PRUNUSKE CHATHAM, INC.

Willow Creek Road 2nd Bridge Area Fish Passage Project: Phase I

Interim Report – 30% Design and the Preferred Alternative

October 2008

Introduction

Willow Creek, a tributary to the lower Russian River, is considered a high priority watershed for California Department of Fish and Game's coho re-stocking program (Coho Salmon: Recovery Strategy for California [DFG 2004]). Viability of the watershed for the coho recovery program is presently limited due to fish passage restrictions related to the County Road in the vicinity of 2nd Bridge. In spring 2007 the Willow Creek Technical Advisory Committee (TAC) reviewed a range of culvert replacement options to restore fish passage at the second bridge roadway. This discussion occurred after it was determined that re-routing the road and removing the second bridge floodplain crossing is not feasible. A consensus was reached to design and install a culvert replacement structure at the valley thalweg (west side of the second bridge roadway) that will provide for channel development, hydraulic connectivity, fish passage, and at least a 20-50 year lifespan.

Severe channel aggradation in lower Willow Creek in the vicinity of 2nd Bridge up to 3rd Bridge has led to abandonment of the historic channel on the east side of the valley. The flow is now concentrated on the west side of the valley where elevations are lowest (Figure 1). The roadway across the valley floor and floodplain at the second bridge crossing acts as a low-head dam, trapping streamflow and sediment and restricting fish passage upstream and downstream during spring and winter base-flow conditions. The 24-inch culverts at the west end of the valley crossing are often blocked with debris during annual high flows. The streamflow slows and spreads across the floodplain, overtopping the roadway during most high flows (Figures 2 and 3). This condition does not provide a clear path for upstream salmonid migration. With a lack of channel continuity in this reach, upstream migration by adults and downstream migration by juveniles is severely restricted.

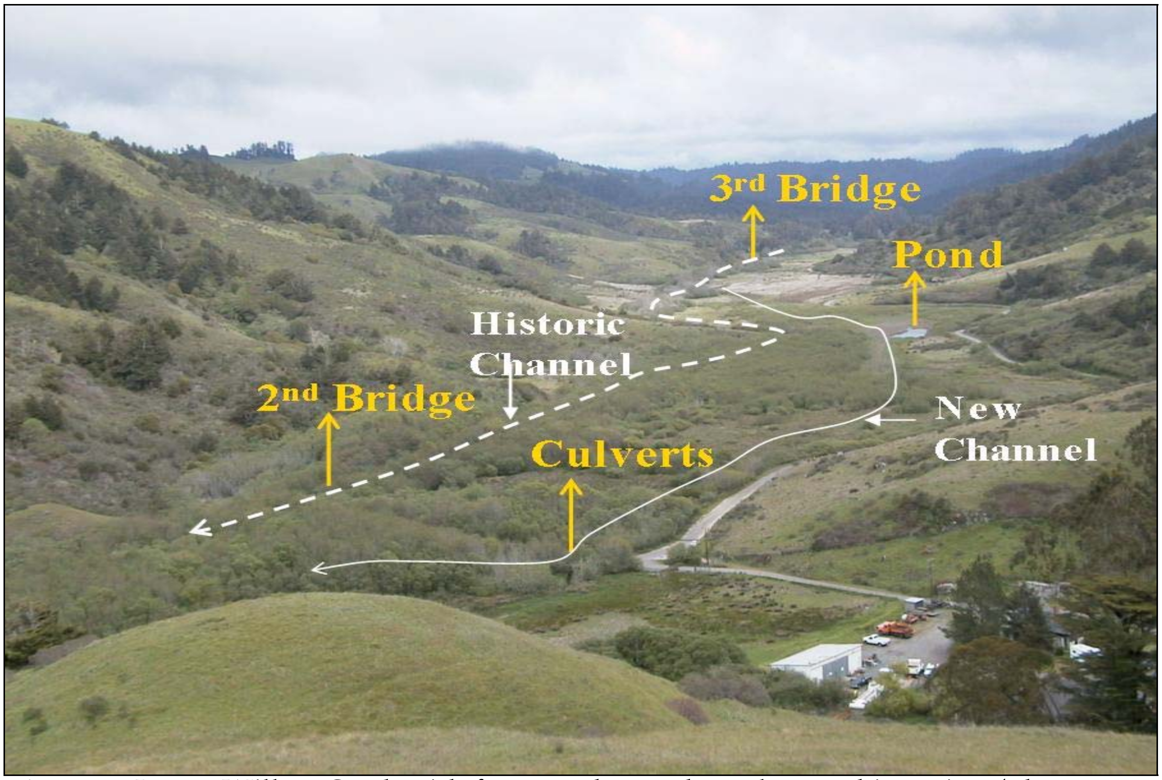

Figure 1. *Lower Willow Creek with features shown that relate to this project (photo looking up the watershed).*

Figure 2*. Aerial view of the second bridge crossing after high flows on January 28, 2008. Note ponded water at culvert locations and southern approach.*

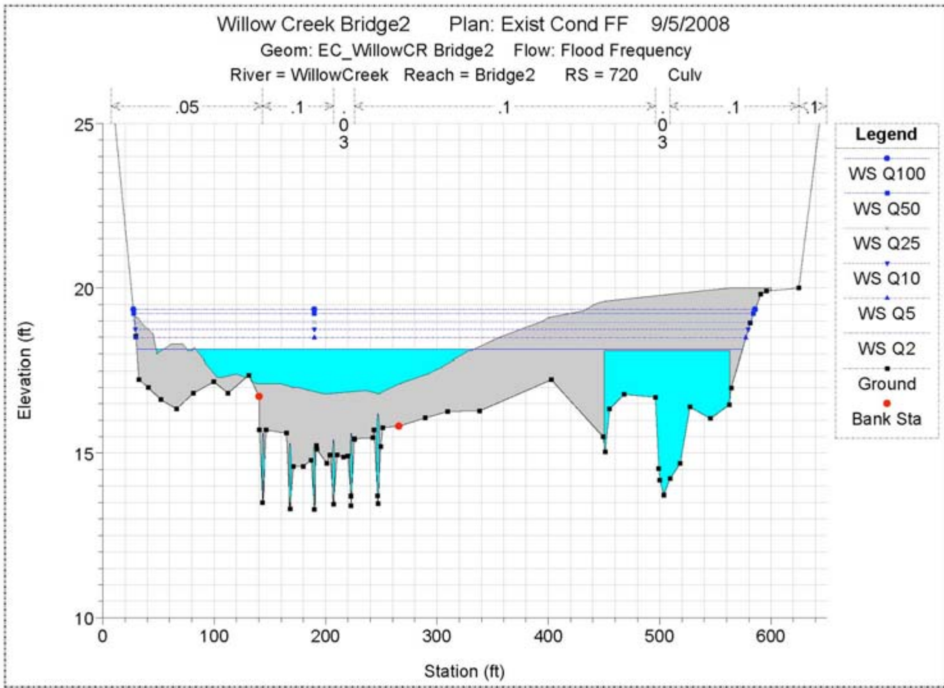

Figure 3. *Hydraulic model results of the existing conditions at the second bridge crossing looking downstream at the road (dark grey is the road fill). Note that all flood flows overtop the road at the culverts on left side of the image.*

Multiple options for replacing the culverts were assessed during the 30% design phase of the project including segmented box culverts, pipe arch culverts, arched bottomless culverts, and bridges. This report briefly summarizes the site constraints, the viability of the structure options, and a description of the preferred alternative structure.

Project Site Evaluation and Constraints

The physical features of lower Willow Creek are a result of two landscape-forming processes that are described in detail in the report titled *Sustainable Channel Development in Lower Willow Creek* (PCI 2005). The following are excerpts from this report:

> The first is the approximately 1.5 mile wide San Andreas Fault Zone, comprised of the San Andreas Fault and smaller parallel faults that divide the North American and the Pacific Plates along the coastline (DPR 2004). The active San Andreas Fault sits just offshore at the mouth of the Russian River, with the western side moving northward at a rate of approximately 2 inches per year. Many smaller faults that follow a northwest to southeast orientation split off diagonally from the San Andreas Fault Zone

(CDFG 2002). Willow Creek traces an inactive fault contact between the fragmented and sheared Franciscan complex rocks on its south side and a conglomerate member of the Great Valley sequence on its north side (Trihey 1997).

The second large, landscape-shaping Pleistocene event was the Wisconsin stage of the last ice age (15-20,000 years ago). The ice sheets did not reach into this area; however, during this period, sea level was 350 to 420 feet lower and 10 miles west of its current levels (Imbrie 1979; Parkman 2003). The large coastal rivers would have responded to this sea level lowering by downcutting into the valley floors at an accelerated rate. Tributaries, especially those close to the coast, would also have downcut rapidly in response to the low sea level. As the ice age came to an end and sea levels began to rise, the coastal rivers and tributaries went through a period of rapid deposition. The Russian River filled its valleys with deep deposits of alluvial material comprised of gravel, coarse sand, silt, and clay lenses (PWA 1993). Wells drilled near the mouth of the Russian River penetrate 125 feet of alluvium before reaching the bedrock floor, and at Guerneville the alluvium is 80 feet below sea level (Higgins 1952).

As Willow Creek is only 2.3 miles upstream from the mouth of the Russian River, it would have experienced the greatest degree of downcutting and widening during the lowered sea level conditions. As sea level rose at the end of the last ice age thick deposits of alluvium were deposited in the lower reaches of the Russian River and its tributaries. The lower 3 miles of Willow Creek is a wide, flat alluvial valley formed during depositional conditions such as increased base level and high rates of sediment yield from the watershed.

Geotechnical borings at the project site confirm that the alluvial fill in lower Willow Creek is similar in depth to the alluvium in the Russian River. The borings were drilled to 70 feet without encountering bedrock or coarse material (RGH 2008). Sedimentation of this valley is still occurring (PCI 2005). Stream gradients in this section are typically less than 1%. From 3rd Bridge down to the mouth the average historic channel slope is 0.3%. The channel and valley slopes downstream of second bridge are very low at 0.05%. At the project site the average slope for 500 feet of stream channel centered on the road is 0.3%. These low slopes create slow, subcritical flow conditions through the reach that promote sediment deposition.

Hydrology

The hydrology of the Willow Creek watershed is best described in the *Sustainable Channel Development in Lower Willow Creek* report (PCI 2005). Willow Creek flows from an 8.7-square mile watershed into the Russian River. The watershed area at the second bridge crossing is approximately 8.2 square miles.

Streamflow patterns in Willow Creek are typical of small coastal watersheds in temperate climates. Peak flows are flashy and occur during large winter storms, usually in December through March. Between storms, subsurface runoff produces a raised winter base-flow from November through April. The Willow Creek watershed has never been gaged. Several studies have measured individual storm events throughout the watershed, but there has been no regular effort to monitor daily or peak streamflow. The recurrence interval of flood magnitudes has been estimated for Willow Creek in previous studies conducted in 1987 and 1995 using regional stream gaging data. Those data were not used in this analysis because of the high potential error range inherent in the extrapolation methods and assumptions used to produce that data. The flows of interest in this project are the channel-forming and maintenance flows and the daily averaged base flows that are sustained during the fish migration period. Table 1 presents the discharges used in this study to assess channel capacity and flooding potential at the project site under existing and proposed project conditions.

Table 1. *Streamflows used in the hydraulic analysis (HEC-RAS) of proposed project designs.*

Flood Recurrence Interval	Q2	Q5	Q10	Q25	Q50	Q100
Discharge (cfs)	730	1110	1450	1815	2200	2460

Hydraulics

Hydraulic analyses of the existing site conditions indicate that the culverts and road are overtopped when flows are in the range of 200 to 250 cfs, which corresponds to a water surface elevation of 16.9 feet on the upstream side of the culverts, assuming the culverts are in a clean condition. Most of the culverts contain a residual amount of sediment, and the inlets are partially occluded with vegetation and debris; causing the culverts to overtop when flow is less than 200 cfs. In general, the road has a tendency to be overtopped at the culverts at least once each year. Preliminary hydraulic analysis of the preferred alternative is presented later in this report.

Geotechnical Considerations

A geotechnical study was conducted as part of the 30% design phase of this project. Refer to the Geotechnical Study Report (RGH 2008) for detailed site analysis and recommendations. The geotechnical analysis indicates that the site soil conditions are complex and limit the feasibility of the structure types available for consideration. Construction materials, consolidation settlement, liquefaction and ground motion during a seismic event, and ground displacement after a seismic event are the primary geotechnical considerations.

Construction materials include considering what soils on site can be used for new fill and spoils that may need to be exported as part of the project. The upper 8 feet of soils on this site consist of clayey gravel that may be reusable as fill. The soft clays and looser sand and gravel below the upper 8 feet are not suitable for engineered fill without supplemental material brought to the site and mixed in.

In addition, for all subsurface soils, the moisture content may be excessive and need to be dried back or mixed with drier material.

Approximately 2 feet of material below the existing pavement surface will need to be excavated before new fill can be placed. If any excess excavated material from the project is generated it will have to be disposed of in upland areas or at an approved landfill. The quantity of these materials is determined in final design as part of the grading plan with the preferred structure type.

Consolidation settlement occurs over an initial period of time as the soils settle under the new loads from road fills and structures that are not founded on bedrock. The soils on this site are susceptible to consolidation of up to a few inches. Settlement occurs over time, and any maintenance required to adjust the road surface can occur as part of normal wear and tear repairs. Settlement of up to a few inches is not considered significant for either road maintenance or for the hydraulic or channel maintenance performance.

The site is highly susceptible to a seismic event given the underlying geology and proximity to the San Andreas Fault. Both liquefaction and ground motion potential are high and must be considered in the design. Liquefaction-prone soils are found throughout the site but in varying thicknesses across the floodplain. The amount of potential movement and settlement is related to the composition and thickness of the sediments. Thus, there is potentially significant differential settlement and lateral movement potential in the project site. This possibility raises concerns of significant uneven ground displacement after an earthquake that would result in impassable road conditions. The design and structure of the culvert replacement should be carefully considered for seismic mitigation.

<u>County Considerations</u>

The current General Plan designates each roadway into one of six functional classifications and establishes design standards for each classification. These standards help streamline the design and right-of-way acquisition process whenever roads are improved. Willow Creek Road is designated as a minor road. Its functional classification is "Local Road," which is to provide access to property and carry local traffic to collector roadways. The standards for a local road are to have two travel lanes and a right-of-way width of 50 feet. The pavement width may vary. The current pavement width in the vicinity of the replacement crossing is 20 feet.

The following policies apply to local rural roads:

1) The needed number of travel lanes is usually two but may be one on some remote roadways and some rural bridges.
2) Design local roads for reasonable access by emergency and service vehicles.
3) When practical, locate horizontal and vertical road alignments to correspond to natural topography. Minimize grading.
4) Layout local roads and streets to avoid adverse concentration of stormwater runoff.
5) In agricultural areas, include measures such as road signs, wider shoulders, turnouts or over/under-passes to provide safer highways for the agricultural industry, residents, and visitors.

Due to its location in the coastal zone, the County requested that the culvert replacement structure be composed of concrete, not steel.

Design Criteria

Given the above considerations, which can be both constraints and opportunities, the foremost design criteria to follow in the design of a replacement crossing for the culverts are:

- Minimum effective structure span for the channel to allow for natural channel dimensions,
- Maximum elevation of the road surface and minimum channel elevation,
- Minimum effective flow area for channel formation, maintenance, and fish passage,
- Road performance and flooding risk, and
- Overall project costs including final design, permitting, and construction

The first three criteria in combination generally determine the physical feasibility of a structure type. The minimum effective structure span is considered to be 40 feet. The maximum elevation of the road surface is 25 feet, which allows for up to a 4% slope on the road approaches leading up the replacement crossing area. The minimum channel elevation in the thalweg (lowest elevation in the low flow channel) is a function of the channel slope and downstream elevations. The thalweg elevation approximately 250 feet downstream is 11.8 feet. Using a channel slope of 0.3% and projecting up to the crossing replacement area gives 12.5 feet for the lowest expected channel thalweg elevation. This elevation is not constant along the channel cross section, and all natural channels have some elevation complexity such as floodplains. The general floodplain elevation in the vicinity of the replacement crossing is 15.0 feet and is the elevation used in determining the effective channel elevation for flood flow area analysis since the low flow channel makes up only a small percentage of the total cross section area.

The overall project cost criteria is to be least expensive at project completion given that all of the other criteria are met by a particular structure type. The project costs should include final design, permitting, and construction since some structure types may include varying amounts in any of these three categories.

Crossing Structure Type Options and Evaluation

There are multiple structure types that can be considered with varying degrees of risk. The options that are considered suitable for the culverts replacement include segmented embedded box culverts, embedded pipe arches, arched bottomless culverts, and bridges.

<u>Segmented box culverts</u> are side-by-side prefabricated concrete boxes that are in segments end-to-end. They are installed by placing them on a bed of conditioned material or suitable subgrade in sections. They typically come prefabricated in dimensions that allow for truck transport to the site. The largest single unit span available in precast concrete box culverts is 12 feet. The culvert height can vary

between 6 feet and 12 feet for this span length. The box dimension considered for this site is 10 feet by 12 feet (height x span). A series of boxes can be placed side-by-side to make a cumulative effective span and would be considered a culvert system of cells. Embedding the culverts up to 50% of the culvert height relative to the channel elevations allows for a natural channel bed within each set of boxes.

Segmented box culverts will be subjected to potentially significant differential settlement due to liquefaction because the susceptible soils do not extend evenly throughout the area to be improved. In addition, they may not perform well under consolidation settlement because the differential settlement may not only occur end-to-end of one segment, but side-to-side. As a result, the road may require constant maintenance due to the movements, and possibly may not be passable after an earthquake.

A thick subgrade and mat slab for the segmented box culverts and a wide border area would be needed to minimize the differential settlement potential. Construction of the mat slab would require significant site prep, groundwater pumping, and concrete set time in the saturated alluvial soils, increasing the construction period, costs, and resource impacts.

Another disadvantage of using side-by-side culverts as a system of cells for a cumulative effective span and channel width is that the intermediate structural parts of the system on the upstream face can trap debris at flood flows, reduce conveyance, and alter the channel morphology. A common occurrence is that the low flow channel becomes discontinuous along the length of the culverts and floodplain functions are not consistent.

<u>Pipe arch culverts</u> are prefabricated metal pipes that are "squashed" to make them wider than they are tall. They are also installed by placing them on a bed of conditioned material or suitable subgrade. The largest pipe arch dimensions considered for this site are 15 feet by 22 feet (height x span). A series of pipe arches can be placed side-by-side to make a cumulative effective span and would be considered a culvert system of cells. Embedding the culverts up to 40% of the culvert height relative to the channel elevations allows for a natural channel bed within each set of pipes. Pipe arches require a minimum amount of cover over the top as engineered fill depending on the span. For a span of 22 feet a minimum cover of 3 feet is required. Compared to other structure options that either incorporate the road bed or require minimal cover, the 3-foot cover considerably increases the road height and associated fill for the approaches.

The geotechnical constraints, construction constraints, and conveyance issues associated with the segmented box culverts apply to the pipe arch culverts. In addition, the County would prefer a concrete structure to maximize lifespan in the coastal environment.

<u>Arched bottomless culverts</u> are either metal or concrete sections mounted on side strip footings or a base slab. The side strip footings allow for a natural channel between them. A base mat slab would need to be embedded below the lowest anticipated channel scour elevation to allow for a natural channel on top of it, or the side strip footings need to be mounted on a pile cap. The span of channel for

the arch depends on the arch geometry. Concrete arch geometries are best where there is a lot of fill over the top and room to rise above the channel. Metal arches are more suitable for low-rise configurations. All arches typically require a minimum of 2 feet of engineered fill over the top as part of a critical back-fill zone that ensures structural integrity. The largest concrete arch span is 60 feet with a height of 12 feet. There are many smaller combinations of these arches with varying height to span ratios.

Based on the geotechnical constraints and the site limitations, a concrete arched bottomless culvert would need to be supported by a concrete footing supported by driven piles. The effective flow area of the structure is limited by the arched form, which reduces conveyance during high flows. The 2 feet of engineered fill required will increase road height and associated road fill.

Bridges suitable for this site are either precast or poured-on-site concrete, single-span, pile supported. The other types of bridge options include girder bridges, truss bridges, and suspension bridges. Girder bridges are not considered viable at this location due to the girder thickness that is likely required for a significant span, which can occlude flow area. For example, the third bridge on Willow Creek Road is a girder bridge with a span of 58.5 feet and girder thickness of 3 feet. Truss and suspension bridges are not considered for this site due to the large amount of flow-occluding superstructure that would be required for a significant span.

There are two options for bridge footings: spread-footing supported and pile supported. The spread-footing supported bridge should settle relatively evenly under consolidation settlement and could be designed to allow flexibility along the length. However, the bridge may not perform well if differential settlement occurs along the diagonal axis, which is possible at this site because of the variability of the subsurface material. To reduce the impacts of settlement on the structure, a bridge needs to be supported on driven piles.

As span lengths increase so does bridge deck thickness. To minimize road elevations, and thus road fill, an ideal deck thickness is 1 foot. A maximum bridge span with 1 foot deck is 48 feet.

Preferred Crossing Structure Type

Based on the evaluation of the crossing structure types, a precast, single-span bridge was chosen as the preferred crossing structure at the Willow Creek culvert replacement site. Construction costs for precast concrete bridges are similar to concrete arched culverts. A bridge is preferred over an arched open-bottom culvert because of its greater channel capacity for a given base width and because it does not require additional fill (up to 2’) on top of the structure for the road base.

Pacific Bridge out of Sandy, Oregon designs and constructs precast bridges for culvert replacement projects (see photos below for examples). A standard maximum free span width of this type of bridge is 43 feet with 2.5-foot abutments on either side.

Photos courtesy of Pacific Bridge, 2008

Preliminary design details for the 90% design (construction bid ready) for a bridge of the type shown above, include:

- A bridge opening width of 43 feet,
- A bridge deck width of at least existing pavement width (20 feet),
- A bridge deck at an elevation of 20 feet NGVD,
- The bridge abutments supported by driven pipe piles,
- The bridge approaches graded to meet existing bridge elevation on the eastern approach and the 18-foot road contour on the western approach, and
- The channel thalweg at 12.5 feet.

Hydraulic analyses of these design parameters indicate that the second bridge crossing and approaches will not be submerged during design high-flow events (Figure 4). This analysis does not take into account potential backwater effects from the Russian River.

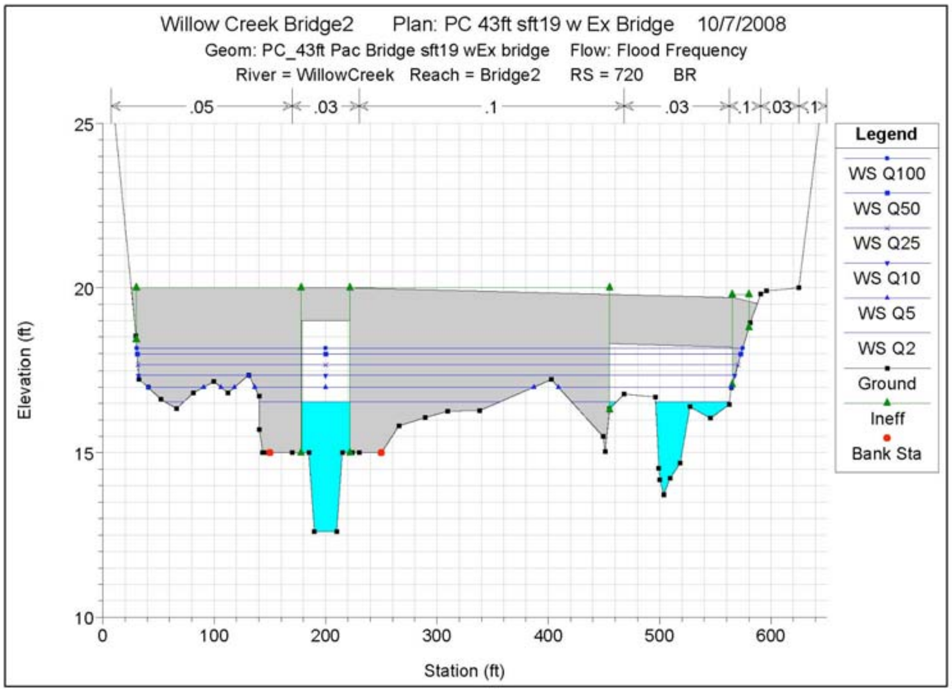

Figure 4. *Hydraulic model results of the preferred structure at the second bridge crossing looking downstream at the road (dark grey is the road fill). Note that all flood flows are contained within the channel and floodplain, and they do not overtop the roadway.*

References

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