Basis of Design Report for the

Upper Tryon Creek Stream Enhancement Design Project

Smith River, California

July 10, 2020

Prepared for:

SMITH RIVER ALLIANCE

California Department of Fish and Wildlife
Fisheries restoration Grant Program (FRGP Agreement No. P1810510)

Prepared by:

Michael Love & Associates
Hydrologic Solutions
PO Box 4477 • Arcata, CA 95518 • (707) 822-2411

Basis of Design Report for the

Upper Tryon Creek Stream Enhancement Design Project

Smith River, California

Prepared for:

Smith River Alliance
California Department of Fish and Wildlife (FRGP Agreement No. P1810510)

Prepared by:

Rachel Shea, P.E.
Engineering Geomorphologist
License No. C72614
Michael Love & Associates, Inc.
shea@h2odesigns.com • (707) 822-2411 x3

Michael Love P.E.
Principal Engineer
License No. C71681
Michael Love & Associates, Inc.
mlove@h2odesigns.com • (707) 822-2411 x1

Ryley Tauzer, E.I.T.
Staff Engineer
Michael Love & Associates, Inc.
rtauzer@h2odesigns.com • (707) 822-2411 x4

July 10, 2020

Cover photo: Tryon Creek Upstream of Lake Earl Drive (January 2020)

Table of Contents

Appendices

1 INTRODUCTION

1.1 Purpose of Report

The purpose of this Basis of Design Report (BODR) is to present the analyses and decisions supporting the design for restoring and enhancing 4,400 feet of Upper Tryon Creek stream channel. The enhancements were developed using a reference-reach based natural channel design approach, and includes restoring the historical meanders in the stream channel, eliminating existing earthen berms on the floodplain, creating multiple backwater alcoves, installing large wood structures, and creating a fenced 85-foot wide riparian area along the length of the restored channel.

This report also provides design information for a new 50-foot span prefabricated agricultural bridge crossing and an NRCS-style low-water agricultural stream crossing. These two crossings will replace three existing low-water stream crossings. Design plans for the project are included in Appendix A.

1.2 Project Area

Palmer Westbrook Inc. owns pasture along a 4,400-foot long reach of upper Tryon Creek, near the town of Fort Dick, which is primarily used for cattle grazing. The Smith River Alliance (SRA), working the landowner, USDA-Natural Resources Conservation Service (NRCS), and the Del Norte County Resource Conservation District (RCD), have secured funding from the California Department of Fish and Wildlife (CDFW) Fisheries Restoration Grants Program (FRGP Grant Agreement No. P1810510) to develop restoration designs for this reach of Tryon Creek. The stream within the project area crosses under Lake Earl Drive, with approximately 3,000 feet of channel downstream and 1,400 feet upstream of the road crossing (Figure 1-1). Highway 101 is located about 800 feet upstream of the project area.

The project reach, in its current condition, is highly degraded. The channel is ditched and relatively featureless, with sections choked with debris and invasive Himalayan blackberry. Livestock have full access to the stream and there is a lack of riparian vegetation over approximately 70% of the project length. Much of the channel has been ditched, eliminating the once sinuous planform and resulting channel complexity.

There are three low-water livestock crossings consisting of small undersized culverts that are problematic for conveyance of flow, sediment, and debris. Upstream of these crossings is aggraded fine sediment.

Although the reach does not contain any obvious patches of invasive reed canary grass (RCG), it is present in the adjacent downstream reaches and seed source are likely within the project area.

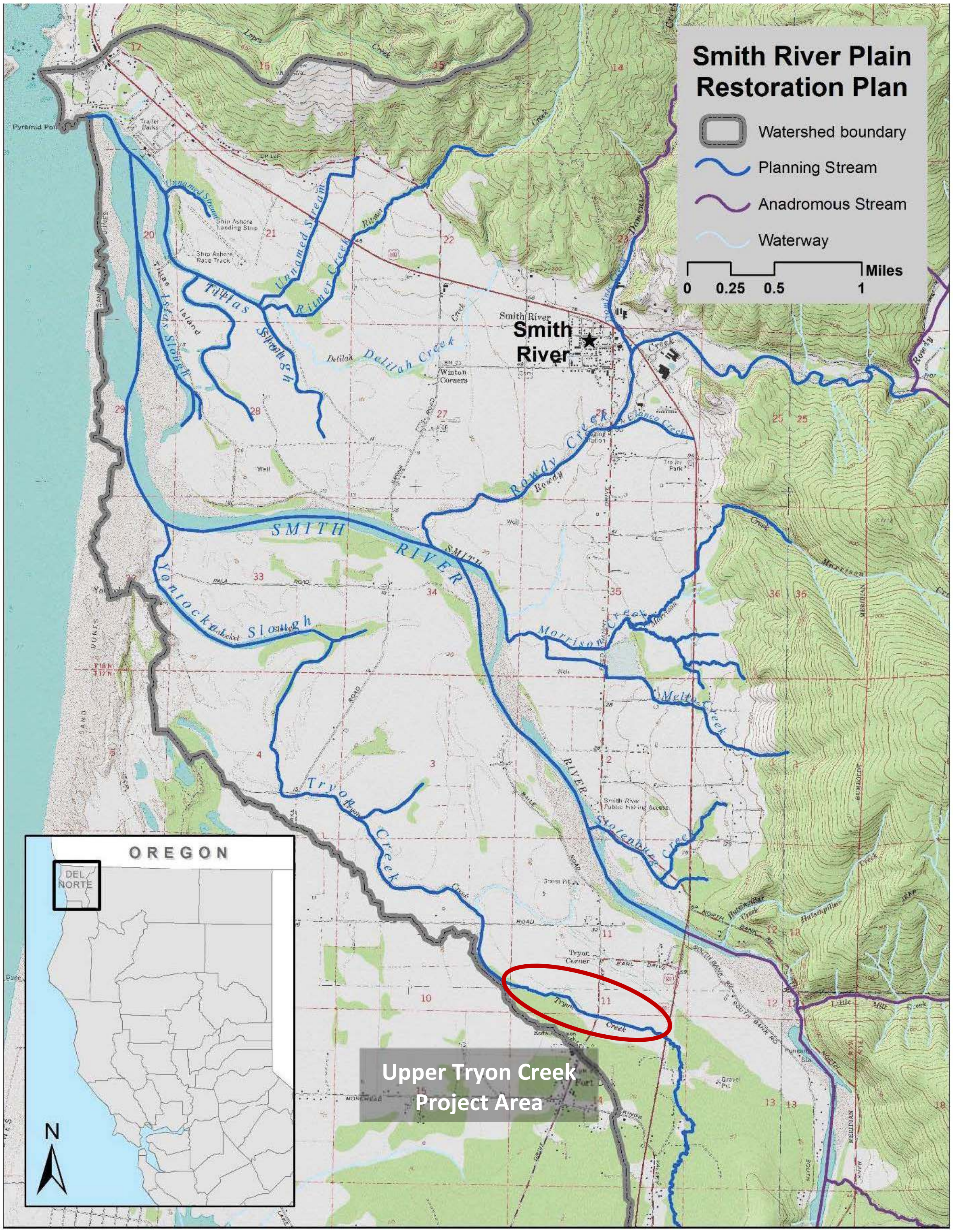


Figure 1-1. Plan view map of Tryon Creek (adapted from Parish, 2018). Approximate project area is circled.

1.3 Project Objectives

Through the FRGP grant from CDFW, the Smith River Alliance (SRA) retained the services of Michael Love & Associates, Inc. (MLA) to study the project area and identify potential actions to enhance or restore Tryon Creek within the project area. SHN Consulting Engineers & Geologists, Inc. was retained to serve as the project engineering geologist and lead design of the bridge foundation. SRA lead the development of the riparian planting plan.

This report summarizes activities performed to characterize the project area, assess existing conditions, and to develop design plans for the project. Project objectives include:

- Improve geomorphic functionality and channel complexity of Tryon Creek
- Reduce livestock impacts through fencing,
- Enhance riparian habitat
- Remove the three undersized culvert crossings and replace them with one bridge crossing and one low-water crossing.
- Balance the needs of the landowners with the ecological needs of the area

1.4 Project Approach

Designs for the Tryon Creek channel enhancements and restoration followed reference reach-based channel restoration approaches (CDFG, 2009; USFS, 2008). Reference reach-based channel design is conducted using a combination of geomorphic, hydrologic, and hydraulic analyses of an adjacent, properly functioning, geomorphically stable channel reach. The reference reach information is then used to design the project channel with similar characteristics so it has similar geomorphic stability and functionality as the reference reach.

Designs for the new bridge and low-water crossings were based on stream-simulation design methodologies (CDFG, 2009; USFS, 2008). In stream simulation design of road-stream crossings the reference-reach based approach is applied such that the restored channel through the crossing has similar geomorphic form and function as the reference reach; thus providing no more of an impediment to movement of aquatic organisms than the adjacent natural channel. A stream-simulation crossing is also designed to fully-span the bankfull channel width and convey the 100-year flow without submerging the soffit of the crossing.

1.5 Natural Resources of the Smith River and Tryon Creek

SRA has performed numerous studies on the wildlife, water quality, fisheries, and riparian habitat within the Smith River basin, including Tryon Creek. Their findings are summarized in the following sections.

1.5.1 <u>Fisheries</u>

The Smith River is often described as a "Salmon Stronghold" because of its irreplaceable value to salmonid population resilience and biodiversity. This is especially important due to the Smith River's southern position in context to the greater Pacific salmonid range in the Pacific Northwest. This label is largely the result of resilient habitats and existing protections on public land in the upper Smith River watershed. Despite the conservation throughout much of the watershed, the tributaries and slough channels of the working lands in Smith River Plain have been modified or simplified to the detriment of fish populations and ecosystem health (Parish, 2018).

The Smith River Coho Salmon population is at a high risk of extinction, including in the Smith River watershed (NMFS, 2014). Restoration of rearing habitat in the estuary remains vital for the management and protection for salmonid populations, especially for Coho Salmon that tend to thrive in this low-gradient environment (Parish and Garwood 2015, 2016, Parish 2018). Tryon Creek is low-gradient from its forested headwaters to Yontocket Slough and contained some of the highest intrinsic potential for Coho Salmon within the Smith River (NMFS, 2014). The Upper Tryon Creek Stream Enhancement Project will implement identified coho recovery strategies including increasing channel complexity, floodplain connectivity and riparian function (NMFS 2014).

Restoration of Upper Tryon Creek supports diverse salmonid life histories. Recent studies on Coho Salmon life histories have shown early emigrates to non-natal rearing habitat contribute to approximately 30-percent of adult escapement (Bennett et al. 2014, Jones et al. 2014). Salmonid occupancy studies in the Smith River estuary found fall pit-tagged Coho Salmon from Mill Creek later reared in non-natal estuary tributaries, including Tryon Creek (Parish and Garwood 2016). Juvenile salmonids were detected rearing in Tryon Creek and Yontocket Slough for five consecutive years from 2012 to 2016 (Parish and Garwood 2015, Parish and Garwood 2016). Furthermore, these studies found that juvenile salmonids utilize tributaries and slough channels far more often than mainstem habitat during the winter, and out-migrating smolts were consistently larger than their upstream cohorts that reared in natal habitats (Parish and Garwood 2016). These findings highlight the importance of Smith River Plain tributaries for salmonid recovery.

Spawning gravels are present in Tryon Creek upstream of the project reach. While no documented spawning has been observed, juvenile Chinook Salmon (*Oncorhynchus tshawytscha*), unidentified trout (*Oncorhynchus sp.*), and Coastal Cutthroat Trout (*Oncorhynchus clarkii clarkii*) have been documented rearing in Tryon Creek upstream of the project area during the summer months (Walkley and Garwood 2017). All of these species would benefit from the restoration actions in the project reach. By focusing actions on developing new habitats and enhancing existing natural processes important to salmonids rearing and migration, this project will increase the overall capacity and duration of these habitats.

1.5.2 Wildlife

Wildlife in the project area include seasonal and resident populations of waterfowl, shorebirds, raptors, migrating songbirds, Northern red-legged frog (*Rana aurora*), Foothill yellow-legged frog (*Rana boylii*), Northwestern Salamander (*Ambystoma gracile*), western pond turtle (*Actinemys marmorata*), North American beavers (*Castor Canadensis*), black tailed deer (*Odocoileus hemionus*) and Roosevelt elk (*Cervus Canadensis roosevelti*). The project site is currently a wildlife corridor for a resident herd of Roosevelt elk that uses the forest to the south of Tryon Creek for cover and protection, and the pastures to the north for forage. The riparian fencing design for the project will allow for continued migration of elk herds, and plant installations will utilize strategies to inhibit browsing.

Beaver browse, dams and bank lodges have been documented upstream and downstream of the project site (Parish and Garwood 2015, Parish 2016). It is likely that beaver will migrate through the project site and play an important role in the long-term health and recovery of Tryon Creek. In the short-term, beavers could slow the establishment of riparian vegetation. A habitat restoration project in Strawberry Creek, a tributary to Redwood Creek in Orick CA, used several methods of protecting riparian plant installations from beaver herbivory. Recommendations in this report are guided by methods used in Strawberry Creek, see Section 7 for more information.

1.5.3 Water Quality and Aquatic Habitat

An 800-foot long reference reach on Tryon Creek, between the upstream extents of the project area and Highway 101 has intact natural meanders, floodplain connectivity, gravel substrate, and a narrow but diverse riparian forest providing large wood recruitment and riparian cover. Recent studies of Coho Salmon (*Oncorhynchus kisutch*) occupancy and distribution in the Smith River Plain found occupancy in winter rearing habitats was positively influenced by increased cover area, a higher cover rating and the amount of turbulent flow (Parish and Garwood, 2015).

Tryon Creek does not flow year-round at the project site and typically goes dry during the summer months. Dissolved Oxygen levels below 2 mg/l are lethal to juvenile salmonids (Water Quality Assessments 1996). Parish and Garwood (2016) monitored dissolved oxygen in Tryon Creek and Yontocket Slough and found dissolved oxygen readings within salmonid tolerance thresholds during the winter. However, dissolved oxygen levels decreased in the springtime reaching below the 2mg/l tolerance threshold in Yontocket Slough by April. Reed canary grass (RCG) (*Phalaris arundinacea)* is abundant in Yontocket Slough and Lower Tryon Creek and likely contributes to low dissolved oxygen and water quality in the drainage (Tu et al. 2004, Love 2006, RNP 2014, Parish and Garwood 2016).

Restoration of the project reach will enhance vital refugia habitats for winter-rearing Coho Salmon, similar to that of its upstream reference reach. This project is designed to increase overwinter survival, produce greater productivity and enhance overall population resilience by maximizing life history diversity opportunities in key coastal plain winter habitats (Koski 2009, Wallace and Allen 2009, Bennett et al. 2014, Wallace et al.2015, Levings 2016).

1.5.4 Riparian Vegetation

SRA performed a detailed assessment of the riparian resources and invasive plants within the project area, which is summarized in the *Upper Tryon Creek Riparian Planting and Fencing Plan* (Appendix J). Results from this assessment informed the plant palate for the riparian plan and invasive plant treatment actions, as discussed in Section 7.

2 SITE CHARACTERIZATIONS

2.1 Topography

LiDAR topography of the project area was obtained from the Coastal LiDAR provided by the California Ocean Protection Council. The LiDAR was flown between 2009 and 2011. The LiDAR topography did not contain sufficient detail of the Tryon Creek channel and banks due to vegetation and water within in the channel during the flight.

To supplement the LiDAR, MLA staff performed a detailed topographic survey of Tryon Creek within the project reach and partial survey of the channel in the reference reach. The detailed survey included the thalweg, toe and tops of banks, breaks in slope and historical flow scarps. The survey of the reference reach included thalweg and geomorphic features where possible. In total, the survey included approximately one mile of channel, starting at the lower end of the property and extending upstream, almost to Highway 101. The dimensions and elevations of low water crossings and the Lake Earl Drive bridge were also surveyed. SRA provided GPS points of larger trees and irrigation lines within the project area. The field survey was conducted during three site visits between November 2019 and January 2020.

Permanent survey control points were installed along Lake Earl Drive. The controls were tied to North American Datum 1983 (NAD83) California State Plane, Zone 1, in feet, and North American Vertical Datum of 1988 (NAVD88) in feet using a geodetic quality GNSS receiver by Reily H. Smith (CA professional land surveyor). The control point information allowed the total station survey to be adjusted to real coordinates and aligned with LiDAR topography.

The LiDAR and field-run topographic survey were merged to create a combined digital terrain model (DTM) and basemap of the project area with 1-foot contours, as shown on Figure 2-1. Approximate parcel lines were obtained from the Del Norte County geographic information services website.

A stationed channel centerline alignment was developed, with stationing starting at the property boundary at the downstream end of the project (just upstream of the neighbor's bridge) and increasing upstream to Highway 101. Figure 2-1 shows a plan-view map and Figure 2-2 shows a thalweg and floodplain profile of the project area of Tryon Creek, including the reference reach.

NOTE: NOT ALL FENCES SHOWN

Michael Love & Associates, Inc.
PO Box 4477 • Arcata, CA 95518 • (707) 822-2411

SMITH RIVER ALLIANCE
PO Box 2129 Crescent City, CA 95531

UPPER TRYON CREEK ENHANCEMENT PROJECT
Del Norte, California

EXISTING CONDITIONS TOPOGRAPHIC MAP OF TRYON CREEK

FIGURE

2-1

2/28/20 Q:\Tryon Creek Restoration\7_CAD-GIS\Civil3D\Sheets\1_EXISTING_CONDITIONS.dwg

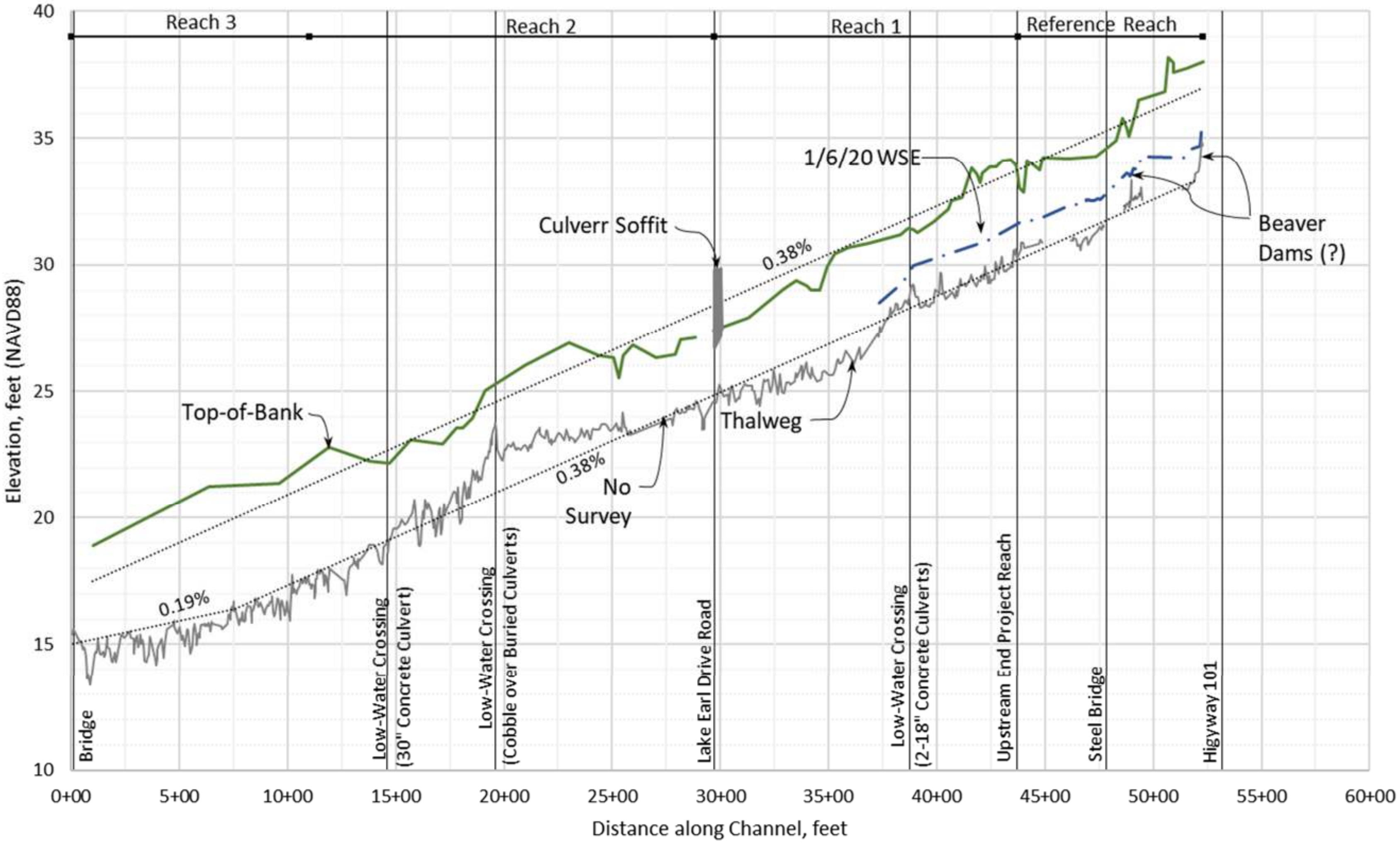


Figure 2-2. Channel and floodplain profile of the project area and reference reach of Tryon Creek, with overall slopes provided. Water surface elevation (WSP) profile shown in the upstream end of the project reach and in the reference reach.

2.2 Hydrology

Tryon Creek has a drainage area of 1.9 square miles at the downstream end of the project area. The watershed has a mixed land use with the headwaters (upstream of Highway 101) comprised of residential and commercial timber harvest property. Downstream of Highway 101, the stream flows through agricultural pastures. Primary land use includes livestock grazing, pastured chickens, wildlife grazing (geese and elk) and residential. The land surrounding the project area is utilized for livestock grazing. The project reach typically goes dry during the summer months.

Tryon Creek is not gaged, necessitating prediction of flows using indirect methods. For comparative purposes, peak flow hydrographs were developed using two methods: (1) Win TR-55 (USDA, 2013) and (2) the USGS Region 1 North Coast regression equations (Gotvald, et al., 2012).

Flows computed using TR-55 were based on runoff curve number and times of concentration. The drainage basin was modeled as seven separate subbasins using 24-hour rainfall depths for varying return periods from 2-year to 100-year (NOAA, 2019), applied across a Type 1A rainfall distribution, (USDA, 2013). Weighted curve numbers for each sub-basin were derived using aerial analysis of land use and NRCS Hydrologic Soil Group designations (NRCS, 2019). Times of concentration for sub-basins were calculated using the California Culverts Practice equation (Chow et al., 1988), which is dependent on watershed area and flow path length.

The USGS regression equations (Gotvald et al., 2012) are based on drainage area and mean annual precipitation (MAP). The computations were prepared using the USGS StreamStats Version 3.0 (https://streamstats.usgs.gov/ss/), which indicated a MAP of 73.7 inches.

Peak flows predicted in Tryon Creek are presented in Table 2-1. Both TR-55 and the USGS regression equations estimate peak flows for events as frequent as a 2-year event. More frequent flow events were extrapolated using log-linear regression equations fit to the data. Flow hydrographs developed using TR-55 are shown in Appendix C, and have the same peak flow shown in Table 2-1.

The flow estimations predicted by each method were slightly different, which is expected given the different methodologies used to predict the flows. For design purposes, the TR-55 peak flow results were used.

Because the crossing replacement was designed using the Stream Simulation Methodology (CDFG, 2009), fish passage flows were not computed.

Hydrologic computations are shown in Appendix C.

Table 2-1. Summary of peak flows in Tryon Creek at the downstream limit of the project area using two method of flow estimation.

Method	Return Period of Peak Flow						
	1.1-Year[1]	1.5-Year[1]	2-Year	5-Year	10-Year	50-Year	100-Year
TR-55 (2013)	104 cfs	165 cfs	239 cfs	394 cfs	529 cfs	859 cfs	1009 cfs
USGS Regression Equations (2012)	122 cfs	177 cfs	223 cfs	396 cfs	519 cfs	799 cfs	924 cfs

[1] *Extrapolated using log-linear regression*

2.3 FEMA Flood Mapping

Tryon Creek is mapped as Zone AE by FEMA within the Smith River flood zone on the Flood Insurance Rate Map (FIRM) Panel 207 (FEMA, 2010). Zone AE indicates that baseflood elevations (BFEs) have been established based on the 100-year Smith River flow. The BEFs are over 10 feet deep within the project area. The project area is not in a designated floodway. FEMA FIRM maps for the project area are shown in Appendix C.

A plan view map from FEMA's National Flood Hazard Layer (NFHL) Viewer is also shown in Appendix C. The map shows that during the baseflood event, flood waters are impounded by the Highway 101 roadway embankment, forcing all flows through the bridge on the mainstem of the Smith River and through an overflow bridge to the south of the river, but north of Tryon Creek. Tryon Creek receives floodplain flows that pass through the overflow bridge on Highway 101 and into the Tryon Creek stream corridor downstream of Lake Earl Drive. Downstream of Highway 101 flows in the main river and Tryon Creek are separated by a ridge of higher ground on the floodplain, which experiences only one to two feet of depth during the baseflood event. Floodplain flows west of this high ground follow the alignment of Tryon Creek, and ultimately flow south into Lake Earl rather than into Yontocket Slough and the Smith River estuary.

Based on the water surface contours shown on the FIRM in Appendix C, much of the Tryon Creek project reach is located within a backwater zone during the baseflood event. This backwater is associated with floodplain flows being constricted by higher ground to the south and north as the waters are funneled into the Lake Earl basin.

The landowner indicated that Tryon Creek begins to receive flow from the Smith River when the USGS stream at the Highway 101 Dr. Fine Bridge gage reaches Flood Stage.

2.4 Geotechnical Investigation

SHN performed limited geotechnical investigation of the project area, including four hand augered borings (SHN, 2020). Their complete report is presented in Appendix B. The geotechnical investigation identified that the subsurface is composed of stream and floodplain deposits, comprised of sands, silts, clays and gravels. Generally, the upper portions of the borings were comprised of silts, and sandy silts, with lean clays and sandy lean clays at depth.

Based on the results of the geotechnical investigations, SHN made recommendations for the foundations of the prefabricated bridge that will be installed as part of the project, as discussed in Section 4.1.2.

2.5 Geomorphic Assessment

To understand the geomorphic processes of the current Tryon Creek channel and to establish design parameters for the channel realignment, MLA conducted a geomorphic assessment of the 4,400 feet project reach, and 800 feet of a relatively undisturbed reference reach area between the project area and Highway101.

The geomorphic assessment of the project area and reference reach included the following:

- Detailed survey of the channel profile, bankfull, and top of bank, and storm rack line elevations where visible
- Measurements of active channel and bankfull widths in the reference reach
- Field-level geomorphic sketches of surveyed channel reach and sketches detailing the

arrangement of large wood features in the reference reach that provided geomorphic controls

- Historical analysis of the channel location and planform geometry based on maps and aerial photographs
- Hydraulic analyses to determine bankfull channel capacity and associated return period, as well as flooding extents and patterns of larger storm events

No pebble counts were performed because the channel is comprised of fine-grained materials, with only occasional coarser grained material that appear to originate from lag deposits.

2.5.1 Overview of Existing-Condition Chanel Geomorphology

Figure 2-1 shows a plan-view map and Figure 2-2 shows a thalweg and floodplain profile of the project area of Tryon Creek, including the reference reach.

Tryon Creek is a low-gradient channel that flows across the floodplain of the Smith River. The channel within the project area has a 0.38% slope, which parallels the slope of the floodplain. The slope of the channel drops to 0.19% at the downstream end of the project area. The channel is typically trapezoidal in shape with an 8- to 15-foot bottom width and 2.5- to 5-foot bankfull depth. In most locations, above the bankfull elevation, the channel flows onto the floodplain.

The alluvium within Tryon Creek channel bed and banks appears to be lag deposits originating from past alignments of the Smith River channel, with the material size and frequency varying by location.

In the 800-foot long reference reach upstream of the project area, the channel has a meandering planform. The channel planform in the project area upstream and downstream of Lake Earl Drive has been ditched and straightened. In the downstream reaches of the project area, the channel flows along the valley wall and the planform is controlled by the overall topography of the Smith River floodplain and hillslope to the south. The LiDAR DTM indicates that the base of the hillslope to the south of the channel was carved by historical alignments of the Smith River.

The channel banks are comprised primarily of fine-grained cohesive materials, though there are some localized areas where the channel banks have a gravel and cobble component, likely a remnant of the river. In the stream channel, there are occasional areas where individual pieces of gravel and cobble are present on the stream bottom, which appear to be lag deposits. If it were in transport, it would not consist of a substantial sediment load. There are few depositional features, and those present are composed of fine-grained materials. Field evidence suggests that most sediment transport within Tryon Creek occurs as suspended and washload.

The elevation of the channel thalweg varies, but is controlled mostly by differences in the stiffness of the substrate. There are no defined alluvially-formed riffles, but pools typically are forced in meander bends, by tree roots, and by partially spanning wood and debris jams. Pools were typically less than 1-foot deep. At some locations within the project reach, the channel bottom was so soft, it was difficult to determine the thalweg elevation.

The hillslope to the south of the channel is forested with large spruce and redwood trees. Old growth stumps are present both on the hillslope and floodplain adjacent to the creek. There are occasional old-growth stumps on the north side of the channel, indicating that at one time the channel reach was located in an old-growth forest consisting of redwood, spruce and associated understory.

Upstream of Lake Earl Drive – Reach 1

The project area includes 1,400 feet of channel upstream of Lake Earl Drive. The reference reach for the project is located immediately upstream of the project area, extending 800 feet to Highway 101. As shown on Figure 2-3, the channel within the project area has been ditched and straightened, and has discontinuous spoil piles on both sides originating from channel maintenance. The channel is typically trapezoidal in shape with a 10- to 15-foot bottom width and a 2- to 4-foot depth before flowing onto the floodplain. There is little riparian vegetation, except occasional alders and thickets of invasive blackberry.

There are livestock pastures on both sides of the channel, and livestock have full access to the channel on the south side. A livestock crossing is located near the upstream end of the project area consisting of double 18-inch concrete pipes surrounded by placed cobble (Figure 2-4). The channel has shifted to the south due to clogging of the pipes, requiring the livestock to wade through the channel to access the crossing.

As shown on the channel profile on Figure 2-2, between the livestock crossing and Lake Earl Drive the channel thalweg is at a lower elevation than the overall slope, likely a result of being ditched. In addition to being artificially straightened, confined by berms, and impacted by livestock, the channel appears to be over-widened. In several locations the channel bottom is comprised of soft muck and dense grasses where baseflow has formed multiple flow paths.

It is evident on the ground and in the LiDAR and aerial photography that there was once a sinuous channel located slightly to the south of the current channel (Figure 2-1). The old channel is mostly filled in, but consist of a low area that is wetter than the surrounding ground. See Section 2.5.2 for additional detail.

The bridge crossing at Lake Earl Drive consist of a 15-foot span concrete crossing. Because the bottom of the structure is comprised of a natural streambed, it was not possible to determine if the structure has a concrete bottom. The soffit of the crossing is near the floodplain elevation. Both Caltrans and Del Norte County were unable to locate as-built records for this crossing.

Downstream of Lake Earl Drive

The downstream reaches of the project area extend approximate 3,000 feet downstream of Lake Earl Drive to the property boundary. There are two distinct reaches within this section of channel. Livestock have full access to the stream from several pastures along both of these reaches.

Reach 2 (11+00 to 29+00)

The channel remains ditched and straightened for about 1,600 feet downstream of Lake Earl Drive, though there are only occasional spoil piles adjacent to the channel in this reach (Figure 2-5). The channel is typically trapezoidal in shape with a bottom width that varies from 9 to 14 feet and a 2- to 3-foot deep bankfull depth before flows spill onto the floodplain. Grasses within the channel cause high flow resistance.

There is little riparian area along this reach of channel, except for one 200-foot long length of channel surrounded by a dense thicket of willows about 200 feet downstream of Lake Earl Drive. Within the thicket, there are numerous partially spanning downed limbs and debris jams that lead to a poorly defined channel and multiple flow paths. This area was so dense it was not possible to access for survey.

Figure 2-3. Tryon Creek project reach upstream of Lake Earl Drive (looking upstream). The stream channel has been ditched and straightened, with discontinuous spoil piles on both sides of the channel (Photo date January 2020).

Figure 2-4. Livestock crossing upstream of Lake Earl Drive (looking downstream) consisting of two 18-inch concrete pipes surrounded by placed cobble. (Photo date January 2020).

There is a low-water crossing near station 19+62, which consists of concrete pipes buried by a thick layer of salvaged cobbles that extend for a distance downstream of the crossing (Figure 2-6). As evident in the photograph and on Figure 2-2, the crossing is about a foot higher than the upstream channel bottom. When the stream is flowing, the crossing creates a backwater and a steep riffle over the top and downstream of the crossing. It appears that some aggradation may be occurring upstream of the crossing.

Near station 14+00 there is a 30-inch diameter concrete culvert forming a "vented" low-water crossing (Figure 2-7). Though narrower than the channel bottom, the crossing does not seem to be affecting stream stability near the crossing. The culvert is in poor shape, with decoupled joints and cracking.

Near station 12+00 is a remnant of the historical Tryon Creek channel that remains connected to the current channel and provides some off-channel backwater and wetland habitat likely suitable as velocity refugia and foraging habitat for rearing salmonids.

Reach 3 (0+00 to 11+00)

At about station 11+00, the channel begins to flow against the toe of a steep slope, which, as is visible on the LiDAR DTM, was once formed by a historical meander bend of the Smith River. The toe of this slope generally dictates the planform of Tryon Creek in this reach (Figure 2-8), except where two small meanders have formed near stations 6+00 and 10+00 (Figure 2-9). The channel retains its trapezoidal shape, but narrows to 8 to 13 feet, with occasional wider areas. The channel also deepens to about 4 feet before it flows onto the floodplain.

Figure 2-5. Ditched and straightened channel in Reach 2, downstream of Lake Earl Drive (looking downstream) (November 2019).

Figure 2-6. Low-water crossing with buried culverts overlain by placed cobbles, located in the middle of Reach 2 (looking downstream). (November 2019).

Figure 2-7. 30-inch culverted low-water crossing near the downstream limits of Reach 2 (looking downstream). (January 2020).

Figure 2-8. Channel flowing along base of hillslope in Reach 3 (looking downstream). (January 2020).

Figure 2-9. Channel in a meander bend in Reach 3 of the project area (looking downstream). (January 2020).

Generally, this reach is more forested than upstream, with large spruce and redwood trees and stumps on south slope, and large alder trees on one or both sides of the channel. Livestock access into this reach of channel has resulted in a trampled and grazed riparian area, flattened channel banks, and a thick mucky channel bottom. The landowner has indicated that elk also use this channel and overbank area heavily.

There are numerous areas where downed trees or debris jams are within the active channel, creating channel complexity.

The bridge on the downstream adjoining property is a full-spanning railroad car bridge. Measurements from LiDAR DTM indicate that it is about 80 feet long with a deck elevation of about 24 feet, and is sloped. This places the deck approximately 9 feet below the FEMA baseflood elevation at this location.

2.5.2 Evaluation of Historical Conditions in Tryon Creek

Historical locations and planform geometry of Tryon Creek, available historic maps and aerial photographs, and LiDAR topography were reviewed to provide insights into the historical morphology of Tryon Creek. Historical maps and aerial photographs of Tryon Creek are available dating back to 1856, and were previously consolidated and ortho-rectified in a historical atlas of the lower Smith River (Laird, 2005).

Overview

Figure 2-10 shows a hillshade relief topographic map of the southern portion of the Smith River plain, along the flow path of Tryon Creek flows. Numerous looping scarps along the higher ground south of the river indicate historical locations of the Smith River, where it once flowed against the hillslopes at various times through history. Except between Highway 101 to just downstream of Lake Earl Drive, most of Tryon Creek appears to be flowing along the base of the hillslope, occupying historical meander scars from the Smith River.

In the earliest mapping on an 1856 plat map, Tryon Creek is shown as Tolowa Creek, and flowed generally in the same location as the current channel. Numerous spruce trees are marked on the map. Unlike now, where Tryon Creek turns north to drain into Yontocket Slough (Ottawa Slough on the plat map), in 1856 Tryon Creek turned south near where it currently crosses under Lower Lake Road and drained into Lake Earl through a wetland area labeled as “Spruce and Pine.” Several later maps, including the 1952 USGS map, continued showing Tryon Creek flowing into a wetland area draining to Lake Earl. Sometime before the 1965 aerial imagery, Tryon Creek was turned north to drain into Yontocket Slough, which drains into the Smith River.

Lake Earl Drive previously served as Highway 101, though it was shown as a County Road on an 1863 map. The current alignment of Highway 101 was a railroad line until after the 1950’s when the current location of Highway 101 was constructed.

The December 22, 1964 flood on the Smith River at Highway 101 Dr. Fine Bridge (FTDC1) produced the highest flow on record. The estimated peak flow during the 1964 event at Highway 101 was 207,000 cfs (https://www.cnrfc.noaa.gov). FEMA estimated a peak flow of 218,000 cfs for a 1% annual-chance flood (100-year return period) at Dr. Fine Bridge. The 1965 aerial image of the project area shows that the flood inundated Tryon Creek, especially downstream of Lake Earl Drive, leaving deposits of sediment and debris in the fields adjacent to the stream.

2.5.3 Historical Locations of Tryon Creek within the Project Area

Figure 2-11 shows a 1942 aerial photographs with a tracing of the location of Tryon Creek in 1942. The current location of Tryon Creek is shown for reference. Figure 2-12 shows tracings of the remnants of historical channel alignments evident on various historical aerials and maps. Unlike Figure 2-11, which reflects the channel location at the time of the photograph, the tracings on Figure 2-12 reflect historical channel locations prior to when the photograph was taken. The tracings reflect low areas in the topography that indicate historical locations of the channel.

Upstream of Lake Earl Drive (Reach 1)

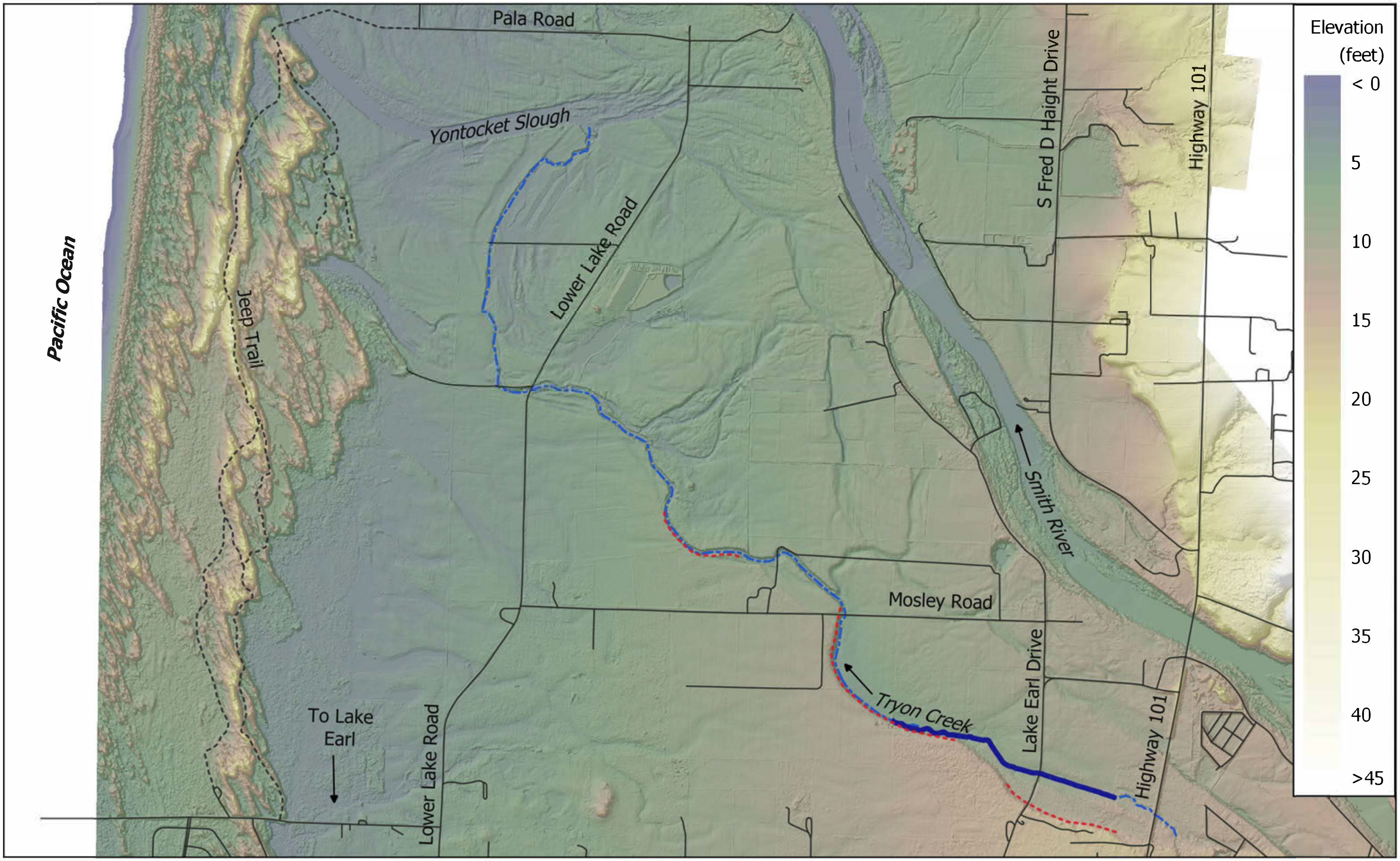
As shown on Figure 2-11 and Figure 2-12, Tryon Creek flowed in several different locations along the floodplain, ranging from a highly sinuous channel close to its current alignment (evident on the 1958 and 1965 aerial photos), to taking a more gentle sweep to the north, (evident on the 1942 aerial photo). Where the channel historically flowed along the northern alignment, the ground is still low and floods about once per year or so, flowing over Lake Earl Drive, according to the landowner.

By 1942, Tryon Creek was ditched and straightened along most of its length between Highway 101 and Lake Earl Drive. At some point, a berm, that is still functional, was constructed at the upstream extents of the ditched channel, running north-south along the property line, to prevent the channel from re-occupying its northern flow path.

For about 800 feet downstream of Highway 101 the channel has retained the same planform geometry as it has since the 1942 aerial photograph, though a large portion of the riparian area had been cleared from this area numerous times from 1942 until the present.

Downstream of Lake Earl Drive

Downstream of Lake Earl Drive, the flow path traced on the 1942 aerial photograph continued to flow to the north of the existing channel alignment. This flow path ultimately merged with the current alignment of Tryon Creek in Reach 2, where it flows along the base of the hillslope along a historical meander scarp left by the Smith River. A separate channel alignment, evident on the 1958 aerial photograph, indicates that Tryon Creek once flowed along a sinuous channel close to the current channel alignment, but then turned to the north, meeting the trace of the channel evident on the 1942 alignment. The channel was ditched into its current alignment downstream of Lake Earl Drive sometime between 1972 and 1993.



0 2000 4000 ft

CA STATE PLANE ZONE 1 FEET
NAVD88 VERTICAL DATUM
2009-2011 CA COASTAL CONSERVANCY LIDAR

Legend

- Tryon Creek
- Project Reach
- Historical Meander Scarps from Smith River

SMITH RIVER ALLIANCE

Michael Love & Associates
Hydrologic Solutions

Upper Tryon Creek Stream Enhancement
Design Project

Figure 2-10.
Hillshade Relief Topographic Map of Smith River Floodplains and Tryon Creek

Filepath: Q:\Tryon Creek Restoration\7_CAD-GIS\QGIS\Working\Smith_River_Historic_Atlas-Tryon.qgs.qgz

Michael Love & Associates, Inc. P.O. Box 4477, Arcata, CA 95521 (707) 822-2411

Legend

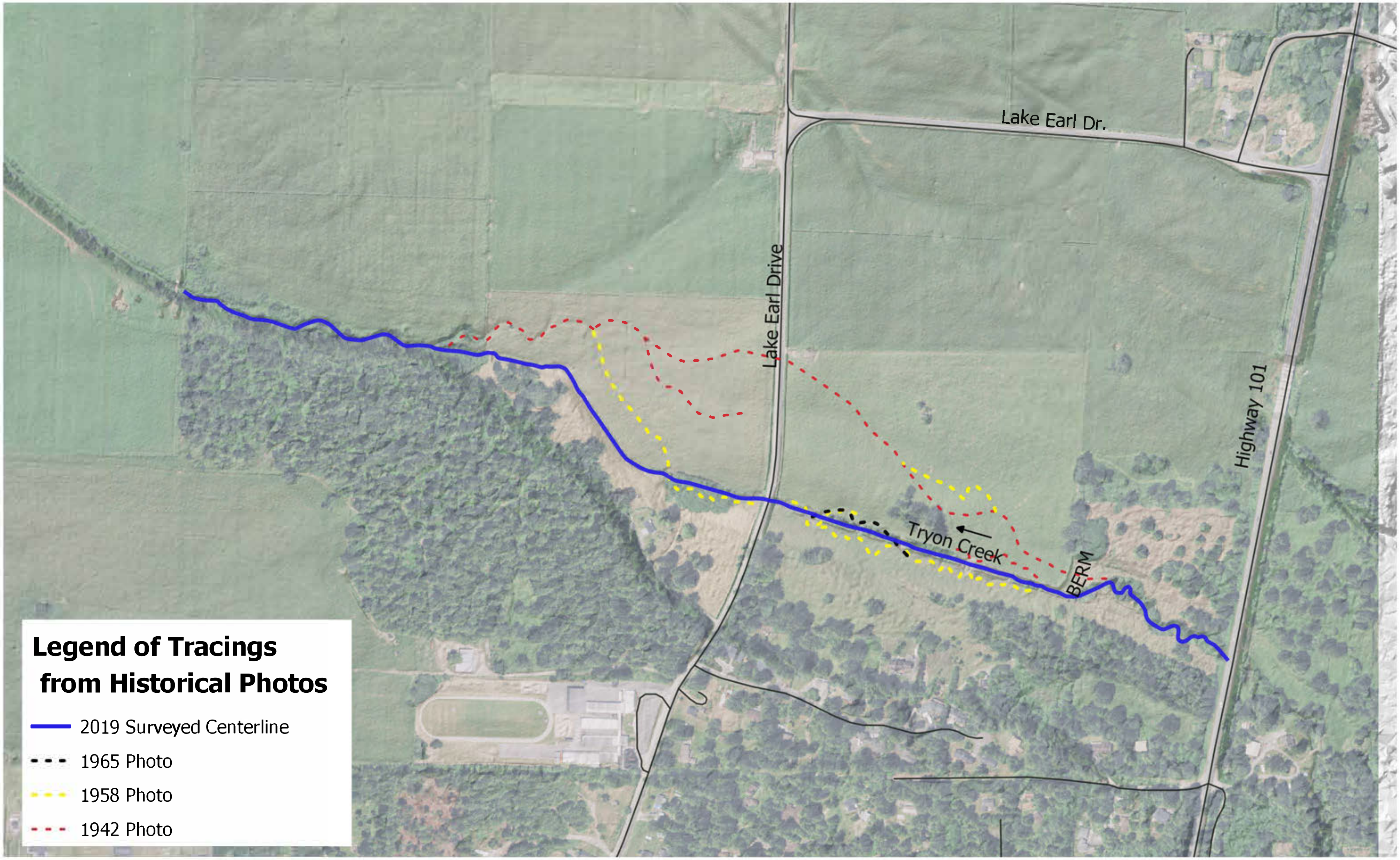
- 2019 Surveyed Centerline
- 1942 Centerline

SMITH RIVER ALLIANCE

Michael Love & Associates
Hydrologic Solutions

Upper Tryon Creek Stream Enhancement Design Project

Figure 2-11
Historical Map Analysis
1942 Aerial Photograph and Stream Centerline



0 500 1000 ft

CA STATE PLANE ZONE 1 FEET

SMITH RIVER ALLIANCE

Michael Love & Associates

Hydrologic Solutions

Upper Tryon Creek Stream Enhancement
Design Project

Figure 2-12
Historical Map Analysis
Channel Location Tracings

Filepath: Q:\Tryon Creek Restoration\7_CAD-GIS\QGIS\Working\Smith River Historic Atlas-Tryon.qgs.qgz

In the downstream project reach (Reach 3) the stream flows along the base of the hillslope, occupying historical meander scars from the Smith River, except for small localized meanders. Inspection of the early mapping and photographs indicate that Tryon Creek has followed this alignment since it was first mapped in 1856.

2.5.4 Reference Reach Characteristics

The historical analysis indicated that an approximately 800-foot long reach of Tryon Creek downstream of Highway 101 has retained the same planform geometry since the first aerial imagery from 1942. Though a large portion of the riparian area had been cleared from this area numerous times between 1942 and present, and the current riparian corridor is narrow, the channel appears to be stable. Because of its stability, and because this reach of channel appears to reflect a similar planform geometry that historically characterized Tryon Creek within the project reaches 1 and 2 as a whole, this section of channel was selected as a reference reach for the project. The reference reach is shown on the channel profile on Figure 2-1 and in plan view on Figure 2-2.

Methods

The reference reach was evaluated to identify the dimensions and variability in stable channel slope, cross section, and planform geometry for use in designing the channel restoration. The reference reach characterization consisted of a topographic survey of the channel planform, thalweg profile, and select channel cross sections. Additionally, measurements of active channel width (channel bottom width) and bankfull width and depth were measured using a cloth tape. "Bankfull" was defined as where flow spilled out of one or both banks onto the broad floodplain. Dense brush limited a full survey of the referee reach. Therefore, three typical sections of channel were selected for survey.

Sinuosity and the meander corridor width (meander amplitude) were measured in the reference reach and based on historic planform geometry in the project reaches. Where historical geometry was obscured or where it was not feasible to re-occupy the historical channel, the tracings of historical channel locations were used for the planform design. By re-occupying and copying historical channel alignments, the geometry of the restored planform will be similar to the historical channel.

The results of the reference reach analyses are summarized in Table 2-2. Measurements and geomorphic sketch maps are shown in Appendix D.

Results

The reference reach of Tryon Creek represents a typical forested floodplain channel flowing through fine cohesive sediments (Schumm, 1985). Generally, this type of channel flows out of bank fairly frequently, the channel platform is highly sinuous, and the channel profile controlled by cohesive materials, large wood, vegetation, and roots. Sediment transport occurs mostly as suspended and washload. Photographs of the reference reach are show in Figure 2-13 and Figure 2-14.

Generally, the reference reach channel consisted of a shallow single-thread trapezoidal channel with a bottom width ranging from about 5 to 9 feet (Table 2-2). Typical bankfull channel depths ranged from 2.3 to 3.7 feet, before flows spilled onto the floodplain on one or both sides. Bankfull width ranged from 11 to 21 feet.

Figure 2-13.Typical sinuous channel and riparian area within the reference reach (Photo date January 2020).

Figure 2-14. Partial to full-spanning wood and debris jams are common in the Tryon Creek reference reach. (January 2020).

In many locations, the channel banks were characterized by an erosional feature causing a break in slope midway up the banks, with a more-gentle slope to the top of bank and floodplain. Though both of these features were surveyed, "bankfull" was defined as the top of the channel bank where flows spread onto the floodplain. The lower feature was labeled as a "low bank." Section 2.6.1 presents an analysis of the flow frequencies associated with both of these features.

The channel banks are comprised primarily of fine-grained materials, though there are some localized areas where the channel banks have a gravel and cobble component, likely remnant deposition from the river. Within the stream channel, there are occasional areas where individual pieces of gravel and cobble are present on the stream bottom, but it appears to be primarily a lag deposit. If transported, it would comprise a negligible component of the overall sediment load.

As shown in Figure 2-2, the channel thalweg and the floodplain in the reference reach have an overall slope of 0.38%, the same slope as the project reaches (except downstream of station 7+00). There is little channel profile variability, with pools typically less than 1 foot deep, with the depth likely limited due to the stiffness of the clay substrate. Despite the channel thalweg profile having little variability, there are numerous partially spanning downed limbs and small debris jams that cause a high level of planimetric and flow complexity. Near the upstream limit of the reference reach there appeared to be at least two beaver dams that spanned the channel, causing a backwater upstream and about a 1-foot drop in the water surface profile.

The planform analysis indicated that the reference reach and historical channels generally maintained a sinuous planform geometry that was limited to a narrow corridor width. Measured planform sinuosity in the reference reach and along historical channel tracings ranged from 1.1 to 1.4, with an average of 1.3. The meander corridor width ranged from 26 feet to 100 feet, averaging 54 feet in width (Table 2-2).

Table 2-2. Summary of Tryon Creek reference reach channel hydraulic geometry.

Values	Active Channel Width	Low Bank Width	Bankfull Width	Bankfull Depth	Planform Sinuosity[1]	Meander Corridor Width[1]
No. of Measurements	21	10	10	11	9	19
Average Value	7.0	10.2	14.0	3.0	1.3	54
Minimum Value	4.7	9.0	10.9	2.3	1.1	26
Maximum Value	8.9	12.0	21	3.7	1.4	100
Median Value	7.0	10.0	13.2	3.1	1.2	50

[1] *Based on reference reach and historical tracings of channel alignments in project area*

2.6 Existing-Condition Hydraulics

2.6.1 Bankfull Flow Verification

Bankfull flow, often called the channel-forming discharge, is the flow that performs the most "work" on the channel in terms of sediment transport, erosion and deposition over time in an alluvial channel (Wolman and Miller, 1960). This flow forms and maintains the shape, size and profile of the stream channel. Though larger flow events do more "work," they occur infrequently and have less influence on overall channel morphology. In unconfined alluvial channels, the bankfull flow is the flow that just begins to spill onto the floodplain. Bankfull flow has been found to frequently have return periods ranging from 1 year to 2.5 years (Leopold, 2005).

WinXSPro (USFS, 2005) was used to assess the existing channel capacity in the reference reach. Two cross sections were evaluated using a slope of 0.38%, the slope of the surveyed water surface in the reference reach. Stage-dependent channel hydraulic variables computed by WinXSPro were used with a depth-dependent channel roughness determined using Jarret (1985) to determine the flow at the top of the channel banks before flows spilled onto the floodplain.

The WinXSPro analysis identified that flows begin to spill out of bank between a 1.01- and 1.1-year flow event (between 84 and 104 cfs) with flow depths between 2.7 and 3.2 feet. The "low bank" feature appears to be inundated by flows much less than a 1-year flow event, suggesting that it is an erosional feature likely created by higher velocities during bankfull flow events. Computations are shown in Appendix D.

2.6.2 2-Dimensional Hydraulic Modeling

A two-dimensional (2-D) hydraulic model was used to evaluate the magnitude and frequency of 1.1-, 2-, 10-, and 100-year Tryon Creek flow events. The results of the existing-condition models were then used to compare the overbank inundation patterns and frequency that would be expected to occur with the proposed design (Section 5). The following sections present model development and results for the 2-D hydraulic analyses.

2-D Model Setup

A 2-D model was developed for existing conditions using HEC-RAS 5.0.7 (USACE, 2016a, b, c). The model domain encompassed about 207 acres of stream channel and floodplain within the project area. The model domain was established to include the inundation extents of a 100-year flow event on Tryon Creek within the project area.

The combined surface topography from the LiDAR and survey data was exported from AutoCAD Civil 3D as a one-meter average grid digital elevation model (DEM) and used in HEC-RAS to create a 2-D flow area. The 2-D flow area mesh had 15-foot by 15-foot grid spacing on average, with smaller sizes to define the stream channel. Breaklines were used to align the edges of the grid cells at elevational control points, such as the top-of-bank, berms and roadway edges, to limit false flow patterns caused by cells straddling a high point.

The channel crossing under Lake Earl Drive was modeled as a culvert with a 90° beveled headwall, and the roadway above the culvert was modeled as a broad crested weir. The surveyed road elevation was used as the weir crest, and a 2.6-foot high by 14.5-foot wide opening was used to simulate the culvert opening. The surveyed thalweg elevations at the upstream and downstream ends of the culvert were used to set the natural stream bottom elevation of the opening. The actual invert elevation of the crossing is unknown because it is beneath the channel bottom.

Manning’s n roughness values were estimated by delineating areas by aerial imagery and topography and choosing roughness values based on field observations and Chow (1959). Manning’s roughness values for the existing-conditions model are shown in Table 2-3.

The model upstream boundary condition consisted of 2-, 10-, and 100-year flow hydrographs developed using TR-55 (Section 2.2). The 1.1-year flow hydrograph, peaking at 104 cfs, was scaled from the 2-year hydrograph. Modeling for the 1.1-, 2-, and 10-year events were executed using the ‘diffusion wave’ computational method, which is a faster, though slightly less accurate. The modeling for the 100-year event was performed using the ‘full momentum’ computational method which applies the Full St. Venant equations. Modeling using the full momentum method is recommended for around bridges where detailed hydraulics are needed (USACE, 2016b).

The downstream boundary condition extended along the full width of the downstream model grid and was set to a normal depth with a slope of 0.4%, reflecting the slope of the floodplain. The unsteady flow analysis was executed with variable timesteps between 0.1 and 80 seconds, depending on the courant condition.

All modeling was based on flows computed by TR-55 for Tryon Creek. Tryon Creek has a substantially smaller watershed than the Smith River, and flows in the stream are expected to peak well before the Smith River. Therefore, the effects of the Smith River floodplain flows on Tryon Creek flood flows were not evaluated.

Table 2-3. Manning’s roughness coefficient values used for the existing-condition 2-D modeling.

Description	Manning’s Roughness Value (n)
Deciduous Woodland	0.08
Forest	0.10
Willow Thicket	0.15
Grassland and Forested Mixture	0.050
Pasture	0.035
Open Channel	0.050
Road	0.016
Concrete Culvert	0.011
Bed Material in Culvert	0.035

2-D Model Results

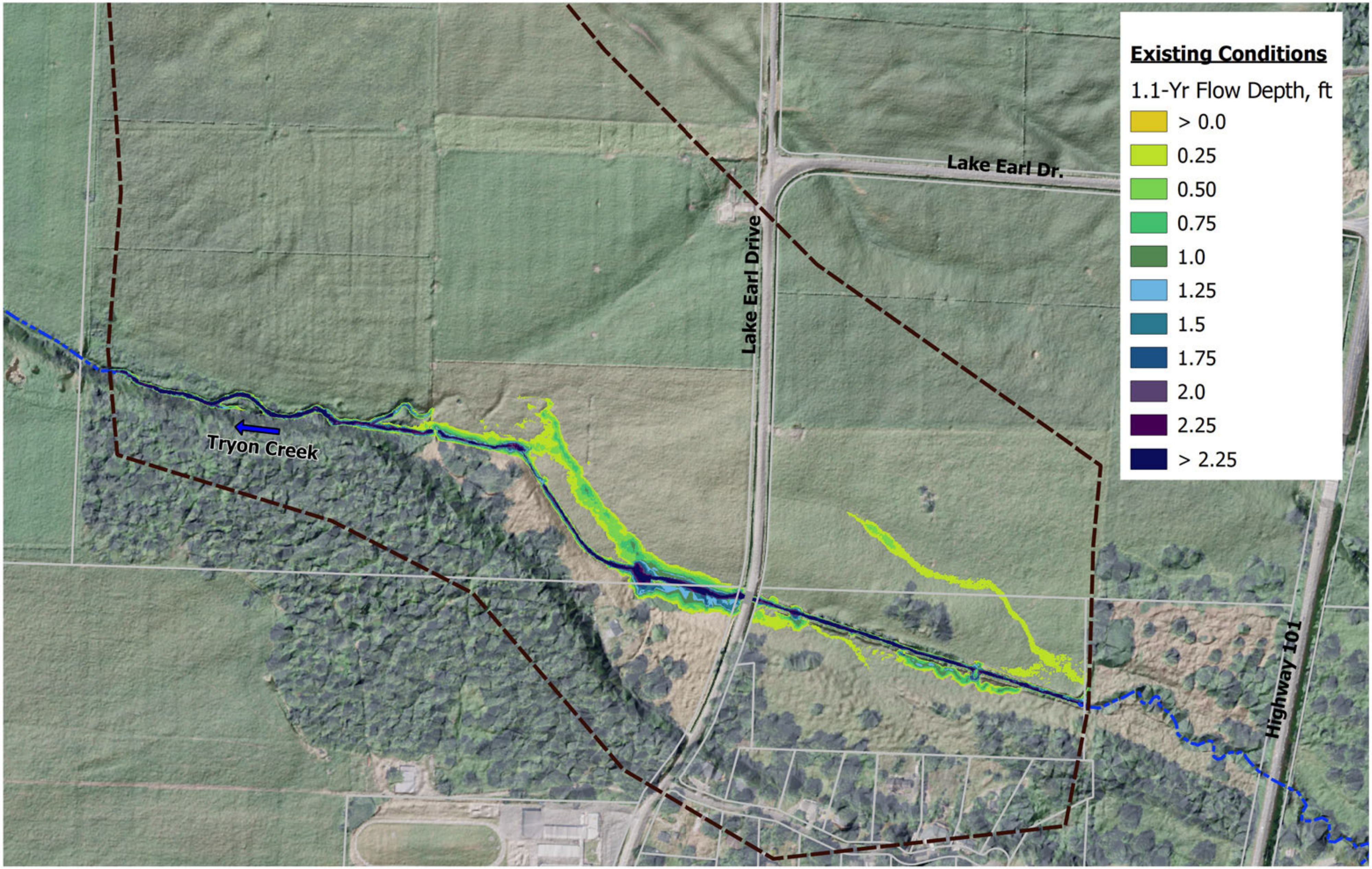
Figure 2-15 through Figure 2-17 present the 2-D model predicted peak inundation depths and extents for a 1.1-, 2- and 100-year flow event on Tryon Creek, respectively. Additional model results for flow depths and velocities are shown in Appendix E. Figure 2-18 shows the model-predicted water surface profile for the 1.1-, 10-, and 100-year flow events.

As shown on Figure 2-15, flows are generally contained in the channel during a 1.1-year flow event, except in a few localized areas. Upstream of Lake Earl Drive, overbank inundation occurs to the south of the existing channel, where abandoned historical channel scars are present. Additionally, there may be some shallow overbank flooding in the abandoned channel scar to the north of the channel. Overbank flooding also occurs in the willow thicket downstream of Lake Earl Drive, where flows then follow a depression to the north of the channel formed by an abandoned historical channel. The landowner has indicated that floodwaters frequently inundate this area and do not drain well due to hummocky ground.

During the peak of a 2-year flow event, as shown on Figure 2-16, channel capacity is exceeded and water begins inundating the floodplains. The discontinuous berms adjacent to the channel upstream of Lake Earl Drive do not appear contain flow within the channel, and form "islands" of dry land. Additionally, flows on Tryon Creek can be expected to overtop the berm near the upstream end of the project area and flow down the abandoned historical channel in the field to the north. These flows will spill over Lake Earl Drive about 400 feet north of the existing road crossing, and continue flowing through the pasture to the north of the channel for about 1,000 feet before returning to the Tryon Creek channel. Downstream of Lake Earl Drive, the 2-year flooding depths are deeper in the willow thicket, and more flow is forced into the abandoned historical channel north of the existing channel. In the downstream portions of the project area (Reach 3), where the channel is deeper, the 2-year flow is mostly contained within the channel.

Figure 2-17 shows the maximum flow depths and extents for a 100-year event on Tryon Creek, which follow the same patterns a 2-year event, but much larger in extent. Additionally, flows spill onto the floodplain in the downstream reaches of the channel (Reach 3). In this area, the floodplain is sloped towards the south, such that the floodplain flows remain connected to the channel.

Water surfaces profiles on Figure 2-18 shows that the 1.1-year flow is generally contained within the top of the channel bank, except in localized areas, such as the willow thicket where the overbanks are low. Flows begin to overtop the Lake Earl Drive crossing at about a 10-year event, but, as shown on Figure 2-17, are also conveyed over Lake Earl Drive about 200 feet to the north of the existing road crossing during a 2-year event and larger. The crossing may go into pressure flow during a 1.1-year flow event, indicating that the culvert is undersized. Pressure flow could cause local scour within and downstream of the crossing.



0 500 1000 ft

CA STATE PLANE ZONE 1 FEET

Legend

- Model Boundary
- Tryon Creek
- Parcel Boundaries

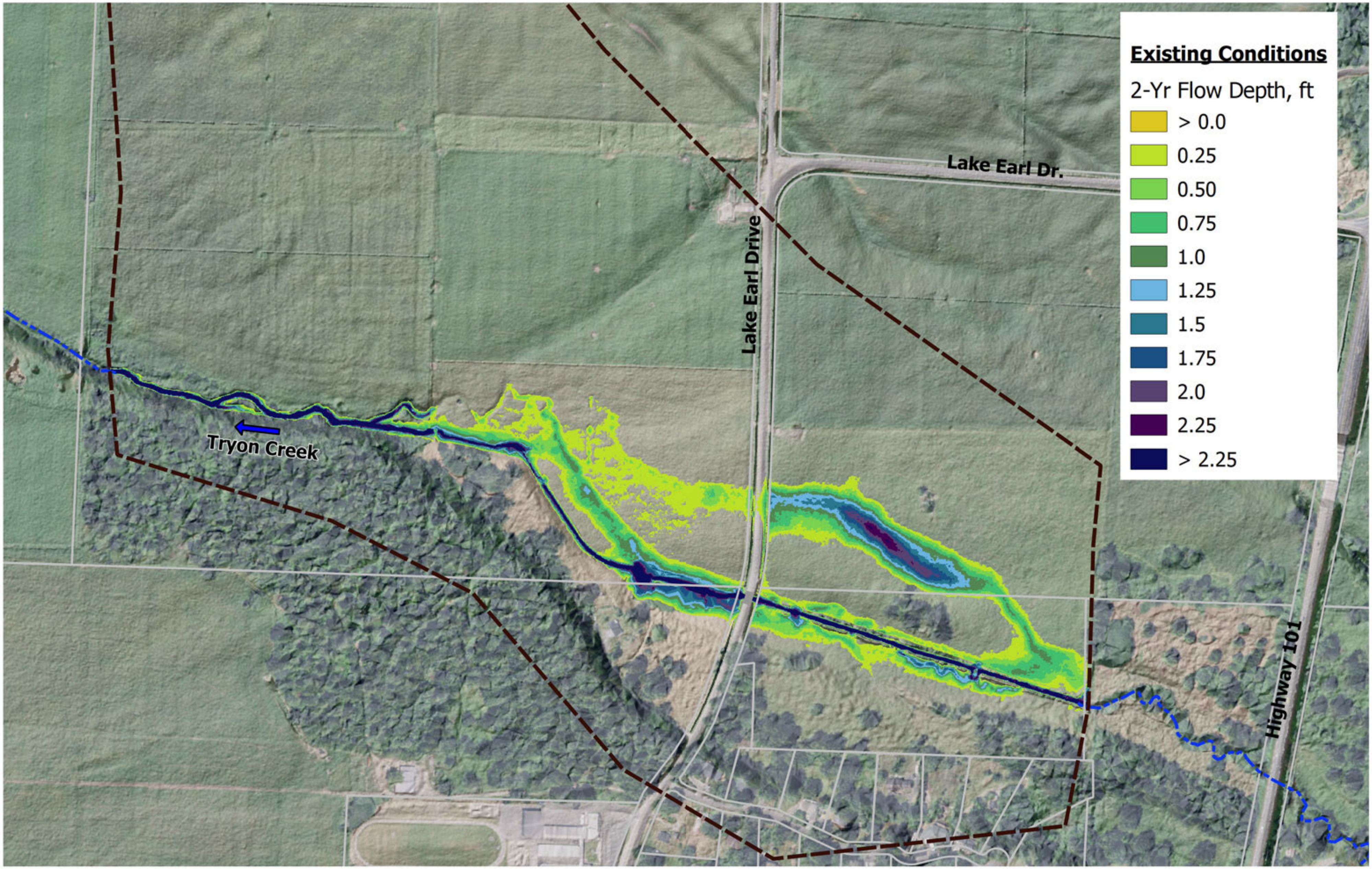
SMITH RIVER ALLIANCE

Michael Love & Associates
Hydrologic Solutions

Upper Tryon Creek Stream Enhancement Design Project

Figure 2-15
Plan View of Existing-Condition Peak Flood Depths and Extents During a 1.1-Year Flow Event (Peak Flow of 104 cfs) on Tryon Creek

Filepath: Q:\Tryon Creek Restoration\7_CAD-GIS\QGIS\Working\Model_Results.qgz



0 500 1000 ft

CA STATE PLANE ZONE 1 FEET

Legend

- ▭ Model Boundary
- - - Tryon Creek
- ▭ Parcel Boundaries

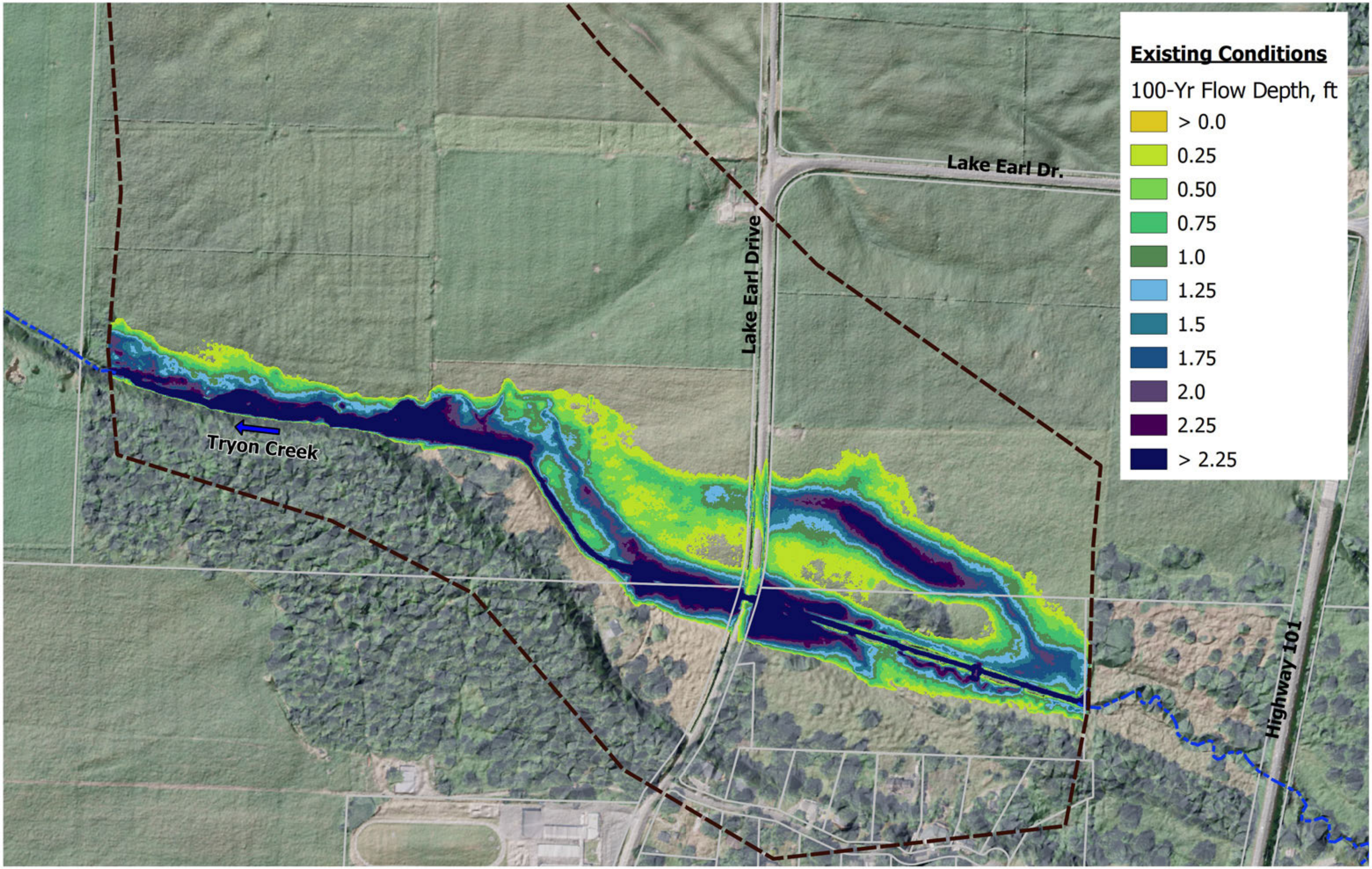
SMITH RIVER ALLIANCE

Michael Love & Associates
Hydrologic Solutions

Upper Tryon Creek Stream Enhancement Design Project

Figure 2-16
Plan View of Existing-Condition Peak Flood Depths and Extents During a 2-Year Flow Event (Peak Flow of 239 cfs) on Tryon Creek

Filepath: Q:\Tryon Creek Restoration\7_CAD-GIS\QGIS\Working\Model_Results.qgz



0 500 1000 ft

CA STATE PLANE ZONE 1 FEET

Legend

- ▭ Model Boundary
- --- Tryon Creek
- ▭ Parcel Boundaries

SMITH RIVER ALLIANCE

Michael Love & Associates
Hydrologic Solutions

Upper Tryon Creek Stream Enhancement
Design Project

Figure 2-17
Plan View of Existing-Condition Peak Flood Depths and Extents During a 100-Year Flow Event (Peak Flow of 1,009 cfs) on Tryon Creek

Filepath: Q:\Tryon Creek Restoration\7_CAD-GIS\QGIS\Working\Model_Results.qgz

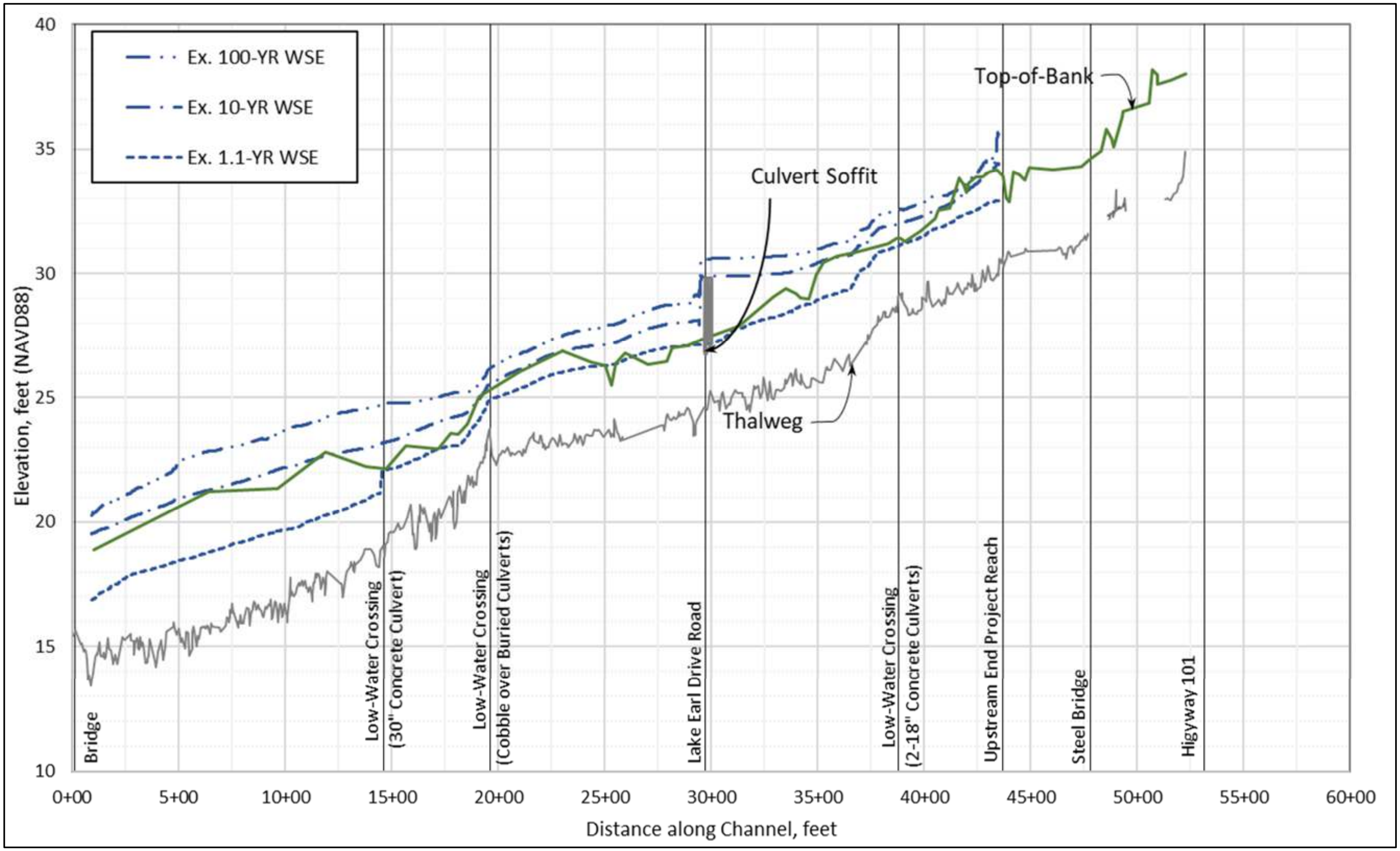


Figure 2-18. Model-predicted peak water-surface profiles for the 1.1-, 10- and 100-year flow events on Tryon Creek. Flows begin to overtop Lake Earl Drive at the crossing at about a 10-year event, but flows are also conveyed over Lake Earl Drive about 200 feet to the north of the existing road crossing during a 2-year event and larger.

3 STREAM CHANNEL DESIGN

3.1 Design Objectives

The design intent for the project is to re-establish the Tryon Creek stream channel in its historical alignment and create a geomorphically stable channel similar to the reference reach, while achieving the project objectives outlined in Section 1.3. Other design objectives included:

- Establish a fenced riparian corridor that averages 35 feet wide beyond the design top of channel bank
- Create highly diverse native riparian area including conifers to shade-out and control reed canary grass
- Incorporate bioengineered bank stabilization to rapidly achieve bank stability similar to the reference reach
- Install large wood structures for both geomorphic control and to provide habitat complexity
- Minimizing tree removal, as feasible

Additional design objectives for the new agricultural bridge and low-water crossing are presented in Section 4 of this report.

Design plans for the channel restoration are shown in Appendix A. Details of specific project components are discussed in the following sections.

3.2 Planform Geometry

The restored channel will generally follow the existing channel alignment, but will be located within a fenced riparian corridor with a total width of 85 feet (15-foot bankfull channel width plus 35 feet of riparian corridor per side), (See Section 7).

Within the fenced riparian corridor, the channel will be realigned to a more sinuous geometry from the upstream end of the project area at station 46+40 to downstream at station 14+00. The historical alignment of Tryon Creek will be reoccupied where it is feasible. Specifically, the new channel between about station 36+00 to 42+00 will be restored to the alignment evident currently and on the 1958 aerial photographs (Figure 2-12). In other locations, the restored channel realignment will be based on tracings of the historical channel that were “copied” and “moved” to create the restored channel alignment.

Restoring the meanders within the channel increases the overall channel length within the realigned area by about 289 feet, which will produce a sinuosity of 1.1. It was not feasible to design a more sinuous channel because of land use constraints.

The meander corridor for the design channel will range from about 50 to 60 feet, about the average width of the historical and reference reach meander corridor (Table 2-2).

Downstream of station 14+00, the channel currently follows its historical alignment against the valley wall and is more forested. Restoration downstream of station 14+00 will consist of fencing and enhancing the riparian area, as described in Section 7.

3.3 Cross Sectional Shape

The cross-sectional shape of the restored channel between station 14+00 and 46+40 was based on reference reach values summarized in Table 2-2, and is shown in Figure 3-1. The channel will be trapezoidal in shape with an 8-foot bottom width and 1.5H:1V side slopes. The channel bottom width was based on the larger active channel widths measured in the reference reach. The channel banks in the reference reach are stabilized in part by tree roots. A newly constructed channel will not have the extra reinforcement of the tree roots. The constructed extra channel width will reduce the erosive forces on the banks, maintaining stability until the vegetation becomes established.

The floodplain within the riparian corridor will be graded to drain towards the channel. The bankfull depth, where flows spill onto the floodplain, will be 2.5 feet deep (excluding pools), before it spills onto the floodplain. The design bankfull depth is on the low side of the bankfull depths measured in the reference reach, but was necessary to achieve positive drainage of the floodplain towards the channel.

The design bankfull width will be 15.5 feet wide, widening to about 25-feet wide at meander bends where a point bar will be graded on the inside of the meander bend. The point bar design was obtained from the dimensions of the low benches observed in the reference reach.

Upstream of Lake Earl Drive, the existing spoil piles adjacent to both sides of the channel will be removed, and the earth from the piles incorporated into the project. The existing channel will be filled-in at locations where the realignment will create a new channel.

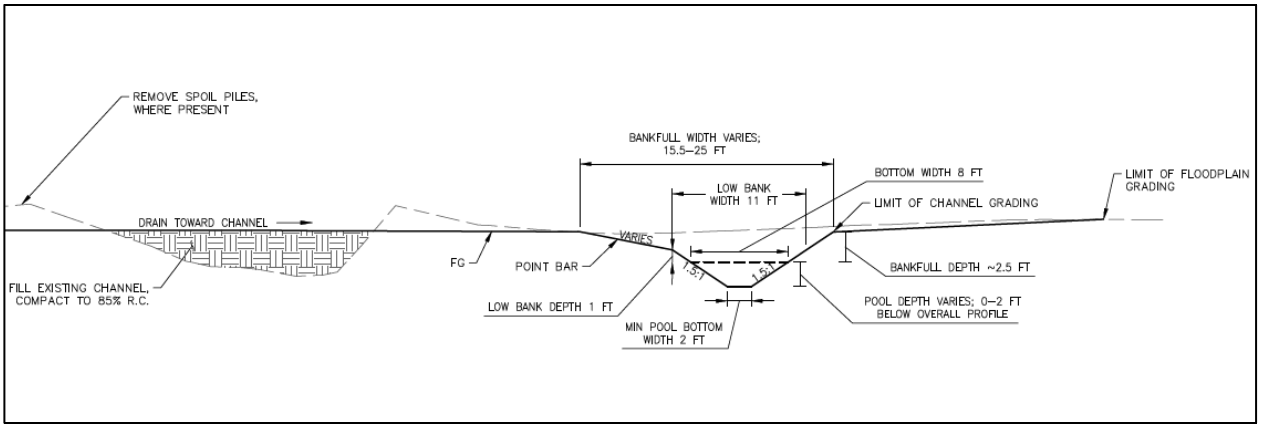


Figure 3-1. Typical design cross section for Tryon Creek.

3.4 Channel Profile

The overall slope of the restored and realigned reaches of the channel will be 0.36%, which is slightly less than the 0.38% slope of the reference reach upstream. The geomorphic assessment found that sediment transport in the existing channel occurs primarily as fine-grained suspended load, with minimal in-channel deposition. Therefore, slight reduction in the design channel slope is not expected to result in sediment deposition and channel instabilities.

To create more habitat complexity, pools with residual depths of 2 feet will be constructed on the outside of meander bends, where flow scouring forces typically create pools. To maintain the pool depths, restore habitat, and create flow complexity, several different types of large wood features will be installed within the channel (Section 3.6). Over time, habitat and flow complexity is expected to increase with the growth of the riparian area, which will then supply wood and debris of various sizes to the channel.

3.5 Backwater Alcoves

A total of eight new off-channel alcoves will be constructed (Alcoves A through G), and the existing alcove near station 12+00 will be enhanced (Alcove H). The water levels within the alcoves will be controlled through backwatering from the stream. The intent of the alcoves is to provide off-channel high-flow refugia for rearing salmonids and deep pools (1.7 to 4.4 feet winter baseflow), for water quality and refuge from predators.

A wetland bench in each alcove was designed to have shallow submergence during winter baseflows, to support emergent wetland vegetation and increase primary productivity for foraging salmonids. The allcove connection, or "throat" is the same elevation as the channel thalweg, and water levels in the alcoves will be governed by the water levels in the stream channel. The alcoves will also transition overbank flow back into the stream channel at higher flows.

Alcove H is the remnant of a historical channel of Tryon Creek. The bottom of Alcove H will be deepened as much as feasible without disturbing the riparian vegetation around the alcove.

Table 3-1provides a summary of the total length, area and residual pool depth of each alcove.

Table 3-1. Tryon Creek alcove length, area, and residual depth at winter baseflow.

Alcove	Length	Area	Residual Depth
Alcove A (New)	130 feet	3,066 square feet	3.5 feet
Alcove B (New)	97 feet	2,435 square feet	3.6 feet
Alcove C (New)	81 feet	1,988 square feet	4.4 feet
Alcove D (New)	68 feet	1,612 square feet	2.6 feet
Alcove E (New)	70 feet	1,160 square feet	1.7 feet
Alcove F (New)	57 feet	900 square feet	1.7 feet
Alcove G (New)	111 feet	2,691 acres	2.4 feet
Alcove H (Enhanced)	280 feet (Approx.)	9,780 square feet (Approx.)	Field Fit

3.6 Large Wood Features

Habitat complexity in both the reference reach and the wooded channel reach at the downstream end of the project area is created mostly by the channel planform geometry and the presence of partial to full-spanning jams comprised of materials ranging from debris and limbs, to larger trees. Some of the jams are more transient, while others are more permanent.

Both partial and full-spanning large wood structures will be incorporated into the project area. The intent of the structures is for local streambank protection, and to create pool scour, flow complexity, and cover for fish. Types of large wood structures are proposed for the project are single root wads, log overhang structures, and scour logs. The following sections describe each large wood structure, and Section 6 presents computations of structure stability.

3.6.1 Root Wads

Root wads are expected to consist of trees with root fans, as shown in Figure 3-2. The design intent for a root wad is to protect the channel bank on the outside of a meander bend, force or maintain a small scour pool, and create an overhang for cover and edge complexity for rearing fish. Root wads are generally located in in pools on the meander bends, and in some alcoves where other wood structures were too large. To provide stability, the trunk end of the root wad will be pinned using rebar and bolts to a vertical log pile driven into the ground and the trunk end buried.

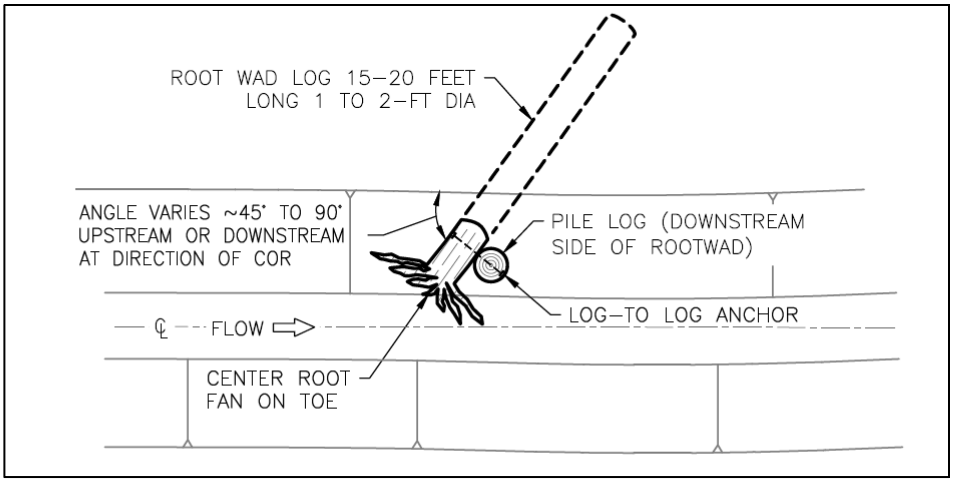


Figure 3-2. Typical plan view of a root wad anchored with a log pile on the downstream side.

3.6.2 Scour Logs

Scour logs will consist of a tree trunk or wood chunk. Scour logs mimic downed wood that partially spans the channel in the reference reach, with flow passing both under and over the log. The flow passing under the log creates a scour hole. Figure 3-3 shows a typical cross section of a scour log.

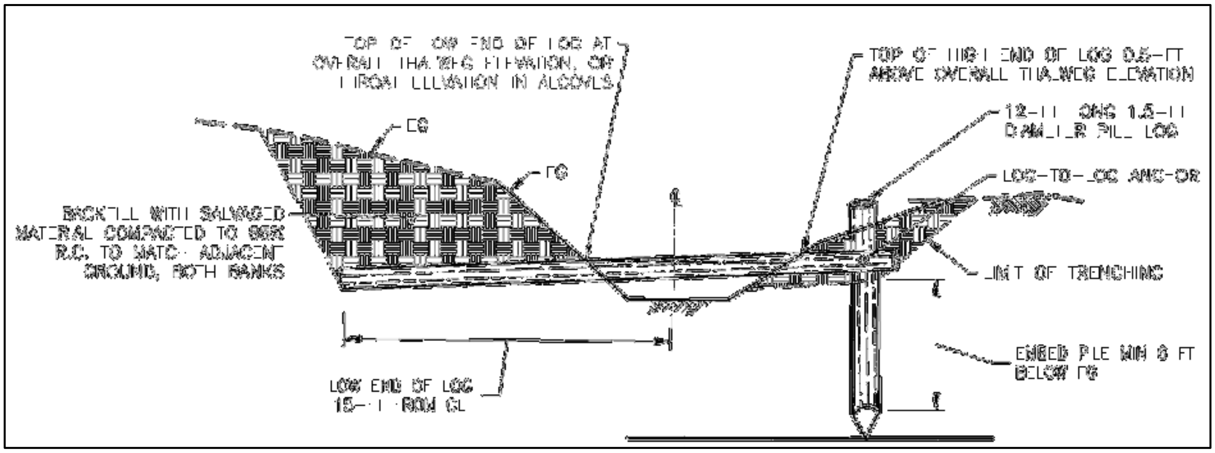


Figure 3-3. Typical cross section of a scour log anchored with a log pile on the higher side of the structure.

The intent of scour logs is to create a scour pool, creating cover and a pool for fish habitat. Scour logs are generally located in pools on meander bends. The low side of the log is placed at the elevation of the overall channel slope, thus it is not intended to provide grade control. They are also shown in several alcoves, where they are expected help promote scour of deposited fine sediment, create an overhang structure for cover, and a perching area for birds. To provide stability, the high side of the scour log will be pinned using rebar and bolts to a vertical log pile driven into the ground, and the low side of the log buried.

3.6.3 Log Overhang Structures

Log overhang structures will consist of three logs. Two "support" logs will project from the channel bank, and a third log will be pinned to the support logs parallel to stream flow, as shown in Figure 3-4. Brush or tree root balls are pinned under the crossing log. Two driven log piles anchored to the structure will provide structure stability. The ends of the support logs are buried.

Log overhang structure are used for two different purposes. In alcoves, the structures are used to create a large overhanging area with complexity created by the brush as shade or predator refugia for rearing fish. Small scour pools may form under these structures when the alcoves receive flows from the floodplain.

On the main channel, log overhang structures are used to protect the streambank and create "hammerheads" in tighter meander bends. The hammerhead function of the structure is to protect the streambank with a non-erosive revetment of logs, forcing flows to expend their energy by forming scour pools at the structure.

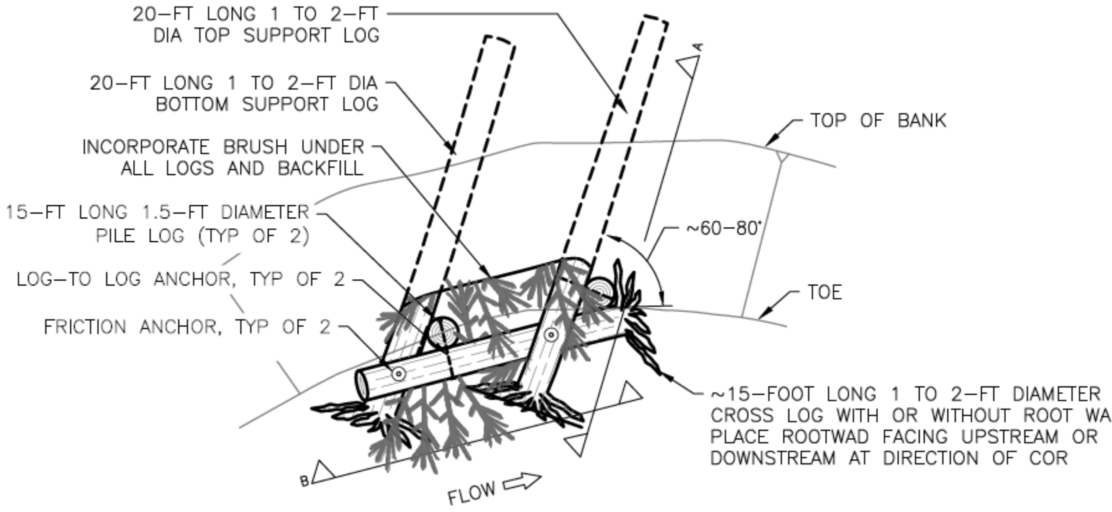


Figure 3-4. Typical plan view of log overhang structure.

4 STREAM CROSSING DESIGNS

The two existing low-water crossings downstream of Lake Earl Drive will be replaced with a single full-span bridge at station 14+50, near the existing downstream most low-water crossing. A new low-water crossing will be constructed upstream of Lake Earl Drive at station 42+10, slightly upstream of the existing crossing.

4.1 New Bridge

A new bridge will be constructed near station 14+50, just upstream of where an existing cattle lane crosses the stream. The hydraulic design of the new bridge was based on stream simulation design methodologies (CDFG, 2009; USFS, 2008). A stream-simulation crossing is designed to fully-span the bankfull width of the design channel and convey the stream's 100-year flow event to maintain stable geomorphic processes through the crossing and reduce the risk of plugging with debris.

4.1.1 Bridge Superstructure

The new bridge will consist of a 50-foot span, 14-foot wide prefabricated Big R bridge (or similar), which is a steel-beam bridge with precast concrete strip footings. The bridge deck will consist of a steel pan that can be filled with gravel, paved, or covered with wooden wearing boards. Standard shop drawings for a Big R bridge and precast footings are shown in Appendix A.

A layout of the new bridge and approaches is shown in Appendix A. The southern bridge approach will connect with an existing gravel road, the bridge will cross the stream nearly perpendicularly to the flow, and the northern approach will parallel an adjacent fence line. The roadway approaches to the bridge were designed with a maximum 6% slope to allow access for farm equipment towing trailers with 40-foot irrigation pipe.

The bridge was designed to provide freeboard above the 100-year water surface elevation on Tryon Creek, but would be inundated during the 100-year (baseflood) Smith River event (See Section 5).

4.1.2 Geotechnical Investigation and Bridge Foundation Design

As part of their limited geotechnical investigation of the project area (Appendix B), SHN (2020) performed two hand auger borings at the proposed foundation locations for the new bridge and made recommendations for a foundation system for the bridge. The subgrade at the proposed bridge foundation locations was found to be saturated and compressible soils subject to settlement. It is anticipated that compaction of the native material to support footings for the bridge structure will not be feasible. Because of the subgrade conditions, SHN recommended a stabilization mat be installed under each of the bridge footings. The purpose of the stabilization mat is to distribute the load of the bridge footing across a broad area using a flexible, low density, laterally constrained structure that will maintain its integrity if settlement occurs.

SHN recommended a stabilization mat consisting of welded wire gabions filled with crushed aggregate, wrapped in filter fabric. A schematic cross section of a stabilization mat is shown in Figure 4-1. The mat should be designed to provide a basal footing load of 1,000 pounds per square foot (psf). The concrete strip footings of the bridge should be centered on the stabilization mat and not exceed a load of 2,500 psf. The thickness of the mat should be minimum ¼ of the basal width. The base of the mat closest to the channel should be constructed on or behind a sloping plan of 2H:1V starting at the edge of the channel bottom.

The size of the stabilization mat is dependent on the size of the bridge footing, which varies with manufacturer. Assuming a 5-foot wide footing and a standard load of 2,500 psf exerted by the footing, the stabilization mat under each bridge abutment will need to be about 12.5 feet wide, about 18 feet long, and 3.1 feet thick. The final dimensions of the stabilization mat will be determined as part of the project implementation phase, once the prefabricated bridge is procured and bridge loading calculations provided by the manufacturer. A cross section and detail of the bridge and the stabilization mat are shown in Appendix A.

It can be expected that due to the low bearing capacity of the subgrade soils, some settlement could still occur. However, the bridge will be located on a gravel agricultural road, which can be regraded to meet the bridge approaches if settlement occurs.

Rock slope protection (RSP) will be placed under the bridge and under the channel subgrade to protect against scour. Additional details of the RSP sizing and scour analysis are presented in Section 5.2.3.

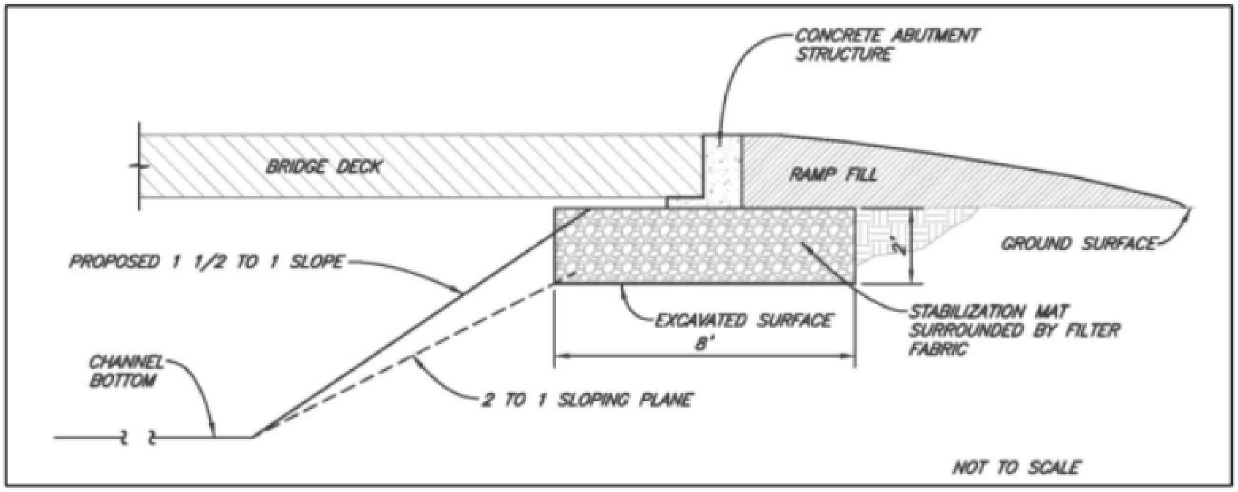


Figure 4-1. Schematic drawing of a foundation system for bridges, SHN (2020).

4.2 Low-Water Stream Crossing

A new low-water crossing will be constructed upstream of Lake Earl Drive near station 42+10 to replace the existing low-water crossing. The low-water crossing will consist of aNRCS-765 Stream Crossing, designed in accordance with NRCS standards. The crossing will consist of angular 4- to 8-inch aggregate infilled with smaller material to seal the placed rock. The sealing with smaller material will prevent stream flows from percolating into the crossing, which could potentially dry the channel over the crossing.

The crossing will primarily be used during the dry season, when the channel is dry. It will be used for cattle crossing the channel to the south pasture, and potentially by ranch trucks. Although infrequent, there are times during the wet season that cattle may need to be moved quickly to the south pasture and higher ground when the Smith River is predicted to reach flood stage.

The crossing will be 16 feet wide, as specified by NRCS to accommodate agricultural equipment. The crossing will be constructed with 8H:1V (12.5%) approach slopes with 5-foot long flat transitions on the ends. In total, the crossing will be approximately 58 feet long.

At the request of the landowner, an irrigation pipe will be buried under the crossing, with risers, and connecting hardware at each end of the crossing. To be designed by NRCS, this will allow irrigation of the south pasture while eliminating the practice of stringing a waterline over the channel during the dry season, which could impact riparian revegetation efforts.

Construction details and specifications for the stream crossing are shown in Appendix A.

5 PROPOSED-CONDITION HYDRAULICS

5.1 2-D Model Setup

A proposed-condition hydraulic model was developed to evaluate the effects of the proposed project on channel capacity, flow conveyance, flooding extents, and the 100-year water surface elevation for Tryon Creek. The results of the modeling were also used to assess the stability of the large wood features, to size the rock slope protection (RSP) under the new bridge, and to perform a scour analysis for the bridge.

The proposed-condition model was created by modifying the 2-D existing-condition HEC-RAS model (Section 2.6). Modifications included replacing the existing-condition terrain with the proposed terrain to reflect proposed grading of the channel and floodplain, berm removal upstream of Lake Earl Drive, the proposed bridge approaches, and removal of the existing low-water crossing culverts.

All model roughness values remained the same, except that the proposed riparian corridor was modeled with a roughness of 0.08 to simulate light brush and trees in the new riparian area and an open channel was modeled through the willow thicket downstream of Lake Early Drive.

The 1.1-, 2-, 10-, and 100-year flow events were modeled. Similar to existing conditions, modeling for all flow events except the 100-year were executed using the diffusion wave computational method. Modeling for the 100-year event was performed using the full momentum computational method, which applies the full St. Venant equations.

5.2 2-D Model Results

5.2.1 Flood Extents, Depths and Velocities

Figure 5-1 and Figure 5-2 show 2-D model-predicted peak inundation depths and extents for 1.1-year and 2-year peak flow events. Figure 5-3 shows show 2-D model-predicted peak flow velocities during a 100-year flow event on Tryon Creek. Figure 5-4 shows model-predicted water-surface profiles for the existing and proposed 1.1-, 2-, and 10-year peak flows on Tryon Creek. Figure 5-5 shows model predicted water surface profiles for the existing and proposed condition 100-year peak flow on Tryon Creek. Additional model results are shown in Appendix F.

Model results indicate the proposed project will slightly increase flow conveyance in the main channel and adjacent floodplain, thus causing les flow to be directed to the low area north. This results in slightly more flow being conveyed to the culvert crossing at Lake Earl Drive than under existing conditions, as shown in Table 5-1. The increase in conveyance is a result of a more uniform channel cross section and profile, as well as removal of dense thickets of vegetation that currently obstruct the channel. Flows not conveyed in the main channel to Lake Earl Drive will continue to flow in the pasture to the north and over Lake Earl Drive. Except for the 1.1-year event, the increase in channel conveyance in the main channel slightly increased proposed-condition water surface elevations at the Lake Earl Drive culvert, and decreased flooding depths and flows over the roadway to the north of the crossing.

Table 5-1. Combined flow conveyed through the culvert and over the road at Lake Earl Drive crossing. Remainder of the flow is conveyed over Lake Earl Drive further to the north.

Flow Event (Total Flow)	Existing Conditions	Proposed Conditions
1.1-Year (104 cfs)	104 cfs	104 cfs
2-Year (239 cfs)	199 cfs	205 cfs
10-Year (52 cfs)	259 cfs	395 cfs
100-Year (1009 cfs)	715 cfs	736 cfs

A shown on Figure 5-1 and Figure 5-4, during a 1.1-year flow event, floodwaters are mostly contained within the channel near the top of bank elevation, except for some shallow overbank flooding onto the graded floodplain that is expected to drain back into the channel as flows recede, rather than pond on the floodplain like they do now. Overbank flow around the willow thicket is expected to still occur, but to be shallower than existing conditions (Figure 2-15). As shown in Figure 5-1 and Appendix F, channel flows are expected to backwater into the alcoves, and water velocities in the alcoves are expected to remain less than 0.5 fps.

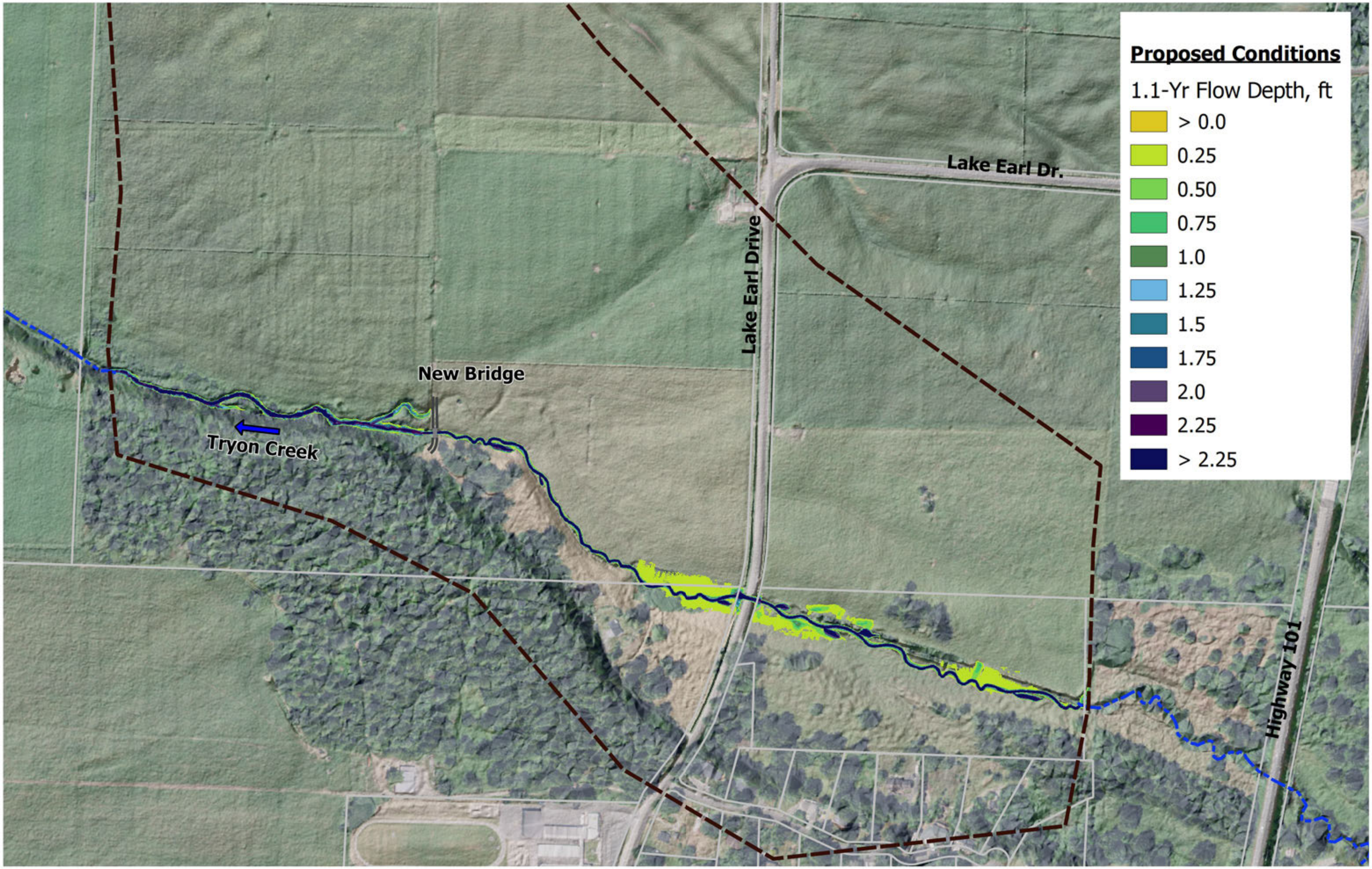
As flows increase to the peak of a 2-year event and higher, overbank inundation patterns are expected to be similar to existing conditions (Figure 2-16), though slightly shallower due to the increased channel capacity (Figure 5-2 and Appendix F). The proposed floodplain grading will allow flows adjacent to the channel to drain back into the channel, improving overbank drainage from current conditions and reducing potential for fish standing.

Proposed-condition 2- and 10-year water surface elevations (WSEs) will be slightly higher upstream of Lake Earl Drive due to the increased flow in the main channel and decreased flow over the pasture to the north (Table 5-1). Downstream of Lake Earl Drive, WSEs during a 2-year event and large will be lower than existing conditions in most of the project reach as a result of removing the existing low-water crossings.

Figure 5-2 and in Appendix F shows that all constructed alcoves will experience overbank flows passing through the alcoves, scouring accumulated sediment that may have deposited. The alcoves will experience the highest through-flow velocities during a 2-year event. During large flow events, flows are backwatered on the floodplain sufficiently to maintain lower velocities in the alcoves.

Figure 5-5 indicates the project can be expected to slightly increase Tryon Creek 100-year water surface elevations in localized areas upstream of Lake Earl Drive. This increase in water level is not expected to extend upstream to Highway 101. The new bridge and associated approaches will cause slightly more than 1-foot of increase in the 100-year water surface elevation extending about 500 feet upstream of the bridge, but this rise will not extend to Lake Earl Drive.

The Tryon Creek 10- and 100-year flow patterns are not expected to change substantially from existing conditions. Under proposed conditions, 10- and 100-year floodplain flows upstream of the northern bridge approach will be deeper and have lower velocities. Additionally, flows will split around the northern bridge approach, with the bulk of the flow passing under the bridge and some flow passing to the north of the approach. As shown in Appendix F, during the 100-year event high water velocities may occur around the north side of the bridge approach. The higher velocities may cause local erosion of the cattle lane in this area during the 100-year event. Erosion in this area will not affect the integrity of the bridge, and can be repaired with localized grading after the extreme flow event.



0 500 1000 ft

CA STATE PLANE ZONE 1 FEET

Legend

Model Boundary

Tryon Creek

Parcel Boundaries

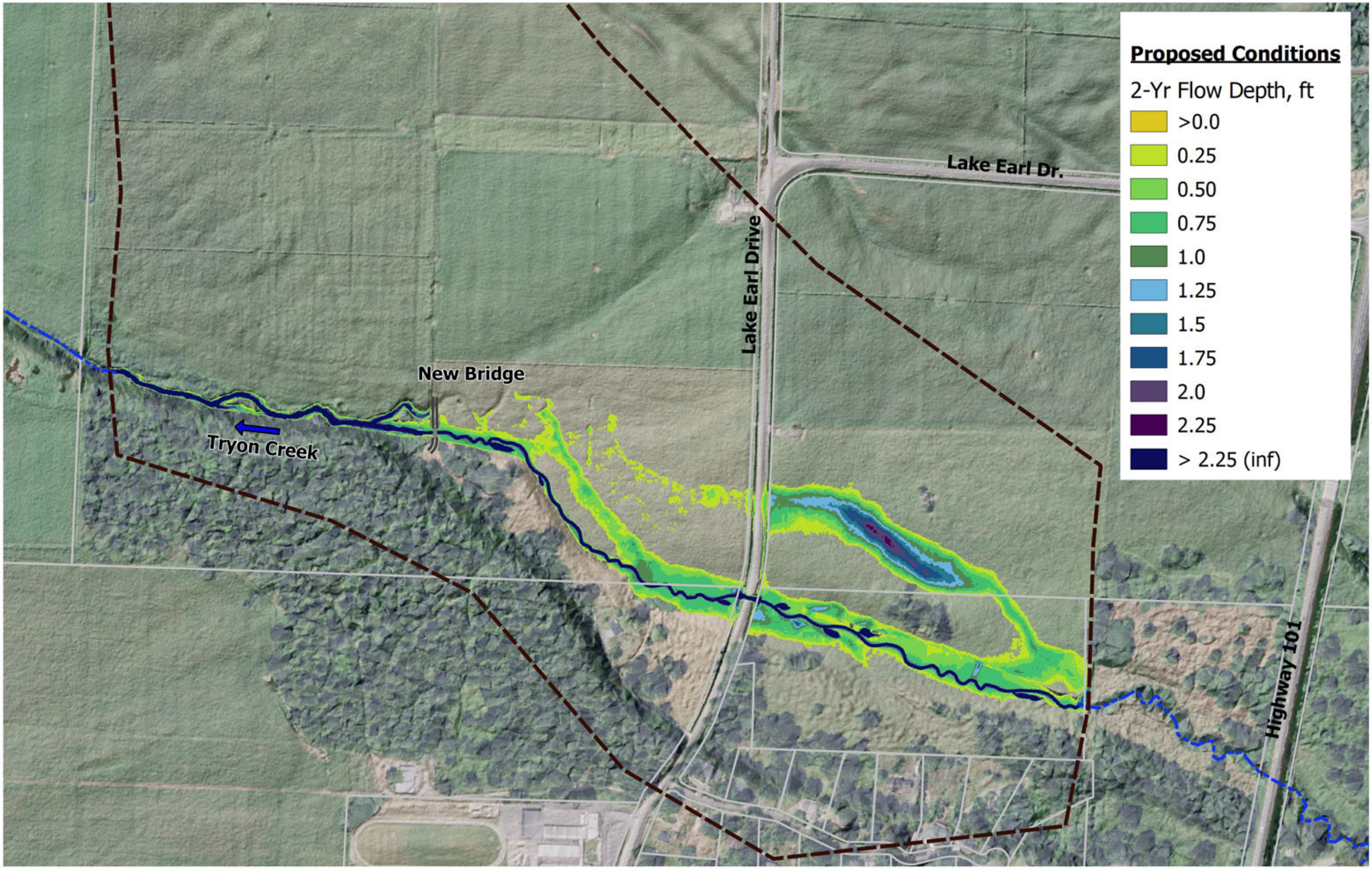
SMITH RIVER ALLIANCE

Michael Love & Associates
Hydrologic Solutions

Upper Tryon Creek Stream Enhancement Design Project

Figure 5-1
Plan View of Proposed-Condition Peak Flood Depths and Extents During a 1.1-Year Flow Event (Peak Flow of 104 cfs) on Tryon Creek

Filepath: Q:\Tryon Creek Restoration\7_CAD-GIS\QGIS\Working\Model_Results.qgz



0 500 1000 ft

CA STATE PLANE ZONE 1 FEET

Legend

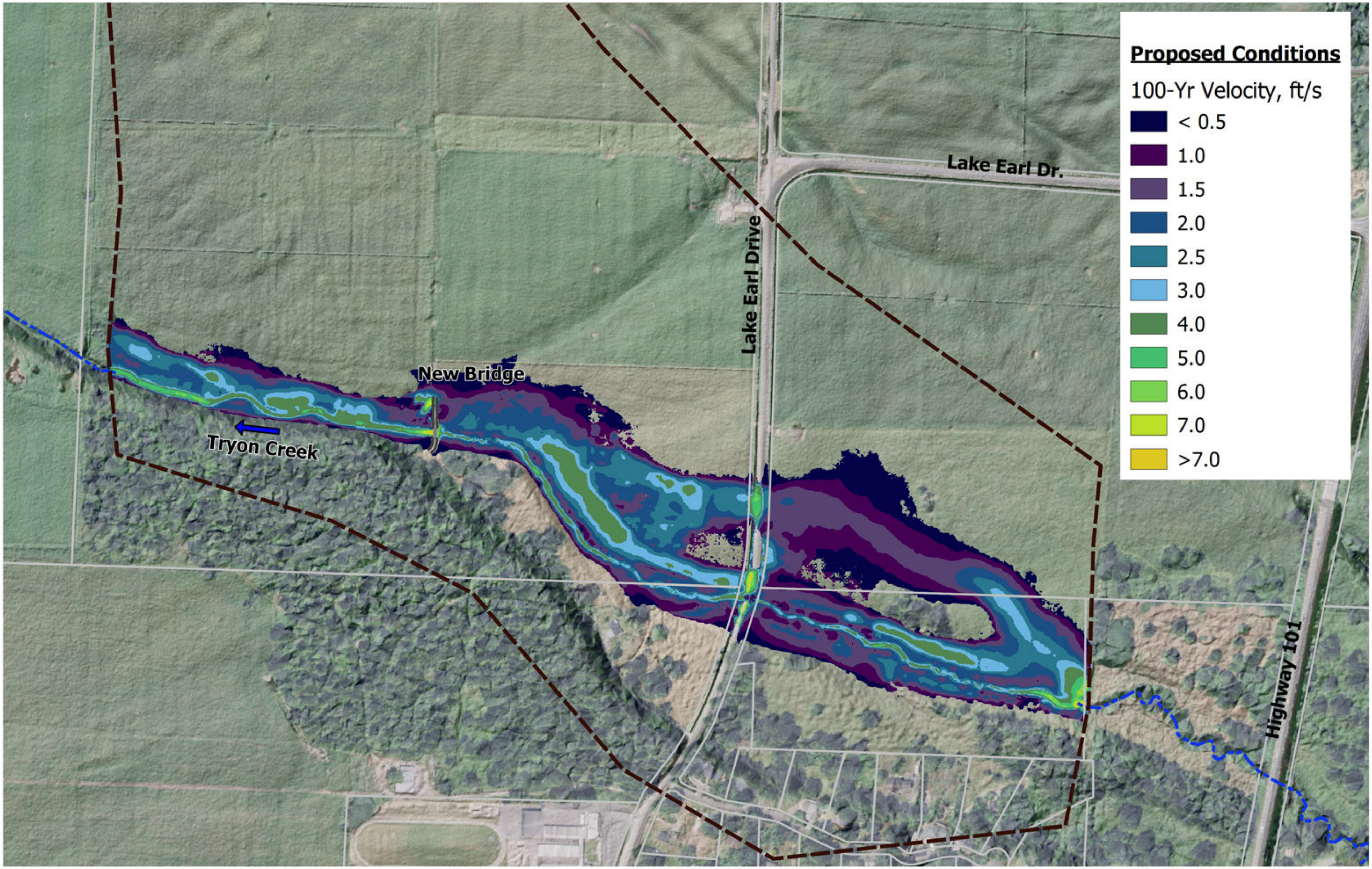
- Model Boundary
- Tryon Creek
- Parcel Boundaries

SMITH RIVER ALLIANCE

Michael Love & Associates
Hydrologic Solutions

Upper Tryon Creek Stream Enhancement Design Project

Figure 5-2
Plan View of Proposed-Condition Peak Flood Depths and Extents During a 2-Year Flow Event (Peak Flow of 239 cfs) on Tryon Creek



0 500 1000 ft

CA STATE PLANE ZONE 1 FEET

Legend

Model Boundary

Tryon Creek

Parcel Boundaries

SMITH RIVER ALLIANCE

Michael Love & Associates
Hydrologic Solutions

Upper Tryon Creek Stream Enhancement Design Project

Figure 5-3
Plan View of Proposed-Condition Peak Flood Velocities and Extents During a 100-Year Event (Peak Flow of 1,009 cfs) on Tryon Creek

Filepath: Q:\Tryon Creek Restoration\7_CAD-GIS\QGIS\Working\Model_Results.qgz

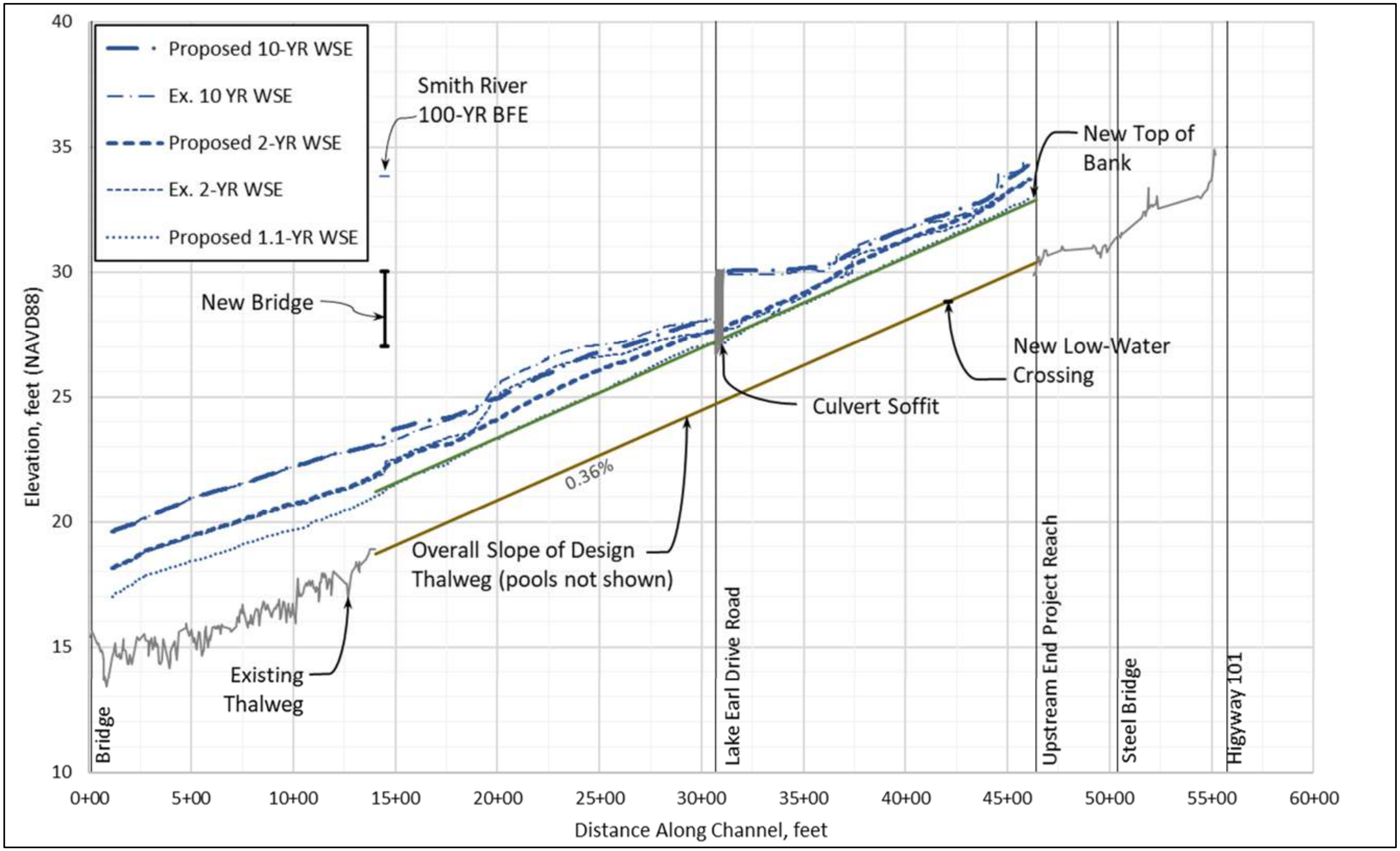


Figure 5-4. Design profile for Tryon Creek with model-predicted 1.1-, 2- and 10-year water surface profiles for existing and proposed conditions. For clarity, the existing condition 1.1-year model results are not shown.

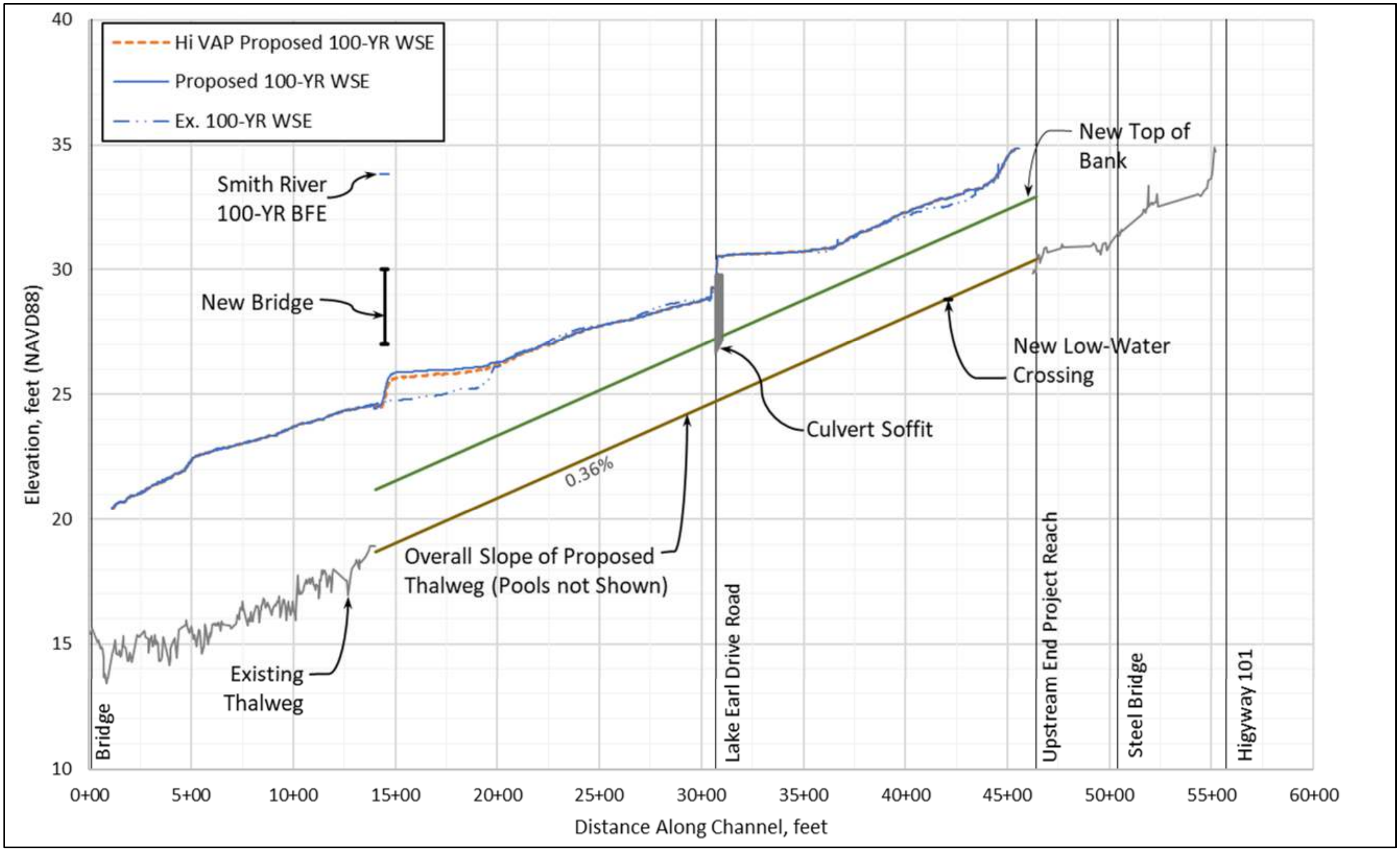


Figure 5-5. Design profile for Tryon Creek with model-predicted 100-year water surface profile for existing and proposed conditions.

5.2.2 Establishment of Bridge Elevation

Following CDFG (2009) guidelines, the bottom elevation of the new bridge was set above the Tryon Creek 100-year water surface elevation. CDFW (2009) recommends that the 100-year flow does not impinge on the face of a bridge under High Vertical Adjustment Potential (High VAP) condition. The High VAP condition considers potential large wood blockages or sediment aggradation within the channel that decrease the channel capacity. For Tryon Creek, the High VAP condition evaluated assumed the channel could become blocked with debris and sediment upstream, downstream, and under the bridge crossing. The design also aimed to place the bridge spread-footings above the Tryon Creek 100-yeear water surface elevation to reduce risk of scour around the footings, with the understanding that the welded wire gabion baskets will provide scour protection.

Figure 5-5 shows model predicted water-surface profiles for the existing and proposed 100-year peak flow on Tryon Creek. The proposed High VAP water surface profile is also shown. The predicted 100-year water surface elevation at the bridge is 25.5 feet. The predicted High VAP WSE at the bridge is lower than if the channel were not obstructed. The obstruction in the channel for the High VAP condition results in additional flow going around the northern bridge approach.

Based on the results of the hydraulic modeling, it is recommended the bottom of the bridge footings be set at a minimum elevation of 25.5 feet, just above the expected 100-year WSE. The bottom of the bridge should be set at a minimum elevation of 27.0 feet, providing 1.6 feet of freeboard during a 100-year event. The bridge superstructure, excluding footings, is expected to be about 3-feet thick, resulting in a bridge deck elevation of approximate 30.0 feet. The final deck elevation will be determined once the prefabricated bridge is procured superstructure thickness is provided.

Figure 5-4 shows the entire bridge superstructure will be submerged during the baseflood (100-year flow) event on the Smith River. Therefore, the new Tryon Creek bridge and footings should be designed to remain stable when subjected to flow impingement.

5.2.3 Bridge Scour Analysis

To assess the stability of the channel and abutments around the bridge during a Tryon Creek 100-year flow event, a series of scour analyses were prepared. The potential for scour to occur under the new bridge crossing was assessed using Federal Highway Administration's HEC-18 procedures (FHWA, 2012). The scour analyses included long-term scour (incision), contraction scour, and local abutment scour. The sum of the three types of scour indicates the total scour depth that the structure should be designed to accommodate. This may be through design of the bridge foundation or by employing scour countermeasures to prevent failure of the bridge from a scour event.

All analyses were performed for a 100-year flow event on Tryon Creek without consideration of a backwater from the Smith River. Based on the FEMA baseflood elevations, which show a relatively low water surface slope through the project reach (Appendix C), it appears that the scour associated with the Smith River 100-year flood would be less than that produced during the 100-year flow event on Tryon Creek.

Long-Term Scour (Channel Stability)

The long-term scour computed using FHWA methods is analogous to the Low Vertical Adjustment Potential Profile evaluation as defined by CDFW (2009). Long-term scour consists of potential channel incision, localized pool scour, and lateral migration that could occur during the lifespan of the structure. Tryon Creek is a low-gradient channel that accesses its floodplain frequently, and there are no known knickpoints downstream of the project area. Therefore, Tryon Creek is not expected to incise.

The geomorphic analysis presented in Section 2.5 indicates that naturally scoured pools typically were no deeper than 1 foot deep. The proposed design includes constructed pools up to 2 feet deep, with large wood features to maintain the pool depths. Therefore, long-term scour at Tryon Creek can be expected to be approximately 2 feet below the overall constructed channel profile.

Section 2.5.2 provided an analysis of the lateral migration potential of Tryon Creek. As shown in Figure 2-12, Tryon Creek historically appeared to flow along two primary alignments, with the northern alignment being abandoned by 1942 when the channel was moved to its current alignment by the landowners. Because the channel has remained within its current ditched alignment since 1942 with minimal lateral movement, there is a low probability that the restored channel alignment will shift substantially.

Scour computations are shown in Appendix G.

Contraction Scour Computation

Figure 5-2 shows a plan view of water velocities and direction. As flows approach the bridge, floodplain flows split, with approximately 732 cfs conveyed under the bridge and about 277 cfs around the northern bridge approach. Flows constricted under the bridge expand back onto the floodplain immediately downstream. This constriction can result in substantial contraction scour.

Live-bed contraction scour at the new crossing was computed using the Modified Laursen equation (FHWA, 2012). This equation computes the average channel depth during scour at the crossing based on the changes in average flow depth, top width, and area between channel cross sections upstream and in the contracted reach within the crossing. The hydraulic variables used for the "uncontracted" cross section were average values derived from HEC-RAS results at a 21-foot long cross section (Section B) spanning the bankfull channel upstream of the bridge, representing the stable channel dimensions transporting sediment. A grain size of 2 mm (coarse sand) was used to

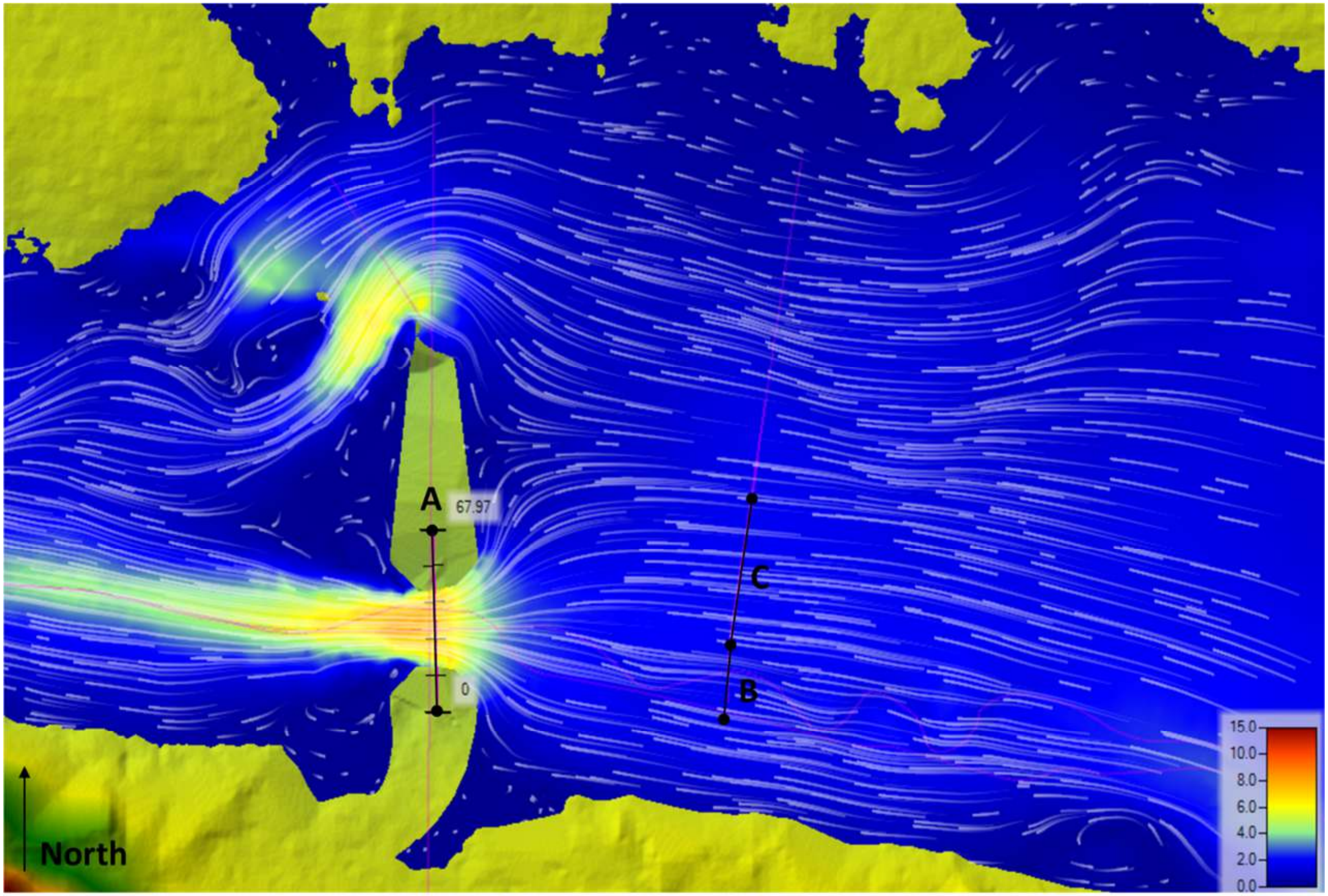


Figure 5-6. Plan view of proposed-condition peak 100-year water velocities in feet per second at the proposed bridge crossing. The white tracers reflect flow direction. Cross sections (A, B, and C) used for the scour analysis are indicated.

determine the critical velocity, which defines the extent of the channel transporting sediment. Cross section A, directly under the bridge, was used for the "contracted" section. A k_1 value of 0.64 was used to reflect the streambed material, assumed to be a combination of bed and suspended load.

The computations indicated that up to 9 feet of contraction scour could occur during a 100-year event. The scour is caused primarily by the large amount of flow being forced through the relatively narrow opening of the bridge. Because substantial scour is expected to occur, it will be necessary to install scour countermeasures to protect the bridge abutment and foundation and minimize the amount of scour that actually occurs (See Bridge Scour Countermeasure Design section).

Abutment Scour Computation (Local Scour)

Abutment scour can occur due to flow acceleration along the bridge approach and abutment. Also, vortices form as flow expands on the downstream sidethe crossing, which can erode the downstream face of the abutments. Abutment scour could also occur due to channel migration impinging on the bridge approach.

Local abutment scour was computed using the Froelich equation (FHWA, 2012). This equation computes the average channel depth during scour in the cross section under a bridge based on floodplain flow depth, length the abutments projection into the flow, and Froude number. A K_1 value of 0.55 was used to simulate a spill-through abutment, and a K_2 value was derived assuming the face of the abutments will be 90-degrees to flow. The hydraulic variables used for the "approach" cross section were derived from a cross section extending across the channel and floodplain, ending at the location where flows split to the north and are conveyed around the bridge approach rather than under the bridge.

The computations indicated up to 10.1 feet of abutment scour could occur during a 100-year event.

Total Potential Scour Depth

Table 5-2 summarizes the scour depths predicted for various types of scour. HEC-18 recommends that total potential scour depth be the sum of contraction, abutment and long-term scour. The total scour depth predicted for the proposed agricultural bridge over Tryon Creek is 20.9 feet.

Abutment scour includes contraction scour in many cases (FHWA, 2012). Additionally, FHWA (2012) indicates that abutment scour computed with the Froelich equation is typically very conservative, especially when the bridge abutment and channel banks are well vegetated. It is likely that the predicted depth of abutment scour will not occur. However, because substantial contraction scour is still expected to occur, it will be necessary to install scour countermeasures to protect the bridge approaches and foundation. The scour countermeasures will also protect the bridge abutments from erosion due to the potential formation to flow vortices downstream of the crossing.

Table 5-2. Summary of predicted scour depths at the proposed Tryon Creek bridge. Total potential scour depth is measured from the finished channel bed under the bridge.

Type of Scour	Scour Depth
Long-Term Scour	2.0 feet
Contraction Scour Depth	8.8 feet
Abutment Scour	10.1 feet
Total Potential Scour Depth	**20.9 feet**

Bridge Scour Countermeasures

The scour analysis indicted that a substantial amount of bridge scour could occur during a 100-year flow event on Tryon Creek. Caltrans Rock Slope Protection (RSP) was selected as the scour countermeasure for the project because it is the most common and cost-effective measure compared to other methods (FHWA, 2009).

RSP sizing was evaluated using three methods. FHWA (2009) recommends using a modified form of the Ishbash Equation (FHWA, 2009 equation 14.1), which is based on velocity and depth of flow under the bridge, and yields the D_{50} (intermediate size) for a gradation of RSP. Caltrans recommends two methods for sizing RSP; the Caltrans Highway Design (Caltrans, 2020) recommends the USACE (1994) equation 3-3 while the Caltrans California Bank and Shore Rock Slope Protection Design manual (Caltrans, 2000) includes an alternative RSP sizing method. The USACE (1994) equation is based on bank slope angle, and average velocity and local depth, and yields a D_{30} and D_{50} value for RSP. The Caltrans RSP method is based on side slope and velocity, and yields a minimum stable rock size. RSP scour countermeasures for all three methods are provided in Appendix H.

The three RSP sizing equations predicted a D_{50} rock size of 0.8 to 1.4 feet, with a minimum size of 0.61 feet. Therefore, ¼ Ton RSP size class would be suitable for scour countermeasures (D50 of 1.8 feet).

FHWA (2009) recommends that RSP scour countermeasures be placed across the channel and around the nose of bridge abutment, extending away from the channel two times the flow depth, or 25-feet (whichever is greater). Inspection of the model-predicted water velocities in Figure 5-2 show high velocities that could cause scour are concentrated around the bridge opening, and do not extend 25-feet behind the toe of the abutment. Therefore, it is recommended that RSP be placed the full height of the abutment and wrap around the nose of the abutment, extending approximately 16 feet back.

To limit the depth of scour in the stream channel, RSP will be buried under the entire stream bottom. To maintain a natural channel bottom, even if a 2-foot deep pool forms, the RSP would be placed 2.5 feet beneath finished grade. Therefore, the RSP under the channel should only become exposed during an extreme scour event and would be covered over with sediment deposition as the flow event recedes.

The intent of the RSP is to act as a scour countermeasure, but also to maintain the stability of the streambanks where there is not enough sun for stabilizing vegetation to grow. Voids in the RSP below the channel bottom will be filled with salvaged streambed material to control porosity and help maintain flows on the streambed surface. Voids in the exposed RSP above the channel bottom will be filled with soil to create a safe walking surface for wildlife passing under the bridge.

6 DESIGN OF IN-STREAM FEATURES

6.1 Large Wood Feature Design

This section described the risk analysis and structural stability designs for the large wood features that will be incorporated into the project area, including rootwads, scour logs, and log overhang structures.

6.1.1 Log Structure Components

The proposed log structures will be constructed using 15- to 30-foot long, 1- to 1.5-foot diameter trees, with or without root wads, as specified. It is anticipated that logs will be purchased and consist of Douglas fir. The structures will be anchored by a combination of burial in the ground and anchoring to log piles driven into the ground.

6.1.2 Risk Assessment and Structure Design Criteria

Risks of the placed large-wood structures to public safety and property damage were evaluated using methods presented in Knutson & Fealko (2014). The risk assessment resulted in the selection of a design flow and structure stability factor of safety commensurate with the level of risk associated with the project.

The project will be located on private property within a fenced area. It is not expected that people will be boating or walking in the stream. Therefore, it was determined that there is low risk to public safety.

Tryon Creek is located within in an area mapped by FEMA as ZONE AE, with flood elevations mapped throughout the project area and downstream to Lake Earl Drive. Also, there are numerous private bridges and buildings downstream of the project area that could be impacted by a piece of large wood that may become dislodged from a constructed large wood structure. Therefore, it was determined that Tryon Creek can be considered to present a high risk for property damages.

6.1.3 Structure Design Flow

Knutson and Fealko (2014) recommend that large wood structures constructed in areas with a low risk for public safety and high risk for property damage be designed to remain stable in flows up to a 100-year event. A minimum Factor of Safety (FS) of 2 is recommended for structure stability based on resisting vertical and moment-based forces, and a FS of 1.75 for sliding or overturning. Structure overturning was not evaluated for this project because the structures are low profile and not expected to be subject to overturning forces.

6.1.4 Structure Stability Assessment

Vertical Force and Moment-Based Stability Analyses

A Microsoft Excel spreadsheet developed by Rafferty (2016) was used to evaluate the stability of the large wood structures. This spreadsheet computes vertical and moment-based forces on a structure including buoyancy, lift, and dead-man ballast; and horizontal forces including drag, passive soil pressure, and frictional resistance. Factors of safety are computed for both vertical and horizontal forces, and using a moment-based analysis for the resultant of the combined horizontal and vertical forces. The computations consider interacting forces between adjacent logs.

Driven log piles anchored to the logs in the structures will be used to provide structure stability. Pile pull-out capacity and required embedment depth was determined using methods in Knudsen and

Fealko (2014), applying the results of the moment-based vertical force computations specific to each structure. The pile capacity computations considered the weight and buoyant force of the pile log.

Wood and Soil Properties and Hydraulic Conditions

The density of Douglas fir was used for the computations. (25.9 lbs/ft^3, USDA, 2009). Dry wood was used for all computations. If redwood is used for the structures, the stability computations will need to be reassessed because dry redwood is less dense than Doulas fir.

Only one of the soil borings was advanced to the anticipated depths that the piles will need to be embedded (See boring HB-1, Appendix B). The subgrade at that depth was described as a stiff, low plasticity lean clay (CL) with sand. No geotechnical properties were provided. Therefore, the streambank into which the structure will be buried was assumed to have standard industry values for a sandy or silty-clay (CL), including a dry unit weight of 124 lbs/ft^3, a porosity of 0.41, and an internal friction angle of 31°. The streambed material over which frictional forces were computed was assumed to be silt.

The proposed-condition 100-year water depth, velocity, and channel area were used in the computations. Hydraulics were obtained from the proposed-condition 100-year HEC-RAS 2-D hydraulic model (Section 5). The computations were prepared with the structures fully submerged.

Computations are provided in Appendix I for each type of structure. Necessary pile embedment are provided for each structure type on the design plans in Appendix A.

7 RIPARIAN RESTORATION

A riparian corridor averaging 35 feet wide on each side of the channel will be established as part of the project. The design top-of-bank (bankfull) width for the channel will be about 15 feet. Therefore, the total riparian corridor, including bankfull channel, should be 85 feet wide. Both sides of the riparian area will be fenced to exclude livestock. The locations of the fence are shown on the design plan in Appendix A.

SRA has developed a comprehensive riparian planting, fencing, monitoring and maintenance plan for the riparian corridor, which is presented in Appendix J. The following sections summarize aspects of the SRA plan.

7.1 Bioengineering

Bioengineering bank stabilization, such as live stakes and live plant divisions salvaged during project construction, will be used in select locations to accelerate bank stabilization with species that rapidly develop a root mass. Live divisions will accelerate bank stabilization and mitigate disturbance to existing native plant populations.

Bioengineering will consist of willow and cottonwood live stakes interspersed with *Carex* and *Juncus* species. Live stakes will be collected from onsite or nearby Pacific willow and black cottonwood trees. Pacific willow and cottonwood are fast growing and easily established from cuttings, and generally have an upright growth form, thus less likely to grow into thickets that restrict the channel size and flow.

7.2 Riparian Corridor Establishment

The Tryon Creek project area between stations 14+00 and 46+30 currently lacks riparian cover. The riparian area will be restored using a diverse plant palate of conifers, hardwoods and shrubs to create a multi-story mixed canopy riparian forest that mimics the forest in the referent reach. The planting list for the mixed canopy riparian forest is show in Table 7-1. Installed planting will be irrigated.

The project area between station 0+00 and 14+00 has a diverse riparian forest along the south bank of Tryon Creek. The north side of the channel has a patchy distribution of deciduous hardwoods and pasture that extends up to Tryon Creek. Natural recruitment of willow and alder trees is expected to continue within the fenced riparian corridor and so mixed canopy planting is not recommended for this reach. Bare ground and areas currently trampled by elk and cattle could benefit from the bank stabilization provided by wide spreading roots of conifer trees. Added shade will also prevent reed canary grass establishment in this area. Table 7-2 summarizes the recommended plant palate to introduce conifers to the downstream portion of the project.

Multiple strategies will be utilized to deter and protect riparian plant installations from elk, beaver and cattle herbivory. Some of the techniques will provide multiple benefits for browse protection, invasive plant control and rapid bank stabilization. Browse protection strategies include areas of dense planting, broadcast seeding with desirable forage species, large container plants, browse resistant species, tree cages and applications of abrasive tree paint. Plant protection will be customized to several growth patterns and aim to minimize cost and maintenance needs.

Table 7-1. Plant species list for mixed canopy riparian area that will be installed between stations 14+00 and 46+30.

Form/ Stratum	Common name	Latin name
Overstory Trees	coast redwood	*Sequoia sempervirens*
	Sitka spruce	*Picea sitchensis*
	western hemlock	*Tsuga heterophylla*
	California bay laurel	*Umbellularia californica*
	pacific willow	*Salix lasiandra*
	Oregon ash	*Fraxinus latifolia*
Mid-story Trees and Shrubs	red alder	*Alnus rubra*
	vine maple	*Acer circinatum*
	cascara	*Frangula purshiana*
	pink flowering currant	*Ribes sanguineum*
	western hazelnut	*Corylus cornuta*
	pacific ninebark	*Physocarpus capitatus*
	twinberry	*Lonicera involcrata*
	Elderberry	*Sambucus racemosa*

Table 7-2. Plant species list for conifer enhancement area.

Form/Stratum	Common name	Latin name
Conifer Trees	coast redwood	*Sequoia sempervirens*
	Sitka spruce	*Picea sitchensis*
	western hemlock	*Tsuga heterophylla*
	western red cedar	*Thuja plicata*

7.3 Erosion Control Seeding

The entire project limit of disturbance (LOD), except the active channel, will be seeded. Broadcast seeding will encourage rapid establishment of vegetation, reduce competition from non-native invasive plants and stabilize disturbed soil.

Three seeding mixes are specified. A seed mix composed of palustrine emergent wetland is specified species for the bankfull channel slopes, point bars and wetland enhancement area that will be regularly inundated in the winter. A second mix is specified for the upper riparian buffer and will be composed of annual and perennial riparian grasses and forbs tolerant of some seasonal flooding and fast-growing tree and shrub species. A third mix, composed of native pasture grasses will be installed outside the fenced riparian area, where grazing will continue.

The seed mixes will include quick growing annual and perennial species for erosion control. Recommended wetland species include but are not limited to: slough sedge (*Carex obnupta)*, soft rush (*Juncus effuses)*, small fruited bulrush *Scirpus microcarpus*, Pacific silverweed (*Potentilla anserina)*, hardhack (*Spirea douglasii)* meadow barley (*Hordeum brachyantherum)* and spikerush (*Eleocharis sp)*.

Recommendations for the upper riparian buffer seed include species identified at, or near, the project site that tolerate seasonal inundation and germinate readily from seed. Species include but are not limited to California brome (*Bromus carinatus),* blue wild rye *(Elymus glaucus),* small fescue (Vulpia microstachys), meadow barley (Hordeum brachyantherum), tomcat clover *(Trifolium willdenovii),* fringecup (*Telima grandifolia),* Pacific ninebark *(Physocarpus capitatus),* wax myrtle *(Morella californica)* and red alder (*Alnus rubra)*.

7.4 Riparian Fencing

The riparian fencing design will follow NRCS standards for cattle exclusion along riparian areas and production needs for the ranching operation. The landowners prefer a 48" tall woven wire field fence with two barbed wires on the top for effective means of controlling cattle movement. Approximately 8,700 feet of fencing is needed to fully exclude cattle along both banks of Tryon Creek.

The placement, height and fencing materials will be selected to prevent cattle access to the stream while also allowing wildlife passage following CDFW guidelines for wildlife friendly fencing.

7.5 Invasive Plant Management

Invasive species of concern within the project site are Himalayan blackberry ((*Rubus armeniacus*) and reed canary grass (RCG) (*Phalaris arundinacea*). Site preparation, revegetation techniques, and site maintenance will ensure that invasive plant populations are controlled. Site maintenance is essential for project success because clearing and revegetation alone may not result in invasive plant control and native species establishment. Long term control of invasive plants will come from establishing shade and a diverse multi-layer riparian forest. Short and long-term strategies and adaptive management are needed to ensure control of RCG and Himalayan blackberry.

Blackberry is common throughout the project area. During implementation, blackberry within the limit of disturbance (LOD) will be mechanically removed, including the top 6-inches of soil to ensure that all rhizomes are removed. After implementation, maintenance of the project area will include manual blackberry removal. Over time, shading from the riparian area is expected to control the blackberry.

RCG is not present on site, but could become established at the site through wind dispersal of seeds from downstream infestations in Tryon Creek and Yontocket Slough. Ground disturbance from project construction and subsequent cattle exclusion will create ideal conditions for colonization by fast growing opportunistic invasive plants. Short-term RCG controls recommended by SRA include prescribed grazing to control the grasses until the forest canopy can provide sufficient shade to manage the grasses.

7.6 Monitoring, Maintenance, and Adaptive Management

SRA has proposed a detained monitoring, maintenance, and adaptive plan for the off-channel habitat, riparian area and vegetation management. See Appendix J and L for additional details.

8 CONSTRUCTION LOGISTICS

8.1 Construction Access, Staging Areas, and Limit of Disturbance

The project area is located in open pastures owned by the Palmer Westbrook Inc. There is little riparian area, except for localized areas of trees along the stream channel.

Construction access will be through two existing gates along Lake Earl Drive about 600 feet north of the stream crossing. Two 100-foot by 100-foot staging areas are provided at the gates. A third 100-foot by 100-foot staging area is located upstream of Lake Earl Drive near the low-water stream crossing to provide space for stockpiling of materials necessary for the crossing. A fourth, 200-foot by 100-foot staging area is located near the new bridge crossing to provide additional storage space for the bridge construction.

The project limit of disturbance (LOD) encompasses the construction access and staging areas. Upstream of Lake Earl Drive, the LOD is located 20 feet outside the extents of the proposed fencing to provide ample area for equipment maneuverability and to minimize compaction of the graded floodplain. Downstream of Lake Earl Drive, the LOD follows the limit of grading to the south of the stream to preserve the forested areas on the adjacent hillslope. North of the stream, the LOD is located about 20 feet outside the extents of the proposed fencing, except within a few localized areas where the floodplain grading is expected to extend beyond the fenceline.

The total LOD area for the project is 477,002 square feet (10.95 acres). All of these areas are shown on the plans and should be included in CEQA/NEPA and permit applications, but not all areas within the LOD may end up being utilized by the contractor.

8.2 Clearing, Grubbing, Tree Removal, and Plant Salvage

The project specifications indicated that vegetation clearing should be minimized as much as feasible, while allowing equipment maneuverability. A feasible, trees should be limbed rather than removed. If removal is necessary, the stump and root system should be retained as much as possible. Grubbing, the removal of roots from the ground, is discouraged so that the roots in the ground continue to provide bank strength.

No large tree removal is anticipated for the project, though some removal of small trees and underbrush will occur. Tree removal will occur only within the limits of the channel grading. Trees located within the floodplain grading will be retained by grading around the tree, leaving its root system intact. In total, trees that will be removed consist of 12 red alder (*Alnus rubra*) trees, between 6 and 24 inches in diameter (dbh). Wood and slash created by the tree and understory removal will be incorporated into the large wood instream structures.

As indicated in Section 7, native slough sedge (*Carex obnupta*) and various species of Juncus will be salvaged from the project, divided and planted along the channel banks. Additionally, willows and cottonwoods cuttings will be collected from nearby sites, or on-site if available.

8.3 Water Management

Tryon Creek generally goes dry during the summer months, though the depth to groundwater is unknown. The geotechnical investigation encountered standing water on the surface and groundwater between 2.25 and 2.75 feet below the ground surface on 3/25/20, near the end of the rainy season. However, conditions in March are not expected to reflect conditions during construction, which would be expected to occur from July through October, during the dry season.

Project planning should consider that the stream may contain water at the beginning of construction, and that removal of salmonids and other aquatic organisms may be necessary. A clear water diversion to reroute clean stream flow around the work area may be necessary, but unlikely.

Dewatering of seepage into the work area is expected to be necessary, and will be critical to ensure that materials do not become super-saturated and unworkable. As shown on the design plans, dewatering systems typically include pumping within an isolated work area. At Tryon Creek, the pumped sediment-laden water can be discharge on the flat floodplain surface far enough away that dirty water does not return to the stream, but instead infiltrates into the ground.

The contractor will be required to submit a water management plan for approval that describes their proposed approach, layout, and materials. The contractor will be required to work with a qualified fisheries biologist responsible for removing fish and other aquatic organisms from the work area prior to dewatering.

8.4 Excavation, Backfill and Spoils Management

Total excavation for the project will be 5,500 cubic yards (cy). Assuming a 10% shrinkage factor during backfill placement, backfill for the project will be 4,620 cy, with an excess of 880 cy of material.

The primary excavation methods that will likely be utilized include track mounted excavators and bulldozers. Excavated material will be either placed directly into areas specified for backfill, or loaded into trucks and hauled to areas where backfill is specified. As recommended by SHN (2020), all backfill will be compacted to 90% relative compaction (RC). Geotechnical testing will be required for subgrade compaction and placement of the soil stabilization mats for the bridge. Compaction for backfill in the existing stream channel and for installation of large wood structures will not be tested. However, backfill in these areas is specified to be installed in compacted lifts and will be overseen by an experienced construction observer. Compaction methods expected to be used include multiple passes using tracked equipment, roller compactors, or “jumping jacks.”

Restoration of the historical channel within the “willow thicket” downstream of Lake Earl Drive will be accomplished by a combination of select tree clearing, pruning, and excavation. Due to the small size of the new channel, and to minimize damage to the riparian area outside of the new channel, smaller equipment may be necessary.

Earthwork operations will yield an excess of about 880 cy. Excess materials will be placed strategically within the limit of grading to improve flow patterns and drainage on the restored.

8.5 Opinion of Probable Construction Cost

An Opinion of Probably Construction Costs (OPCC) is included in Appendix K. The OPCC includes quantities and unit costs for implementation of the project and post-project monitoring and maintenance of the riparian plantings. The OPCC does not include costs for permitting, environmental documents, or construction management and oversight.

The OPPC for implementing the project is $1.29 million. This includes a 15% contingency to account for unanticipated site conditions and price fluctuations for material and fuel. The estimated cost also includes a 3% price escalation computed over 2 years to account for price adjustments between now and when the project is constructed.

9 REFERENCES

Bennett, M. (2006). Managing Himalayan blackberry in western Oregon riparian areas. Oregon State University Extension Catalog. http://extension.oregonstate.edu/catalog EM8894

Caltrans. 2020. Highway Design Manual Chapter 870-Bank Protection-Erosion Control.

Caltrans. 2000. California Bank and Shore Rock Slope Protection Design. Final Report No. FHWA-CA-TL-95-10. Caltrans Study No. F90TL03.

CDFG. 2009. Part XII: Fish passage design and implementation. In the California Salmonid Stream Habitat Restoration Manual. California Department of Fish and Game.

Chow, V.T., D.R. Maidment and L.W. Mays. 1988. Applied Hydrology (McGraw-Hill Series in Water Resources and Environmental Engineering). McGraw-Hill Inc, Ney York.

Chow, V.T., 1959. V.C. Open-Channel Hydraulics. McGraw-Hill Company, New York. 680 pp.

FEMA. 2010. Flood Insurance Rate Map Panel 207 from the Del Norte County California and Incorporated Areas Flood Insurance Study (06015CV000C) Effective date August 31, 2018).

FHWA. 2012. Evaluating Scour at Bridges. Hydraulic Engineering Circular 18. Publication No. FHWA-HIF-12-003.

Knutson & Fealko, 2014. Large Woody Material-Risk Based Design Guidelines. Bureau of Reclamation, Pacific Northwest Region Resource & Technical Services.

Jarrett, R. 1985. Determination of roughness coefficients for streams in Colorado. Water-Resources Investigations Report 85-4004. USGS Water Resources Investigations Report.

Jones, K., T. Cornwell, D. Bottom, L. Campbell, and S. Stein. 2014. The contribution of estuary-resident life histories to the return of adult Oncorhynchus kistuch. Journal of Fish Biology 85: 52-80.

Laird, A. and McBain & Trush, Inc. 2014. Atlas of the Historic Channel Planforms Lower Reach of the Smith River. Prepared for Smith River Advisory Council and Smith River Alliance.

Leopold. L. 2005. A View of the River. The President and Fellows of Harvard College. 298 pp.

Levings, C. 2016. Ecology of salmonids in estuaries around the world. University of British Columbia. 371 pp.

Love, M and Associates. 2006. Yontocket Slough, Fish Passage and Habitat Enhancement Planning Project. Final Report to California Department of Fish and Game, Contract P0310326. May 2006, 168 p.

National Park Service (NPS). 2014. Strawberry Creek Restoration Environmental Assessment. U.S. Department of the Interior, Redwood National Park., Humboldt County, California, February 2014. 150 p.

NMFS. 2014. Final Recovery Plan for the Southern Oregon/Northern California Coast Evolutionarily Significant Unit of Coho Salmon (Oncorhynchus kisutch). NOAA Fisheries West Coast Region.

NOAA. 2019. Atlas 14 Point Precipitation Frequency Estimates: CA [online database]. Available https://hdsc.nws.noaa.gov/hdsc/pfds

NRCS. 2019. Web Soil Survey [online database]. United States Department of Agriculture. Available https://websoilsurvey.sc.egov.usda.gov.

Parish, M. 2018. Smith River Plan Stream Restoration Plan. Del Norte County, CA. Final Report to the California Coastal Conservancy Water Quality, Supply and Infrastructure Improvement Act Agreement No. 16-027.

Parish, M. 2016. Beaver Bank Lodge Use, Distribution and Influence on Salmonid Rearing Habitats in the Smith River, CA. [Thesis] Humboldt State University, Arcata, CA. 95p

Parish, M. and J. Garwood. 2016. Salmonids throughout the Lower Smith River Basin and Estuary, Del Norte, County, CA. Smith River Alliance.

Parish, M. and J. Garwood. 2015. Available Aquatic Habitat within the Lower Smith River Basin and Estuary, Del Norte County, CA. Smith River Alliance.

Rafferty, M. 2016. Computational Design Tool for Evaluating the Stability of Large Wood Structures. Technical Note TN-103.1. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, National Stream & Aquatic Ecology Center. 27 p. http://www.fs.fed.us/biology/nsaec/products-tools.html

SHN. 2020. Limited Geotechnical Evaluation, Tryon Creek Propose New Bridge and Channel Restoration, Del Norte County, California. Prepared for Michael Love & Associates, Inc.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at the following link: https://websoilsurvey.sc.egov.usda.gov/.

Schumm, S. 1985. Patterns of Alluvial Rivers. Annual Review of Earth and Planetary Science 13 (1) 5-27.

Tu, Mandy, 2004. Reed Canarygrass Control & Management in the Pacific Northwest. The Nature Conservancy's Wildlife Invasive Species Team. http://www.invasive.org/gist/moredocs/phaaru01.pdf

USACE. 1994. 1994. Hydraulic Design of Flood Control Channels. USACE 1110-2-1601.

USACE. 2016a. HEC-RAS, River Analysis System: Version 5..7, U.S. Army Corps of Engineers, Hydrologic Engineering Center.

USACE. 2016b. HEC-RAS, River Analysis System. Hydraulic Reference Manual: Version 5.0, U.S. Army Corps of Engineers, Hydrologic Engineering Center.

USACE. 2016c. HEC-RAS, River Analysis System 2D Modeling User's Manual: Version 5.0, U.S. Army Corps of Engineers, Hydrologic Engineering Center.

USDA, U.S. Forest Service. 2009. Specific Gravity and Other Properties of Wood and Bark for 156 Tree Species Found in North America. Research Note NRS-38.

USDA. 2013. Win TR-55 Small Watershed Hydrology. NRCS Conservation Engineering Division. Version 1.00.10.

USFS. 2008. Stream simulation: an ecological approach to road stream crossings. USDA United States Forest Service National Technology and Development Program, San Dimas, CA.

USFS. 2006. Low-Water Crossings: Geomorphic, Biological, and Engineering Design Considerations. USDA United States Forest Service National Technology and Development Program.

USFS. 2005. WinXSPro, Version 3.0. USDA Forest Services, Rocky Mountain Research Station, Stream Systems Technology Center, Ft. Collins CO.

Walkley, J. and Garwood. 2017. 2011-2016 Salmonid Redd Abundance and Juvenile Salmonid spatial Structure in the Smith River Basin, California and Oregon. Final Report to the California Department of Fish and Wildlife, Fisheries Restoration Grants Program, Contract: P1210524. Smith River Alliance, Crescent City, CA. 51p.

Wolman, M. G., and Miller, J. P. 1960. Magnitude and frequency of forces in geomorphic processes. Journal of Geology 68, 54-7 4.