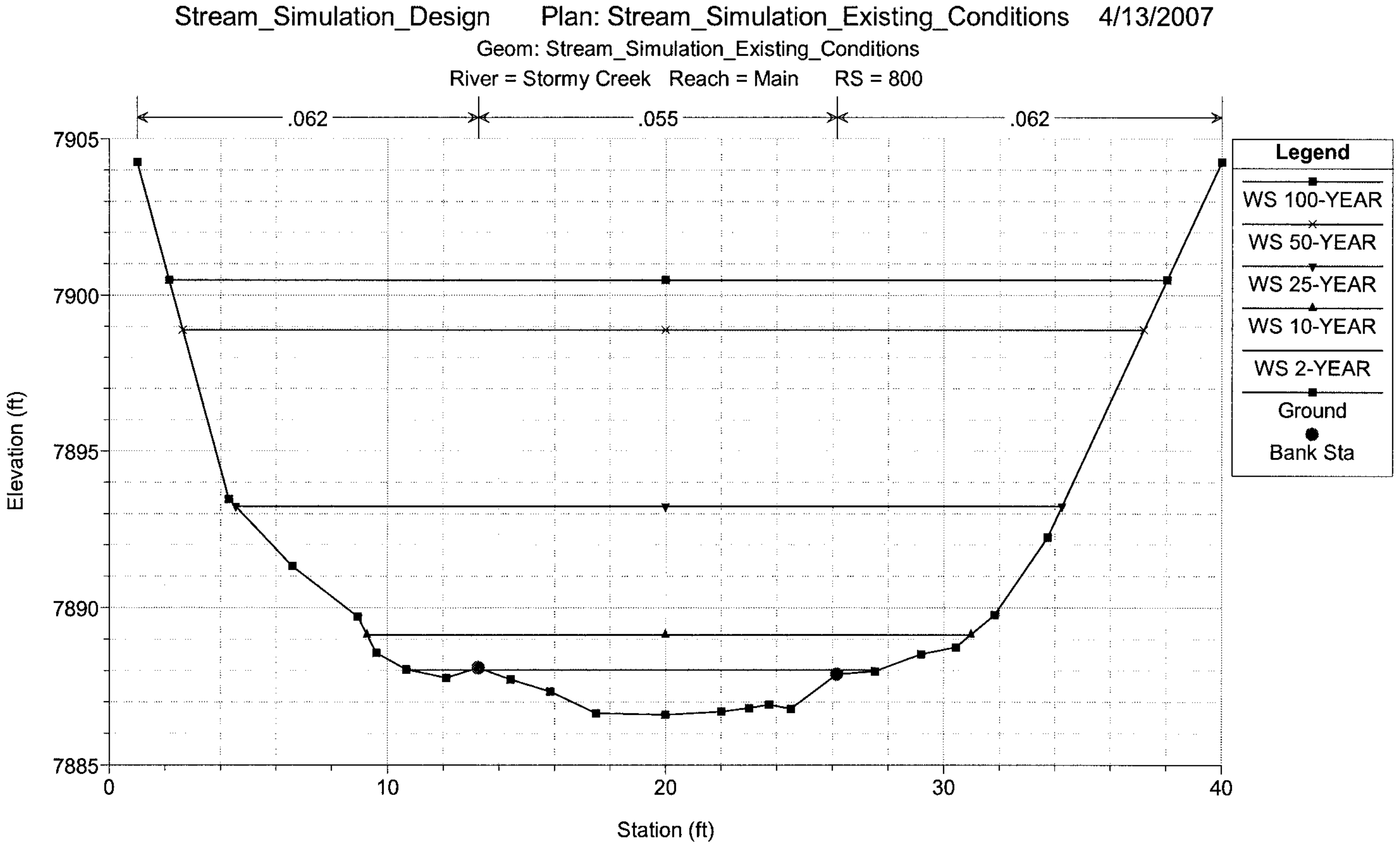
Flooding Source/Stream Name	Hydraulic Method/Model Used	Method/Model Analysis Date	Exhibit No.	
			Paper Copy	Electronic Copy
Stormy Creek	HEC-RAS	Model created: 8/23/06	/	
	Existing Conditions			.p01 .g01 .f01
	Proposed Conditions			.p02 .g02 .f01

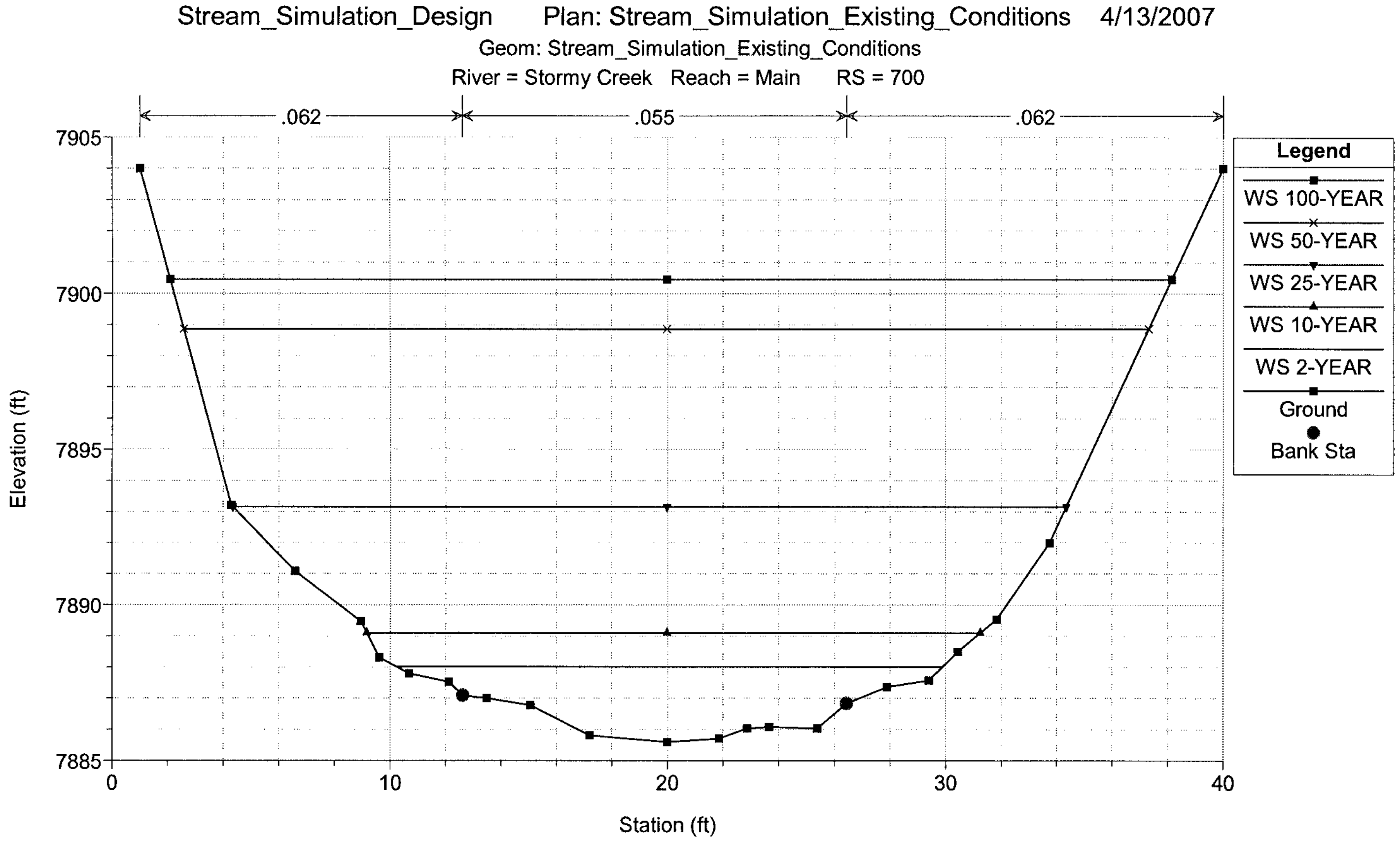


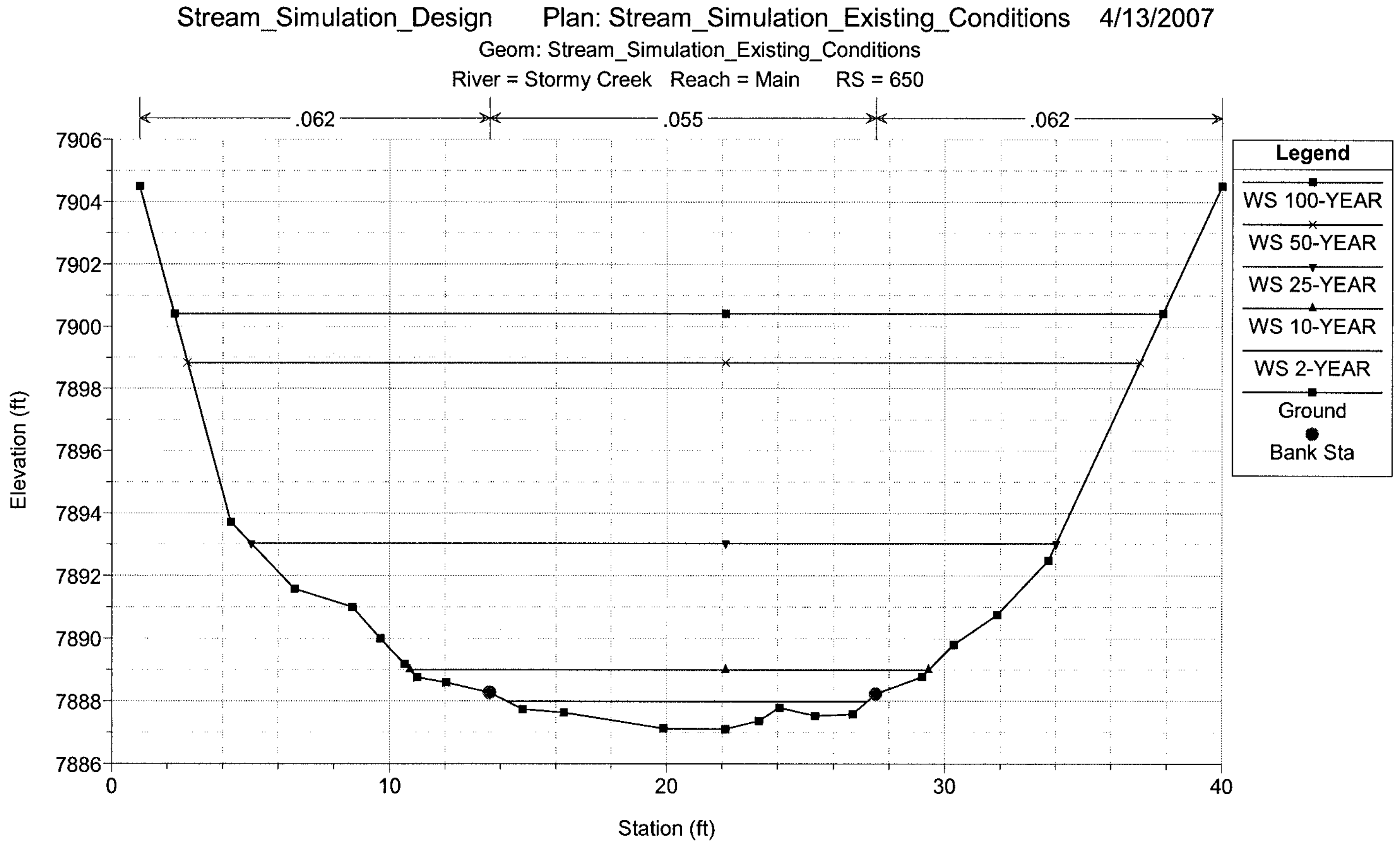
Stream_Simulation_Design Plan: Stream_Simulation_Existing_Conditions 4/13/2007

Geom: Stream_Simulation_Existing_Conditions

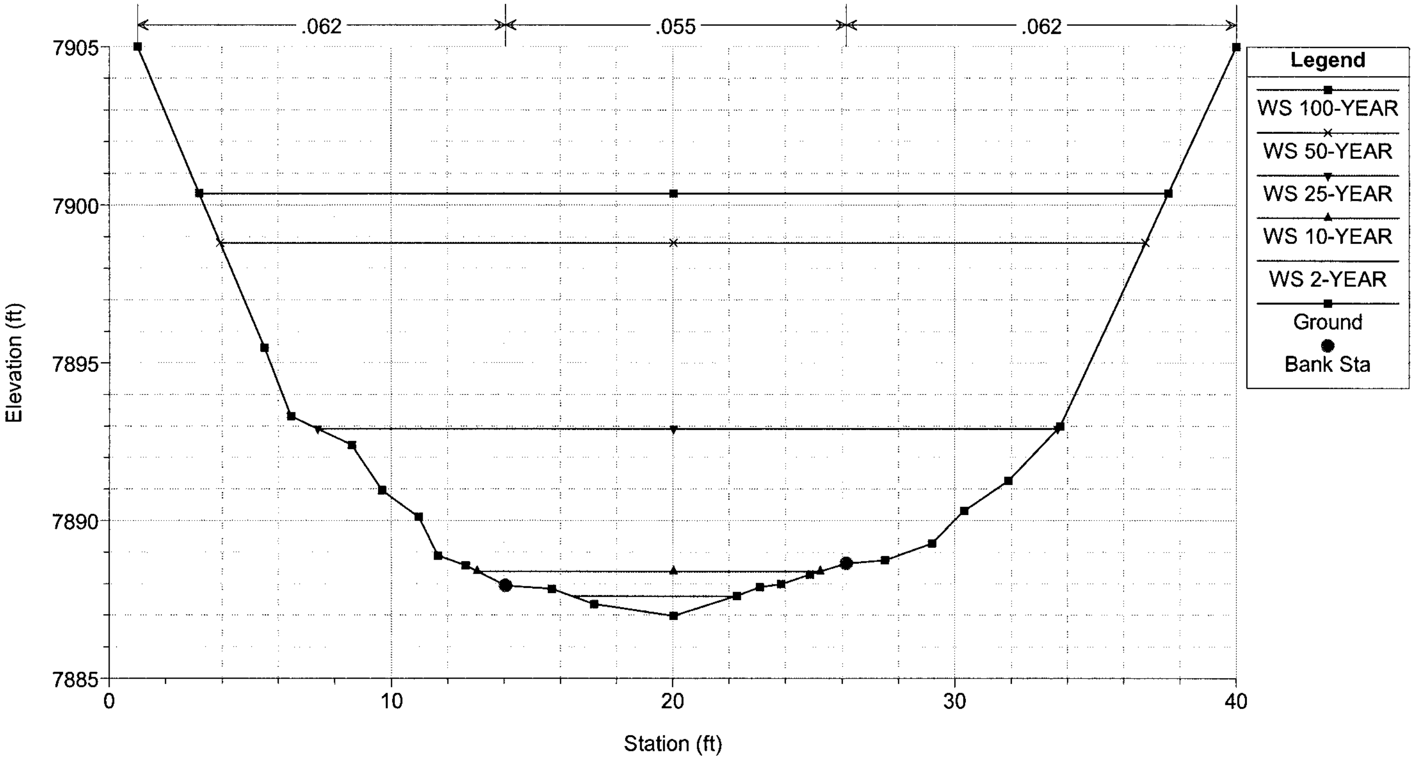

Stream_Simulation_Design Plan: Stream_Simulation_Existing_Conditions 4/13/2007
Geom: Stream_Simulation_Existing_Conditions
River = Stormy Creek Reach = Main RS = 1000
.062
.055
.062
7906
7904
7902
7900
7898
7896
7894
7892
7890
7888
Elevation (ft)
0
10
20
30
40
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 25-YEAR
WS 10-YEAR
WS 2-YEAR
Ground
Bank Sta


Stream_Simulation_Design Plan: Stream_Simulation_Existing_Conditions 4/13/2007
Geom: Stream_Simulation_Existing_Conditions
River = Stormy Creek Reach = Main RS = 800
.062
.055
.062
7905
7900
7895
7890
7885
Elevation (ft)
0
10
20
30
40
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 25-YEAR
WS 10-YEAR
WS 2-YEAR
Ground
Bank Sta

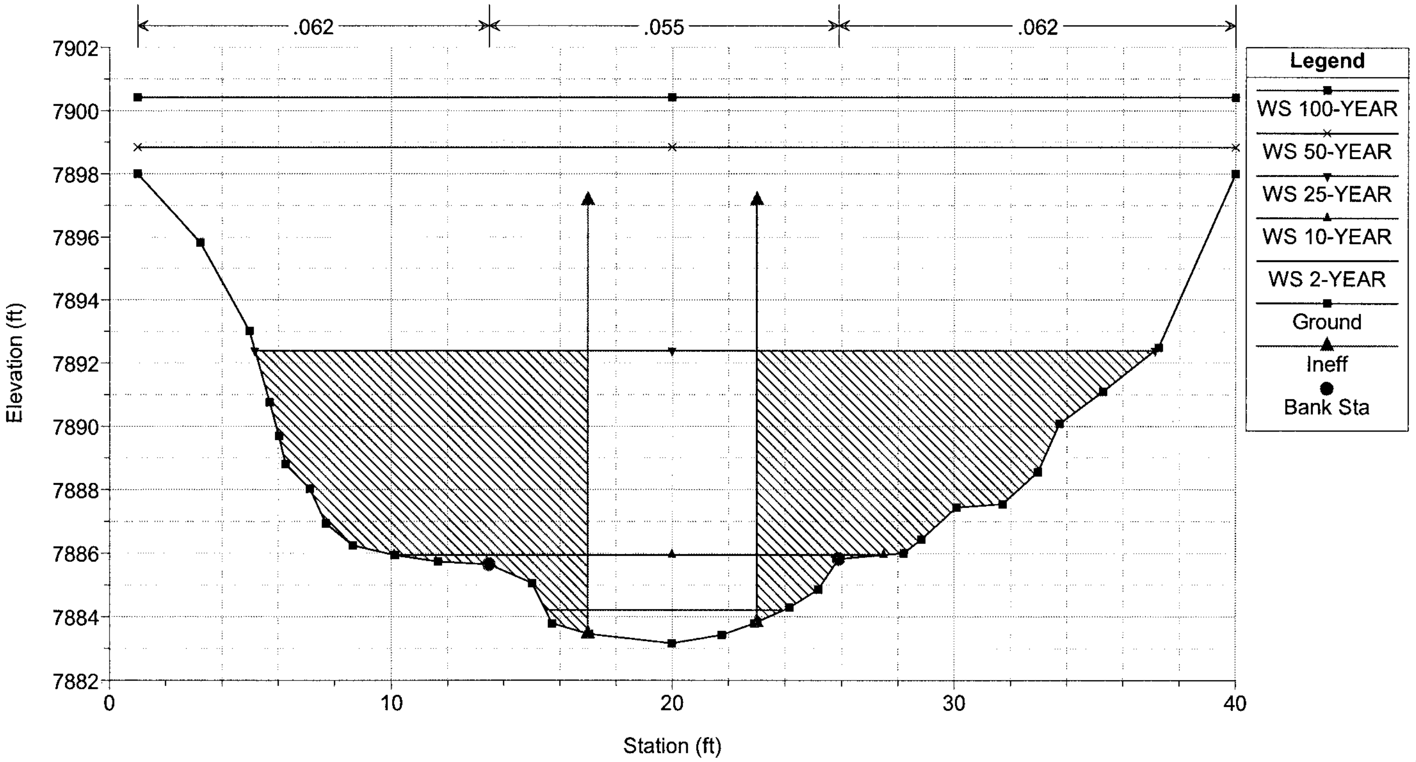

Stream_Simulation_Design Plan: Stream_Simulation_Existing_Conditions 4/13/2007
Geom: Stream_Simulation_Existing_Conditions
River = Stormy Creek Reach = Main RS = 700
.062
.055
.062
Elevation (ft)
7905
7900
7895
7890
7885
Station (ft)
0
10
20
30
40
Legend
WS 100-YEAR
WS 50-YEAR
WS 25-YEAR
WS 10-YEAR
WS 2-YEAR
Ground
Bank Sta

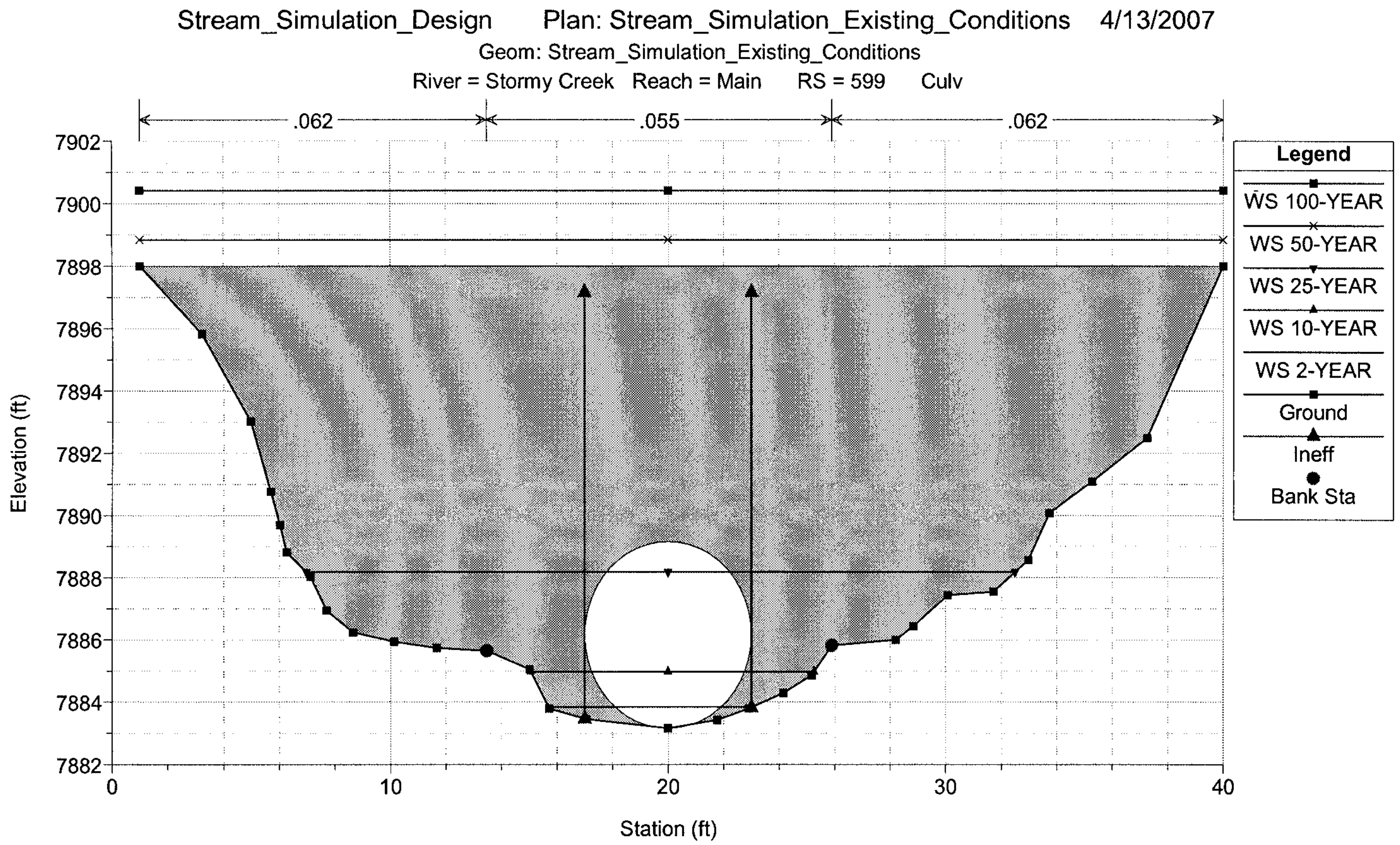

Stream_Simulation_Design Plan: Stream_Simulation_Existing_Conditions 4/13/2007
Geom: Stream_Simulation_Existing_Conditions
River = Stormy Creek Reach = Main RS = 650
.062
.055
.062
Elevation (ft)
7906
7904
7902
7900
7898
7896
7894
7892
7890
7888
7886
Station (ft)
0
10
20
30
40
Legend
WS 100-YEAR
WS 50-YEAR
WS 25-YEAR
WS 10-YEAR
WS 2-YEAR
Ground
Bank Sta

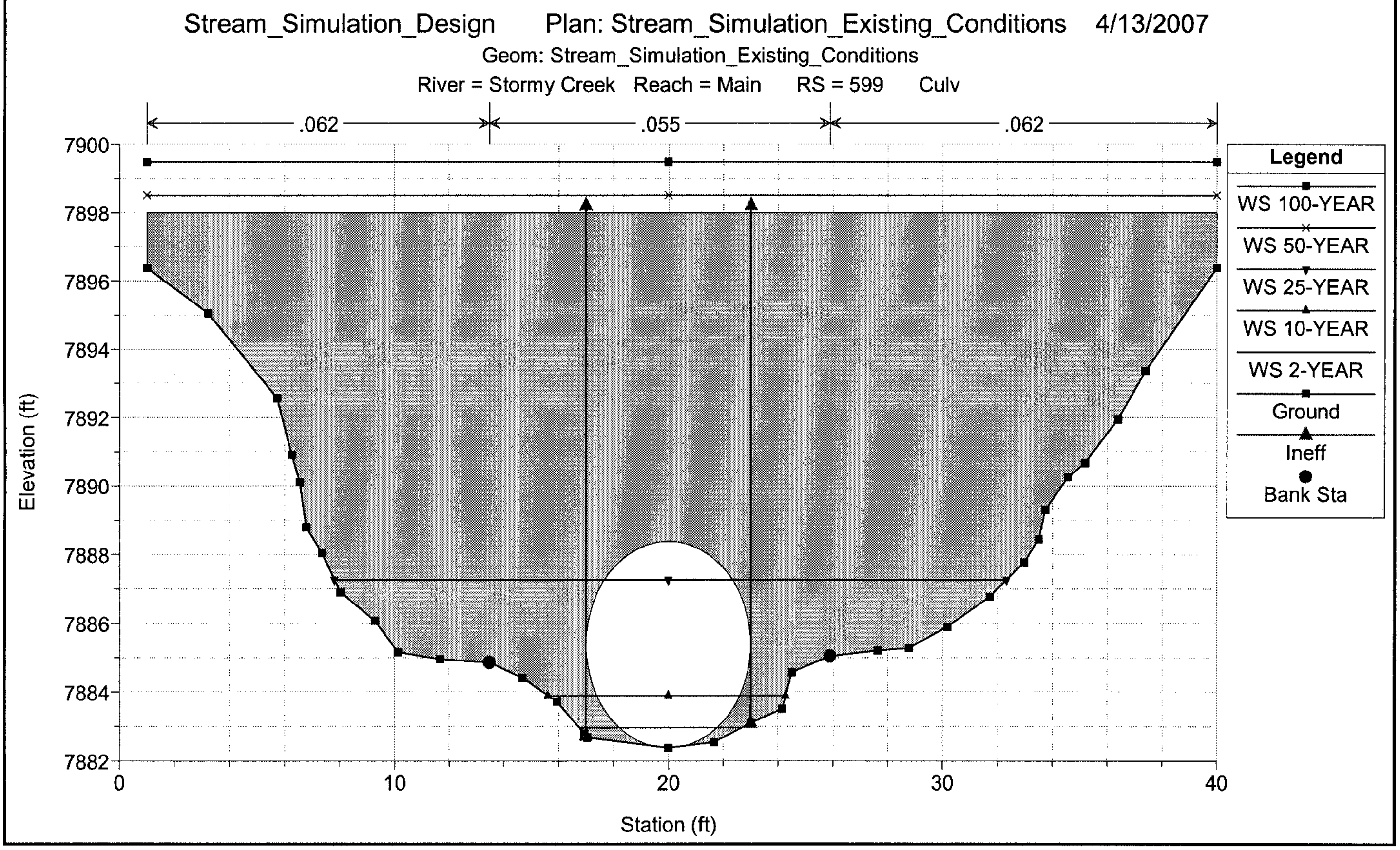
Stream_Simulation_Design Plan: Stream_Simulation_Existing_Conditions 4/13/2007
Geom: Stream_Simulation_Existing_Conditions
River = Stormy Creek Reach = Main RS = 625

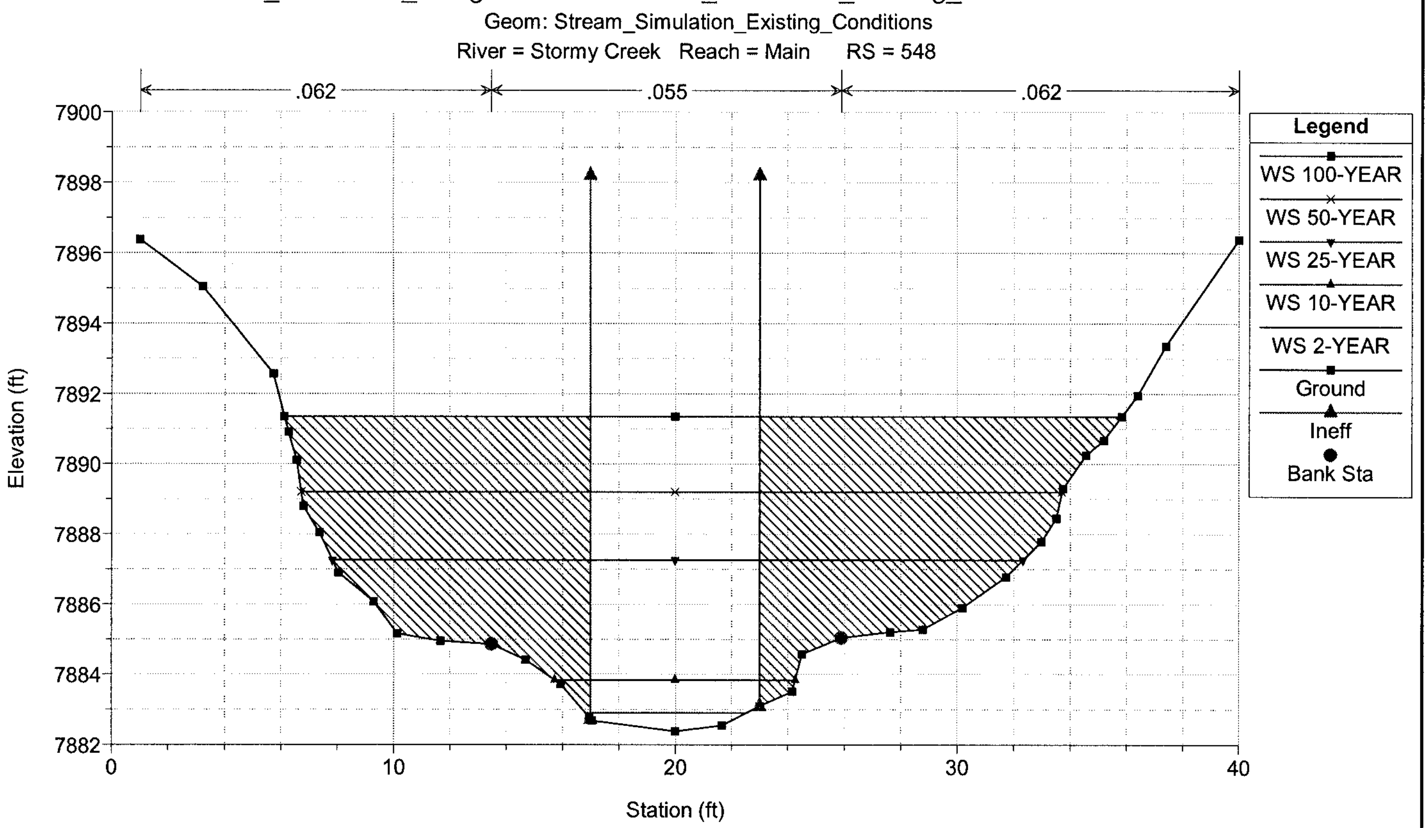


Stream_Simulation_Design Plan: Stream_Simulation_Existing_Conditions 4/13/2007
Geom: Stream_Simulation_Existing_Conditions
River = Stormy Creek Reach = Main RS = 600




Stream_Simulation_Design Plan: Stream_Simulation_Existing_Conditions 4/13/2007
Geom: Stream_Simulation_Existing_Conditions
River = Stormy Creek Reach = Main RS = 599 Culv
.062
.055
.062
Elevation (ft)
7902
7900
7898
7896
7894
7892
7890
7888
7886
7884
7882
0
10
20
30
40
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 25-YEAR
WS 10-YEAR
WS 2-YEAR
Ground
Ineff
Bank Sta

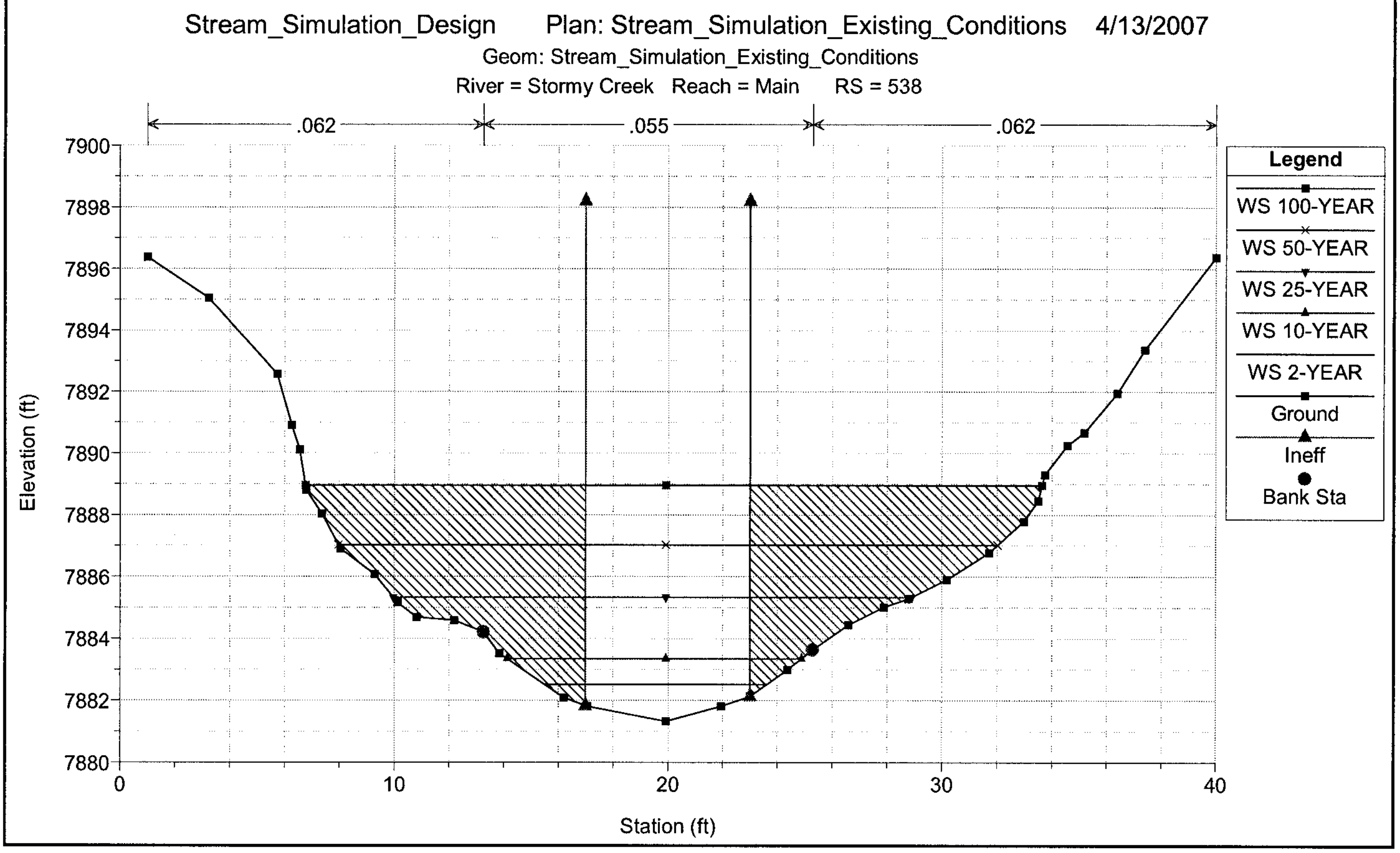

Stream_Simulation_Design Plan: Stream_Simulation_Existing_Conditions 4/13/2007
Geom: Stream_Simulation_Existing_Conditions
River = Stormy Creek Reach = Main RS = 599 Culv
.062
.055
.062
Elevation (ft)
7900
7898
7896
7894
7892
7890
7888
7886
7884
7882
0
10
20
30
40
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 25-YEAR
WS 10-YEAR
WS 2-YEAR
Ground
Ineff
Bank Sta



Stream_Simulation_Design Plan: Stream_Simulation_Existing_Conditions 4/13/2007

Geom: Stream_Simulation_Existing_Conditions

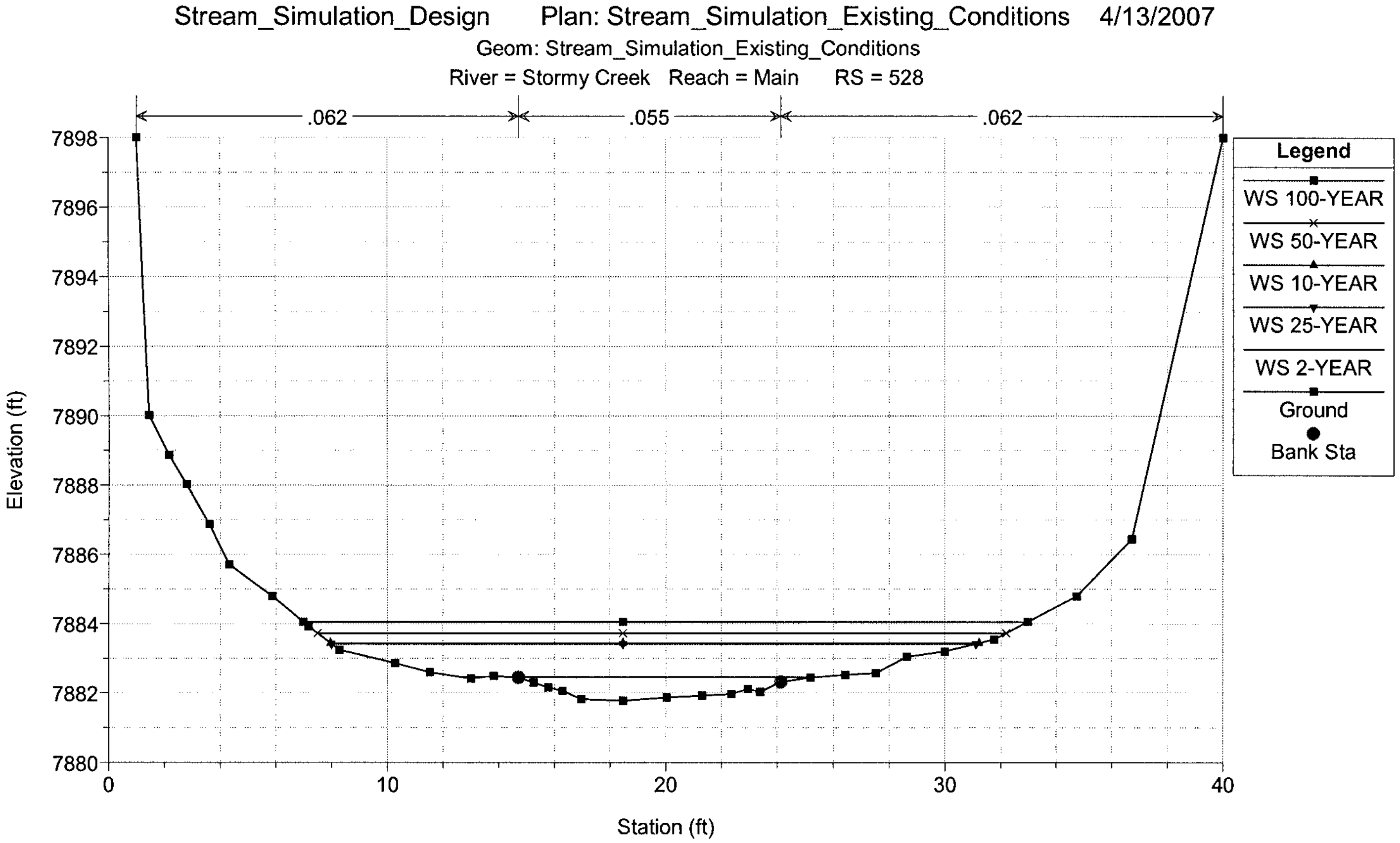
River = Stormy Creek Reach = Main RS = 548

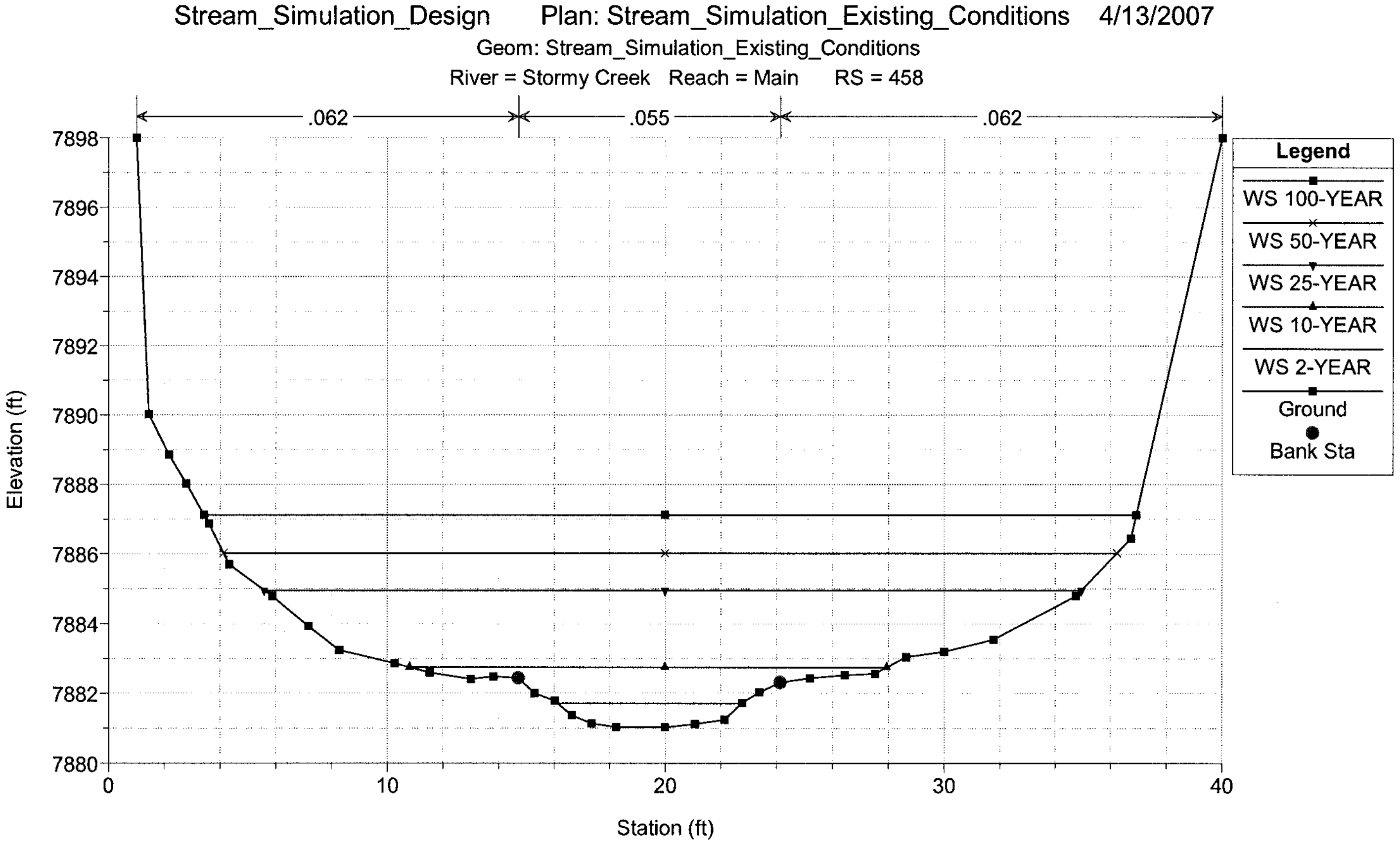


Stream_Simulation_Design Plan: Stream_Simulation_Existing_Conditions 4/13/2007

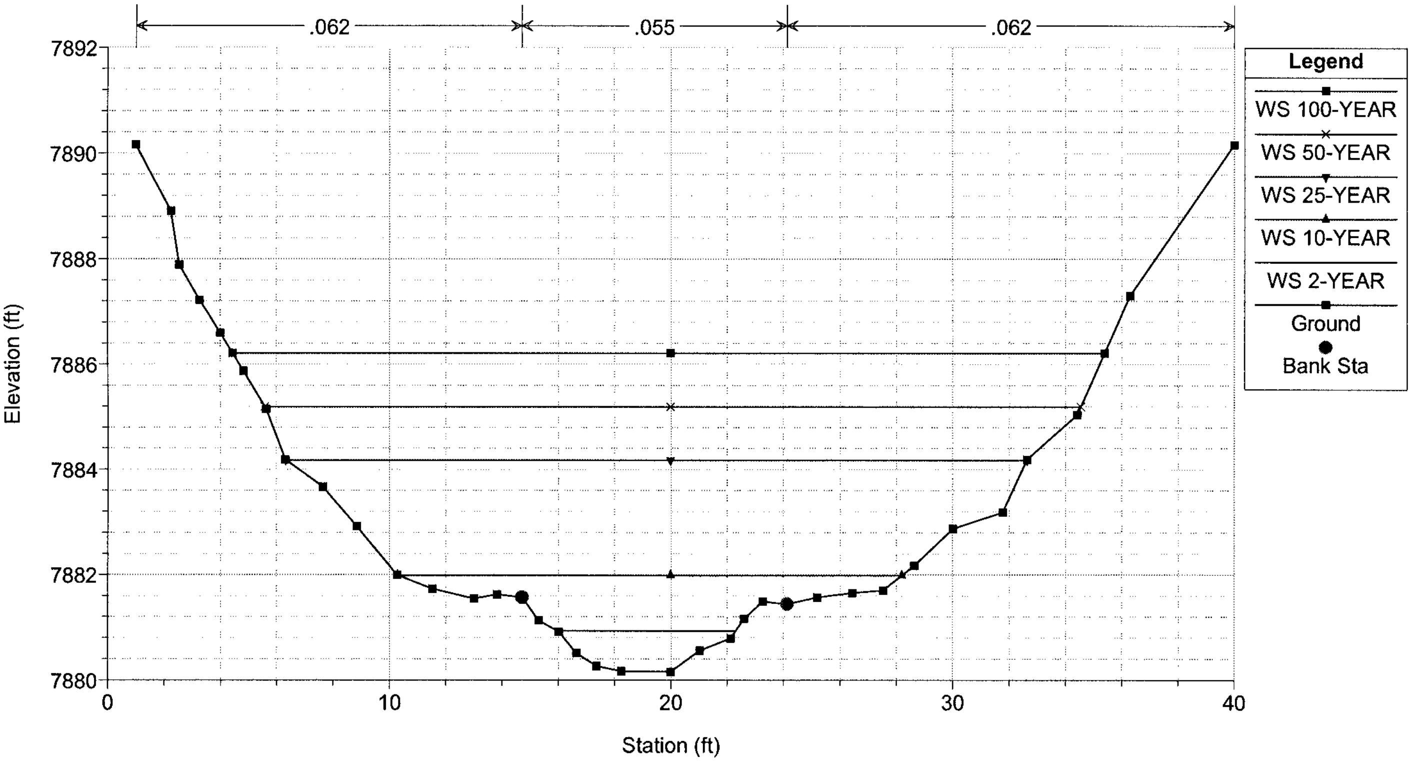
Geom: Stream_Simulation_Existing_Conditions

River = Stormy Creek Reach = Main RS = 538

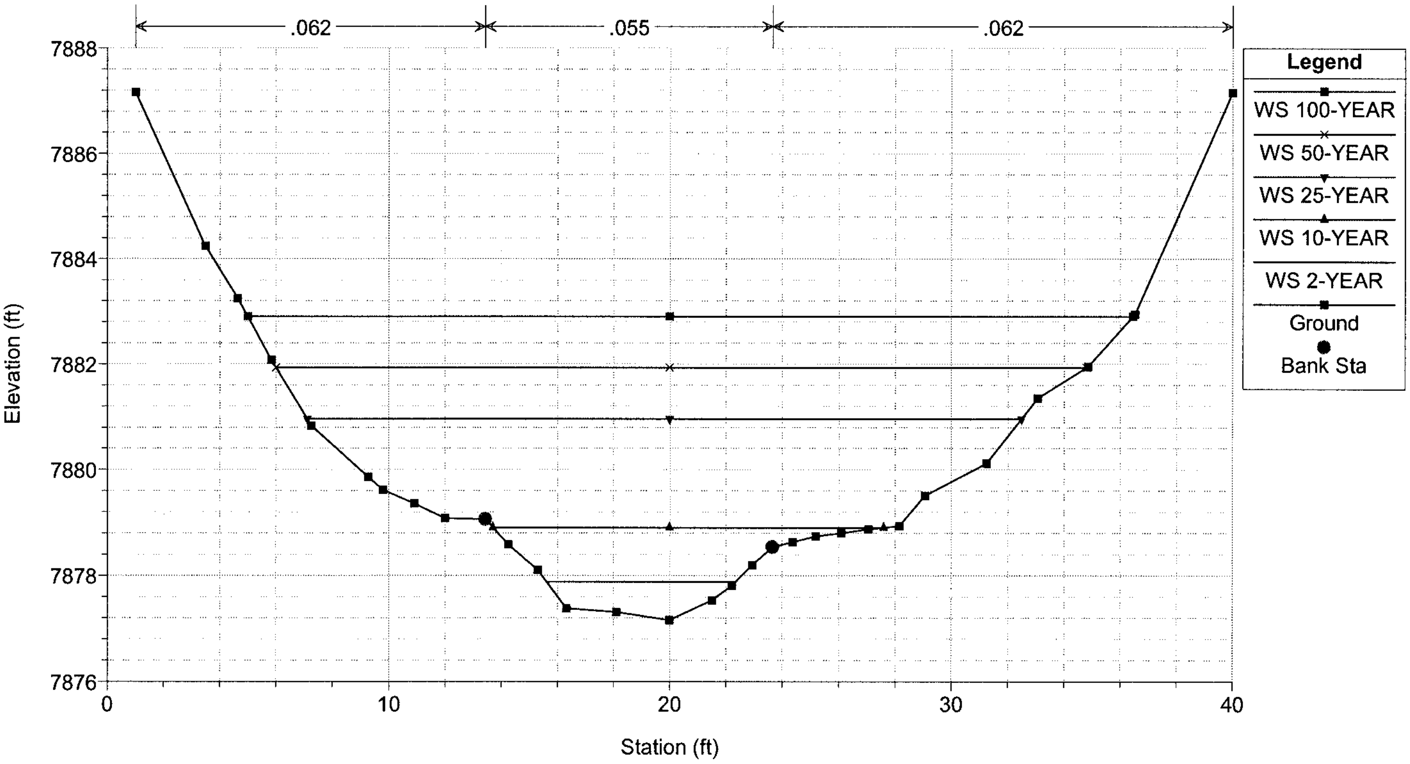

Stream_Simulation_Design Plan: Stream_Simulation_Existing_Conditions 4/13/2007
Geom: Stream_Simulation_Existing_Conditions
River = Stormy Creek Reach = Main RS = 528

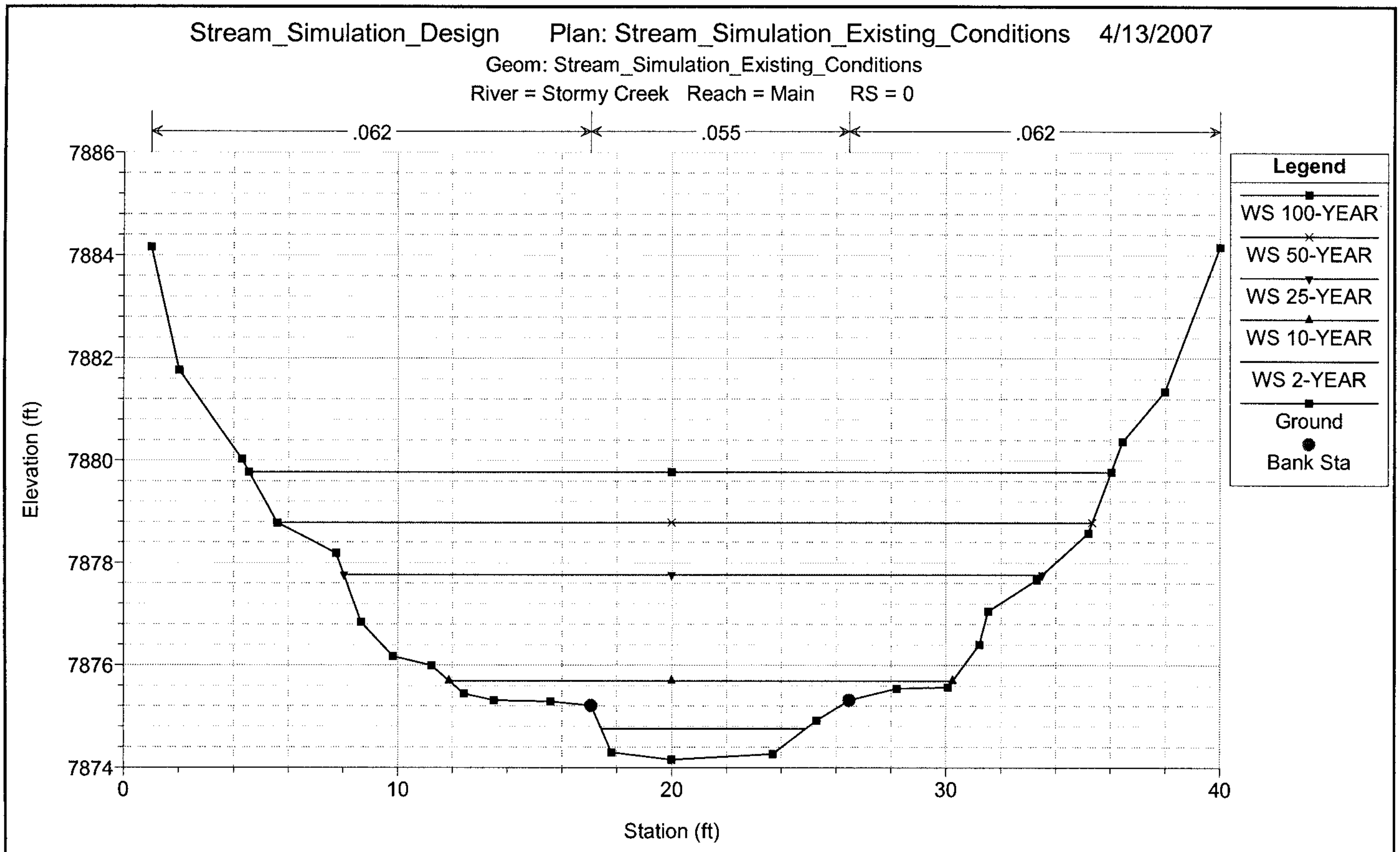

Stream_Simulation_Design Plan: Stream_Simulation_Existing_Conditions 4/13/2007
Geom: Stream_Simulation_Existing_Conditions
River = Stormy Creek Reach = Main RS = 458

Stream_Simulation_Design Plan: Stream_Simulation_Existing_Conditions 4/13/2007
Geom: Stream_Simulation_Existing_Conditions
River = Stormy Creek Reach = Main RS = 400



Stream_Simulation_Design Plan: Stream_Simulation_Existing_Conditions 4/13/2007
Geom: Stream_Simulation_Existing_Conditions
River = Stormy Creek Reach = Main RS = 200





Stream_Simulation_Design Plan: Stream_Simulation_Existing_Conditions 4/13/2007

Geom: Stream_Simulation_Existing_Conditions

River = Stormy Creek Reach = Main RS = 0

HEC-RAS Plan: Existing River: Stormy Creek Reach: Main

Reach	River Sta	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
		(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main	1000	7.00	7889.16	7889.64	7889.64	7889.82	0.064837	3.34	2.09	6.01	1.00
Main	1000	47.00	7889.16	7890.47	7890.47	7890.82	0.032256	4.97	11.25	17.63	0.84
Main	1000	342.00	7889.16	7893.53	7892.20	7893.89	0.006998	5.68	78.13	25.30	0.49
Main	1000	576.00	7889.16	7898.95	7893.08	7899.06	0.000770	3.29	246.46	34.42	0.19
Main	1000	880.00	7889.16	7900.59	7894.00	7900.75	0.000996	4.16	303.63	35.66	0.22
Main	800	7.00	7886.60	7888.02	7887.00	7888.03	0.000407	0.54	13.39	16.45	0.09
Main	800	47.00	7886.60	7889.14	7887.71	7889.17	0.001196	1.50	35.45	21.70	0.18
Main	800	342.00	7886.60	7893.24		7893.35	0.001145	3.00	141.66	29.72	0.21
Main	800	576.00	7886.60	7898.89		7898.95	0.000305	2.38	323.79	34.57	0.12
Main	800	880.00	7886.60	7900.49		7900.60	0.000453	3.16	380.21	35.89	0.15
Main	700	7.00	7885.60	7888.02		7888.02	0.000041	0.26	29.19	19.69	0.03
Main	700	47.00	7885.60	7889.10		7889.11	0.000352	1.02	51.87	22.09	0.10
Main	700	342.00	7885.60	7893.16		7893.25	0.000761	2.66	158.76	29.99	0.18
Main	700	576.00	7885.60	7898.87		7898.93	0.000243	2.23	343.63	34.75	0.11
Main	700	880.00	7885.60	7900.46		7900.56	0.000371	2.99	399.92	36.07	0.14
Main	650	7.00	7887.10	7887.99		7888.01	0.003130	0.99	7.08	13.00	0.24
Main	650	47.00	7887.10	7888.99		7889.06	0.003965	2.17	22.94	18.69	0.31
Main	650	342.00	7887.10	7893.03		7893.19	0.001764	3.46	119.75	28.99	0.26
Main	650	576.00	7887.10	7898.84		7898.91	0.000348	2.48	304.84	34.32	0.13
Main	650	880.00	7887.10	7900.41		7900.54	0.000509	3.27	359.90	35.62	0.16
Main	625	7.00	7886.97	7887.60	7887.60	7887.78	0.065664	3.40	2.06	5.85	1.01
Main	625	47.00	7886.97	7888.39	7888.39	7888.79	0.048978	5.12	9.33	12.19	1.00
Main	625	342.00	7886.97	7892.91		7893.13	0.002628	4.12	102.11	26.26	0.32
Main	625	576.00	7886.97	7898.81		7898.90	0.000442	2.79	278.43	32.83	0.15
Main	625	880.00	7886.97	7900.37		7900.52	0.000639	3.66	330.84	34.38	0.18
Main	600	7.00	7883.16	7884.22	7883.71	7884.25	0.003327	1.38	5.08	8.50	0.26
Main	600	47.00	7883.16	7885.94	7884.62	7886.09	0.003683	3.04	15.44	17.38	0.33
Main	600	342.00	7883.16	7892.40	7888.05	7893.02	0.002971	6.31	54.16	31.96	0.37
Main	600	576.00	7883.16	7898.84	7889.98	7898.88	0.000154	1.86	425.05	39.00	0.08
Main	600	880.00	7883.16	7900.42	7892.14	7900.49	0.000246	2.52	486.60	39.00	0.11
Main	599	Culvert									
Main	548	7.00	7882.38	7882.91	7882.91	7883.09	0.064486	3.46	2.02	5.73	1.01
Main	548	47.00	7882.38	7883.84	7883.84	7884.44	0.040288	6.22	7.56	8.55	0.98
Main	548	342.00	7882.38	7887.27	7887.27	7889.56	0.026699	12.16	28.12	24.51	0.99
Main	548	576.00	7882.38	7889.20	7889.20	7892.46	0.023890	14.49	39.75	27.00	0.99
Main	548	880.00	7882.38	7891.36	7891.36	7895.69	0.021820	16.71	52.68	29.72	0.99
Main	538	7.00	7881.33	7882.52	7881.98	7882.55	0.003015	1.33	5.24	8.14	0.25
Main	538	47.00	7881.33	7883.35	7882.88	7883.67	0.014738	4.60	10.21	10.76	0.62
Main	538	342.00	7881.33	7885.33	7886.31	7889.04	0.059193	15.45	22.14	18.93	1.42
Main	538	576.00	7881.33	7887.02	7888.27	7891.97	0.047865	17.85	32.26	24.06	1.36
Main	538	880.00	7881.33	7888.95	7890.43	7895.20	0.040118	20.06	43.87	26.88	1.31
Main	528	7.00	7881.78	7882.46		7882.50	0.008381	1.52	4.72	12.11	0.38
Main	528	47.00	7881.78	7883.44		7883.52	0.005359	2.52	23.05	23.26	0.37
Main	528	342.00	7881.78	7883.41	7884.46	7887.83	0.301564	18.70	22.56	23.11	2.75
Main	528	576.00	7881.78	7883.72	7885.23	7890.73	0.382945	23.98	29.95	24.70	3.20
Main	528	880.00	7881.78	7884.05	7886.03	7893.90	0.438796	28.81	38.32	26.01	3.52
Main	458	7.00	7881.03	7881.72		7881.78	0.012734	1.96	3.58	6.63	0.47
Main	458	47.00	7881.03	7882.75		7882.94	0.013464	3.61	14.35	17.15	0.55
Main	458	342.00	7881.03	7884.96	7884.29	7885.43	0.011508	6.43	68.54	29.36	0.60
Main	458	576.00	7881.03	7886.02	7885.09	7886.63	0.010684	7.39	101.43	32.10	0.61
Main	458	880.00	7881.03	7887.12	7885.91	7887.87	0.010247	8.35	137.62	33.49	0.62
Main	400	7.00	7880.16	7880.93	7880.69	7881.00	0.014280	2.06	3.40	6.34	0.50

HEC-RAS Plan: Existing River: Stormy Creek Reach: Main (Continued)

Reach	River Sta	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
		(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main	400	47.00	7880.16	7881.98	7881.63	7882.17	0.013311	3.55	14.99	17.89	0.55
Main	400	342.00	7880.16	7884.18		7884.72	0.012878	6.75	63.88	26.30	0.64
Main	400	576.00	7880.16	7885.19		7885.93	0.013056	8.05	91.87	28.95	0.67
Main	400	880.00	7880.16	7886.21		7887.18	0.013383	9.34	122.46	30.95	0.70
Main	200	7.00	7877.16	7877.88		7877.95	0.016265	2.10	3.34	6.75	0.53
Main	200	47.00	7877.16	7878.90		7879.13	0.017406	3.86	12.61	13.89	0.62
Main	200	342.00	7877.16	7880.96	7880.64	7881.68	0.017999	7.56	55.66	25.38	0.74
Main	200	576.00	7877.16	7881.94		7882.89	0.017612	8.92	81.88	28.81	0.77
Main	200	880.00	7877.16	7882.90		7884.10	0.017553	10.22	111.05	31.45	0.79
Main	0	7.00	7874.16	7874.76	7874.56	7874.82	0.015003	1.97	3.56	7.46	0.50
Main	0	47.00	7874.16	7875.69	7875.41	7875.89	0.015014	3.69	14.42	18.37	0.58
Main	0	342.00	7874.16	7877.76	7877.19	7878.36	0.015017	7.06	60.53	25.47	0.68
Main	0	576.00	7874.16	7878.79	7878.07	7879.60	0.015017	8.45	88.50	29.75	0.71
Main	0	880.00	7874.16	7879.78	7879.07	7880.81	0.015018	9.69	118.83	31.46	0.74

Plan: Existing   Stormy Creek   Main RS: 599   Culv Group: Culvert #1   Profile: 25-YEAR

Q Culv Group (cfs)	342.00	Culv Full Len (ft)	
# Barrels	1	Culv Vel US (ft/s)	13.54
Q Barrel (cfs)	342.00	Culv Vel DS (ft/s)	13.86
E.G. US. (ft)	7893.02	Culv Inv El Up (ft)	7883.16
W.S. US. (ft)	7892.40	Culv Inv El Dn (ft)	7882.38
E.G. DS (ft)	7889.56	Culv Frctn Ls (ft)	0.77
W.S. DS (ft)	7887.27	Culv Exit Loss (ft)	0.69
Delta EG (ft)	3.46	Culv Entr Loss (ft)	1.99
Delta WS (ft)	5.13	Q Weir (cfs)	
E.G. IC (ft)	7892.80	Weir Sta Lft (ft)	
E.G. OC (ft)	7893.02	Weir Sta Rgt (ft)	
Culvert Control	Inlet	Weir Submerg	
Culv WS Inlet (ft)	7888.18	Weir Max Depth (ft)	
Culv WS Outlet (ft)	7887.27	Weir Avg Depth (ft)	
Culv Nml Depth (ft)	4.89	Weir Flow Area (sq ft)	
Culv Crt Depth (ft)	5.02	Min El Weir Flow (ft)	7898.01

Errors Warnings and Notes

Note:	During the supercritical calculations a hydraulic jump occurred at the outlet of (leaving) the culvert.
Note:	Multiple critical depths were found at this location. The critical depth with the lowest, valid, energy was used.
Note:	During supercritical analysis, the culvert direct step method went to normal depth. The program then assumed normal depth at the outlet.
Note:	The flow in the culvert is entirely supercritical.

Form 6C - Stream Simulation Design Option

Form 6C provides guidance to correctly design a culvert that meets streambed stability requirements, while also satisfying traffic safety, hydraulic impacts, and scour concerns.

The Stream Simulation Design Option requires a second site visit to correctly identify an appropriate reference reach, and to take soil samples in order to perform a sieve analysis. These two items were not included in Form 2 - Site Visit Summary because they can be time consuming, costly, and are not required for the other design options.

An acceptable reference reach is determined by selecting a channel reach that best represents the creek in profile, cross section, and bed material, as well as forming features such as banklines, bed forms, and key features. For this particular example, a reference reach was found about 120 feet upstream of the culvert inlet that was identified as a "plane-bed" channel type having a gravel-cobble bottom. The banks of this reference reach are lined with rocks with a rough diameter range of 8 inches to 18 inches, which qualifies as a ¼ -Ton RSP material class. Based on field observation, a cross section of the reference reach was sketched on Form 6C.

While sketching the reference reach cross section in the field, the channel bankfull width was determined. The bankfull channel is defined by the bankfull discharge, which is the discharge that fills a stable alluvial channel up to the elevation of the active floodplain. Identification of the bankfull channel was based on the determination of the minimum channel width to depth ratio determined from cross sectional measurements of stable channel reaches upstream and downstream of the proposed culvert location. For this particular example, the bankfull channel width was determined at 12 feet. The culvert width for the Stream Simulation Design Option is required to span the bankfull channel; therefore, the proposed culvert width was also 12 feet in diameter.

Within the reference reach, the District Lab collected four samples at random locations from the creek bed in order to perform a sieve analysis of each sample. After reviewing the test results of each sample prepared by the Lab, the average sample was selected and a grain-size distribution curve was developed.

The long profile illustrates or predicts the effects on stream behavior due to an undersized culvert with high velocities. The average equilibrium state is identified, which allows the deposition at the inlet to be removed and the scour pool at the outlet filled.

As a part of the Stream Simulation design process, the streambed and creek features (ie. rock bands, boulder clusters, and banklines) must be analyzed and designed properly to mimic conditions outside the culvert within the culvert. The first step in performing this task is to check bed stability and creek feature stability.

Bed stability is checked by using the average sample test results. The bed material to be placed in the culvert must be stable for a Q_{25} storm at a minimum. If the existing bed material from the reference reach is not stable for a Q_{25}, considering the hydraulic conditions inside the culvert, a new bed-material gradation must be developed that will be stable for at least a Q_{25} storm event.

For this design example, the existing bed material from the reference reach was found to be unstable using Laursen's critical-velocity equation given a Q_{25} storm event. The D_{50} target particle size of the reference reach is 0.85 inches, while the calculated D_{50} is 1.38 inches. Therefore, a parallel and proportional gradation curve was generated using the controlling D_{50} equal to 1.38 inches, which will comprise stable material for a Q_{25} storm event.

Based on the new gradation curve, in addition to bankline and bed features found in the field, a typical cross section of the culvert and interior bed material was created. This simulated streambed also includes a low-flow channel that is intended to provide shape to the initial bed. As calculated, the initial bed will remain stable for Q_{25} flows and less.

Creek feature stability is also checked by determining if the field measured rough rock diameter is appropriate for the Q_{25} storm. A creek feature to be placed in the culvert must be stable for a Q_{25} storm at a minimum. If the existing bed material from the reference reach is not stable for a Q_{25}, considering the hydraulic conditions inside the culvert, a new creek feature RSP class must be selected so that it will be stable for at least a Q_{25} storm event.

The banks of this reference reach are lined with rocks with a rough diameter range of 8 inches to 18 inches, which qualifies as a ¼ -Ton RSP material class. This ¼ -Ton RSP material must be checked for stability.

The proposed average culvert velocity for the Q_{25} storm is 7.4 ft/s calculated by the HEC-RAS model. The corresponding minimum stable diameter found in *Appendix N - Rock Weir Design, Table N-3: Boulder Cluster Design Method - Minimum Rock Diameter*, is approximately 0.45 ft. The minimum stable diameter is equivalent to the rough D_{50} provided in *Table N-1: Caltrans RSP Class Rough Diameter*. A rough D_{50} of 0.45 ft is equivalent to a Caltrans RSP class of cobbles. Therefore, the proposed creek feature RSP class of ¼ -ton will create a more than stable condition in the culvert.

Appendix N - Table N-3: Boulder Cluster Design Method - Minimum Rock Diameter

GENERIC ROCK CLASS	**MIN. STABLE DIAMETER (D_{50}) (inches)**	**τ_c (lb/sf)**	**v_c (ft/s)**
Very Large Boulder	6.67 ft (>80)	37.4	25
Large Boulder	3.33 ft (>40)	18.7	19
Medium Boulder	1.67 ft (>20)	9.3	14
Small Boulder	0.83 ft (>10)	4.7	10
Large Cobble	0.42 ft (>5)	2.3	7
Small Cobble	0.21 ft(>2.5)	1.1	5

Appendix N - Table N-1: RSP Class Rough Diameter

Caltrans RSP CLASS	**ROUGH D_{50} (FEET)**
Cobble	0.66
Backing No. 1	0.95
Light	1.32
¼ Ton	1.79
½ Ton	2.26
1 Ton	2.85
2 Ton	3.59
4 Ton	4.50
8 Ton	5.70

Although no specific species, depth, or velocity criteria had to be met, hydraulic analyses for hydraulic impacts and scour were satisfied.

FISH PASSAGE: STREAM SIMULATION DESIGN OPTION FORM 6C

Project Information Route 333 4-Lane	Computed: EKB	Date: 8/29/06
	Checked: LEF	Date: 8/26/06
Stream Name: Stormy Creek County: Morro	Route: 333	Postmile: 34.1

General Considerations

The **Stream Simulation** method strives to result in the same passage conditions within the culvert as those seen in the selected reference reach, to the extent practical. The Stream Simulation process includes these four steps: 1) Develop long profile and define the reference reach, 2) Establish proposed structure settings and dimensions, 3) Design bed material and shape, and 4) Check bed stability.

Hydrology Results - Peak Discharge Values

50% Annual Probability (2-Year Flood Event)	7 cfs	10% Annual Probability (10-Year Flood Event)	47 cfs
4% Annual Probability (25-Year Flood Event)	342 cfs	2% Annual Probability (50-Year Flood Event)	576 cfs
1% Annual Probability (100-Year Flood Event)	880 cfs		

Develop Long Profile and Define the Reference Reach

Attach channel profile sheet. ☒ Yes ☐ No

Identify reference reach on long profile with characteristics that will be appropriate for the replacement culvert. ☒ Yes ☐ No

Identify channel type and key features that vary depending on the bed mobility. ☒ Yes ☐ No

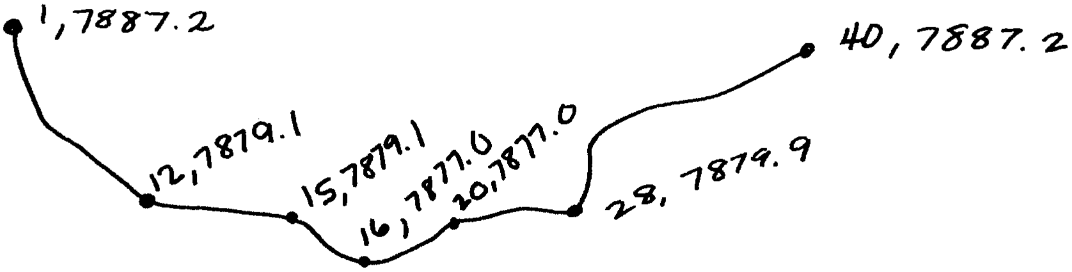
Identify location of bed material samples on profile. ☒ Yes ☐ No

Identify typical channel cross-sections. ☒ Yes ☐ No

Identify channel characteristics and processes on long profile. ☒ Yes ☐ No

Plot stream/culvert profile or range of profiles for consideration. ☒ Yes ☐ No

Illustrate the typical reference reach cross-section:



FISH PASSAGE: STREAM SIMULATION DESIGN OPTION — FORM 6C

Bankfull Channel: The channel defined by the bankfull discharge, which is the discharge that fills a stable alluvial channel up to the elevation of the active floodplain. Identification of the bankfull channel should be based on the determination of the minimum channel width to depth ratio determined from cross sectional measurements of stable channel reaches upstream and downstream of the proposed culvert location.

Bankfull channel width = 12 ft

Estabilsh Proposed Culvert Settings and Dimensions

Culvert Width: Culvert width is the width needed to span the bankfull channel. If permanent banklines are constructed of rock, adequate culvert width must be provided to span the bed plus the size of the rock on both banks. For an initial estimate of the minimum culvert width, add twice the diameter of the largest material in the bed to the bankfull width. A stability analysis might show that other bed material is needed.

Culvert Width = 12 ft

Culvert Length: Culvert length must be greater than 100 feet

Culvert Length = 140 ft

Culvert Embedment: A circular culvert embedded into the streambed no less than 30% but no more than 50% of its rise is a good practical guide.

Upstream embedment = 3.6 ft	Downstream embedment = 3.6 ft

Culvert Slope Culvert slope does not greatly exceed slope of natural channel, slopes of 6% or less

Upstream invert elevation = 7883.16 ft ([✓ NGVD 29] or NAVD 88)	Downstream invert elevation = 7881.03 ft ([✓ NGVD 29] or NAVD 88)

Summarize Proposed Culvert Physical Characterstics

Inlet Characteristics

Inlet Type	☐ Projecting	☒ Headwall	☐ Wingwall
	☐ Flared end section	☐ Segment connection	☐ Skew Angle: °

Barrel Characteristics

Diameter: 144 in	Fill height above culvert: approx. 8.8 ft
Height/Rise: ft	Length: 140 ft
Width/Span: ft	Number of barrels:

Culvert Type	☐ Arch	☐ Box	☒ Circular
	☐ Pipe-Arch	☐ Elliptical	

FISH PASSAGE: STREAM SIMULATION DESIGN OPTION FORM 6C

Culvert Material	☐ HDPE ☐ Spiral Rib / Corrugated Metal Pipe	☐ Steel Plate Pipe	☐ Concrete Pipe

Horizontal alignment breaks: NONE ft

Vertical alignment breaks: NONE ft

Outlet Characteristics

Outlet Type	☐ Projecting ☐ Flared end section	☒ Headwall ☐ Segment connection	☐ Wingwall Skew Angle: °

Summarize Proposed Bridge Physical Characterstics N/A

Bridge Physical Characteristics

Elevation of high chord (top of road): ft (NGVD 29 or NAVD 88)

Elevation of low chord: ft (NGVD 29 or NAVD 88)

Channel Lining	☐ No lining	☐ Concrete	☐ Rock	☐ Other

Pier Characteristics (if applicable) ☐

Number of Piers: ft	Upstream cross-section starting station: ft
Pier Width: ft	Downstream cross-section starting station: ft
Pier Centerline Spacing: ft	Skew angle: °

Pier Shape	☐ Square nose and tail ☐ Twin-cylinder piers with connecting diaphragm	☐ Semi-circular nose and tail ☐ Twin-cylinder piers without connecting diaphragm	☐ 90° triangular nose and tail ☐ Ten pile trestle bent

Define Bed Material and Shape

Create reference grain-size distribution curve from reference reach material. ☒ Yes ☐ No

Bed Stability Analysis

1. Establish bed design flows	25-Year design storm, Q = 342 cfs
2. Determine average water depth in culvert	Culvert inlet water depth, y = 4.09 ft Culvert outlet water depth, y = 4.37 ft

	Average water depth, y =	4.23	ft
3. Determine average water velocity in culvert	Culvert inlet velocity, V_c =	7.12	ft/s
	Culvert outlet velocity, V_c =	6.68	ft/s
	Average culvert velocity, V_c =	6.90	ft/s

4) Solve the bed stability equation by calculating D_{50} using Laursen's Equation.

Solve Laursen's equation for Culvert bed material D_{50} Where V_c is critical velocity above which bed material of size D and smaller will be transported, (ft/s), y is average depth of flow within the culvert structure, (ft), and D_{50} is particle size in a mixture of which 50 percent are smaller, (ft).	$D_{50} = (V_c / 11.17y^{1/6})^3$ $D_{50} = 0.115$ (1.38 in)	ft

5. Is the calculated D_{50} equal to or less than the reference reach D_{50}? ☐ Greater than or equal to ☒ Less than

If greater than or equal to, use reference bed material in culvert. ☐

If less than, adjust reference grain-size distribution curve to match caclulated D_{50}. ☒

Creek Feature Stability Analysis (ie. Rock bands, Boulder Clusters, Banklines)

1. Establish bed design flows	25-Year design storm, Q =	342	cfs
2. Determine average water velocity in culvert	Culvert inlet velocity, V_c =	7.12	ft/s
	Culvert outlet velocity, V_c =	7.68	ft/s
	Average culvert velocity, V_c =	7.40	ft/s
3. Determine average field rock size diameter	Average field rock size diameter, D_{field} =	$\frac{1}{4}$-ton 1.79	ft
4. Select minimum stable diameter (D_{50}) corresponding to average culvert velocity	Minimum stable diameter, D_{50} =	0.45	ft
5. Calculated Caltrans RSP Class rough diameter	Calculated Caltrans RSP Class rough diameter, D_{rsp} =	0.66	ft

If minimum stable diameter is greater than average field rock size diameter, the average field rock size diameter must be increased.
If minimum stable diameter is less than the average field rock size diameter, select the corresponding RSP class rough diameter.

6. Selected Caltrans RSP Class	Selected Caltrans RSP Class = cobble

FISH PASSAGE: STREAM SIMULATION DESIGN OPTION FORM 6C

Maximum Allowable Inlet Water Surface Elevation

Culvert ☒

A culvert is required to pass the 10-year peak discharge without causing pressure flow in the culvert,	Allowable WSEL:	7891.56 ft
And shall not be greater than 50% of the culvert height or diameter above the top of the culvert inlet for the 100-Year peak flood.	Allowable WSEL:	7897.56 ft

Bridge ☐ N/A

A bridge is required to pass the 50-year peak discharge with freeboard, vertical clearance between the lowest structural member and the water surface elevation,	Allowable WSEL:	ft
While passing the 100-year peak or design discharge under low chord of bridge.	Allowable WSEL:	ft

Establish Allowable Hydraulic Impacts

Is the crossing located within a floodplain as designated by the Federal Emergency Management Agency or another responsible state or local agency? ☐ Yes ☒ No

If yes, establish allowable hydraulic impacts and hydraulic design requirements with the appropriate agency. Attach results.

Will the project result in increase capacity of an existing crossing? ☐ Yes ☒ No

If yes, will it significantly increase downstream peak flows due to the reduced upstream attenuation? ☐ Yes ☒ No

If yes, consult District Hydraulics. Further analysis may be needed.

Will the project result in a reduction in flow area for the 100-year peak discharge? ☐ Yes ☒ No

If yes, establish the allowable increase in upstream water surface elevation and establish how far upstream the increased water surface may extend.

Develop and run Hydraulic Models to compute water surface elevations, flow depths, and channel velocities for the 2-, 10-, 50-, and 100-year peak or design discharges reflecting existing and project conditions. ☒ Yes ☐ No

Evaluate computed water surface elevations, flow depths, and channel velocities. ☒ Yes ☐ No

Water surface elevation at inlet for the 10-year peak discharge: 7884.38 **ft**

Does the water surface elevation exceed the allowable elevation? ☐ Yes ☒ No

If yes, modify design to comply and rerun hydraulic analyses to verfiy.

Maximum Culvert and Channel velocities at inlet and outlet transition for the peak or design discharge: 25-Year

Range of velocities for Inlet transition:	7.82	**ft/s**	**to**		**ft/s**
Range of velocities for Culvert portion:	7.12	**ft/s**	**to**	6.68	**ft/s**

FISH PASSAGE: STREAM SIMULATION DESIGN OPTION

FORM 6C

Range of velocities for Outlet Transition: 7.06 ft/s to ft/s

Do the velocities exceed the permissible scour velocities? ☐ Yes ☒ No

If yes, revise design to reduce velocities and rerun hydraulic analyses to verfiy, or design erosion protection.

Comparison between existing and project future condition water surface elevations for the 10-Year and 100-Year peak flow:

Cross-Section	**10-Yr WSEL**	**10-Yr WSEL**	**Difference**	**100-Year WSEL**	**100-Year WSEL**	**Difference**
	Existing Conditions (ft)	**Future Conditions (ft)**	**(ft)**	**Existing Conditions (ft)**	**Future Conditions (ft)**	**(ft)**
1 400	7881.98	7881.98	0	7886.21	7886.21	0
2 548/458	7883.84	7882.75	-1.09	7891.36	7887.22	-4.14
3 600	7885.94	7884.50	-1.44	7900.42	7893.06	-7.36
4 800	7889.33	7888.04	-1.29	7900.49	7894.56	-5.93

If WSELs increase, does the increase exceed the maximum elevation? ☐ Yes ☒ No

Maximum elevation: 7897.56 ft

If yes, revise the design and rerun hydraulic analyses to verify.

If WSELs decrease, does it appear that the attenuation of peak flow will significally change? ☐ Yes ☒ No

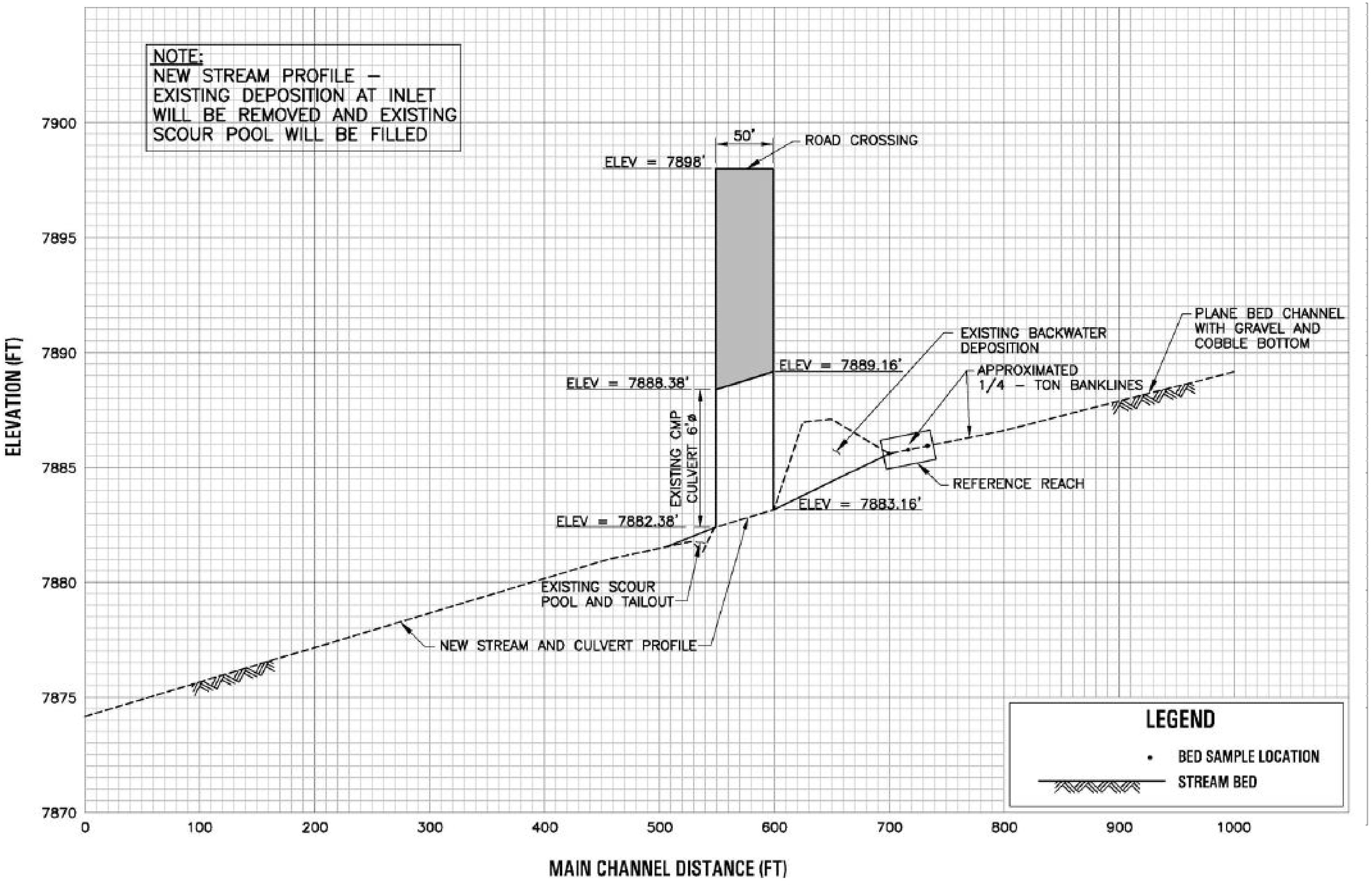
If yes, evaluate to determine if downstream hydraulic impacts are significant and modify design as appropriate.

Proposed Profile Drawing Attached ☒ Yes ☐ No

Hydraulic Analysis Index Sheet Attached ☒ Yes ☐ No

Bed Stability Analysis Calculations Attached ☒ Yes ☐ No

Grain-Size Distribution Curve Attached ☒ Yes ☐ No



NOTE:
NEW STREAM PROFILE – EXISTING DEPOSITION AT INLET WILL BE REMOVED AND EXISTING SCOUR POOL WILL BE FILLED

P:/06938/38713 TO7 Fish Passage/5.0 Project Data/AutoCAD/General Details/Stream-Stimulation-exist.DWG
05-10-07 AJACKSON 18:23:23

Issue No.	Description	Date	Drwn.	Chkd.	Resp. Engr.	Proj. Mgr.

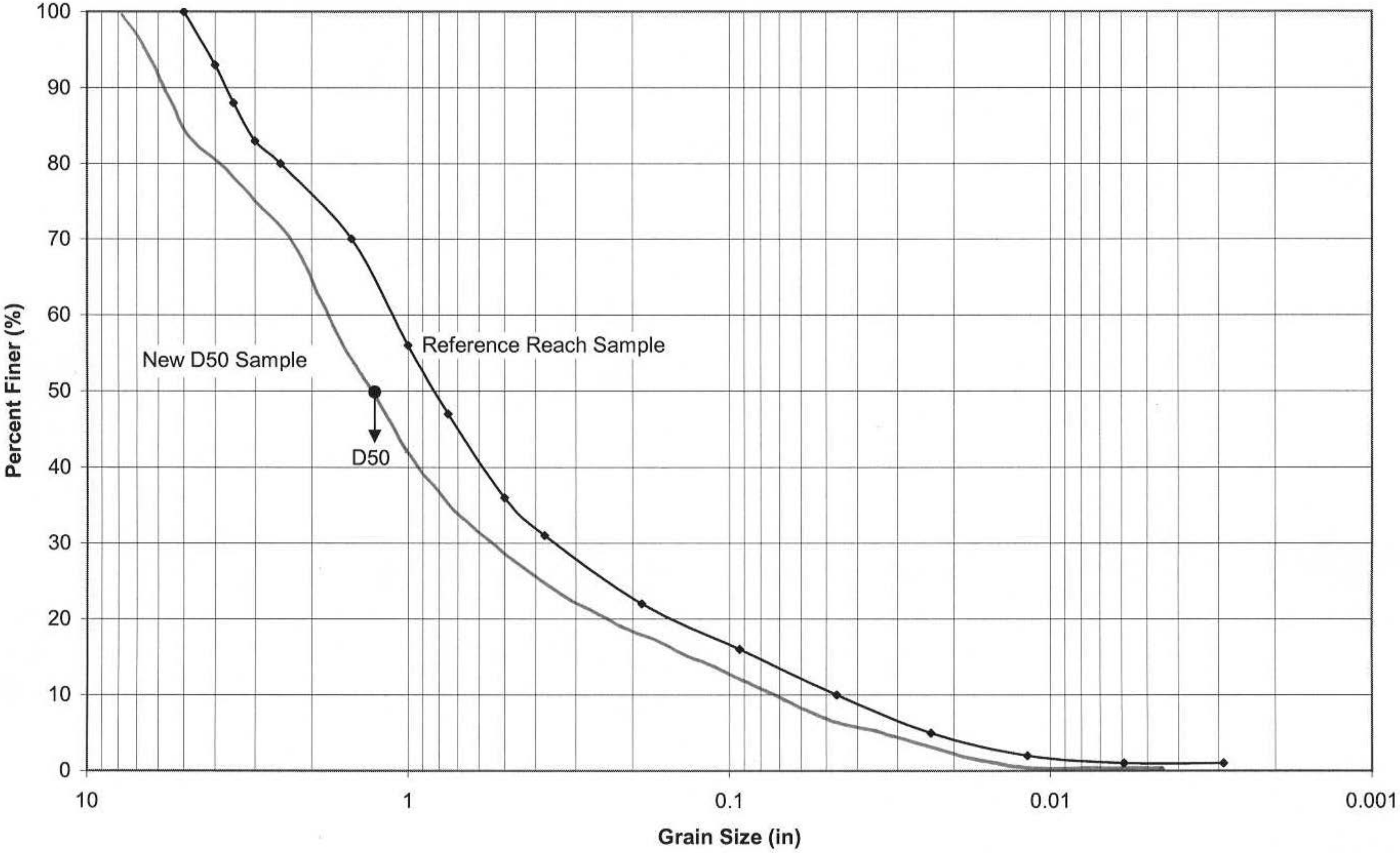
Project Manager LEF
Designed EKB
Designed
Checked
Drawn AJ

Route 333 6 Lane
at Stormy Creek

STREAM SIMULATION DESIGN
LONG PROFILE

Date
Scale HORIZ: 1" = 50'
VERT: 1" = 5'
Project No. 06938–38713
File Name Stream–Stimulation–exist.DWG
Drawing No. 1
Issue

Grain Size Distribution Curve



Bed Stability Computation Summary

Project Information:	Route 333 4-Lane	Computed: EKB	Date: 6/31/2006
		Checked: LEF	Date: 7/1/2006
Stream Name: Stormy Creek	County: Mono	Route: 333	Postmile: 12.8

Calculations:

1) Establish Bed Design Flows

25-Year Design Storm, Q = 342 cfs

2) Determine Average Water Depth in culvert:

inlet depth: 7887.25 ft - 7883.16 ft = 4.09 ft
outlet depth: 7885.40 ft - 7881.03 ft = 4.37 ft

average depth: 4.09 ft + 4.37 ft / 2 = 4.23 ft

3) Determine Average Velocity in culvert:

inlet velocity: 7.12 ft/s
outlet velocity: 6.68 ft/s

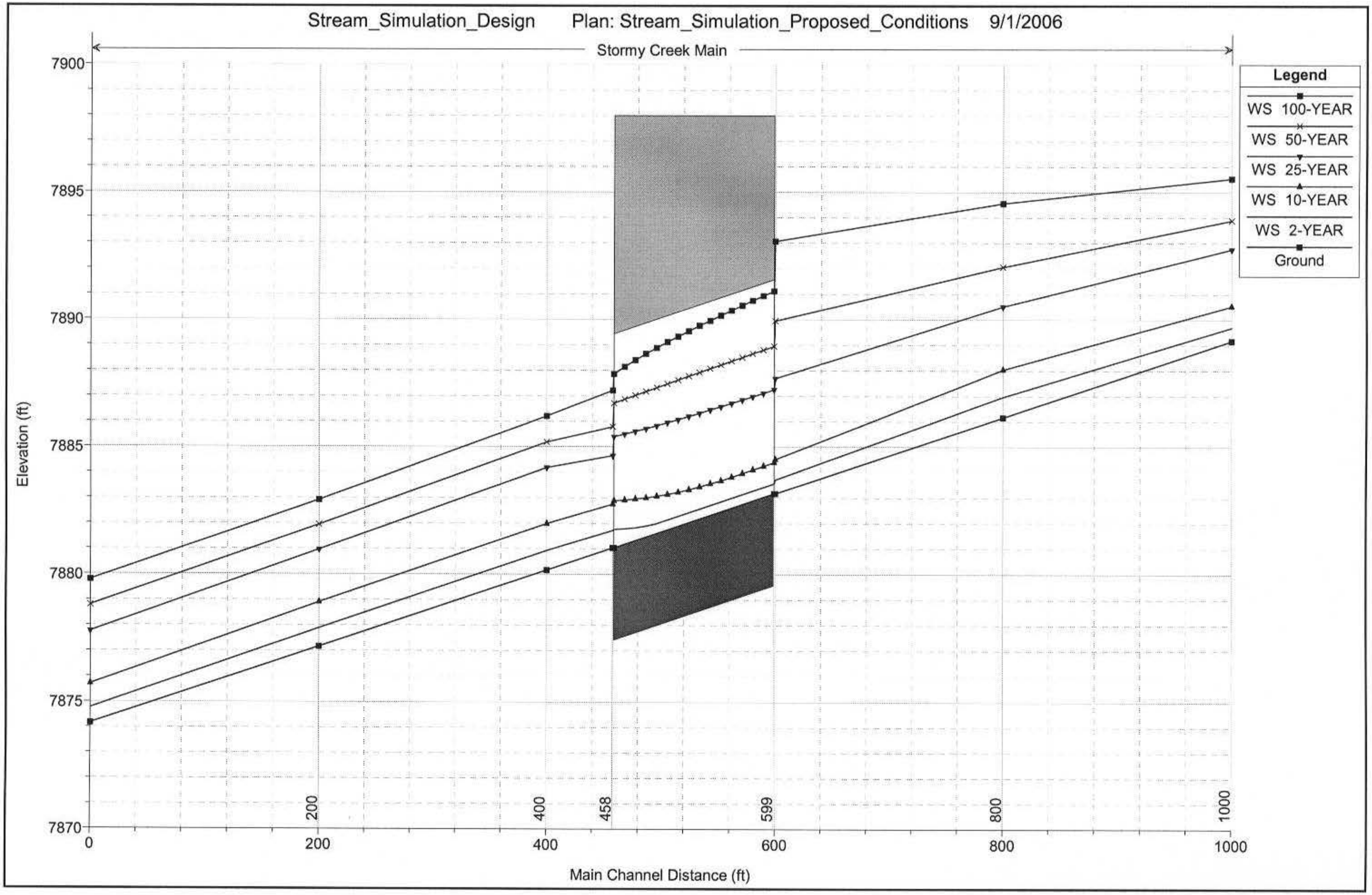
average velocity: 7.12 ft/s + 6.68 ft/s / 2 = 6.90 ft/s

4) Solve for D50

Larsen's Equation was selected to solve for D50

D50 = (Vc / 11.17 y^(1/6))^3
D50 = (6.90 ft/s / 11.17 * (4.23 ft^(1/6)))^3

D50 = 0.115 ft = 1.38 in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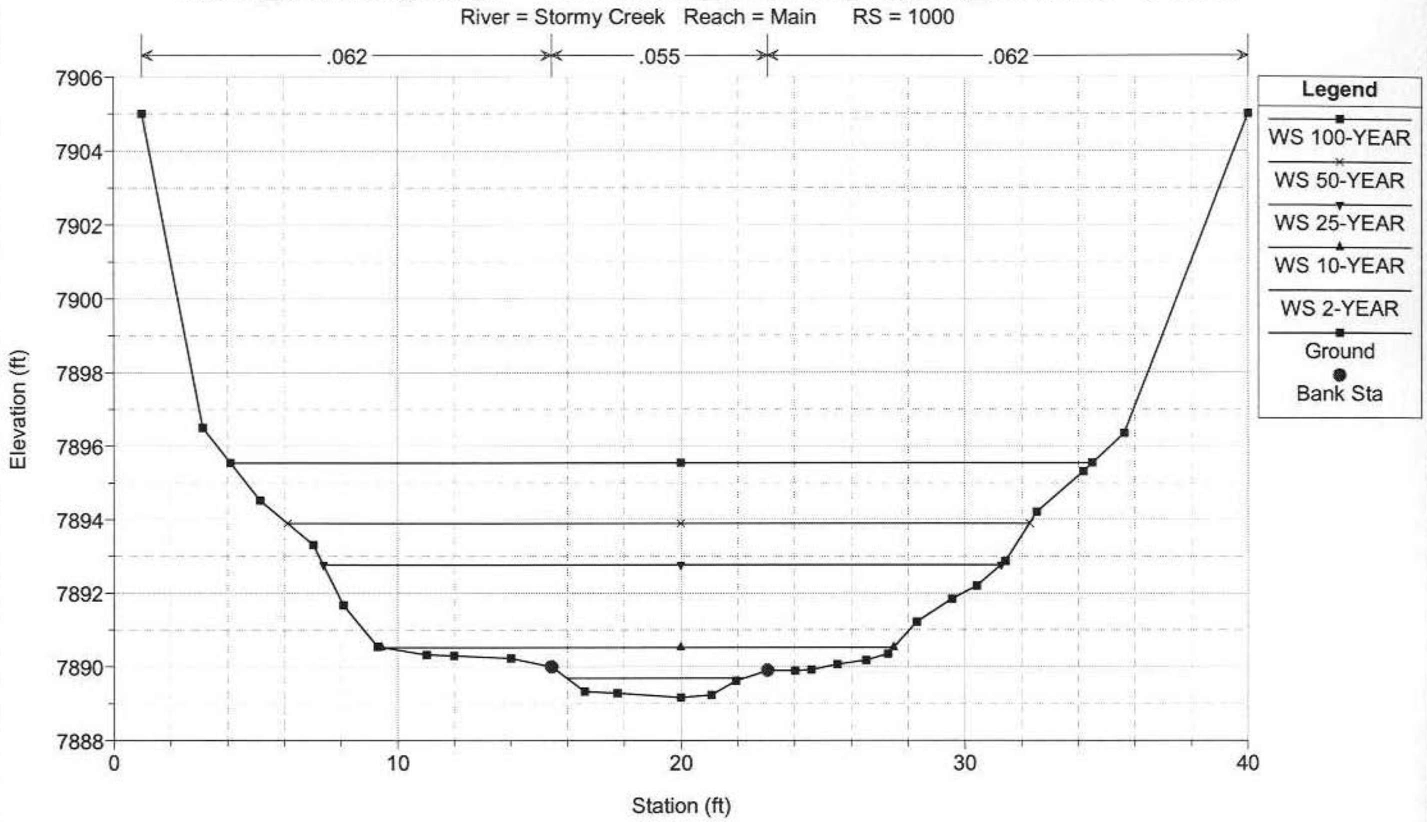
Stormy Creek Main
Legend
WS 100-YEAR
WS 50-YEAR
WS 25-YEAR
WS 10-YEAR
WS 2-YEAR
Ground
Elevation (ft)
7900
7895
7890
7885
7880
7875
7870
200
400
458
599
800
1000
0
200
400
600
800
1000
Main Channel Distance (ft)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River = Stormy Creek Reach = Main RS = 1000
.062
.055
.062
Elevation (ft)
7906
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7902
7900
7898
7896
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7888
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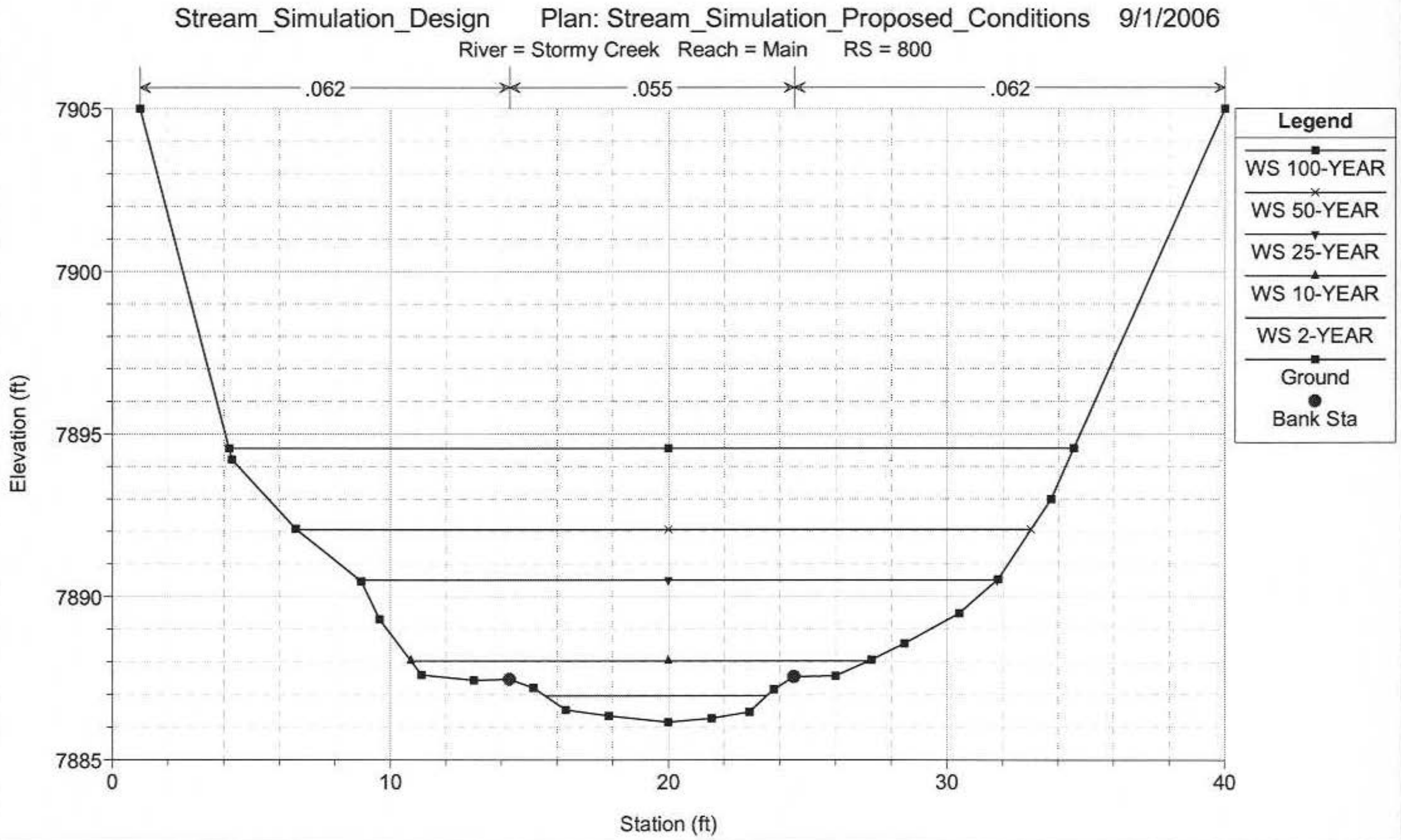
20
30
40
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 25-YEAR
WS 10-YEAR
WS 2-YEAR
Ground
Bank Sta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.062
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.062
Elevation (ft)
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Station (ft)
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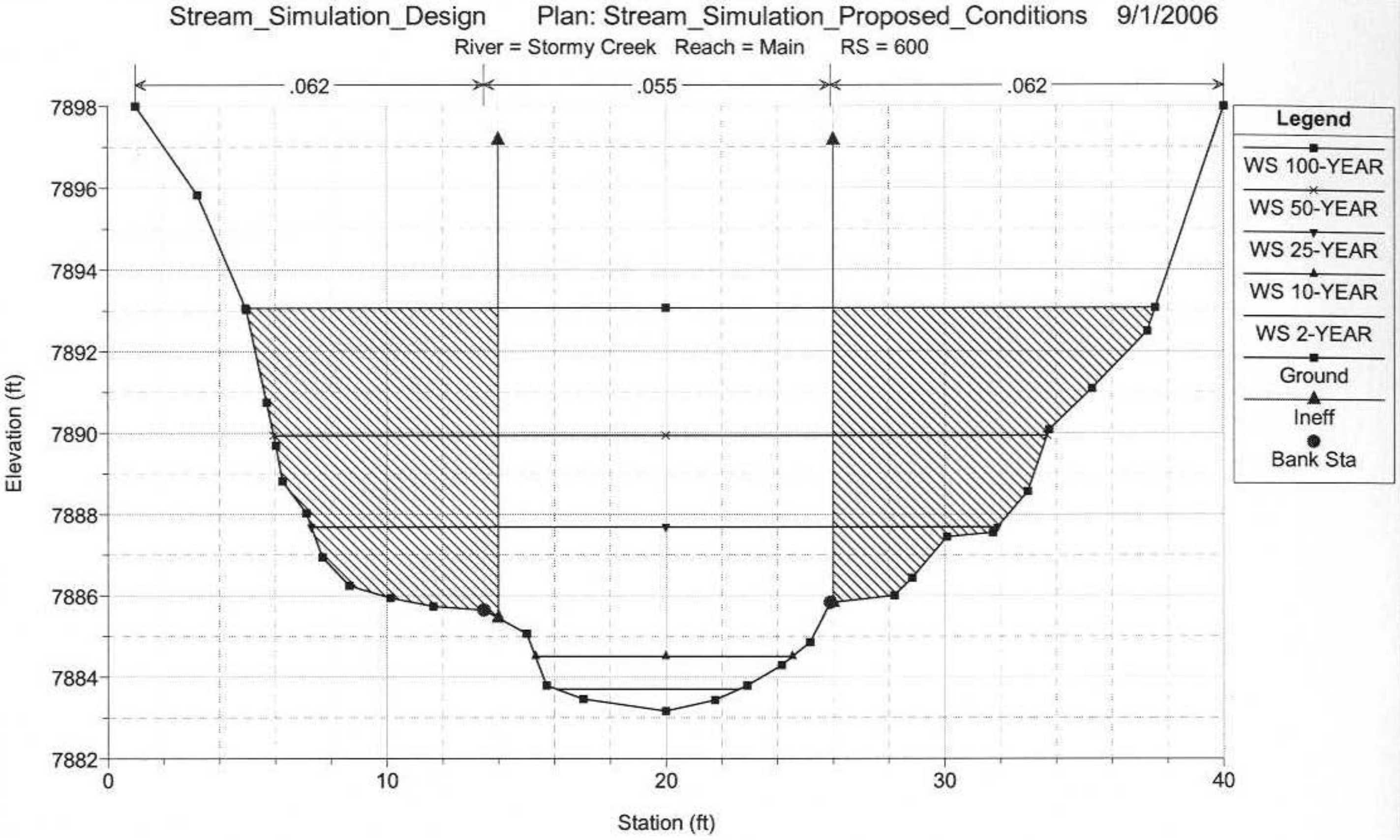
WS 25-YEAR
WS 10-YEAR
WS 2-YEAR
Ground
Bank Sta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River = Stormy Creek Reach = Main RS = 600
.062
.055
.062
Elevation (ft)
7898
7896
7894
7892
7890
7888
7886
7884
7882
0
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20
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Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 25-YEAR
WS 10-YEAR
WS 2-YEAR
Ground
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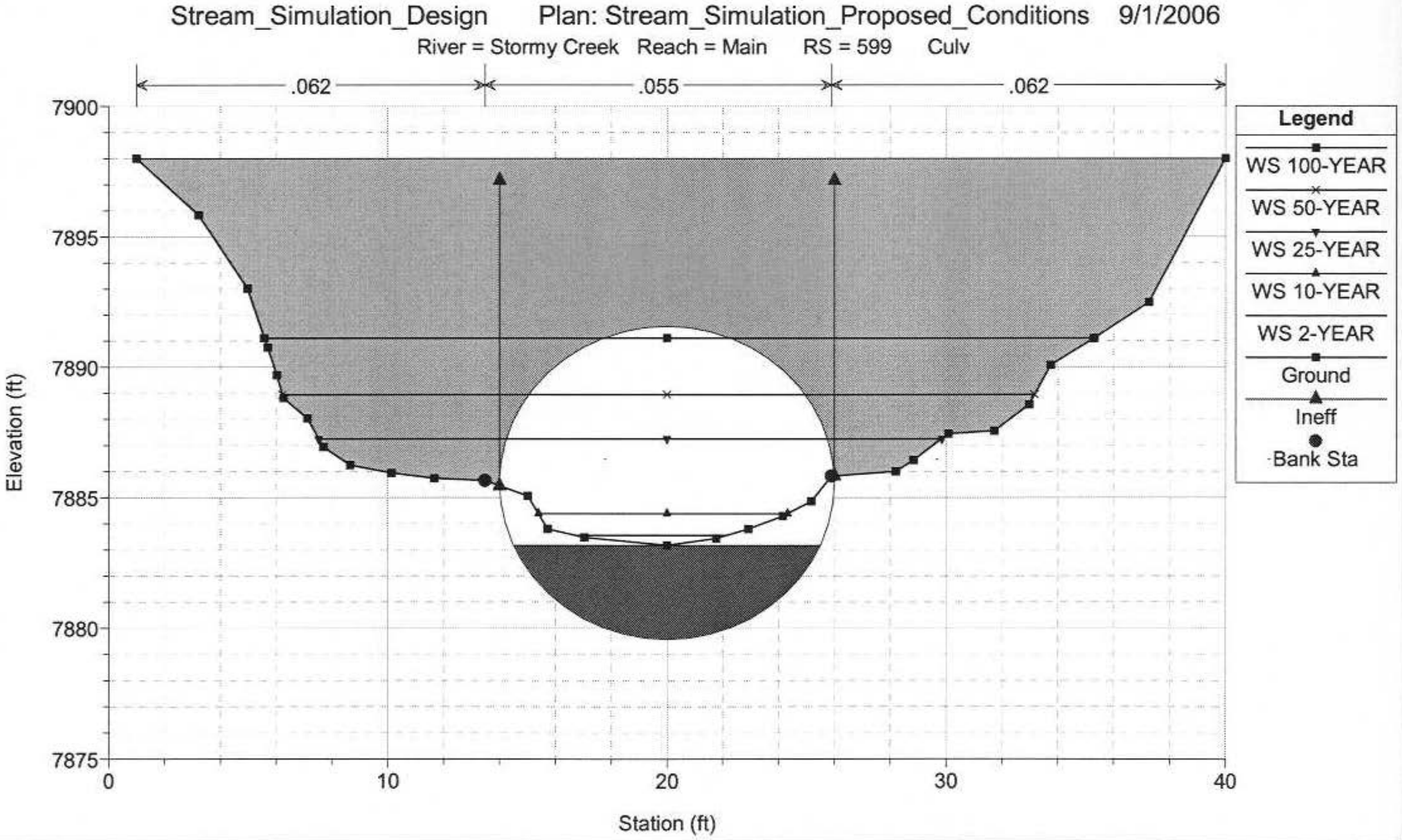
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River = Stormy Creek Reach = Main RS = 599 Culv
.062
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.062
Elevation (ft)
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7890
7885
7880
7875
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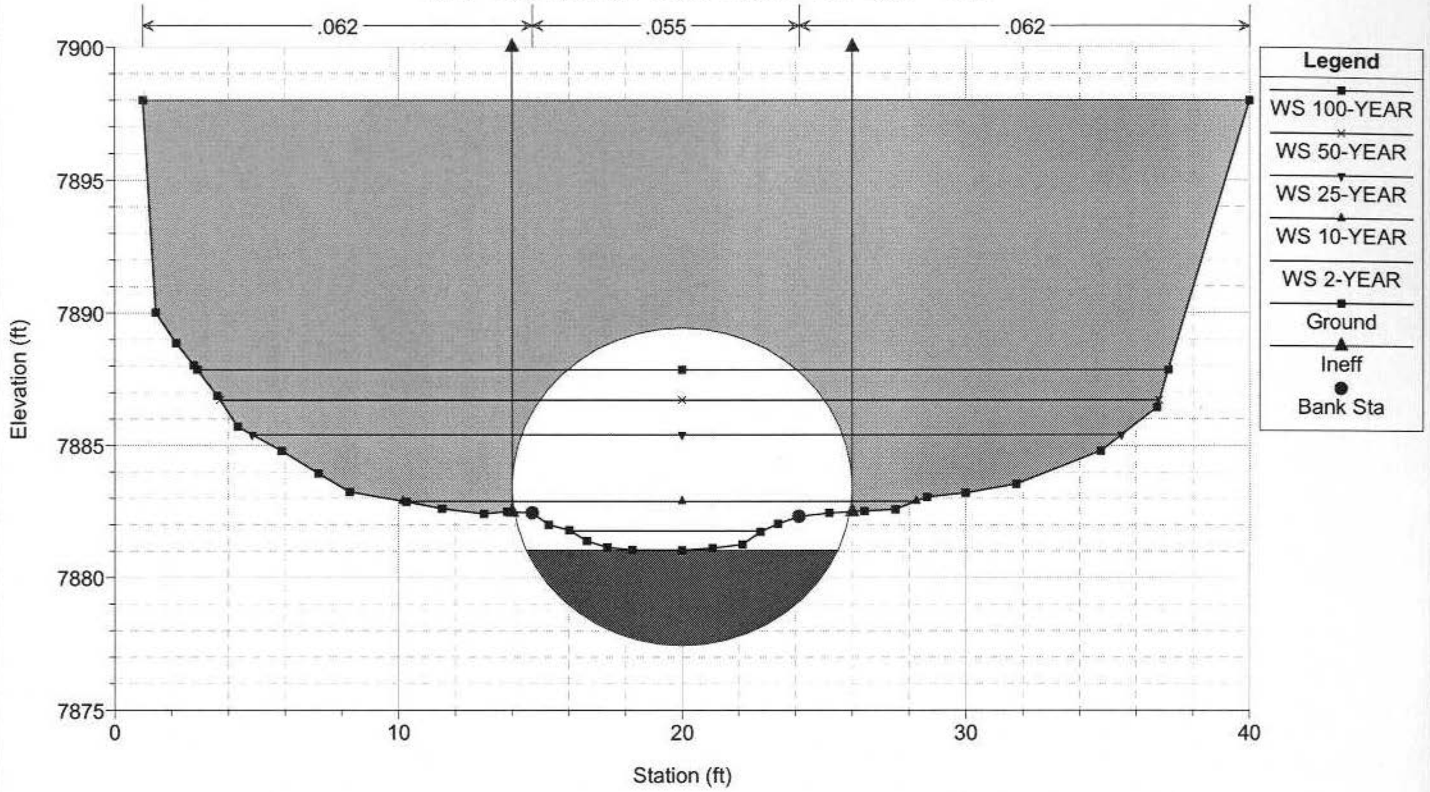
Station (ft)
Legend
WS 100-YEAR
WS 50-YEAR
WS 25-YEAR
WS 10-YEAR
WS 2-YEAR
Ground
Ineff
Bank Sta

Stream_Simulation_Design Plan: Stream_Simulation_Proposed_Conditions 9/1/2006
River = Stormy Creek Reach = Main RS = 599 Culv



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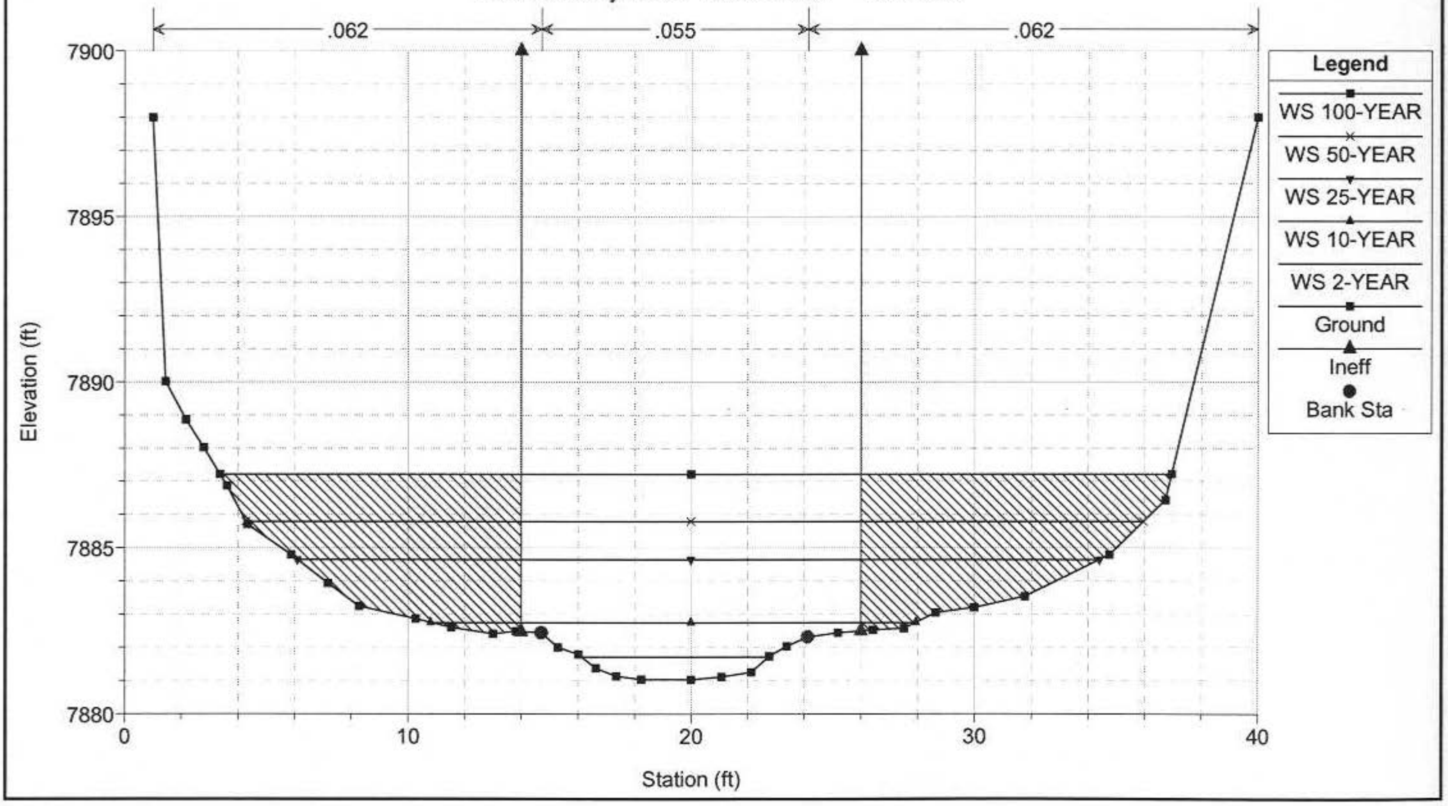

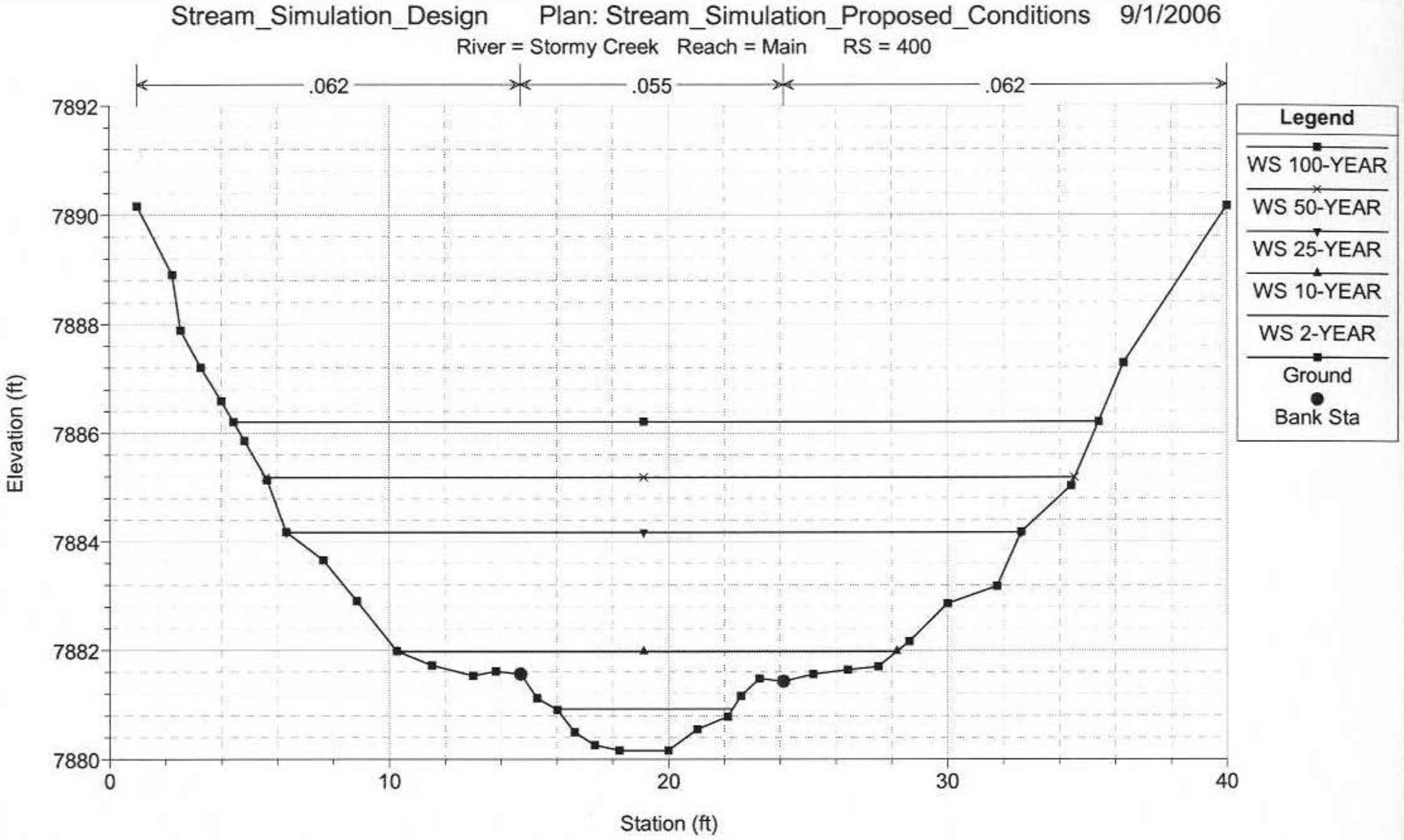
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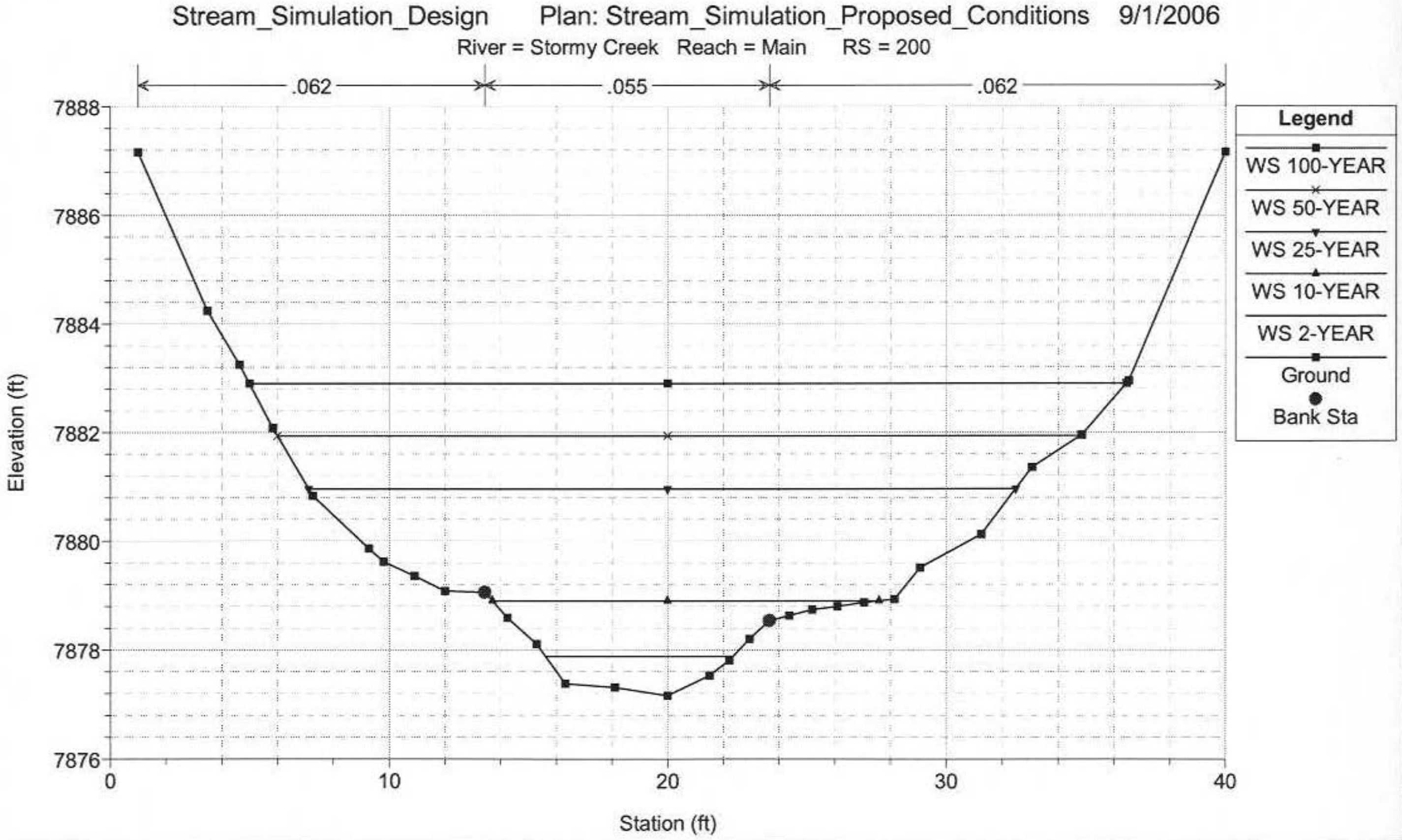
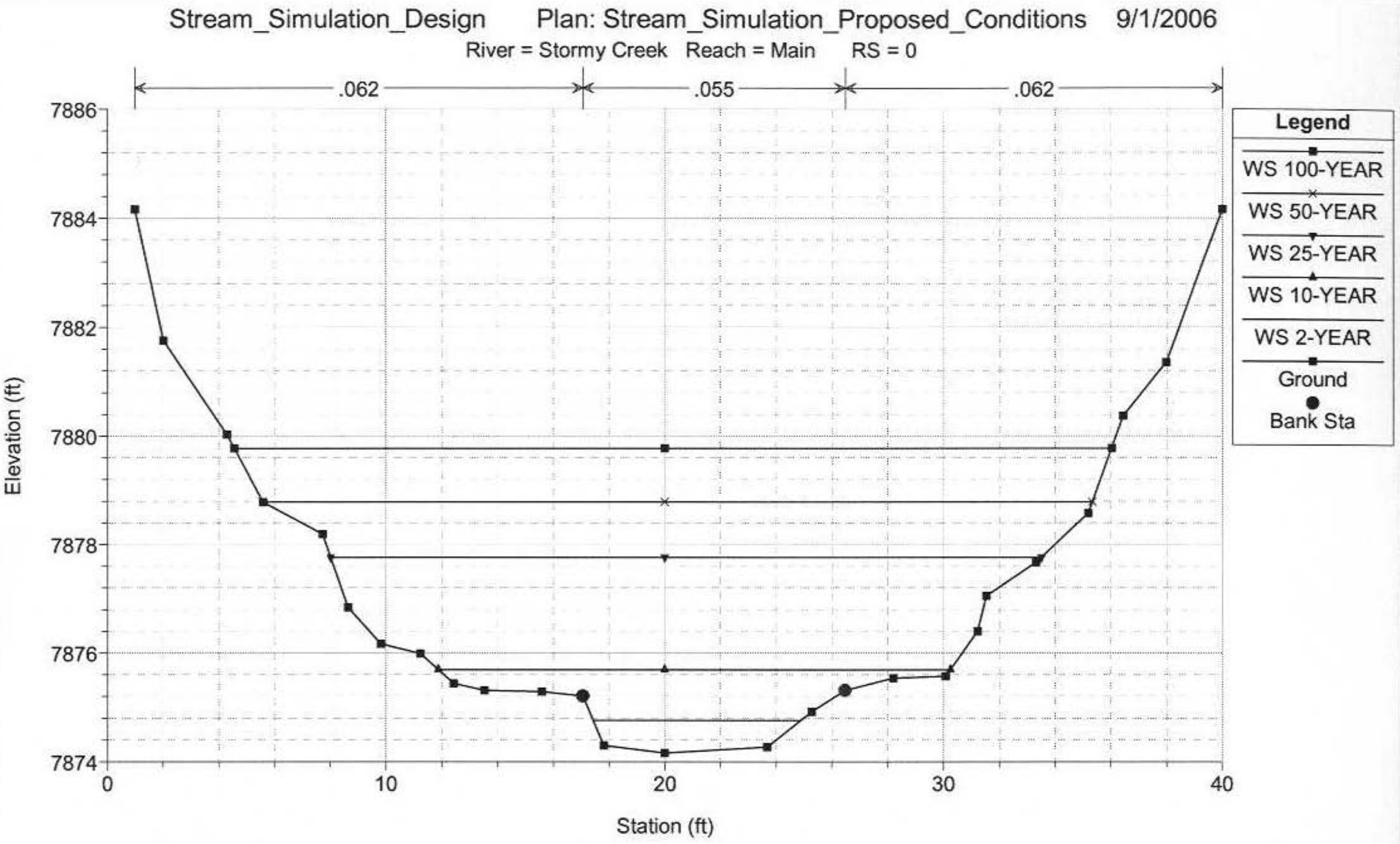
9/1/2006
River = Stormy Creek
Reach = Main
RS = 400
.062
.055
.062
Legend
WS 100-YEAR
WS 50-YEAR
WS 25-YEAR
WS 10-YEAR
WS 2-YEAR
Ground
Bank Sta
Elevation (ft)
7892
7890
7888
7886
7884
7882
7880
0
10
20
30
40
Station (ft)


Stream_Simulation_Design
Plan: Stream_Simulation_Proposed_Conditions
9/1/2006
River = Stormy Creek
Reach = Main
RS = 200
.062
.055
.062
Legend
WS 100-YEAR
WS 50-YEAR
WS 25-YEAR
WS 10-YEAR
WS 2-YEAR
Ground
Bank Sta
Elevation (ft)
7888
7886
7884
7882
7880
7878
7876
0
10
20
30
40
Station (ft)


Stream_Simulation_Design Plan: Stream_Simulation_Proposed_Conditions 9/1/2006

River = Stormy Creek Reach = Main RS = 0

HEC-RAS Plan: Proposed River: Stormy Creek Reach: Main

Reach	River Sta	Profile	Q Total	W.S. Elev	Min Ch El	Diff	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)		(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main	0	2-YEAR	7.00	7874.76	7874.16	0.60	7874.56	7874.82	0.015003	1.97	3.56	7.46	0.50
Main	0	10-YEAR	47.00	7875.69	7874.16	1.53	7875.41	7875.89	0.015014	3.69	14.42	18.37	0.58
Main	0	25-YEAR	342.00	7877.76	7874.16	3.60	7877.19	7878.36	0.015017	7.06	60.53	25.47	0.68
Main	0	50-YEAR	576.00	7878.79	7874.16	4.63	7878.07	7879.60	0.015017	8.45	88.50	29.75	0.71
Main	0	100-YEAR	880.00	7879.78	7874.16	5.62	7879.07	7880.81	0.015018	9.69	118.83	31.46	0.74
Main	200	2-YEAR	7.00	7877.88	7877.16	0.72		7877.95	0.016265	2.10	3.34	6.75	0.53
Main	200	10-YEAR	47.00	7878.90	7877.16	1.74		7879.13	0.017406	3.86	12.61	13.89	0.62
Main	200	25-YEAR	342.00	7880.96	7877.16	3.80		7881.68	0.017999	7.56	55.66	25.38	0.74
Main	200	50-YEAR	576.00	7881.94	7877.16	4.78		7882.89	0.017604	8.92	81.90	28.81	0.77
Main	200	100-YEAR	880.00	7882.90	7877.16	5.74		7884.10	0.017547	10.22	111.06	31.46	0.79
Main	400	2-YEAR	7.00	7880.93	7880.16	0.77	7880.69	7880.99	0.014294	2.06	3.40	6.35	0.50
Main	400	10-YEAR	47.00	7881.98	7880.16	1.82	7881.63	7882.16	0.013217	3.54	15.03	17.92	0.55
Main	400	25-YEAR	342.00	7884.18	7880.16	4.02		7884.72	0.012826	6.74	63.97	26.31	0.64
Main	400	50-YEAR	576.00	7885.18	7880.16	5.02	7884.38	7885.92	0.013052	8.05	91.87	28.95	0.67
Main	400	100-YEAR	880.00	7886.21	7880.16	6.05	7885.28	7887.17	0.013336	9.33	122.60	30.96	0.70
Main	458	2-YEAR	7.00	7881.72	7881.03	0.69	7881.49	7881.78	0.012907	1.97	3.56	6.63	0.47
Main	458	10-YEAR	47.00	7882.75	7881.03	1.72	7882.35	7882.96	0.014048	3.69	13.27	17.15	0.57
Main	458	25-YEAR	342.00	7884.65	7881.03	3.62	7884.59	7886.09	0.031092	9.94	36.02	28.32	0.98
Main	458	50-YEAR	576.00	7885.79	7881.03	4.76	7885.79	7887.92	0.030459	12.05	49.76	31.68	1.02
Main	458	100-YEAR	880.00	7887.22	7881.03	6.19	7887.22	7889.95	0.026734	13.63	66.87	33.58	1.00
Main	599		Culvert										
Main	600	2-YEAR	7.00	7883.70	7883.16	0.54	7883.70	7883.87	0.068433	3.29	2.13	6.57	1.02
Main	600	10-YEAR	47.00	7884.50	7883.16	1.34	7884.50	7884.97	0.049529	5.47	8.60	9.22	1.00
Main	600	25-YEAR	342.00	7887.69	7883.16	4.53	7886.89	7888.58	0.015953	7.59	45.16	24.60	0.69
Main	600	50-YEAR	576.00	7889.94	7883.16	6.78	7888.09	7890.93	0.009497	7.99	72.18	27.73	0.57
Main	600	100-YEAR	880.00	7893.06	7883.16	9.90	7889.46	7894.07	0.005505	8.04	109.65	32.60	0.47
Main	800	2-YEAR	7.00	7886.97	7886.16	0.81		7887.00	0.006721	1.50	4.65	7.98	0.35
Main	800	10-YEAR	47.00	7888.04	7886.16	1.88	7887.43	7888.16	0.007664	2.93	17.70	16.49	0.43
Main	800	25-YEAR	342.00	7890.51	7886.16	4.35		7890.99	0.009150	6.20	67.33	22.92	0.55
Main	800	50-YEAR	576.00	7892.06	7886.16	5.90		7892.63	0.007309	6.91	105.59	26.40	0.52
Main	800	100-YEAR	880.00	7894.56	7886.16	8.40		7895.05	0.003997	6.57	177.07	30.37	0.41
Main	1000	2-YEAR	7.00	7889.69	7889.16	0.53	7889.64	7889.82	0.044613	2.94	2.38	6.27	0.84
Main	1000	10-YEAR	47.00	7890.52	7889.16	1.36	7890.47	7890.82	0.026834	4.67	12.10	18.06	0.78
Main	1000	25-YEAR	342.00	7892.77	7889.16	3.61	7892.20	7893.38	0.015607	7.39	59.30	23.90	0.71
Main	1000	50-YEAR	576.00	7893.90	7889.16	4.74	7893.09	7894.70	0.014386	8.61	87.48	26.16	0.72
Main	1000	100-YEAR	880.00	7895.54	7889.16	6.38	7893.99	7896.35	0.010162	8.90	134.01	30.39	0.63

Plan: Proposed Stormy Creek Main RS: 599 Culv Group: Culvert #1 Profile: 25-YEAR

Q Culv Group (cfs)	342.00	Culv Full Len (ft)	
# Barrels	1	Culv Vel US (ft/s)	7.12
Q Barrel (cfs)	342.00	Culv Vel DS (ft/s)	6.68
E.G. US. (ft)	7888.59	Culv Inv El Up (ft)	7879.56
W.S. US. (ft)	7887.69	Culv Inv El Dn (ft)	7877.43
E.G. DS (ft)	7886.09	Culv Frctn Ls (ft)	1.95
W.S. DS (ft)	7884.65	Culv Exit Loss (ft)	0.00
Delta EG (ft)	2.50	Culv Entr Loss (ft)	0.55
Delta WS (ft)	3.04	Q Weir (cfs)	
E.G. IC (ft)	7887.69	Weir Sta Lft (ft)	
E.G. OC (ft)	7888.59	Weir Sta Rgt (ft)	
Culvert Control	Outlet	Weir Submerg	
Culv WS Inlet (ft)	7887.25	Weir Max Depth (ft)	
Culv WS Outlet (ft)	7885.40	Weir Avg Depth (ft)	
Culv Nml Depth (ft)	7.66	Weir Flow Area (sq ft)	
Culv Crt Depth (ft)	6.59	Min El Weir Flow (ft)	7898.01

Summary Statement

The initial goals of this replacement culvert design project included widening the roadway, designing a structurally sound culvert, passing the 100-Year storm event, creating a friendly fish passage design for all species, preventing hydraulic design threats downstream, meeting permissible scour velocities in the channel, and meeting species-specific depth and velocity criteria.

Specifically for fish passage, all criteria for the Stream Simulation Design Option were successfully met by following the process laid out within the forms. An overview of the steps include researching existing data and available information, collecting all required parameters at the site, selecting the best fish passage design option for the site, completing the hydrology and efficiently brainstorming and completing the hydraulic modeling, and finally meeting all requirements of the Stream Simulation Design Option.

Recreating the bankfull within the culvert was a viable alternative to the other design options. Continuous continuity between the culvert and natural channel was possible by using the Stream Simulation Design Option. This method can be extremely beneficial to the passage of fish over lengths greater than 100 ft.

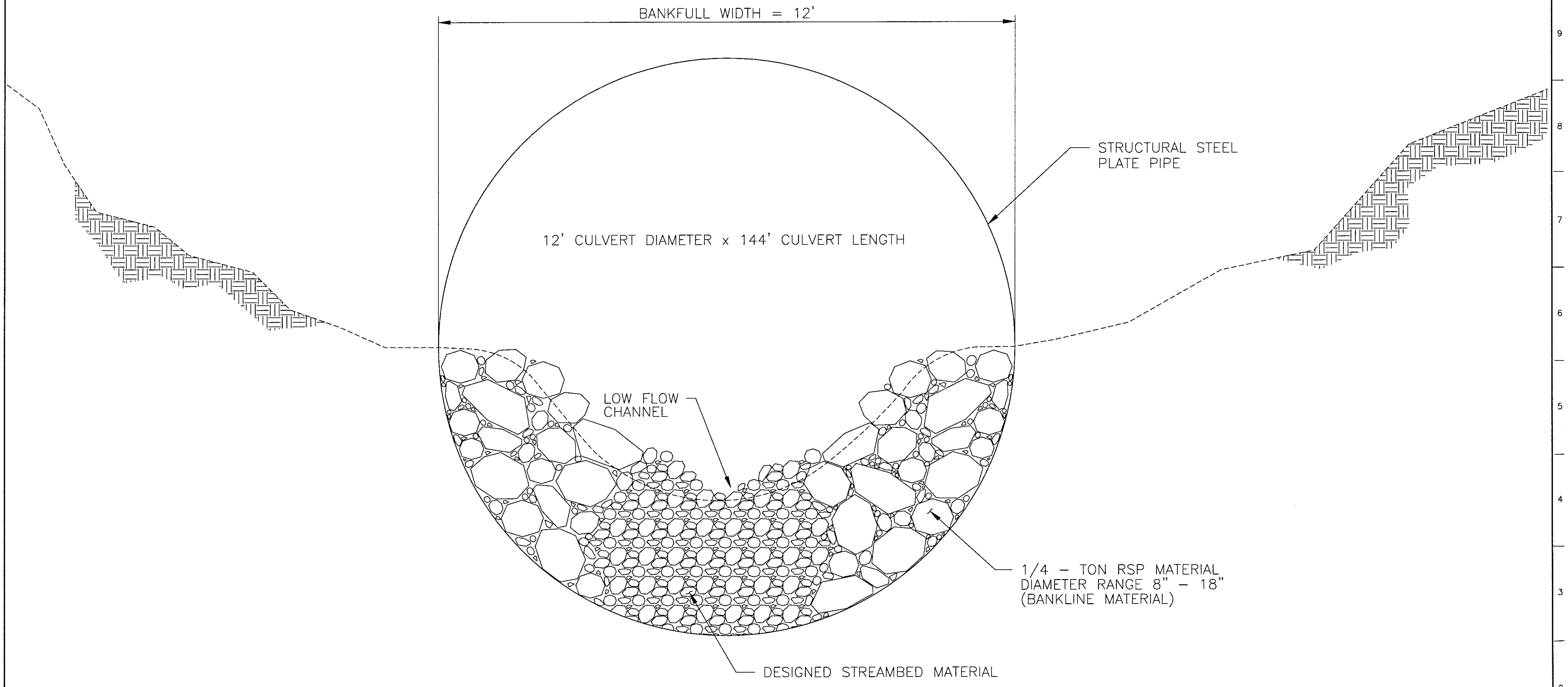
As found in the problem statement, the goal was providing cross drainage for Stormy Creek that met hydraulic standards in the Caltrans Hydraulic Design Manual, as well as fish standards in the California Department of Fish and Game Culvert Criteria and the NOAA Fisheries Guidelines for Salmonid Passage at Stream Crossings.

Summary Data Table1: Culvert Velocities

Geometry Condition and Flood Event	Permissible Velocity for Intermittent (25 -Year Event) Flows in Unlined Channels (ft/s)	Upstream Velocity in Culvert (ft/s)	Downstream Velocity in Culvert (ft/s)
Existing Conditions 25-Year Event	7.90	5.00	8.00
Proposed Conditions 25-Year Event	7.90	7.82	7.06

Summary Data Table 2: Culvert Depths

Geometry Condition	Flood Event	Water Depth inside Culvert at Inlet (ft)	Water Depth inside Culvert at Outlet (ft)
Existing Conditions	4% Annual Probability (25-Year Event)	5.02	4.89
Proposed Conditions	4% Annual Probability (25-Year Event)	4.09	4.37



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09-28-06 AJACKSON 11:29:20

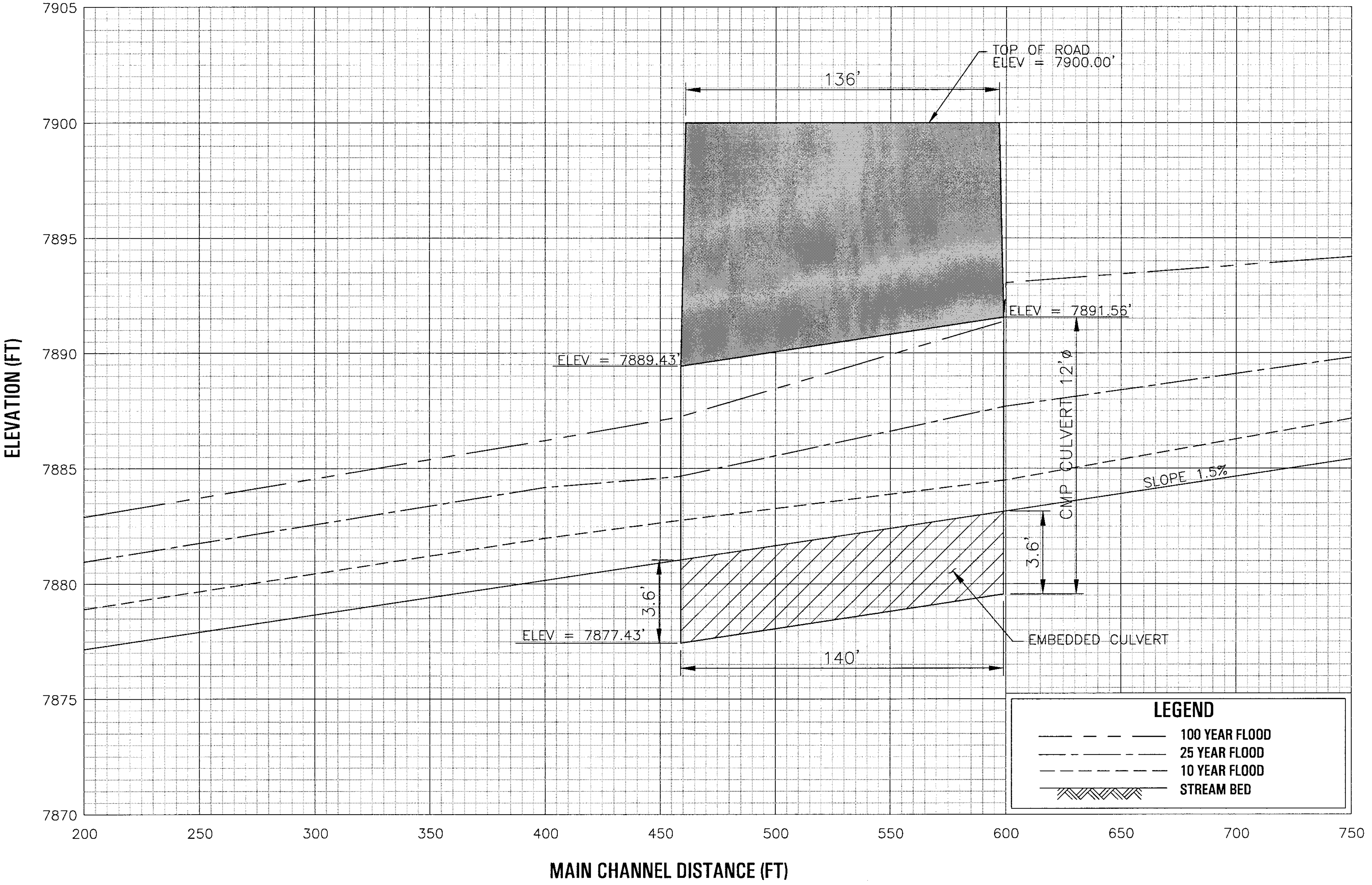
Issue No.	Description	Date	Drwn.	Chkd.	Resp. Engr.	Proj. Mgr.

Project Manager LEF
Designed EKB
Designed
Checked JJL
Drawn AJ

ROUTE 333 4 LANE
@ STORMY CREEK

STREAM SIMULATION DESIGN
PROPOSED CULVERT CONDITIONS

Date
Project No. 06938-38713
Drawing No. **1**
Issue
Scale 1" = 1'
File Name Culvert-Detail.DWG



P:/06938/38713 T07 Fish Passage/5.0 Project Data/AutoCAD/General Details/Stream-Stimulation.DWG
09-01-06 AJACKSON 14:24:47

Issue No.	Description	Date	Drwn.	Chkd.	Resp. Engr.	Proj. Mgr.

Project Manager
LEF

Designed
EKB

Designed

Checked
JJL

Drawn
AJ

Route 333 6 Lane
at Stormy Creek

STREAM SIMULATION DESIGN

PROPOSED CONDITIONS

Date

Scale HORIZ: 1" = 50'
VERT: 1" = 5'

Project No. 06938-38713

File Name Stream-Stimulation.DWG

Drawing No. 1

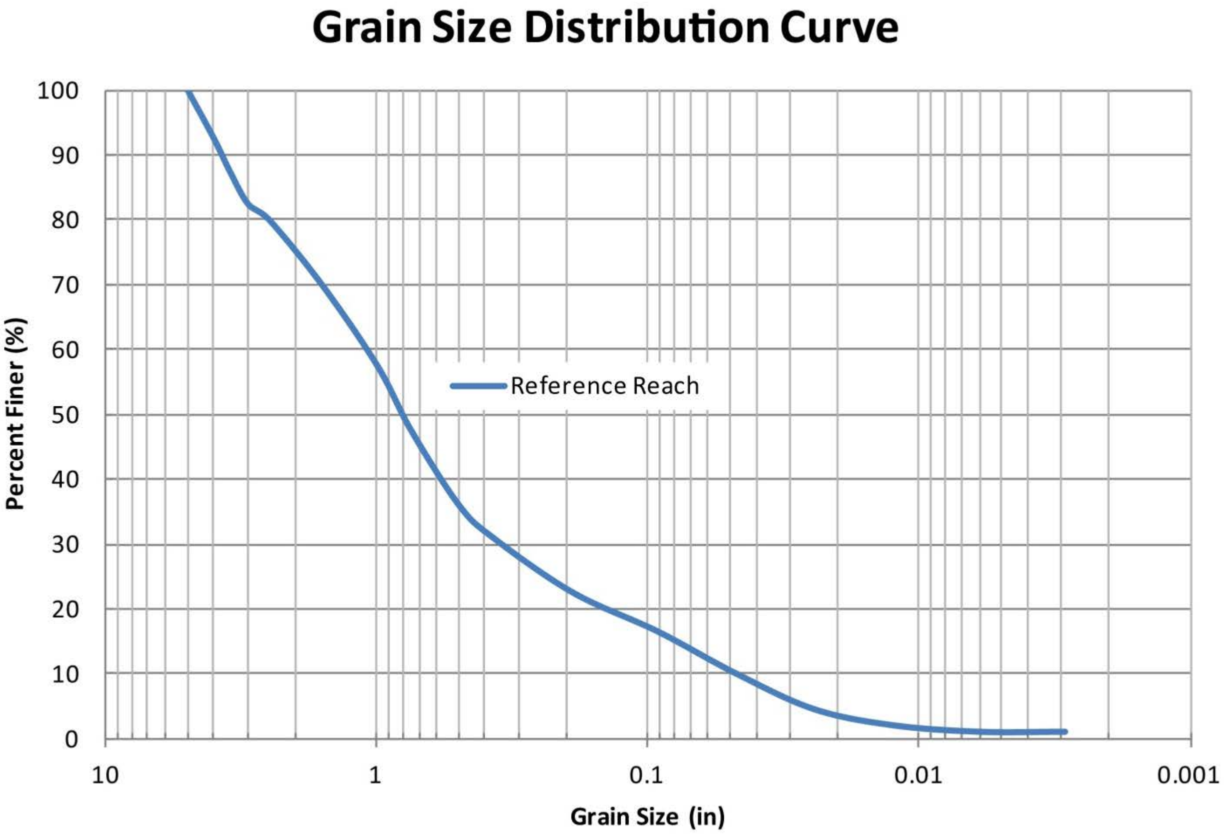
Issue

Updated Method for Stream Simulation Culvert or Bridge Bed Material Sizing

October 2014

In theory, the D_{84} particle controls channel roughness, channel form, and bed mobility. The design premise for stream simulated culvert or bridge bed sizing is that the $\mathbf{D_{84}}$ particle in the stream reference reach and the "design" $\mathbf{D_{84}}$ particle will become mobile at similar flows considering differing hydraulic conditions between the simulation culvert or bridge and the natural stream. The design $\mathbf{D_{84}}$ particle diameter must be sized to meet the bed mobility condition within 25% of the reference reach $\mathbf{D_{84}}$ particle size. Particle size and bed mobility similarities are the two main criteria and must be achieved in the sizing of a stream simulated culvert or bridge bed.

In this guidance document, the process for analyzing stability/mobility and sizing the design bed material is based on the U.S. Forest Service method. This method of analysis and design is recognized by CA Fish & Wildlife.



Step 1. For the reference reach stream bed, request soil sampling (1 ft depth), sieve analysis, and gradation curve generation from District Materials Lab.

Step 2. From the gradation curve, determine D_{16}, D_{50}, D_{84} particle sizes of the reference reach streambed.

$\mathbf{D_{16} = 0.07\ in}$
$\mathbf{D_{50} = 0.85\ in}$
$\mathbf{D_{84} = 3.25\ in}$

Step 3. Using reference reach cross-sectional and long- profile data, find the active channel width and stream gradient (slope).

Active Channel Width = 12 ft
Stream Gradient = 1.48%

Step 4. Create a HEC-RAS model that includes the reference reach, and iterate flow values until active channel flow width from Step 3 has been achieved. From results, find flow area and wetted perimeter for active channel discharge. Calculate hydraulic radius (R).

$$\boldsymbol{R = \frac{Flow\ Area}{Wetted\ Perimeter} = \frac{9.02}{10.32} = 0.874\ ft}$$

Step 5. Determine whether to use the Modified Shields or Critical Unit Discharge Method for stability/mobility analysis by calculating parameters unique to each method:

Modified Shields Method

Bed slope < 5%	**1.48% < 5%?**	**OK**
$R/D_{84} > 5$	**0.874 ft/0.27 ft = 3.22 > 5?**	**NOT OK**
$D_{84}/D_{50} < 25$	**1.4/0.85 = 1.65 < 25?**	**OK**
Bed particle range between 0.39” – 9.75”	**0.003” – 5.0”?**	**NOT OK**

Critical Unit Discharge Method

Bed slope between 2% - 5%	**1.48%?**	**NOT OK**
2.75” < D_{50} < 5.5”	**2.75” < 0.85” < 5.5”?**	**NOT OK**
6” < D_{84} < 9.75”	**6” < 3.25” < 9.75”?**	**NOT OK**
$R/D_{84} < 5$	**0.874 ft/0.27 ft = 3.22 < 5?**	**OK**

Note: Choose the stability/mobility method where most parameters are met. **Use Modified Shields Method.**

Step 6.

a. Choose a minimum of 5 flows between zero and bankfull discharge values to be used in the mobility/stability discharge analysis.

Q_a = 6 cfs
Q_b = 8 cfs
Q_c = 10 cfs
Q_d = 12 cfs
Q_e = 14 cfs

Step 7.

a. Using HEC-RAS model that includes the reference reach, perform analysis for each of the flows chosen in Step 6a.

Step 8.

a. From HEC-RAS model results for each of the trial flows, find flow area, wetted perimeter, energy slope. Calculate hydraulic radius for each flow.

Q_a = 6 cfs
Flow area = 3.32 ft^2
Wetted perimeter = 7.74 ft
Energy slope = 0.0138 ft/ft
Hydraulic radius = A/P = 3.32/7.74 = 0.43 ft

Q_b = 8 cfs
Flow area = 4.04 ft^2
Wetted perimeter = 8.08 ft
Energy slope = 0.0135 ft/ft
Hydraulic radius = A/P = 4.04/8.08 = 0.50 ft

Q_c = 10 cfs
Flow area = 4.72 ft^2
Wetted perimeter = 8.39 ft
Energy slope = 0.0132 ft/ft
Hydraulic radius = A/P = 4.72/8.39 = 0.56 ft

Q_d = 12 cfs
Flow area = 5.35 ft^2
Wetted perimeter = 8.67 ft
Energy slope = 0.0131 ft/ft
Hydraulic radius = A/P = 5.35/8.67 = 0.62 ft

Q_e = 14 cfs
Flow area = 5.94 ft^2
Wetted perimeter = 8.92 ft
Energy slope = 0.0131 ft/ft
Hydraulic radius = A/P = 5.94/8.92 = 0.67 ft

Step 9.

a. In table below, determine Shields parameter based on median bed material (D_{50}). This will be the value τ_{D50} to use in Step 10.

Particle Classification Name	Range of Particle Diameters	Shields Parameter
	(in)	(dimensionless)
Coarse Cobble	5 – 10	0.054 – 0. 054
Fine Cobble	2.5 – 5	0.052 – 0.054
Very Coarse Gravel	1.25 – 2.5	0.05 – 0.052
Coarse Gravel	0.63 – 1.25	0.047 – 0.05
Medium Gravel	0.31 – 0.63	0.044 – 0.047
Fine Gravel	0.16 – 0.31	0.042 – 0.044
Very Fine Gravel	0.079 – 0.16	0.039 – 0.042
Very Coarse Sand	0.039 – 0.079	0.029 – 0.039
Coarse Sand	0.019 – 0.039	0.033 – 0.029
Medium Sand	0.0098 – 0.019	0.048 – 0.033
Fine Sand	0.0049 – 0.0098	0.072 – 0.048
Very Fine Sand	0.0025 – 0.0049	0.109 – 0.072
Coarse Silt	0.0012 – 0.0025	0.165 – 0.109
Medium Silt	0.000614 – 0.0012	0.25 – 0.165
Fine Silt	0.000307 – 0.000614	0.3 – 0.25

Use Shields Parameter = 0.049

Step 10.

a. Find driving force: boundary shear stress and calculate entrainment threshold for D_{84} particle for each flow from Step 6a.

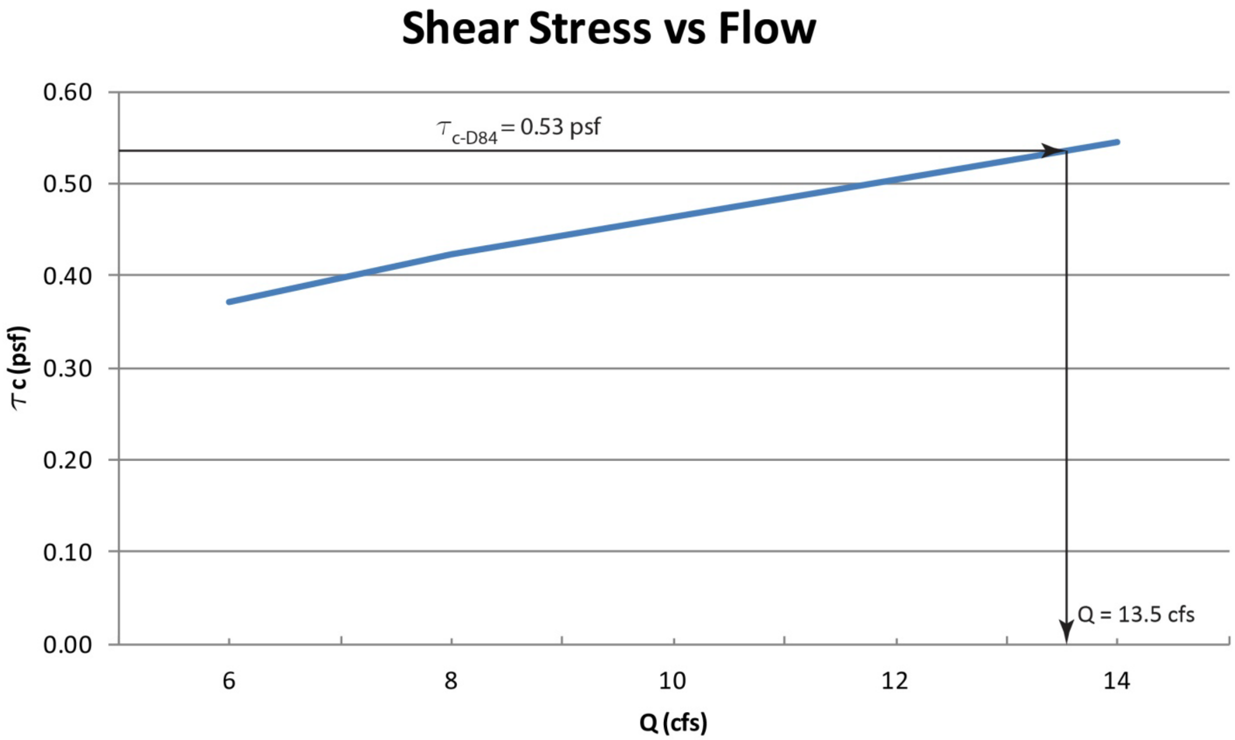
Modified Shields Method								
Hydraulics				Particle Mobility/Stability				
Discharge	Energy Slope	Hydraulic Radius	Driving Force: Boundary Shear Stress	D_{50}	D_{84}	Shield's Entrainment for D_{50}	Critical Shear Stress to Entrain D_{84} Particle Size	D_{84} Particle Mobile
Q (cfs)	S_e (ft/ft)	R_c (ft)	τ_c (psf)	(ft)	(ft)	τ_{D50}	$\tau_{c\text{-}D84}$ (psf)	(yes/no)
REFERENCE REACH CROSS SECTION								
6	0.0138	0.43	0.370	0.071	0.271	0.049	0.53	No
8	0.0135	0.50	0.423	0.071	0.271	0.049	0.53	No
10	0.0132	0.56	0.464	0.071	0.271	0.049	0.53	No
12	0.0131	0.62	0.504	0.071	0.271	0.049	0.53	No
14	0.0131	0.67	0.545	0.071	0.271	0.049	0.53	Yes
$\tau_c = \gamma R_c S_e$								
$\tau_{c\text{-}D84} = 102.6\ \tau_{D50}\ D_{84}^{0.3}\ D_{50}^{0.7}$								

Step 11.

a. Compare driving force and threshold movement values to determine D_{84} particle mobility at each flow. If D_{84} does not become mobile for any of the trial flows, select flows greater than bankfull discharge and repeat Steps 6a – 10a until a flow is found that moves the D_{84} particle.

Step 12.

a. Plot τ_c vs Q. Find the correspond flow with $\tau_{c\text{-}D84}$ threshold shear. This will be the critical flow that causes incipient motion of the D_{84} particle within the reference reach.



Note: Based on Modified Shields analysis, the D_{84} = 3.25 in particle will mobilize at Q = 13.5 cfs within the reference reach.

Step 13. Select an initial D_{84} particle size for the design bed material to be placed inside the stream simulation culvert. The goal is to select a size that will mobilize inside the culvert with a similar discharge as the reference reach (Q = 13.5 cfs).

Initial D_{84} = 4.0 in, corresponding D_{50} = 1.0 in considering parallel gradation with reference reach soil sample.

Repeat Steps 6a – 12a for the design reach inside the stream simulation culvert.

Note: The HEC-RAS model for Step 7a must include the stream simulation culvert. Also, the method for finding wetted perimeter and flow area (Step 8a) will be different for the culvert than the reference reach. In HEC-RAS, the culvert tabular results do not present wetted perimeter and flow area values. For the culvert, the flow area and wetted perimeter will need to be measured and calculated manually from the wetted cross section graphical results in HEC-RAS. Once these values are measured and calculated, hydraulic radius can be obtained.

Repeat Step 6.

a. Choose a minimum of 5 flows between zero and bankfull discharge values to be used in the mobility/stability discharge analysis.

Q_a = 8 cfs
Q_b = 10 cfs
Q_c = 12 cfs
Q_d = 14 cfs
Q_e = 16 cfs

Repeat Step 7.

a. Using HEC-RAS model that includes the reference reach, perform analysis for each of the flows chosen in Step 6a.

Repeat Step 8.

a. From HEC-RAS model results for each of the trial flows, find flow area, wetted perimeter, energy slope. Calculate hydraulic radius for each flow.

   Q_a = 6 cfs
   Flow area = 3.79 ft^2
   Wetted perimeter = 7.56 ft
   Energy slope = 0.0153 ft/ft
   Hydraulic radius = A/P = 3.79/7.56 = 0.50 ft

   Q_b = 8 cfs
   Flow area = 4.41 ft^2
   Wetted perimeter = 8.04 ft
   Energy slope = 0.0157 ft/ft
   Hydraulic radius = A/P = 4.41/8.04 = 0.55 ft

   Q_c = 10 cfs
   Flow area = 5.01 ft^2
   Wetted perimeter = 8.48 ft
   Energy slope = 0.0159 ft/ft
   Hydraulic radius = A/P = 5.01/8.489 = 0.59 ft

   Q_d = 12 cfs
   Flow area = 5.61 ft^2
   Wetted perimeter = 8.90 ft
   Energy slope = 0.0158 ft/ft
   Hydraulic radius = A/P = 5.61/8.90 = 0.63 ft

   Q_e = 14 cfs
   Flow area = 6.17 ft^2
   Wetted perimeter = 9.29 ft
   Energy slope = 0.0159 ft/ft
   Hydraulic radius = A/P = 6.17/9.29 = 0.66 ft

Repeat Step 9.

a. In table below, determine Shields parameter based on median bed material (D_{50}). This will be the value τ_{D50} to use in Step 10.

Particle Classification Name	Range of Particle Diameters	Shields Parameter
	(in)	(dimensionless)
Coarse Cobble	5 – 10	0.054 – 0. 054
Fine Cobble	2.5 – 5	0.052 – 0.054
Very Coarse Gravel	1.25 – 2.5	0.05 – 0.052
Coarse Gravel	0.63 – 1.25	0.047 – 0.05
Medium Gravel	0.31 – 0.63	0.044 – 0.047
Fine Gravel	0.16 – 0.31	0.042 – 0.044
Very Fine Gravel	0.079 – 0.16	0.039 – 0.042
Very Coarse Sand	0.039 – 0.079	0.029 – 0.039
Coarse Sand	0.019 – 0.039	0.033 – 0.029
Medium Sand	0.0098 – 0.019	0.048 – 0.033
Fine Sand	0.0049 – 0.0098	0.072 – 0.048
Very Fine Sand	0.0025 – 0.0049	0.109 – 0.072
Coarse Silt	0.0012 – 0.0025	0.165 – 0.109
Medium Silt	0.000614 – 0.0012	0.25 – 0.165
Fine Silt	0.000307 – 0.000614	0.3 – 0.25

Use Shields Parameter = 0.049.

Repeat Step 10.

a. Find driving force: boundary shear stress and calculate entrainment threshold for D_{84} particle for each flow from Step 6a.

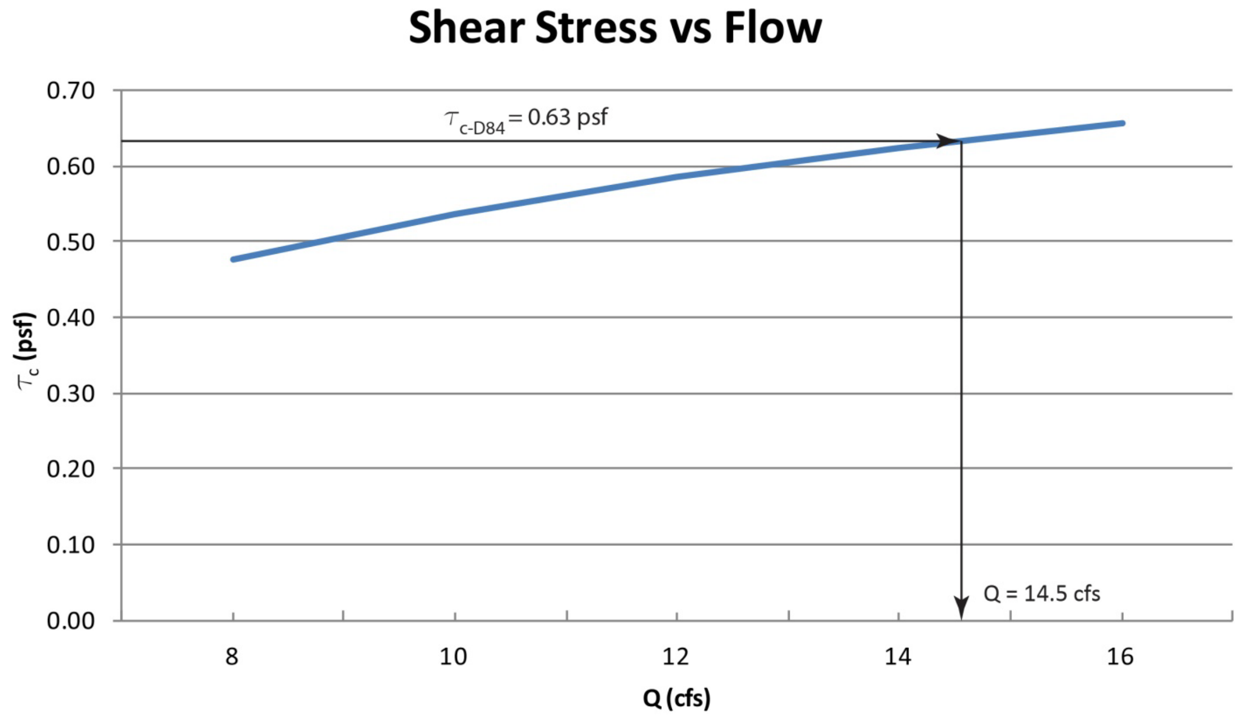
Modified Shields Method								
Hydraulics				Particle Mobility/Stability				
Discharge	Energy Slope	Hydraulic Radius	Driving Force: Boundary Shear Stress	D_{50}	D_{84}	Shield's Entrainment for D_{50}	Critical Shear Stress to Entrain D_{84} Particle Size	D_{84} Particle Mobile
Q (cfs)	S_e (ft/ft)	R_c (ft)	τ_c (psf)	(ft)	(ft)	τ_{D50}	$\tau_{c\text{-}D84}$ (psf)	(yes/no)
DESIGN REACH CROSS SECTION								
8.00	0.01527	0.50	0.478	0.08	0.333	0.049	0.63	No
10.00	0.01569	0.55	0.537	0.08	0.333	0.049	0.63	No
12.00	0.01587	0.59	0.585	0.08	0.333	0.049	0.63	No
14.00	0.01584	0.63	0.623	0.08	0.333	0.049	0.63	No
16.00	0.01587	0.66	0.657	0.08	0.333	0.049	0.63	Yes
$\tau_c = \gamma R_c S_e$								
$\tau_{c\text{-}D84} = 102.6\, \tau_{D50}\, D_{84}^{0.3}\, D_{50}^{0.7}$								

Repeat Step 11.

a. Compare driving force and threshold movement values to determine D_{84} particle mobility at each flow. If D_{84} does not become mobile for any of the trial flows, select flows greater than bankfull discharge and repeat Steps 6a – 10a until a flow is found that moves the D_{84} particle. If all flows cause movement in D_{84} particle, choose lower flows until a flow is found where D_{84} particle is stable

Repeat Step 12.

a. Plot τ_c vs Q. Find the corresponding flow with $\tau_{c\text{-}D84}$ threshold shear. This will be the critical flow that causes incipient motion of the D_{84} particle within the design reach.

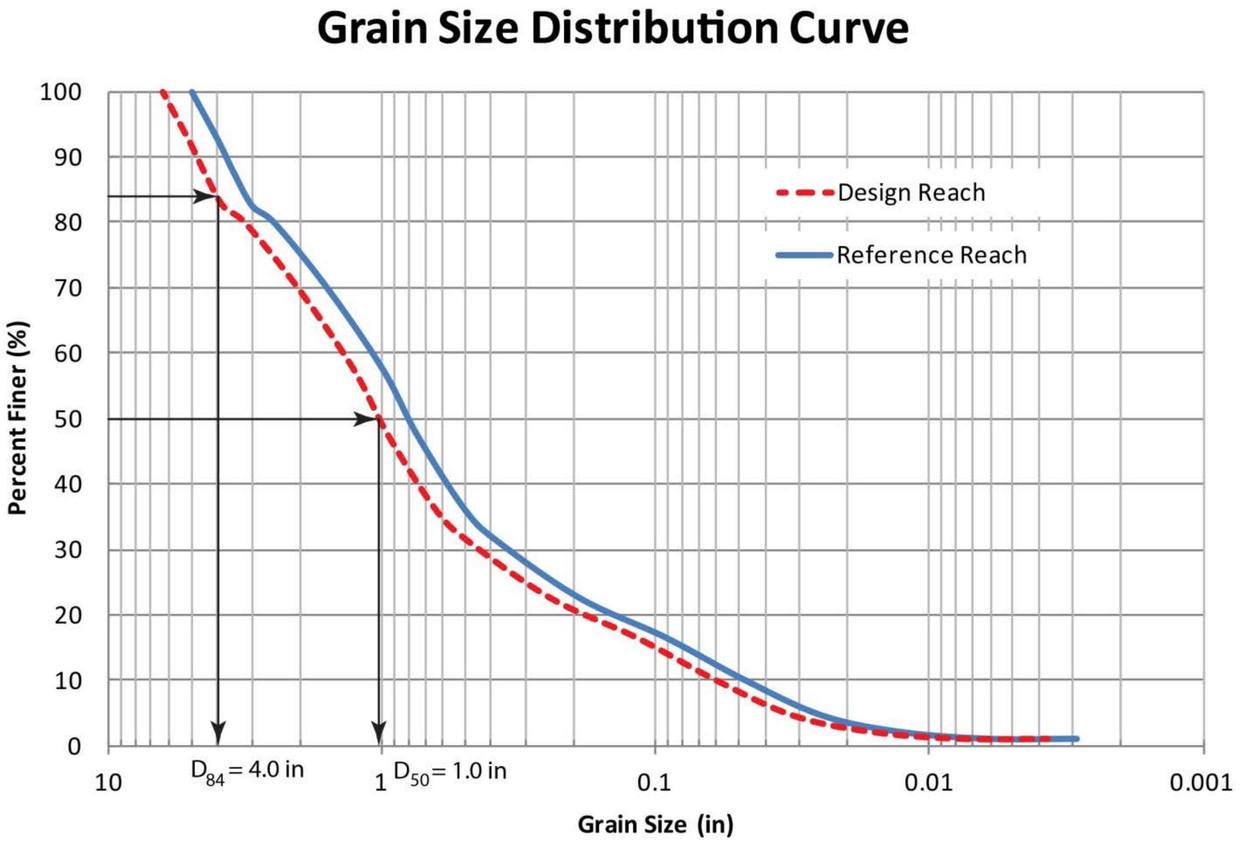


Note: Based on Modified Shields analysis, the D_{84} = 4.0 in particle will mobilize at Q = 14.5 cfs within the design reach.

Step 14. Compare critical flow of the reference reach and design reach that causes respective **D_{84}** particle to move. Also, compare **D_{84}** particle sizes between reference reach and design reach. Are the sizes within 25% of each other, and do they mobilize at similar flows?

The design D_{84} particle size is 23% larger than the reference reach, which is within 25% (recommended) of the reference reach D_{84} particle size. Also, the design D_{84} particle mobilizes at a similar discharge as the reference reach (13.5 cfs vs. 14.5 cfs), therefore design D_{84} particle is acceptable.

Step 15. Once the final D_{84} particle diameter has been determined, shift the gradation curve from the reference reach to match the D_{84} design particle diameter. This will create parallel gradation between the reference reach and the design reach.



Step 16. From the new design reach gradation curve, determine D_8 and D_{16} particle size.

D_8 = 0.050 in
D_{16} = 0.125 in

Step 17. Using Fuller-Thompson method, calculate D_8 and D_{16} particle size to achieve a high density mixture to seal simulated bed and control permeability. In the equations below, use D_{50} from the design gradation curve. The values of "n" will typically range between 0.45 – 1.1 to meet the high density mixture desire. The goal in this analysis is to have D_8 particle diameter be approximately 0.08 in and the value of "n" should be chosen accordingly. If the reference reach D_8 and D_{16} particle sizes are below the calculated particle sizes, the gradation curve for the simulated culvert bed will not need to be adjusted.

$$\boldsymbol{D_{16} = 0.32^{1/n} D_{50}}$$

$$\boldsymbol{D_{8} = 0.16^{1/n} D_{50}}$$

D_{50} = 1.0 in
Use "n" = 0.7

$$\boldsymbol{D_{16} = 0.32^{\frac{1}{0.7}}(1.0\ in) = 0.19\ in}$$

Calculated D_{16} = 0.19 in > Design D_{16} = 0.125 in OK

$$\boldsymbol{D_{8} = 0.16^{\frac{1}{0.7}}(1.0\ in) = \ 0.07\ in}$$

Calculated D_8 = 0.07 in > Design D_8 = 0.050 in OK

Because design D_8 and D_{16} are less than calculated D_8 and D_{16}, no need to adjust design gradation curve to meet the high density mixture criteria.

Step 18. Calculate stream simulation bed minimum thickness.

Min. Thickness = 4 × D_{84} design reach = 4 × 4.0 = 16.0 in

APPENDIX M

CONSTRUCTION CONSIDERATIONS

The primary concerns about construction's impact on fish habitat involve potential creation of passage barriers, release of sediment or pollutants, and removal of stream bank vegetation.

NOTE: The material presented in this Appendix is extracted from the *Fish Habitat Manual* (Alberta Transportation, n.d.) and from the *California Salmonid Stream Habitat Restoration Manual* (CDFG 2003).

M.1. Instream Work

- Plan the project so that the amount of instream work is kept to a minimum
- Where possible, plan instream work to occur as a single event
- Restrict instream work to low flow periods where possible
- Restrict instream work to the dry period if the channel is seasonally dry
- Limit machinery access to a single point on one bank
- Prior to construction, determine locations and equipment access points that minimize riparian disturbance. Avoid affecting less stable areas.
- Limit distance between the machinery access point and work site
- Adhere to timing restrictions
- Minimize flow constriction
- Consider an instream pad built of washed gravel where instream equipment activity would generate excess sediment
- Fish rescue

M.1.1. General Work Area

- Keep right-of-way for channel crossings as narrow as possible within the constraints of safety and construction requirements
- Limit removal of vegetation to the width of the right-of-way. Retain as much understory brush and as many trees as feasible, emphasizing shade-producing and bank-stabilizing vegetation.
- Clear vegetation by hand from unstable banks subject to erosion, avoiding the use of heavy machinery
- Develop sediment control plans and install sediment control measures before starting work
- Stockpile topsoil removed from the right-of-way outside of the active floodplain and use measures such as silt fences and holding ponds to prevent stockpile runoff from entering the stream channel
- Minimize temporary stockpiling of excavated material
- Direct runoff containing sediment away from the stream into a vegetated area
- Construct suitably sized settling ponds to precipitate suspended sediment before water is discharged into the stream channel
- Stabilize soils subject to erosion as soon as practical by seeding, spreading mulch, or installing erosion control blankets
- Allow at least four weeks of growing season when using seeding to stabilize soils subject to erosion
- Maintain a vegetated buffer strip between the work site and stream channel except at the actual crossing location

Machinery

- Ensure that machinery arrives onsite washed, clean, and in good working condition, showing no signs of fuel or oil leaks
- Install stabilized entrances at vehicle and machinery access points
- Limit the amount and duration of instream work with heavy machinery. Work from the banks where possible.
- 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.
- Locate areas for fuel storage, refueling, and servicing of construction equipment in an upland location well removed from the stream channel
- Wash and service vehicles and machinery at locations well removed from the stream channel
- Work on instream pads composed of washed gravel to minimize sediment entrainment

Potentially Toxic Materials

- Prevent any construction debris from falling into the stream channel. Remove any material that does fall into a stream during construction in a manner that has minimal impact to the streambed and water quality.
- Use bio-friendly hydraulic fluids in equipment operating in or adjacent to the stream. If riparian vegetation is to be removed with chainsaws, consider using saws currently available that operate with vegetable-based bar oil.
- Store fuel, lubricants, hydraulic fluid and other potentially toxic materials at locations well removed from the stream channel
- Isolate storage areas so that spilled fluids cannot enter the stream
- Prepare a spill contingency plan
- Maintain spill cleanup supplies onsite and be knowledgeable in their proper use and deployment
- In the event of a spill, immediately cease work, start cleanup, and notify the appropriate authorities
- Ensure treated lumber is completely dry (no evidence of treatment material seepage) before use in or near the stream
- Treat or paint lumber used in construction at a site well removed from the stream
- Use bridge skirts or other appropriate measures to prevent material from entering the stream channel when painting, cleaning, or resurfacing bridge deck and superstructures
- Do not use ammonium nitrate fuel oil-based explosives
- Do not allow petroleum products, fresh cement, or deleterious materials to enter the stream channel

Cofferdams and Berms

- Use cofferdams (earth fill, sheet pile, or other proprietary designs) to separate instream work site from flowing water
- Use clean, washed material for construction and face berms with clean granular material

- Design cofferdams to accommodate the expected flows of the stream
- Limit cofferdams to one side of the stream channel at any one time and ensure that they block no more than one-third of the channel
- Restore the original channel bottom grade after removing cofferdams
- Treat all water pumped from behind the cofferdams to remove sediment before discharge

Temporary Diversion Channels

- Construct temporary diversion channels "in the dry", starting from the downstream end
- Design temporary diversion channels to accommodate expected flow from storm events
- Use erosion control methods where appropriate. Maintain erosion control measures in place at all times during construction.
- Maintain a supply of erosion control materials onsite to facilitate a quick response to unanticipated storm events or emergencies
- Leave the existing channels untouched until the temporary diversions are constructed and erosion protection is in place
- Open diversion channels from the downstream end first
- Use clean, washed material to close existing channels and divert water to temporary diversion channels
- Use gradient controls to ensure that diversion channel slopes correspond to the existing channel gradients
- Protect unstable bends from erosion

Pumped Diversions/Dewatering

- Use only where a channel must be completely blocked to allow work "in the dry". Do not use at a time when there are fish passage concerns.
- Prior to dewatering, determine the best means to bypass flow through the work area to minimize disturbance to the channel and to avoid mortality of fish and other aquatic vertebrates
- Coordinate project site dewatering with a fisheries biologist. Fish relocation activities must be performed only by qualified fisheries biologists in possession of the requisite permits.
- 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
- Size and screen intakes to prevent debris blockage and fish mortality
- Size the pumping system to accommodate expected flow from storm events
- When periodically pumping seepage from the work area, 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. Cover pump intakes with 1/8-inch mesh to prevent entrainment of any fish or amphibians that were not previously removed. Check intakes 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 the stream channel
- Armor the discharge point with clean rock to prevent erosion

Reclamation and Site Cleanup

- Begin reclamation and site cleanup as soon as construction has been completed
- Decompact disturbed soils at project completion as the heavy equipment exits the construction area
- Remove all waste material from active floodplain
- Remove all temporary fill in its entirety prior to close of work window
- Re-contour, stabilize, and re-vegetate disturbed areas to suit original conditions. Stabilize all exposed soil with mulch, seeding, and/or by placement of erosion control blankets.
- Re-vegetate disturbed and decompacted areas with native species specific to the project location. The native species should encompass a diverse community of woody and herbaceous species.
- Remove all temporary facilities and structures
- Stabilize all slopes leading directly to the stream channel
- Seed exposed slopes immediately if there are at least four weeks remaining in the growing season. If this is not possible, immediately re-vegetate slopes in the next growing season.

M.1.2. Construction Bid Period and Completion

It is important that the designers be part of the bid evaluation and construction process to assure the intent of the design is carried through the selection process and construction activities. Understanding by the contractor of the bid requirements, and the construction means and methods, relative to the fish passage design intent is necessary to minimize any misunderstandings or misconceptions.

APPENDIX N
ROCK WEIR DESIGN

N. Rock Weir Design

N.1 Rock Weir Sizing

The rock within a rock weir must resist active forces of drag, lift, and buoyancy while subjected to flowing water in a creek. The cap layer rocks, as well as the rocks beneath in a weir, will resist the collective active forces, and must be sized accordingly. The methods for sizing rocks comprising a rock weir are Field Inspection, Rock Slope Protection (RSP) Revetment Design, Boulder Cluster Design, and Hydrostatic (Overturning Moment).

After calculating rock size using the three methods mentioned above, engineering judgment shall be incorporated in deciding which result should be used for design and construction. The most conservative or largest rock size is not necessarily the best choice, especially if a great disparity exists between the sizes calculated using the other methods.

N.1.1 Field Inspection Method

In addition to the project limits within the creek, upstream and downstream reaches should be investigated for large, stable rocks (boulders) in the stream that appear to be immobile during overtopping flows. Some stability indicators to look for in the field are salt and silt stains on a boulder, moss and lichen growth on a boulder, and bar or terrace development around a boulder or group of boulders. These bars typically contain vegetation, as well as coarse gravels and cobbles.

Once stable rocks are located in the field, their rough diameters need to be measured in the direction of at least two of the three principle axes (long, short, and middle). The measurements of each boulder should be averaged to find their approximate or rough diameter. After the rough diameters are determined, use Table N-1 to find the RSP Class corresponding to the rough D_{50} measured in the field. The information in Table N-1 is consistent with the *California Bank and Shore Rock Slope Protection Design Report (CA RSP Report):*

RSP Class	**Rough D_{50} (ft)**
Cobble	0.66
Backing No. 1	0.95
Light	1.32
¼ Ton	1.79
½ Ton	2.26
1 Ton	2.85
2 Ton	3.59
4 Ton	4.50
8 Ton	5.70

Table N-1. RSP Class Rough Diameter

N.1.2 RSP Revetment Design Method

When using this method, a rock weir is analyzed as a revetment following the procedures outlined in the *CA RSP Report*. The minimum weight of rock that will resist forces from flowing water and remain stable is calculated based on a factored velocity, rock angle of repose, and rock specific gravity.

Because the *CA RSP Report* equation is being applied to the sizing of a rock weir rather than an RSP revetment, certain modifications can be made. For instance, the angle of repose of the stacked/placed rock can be simplified for rock weir analysis. When stacking or placing rock to build a weir, the steepest repose angle, recommended by the *CA RSP Report,* will be used to reduce rock quantity, as well as improve constructability. Basically, the flatter the rock weir side slope, the wider its base width will be (See Figure N-3), and the greater potential that individual weirs within a series will intersect or conflict with each other. It would be difficult to construct the weirs to the proper dimensions and tolerances if the rocks are all merged together. This would compromise the function of the weir, in addition to complicating the construction process. So, it is advantageous to have the steepest slope feasible for rock placement to avoid these problems.

In contrast, the rock for a revetment is controlled by the natural slope of the banks and will change at each project site, whereas the rock within a weir can placed at the same angle of repose in all cases with only minor influence from each site condition. Given 1.5:1 as the recommended slope for rock weir placement for all cases, the angle of repose will be 36.3 degrees. Therefore, a modified version of the *CA RSP Report* equation can be expressed as follows:

$$W = \frac{0.00002V^6SG}{0.207(SG-1)^3}$$

Where:

W = minimum rock mass (pounds)

*V = 1.33 V_{max} (ft/s)

SG = rock specific gravity

*In RSP revetment design, the velocity term is factored to consider parallel or impinging flow conditions. For parallel flow, the average stream velocity is multiplied by a 0.67 factor, while a 1.33 factor is applied to average stream velocity for impinging flow conditions.

For in-stream weirs, flow will be impinging on the weir in all cases and a 1.33 factor is applied to increase average stream velocity as applied in the *CA RSP Report*. Basically, the velocity vector from the stream flow will act directly on a weir in a perpendicular direction, and it will be also be subjected to secondary currents providing higher than average velocities. The average stream velocity should correspond with a 50-year flow at a minimum for rock weir sizing.

The calculated weight (W) will correspond to an RSP material class, which is summarized in Table N-2. For example, W= 1000 pounds corresponds to a ½ Ton RSP class, W= 2000 pounds corresponds to a 1-Ton weight class, etc. When sizing rock weirs, ½ -Ton RSP is the lightest rock to be used to ensure conservatism due to adapting design methods that were not developed specifically for rock weir analysis.

Caltrans RSP Class	Weight (lbs)
Backing No. 1	75
Light	200
¼ Ton	500
½ Ton	1000
1 Ton	2000
2 Ton	4000
4 Ton	8000

Table N-2. Caltrans RSP Class Weights

N.1.3 Boulder Cluster Design Method

This simplistic approach uses a table containing minimum boulder diameters and their associated critical shear stress (τ_c) and critical velocity (v_c) assuming a rock/boulder angle of repose equal to 42 degrees (approximately 1.8:1) and rock specific gravity equal to 2.65. The τ_c and v_c values were determined considering drag, lift, and buoyancy forces acting on the rocks/boulders. For the minimum diameter given in the following table, the rock/boulder will be stable during turbulent flow with it fully immersed. In other words, incipient motion will occur for a given rock/boulder diameter when stream velocities are higher than the critical velocity shown in Table N-3.

Generic Rock Class	Min. Dia. (in)	τ_c (lb/sf)	v_c (ft/s)
Very Large Boulder	>80	37.4	25
Large Boulder	>40	18.7	19
Medium Boulder	>20	9.3	14
Small Boulder	>10	4.7	10
Large Cobble	>5	2.3	7
Small Cobble	>2.5	1.1	5

Table N-3. Boulder Cluster Design Method- Minimum Rock Diameter

If an average stream velocity equals 16 ft/s, a minimum rock diameter of 28 inches can be interpolated from Table N-3. From Table N-1, a 28-inch or 2.33-foot rough diameter boulder would be classified as a ½ Ton RSP class, having weight equal to 1000 pounds.

N.1.4 Hydrostatic (Overturning Moment) Method

This analysis method is best applied to a Rock Weir (Type 2) described in Section N.8. For this method, resultant pressure and buoyancy forces are considered acting on a single rock within a weir, and this rock will resist these forces through its mass. Frictional resistance between the rock being analyzed and the stream bed would also resist these active forces, but is being ignored because this force is fairly small. Conservatism is further applied by also ignoring the mass resistance of backfill on the downstream side of a rock. Essentially, a top layer rock is analyzed on a level, frictionless plane where only its mass will prevent movement. A free-body diagram of the hydrostatic forces is shown in Figure N-1.

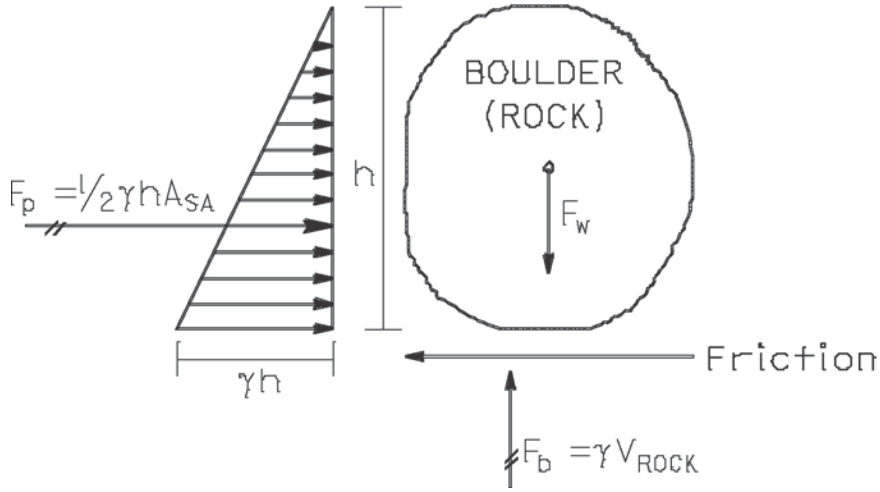


Figure N-1. Rock Free Body Diagram

F_p= Pressure Force (lb)

F_b= Buoyancy Force (lb)

F_w= Mass of Boulder (Rock) (lb)

h= Height of Water Column Associated With Design Storm Flow (ft)

γ= 70 lb/ft^3 (Water & Suspended Sediment)

A_{SA}= Surface Area of Boulder (Rock) (ft^2)

V_{ROCK}= Volume of Boulder (Rock) Based on Radius= $4/3\pi r^3$ (ft^3)

The first step is to determine the height of the water column or flow depth associated with the design flow, which is typically done by developing a HEC-RAS model of the stream. Secondly, an initial estimate of rough rock diameter is performed so that mass, rock volume, and surface area can be calculated.

Once the active and resistive forces are determined for a chosen rock diameter, overturning moments can be calculated and stability analyzed based on the ratio of the sum of active and resisting overturning moments. Moment-ratios ($\Sigma M_{Resist}/\Sigma M_{Active}$) below 1 signify instability, equal to 1 indicate neutral stability, and ratios above 1 show stability. Rock diameter can be varied until proper stability results are achieved. See Table N-4 for example overturning moment and stability analysis.

f_P (LBS)	F_B (LBS)	F_W (LBS)	M_P (FT-LBS)	M_B (FT-LBS)	M_W (FT-LBS)	ΣACTIVE: M_P+M_B (FT-LBS)	ΣRESIST: M_W (FT-LBS)
6,752	13,504	24,000	22,147	45,795	120,000	67,942	120,000

Table N-4. Example Summary of Hydrostatic Forces (F) and Overturning Moments (M)

$$\text{Factor of Safety} = \Sigma M_{Resist}/\Sigma M_{Active} = 120{,}000/67{,}942 = 1.8$$

N.2 Rock Weir Embedment

The depth or embedment of the rock weir is dependent upon the estimated scour potential for the site. An exact method for determining scour depth at a rock weir does not exist, but it can be estimated by one of two methods: Field Inspection/Topographic Survey and Toe-Scour Estimate Equation.

N.2.1 Field Inspection/Topographic Survey Method

Because scour depths typically are not observed during the peak of a significant storm when flow and sediment movement would be at their highest, a safety factor of 1.2 is applied to observed scour depths. As flow decreases on the descending limb of a hydrograph, suspended sediment begins to deposit. This means that scour holes found in the field during clear weather conditions are smaller than during peaks of storm events.

$$\text{Design Scour Depth} = 1.2(D_{FOD})$$

Where:

D_{FOD} = Field Observed Depth of Scour

N.2.2 Toe-Scour Estimate Method

For this method, scour depth will be calculated considering the rock weir as a stabilized bendway. Similar to a bendway section of channel, the vortex-shaped rock weir will be subjected to secondary currents, which cause higher velocities and shear stresses. These conditions will trigger greater scour around a rock weir, as well as changes in sediment transport and supply.

The toe-scour equation is empirical and was developed by synthesizing laboratory and field data. The scour depth calculation is dependent upon mean channel depth and water surface width upstream of a bend or weir, in addition to centerline bend radius and maximum water depth in bend.

Within the scour depth calculation, two ratios are incorporated. The first ratio is the centerline bend radius divided by the water surface width upstream of a bend or weir (R_c/W), while the second ration is this same water surface width divided by the mean channel depth upstream of a bend or weir. (W/D_{mnc}). Since the equation is empirical, limits apply to its use, more specifically to the R_c/W and W/D_{mnc} ratios. Based on the range of field and laboratory data sets, R_c/W is limited from 1.5 to 10 and W/D_{mnc} limited from 20 to 125. In other words, when W/D_{mnc} is calculated to be less than 20, a value of 20 must be used. Conversely, a value of 125 must be used when W/D_{mnc} is calculated to be above 125.

As for the R_c/W ratio, it is of course dependent upon the centerline bend radius. Because the toe-scour equation is being adapted to apply to rock weir design in straight and bending channel sections, 1.5 will be used as the default value. By using 1.5 for all cases, calculated potential scour depths will be conservative.

Finally, the equations used in estimating scour depth in this method are:

$$\text{Scour Depth} = D_{mxb} - D_{mnc}$$

Where:

D_{mxb} = maximum water depth at weir (feet)

D_{mnc} = mean channel depth upstream of weir (feet)

$$D_{mxb} = 1.14D_{mnc}\left(1.72 + \frac{0.0084W}{D_{mnc}}\right)$$

Once the scour depth is calculated, this depth will be used to specify the embedment depth of the rock weir with reference to the channel bed finished grade surface. The height of rock weir above the channel bed will be determined during the hydraulics analysis.

The total height of the rock weir, equal to the height above channel bed plus the embedment depth, must be equal to or greater than the recommended RSP class thickness recommended by the *CA RSP Report* displayed in Table N-5.

Caltrans RSP Class	Minimum Thickness (ft)
½ Ton	3.40
1 Ton	4.30
2 Ton	5.40
4 Ton	6.80
8 Ton	8.50

Table N-5. Minimum Caltrans RSP Class Thickness

After the height of the weir is determined through hydraulics analysis, which is measured above the channel bed, the total rock weir thickness must be equal to or greater than the required minimum found in Table N-4. If the embedment depth plus the rock weir height is less, the minimum RSP Class layer thickness would control.

Below the rock weir, a 1.8-foot (or 2-foot) layer of Backing No. 1 RSP underlain by RSP Fabric is needed to provide filtration beneath all rock weirs. This filter layer will prevent soil movement and loss of fines from piping, and ultimately improve rock weir stability.

See Figure N-3 for embedment depth, rock weir height, and filter layer illustrations.

together with their combined mass would have to be constructed to obtain an adequate resisting moment. Using two rows of 5-foot (6-Ton) rocks, placed one behind the other in the direction of Rock Weir Geometry

The components of rock weir geometry include crest width, side slope ratio, and plan-view radius. As mentioned previously, the side slope ratio will be 1:1.5 for all rock weirs, but the crest width and plan-view radius must be calculated. The crest width is simply expressed below, where D_{50} is associated with the rock weir RSP class.

$$\text{Crest Width} = 2\ (\text{Rock Weir } D_{50})$$

The other rock weir geometry element to consider is the arc, plan-view shape. See Figure N-1. The mid-chord offset of the arc is equal to 3 times D_{50} of the rock weir RSP class. The chord length will equal the distance between the left and right toes of slope. After determining the mid-chord offset and chord length, the radius of the arc can be determined with the equation below:

$$R = \frac{L^2}{8m} + \frac{m}{2}$$

Where:

R = rock weir radius (feet)

L = chord length (feet)

m = mid-chord offset= 3 D_{50} (feet)

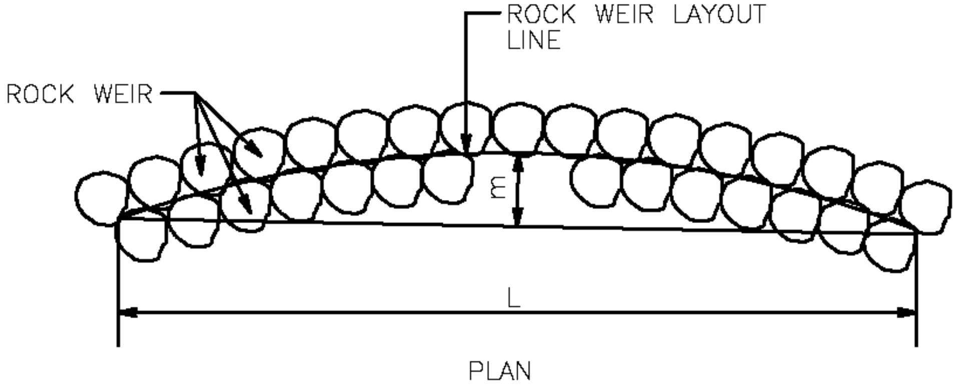


Figure N-2. Rock Weir Plan

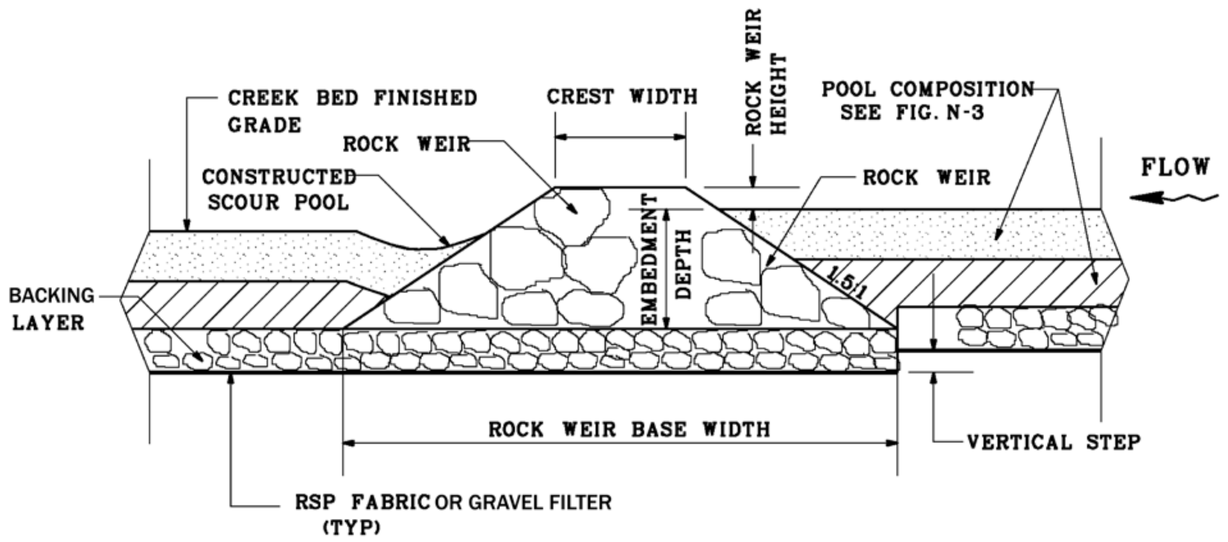


Figure N-3. Rock Weir (Type 1) Profile

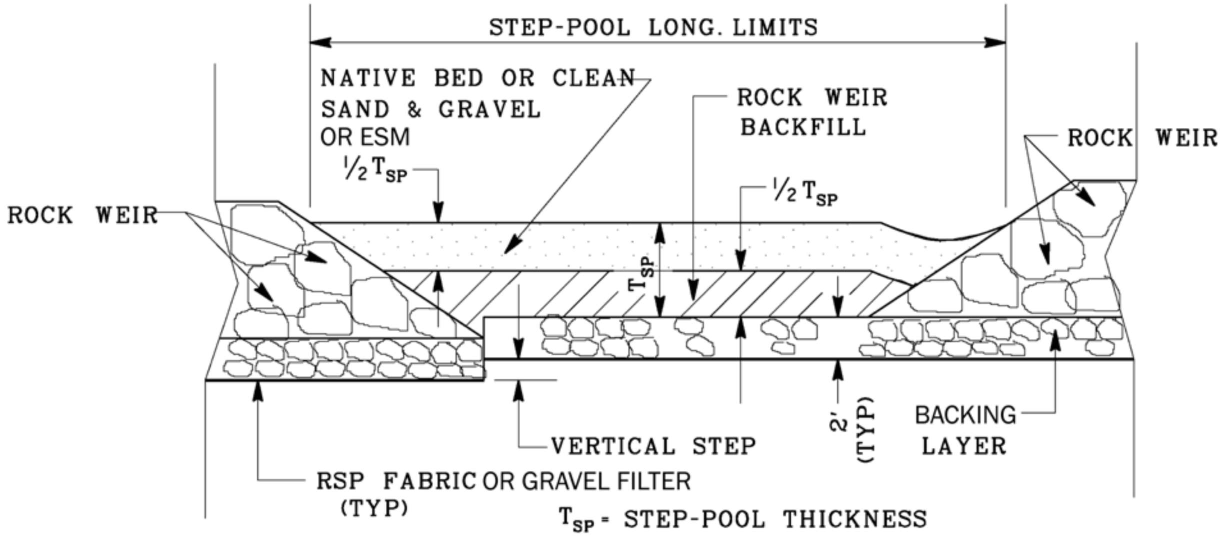


Figure N-4. Step-Pool Profile

N.3 Step-Pool Composition

The portion of the creek between rock weirs is the pool or step-pool, which has a total thickness defined in Figure N-4 as Tsp. The total thickness is measured from the creek bed finished grade to the top of the backing layer. Tsp dimensions will vary for each project depending on rock weir embedment depth and vertical step height within the pools.

As also seen in Figure N-4, the step-pool is composed of two layers of equal thickness. The top layer is either native bed material, clean sand and gravel, or engineered stream bed mix (see Section N.4), and these materials should be well compacted to 90% relative compaction during placement. The function of the top layer is to support habitat and to allow the development of various micro-pools that will promote resting areas for fish as they move through the rock weir/step-pool system.

During construction, the top 1-feet to 3-feet of the excavated creek bed can be stockpiled on site and later placed or returned to the creek as the step-pool top layer according to specified dimensions. If the excavated material is deemed unsuitable, clean sand and gravel can be imported and placed. The following is a recommended gradation for clean sand and gravel:

Sieve Size	Percentage Passing
1”	100
¾”	60-90
No. 4	25-60
No. 30	0-20

Table N-6. Clean Sand and Gravel Gradation

For bottom layer of the step-pool, a rock weir backfill is recommended that has cohesive properties and well-compacted (roughly 90% relative compaction), somewhat similar to structure backfill. The purpose of this rock weir backfill is to provide stability of the weir at its base, as well as aid in scour resistance. With its cohesive properties, the rock weir backfill will also reduce potential for surface flows becoming subsurface that can occur with a constructed streambed. The properties of the recommended rock weir backfill are as follows:

Minimum Sand Equivalent	50
Maximum Aggregate Size	3”
Maximum Plasticity Index	20
Minimum Plasticity Index	12

Table N-7. Rock Weir Backfill Properties

At the downstream end of a rock weir within the step-pool, a scour pool should be constructed. This scour pool will encourage fish to rest before jumping over the rock weir and continuing their journey. As stated previously, a 2-foot flow depth shall be provided at the downstream end of a rock weir. Even though a scour pool will form naturally over time as flow plunges over a weir, the constructed scour pool will provide immediate benefit after construction.

For recommended “Place Native Creek Bed Material”, ”Clean Sand and Gravel”, and “Rock Weir Backfill” non-standard special provisions, see Appendix O.

N.4 Engineered Streambed Mix (ESM)

For steeper gradient streams, a roughened channel may be desired between rock weirs to provide additional energy dissipation. The ESM can replace the cap layer of clean sand and gravel or native bed material. When this is the case, the following procedure for determining key particle sizes is suggested and is based on equations from CA Fish & Wildlife’s *Part XII:Fish Passage and Design Implementation* document.

Step 1: Calculate D_{30} of the ESM:

$$D_{30}= 1.95S^{0.555}(1.25q)^{2/3}g^{-1/3}$$

D_{30}= Stable particle size smaller than 70% of ESM (ft)

S= Sreambed or Pool Slope (ft/ft)

g= Gravity (32.2 ft/s^2)

q= Unit Discharge (ft^2/s)= Q/W

Q= Full Main Channel Flow

W= Active Channel Width

Step 2: Calculate D_{84} of the ESM:

$$D_{84}= 1.5D_{30}$$

D_{84}= Stable particle size smaller than 16% of ESM (ft)

Step 3: Calculate D_{50} of the ESM:

$$D_{50}= 0.4D_{84}$$

D_{50}= Stable particle size smaller than 50% of ESM (ft)

Step 4: Calculate D_{100} of the ESM:

$$D_{100}= 2.5D_{84}$$

D_{100}= Largest stable particle size of ESM (ft)

Step 5: Calculate D_{16} and D_8 of the ESM using the Fuller-Thompson equations. In order to promote high density soil mix, use an "n-value" in below equations that will produce a D_8 particle size around 0.08" (2 millimeters).

$$D_{8=}\ 0.16^{1/n}D_{50}$$

n= 0.45 to 1.1

D_{50}= Stable particle size smaller than 50% of ESM (inches)

D_8= Stable particle size smaller than 92% of ESM (inches)

$$D_{16=}\ 0.32^{1/n}D_{50}$$

D_{16}= Stable particle size smaller than 84% of ESM (inches)

When boulder clusters are needed within the engineered stream bed mix, they are to be sized using the "Boulder Cluster Design Method" from Section N.1.3. Because boulder clusters are considered to be permanent stream features, they should be sized for the Q_{25} to Q_{50} storm.

N.5 Bank and Toe Stabilization

Because of energy losses caused by rock weirs, turbulent backwaters can be created, especially during overtopping and flanking conditions. The banks and toes are vulnerable to scour under these conditions, and they should be stabilized through rock slope protection (RSP) or a combination of RSP and vegetation where appropriate.

The Caltrans standard for bank and toe protection design is in the *Highway Design Manual (HDM),* Chapter 870 Channel and Share Protection - Erosion Control. According to Topic 873 Design Concepts, a suggested RSP design event is the 50-year storm, average stream velocity and water surface level are calculated to determine rock size and design high water on the bank (design high water + freebroad = design height). As also stated in Topic 873, the design height estimation should, in addition, take into account other factors, such as historic high water marks, size and nature of debris, as well as construction costs. Basically, engineering judgment must be exercised in adjusting the design RSP height up or down from the calculated 50-year average flow depth, but freeboard must be considered as well.

If the combined RSP and vegetative revetment is desired, the decision for determining the minimum RSP height and design velocity is at the discretion of the District Hydraulics Engineer. The District Landscape Architect must be consulted in determining the proper plants and grasses to be specified for each project. For all projects, the toe of bank, which is highly susceptible to scour, must be stabilized with RSP to 3 feet above the toe at a minimum. See Figure N-5 for a typical step-pool cross section showing pool composition and bank protection.

N.6 Gravel Filter (Alternative to RSP Fabric)

In FHWA's HEC-23 document, discussion is presented regarding subsurface flows. As flow moves through the stream channel, the native base soil is subjected to a combination of groundwater seepage through the subsurface and turbulence from stream surface water, which causes piping beneath RSP and fine soil particles to migrate. A filter placed between the base soil and RSP layer will promote retention of fines in the base soil while still maintaining permeability and free passage of groundwater within the base soil and RSP interface

In lieu of the common RSP fabric filter, a gravel filter can be specified and placed between the native base soil and rock or constructed stream bed channel and slopes. In general, gravel filters are preferred by resource agencies over RSP fabric because of their more natural qualities and less disruption of stream ecology.

In determination of proper gravel filter gradation, the Terzaghi method is listed as one of two recommendations in *HDM Index 873.3 (2) (a) (1) (e) Gravel Filter*. This method is well-known and is cited in many textbooks and professional papers. From Terzaghi, gravel filter design must meet two main criteria: interface stability (also known as piping) and permeability. In order to meet the piping criterion, the filter aggregate cannot be too large that would decrease base soil retention, yet to meet the permeability criterion, the aggregate cannot be too small that would inhibit seepage from the base soil subsurface through the filter. The governing equations for each Terzaghi criterion are as follows:

Piping (Interface Stability) Criterion: $(D_{f15}/D_{b85}) \leq 5$

D_{f15}= filter aggregate diameter that is smaller than 85% of filter aggregates, but larger than 15%

D_{b85}= base soil particle diameter that is smaller than 15% of soil particles, but larger than 85%

Permeability Criterion: $(D_{f15}/D_{b15}) > 5$

D_{b15}= base soil particle diameter that is smaller than 85% of soil particles, but larger than 15%

In order to use the Terzaghi method and verify the piping and permeability criterion, soil samples from the project site must be obtained for testing. A request needs to be made of the District Materials Lab for native soil samples to be collected from the streambed or banks. The request must give direction for samples to be taken every 100 feet along the length of the reference reach, or a minimum of 3 samples total. Each must contain the top 1-foot of native soil from the

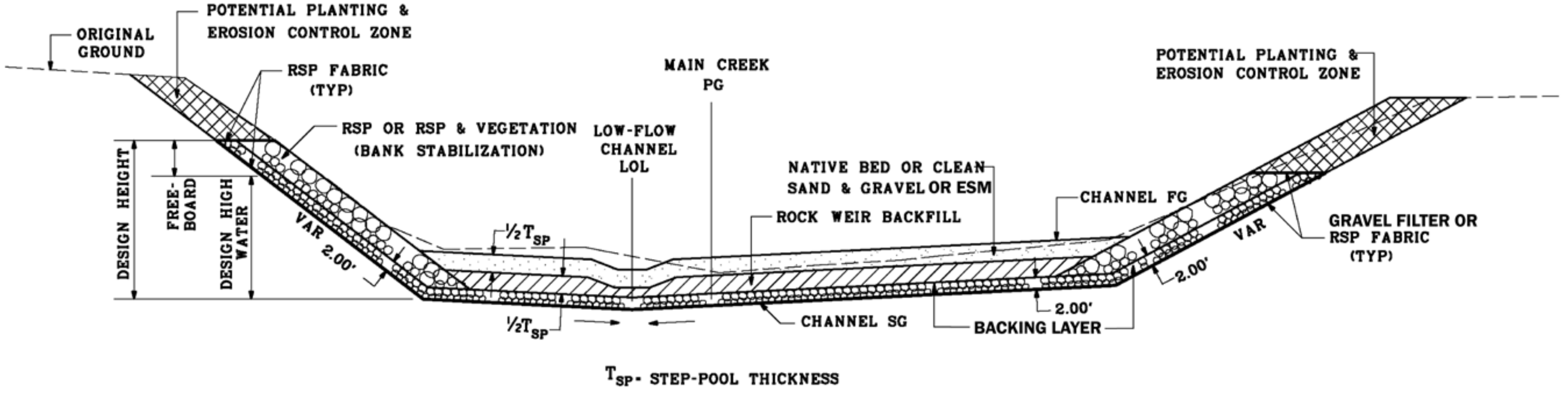


Figure N-5. Step Pool Cross Section

stream bed and/or banks. After the samples have been collected, a sieve analysis and generation of gradation curves of each sample must also be requested of the Material Lab.

For gravel filter analysis and design procedures, see Caltrans *Design Information Bulletin 87-01 (Hybrid Streambank Revetments: Vegetated Rock Slope Protection)*.

N.7 Rock Weir and Step-Pool Layout

Through an iterative hydraulics analysis, the spacing and height of the rock weirs, as well as the low-flow notch/channel dimensions are verified. These components are varied during the hydraulics modeling process until the velocity and depth requirements are satisfied as outlined in the CDFG *Culvert Criteria For Fish Passage* and the NOAA Fisheries *Guidelines For Salmonid Passage At Stream Crossings* depending on target lifestage and species. When low fish-passage flow occurs, a minimum 1-foot flow depth should be maintained within the step-pools, but a minimum 2-foot depth must be provided within the “jump” pool (constructed scour pool) at the base of each weir.

For a series of rock weirs, the minimum spacing is 25 feet. This is mainly governed by the construction process, where individual rock weirs could intersect and their physical definition could be lost if they are placed too close together. Instead of having a series of individual rock weirs, a larger pile or mass will develop without clear definition of each rock weir and the pools between them. If this occurs, the rock weirs and pools will not function properly for fish passage. This is why it is important that rock weirs are at least spaced at 25-foot intervals.

At each rock weir, a 0.5-foot to 1-foot (maximum) vertical step in the new stream profile is typically placed to minimize the longitudinal pool slope between weirs and eliminate a vertical and/or velocity barrier to fish. The rock weir will dissipate the increase of energy at a step. With a flatter pool slope, the velocity and depth criteria are more easily achieved. The use of vertical steps is especially beneficial when dealing with significant elevation changes within the project limits, which would create steep pool slopes. The overall stream gradient can be softened by having up to 1-foot grade changes at each weir location, yet provide relatively flat pool slopes or smaller grade changes between weirs. For rock weir design, the pool slope can vary between 0% and 4%, but is ultimately controlled by the velocity and depth criteria.

In order to determine the number of rock weirs, the preliminary rock weir spacing, the preliminary project length, the number of step-pools, the step-pool slope (gradient), and the number of vertical steps, the procedure below should be followed. Figure N-6 shows a vertical barrier (excessive scour pool) just below a perched culvert, which is a very common application for rock weir/step-pool system in mitigating this type of barrier or impediment.

Step 1: Assume a vertical step height ($\mathbf{d_1}$) where 0.5 feet is the minimum and 1-foot is the maximum. Find $\mathbf{d_3}$, the height of the vertical barrier, by subtracting the bottom elevation of the scour pool from the upstream conform elevation (top of the excessive scour pool). Divide $\mathbf{d_3}$ by $\mathbf{d_1}$ and round down to the nearest whole number to determine the number of vertical steps required to overcome the vertical barrier, which is also the number of rock weirs and step-pools.

$$\textit{\# of Vertical Steps} = \textit{\# of Rock Weirs} = \textit{\# of Step-Pools} = \boldsymbol{d_3/d_1}\ \textbf{\textit{(Round Down)}}$$

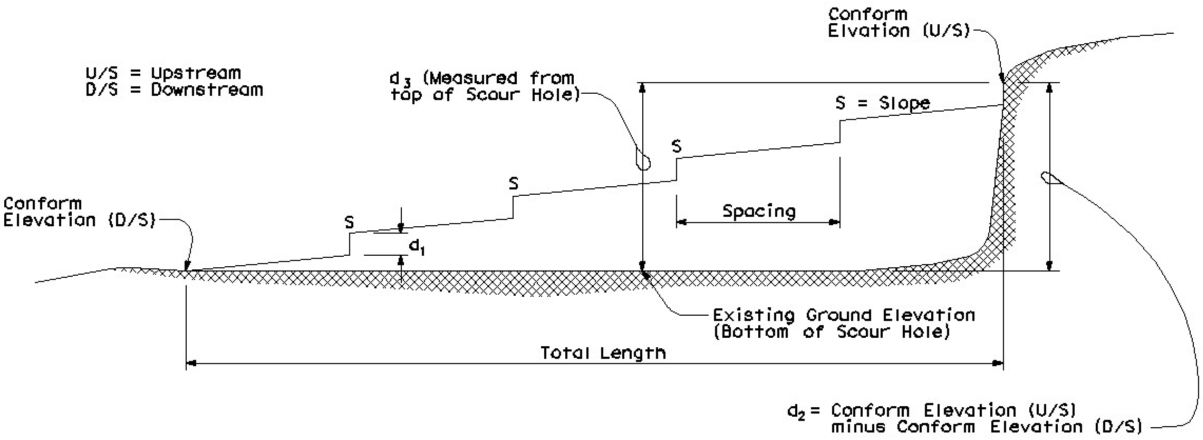


Figure N-6 Rock Weir/Step-Pool Layout

Step 2: Assume a preliminary rock weir spacing (25 feet minimum) that will also equal the step-pool longitudinal length. Calculate the total project length, in other words the longitudinal length of the rock weir/step-pool system, by multiplying the number of step-pools by the step-pool length.

NOTE: The rock weir spacing and subsequent step-pool length is preliminary until depth and velocity criteria have been met, which will be verified by the hydraulic modeling.

Preliminary Rock Weir Spacing= Preliminary Step-Pool Length

Total Project Length= (# of Step-Pools) (Step-Pool Length)

Step 3: Find $\mathbf{d_2}$, the elevation difference in the total project length, by subtracting the downstream and upstream conform point elevations. The distance between these conform points is, of course, the total project length from Step 2. The upstream conform point is normally around the top of the scour pool.

Step 4: Determine the step-pool slope based on $\mathbf{d_1}$, $\mathbf{d_2}$, the number of vertical steps, the number of step-pools, and the step-pool length.

$$Step\ Pool\ Slope\ \left(ft/ft\right) = \frac{d_2 - \left[d_1\left(\#\quad of\quad vertical\quad steps\right)\right]}{\left(\#\quad of\quad step\quad pools\right)\left(step\quad pool\quad length\right)}$$

After the general configuration of the rock weirs and step-pools has been found following the steps above, a preliminary rock weir height (6 inches minimum) can be determined. In the hydraulics analysis, special attention must be made to maximum drops stated in the State and Federal criteria. For all adult species, the maximum drop in water surface is 1 foot, while juvenile salmonids can only tolerate 6 inches. At the downstream base of each rock weir, a 2-foot jump pool should be provided for all species and lifestage. As can be seen in Figure N-3, the rock weir height is measured from the channel finished grade to the top of the weir crest.

By using Figure N-7 and the associated equations, a preliminary (first trial) rock weir height can be found. In this Figure, a pool between two rock weirs is shown in a creek. A line representing level water surface has been drawn from the top of the upstream side of the downstream weir to the downstream side of the upstream weir. By assuming a rock weir height ($\mathbf{h_1}$) and using the preliminary step-pool length and slope determined above, $\mathbf{h_3}$ can be calculated. Once $\mathbf{h_3}$ is known, $\mathbf{h_4}$ can be determined, where $(\mathbf{h_3+h_4})$ equals the total jump pool depth. The $\mathbf{h_4}$ dimension is the height or depth of the constructed scour pool and must be at least 0.5 feet for constructability purposes. From hydraulic modeling in HEC-RAS, appropriate rock weir height and spacing will be verified if $\mathbf{h_1}$ and $\mathbf{h_2}$ are of minimum depth according to lifestage/species in the CDFG and NMFS criteria, and also that $(\mathbf{h_3+h_4})$ is around 2 feet or greater.

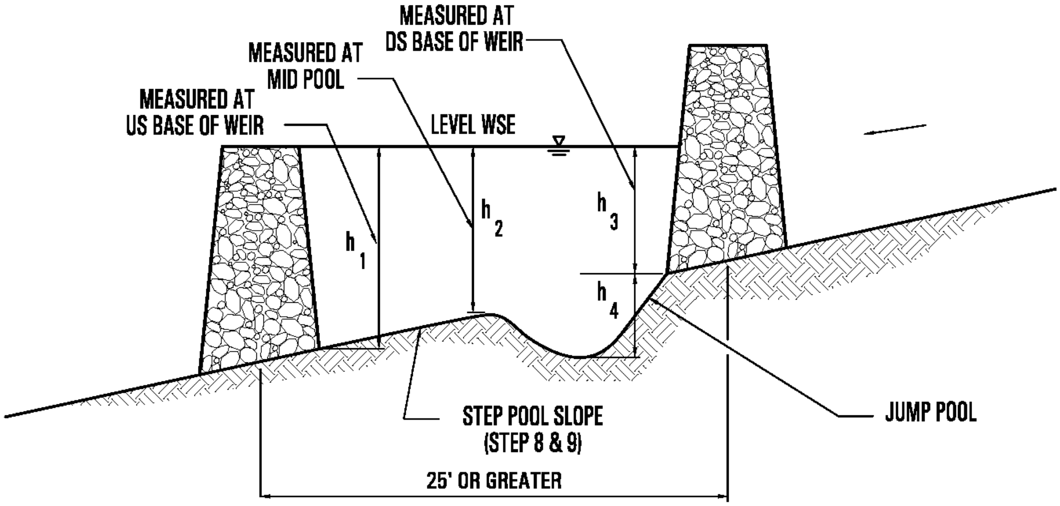


Figure N-7. Preliminary Rock Weir Height Determination

$$h_3 = h_1 - [(\text{Step-Pool Length})\ (\text{Step-Pool Slope in ft/ft})]$$

$$h_4 = (2\ \text{feet}) - h_3$$

$$h_3 + h_4 \geq 2\ \text{ft, where } h_4 \geq 0.5\ \text{ft (minimum)}$$

Once the weir height (preliminary or final) has been determined, the low-flow notch and low-flow channel can be sized using the following minimum dimensions: 6-inch depth, 2-foot base width, and 4-foot top width. Basically, the low-flow notch and channel dimensions will be consistent. As the name suggests, the function of the low-flow notch and channel is to provide minimum flow depths during low fish-passage flow. The top of a rock weir and the channel bed must have a 4% to 5% cross slope toward the low-flow notch/channel so that water will be concentrated and minimum depth is more easily attained. See Figure N-9 for cross sections of the low-flow notch and channel.

During construction, a rock weir is normally built in full without the notch in order to have proper placement and locking of rocks. After it is built, rock is removed to form the notch. Of course given the variable physical sizes of the individual rocks, the dimensions specified on the plans for a notch are somewhat approximate. Because of this situation, the D_{50} of the rock weir should also be considered in determining the dimensions of the low-flow notch. The cross-sectional dimensions of the notch cannot be less than D_{50}.

Another factor to consider in the design of the low-flow notch and channel is meandering and sinuosity of the notch and channel in plan view. By having this, channel length is increased and longitudinal slope is decreased, which further contributes to having adequate fish-passage depth and velocity especially in a steep slope environment. While a standard for the sinusoidal pattern does not exist, the engineer can use judgment in approximating a meandering low-flow channel around the creek centerline as shown in Figure N-8. The need and desire for low flow notch/channel features should be discussed with resource agencies during preliminary design stage.

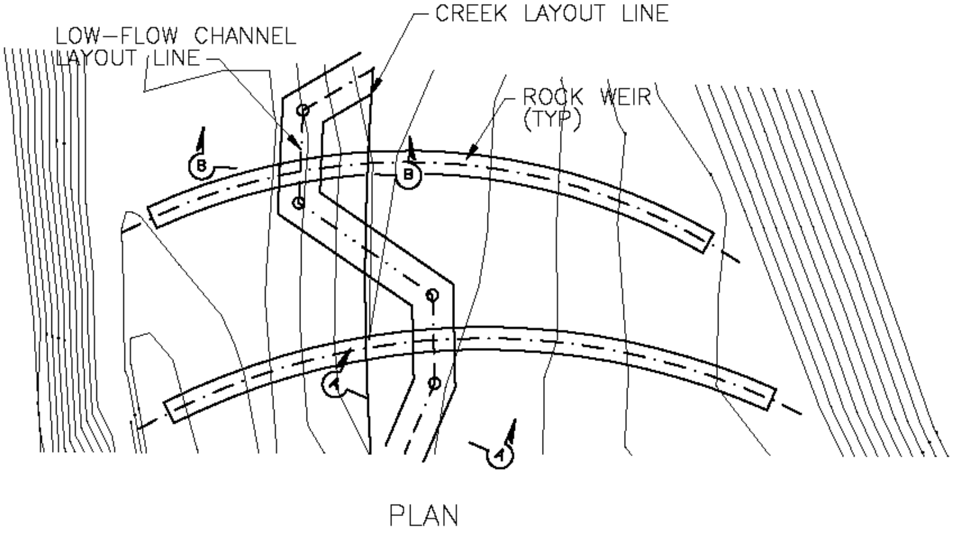


Figure N-8. Rock Weir and Low-Flow Notch/Channel Plan

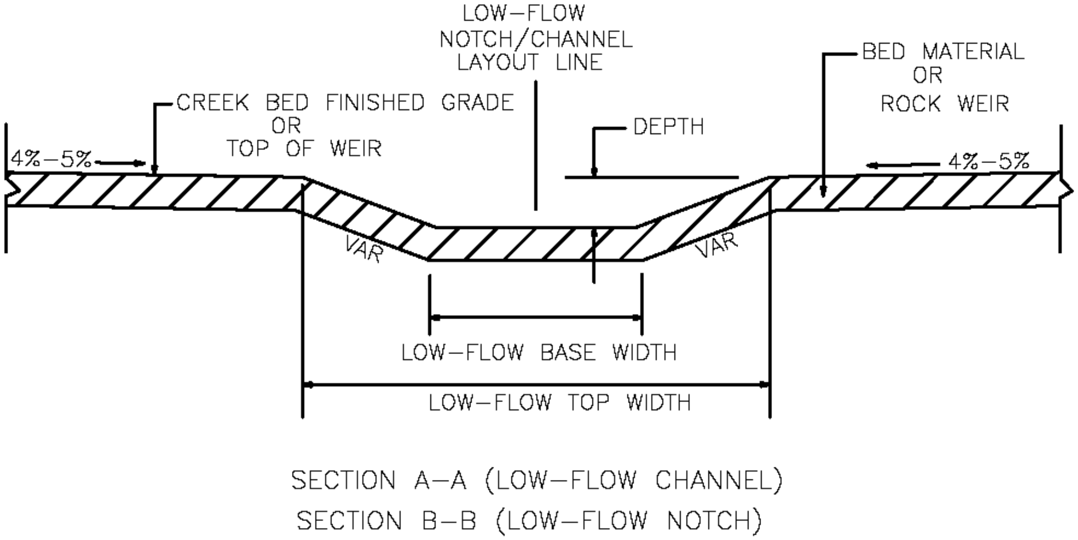


Figure N-9. Low-Flow Notch/Channel Cross Section

N.8Rock Weir Types

Type 1: This type of rock weir, shown in Figure N-2, is specified by RSP Class consistent with Section N.1. Within an RSP Class, the size of the actual rock can vary according to the Standard Specifications (Section 72) mass gradation. For instance, a 1-T (Ton) RSP Class could consist of 2 Ton rock size (95-100%), 1 Ton rock size (50-100%), and ½ Ton rock size (0-5%). One of the reasons for this variability in rock size is to promote a more well-graded mix that will have less voids and more stability when placed in the field.

If a creek bed width is small (less than 25 feet), the number of rocks comprising a rock weir will also be small. With fewer rocks and smaller volumes delivered to a construction site from a quarry, the potential is greater for receiving rocks that may be too large or too small for proper construction of the weirs considering their dimensions shown on the plans based on a specific RSP Class. For creek bed widths greater than 25 feet, the total volume of rocks required for a rock weir should be adequate enough where a reasonable gradation of rock sizes within an RSP Class will be delivered to the site. This is the reason that a Rock Weir (Type 1) is only recommended for creek bed widths greater than 25 feet.

Due to the variability in rock size, shape, and diameter associated with an RSP Class, the more difficulty the contractor will have in building rock weirs according to the typically tight weir dimensions shown on plans. This variability in size and shape is good for locking the rocks together during construction to seal the weirs, but it is harder to achieve the specified grades and elevations. In order to properly construct a rock weir, it may require the contractor several attempts at placing, removing, and placing again individual rocks of various size and shape to find the correct fit that will meet the specified grades, widths, and heights. This means that the labor and equipment costs are higher than normal RSP construction, but the material costs will be typical because the Caltrans RSP Classes are known by the commercial quarries and are usually readily available. Because of the additional labor and equipment costs, the unit price for an RSP Class will have to be higher for rock weir construction than bank revetment or energy dissipater construction. As a rule of thumb, it is recommended to increase the unit cost of a standard RSP Class item by 25-33% to account for the additional labor and equipment costs of a Rock Weir (Type 1) special BEES item.

Essentially, the positive and negative aspects of using a Rock Weir (Type 1) can be summarized by saying that their construction is labor intensive, but their material is easy to supply.

See Appendix O for a recommended Rock Weir (Type 1) NSSP.

Type 2: Instead of specifying an RSP Class, a Rock Weir (Type 2) is specified by a "rough" diameter of rock size. After an RSP Class is determined for rock sizing in Section N.1, the D_{50} of the chosen RSP Class will be used as the "rough" diameter. This type of rock weir must contain two rows of individual rocks to aid in sealing the weirs, and may have one or two layers of rock as needed based on required embedment depth. See Figures N-10 and N-11 for profile views.

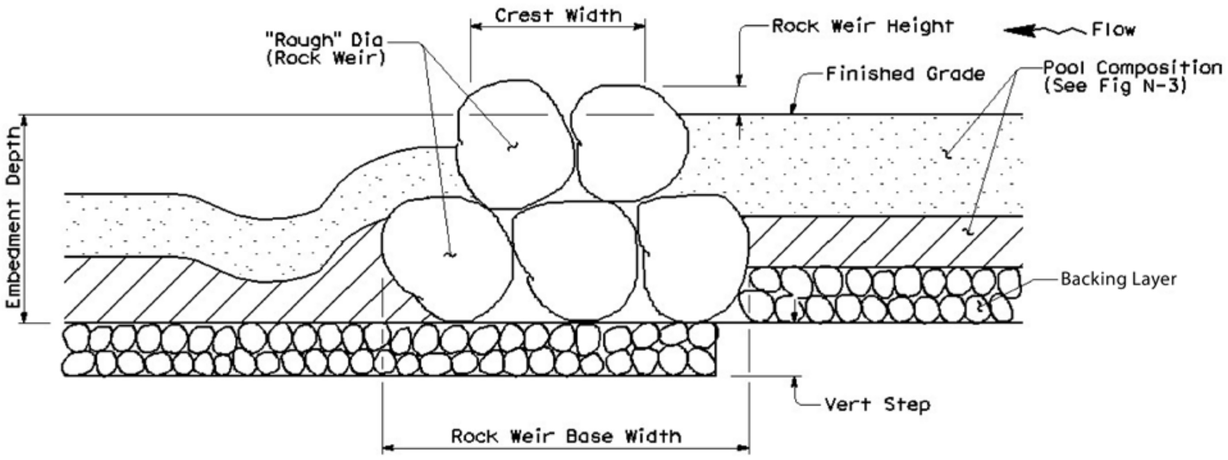
When using a Rock Weir (Type 2), a rock isometric detail, shown in Figure N-12, must be used to show how the rock diameter is measured on the x, y, and z axes. This detail is essential and crucial for the contractor and quarry to use in locating the proper rocks, and also crucial for the construction inspector to verify and approve of their use.

Because the rocks comprising a Rock Weir (Type 2) will be consistent in size and relative shape, they will be much easier to place making the physical construction of this type of weir simpler than a Rock Weir (Type 1). The grades, elevations, heights, and widths will be easier to achieve with this consistent rock, but it is critical that backfill be placed and compacted in the rock weir voids to further seal the weirs. By having such consistent size and shape of rock, the potential for voids is greater than the gradation of rock in an RSP Class and must be properly dealt with during construction. In Appendix O, a recommended Rock Weir (Type 2) NSSP describes the gradation of backfill, which is called rock weir void filler, and its method of compaction.

While the physical construction of a Rock Weir (Type 2) is simpler, the difficulty for the contractor will be in selecting the consistent size rocks according to the rock isometric detail.

Basically, the positive and negative aspects of using a Rock Weir (Type 2) are the opposite of a Rock Weir (Type 1). For a Rock Weir (Type 2), the labor and equipment time will be normal for typical RSP construction, if not less, but the cost in selecting and supplying the material will be much greater. In determining a unit cost for a Rock Weir (Type 2) special BEES item, it is recommended to perform a force account analysis similar to extra work construction contract change orders for a specific project by estimating labor and equipment hours for weir construction, material costs with the additional labor in choosing the rock, delivery (trucking) of the rock from quarry to site, and applying the proper markups and surcharges.

Given this difficulty in selecting and finding the unique rock for a Rock Weir (Type 2), its availability may be questionable for large volumes. A contractor may not be able to find enough rock to construct the weirs for wide bottom creeks requiring large volumes. This is the main reason that this type of rock weir is recommended for smaller creek bed widths of 25 feet or less, where the volume of rock will be less and easier to provide this unique rock. The use of a Rock Weir (Type 2) for smaller stream widths will also eliminate the inconsistent rock gradation problem, associated with an RSP Class, discussed above for a Rock Weir (Type 1).



Crest Width = (2)("Rough Dia")
Rock Weir Base Width = (3)("Rough Dia")
Embedment Depth = [(2)("Rough Dia") - (Rock Weir Height)] ≥ Calculated Scour Depth

Figure N-10 Rock Weir (Type 2) Profile - Two Rock Layers

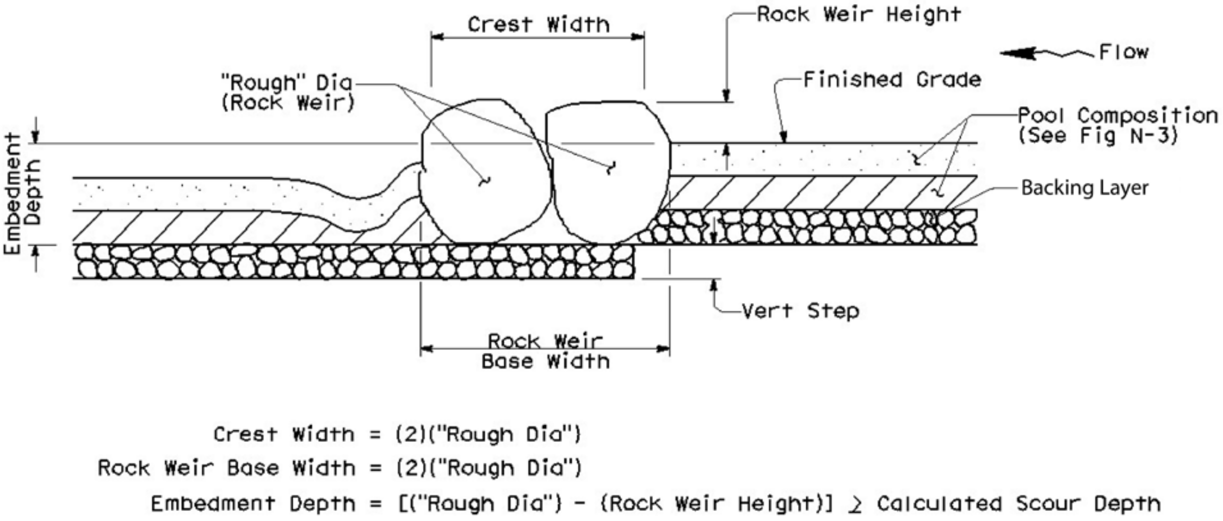


Figure N-11 Rock Weir (Type 2) Profile - One Rock Layer

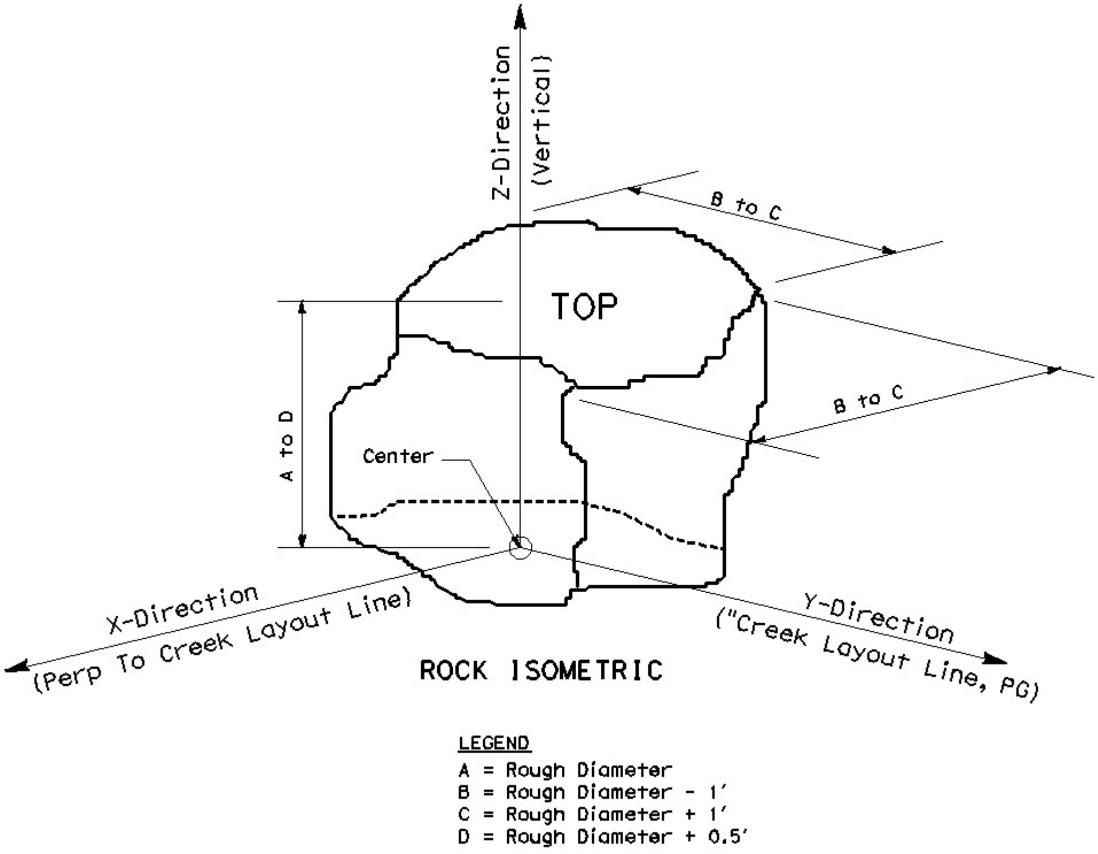
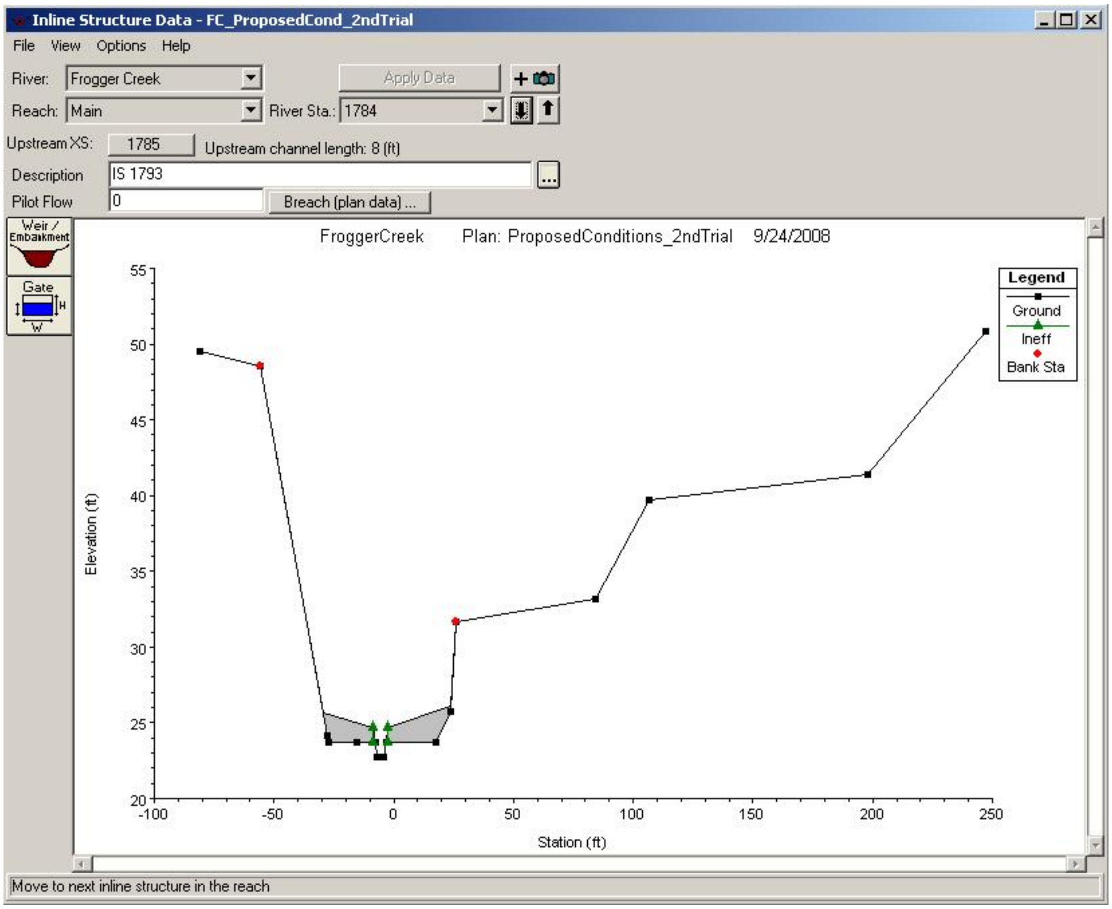


Figure N-12 Rock Isometric Construction Detail

N.9 Rock Weir Hydraulic Modeling

For modeling low and high fish passage flows, as well as flood flows, HEC-RAS is the software of choice given its ability to analyze in-line structures. Considering the typical crest width (breadth of crest), a rock weir is classified as broad-crested and will be analyzed in this manner by HEC-RAS. In cross section, HEC-RAS has the capability of considering a weir's theoretical shape (in-line structure), including the low-flow notch, in its analysis by entering/defining section coordinates shown in Figure N-12, but is limited in considering a weir's plan view orientation. As discussed in Section N.3, a weir should have an arc shape in plan view, but HEC-RAS will only recognize it with a perpendicular orientation associated with one specific River Station. Therefore, an arc-shaped rock weir must be entered as straight and perpendicular to the stream cross section at an identified River Station for hydraulic modeling purposes.

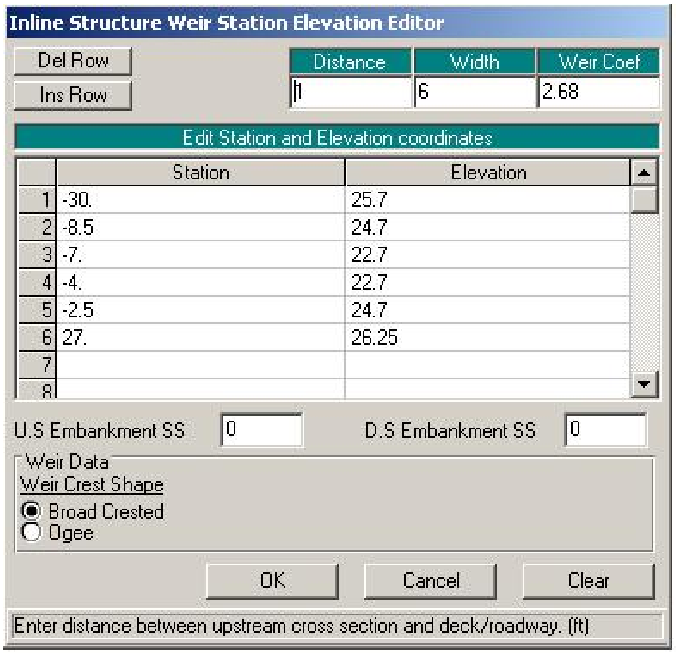
In order to develop an accurate water surface profile, it is recommended that at least three cross sections be created between rock weirs: one cross section immediately downstream of a weir, one cross section at the mid-point of the pool between weirs, and one cross section just upstream of a weir. The most critical cross section, which will have the lowest depth, is the one immediately downstream of a weir within the plunge/jump pool. Depth at this cross section especially, as well as the other cross sections, should meet minimum design criteria.


Inline Structure Data - FC_ProposedCond_2ndTrial

River: Frogger Creek
Reach: Main
River Sta.: 1784
Upstream XS: 1785
Upstream channel length: 8 (ft)
Description: IS 1793
Pilot Flow: 0

FroggerCreek Plan: ProposedConditions_2ndTrial 9/24/2008

Move to next inline structure in the reach



Distance	Width	Weir Coef
1	6	2.68

	Station	Elevation
1	-30.	25.7
2	-8.5	24.7
3	-7.	22.7
4	-4.	22.7
5	-2.5	24.7
6	27.	26.25
7		
8		

U.S Embankment SS: 0
D.S Embankment SS: 0

Weir Crest Shape
● Broad Crested
○ Ogee

Enter distance between upstream cross section and deck/roadway. (ft)

Figure N-13 Rock Weir Cross Section (HEC-RAS)

In order to determine a broad-crested weir coefficient to be used in HEC-RAS modeling, the procedure below should be followed using Table N-8. For each flow, it is recommended to determine a new weir coefficient because of its dependency on head above a weir.

Step A: Estimate the highest weir coefficient using the highest head for the previously calculated crest width (breadth of crest of weir) from Table N-8 Broad Crested Weir Coefficient.

Step B: Run the proposed HEC-RAS model and find the average head (weir average depth) over a baffle for the Low Fish Passage Flow from HEC-RAS results.

Step C: Given the average head (weir average depth) from the HEC-RAS results and the crest width (breadth of crest of weir), find a second weir coefficient from Table N-6 Broad Crested Weir Coefficient.

Step D: Run the proposed HEC-RAS model with the second weir coefficient from Step C and find the average head (weir average depth) over a baffle for the Low Fish Passage Flow from HEC-RAS results.

Step E: Given the average head (weir average depth) from the HEC-RAS results and the crest width (breadth of crest of weir), find a third weir coefficient from Table N-6 Broad Crested Weir Coefficient.

Step F: Compare weir coefficient from Step C and Step E. If weir coefficients are close in value, then use Step E weir coefficient for remaining HEC-RAS modeling. If weir coefficients are not close in value, repeat Steps C-F until an appropriate weir coefficient is found.

Head (ft)	Breadth of Crest of Weir (ft)										
	0.50	0.75	1.00	1.50	2.00	2.50	3.00	4.00	5.00	10.00	15.00
0.2	2.80	2.75	2.69	2.62	2.54	2.48	2.44	2.38	2.34	2.49	2.68
0.4	2.92	2.80	2.72	2.64	2.61	2.60	2.58	2.54	2.50	2.56	2.70
0.6	3.08	2.89	2.75	2.64	2.61	2.60	2.68	2.69	2.70	2.70	2.70
0.8	3.30	3.04	2.85	2.68	5.60	2.60	2.678	2.68	2.68	2.69	2.64
1.0	3.32	3.14	2.98	2.75	2.66	2.64	2.65	2.67	2.68	2.68	2.63
1.2	3.32	3.20	3.08	2.86	2.70	2.65	2.64	2.67	2.66	2.69	2.64
1.4	3.32	3.26	3.20	2.92	2.77	2.68	2.64	2.65	2.65	2.67	2.64
1.6	3.32	3.29	3.28	3.07	2.89	2.75	2.68	2.66	2.65	2.64	2.63
1.8	3.32	3.32	3.31	3.07	2.88	2.74	2.68	2.66	2.65	2.64	2.63
2.0	3.32	3.31	3.30	3.03	2.85	2.76	2.72	2.68	2.65	2.64	2.63
2.5	3.32	3.32	3.31	3.28	3.07	2.89	2.81	2.72	2.67	2.64	2.63
3.0	3.32	3.32	3.32	3.32	3.20	3.05	2.92	2.73	2.66	2.64	2.63
3.5	3.32	3.32	3.32	3.32	3.32	3.19	2.97	2.76	2.68	2.64	2.63
4.0	3.32	3.32	3.32	3.32	3.32	3.32	3.07	2.79	2.70	2.64	2.63
4.5	3.32	3.32	3.32	3.32	3.32	3.32	3.32	2.88	2.74	2.64	2.63
5.0	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.07	2.79	2.64	2.63
5.5	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32	2.88	2.64	2.63

Table N-8 Broad Crested Weir Coefficient

N.10 Energy Dissipation Factor

In the pool between weirs, turbulence is created as energy is dissipated. This turbulence can be defined or measured by an Energy Dissipation Factor (EDF) having ft-lb/ft^3/sec units. When turbulence is too high, it can be an impediment for fish passage. EDF criteria for pools between weirs and roughened channels are not well developed, but generally EDF should not exceed 7 ft-lb/ft^3/sec.

The following equation is used to calculate EDF:

$$EDF = \frac{\gamma Q S_o}{A_{wet}}$$

Where:

EDF = Energy Dissipation Factor (ft-lb/ft^3/sec)

γ = Unit weight of water (62.4 lb/ft^3)

S_o = Existing culvert slope (ft/ft)

A_{wet} = Wetted cross-sectional flow area (ft^2) between weirs under high fish passage flow

N.11 Rock Weir Design Steps

Step 1: Prepare an Existing Conditions HEC-RAS hydraulic model and find the average velocity for the 50-Yr Event, check existing bridge capacity for 50-Yr and 100-Yr or existing culvert capacity for 100-Yr HDM criteria.

Step 2: Calculate rock weir size.

Step 3: Find potential scour depth for rock weir embedment.

Step 4: Determine step pool composition and thickness.

Step 5: Determine crest width.

Step 6: Calculate plan view radius of vortex shape.

Step 7: Size RSP for bank and toe stabilization.

Step 8: Estimate number of steps (1 ft max per step), rock weirs, step pools, as well as linear spacing of rock weirs.

Step 9: Develop a preliminary reach profile including longitudinal slope of step pools and vertical step height.

Step 10: Estimate a trial rock weir height and "constructed" jump pool depth.

Step 11: Estimate trial geometry for low flow channel and notch (depth, bottom width, side slopes) Use minimum suggested dimensions for first trial.

Step 12: Prepare HEC-RAS plan of proposed conditions using Low and High Fish Passage Design flows and determine weir coefficient through iterative process (calibrate with Low Fish Passage Flow).

Step 13: Find average weir depth and average channel depth for Low Fish Passage Flow. Check HEC-RAS Proposed Conditions 1st Trial plan against criteria. Perform hand calculations to check velocity through low flow notch. Note, velocity will be checked using High Fish Passage Flow. Calculate EDF.

Step 14: Identify velocity and depth at appropriate cross-sections from HEC-RAS model and hand calculations and compare against design criteria. If velocity or depths are not met, change rock weir spacing, rock weir height, and/or low flow channel/notch geometry to ultimately meet design criteria. Re-run HEC-RAS models and perform hand calculations as needed. Once criteria have been met, summarize calculated velocities in *Velocity Criteria Versus Design (High Fish Passage Flow)* and depths in *Depth Criteria Versus Design (Low Fish Passage Flow)* tables in Form 6E.

Step 15: Add 50-Year and/or 100-Year peak discharges to Proposed Conditions 2nd Trial Plan and evaluate results.

Step 16: Based on final weir height, calculate rock weir base width.

APPENDIX O

ROCK WEIR AND ASSOCIATED MATERIALS, NON-STANDARD

NOTE: The following Non-Standard Special Provisions (NSSP) have been used in previous rock weir costruction projects, but will still require review and approval from HQ Hydraulics and possibly HQ Construction on a project-per-project basis. Also, each NSSP will require conversion to plain language style.

O.1 ROCK WEIR (TYPE 1) NSSP

NOTE: **See Appendix N Rock Weir Design, Section N.8 Rock Weir Types, for description.**

10-1.___ROCK WEIR (TYPE 1)

This work shall consist of excavating the entire main channel, furnishing and placing two lifts of _________ Ton rock, as well as furnishing, placing, and compacting rock weir void filler in the voids between the individual rocks of each rock weir. The rock weirs shall be constructed in conformance with the plans, the Standard Specifications, these special provisions, and as directed by the Engineer.

MATERIAL

The _________ Ton rock shall conform to Section 72-2.02, "Materials," of the Standard Specifications. This rock shall also conform to dimensions shown on details from the plans, and shall be verified by the Engineer prior to its placement.

Rock weir void filler shall consist of a coarse and fine aggregate mixture conforming to the gradation requirements shown in the following table:

ROCK WEIR VOID FILLER GRADATION

SIEVE SIZE	PERCENT PASSING
3"	95-100
2"	85-98
1 ½"	51-90
1"	27-60
¾"	18-45
½"	5-25
3/8"	2-18
No. 4	0-6

PLACEMENT

The _________ Ton rocks shall be placed individually in two lifts of equal thickness, and arranged so that each rock has a 3-point contact with adjacent rock. Placing _________ Ton rock by dumping will not be permitted.

After each lift of _________ Ton rock has been placed, rock weir void filler shall be dumped between the voids of each rock and compacted by a hand-tamping method until voids are full of rock weir void filler. The excess rock weir void filler on top of the _________ Ton rock shall be removed.

Rock weir void filler shall be delivered as a uniform mixture of coarse and fine aggregate, and shall be deposited in a manner to avoid segregation.

MEASUREMENT

The quantity of rock weir shall be measured by the cubic yard, and shall be determined from the plans or by dimensions directed by the Engineer. Rock weir quantities in excess of these dimensions will not be paid for.

PAYMENT

The contact price paid per cubic yard for rock weir shall include full compensation for furnishing all labor, materials, and performing all work associated with rock weir construction. The rock weir construction shall include performing main channel excavation, furnishing

_________ Ton rock and performing its placement, in addition to furnishing rock weir void filler and performing its placement and compaction.

Excess excavated material from the main channel shall be disposed if as directed by the Engineer and in conformance with Section 7-1.13, “Disposal of Material Outside the Highway Right of Way,” of the Standard Specifications. The disposal of this excess material will also be included in the contract price paid per cubic yard of rock weir, and no separate payment will be allowed.

O.2 ROCK WEIR (TYPE 2) NSSP

NOTE: **See Appendix N Rock Weir Design, Section N.8 Rock Weir Types, for description. Also see Figure N-11 in Appendix N for required rock isometric construction detail that must be inserted into plans for use with Rock Weir (Type2).**

10-1.___ROCK WEIR (TYPE 2)

This work shall consist of excavating within the main channel, furnishing and placing ______-foot “rough” diameter rock, as well as furnishing, placing, and compacting rock weir void filler in the voids between the individual rocks of each rock weir. The rock weirs shall be constructed in conformance with the plans, the Standard Specifications, these special provisions, and as directed by the Engineer.

MATERIAL

The ______-foot “rough” diameter rock is an approximate dimension of an irregularly shaped object. Both rounded and angled rocks may be used. Apparent specific gravity, absorption, and durability index properties of the ______-foot “rough” diameter shall conform to Section 72-2.02, “Materials,” of the Standard Specifications. This rock shall also conform to dimensions shown on details from the plans, and shall be verified by the Engineer prior to its placement.

Rock weir void filler shall consist of a coarse and fine aggregate mixture conforming to the gradation requirements shown in the following table:

ROCK WEIR VOID FILLER GRADATION

SEIVE SIZE	PERCENT PASSING
3”	95-100
2”	85-98
1 ½”	51-90
1”	27-60
¾”	18-45
½”	5-25
3/8”	2-18
No. 4	0-6

PLACEMENT

The ______-foot “rough” diameter rocks shall be placed individually in two rows, in one or two layers, as shown on the plans, and arranged so that each rock has a 3-point contact with adjacent rock. The range of dimensions for individual rocks and their orientation to the placement surface, as shown on the plans, shall be followed and verified by the Engineer. Stagger rows of rocks by placing a back row rock between two front row rocks in order to reduce voids. Placing ______-foot “rough” diameter rock by dumping will not be permitted.

After the ______-foot “rough” diameter rocks are placed, rock weir void filler shall be dumped between the voids of each rock and compacted by a hand-tamping method until voids are full of rock weir void filler.

Rock weir void filler shall be delivered as a uniform mixture of coarse and fine aggregate, and shall be deposited in a manner to avoid segregation.

MEASUREMENT

The quantity of rock weir shall be measured by the cubic yard, and shall be determined from the plans or by dimensions directed by the Engineer. Rock weir quantities in excess of these dimensions will not be paid for.

PAYMENT

The contract price paid per cubic yard for rock weir shall include full compensation for furnishing all labor, materials, and performing all work associated with rock weir construction. The rock weir construction shall include performing main channel excavation, furnishing ______-foot "rough" diameter rock and performing its placement, in addition to furnishing rock weir void filler and performing its placement and compaction.

Excess excavated material from the main channel shall be disposed of as directed by the Engineer and in conformance with Section 7-1.13, "Disposal of Material Outside the Highway Right of Way," of the Standard Specifications. The disposal of this excess material will also be included in the contract price paid per cubic yard of rock weir, and no separate payment will be allowed.

O.3 ROCK WEIR BACKFILL NSSP

10-1.___ROCK WEIR BACKFILL

This work shall consist of furnishing, placing, and compacting rock weir backfill conforming to the plans, the Standard Specifications, these special provisions, and as directed by the Engineer.

MATERIAL

Rock weir backfill shall conform to the properties below:

Rock Weir Backfill Properties

Maximum Sand Equivalent = 50
Maximum Aggregate Size = 3-inches
Maximum Plasticity Index = 20
Minimum Plasticity Index = 12

Excess excavated material from the main channel may be used for rock weir backfill if the above properties are met. The process of using the alternative material shall be in conformance with Section 4-1.05, “Use of Material Found on the Work,” of the Standard Specifications.

PLACEMENT

The rock weir backfill shall be placed in uniform layers, and shall be brought up uniformly on all appropriate sides of the rock weirs. The thickness of each layer of backfill shall not exceed 8 inches before compaction. Rock weir backfill shall be compacted to a relative compaction of not less than 90 percent.

MEASUREMENT

The quantity of rock weir backfill shall be measured by the cubic yard, and shall be determined from the plans or by dimensions directed by the Engineer. Rock weir backfill quantities in excess of these dimensions will not be paid for.

PAYMENT

The contract price paid per cubic yard for rock weir backfill shall include full compensation for furnishing all labor, materials, incidentals, and performing all work associated with hauling, placing, and compacting the rock weir backfill. All work must be complete in place as shown on the plans, specified in these special provisions, and as directed by the Engineer.

O.4 CLEAN SAND AND GRAVEL NSSP
(Updated October 2014)

10-1.___CLEAN SAND AND GRAVEL

This work shall consist of excavating the low-flow channel, in addition to furnishing, placing, and grading the clean sand and gravel placed on the rock weir backfill layer. The placement and grading of the clean sand and gravel shall include both the low-flow and main channels, and shall conform to the plans, these special provisions, and as directed by the Engineer.

MATERIAL

The sand and gravel shall be clean and free of organic matter and other deleterious substances. The clean sand and gravel shall conform to the gradation requirements shown in the following table:

Clean Sand and Gravel Gradation

SIEVE SIZE	PERCENT PASSING
1”	100
¾”	60-90
No. 4	25-60
No. 30	0-20

PLACEMENT

The sand and gravel mixture shall be delivered as a uniform mixture, and shall be deposited in a manner to avoid segregation. The material shall be spread and graded to conform to the required thickness, grade, and details shown on the plans. . Clean sand and gravel shall be compacted to a relative compaction of not less than 90 percent.

MEASUREMENT

The clean sand and gravel quantity will be measured by the cubic yard, and shall be determined from the plans or by dimensions directed by the Engineer. Clean sand and gravel quantities in excess of these dimensions will not be paid for.

PAYMENT

The contract price paid per cubic yard for clean sand and gravel shall include full compensation for furnishing all labor, materials, incidentals, and performing all work associated with creek bed material construction. This construction process shall include furnishing, hauling, placing, and grading clean sand and gravel, in addition to performing excavation of the low-flow channel. All work must be complete in place as shown on the plans, specified in these special provisions, and as directed by the Engineer.

The excavated material from the low-flow channel shall be disposed of as directed by the Engineer, and shall be included in the contract price paid per cubic yard of clean sand and gravel.

O.5 PLACE NATIVE CREEK BED MATERIAL NSSP

(Updated October 2014)

10-1.___PLACE NATIVE CREEK BED MATERIAL

This work shall consist of stockpiling the top _____ feet of the main channel (station limits shown on plans), as well as placing and grading the stockpiled native creek bed material. The placement and grading of the native creek bed material shall conform to the plans, these special provisions, and as directed by the engineer.

MATERIAL

Native creek bed material is comprised of the top _____ feet of the main channel, excavated from station limits shown on the plans, which includes but not limited to rock, cobble, gravel, and fine aggregate. The excavated material is to be stockpiled on a plastic liner at a location designated by the Engineer.

The plastic liner shall be single ply, new polyethylene sheeting, a minimum of 0.1-inch thick and shall be free of holes, punctures, tears or other defects that compromises the impermeability of the material. Plastic liner shall not have seams or loose joints. All joints between the edges shall be lapped or joined with commercial quality waterproof tape.

PLACEMENT

From the stockpile location, the native creek bed material shall be hauled to its final position, spread, and graded to conform to the required thickness, grade, and details shown on the plans. . Native creek bed material shall be compacted to a relative compaction of not less than 90 percent.

MEASUREMENT

The quantity of place native place creek bed material shall be measured by the cubic yard of native creek bed material placed into its final position, and shall be determined from the plans or by dimensions directed by the Engineer. Place native creek bed material quantities in excess of these dimensions will not be paid for.

PAYMENT

The contract price paid per cubic yard for place native creek bed material shall include full compensation for furnishing all labor, materials (including plastic liner), incidentals, and performing all work associated with hauling, stockpiling, and placing native creek bed material. All work must be complete in place as shown on the plans, specified in these special provisions, and as directed by the Engineer.

The excess material excavated from the main channel and stockpiled shall be disposed of as directed by the Engineer, and shall be included in the contract price paid per cubic yard of place native creek bed material, and therefore no additional payment will be allowed.