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Design Report for Janes Creek Roughened Channel

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Project Description

This project will open up fish access to the north branch of South Fork Janes Creek by constructing a roughened rock channel over an abandoned 4-ft high water supply dam. The existing dam spillway, which is a perched concrete box culvert, will be removed and replaced with the roughened channel. The roughened channel is designed to provide passage for both adult and juvenile salmonids, as well as other aquatic species. It is also designed to maintain the existing wetland upstream of the dam along with the associated sediments that could otherwise be mobilize and released downstream. Since the private haul road that runs along the top of the dam must be maintained, a 40-ft long prefabricated bridge will be installed across the top of the roughened channel. While the design and installation of the bridge is the responsibility of others, the bridge must be placed sufficiently high enough to accommodate passage of the estimated 100-year peak flow.

Overview of Report

This report summarizes the design criteria, design approaches, and specifications for the Janes Creek roughened channel. Michael Love & Associates and Winzler & Kelly Consulting Engineers were responsible for design of the roughened channel. Design of the bridge crossing is the responsibility of others and beyond the scope of this report. To design the roughened channel assumptions had to be made regarding the placement of the bridge.

1. The new bridge will be located in the same place and with the same orientation (in plan view) as the existing box culvert.

2. Based on previous conversations with the client (Humboldt Fish Action Council), the new bridge will be 40-feet in length, with at least a 30-ft free-span available over the new channel.

If the designed bridge does not conform to any of these assumptions, the roughened channel design will need to be reevaluated.

Background

Janes Creek is a small coastal stream that drains into the northern end of Humboldt Bay. It historically sustained populations of coho salmon, steelhead trout, and cutthroat trout (per. com., Dr. Terry Roelofs). Over the past hundred years fish populations have declined within the watershed. Much of the decline can be attributed to migration barriers created by tidegates, dams, and culverts combined with degradation of the estuary and loss of in-channel spawning and rearing habitat.

Recently the City of Arcata, with assistance from other local restorationists, has begun a large scale effort to improve access and habitat for salmonids in Janes Creek. Restoration of the estuary along with improving access to the high quality low-gradient upstream habitat will likely revitalize exiting populations of coho salmon and steelhead within Janes Creek.

After crossing under the Highway 101 Bridge, Janes Creek forks and head east towards Fickle Hill. The South Fork, where the project is located, quickly heads into the forested hills to the east. Along the lower portions of Fickle Hill the South Fork is low gradient and marshy, with large areas dominated by wetland vegetation, such as skunk cabbage. Thick canopy created by mature redwood, spruce, and alder dominate these reaches. However, an abandoned water supply dam located at the lower end of the north branch of South Fork Janes Creek blocks access to approximately 5,000 feet of excellent quality spawning and rearing habitat.

About 2,360 feet upstream of the existing dam there is the first of three culverts that function as partial barriers, blocking juvenile passage and hindering adult passage at certain flows. Replacement of these three culvert stream crossings is planned for a later phase of the overall watershed restoration. Even with these culverts in place, providing fish passage over the existing dam will provide immediate access to a substantial amount of excellent spawning and rearing habitat for salmonids. Much of the 2,360 feet of habitat between the dam and the first culvert is low gradient and marshy, ideal rearing habitat for juvenile coho.

Description of Project Site

The abandoned water supply dam was constructed in the 1950's to provide water to a small mill that was located immediately downstream. The mill closed long ago and the small reservoir has completely filled-in with sands and silts. All of the flow currently plunges over the dam spillway, falling 3 to 4 feet before landing in a shallow plunge pool. The existing structure completely blocks upstream movement for all fish.

The dam consist of an earthen-fill levee roughly 250-ft long and 3 feet high that spans the marshy floodplain perpendicular to the stream channel. At the location of the stream channel a perched 9-ft wide concrete box culvert functions as the spillway. The dam and associated fill also serves as an infrequently used haul road by the landowner, Green Diamond Resources Company.

Within the old reservoir, immediately upstream of the dam, a meandering stream channel has reestablished itself and the area is considered valuable wetland habitat. However, during larger storm events the hydraulic capacity of the existing spillway becomes overwhelmed, causing ponding of water, which eventually overtops the dam. Currently, the low point along the dam is

located approximately 65 feet away from the channel and spillway. As a result, overtopping waters do not flow immediately back into the stream channel. Instead, waters have eroded a gully running across the floodplain that continues to grow in size.

Overview of Roughened Channel Designs

A roughened channel or "nature-like" fishway is an oversteepened channel designed to allow for passage of fish and other aquatic organisms in addition to accommodating peak flows and associated debris and sediment. Common applications include dam bypasses and as "fish friendly" grade control within altered channels such as Janes Creek at the abandoned water supply dam. The primary hydraulic function of a roughened channel is to create conditions suitable for fish passage while dissipating energy through an oversteepened section of channel.

The steep sections of a roughened channel contain rock cascades, which increase the channel's overall roughness and dissipate energy. These cascades form complex flow patterns with large variations in water velocities, providing migrating fish numerous pathways to choose from as they swim upstream. For this type of application, a small shift in rock arrangement typically does not affect the functionality of roughened channels.

A roughened channel more readily accommodates passage of water, wood, and sediment while allowing free movement of other aquatic species besides fish. In general, construction of a roughened channel requires skilled equipment operators, a large quantity of rock and other imported material, and on-site construction guidance from persons familiar with this type of design.

Design Flows

The design process required estimating the peak design flow and the fish passage design flows. The following watershed statistics were to estimate flows:

Watershed Statistics		
Drainage Area (DA):	0.74	mi^2
Mean Annual Precipitation (MAP):	48.0	in/yr (from USDA-NRCS, 1999)
Mean Basin Elevation (E):	< 1000	ft
Average Annual Runoff[1]:	33.1	in/yr
Average Annual Flow (Q_{ave}):	1.4	cfs

[1] Calculated using regional equation developed by Rantz (1968) and used to estimate Q_{ave}.

Peak Design Flows

The peak design flow for maintaining a stable roughened channel was set at the flow having a 100-year recurrence interval, as recommended by NOAA Fisheries (2001) and California Department of Fish and Game (CDFG, 2002) stream crossing design guidelines.

Magnitudes of peak flows associated with varying recurrence intervals were estimated using three different methods: (1) rational method, (2) regional flood estimation regression equations by the USGS for the North Coast (Waananen and Crippen, 1977), and (4) probabilistic analysis of local streamflow records using standard procedures outlined in Bulletin 17B (USGS, 1982). The following table summarized the results:

Estimated peak flows and recurrence intervals for the Janes Creek project site.

Estimated Peak Flow	1.5 year (cfs)	2 year (cfs)	10 year (cfs)	25 year (cfs)	50 year (cfs)	100 year (cfs)
(1) Rational Method[1]	-	65	129	181	233	291
(2) Waananen and Crippen, 1977	-	84	174	224	251	304
(4) Ave. of Local Streamflow Records adjusted by drainage area[2]	64	80	159	202	237	274
AVERAGE:	64	76	154	202	240	290

[1] Used IDF curves from Eureka and Kneeland to estimate rainfall intensity. Estimated time of concentration was 32 min.

[2] Used four stream gages (NF Mad River, Little River, Jacoby Creek, and Elk River) and adjusted peak flow estimates by drainage area.

The variation in estimates for the 100 year peak flow was relatively small (10%). For the peak design flow for the roughened channel we selected the average of the three estimates, **290 cfs**.

Fish Passage Design Flows

As part of designing the roughened channel element of the project, fish passage conditions (depths, velocities, and turbulence) were analyzed. This required defining the range of flow in which fish passage is of concern. Generally, passage is not required at extremely low or high flows, when fish are not expected to be moving. Fish passage design flows are defined by NOAA Fisheries (2001) and CDFG (2002). Lower and upper fish passage design flows are prescribed for adult salmon and steelhead, adult resident trout, and juvenile salmonids. Passage flows are defined in terms of exceedance flows, which are obtained from flow duration curves (FDC's).

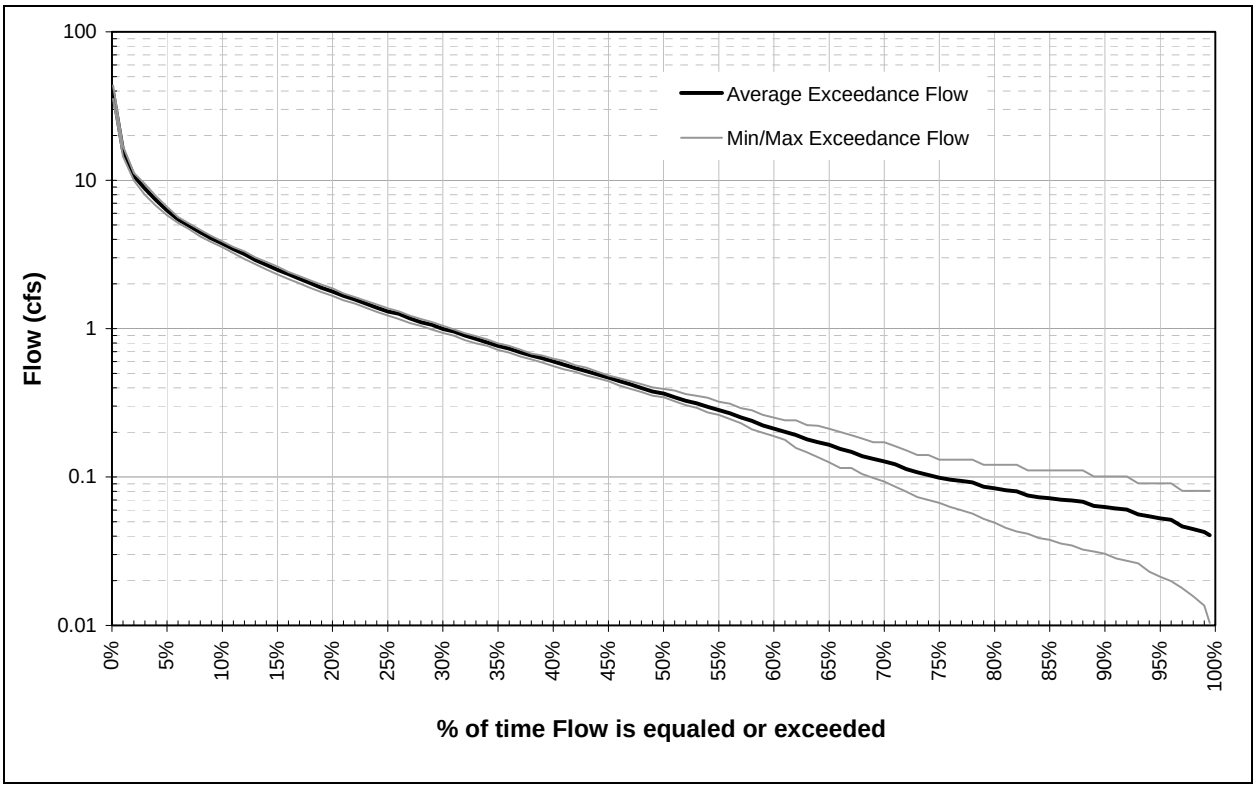
Fish Passage Design Flow Criteria as defined by NOAA Fisheries and CDFG.

Species and Lifestage	Lower Design Flow Criteria	Upper Design Flow Criteria
Adult Salmon and Steelhead	50% exceedance flow or 3 cfs (whichever is greater)	1% exceedance flow
Adult Rainbow and Cutthroat Trout	90% exceedance flow or 2 cfs (whichever is greater)	5% exceedance flow
Juvenile Salmonids	95% exceedance flow or 1 cfs (whichever is greater)	10% exceedance flow

Since no long-term stream flow gage is maintained on Janes Creek, FDC's from three nearby streams were used to estimate passage flows. All three of the FDC's were normalized by the estimated average annual flow of the gaged stream (Qave). For each gaged stream Qave was estimated using a regional regression equation developed by Rantz (1968) for average annual runoff for the north coastal California region. By taking the average of the normalized FDC's a regional FDC was developed. The regional FDC was then transformed into a FDC specific to the project site using the estimated Qave for Janes Creek.

Streamflow gaging station records used to develop a regional flow duration curve to estimate project fish passage design flows.

USGS Station No.	Station Name
11481200	Little River Nr Trinidad
11480800	NF Mad R. Nr Korbel
11480000	Jacoby C Nr Freshwater



Flow duration curve (FDC) for the project site on Janes Creek.

Fish Passage Design Flows for Janes Creek

Species and Lifestage	Lower Fish Passage Flow	Upper Fish Passage Flow
Adult Salmon and Steelhead	**3.0 cfs (0.4 cfs)**	**15.9 cfs**
Adult Rainbow and Cutthroat Trout	**2.0 cfs (0.1 cfs)**	**6.3 cfs**
Juvenile Salmonids	**1.0 cfs (0.1 cfs)**	**3.7 cfs**

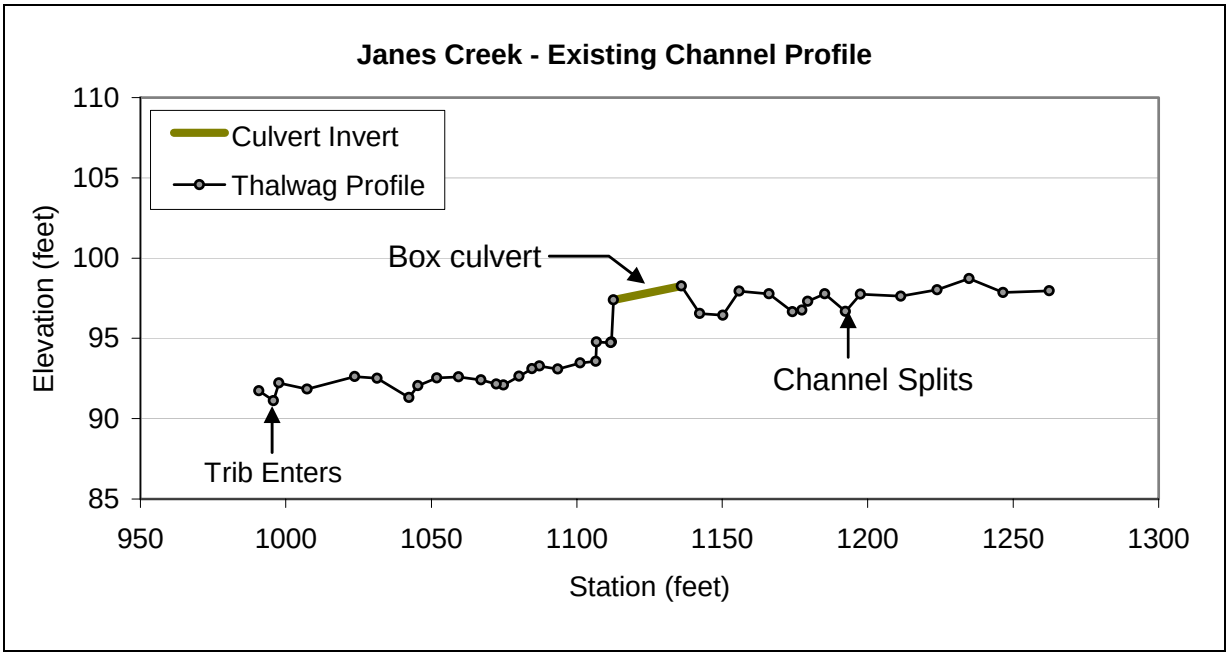
Roughened Channel Design

Existing Channel Slope

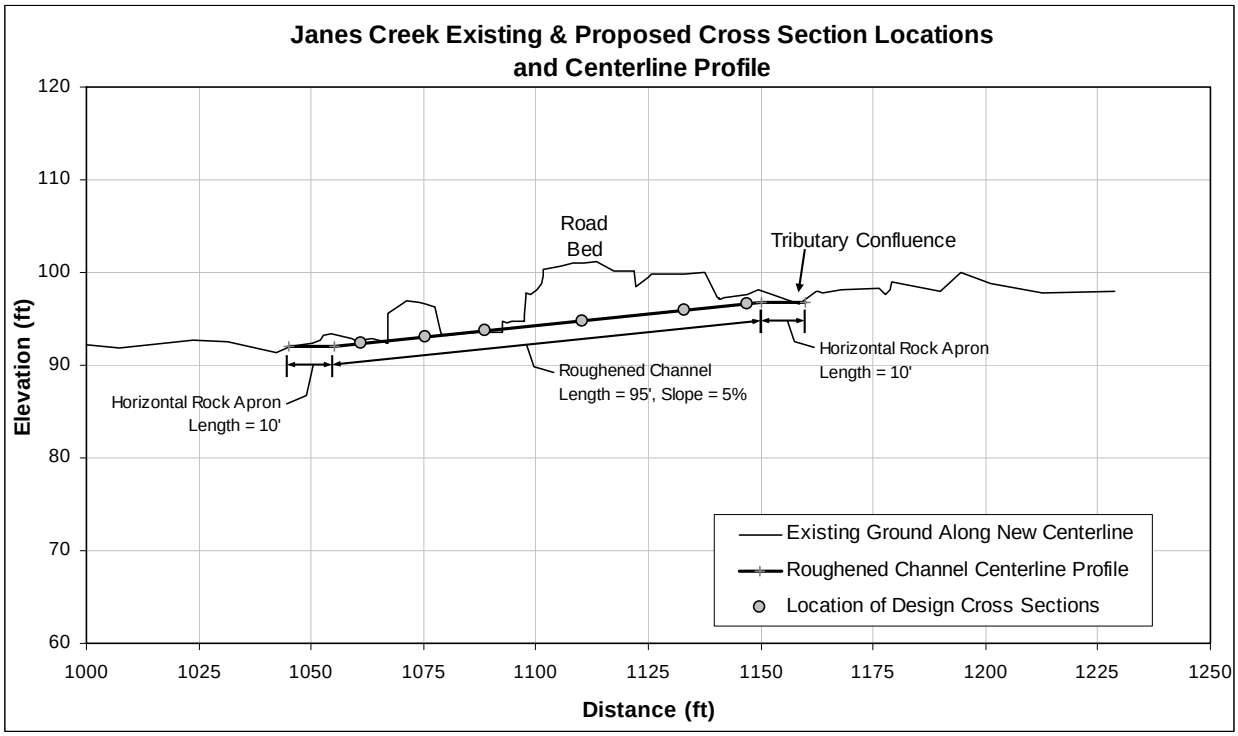
Surveying a longitudinal profile through the project site is essential for developing successful channel designs. In December 2004 we conducted a topographic survey at the location of the existing crossing and proposed roughened channel. The total longitudinal profile was 270 ft. The average channel slope above and below the dam were 1.23% and 1.69%, respectively.

Design Slope

The proposed roughened channel slope is 5%. This provides a balance between (1) minimizing the length f the roughened channel and (2) maintaining suitable fish passage and bed stability within the constructed channel. Horizontal 10-ft long rock aprons are included at the upstream and downstream ends to ensure a stable transition between the natural channel and the constructed roughened channel. To join the upstream and downstream channels the roughened channel makes two gradual turns (approximately 22 degrees and 14 degrees). This also allows the roughened channel to be aligned perpendicular to the bridge, maximizing conveyance of flood flows and minimizing the possibility of plugging with debris.



Longitudinal profile of Janes Creek showing existing channel and box culvert that serves as the spillway.



Design profile for the roughened channel.

Engineered Streambed Material

Bed Stability Analysis

The stability analysis determines the minimum rock sizing necessary to maintain a stable channel during a particular peak flow event. For this analysis, we used the 100-year peak flow of 290 cfs.

While no explicit design equations or regulatory criteria exist specifically for roughened channel designs, there are generally accepted methods used to determine stable particle sizes. For this analysis we used two methods: the Unit-Discharge Bed Equation as defined by Bathurst (1978) for incipient motion of the D_{84} particle, (84% of the particles have a smaller diameter than the d_{84}) and the US Army Corps of Engineers Steep Slope Riprap Design for the D_{30} particle (ACOE, 1994).

Since the ACOE riprap design usually calls for a uniform gradation of rock size resulting in a porous bed, which is undesirable streambed material, the *Design of Road Culverts for Fish Passage* (WDFW, 2003) recommends using a D_{84} that is 1.5 times larger than the stable particle size estimated using the ACOE method. Once the D_{84} has been calculated, the $D_{7,}$ D_{16}, D_{50}, and D_{100} can be determined by applying the methods outlined in WDFW (2003). This defines the engineered streambed material to be used in construction of the roughened channel bed. It is expected that the engineered mixture will stay in place through the 100-year flood with only minor adjustments to channel shape.

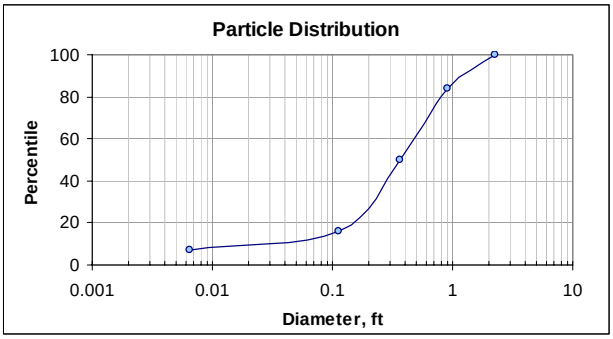
The stability analysis required an iterative process involving the interdependent variables of particle size, channel roughness, and channel geometry. For the stability analysis, we assumed the water surface slope during the 100-year peak flow would be equal to the overall slope of the roughened channel, with the high flow drowning-out individual large boulders. The WinXSPRO model (USFS, 2005) was used to determine hydraulic parameters needed in the stability analysis.

Particle Distribution of Engineered Streambed Material

Based on the stability analysis and channel geometry the streambed material for the new roughened channel shall comprise of the following distribution:

Percentile	**7**	**16**	**50**	**84**	**100**
Diameter (ft)	0.007*	0.12	0.4	0.94	2.4

* material comprising sands and silts.



The D_{16} is the equivalent of 16% of the bed material passing (finer than) a sorting screen of the indicated size. D_7, D_{50}, D_{84}, and D_{100} is the equivalent of 7% passing, 50% passing, 84% passing and 100% passing respectively.

Making the engineered streambed material requires mixing different sized material to arrive at the correct proportions. The table presented below is intended to aid in developing the specified project mix.

Composition of engineered streambed material

Percent of Mix	**Rock Size**
16%	0.94 ft - 2.4 ft
34%	0.40 ft - 0.94 ft
34%	0.12 ft - 0.40 ft
9%	0.007ft - 0.12 ft
7%	Sand and Silt

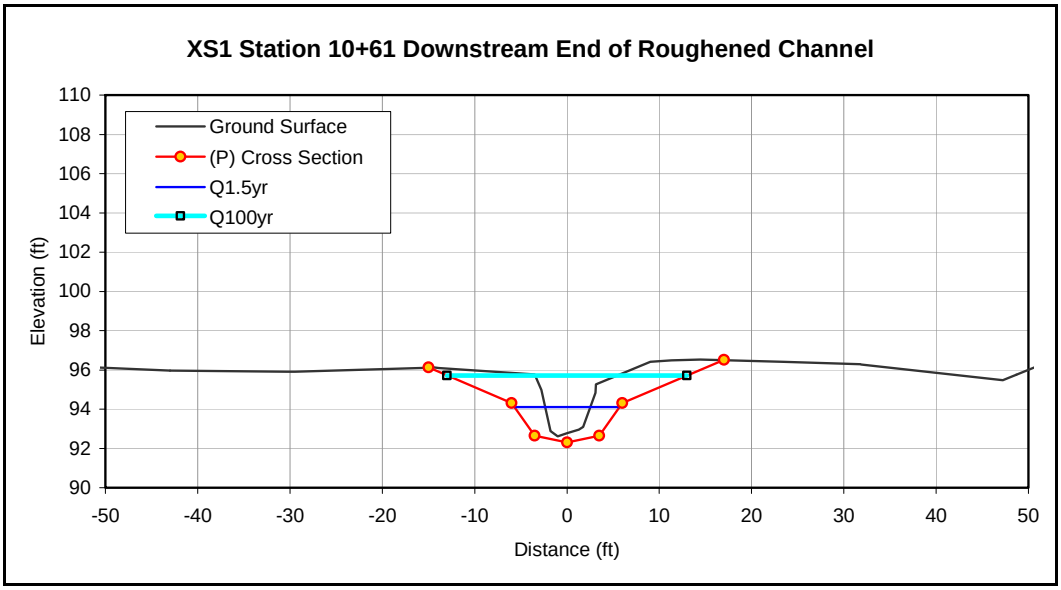
Design Cross Sections

An iterative process was used to design the roughened channel shape so that it provides optimal fish passage conditions.

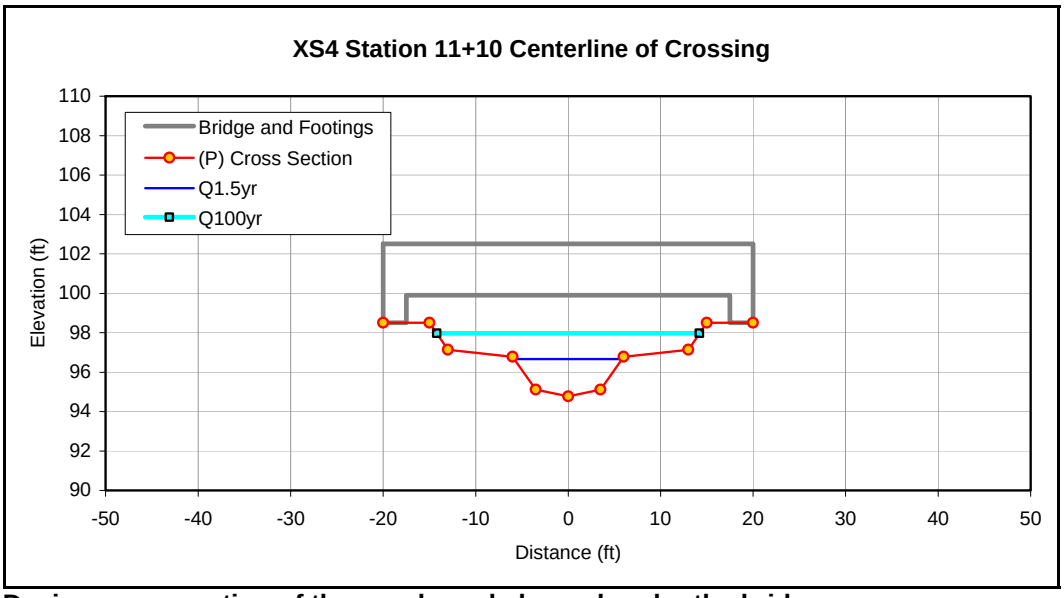
To determine the bank heights and channel width, we assumed the stream's bankfull flow had a 1.5-year return period of 65 cfs. Using an active channel base width of 7-ft and bankfull width of 12-ft, the resulting bankfull depth of flow was roughly 2-ft. To concentrate low flows, ensure

adequate water depth for adult fish, and provide slower edge-water for smaller fish the design channel bottom is sloped 10H:1V slope towards the center.

The predicted water surface for the 100-year peak flow (290 cfs) was calculated for each cross section. The predicted 100-year water surface stays within the confinement of the channel and adjacent slopes throughout the project area. Assuming the bottom of the bridge deck is placed at elevation 100-feet, the 100-year water surface would be 2.0-feet below. Additionally, the channel elevation and shape at the upstream side of the bridge were designed so the headwater at the 100-year flow is below the low point on the road, which will minimize the potential of overtopping. This provides ample room the peak flow and associated large wood and sediment to pass under the bridge.



Design cross section near the downstream end of the roughened channel.



Design cross section of the roughened channel under the bridge.

Fish Passage Analysis

The fish passage analysis and the stability analysis of the roughened channel (described above) were interrelated, using an iterative process that converged on a final preferred design. Although not all passage criteria could be satisfied at all fish migration flows, the final roughened channel design provides hydraulic conditions that should allow passage of all size classes of salmonids at most flows.

Fish Passage Criteria

The CDFG and NOAA Fisheries fish passage guidelines prescribe minimum water depths and maximum average water velocities for fish passage at stream crossings. To provide unimpeded adult and juvenile passage, depth and velocity criteria should be satisfied between the lower and upper fish passage design flows. However, CDFG and NOAA Fisheries guidelines recognize the criteria cannot always be satisfied, and suggest they be applied as a project goal instead of a strict requirement.

Summary of Hydraulic Conditions

Using the Thorne and Zevenbergen equations (1985) to predict roughness coefficients based on particle size, model predicted water velocities and depths at the upper and lower fish passage design flows are presented in the table below. Based on results from the stability analysis, we used a stable D_{84} particle of 0.94 feet.

CDFG and NOAA Fisheries Fish Passage Depth and Velocity Criteria

Species and Lifestage	Minimum Water Depth	Max. Water Velocity (distance < 60 ft)
Adult Salmon and Steelhead	1.0 ft	6 fps
Adult Rainbow and Cutthroat Trout	0.67 ft	4 fps
Juvenile Salmonids	0.5 ft	1 fps

Water Depths

Although depth and velocity criteria are not satisfied at all fish passage design flows, they are within reason. The only violation of the depth criteria occurs at the lower adult salmon and steelhead design flow (0.8 ft at 3 cfs). However these depths are sufficient to fully submerge most salmon and steelhead trout. It is important note that the calculated depths are averages but the roughened channel will have numerous deeper pools that fish can hold in while swimming upstream. Also, like the designed roughened channel, the adjacent natural stream channel has numerous spots that depths are less than 1-ft deep at 3 cfs.

Water Velocities

Water velocity at the upper juvenile salmonid design flow of 3.7 cfs is estimated to be 1.1 feet per second (fps), slightly exceeding the 1 fps recommended maximum velocity. However, the model velocities are estimates of average cross sectional velocities. Observations of juvenile salmonids swimming in channels and through culverts have shown they almost invariably swim

in areas of lower velocity found along the culvert walls and channel margins (Powers *et al*, 1997). By design, a roughened channel provides a wide distribution in water velocities, with many areas of slower water. It is expected a juvenile fish would be able to migrate upstream through slower waters along the channel banks even though the average water velocity exceeds 1 fps.

Flow characteristics at the lower fish passage design flows.

Species and Lifestage	Lower Passage Design Flow (cfs)	Predicted Depth (ft)	Predicted Velocity (fps)
Adult Salmon and Steelhead	3.0	0.5	1.0
Adult Rainbow and Cutthroat Trout	2.0	0.5	0.8
Juvenile Salmonids	1.0	0.4	0.5

Flow characteristics at the upper fish passage design flows within the roughened channel.

Species and Lifestage	Upper Passage Design Flow (cfs)	Predicted Depth (ft)	Predicted Velocity (fps)
Adult Salmon and Steelhead	15.9	1.0	2.4
Adult Rainbow and Cutthroat Trout	6.3	0.7	1.5
Juvenile Salmonids	3.7	0.6	1.1

A D_{84} of 0.94 feet was used in the Thorne and Zevenbergen method to predict velocity and depth.

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