Assessing the Feasibility of Anadromous Fish Passage Above Lake Shastina

Via Parks Creek and a Constructed Bypass Channel

Prepared for:

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1 INTRODUCTION

The Shasta River was historically one of the most productive salmon bearing tributaries in the Klamath Basin, with annual adult escapements ranging in the tens of thousands of Chinook salmon (*Oncorhynchus tshawytscha)* and thousands of coho salmon (*O. kisutch)* and steelhead (*O. mykiss)* (Wales 1951). Even as late as 1931, there were 81,000 Chinook salmon migrating up the Shasta River (Wales 1951); however, salmonid populations have been declining in the Shasta Basin throughout the 1900s in part due to hydrologic alteration and habitat degradation. The completion of Dwinnell Dam in 1928, which formed Lake Shastina (Figure 1), blocked access to approximately 22% of the available salmon and steelhead spawning and rearing habitat in the Shasta Basin (Cannon 2011), and within 10 years, the spring-run Chinook were extirpated (Moyle 2002). Over the last several decades, salmonid populations have continued to sharply decline throughout the Klamath Basin, precipitating a long series of regulatory and basin management processes focused on recovering salmonid species, particularly coho salmon.

In 1997, the National Marine Fisheries Service (NMFS) listed the coho salmon Southern Oregon–Northern California Coast Evolutionarily Significant Unit as threatened under the Federal Endangered Species Act of 1973. In 2005, coho salmon ranging from San Francisco to the Oregon border were listed as threatened under the California Endangered Species Act. In Siskiyou County, the Shasta –Scott Recovery Team plan, which was incorporated into the State Coho Recovery Plan, initiated the development of a programmatic, voluntary, incidental take program (ITP) that outlined coho recovery tasks while protecting and bringing agricultural operators into compliance with the California Department of Fish & Wildlife (CDFW) codes. One of the recovery tasks outlined in the ITP was to evaluate anadromous fish access to the Shasta River upstream of Dwinnell Dam (ESA 2008). Although the ITP was halted in 2011, interest in anadromous fish passage above Dwinnell Dam has continued. Access to spawning and cold water rearing habitat upstream of Lake Shastina may substantially enhance the recovery opportunities for native anadromous salmonids. However, the feasibility of achieving anadromous fish passage above Dwinnell Dam, the implications to property and water rights, and the effects of current land use and water management on salmonid habitat upstream of Lake Shastina are uncertain.

Dwinnell Dam seasonally impounds up to 50,000 acre-feet of water in Lake Shastina for municipal and agriculture uses. Montague Water Conservation District (MWCD), which operates Dwinnell Dam, conveys water from Lake Shastina to the communities of Shastina and Montague, as well as to numerous family farms and ranches lower in the basin through a 60-mile long canal and ditch system. In December 2013, a settlement (Settlement) was signed between the Klamath Riverkeeper, Karuk Tribe, and MWCD, which dismissed earlier litigation over the operation of Dwinnell Dam and other Shasta diversions. As part of the Settlement, the plaintiffs (Klamath Riverkeeper and Karuk Tribe) agreed "not to file court claims against third parties (such as NMFS) seeking removal of Dwinnell Dam if other measures for securing anadromous fish passage to the upper Shasta River have been shown to be infeasible" (United States District Court 2013). The Karuk Tribe subsequently requested proposals to analyze the feasibility of strategies to provide fish passage past Dwinnell Dam to the upper Shasta River. This study has been developed to meet that request.

2 OBJECTIVE

To date, several reports have proposed and evaluated strategies to provide anadromous fish passage above Lake Shastina to the upper Shasta River (ESA 2008; Podlech 2009; Cannon 2011). Proposed fish passage alternatives have included fish ladders at Dwinnell Dam, trap and haul programs, fish bypass via a constructed channel (Figure 2), and dam removal. The existing reports have evaluated the physical and biological tradeoffs for various passage alternatives and suggested areas for further study. A lack of conceptual designs, topographic analyses, feasibility criteria, and uncertainty about upstream habitat conditions has generally precluded a determination of the feasibility or infeasibility of any one fish passage option (Podlech 2009).

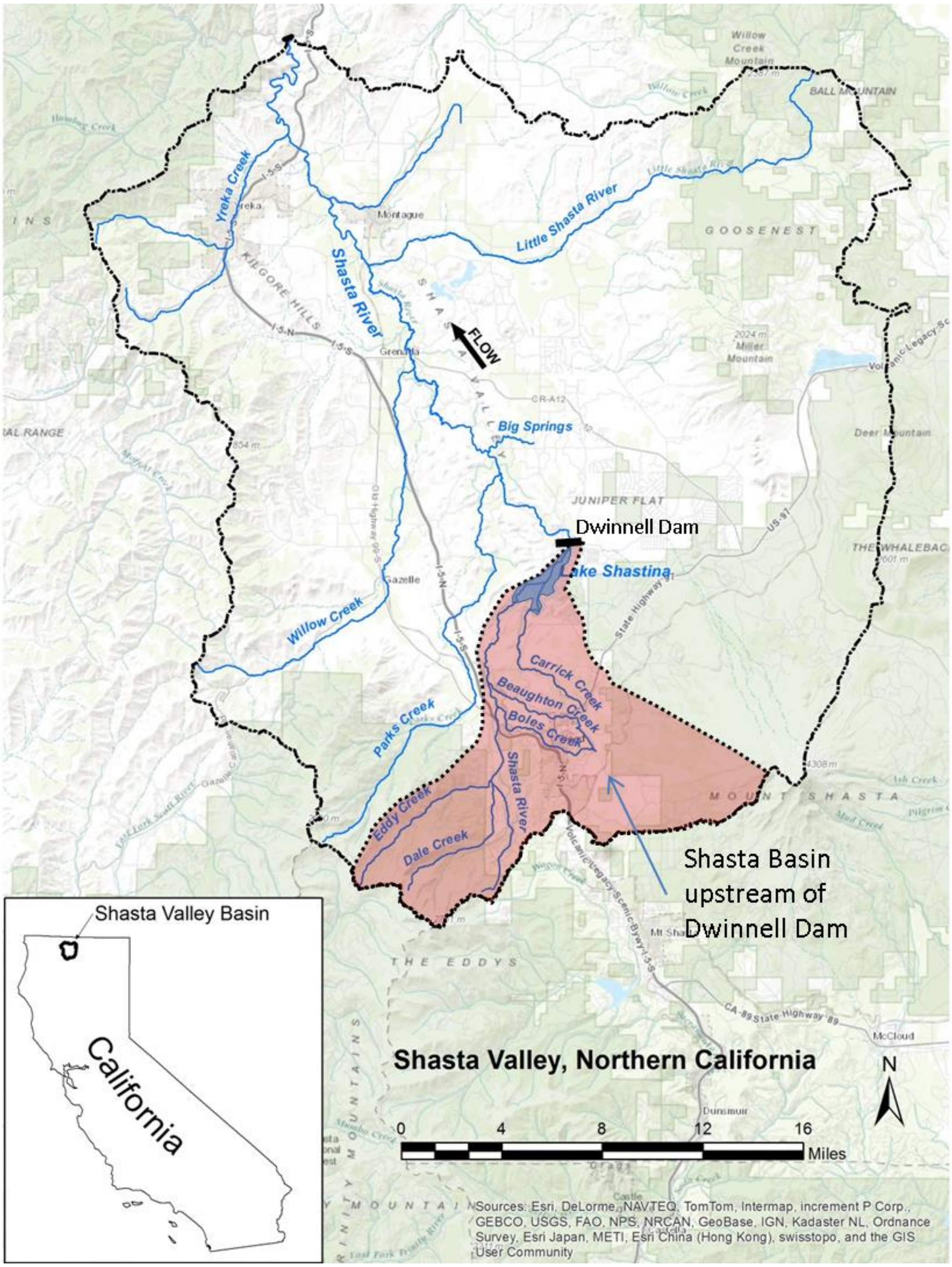

Figure 1. The Shasta Basin, showing the portion of the Shasta River watershed upstream of Dwinnell Dam.

Podlech (2009) and Cannon (2011) recommended further evaluation of the fish ladder and bypass channel alternatives, including the development of conceptual designs, while citing concerns over downstream collection efficiency and the negative effects of stress associated with trap and haul systems. The existing reports indicate that the bypass channel alternative provides the most natural solution for fish passage, the greatest potential for secondary benefits (including improvements to salmonid habitat in Parks Creek), and the least potential for impacts from operation and management of the Lake Shastina Reservoir. In addition, the bypass alternative eliminates the need for reservoir transit of anadromous fish, which could cause stress and mortality to migrating fish when reservoir levels reach annual lows. The bypass alternative also was specifically mentioned in the Settlement (USDC 2013). However, feasibility of a fish bypass is uncertain. Implementation cost, design and infrastructure considerations, landowner participation, water rights issues, and operational constraints must all be considered in a feasibility analysis.

Therefore, the purpose of this study is to expand upon the existing body of work to provide a more detailed analysis of the opportunities, constraints, and feasibility associated with a fish bypass via a constructed channel connecting Parks Creek to the Shasta River above Dwinnell Dam. To that end this report includes a comparative analysis of potential bypass routes (Section 4), a preliminary conceptual design (Section 5), and cost estimate (Section 6) for one preferred bypass route. Also included is analyses and discussion of the hydraulic requirements of the bypass (Section 7.1), potential response of focal species (Section 7.2), constraints and uncertainties to the bypass alternative (Section 7.3) and the auxiliary benefits of the bypass alternative (Section 7.4). Ultimately, feasibility must be determined by the settlement parties, funding parties, resource agencies, and land-owners who would be involved in the construction, management, and permitting of a by-pass channel. However, to inform that process, Section 8 includes a summary of five elements of feasibility: engineering design (Section 8.1), cost (Section 8.2), water availability (Section 8.3), land owner agreements (Section 8.4), and the response of focal species (Section 8.5).

3 FOCAL SPECIES, LIFE STAGES AND BIOLOGICAL CONSIDERATIONS

Focal species and life stages considered for the feasibility assessment of a bypass channel include adult upstream migration and juvenile downstream migration for fall-run Chinook salmon, coho salmon and steelhead trout. Besides the potential to expand the spawning and rearing opportunities for current anadromous populations, a portion of the resident rainbow trout population, which occurs upstream of Shastina and likely descended from the historic anadromous population, would have the opportunity to become smolt and join the anadromous population as steelhead. Lestelle (2012) stated that if a bypass channel was successfully constructed, a reintroduction of spring Chinook could be planned and implemented. While Spring-run Chinook were considered for inclusion as a focal species; reconnaissance of the mainstem Shasta River above Dwinnell Dam indicated a lack of deep-pool adult holding habitat, critical for adult spring-run Chinook holding, which together with their present extirpated status, precluded them from being included as a focal species for the bypass alternative feasibility evaluation at this time. However, the information in this report could be used, in part, to evaluate the potential for spring-run reintroduction in the future.

The operation of a bypass channel must be designed to accommodate the life history periodicities of focal species. Adult fall-run Chinook salmon migration and spawning typically occurs from mid-September through December in the Shasta Basin (McBain & Trush Inc. 2012b). Coho salmon migration begins later than September, typically from mid-October through December. Steelhead spawning typically occurs later, between December and early April. Within the current range of anadromous fish access, high priority reaches for Chinook salmon spawning include the mainstem reach of the Shasta River located just downstream of Parks Creek, Big Springs Creek, and the Shasta River from Big Springs Creek downstream to Grenada Irrigation District (Deas et al. 2004; Jeffres et al. 2008, 2010; Chesney et al. 2009).

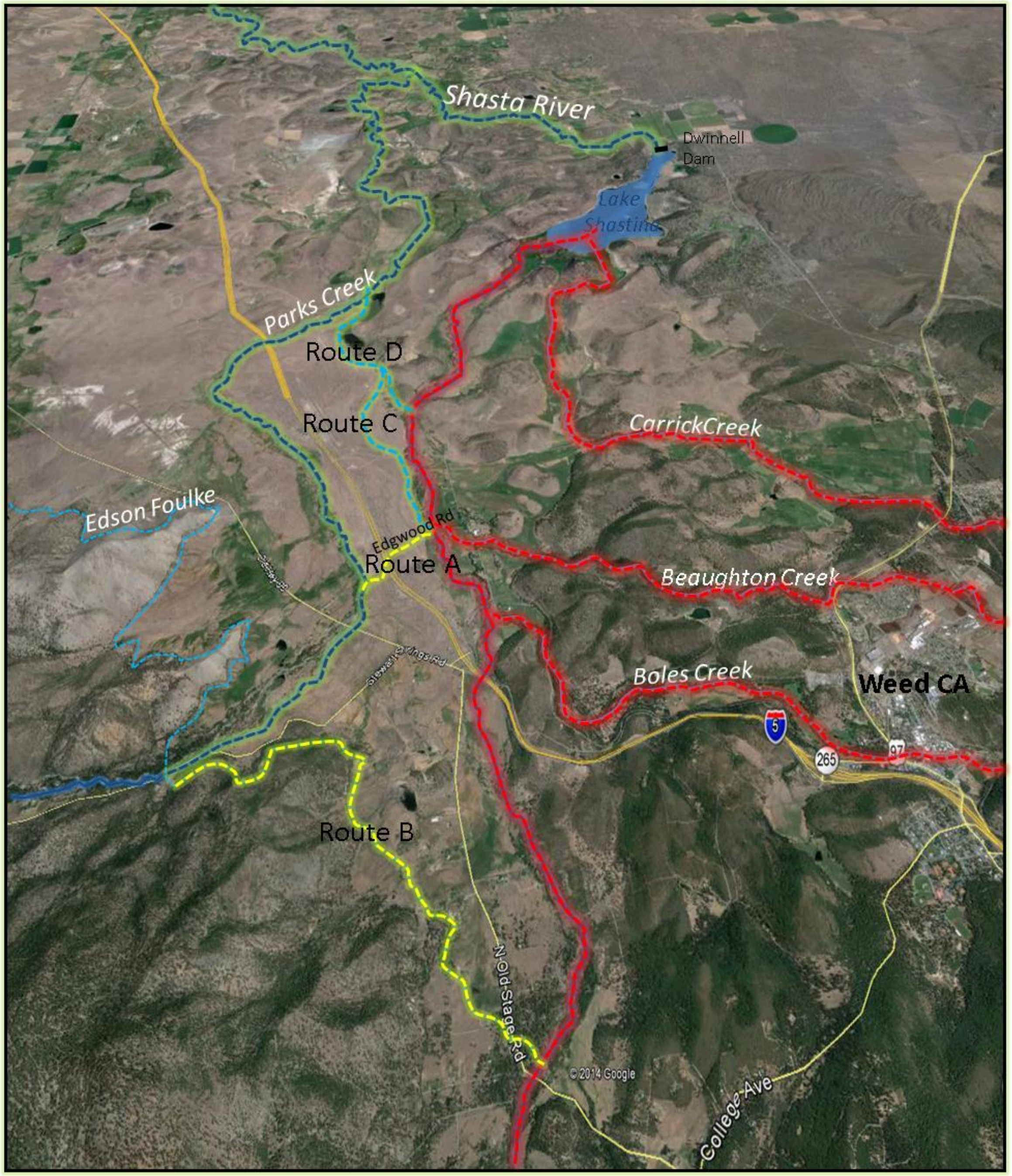

Figure 2. Potential bypass channel locations connecting Parks Creek to the Shasta River upstream of Lake Shastina. Channel locations are based in part on Podlech (2009) and Cannon (2011).

After spawning and emergence, juvenile coho and steelhead typically over-summer in cold water environments while fall-run juvenile Chinook salmon typically smolt and migrate to the ocean in their first year. Late spring and summer water temperatures are considered by many to be the primary factor limiting the recovery of most salmonid populations and particularly coho salmon (Chesney et al. 2009, Jeffres et al. 2008; Jeffres et al. 2009; NRC, 2004 cited in Nichols et al. 2013). Therefore, the effect of a bypass channel on late spring and summer rearing opportunities is of particular importance. A discussion of physical and thermal habitat conditions upstream of Lake Shastina, and the potential response of focal species to accessing that habitat included in Section 7.2 of this report. The success of a bypass channel depends not only on fish migration through the constructed channel, but also linking fish passage to successful life history tactics, including all the freshwater components of the anadromous life cycle at potential spawning and rearing destinations upstream of Lake Shastina.

4 DISCUSSION OF ROUTE SELECTION

Only the physical and biological considerations of alternate bypass routes were compared for the purposes selecting a route for conceptual design and cost analysis. The physical and biological criteria used in evaluating bypass routes included:

- The suitability of existing topography and expected earthworks required for construction;
- Opportunity to provide appropriate gradient (which determines sediment size and sediment transport capacity in the bypass channel);
- Infrastructure constraints along the bypass route (e.g., bridges, undercrossings, and diversion structures); and
- The effect of bypass channel confluence locations (e.g. point of diversion from Shasta River and point of inflow to Parks Creek) on the life history of focal species.

In addition to these physical and biological considerations, the hydraulic requirements of the bypass, potential response of focal species, landowner agreements, water rights, and regulatory constraints are also key components of feasibility. However, these components (discussed Section 7) must be addressed for all potential bypass routes and are less dependent on route location than the physical and biological criteria above.

The location where a bypass channel would divert flow from Shasta River is a primary considerations when comparing alternate bypass routes because it affects the use of upstream habitat. While Chinook, coho salmon, and steelhead have been shown to readily colonize newly accessible habitat (Anderson et al. 2014; Anderson and Quinn 2007), migrating adult salmonids typically only travel upstream to reach their spawning destination. If a proposed bypass channel deposits adult salmon into the upper Shasta River *upstream* of the high value spawning habitat, it is unlikely that adult fish would swim *downstream* to access that habitat. Although the physical and biological cues which guide migrating adult salmon to their selected spawning grounds are not fully understood, the two most widely accepted hypotheses include scent and geomagnetic stimulation or both (Ueda 2014). In either case, a bypass channel that deposits salmon above the high value spawning habitat and requires salmon to swim *downstream* to access that habitat is less desirable for the recolonization of sustainable spawning since: (1) it would not provide a pathway for upstream scent components, e.g., pheromones or amino acids (Wisbey and Hasler 1954; Nordeng 1977; Bandoh et al. 2010), to reach adult fish downstream; and (2) it would be contrary to the geomagnetic direction for the intended spawning destination.

Based on a reconnaissance-level survey of habitat type, literature reviews, and a longitudinal profile of the upper Shasta River (Figure 3), the six miles of the Shasta River between Lake Shastina and Hwy I-5 is a low gradient reach (0.5%–1%), displaying pool–riffle morphology and sediment size distribution consistent with the needs of salmon and steelhead spawning. Although some vegetation has encroached onto the gravel bars in this reach, the Shasta River below I-5 (Figure 4) is typically less confined and composed of smaller substrate than the reach upstream of I-5 (Figure 5). Upstream of Hwy I-5, the Shasta River becomes a moderate gradient stream (1%–3%) with predominately cobble substrate and run/step-run mesohabitat, which is less favorable for salmonid spawning. Modified Wolman pebble counts, completed in selected pools tails approximately two miles upstream of I-5, confirm that substrate was larger than ideal for coho, Chinook and steelhead spawning in this reach (Table 1). A reconnaissance-level survey from Yokel (2009 as cited in Podlech 2009) also concluded that the majority of high value spawning habitat for coho and Chinook salmon likely occurs between Dwinnell Reservoir and the I-5 crossing.

Therefore, alternate bypass routes were evaluated in part by how much of this high value habitat occurred upstream of their confluence locations with the Shasta River.

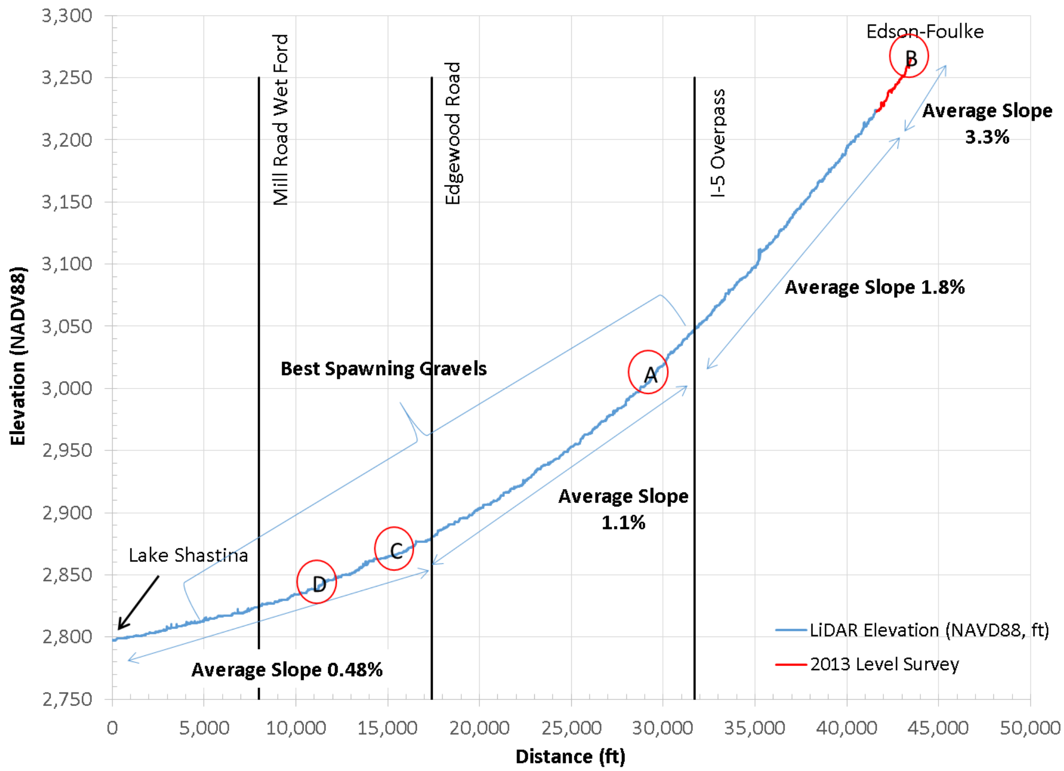

Figure 3. Longitudinal profile showing change in elevation from Lake Shastina up to Edson-Foulke Diversion Canal, and showing the confluence locations of potential bypass routes A through D.

Four potential bypass routes were identified from Podlech (2009) and Cannon (2011; Figure 2). These routes were examined to identify the best route for conceptual design. The potential bypass routes included:

Route A. A canal which diverts flow from the Shasta River just upstream of the I-5/Edgewood Road undercrossing, flows under I-5 at the undercrossing and down Old Hwy 99, entering Parks Creek just downstream of the Old Hwy 99 Bridge.

Route B. Utilizing the existing Edson-Foulke Diversion Canal between Parks Creek and the upper Shasta River.

Route C. A canal which diverts flow from the Shasta River immediately downstream of the Edgewood Road Bridge, crosses Slough Road first near Edgewood Road Bridge and again at the top of the grade above the stock ponds on Emmerson Investment’s Big Springs Ranch before descending to Parks Creek due north of the Big Springs Ranch stock ponds.

Route D. A canal which diverts flow from the Shasta River east of the Mills Rd–Slough Road intersection and flows along the north side of Slough Road before descending to Parks Creek due north of the Big Springs Ranch stock ponds. Routes C and D use the same path from Slough Road to Parks Creek.

Figure 4. Google Earth image showing the Shasta River between I-5 and the Edgewood Road Bridge. This reach is predominately low gradient (~ 1% slope) with gravel and cobble substrate.

Figure 5. Google Earth image showing the Shasta River approximately 1 mile upstream of I-5. This reach is moderate gradient (~ 2%–3%) slope with predominately cobble substrate and run/step-run mesohabitat.

Table 1. Pebble counts at selected pool tails in the upper Shasta River.

Approximate distance upstream of Lake Shastina (ft)	Date	D_{84} (mm)	D_{50} (mm)
42,000	9-16-12	145	71
42,000[1]	7-26-13	177	85
43,500	7-26-13	148	71
44,500[2]	7-26-13	125	54

[1] A large event in December of 2012 appreciably changed this pool tail substrate composition
[2] Upstream of Edson-Foulke Diversion Dam

Route A: Route A was loosely based on a design originally proposed in ESA (2008) and discussed in Podlech 2009. Although Route A is the shortest of the examined routes at 5,400 ft; it has an unfavorable topographic profile, as discussed in Podlech (2009), and would require a very large amount of excavation, including excavation near the I-5 undercrossing (Figure 6). In addition, the maximum potential slope of the channel from the Shasta River down to Parks Creek would be less than 0.2% (Figure 6). Such a low gradient reduces sediment transport potential and increases fine sediment deposition, which may require frequent maintenance in the bypass channel. Route A also has significant infrastructure constraints. At least three road crossings would be necessary, including the I-5 on-ramp and off-ramp at the Edgewood Road undercrossing and Edgewood Road itself. It is uncertain whether enough space exists next to Edgewood Road as it crosses under I-5 to excavate a bypass channel. Finally, Route A also connects with the Shasta River approximately 5 miles upstream of Lake Shastina, and ¼ mile downstream of the I-5 undercrossing, which is upstream of most of the expected high value spawning habitat. For these reasons, Route A was not considered a viable option for conceptual design.

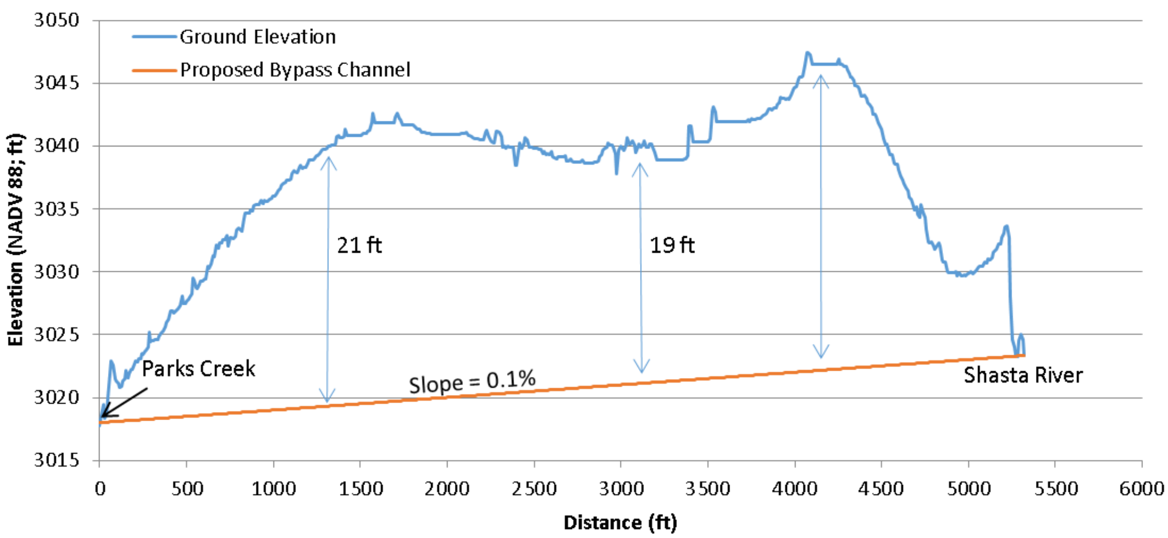

Figure 6. A conceptual longitudinal profile of Route A, based on the ESA (2008). The elevation profile was derived from a LiDAR-based digital elevation model (DEM) with 5 ft resolution. The proposed channel slope in this case is a straight line since no optimization of cut/fill is possible due to the small difference between the Parks Creek elevation and the Shasta River elevation.

Route B: Route B utilizes the Edson-Foulke Diversion Canal, which provides a potential economic advantage in that a new canal would not need to be constructed, although improvements may be needed to the canal before salmon could use it for migration. The Edson-Foulke Diversion Canal transfers water from the upper Shasta River for irrigation, flowing along the eastern wall of the Trinity Alps, and crossing under Parks Creek and Stewarts Springs Road in a large culvert. With a moderate slope and a bottom width between 4 ft and 10 ft, the Edson-Foulke Canal is suitably sized for migrating salmonids. The Edson-Foulke Canal between Parks Creek and the Shasta River is approximately 19,200 ft, making Route B the longest of the examined routes. A fish passage structure would have to be constructed at the culvert under Stewarts Springs Road and Parks Creek to allow salmon to access the Edson-Foulke Canal. The Edson-Foulke Canal is currently used for agricultural water delivery, so any fish passage structure would also have to supply a controlled quantity of flow to the canal on the north side of Parks Creek. Beyond the regulatory and water rights issues of using an existing diversions canal for fish passage, a primary disadvantage of Route B is that its confluence with the Shasta River, at the Edson-Foulke Diversion Dam (EFDD), is approximately two miles upstream of I-5 and upstream of the priority spawning destinations for coho and Chinook salmon (Figure 2 and Figure 3). While steelhead spawning likely exists above the EFDD, other salmon species would have to swim downstream to spawn, which is perhaps unlikely (see discussion in Section 4). For this reason, and the complications of agricultural water delivery, Route B was not considered a viable option for continuing with conceptual design.

Routes C and D: Routes C and D intersect with Parks Creek just downstream of Slough Road and the stock ponds on Emmerson Investment Big Springs Ranch (Figure 7). Neither of these routes cross I-5 and both have diversion points from the Shasta River toward the downstream section of the expected high value salmon spawning habitat (Figure 3). The diversion point for Route C is immediately downstream of the Edgewood Road Bridge and approximately 0.7 miles upstream from the diversion point for Route D, which occurs just as the Shasta River veers away from Slough Rd. Route C is the longer of the two routes at ~16,000 ft, while Route D is 14,000 ft. Route C would require two crossings of the Slough Rd, while Route D would require a single culvert at the Mills Rd–Slough Road intersection. Both routes would require at least one crossing for cattle near the Emmerson stock ponds just upstream of Parks Creek.

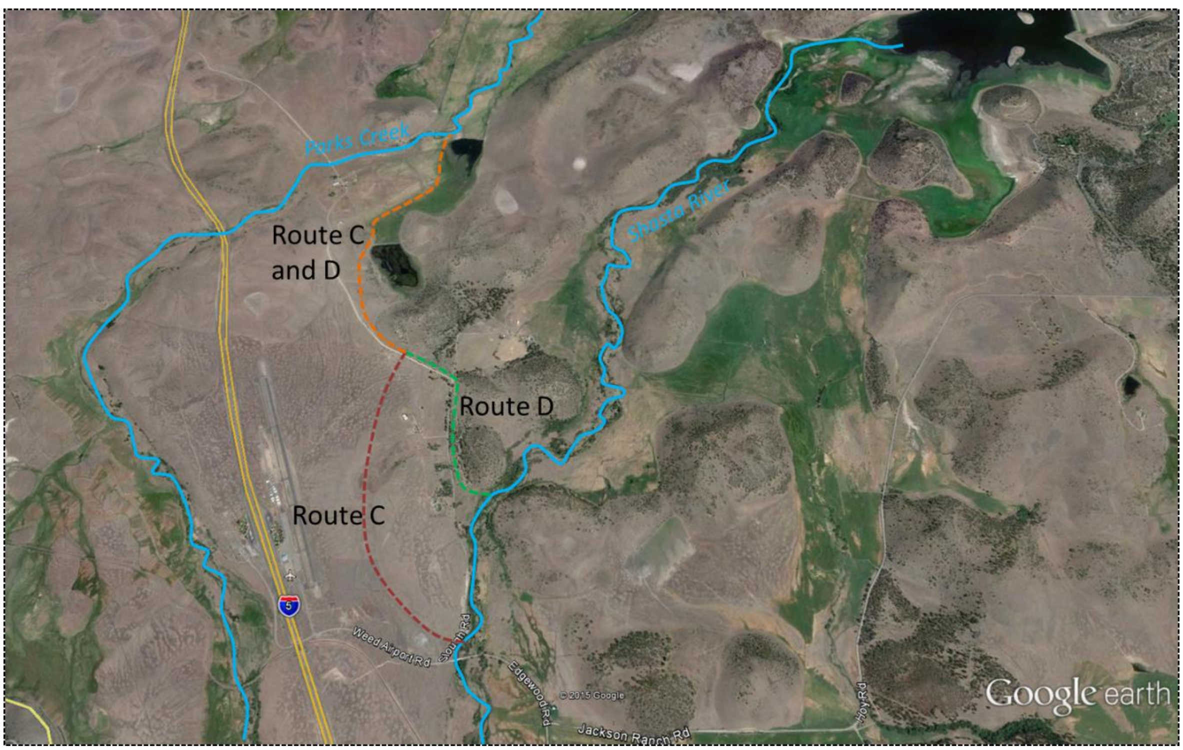

Figure 7. Routes C and D both use the same downstream channel location from Slough Rd. Red circle shows the location of the photo from Figure 16.

Although both routes C and D provide favorable topography for a bypass channel flowing from the Shasta River to Parks Creek, Route D is shorter, requires less earthwork and fewer road crossings. In addition, the topography of Route D is simpler, with average design gradients between 0.3% and

3.3% (Figure 8). Based on these physical characteristics, Route D was selected for an initial conceptual design.

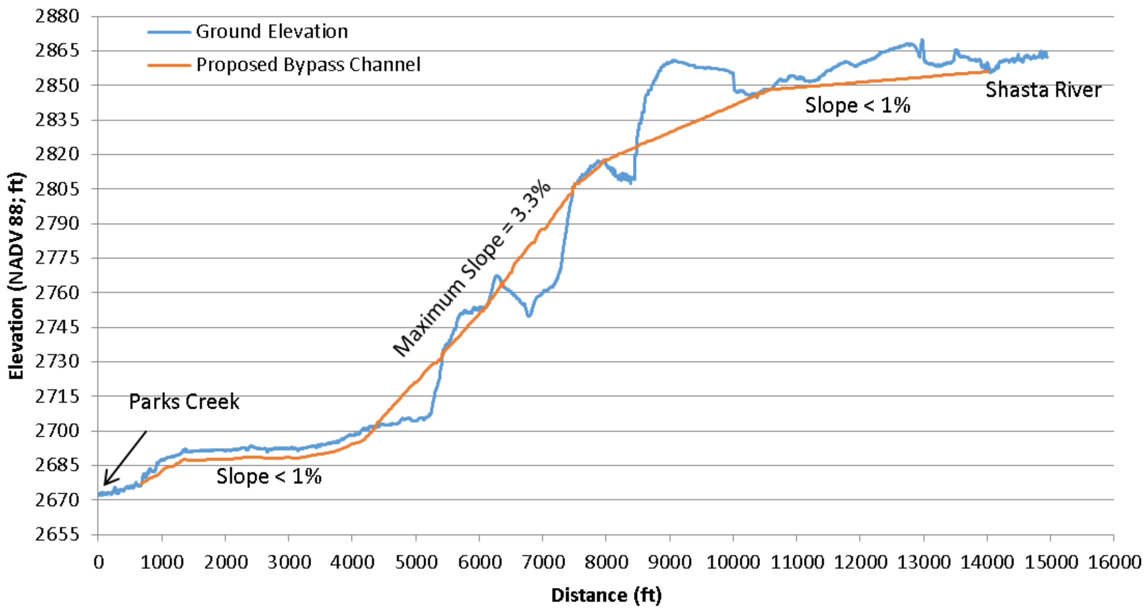

Figure 8. A conceptual longitudinal profile of Route D. The proposed channel slope is a conceptual example of how cut and fill can be optimized to reduce construction and materials cost.

5 CONCEPTUAL DESIGN FOR BYPASS ROUTE D

The conceptual design for bypass Route D includes: (1) planform drawings for the alignment of Route D, (2) conceptual longitudinal and cross section profiles, (3) an estimate of earthworks (cut and fill volumes) necessary to construct the project, (4) anticipated construction and material needs and their costs, (5) assumptions for permitting, construction layout, and mobilization costs.

Planform drawings for the alignment of Route D as well as conceptual longitudinal and cross section profiles were developed to inform a conceptual project design (Figure 9, Figure 10). Topography from a digital elevation model (DEM) with 5 ft resolution was used to prepare the existing ground profile. Topography from the DEM and the conceptual design alignment and thalweg profile were imported to AutoCAD Civil 3D to estimate the cut and fill volume needed to construct the bypass channel. A conceptual design surface was generated using a trapezoidal channel geometry consisting of a 10 ft wide bottom width and 2:1 (Horizontal:Vertical) side slopes applied to the channel alignment and thalweg profile. Cut and fill volumes were then estimated by differencing the existing conditions topography from the conceptual design surface (Figure 10). The area was computed in AutoCAD Civil 3D based on the projected top widths for areas of cut and bottom widths for areas of fill along the conceptual design alignment.

There is potential to balance cut and fill volumes for Route D in order to reduce the need for hauling material offsite. Reaches of cut were identified as locations where excavation would be necessary while reaches of fill were identified as locations were the channel bed would need to be raised in order to maintain desired channel gradient. The location of the conceptual design thalweg was estimated by visually balancing cut and fill reaches along Route D (solid line in Figure 10). The actual location and optimal thalweg elevation of Route D would be improved during more detailed survey of existing ground as part of engineering design.

The estimated earthwork volume needed to construct this conceptual design for Route D was computed to be 118,500 yards^3 of cut and 75,000 yards^3 of fill. To account for potential error in the

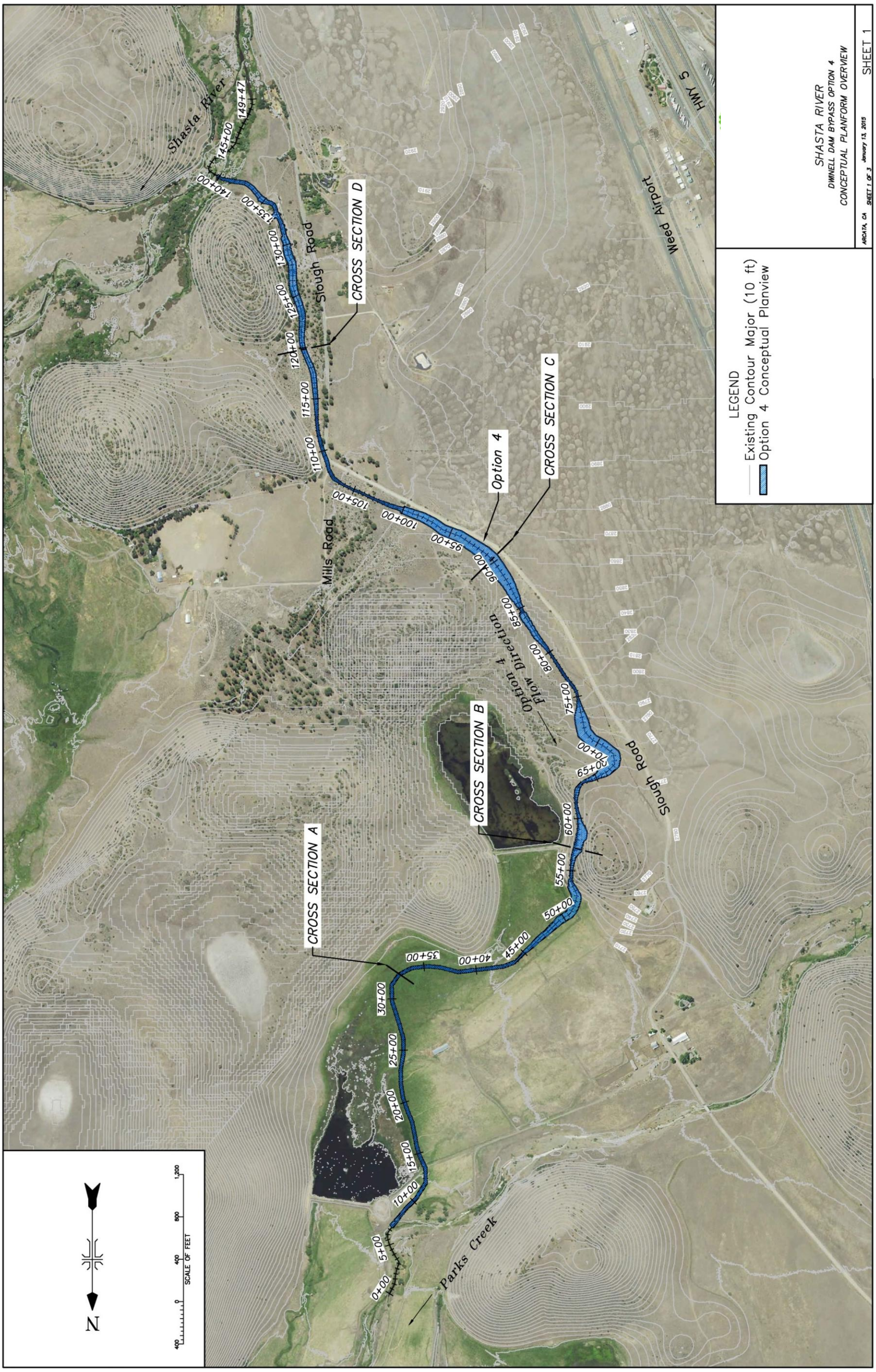

Figure 9. Planform view of bypass Route D (Option 4), showing channel widths and the locations of cross sections from Figure 10.

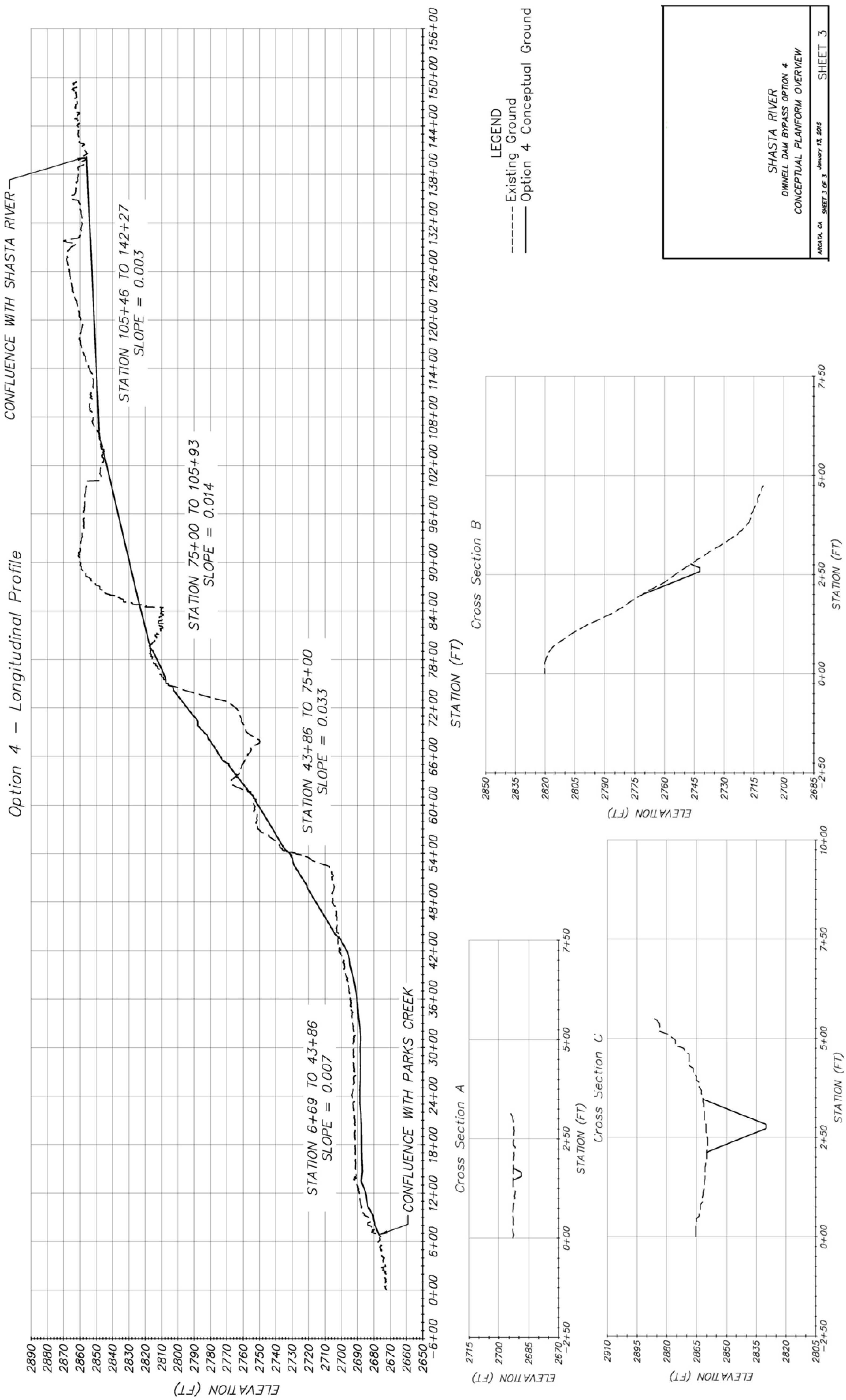

Figure 10. The existing ground profile, conceptual design thalweg profile, and selected cross section profiles from Route D (Option 4) were developed from LiDAR and created in AutoCAD Civil 3D.

existing DEM and the estimated material necessary for levees along the perched reaches of the bypass channel, a 50% contingency was added to the cut-fill volume estimates. This resulted in a revised estimate of 177,750 $yards^3$ of cut and 112,500 $yards^3$ of fill. A 50% contingency was also added to the conceptual project area to account for levee widths and variation in side slopes, increasing the total estimated constructed area from 15 acres to 23 acre

5.1 Construction Materials

In addition to cut-fill volume estimates, anticipated construction and material needs for the bypass channel include impermeable bed lining, gravel and cobble material for the channel bed, log and boulder habitat and grade control structures, finish contour grading, culvert installation at road crossings, cattle fencing, and revegetation along the channel. The cost estimates and assumptions for these tasks, including permitting, construction layout, and mobilization costs are shown and discussed in Section 6. Volume and quantity estimates for specific materials are discussed below:

- Gravel supply was estimated at 6,500 $yards^3$. This number was based on a 10 ft bottom width, 1.25 ft depth of gravel and 14,000 ft length.

  $(10 \text{ ft} \times 1.25 \text{ ft} \times 14{,}000 \text{ ft}) / (27 \text{ ft}^3 \text{ per yd}^3) = 6{,}481 \text{ yards}^3$
- Boulder and cobble supply was estimated for approximately 1 mile of roughened channel.
- 25 boulder/log grade control structures were added to provide grade control every 200 ft over the approximately 1 mile of higher gradient reach (3%) from the top of the grade at Slough Rd, down to the Emmerson stock ponds.
- 120 small log structures (15 or fewer logs) were included to improve juvenile habitat and hydraulic function along the length of the channel.
- Bentonite clay channel lining to prevent infiltration of flow in the bypass channel was estimated for 210,000 ft^2. This number was based on a 15 ft top width, a 10 ft bottom width, 2.5 ft depth on both sides of the canal, and 14,000 ft length.

  14,000 ft channel length × 15 ft width (10ft bottom width + (2 × 2.5 ft up either side of trapezoidal canal)) = 210,000 ft^2
- Finish contour grading costs were estimated per unit acre for 23 acres.
- Revegetation costs were estimated for 18 acres, which was the total area minus the active channel.
- Two head gates to regulate low flow and high flow entrance to the bypass channel (see discussion in Section 5.2) were included in the estimate.
- A fish screening structure (see discussion in Section 5.2) was included in the estimate.
- Two culvert installations were included, one at Mills Rd–Slough Road intersection and one on Emmerson Ranch cattle road.
- Cattle fencing along both sides of the lower 0.8 miles of the canal on the Big Springs Ranch property was included in the estimate.

5.2 Discussion of Entrance Conditions, Flow Regulations and Fish Screens

The bypass channel entrance conditions must be regulated to control distribution of streamflow between the Shasta River and the bypass. During the high flow events of December 2014 and February 2015 the Edgewood gage (USGS 11516750), just upstream of Lake Shastina, recorded a change in stage of almost 8 ft from baseflow (Figure 11). The December 2014 and February 2015 events represented a 5 to 10 year event in many places across central Northern California (Figure 12). A headgate system to regulate flow into the bypass must be designed to prevent high flow events from causing scouring or damaging flows to enter the bypass channel.

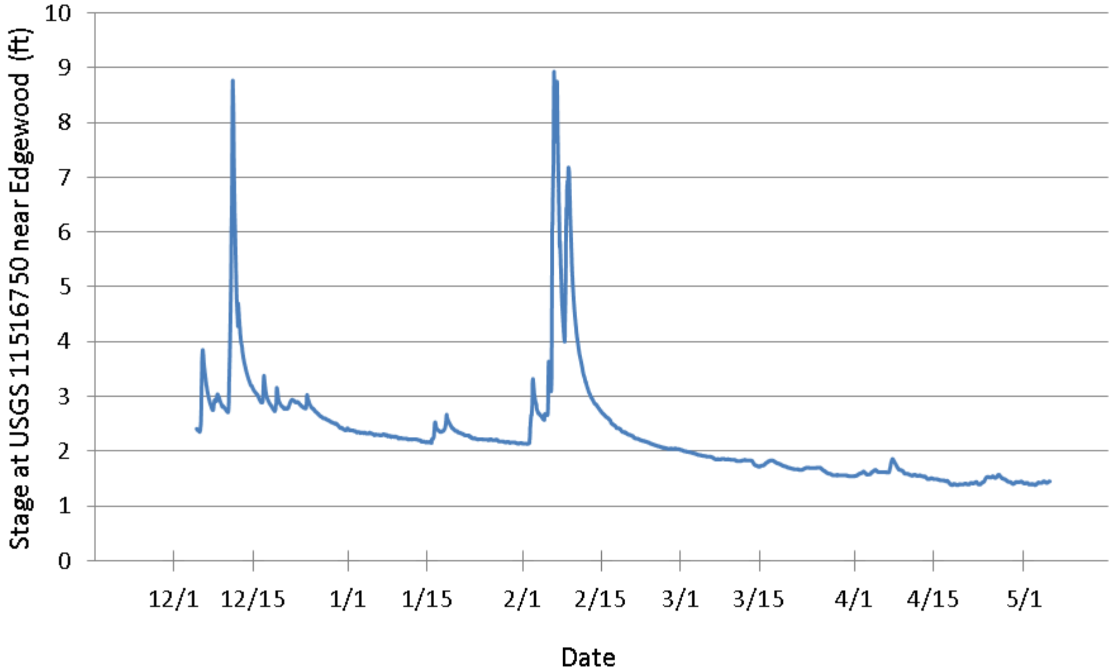

Figure 11. Change in stage during the December 2014 and February 2015 high flow vents on the upper Shasta River at the Edgewood Gage (USGS 11516750).

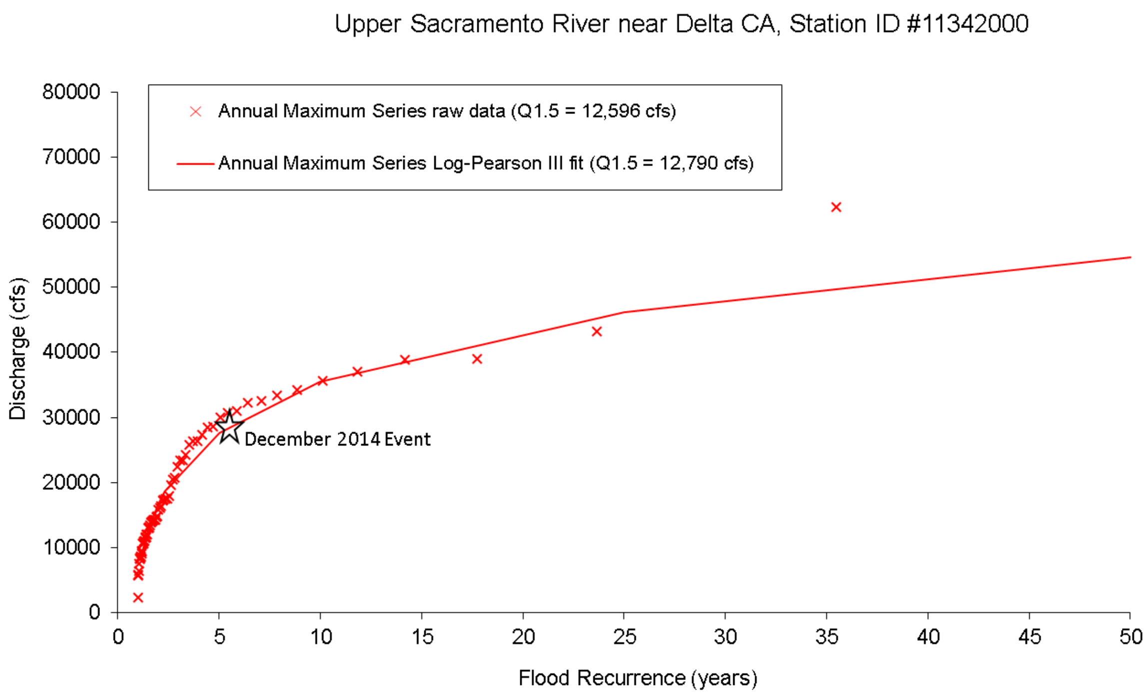

Figure 12. The December 2014 peak flow event was approximately a 6- or 7-year event on the nearby upper Sacramento River.

With an estimated change in stage in excess of 7.5 ft for a 5- to 10-year peak flow event, and higher for a 100-year event, it may be difficult for a single headgate to regulate inflow to the bypass during both baseflow and flood events. Rather, installing two headgates, one to regulate low flow and one to regulate high flow, may be a preferred solution. Figure 13 shows a conceptual drawing for a two headgate bypass channel entrance design. In addition to regulating flow into the bypass, existing diversions in the proximity of the bypass entrance would have to be maintained. A low head weir could be used to control water surface elevations to supply flow for existing diversions, the proposed bypass diversion, and the mainstem Shasta River.

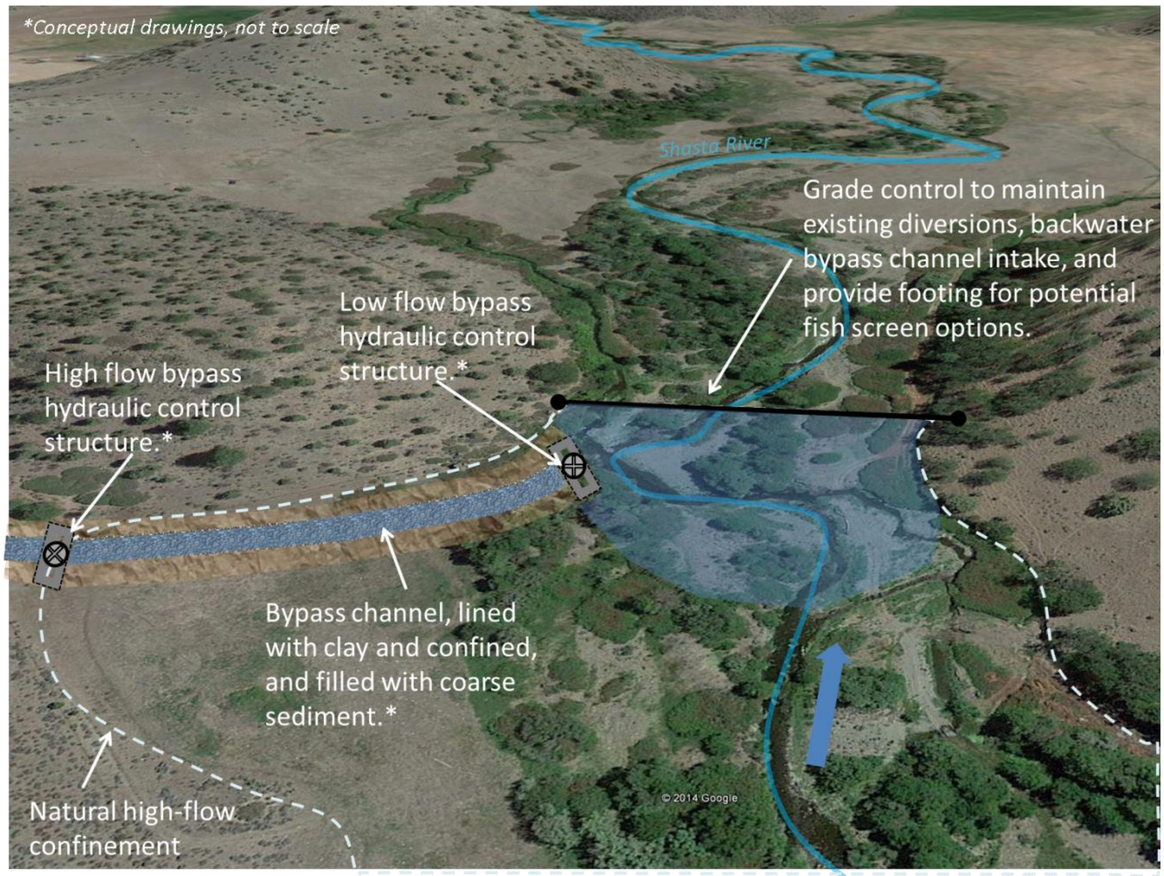

Figure 13. Conceptual drawing of the proposed bypass channel entrance (for Route D) at the Slough Road location.

A management plan would also be necessary to address the fate of out-migrating smolt, which may swim downstream of the bypass and into Lake Shastina. Management options could include a range of fish screens and fish deterrents downstream of the bypass entrance, a trap and haul system, or no action. None of these options are certain and a certain percentage of downstream migrating juveniles would be expected to enter Lake Shastina either during high flow events or through upstream canals. Therefore, regulatory implications of anadromous salmonids in Lake Shastina would have to be addressed under any scenario, including MWCD acquiring permits from NMFS to ensure compliance and protection under the Endangered Species Act.

A literature review of fish screen installation projects on similarly scaled streams yielded cost estimates between $185,000 and $2,000,000 or more. Much of the range in cost for fish screens depends on the type of fish screen (e.g., inclined plate, conical, or rotary), the desired level of deterrence, and level of automation. A low head weir (discussed above for regulating flow between the mainstem and diversions) may also serve as the footing for a fish screen. Additional considerations for fish screen installation include: period of diversion, confinement, design flows, design criteria and debris management.

- **Period of Diversion:** Would the fish screen be in place year round? If so, it would require more maintenance and must be constructed to handle sediment and wood transport during big winter storms. If not, maintenance costs may be reduced; however, the potential for winter redistribution of juveniles into the Lake Shastina still exists;
- **Confinement:** Does adequate confinement exist at the point of diversion so that fish are not able to route around the screen?
- **Design Flows:** A fish screen would be constructed to operate over a specific range of flows. Fish ladder design must take into consideration both the estimated peak flows and the range of flows expected during the smolt outmigration period. Juvenile salmon may swim downstream during winter redistribution or be washed downstream during peak winter flow events. Tradeoffs will exist between the range of design flows, construction and maintenance costs, and the efficiency of the fish screen. Figure 14 shows the estimated unimpaired flows at the Edgewood gage between 1959 and 1968. During this time, flows rarely exceeded 200 cfs when smolts were out-migrating (April to July); however, winter flows regularly exceeded 500 cfs with peak events of several thousand cfs. The December 2014 event is estimated at over 2000 cfs in the upper Shasta River above I-5 (McBain Associates unpublished data, 2015). Numerous mainstem and tributary diversions effect the spring and summer flow upstream of Lake Shastina. The total maximum diversions at and above the Edson-Foulke Diversion Dam (Figure 2) in spring and summer of 2013 were approximately 50 cfs (John Clement, personal communication). Figure 15 shows measured flow below the EFDD during the spring and summer of 2013 as well as estimated unimpaired flow over that same period.

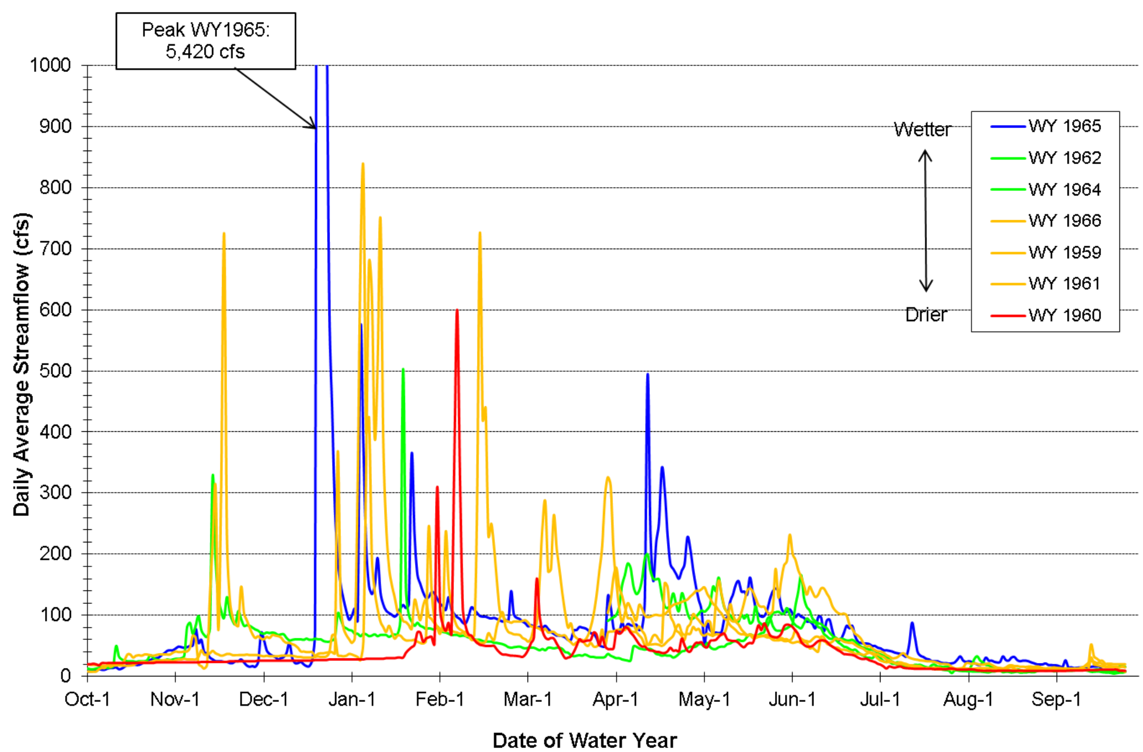

Figure 14. Estimated unimpaired annual hydrographs for the Shasta River at Edgewood, California. Flow estimates are based on Edgewood Gage (USGS 11516750) and Water Master Reports for streamflow in the Edson-Foulke Canal from 1959 to 1967. Does not take into account any diversions upstream of Edson-Foulke.

- **Design Criteria:** CDFW fish screen criteria exist for: structure placement, approach velocity (local velocity perpendicular to the structure face), sweeping velocity (local velocity parallel to the structure face), and screen construction materials and opening.
- **Debris Management:** Methods must be employed to keep the screen and bypass system free of debris, including trash racks, screen cleaning systems, and sediment management.

Ultimately, these considerations would be addressed in a preliminary fish screen design as part of the engineering design for a bypass alternative. A comprehensive review of fish screen cost and comparison was beyond the scope of this study; however a preliminary literature review for similar fish screen projects yielded installed project costs between $250,000 and $2,000,000 with appreciable variability depending on degree of automation, design flows, and debris management.

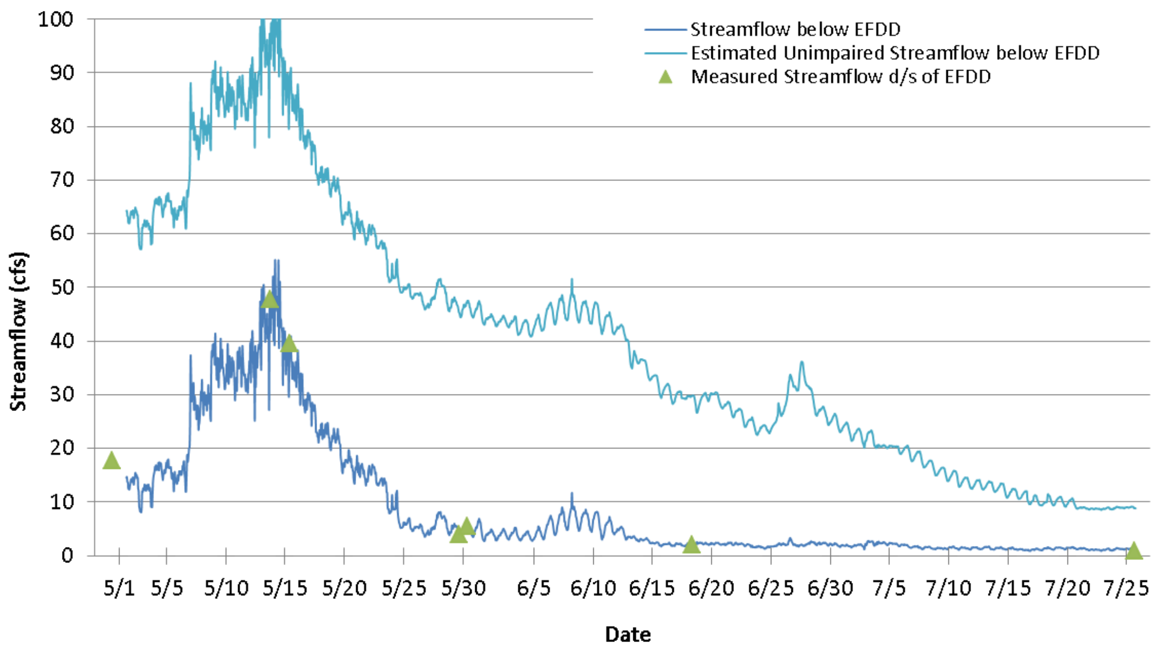

Figure 15. Measured streamflow in the upper Shasta River below the Edson-Foulke Diversion Dam (EFDD) between From May 1 to July 25, 2013, and an estimate of unimpaired flow at the same location. Unimpaired flow is based on: (1) measured flow, (2) Edson-Foulke diversion rates, and (3) an estimate of upstream diversions during spring and summer of 2013.

6 ESTIMATED COSTS

The project cost estimation for this conceptual design utilized a spreadsheet developed by the Trinity River Restoration Program (TRRP) based on actual construction costs for rehabilitation projects implemented on the Trinity River between 2010 and 2012. Cost per unit was provided for the construction materials listed in Section 0. Mobilization and job lay costs were estimated based on cut volumes. Turbidity control was based on volume of placed material and site preparation costs were based on the total job footprint. Costs for project permitting, design (including survey and modeling), and construction management were based on percentage of implementation costs using standard values from TRRP and Tuolumne River Conservancy projects. The primary uncertainties in cost estimations included the fish screen, bypass flow regulation system, permitting and agency coordination, and total project footprint. As discussed, a preliminary literature review for similar fish screen projects yielded installed project costs between $250,000 and $2,000,000. A moderate estimate of $1,000,000 was used for the fish screen cost; however, this may vary significantly depending on management decisions with respect to period of operation, screen type, level of deterrence, and level of automation. In addition, a no screen option or simple deterrence option may be implemented, in which out-migrating smolts are funneled towards the bypass channel. Given the uncertainty around these issues, a total project cost contingency factor of 25% was incorporated. The total project cost contingency is in addition to the 50% contingency for the cut-fill volume estimate, which was built into the unit costs in Table 2. The final cost estimation for the project, including the 25% contingency, is $15.3 million in 2012 U.S. dollars.

Table 2. Conceptual design cost estimate for construction of bypass Route D.

Description	Qty	Unit[a]	Unit Cost	Total
In-Channel Excavation (Dry + Haul)	177,750	cy	$7.00	$1,244,250
Upland / Channel Spoil	177,750	cy	$2.00	$355,500
Gravel Supply (Buy or Process on-site)	6,500	cy	$40.00	$260,000
In-Channel Fill (Placed)	6,500	cy	$20.00	$130,000
Roughened Channel	4,667	LF	$100.00	$466,700
Log/ Boulder Grade Control	25	ea	$1,500.00	$37,500
Log/ Habitat Structure (15 or less Logs)	120	ea	$10,000.00	$1,200,000
Mobilization	177,750	cy	$1.00	$177,750
Job Layout	177,750	cy	$0.25	$44,438
Turbidity Control/ Water Management	6,500	cy	$10.00	$65,000
Harvest & Haul Large Wood	889	ea	$750.00	$666,750
Stockpiled Materials	889	hrs	$650.00	$577,850
Site Prep.	23	ac	$5,000.00	$115,000
Final Site Prep.	23	ac	$1,000.00	$23,000
Contour Grading	23	ac	$1,200.00	$27,600
Riparian Planting	18	ac	$50,000.00	$900,000
Headgate (low flow and high flow)	2	ea	$100,000.00	$200,000
Fish Screen	1	ea	$1,000,000	$1,000,000
Culvert (Mills Rd)	1	ea	$120,000.00	$120,000
Culvert Emmerson Ranch	1	ea	$120,000.00	$120,000
Canal Lining	210,000	ft^2	$4.50	$945,000
Fencing (lower 0.8 miles on Emmerson)	10,000	ft	$8.00	$80,000
			Subtotal	**$8,756,338**
Project Permitting	10% of Implementation Costs			$875,634
Design (survey, modeling, design)	25% of Implementation Costs			$2,189,084
Construction Management	5% of Implementation Costs			$437,817
			Total	$12,258,873
			Total + 25% Contingency	**$15,323,591**

Notes:

1) Mobilization at $1.00/cy for 50,000 cy and greater, and $2.00 /cy for 50,000 cy and under.
2) Job Layout/Surveying at $0.25/cy for 50,000 cy and greater, and $0.50 /cy for 50,000 cy and under.
3) Turbidity Control/Water Management based on the amount of wet excavation & Gravel Placement.
4) Harvest & Haul Large Wood is estimated @ 35 logs per structure & 0.005% of total excavation.
5) Stockpiled Materials is estimated at 0.005% of total excavation.
6) Wet Haul is estimated at 25% of total excavation.

[a]cy = cubic yards, LF = linear feet, hrs = hours, ft = feet, ea = each, ac = acres.

7 DISCUSSION

Sections 4, 5, and 6, provide a review of the physical and biological consideration of route selection, and conceptual design and cost analysis for a preferred route. While these analyses are a fundamental in assessing the feasibility of a bypass channel, there are additional considerations on which feasibility may hinge including: the hydraulic requirements of the bypass, the potential response of focal species, landowner agreements, water rights, and regulatory response. Chapter 7 includes a discussion of these considerations as well as a review of potential auxiliary benefits (both ecological and water management) to the bypass alternative.

7.1 Discussion of Hydraulic Requirements of the Bypass

A primary consideration for the feasibility of a bypass channel is the diversion rates required to operate the bypass. The quantity of flow necessary to successfully pass adult and juvenile fish is based on bypass channel geometry, gradient, and substrate. To some extent, channel design can influence the quantity of flow necessary for a bypass, and tradeoffs exists between the flow required for fish passage, the level of engineering, that natural character of the channel and the cost of design and construction. In any case, a constructed channel for fish passage is designed to provide an hydraulic environment that does not challenge the swimming and leaping abilities of the target fishes at target flows. Criteria for the hydraulic design of roughened channels for adult and juvenile salmonids are provided in CDFG (2002), NOAA (2001), and CDFG (2009). These guidelines used in California include:

- **Minimum Water Depth at the Low Fish Passage Design Flow**
  - Adult steelhead and salmon: 1 ft
  - Juvenile salmonids: 0.5 feet
- **Maximum Cross-Sectional Averaged Water Velocity**
  - Juvenile Salmonids: 1 foot/second
  - Adult Resident Trout: 4 feet /second
  - Adult salmon and steelhead: 6 feet/second
- **Energy Dissipation Factor**
  - Adult Steelhead: 7.0 foot-pounds/second/cubic foot

When a fish passage channel is being proposed, an upper and lower design flow are typically identified based on specific annual streamflow exceedences for the target reach. A channel design is then selected which can provide the hydraulic requirements for fish passage between the upper and lower designs flows, given the physical constraints of the site. In this case, since the bypass channel would not be part of the mainstem Shasta River, and inflow to the bypass channel would presumably be regulated, the design flows for fish passage in the bypass channel may not need to be based on an annual exceedence in the mainstem Shasta River. Rather, the design flow to the bypass channel would likely depend primarily on channel design to meet the hydraulic criteria for fish passage and secondarily on water availability, regulatory constraints, and on the potential auxiliary benefits of additional flow routing into Parks Creek.

The computation of channel design flows would be conducted as part of an engineering design process; however, since streamflow requirements to the bypass are important in the context of feasibility, Manning's equation was used to estimate a preliminary range of flows required to meet the hydraulic requirements for adult and juvenile salmon and steelhead passage. The gradient along the upper ⅓ and lower ⅓ of the bypass channel is less than 1%, with a steeper reach of up to 3% in the mid-section (Figure 8). Providing adequate hydraulic conditions for fish passage will require a less engineered channel in the low gradient reaches but roughness and channel geometry will need to be adjusted in the higher gradient reaches. Fish passage in the higher gradient reach could be provided by installing a boulder-step run or roughened channel design with modified channel geometry. Figure 16 shows a conceptual drawing of the bypass channel with boulder structures to distribute the channel gradient and provide favorable hydraulics for salmonid passage. Table 3 provides an estimate of flow rate, average velocities, channel dimensions and hydraulic characteristics that could meet adult and juvenile salmonid passage criteria along Route D. In an engineering design process, these calculations would be refined using a 1-D or 2-D hydraulic model; however, Table 3 provides a starting point for considering flow allocations necessary to operate the Route D bypass alternative.

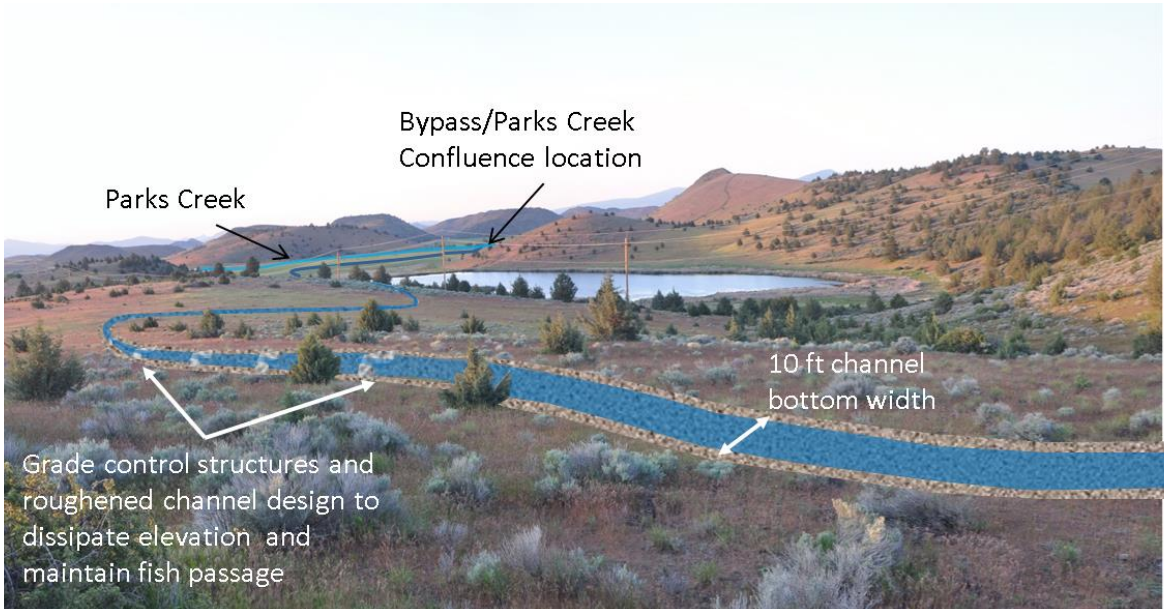

Figure 16. Conceptual drawing of bypass channel from top of Slough Road grade down to Emmerson stock ponds and Parks Creek confluence.

Table 3. Estimated hydraulic characteristics at adult and juvenile passage flows in a trapezoidal bypass channel along Route D.

Hydraulic Characteristics	**Adult Passage**		**Juvenile Passage**	
	Low Gradient	**High Gradient**	**Low Gradient**	**High Gradient**
Depth of Flow (ft)	1	1	0.5	0.5
Bottom Width (ft)	7	5	7	5
Side Slope (H:V)	2:1	2:1	2:1	2:1
Manning's *n*	0.065	0.15	0.065	0.15
Channel Bottom Slope	0.003	0.03	0.003	0.03
Cross-Section Area (ft^2)	9	7	4	3
Wetted Perimeter (ft)	11.5	9.4	9.2	7.2
Hydraulic Radius (ft)	0.78	0.74	0.43	0.41
Velocity (ft/sec)	1.1	1.4	0.72	0.96
Streamflow (cfs)	9.6	9.8	2.9	2.9
Energy Dissipation Factor	0.20	2.63	0.13	1.8

Note that in Table 3 the bottom widths are based on channel geometry after gravel and cobbles are added to the channel, not the excavated 10ft channel width used in the conceptual design and cost estimates.

Using the preliminary flow estimates from Table 3, and life history timings for the focal species, it is possible to estimate the total volumetric requirements to operate the bypass for migrating adult salmon and out-migrating smolts and juveniles. One cfs of diversion for 24 hrs represents 1.98 ac-ft of potential water storage. Operation of the bypass between Sept 15 and April 30 for adult passage (including steelhead kelt out-migration) at a design flow of 10 cfs would therefore require 4,530 ac-ft of storage. Operation of the bypass at 3 cfs for juvenile passage during the rest of the year (May 1–September 14) would require 810 ac-ft of storage. Under this periodicity and flow rate, the total annual water budget to operate the bypass would equal 5,340 ac-ft. It is possible that this volume estimate could be reduced 20% or more by increasing roughness or including designed grade control/fish passage structures in the bypass channel. The primary tradeoffs in the discussion of flow allocation will be between channel design, implementation cost, hydraulic criteria in the bypass channel, and the downstream effects of water from the bypass channel (Section 7.4).

7.2 Biological Response of Focal Species to a Bypass Channel

The ecological implications of a bypass channel between Parks Creek and the upper Shasta River go beyond salmonid passage. Water temperature, nutrients and foodweb dynamics, and non-salmonid fish species including anadromous and resident lamprey would all be affected. In general restoring connectivity is a primary benefit for the ecological health of rivers (Kondolf et al 2006); however, uncertainty exists about how extant populations will adapt to newly accessible habitat. For the purposes of this study, we will address some of primary potential changes for anadromous salmonids.

7.2.1 Spawning Habitat

High quality spawning habitat upstream of Lake Shastina would be attractive to Chinook, coho and steelhead trout. Anadromous spawning habitat above is estimated at approximately 20% of the total available salmon and steelhead spawning habitat Shasta Basin (Cannon 2011). However, the implications of access to this additional spawning habitat may not be the same for all salmonid species. Based on current and projected coho salmon population estimates by CDFW, the quantity of spawning habitat currently available (below Lake Shastina) would likely accommodate current populations and projected future populations of coho (McBain & Trush 2010). However; the streamflows available during spawning season below Dwinnell Dam may not have sufficient magnitude and duration to (1) provide spawning opportunities for a variety of water year types, (2) scour and redeposit spawning gravels between years, and (3) flush fine sediment from pools and spawning gravels (McBain & Trush 2010). The larger magnitude and duration of streamflow during spawning season upstream of Dwinnell Dam could improve spawning success for all salmonid species. In addition, the proximity of upstream spawning destinations to newly accessible cool summer refugia above Lake Shastina could improve the survival of juvenile coho and reduce density dependent pressure on limited summer rearing habitat in Parks Creek and the Shasta River above Parks Creek.

When both fall-run and spring-run Chinook occur in a single mainstem river, the earlier spring run will typically migrate to the upper reaches to spawn while the fall-run Chinook will typically spawn in the lower mainstem (Lestelle 2012). However, fall-run Chinook salmon are expected to benefit from additional upstream spawning habitat, particularly during high escapement years when coarse sediment storage may be limiting Chinook salmon fry production in the lower Shasta River due to superimposition losses (McBain & Trush 2010). Lestelle (2012) noted that the mainstem Shasta and several spring-fed tributaries were likely the “core spawning areas of the historic spring

Chinook population", as well as an important spawning area for coho, besides providing both summer and winter rearing habitat. Of the extant salmonid runs, winter steelhead may be the species likely to benefit the most from access to upstream spawning habitat, particularly higher gradient reaches where adult Chinook and coho are less likely to access (due to their preference for lower gradient spawning habitat). The year round cool flows in the Shasta headwaters and the higher gradient reaches are typical of steelhead spawning and rearing habitat, and a robust population of resident *O. mykiss* currently occurs in the upper watershed.

7.2.1 Juvenile Rearing

Late spring and summer water temperatures in the Shasta Basin are considered by many to be the primary factor limiting the recovery of most salmonid populations and particularly coho salmon (Chesney et al. 2009, Jeffres et al. 2008; Jeffres et al. 2009; NRC, 2004 cited in Nichols et al. 2013). The Shasta River exhibits hybridized characteristics of both "spring-dominated" and "rainfall/snowmelt runoff-dominated" rivers, (Jeffers at el. 2008) and this is still true in the upper basin. While the mainstem upper Shasta River lacks the abundant emergent macrophytes and classical spring fed geomorphic characteristics of the Shasta River below Big Springs Creek, it still displays a consistent spring-driven summer baseflow which provides the cold yet productive aquatic environment in which salmonids thrive.

To date, a primary assumption has been that low flows and high water temperatures below water diversions in the upper Shasta Basin are a key constraint on juvenile rearing habitat (Cannon 2011), and may limit the value of upstream passage. While summer water temperatures are expected to be warm in the mainstem river above Lake Shastina, measured water temperatures up to ½ mile downstream from the Edson-Foulke diversion (above I-5) have remained surprisingly cool even under highly modified flow regimes and during dry water years (Figure 17).

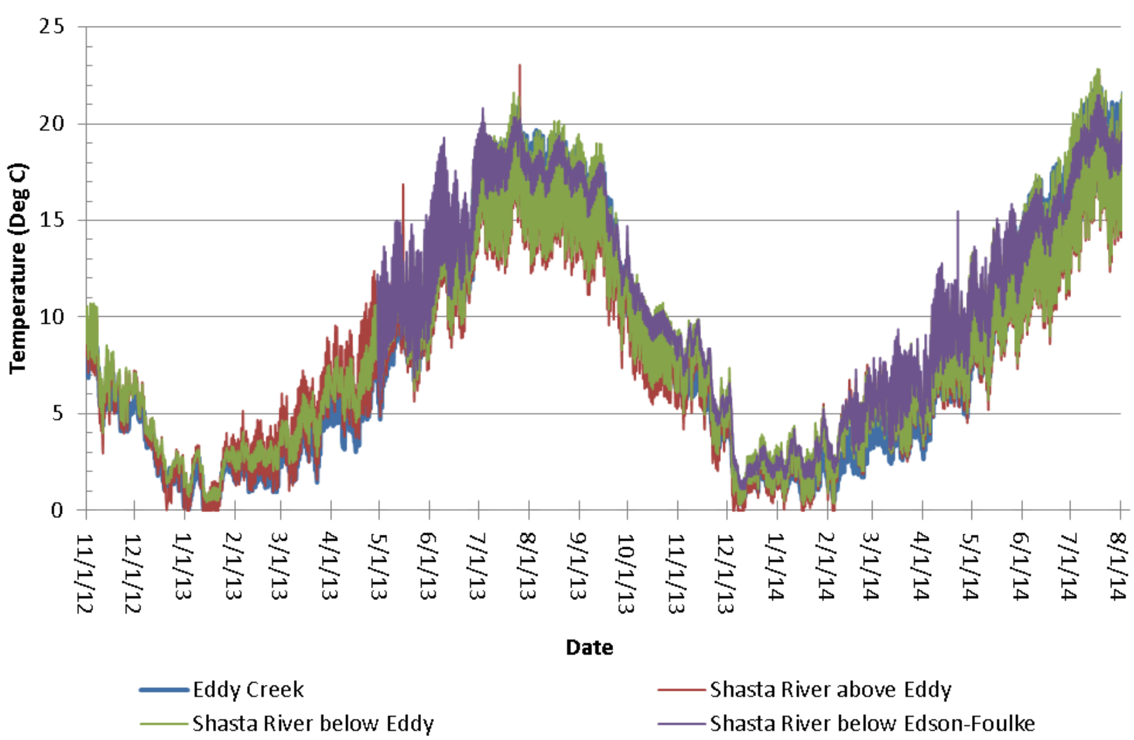

Figure 17. Hourly water temperature in Eddy Creek, Shasta River above Eddy Creek, Shasta River below Eddy Creek and Shasta River 1500 ft below Edson-Foulke Dam.

For example, although summer streamflows downstream of the Edson-Foulke diversion are typically less than 1-2 cfs, streamflow is frequently disconnected, and summer air temperatures exceed 90 F (32.2 C$^{\circ}$), measured hourly water temperatures in the Shasta River below the Edson-Foulke diversion between May 1st and October 31st of 2013 and 2014, only exceeded 20 C$^{\circ}$ 2% of the time, exceeded 18 C$^{\circ}$ 19% of the time, and 16 C$^{\circ}$ 39% of the time. Considering that 2014 was a record low flow year with warm summer water conditions throughout the Shasta Basin, the thermographs in Figure 17 indicate that mainstem thermal conditions occur in the parts of the Shasta River which are adequate for rearing juvenile salmonids during most years.

Regardless of the cool mainstem water temperatures in the Shasta River upstream of I-5, some increase in summer baseflow (see Figure 15) would be necessary to provide juvenile passage, extend the range of good thermal conditions, and improve rearing and smolt outmigration habitat for juvenile salmonids below diversions (McBain Associates unpublished data, 2015). Figure 18 shows hydraulic disconnection at a critical riffle downstream of a primary diversion on the upper Shasta River during late summer of 2014. Based on the results in Table 3, and the hydrographs shown in Figure 15, some increase in summer flows would also be necessary to operate a bypass channel. Although the flow estimates from Table 3 are preliminary, increasing summer baseflows in the upper Shasta River to supply a bypass channel would simultaneously improve juvenile rearing habitat and likely extend the length of good thermal conditions from upstream sources by increasing the thermal mass of cold water and reducing the rate of warming. In addition, increases in summer baseflow create opportunity for additional ecological and water management benefits in Parks Creek and the Shasta River below Parks Creek (Section 7.4).

Figure 18. Disconnected pools and dry riffles on 8/15/14. Shasta River 2700 ft (0.52 mi) downstream of a major diversion. Measured streamflows less than 1 cfs tend to produce reaches of disconnectivity and subsurface flow even with contributions of baseflow and groundwater in this reach; however, water temperatures remained cool, even in isolated pools.

Spring-fed tributaries to the upper Shasta River such as Carrick, Beaughton, and Boles creeks provide cool and high-quality water, yet numerous active diversions may reduce the capacity for summer rearing in these streams. Carrick Creek is downstream of Route D and so anadromous salmonids would not be expected to access Carrick Creek under this conceptual design. A key uncertainty for Boles Creek and Beaughton Creek is whether existing management, crossings and impoundments would allow for summer rearing opportunities in these streams. According to Cannon (2011), there are 21 summer diversions on Beaughton Creek and associated springs with a total diversion rate of 10 cfs and 30 active diversions located on Boles Creek and numerous associated springs with a total summer diversion rate of 18 cfs. Eddy and Dale Creek in the Shasta headwaters (Figure 1) provide cool, snowmelt driven baseflows and higher summer flows since they are upstream of most larger diversions (one large diversion exists on Eddy Creek). In the NMFS Coho recovery plan, Dale Creek was given a high Intrinsic Potential value for coho rearing (>0.66 in William et al 2006) and the riparian cover and stream corridor is considered in good condition in Shasta Headwater tributaries (NMFS 2014a).

Another uncertainty that must be addressed is whether juvenile coho and steelhead would migrate upstream from the high value spawning destinations in Figure 3 and even below the bypass in Parks Creek, to Shasta River headwater tributaries such as Dale and Eddy Creek. Resident rainbow trout are distributed throughout these reaches and hydraulic conditions for trout passage occur upstream of I-5 during the spring and early summer (McBain Associates unpublished data, 2015). Lestelle (2012) notes two periods of juvenile coho redistribution in the Shasta, one in the summer when mainstem temperatures exceed 19 C$^{\circ}$ and juveniles seek cooler refugia, and another in fall and early winter, covering much longer distances, when juvenile coho seek suitable, lower velocity overwintering habitat (Lestelle 2012). In addition, personal communications with CDFW staff indicate that juvenile coho have been observed traveling long distances to seek out cool summer refugia in the lower Shasta River (Chris Adams, CDFW, personal communication, 2015). If fish passage conditions above Lake Shastina were met during seasonal redistribution (winter and spring) it is a reasonable assumption that juvenile coho and certainly steelhead would migrate from high quality spawning habitat (upstream of Lake Shastina) to spring-fed tributaries or the upper mainstem and Shasta River headwater tributaries. However, if the hydraulic requirements for juvenile passage to cold water tributaries or upper mainstem reaches is not met, there is a risk of stranding juveniles in the reach directly above Lake Shastina or in the Bypass itself where summer water temperatures may become stressful to juvenile rearing. A complete survey of passage impediments to juvenile salmonids along the upper Shasta River has not been accomplished; however, a fish ladder was installed in 2011 at the site of Edson-Foulke Diversion and an ongoing study by CDFW staff and McBain Associates has been evaluating the efficiency of the ladder.

7.2.1 Life History Tactics and Population Resilience

For all life stages, a primary benefit of access to additional upstream habitat is the increased population resilience associated with a wider array of life history tactics (LHTs) for the Shasta River salmonid population (McBain Associates 2009). A life history tactic (LHT) is a unique pathway in space and time that an annual salmonid cohort follows through successive life stages: adult migration, spawning and egg incubation, early fry emergence, juvenile rearing, and smolt outmigration. Healy (2009) says of pacific salmonids that “the capacity of the species to respond to environmental variation by producing different phenotypes with different yet successful reproductive tactics is one of the species’ great adaptive strengths.” By providing access to additional spawning, and particularly juvenile rearing habitat on the upper Shasta River, many new life history tactics for Shasta salmon and steelhead populations are added to the current portfolio of LHTs. How much these new LHTs will increase population resilience is difficult to quantify, but given the effects of a changing climate and streamflow regulation in the Shasta Basin, increased population resilience is a primary management concern for the recovery of native salmonids.

7.3 Constraints to a Bypass Alternative

There are several constraints and uncertainties which affect the feasibility of a bypass option including: (1) streamflow availability, (2) land-owner agreements and permitting, and (3) implications for MWCD water rights, and the Settlement process. Below we briefly outline these constraints and discuss potential steps to address them.

7.3.1 Streamflow Availability

As discussed in Section 7.2.1, summer and early fall instream flows in the Shasta River may not be adequate, particularly in drier water years, to meet the streamflow requirements of a bypass diversion or to provide the hydraulic conditions for juvenile rearing habitat. Under the current water adjudication, new water rights are probably not available to support additional flow. According Cannon (2011), there are 67 water diversions on the upper mainstem Shasta River and headwater forks of the Shasta River, upstream of Dwinnell Reservoir. Not including diversions on Boles, Beaughton and Carrick Creeks, the total the total summer (March 1 – November 1) diversion allocations in the upper Shasta Basin amount to112 cfs, while permitted winter (November 1 – March 1) diversions are 19 cfs. Total maximum diversions at and above the Edson-Foulke Diversion (Figure 2) in spring and summer of 2013 were approximately 50 cfs (John Clement, personal communication, 2013).

Without readjudication of water rights, the potential sources of instream flows to operate a bypass channel could include changing the point of diversion for MWCDs environmental flow commitments (see discussion in 7.3.3 below) and efficiency improvements in the larger upstream diversion canals, most of which are unlined and experience flow loss to infiltration. Efficiency improvements in upstream diversion canals would likely require a negotiated process between property owners, water rights holder and resource agencies and could involve a 1707 agreement. While lining diversion canals is an expensive undertaking (we estimated conservative price of \$4.50 per ft^2 for lining canals with bentonite clay in Table 2), the current drought climate, and funding water management and fisheries (e.g. California Proposition 1), may provide the right economic incentive to fund such efficiency improvements and to negotiate some instream flow dedication for the recovered flows. Without additional instream flow dedication from any source, the bypass may still be able to provide opportunistic juvenile passage and adult passage between Parks Creek and the Shasta river, but summer rearing habitat would be limited particularly in the mainstem Shasta River and opportunity for juveniles to migrate from the bypass to upstream cold water refugia is uncertain.

7.3.2 Uncertain Land-Owner Agreements for Property Access to Build Canal

The bypass route evaluated in this report (Route D) would require constructing a canal on private property. Two primary ranching operations would be effected, Mills Ranch and Emmerson Big Springs Ranch. The incentives and constraints for land-owner cooperation must be fully evaluated and land-owner participation is fundamental to the bypass alternative. Potential invectives could include: issuance of ESA permits to protect landowners from incidental take due to operation of the bypass, improvements to roads and culverts adjacent to the bypass canal, other landowner protections in the context of ongoing programs (such as NMFS Drought Initiative Agreement or the Safe Harbor process), and monetary incentives. At the end of the day, agreements would have to be reached between land-owners and regulatory agencies for the bypass project to be implemented. This is perhaps the primary hurdle to the bypass alternative.

7.3.3 Implications for MWCD Water Rights and the Settlement Process

Under current operations, MWCD can release streamflow from their conveyance canal to the Shasta River downstream of Dwinnell Dam. As part of the Karuk-MWCD Settlement (Section V) the settlement parties are to meet with resource agencies (CDFW and NMFS) to develop a series of releases of "Environmental Water" and to identify the condition of water for environmental purposes (USDC 2013). It is uncertain how the bypass concept could affect MWCDs future operations within these agency processes. A key concept for the bypass is whether MWCD could simply change their point of streamflow dedication from the current locations (canal below

Dwinnell) to a bypass channel upstream of Lake Shastina for some portion of their future instream flow dedication. This could allow some water that is diverted through the MWCD Parks Creek Canal to flow back into Parks Creek via the bypass channel. Even if some or all of MWCD's environmental flow commitments are transferred to the bypass, the implications of reduced flow in the Shasta River between Dwinnell Dam and Parks Creek must be considered (see Section 7.4 below). The bypass flow requirements must also be weighed against the objectives of environmental flow releases. For example, the timing, magnitude, duration and frequency of flow to meet the environmental objectives of the Settlement may not be the same as instream flows required for bypass operation. However, some synthesis of these flows is likely possible particularly due to fishery and ecological benefits associates with increased baseflow to Parks Creek and the Shasta River below Parks Creek.

7.4 Auxiliary Benefits

Besides achieving anadromous fish passage above Dwinnell Dam, the operation of a bypass channel could provide a number of direct or potential ecological and water management benefits, primarily associated with increased baseflow to Parks Creek and the Shasta River below Parks Creek. These include direct improvements to passage and juvenile rearing conditions, opportunity for improved diversion management, potential for increased efficiency in water delivery and improved summer rearing conditions below Dwinnell Dam.

7.4.1 Direct Ecological Benefits to Parks Creek and the Shasta River below Parks Creek.

In Parks Creek, as in most of the Shasta Basin, late spring and summer water temperatures are the primary factor limiting salmonid recovery (McBain & Trush 2012a). The NMFS 2014 Shasta River/Parks Creek Drought Initiative identified a primary objective of providing fish passage flows in Parks Creek to allow fry and juvenile coho salmon to move into thermal refugia habitats which remain cold during the late summer months (NMFS 2014b). The operation of a bypass channel would extend the duration of good passage conditions for juvenile salmonids in Parks Creek during the spring and summer months and improve connectivity to spring sources. In addition, increased baseflow between mid-spring and early summer would likely improve the productive capacity of mainstem Parks Creek and the Shasta River below Parks Creek promoting successful smolt outmigration, and extending range of late spring early summer rearing (McBain & Trush 2012a).

7.4.2 Increased Flow Reliability and Opportunity for Improved Diversion Management

Besides the direct ecological benefits of increased baseflow to Parks Creek, the opportunity for improved water management also increases with the operation of a bypass channel. Water transactions and changing points of diversion have been implemented as a means to protect cold water spring sources for over summering refugia in the Shasta (Willis et al. 2015, NMFS 2014b). Currently, spring sources in Parks Creek and the Shasta River below Parks Creek have been developed for agricultural diversions since the provide steady year round flow conditions. Increased baseflow in mainstem reaches would improve the year round reliability of mainstem points of diversion (PODs), making viable option for agricultural diversions (as opposed to existing spring-based PODs) than in the past. Shifting PODs to mainstem locations could protect vital spring based refugia for summer rearing habitat. In addition, the bypass would provide an opportunity for pre-summer or winter re-distribution of juvenile coho and steelhead to upstream cold water refugia which could reduce density depend pressure in the limited spring fed summer refugia locations upstream of Big Springs Creek.

7.4.3 Reducing Summer Releases from Dwinnell Dam to the Shasta River

In the mainstem Shasta River below Dwinnell Dam, priority reaches for over-summer juvenile rearing habitat are from Clear Springs downstream past the confluence with Big Springs Creek. Summer time streamflow releases from the MWCD canal into the upper Shasta River may be detrimental to summer refugia if water temperature in the Lake Shastina and the MWCD canal are too warm (McBain & Trush 2012a). Lake Shastina exhibits seasonal thermal stratification patterns and typically the months of June, July, and August are strongly stratified with surface temperatures exceeding 20 C° (Vignola and Deas 2005). If favorable temperature conditions cannot be maintained above Clear Springs due to warm-water releases occurring from Dwinnell Dam, then a high priority would be to prevent warm-water releases from adversely affecting cold water flowing into the mainstem from Clear Springs (McBain & Trush 2012a). By reducing the summer time environmental flow releases below Dwinnell Dam, summer refugia in this reach (particularly Clear Springs) may be improved. However a tradeoff exists between improving summer thermal refugia and reducing habitat area. McBain & Trush (2012a) identified 6 cfs as an interim instream flow requirement to provide good juvenile rearing habitat in this reach. While spring sources in this reach (Rogenbuck, Hidden Valley and Clear Springs) may provide baseflow, existing diversions and water rights reduce the contribution of these spring flows to the mainstem. The potential opportunity for water transactions (e.g. between MWCD canal and spring sources) in this reach may be reduced if some quantity of MWCDs environmental flow releases are routed through the bypass.

7.4.4 Reducing Flow Losses Due to Seepage and Evaporation in Lake Shastina

The bypass channel described in this conceptual design would be lined to reduce infiltration losses (see Section 5 and Table 2). By routing some portion of the environmental flow releases around Lake Shastina to a lined, upstream bypass channel, seepage and evaporation losses in Lake Shastina may be reduced. Accurate and current seepage and evaporation losses were not identified in this report, but Vignola and Deas (2005) cited estimated seepage and evaporation loss from DWR Watermaster service records in the range of 6,500 acre feet and possibly much higher, largely as a function of storage (i.e. losses increase with increased reservoir storage). If the operation of a bypass channel reduced the storage volume and storage time of environmental flows in Lake Shastina, some reduction on seepage and evaporation losses would be expected. The environmental effects of this reduced seepage are difficult to quantify as seepage from Lake Shastina may support some spring sources which provide thermal refugia. Connectivity between Lake Shastina seepage and spring sources is not well understood at this time.

8 DISCUSSION OF FEASIBILITY

As described in Section 2, the purpose of this study is to expand upon the existing body of work to provide a more detailed analysis of the opportunities, constraints, and feasibility associated with a fish bypass via a constructed channel connecting Parks Creek to the Shasta River above Lake Shastina. This report attempts to formalize the variables, known and unknown quantities, and constraints and benefits of a potential bypass channel. In addition, this report attempts to use quantifiable terms, volume and costs estimates which can serve as the basis for analyzing feasibility. Feasibility must ultimately be determined by the settlement parties, funding parties, resource agencies, and land-owners who would be involved in the construction, management, and permitting of a by-pass channel. However, based on the information analysis, the feasibility of specific elements of a bypass channel can be discussed in more detail. Below we synthesize the information in this report to discuss the feasibility of five elements of a constructed bypass channel connecting Parks Creek to the Shasta River above Dwinnell Dam: (1) construction, design and engineering; (2) cost; (3) water availability; (4) land owner agreements; and, (5) biological response.

8.1 Construction, Design and Engineering

Based on the route selection, topographic, and conceptual design process described in Sections 4 and 5, at least two routes exist which provide reasonably favorable topography for a bypass channel flowing from the Shasta River to Parks Creek. Routes C and D (Section 4) both provided reasonable design gradients and the required earthworks for channel construction, though large, were within the range of several funded and constructed channel restoration projects on the Tuolumne and Trinity Rivers (McBain & Trush 2000; TRRP 2010). Neither Route required an underpass on the I-5, or bypassed areas with known sensitive infrastructure. Adequate space appears to exist for the staging and management of construction materials. Based on topography and the conceptual design in Section 5, the design construction of a bypass channel which meets state and federal fish passage criteria is not expected to require exceptional measures or methods such as concrete ladders and engineered/concrete grade control structures. The entrance conditions can be managed using a range of headgate designs and technology, but at a basic level, would not require anything more sophisticated than the existing flow control methods currently used by Watermasters throughout the Shasta Basin. Given these considerations, the construction, design, and engineering of bypass channel between the Shasta River and Parks Creek is considered feasible.

8.2 Cost

Section 6 provides a cost estimation for the permitting, design, and construction of a bypass channel based on actual construction costs for rehabilitation projects implemented on the Trinity River between 2010 and 2012. This cost estimation included all the elements of permitting, design, and construction discussed in Section 5, with the acknowledgment of key uncertainties about fish screening, bypass flow regulation system, agency coordination, and total project footprint. A number of contingencies were included to address these uncertainties and, in our research and literature review, we typically chose the more conservative costs estimate for most design and construction features. Operation and maintenance costs were not included in this analysis. The estimated total design, permitting and construction cost for this project was $15.3 million dollars, including contingencies for uncertainty. Ultimately the economic feasibility of this budget is based on how funding parties evaluate the projects value and ability meeting their social and environmental goals. However, given the funding available for river and salmon restoration in California the project cost is not unprecedented or unrealistic. Proposition 1 in California established approximate $1.5 billion to fund competitive grants for watershed, lake, and stream restoration. In addition NMFS Coho Recovery cost estimates for the Scott and Shasta exceed $3.5 billion.

8.3 Water Availability

Under existing water management conditions, instream flows in the upper Shasta River are not adequate to continuously operate a bypass channel at the diversion rates estimated in Table 3. Diversions from the existing adjudicated water rights in the upper Shasta Basin exceed the unimpaired summer streamflow in most water years. Without a readjudication of water rights, the primary sources of instream flows to operate the bypass could include (1) changing the point of diversion for MWCDs environmental flow commitments to the bypass channel and (2) efficiency improvements in the larger upstream diversion canals, coupled with 1707 dedications. As with landowner agreements, these types of transactions will require a cooperative solution, water transaction, or settlement of some kind. The feasibility of routing some or all of MWCD environmental flow commitments through the bypass channel depends largely on interactions between the settlement parties and resource agencies. While the water supply needed to operate the bypass could likely be acquired through a combination of these measures, the feasibility of agreements necessary to supply instream flows for the bypass cannot be determined in this report.

8.4 Land Owner Agreements

Both of the viable bypass channel routes discussed in Section 4 would require constructing some portion of the channel on private property. As with water availability, land owner agreements to construct and operate a bypass channel depend on interactions between land-owners, regulatory agencies, and funding partners. While potential incentives exists for regulatory agencies (increased likelihood of achieving salmonid restoration goals) and landowners (ESA permits and liability protection, infrastructure improvements, monetary incentives) the feasibility of agreements between land-owners, regulatory agencies, and funding parties cannot be determined at this time.

8.5 Biological Response

The operation of a bypass channel would represent a change in the current ecological makeup of the upper Shasta Basin. In addition to passage for anadromous salmonids to the upper basin, water temperature, nutrients and foodweb dynamics, and non-salmonid fish species including anadromous and resident lamprey would all be affected. From the perspective of salmonid species, Chinook, coho, and steelhead have been shown to readily colonize newly accessible habitat, (Anderson et al. 2014; Anderson and Quinn 2007). Podlech (2009) estimates that 27 miles of suitable coho habitat would be accessible above Lake Shastina with only 10.6 miles of habitat available in 2009 due to "known significant barriers." Since 2009 installation of a fish ladder in the upper watershed added over five miles of potential access to cold headwater tributaries (including Dale and Eddy Creek). Cannon (2011) estimated: "12 miles of accessible habitats to salmon and steelhead above Dwinnell Dam in the mainstem Shasta River, plus a similar amount in tributary creeks." Regardless of the exact number of miles, the potential habitat represents a large quantity of rearing habitat compared to the 6 miles of mainstem river between Dwinnell Dam and Big Springs Creek and the roughly 6 miles of habitat in Parks Creek downstream of I-5.

Instream flows for salmonid spawning in the reach above Lake Shastina will have a larger magnitude and duration than key downstream spawning destinations identified by Jeffres et al. (2008, 2010) and Chesney et al. (2009) due to operation of Dwinnell Dam. Some uncertainty exists as to: (1) whether juvenile coho and steelhead can migrate to the Shasta headwater tributaries such as Dale and Eddy Creek, and (2) how much access to suitable habitat exists in the cold, spring fed tributaries (e.g. Beaughton, and Boles Creeks). Podlech estimated that 4 miles habitat was available in the Beaughton Creek watershed and 0.5 miles in Boles Creek. However, even under the most conservative scenario mainstem water temperatures at mainstem locations above I-5 are within the acceptable range for rearing salmonids (Figure 17) under existing conditions and increased flows (for operation of the bypass) would likely improve both thermal and hydraulic habitat for rearing salmonids.

In addition, operation of a bypass channel would extend the duration of good passage conditions for juvenile salmonids in Parks Creek during the spring and summer months, improving connectivity to spring sources and increasing productive capacity of mainstem Parks Creek and the Shasta River below Parks Creek. Given the above considerations, it is reasonable to expect the operation of a bypass channel could play a key role in restoring the Shasta River coho and steelhead populations, and a supporting role in maintenance of the fall-run Chinook, by increasing the quantity and quality of spawning and rearing habitat, particularly over-summering habitat for coho and steelhead, and by providing an opportunity for new life history tactics to emerge for anadromous salmonids in the upper Shasta River.

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APPENDIX A

The draft study plan for this assessment was sent to Karuk Tribe and MWCD for review and comments on 10-16-2014. Comments were received and a response to comments was prepared. The final study plan was modified based on MWCD and Karuk tribe comments. The comments and response to comments on the study plan are included below. A draft of the final report was provided to Karuk Tribe and MWCD for review and comments on May 22, 2015. Written comments were not received.

Comments and Response to Comments from the October 2014 Study Plan

Craig Tucker Comment #1: Do we really want to exclude Springer's?

MA Response: In terms of quantifying hydraulic conditions in the bypass channel (relationship between channel geometry, sediment, and flow magnitude), the passage criteria for adult spring-run chinook will not be different from fall-run. So we will evaluate the magnitude of flow needed to pass both spring-run and fall-run chinook. In evaluating management options for spring run chinook, the key questions are – where would adult spring-run Chinook hold in the Shasta Basin (including the upper reaches above Lake Shastina), and when would they migrate to the upper river? If the adults held in the lower river, and migrated up through the bypass in early fall – that strategy would require the bypass to operate in a similar way as for fall-run chinook (although perhaps allowing passage several weeks earlier). However, if the adults immediately migrated to the upper river and held throughout the summer above Lake Shastina, then adult passage in the bypass channel would be necessary throughout the late spring and early summer. Therefore, since we aren't really sure what the primary spring-run life history tactic was in the upper Shasta River, and since the upper mainstem Shasta river doesn't currently have many (any?) good adult spring run holding pools, we prioritized the fall and winter-run salmonid species, but will include a brief discussion about the implications of managing the diversion for different spring-run life history tactics.

Craig Tucker Comment #2: I don't think you need to evaluate this in the context of the flow schedule described by agreement since it's an interim flow requirement pending MWCD getting ESA permits for implementation of their CHERP…so we don't know what the flow requirements will be in the future and the settlement flows may not be relevant…make sense?

MA Response: Point taken. We will evaluate the hydraulic and hydrologic requirements of the bypass, and include a general discussion of how existing water allocations could effect and be effected by those requirements.

Gary Black Comment #1: Focusing only on the draft work product scope, is this an alternatives analysis yielding a preferred design for implementation/construction OR a design to be placed against a feasibility analysis?

MA Response: Originally we had intended to provide a broad evaluation of strategies for anadromous fish passage past Lake Shastina to the Upper Shasta River – comparing the opportunities and constrains of various methods including fish ladders, trap and haul, and fish bypass. However, after reading Podlech et al. (2009) and Cannon (2011) we realized that much of the work towards a broad, comparative analysis was already completed. Given the content of the existing reports that have been prepared on this topic, we chose to focus on conceptual designs and a more detailed analysis of the bypass channel alternative (for the reasons mentioned page 3 PP 2 on the study plan).

The product we are envisioning from this analysis is a technical report that provides:

1. A comparative analysis of various bypass routes,
2. Greater resolution on the physical, biological, economic, and community/landowner based opportunities and constraints for one or more preferred routes. This will involve the bullet points listed under the "Study Plan" heading on page 5 of the draft I sent to you.
3. A discussion and recommendation on the "infeasibility" of the bypass alternative.

The Settlement doesn't define feasibility of a bypass alternative; rather it defines infeasibility, primarily as a function of land access, water rights, bypass function, costs, and cooperation with local landowners. We will structure this report to try and provide enough information so that the settlement parties can determine whether the bypass options we are evaluating are infeasible or not based on the definition in the Settlement. In addition to that, we'd like to address some of the opportunities and constraints not mentioned in the settlement for example: (1) fish screens and regulatory constraints/opportunities with respect to anadromous fish potentially entering the reservoir and (2) biological opportunities and constrains with respect to upstream spawning and rearing opportunities.

Page 28 and 29 of the settlement also addresses how the parties can coordinate with respect to resolution of feasibility. We hope that this document will inform that coordination and provide adequate information for all parties to make determinations.

Gary Black Comment #2: Walk me through which one comes first in your views (design or feasibility... or is simultaneous)? Who gets to determine feasibility??? Especially recognizing differences between biological and construction feasibility. This product does not really address the difference between biological and construction but it needs to be addressed.

Based on how the settlement described infeasibility, it seems to me that the design issues of land access, water rights, bypass function, costs, and cooperation with local landowners need to be addressed first, and then the settlement parties can then make their own determinations on whether the preferred bypass alternative is infeasible. Page 28-29 of the settlement doesn't appear to mention biological feasibility, but I agree that it should be addressed in this assessment, and that has been our intent (see bullet 9 on page 5 of the study plan). We hope to provide information in this analysis, specifically about biological feasibility and regulatory constraints which are not explicitly mentioned in the Settlements discussion of infeasibility in Page 28.

Gary Black Comment #3: What is your timeline for completion of this product?

Our proposed timeline is as follows:

Develop Study Plan and incorporate Karuk and MWCD comments	– October 31, 2014
Conduct Conceptual Design and Feasibility Analysis	– January 31, 2015
Presentation and Solicitation of Comments	– February, 2015
Produce a draft report (including feedback)	– March 13, 2015
Receive Additional Comments	– March 20, 2015
Produce Final Report with Response to Comments	– March 31, 2015

Gary Black Comment #4: I am assuming this investigation is for bypass only? Please confirm.

Yes.

Gary Black Comment #5: Gabe, per our conversation, methods to move emigrating fish to the by-pass channel needs to be part of your design scope.

At this point, the bypass alternatives we are investigating will be based volitional access for upstream migrating adults; however, a fish screen and guidance would be necessary to avoid downstream migrating juveniles swimming into Dwinnell Reservoir. Whether or not a fish screen can operate effectively over the range of flows that occur during smolt outmigration is uncertain and we will provide some investigation and discussion of this issue including literature review of similarly scaled projects and costs. We will also include a discussion of the potential issues associated with anadromous entering into the Dwinnell Reservoir.

Gary Black Comment #6: Gabe, we also touched briefly on community involvement. Provide more thought on that.

As mentioned above, some of the main components to determine infeasibility are land access, water rights considerations, and cooperation with local landowners. All of these will require an effort to communicate the requirements, physical structure, and function of the bypass alternative, as well as the results of our feasibility analysis, with landowners who could directly participate or be affected by this project. We plan to do this in two ways. First, we would invite landowners to a presentation in which we would describe the study plan context, the potential bypass routes, and then more detail about the preferred route, tradeoffs and feasibility analysis. After we gave this presentation, we would solicit verbal feedback, as well as accept written feedback if folks preferred that. We would incorporate landowner feedback into the draft report, as described in the study plan. After we complete the draft report, we plan send it to Karuk Tribe, MWCD, and other interested parties, included any landowners who request it. Folks can than comment on this report and we can address comments and complete a response to comments, which we will include as an addendum in the final report.

As a final note on this, our budget for this project is limited, and therefore we cannot guarantee to address an unlimited number of comments. We will prioritize our response to comments to Karuk and MWCD (first), landowners who own property which the preferred bypass would cross (second), and other interested parties (third).

8-7-2015: NOTE – McBain Associates presented the findings of the conceptual design and feasibility assessment (from this report) to Karuk Tribe and MWCD on February 17, 2015. At that meeting, it was requested that we not present this information to the public until MWCD and others were able to review the study in light of ongoing management and regulatory processes.