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Basis of Design Report & Feasibility Analyses for Marshall Ranch Streamflow Enhancement Project

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Cover photo: Location of proposed off-channel pond (top photo) and Redwood Creek downstream from the proposed flow augmentation delivery location (bottom photo).

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EXECUTIVE SUMMARY

The primary goal of the Marshall Ranch Flow Enhancement Project (Project) is to augment dry season stream flow in Redwood Creek to significantly improve aquatic habitat conditions. The Salmonid Restoration Federation (SRF) has been monitoring dry season flows in the Redwood Creek watershed over the past eight years. During 2013 through 2018, flows at all gaging stations along Redwood Creek mainstem dropped below 5 gallons per minute (gpm) for multiple weeks, including long channel reaches where flows ceased completely. The 2019 water year had anomalously high flows mainly due to a relatively wet winter combined with significant precipitation in May. However, 2020 and 2021 are proving to be the driest years documented with flows dropping precipitously in late July and August to 0 to 5 gpm at all mainstem monitoring stations. These severe low flow conditions are likely to persist for several months. Dry stream conditions make it very difficult for salmonids and other native aquatic species to survive. A variety of sources likely contribute to the low-flow conditions including current human consumptive use, climate change (longer dry seasons), and legacy land use impacts (roads and timber harvest).

The Project is being designed to significantly improve these dry-season conditions. Ten million gallons of off-channel storage is proposed that will capture winter rainfall and runoff and release approximately 30 gpm of cool clean water into 5.5 miles of Redwood Creek during the 5-month dry season. The released water will have suitable temperatures via piped outflow from the bottom of the reservoir and water quality will be maintained by on-demand aeration and cooling/filtration gallery. This flow input is expected to have a significant and measurable benefit to salmonids and other aquatic habitat in Redwood Creek. The volume of flow augmentation from this single project is expected to be approximately equal to 30% of the estimated human consumptive use within the southwestern half of the Redwood Creek watershed including the Miller Creek, China Creek, Dinner Creek, and Upper Redwood Creek mainstem sub-watersheds (Stillwater Sciences 2017).

Flow augmentation pilot projects in Russian River tributaries including Dutch Bill Creek, Porter Creek, and Green Valley Creek have successfully improved instream aquatic habitat for salmonids during the dry season (RRCWRP 2017, Grantham et. al. 2018, RRCWRP 2019). Specifically, the Porter Creek and Green Valley Creek projects have utilized water stored in agricultural ponds to augment dry season streamflow which has resulted in greater pool connectivity and wetted channel area, as well as significant increases in dissolved oxygen (DO) levels.

A fire suppression component is also being designed into the project. The pond will be accessible for helicopters to dip their buckets and a fire hydrant is also being proposed for access by fire engines during emergencies.

Selection of the Marshall Ranch off-channel pond site has been guided by office- and field-based assessments of a significant portion of the Redwood Creek watershed. Based on these assessments, the proposed site is uniquely suited for the project due to the following factors: 1) the project area is comprised of a broad area with gentle topography, 2) the site is not within the Redwood Creek floodplain or within the potential Redwood Creek channel migration corridor, 3) there are no watercourses, wetlands, or other sensitive plant species within the proposed pond footprints so environmental impacts are minimized, 4) the pond sites are located at an elevation with enough pressure head to deliver the entire pond volume to Redwood Creek by gravity, and 5) the Marshall Ranch LLC (landowner) is fully supportive of the project.

The project has gone through several design iterations with a goal of gaining stakeholder and community support while also reducing long term operational costs and potential risks. An initial design iteration was completed in September 2019, a second design iteration was completed in September 2020, and a third design iteration was completed in August 2021 (the project proposed herein) as shown in Appendices A.1 to A.3. Between the 2020 and 2021 design iterations, the size of the Project has been decreased from 15.3 to 10 million gallons, based on the future objective of developing a new 5.5-million-gallon project on nearby property owned by Lost Coast Forestlands (LCF). The Marshall and LCF projects combined will generate the original target flow augmentation of 50 gpm during the 5-month dry season.

This report and associated engineering design describe the 10-million-gallon project on the Marshall Ranch designed to provide 30 gpm of flow augmentation to Redwood Creek during the 5-month dry season. The current design addresses the three primary substantive community concerns raised during the CEQA public comment period for the 2020 project design:

1) the risk of catastrophic pond failure has been drastically reduced by dividing storage into two ponds and reducing the original pond volume from 15.3 million gallons to 3.8 million gallons;
2) the current design approach allows for a separate but related flow enhancement project (i.e. future LCF project) that benefits upstream reaches of Redwood Creek with significant aquatic habitat value; and
3) the current design allows for filling of the pond and cooling of the outflow via passive gravity systems and does not rely on significant long-term energy use.

The project team has secured a commitment from the WDH Foundation to provide funding for long-term operations, maintenance, and monitoring. A 501c3 non-profit organization is being formed with the role of managing the project and will sub-contract various aspects of long-term operations, maintenance, and monitoring to SRF, Stillwater Sciences, and Eel River Watershed Improvement Group.

A key project component that will require significant attention from the project team and agency staff over the coming year is securing an Appropriative Water Right for the project that allows for wet-season diversion from two seasonal tributaries to Redwood Creek to optimize the Project's ability to augment dry season flow. It is widely agreed upon that there is "available" water in Redwood Creek during the wet season. However, the challenge that faces the project team and regulators is defining an allowable diversion schedule that balances the need to protect instream resources during the wet season while supporting the Project goal of dry season flow enhancement. Stillwater Sciences has prepared a Water Availability Analysis Report included in Appendix C.

The Project was also discussed at the Redwood Creek Salmon Habitat and Restoration Priorities (SHaRP) meeting held in Arcata in June 2019. The meeting was attended by local restoration practitioners and fisheries staff from CDFW and NOAA. Feedback was overwhelmingly positive in terms of the Project fitting into coho recovery strategies for Redwood Creek. Additionally, the project team looks forward to working closely with CDFW and SWRCB to integrate the Project into existing agency activities in Redwood Creek. Specifically, CDFW has conducted an instream flow study in Redwood Creek and the SWRCB is conducting hydrologic and temperature modeling within the South Fork Eel River watershed. It is the project team's goal to coordinate closely with agency staff as studies are finalized and align the project with these regional initiatives.

1 INTRODUCTION

This report provides the basis of design for a large-scale streamflow enhancement project. Current design work is being funded through the California Wildlife Conservation Board's Streamflow Enhancement Program and State Coastal Conservancy. The Project will capture and store winter runoff in 10 million gallons of off-channel water storage and release the stored water into Redwood Creek during the dry season at a rate of approximately 30 gallons per minute. This Project seeks to improve habitat for coho salmon (*Oncorhynchus kisutch*) and steelhead (*Oncorhynchus mykiss*) in Redwood Creek, an important salmon bearing tributary to the South Fork Eel River, by addressing the limiting factor of low summer streamflows. The South Fork Eel River is one of five priority watersheds selected for flow enhancement projects in California by the State Water Resources Control Board (SWRCB) and California Department of Fish and Wildlife (CDFW) as part of the California Water Action Plan effort (SWRCB 2019). Redwood Creek is a critical tributary to the South Fork Eel River that historically supported coho and Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead.

Salmonid Restoration Federation (SRF) is the project lead and Stillwater Sciences is the technical lead with support from SHN Engineers and Geologists (Geotechnical Engineering and Water Conveyance Infrastructure), William Rich and Associates (Cultural Resources), and Hicks Law (Water Rights and Legal Consulting). The project is located on the 2,942-ac Marshall Ranch property near the unincorporated community of Briceland, in Southern Humboldt County, CA (Figure 1). This project was identified as the highest priority flow enhancement project during a feasibility study conducted by SRF and Stillwater Sciences within a portion of Redwood Creek (Stillwater Sciences 2017).

This Basis of Design (BOD) Report presents the preferred design alternative based on field and office-based analyses, as well as specific input from the landowner and Technical Advisory Committee (TAC), neighbors, and community. TAC members for this project include representatives from California Department of Fish and Wildlife (CDFW), the National Marine Fisheries Service (NMFS), North Coast Regional Water Quality Control Board, and California Wildlife Conservation Board. During the design and review process, project opportunities and constraints were identified, and project alternatives were evaluated as described in Section 10 below. Specifically, there have been three design iterations as shown in Appendices A.1 to A.3 with the 90% design shown in Appendix A.3 being advanced as the preferred alternative.

Recent flow enhancement initiatives in lower Russian River tributaries are analogous to this Project and have displayed that direct augment is one of the most successful approaches to date for enhancing dry-season streamflow. Flow releases from agricultural ponds in Green Valley Creek and Porter Creek have resulted in significant instream benefits (Grantham et.al. 2018, RRCWRP 2019). As described in Ruiz et al. (2018) of California Sea Grant, the project began in 2015 and is ongoing. Data shows that flow augmentations in all years from 2015-2018 were able to appreciably increase wetted channel habitat, increase dissolved oxygen in the stream, and decrease water temperature downstream from the flow augmentation release points. For example, releases into Dutch Bill Creek averaging 36 gpm beginning in late August of 2015 and were able to cumulatively re-wet more than 2,300 feet of stream channel with effects measurable up to 1.8 miles downstream.

While modest compared to winter flows, these augmentations have the potential to increase pool connectivity and water quality. A foundational hypothesis for this Project, that increased pool connectivity will bolster over-summer salmonid survival, is strongly supported by the work of Obedzinski et al. (2018). Their study found that days of disconnected surface flow showed a strong negative correlation with juvenile coho salmon survival rate in four tributaries to the Russian River. Provided with this evidence, it is anticipated that the Project's release of approximately 30 gallons per minute into Redwood Creek throughout the dry season can result in significant aquatic habitat benefit.

2 PROJECT DESCRIPTION

The primary objective of this project is construction of 10 million gallons of off-channel water storage and associated plumbing infrastructure designed to deliver approximately 30 gallons per minute of flow augmentation to Redwood Creek during the 5-month dry season to improve instream aquatic habitat. Storage will be in two ponds and five tanks filled with wet-season runoff including rainwater catchment and water diverted from two small Redwood Creek tributaries. Other ancillary project components include:

- Installation of a large wood habitat enhancement and bank stabilization structure in Redwood Creek.
- Stabilization of two gullied tributaries with approximately 10 rock armor grade control structures and regrading.
- Construction of a passive "cooling and filtration gallery" in the existing gully to determine the viability of this innovative approach to address water quality and temperature issues associated with the flow releases from the pond.
- Construction of a solar power system including a 1 KW solar array, battery bank, inverter, internet connection, and small control center building to support operations and monitoring capabilities.
- Upgrading access roads within the project area including three road/stream crossing upgrades and gravel surfacing to provide year-round access.
- Construct cattle exclusion fencing to protect riparian areas within the project vicinity.
- Installation of plumbing infrastructure to allow for a portion of the water stored in the tanks to be utilized for domestic, ranch, and fire suppression needs including two fire hydrants.

3 PROBLEM STATEMENT

Aquatic habitat in Redwood Creek is impaired due to a variety of factors including low dry-season flows, high water temperatures, excessive fine sediment, and lack of habitat complexity (CDFW 2014). There are two fish species with threatened status that are expected to benefit from this project: (1) southern Oregon/northern California coho salmon (*Oncorhynchus kisutch*) (SONCC) which are designated as state and federally threatened and (2) Northern California steelhead (*Oncorhynchus mykiss*) which are federally threatened and are a CDFW species of special concern. Historically, these fish flourished in Redwood Creek. However, rearing habitat for juvenile salmonids has been substantially degraded and the current lack of dry season flow is likely the leading factor. (NMFS and CDFW 2019).

Dry season flows (i.e., June - October) in north coastal California watersheds have decreased over the past half century (Sawaske and Freyberg, 2014; Asarian, 2014) likely due to a combination of changes in climate, land use and associated consumptive water demand, and vegetative cover. In watersheds most impacted by industrial and non-industrial timber harvest, homesteading, and cannabis cultivation, diminished streamflow is having lethal or sub-lethal effects on juvenile salmon and steelhead and is also negatively impacting sensitive amphibian species (Bauer et al 2015).

Today, remnant fish populations survive in Redwood Creek (NMFS 2014), but despite considerable expenditures in habitat restoration projects (i.e. sediment reduction and placement of large wood habitat structures), many stream reaches don't have sufficient flow to maintain the diminishing populations. This project will address this key limiting factor by storing runoff during the wet season and strategically releasing the stored water to enhance flows in a critical reach of Redwood Creek during the dry season.

The Redwood Creek watershed is located within the South Fork Eel River ESU, which NOAA identifies as a core population vital to the preservation of Southern Oregon Northern California Coast (SONCC) coho salmon (NMFS 2014). The SONCC coho recovery plan indicates the need for "improving flow timing or volume" in each of the first ten action items in the SONCC Coho Recovery Plan (NMFS 2014).

In summary, the primary focus of this project is increasing dry season flows in critical reaches of Redwood Creek. Additional project elements will also address several other limiting factors including a large wood structure to increase habitat complexity and gully stabilization treatments to reduce fine sediment inputs.

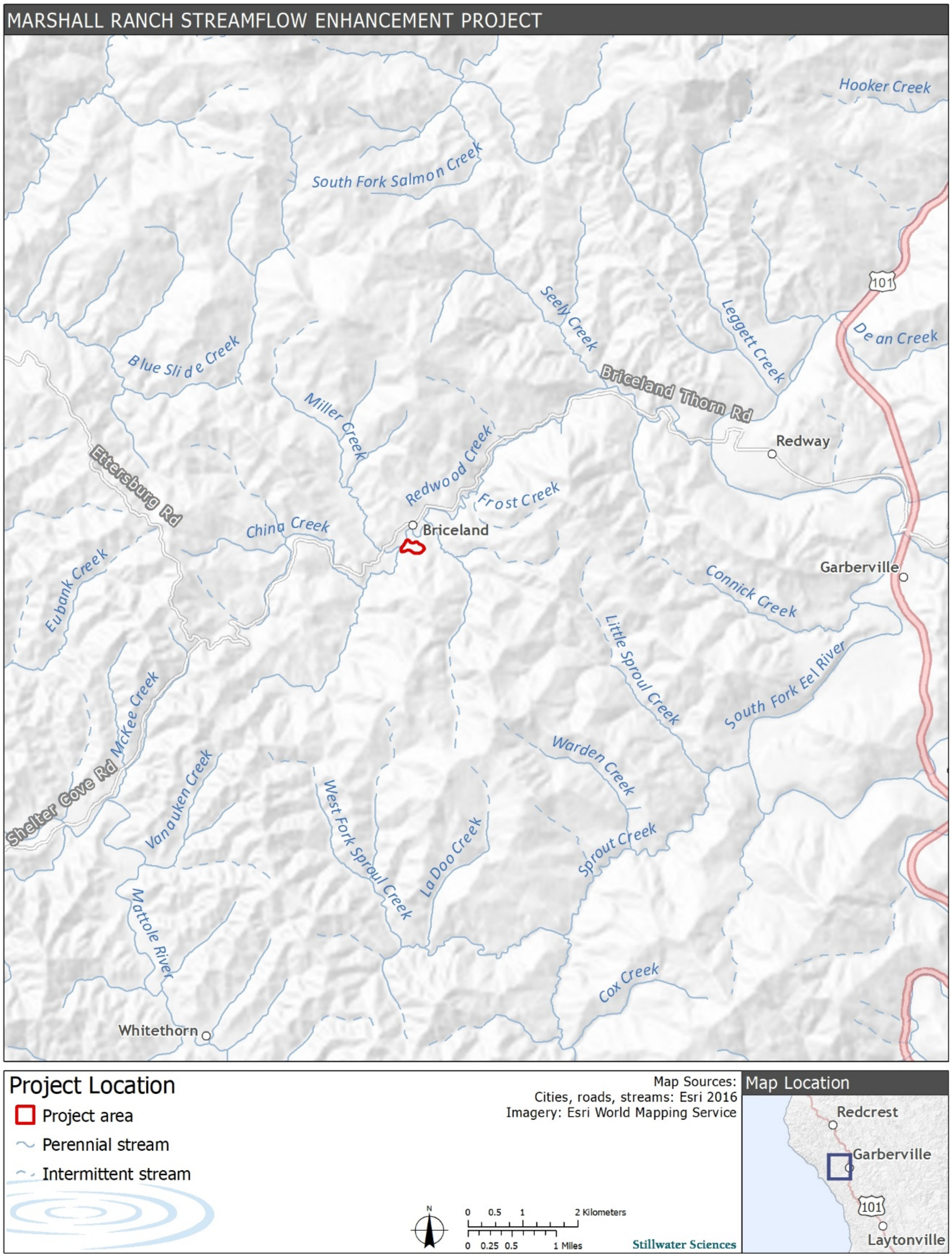

Figure 1. Vicinity map.

4 GEOLOGY AND TECTONICS

The Redwood Creek watershed is in a tectonically active plate-boundary deformation zone, defined by right-lateral movement along the San Andreas Fault Zone that separates the Pacific plate to the west from the North American plate to the east (Kelsey and Carver 1988). Northward progression of the San Andreas Fault Zone is characterized by lateral shearing and vertical compression due to the major westward turn in the fault zone upon reaching the Mendocino Triple Junction near Cape Mendocino. These primary deformation styles are what create the dominant NNW-SSE trending topographic and structural grain in the region (Kelsey and Carver 1988). The evolution of this regional topographic and structural grain has developed pervasive shearing, fracturing, and faulting throughout the north coast of California.

The Garberville-Briceland fault zone trends NNW-SSE across the watershed (Figure 2) (McLaughlin et al. 2000). The fault zone consists of multiple named and unnamed fault traces with varying orientations of displacement. Although recent displacement along the fault zone is undifferentiated, it is considered Quaternary in age (i.e., active within the last 1.6 million years). The Briceland Fault trace is approximately 4,300 feet northeast of the project site and the Garberville Fault trace is approximately 2.75 miles to the northeast (Figure 2).

The Redwood Creek watershed is primarily underlain by the diverse Coastal and Central belts of the Franciscan Complex, the younger marine and non-marine Wildcat Group, and minor amounts of serpentinized peridotite of the Coast Range Ophiolite (Figure 2). The project site is located along mainstem Redwood Creek between the Miller Creek and Somerville Creek confluences. The site is partially underlain by an isolated exposure of Pliocene-aged moderately consolidated sandstone, argillite, and conglomerate, included by some with the Wildcat Group (McLaughlin et al. 2000). The area surrounding the project site, and most of the Redwood Creek watershed, is underlain by various subunits of the Eocene to Paleocene Yager terrane (Franciscan Complex Coastal Belt), which primarily consists of sheared and highly folded mudstone (McLaughlin et al. 2000). The mudstone includes minor rhythmically interbedded arkosic sandstone and local lenses of conglomerate. This lithology produces terrain with relatively irregular topography lacking a well-incised system of sidehill drainages when compared to other subunits of the Franciscan Complex Coast Belt.

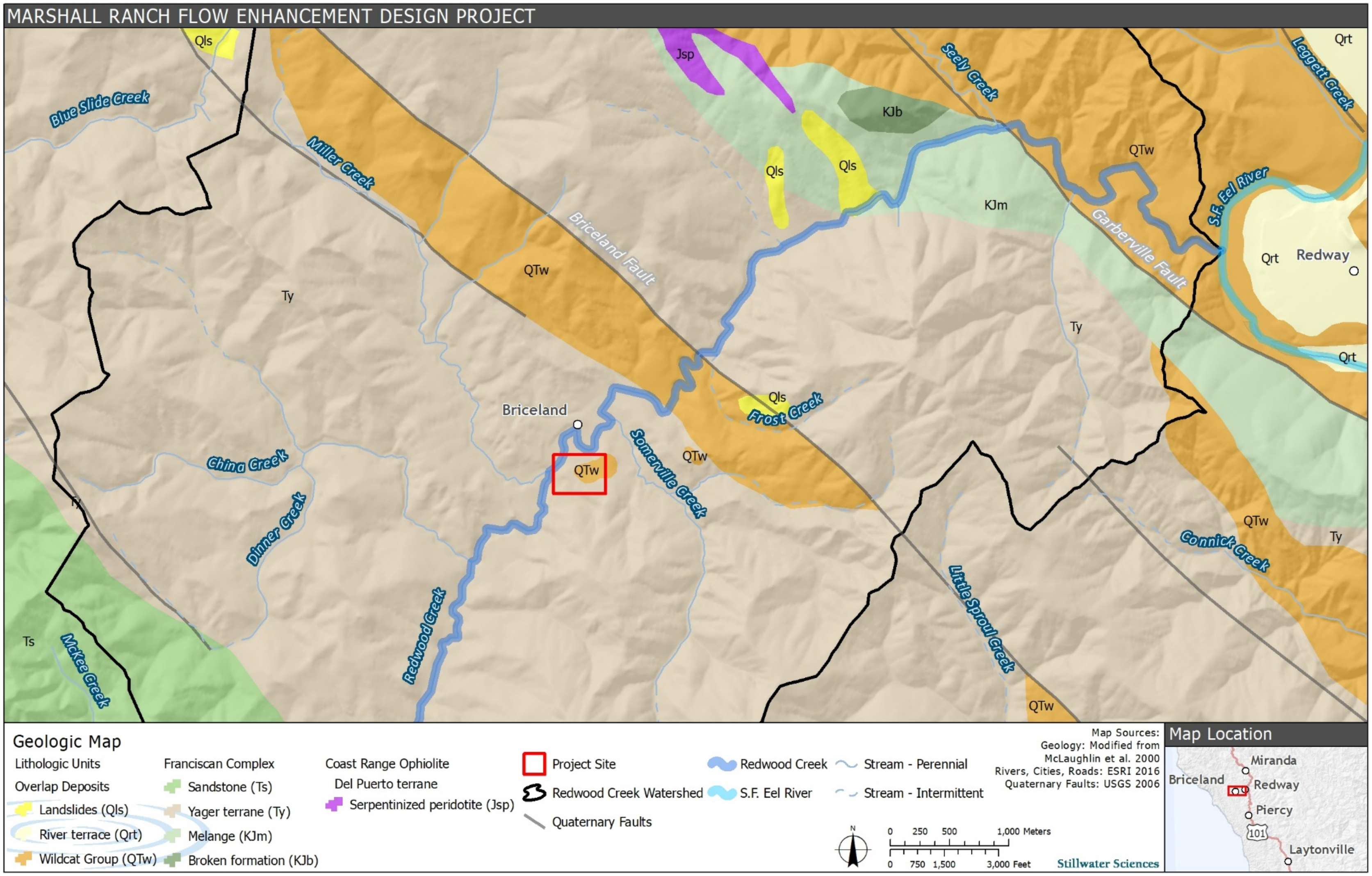

Figure 2. Generalized geologic map of the Redwood Creek watershed and project vicinity.

5 GEOMORPHIC ASSESSMENT

A geomorphic assessment was conducted to characterize the existing geomorphology of the project area, assess risks associated with potential hazards, support the opportunities and constraints assessment, and inform project designs. Specifically, the geomorphic assessment included a topographic survey that was integrated with 2007 LiDAR data, review of existing data, and a field assessment. Existing data that were reviewed included geologic mapping (McLaughlin et al. 2000), geomorphic and landslide mapping (Spittler 1984), and historical aerial photographs from 1942, 1947, 1954, 1963, 1965, 1984, 1988, 1996, 2000, 2005, 2009, 2010, 2012, and 2014. A geotechnical investigation was also conducted by SHN Engineers & Geologists and is described below in Section 6.

Hillslope and stream channel morphologies in the Redwood Creek watershed are similar to those found throughout the western side of the South Fork Eel River basin, due to the prevalence of the underlying Franciscan Coastal Belt terranes. Although there is variability among the terranes, the rock strength in Coastal Belt rocks typically leads to steeper, ridge-and-valley topography with organized drainage networks. Small to large-scale landslides are still common in the basins that drain the Coastal Belt terranes, particularly where sedimentary rocks are less competent and in mélange units.

Upper elevations in the Redwood Creek basin are characterized by narrow, steep-walled canyon slopes that are covered by relatively thin soils and dense conifer and hardwood stands and drained by perennial and intermittent streams. At mid-elevations, the steep canyons transition into gently rounded upland ridges supporting grass meadows and shrub and oak woodland vegetation. The valley width greatly expands near Briceland, where Redwood Creek meanders between large elevated terraces (Figure 3). Channel incision in the Redwood Creek basin is likely due to ongoing tectonic uplift related to the nearby Mendocino Triple Junction, extensive anthropogenic land-use practices, and climate change altering hydrologic patterns. The flight of terrace and floodplain surfaces in the project vicinity record over 120 feet of vertical incision of Redwood Creek.

The project site consists of Pleistocene-era fluvial terraces and lower floodplain surfaces adjacent to Redwood Creek, which flows from the southwest to the northeast across the project area (Figure 3). Upland hillslopes border the site to the south and east. The project site is bound by small intermittent streams to the east and west that are tributary to Redwood Creek. These streams are hereinafter referred to as the east-side and west-side tributaries. The northern central edge of the upper terrace has been eroded by a third smaller drainage. Multiple landslide features are located around the project area and are further described in the following sections.

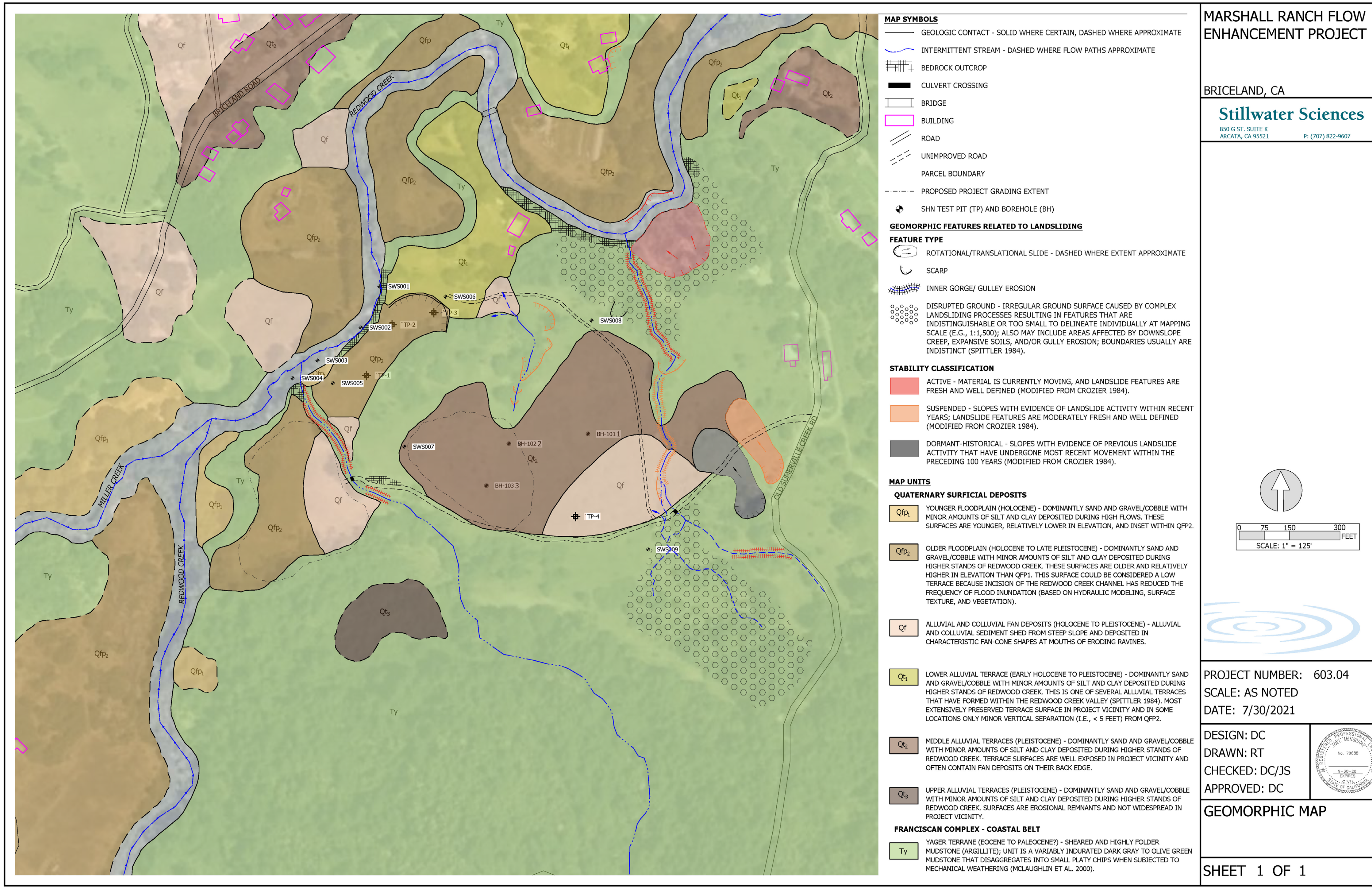

Figure 3. Geomorphic map.

5.1 Field Assessment

The geomorphic field assessment of the project area consisted of evaluating the site topography and surficial drainage features, logging shallow stratigraphy, and further characterizing features related to landsliding.

5.1.1 Proposed pond sites

The proposed eastern pond site is on a broad gently sloping Redwood Creek fluvial terrace tread (Qt_2 in Figure 3), approximately 900 feet east-west by 450 feet north-south (Figure 4). The terrace tread, or surface, slopes approximately 5% to the NNW towards Redwood Creek. The terrace has a low-gradient alluvial fan deposited by the east-side tributary on its back edge and upland hillslopes to the south and east. The east-side tributary has eroded a moderately incised channel 6-8 feet deep, which bisects the terrace and fan deposits. The central drainage has eroded the northern edge of the terrace tread and has deposited a small alluvial fan on the adjacent lower terrace (Qt_1) to the north. The pond-site terrace surface is approximately 90 feet higher in elevation than the adjacent Redwood Creek thalweg located approximately 350 feet to the northwest. An unimproved access road travels west from Old Somerville Creek Road along the back edge of the terrace and down toward the floodplain near the Redwood and Miller creek confluence. The east-side tributary passes under the access road through a culvert. Yager terrane argillite bedrock is exposed in a road cut on the terrace riser above the west-side tributary. The terrace tread is vegetated with grass and bushes, with trees around portions of its perimeter.

The proposed western pond site is located on the floodplain surface (Qfp_2 in Figure 3) to the west of the eastern pond terrace, at the bottom of a steep terrace riser (Figure 5). The floodplain is an elongated, relatively flat surface parallel to Redwood Creek. The west-side tributary crosses the floodplain and has deposited an alluvial fan on its back edge. The west-side tributary has eroded a moderate to deeply incised channel, up to 15 feet in some locations, that bisects the fan and floodplain deposits. The floodplain is 18-20 feet above the adjacent Redwood Creek thalweg. The channel bank is steep to vertical with a well-exposed Yager terrane argillite strath surface that extends approximately 450 downstream from the west-side tributary confluence with Redwood Creek (Figure 6). A groundwater spring at the bedrock strath-alluvial fill contact near the natural low-point in the floodplain is the only groundwater seep along the Redwood Creek project reach observed in summer/fall months. The spring was originally located under a large bay tree (Figure 6), which toppled into the creek channel during the 2018/2019 winter. Remnants of the floodplain surface are expansive and border much of Redwood Creek in the project vicinity. Due to recent incision over the past decades to centuries, the floodplain is infrequently inundated by only the largest flood events (e.g., 100-year recurrence interval) (Stillwater Sciences 2018). The Qfp_2 floodplain on the northwest side of Redwood Creek is 4-6 feet lower in elevation than the proposed western pond site and would therefore inundate first during a large flood event. The west-side tributary passes under the unimproved access road through a culvert crossing. The floodplain is vegetated with grass and bushes, trees around portions of its back edge, and a narrow and dense riparian corridor along the Redwood Creek channel bank.

Figure 4. Intermediate terrace surface (Qt_2), view looking west across proposed western pond site. Incised east-side tributary visible in foreground.

Figure 5. Intermediate floodplain surface (Qfp_2), view looking northeast. West-side tributary just out of view to right of photo.

Figure 6. Redwood Creek channel downstream from the proposed flow delivery point. Bedrock strath-terrace fill contact well exposed along this reach. Groundwater spring near undercut bay tree is only spring along project reach observed during summer months.

5.1.2 Surficial drainage features

As described above, the project area has three separate surface drainages that have varying impacts to the site. Each of the three drainages are further described below.

5.2.2.1 West-side tributary

The west-side tributary is the largest of the three drainages (approximately 0.05 square miles) in the project area and flows south to north along the western side of the site (Figure 3). The stream originates on the steep forested hillslopes to the south of the project site and flows primarily through a steep bedrock canyon before flowing across an alluvial fan and floodplain where it meets Redwood Creek. Only the downstream extent of the tributary and lower portions of the canyon were investigated as part of the geomorphic assessment, considering this is where potential impacts to the proposed project are most likely.

Upon exiting the canyon and flowing across the alluvial fan, the tributary has incised a moderately deep channel (i.e., 10 to 15 feet). The channel here is actively eroding and is likely exacerbated by concentrated runoff from the access road upslope. The access road off Old Somerville Creek Road crosses the channel over a double-barrel 8-inch corrugated metal pipe culvert crossing. The channel is not incised at the culvert crossing; however, the culvert outfall has incised a large scour hole approximately 8 feet wide and 10 feet deep (Figure 7). The culvert has likely promoted downstream channel incision and fill under the culvert is resisting the headward propagation of the incision, creating a 10-foot knickpoint in the channel. It is difficult to tell when the crossing was constructed based on the historical aerial photos, although the access road is clearly visible in photos from the 1940's. From the road crossing down to the Redwood Creek confluence, the channel is actively incising with up to 12-15 feet of incision in some locations (Figure 8). Development of the incision along this portion of the tributary is difficult to determine across the aerial photo time-series record due to tree cover, although it appears to have increased following the historic 1964 storm and flood event. A Redwood Creek argillite bedrock strath is exposed in the lowest 50 feet of the tributary channel, and slopes toward Redwood Creek based on the exposure in the tributary cut-banks.

5.2.2.2 Central drainage

The central drainage is small and consists of an eroded gully along the northern edge of the pond-site terrace riser (Figure 9). The drainage collects runoff from the proposed pond site and transports it onto a small alluvial fan and lower terrace surface to the north. The fan and lower terrace surface lack an actual channel but at least two poorly defined flow paths are evident: one to the west and one to the north towards the neighboring parcel. On the main terrace riser, the drainage has eroded a moderately incised gully up to 15 feet deep that exposes argillite bedrock at its base. Groundwater was observed seeping at the bedrock-fill contact during summer/fall months. Several small scarps in the alluvium at the head of the incised gully form 0.5-2-foot knickpoints in the drainage. These knickpoints and other scarps on the eastern flank of the gully appear to have had some recent activity, albeit minor, and don't appear to have had significant movement over the historical photo time-series record.

5.2.2.3 East-side tributary

The east-side tributary flows south to north along the east side of the site (Figure 10). The stream originates on the partially forested hillslope immediately south of the pond footprint and flows across the terrace before descending down the terrace riser to meet Redwood Creek. The entire stream length was investigated as part of the geomorphic assessment.

The stream lacks a well-defined primary channel in its headwater area due to the irregular topography it flows across (see Section 5.1.3 for further discussion). Additionally, a lead-off ditch along Old Somerville Road routes concentrated road-runoff into the drainage and has formed a large actively eroding gully. The multiple flow paths mostly converge at a culvert crossing under the access road. A secondary gully just to the west of the crossing causes some runoff to flow over the road and divert across the pond site. Downstream of the culvert crossing the stream flows across an alluvial fan and terrace tread where it has eroded a moderately incised (6 to 8 foot depth) channel. The over-steepened banks are incising via sloughing and block-toppling. Incision dramatically increases at the scarp near the outer edge of the terrace tread (see Figure 10). This increased incision is likely due to anthropogenic impacts, a natural transition from a gently sloping fan and terrace tread to a steep terrace riser, and landsliding further downstream. The change in incision depth is also controlled by a large in-channel debris pile of tires, scrap metal, and appliances placed by landowners. The lowest portion of the stream flows down a steep hillslope with irregular hummocky topography and a large active landslide (see Section 5.1.3 for further discussion). Incision along the entire stream length noticeably increased following the 1964 storm and flood event, as seen in the 1965 aerial photo.

Figure 7. Approximately 10 feet of channel incision at culvert outlet along west-side tributary. Photo taken just upstream from Figure 8.

Figure 8. Typical channel incision along west-side tributary, just upstream from Redwood Creek confluence.

Figure 9. Scarp on main terrace riser above central drainage.

Figure 10. Typical channel incision along east-side tributary. Block-topple in foreground and sloughing on far bank.

5.1.3 Features related to landsliding

Geomorphic features related to landsliding were investigated using the aerial photo time-series, LiDAR-derived topography and hillshades, and during the field assessment. Landslide features were initially mapped and classified in the office and then further characterized and validated in the field. Landslides were classified based on feature types used by Spittler (1984) for the North Coast Watershed Assessment Program (e.g., translational/rotational slide, earthflow, inner gorge, disrupted ground, etc.). Stability classifications modified from Crozier (1984) were also assigned to each mapped landslide feature and are color-coded in Figure 3.

5.1.4 Summary

Although there are unstable geomorphic features in the vicinity, the Project proposes design features that will increase geomorphic stability within the project vicinity including gully stabilization and reduction of groundwater levels. Furthermore, multiple lines of scientific evidence support the findings that the Pleistocene terrace where the eastern pond is proposed has been stable for a minimum of 10,000 years. The western pond is on a lower terrace that has likely been an active floodplain in more recent history (i.e. within the last 10,000 years), but under current conditions there are no current geomorphic drivers that are expected to negatively impact the proposed pond at this site.

Figure 11. Disrupted ground upslope from pond site. Hillslope has remained relatively stable and vegetated over photo time-series record (i.e., since 1942).

6 GEOTECHNICAL INVESTIGATION AND SEISMIC SLOPE STABILITY ANALYSES

SHN Engineers and Geologists conducted the geotechnical investigation for the site. A full Geotechnical Report is included in Appendix B and found the project to be feasible from a geohazard and geotechnical standpoint. Specifically in Section 5.7 the report states that "what low risk is associated with the site has been mitigated through development of an extremely conservative design plan".

Based on the geotechnical investigation, groundwater well data (see Section 8.5) and the revised pond layout included in Appendix A.3, no plausible mechanisms for massive pond failure were identified.

7 TOPOGRAPHIC DATA

7.1 Field Survey

Stillwater staff conducted field surveys using a total station and differential GPS. The primary goals of the field effort were to: (1) survey cross sections along the Redwood Creek channel thalweg at the downslope extent of the proposed site to be used for hydraulic modeling; (2) obtain additional topographic data in areas where project features are proposed; and (3) survey existing features (e.g., buildings, trees, roads, and fences). A differential GPS (approximately 0.4 feet horizontal accuracy and 0.7 feet vertical accuracy) was used to establish survey control points. These control points were used to orient the surveys and relate them to a projected coordinate system so that they could be combined with existing Light Detecting and Ranging (LiDAR) topographic data. All elevations and horizontal positions shown in the plans use the local coordinate system based on these control points.

7.2 Merging Field and LiDAR Data

The field survey data was merged with 2018 USGS LiDAR. The first step in merging the topographic data sets was to overlay the new field data on the LiDAR DEMs in AutoCAD Civil3D (CAD) to check for general consistency between the two datasets. Once consistency was confirmed, new ground surfaces were created based on the field-surveyed topography and combined with the LiDAR DEMs to create a new existing ground surface DEM for each project reach. Because the extent of the topo survey was limited to the areas described above, constructing a merged terrain model from the available LiDAR and topo survey data required interpolation and interpretation of ground surface elevations in some areas lacking data and/or resolution. Due to the limited accuracy of the LiDAR data especially in the near-channel portion of the project area, it was used only to provide general topographic context and approximate elevations for areas not characterized with field-based topographic data.

8 HYDROLOGIC ANALYSIS

An assessment of site hydrology has been conducted to inform the alternatives analyses and design process. There are five key components of the hydrologic assessment:

1. Determine key regulatory considerations that influence pond size and the ability to fill pond from surface water diversion;
2. Determining the best approach to fill the ponds through a combination of direct rainfall input, sheet flow from the hillside, and diversions from surface water; and
3. Utilize existing flow monitoring data to determine a realistic/desirable flow enhancement benefit that the project can achieve.
4. Assess 100-yr storm flows to provide the basis for project design of instream and near-stream features.
5. Assess groundwater data and how groundwater dynamics are expected to affect the project.

Each of these components are discussed below.

8.1 Regulatory Considerations

There are three primary state agencies that could have jurisdiction over this project. These include:

1. CA Department of Water Resources – Division of Safety of Dams (DSOD) regulates dams above a certain size;
2. CA State Water Resources Control Board (SWRCB) requires an Appropriative Water Right for diverting water from a stream and storing it for more than 30 days; and
3. CA Department of Fish and Wildlife (CDFW) requires a Lake and Streambed Alteration Agreement (LSAA) for installing infrastructure and diverting water from a stream.

8.1.1 DSOD jurisdiction

Jurisdictional dams are dams that are under the regulatory powers of the State of California. A "dam" is any artificial barrier, together with appurtenant works as described in the California Water Code. If the dam height is more than 6 feet and it impounds 50 acre-feet or more of water, or if the dam is 25 feet or higher and impounds more than 15 acre-feet of water, it will be under DSOD jurisdictional oversight, unless it is exempted. The DSOD Jurisdictional Size Chart (Figure 12) summarizes the above criteria. Jurisdictional height of a dam, as determined by DSOD, is the vertical distance measured from the lowest point at the downstream toe of the dam to its maximum storage elevation, which is typically the spillway crest.

There are significant annual reporting requirements and fees associated with jurisdictional dams, so from a long-term operations perspective, falling outside of DSOD is desirable. Therefore, a strong consideration in sizing the pond was to stay below a 25-foot dam height and 15 acre-feet (16.3 million gallons) of water storage.

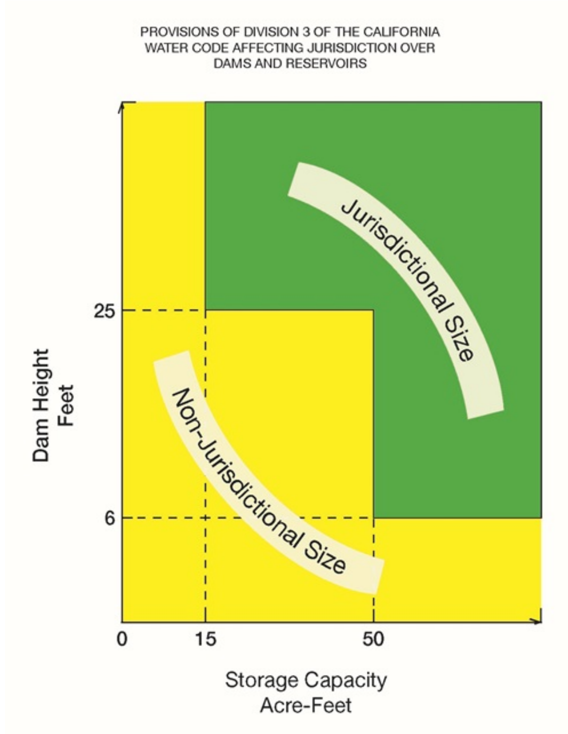

Figure 12. DSOD jurisdictional chart.

8.1.2 SWRCB appropriative water rights

Based on site geometry and the desired project outcome of maximizing flow enhancement inputs, it is not feasible to design this project to capture rainwater and sheet flow only. Therefore, it is anticipated that the Project will require an Appropriative Water Right to divert surface water from a stream and store that water for more than 30 days.

8.1.3 CDFW LSAA

Based on preliminary input from local staff, CDFW is generally supportive of the project. However, based on the project team's experience permitting water diversions on other projects, CDFW is likely to impose limitations on the diversion season and percentage of flow that can be taken from a stream.

8.1.4 Other regulatory requirements

Other permits will be required for the Project but the conditions/stipulations of those permits are not anticipated to govern the project design. These additional permits include:

1. Special Permit from Humboldt County for work within the Streamside Management Areas;
2. Grading and Building Permits from Humboldt County for construction of project infrastructure;
3. 401 Certification from SWRCB for instream work; and
4. 404 Permit from US Army Corps of Engineers.

8.2 Filling the Ponds During the Wet Season

Five different sources for filling the pond were analyzed:

1. Direct precipitation falling into the ponds;
2. Sheet flow from the hillslopes that drain into the ponds;
3. Surface water diversion from the tributary to the east of the site;
4. Surface water diversion from the tributary to the west of the site; and
5. Surface water diversion from Redwood Creek.

8.2.1 Water availability from upslope sources

To assess the water availability from Sources 1-4 listed above, the Rational Method (also known as the Rational Formula) was used to calculate expected seasonal runoff. The Rational Formula incorporates a combination of rainfall intensity, drainage area and runoff coefficient to estimate maximum flows and is defined as follows:

$$Q = CIA$$

Where:
Q = Flow Discharge
C = Runoff Coefficient
I = Rainfall Intensity
A = Area

This application of the Rational Method varies from the typical application in that here it is being used to estimate total runoff generated over the entire wet season, so the “annual design rainfall” is substituted for “rainfall intensity” in these calculations.

8.2.2 Expected annual rainfall

Two methods were applied to determine an appropriate annual rainfall to utilize for project design considerations:

1. Local rain gage data compiled by the Mattole Restoration Council (Figure 13); and
2. Annual rainfall for Briceland, CA based on PRISM Climate Group interpolations (Figure 14).

Based on these two data sources, an annual rainfall amount of 48 inches was selected as the design precipitation which represents a dry year with precipitation between the 5th and 10th percentile. This “design precipitation” was selected based on the goal that the project function at capacity during 90% to 95% of precipitation seasons. However, it was also not desirable to limit the project capacity by designing for the most extreme drought years.

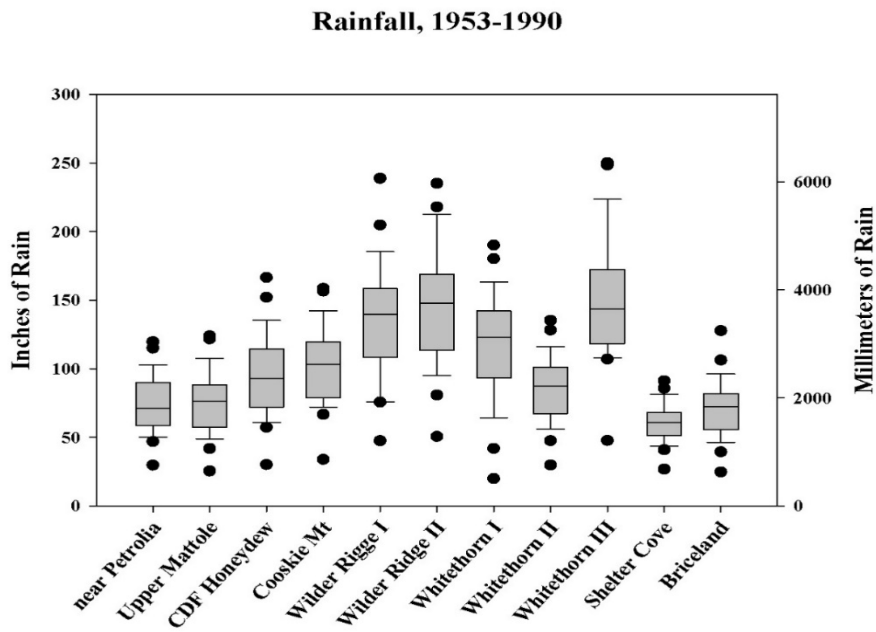

Figure 13. Local rain gage data (Mattole Restoration Council).

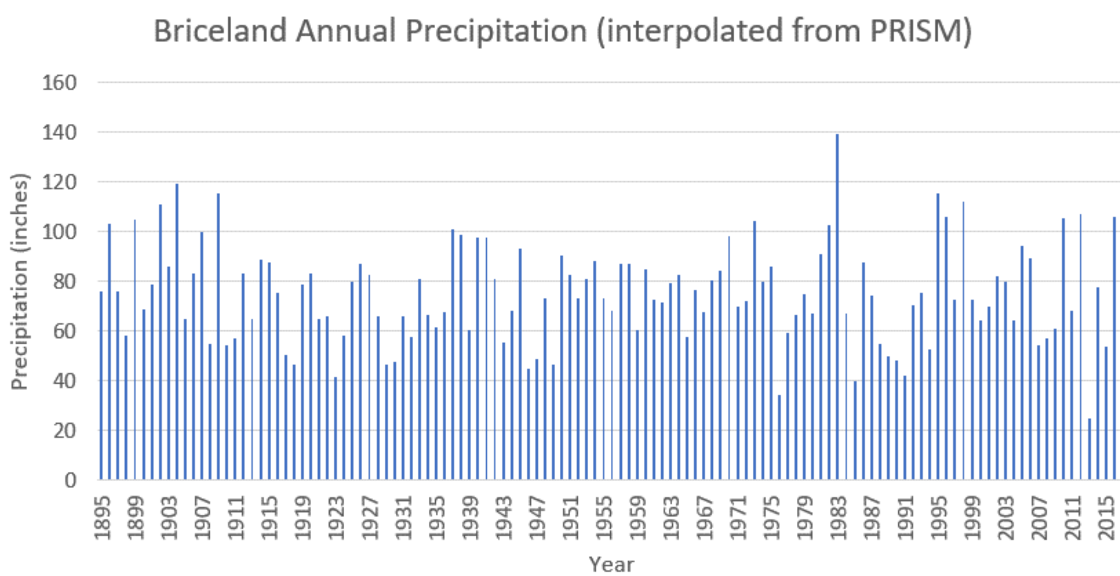

Figure 14. Briceland Annual Precipitation (PRISM).

8.2.3 Calculations

Table 1 below summarizes each of the four potential upslope water sources for the pond and calculates total expected water volume input based on 48 inches of annual precipitation. Note that for the Eastern and Western Tributaries we have reduced the runoff coefficient to 0.2 (from typical 0.4) assuming that bypass flow would be required for CDFW LSAA permit conditions.

Table 1. Summary of rational method calculations for upslope water sources.

Source	Area (acres)	Runoff coefficient	Intensity/Annual Precipitation (inches)	Volume (gallons)
Eastern Pond (direct precipitation)	1.3	1.0	48	1,656,000
Western Pond (direct precipitation)	1.8	1.0	48	2,346,000
Hillslope draining into Eastern Pond	2.5	0.4	48	1,303,000
Hillslope draining into Western Pond	5.0	0.4	48	2,607,000
Diversion from Eastern Tributary	4.0	0.2	48	1,043,000
Diversion from Western Tributary	20.0	0.2	48	5,213,000
Total				**14,168,000**

Based on the results shown in Table 1, the upslope sources have the capacity to deliver approximately 14 million gallons to the ponds based on 48 inches of annual precipitation. The total proposed volume of the ponds and tanks is 10 million gallons, so these sources provide sufficient annual water supply. However, it should be noted that the information in Table 1 is approximate and was used for planning-level analysis only. In particular, the estimates of runoff generated from hillslope sheetflow may be higher than can be actual runoff volumes. Additional detailed analyses and calculations are included in the Water Availability Analysis (Appendix C) that supersede the preliminary results presented in Table 1. Based on recent years trending toward less annual rainfall, the project is being designed to allow for flexibility to fill the total storage volume even during years where less than 48 inches of precipitation occurs.

8.2.4 Water availability for diverting from Redwood Creek

Pumping water from Redwood Creek during the wet season was also determined to be a viable option for filling the pond. This source has some advantages considering that the proposed diversion would likely be a small percentage of total flow in the creek during the wet season diversion period. A Water Availability Analysis is included in Appendix C. Based on that document, there is sufficient water available in Redwood Creek to pump during the wet season to fill the pond.

The previous project design iterations with one 15.3-million-gallon pond (Appendix A.1 and A.2) required a diversion from Redwood Creek to fill the pond. Those design scenarios proposed a 200 gallons-per-minute diversion during approximately one month of the wet season with a total diversion volume of approximately 10 million gallons. However, based on the current design iteration that includes two smaller ponds and supplemental tanks with a total volume of 10 million gallons, it has been determined that diversion from Redwood Creek is no longer necessary with the upslope sources discussed in Section 8.2.3 having sufficient runoff to fill the proposed storage.

The Appropriative Water Right is still required to divert from the two seasonal tributaries and the application that was previously filed with the SWRCB has been amended to update the location and volume of diversion.

8.3 Existing Flow Data and Expected Flow Enhancement Benefit

SRF began monitoring dry season flows in Redwood Creek in 2013. Flow monitoring results for station RC-4, located near Redwood Creek's confluence with the south Fork Eel, is shown on Figure 15. As this figure depicts, dry-season flows in Redwood Creek are extremely low with flows at RC-4 dropping below 5 gallons per minute during each of 2013 through 2018 dry seasons (2019 was anomalously high). Flows at all other monitoring stations throughout the watershed follow similar trends with zero flow recorded at the majority of monitoring stations during most years. Based on this data, the proposed project benefit of approximately 30 gallons per minute of flow augmentation provides a substantial and meaningful increase above current dry season base flow. Additionally, water temperatures of the flow releases are anticipated to be suitable for salmonids during most years as described in Appendix J.

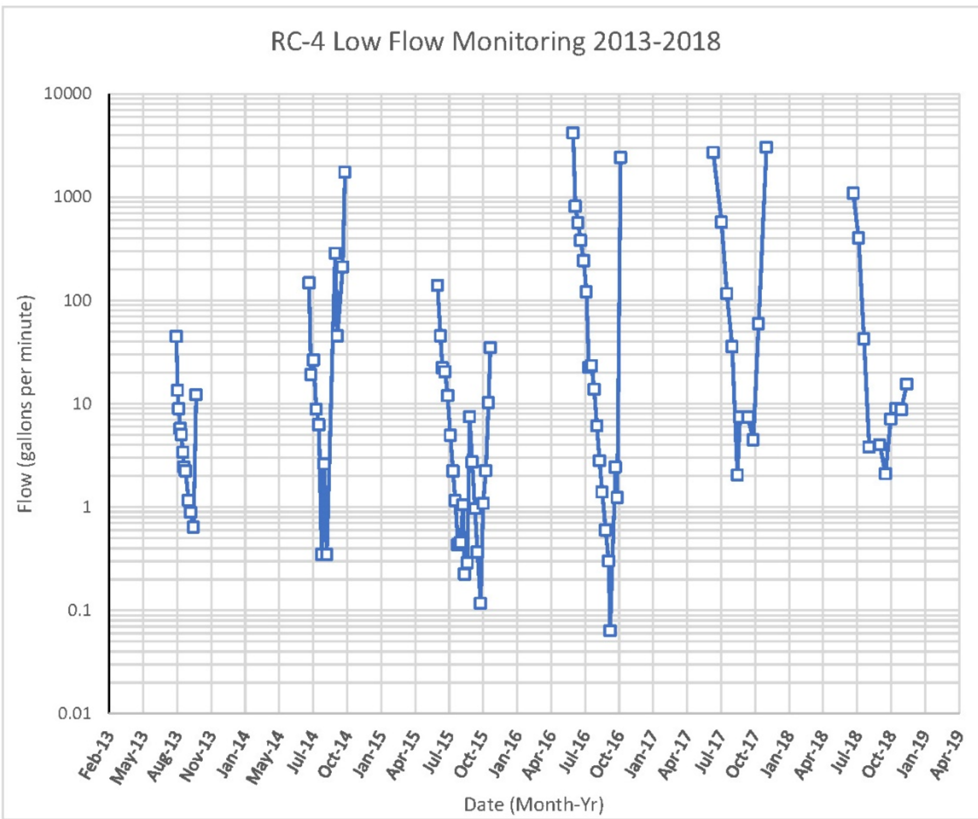

Figure 15. Dry season flow monitoring results for Redwood Creek mainstem near confluence with South Fork Eel.

8.4 100-year Storm Event Analysis

The 100-year storm event analyses utilized Rational Method runoff calculations for the upslope areas and Class III drainages running through and adjacent to the Project as well as more in-depth hydrologic and hydraulic analyses for mainstem Redwood Creek.

8.4.1 100-year storm event rational method calculations

Based on the Rational Formula defined in Section 8.2.1 above, 100-yr discharges were calculated for the outfalls of the ponds as well as the eastern and western tributaries. This method is appropriate for determining flow rates for relatively small drainage areas of less than 200 acres according to Cafferata et. al. (2004).

8.4.1.1 Determining storm duration

For the Rational Method analysis, the total area, slope, and longest flow path for each drainage was determined based on field observations and analyses of a USGS topographic map. Based on these values (summarized on Table 2), the "Time to Concentration" was estimated using the Airport Drainage Formula. The "Time to Concentration" is defined as the time it takes runoff to travel along the longest flow path within the contributing watershed and arrive at a site crossing. Per Cafferata et. al., the "Time to Concentration" can be found with the following Airport Drainage Formula[1]:

$$T_c=((1.8)(1.1-C)(D^{0.5}))/(S^{0.33})$$

Where:

Tc=Time of Concentration (minutes)
C=Runoff Coefficient (dimensionless, 0<C<1.0)
D=Distance (in feet from the point of interest to the point in the watershed from which the time of flow is the greatest)
S = Slope (percent)

[1] Note that two methods for determining Time to Concentration were described in Cafferata et. al. including (1) the Kirpich formula and (2) the Airport Drainage equation. The Kirpich Formula was developed in 1940 based on precipitation and runoff data from seven rural watersheds in Tennessee with average slopes ranging from 3% to 10%. We believe that the Kirpich Formula does not provide good estimates for Time to Concentrations on steeper northern California watersheds. Additionally, Yee (1994) recommends use of the Airport Drainage equation.

Table 2. Summary of time-to-concentration analyses.

Site	Drainage area (ac)	Longest flow path (ft)	Maximum elevation change (ft)	Slope (%)	Time to concentration (min)	100-year intensity (in/hr)
Hillslope draining to Eastern Pond	2.5	600	80	13	13	3.1
Direct rainfall on Eastern Pond	1.3	0	0	0	13	3.1
Hillslope draining to Western Pond	5.0	720	200	28	11	3.3
Direct rainfall on Western Pond	1.8	0	0	0	11	3.3
Eastern Tributary	4.0	700	120	17	13	3.1
Western Tributary	20.0	2500	520	21	23	2.2

* Time to concentration for Eastern and Western Ponds match associated hillslope time to concentrations.

8.4.1.2 Precipitation data

The intensity-duration-frequency (IDF) curve used for the Rational Method analysis came from National Oceanic and Atmospheric Administration's National Weather Service Hydrometeorological Design Studies Center Precipitation Frequency Data Server (PFDS).[2] Rainfall intensity was determined from the IDF curves for the 100-year recurrence interval for storm durations equivalent to the "Time to Concentration" for the project sites. The 100-year rainfall intensity from the PFDS for each site is also shown on Table 2.

8.4.1.3 Runoff coefficients

Cafferata et. al. suggests a runoff coefficient ranging from 0.30 to 0.45, depending on the specific location of the crossing. Per Buxton et. al. (1996), as cited in Cafferata et. al., a runoff coefficient value of 0.4 is recommended for North Coast California specifically. Additionally, a runoff coefficient of 0.4 reflects woodland with heavy clay soil, soil with a shallow impeding horizon, or shallow soil over bedrock per Figure 16 taken from Appendix A, Table A-1 of *The Handbook for Forest, Ranch and Rural Roads* (Weaver et. al. 2015).

For this property, we have used a Runoff Coefficient of 0.4 because the drainage areas consist of mostly woodland with soil with a shallow impeding horizon. For the rain falling directly on the ponds, the runoff coefficient is 1.0.

[2] http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html

Soils	Land use or type	C value
Sandy and gravelly soils	Cultivated	0.20
	Pasture	0.15
	Woodland	0.10
Loams and similar soils without impeded horizons	Cultivated	0.40
	Pasture	0.35
	Woodland	0.30
Heavy clay soil or those with a shallow impeding horizon; shallow over bedrock	Cultivated	0.50
	Pasture	0.45
	Woodland	0.40

Figure 16. Runoff coefficients (adopted from Appendix A, Table A-1 of the *Handbook for Forest, Ranch and Rural Roads* [2015]).

8.4.1.4 Storm discharges

Discharges from the Rational Method calculations for 100-year storm events are shown on Table 3.

Table 3. 100-year discharges.

Site	100-year discharge (cfs)
Hillslope draining to Eastern Pond	3
Direct rainfall on Eastern Pond	4
Hillslope draining to Western Pond	7
Direct rainfall on Western Pond	6
Eastern Tributary	5
Western Tributary	18

8.4.1.5 Drainage structure sizing

New drainage structures will be needed for the access road to the project which crosses the Eastern and Western Tributary and the outlets of the ponds with runoff generated from both the "hillslope draining to" each pond and the "direct rainfall on" each pond. These drainage structures are required to carry 100-year discharges and are sized using the FHWA Culvert Capacity Inlet Control Nomograph (Figure A-1 of Weaver et. al. 2015) using an HW/D ratio of 0.67, as shown in Figure 17 below. The required culverts for both tributaries and pond outflows are shown in Table 4.

Table 4. Drainage Structure Sizes

Site	100-year discharge (cfs)	Culvert diameter required (inches)
Eastern Pond Outflow	7	30
Western Pond Outflow	13	36
Eastern Tributary	5	24
Western Tributary	18	36

The rock armored grade control structures proposed for stabilization in the Western Tributary have also been designed to accommodate the 100-yr storm flows listed in Table 3.

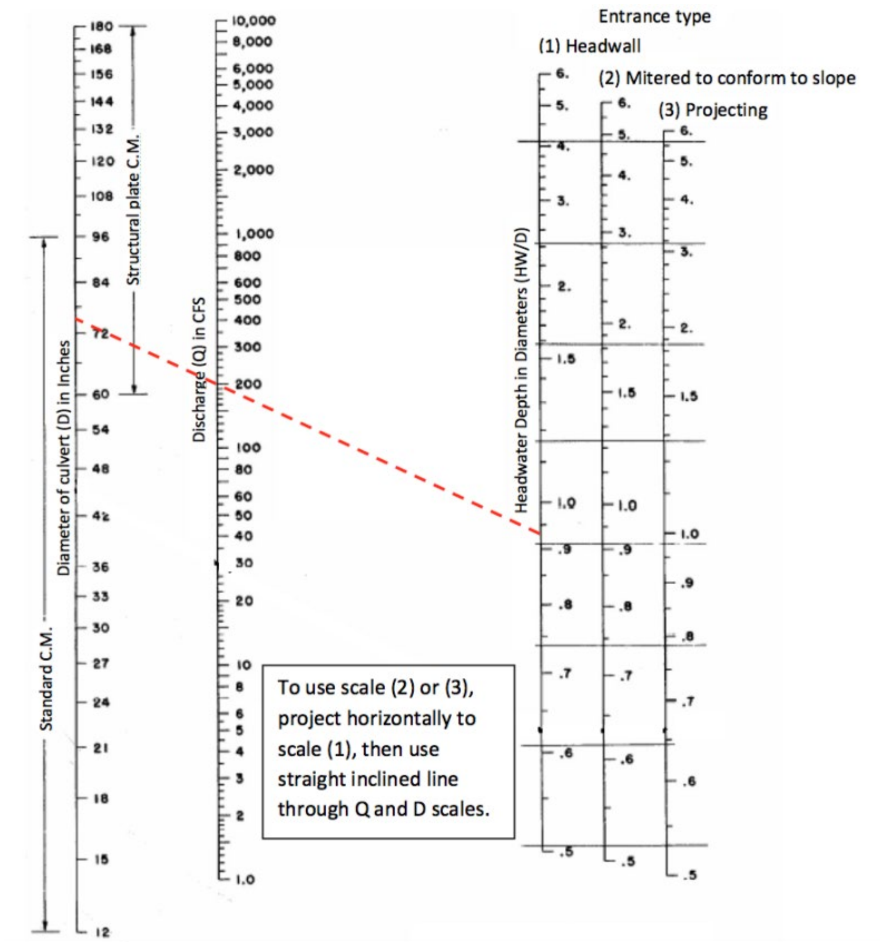

Figure 17. Culvert Capacity Inlet Control Nomograph (adopted from Appendix A, Table A-1 of *The Handbook for Forest, Ranch and Rural Roads* [Weaver et. al. 2015]).

8.4.2 Hydrologic and hydraulic overview for Redwood Creek mainstem

To understand the flow dynamics that will act on the instream features proposed in Redwood Creek and to estimate flooding potential at the project site, flow hydraulics were modeled using the U.S. Army Corps of Engineers' (USACE) *Hydrologic Engineering Center's River Analysis System (*HEC-RAS). HEC-RAS is a one-dimensional hydraulic model that is widely used for floodplain mapping and estimating general flow characteristics. This one-dimensional model assumes uniform flow direction and constant velocity distribution within the channel and floodplain portion of each cross section. Flow is modeled based on topography at a channel cross section without considering the effects of channel topography between cross sections. Therefore, it is important that these limitations are closely considered during hydraulic model setup, calibration, and application.

8.4.2.1 Hydrologic data overview

The first step in this hydraulic modeling process is to determine the hydrologic data that will be the principal input to HEC-RAS. The primary hydrologic data sets analyzed for this project were flood frequency flows (also known as recurrence interval flows) which represent higher flows that are expected to occur at a specific frequency (i.e., a 100-year flow would be expected to occur every 100 years on average). These flood frequency flows, especially those from half of “bankfull” to 2-year discharges, are biologically significant because they occur during most winters and are swift enough to flush salmonids out of the system and/or cause mortality if insufficient low-velocity habitat is available at such flows. For this analysis, 1.5-year recurrence interval flows are considered to be synonymous with “bankfull” flows. In addition, it is critical to analyze flows from larger events ranging from 2- to 100-year to determine erosion potential and flooding hazards for adjacent property and infrastructure, as well as the stability of the features being installed under high flow conditions.

Flood frequency discharges for each project reach were determined based on (1) US Geological Survey (USGS) gage data, (2) Federal Emergency Management Agency (FEMA) flood insurance studies, and (3) USGS Streamstats data. Each of these data sources are discussed below.

8.4.2.2 USGS gage data

USGS gage #11476500 has recorded annual peak flows in SF Eel River near Miranda for approximately 75 years. For this analysis, peak flow records from October 1939 to September 2016 were used. With these records, Log-Pearson Type III distributions can be used to predict the magnitude of peak flows for specific storm events. Considering the timeframe during which peak flows have been measured, this gage data is particularly accurate in predicting flows for storm events with recurrence intervals of 10 years and less.

Considering that the project reach is not located at the same location as the USGS gages, flows were estimated at each project site using the USGS formula for calculating magnitude and frequency of floods in California:

$$Q_u = Q_g(A_u/A_g)^b$$

Where: b = 0.9 for 2-year event and b = 0.87 for 100-year event

Q_u = Ungauged discharge
Q_g = Gauged discharge
A_u = Ungauged drainage area
A_g = Gauged drainage area.

Results from these calculations are shown in the first row of Table 5. Based on the updated project design proposing a pond on the western terrace, the hydraulic has been extended upstream to ensure that the pond will not be impacted by 100-yr WSEs. The hydraulic model now incorporates a major tributary confluence where Miller Creek enters Redwood Creek from the north. The flow allocation between these major tributaries has been determined via proration by drainage area as described on the bottom rows of Table 5.

Table 5. Flood frequency discharge estimates for the Redwood Creek Project Reach.

Discharge location and description:	100-year discharge (CFS)	50-year discharge (CFS)	25-year discharge (CFS)	10-year discharge (CFS)	5-year discharge (CFS)	2-year discharge (CFS)	1.5-year discharge (CFS)
Redwood Creek Downstream from Miller Creek confluence: Log-Pearson Analysis based on USGS Gage at Miranda (537 sq mi) adjusted for Drainage Area Difference based on USGS Formula				3,100	2,400	1,400	800
Redwood Creek Downstream from Miller Creek confluence: FEMA prorated	3,500	3,400		2,200			
Redwood Creek Downstream from Miller Creek confluence: USGS Streamstats for Project Site (10.7 sq mi)	3,850	3,340	2,840	2,170	1,660	930	
Redwood Creek Downstream from Miller Creek confluence: Average Combined	**3,700**	**3,400**	**2,840**	**2,500**	**2,000**	**1,200**	**800**
Miller Creek (3.7 sq mi drainage area) proration from Downstream Redwood Creek reach	**1,280**	**1,180**	**980**	**860**	**690**	**410**	**280**
Upstream Redwood Creek (7.0 sq. mi. drainage area) proration from Downstream Redwood Creek reach	**2,420**	**2,220**	**1,860**	**1,640**	**1,310**	**790**	**520**

8.4.2.3 FEMA Flood Insurance Studies

FEMA has authored a Flood Insurance Study (FIS) for Humboldt County which includes Redwood Creek (FEMA 2017). The FIS focuses on the area around Redway, downstream of the project reach. The FIS does not provide 100-year flood water surface elevations (WSEs) for the project reach, but does provide a map of estimated 100-year floodplain extents. In addition, FEMA flood discharges for SF Eel River can be prorated by drainage area to estimate flows for the project reach. FEMA predicts flood discharges for 10-, 50-, 100- and 500-year storms.

8.4.2.4 USGS Streamstats data

The USGS operates the interactive Streamstats website which can be found at: (http://water.usgs.gov/osw/streamstats/california.html)

This website uses a geographic information system (GIS) and flow regression equations to calculate storm discharges at any point along watercourses. Streamstats provides discharge data for 2-, 5-, 10-, 50- and 100-year storms. Streamstats results at the project site are shown in the third row of Table 1.

8.4.2.5 Discharges

Discharges used in the Redwood Creek hydraulic model are listed in the bottom row of Table 5. These flows have been calculated by averaging the discharges listed in the top two rows of the table. These values have been rounded to two significant digits to reflect the uncertainty of these estimates.

In addition to the flood frequency flows, additional low and moderate flows have also been modeled in HEC-RAS which correspond to winter base flow and a typical late spring/early summer flow. These flows have biological significance for restoration, especially related to spring and summer rearing as well as over-wintering habitat for salmonids. Note that for much of the summer, flows in Redwood Creek drop below 1 cfs (Stillwater 2017). However, due to the level of detail of topographic data gathered as well as hydraulic modeling constraints, there is minimal value-added in modeling flows less than 1 cfs. The low to moderate flows used in the hydraulic model are shown in Table 6. The typical winter discharge was calculated by prorating flows for the project site based on average January, February, and March flows measured at USGS gage #11476500 (SF Eel near Miranda). The typical spring/early summer discharge was calculated by prorating flows for the project site based on average May, June, and July flows measured at USGS gage #11476500 (SF Eel near Miranda).

Table 6. Additional discharge estimates used for the Redwood Creek hydraulic model.

	0.5 bankfull discharge (CFS)	Typical winter discharge (CFS)	Typical late spring/early summer discharge (CFS)
Redwood Creek Downstream reach	400	88	1
Miller Creek	140	30	1
Redwood Creek Upstream reach	260	58	1

8.4.2.6 Existing conditions hydraulic modeling

Existing conditions topography used for the HEC-RAS model was based on the DEM described in Section 7 of this report. Plan view locations of all HEC-RAS cross-sections are shown on Figure 18. Typically, cross sections are cut perpendicular to the channel thalweg. However, in cases where there is significant channel sinuosity, which is the case for this project, some skewing of the sections is required to properly model the channel and floodplain curvature. Based on sensitivity analyses conducted in HEC-RAS with different cross section placements, it was determined that the slight skewing of the cross sections away from perpendicular does not lead to significant differences in modeled outputs of velocities or flood elevations.

Cross-sections of the channel were cut from the Triangular Irregular Network (TIN) surface in AutoCAD and exported directly to HEC-RAS in order to create the hydraulic model. Manning's "n" roughness values used in HEC-RAS were 0.05 for the channel, based on the HEC-RAS Reference Manual recommendations for a "clean and winding natural stream with some pools, shoals, weeds and stones"; and 0.06 for all banks and floodplains based on a conservative value for "light brush and trees in summer." These values were calibrated based on previous work that Stillwater conducted for a restoration design project just downstream from this project (see discussion below). Flow was modeled in a subcritical regime with a normal depth downstream boundary condition at a slope of 0.0055 held constant for all flow stages.

8.4.2.7 Hydraulic model calibration

The existing conditions HEC-RAS model was calibrated using field-based evidence of 2017 high flow. Based on a review of Water Year 2017 peak flows on Bull Creek, the highest flow event which occurred on January 10, 2017 was approximately a 2-year recurrence interval flood. At Station 17+00, flood debris caught in tree branches was observed at elevations between 464 and 465.5. Based on the positioning of the tree branches where observations were made, it is likely that during high flows they were bent down several feet. The initial HEC-RAS model run predicted 2-year water surface elevations (WSEs) flows of 462.7 feet. To calibrate the model to more accurately match field observations, all Manning's n roughness values were increased by 0.005 which consequently increased the WSE at Station 17+00 to 463.3 feet which closely matches field observations assuming the branches were pushed down several feet.

8.4.2.8 Existing conditions hydraulic model results

The existing average stream channel velocity and mean total shear value results from HEC-RAS for 100-year, 10-year, 2-year, and 1.5-year flows are shown on Table 6. The corresponding WSEs and floodplain extents for these return periods are shown on Figure 18 and Figure 19. A full tabulation of hydraulic model outputs are included in Appendix D. Figure 18 shows the longitudinal profile of the channel invert and WSEs throughout the project area. Note that the Project is located within the upstream extent of the modeled profile between HEC-RAS Stations 3000 and 4200.

Within the project reach, the 100-year flows are almost entirely contained within the channel as shown on Figure 19 due to the generally incised nature of the Redwood Creek. Therefore, there are no significant constraints in placing fill or constructing infrastructure adjacent to Redwood Creek based on 100-yr flow. Furthermore, the floodplain terrace to the north of Redwood Creek is significantly lower than the terrace to the south of the creek. Therefore, even if future WSEs were higher than the model results, flooding would extend across the northern floodplain and would not reach the southern terrace where project features are proposed.

The incised and confined nature of the channel will generate high velocities and deep flows that will exert strong forces on proposed instream structures. Therefore, a stability analyses is necessary for the design of proposed instream structures (see Section 12 below).

Table 7. HEC-RAS model outputs for average channel velocity and shear for the modeled project reach.

Flow metrics	Average existing total velocity (feet per second)	Average existing total shear (pounds per square foot)
Spring/Early summer	0.64	0.13
Typical winter	2.23	0.46
0.5 Bankfull	3.49	0.79
1.5-year	4.27	0.97
2-year	4.78	1.09
5-year	5.41	1.27
10-year	5.71	1.35
25-year	5.88	1.36
50-year	6.12	1.37
100-year	6.22	1.38

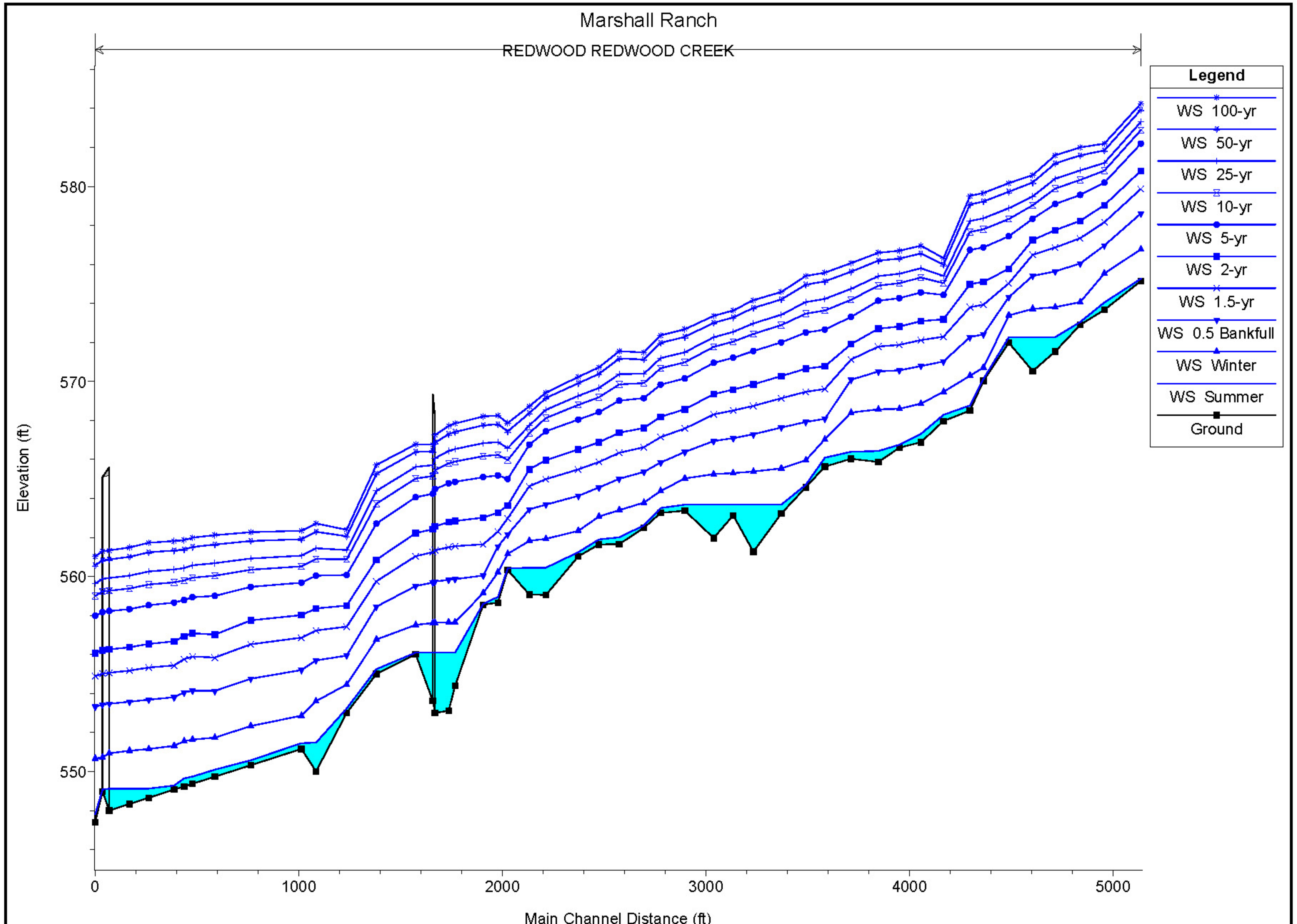

Figure 18. Modeled water surface elevations in the project reach.

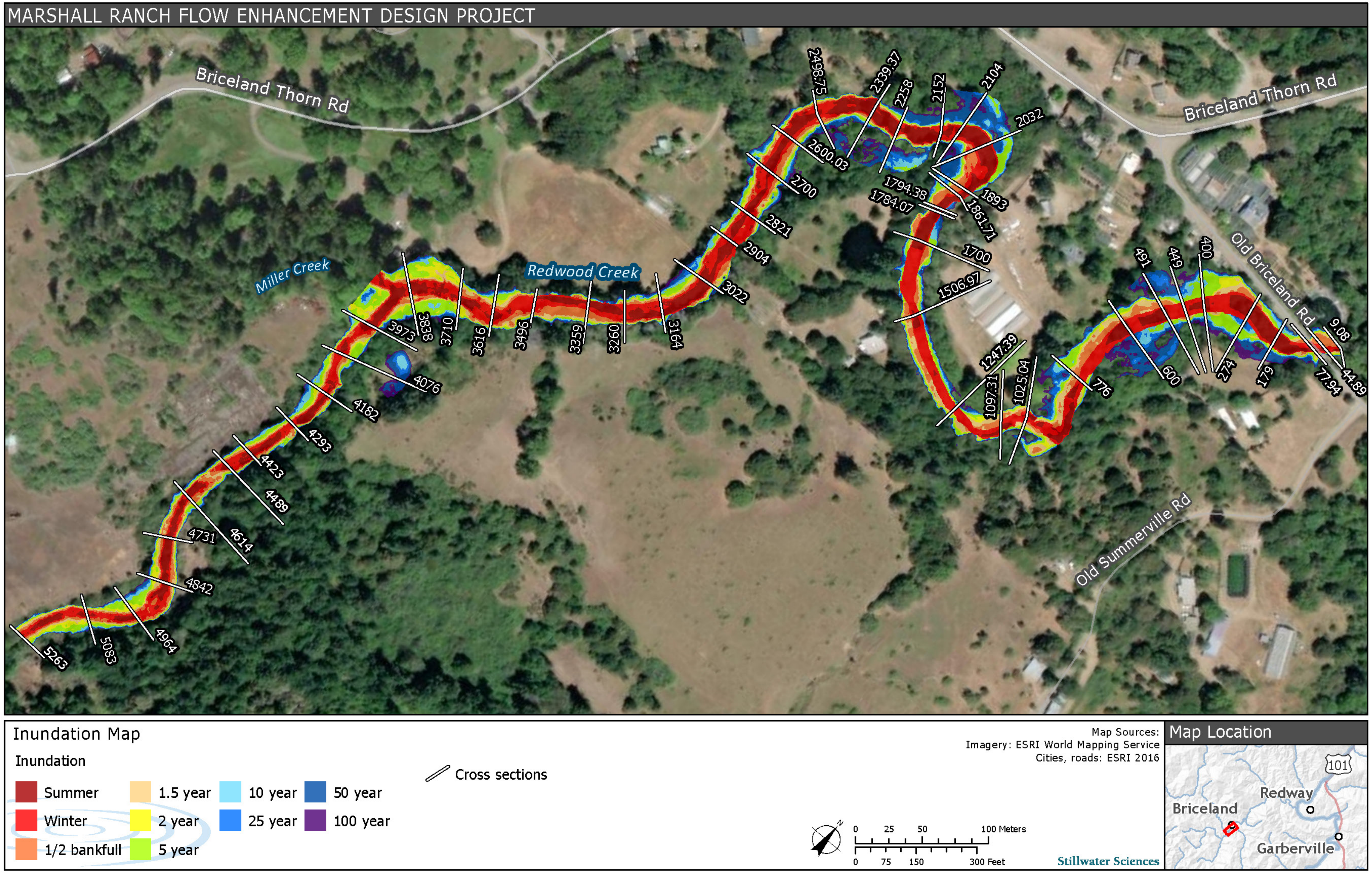

Figure 19. Inundation at various flows within the project reach.

8.4.2.9 Proposed conditions hydraulic modeling results

The proposed features within Redwood Creek are not expected to significantly change hydraulic dynamics so no proposed-conditions modeling will be conducted.

8.5 Groundwater

Groundwater wells were installed in November 2018 inside two of the boreholes (BH-101 and BH-103) and three of the test pits (TP-1, TP-2, and TP-3). Groundwater wells consisted of screened 2-inch diameter PVC pipe with data loggers measuring water elevations at 15 minute intervals. Note that the wells within BH-101 and BH-103 were constructed using standard well installation techniques with a bentonite seal around the top of the well to prevent direct precipitation and ponding around the well head from influencing measured groundwater levels. The wells within TP-1, TP-2, and TP-3 were constructed more coarsely with vertical standpipes stuck into the test pit and backfilled with loose dirt by an excavator bucket (i.e. there was no seal or soil mounding around the well head to reduce pooling and accelerated infiltration during and after significant precipitation events).

Groundwater monitoring results for the five wells are shown on Figure 20. Even with the different installation techniques, the groundwater levels measured within each well follow similar patterns. As expected, the groundwater dynamics at the site are governed by precipitation events with significant rainfall leading to increased groundwater levels within the wells. Within BH-101 and BH-103, during the dry season, the groundwater levels are perched just above the bedrock interface which is consistent with the findings from the geotechnical investigations (note that the bedrock is nearly impervious). Then, during significant rainfall events, the groundwater levels spike.

There was a visible difference between groundwater dynamics at BH-101 compared to BH-103. At BH-101 groundwater was either at the ground surface or within several feet of the ground surface during approximately two months of the 2018/2019 wet season whereas BH-103 just had several groundwater level spikes that neared the ground surface. This is likely due to surface runoff from the Eastern Tributary infiltrating into the terrace upslope from BH-101. Groundwater within the lower terrace was also near the ground surface during wet periods. Based on these groundwater dynamics, a French drain is proposed under the western pond (lower terrace) due to the expected presence of significant groundwater during much of the wet season while no French drain is proposed under the eastern pond (upper terrace near BH 103) due to generally less groundwater with only occasional spikes during significant rainfall events.

Concerns have been raised by agency staff and community members that the project could negatively impact natural groundwater inputs from the project site vicinity through installation of the french drain under the pond. The french drain is designed to drain groundwater from the lower terrace to prevent bubbling under the pond liner and significantly reduce slope stability concerns. As shown by the well data (Figure 20), under existing conditions groundwater is almost entirely drained from the shallow soil layer within two months following significant precipitation events. Furthermore, the underlying shale bedrock is impervious and does not allow for groundwater recharge. Therefore, nearly all groundwater is drained from the site and delivered to Redwood Creek before low flow conditions are reached in the mid to late summer. Therefore, the groundwater inflows provided by the site under current conditions do not measurably increase dry season flows.

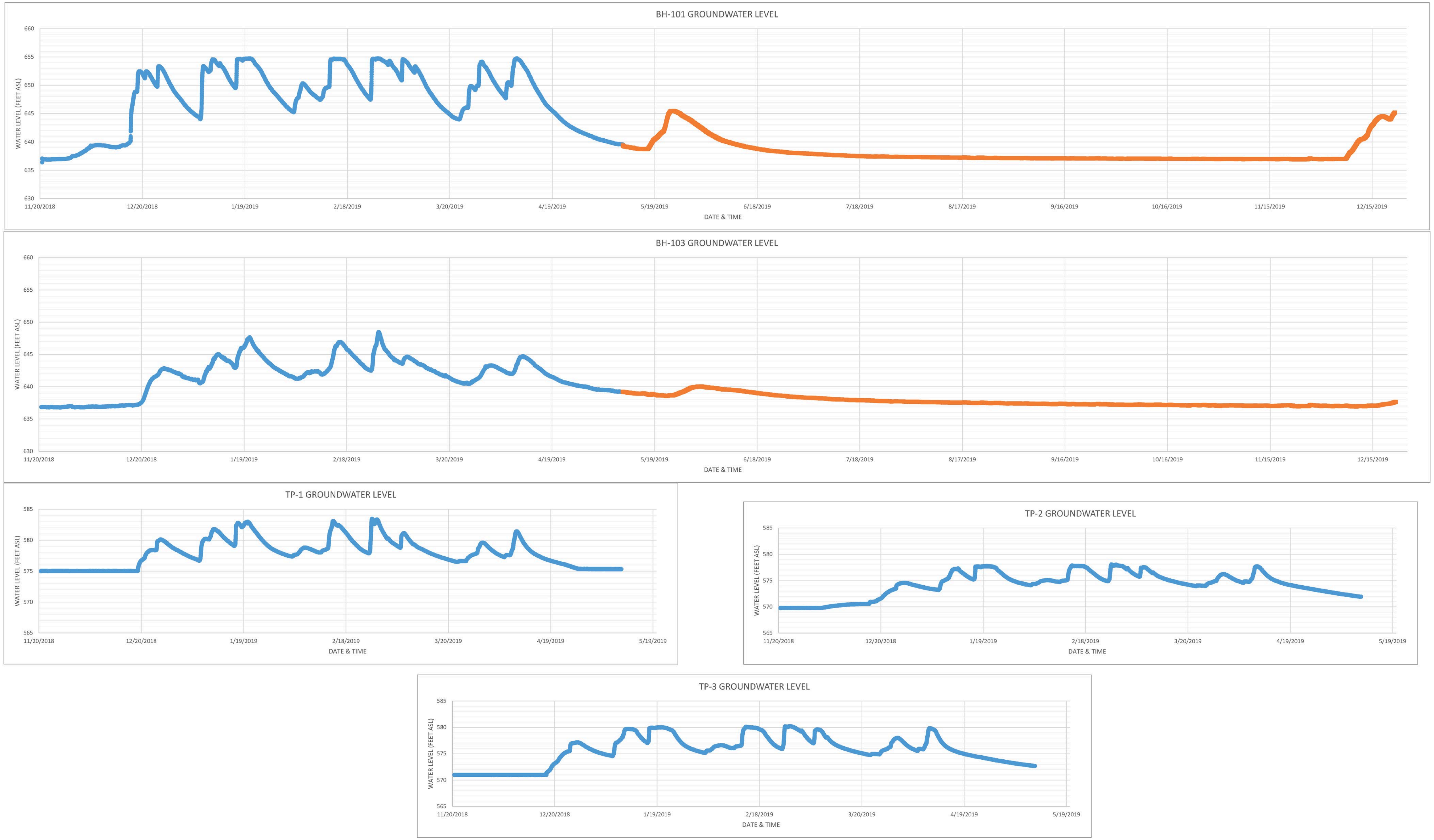

Figure 20. Groundwater monitoring results.

9 ADDITIONAL SITE EVALUATIONS

9.1 Cultural Resources

Findings from a cultural resources study are included in Appendix E. The proposed project design was developed with consideration of cultural resources, so no significant impacts are expected as long as the recommendations in the cultural resources study are followed. A cultural resources construction monitor has been included in the implementation project budget.

9.2 Biological Resources

Findings from a Biological Resources study are included in Appendix F. The proposed project design was developed with the goal of enhancing local aquatic habitat, so no significant impacts are expected as long as the recommendations in the Biological Resource Technical Report are followed.

10 ALTERNATIVES ANALYSES

Based on the results of the multiple analyses described above, the project is feasible. An alternatives analysis was conducted in three phases with an initial phase defining the optimal size and filling/draining mechanisms for the reservoir, a second phase assessed in more detail specific project design considerations and features that maximize benefits and reduce risk, and a third phase took into account a broader watershed-scale perspective.

10.1 Phase I Analyses

A matrix of proposed project alternatives (Table 8) was developed to compare the flow enhancement benefits resulting from project with various pond sizes and metered versus passive pond outflow approaches.

Table 8. Summary Table of project alternatives.

Pond volume (gals)	Pond volume after evaporation loss (gals)	Flow benefit with mechanized outflow valve, assumes 5-month release time (gpm)	Flow benefit with passive outflow, assumes 5-month release time (gpm)	Comments
6,000,000	4,000,000	19	12	Fills with rainfall only
8,500,000	5,666,667	26	16	Fills with Rainfall, Trib A and hillslope
13,500,000	9,000,000	42	26	Fills with Rainfall, Trib A, Trib B and hillslope
16,300,000	10,866,667	50	31	Maximum capacity to be exempt from DSOD Jurisdiction; needs water pumped from Redwood Creek to fill
21,500,000	14,333,333	66	41	Maximum size based on site conditions and filling capacity based on realistic water sources

Based on this matrix of alternatives the design team selected a 16-million-gallon pond with mechanized outflow capable of delivering 50 gallons per minute of flow to Redwood Creek during a 5-month dry season. Preliminary vetting of this alternative was also conducted at the February 2019 TAC meeting with member of the TAC generally supporting this alternative. The preferred alternative provides a substantial flow benefit of 50 gallons per minute while being generally conservative in utilizing the available topography. This alternative is also exempt from DSOD fees and reporting which will reduce long-term operations and maintenance costs.

This alternative was advanced to the draft 65% design level with excerpts from that design included in Appendix A.1 (Draft 65% Designs Excerpts 2019). Note that based on input from adjacent landowners, further analyses were conducted, and several significant design alternatives were considered through a Phase II alternatives analyses as described below.

10.2 Phase II Analyses

Phase II of the alternatives analyses focused mainly on analyzing specific design alternatives that reduced project risks to the lowest practicable level while increasing functionality and longevity and maintaining a total volume of approximately 16 million gallons. Four new design alternatives were analyzed to increase pond stability and general long-term durability of the project:

1) **Lowering the pond elevation by eight feet.** With this grading approach, approximately 90,000 cubic yards (CY) of earth will be excavated from the terrace and approximately 3000 CY will be used to construct the berm. This will result in a net off-haul of 87,000 CY of earth or ~120,000 tons. With the pond at full capacity (65,000 tons of water), the proposed design will result in a net reduction of weight on the terrace of 55,000 tons. Note that the fill that was previously proposed under the solar arrays has been eliminated. In summary, the current design significantly reduces the soil weight on the existing terrace.
2) **Relocation of the pond spillways.** Based on the lower pond elevation, a rock-lined spillway draining out of the western extent of the pond is now feasible. This new alignment distances the spillway from the adjacent property owners. Also, the change from a culvert spillway (in the previous design phase) to a rock-lined spillway will increase longevity and reduce long-term maintenance costs.
3) **Installation of a pond liner, French drain, and subsurface restrictive barrier.** These design alternatives are being considered to ensure that the project will results in a decrease in groundwater levels downslope from the pond as compared to current groundwater levels. Results of the slope stability analyses showed that a high groundwater table increases risk of slope instability. The previous design iteration included a compacted clay liner on the inside of the pond to control seepage. However, valid concerns were raised about the longevity of that liner with wetting, drying, shrinking and swelling, as well as erosion of the native soil liner over time as the pond was filled and drained every year. Therefore, three significant design modifications for sealing the pond and reducing downslope groundwater are currently being considered: 1) a high grade plastic liner (guarantee of 25 years, life expectancy of 140 years) protected by geotechnical fabric and buried under six inches of gravel, 2) a French drain to collect and drain all groundwater flowing from upslope and under the pond liner, and 3) a subsurface restrictive barrier under the pond berm as a redundant safety feature to prevent downgradient flow of groundwater. Multiple groundwater wells will be installed in the

area downslope of the pond to ensure that groundwater levels remain lower than pre-project conditions. Data recorders measuring groundwater levels will be connected to an online network so that groundwater data can be analyzed and viewed in real time.

4) **Grade control structures in central gully.** Even though the project is likely to significantly reduce runoff rates within the central gully, continued degradation of this gully over time has the potential to slowly erode the terrace where the pond is proposed.
5) **Backup energy system.** Install backup energy system with batteries, inverter, small solar array and micro-hydro to provide capability to operate and monitor project even during power outage.

This project alternative is further described in Appendix A.2 (Draft 90% Designs Excerpts 2020). The project team believed that inclusion of these design alternatives resulted in a project that minimizes risk and maximizes long-term functionality. However, during the CEQA public comment period it became clear that strong opposition to the project still existed even with the significant design modifications. Substantive public comments were critical of the project within three primary areas: 1) concerns with long-term stability of the pond considering the scale of earthwork, 2) the desire to implement flow enhancement within the Redwood Creek watershed upstream from Briceland, and 3) the desire for a less mechanized project that would function without significant long-term electricity use. To address these considerations, a Phase III alternatives analyses was conducted.

10.3 Phase III Analyses

The third phase of the alternatives analyses looked at the option of downsizing the storage and flow enhancement volume on the Marshall Ranch while adding flow enhancement projects elsewhere in the watershed to address the three substantive public comments described above. To do this, the project team looked for opportunities outside the Marshall Ranch within the upper portions of the Redwood Creek watershed where large scale flow enhancement could be feasible. Previous on-the-ground watershed assessments throughout Redwood Creek had not identified any other feasible sites for large scale flow enhancement with willing landowners. However, in early 2020 Lost Coast Forestlands (LCF) acquired approximately 1000 acres of property in Upper Redwood Creek and in early 2021 the project team began assessing flow enhancement feasibility on that property. Based on several months of assessment, analysis, and agency discussions, it has been determined that there is strong likelihood of a feasible opportunity for significant flow enhancement via 5 to 6 million gallons of off-stream water storage on the LCF property.

This finding was incorporated into the third phase of Marshall Ranch alternative analyses with the project team looking at the potential for a smaller Marshall Ranch project whereby the Marshall and LCF projects combined would generate the target 15 million gallons of off-stream storage and 50 gpm of flow augmentation during the five-month dry season. By including a project on LCF property and reducing the water storage on the Marshall Ranch to 10 million gallons, the revised design addresses all three of the substantive public comments described in Section 10.2 above.

This preferred project alternative for the Marshall Ranch site is further described in Section 11 below and in Appendix A.3 (Draft 90% Designs 2021).

11 PROJECT DESIGN

Based on multiple rounds of alternatives analyses and solicitations/incorporation of public comments, the primary project objective for the Marshall Ranch is to construct 10 million gallons of off-stream water storage intended to deliver approximately 30 gpm of flow augmentation to Redwood Creek during the five-month dry season. This project includes the following components:

11.1 Main Components of Water Storage and Augmentation System

11.1.1 Ponds

Construction of off-channel ponds will include excavation and placement of earthen berms and spillways built into the natural topography. Construction will include removal of topsoil from the reservoir area. The topsoil will be saved and spread around the reservoir area along with mulch after construction. All critical fill placement will be subject to compaction testing to ensure 90% minimum compaction. Excavated material not used to build the berms will be placed and compacted in a designated fill areas as shown on the plans.

The project team originally proposed natural clay liners, but based on varied subsurface stratigraphy at the site, HDPE pond liners with associated woven geotextile fabric and gravel topping will be utilized. This approach is expected to maintain higher water quality in the pond by eliminating the rilling, erosion, and sedimentation that would have resulted from yearly filling of the pond with a natural clay liner. It also improves slope stability and eliminates seepage thereby resulting in better functionality of the ponds both in terms of water quality/quantity and long-term stability.

The Western Pond has a rock lined spillway sized for the 100-yr storm discharge. The Eastern Pond has an 18” diameter culvert as the primary spillway and a secondary rock lined spillway with capacity for 100-yr storm discharge.

11.1.2 Diversion Structures in Seasonal Tributaries

Two gravity fed screened inlet structures will be installed in two seasonal tributaries to allow for supplemental filling of the ponds. Water will only be diverted from the Redwood Creek tributaries during the wet season.

11.1.3 Flow enhancement delivery system and cooling/filtration gallery

The two ponds will be connected via piping and valves. Pond outflows will have screened outlets near the bottom of each pond. Valves and flow meters will control the amount of water that is released from the ponds.

During periods of the summer when water temperatures begin to warm, water will be directed into a cooling/filtration gallery prior to release to the creek. The cooling/filtration gallery will consist of an existing gully filled with ~1,350 CY of sand/gravel material sorted onsite. Initial reservoir drawdown modeling has been conducted and is discussed in Appendix H. That analysis suggests that under standard operating conditions the Western Pond will be greater than 20 feet deep during the peak of the dry season (August/September) so water should be stratified and temperature concerns should not be an issue considering that water is drawn out of the bottom of the reservoir.

In summary, the analyses indicate that the current pond design will result in flow releases with temperatures suitable for juvenile salmonids throughout the year under a standard management scenario. Under unusual circumstances, however, cooling pond water temperatures may be beneficial, and the cooling/filtration gallery will meet that need.

11.2 Additional Components

There are numerous additional project components that are required to meet the main project objective of flow enhancement as described below.

11.2.1 Off-grad energy system

A 1.0 KW solar array, battery bank, inverter, and control center building will allow for real time operations and monitoring capabilities.

11.2.2 Gully stabilization treatments

Approximately 10 rock armor grade control structures will be installed to stabilize two actively eroding intermittent drainages adjacent to the Project. The gully stabilization features are also expected to offset shallow groundwater draining that results from installation of the french drain under the pond. Specifically, treatments in the western tributary gully will significantly reduce incision rates and slow groundwater discharge.

11.2.3 Large wood structures in Redwood Creek

Instream habitat enhancement features will be constructed along Redwood Creek mainstem to improve summer rearing habitat for salmonids within the vicinity of the Project and also reduce bank erosion potential in the vicinity of the Western Pond. This includes construction of one large wood habitat enhancement structure.

11.2.4 Access road upgrades

The access roads within the Project vicinity will be improved to provide year-round access for monitoring, operations, and maintenance of all Project components. This will include reshaping and surfacing with gravel and upgrade to three small road/stream crossings.

11.2.5 Riparian fencing

Fencing will be installed to exclude cattle from watercourses and other unstable areas within the project area.

11.2.6 Additional water storage and fire suppression infrastructure

Five 100,000-gallon water storage tanks are included as part of the project to provide additional flow enhancement supply as well as water for domestic use and ranching activities on APN 220-061-011, and water supply for emergency fire suppression.

11.3 90% Design Engineer's Cost Estimates

The 90% cost estimates are shown on Table 9 and represent costs associated with the project design shown in Appendix A.3. Due to the complexity of the Project, a budget contingency is included.

Table 9. 90% Design engineer's cost estimate.

No.	Item	Unit Cost	Quantity	Units	Total cost
1	Mobilization	$200,000	1	Lump Sum	$200,000
2	Clearing and Grubbing	$100,000	1	Lump Sum	$100,000
3	Rough Earthwork (cut/fill balanced onsite)	$20	35630	Cubic Yard	$712,600
4	Pond Liners installation and materials	$500,000	1	Lump Sum	$500,000
5	Gully Stabilizing Grade Control Structures	$3,000	10	Each	$30,000
6	Additional Gully Armoring (rock placed)	$150	100	Tons	$15,000
7	Filtration/cooling gallery	$40	1350	Cubic Yard	$54,000
8	Dewatering	$20,000	1	Lump Sum	$20,000
9	Instream Large Wood Placed and Anchored	$2,000	8	Each	$16,000
10	Instream Boulders Placed and Anchored (as applicable)	$150	100	Tons	$15,000
11	Pond outflow pipeline materials and installation	$250,000	1	Lump Sum	$250,000
12	Spillways	$60,000	1	Lump Sum	$60,000
13	French drain materials	$50,000	1	Lump Sum	$50,000
14	100,000 gal water tanks	$80,000	5	Each	$400,000
15	Fencing	$100,000	1	Lump Sum	$100,000
16	Operations building and Electrical system	$100,000	1	Lump Sum	$100,000

17	Access road improvements and surfacing	$120,000	1	Lump Sum	$120,000
18	Erosion Control and Revegetation	$100,000	1	Lump Sum	$100,000
19	Post Project Monitoring Equipment (flow and groundwater)	$60,000	1	Lump Sum	$60,000
20	SRF Project Management	$200,000	1	Lump Sum	$200,000
21	ERWIG Project Management	$20,000	1	Lump Sum	$20,000
22	Cultural Resources Monitor	$25,000	1	Lump Sum	$25,000
23	Legal and Ranch Oversight	$140,000	1	Lump Sum	$140,000
24	SHN Engineering Oversight	$30,000	1	Lump Sum	$30,000
25	SHN Soils Testing	$15,000	1	Lump Sum	$15,000
26	Stillwater, Engineering, construction oversight, As-builts, Monitoring	$300,000	1	Lump Sum	$300,000
27	5% Contingency	$363,260	1	Lump Sum	$363,260
Total construction cost:					**$3,995,860**

12 STABILITY ANALYSES FOR LARGE WOOD

12.1 Stability Analyses Overview

A Large wood structure stability analysis was used to refine the project design based on the methodology presented in Castro and Sampson (2001). The constants, freebody diagram and equations from Castro and Sampson are included in Appendix G. In summary, this method uses a basic force balance approach in the vertical and horizontal directions to ensure that each wood structure will be stable during a specific flow regime. The calculation process begins with a sum of vertical forces to determine the boulder weight that is necessary to give each structure a factor of safety of 1.5 for buoyancy. Then based on these boulder weights, the factor of safety for momentum is calculated and more boulders are added as necessary to give each structure a momentum (sliding) factor of safety of 2.0 or greater. This stability analyses approach has been reviewed and approved by CDFW Engineer Marcin Whitman for application on several projects in Marin County.

No specific calculations were made for scour or rotational stability because the proposed large wood structures are intended to be dynamic and settle into the bed and banks as scour occurs. This is achieved by utilizing the combination of boulder ballast, live tree anchoring, and triangular anchoring of the placed large wood to allow for hinging and settlement of the structures if extensive scour occurs. Additionally, the risk of excessive scour and rotational instability will be managed by thorough oversight during construction by the engineer as well as field engineering to fine-tune the wood and boulder installation to insure proper placement.

12.1.1 Stability analyses parameters

Below is a list of assumptions that provide the basis of these calculations:

- Analysis based on maximum velocities at each station from HEC-RAS existing conditions model output. Velocity used in analyses is from adjacent station with highest output velocity.
- All boulders submerged at 100-year flows.
- Rootwad dimensions: 4 ft diameter x 4 ft length with porosity = 0.3.
- Channel bed and banks composed of medium gravel: Friction angle = 40 degrees, which results in coefficient of friction for bed of 0.84 (Castro and Sampson).
- All wood is calculated as dry Douglas Fir: density = 33.7 lb/ft^3 (Castro and Sampson).
- Anchor to live tree is assumed to be equivalent to 4 tons of ballast and 4 tons of momentum-resisting force.
- For flow force calculation on multi-log structures located along a stream bank parallel to flow, calculations may assume a shadow effect (i.e. flow does not act on all logs).
- Θ (angle from rootwad face to vertical) = 0.

12.1.2 Stability analyses uncertainties and factors of safety

There are several areas of uncertainty associated with this stability analyses as discussed below. However, we are confident that the structures will be relatively stable for the 20-year design life of the wood structures due to the Factors of Safety built into this analysis and the on-site engineering and geomorphic expertise that will guide the final layout of the structures (based on design, installation and monitoring of 50+ similar wood structures by project team). In addition, stability will be guaranteed through proper installation as described in the plans and specifications and guided by technical oversight.

The first area of uncertainty is that average flow velocities through each project reach (determined by HEC-RAS) are used for the stability analyses. In reality, water velocities vary greatly both laterally across the channel cross section and with depth. However, we believe that using average velocities is a conservative estimate because the highest velocities generally occur well away from the channel margins and all the proposed structures are located along the streambanks. However, in some cases, especially along outside bends, velocities along the banks can be as high or higher than velocities in the middle of the channel. In these areas, structures will be designed with greater Factors of Safety for sliding stability (momentum) considering the higher shear forces that may act against them.

A second area of uncertainty is the possibility that the position of the wood structures may adjust due to scour or racking of significant new wood against the structure. Most of the structures are built along the banks with strong anchor points to existing trees or new boulders, and in many cases, the structures have been designed so that the force of the flow will hold them in place (i.e. proposed placement in channel expansion zones). In the case of these structures, minor scour and settling may help the structure stay in place because it will increase resistant forces via wedging. However, some structures may have the potential to rotate if significant scour and racking of additional wood occurs. For structures with significant potential for rotation, it is recommended that anchor boulders be keyed deeply into the channel bed and bank and that the engineer/geologist is onsite for construction to insure proper installation.

A third area of uncertainty is the possibility of contractor error or faulty materials (wood or rock with insufficient strength) leading to failure of one or more of the anchoring connections. As such, we will include a significant amount of redundancy in the anchoring of each structure. To further ensure the quality of anchoring, we strongly recommend that a contractor is selected that has previous experience with implementation of large wood projects. Also, it is recommended that an engineer and/or geologist is onsite during large wood placement and anchoring to insure proper installation.

13 LONG TERM OPERATIONS AND MAINTENANCE

A critical component of the project is to ensure that long-term operations, maintenance, and monitoring activities are conducted appropriately and funded. The project team has secured foundation funding to cover long term operations and maintenance as described in Table 10.

Table 10. Projected Long Term Project Costs (years 1-20 post construction).

	Line Item	Annual Budget	Total Cost
Year 1-3	Marshall Ranch 501c3 - General Operations	$10,000	$30,000
	Stillwater Sciences - Engineering support for operations, maintenance, and monitoring (100 hrs/yr)	$15,000	$45,000
	Hicks Law - Legal Services (20 hrs/year)	$6,000	$18,000
	SRF/ERWIG - Annual flow monitoring & project operations (500 hrs/year)	$15,000	$45,000
	Project Adaptive Management Costs	$15,000	$45,000
	Total Cost (years 1-3)	**$61,000**	**$183,000**
Year 4-20	Marshall Ranch 501c3 - General Operations)	$8,000	$136,000
	Stillwater Sciences - Engineering support for operations, maintenance, and monitoring (40 hrs/yr)	$5,400	$91,800
	Hicks Law - Legal Services (5 hrs/year)	$1,500	$25,500
	SRF/ERWIG - Annual flow monitoring and project operations (300 hrs/year)	$9,000	$153,000
	Specific Equipment Replacement/Repair Costs	$5,000	$85,000
	State Licensing & Permit fees	$1,000	$17,000
	Total Cost (years 4-20)	**$29,900**	**$508,300**

Note that additional analyses will be conducted to better refine the operations, maintenance, and monitoring plan and costs. The project team anticipates developing a detailed Operations and Maintenance (O&M) Report that will be reviewed and approved by regulatory agency staff prior to the initiation of construction. Costs to conduct in-depth monitoring and adaptive management activities during the first three years of Project operations will be covered through WCB implementation funding. We anticipate working closely with agency staff during the immediate post-project period to optimize project function.

14 PROJECT RISK AND PERFORMANCE ASSESSMENT

There are several areas of potential project risks that have been thoroughly evaluated during the project planning and design process. Project impacts and approaches to minimize those impacts are discussed in Appendix I including design features, proposed mitigation measures, and monitoring and reporting. The evolution of the project design from the first design iteration shown in Appendix A.1 to the third design iteration shown in A.3 have resulted in a significant reduction in risk.

A summary of project risks and risk management is summarized below.

14.1 Risk and Management of Pond and Hydraulic Appurtenances Failure

1) Risk: Failure of the earthen fill that constitutes the pond berm is a project risk that could result in damage to downslope property and infrastructure.

   Management: The total project storage volume has been decreased by ~5 million gallons from previous design iterations and the storage has been divided into two ponds which greatly reduces the height and amount of earthen fill. The Western Pond is located adjacent to Redwood Creek with no properties or infrastructure immediately below the pond berm. The Eastern Pond has a total volume of less than 4 million gallons and is constructed via excess cut to reduce berm height.

   Additionally, reservoir level measurements will be closely monitored post-construction to ensure that the pond is functioning as designed. Throughout, the planning, design, construction, and monitoring phases, the Project has and will utilize best professional practices with a team of licensed professionals working together to minimize project risk while maximizing benefits. Secured foundation funding will provide resources for monitoring, operations, and maintenance of the system.

2) Risk: The most common failure mechanism of ponds and reservoirs is the failure of the overflow/spillway system. This can lead to significant erosion and mass wasting and can ultimately cause complete failure of the storage pond if left untreated.

   Management: The project design includes spillways sized to pass 100-yr storm discharges. The spillways will be positioned to drain as far away as possible from the nearest neighbor downslope from the project. Secured foundation funding will provide resources for monitoring, operations, and maintenance of the spillway.

3) Risk: Although it would likely not result in catastrophic failure of the Project, there is a risk of failure or malfunction of the flow enhancement piping, flow meter, valves, and cooling gallery.

   Management: These systems will be constructed with redundancy wherever practicable. Secured foundation funding will provide resources for monitoring, operations, and maintenance of these systems.

14.2 Risks and Management Associated with Instream Structures (Redwood Creek mainstem)

1) Risk: This reach of Redwood Creek within the project area is incised approximately 10- to 15 feet below the adjacent terrace and large flow events (including the 100-year flood) are largely confined within the channel. As such, all proposed work must carefully consider the forces acting on the bed and banks during storm events. Additionally, there are several bridges downstream that could be adversely affected by mobilized large wood.

Management: To ensure that wood structures are not disarticulated and transported downstream, stability of the structures for a 20-year design life will be insured through the stability analyses described above construction oversight and post-project monitoring by the project engineer and/or geologist. Post-project monitoring should be conducted during the first two winters following significant storm events, and in following years during flow events that exceed those that the new features have previously been exposed to. This monitoring should identify changes in site conditions that may affect functionality and durability (i.e. newly mobilized large wood, new significant scour, or repositioning of an existing structure).

2) Risk: Large wood structures typically have a design life of approximately 20 years due to declining strength related to wood decay, so it is critical to design the project to account for this reality.

   Management: To account for the estimated 20-year design life of the large wood, the boulders are included in each structure will be placed tucked against the bank such that they will continue to provide bank stability and pool complexity even after the wood rots. The incorporation of riparian planting in the design will provide additional riparian wood and root matter that after 20 years will replace the rotten large wood in many cases.

3) Risk: In a future large storm event, sediment delivered to the project reach from upstream sources may change channel morphology in ways that adversely impact the functionality of the proposed structures.

   Management: The addition of large wood and boulder structures within the Project reach are expected to make channel morphology and habitat within the Project area more resilient to potential future geomorphic changes. Furthermore, the Project does not consist of any features that significantly change channel geometry or slope that could be susceptible more susceptible to failure during future large storm events.

14.3 Overall Risks and Management Approaches Associated with Long-term Project Results

1) Risk: Water produced by the project is diverted out of Redwood Creek by downstream water users. Under applicable provisions of California water law, property owners downstream of the project site whose parcels are adjacent to Redwood Creek have the riparian rights to take and use the “natural flow” of the stream for certain limited purposes. Additionally, some downstream property owners may have appropriative rights to divert water.

   Management: Downstream diverters are required by law to report their diversions to CDFW and State Water Resources Control Board (SWRCB) and those agencies have the authority to control the amount and timing of those diversions. The project team is currently conducting broad outreach among property owners and regulatory agency staff (CDFW and SWRCB) to inform all parties about the project and develop a regulatory framework, engage the community, and prepare for monitoring/enforcement activities after the project is constructed. The project team will also provide technical and coordinate grant funding opportunities to assist landowners within critical stream reaches to increase their water storage capacity.

2) Risk: Water quality and temperature produced by the pond is not suitable for aquatic species in downstream channel.

   Management: The project planning process has taken these risks into consideration with the pond and water delivery systems designed such that appropriate temperature and water quality are maintained. The water delivery system will draw water out of the bottom of the pond which will have low temperatures for most of the year. An on-demand circulation system will be installed in the pond to maintain water quality. As necessary, a cooling/filtration gallery will be utilized to decrease the temperature of flow releases. Detailed post-project monitoring and adaptive management actions will be utilized to change pond operations as necessary. Furthermore, case studies from Russian River tributaries have shown that similar project greatly improved water quality and specifically dissolved oxygen (RRCWRP 2017, Grantham et. al. 2018, RRCWRP 2019).

3) Risk: Although we know that fish need water to survive, there is some uncertainty regarding how the aquatic habitat will respond to enhanced flows, how to measure and quantify that response, and how to adjust the project flow delivery to maximize aquatic habitat benefit.

   Management: Based on similar projects conducted in Sonoma County in lower Russian River tributaries over the past several years, direct flow augmentation has been very effective in improving downstream aquatic habitat (Ruiz et al. 2018, Obedzinski et al. 2018, RRCWRP 2017, Grantham et. al. 2018, and RRCWRP 2019). However, as this habitat enhancement approach continues to develop, the risk can be addressed by post project monitoring of downstream discharge, temperature, dissolved oxygen levels, fish abundance, and fish health. Based on monitoring results from this and other projects, the Project operations can be adjusted to maximize aquatic habitat benefit.

15 CONCLUSION

Although there are risks associated with this project, the management actions described in Section 14 above reduce project risk to an acceptable level when compared to the expected project benefits. The "no-project alternative" will result in continued degradation of dry-season aquatic habitat in Redwood Creek. Also, this project will significantly improve the community's resilience to wildfire.

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