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Final Basis of Design Report - Middle Stotenburg Creek Coho Habitat Enhancement Design Project

PREPARED FOR

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California Department of Fish and Wildlife
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Cover photo: middle Stotenburg Creek just upstream of tributary confluence, view looking upstream.

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1 INTRODUCTION

The Smith River Alliance (SRA) retained Stillwater Sciences (Stillwater) to implement the Middle Stotenburg Creek Coho Habitat Enhancement Design Project (middle Stotenburg Creek enhancement project), with the objectives of designing improved fish passage, enhanced seasonal instream rearing habitat, and riparian condition along approximately 0.22 miles of middle Stotenburg Creek in northern Del Norte County. This final basis of design (BOD) report presents the preferred design alternative that was selected during Technical Advisory Committee (TAC) meetings in June and October 2020, and through additional email correspondence with the TAC.

TAC members for this project include representatives from California Department of Fish and Wildlife (CDFW) and National Oceanographic Atmospheric Administration (NOAA) Fisheries, as well as other stakeholders involved in the planning and design process (Table 1-1).

Table 1-1. Technical Advisory Committee members and other project stakeholders.

Technical Advisory Committee	
Member	**Affiliation**
Beatrijs deWaard	CDFW
Mark Smelser	CDFW
Kristine Pepper	CDFW
Bob Pagliuco	NOAA Fisheries
Other project stakeholders	
Jeff Daniels	Del Norte County Roads Division
Morgan Love	Landowner
Pacific Power	Landowner/Public Utility

1.1 Project Location

The project site is located along middle Stotenburg Creek approximately six miles upstream from the mouth of the Smith River, and 2.75 miles south of the town of Smith River in northern Del Norte County, California (Figure 1-1). Stotenburg Creek originates on the western slope of the Coast Range mountains and flows across the coastal plain before entering the right bank of the lower Smith River just downstream from the Highway (HWY) 101 bridge (Dr. Fine bridge). Stotenburg Creek is the first tributary to enter the Smith River after it exits its canyon and flows onto the coastal plain. The project reach is approximately 0.15 miles long, beginning upstream of the Cedar Lodge Lane crossing and extending across a low-gradient alluvial terrace and alluvial fan. The project site includes a tributary confluence and the downstream extent of the tributary. Downstream of the project site Stotenburg Creek flows for approximately 0.5 miles before meeting the Smith River. This 0.5-mile reach is the site of the Lower Stotenburg Creek Coho Habitat Enhancement Design Project (further described below in Section 1.2 *Need for the Project*).

1.2 Need for the Project

The Smith River is the largest free-flowing intact watershed in California and is considered a premier "Salmon Stronghold" along the Pacific coast and "irreplaceable" with respect to salmonid population resiliency (Wild Salmon Center 2012). However, these endorsements are largely based on the rivers undammed status, because much of the upper watershed is publicly owned and holds many designations with associated protections (e.g., National Recreation Area, National and State Park, Wilderness, Wild and Scenic River, etc.), and because land use has changed less here than in many other California watersheds (NOAA 2014). Notwithstanding, the Smith River coastal plain and estuary, the area with the greatest potential to support coho salmon (NMFS 2014), has had large reductions in available habitats and much of those remaining have been severely degraded due to anthropogenic changes related to agriculture, timber harvest, and road construction (Voight and Waldvogal 2002, NOAA 2014, Parish and Garwood 2015). These changes have resulted in reduced channel complexity, less off-channel and slough habitats, and less spatial and temporal access to remaining seasonal salmonid rearing habitats. Fish barriers at road crossings are listed as a high threat to juvenile and smolt coho salmon in the lower Smith River. Over the past decade, most major legacy barriers have been treated in reaches of the Smith River upstream of the coastal plain. However, numerous barriers in tributary streams within the estuary and coastal plain at private road crossings have received much less attention. The cumulative impact of these barriers results in decreased access to valuable rearing habitats. For these reasons, the impaired condition of the lower Smith River and estuary has been identified as the most significant threat to salmonids in the basin (Voight and Waldvogal 2002, CDFW 2004, NOAA 2014, Parish and Garwood 2015).

Tributaries within and proximal to estuaries and stream-estuary ecotones provide vital winter refuge habitat for juvenile coho salmon. These habitats contribute to higher survival, greater productivity, and higher overall population life history diversity (Otto 1971, Koski 2009, Wallace et al. 2015, Levings 2016). Recent winter surveys documented juvenile coho salmon, steelhead, and coastal cutthroat trout rearing throughout the lower 0.6 miles of Stotenburg Creek (Garwood and Bauer 2013, Parish and Garwood 2015 and 2016), including marked juvenile coho that migrated from Mill Creek to overwinter in the coastal plain (Parish and Garwood 2016). Furthermore, patches of quality rearing habitat are currently present in Stotenburg Creek, some of which have been enhanced by beaver activity (Parish and Garwood 2015 and 2016). Unfortunately, due to a lack of surface flow connection at crossings and at the creek mouth, fish utilizing Stotenburg Creek during high-flow events have the potential to be stranded as flow recedes during the late spring and early summer months (Parish and Garwood 2015 and 2016). The privately owned crossing within the project reach is undersized and limits fish passage and natural stream function. Lastly, increased habitat complexity is needed as the channel remains shallow and simplified throughout substantial portions of the project reach, even during elevated winter flows (Parish and Garwood 2016). Despite these limitations, Stotenburg Creek was found to have an abundance of overwintering coho salmon across multiple winters based on minnow trapping surveys (Garwood and Bauer 2013, Parish and Garwood 2015). Based on sampling throughout the lower Smith River, Parish and Garwood (2016) found Stotenburg Creek had the second highest capture rates of juvenile coho salmon after Morrison Creek, which is a much larger drainage.

By working with willing landowners, the middle Stotenburg Creek enhancement project is addressing key limiting factors for the juvenile coho salmon life stage in the Smith River, including passage barriers, the lack of floodplain and channel structure, and other impacts related to agricultural practices. The project reach is located immediately upstream of the Lower Stotenburg Creek Coho Habitat Enhancement Design Project, which involved 100% engineered design plans and specifications for similar fish passage and habitat enhancement objectives that was completed in October 2019. Implementation funding for the lower Stotenburg Creek enhancement project was applied for through the FRGP 2020 Proposal Solicitation Notice (PSN). Both the lower and middle Stotenburg Creek enhancement projects are designed to help SONCC coho salmon recover in the Smith River by improving fish passage, enhancing habitat complexity and riparian function, and extending migration timing and survival for juvenile coho salmon rearing in Stotenburg Creek. Other salmonid species in the Smith River, including Chinook salmon, steelhead, and cutthroat trout will also benefit from these projects.

Figure 1-1. Location of the middle Stotenburg Creek project area in northern Del Norte County.

2 EXISTING CONDITIONS

2.1 Geology and Tectonics

The Stotenburg Creek drainage is located on the western portion of the Smith River watershed, on the transition from the Coast Range mountains to the Smith River coastal plain. This portion of northwestern California is in a tectonically active plate-boundary deformation zone defined by compression and uplift along the Cascadia subduction zone. This deformation is manifest by multiple northwest-southeast trending thrust faults (further described below) that create a dominant topographic and structural grain in the region (Kelsey and Carver 1988).

The headwater hillslopes of Stotenburg Creek are located approximately 2 miles west of the Coast Range thrust fault ("South Fork fault" of Irwin 1972), along which graywacke and mélange units of the Eastern Belt of the late Mesozoic-aged Franciscan complex are thrust below Klamath Mountain ophiolite terranes (Aalto 1989) (Figure 2-1). Overlying the Franciscan complex along the coastal plain is the Pliocene-Pleistocene marine fossiliferous siltstone and sandstone St. George formation (Diller 1902, Maxson 1933, Stone 1993, Aalto et al. 1995). The St. George formation contains trace pebbles, carbonized wood, and fragmented molluscan shells; and is exposed in the wave-cut cliffs between Crescent City and Point St. George and encountered in borings beneath the coastal plain. Overlying the Franciscan complex and St. George formation is the Battery formation, which Maxson (1933) defined as poorly consolidated marine and terrigenous sands with interbedded clay. The Battery formation, which is a marine terrace deposit with interfingering dune sands and alluvial gravels, consists primarily of medium-grained sands alternating with blue-gray silty clay and imbricated gravels. The Battery formation overlies marine abrasion platforms dated at approximately 80, 105, and 125+ thousand years old (i.e., late Pleistocene) based on fossils, soil correlation, and amino acid racemization age correlation of the clam *Saxidomus giganteus* (Addicott 1963, Kennedy et al. 1982, Polenz and Kelsey 1999). As the coastline retreated westward following late Pleistocene sea-level high stands, the paleo Smith River incised into the Battery formation and deposited large alluvial terraces that cover the majority of the northern coastal plain (Delattre and Rosinski 2012) (Figure 2-1). The Project reach of Stotenburg Creek flows through these latest Pleistocene-Holocene terrace and floodplain deposits and the alluvial fan developed along their back edge.

Faults in the project vicinity include the Bald Mountain-Big Lagoon fault zone, Lost Man fault, and the Saint George fault (Clarke and Field 1989, Clarke 1992); all of which are offshore thrust faults located to the southwest of Crescent City. The Bald Mountain-Big Lagoon fault zone is considered late Quaternary in age, meaning it has been active in the last 700,000 years (Clarke and Field 1989). Although recent displacement along the Lost Man and Saint George faults is undifferentiated, they are considered Quaternary in age (i.e., active within the last 1.6 million years). Displacement along these thrust faults has caused the uplift of the coastal bluffs between the Crescent City harbor and Point St. George, which expose Franciscan and St. George formation rocks (Figure 2-1). Tectonic thrusting has also created the broad syncline across the coastal plain. The Rowdy Creek fault ("Smith River fault" of Clarke [1992]) has been recognized in offshore seismic lines but is queried onshore due to its lack of evidence other than the topographic transition from coastal plain to upland hillslopes (Figure 2-1). The Del Norte fault was first proposed by Maxson (1933) to account for the abrupt, north-south trending eastern boundary of the coastal plain with upland hillslopes. Some researchers have adopted Maxson's proposed fault (Back 1957, Roberts and Dolan 1968, Stone 1993) while others have questioned the faults existence (DWR 1987, España Geotechnical Consulting 1993) due to a lack of exposure or other evidence.

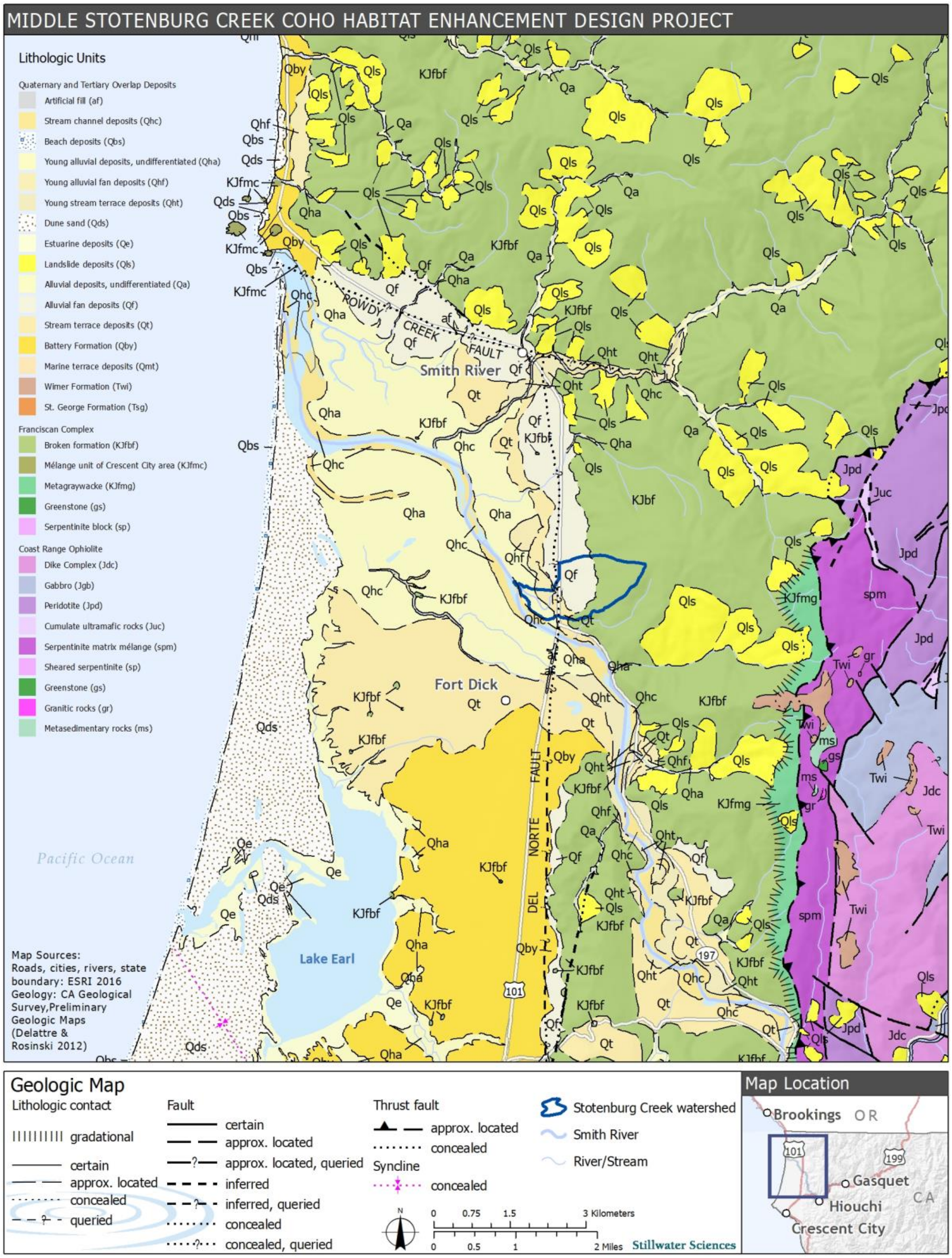

Figure 2-1. Geologic map of the Stotenburg Creek watershed and surrounding portions of Del Norte County.

2.2 Geomorphology

A geomorphic assessment was conducted to characterize the existing geomorphology of the project area, assess risks associated with potential hazards, support an opportunities and constraints assessment, and inform project designs. Specifically, the geomorphic assessment included a topographic survey that was integrated with 2010 LiDAR data, review of existing information, and a field assessment. Existing information that was reviewed includes geologic mapping (Delattre and Rosinski 2012), geomorphic and landslide mapping (Davenport 1983), well completion reports filed with the Department of Water Resources (DWR), and a series of historical aerial photographs from 1942 to 2015.

Hillslope and stream channel morphologies in the Stotenburg Creek watershed are similar to others along the northern and eastern margin of the Smith River coastal plain, due to the similar topographic and lithologic transition from upland hillslopes underlain by Franciscan sedimentary bedrock to alluvial terraces and floodplains composed of late quaternary fluvial sediments. Landslides are common in the Franciscan rock, although there is no evidence of moderate to large-scale hillslope instability in the upper Stotenburg Creek watershed (Figure 2-1).

Upper elevations of the Stotenburg Creek watershed are characterized by steep hillslopes (30-40%) covered with well-drained colluvial soils and a dense second-growth conifer forest of spruce, fir, and redwood. The creek lacks a defined primary channel in the upland hillslopes. Multiple smaller channels flow through rural ranch properties across an alluvial fan at the base of the hillslope and converge to form a main channel upstream of HWY 101. Stotenburg Creek flows southwest passing under the highway and the County road (Fred Haight Dr.) before making an abrupt turn to the northwest and flowing across the flat alluvial floodplain within the project area (Figure 2-2). A tributary converges with the main Stotenburg Creek channel within the project area. This channel also originates on the hillslopes to the east of HWY 101 and has a small on-channel pond within its alluvial fan reach.

The project site consists of the main Stotenburg Creek channel extending approximately 0.15 miles upstream from where the lower Stotenburg Creek enhancement project ends. This transition point is approximately 200 feet upstream of the Cedar Lodge Ln. crossing (Crossing 4 from the lower Stotenburg Creek project). To maintain continuity with designs developed for the lower Stotenburg Creek project, the middle Stotenburg Creek project evaluates channel conditions and design elements extending to the downstream side of Crossing 4 (Figure 2-2).

The project reach of Stotenburg Creek flows to the southwest across the distal edge of an alluvial fan before turning and flowing northwest across a low-gradient alluvial terrace of the Smith River. The tributary flows across the same transition from alluvial fan to terrace. Pastures on the alluvial surfaces have been used for cattle grazing in the past but more recently for a small number of horses. The project site contains one private road culvert crossing, Crossing 5 (further described in Section 2.2.3 *Field Assessment*). Crossing 4, located just downstream of the site, was addressed in the lower Stotenburg Creek enhancement project. The Fred Haight Dr. crossing of Stotenburg Creek, located at the upstream end of the project reach, is not included as a formal element of this project. However, the 53-ft-long, 5-ft-diameter corrugated metal culvert pipe is undersized and has a shotgun outlet. Improving fish access into the culvert outlet is considered in the project designs as an interim measure until the crossing is upgraded.

Riparian condition along the creek channel in the project reach is varied with no woody riparian vegetation in the lower segment transitioning to densely vegetated with shrubs and trees (e.g., salmon berry, willow, alder, and California bay laurel), invasive Himalayan blackberry, and some conifers. The tributary channel in the project reach is densely vegetated with the same riparian shrubs, trees, and Himalayan blackberry.

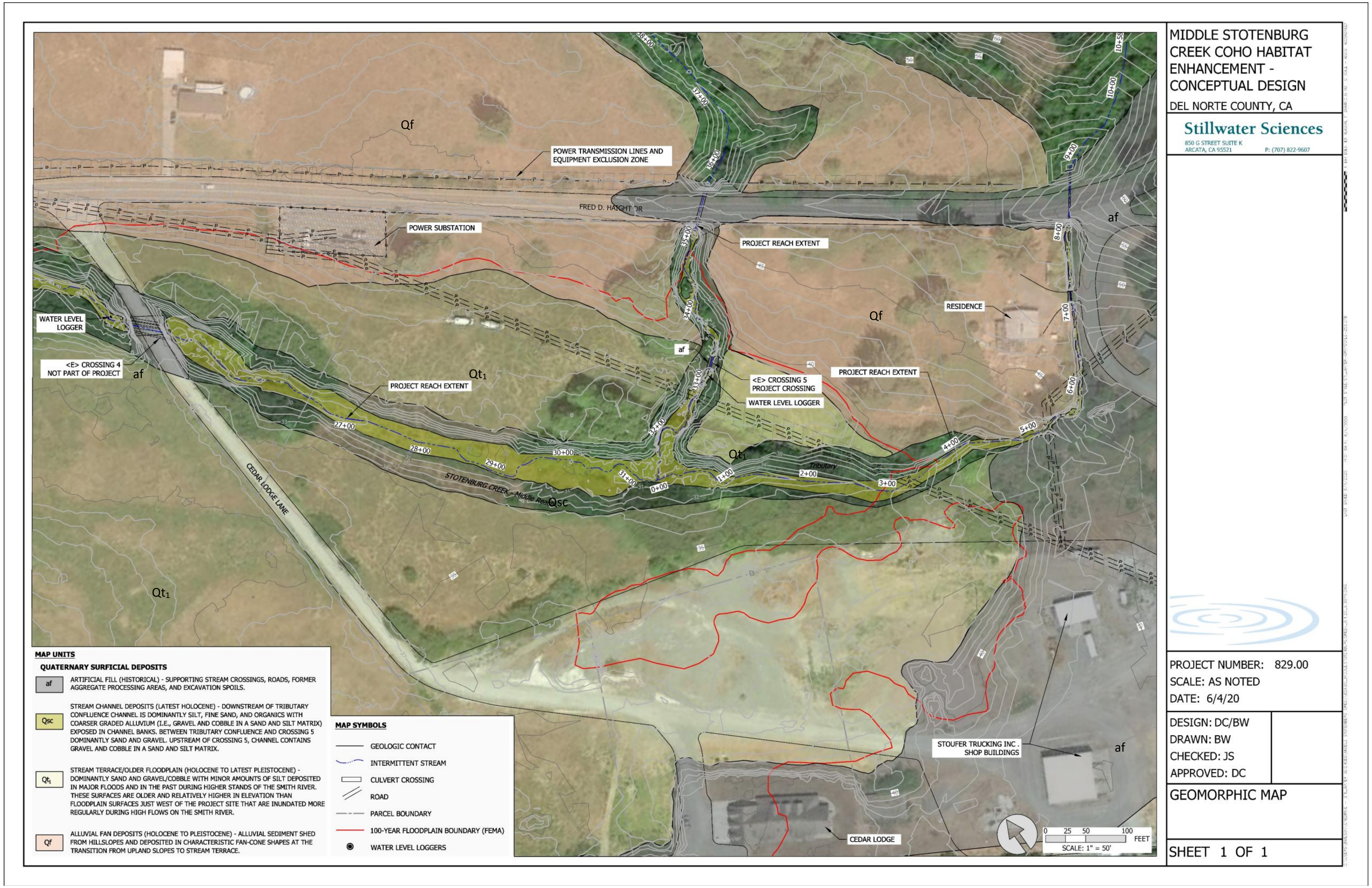

Figure 2-2. Geomorphic map of middle Stotenburg Creek.

2.2.1 Aerial photograph interpretation

LiDAR-derived topography and historical aerial photography were reviewed to characterize the long-term geomorphic change along Stotenburg Creek within the project area. Photographs were acquired from the U.S. Forest Service, California Department of Forestry, USGS, and Google Earth and include the following years: 1942, 1948, 1958, 1965, 1972, 1988, 1993, 2003, 2005, 2009, and 2015. Cropped portions of each aerial photograph for the project area are located in Appendix E. The photographs include a channel centerline of Stotenburg Creek derived from 2010 LiDAR data.

1942 and 1948 photographs

In 1942 and 1948 Stotenburg Creek appears to be located primarily along the same alignment as it is today. The project vicinity along the lower Smith River had already begun to be utilized for agricultural purposes, as evidenced by fences, hedge rows, and managed fields with different uses. However, the floodplain along the southwestern side of the creek does not appear to have been modified for agricultural use. Substantial portions of the project area were more forested with conifers than they are today. The current alignment of Highway 101 had not yet been built and Fred Haight Dr. was the primary road through the area. Some evidence of gravel mining is visible on Smith River gravel bars upstream and downstream from the project site. The active Smith River channel was further east than it is today and ran along the margin of the Qt_1 terrace (Figure 2-2). The power substation along Fred Haight Dr. is evident in the 1948 photograph, as well as the clearing in the trees along the power line alignment extending to the southeast across the project site.

1958 photograph

This photograph shows substantial land use modifications that occurred in the project vicinity during the preceding decade. Large portions of the project area were logged, new roads and houses were constructed, agricultural activity expanded, and a gravel mining operation was established on the terrace to the immediate southeast of the project site. This photograph documents the geomorphic change along the Smith River corridor from the 1955 flood, which is the third largest in the Smith River period of record with a flood frequency of approximately 30 years (based on a log-Pearson Type III distribution [USGS 1982]). The Smith River channel migrated westward, exposing a large lateral gravel bar to the southwest of the middle Stotenburg project reach, which supplied the mining operation. The Stotenburg Creek alignment appears to have been altered very little if at all. The largest difference along the creek corridor is the reduction in riparian cover, with grass pasture and freshly cleared land visible on both sides of the channel. A structure had been built at the site of the current residence along the tributary channel, although the footprint does not match the present-day building. The partially completed Highway 101 indicates highway construction was in progress.

1965 photograph

This photograph was taken in the summer following the historic 1964 flood, which is the flood of record for the Smith River with a flood frequency of approximately 230 years (based on a log-Pearson Type III distribution [USGS 1982]). The main Smith River corridor experienced major geomorphic changes in channel alignment, pool and bar scour, floodplain deposition, and eroding riparian vegetation. There is evidence of widespread flood damage to fields and roads across the Smith River coastal plain. Multiple large gravel mining operations are visible throughout the lower river and were likely supplying aggregate for constructing new roads (including the present-day Highway 101) and levees along the lower river downstream from the project site. Despite the significant geomorphic changes to the Smith River, the Stotenburg Creek alignment was not altered by the 1964 flood. The largest changes to the creek appear to be removal of riparian vegetation and scouring along the reaches of the creek downstream of the project site. The pasture between middle Stotenburg Creek and the tributary had recently been logged and it appears the Crossing 5 location was being used as a stream crossing, but it is unknown if a culvert was in place. A small structure was constructed in the pasture adjacent to Stotenburg Creek next to Crossing 5. Widespread fine sediment deposition across the Qt_1 terrace on the southwest side of the creek and scour along lower Stotenburg Creek indicate that substantial portions of the project area were inundated during the flood.

1972 photograph

The 1972 photograph was taken in the summer following the 1972 flood, which is the second largest on the Smith River in the period of record with a flood frequency of approximately 55 years. The Smith River channel widened and was multi-thread in the project area. The lateral gravel bars along the Smith River were largely devoid of riparian vegetation as a result of scour from the 1964 and 1972 floods. Flood flows may have partially inundated portions of the Qt_1 terrace along lower Stotenburg Creek downstream of the project reach, although the Stotenburg Creek channel alignment remained stable and unaffected. Riparian vegetation regrowth is evident along lower Stotenburg Creek, but areas in the project reach were logged, likely to expand cattle grazing. Gravel mining operations continued on nearby Smith River gravel bars.

1988 photograph

The Stotenburg Creek alignment remained stable and riparian vegetation expanded slowly along the creek and river corridors, as well as on the gravel bars scoured during the 1964 and 1972 flood events. A well-defined track across the creek at Crossing 5 suggests a culvert was installed. The mining operations to the south of the project site are no longer evident, and the Calvary Chapel was constructed at the intersection of Highway 101 and Fred Haight Dr.

1993 photograph

The Smith River began migrating back to the east, likely occupying gravel mining excavations. Gravel bars on the east side of the Smith River appear freshly mobilized with little to no vegetation, whereas the gravel bar on the west side of the river reestablished a riparian forest. Mining operations resumed on the east-bank gravel bars with processing facilities on the terrace just south of the project site. Riparian vegetation along Stotenburg Creek appears comparable to previous photographs and much of the flowing channel is visible. The small structure near Crossing 5 is gone and the residence along the tributary channel appears comparable to present day.

2003 photograph

The project site appears relatively comparable to conditions in the 1993 photograph. Gravel mining and processing continued to the south of the project site. A new road was constructed from the gravel processing area up to the southern edge of Stotenburg Creek at the Crossing 4 location. An additional Google Earth image shows that Crossing 4 was constructed between July 2003 and June 2004. Riparian vegetation along Stotenburg Creek within the project area is denser than in previous photographs.

2005, 2009, and 2015 photographs

The most substantial change seen across the 2005, 2009, and 2015 photographs is increased riparian growth across the project reach and varying activity at the gravel mining and processing site just south of the project reach. In the 2005 photograph it appears gravel mining and processing ceased, the large residence (i.e., cedar lodge) at the end of Cedar Lodge Ln. was under construction, and truck traffic is visible at the Stouffer Trucking shop buildings between the cedar lodge and Calvary Chapel.

2.2.2 Topography

Stillwater and SRA staff conducted a field topographic survey in the fall of 2019 using a robotic total station and real-time kinematic (RTK) GPS. The primary goals of the topographic survey were to characterize the existing conditions topography to support geomorphic assessment, hydraulic modeling, and engineering designs. The survey focused on a thalweg longitudinal profile of the project reach including channel bank tops and toes, and complete topography at crossings and in areas where habitat enhancement designs are proposed. The RTK GPS was used to establish a network of survey control points throughout the project site. In the office, survey data were post-processed using an RTK base station position correction from the National Geodetic Survey (NGS) Online Positioning User Service (OPUS) and aligned to the NAVD88 vertical datum.

The field survey data were integrated with 2010 NOAA Coastal LiDAR point cloud data. The LiDAR points were shifted to better characterize local 2019 field conditions. The horizontal shift (0.12 feet south) was determined using NGS Coordinate Conversion and Transformation Tool (NCAT) to convert from the input datum (NAD83[NSRS2007]) to the output datum (NAD83[2011]) at the approximate central location of the project area. The vertical shift (+0.14 feet) was determined by comparing 2019 field-surveyed elevations collected along the Fred Haight Dr. road alignment within the project area to the horizontally adjusted LiDAR point cloud data. Additionally, topographic survey data from the upstream portion of the lower Stotenburg Creek reach around Crossing 4 were appended to provide longitudinal continuity between the two projects.

2.2.3 Field assessment

The geomorphic field assessment of the project area consisted of evaluating floodplain and channel morphology, assessing road-stream crossings, investigating shallow stratigraphy exposed in cutbanks, identifying potential habitat enhancement locations, and measuring bankfull and active channel widths to support crossing designs. Methods for measuring bankfull and active channel widths followed Part XII of the California Salmonid Stream Habitat Restoration Manual (CDFW 2009) and the Stream Simulation approach (USDA Forest Service 2008). Results and interpretations from the field assessment are summarized below, beginning just upstream of Crossing 4 and moving upstream. Figure 2-3 is a longitudinal profile of the project reach highlighting channel slopes and key points of interest referenced throughout the following section.

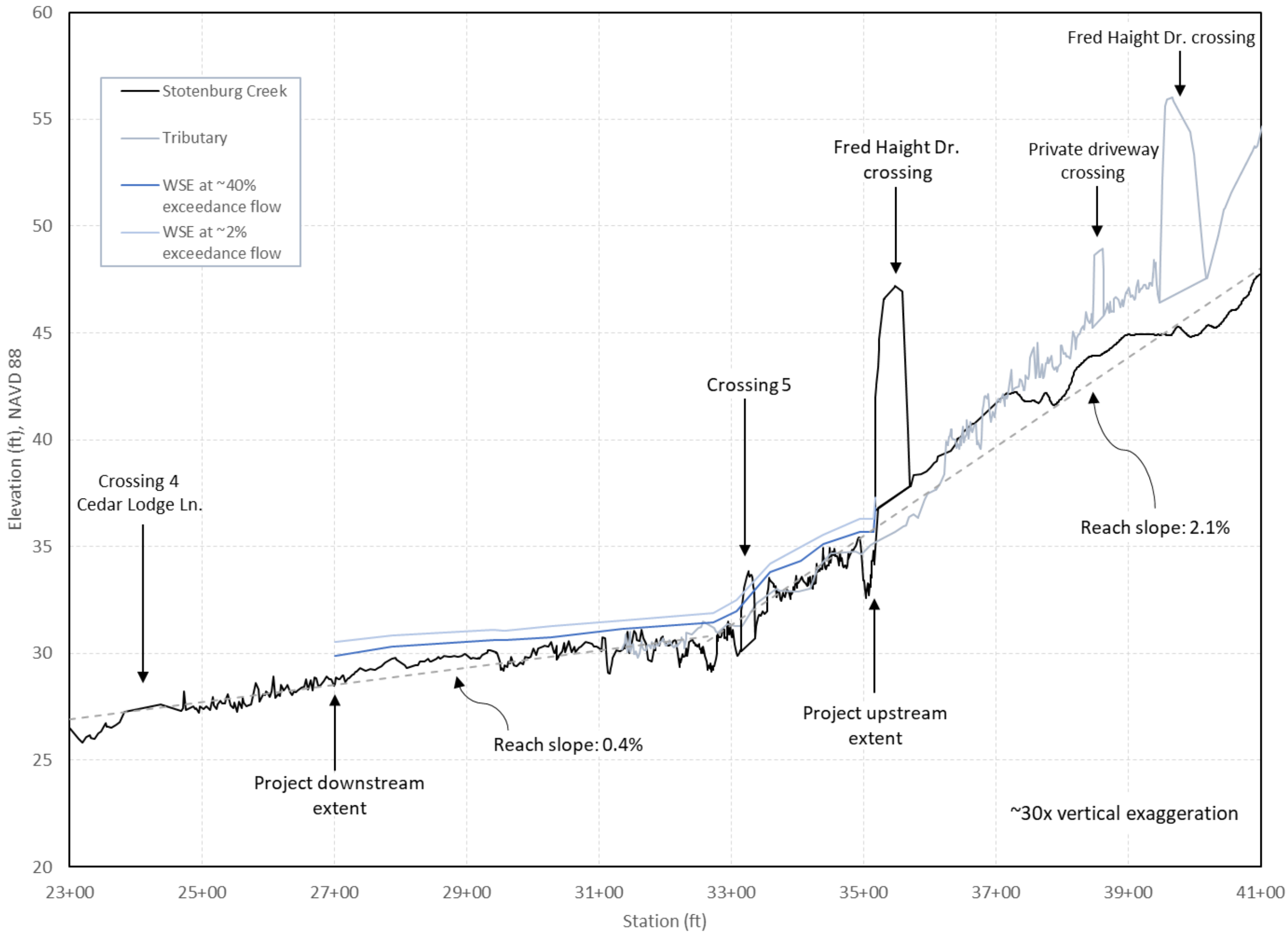

Figure 2-3. Stotenburg Creek longitudinal profile along the project reach.

Crossing 4 to tributary confluence

Crossing 4 and its proposed upgrades were thoroughly discussed in the lower Stotenburg Creek enhancement project final basis of design report and supporting design planset (Stillwater Sciences 2019). Upstream of the crossing the channel is wide, relatively flat-bottomed, and supports dense riparian cover. The riparian cover continues for approximately 250 feet upstream of the crossing before opening to a segment of channel with only grasses and hydrophytic vegetation. This transition, at Sta 27+00, is the downstream extent of the middle Stotenburg Creek project reach (Figures 2-2, 2-4, and 2-5). Continuing upstream, the channel remains straight, wide, and flat bottomed. The channel in this reach appears to have been anthropogenically modified to a trapezoidal form. However, the channel has similar geometry in the immediate upstream and downstream reaches that have not been as clearly modified for grazing purposes. The channel segment devoid of riparian vegetation is approximately 250 feet long and was progressively cleared between 1948 and 1965. There is little hydraulic complexity and minimal sediment transport or deposition. Channel bed substrate is dominated by silt and sand, and at typical winter flows the creek is very shallow and multi-threaded (Figure 2-5). Due to the low channel gradient (approximately 0.2%) and lack of riparian cover, the bed and banks are completely colonized by grasses and hydrophytic vegetation. Currently, the landowners mow the channel bed and banks in the summer and horses freely graze the area.

At approximately Sta 29+20, the channel re-enters dense riparian vegetation and channel geometry and gradient remains consistent to immediately downstream. However, the channel bed becomes more dynamic with clearly defined prominent flow paths indicated by exposed alluvial deposits of loose sand, silt, and trace gravel. The wide channel bottom has complex flow paths, abundant smaller wood pieces (e.g., small logs and branches), and herbaceous hydrophytic vegetation (Figure 2-6). In recent years, SRA staff have documented beaver dams in this reach, although currently there are no actively maintained dams. Vegetation on the right bank is dominated by mature stands of California bay laurel and native shrubs. The left bank is dominated by willow and Himalayan blackberry. The riparian forest provides a sustainable source of large wood for this portion of the creek, as well as a potential source of native vegetation to naturally colonize areas where invasive blackberry will be removed.

Figure 2-4. The downstream end of the project reach is at the riparian margin at photo upper right. View looking downstream.

Figure 2-5. Stotenburg Creek in the downstream project reach is shallow and multi-threaded at typical winter base flows. View looking upstream from Sta 27+20.

Figure 2-6. Stotenburg Creek looking downstream from the tributary confluence. Reach lacking riparian vegetation is barely visible in background.

Tributary confluence to Crossing 5

The tributary confluence area is broad with abundant hydrophytic vegetation and overhead riparian canopy. Although there are low-flow channels for Stotenburg Creek and the tributary defined by freshly mobilized bed substrate, the confluence area has a noticeable wetland character. At elevated winter flows, the entire confluence area is inundated with shallow, low-velocity flow. The Stotenburg Creek channel enters the confluence area at a slightly increased gradient (approximately 0.8%) compared to further downstream (Figure 2-7). Upstream of this transition at Sta 31+75, the channel widens and becomes multi-threaded, meandering around large instream wood and deposits of freshly mobilized sediment (Figure 2-8). The channel width, gradient, and presence of large wood create scour pools and sort bed material into distinct deposits with varying grain size distributions. Channel substrate is coarser than downstream and is dominantly medium to coarse sand and fine gravel.

The channel constricts again at Sta 32+60 and remains so for approximately 70 feet, upstream to Crossing 5 (Figure 2-9). Typical winter baseflows are confined within a low-flow channel that is approximately 2-3 feet wide by 1-2 feet deep. There are flat inset benches on either side of the low-flow channel that are inundated during higher flow events. This segment of the creek does not appear incised based on continuity with the longitudinal profile upstream and a downstream and lack of over steepened eroding cutbanks. The confined low-flow channel is likely due to the undersized culvert at Crossing 5 concentrating flow into a narrow channel and a long history of agricultural land use with livestock freely crossing the creek and causing bank erosion related to trampling. Channel gradient noticeably increases to approximately 2.2% at Sta 32+75 where the channel is flowing across the backedge of the stream terrace and approaching the alluvial fan (Figure 2-2).

Figure 2-7. Stotenburg Creek flowing into the broad tributary confluence area that supports abundant hydrophytic vegetation. Flow is from left to right. Person in upper left for scale.

Figure 2-8. Stotenburg Creek just upstream of the tributary confluence has multi-threaded flow paths, scour holes, large wood, and sorted bedload substrate in discrete deposits. Flow is from right to left.

Figure 2-9. Just downstream of Crossing 5 Stotenburg Creek is confined in a relatively deep narrow channel for approximately 70 feet. People in background standing on Crossing 5 road fill. Flow is from top to bottom.

Crossing 5

Crossing 5 is a 2.5-foot diameter corrugated metal pipe (CMP) culvert that slopes 2.9% and is approximately 21 feet long (Figures 2-10 and 2-11). The crossing supports a single-lane roadway and was likely constructed sometime between 1965 and 1988 as the surrounding area was logged and cleared for agricultural use. Currently, the crossing is infrequently used to move horses and a tractor between pastures, and the landowners intend to retain a year-round crossing at this location for the same type of use. The culvert is hydraulically undersized and is a partial fish passage barrier for adult and juvenile salmonids at all flows. The inlet is at grade, however, due to its small size it is frequently blocked with branches and debris. At moderate winter flows the creek diverts the channel upstream of the crossing and partially flows overland to the west of the culvert alignment before reentering the creek channel approximately 30 feet downstream of the culvert. The outlet is at grade but due to regular overtopping flows the fill around the pipe outlet is scoured and actively eroding. The pipe has some damage from rust and collapse but is otherwise intact. Water surface elevation has been monitored by a level logger on the downstream side of the crossing since October 2019.

Figure 2-10. View looking upstream at Crossing 5 outlet, visible in photo center. Culvert is 2.5 feet in diameter. Water level logger standpipe visible in foreground is approximately 5 feet tall.

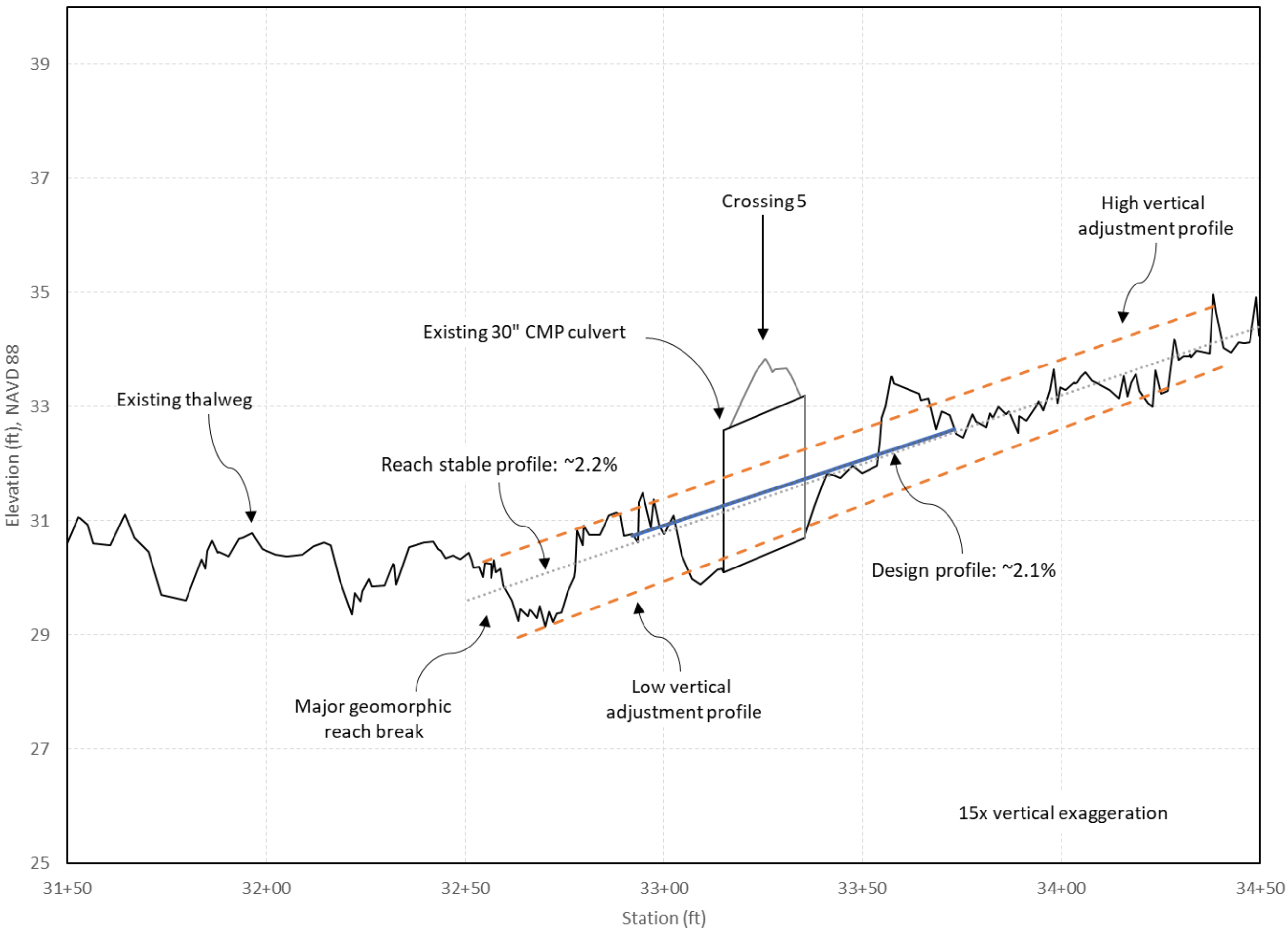

Figure 2-11. Longitudinal profile at Crossing 5. Note: methods for determining vertical adjustment profiles are described below in Section 6.4.1 *Stream simulation channel design*.

Crossing 5 to Fred Haight Drive

The active Stotenburg Creek channel just upstream of Crossing 5 contains abundant live willow, which restricts flow and causes diversion as described above. Flow diversion is also common since the thalweg elevation just upstream of Crossing 5 is only approximately 1 to 2 feet lower than the road surface on the crossing. The undersized culvert has likely promoted sediment deposition on the upstream side of the crossing. The flat grass-covered area adjacent to the channel and crossing regularly receives overland flow in the winter. Overall, the reach is slightly more sinuous than downstream and channel gradient is comparable to downstream of Crossing 5, at approximately 2.2%. The channel slope is controlled by the creek transitioning from flowing over a stream terrace to an alluvial fan (Figures 2-2 and 2-3). The gradient increase is also indicated by a coarsening of the bed substrate from dominantly sand and fine gravel to medium/coarse gravel and cobble (Figure 2-12). The substrate is suitable for salmonid spawning, although no spawning activity has been observed during fish monitoring conducted by SRA in recent years. The creek channel widens upstream of Sta 34+00 and a side channel between Sta 34+00 and 34+60 is active during elevated winter flows. The channel then constricts again before reaching a large scour pool created by the outlet of the culvert crossing under Fred Haight Dr. During typical winter baseflows the scour pool is 10-15 feet wide and 3.5-4.5 feet deep. The culvert has a shotgun outlet that is corroding and breaking apart. The jump into the culvert is approximately 1 foot at a typical winter baseflow (e.g., Figure 2-13 through 2-15). The channel corridor upstream of approximately Sta 34+00 contains thick stands of Himalayan blackberry, particularly on the northeastern side where there is no overhead riparian cover. The western bank has cover provided by California bay laurel and redwood and the blackberry is noticeably less established.

There are very limited options for selecting a reference reach to provide guidance on channel design for the Crossing 5 replacement, due to the major geomorphic transition downstream of Crossing 5 and a lack of access upstream of Fred Haight Dr. (further described below in Section 6.5 *Fred Haight Drive Crossing*). However, portions of the creek channel between the Fred Haight Dr. scour pool and Crossing 5 are relatively suitable as a reference reach. The reach is shorter than preferred for a reference reach evaluation and there are anthropogenic effects related to the upstream and downstream culverts (e.g., scour pool below Fred Haight Dr. and in-channel sediment deposits above Crossing 5) that need to be carefully considered. However, the channel slope is approximately equal to the design profile at Crossing 5, which is an important criterion for selecting a reference reach. Multiple width measurements were taken in the reference reach of the active channel and the top-of-bank. Average active channel widths are approximately 7 to 9 feet and top-of-bank widths are approximately 10 to 13 feet. Channel bed substrate is dominantly very coarse gravel (D_{50} of 50-64 mm) with some small cobble (D_{84} of 100-128 mm). The bed also contains a matrix of sands and silts in interstitial spaces and larger deposits in low-velocity pockets. The coarser substrate is not imbedded, and the active channel bed appears mobile. The process of incorporating the reference reach measurements and evaluation into the stream simulation design at Crossing 5 is further described below in Section 6.4.1 *Stream simulation channel design*.

Figure 2-12. View looking downstream from Sta 34+70. Channel substrate is gravel-cobble. Side channel at photo right is active during moderate winter flows.

Figure 2-13. Middle Stotenburg Creek crossing at Fred Haight Dr. Culvert is 5 feet in diameter.

Figure 2-14. Middle Stotenburg Creek crossing at Fred Haight Dr. in October 2019.

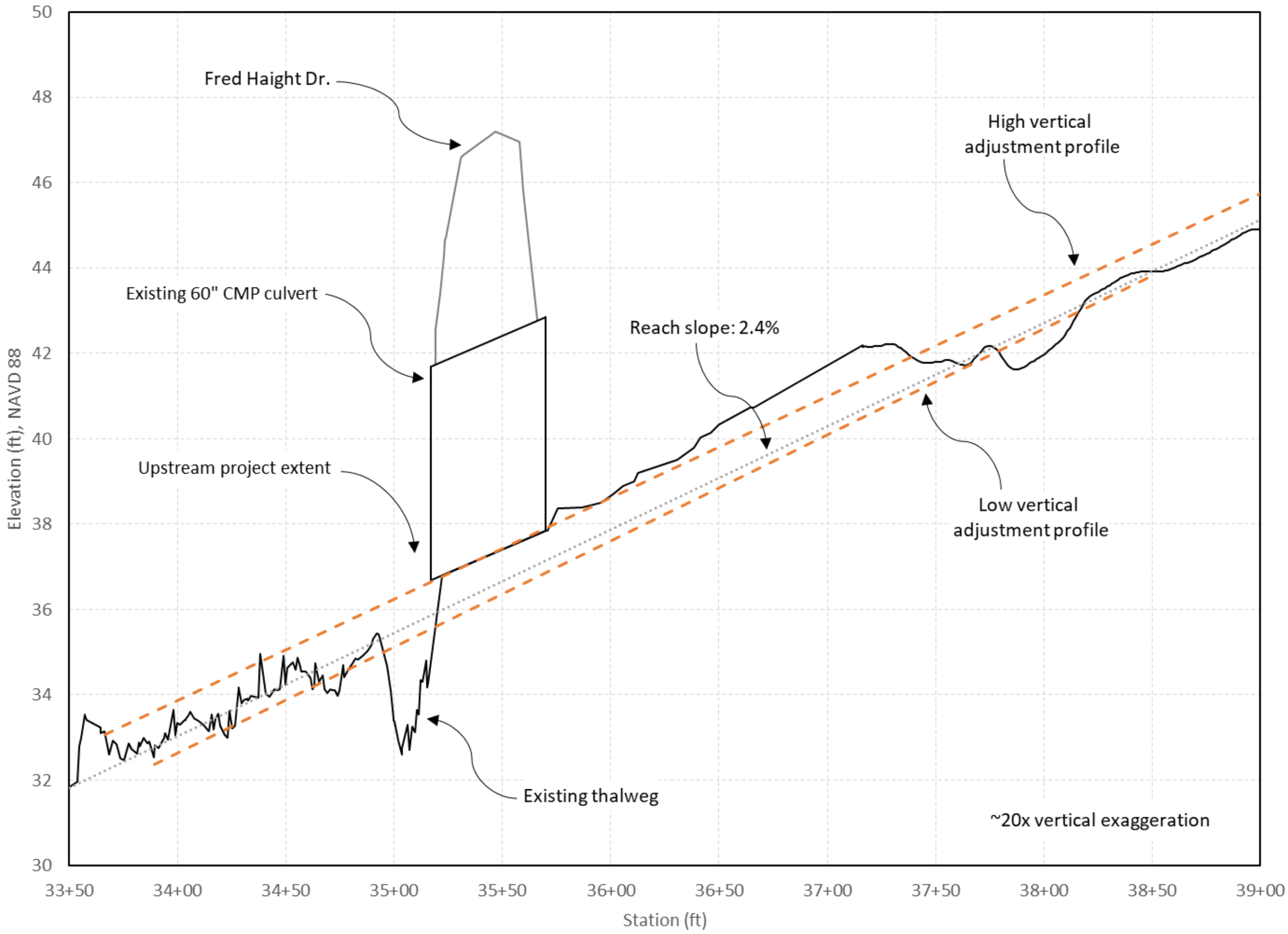

Figure 2-15. Longitudinal profile at Fred Haight Drive crossing. Note: methods for determining vertical adjustment profiles are described below in Section 6.4.1 *Stream simulation channel design*.

Tributary stream

The tributary stream meets Stotenburg Creek in the broad confluence area described above. At 128 acres, the tributary drainage area is approximately 44% of the Stotenburg Creek drainage area upstream of the confluence. The most downstream 75 to100 feet of the tributary channel is a continuation of the broad confluence area with abundant instream wood, riparian cover, and herbaceous hydrophytic vegetation. Further upstream, the channel narrows and is dominated by thick woody riparian vegetation from the water surface extending to the upper canopy. The active channel during a typical winter baseflow is approximately 3 feet wide and 0.5 feet deep (Figure 2-16), and bed substrate is dominantly silt and sand. This channel geometry and riparian condition continues upstream to the project area boundary.

Beyond the project area boundary, the channel gradient increases where the creek transitions from flowing over stream terrace to alluvial fan, comparable to the gradient change on Stotenburg Creek (Figure 2-3). The increase is channel gradient also corresponds to coarsening of the channel bed. Further upstream the channel abruptly turns north and continues in a straight, narrow, excavated ditch between a residence and private road (Figure 2-17).

Figure 2-16. Tributary stream approximately 100 feet upstream of the confluence with Stotenburg Creek. Flow is toward the viewer.

Figure 2-17. Tributary stream near residence. Fred Haight Dr. visible in background.

Fred Haight Drive stormwater runoff

The entire northeastern margin of the project area is bordered by Fred Haight Dr., which is a paved two-lane County road that is regularly trafficked. The road descends from HWY 101, which is on an upper terrace, and crosses over the Stotenburg Creek tributary channel before flattening to an approximately level grade that it maintains across the remaining extent of the project area (Figure 2-2). The road surface is in-sloped along the descending turn between HWY 101 and the tributary crossing and stormwater runoff is diffuse into the dense vegetation bordering the north side of the road (Appendix B, Sheet 4). Runoff also flows down the paved private road that parallels the tributary channel northwest of the Calvary Chapel. This segment of road primarily has diffuse drainage into the grass and shrubs bordering the road. Stormwater runoff from the flat parking area west of the chapel is partially routed to the tributary channel via a ditch (Appendix B, Sheet 4). The ditch is approximately 180 feet long, densely vegetated, and is not actively eroding or contributing fine sediment to the creek channel. The Fred Haight Dr. road surface is crowned between the tributary crossing and the power substation and road runoff drains diffusely into the grass, shrubs, and trees bordering the road. Between the substation and Cedar Lodge Ln. the road surface is out-sloped and runoff drains diffusely into the grass and shrubs along the southwest side of the road (Appendix B, Sheet 3). Due to the relatively level road grades in the project area and small contributing drainage area, there is little to no evidence of erosion (e.g., gullying, slumping, etc.) and fine sediment production related to road runoff. The diffuse drainage conditions prevent concentrated flow paths and minimize potential stream impacts associated with roadway contaminants.

2.3 Riparian Vegetation

The riparian vegetation field assessment was conducted in the summer of 2020 to characterize vegetation composition and structure along the riparian corridor in the project area. Results from this assessment informed the plant selection for the riparian planting plan and the recommended invasive weed removal techniques.

The downstream portion of the middle Stotenburg Creek project reach presently lack native woody riparian vegetation and naturalized grasslands extend into the stream channel banks. In this area, dense herbaceous cover by naturalized grasses and forbs is prevalent within the creek's fully exposed bed and banks and includes *Agrostis stolonifera* (creeping bent grass), *Alopecurus geniculatus* (water foxtail), *Rumex acetosella* (sheep sorrel), *Eleocharis macrostachya* (pale spikerush), *Ranunculus repens* (creeping buttercup), *Veronica persicaria* (Persian speedwell), *Lotus corniculatus* (bird's-foot trefoil), and *Oenanthe sarmentosa* (water parsley). The established riparian corridor in the central and upstream portions of the project reach consists of a mixed hardwood-softwood riparian forest with moderate to high cover by woody understory vegetation. A stand of retained *Umbellularia californica* (California bay laurel) with low shrub cover and an established herbaceous understory is present in this section of the riparian corridor. *Picea sitchensis* (Sitka spruce), *Pseudotsuga menziesii* var. *menziesii* (Douglas-fir), and *Sequoia sempervirens* (coast redwood) are dispersed in the project area and were likely a historical component to the overstory canopy along the project reach. *Rubus armeniacus* (Himalayan blackberry), a nonnative species with a high weed rating by California Invasive Plant Council (Cal-IPC), formed dense thickets in the riparian understory at the upstream project extent near Fred Haight Dr. Native understory vegetation was low to absent in areas with a high prevalence of Himalayan blackberry. Various willows (*Salix* species) with moderate disturbance by nonnative herbaceous species (e.g., *Cirsium vulgare* [bull thistle], *Senecio jacobaea* [tansy ragwort]) forms a dense riparian scrub downstream of the Project.

3 HYDROLOGY AND HYDRAULICS

To understand the flow dynamics along the project reach, 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 widely used for floodplain mapping and estimating general flow characteristics. Hydraulic modeling was conducted using a one-dimensional (1-D) approach. The 1-D 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.

3.1 Hydrology

A hydrologic analysis is required to determine stream flow data that is the principle input to HEC-RAS. Stotenburg Creek is an ungaged stream, so relevant discharges were calculated using prorations from nearby gaged streams and using regional flow regression equations. Streamflow records from multiple U.S. Geological Survey (USGS) gages were used in the hydrologic analysis (Table 3-1 and 3-2). The gages were selected based on multiple criteria including: (1) proximity to the project area, (2) similar topography, climate, and underlying geology to Stotenburg Creek, (3) relatively comparable drainage areas to Stotenburg Creek, and 4) long periods of record (i.e., greater than 50 years). The hydrologic analysis uses the same methods as were used for the lower Stotenburg Creek habitat enhancement project.

Peak streamflow and mean daily flow records were analyzed from the USGS gages to produce flood frequency and flow exceedance probability estimates, respectively. Peak flow estimates from the flood frequency analysis have specific recurrence intervals, or frequencies (e.g., a 100-year peak flow has a 1% chance of occurring any year, or once in 100 years, on average). Smaller flood frequency flows with more regular recurrence intervals (i.e., 1.5- and 2-year flows) are biologically and geomorphically significant because they occur during most winters and can create high velocities (in undersized crossing and/or in the open channel) capable of flushing juvenile salmonids out of the creek and/or cause mortality if insufficient low-velocity refugia habitat are available. For this analysis, we assume the 1.5-year recurrence interval flow approximates the "bankfull" flow. It is also critical to analyze flows from larger flood events ranging from 2- to 100-year recurrence intervals to determine adequate sizing for stream crossings, erosion potential and flooding hazards for adjacent property and infrastructure, as well as the stability of the proposed enhancement features.

The flood frequency analysis used a Log-Pearson III distribution and methods consistent with USGS Bulletin 17B (USGS 1982). Because the project reach includes a primary tributary confluence, design flows had to be calculated in two locations: on Stotenburg Creek and on the tributary just upstream of their confluence. The discharge for the reach downstream of the confluence is the sum of these two inputs. For proration calculations, a drainage area of 0.45 square miles (290 acres) was used for Stotenburg Creek and a drainage area of 0.2 square miles (128 acres) was used for the tributary. Peak flow estimates (provided in Table 3-1 and 3-2) were prorated for Stotenburg Creek following the flow transference equation of Waananen and Crippen (1977):

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

Where: b = 0.87 for 100- to 5-year events, b = 0.9 for 2- and 1.5-year events, and b = 1 for exceedance flows

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

Peak flow estimates for the tributary watershed were also calculated using the flow transference equation of Waananen and Crippen (1977), however, they are likely overestimates due to the tributary's substantially smaller drainage area. At 128 acres, the tributary watershed is more appropriately sized to use the Rational Method to calculate a 100-year recurrence interval discharge. The Rational Method (also known as the Rational Formula) is appropriate for determining 100-year flood flows for relatively small drainage areas of less than 200 acres (Cafferata et al. 2017). The Rational Method incorporates a combination of rainfall intensity, drainage area, and runoff coefficient to estimate maximum flows. The Rational Formula is defined as:

$$Q = CIA$$

Where:

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

For the Rational Method analysis, the drainage area, slope, and longest flow path were determined based on topographic GIS analysis of LiDAR and field-surveyed data. 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 drainage area and arrive at a point of interest. Per Cafferata et al. (2017), the "Time to Concentration" is determined using the Airport Drainage equation[1]:

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

Where:

T_c=Time to 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)

Precipitation data for the Rational Method calculation use the intensity-duration-frequency (IDF) curve from National Oceanic and Atmospheric Administration's (NOAA) National Weather Service Hydrometeorological Design Studies Center Precipitation Frequency Data Server

[1] Note that two methods for determining Time to Concentration were described by Cafferata et al. (2017) 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 adequate estimates for Time to Concentrations on steeper northern California watersheds. Additionally, Yee (2004) recommends use of the Airport Drainage equation.

(PFDS). 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 site. A runoff coefficient of 0.35 was used based on the land use and type (i.e., both woodland and pasture) and underlying soils in the tributary watershed. Other peak flow estimates for the tributary creek (i.e., 1.5-year to 50-year recurrence interval) were calculated from the prorated Log-Pearson III (USGS 1982) values using a proportional relationship between the 100-year peak flows determined from the Log-Pearson III distribution and Rational Method.

In addition to peak flow estimates, moderate and low flows were also modeled in HEC-RAS, which correspond to upper fish passage flows, typical winter base flow, and late spring/early summer low flow (Tables 3-1 and 3-2). These relatively smaller flows have biological significance for fish passage and habitat enhancement objectives, especially related to over-winter rearing habitat for salmonids. The 2% exceedance flow has been identified in other coastal basins as the highest flow when fish passage is likely to occur. The 20% exceedance flow represents the typical winter base flow when juvenile salmonids will be rearing in the creek. The 95% exceedance flow represents the lowest flows when fish rearing and outmigration are likely to occur. These biologically relevant exceedance flows were calculated from the same regional USGS gage records as used in the peak flow analysis and were prorated based on the drainage area ratio to the project site. Note that Stotenburg Creek is intermittent and goes dry every year in the late spring or early summer. 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 approximately 0.1 cubic foot per second (cfs). The 95% exceedance flows for Stotenburg Creek and the tributary upstream of their confluence are both less than 0.1 cfs. Therefore, a flow of 0.7 cfs and 0.3 cfs were used for Stotenburg Creek and the tributary, respectively, in place of the 95% exceedance flow for the late spring/early summer discharge. An average of the prorated USGS gage flows were used as input in the 1-D hydraulic model (described below in Section 3.2 *Hydraulic Modeling*).

Table 3-1. Modeled flood frequency and exceedance discharge estimates for Stotenburg Creek upstream of tributary confluence.

Discharge location and description:	Period of record (years)	100-yr peak flow (cfs)	50-yr peak flow (cfs)	25-yr peak flow (cfs)	10-yr peak flow (cfs)	5-yr peak flow (cfs)	2-yr peak flow (cfs)	1.5-yr peak flow (cfs)	2% exceedance flow (cfs)[1]	20% exceedance flow (cfs)[1]	95% exceedance flow (cfs)[1]	Low flow for HEC-RAS (cfs)
Prorated from USGS Gage No. 11481200 Little River near Trinidad, CA (40.5 sq mi)[2]	63	255	235	211	177	148	87	67	10.8	1.94	0.05	-
Prorated from USGS Gage No. 11476600 Bull Creek near Weott, CA (27.6 sq mi)[2]	57	258	230	201	159	125	66	51	14.8	2.36	0.01	-
Prorated from USGS Gage No. 11482468 Little Lost Man Creek near Orick, CA (3.46 sq mi)[2]	13	225	190	158	117	87	45	33	9.4	1.83	0.03	-
Prorated from USGS Gage No. 14378800 Harris Creek near Brookings, OR (1.28 sq mi)[2, 3]	14	253	219	186	145	115	71	57	-	-	-	-
Prorated from USGS Gage No. 11533000 Lopez Creek near Smith River, CA (0.92 sq mi)[2]	12	486[4]	394[4]	311[4]	216[4]	154	78	56	18.2	3.50	0.05	-
Prorated from USGS Gage No. 11480000 Jacoby Creek near Freshwater, CA (6.05 sq mi)[2]	19	285	248	211	164	129	73	56	8.5	1.35	0.07	-
Average for Stotenburg Creek upstream of tributary confluence (0.45 sq mi)	-	**255**	**224**	**193**	**153**	**126**	**70**	**53**	**12.4**	**2.2**	**0.04[5]**	**0.7**

Notes:

[1] Exceedance flows calculated using standard flow duration analysis and prorated for drainage area difference

[2] Log-Pearson Type III distribution based on USGS stream gage prorated for drainage area difference using USGS flow transference formula (Waananen and Crippen 1977)

[3] Harris Creek gage only has peak flow data available

[4] Peak flow estimates > 5-year flow are anomalously high and not used in calculation (short period of record that includes 1964 and 1972 floods, two largest in Smith River record)

[5] Flow not modeled in HEC-RAS

Table 3-2. Modeled flood frequency and exceedance discharge estimates for tributary upstream of Stotenburg Creek confluence.

Discharge location and description:	Period of record (years)	100-yr peak flow (cfs) Rational Method	50-yr peak flow (cfs)	25-yr peak flow (cfs)	10-yr peak flow (cfs)	5-yr peak flow (cfs)	2-yr peak flow (cfs)	1.5-yr peak flow (cfs)	2% exceedance flow (cfs)[1]	20% exceedance flow (cfs)[1]	95% exceedance flow (cfs)[1]	Low flow for HEC-RAS (cfs)
Prorated from USGS Gage No. 11481200 Little River near Trinidad, CA (40.5 sq mi)[2]	63	-	-	-	-	-	-	-	4.8	0.85	0.022	-
Prorated from USGS Gage No. 11476600 Bull Creek near Weott, CA (27.6 sq mi)[2]	57	-	-	-	-	-	-	-	6.5	1.04	0.006	-
Prorated from USGS Gage No. 11482468 Little Lost Man Creek near Orick, CA (3.46 sq mi)[2]	13	-	-	-	-	-	-	-	4.2	0.81	0.012	-
Prorated from USGS Gage No. 14378800 Harris Creek near Brookings, OR (1.28 sq mi)[2, 3]	14	-	-	-	-	-	-	-	-	-	-	-
Prorated from USGS Gage No. 11533000 Lopez Creek near Smith River, CA (0.92 sq mi)[2]	12	-	-	-	-	-	-	-	8.0	1.54	0.022	-
Prorated from USGS Gage No. 11480000 Jacoby Creek near Freshwater, CA (6.05 sq mi)[2]	19	-	-	-	-	-	-	-	3.7	0.60	0.030	-
Average for tributary input (0.2 sq mi)	**-**	**82**	**72**[4]	**62**[4]	**49**[4]	**41**[4]	**22**[4]	**17**[4]	**5.5**	**1.0**	**0.018**[5]	**0.3**

Notes:
1 Exceedance flows calculated using standard flow duration analysis and prorated for drainage area difference
2 Log-Pearson Type III distribution based on USGS stream gage prorated for drainage area difference using USGS flow transference formula (Waananen and Crippen 1977)
3 Harris Creek gage only has peak flow data available
4 Flow estimate calculated using a proportional relationship between the 100-year peak flows determined from the Log-Pearson III distribution and Rational Method
5 Flow not modeled in HEC-RAS

3.2 Hydraulic Modeling

3.2.1 Existing conditions hydraulic modeling

Existing conditions topography used in the HEC-RAS model was taken from the topographic survey and integrated LiDAR data that were described above in Section 2.2.2 *Topography*. Typically, cross sections are cut perpendicular to the channel thalweg.

Cross-sections of the channel were cut from the Triangular Irregular Network (TIN) surface in AutoCAD and exported to HEC-RAS to create the hydraulic model. The Manning's n roughness value of 0.055 was used for the channel, based on the HEC-RAS Reference Manual conservative recommendation for a "clean and winding natural stream with some pools, shoals, weeds, stones and ineffective slopes and sections"; and 0.065 for all banks and floodplains based on a conservative value for "medium to dense brush, in winter". Water surface elevations for the downstream boundary condition were determined by field measurements for lower flows (i.e., 2-year flow, 1.5-year flow, 2% and 20% exceedance flows, and the 1 cfs low flow condition). Flow was simulated in a subcritical regime with steady flow for each model run.

3.2.2 Hydraulic model calibration

Calibration of the existing conditions 1-D HEC-RAS model was conducted using field water level logger data and field observations from the 2019-2020 winter. Water surface elevations along Stotenburg Creek were either measured simultaneous with a flow event or marked and subsequently surveyed. The flows used for model calibration corresponded to approximately a 2% exceedance flow and 18% exceedance flow. The initial HEC-RAS model runs predicted water surface elevations (WSEs) slightly lower than those measured in the field. To calibrate the model to match field observations more accurately, all Manning's n roughness values were slightly increased to values reported above, which correspondingly increased the WSEs to closely match field conditions.

3.2.3 Existing conditions hydraulic model results

Hydraulic modeling was conducted for the existing conditions, including the culverts at Crossing 5 and Fred Haight Drive. Figure 3-1 shows the longitudinal profile of the channel thalweg and modeled water surface elevations (WSE) throughout the project reach. Note that the stationing along the horizontal axis in Figure 3-1 are different than the actual channel station numbers. The zero distance in Figure 3-1 corresponds to Sta 27+00. Key results from the existing conditions model include:

- Crossing 5 is overtopped by the 1.5-year flow and higher due to elevated WSE along Stotenburg Creek.
- The Fred Haight Dr. crossing is overtopped by the 100-year flow and is significantly undersized to convey flood flows between the 50-year and 10-year events.
- All modeled flows are contained within the channel in the project reach (i.e., downstream of Fred Haight Dr.
- Downstream from Crossing 5 channel gradient decreases and flow velocities generally decrease (e.g., <1ft/s) at late spring/summer low flows and 20% exceedance flows.

A full tabulation of hydraulic model outputs is included in Appendix C. Proposed conditions hydraulic modeling results from the conceptual design process are discussed below in Section 4.4

(Conceptual Design Alternatives) *Proposed Conditions Hydraulic Modeling*. Proposed conditions hydraulic modeling results are discussed below in Section 5.2 (Preferred Alternative – Final Design) *Proposed Conditions Hydraulic Modeling*.

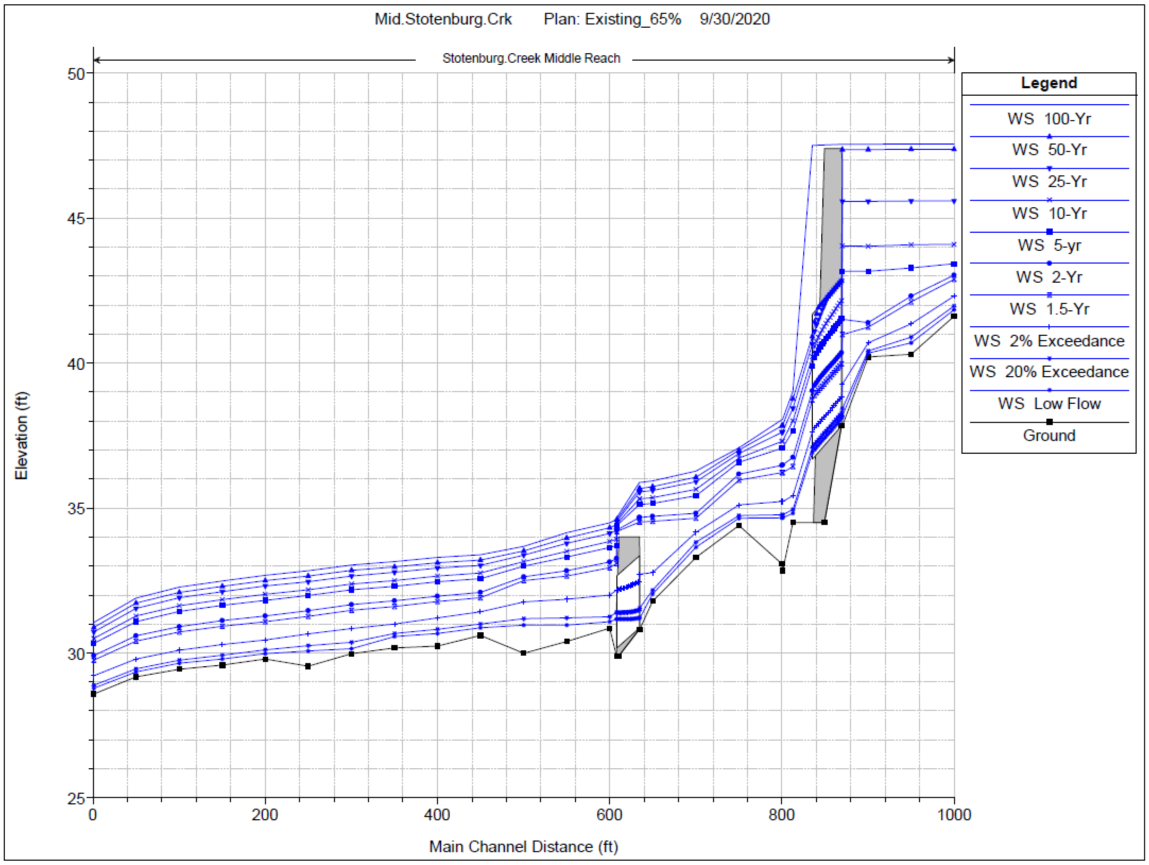

Figure 3-1. Modeled water surface elevations under existing conditions in the project reach.

4 CONCEPTUAL DESIGN ALTERNATIVES

4.1 General Design Objectives

Conceptual design alternatives for the middle Stotenburg Creek enhancement project are shown in Appendix A. The conceptual design plans focus on several key enhancement components including:

1. **Fish Passage** – Fish passage is currently an impairment within the project reach. The conceptual design plans include replacing Crossing 5 with an adequately sized fish passage-friendly design. Conceptual design alternatives for the new Crossing 5 include either a box culvert or bridge. The crossing alternatives were designed following the methods of Part XII of the California Salmonid Stream Habitat Restoration Manual (CDFW 2009) and the Stream Simulation approach (USDA Forest Service 2008); and are designed to accommodate a 100-year flood on Stotenburg Creek with sufficient freeboard to pass sediment and large woody debris. The conceptual design alternatives also include a sequence of grade-control log weirs on the downstream side of the Fred Haight Dr. culvert

crossing. The weirs are designed to elevate the pool water surface elevation to improve fish passage conditions into the culvert.

2. **Winter/Spring Rearing Habitat** – Seasonal winter and spring rearing are key ecological uses of Stotenburg Creek for juvenile salmonids. Conceptual design plans include enhancing and expanding multiple seasonal rearing habitats. Enhancement objectives focus on expanding low velocity refugia by constructing a sequence of beaver dam analogues (BDAs) to increase habitat complexity, expand backwatering in the upstream low gradient reach, and extend seasonal rearing into the late spring and early summer. Large wood structures are also proposed, as an alternative to BDAs, to diversify habitat, increase hydraulic complexity, and restore stream conditions lacking in Stotenburg Creek due to historical logging.
3. **Riparian Function** – In general, Stotenburg Creek within the project reach is densely vegetated with riparian trees and shrubs, as well as invasive Himalayan blackberry. However, discrete sections of the channel lack woody riparian vegetation and are accessible to grazing livestock. Designs include planting native riparian vegetation and removing invasive blackberries.
4. **Livestock Exclusion** –Currently, the project reach has no permanent livestock exclusion fencing, although portions have temporary hotlines. Conceptual design plans include constructing permanent exclusion fencing along the entire stream corridor that connects with existing fencing along roadways.

The conceptual design alternatives are not intended to be mutually exclusive. Some elements of each alternative could be incorporated with the other alternative, if desired. These options were discussed with the TAC during the first review meeting in July 2020.

4.2 Alternative 1

Conceptual design Alternative 1 (Appendix A, Sheets 1, 2, and 4) consists of a suite of actions that address all key enhancement components described above, including:

- Construct a sequence of three BDAs with 0.5-foot crest elevation increases from Sta 27+20 to 27+50.
- Construct new Crossing 5 on same alignment with a 16-foot x 40-foot prefabricated bridge (e.g., Kernen Construction prefab bridge). Designs likely to include stabilization mats (further described below in Section 5.3 *In Situ Soil Strength and Bridge/Box Culvert Factor of Safety*) and rock slope protection to support and protect bridge abutments.
- Mechanical and hand removal of invasive Himalayan blackberry.
- Riparian and conifer plantings at select areas devoid of vegetation.
- Construct new cattle exclusion fencing along stream corridor throughout entire project reach.
- Construct a narrow seasonal access ford across channel in reach lacking riparian vegetation. To be used only when creek is dry and for horse and four-wheeler purposes.

4.3 Alternative 2

Conceptual design Alternative 2 (Appendix A, Sheets 1, 3, and 4) consists of some of the same design feature as Alternative 1 with the following differences:

- Instead of BDAs, install multiple (~6) large wood structures from Sta 27+00 to 29+00 to improve habitat quality and create more dynamic flow conditions.
- Construct new Crossing 5 on same alignment with a 12'-5" wide x 7'-4" high x 44.5' aluminum box culvert (e.g., Contech ES) embedded approximately 2' into channel bed and back filled with native streambed material. Designs likely to include a two-layer engineered foundation composed of a relatively finer crushed aggregate bedding (i.e., Caltrans Class 2) overlying a coarser crushed aggregate (i.e., Caltrans Class 1) subbase (further described below in Section 5.3 *In Situ Soil Strength and Bridge/Box Culvert Factor of Safety*).
- Construct three grade control log weirs just downstream of Sta 35+00 to increase water surface elevation in the Fred Haight Dr. culvert outlet pool and improve fish passage conditions through the crossing.

4.4 Proposed Conditions Hydraulic Modeling

Proposed-conditions hydraulic modeling of the features described above in Sections 4.2 and 4.3 was conducted by grading the features in AutoCAD and re-cutting cross sections in HEC-RAS. Results from the proposed conditions modeling are shown in Figures 4-1 and 4-2. Flow velocity reductions through Crossing 5 at fish passage flows are provided in Table 5-1 in Section 5.2 (Preferred Alternative – Final Design) *Proposed Conditions Hydraulic Modeling*. Increased water surface elevation in the outlet scour pool of the Fred Haight Drive crossing are provided in Table 4-1. Increases in inundated water surface area in the reach upstream of the proposed BDAs are shown in Table 4-2. Cross section and tabulated model results for existing and proposed conditions are provided in Appendix C.

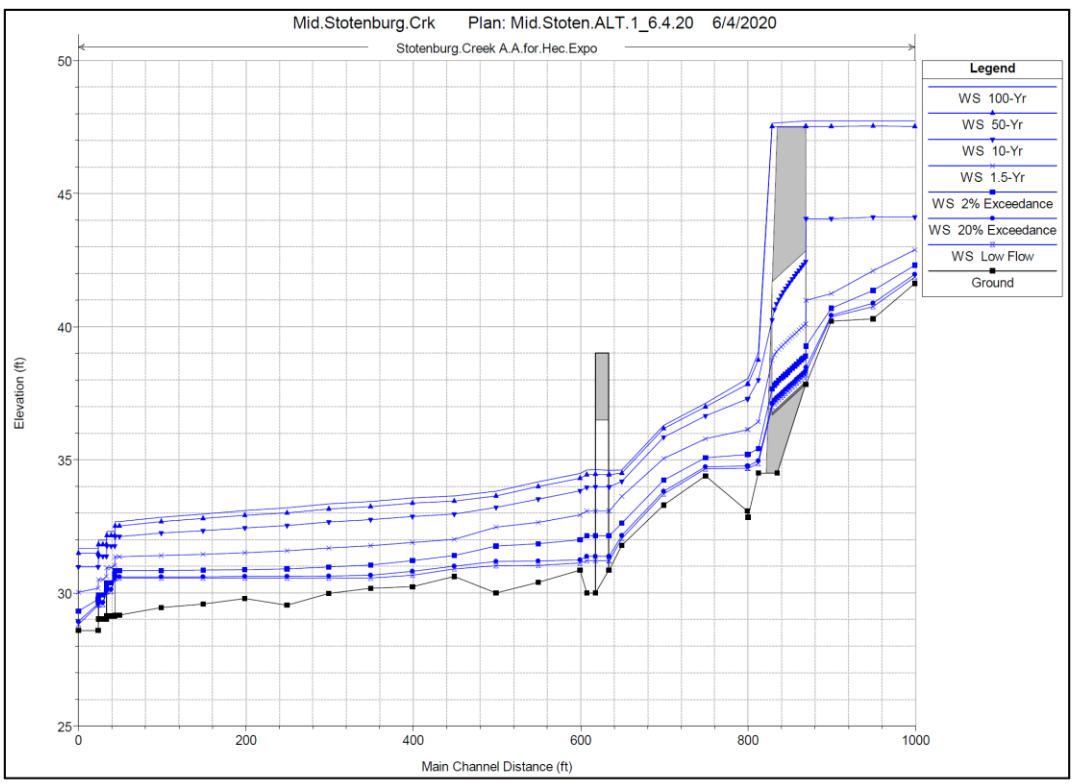

Figure 4-1. Modeled water surface elevations under design Alternative 1 proposed conditions.

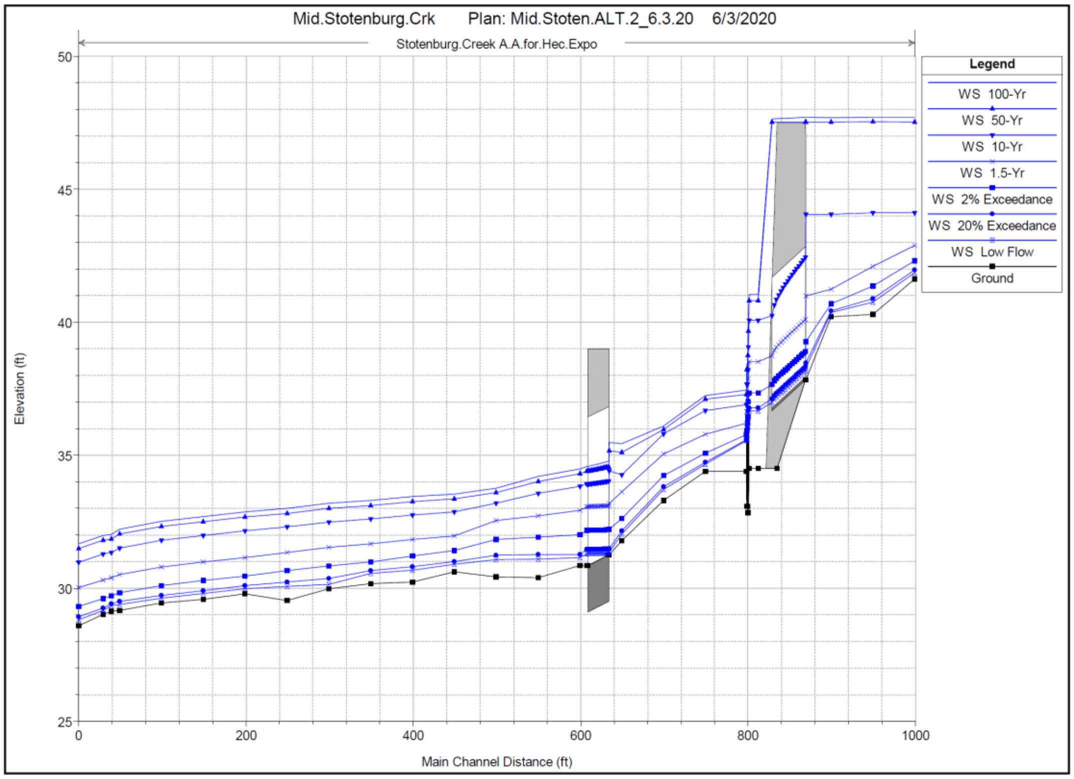

Figure 4-2. Modeled water surface elevations under design Alternative 2 proposed conditions.

Table 4-1. Comparison of existing versus proposed Alternative 2 HEC-RAS modeled water surface elevation in Fred Haight Dr. culvert outlet pool.

Flow	Existing WSE[1] (ft)	Proposed WSE- Alternative 2 (ft)	Increase in WSE- Alternative 2 (ft)
Low flow (0.7 cfs)	34.86	36.67	1.81
20% exceedance	34.95	36.78	1.83
2% exceedance	35.42	37.35	1.93
1.5-yr	36.43	38.52	2.09
10-yr	38	40.07	2.07
50-yr	38.76	40.81	2.05
100-yr	39.03	41.05	2.02

Notes:
[1] WSE = water surface elevation

Table 4-2. Comparison of existing versus proposed Alternative 1 HEC-RAS modeled water surface areas in reach upstream of proposed BDAs.

Flow	Existing water surface area (square feet)	Proposed water surface area (square feet)	Change in water surface area (square feet)	Percent increase in water surface area
Late spring (1 cfs)	6,034	12,546	6,512	108%
20% exceedance	9,129	13,758	4,629	51%
2% exceedance	15,554	17,186	1,632	10%
1.5-yr	19,861	21,216	1,355	7%
10-yr	25,090	26,239	1,149	5%
50-yr	27,860	28,869	1,009	4%
100-yr	28,952	29,890	938	3%

4.5 Planning-level Construction Cost Estimate

Tables 4-3 and 4-4 provide planning-level cost estimates for Alternatives 1 and 2, respectively.

Table 4-3. Cost estimate for Alternative 1 based on 30% design.

No.	Item	Unit cost	Quantity	Units	Total cost
1	Mobilization	$40,000	1	LS	$40,000
2	Clearing and grubbing	$20,000	1	LS	$20,000
3	Dewatering	$20,000	1	LS	$20,000
4	Construct 3 BDAs	$5,000	3	LS	$15,000
5	Seasonal access ford	$10,000	1	LS	$10,000
6	Crossing 5 upgrade with 40' x 16' Kernen bridge	$100,000	1	LS	$100,000
7	Planting	$10,000	1	LS	$10,000
8	Mulch	$1,500	1	LS	$1,500
9	Seeding	$1,000	1	LS	$1,000
10	Temporary wildlife fencing	$10	1500	LF	$15,000
11	Temporary irrigation	$8	1000	LF	$8,000
12	Removal of Himalayan blackberry	$15,000	1	LS	$15,000
13	Exclusion fencing and gates	$11.50	2260	LF	$25,990
14	Permits (CDFW 1602)	$5,500	1	LS	$5,500
15	Engineering - bid support, construction oversight, as-builts	$40,000	1	LS	$40,000
Total construction cost:					**$326,990**
Total construction cost plus 10% contingency:					**$359,689**

Table 4-4. Cost estimate for Alternative 2 based on 30% design.

No.	Item	Unit cost	Quantity	Units	Total cost
1	Mobilization	$40,000	1	LS	$40,000
2	Clearing and grubbing	$20,000	1	LS	$20,000
3	Dewatering	$20,000	1	LS	$20,000
4	Large wood structures—placed and anchored	$2,500	6	each	$15,000
5	Seasonal access ford	$10,000	1	LS	$10,000
6	Crossing 5 upgrade with aluminum box culvert (12'-5" wide x 44.5' long x 7'-4" rise)	$130,000	1	LS	$130,000
7	Grade control log weirs - placed and anchored	$5,000	3	each	$15,000
8	Planting	$10,000	1	LS	$10,000
9	Mulch	$1,500	1	LS	$1,500
10	Seeding	$1,000	1	LS	$1,000
11	Temporary wildlife fencing	$10	1500	LF	$15,000
12	Temporary irrigation	$8	1000	LF	$8,000
13	Removal of Himalayan blackberry	$15,000	1	LS	$15,000
14	Exclusion fencing and gates	$11.50	2260	LF	$25,990
15	Permits (CDFW 1602)	$5,500	1	LS	$5,500
16	Engineering - bid support, construction oversight, as-builts	$40,000	1	LS	$40,000
Total construction cost:					**$371,990**
Total construction cost plus 10% contingency:					**$409,189**

5 PREFERRED ALTERNATIVE – FINAL DESIGN

5.1 Selection of a Preferred Alternative

The TAC concluded during their meeting on July 1, 2020 that Alternative 2 was the preferred alternative and should be advanced. The final design planset (provided in Appendix B) incorporates multiple revisions and design options that have been agreed upon during ongoing discussion with the TAC and stakeholders, including:

- Large wood structures are preferred in the downstream project reach (Sta 27+00 to 29+00) instead of a series of BDAs. This decision was made with the interest in diversifying hydraulic and habitat enhancement features and restoring a channel condition that was historically present in Stotenburg Creek but has largely been removed due to logging. The lower Stotenburg Creek habitat enhancement project (Stillwater Sciences 2019) includes constructing a series of BDAs just downstream of the middle project reach. Beaver are also already active in the middle Stotenburg Creek reach and we anticipate they may build dams that incorporate the proposed large wood structures. The Stotenburg Creek channel likely contained abundant large wood prior to European arrival in the Smith River coastal plain, however, most large conifers in the project area were logged between 1948 and 1965 (see Appendix E).

  The large wood structure designs were updated to utilize log pile ballasting instead of the boulder ballast proposed in the 65% design planset. The stability of using log piles is evaluated below in Section 6.2 *Large Wood Stability* and the design details are shown in the final design planset (Appendix B).
- The seasonal access ford at Sta 29+10 is included in the final design, although without rock armoring as proposed in the 30% conceptual alternative designs. The ford includes new gates on either side of the creek and minor grading on the right bank to reduce the slope for horse and 4-wheeler access. The ford will only be used during dry months when there is no flow in the channel to access the pasture on the other side of the creek, and therefore does not need rock armoring.
- An aluminum box culvert was proposed in Alternative 2 in the conceptual design planset, however, the prefabricated bridge from Alternative 1 (e.g., Kernen bridge or equivalent) is preferred for the Crossing 5 replacement due to cost (including reduced long-term maintenance), flood flow conveyance capacity, and resilience in the event of channel aggradation, or degradation. A prefabricated bridge can be installed at the site cost-effectively using a large excavator and supporting equipment.
- The grade control log weirs at the upstream extent of the project reach (Sta 34+60 to 35+00) are designed to raise the water surface elevation below the Fred Haight Dr. culvert to improve fish passage and prevent additional erosion in the outlet scour pool. The position and elevation of the weirs have been adjusted to be compatible with the potential hydrogeomorphic response following the foreseeable replacement of the Fred Haight Dr. crossing.

  The weir designs have been revised to multi-log structures that consist of three logs stacked vertically and pinned with rebar. The stability of multi-log weirs is evaluated below in Section 6.2 *Large Wood Stability*.
- Riparian plantings will be protected from beaver and ungulate browsing by perimeter fencing around each planting polygon. Riparian plantings will be temporarily irrigated during the dry season until becoming established.

5.2 Proposed Conditions Hydraulic Modeling

Proposed-conditions hydraulic modeling of the preferred alternative was conducted by grading the features in AutoCAD and re-cutting cross sections in HEC-RAS. Results from the proposed conditions modeling are shown in Figure 5-1. Note that, as discussed during the first TAC meeting, the profile in Figure 5-1 includes a mock-up of a reasonably likely future crossing structure at Fred Haight Dr., although the crossing invert elevation is the same as current existing conditions. The mock-up structure is an aluminum box culvert 16 feet-10 inches wide, 8 feet-3 inches high, and 2 feet of embedment below the channel grade. The hydraulic modeling presented in Section 4.4 (Conceptual Design Alternatives) *Proposed Conditions Hydraulic Modeling* does not include this mock-up version of the Fred Haight Dr. crossing. For further discussion of evaluating a future crossing replacement at Fred Haight Dr., see Section 6.5 *Fred Haight Drive Crossing*.

Flow velocity reductions through Crossing 5 at fish passage flows are provided in Table 5-1. Increased water surface elevation in the outlet scour pool of the existing Fred Haight Dr. crossing, which will not be replaced during implementation of this project, are provided in Table 4-2 in Section 4.4 (Conceptual Design Alternatives) *Proposed Conditions Hydraulic Modeling*. Cross section and tabulated model results are provided in Appendix C.

During the final design process additional assessment was conducted using the FishXing software design tool to evaluate fish passage at the Fred Haight Dr. crossing under existing and proposed conditions. Based on FishXing results for existing conditions, the crossing is 0% passable to juvenile salmonids due to leap height and 0% passable to resident salmonids due to leap height and depth through the culvert. The crossing is 97% passable to adult salmonids with the reduced passage condition due to depth at lower migration flows. Based on FishXing results for proposed conditions (i.e., with the grade-control log weirs), there are small improvements to fish passage for juveniles and residents; however, there is no impact to adult passage since the barrier is a result of shallow water depths in the culvert at lower migration flows. Passage for residents is improved from 0% to approximately 2.8%. In general, depth is not suitable for passage at lower migration flows and velocity is too great at higher migration flows. Passage for juveniles is improved from 0% to approximately 13.1%. The proposed conditions make the culvert passable at lower migration flows but velocity is still a barrier at higher migration flows.

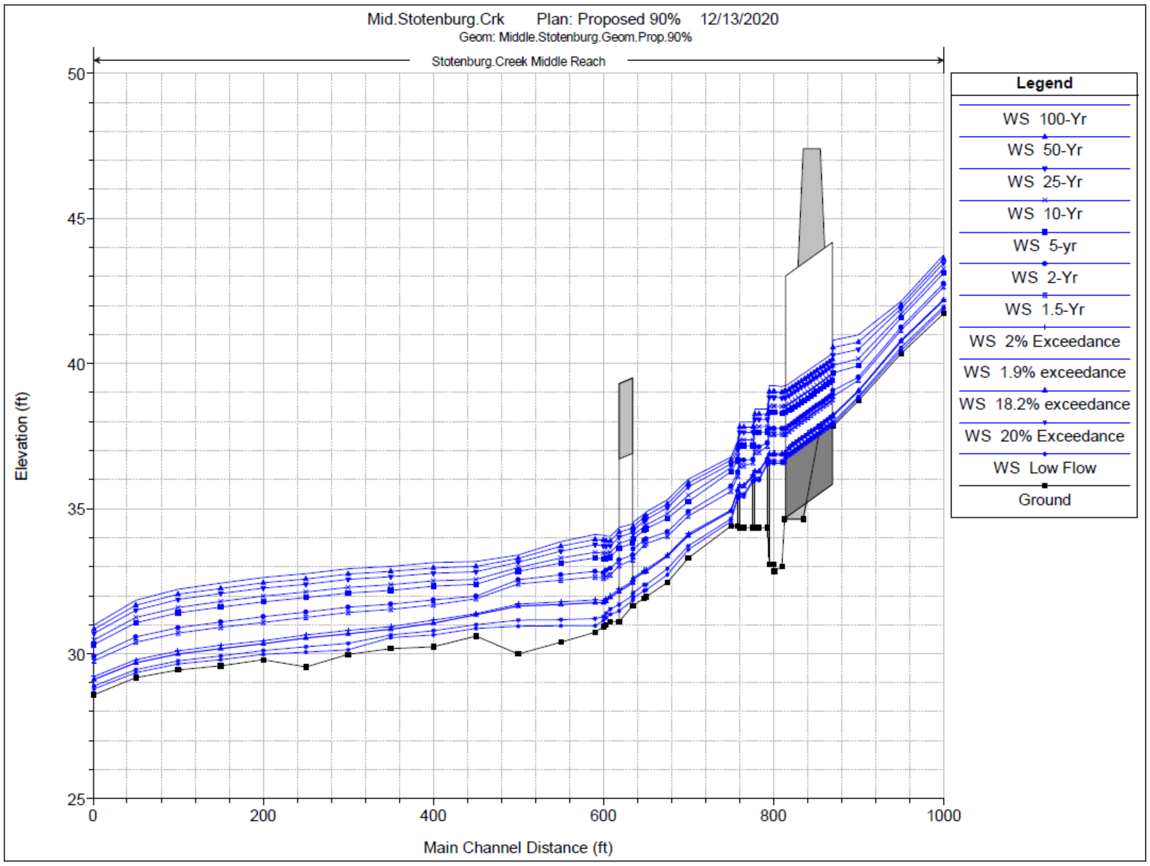

Figure 5-1. Modeled water surface elevations under proposed conditions in the project reach.

Table 5-1. Comparison of existing versus proposed HEC-RAS modeled velocities at Crossing 5 for fish passage flows.

Flow	Existing culvert velocity (ft/s)	Proposed average velocity under bridge (ft/s)	Reduction in velocity (ft/s)
Low flow (0.7 cfs)	1.5	1.4	0.1
20% exceedance	2.2	1.9	0.3
2% exceedance	3.6	2.6	1.0
1.5-yr	4.6	3.8	0.8

5.3 Final Design Cost Estimate

Table 5-2 provides a planning-level cost estimate for the final design. Note that this estimate does not include permitting or project management. An ecological cost-benefit analysis is provided in Appendix F.

Table 5-2. Cost estimate for final design.

No.	Item	Unit cost	Quantity	Units	Total cost
1	Mobilization	$40,000	1	LS	$40,000
2	Clearing and grubbing	$15,000	1	LS	$15,000
3	Dewatering	$20,000	1	LS	$20,000
4	Large wood habitat structures—placed and anchored with piles	$5,500	6	each	$33,000
5	Excavation (Crossing 5 and log structures)	$30	180	CY	$5,400
6	Crossing 5 upgrade with 40' x 16' prefabricated bridge (placed) and new road approaches	$120,000	1	LS	$120,000
7	Rock slope protection (RSP) - placed	$150	115	CY	$17,250
8	Streambed material at Crossing 5 - placed	$100	110	CY	$11,000
9	Grade control log weirs - placed and anchored	$3,000	9	each	$27,000
10	Engineered streambed material (ESM) at log weirs - placed	$100	50	CY	$5,000
11	Planting	$15,000	1	LS	$15,000
12	Mulch	$1,500	1	LS	$1,500
13	Seeding	$1,000	1	LS	$1,000
14	Temporary wildlife fencing	$10	1500	LF	$15,000
15	Temporary irrigation	$10,000	1	LS	$10,000
16	Removal of Himalayan blackberry	$15,000	1	LS	$15,000
17	Exclusion fencing and gates	$11.50	2500	LF	$28,750
18	Engineering - bid support, construction oversight, as-builts	$40,000	1	LS	$40,000
Total construction cost[1]:					**$419,900**
Total construction cost plus 5% contingency[1]:					**$440,895**

Notes:
[1] Total cost estimate does not include permitting or project management.

6 DESIGN DEVELOPMENT, FEASIBILITY, AND RISK ASSESSMENT

Feasibility and risk assessments were conducted to identify opportunities and constraints at the project site, characterize existing conditions and potential risks, and to support design development consistent with project goals and appropriate risk management. The assessments were discussed with project stakeholders during the first two TAC review meetings and were further developed as design plans were advanced to the 100% level. Refer to the final design planset in Appendix B.

6.1 Riparian Vegetation Enhancement

6.1.1 Riparian planting

Riparian planting will establish native woody vegetation where it is currently lacking and will join the middle Stotenburg Creek riparian areas into one contiguous corridor. Including cover by shrubs and ferns will reduce nonnative woody recruitment and provide additional forage for wildlife. Establishing native herbaceous species is recommended at this location to decrease nonnative plant growth in the understory and provide additional pollinator habitat. Additionally, success in other revegetation projects shows supplementing riparian tree plantings with grasses may provide additional soil reinforcement in the early years of tree establishment (Pollen-Bankhead and Simon 2010). Willow shrub recruitment is anticipated in the project reach without additional planting based on the abundant cover of this species downstream. Riparian forest would be composed of moderate to tall trees intermixed with shorter shrubs for an overall cover of at least 70%. The downstream fill slope at the Fred Haight Dr. crossing will be planted with willow poles for temporary vegetative cover since anticipated future disturbance associated with culvert replacement will disturb the restored area.

Table 6-1 provides the native species recommended for planting in the riparian restoration area (approximately 0.5 acres total) to achieve shaded stream cover and a diverse multi-tiered canopy beneficial to wildlife and riparian function. Species include those observed in the adjacent riparian areas along with suitable species known to occur in the region. Planting densities and spacing recommendations provided in Table 6-1 vary by species and follow guidance from the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) *California Electronic Vegetative Guide* (NRCS 2020). In general, tree and large shrub species will be planted 10 to 14 feet apart and smaller shrubs will have 6 to 8 foot spacing. Plantings along the streamside edge will include species with rapid root development and higher tolerance to wet conditions to achieve bank stabilization and a partially shaded stream surface. Herbaceous species will be planted from containers and/or seed in densities based on seasonal availability during the time of plant installation. Containers will be interplanted between the tree and shrub planting basins in locations best suited for the species (e.g., full to moderate sun exposure, full shade) and in openings of overstory cover. Native grass and forb seed will be hand broadcasted.

Table 6-1. Selected native plant species for riparian habitat planting.

Scientific name	Common name	Form	Material	Spacing (feet)
Trees				
Alnus rubra	red alder	tree	container	14
Fraxinus latifolia	Oregon ash	tree	container	14
Picea sitchensis	Sitka spruce	tree	container	10
Sequoia sempervirens	coast redwood	tree	container	10
Salix lasiandra	Pacific willow	tree	cuttings/pole	10
Umbellularia californica	California bay laurel	tree	container	10
Shrubs				
Cornus sericea subsp. *sericea*	red osier dogwood	shrub	container	8
Frangula purshiana	cascara	shrub	container	6
Lonicera involucrata	twinberry	shrub	container	6
Physocarpus capitatus	Pacific ninebark	shrub	container	6
Ribes sanguineum	red-flowering currant	shrub	container	6
Rubus parviflorus	thimbleberry	shrub	container	6
Sambucus racemosa var. *racemosa*	red elderberry	shrub	container	6
Symphoricarpos albus var. *albus*	common snowberry	shrub	container	6
Suggested Herbaceous Understory				
Achillea millefoliata	common yarrow	forb	seed	broadcast
Athyrium felix-femina	common lady fern	fern	container	interplanting
Bromus carinatus	California brome	grass	seed	broadcast
Festuca rubra	red fescue	grass	seed	broadcast
Hordeum brachyantherum	meadow barley	grass	seed	broadcast
Polystichum munitum	Sword fern	fern	container	interplanting
Scrophularia californica	California figwort	forb	seed	broadcast
Symphyotrichum chilense	Pacific aster	forb	seed	broadcast

To the extent possible, planting material should be sourced from the Smith River coastal plain ecoregion (Level IV Ecoregion 1a) and locally harvested from mature parent material in varied locations within the lower Smith River and tributaries to account for local adaptation of species in the region and to maintain genetic variation in the restoration area. Using plant material adapted to local conditions (i.e., locally adapted) will ensure better long-term establishment (Withrow-Robinson and Johnson 2006). Prior to planting, site preparation of the planting areas will include nonnative invasive weed management (described below in Section 5.3.2 *Invasive Weed Removal*) and soil amelioration. If necessary, additional soil amendments will be added to the planting substrate and post-implementation planting basins will be mulched.

In addition to the proposed permanent cattle exclusion fence separating the pasture from the riparian corridor, temporary wildlife-exclusion fencing would be installed to protect the initial plantings from wildlife browsing, primarily from beaver, elk, and deer. Considering the areas planned for riparian planting are spatially discrete, the wildlife-exclusions fencing would surround each planting polygon. Individual tree shelters would not be installed initially, however if herbivory damage is noted post-implementation and is found to be impacting seedling success, then plant protectors would be installed.

Supplemental irrigation should be utilized following the initial planting effort to assist in the successful establishment of riparian plantings. Irrigation would be temporary as riparian plants need to be self-sustaining after establishment (approximately 2 years). Ideally, irrigation would be sourced from existing wells on the property. However, if insufficient water supply is available during the dry season then temporary irrigation tanks or water trucks should be used. A water truck is a feasible alternative at the site considering the planting areas are easily accessed by vehicle from Fred Haight Dr. Timing the planting effort closer to the wet season will reduce the number of water truck deliveries to the site. Any temporary irrigation materials would be removed from the site upon plant establishment.

6.1.2 Invasive weed removal

Removal of Himalayan blackberry within the riparian corridor of middle Stotenburg Creek will allow for reestablishment of a diverse native understory. Since Himalayan blackberry varies in prevalence and establishment within the project area both mechanical (i.e., machinery) and manual (i.e., hand removal) control methods are recommended. The east bank of the upstream riparian planting area has dense establishment by Himalayan blackberry (approximately 3,000 sq/ft) that is easily accessible from the adjacent pasture and mechanized removal is recommended (e.g., field mower/weed-eater, excavator, backhoe, etc.). While employing this method, above-ground damage to neighboring riparian shrubs should be minimized to the extent possible. If damage to the riparian area is considerable (i.e., large areas without riparian cover) and/or affected native woody species are not anticipated to recover (e.g., re-sprout) then additional riparian planting may be required. Prior to and/or during the Himalayan blackberry mechanized removal efforts, a botanist would inform operators on native cover and provide recommendations to minimize impacts to these species, as needed. If root crowns are left intact, multiple efforts may be required prior to the successful removal of the species. Mechanized removal methods would be conducted during the dry season or dry channel conditions.

Manual (i.e., hand removal) control methods are recommended in areas with established native understory to limit damage to native woody vegetation. This method should be used in the channel and on the west bank of the upstream planting area. Manual methods include hand pulling, hand hoeing, digging/grubbing, and cutting using non-mechanized equipment (e.g., machetes, loppers, clippers, hori hori, etc.). Manual removal efforts in areas with low Himalayan blackberry may be implemented year-round since manual weed removal is not restricted by stream channel conditions.

Himalayan blackberry readily propagates from root fragments and cane cuttings (Sol 2004) so slash created from either removal method should be removed from the site, burned onsite following regional ordinances, or fed through a mechanical chipper and used as mulch.

6.2 Large Wood Stability

Quantitative wood stability analyses were conducted for the proposed wood structures between Sta 27+00 and 29+00, and the grade-control log weirs at the upstream end of the project reach. The analyses use a Microsoft Excel macro developed by Rafferty (2016). The constants, input variables, freebody diagram, and equations from Rafferty are included in Appendix D. The analyses use a basic force balance approach in the vertical, horizontal, and rotational directions to ensure that each wood structure will be stable during a specific flow regime. The calculation process uses a sum of forces to determine each structures factor of safety (FOS) in the vertical (buoyancy), horizontal (momentum or sliding), and rotational (moment or overturning) directions. Structures are designed to achieve a minimum factor of safety of 1.5 in each direction by varying log size, log type, burial depth, and incorporating other stabilizing methods like boulder ballast and log piles.

Based on input from the TAC during the 65% design review meeting in October 2020, additional wood stability analyses were conducted to evaluate multi-log structures for the grade control weirs in the upstream project reach and using log piles instead of boulder ballast for the downstream log structures between Sta 27+00 and 29+00. Log piles can be effectively used at the site with minimal cost increases and provide a more ecologically appropriate method in the low-gradient floodplain setting compared to large boulders. Rafferty (2016) does not include a specific method for designing with log piles, however, the forces involved with piles can be calculated separately and manually included into the overall force balance of the wood structure. Log piles were evaluated following the methods of Knutson and Fealko (2014) to determine forces associated with buoyancy, skin friction, embedment, scour, shear, and overturning.

The following is a list of key design parameters and assumptions that provide the basis of stability calculations for the wood structures between Sta 27+00 and 29+00 (for specific details see Appendix D):

- Analyses are based on 100-year flow velocity, depth, and width outputs from HEC-RAS model.
- All boulders and logs are fully submerged. Tops of wood piles and rootwads may slightly extend above the water surface.
- Key log members (horizontal logs): 40-foot length x 2-foot diameter with rootwad dimensions: 5-foot diameter x 3-foot length and porosity = 0.2.
- Log piles: 14-foot length x 1.25-foot diameter, 10.5-foot embedment, two piles per structure driven near toe of bank slope.
- Channel banks composed of gravel and sand, channel bed surface composed of medium sand and gravel and sand subsurface.
- Key log members calculated as young coastal redwood: dry unit weight = 24.5 lb/ft^3, green unit weight = 50 lb/ft^3. Log piles calculated as coastal Douglas fir: dry unit weight = 33.5 lb/ft^3, green unit weight = 38 lb/ft^3
- Calculations assume localized scour around logs.
- Minimum factor of safety equals approximately 2, or greater, so if one pile is lost structure should remain intact.

The following is a list of key parameters and assumptions that provide the basis of stability calculations for the grade control log weirs between Sta 34+50 and 35+00 (for specific details see Appendix D):

- Analyses are based on 100-year flow velocity, depth, and width outputs from HEC-RAS model.
- All logs are fully submerged.
- Each weir consists of three vertically stacked logs pinned together with rebar.
- Log dimensions: 18-foot to 10-foot lengths x 1.75-foot diameter. Each weir consists of a longer top log then tappers with the middle and bottom logs.
- Weirs are ballasted by burial in channel banks with native soils and in channel bed with coarse engineered streambed material.

- Weirs are designed with coarse rock armoring on either end to prevent flanking scour; however, these rocks are not anchored to the logs and are not required for achieving adequate factor of safety.
- Wood calculated as young coastal redwood: dry unit weight = 24.5 lb/ft^3, green unit weight = 50 lb/ft^3.
- Calculations assume localized scour around logs.
- Minimum factors of safety for the three weirs equal approximately 2.5 to 4.

Incorporating large wood structures into the project will expand habitat variability and increase flow dynamics that promote localized sediment mobilization and sorting. Prior to agricultural land uses, this reach of Stotenburg Creek had abundant large wood considering the dense conifer forests evident in early historical aerial photographs (see Appendix E). The proposed log weirs near Sta 35+00 will control the steep channel grade downstream of the Fred Haight Dr. crossing and improve fish passage conditions by reducing the jump height into the culvert. The log weirs are designed at a compatible elevation with the likely future re-design of the crossing. Log weirs provide some flexibility for achieving precise elevation control since they can be further notched with a chainsaw following construction, if deemed appropriate.

Risks associated with log instability are minimized due to the factors of safety built into the calculations and the on-site engineering and geomorphic expertise that will guide the final layout and construction of the structures. In addition, long-term stability will be achieved by proper installation guided by technical oversight and described in the final design plans and specifications. To further ensure the quality of anchoring, we strongly recommend that a contractor is selected who has previous experience with implementing large wood projects.

It is possible that the position of the wood structures may adjust due to scour or racking of significant new wood and debris. It is possible that minor scour and settling may help the structure stay in place because it will increase resisting forces via wedging against anchor boulders/piles and settlement of overlying substrate. However, some structures may have the potential to rotate and/or translate if significant scour and racking of additional wood occurs.

Although there is inherent uncertainty and risk associated with constructing large wood structures in active stream channels (e.g., wood decay, faulty materials, contractor error, extreme flow events, etc.), we believe the proposed structures provide cost-effective enhancement objectives. 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. In the event of a disarticulated wood structure, there is relatively low risk of downstream adverse impacts. Existing downstream infrastructure includes undersized culverts at Crossing 4, Crossing 2, and Crossing 1 (from the lower Stotenburg Creek habitat enhancement project [Stillwater Sciences 2019]). Assuming implementation of the proposed middle Stotenburg Creek habitat enhancement project would occur following implementation of the lower Stotenburg Creek project, downstream infrastructure would include a large box culvert at Crossing 4 and bridge at the new Crossing 1 location. Crossing 2 would be removed and restored to natural channel conditions. Considering the dense riparian vegetation within the active creek channel immediately downstream of the project reach, it is likely that mobilized large wood would be retained in-channel before reaching Crossing 4. If able to reach Crossing 4, a log would likely transport through the 24-foot-wide box culvert and be retained within the even denser riparian vegetation on the downstream side of the crossing. It is highly unlikely that a log could transport the more than 1,300 feet of channel length between Crossing 4 and the new Crossing 1 location due to similarly dense riparian vegetation, and therefore there is low risk to a new bridge at that site.

6.3 Construction Access and Logistics

In general, there is good access across the site from Fred Haight Dr. and Cedar Lodge Ln. There are existing access points to the site adjacent to the power substation and the southeast side of the Fred Haight Dr. crossing. There are large staging areas and unimpeded access to the channel from both sides between Sta 27+00 and 29+00 to construct large wood structures, riparian plantings, and exclusion fencing. The approaches to Crossing 5 are partially overgrown with vegetation and would require minor grubbing prior to culvert removal and installation of the new bridge. However, access is not restricted by mature trees and the overhead power lines are high enough to not preclude equipment access. Pacific Power regularly mobilizes large equipment to this site to clear canopy vegetation from the power line alignment. If the power lines were a potential concern, approaching the crossing from the east with tall equipment would avoid any issues. Access to the upper project reach for Himalayan blackberry removal, riparian planting, and log weir construction is likely preferred from the east bank. Although both banks have similar slopes, the west bank has established redwood and bay laurel trees, whereas the east bank is dominantly Himalayan blackberry, which is proposed to be removed.

Any potential hazard associated with the overhead power lines can be avoided by using one of the multiple suitable access points across the site. There are no known buried utilities in the construction footprints, as confirmed by the landowners. However, if needed, underground service alert (USA) will be consulted.

6.4 Crossing 5

The crossing designs call for a prefabricated bridge (e.g., Kernen bridge or equivalent), 40 feet long and 16 feet wide, at the same location as the existing culvert. The precast concrete bridge deck is designed with railings and will support typical ranch traffic. The creek channel through the crossing follows a stream simulation design.

6.4.1 Stream simulation channel design

The design profile at Crossing 5 is 2.1% and is based on geomorphic site characteristics including the reach stable profile. The design profile is between the high and low vertical adjustment profiles (see Figure 2-11), which bound the potential range of elevations the channel is likely to experience during the lifespan of the project. The vertical adjustment profiles are a best estimate of these possible future channel profiles through the site and are established from the geomorphic assessment of the reach and regression analysis of the longitudinal profile.

A channel slope of 2.1% is in the upper range for a stream simulation design approach, and lower than the typical 3%-5% for a roughened channel. The channel design through the crossing follows the stream simulation approach, and the design team evaluated incorporating concepts from roughened channels, such as including rock grade control keyway structures. However, considering the site is likely to aggrade in the foreseeable future (see Section 6.5 *Fred Haight Drive Crossing* below), grade control structures were omitted from the final design planset.

The channel cross-sectional geometry is designed primarily based on measurements from the reference reach, as well as the bridge abutment design and stream banks upstream and downstream of the crossing site. Floodplain benches approximately 6 feet wide on both sides of the channel, similar to the bench in the reference reach, will increase flow conveyance capacity under the bridge. The current undersized culvert has caused deposition of fine sediment on the upstream side, which will be excavated along with the crossing fill prior to constructing the new bridge.

Immobile rocks should be placed partially buried as dispersed bankline and keystone rocks within the bed to increase hydraulic variability, create micro low velocity refugia for aquatic species, and provide bank toe stability. These rocks are sized using the methods from USACE (1994), Bates et al. (2003), and CDFW (2009) for determining immobile rock size at a stable bed design flow (i.e., 100-year flow), and should consist of angular boulders approximately 1.0 to 1.25 feet in diameter. However, the majority of the bed substrate within the stream simulation reach will be a well-graded mix that follows the size distribution from the reference reach with a median rock diameter (D_{50}) of very coarse gravel (i.e., 50-64 mm), D_{84} of small cobble (i.e., 100-128 mm), and a matrix of coarse sand and silt. This streambed mixture should be placed in lifts 0.5 to 0.75 feet thick to a finished thickness of approximately 1.25 to 1.5 feet. Smaller material should be tamped, jetted, and/or flooded into place to minimize hyporheic flow. During construction, contractors should use pumped water to ensure the finished channel can convey surface flow prior to leaving the site. Streambed material will be placed along 85 feet of channel length, within the limits of grading (see Appendix B, Sheet 5). The channel design also includes a pilot low-flow channel (~4 feet wide and 0.75 feet deep) to prevent very shallow sheet flow. This low-flow channel is expected to be dynamic and evolve within the first year.

6.4.2 Scour

The stream simulation channel at Crossing 5 has a natural channel bottom and is susceptible to scour, which could potentially undermine the bridge abutments. Scour was analyzed at the crossing site following the methods of the Federal Highway Administration's (FHWA) Hydraulic Engineering Circular No. 18 (HEC-18) (FHWA 2012). The scour analysis uses hydraulic results from the HEC-RAS modeling of proposed conditions and includes three types of scour: long-term scour (incision), contraction scour, and local abutment scour.

Long-term scour (incision) at the crossing site was determined from the longitudinal profile analysis described above in Section 6.4.1 *Stream simulation channel design* and is based on regression analysis of the low vertical adjustment profile (Figure 2-11). The low vertical adjustment profile depicts the lowest elevation to which the channel bed could reasonably degrade during the lifespan of the project. This scour depth equals approximately 0.91 feet.

Contraction scour was evaluated using live-bed contraction scour Equations 6.2 and 6.3 (modified Laursen equations) from FHWA (2012), with input variables obtained from HEC-RAS results of proposed conditions. As indicated in Equation 6.2, given the HEC-RAS predicted channel bed shear values and median streambed material size (D_{50}), a combination of bedload and suspended load transport are assumed with a k_1 value equal to 0.59. Per Note 4 of FHWA (2012), the 100-year water surface top width is used in lieu of bottom width and the Q_1 and Q_2 terms of Equation 6.2 are assumed to be equal. The analysis indicates the crossing creates approximately 0.17 feet of horizontal contraction and scour depth of approximately 0.23 feet. Per Note 8, the Clear-Water Contraction method of Section 6.5 was also applied. As shown in Equations 6.4 and 6.5, the diameter of the proposed streambed material is incorporated into the computations, and the Clear-Water Method of determining contraction scour predicts no scour would occur. While Equation 6.2 and Note 8 allow the minimal estimate to be adopted, the designs retain the 0.23 feet of predicted contraction scour.

Predicted scour at the bridge abutments was also determined using FHWA (2012). Scour at an abutment can be estimated with Froehlich's Equation (Equation 8.1). Per Table 8.1 and Figure 8.6 from FHWA (2012) the coefficient of embankment type (k_1) is assumed to be 0.55. The abutment is only slightly oblique to the predominant longitudinal flow, therefore, k_2 is assumed to be 1.04, given the prescribed methods of Equation 8.1. HEC-RAS analysis results were used to obtain range of scour depth estimates based on varying flow depth terms. A range of estimates of scour depths were produced representing average and maximum depth estimates along with an estimate derived from the Froude definition supplied in Equation 8.1. The anticipated depth of overbank flow during a 100-year event is anticipated to be 0.23 to 0.82 feet. Given this range of depths, scour estimates range from 0.95 to 2.32 feet. The maximum value of 2.32 feet is adopted for the designs.

HEC-18 recommends that the total potential scour at a bridge equals the sum of long-term scour (incision), contraction scour, and local abutment scour. Therefore, the bridge abutment footings are designed to a depth of 3.5 feet (i.e., 0.91 + 0.23 + 2.32 = 3.46 feet)

6.4.3 Rock slope protection (RSP)

The bridge abutments and channel slopes at the crossing will be protected from scour with rock slope protection (RSP). The RSP will be placed at a thickness of 2.5 feet from the top edge of the stabilization mats (see Section 6.4.3 *In situ soil strength and factor of safety* below) at a 1.5:1 slope down to inset floodplain benches on either side of the active channel. The RSP will extend into keyed toe trenches a minimum of 3.5 feet below the channel bed. Sizing the RSP uses the methods of USACE (1994). The channel slopes will use ¼ to ½ -ton rock and ½ to 1-ton rock in the toe trenches. The RSP will be placed in lifts with care taken to lock the angular boulders together. Void spaces will be filled with smaller rock (e.g., 6-inch) and soil with willow stakes at the upstream and downstream margins. RSP will be placed at a minimum of 2 feet thick. See Appendix B, Sheet 5 for further details.

6.4.4 *In situ* soil strength and factor of safety

The *in situ* silty sand and silty gravel shallow subsoils in the Crossing 5 location have a presumptive vertical foundation bearing capacity of 2,500 pounds per square foot (psf), per Table 1806.2 in Chapter 18 (*Soils and Foundations*) of the 2016 California Building Code. Subsoils were characterized from onsite observations in channel cutbanks and in well-completion reports for water wells in the project vicinity. Using this soil bearing capacity, factors of safety were computed for the different crossing replacement alternatives.

The prefabricated bridge proposed at Crossing 5 is designed to be supported by two precast concrete abutment structures (i.e., strip footings). The bridge abutments bear 1,113 psf under a dead load and 1,271 psf under a live load typical of ranch traffic. These loads correspond to a factor of safety of 1.8 and 1.6, respectively. The bridge abutments will be supported by relatively shallow soils, which are susceptible to settlement. To increase the factor of safety and reduce the potential for settlement, the bridge abutments are designed to be supported on stabilization mats, which consist of a multi-layered bed of well-graded crushed aggregate and two layers of geogrid (Mirafi BXG12 or equivalent), one at the base of the crushed rock and one at mid-height. The entire mat is wrapped in filter fabric to create a laterally constrained structure that will maintain its integrity while undergoing anticipated minor differential settlement. Additional bridge abutment protection measures include constructing rock slope protection (RSP) on the channel banks around the abutments. See Appendix B, Sheet 5 for further details.

6.5 Grade Control Log Weirs

The log weir grade control structures in the upstream project reach (Sta 34+60 to 35+00) will raise the water surface elevation below the Fred Haight Dr. culvert to improve fish passage and are designed to be compatible with the potential hydrogeomorphic response following the foreseeable replacement of the Fred Haight Dr. crossing. The weirs are multi-log structures that consist of three logs stacked vertically and pinned with rebar (see Sheet 5 in Appendix B). The upper and middle weirs have a 0.6-foot jump over their crests with constructed pools on the downstream side to aid in fish passage. The lowest weir crest is at grade with the downstream channel thalweg. The stability of the weirs is described above in Section 6.2 *Large Wood Stability.* Each weir is designed with a low-flow notch (approximately 24 inches wide and 4 inches deep) to direct flow toward the center of the channel, which should preclude flow to concentrate on one side of the log and lead to flanking scour. Several ¼- to ½-ton boulders will be placed on the top of either end of each weir as the finished grades are established to further prevent flanking scour. These boulders are not mechanically anchored to the logs and are not required to achieve the minimum required factor of safety.

The weirs are stabilized by burial in the channel banks with native soils and in the channel bed with coarse engineered streambed material (ESM). Sizing the ESM follows the methods from USACE (1994), Bates et al. (2003), and CDFW (2009) for determining rock size at a stable bed design flow (i.e., 100-year flow). The ESM will have a D_{50} of approximately 4 inches and D_{84} of approximately 10 inches, with smaller rock packed into interstitial void spaces. The ESM will have a well-graded size distribution with approximately 10% of the final mixture consisting of coarse sand and silt. This smaller material should be tamped, jetted, and/or flooded into place to minimize hyporheic flow. Ensuring interstitial void spaces are adequately packed with finer material is essential to maintain surface flow over the weirs. The ESM will be placed in lifts between 0.5 and 1 feet thick.

Streambed scour at the weirs was analyzed following the methods of NRCS (2007). The computations use HEC-RAS results and design specifications to estimate maximum scour depths that could occur on the downstream side of the weirs. Equations TS14B-53 through TS14B-62 (from NRCS 2007) produce estimates of total scour as measured from the downstream control grade or lip of the pool below the weir crest. Equation TS14B-59 indicates that up to approximately 4.5 feet of scour could occur and given a residual pool depth of 2 to 2.5 feet, the minimum thickness of ESM required along the bottom of the pools to protect from scour is approximately 2 feet. Considering the existing streambed material in this reach is dominantly coarse gravel and cobble, the designs reduce the ESM thickness in the center of the pools to a minimum of approximately 8 inches. If finer streambed material is unexpectedly encountered at depth during weir excavation, the ESM thickness should be revised to the 2-foot minimum thickness throughout the reach, as was depicted in the 90% design planset. This decision will be made in the field during weir excavation by the Project Geologist and Project Engineer. The ESM fill against the upstream side of the top log in each weir should initially be 0.75 to 1 foot thick but will likely increase to an assumed 1.25 feet (Y_w). The lowest weir crest will be almost completely embedded into the channel bed with only the crest of the log exposed. This configuration will minimize the length and depth of scour downstream of the last weir. Given Equation TS14B-61 the downstream extent of scour during a 100-year flood event is approximately 19 feet, therefore, ESM should extend 20 feet downstream of the last weir at Sta 34+60. The width and extent of ESM can be adjusted to suit field conditions.

6.6 Fred Haight Drive Crossing

The Stotenburg Creek crossing at Fred Haight Dr. (FHD) is just upstream of the project extent and is technically not part of the project. However, the crossing was evaluated during the design process due to its proximity to the project reach and because the Del Norte County Roads Division is interested in replacing the crossing in the foreseeable future. The design team has been denied access to the reach of Stotenburg Creek upstream of the crossing and, therefore, the field geomorphic assessment and topographic survey ended at the culvert inlet within the road right-of-way. The topographic data presented in this report and in the design plans for upstream of FHD are LiDAR-derived. Although LiDAR can provide detailed information about the ground surface across larger extents, it is not typically capable of accurately depicting local-scale topography in small creek channels under dense tree canopy, like the conditions in Stotenburg Creek upstream of the project reach. Therefore, the design team cannot verify the accuracy of the topographic data upstream of FHD.

The Stotenburg Creek longitudinal profile through FHD (Figure 2-15) shows that the culvert invert is at the high vertical adjustment profile and suggests that the upstream channel (up to potentially Sta 37+40) may be aggraded. This is a reasonable assumption considering the elevation of the culvert invert and because it is undersized. However, the design team has not been able to expand the geomorphic assessment upstream of the County road to evaluate the presence of excess stored sediment in the channel. The portion of the channel visible from the road does not appear to contain excess stored sediment. There are some small branches and vines in the channel just upstream of the crossing, but the culvert inlet is not blocked, and it is at grade with the upstream channel. The culvert is free of debris and the invert is intact, except for the final 1 to 2 feet at the shotgun outlet. The longitudinal profile of the downstream project reach closely follows the overall reach stable profile, which includes the creek upstream of FHD (Figures 2-3, 2-11, and 2-15). The large drop and scour pool at the culvert outlet are because the culvert invert is at the high vertical adjustment profile and the downstream channel is at the overall reach profile. The project reach between FHD and the tributary confluence does not appear sediment-starved, as may be hypothesized due to the undersized culvert at the County road. The reach is not substantially incised, and the bed contains fresh deposits of mobilized sediment. Collectively, these observations suggest that the FHD crossing does not act as a substantial hydrogeomorphic control on this reach of the creek, although it could have in the past. The installation date of the culvert is not known, however, FHD was constructed prior to 1942, as seen in the earliest aerial photograph evaluated for the project.

In addition to the hydrogeomorphic processes of erosion, sediment transport, and deposition, there is also geologic control on the variability of the Stotenburg Creek longitudinal profile upstream and downstream of FHD. This reach of the creek is within the central and distal portion of the alluvial fan that slopes upward to the northeast, so it is not unexpected to have relatively steeper channel slopes through this aggradational surface (Figure 2-2). The reach downstream of Crossing 5 is where the creek transitions from the edge of the alluvial fan to the flat Smith River floodplain.

As part of the project the design team considered potential hydrogeomorphic responses in the upstream and downstream reaches due to the foreseeable replacement of the FHD crossing. The new crossing structure at FHD will have a larger cross-sectional area, which will promote sediment transport. The preferred alternative hydraulic modeling presented in Section 5.2 (Preferred Alternative-Final Design) *Proposed Conditions Hydraulic Modeling* and in Appendix C include a mock-up of a reasonably likely crossing structure, although the crossing invert elevation is the same as current existing conditions. The mock-up structure is an aluminum box culvert 16 feet-10 inches wide, 8 feet-3 inches high, and 2 feet of embedment below the channel grade. Note that the hydraulic modeling presented in Section 4.4 (Conceptual Design Alternatives) *Proposed Conditions Hydraulic Modeling* does not include this mock-up version of the FHD crossing. Assuming streambed material is mobilized from upstream of FHD, it is expected that material will transport, sort, and at least partially deposit within the project reach. Coarser gravel and cobble will likely deposit in the reach from FHD to approximately Sta 32+50, sands will deposit in interstitial voids and in low-velocity areas (e.g., in the lee and stoss of large channel roughness features), and finer sands and silts will transport and primarily deposit downstream of Sta 32+50.

The potential future hydrogeomorphic response of additional sediment transport and deposition within the project reach presents the largest risk to the new Crossing 5. A bridge is preferable, compared to the box culvert included in the 30% conceptual designs, with respect to this risk. Although both crossing types would provide similar sediment transport capacity through the site, a bridge provides larger cross-sectional area to accommodate hydraulic conveyance should the bed partially aggrade. In section view, a bridge crossing widens with increasing height above the bed, whereas an aluminum box culvert slightly narrows, and a concrete box culvert remains at the same width. The bridge design maintains 2.25 feet of freeboard (minimum) between the low chord and modeled 100-year flood water surface elevation, which provides accommodation space for an aggrading bed. The design profile through Crossing 5 (Figure 2-11) also includes grading portions of the upstream and downstream channel to remove anthropogenically-induced fine sediment deposits. This grading will also provide accommodation space for potential future bed aggradation.

6.6.1 Fred Haight Drive crossing upgrade recommendations

Based on the discussions above in Section 6.6 *Fred Haight Drive Crossing*, Section 5.2 *Proposed Conditions Hydraulic Modeling*, and Section 2.2.3 (Existing Conditions) *Field Assessment*, we provide the following design recommendations for upgrading the FHD crossing. These recommendations assume the LiDAR-derived topographic data upstream of the crossing is reasonably accurate. The crossing structure should be designed, at a minimum, to accommodate a 100-year flood event with adequate freeboard (approximately 2 feet) to accommodate transported wood, debris, and sediment bedload. Hydraulic analyses necessary to size the crossing structure were not conducted as part of this project, however, the new crossing will likely need to be a box culvert or bridge. To facilitate natural stream function and fish passage, a more suitable design profile for the crossing would be between the high vertical adjustment profile and the reach slope regression depicted in Figure 2-15. This target invert elevation would reduce the hydraulic drop at the crossing outlet but would likely initiate head-cutting on the upstream side. The crossing replacement project could include channel grading on the upstream side to reduce the slope of the change in profile elevation and additional grade-control structures (e.g., log or rock weirs) could be included, if deemed appropriate based on the field geomorphic assessment and topographic surveys. The proposed log-weirs between Sta 34+60 and 35+00 will serve a comparable function of maintaining an overall reach stable profile and their crest elevations are designed to be compatible with these potential hydrogeomorphic responses. Logs are preferred for the proposed weirs downstream of FHD since they can be further notched with a chainsaw following construction to adjust for varying target channel grades.

6.7 Depth to Bedrock

There are no bedrock outcrops in the project area. Bedrock outcrops on the coastal plain are isolated to dispersed relic sea stacks composed of lithologically competent Franciscan Broken formation. Nearby well-completion reports indicate the bedrock contact is multiple tens of feet below the ground surface. Therefore, it would not be expected to encounter bedrock during subgrade excavation for bridge abutments or large wood installation.

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Appendices

Appendix A

Conceptual Alternative Design Planset

Appendix B

Final Design Planset

Appendix C

HEC-RAS Hydraulic Model Outputs

Appendix C-1: 1-D model output for existing conditions

Appendix C-2: 1-D model output for proposed conditions

Table C-1. HEC-RAS model results for existing conditions.

HEC-RAS Plan: Exist_65% River: Stotenburg.Creek Reach: Middle Reach

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl	Flow Area	Shear Total
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)		(sq ft)	(lb/sq ft)
Middle Reach	1000	100-Yr	255.00	41.62	47.56		47.57	0.000240	1.10	291.54	140.14	0.09	291.54	0.03
Middle Reach	1000	50-Yr	224.00	41.62	47.37		47.39	0.000222	1.03	266.50	130.98	0.09	266.50	0.03
Middle Reach	1000	25-Yr	193.00	41.62	45.59		45.64	0.001314	1.72	115.00	58.30	0.20	115.00	0.16
Middle Reach	1000	10-Yr	153.00	41.62	44.09		44.27	0.011985	3.40	45.01	36.13	0.54	45.01	0.92
Middle Reach	1000	5-yr	126.00	41.62	43.43	43.43	43.86	0.048280	5.30	23.79	27.94	1.01	23.79	2.54
Middle Reach	1000	2-Yr	70.00	41.62	43.03	43.03	43.40	0.050617	4.83	14.50	20.28	1.01	14.50	2.24
Middle Reach	1000	1.5-Yr	53.00	41.62	42.88	42.88	43.21	0.052517	4.56	11.61	18.15	1.01	11.61	2.08
Middle Reach	1000	2% Exceedance	12.00	41.62	42.31	42.31	42.49	0.065074	3.41	3.52	10.01	1.01	3.52	1.41
Middle Reach	1000	20% Exceedance	2.20	41.62	41.97	41.97	42.06	0.078561	2.39	0.92	5.16	1.00	0.92	0.87
Middle Reach	1000	Low Flow	0.70	41.62	41.84	41.84	41.89	0.094422	1.91	0.37	3.31	1.01	0.37	0.65
Middle Reach	950	100-Yr	255.00	40.30	47.56		47.56	0.000057	0.60	534.89	194.11	0.05	534.89	0.01
Middle Reach	950	50-Yr	224.00	40.30	47.37		47.38	0.000052	0.55	498.86	194.11	0.04	498.86	0.01
Middle Reach	950	25-Yr	193.00	40.30	45.60		45.61	0.000224	0.85	232.59	103.20	0.09	232.59	0.03
Middle Reach	950	10-Yr	153.00	40.30	44.09		44.11	0.000905	1.27	120.20	60.83	0.16	120.20	0.11
Middle Reach	950	5-yr	126.00	40.30	43.28		43.33	0.002073	1.65	76.30	48.66	0.23	76.30	0.20
Middle Reach	950	2-Yr	70.00	40.30	42.30	41.56	42.36	0.004859	1.95	35.88	33.77	0.33	35.88	0.32
Middle Reach	950	1.5-Yr	53.00	40.30	42.11	41.42	42.16	0.004690	1.79	29.58	30.81	0.32	29.58	0.28
Middle Reach	950	2% Exceedance	12.00	40.30	41.36	40.91	41.38	0.003830	1.12	10.71	19.40	0.27	10.71	0.13
Middle Reach	950	20% Exceedance	2.20	40.30	40.89		40.90	0.002767	0.64	3.44	11.35	0.20	3.44	0.05
Middle Reach	950	Low Flow	0.70	40.30	40.70		40.70	0.002116	0.43	1.62	7.80	0.17	1.62	0.03
Middle Reach	900	100-Yr	255.00	40.21	47.55		47.56	0.000089	0.82	408.93	148.45	0.06	408.93	0.02
Middle Reach	900	50-Yr	224.00	40.21	47.37		47.37	0.000080	0.76	381.50	148.45	0.06	381.50	0.01
Middle Reach	900	25-Yr	193.00	40.21	45.58		45.60	0.000248	1.03	204.35	71.40	0.09	204.35	0.04
Middle Reach	900	10-Yr	153.00	40.21	44.03		44.06	0.000958	1.45	108.05	52.63	0.17	108.05	0.12
Middle Reach	900	5-yr	126.00	40.21	43.16		43.21	0.002458	1.87	67.32	40.64	0.26	67.32	0.25
Middle Reach	900	2-Yr	70.00	40.21	41.39	41.39	41.76	0.050447	4.91	14.27	19.44	1.01	14.27	2.29
Middle Reach	900	1.5-Yr	53.00	40.21	41.24	41.24	41.57	0.052470	4.62	11.48	17.64	1.01	11.48	2.11
Middle Reach	900	2% Exceedance	12.00	40.21	40.70	40.70	40.86	0.065347	3.27	3.67	11.16	1.01	3.67	1.33
Middle Reach	900	20% Exceedance	2.20	40.21	40.42	40.42	40.49	0.085731	2.07	1.06	7.90	1.00	1.06	0.72
Middle Reach	900	Low Flow	0.70	40.21	40.34	40.34	40.38	0.113526	1.52	0.46	6.75	1.02	0.46	0.48
Middle Reach	870	100-Yr	255.00	37.84	47.55	40.30	47.56	0.000042	0.67	546.10	157.03	0.04	546.10	0.01
Middle Reach	870	50-Yr	224.00	37.84	47.37	40.16	47.37	0.000037	0.62	517.08	157.03	0.04	517.08	0.01
Middle Reach	870	25-Yr	193.00	37.84	45.58	40.01	45.59	0.000080	0.76	309.84	85.06	0.06	309.84	0.02
Middle Reach	870	10-Yr	153.00	37.84	44.04	39.80	44.05	0.000168	0.89	197.14	65.27	0.08	197.14	0.03
Middle Reach	870	5-yr	126.00	37.84	43.17	39.63	43.18	0.000268	0.97	144.12	56.95	0.09	144.12	0.04
Middle Reach	870	2-Yr	70.00	37.84	41.51	39.20	41.52	0.000439	1.02	72.61	34.40	0.11	72.61	0.06
Middle Reach	870	1.5-Yr	53.00	37.84	40.98	39.03	41.00	0.000519	0.99	55.60	30.47	0.12	55.60	0.06
Middle Reach	870	2% Exceedance	12.00	37.84	39.26	38.43	39.27	0.001187	0.83	14.45	16.83	0.16	14.45	0.06
Middle Reach	870	20% Exceedance	2.20	37.84	38.43	38.11	38.44	0.002073	0.63	3.51	9.56	0.18	3.51	0.05
Middle Reach	870	Low Flow	0.70	37.84	38.17	37.99	38.17	0.003566	0.53	1.32	6.95	0.21	1.32	0.04
Middle Reach	869.5		Culvert											
Middle Reach	813	100-Yr	255.00	34.50	39.03	39.03	40.41	0.054307	9.44	27.01	9.90	1.01	27.01	6.23
Middle Reach	813	50-Yr	224.00	34.50	38.76	38.76	40.07	0.054474	9.16	24.46	9.38	1.00	24.46	5.95
Middle Reach	813	25-Yr	193.00	34.50	38.44	38.44	39.69	0.056456	8.96	21.55	8.76	1.01	21.55	5.81
Middle Reach	813	10-Yr	153.00	34.50	38.00	38.00	39.14	0.058323	8.56	17.87	7.97	1.01	17.87	5.47
Middle Reach	813	5-yr	126.00	34.50	37.67	37.67	38.72	0.059614	8.22	15.32	7.40	1.01	15.32	5.18
Middle Reach	813	2-Yr	70.00	34.50	36.74	36.74	37.59	0.062173	7.39	9.47	5.67	1.01	9.47	4.46
Middle Reach	813	1.5-Yr	53.00	34.50	36.43	36.43	37.16	0.062119	6.84	7.75	5.41	1.01	7.75	3.97
Middle Reach	813	2% Exceedance	12.00	34.50	35.42	35.42	35.72	0.066860	4.42	2.71	4.58	1.01	2.71	2.10
Middle Reach	813	20% Exceedance	2.20	34.50	34.95	34.95	35.07	0.084619	2.80	0.78	3.34	1.02	0.78	1.13
Middle Reach	813	Low Flow	0.70	34.50	34.81	34.81	34.88	0.119216	2.06	0.34	3.08	1.09	0.34	0.77

HEC-RAS Plan: Exist_65% River: Stotenburg.Creek Reach: Middle Reach (Continued)

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl	Flow Area	Shear Total
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)		(sq ft)	(lb/sq ft)
Middle Reach	801	100-Yr	255.00	32.84	38.05		38.25	0.004202	3.60	70.85	20.12	0.34	70.85	0.77
Middle Reach	801	50-Yr	224.00	32.84	37.84		38.02	0.003747	3.36	66.73	19.27	0.32	66.73	0.68
Middle Reach	801	25-Yr	193.00	32.84	37.62		37.77	0.003279	3.09	62.52	18.60	0.30	62.52	0.58
Middle Reach	801	10-Yr	153.00	32.84	37.31		37.43	0.002678	2.69	56.89	18.04	0.27	56.89	0.45
Middle Reach	801	5-yr	126.00	32.84	37.08		37.17	0.002247	2.39	52.69	17.57	0.24	52.69	0.36
Middle Reach	801	2-Yr	70.00	32.84	36.48		36.52	0.001259	1.64	42.56	16.38	0.18	42.56	0.18
Middle Reach	801	1.5-Yr	53.00	32.84	36.22		36.25	0.000963	1.38	38.41	15.86	0.16	38.41	0.13
Middle Reach	801	2% Exceedance	12.00	32.84	35.22		35.23	0.000201	0.51	23.53	13.85	0.07	23.53	0.02
Middle Reach	801	20% Exceedance	2.20	32.84	34.76		34.76	0.000017	0.13	17.37	12.99	0.02	17.37	0.00
Middle Reach	801	Low Flow	0.70	32.84	34.65		34.65	0.000002	0.04	15.95	12.67	0.01	15.95	0.00
Middle Reach	800	100-Yr	255.00	33.07	38.04		38.25	0.004380	3.66	69.85	21.21	0.35	69.85	0.78
Middle Reach	800	50-Yr	224.00	33.07	37.83		38.02	0.004097	3.42	65.46	20.71	0.34	65.46	0.70
Middle Reach	800	25-Yr	193.00	33.07	37.61		37.77	0.003780	3.17	60.87	20.19	0.32	60.87	0.62
Middle Reach	800	10-Yr	153.00	33.07	37.30		37.42	0.003202	2.79	54.79	19.47	0.29	54.79	0.49
Middle Reach	800	5-yr	126.00	33.07	37.07		37.16	0.002767	2.51	50.27	18.91	0.27	50.27	0.40
Middle Reach	800	2-Yr	70.00	33.07	36.47		36.52	0.001699	1.77	39.44	17.52	0.21	39.44	0.21
Middle Reach	800	1.5-Yr	53.00	33.07	36.22		36.25	0.001368	1.51	35.04	16.92	0.19	35.04	0.16
Middle Reach	800	2% Exceedance	12.00	33.07	35.22		35.23	0.000394	0.62	19.38	14.50	0.09	19.38	0.03
Middle Reach	800	20% Exceedance	2.20	33.07	34.76		34.76	0.000044	0.17	13.02	13.37	0.03	13.02	0.00
Middle Reach	800	Low Flow	0.70	33.07	34.65		34.65	0.000006	0.06	11.56	13.12	0.01	11.56	0.00
Middle Reach	750	100-Yr	255.00	34.39	37.08	36.83	37.76	0.027251	6.63	39.26	22.14	0.83	39.26	2.79
Middle Reach	750	50-Yr	224.00	34.39	37.00		37.57	0.023442	6.09	37.46	21.29	0.77	37.46	2.38
Middle Reach	750	25-Yr	193.00	34.39	36.87		37.36	0.020802	5.60	34.92	20.32	0.72	34.92	2.06
Middle Reach	750	10-Yr	153.00	34.39	36.72		37.09	0.017003	4.83	31.94	19.68	0.65	31.94	1.59
Middle Reach	750	5-yr	126.00	34.39	36.57		36.87	0.015470	4.36	29.01	19.16	0.61	29.01	1.36
Middle Reach	750	2-Yr	70.00	34.39	36.17		36.33	0.011970	3.26	21.47	17.50	0.52	21.47	0.87
Middle Reach	750	1.5-Yr	53.00	34.39	35.96		36.09	0.011089	2.95	17.96	16.19	0.49	17.96	0.73
Middle Reach	750	2% Exceedance	12.00	34.39	35.10		35.16	0.014032	1.98	6.06	12.04	0.49	6.06	0.43
Middle Reach	750	20% Exceedance	2.20	34.39	34.73	34.67	34.75	0.019937	1.18	1.86	10.64	0.50	1.86	0.21
Middle Reach	750	Low Flow	0.70	34.39	34.64		34.65	0.015946	0.73	0.95	9.38	0.41	0.95	0.10
Middle Reach	700	100-Yr	255.00	33.30	36.27		36.58	0.017186	4.41	57.83	40.64	0.65	57.83	1.49
Middle Reach	700	50-Yr	224.00	33.30	36.07		36.38	0.020964	4.52	49.56	38.96	0.71	49.56	1.63
Middle Reach	700	25-Yr	193.00	33.30	35.90		36.21	0.023062	4.46	43.29	37.30	0.73	43.29	1.63
Middle Reach	700	10-Yr	153.00	33.30	35.64		35.96	0.030237	4.52	33.84	35.00	0.81	33.84	1.78
Middle Reach	700	5-yr	126.00	33.30	35.41	35.24	35.76	0.034359	4.71	26.76	28.53	0.86	26.76	1.96
Middle Reach	700	2-Yr	70.00	33.30	34.82	34.81	35.22	0.050248	5.04	13.89	17.56	1.00	13.89	2.38
Middle Reach	700	1.5-Yr	53.00	33.30	34.65	34.65	35.01	0.054002	4.81	11.02	15.76	1.01	11.02	2.26
Middle Reach	700	2% Exceedance	12.00	33.30	34.17		34.26	0.023254	2.49	4.82	9.77	0.63	4.82	0.68
Middle Reach	700	20% Exceedance	2.20	33.30	33.82	33.71	33.84	0.016974	1.27	1.73	7.70	0.47	1.73	0.23
Middle Reach	700	Low Flow	0.70	33.30	33.65	33.58	33.67	0.024091	1.07	0.66	4.94	0.52	0.66	0.19
Middle Reach	650	100-Yr	255.00	31.79	35.93		36.09	0.005418	3.13	81.34	38.51	0.38	81.34	0.67
Middle Reach	650	50-Yr	224.00	31.79	35.73		35.88	0.005072	3.03	73.95	34.88	0.37	73.95	0.63
Middle Reach	650	25-Yr	193.00	31.79	35.60		35.72	0.004494	2.78	69.45	34.04	0.34	69.45	0.53
Middle Reach	650	10-Yr	153.00	31.79	35.36		35.45	0.004122	2.50	61.18	32.96	0.32	61.18	0.45
Middle Reach	650	5-yr	126.00	31.79	35.16		35.24	0.003869	2.30	54.90	32.11	0.31	54.90	0.39
Middle Reach	650	2-Yr	70.00	31.79	34.71		34.75	0.002643	1.70	41.25	28.50	0.25	41.25	0.22
Middle Reach	650	1.5-Yr	53.00	31.79	34.54		34.57	0.002223	1.45	36.52	28.14	0.22	36.52	0.17
Middle Reach	650	2% Exceedance	12.00	31.79	32.76		32.93	0.030768	3.27	3.67	5.85	0.73	3.67	1.10
Middle Reach	650	20% Exceedance	2.20	31.79	32.16	32.16	32.29	0.074394	2.82	0.78	3.12	1.00	0.78	1.10
Middle Reach	650	Low Flow	0.70	31.79	32.03	32.00	32.08	0.043938	1.67	0.42	2.53	0.72	0.42	0.44
Middle Reach	635	100-Yr	255.00	30.82	35.87	34.46	36.01	0.004354	2.94	86.75	37.67	0.34	86.75	0.58
Middle Reach	635	50-Yr	224.00	30.82	35.68	34.36	35.80	0.004353	2.82	79.37	36.61	0.34	79.37	0.54

HEC-RAS Plan: Exist_65% River: Stotenburg.Creek Reach: Middle Reach (Continued)

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl	Flow Area	Shear Total
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)		(sq ft)	(lb/sq ft)
Middle Reach	635	25-Yr	193.00	30.82	35.55	34.23	35.66	0.003832	2.58	74.87	35.95	0.31	74.87	0.46
Middle Reach	635	10-Yr	153.00	30.82	35.31	34.06	35.39	0.003441	2.31	66.30	34.67	0.29	66.30	0.38
Middle Reach	635	5-yr	126.00	30.82	35.12	33.93	35.19	0.003149	2.11	59.81	33.52	0.28	59.81	0.32
Middle Reach	635	2-Yr	70.00	30.82	34.68	33.32	34.71	0.002200	1.54	45.52	31.26	0.22	45.52	0.18
Middle Reach	635	1.5-Yr	53.00	30.82	34.52	32.86	34.54	0.001791	1.31	40.53	30.40	0.20	40.53	0.14
Middle Reach	635	2% Exceedance	12.00	30.82	32.72	31.92	32.76	0.004024	1.66	7.22	6.20	0.27	7.22	0.24
Middle Reach	635	20% Exceedance	2.20	30.82	31.54	31.38	31.60	0.021677	1.87	1.18	3.33	0.55	1.18	0.44
Middle Reach	635	Low Flow	0.70	30.82	31.20	31.18	31.27	0.066615	2.17	0.32	1.68	0.87	0.32	0.72
Middle Reach	634.5		Culvert											
Middle Reach	608	100-Yr	255.00	29.90	34.61		34.72	0.008799	2.69	94.69	83.18	0.44	94.69	0.60
Middle Reach	608	50-Yr	224.00	29.90	34.43		34.55	0.011658	2.81	79.65	80.92	0.50	79.65	0.69
Middle Reach	608	25-Yr	193.00	29.90	34.23		34.37	0.017314	3.02	63.93	78.49	0.59	63.93	0.85
Middle Reach	608	10-Yr	153.00	29.90	33.93		34.12	0.024523	3.52	43.47	54.18	0.69	43.47	1.16
Middle Reach	608	5-yr	126.00	29.90	33.70		33.93	0.028885	3.85	32.76	39.69	0.75	32.76	1.38
Middle Reach	608	2-Yr	70.00	29.90	33.25		33.48	0.035495	3.83	18.28	25.23	0.79	18.28	1.45
Middle Reach	608	1.5-Yr	53.00	29.90	33.09		33.29	0.029498	3.59	14.77	19.03	0.72	14.77	1.25
Middle Reach	608	2% Exceedance	12.00	29.90	32.17		32.23	0.006715	1.92	6.24	5.52	0.32	6.24	0.34
Middle Reach	608	20% Exceedance	2.20	29.90	31.39		31.40	0.001163	0.70	3.14	3.23	0.13	3.14	0.05
Middle Reach	608	Low Flow	0.70	29.90	31.16		31.16	0.000228	0.29	2.44	2.88	0.06	2.44	0.01
Middle Reach	600	100-Yr	255.00	30.85	34.49		34.65	0.007984	3.18	80.13	51.42	0.45	80.13	0.75
Middle Reach	600	50-Yr	224.00	30.85	34.31		34.47	0.008494	3.15	71.10	48.47	0.46	71.10	0.75
Middle Reach	600	25-Yr	193.00	30.85	34.12		34.27	0.009045	3.10	62.21	45.42	0.47	62.21	0.75
Middle Reach	600	10-Yr	153.00	30.85	33.85		33.99	0.009674	3.03	50.44	39.93	0.48	50.44	0.74
Middle Reach	600	5-yr	126.00	30.85	33.63		33.77	0.011109	3.00	42.04	37.55	0.50	42.04	0.75
Middle Reach	600	2-Yr	70.00	30.85	33.13		33.26	0.016495	2.84	24.68	32.13	0.57	24.68	0.76
Middle Reach	600	1.5-Yr	53.00	30.85	32.94		33.06	0.022500	2.86	18.51	29.97	0.64	18.51	0.83
Middle Reach	600	2% Exceedance	12.00	30.85	31.99		32.13	0.020635	3.01	3.99	5.08	0.60	3.99	0.88
Middle Reach	600	20% Exceedance	2.20	30.85	31.24	31.24	31.36	0.076080	2.75	0.80	3.38	1.00	0.80	1.06
Middle Reach	600	Low Flow	0.70	30.85	31.08	31.08	31.15	0.089850	2.11	0.33	2.38	1.00	0.33	0.75
Middle Reach	550	100-Yr	255.00	30.39	34.14		34.31	0.005972	3.27	78.02	37.13	0.40	78.02	0.73
Middle Reach	550	50-Yr	224.00	30.39	33.96		34.12	0.005893	3.13	71.54	35.92	0.39	71.54	0.68
Middle Reach	550	25-Yr	193.00	30.39	33.77		33.91	0.005773	2.97	64.90	34.63	0.38	64.90	0.63
Middle Reach	550	10-Yr	153.00	30.39	33.51		33.62	0.005561	2.74	55.88	32.77	0.37	55.88	0.55
Middle Reach	550	5-yr	126.00	30.39	33.30		33.40	0.004979	2.55	49.48	29.58	0.35	49.48	0.48
Middle Reach	550	2-Yr	70.00	30.39	32.83		32.89	0.003815	1.93	36.27	26.89	0.29	36.27	0.30
Middle Reach	550	1.5-Yr	53.00	30.39	32.66		32.70	0.003223	1.68	31.60	25.58	0.27	31.60	0.23
Middle Reach	550	2% Exceedance	12.00	30.39	31.85		31.86	0.001987	0.90	13.35	19.72	0.19	13.35	0.08
Middle Reach	550	20% Exceedance	2.20	30.39	31.20		31.20	0.000577	0.43	5.16	9.33	0.10	5.16	0.02
Middle Reach	550	Low Flow	0.70	30.39	30.96		30.96	0.000229	0.22	3.17	7.79	0.06	3.17	0.01
Middle Reach	500	100-Yr	255.00	29.99	33.67		33.93	0.009000	4.10	62.13	27.81	0.48	62.13	1.14
Middle Reach	500	50-Yr	224.00	29.99	33.52		33.75	0.008571	3.86	57.98	27.46	0.47	57.98	1.03
Middle Reach	500	25-Yr	193.00	29.99	33.37		33.57	0.008033	3.59	53.72	27.10	0.45	53.72	0.91
Middle Reach	500	10-Yr	153.00	29.99	33.15		33.30	0.007204	3.20	47.80	26.51	0.42	47.80	0.74
Middle Reach	500	5-yr	126.00	29.99	32.99		33.12	0.006433	2.88	43.69	26.08	0.39	43.69	0.62
Middle Reach	500	2-Yr	70.00	29.99	32.63		32.69	0.004132	2.03	34.45	25.08	0.31	34.45	0.33
Middle Reach	500	1.5-Yr	53.00	29.99	32.49		32.54	0.003276	1.71	31.04	24.71	0.27	31.04	0.24
Middle Reach	500	2% Exceedance	12.00	29.99	31.76		31.77	0.001558	0.85	14.08	18.15	0.17	14.08	0.07
Middle Reach	500	20% Exceedance	2.20	29.99	31.18		31.18	0.000437	0.36	6.04	10.67	0.09	6.04	0.01
Middle Reach	500	Low Flow	0.70	29.99	30.95		30.95	0.000158	0.18	3.84	9.02	0.05	3.84	0.00
Middle Reach	450	100-Yr	255.00	30.61	33.38		33.52	0.006440	2.95	86.35	53.57	0.41	86.35	0.64
Middle Reach	450	50-Yr	224.00	30.61	33.21		33.34	0.007039	2.91	76.95	52.18	0.42	76.95	0.64

HEC-RAS Plan: Exist_65% River: Stotenburg.Creek Reach: Middle Reach (Continued)

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl	Flow Area	Shear Total
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)		(sq ft)	(lb/sq ft)
Middle Reach	450	25-Yr	193.00	30.61	33.02		33.15	0.007809	2.86	67.50	50.86	0.44	67.50	0.64
Middle Reach	450	10-Yr	153.00	30.61	32.75		32.88	0.009801	2.83	54.04	49.04	0.48	54.04	0.67
Middle Reach	450	5-yr	126.00	30.61	32.56		32.68	0.012022	2.81	44.81	47.94	0.51	44.81	0.69
Middle Reach	450	2-Yr	70.00	30.61	32.09		32.24	0.031967	3.06	22.88	45.05	0.76	22.88	1.01
Middle Reach	450	1.5-Yr	53.00	30.61	31.90	31.88	32.09	0.054815	3.50	15.14	36.51	0.96	15.14	1.41
Middle Reach	450	2% Exceedance	12.00	30.61	31.41	31.37	31.54	0.050289	2.83	4.24	13.15	0.88	4.24	1.00
Middle Reach	450	20% Exceedance	2.20	30.61	31.00	31.00	31.10	0.078312	2.44	0.90	4.86	1.00	0.90	0.89
Middle Reach	450	Low Flow	0.70	30.61	30.87	30.87	30.92	0.067052	1.81	0.39	2.91	0.87	0.39	0.55
Middle Reach	400	100-Yr	337.00	30.23	33.30		33.35	0.001818	1.88	178.85	84.47	0.23	178.85	0.24
Middle Reach	400	50-Yr	296.00	30.23	33.11		33.17	0.001833	1.81	163.65	82.71	0.23	163.65	0.22
Middle Reach	400	25-Yr	256.00	30.23	32.93		32.97	0.001850	1.73	148.22	80.87	0.22	148.22	0.21
Middle Reach	400	10-Yr	202.00	30.23	32.65		32.69	0.001889	1.60	126.03	78.16	0.22	126.03	0.19
Middle Reach	400	5-yr	167.00	30.23	32.45		32.48	0.001924	1.51	110.68	76.23	0.22	110.68	0.17
Middle Reach	400	2-Yr	92.00	30.23	31.95		31.98	0.002039	1.24	74.06	71.41	0.22	74.06	0.13
Middle Reach	400	1.5-Yr	70.00	30.23	31.77		31.79	0.002148	1.14	61.26	69.64	0.21	61.26	0.12
Middle Reach	400	2% Exceedance	17.80	30.23	31.20		31.21	0.002802	0.76	23.44	60.24	0.21	23.44	0.07
Middle Reach	400	20% Exceedance	3.20	30.23	30.82		30.82	0.001807	0.46	7.01	27.79	0.16	7.01	0.03
Middle Reach	400	Low Flow	1.00	30.23	30.67		30.67	0.001288	0.29	3.41	20.37	0.13	3.41	0.01
Middle Reach	350	100-Yr	337.00	30.17	33.15		33.23	0.003025	2.33	144.53	72.62	0.29	144.53	0.37
Middle Reach	350	50-Yr	296.00	30.17	32.97		33.05	0.003079	2.25	131.51	70.62	0.29	131.51	0.35
Middle Reach	350	25-Yr	256.00	30.17	32.78		32.85	0.003142	2.16	118.39	68.55	0.29	118.39	0.33
Middle Reach	350	10-Yr	202.00	30.17	32.50		32.56	0.003269	2.03	99.62	65.47	0.29	99.62	0.31
Middle Reach	350	5-yr	167.00	30.17	32.30		32.36	0.003386	1.93	86.74	63.27	0.29	86.74	0.29
Middle Reach	350	2-Yr	92.00	30.17	31.80		31.84	0.003836	1.63	56.33	57.79	0.29	56.33	0.23
Middle Reach	350	1.5-Yr	70.00	30.17	31.61		31.64	0.004171	1.53	45.66	54.85	0.30	45.66	0.21
Middle Reach	350	2% Exceedance	17.80	30.17	30.99		31.01	0.006032	1.11	16.11	41.79	0.31	16.11	0.14
Middle Reach	350	20% Exceedance	3.20	30.17	30.67		30.68	0.005773	0.69	4.67	24.06	0.27	4.67	0.07
Middle Reach	350	Low Flow	1.00	30.17	30.56	30.39	30.56	0.003964	0.43	2.35	18.66	0.21	2.35	0.03
Middle Reach	300	100-Yr	337.00	29.98	33.03		33.10	0.002254	2.12	158.71	73.89	0.26	158.71	0.30
Middle Reach	300	50-Yr	296.00	29.98	32.85		32.91	0.002247	2.04	145.39	71.96	0.25	145.39	0.28
Middle Reach	300	25-Yr	256.00	29.98	32.66		32.72	0.002236	1.94	131.94	69.96	0.25	131.94	0.26
Middle Reach	300	10-Yr	202.00	29.98	32.37		32.42	0.002225	1.79	112.61	66.98	0.24	112.61	0.23
Middle Reach	300	5-yr	167.00	29.98	32.17		32.22	0.002214	1.68	99.29	64.85	0.24	99.29	0.21
Middle Reach	300	2-Yr	92.00	29.98	31.66		31.69	0.002139	1.36	67.72	59.50	0.22	67.72	0.15
Middle Reach	300	1.5-Yr	70.00	29.98	31.47		31.49	0.002196	1.25	56.21	57.42	0.22	56.21	0.13
Middle Reach	300	2% Exceedance	17.80	29.98	30.84		30.84	0.002064	0.77	23.13	46.47	0.19	23.13	0.06
Middle Reach	300	20% Exceedance	3.20	29.98	30.37		30.38	0.005825	0.67	4.81	26.16	0.27	4.81	0.07
Middle Reach	300	Low Flow	1.00	29.98	30.15		30.16	0.022957	0.92	1.09	10.20	0.50	1.09	0.15
Middle Reach	250	100-Yr	337.00	29.54	32.83		32.95	0.004140	2.73	123.35	61.89	0.34	123.35	0.51
Middle Reach	250	50-Yr	296.00	29.54	32.65		32.76	0.004232	2.64	112.26	60.43	0.34	112.26	0.49
Middle Reach	250	25-Yr	256.00	29.54	32.46		32.56	0.004336	2.53	101.05	58.84	0.34	101.05	0.46
Middle Reach	250	10-Yr	202.00	29.54	32.18		32.27	0.004574	2.38	84.80	56.42	0.34	84.80	0.43
Middle Reach	250	5-yr	167.00	29.54	31.98		32.06	0.004816	2.27	73.54	54.67	0.35	73.54	0.40
Middle Reach	250	2-Yr	92.00	29.54	31.46		31.52	0.005959	1.97	46.62	50.25	0.36	46.62	0.34
Middle Reach	250	1.5-Yr	70.00	29.54	31.27		31.32	0.005768	1.87	37.33	42.40	0.35	37.33	0.31
Middle Reach	250	2% Exceedance	17.80	29.54	30.66		30.68	0.005771	1.21	14.77	32.58	0.32	14.77	0.16
Middle Reach	250	20% Exceedance	3.20	29.54	30.24		30.25	0.001524	0.58	5.52	13.39	0.16	5.52	0.04
Middle Reach	250	Low Flow	1.00	29.54	30.07		30.07	0.000629	0.30	3.32	11.11	0.10	3.32	0.01
Middle Reach	200	100-Yr	337.00	29.79	32.67		32.77	0.002912	2.50	139.25	65.47	0.29	139.25	0.38
Middle Reach	200	50-Yr	296.00	29.79	32.49		32.58	0.002820	2.39	127.72	62.70	0.29	127.72	0.36
Middle Reach	200	25-Yr	256.00	29.79	32.30		32.38	0.002763	2.27	116.17	60.64	0.28	116.17	0.33
Middle Reach	200	10-Yr	202.00	29.79	32.02		32.09	0.002749	2.09	99.20	58.14	0.27	99.20	0.29

HEC-RAS Plan: Exist_65% River: Stotenburg.Creek Reach: Middle Reach (Continued)

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl	Flow Area	Shear Total
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)		(sq ft)	(lb/sq ft)
Middle Reach	200	5-yr	167.00	29.79	31.81		31.87	0.002752	1.95	87.34	56.32	0.27	87.34	0.26
Middle Reach	200	2-Yr	92.00	29.79	31.28		31.32	0.002826	1.60	58.51	51.65	0.26	58.51	0.20
Middle Reach	200	1.5-Yr	70.00	29.79	31.08		31.12	0.002876	1.46	48.63	49.66	0.26	48.63	0.17
Middle Reach	200	2% Exceedance	17.80	29.79	30.44		30.46	0.003541	0.94	19.01	43.03	0.25	19.01	0.10
Middle Reach	200	20% Exceedance	3.20	29.79	30.10		30.11	0.006837	0.63	5.12	34.50	0.29	5.12	0.06
Middle Reach	200	Low Flow	1.00	29.79	29.98		29.98	0.011464	0.57	1.75	19.85	0.34	1.75	0.06
Middle Reach	150	100-Yr	337.00	29.58	32.48		32.60	0.003864	2.78	121.52	58.94	0.33	121.52	0.49
Middle Reach	150	50-Yr	296.00	29.58	32.30		32.41	0.003906	2.66	111.38	56.90	0.33	111.38	0.47
Middle Reach	150	25-Yr	256.00	29.58	32.12		32.22	0.003932	2.53	101.10	54.75	0.33	101.10	0.45
Middle Reach	150	10-Yr	202.00	29.58	31.84		31.92	0.003832	2.34	86.21	51.50	0.32	86.21	0.40
Middle Reach	150	5-yr	167.00	29.58	31.63		31.71	0.003759	2.20	75.98	49.26	0.31	75.98	0.36
Middle Reach	150	2-Yr	92.00	29.58	31.11		31.16	0.003539	1.78	51.61	43.85	0.29	51.61	0.26
Middle Reach	150	1.5-Yr	70.00	29.58	30.92		30.96	0.003429	1.61	43.41	41.92	0.28	43.41	0.22
Middle Reach	150	2% Exceedance	17.80	29.58	30.28		30.30	0.002848	0.94	18.86	35.49	0.23	18.86	0.09
Middle Reach	150	20% Exceedance	3.20	29.58	29.92		29.92	0.002343	0.48	6.61	29.33	0.18	6.61	0.03
Middle Reach	150	Low Flow	1.00	29.58	29.79		29.79	0.001888	0.31	3.21	23.46	0.15	3.21	0.02
Middle Reach	100	100-Yr	337.00	29.44	32.27		32.40	0.004072	2.84	119.04	58.51	0.34	119.04	0.51
Middle Reach	100	50-Yr	296.00	29.44	32.09		32.21	0.004220	2.73	108.67	56.66	0.34	108.67	0.50
Middle Reach	100	25-Yr	256.00	29.44	31.91		32.01	0.004248	2.60	98.33	54.71	0.34	98.33	0.47
Middle Reach	100	10-Yr	202.00	29.44	31.63		31.72	0.004283	2.42	83.52	51.77	0.34	83.52	0.43
Middle Reach	100	5-yr	167.00	29.44	31.43		31.51	0.004267	2.28	73.34	49.64	0.33	73.34	0.39
Middle Reach	100	2-Yr	92.00	29.44	30.91		30.96	0.004291	1.88	48.97	44.51	0.32	48.97	0.29
Middle Reach	100	1.5-Yr	70.00	29.44	30.72		30.77	0.004338	1.72	40.73	42.70	0.31	40.73	0.26
Middle Reach	100	2% Exceedance	17.80	29.44	30.09		30.11	0.004969	1.12	15.92	35.31	0.29	15.92	0.14
Middle Reach	100	20% Exceedance	3.20	29.44	29.75		29.75	0.005127	0.63	5.11	27.76	0.26	5.11	0.06
Middle Reach	100	Low Flow	1.00	29.44	29.65	29.56	29.65	0.005144	0.41	2.47	25.80	0.23	2.47	0.03
Middle Reach	50	100-Yr	337.00	29.17	31.90		32.11	0.007952	3.73	90.23	46.10	0.47	90.23	0.96
Middle Reach	50	50-Yr	296.00	29.17	31.71		31.92	0.007995	3.61	82.02	44.32	0.47	82.02	0.91
Middle Reach	50	25-Yr	256.00	29.17	31.54		31.72	0.007941	3.45	74.29	42.83	0.46	74.29	0.85
Middle Reach	50	10-Yr	202.00	29.17	31.27		31.43	0.007894	3.20	63.17	40.60	0.45	63.17	0.76
Middle Reach	50	5-yr	167.00	29.17	31.08		31.22	0.007817	3.00	55.61	39.02	0.44	55.61	0.69
Middle Reach	50	2-Yr	92.00	29.17	30.59		30.68	0.007458	2.45	37.54	34.57	0.41	37.54	0.50
Middle Reach	50	1.5-Yr	70.00	29.17	30.41		30.48	0.007348	2.23	31.37	32.92	0.40	31.37	0.43
Middle Reach	50	2% Exceedance	17.80	29.17	29.80		29.83	0.007018	1.37	12.97	27.40	0.35	12.97	0.21
Middle Reach	50	20% Exceedance	3.20	29.17	29.45		29.46	0.007203	0.76	4.20	21.95	0.31	4.20	0.09
Middle Reach	50	Low Flow	1.00	29.17	29.34		29.34	0.007309	0.52	1.92	17.87	0.28	1.92	0.05
Middle Reach	1	100-Yr	337.00	28.58	31.05	30.65	31.50	0.020028	5.39	62.52	36.72	0.73	62.52	2.09
Middle Reach	1	50-Yr	296.00	28.58	30.88	30.52	31.31	0.020000	5.24	56.45	34.54	0.72	56.45	2.01
Middle Reach	1	25-Yr	256.00	28.58	30.72	30.38	31.11	0.020002	5.00	51.17	33.63	0.72	51.17	1.87
Middle Reach	1	10-Yr	202.00	28.58	30.49	30.17	30.83	0.020007	4.63	43.64	32.30	0.70	43.64	1.66
Middle Reach	1	5-yr	167.00	28.58	30.33	30.03	30.62	0.020013	4.34	38.45	31.35	0.69	38.45	1.51
Middle Reach	1	2-Yr	92.00	28.58	29.91	29.65	30.11	0.020031	3.56	25.82	28.45	0.66	25.82	1.12
Middle Reach	1	1.5-Yr	70.00	28.58	29.75	29.52	29.92	0.020003	3.27	21.38	26.76	0.65	21.38	0.99
Middle Reach	1	2% Exceedance	17.80	28.58	29.21	29.07	29.28	0.020002	2.10	8.48	20.74	0.58	8.48	0.51
Middle Reach	1	20% Exceedance	3.20	28.58	28.89	28.81	28.91	0.020004	1.21	2.64	14.76	0.50	2.64	0.22
Middle Reach	1	Low Flow	1.00	28.58	28.78	28.72	28.79	0.020010	0.84	1.20	11.65	0.46	1.20	0.13

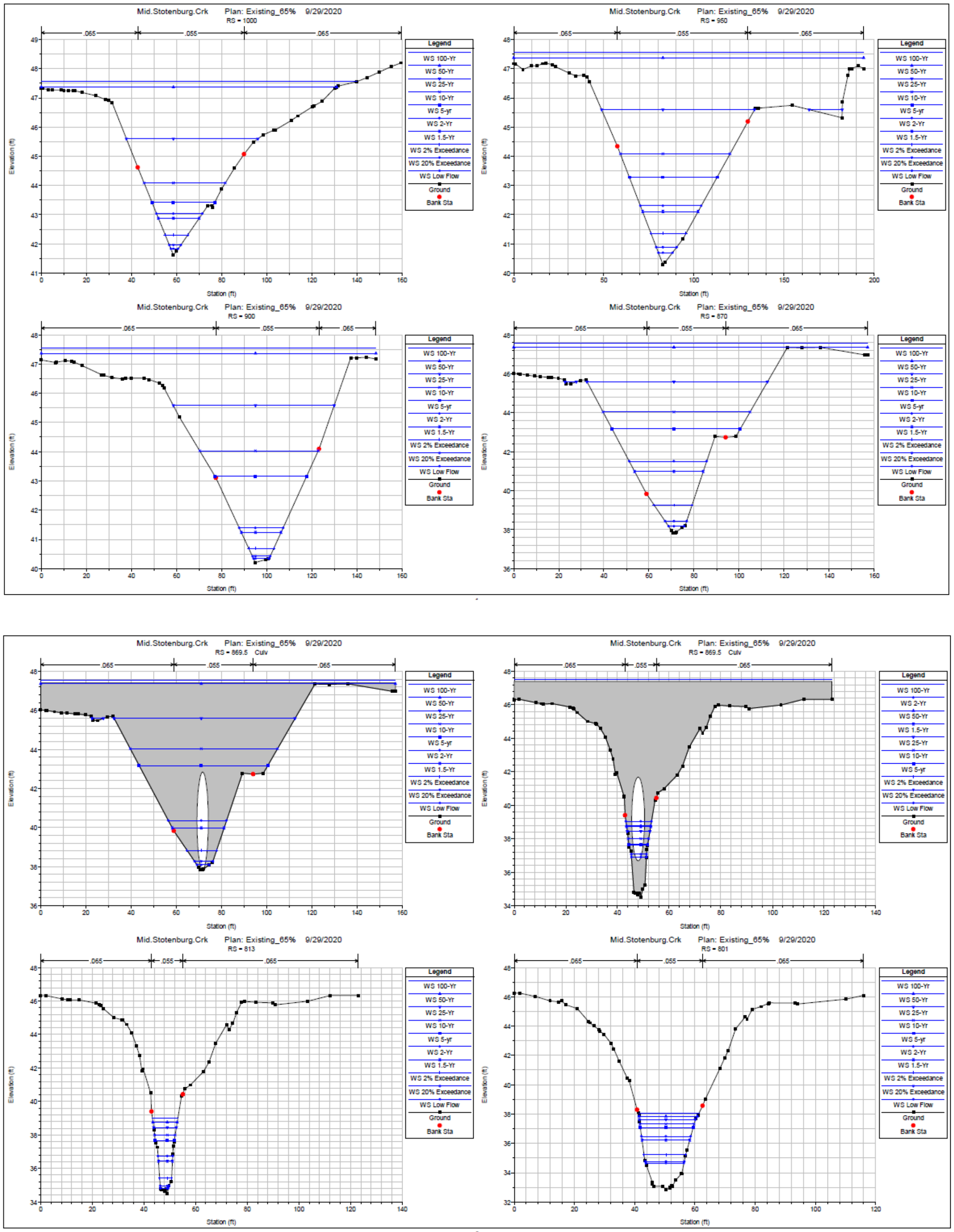


Figure C-1. HEC-RAS model sections for existing conditions.

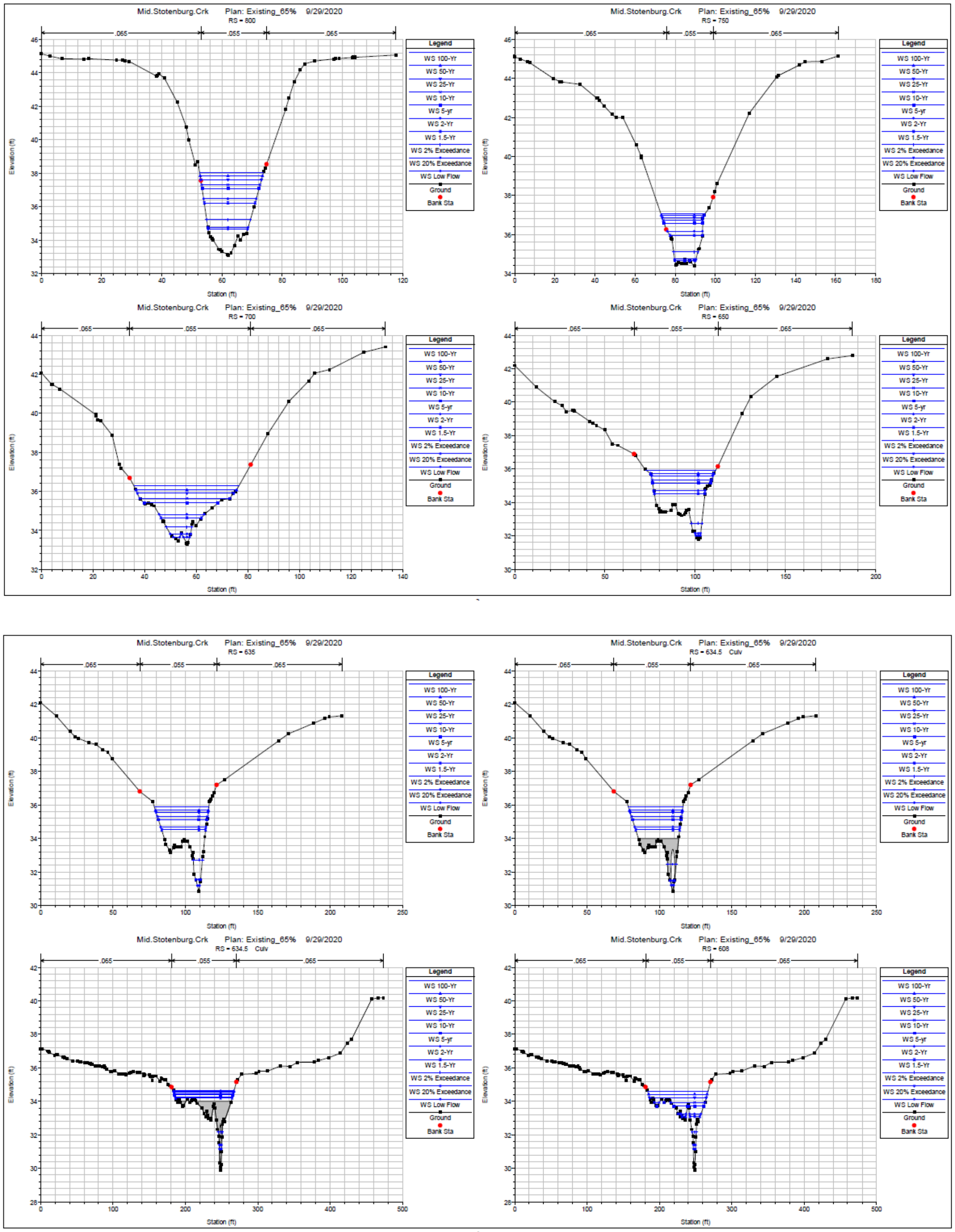


Figure C-1 (cont). HEC-RAS model sections for existing conditions.

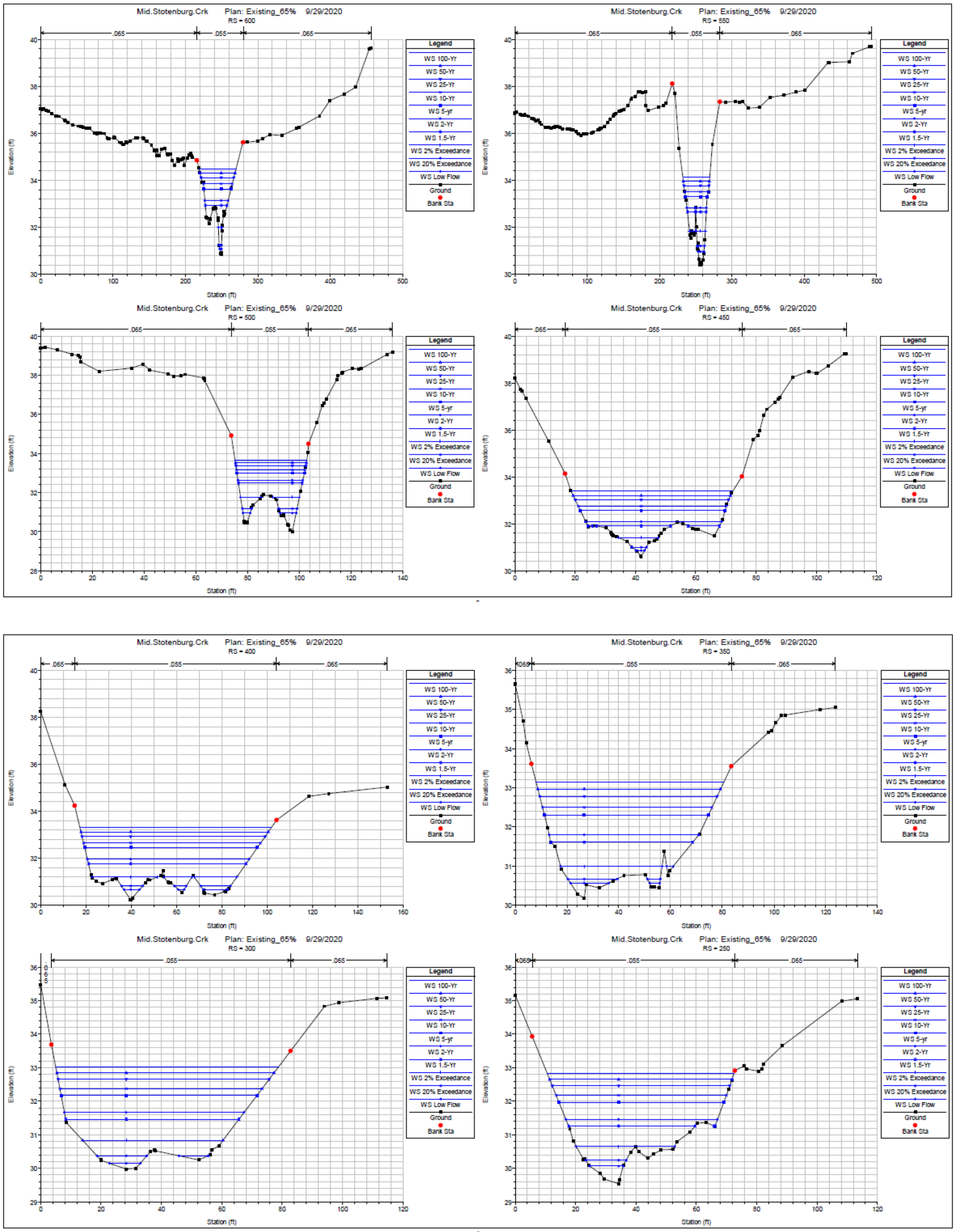
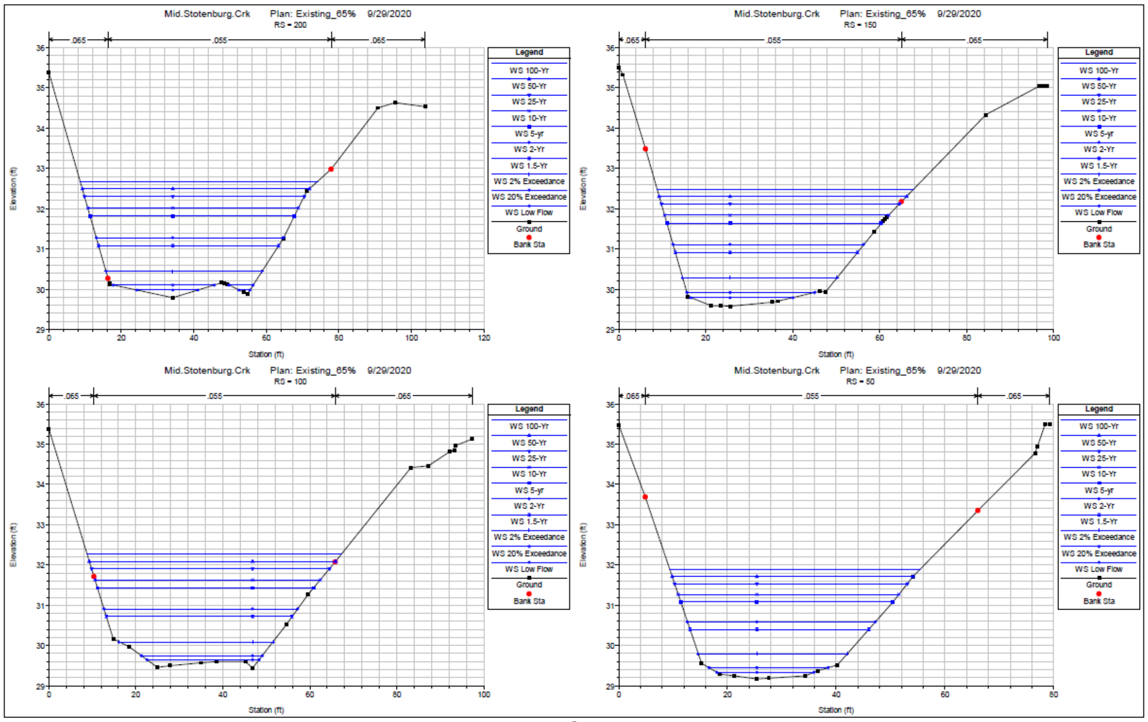


Figure C-1 (cont). HEC-RAS model sections for existing conditions.



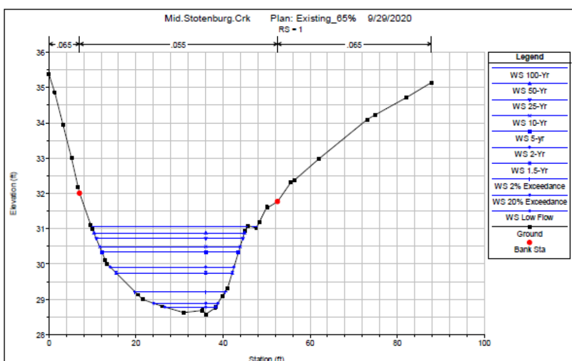


Figure C-1 (cont). HEC-RAS model sections for existing conditions.

Table C-2. HEC-RAS model results for proposed conditions – 90% design.

HEC-RAS Plan: Prop90% River: Stotenburg.Creek Reach: Middle Reach

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl	Shear Total	Hydr Depth
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)		(lb/sq ft)	(ft)
Middle Reach	1000	100-Yr	255.00	41.72	43.74	43.74	44.44	0.021662	7.19	41.89	32.04	0.94	1.75	1.31
Middle Reach	1000	50-Yr	224.00	41.72	43.61	43.61	44.27	0.022090	6.91	37.85	30.72	0.94	1.68	1.23
Middle Reach	1000	25-Yr	193.00	41.72	43.46	43.46	44.08	0.023133	6.65	33.42	29.20	0.95	1.64	1.14
Middle Reach	1000	10-Yr	153.00	41.72	43.27	43.27	43.81	0.024045	6.18	27.92	27.24	0.95	1.52	1.03
Middle Reach	1000	5-yr	126.00	41.72	43.12	43.12	43.61	0.025301	5.85	23.92	25.76	0.95	1.45	0.93
Middle Reach	1000	2-Yr	70.00	41.72	42.75	42.75	43.11	0.028834	4.90	15.25	22.23	0.95	1.23	0.69
Middle Reach	1000	1.5-Yr	53.00	41.72	42.64	42.61	42.93	0.027776	4.35	12.81	21.13	0.91	1.04	0.61
Middle Reach	1000	2% Exceedance	12.00	41.72	42.21	42.18	42.32	0.032701	2.62	4.59	16.21	0.86	0.58	0.28
Middle Reach	1000	20% Exceedance	2.20	41.72	41.96		42.00	0.040778	1.74	1.26	9.41	0.84	0.34	0.13
Middle Reach	1000	Low Flow	0.70	41.72	41.88	41.85	41.90	0.028254	1.12	0.63	6.96	0.65	0.16	0.09
Middle Reach	1000	1.9% exceedance	10.00	41.72	42.17	42.14	42.27	0.033517	2.48	4.03	15.57	0.85	0.54	0.26
Middle Reach	1000	18.2% exceedance	10.00	41.72	42.17	42.14	42.27	0.033517	2.48	4.03	15.57	0.85	0.54	0.26
Middle Reach	950	100-Yr	255.00	40.34	42.14	42.14	42.79	0.022893	6.73	42.41	34.81	0.95	1.73	1.22
Middle Reach	950	50-Yr	224.00	40.34	42.01	42.01	42.63	0.023678	6.49	38.26	33.61	0.95	1.67	1.14
Middle Reach	950	25-Yr	193.00	40.34	41.89	41.89	42.45	0.024150	6.18	34.25	32.42	0.95	1.58	1.06
Middle Reach	950	10-Yr	153.00	40.34	41.71	41.71	42.21	0.025910	5.80	28.47	30.58	0.96	1.50	0.93
Middle Reach	950	5-yr	126.00	40.34	41.58	41.58	42.03	0.027374	5.48	24.46	29.16	0.96	1.43	0.84
Middle Reach	950	2-Yr	70.00	40.34	41.25	41.25	41.58	0.032334	4.61	15.63	25.63	0.98	1.23	0.61
Middle Reach	950	1.5-Yr	53.00	40.34	41.15	41.14	41.41	0.032991	4.16	12.96	24.46	0.96	1.09	0.53
Middle Reach	950	2% Exceedance	12.00	40.34	40.80	40.74	40.88	0.025044	2.27	5.28	18.41	0.75	0.45	0.29
Middle Reach	950	20% Exceedance	2.20	40.34	40.55	40.51	40.58	0.020602	1.34	1.64	10.95	0.61	0.19	0.15
Middle Reach	950	Low Flow	0.70	40.34	40.45		40.46	0.029383	1.08	0.65	7.73	0.66	0.15	0.08
Middle Reach	950	1.9% exceedance	10.00	40.34	40.77	40.70	40.84	0.024453	2.15	4.66	17.36	0.73	0.41	0.27
Middle Reach	950	18.2% exceedance	10.00	40.34	40.77	40.70	40.84	0.024453	2.15	4.66	17.36	0.73	0.41	0.27
Middle Reach	900	100-Yr	255.00	38.71	40.98		41.32	0.007883	4.80	58.67	35.57	0.58	0.80	1.65
Middle Reach	900	50-Yr	224.00	38.71	40.74		41.08	0.009463	4.84	50.25	33.42	0.63	0.87	1.50
Middle Reach	900	25-Yr	193.00	38.71	40.49		40.85	0.011679	4.89	42.20	31.22	0.68	0.97	1.35
Middle Reach	900	10-Yr	153.00	38.71	40.16		40.53	0.016330	4.95	32.33	28.43	0.77	1.14	1.14
Middle Reach	900	5-yr	126.00	38.71	39.93	39.85	40.31	0.021936	5.02	25.94	27.22	0.87	1.29	0.95
Middle Reach	900	2-Yr	70.00	38.71	39.53	39.53	39.85	0.033907	4.55	15.60	25.34	1.00	1.29	0.62
Middle Reach	900	1.5-Yr	53.00	38.71	39.42	39.42	39.69	0.036346	4.17	12.85	24.82	1.00	1.17	0.52
Middle Reach	900	2% Exceedance	12.00	38.71	39.07	39.07	39.18	0.048372	2.67	4.49	20.13	1.00	0.67	0.22
Middle Reach	900	20% Exceedance	2.20	38.71	38.86	38.86	38.91	0.061966	1.85	1.19	11.16	1.00	0.41	0.11
Middle Reach	900	Low Flow	0.70	38.71	38.80	38.78	38.82	0.037381	1.11	0.63	8.78	0.73	0.17	0.07
Middle Reach	900	1.9% exceedance	10.00	38.71	39.04	39.04	39.14	0.049625	2.57	3.89	18.82	1.00	0.64	0.21
Middle Reach	900	18.2% exceedance	10.00	38.71	39.04	39.04	39.14	0.049625	2.57	3.89	18.82	1.00	0.64	0.21
Middle Reach	870	100-Yr	255.00	37.84	40.81	39.68	41.11	0.005248	4.47	58.70	24.58	0.47	0.71	2.39
Middle Reach	870	50-Yr	224.00	37.84	40.55	39.54	40.84	0.005590	4.34	52.64	23.22	0.48	0.71	2.27
Middle Reach	870	25-Yr	193.00	37.84	40.29	39.38	40.56	0.005985	4.18	46.70	21.80	0.48	0.72	2.14
Middle Reach	870	10-Yr	153.00	37.84	39.93	39.17	40.17	0.006533	3.93	39.13	20.62	0.49	0.70	1.90
Middle Reach	870	5-yr	126.00	37.84	39.67	39.01	39.89	0.006978	3.73	33.85	20.12	0.50	0.67	1.68
Middle Reach	870	2-Yr	70.00	37.84	39.07	38.64	39.23	0.008174	3.16	22.17	19.06	0.52	0.55	1.16
Middle Reach	870	1.5-Yr	53.00	37.84	38.86	38.51	38.99	0.008685	2.91	18.23	18.72	0.52	0.50	0.97
Middle Reach	870	2% Exceedance	12.00	37.84	38.23	38.09	38.28	0.011162	1.79	6.70	17.77	0.51	0.26	0.38
Middle Reach	870	20% Exceedance	2.20	37.84	37.98	37.93	37.99	0.014874	1.00	2.19	17.53	0.50	0.12	0.13
Middle Reach	870	Low Flow	0.70	37.84	37.90	37.89	37.91	0.024746	0.74	0.94	17.46	0.56	0.08	0.05
Middle Reach	870	1.9% exceedance	10.00	37.84	38.19	38.07	38.23	0.011521	1.68	5.94	17.73	0.51	0.24	0.34
Middle Reach	870	18.2% exceedance	10.00	37.84	38.19	38.07	38.23	0.011521	1.68	5.94	17.73	0.51	0.24	0.34

HEC-RAS Plan: Prop90% River: Stotenburg.Creek Reach: Middle Reach (Continued)

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl	Shear Total	Hydr Depth
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)		(lb/sq ft)	(ft)
Middle Reach	869.5		Culvert											
Middle Reach	813	100-Yr	255.00	34.63	39.24		39.40	0.001309	3.27	86.54	22.13	0.27	0.26	3.91
Middle Reach	813	50-Yr	224.00	34.63	39.04		39.18	0.001179	3.01	82.18	21.86	0.26	0.23	3.76
Middle Reach	813	25-Yr	193.00	34.63	38.83		38.95	0.001036	2.73	77.69	21.59	0.24	0.19	3.60
Middle Reach	813	10-Yr	153.00	34.63	38.54		38.62	0.000843	2.34	71.32	21.19	0.21	0.15	3.37
Middle Reach	813	5-yr	126.00	34.63	38.31		38.38	0.000703	2.06	66.61	20.89	0.19	0.12	3.19
Middle Reach	813	2-Yr	70.00	34.63	37.76		37.79	0.000384	1.36	55.27	20.15	0.14	0.06	2.74
Middle Reach	813	1.5-Yr	53.00	34.63	37.56		37.58	0.000278	1.11	51.20	19.88	0.12	0.04	2.58
Middle Reach	813	2% Exceedance	12.00	34.63	36.90		36.90	0.000035	0.33	38.47	19.01	0.04	0.00	2.02
Middle Reach	813	20% Exceedance	2.20	34.63	36.64		36.64	0.000002	0.07	33.46	18.65	0.01	0.00	1.79
Middle Reach	813	Low Flow	0.70	34.63	36.56		36.56	0.000000	0.02	32.06	18.55	0.00	0.00	1.73
Middle Reach	813	1.9% exceedance	10.00	34.63	36.86		36.86	0.000026	0.28	37.61	18.95	0.03	0.00	1.98
Middle Reach	813	18.2% exceedance	10.00	34.63	36.86		36.86	0.000026	0.28	37.61	18.95	0.03	0.00	1.98
Middle Reach	810	100-Yr	255.00	33.00	39.20		39.39	0.001649	3.59	81.88	22.84	0.28	0.32	3.58
Middle Reach	810	50-Yr	224.00	33.00	39.01		39.16	0.001470	3.31	77.52	22.22	0.26	0.27	3.49
Middle Reach	810	25-Yr	193.00	33.00	38.81		38.94	0.001275	3.00	73.11	21.57	0.24	0.23	3.39
Middle Reach	810	10-Yr	153.00	33.00	38.52		38.61	0.001013	2.56	66.97	20.64	0.21	0.18	3.24
Middle Reach	810	5-yr	126.00	33.00	38.30		38.37	0.000827	2.24	62.53	19.94	0.19	0.14	3.14
Middle Reach	810	2-Yr	70.00	33.00	37.75		37.79	0.000420	1.46	52.17	18.19	0.13	0.06	2.87
Middle Reach	810	1.5-Yr	53.00	33.00	37.55		37.57	0.000294	1.17	48.58	17.55	0.11	0.04	2.77
Middle Reach	810	2% Exceedance	12.00	33.00	36.90		36.90	0.000031	0.33	37.83	15.49	0.03	0.00	2.44
Middle Reach	810	20% Exceedance	2.20	33.00	36.64		36.64	0.000001	0.07	33.81	14.70	0.01	0.00	2.30
Middle Reach	810	Low Flow	0.70	33.00	36.56		36.56	0.000000	0.02	32.71	14.48	0.00	0.00	2.26
Middle Reach	810	1.9% exceedance	10.00	33.00	36.86		36.86	0.000022	0.28	37.13	15.35	0.03	0.00	2.42
Middle Reach	810	18.2% exceedance	10.00	33.00	36.86		36.86	0.000022	0.28	37.13	15.35	0.03	0.00	2.42
Middle Reach	801	100-Yr	255.00	32.84	39.23		39.35	0.001010	2.72	97.14	24.38	0.22	0.21	3.99
Middle Reach	801	50-Yr	224.00	32.84	39.03		39.13	0.000898	2.50	92.39	23.65	0.20	0.18	3.91
Middle Reach	801	25-Yr	193.00	32.84	38.83		38.91	0.000777	2.25	87.60	22.96	0.19	0.16	3.82
Middle Reach	801	10-Yr	153.00	32.84	38.53		38.59	0.000615	1.92	80.94	21.97	0.16	0.12	3.68
Middle Reach	801	5-yr	126.00	32.84	38.31		38.35	0.000500	1.67	76.14	21.14	0.15	0.09	3.60
Middle Reach	801	2-Yr	70.00	32.84	37.76		37.78	0.000253	1.08	65.11	18.94	0.10	0.05	3.44
Middle Reach	801	1.5-Yr	53.00	32.84	37.56		37.57	0.000174	0.86	61.33	18.50	0.08	0.03	3.32
Middle Reach	801	2% Exceedance	12.00	32.84	36.90		36.90	0.000016	0.24	49.64	17.22	0.03	0.00	2.88
Middle Reach	801	20% Exceedance	2.20	32.84	36.64		36.64	0.000001	0.05	45.12	16.69	0.01	0.00	2.70
Middle Reach	801	Low Flow	0.70	32.84	36.56		36.56	0.000000	0.02	43.87	16.54	0.00	0.00	2.65
Middle Reach	801	1.9% exceedance	10.00	32.84	36.86		36.86	0.000012	0.20	48.86	17.13	0.02	0.00	2.85
Middle Reach	801	18.2% exceedance	10.00	32.84	36.86		36.86	0.000012	0.20	48.86	17.13	0.02	0.00	2.85
Middle Reach	800	100-Yr	255.00	33.07	39.23	36.04	39.34	0.001051	2.67	97.98	26.10	0.22	0.21	3.75
Middle Reach	800	50-Yr	224.00	33.07	39.04	35.86	39.13	0.000946	2.46	92.87	25.42	0.21	0.19	3.65
Middle Reach	800	25-Yr	193.00	33.07	38.83	35.66	38.91	0.000830	2.23	87.70	24.71	0.19	0.16	3.55
Middle Reach	800	10-Yr	153.00	33.07	38.53	35.40	38.59	0.000671	1.91	80.57	22.82	0.17	0.13	3.53
Middle Reach	800	5-yr	126.00	33.07	38.31	35.20	38.35	0.000557	1.67	75.60	21.92	0.16	0.10	3.45
Middle Reach	800	2-Yr	70.00	33.07	37.76	34.73	37.78	0.000287	1.10	63.92	20.54	0.11	0.05	3.11
Middle Reach	800	1.5-Yr	53.00	33.07	37.56	34.56	37.57	0.000201	0.89	59.81	20.06	0.09	0.03	2.98
Middle Reach	800	2% Exceedance	12.00	33.07	36.90	33.84	36.90	0.000020	0.25	47.20	18.53	0.03	0.00	2.55
Middle Reach	800	20% Exceedance	2.20	33.07	36.64	33.45	36.64	0.000001	0.05	42.35	17.91	0.01	0.00	2.37

HEC-RAS Plan: Prop90% River: Stotenburg.Creek Reach: Middle Reach (Continued)

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl	Shear Total	Hydr Depth
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)		(lb/sq ft)	(ft)
Middle Reach	800	Low Flow	0.70	33.07	36.56	33.32	36.56	0.000000	0.02	41.01	17.73	0.00	0.00	2.31
Middle Reach	800	1.9% exceedance	10.00	33.07	36.86	33.78	36.86	0.000015	0.22	46.36	18.42	0.02	0.00	2.52
Middle Reach	800	18.2% exceedance	10.00	33.07	36.86	33.78	36.86	0.000015	0.22	46.36	18.42	0.02	0.00	2.52
Middle Reach	795		Inl Struct											
Middle Reach	783	100-Yr	255.00	34.34	38.42	37.06	38.65	0.003488	3.86	69.25	29.56	0.40	0.48	2.34
Middle Reach	783	50-Yr	224.00	34.34	38.26	36.92	38.46	0.003298	3.61	64.45	28.28	0.38	0.44	2.28
Middle Reach	783	25-Yr	193.00	34.34	38.07	36.75	38.25	0.003103	3.35	59.39	27.00	0.37	0.40	2.20
Middle Reach	783	10-Yr	153.00	34.34	37.82	36.53	37.95	0.002785	2.96	52.71	25.29	0.34	0.34	2.08
Middle Reach	783	5-yr	126.00	34.34	37.62	36.36	37.73	0.002543	2.67	47.87	24.27	0.32	0.30	1.97
Middle Reach	783	2-Yr	70.00	34.34	37.13	35.93	37.18	0.001799	1.93	36.37	22.08	0.26	0.18	1.65
Middle Reach	783	1.5-Yr	53.00	34.34	36.94	35.78	36.98	0.001473	1.64	32.29	21.28	0.23	0.13	1.52
Middle Reach	783	2% Exceedance	12.00	34.34	36.32	35.04	36.32	0.000315	0.60	19.94	18.32	0.10	0.02	1.09
Middle Reach	783	20% Exceedance	2.20	34.34	36.04	34.69	36.04	0.000023	0.15	15.17	16.56	0.03	0.00	0.92
Middle Reach	783	Low Flow	0.70	34.34	35.97	34.56	35.97	0.000003	0.05	13.99	16.22	0.01	0.00	0.86
Middle Reach	783	1.9% exceedance	10.00	34.34	36.27	34.99	36.28	0.000246	0.52	19.11	17.99	0.09	0.02	1.06
Middle Reach	783	18.2% exceedance	10.00	34.34	36.27	34.99	36.28	0.000246	0.52	19.11	17.99	0.09	0.02	1.06
Middle Reach	778		Inl Struct											
Middle Reach	765	100-Yr	255.00	34.34	37.98	37.07	38.33	0.005968	4.89	56.82	26.33	0.52	0.76	2.16
Middle Reach	765	50-Yr	224.00	34.34	37.81	36.91	38.13	0.005756	4.61	52.49	25.25	0.50	0.71	2.08
Middle Reach	765	25-Yr	193.00	34.34	37.63	36.75	37.91	0.005528	4.30	47.97	24.31	0.49	0.64	1.97
Middle Reach	765	10-Yr	153.00	34.34	37.37	36.52	37.59	0.005186	3.86	41.80	23.12	0.46	0.55	1.81
Middle Reach	765	5-yr	126.00	34.34	37.17	36.36	37.36	0.004928	3.53	37.29	22.27	0.44	0.49	1.67
Middle Reach	765	2-Yr	70.00	34.34	36.66	35.93	36.77	0.004233	2.68	26.59	20.10	0.39	0.33	1.32
Middle Reach	765	1.5-Yr	53.00	34.34	36.47	35.77	36.56	0.003908	2.35	22.84	19.25	0.37	0.28	1.19
Middle Reach	765	2% Exceedance	12.00	34.34	35.82	35.05	35.83	0.001557	1.04	11.52	15.48	0.21	0.07	0.74
Middle Reach	765	20% Exceedance	2.20	34.34	35.50	34.69	35.51	0.000191	0.31	7.02	11.87	0.07	0.01	0.59
Middle Reach	765	Low Flow	0.70	34.34	35.41	34.56	35.41	0.000026	0.12	5.94	9.80	0.03	0.00	0.61
Middle Reach	765	1.9% exceedance	10.00	34.34	35.76	34.99	35.78	0.001342	0.93	10.73	15.26	0.20	0.06	0.70
Middle Reach	765	18.2% exceedance	10.00	34.34	35.76	34.99	35.78	0.001342	0.93	10.73	15.26	0.20	0.06	0.70
Middle Reach	760		Inl Struct											
Middle Reach	750	100-Yr	255.00	34.39	36.77	36.70	37.57	0.018966	7.35	37.99	23.44	0.89	1.85	1.62
Middle Reach	750	50-Yr	224.00	34.39	36.66	36.54	37.36	0.017688	6.85	35.50	22.82	0.85	1.66	1.56
Middle Reach	750	25-Yr	193.00	34.39	36.54	36.37	37.14	0.016563	6.35	32.68	22.10	0.82	1.48	1.48
Middle Reach	750	10-Yr	153.00	34.39	36.40		36.86	0.013535	5.47	29.79	21.30	0.73	1.14	1.40
Middle Reach	750	5-yr	126.00	34.39	36.28		36.64	0.011987	4.89	27.13	20.55	0.68	0.96	1.32
Middle Reach	750	2-Yr	70.00	34.39	35.78		36.03	0.013171	4.02	17.69	16.96	0.67	0.83	1.04
Middle Reach	750	1.5-Yr	53.00	34.39	35.59		35.80	0.013152	3.66	14.61	15.81	0.65	0.74	0.92
Middle Reach	750	2% Exceedance	12.00	34.39	34.94		35.02	0.013353	2.19	5.49	12.49	0.58	0.36	0.44
Middle Reach	750	20% Exceedance	2.20	34.39	34.65		34.67	0.009007	1.05	2.10	10.75	0.42	0.11	0.20
Middle Reach	750	Low Flow	0.70	34.39	34.55	34.50	34.56	0.008589	0.67	1.04	10.07	0.37	0.06	0.10
Middle Reach	750	1.9% exceedance	10.00	34.39	34.90		34.96	0.012507	2.01	4.99	12.29	0.56	0.31	0.41
Middle Reach	750	18.2% exceedance	10.00	34.39	34.90		34.96	0.012507	2.01	4.99	12.29	0.56	0.31	0.41
Middle Reach	700	100-Yr	255.00	33.30	36.01	36.01	36.64	0.016374	7.06	47.75	38.51	0.83	1.25	1.24
Middle Reach	700	50-Yr	224.00	33.30	35.88	35.88	36.48	0.016492	6.81	42.85	36.98	0.83	1.17	1.16

HEC-RAS Plan: Prop90% River: Stotenburg.Creek Reach: Middle Reach (Continued)

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl	Shear Total	Hydr Depth
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)		(lb/sq ft)	(ft)
Middle Reach	700	25-Yr	193.00	33.30	35.75	35.75	36.31	0.016218	6.47	38.23	35.91	0.81	1.06	1.06
Middle Reach	700	10-Yr	153.00	33.30	35.46	35.46	36.04	0.019473	6.39	28.74	29.45	0.87	1.16	0.98
Middle Reach	700	5-yr	126.00	33.30	35.23	35.23	35.81	0.023138	6.31	22.73	23.05	0.92	1.39	0.99
Middle Reach	700	2-Yr	70.00	33.30	34.90	34.78	35.24	0.018808	4.77	15.75	18.48	0.80	0.97	0.85
Middle Reach	700	1.5-Yr	53.00	33.30	34.74		35.02	0.018598	4.28	12.96	16.66	0.77	0.88	0.78
Middle Reach	700	2% Exceedance	12.00	33.30	34.13		34.23	0.018993	2.55	4.70	10.86	0.68	0.50	0.43
Middle Reach	700	20% Exceedance	2.20	33.30	33.72	33.71	33.79	0.049165	2.13	1.03	6.38	0.93	0.48	0.16
Middle Reach	700	Low Flow	0.70	33.30	33.58	33.58	33.64	0.063266	1.89	0.37	3.31	0.99	0.43	0.11
Middle Reach	700	1.9% exceedance	10.00	33.30	34.07		34.16	0.020724	2.49	4.02	10.29	0.70	0.49	0.39
Middle Reach	700	18.2% exceedance	10.00	33.30	34.07		34.16	0.020724	2.49	4.02	10.29	0.70	0.49	0.39
Middle Reach	675	100-Yr	255.00	32.46	35.30	35.30	35.90	0.017878	6.70	48.39	44.24	0.85	1.20	1.09
Middle Reach	675	50-Yr	224.00	32.46	35.16	35.16	35.75	0.018998	6.57	42.34	41.06	0.87	1.21	1.03
Middle Reach	675	25-Yr	193.00	32.46	35.03	35.03	35.58	0.019409	6.30	37.05	38.07	0.86	1.16	0.97
Middle Reach	675	10-Yr	153.00	32.46	34.81	34.81	35.34	0.021236	6.01	29.41	33.27	0.88	1.15	0.88
Middle Reach	675	5-yr	126.00	32.46	34.65	34.65	35.15	0.022834	5.75	24.31	29.63	0.90	1.15	0.82
Middle Reach	675	2-Yr	70.00	32.46	34.20	34.20	34.62	0.033325	5.19	13.50	16.93	1.01	1.61	0.80
Middle Reach	675	1.5-Yr	53.00	32.46	34.04	34.03	34.40	0.033001	4.79	11.06	15.00	0.98	1.47	0.74
Middle Reach	675	2% Exceedance	12.00	32.46	33.40	33.37	33.58	0.036126	3.42	3.51	8.34	0.93	0.91	0.42
Middle Reach	675	20% Exceedance	2.20	32.46	32.92		33.00	0.022088	2.23	0.99	3.00	0.68	0.42	0.33
Middle Reach	675	Low Flow	0.70	32.46	32.71		32.75	0.021920	1.60	0.44	2.20	0.63	0.26	0.20
Middle Reach	675	1.9% exceedance	10.00	32.46	33.36	33.31	33.51	0.032480	3.14	3.18	7.93	0.87	0.78	0.40
Middle Reach	675	18.2% exceedance	10.00	32.46	33.36	33.31	33.51	0.032480	3.14	3.18	7.93	0.87	0.78	0.40
Middle Reach	650	100-Yr	255.00	31.95	34.88		35.34	0.012330	5.49	48.15	28.70	0.71	1.24	1.68
Middle Reach	650	50-Yr	224.00	31.95	34.76		35.17	0.012050	5.18	44.60	28.24	0.69	1.14	1.58
Middle Reach	650	25-Yr	193.00	31.95	34.63		34.99	0.011656	4.84	40.96	27.77	0.67	1.04	1.47
Middle Reach	650	10-Yr	153.00	31.95	34.44		34.73	0.011079	4.35	35.88	27.09	0.64	0.89	1.32
Middle Reach	650	5-yr	126.00	31.95	34.30		34.55	0.010694	3.99	32.08	26.57	0.62	0.78	1.21
Middle Reach	650	2-Yr	70.00	31.95	33.96		34.10	0.009377	3.04	23.16	25.31	0.55	0.52	0.91
Middle Reach	650	1.5-Yr	53.00	31.95	33.80		33.91	0.009987	2.77	19.15	24.73	0.55	0.47	0.77
Middle Reach	650	2% Exceedance	12.00	31.95	32.90		32.98	0.015310	2.32	5.16	11.74	0.62	0.41	0.44
Middle Reach	650	20% Exceedance	2.20	31.95	32.38		32.45	0.022581	2.11	1.04	3.61	0.69	0.39	0.29
Middle Reach	650	Low Flow	0.70	31.95	32.19		32.23	0.020613	1.49	0.47	2.60	0.62	0.23	0.18
Middle Reach	650	1.9% exceedance	10.00	31.95	32.83		32.91	0.017133	2.26	4.42	11.36	0.64	0.41	0.39
Middle Reach	650	18.2% exceedance	10.00	31.95	32.83		32.91	0.017133	2.26	4.42	11.36	0.64	0.41	0.39
Middle Reach	648	100-Yr	255.00	31.91	34.81		35.31	0.017547	5.71	46.03	28.53	0.75	1.70	1.61
Middle Reach	648	50-Yr	224.00	31.91	34.70		35.14	0.017136	5.39	42.68	28.12	0.74	1.57	1.52
Middle Reach	648	25-Yr	193.00	31.91	34.57		34.96	0.016722	5.05	39.11	27.69	0.72	1.43	1.41
Middle Reach	648	10-Yr	153.00	31.91	34.39		34.71	0.016129	4.56	34.14	27.07	0.69	1.23	1.26
Middle Reach	648	5-yr	126.00	31.91	34.25		34.52	0.015668	4.19	30.49	26.60	0.67	1.09	1.15
Middle Reach	648	2-Yr	70.00	31.91	33.91		34.07	0.014481	3.24	21.69	25.44	0.61	0.75	0.85
Middle Reach	648	1.5-Yr	53.00	31.91	33.75		33.89	0.016720	3.03	17.52	24.88	0.63	0.72	0.70
Middle Reach	648	2% Exceedance	12.00	31.91	32.88		32.95	0.012328	2.20	5.45	9.77	0.52	0.42	0.56
Middle Reach	648	20% Exceedance	2.20	31.91	32.37		32.40	0.013195	1.46	1.51	5.31	0.48	0.23	0.28
Middle Reach	648	Low Flow	0.70	31.91	32.17		32.19	0.014690	1.12	0.63	3.55	0.47	0.16	0.18
Middle Reach	648	1.9% exceedance	10.00	31.91	32.81		32.88	0.011901	2.06	4.85	9.37	0.50	0.38	0.52
Middle Reach	648	18.2% exceedance	10.00	31.91	32.81		32.88	0.011901	2.06	4.85	9.37	0.50	0.38	0.52
Middle Reach	635	100-Yr	255.00	31.65	34.52	34.31	35.04	0.024592	5.80	44.72	29.30	0.80	2.26	1.53

HEC-RAS Plan: Prop90% River: Stotenburg.Creek Reach: Middle Reach (Continued)

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl	Shear Total	Hydr Depth
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)		(lb/sq ft)	(ft)
Middle Reach	635	50-Yr	224.00	31.65	34.39	34.18	34.87	0.025347	5.56	40.83	28.90	0.80	2.16	1.41
Middle Reach	635	25-Yr	193.00	31.65	34.26	34.06	34.69	0.025653	5.26	37.06	28.50	0.79	2.02	1.30
Middle Reach	635	10-Yr	153.00	31.65	34.08	33.88	34.44	0.025794	4.81	32.03	27.97	0.78	1.79	1.15
Middle Reach	635	5-yr	126.00	31.65	33.95	33.77	34.26	0.025489	4.43	28.52	27.59	0.76	1.60	1.03
Middle Reach	635	2-Yr	70.00	31.65	33.61	33.37	33.82	0.026898	3.63	19.31	25.53	0.74	1.24	0.76
Middle Reach	635	1.5-Yr	53.00	31.65	33.33	33.11	33.58	0.031633	3.98	13.33	17.17	0.80	1.49	0.78
Middle Reach	635	2% Exceedance	12.00	31.65	32.62	32.49	32.72	0.026312	2.59	4.64	9.92	0.67	0.74	0.47
Middle Reach	635	20% Exceedance	2.20	31.65	32.10	32.00	32.16	0.027006	1.94	1.13	3.74	0.62	0.49	0.30
Middle Reach	635	Low Flow	0.70	31.65	31.91	31.84	31.94	0.023977	1.36	0.52	2.69	0.55	0.28	0.19
Middle Reach	635	1.9% exceedance	10.00	31.65	32.56	32.45	32.65	0.026193	2.43	4.12	9.64	0.66	0.68	0.43
Middle Reach	635	18.2% exceedance	10.00	31.65	32.56	32.45	32.65	0.026193	2.43	4.12	9.64	0.66	0.68	0.43
Middle Reach	634.5		Bridge											
Middle Reach	608	100-Yr	255.00	31.10	34.04		34.47	0.017456	5.29	49.61	30.37	0.69	1.73	1.63
Middle Reach	608	50-Yr	224.00	31.10	33.88		34.28	0.018462	5.12	44.81	29.67	0.70	1.70	1.51
Middle Reach	608	25-Yr	193.00	31.10	33.71		34.09	0.019685	4.93	39.90	28.94	0.71	1.65	1.38
Middle Reach	608	10-Yr	153.00	31.10	33.48		33.82	0.021733	4.64	33.37	27.94	0.72	1.59	1.19
Middle Reach	608	5-yr	126.00	31.10	33.32		33.62	0.023480	4.40	28.84	27.22	0.74	1.52	1.06
Middle Reach	608	2-Yr	70.00	31.10	32.94		33.16	0.026891	3.71	18.88	24.28	0.74	1.29	0.78
Middle Reach	608	1.5-Yr	53.00	31.10	32.70		32.92	0.025812	3.80	13.93	16.63	0.73	1.32	0.84
Middle Reach	608	2% Exceedance	12.00	31.10	31.99		32.10	0.027199	2.61	4.60	10.07	0.68	0.76	0.46
Middle Reach	608	20% Exceedance	2.20	31.10	31.54		31.58	0.022814	1.71	1.29	4.65	0.57	0.39	0.28
Middle Reach	608	Low Flow	0.70	31.10	31.35		31.38	0.022605	1.25	0.56	3.20	0.53	0.24	0.17
Middle Reach	608	1.9% exceedance	10.00	31.10	31.94		32.03	0.026594	2.45	4.07	9.61	0.66	0.69	0.42
Middle Reach	608	18.2% exceedance	10.00	31.10	31.94		32.03	0.026594	2.45	4.07	9.61	0.66	0.69	0.42
Middle Reach	603	100-Yr	255.00	30.99	34.05		34.34	0.008967	4.38	61.69	37.82	0.55	0.90	1.63
Middle Reach	603	50-Yr	224.00	30.99	33.88		34.15	0.009496	4.24	55.42	36.52	0.56	0.88	1.52
Middle Reach	603	25-Yr	193.00	30.99	33.71		33.96	0.010139	4.09	49.06	35.16	0.57	0.87	1.40
Middle Reach	603	10-Yr	153.00	30.99	33.46		33.69	0.011221	3.86	40.69	33.29	0.58	0.84	1.22
Middle Reach	603	5-yr	126.00	30.99	33.28		33.49	0.012163	3.67	34.94	31.94	0.59	0.82	1.09
Middle Reach	603	2-Yr	70.00	30.99	32.87		33.02	0.015393	3.12	22.45	28.79	0.62	0.74	0.78
Middle Reach	603	1.5-Yr	53.00	30.99	32.65		32.80	0.012637	3.12	16.98	18.36	0.57	0.71	0.92
Middle Reach	603	2% Exceedance	12.00	30.99	31.89		31.97	0.020196	2.32	5.18	12.54	0.64	0.51	0.41
Middle Reach	603	20% Exceedance	2.20	30.99	31.40	31.32	31.46	0.026438	1.95	1.13	4.30	0.67	0.42	0.26
Middle Reach	603	Low Flow	0.70	30.99	31.23		31.26	0.023810	1.38	0.51	3.03	0.59	0.24	0.17
Middle Reach	603	1.9% exceedance	10.00	30.99	31.81		31.90	0.024999	2.34	4.28	11.98	0.69	0.55	0.36
Middle Reach	603	18.2% exceedance	10.00	30.99	31.81		31.90	0.024999	2.34	4.28	11.98	0.69	0.55	0.36
Middle Reach	600	100-Yr	255.00	30.93	34.08		34.28	0.005529	3.66	75.09	50.89	0.48	0.50	1.48
Middle Reach	600	50-Yr	224.00	30.93	33.91		34.10	0.006103	3.60	66.30	48.64	0.49	0.51	1.36
Middle Reach	600	25-Yr	193.00	30.93	33.72		33.91	0.006879	3.53	57.44	46.27	0.51	0.53	1.24
Middle Reach	600	10-Yr	153.00	30.93	33.46		33.64	0.008441	3.44	45.85	42.96	0.55	0.56	1.07
Middle Reach	600	5-yr	126.00	30.93	33.27		33.45	0.010210	3.38	37.91	40.54	0.59	0.59	0.94
Middle Reach	600	2-Yr	70.00	30.93	32.78		32.97	0.016745	3.47	20.15	27.01	0.71	0.77	0.75
Middle Reach	600	1.5-Yr	53.00	30.93	32.59		32.76	0.010329	3.27	16.21	16.40	0.58	0.62	0.99
Middle Reach	600	2% Exceedance	12.00	30.93	31.84		31.92	0.012514	2.17	5.53	12.05	0.57	0.35	0.46
Middle Reach	600	20% Exceedance	2.20	30.93	31.27		31.36	0.037825	2.32	0.95	4.27	0.87	0.51	0.22
Middle Reach	600	Low Flow	0.70	30.93	31.14		31.18	0.029919	1.56	0.45	3.07	0.72	0.27	0.15
Middle Reach	600	1.9% exceedance	10.00	30.93	31.76		31.83	0.016364	2.23	4.49	11.55	0.63	0.39	0.39

HEC-RAS Plan: Prop90% River: Stotenburg.Creek Reach: Middle Reach (Continued)

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl	Shear Total	Hydr Depth
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)		(lb/sq ft)	(ft)
Middle Reach	600	18.2% exceedance	10.00	30.93	31.76		31.83	0.016364	2.23	4.49	11.55	0.63	0.39	0.39
Middle Reach	590	100-Yr	255.00	30.73	34.11		34.22	0.002097	2.92	108.78	59.39	0.31	0.24	1.83
Middle Reach	590	50-Yr	224.00	30.73	33.94		34.04	0.002121	2.80	98.45	57.38	0.31	0.23	1.72
Middle Reach	590	25-Yr	193.00	30.73	33.75		33.84	0.002139	2.68	87.92	55.25	0.31	0.21	1.59
Middle Reach	590	10-Yr	153.00	30.73	33.49		33.57	0.002147	2.48	73.95	52.29	0.30	0.19	1.41
Middle Reach	590	5-yr	126.00	30.73	33.30		33.37	0.002126	2.31	64.23	50.13	0.30	0.17	1.28
Middle Reach	590	2-Yr	70.00	30.73	32.84		32.89	0.001976	1.85	42.17	44.84	0.27	0.12	0.94
Middle Reach	590	1.5-Yr	53.00	30.73	32.64		32.68	0.001964	1.67	33.74	41.75	0.27	0.10	0.81
Middle Reach	590	2% Exceedance	12.00	30.73	31.85		31.86	0.001708	0.97	12.33	20.31	0.22	0.06	0.61
Middle Reach	590	20% Exceedance	2.20	30.73	31.21		31.22	0.005282	1.01	2.17	7.84	0.34	0.09	0.28
Middle Reach	590	Low Flow	0.70	30.73	30.96		30.98	0.013028	1.05	0.66	4.46	0.48	0.12	0.15
Middle Reach	590	1.9% exceedance	10.00	30.73	31.76		31.77	0.001894	0.95	10.53	19.44	0.23	0.06	0.54
Middle Reach	590	18.2% exceedance	10.00	30.73	31.76		31.77	0.001894	0.95	10.53	19.44	0.23	0.06	0.54
Middle Reach	550	100-Yr	255.00	30.39	33.86		34.09	0.005128	3.86	67.74	35.19	0.45	0.57	1.93
Middle Reach	550	50-Yr	224.00	30.39	33.70		33.90	0.005098	3.67	62.17	34.09	0.45	0.54	1.82
Middle Reach	550	25-Yr	193.00	30.39	33.53		33.71	0.005038	3.45	56.49	32.93	0.44	0.50	1.72
Middle Reach	550	10-Yr	153.00	30.39	33.29		33.44	0.004877	3.11	49.18	29.49	0.42	0.47	1.67
Middle Reach	550	5-yr	126.00	30.39	33.12		33.25	0.004578	2.84	44.30	28.44	0.40	0.41	1.56
Middle Reach	550	2-Yr	70.00	30.39	32.71		32.78	0.003293	2.11	33.13	26.02	0.33	0.24	1.27
Middle Reach	550	1.5-Yr	53.00	30.39	32.54		32.59	0.002854	1.85	28.62	24.71	0.30	0.19	1.16
Middle Reach	550	2% Exceedance	12.00	30.39	31.78		31.79	0.001646	1.00	12.05	17.90	0.21	0.07	0.67
Middle Reach	550	20% Exceedance	2.20	30.39	31.17		31.18	0.000438	0.45	4.91	9.09	0.11	0.01	0.54
Middle Reach	550	Low Flow	0.70	30.39	30.95		30.95	0.000167	0.23	3.08	7.75	0.06	0.00	0.40
Middle Reach	550	1.9% exceedance	10.00	30.39	31.69		31.71	0.001301	0.94	10.65	14.44	0.19	0.06	0.74
Middle Reach	550	18.2% exceedance	10.00	30.39	31.69		31.71	0.001301	0.94	10.65	14.44	0.19	0.06	0.74
Middle Reach	500	100-Yr	255.00	29.99	33.41		33.76	0.008062	4.78	54.73	27.18	0.57	0.92	2.01
Middle Reach	500	50-Yr	224.00	29.99	33.28		33.58	0.007630	4.47	51.26	26.86	0.55	0.83	1.91
Middle Reach	500	25-Yr	193.00	29.99	33.14		33.41	0.007085	4.12	47.72	26.49	0.52	0.73	1.80
Middle Reach	500	10-Yr	153.00	29.99	32.96		33.16	0.006224	3.62	42.90	25.98	0.48	0.59	1.65
Middle Reach	500	5-yr	126.00	29.99	32.84		33.00	0.005366	3.21	39.78	25.65	0.44	0.48	1.55
Middle Reach	500	2-Yr	70.00	29.99	32.55		32.62	0.003186	2.17	32.44	24.84	0.33	0.24	1.31
Middle Reach	500	1.5-Yr	53.00	29.99	32.40		32.45	0.002714	1.85	28.72	24.42	0.30	0.18	1.18
Middle Reach	500	2% Exceedance	12.00	29.99	31.71		31.72	0.001186	0.91	13.19	16.91	0.18	0.05	0.78
Middle Reach	500	20% Exceedance	2.20	29.99	31.16		31.16	0.000325	0.38	5.82	10.53	0.09	0.01	0.55
Middle Reach	500	Low Flow	0.70	29.99	30.95		30.95	0.000112	0.19	3.76	8.95	0.05	0.00	0.42
Middle Reach	500	1.9% exceedance	10.00	29.99	31.64		31.65	0.001031	0.83	11.99	15.73	0.17	0.04	0.76
Middle Reach	500	18.2% exceedance	10.00	29.99	31.64		31.65	0.001031	0.83	11.99	15.73	0.17	0.04	0.76
Middle Reach	450	100-Yr	255.00	30.61	33.17		33.36	0.006074	3.48	75.28	51.95	0.49	0.54	1.45
Middle Reach	450	50-Yr	224.00	30.61	33.00		33.18	0.006932	3.45	66.45	50.71	0.51	0.56	1.31
Middle Reach	450	25-Yr	193.00	30.61	32.82		33.00	0.008098	3.41	57.59	49.46	0.54	0.58	1.16
Middle Reach	450	10-Yr	153.00	30.61	32.57		32.75	0.011249	3.43	44.97	47.96	0.61	0.65	0.94
Middle Reach	450	5-yr	126.00	30.61	32.38		32.57	0.015225	3.48	36.34	46.91	0.69	0.73	0.77
Middle Reach	450	2-Yr	70.00	30.61	31.98	31.98	32.21	0.041362	3.89	18.02	40.64	1.03	1.14	0.44
Middle Reach	450	1.5-Yr	53.00	30.61	31.88	31.88	32.09	0.039280	3.67	14.43	34.02	0.99	1.03	0.42
Middle Reach	450	2% Exceedance	12.00	30.61	31.37	31.37	31.53	0.046459	3.20	3.75	12.27	1.02	0.88	0.31
Middle Reach	450	20% Exceedance	2.20	30.61	31.00	31.00	31.10	0.052424	2.44	0.90	4.86	1.00	0.60	0.19
Middle Reach	450	Low Flow	0.70	30.61	30.87	30.87	30.92	0.044886	1.81	0.39	2.91	0.87	0.37	0.13

HEC-RAS Plan: Prop90% River: Stotenburg.Creek Reach: Middle Reach (Continued)

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl	Shear Total	Hydr Depth
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)		(lb/sq ft)	(ft)
Middle Reach	450	1.9% exceedance	10.00	30.61	31.33	31.33	31.48	0.045895	3.08	3.25	11.19	1.01	0.82	0.29
Middle Reach	450	18.2% exceedance	10.00	30.61	31.33	31.33	31.48	0.045895	3.08	3.25	11.19	1.01	0.82	0.29
Middle Reach	400	100-Yr	337.00	30.23	33.13		33.20	0.001487	2.21	165.07	82.87	0.26	0.18	1.99
Middle Reach	400	50-Yr	296.00	30.23	32.95		33.02	0.001517	2.11	150.57	81.16	0.26	0.17	1.86
Middle Reach	400	25-Yr	256.00	30.23	32.77		32.83	0.001553	2.01	135.89	79.38	0.25	0.16	1.71
Middle Reach	400	10-Yr	202.00	30.23	32.51		32.56	0.001616	1.86	115.06	76.78	0.25	0.15	1.50
Middle Reach	400	5-yr	167.00	30.23	32.32		32.36	0.001667	1.74	100.78	74.96	0.25	0.14	1.34
Middle Reach	400	2-Yr	92.00	30.23	31.85		31.88	0.001851	1.43	66.77	70.41	0.25	0.11	0.95
Middle Reach	400	1.5-Yr	70.00	30.23	31.68		31.70	0.002012	1.32	54.81	68.74	0.25	0.10	0.80
Middle Reach	400	2% Exceedance	17.80	30.23	31.15		31.16	0.002696	0.88	20.49	56.58	0.26	0.06	0.36
Middle Reach	400	20% Exceedance	3.20	30.23	30.79		30.79	0.001708	0.52	6.15	26.24	0.19	0.02	0.23
Middle Reach	400	Low Flow	1.00	30.23	30.65		30.65	0.001217	0.33	3.01	19.34	0.15	0.01	0.16
Middle Reach	400	1.9% exceedance	12.00	30.23	31.05		31.06	0.002388	0.79	15.47	46.48	0.24	0.05	0.33
Middle Reach	400	18.2% exceedance	12.00	30.23	31.05		31.06	0.002388	0.79	15.47	46.48	0.24	0.05	0.33
Middle Reach	350	100-Yr	337.00	30.17	33.01		33.11	0.002242	2.60	134.26	71.05	0.31	0.26	1.89
Middle Reach	350	50-Yr	296.00	30.17	32.83		32.92	0.002320	2.50	121.84	69.10	0.31	0.25	1.76
Middle Reach	350	25-Yr	256.00	30.17	32.64		32.73	0.002417	2.39	109.33	67.08	0.31	0.24	1.63
Middle Reach	350	10-Yr	202.00	30.17	32.38		32.45	0.002602	2.23	91.68	64.12	0.32	0.23	1.43
Middle Reach	350	5-yr	167.00	30.17	32.18		32.25	0.002779	2.11	79.63	62.03	0.32	0.22	1.28
Middle Reach	350	2-Yr	92.00	30.17	31.70		31.75	0.003455	1.80	51.02	56.37	0.33	0.19	0.91
Middle Reach	350	1.5-Yr	70.00	30.17	31.52		31.57	0.003739	1.70	41.10	52.45	0.34	0.18	0.78
Middle Reach	350	2% Exceedance	17.80	30.17	30.94		30.96	0.006537	1.29	13.78	40.61	0.39	0.14	0.34
Middle Reach	350	20% Exceedance	3.20	30.17	30.64		30.65	0.006108	0.81	3.97	22.58	0.34	0.07	0.18
Middle Reach	350	Low Flow	1.00	30.17	30.55	30.39	30.55	0.003709	0.48	2.09	17.94	0.25	0.03	0.12
Middle Reach	350	1.9% exceedance	12.00	30.17	30.84		30.86	0.007725	1.19	10.12	38.50	0.41	0.13	0.26
Middle Reach	350	18.2% exceedance	12.00	30.17	30.84		30.86	0.007725	1.19	10.12	38.50	0.41	0.13	0.26
Middle Reach	300	100-Yr	337.00	29.98	32.92		33.01	0.001599	2.44	150.97	72.77	0.27	0.21	2.07
Middle Reach	300	50-Yr	296.00	29.98	32.74		32.82	0.001603	2.32	138.13	70.89	0.27	0.19	1.95
Middle Reach	300	25-Yr	256.00	29.98	32.56		32.63	0.001607	2.20	125.15	68.93	0.26	0.18	1.82
Middle Reach	300	10-Yr	202.00	29.98	32.29		32.35	0.001611	2.01	106.75	66.05	0.26	0.16	1.62
Middle Reach	300	5-yr	167.00	29.98	32.09		32.14	0.001610	1.87	94.14	64.01	0.25	0.15	1.47
Middle Reach	300	2-Yr	92.00	29.98	31.60		31.63	0.001607	1.49	63.96	58.83	0.24	0.11	1.09
Middle Reach	300	1.5-Yr	70.00	29.98	31.41		31.44	0.001669	1.35	53.11	56.85	0.24	0.10	0.93
Middle Reach	300	2% Exceedance	17.80	29.98	30.80		30.81	0.001718	0.83	21.39	45.76	0.21	0.05	0.47
Middle Reach	300	20% Exceedance	3.20	29.98	30.35		30.36	0.005320	0.76	4.22	23.85	0.32	0.06	0.18
Middle Reach	300	Low Flow	1.00	29.98	30.13		30.15	0.026154	1.12	0.90	9.37	0.64	0.16	0.10
Middle Reach	300	1.9% exceedance	12.00	29.98	30.68		30.69	0.001951	0.75	16.03	43.49	0.22	0.04	0.37
Middle Reach	300	18.2% exceedance	12.00	29.98	30.68		30.69	0.001951	0.75	16.03	43.49	0.22	0.04	0.37
Middle Reach	250	100-Yr	337.00	29.54	32.75		32.89	0.003477	3.05	118.71	61.28	0.35	0.42	1.94
Middle Reach	250	50-Yr	296.00	29.54	32.58		32.70	0.003557	2.92	108.00	59.83	0.35	0.40	1.80
Middle Reach	250	25-Yr	256.00	29.54	32.39		32.51	0.003655	2.79	97.14	58.27	0.35	0.38	1.67
Middle Reach	250	10-Yr	202.00	29.54	32.12		32.22	0.003838	2.59	81.70	55.94	0.35	0.35	1.46
Middle Reach	250	5-yr	167.00	29.54	31.93		32.02	0.004009	2.44	71.07	54.28	0.35	0.32	1.31
Middle Reach	250	2-Yr	92.00	29.54	31.44		31.50	0.004862	2.05	45.34	50.03	0.36	0.27	0.91
Middle Reach	250	1.5-Yr	70.00	29.54	31.25		31.30	0.004945	1.91	36.57	41.70	0.36	0.27	0.88
Middle Reach	250	2% Exceedance	17.80	29.54	30.65		30.67	0.005275	1.25	14.30	32.40	0.33	0.14	0.44
Middle Reach	250	20% Exceedance	3.20	29.54	30.23		30.24	0.001341	0.59	5.40	13.29	0.16	0.03	0.41

HEC-RAS Plan: Prop90% River: Stotenburg.Creek Reach: Middle Reach (Continued)

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl	Shear Total	Hydr Depth
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)		(lb/sq ft)	(ft)
Middle Reach	250	Low Flow	1.00	29.54	30.06		30.06	0.000558	0.31	3.24	10.96	0.10	0.01	0.30
Middle Reach	250	1.9% exceedance	12.00	29.54	30.53		30.55	0.004211	1.10	10.90	25.06	0.29	0.11	0.43
Middle Reach	250	18.2% exceedance	12.00	29.54	30.53		30.55	0.004211	1.10	10.90	25.06	0.29	0.11	0.43
Middle Reach	200	100-Yr	337.00	29.79	32.62		32.73	0.002777	2.63	136.03	64.71	0.29	0.36	2.10
Middle Reach	200	50-Yr	296.00	29.79	32.44		32.54	0.002766	2.50	124.72	61.95	0.29	0.34	2.01
Middle Reach	200	25-Yr	256.00	29.79	32.26		32.34	0.002759	2.37	113.35	60.23	0.28	0.32	1.88
Middle Reach	200	10-Yr	202.00	29.79	31.98		32.05	0.002751	2.16	97.13	57.82	0.28	0.29	1.68
Middle Reach	200	5-yr	167.00	29.79	31.79		31.85	0.002746	2.00	85.92	56.10	0.27	0.26	1.53
Middle Reach	200	2-Yr	92.00	29.79	31.27		31.31	0.002893	1.61	58.05	51.57	0.26	0.20	1.13
Middle Reach	200	1.5-Yr	70.00	29.79	31.08		31.11	0.002934	1.47	48.31	49.59	0.26	0.18	0.97
Middle Reach	200	2% Exceedance	17.80	29.79	30.44		30.46	0.003568	0.94	18.97	43.02	0.25	0.10	0.44
Middle Reach	200	20% Exceedance	3.20	29.79	30.10		30.11	0.006876	0.63	5.11	34.46	0.29	0.06	0.15
Middle Reach	200	Low Flow	1.00	29.79	29.98		29.98	0.011472	0.57	1.75	19.85	0.34	0.06	0.09
Middle Reach	200	1.9% exceedance	12.00	29.79	30.34		30.35	0.003894	0.83	14.45	41.92	0.25	0.08	0.34
Middle Reach	200	18.2% exceedance	12.00	29.79	30.34		30.35	0.003894	0.83	14.45	41.92	0.25	0.08	0.34
Middle Reach	150	100-Yr	337.00	29.58	32.43		32.56	0.003796	3.03	118.48	58.33	0.34	0.48	2.03
Middle Reach	150	50-Yr	296.00	29.58	32.25		32.37	0.003793	2.88	108.44	56.29	0.34	0.45	1.93
Middle Reach	150	25-Yr	256.00	29.58	32.07		32.18	0.003787	2.73	98.36	54.17	0.33	0.42	1.82
Middle Reach	150	10-Yr	202.00	29.58	31.80		31.89	0.003772	2.48	84.22	51.04	0.32	0.38	1.65
Middle Reach	150	5-yr	167.00	29.58	31.61		31.69	0.003758	2.30	74.60	48.96	0.32	0.35	1.52
Middle Reach	150	2-Yr	92.00	29.58	31.10		31.15	0.003614	1.84	50.96	43.70	0.30	0.26	1.17
Middle Reach	150	1.5-Yr	70.00	29.58	30.91		30.95	0.003480	1.66	42.96	41.81	0.28	0.22	1.03
Middle Reach	150	2% Exceedance	17.80	29.58	30.28		30.30	0.002829	0.95	18.82	35.48	0.23	0.09	0.53
Middle Reach	150	20% Exceedance	3.20	29.58	29.92		29.92	0.002335	0.49	6.60	29.31	0.18	0.03	0.23
Middle Reach	150	Low Flow	1.00	29.58	29.79		29.79	0.001887	0.31	3.21	23.46	0.15	0.02	0.14
Middle Reach	150	1.9% exceedance	12.00	29.58	30.17		30.18	0.002692	0.81	14.88	34.33	0.22	0.07	0.43
Middle Reach	150	18.2% exceedance	12.00	29.58	30.17		30.18	0.002692	0.81	14.88	34.33	0.22	0.07	0.43
Middle Reach	100	100-Yr	337.00	29.44	32.22		32.36	0.004048	3.16	115.81	57.94	0.35	0.50	2.00
Middle Reach	100	50-Yr	296.00	29.44	32.04		32.18	0.004047	3.02	105.85	56.14	0.35	0.47	1.89
Middle Reach	100	25-Yr	256.00	29.44	31.86		31.98	0.004040	2.85	95.82	54.23	0.34	0.44	1.77
Middle Reach	100	10-Yr	202.00	29.44	31.59		31.70	0.004014	2.60	81.73	51.40	0.33	0.40	1.59
Middle Reach	100	5-yr	167.00	29.44	31.40		31.49	0.003978	2.41	72.14	49.39	0.33	0.36	1.46
Middle Reach	100	2-Yr	92.00	29.44	30.90		30.95	0.004106	1.93	48.38	44.39	0.31	0.28	1.09
Middle Reach	100	1.5-Yr	70.00	29.44	30.71		30.76	0.004228	1.75	40.32	42.61	0.31	0.25	0.95
Middle Reach	100	2% Exceedance	17.80	29.44	30.09		30.11	0.004997	1.12	15.89	35.29	0.29	0.14	0.45
Middle Reach	100	20% Exceedance	3.20	29.44	29.75		29.75	0.005121	0.63	5.12	27.76	0.26	0.06	0.18
Middle Reach	100	Low Flow	1.00	29.44	29.65	29.56	29.65	0.005187	0.41	2.46	25.79	0.23	0.03	0.10
Middle Reach	100	1.9% exceedance	12.00	29.44	29.98		30.00	0.004877	0.98	12.23	32.54	0.28	0.11	0.38
Middle Reach	100	18.2% exceedance	12.00	29.44	29.98		30.00	0.004876	0.98	12.23	32.54	0.28	0.11	0.38
Middle Reach	50	100-Yr	337.00	29.17	31.84		32.08	0.007665	4.06	87.53	45.52	0.48	0.91	1.92
Middle Reach	50	50-Yr	296.00	29.17	31.67		31.90	0.007689	3.86	80.17	43.96	0.47	0.86	1.82
Middle Reach	50	25-Yr	256.00	29.17	31.50		31.70	0.007723	3.66	72.75	42.53	0.47	0.81	1.71
Middle Reach	50	10-Yr	202.00	29.17	31.25		31.42	0.007783	3.34	62.29	40.42	0.46	0.74	1.54
Middle Reach	50	5-yr	167.00	29.17	31.07		31.22	0.007811	3.11	55.17	38.92	0.45	0.68	1.42
Middle Reach	50	2-Yr	92.00	29.17	30.58		30.68	0.007392	2.51	37.33	34.52	0.42	0.49	1.08
Middle Reach	50	1.5-Yr	70.00	29.17	30.40		30.48	0.007342	2.28	31.11	32.85	0.41	0.43	0.95
Middle Reach	50	2% Exceedance	17.80	29.17	29.79		29.82	0.006997	1.38	12.92	27.38	0.35	0.21	0.47

HEC-RAS Plan: Prop90% River: Stotenburg.Creek Reach: Middle Reach (Continued)

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl	Shear Total	Hydr Depth
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)		(lb/sq ft)	(ft)
Middle Reach	50	20% Exceedance	3.20	29.17	29.45		29.46	0.007213	0.76	4.20	21.95	0.31	0.09	0.19
Middle Reach	50	Low Flow	1.00	29.17	29.34	29.26	29.34	0.007246	0.52	1.92	17.88	0.28	0.05	0.11
Middle Reach	50	1.9% exceedance	12.00	29.17	29.69		29.71	0.007132	1.20	10.00	26.40	0.34	0.17	0.38
Middle Reach	50	18.2% exceedance	12.00	29.17	29.69		29.71	0.007137	1.20	10.00	26.40	0.34	0.17	0.38
Middle Reach	1	100-Yr	337.00	28.58	30.99	30.64	31.49	0.020003	5.68	60.27	35.28	0.74	2.10	1.71
Middle Reach	1	50-Yr	296.00	28.58	30.85	30.51	31.30	0.020008	5.41	55.36	34.35	0.73	1.98	1.61
Middle Reach	1	25-Yr	256.00	28.58	30.70	30.37	31.11	0.020005	5.13	50.29	33.48	0.72	1.85	1.50
Middle Reach	1	10-Yr	202.00	28.58	30.48	30.17	30.82	0.020008	4.71	43.09	32.20	0.71	1.65	1.34
Middle Reach	1	5-yr	167.00	28.58	30.32	30.03	30.62	0.020003	4.39	38.13	31.29	0.69	1.50	1.22
Middle Reach	1	2-Yr	92.00	28.58	29.91	29.65	30.11	0.020031	3.56	25.82	28.45	0.66	1.12	0.91
Middle Reach	1	1.5-Yr	70.00	28.58	29.75	29.52	29.92	0.020003	3.27	21.38	26.76	0.65	0.99	0.80
Middle Reach	1	2% Exceedance	17.80	28.58	29.21	29.07	29.28	0.020002	2.10	8.48	20.74	0.58	0.51	0.41
Middle Reach	1	20% Exceedance	3.20	28.58	28.89	28.81	28.91	0.020004	1.21	2.64	14.76	0.50	0.22	0.18
Middle Reach	1	Low Flow	1.00	28.58	28.78	28.72	28.79	0.020010	0.84	1.20	11.65	0.46	0.13	0.10
Middle Reach	1	1.9% exceedance	12.00	28.58	29.11	28.99	29.17	0.020012	1.84	6.51	19.34	0.56	0.42	0.34
Middle Reach	1	18.2% exceedance	12.00	28.58	29.11	28.99	29.17	0.020012	1.84	6.51	19.34	0.56	0.42	0.34

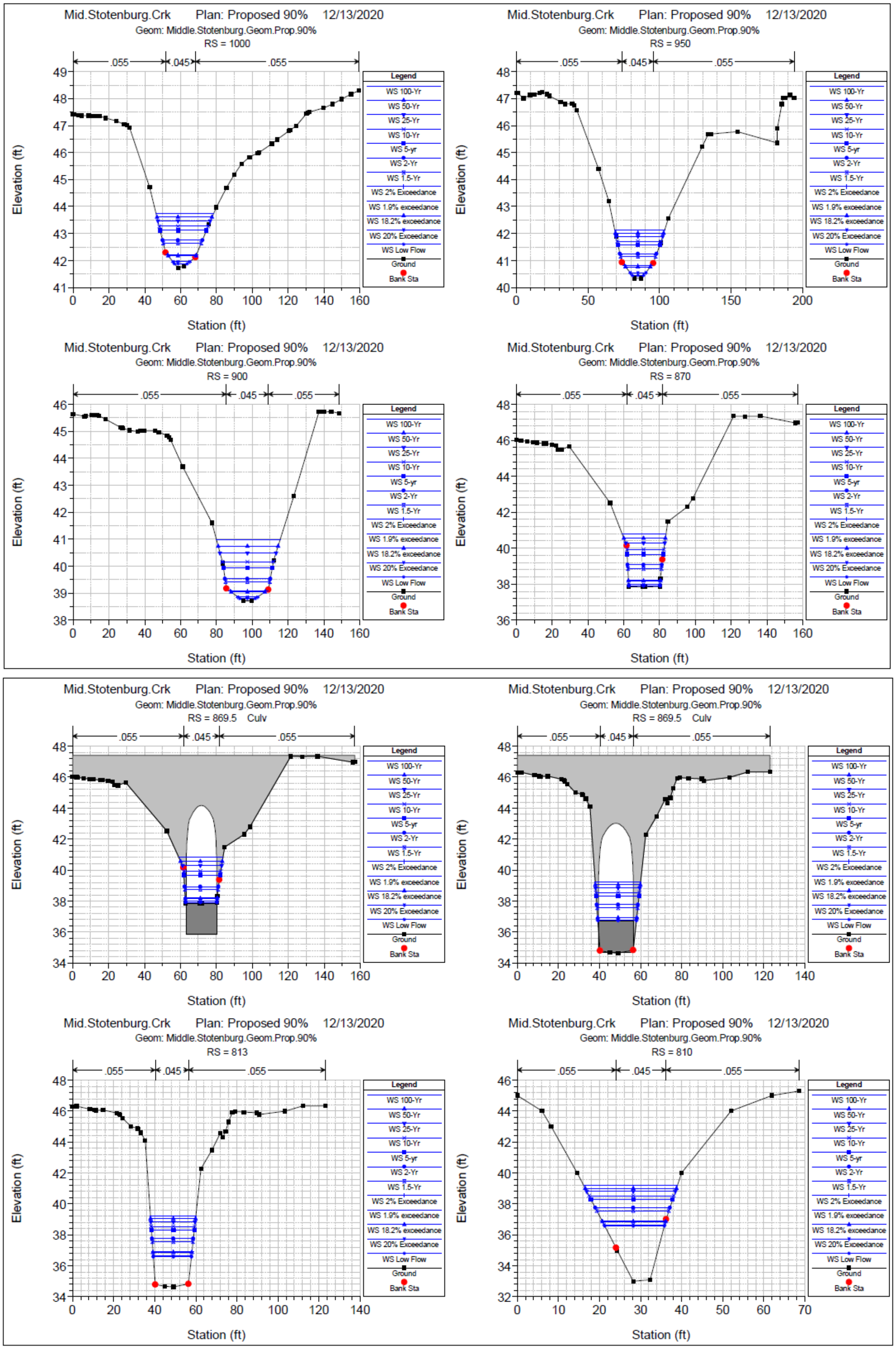


Figure C-2. HEC-RAS model sections for proposed conditions – 90% design.

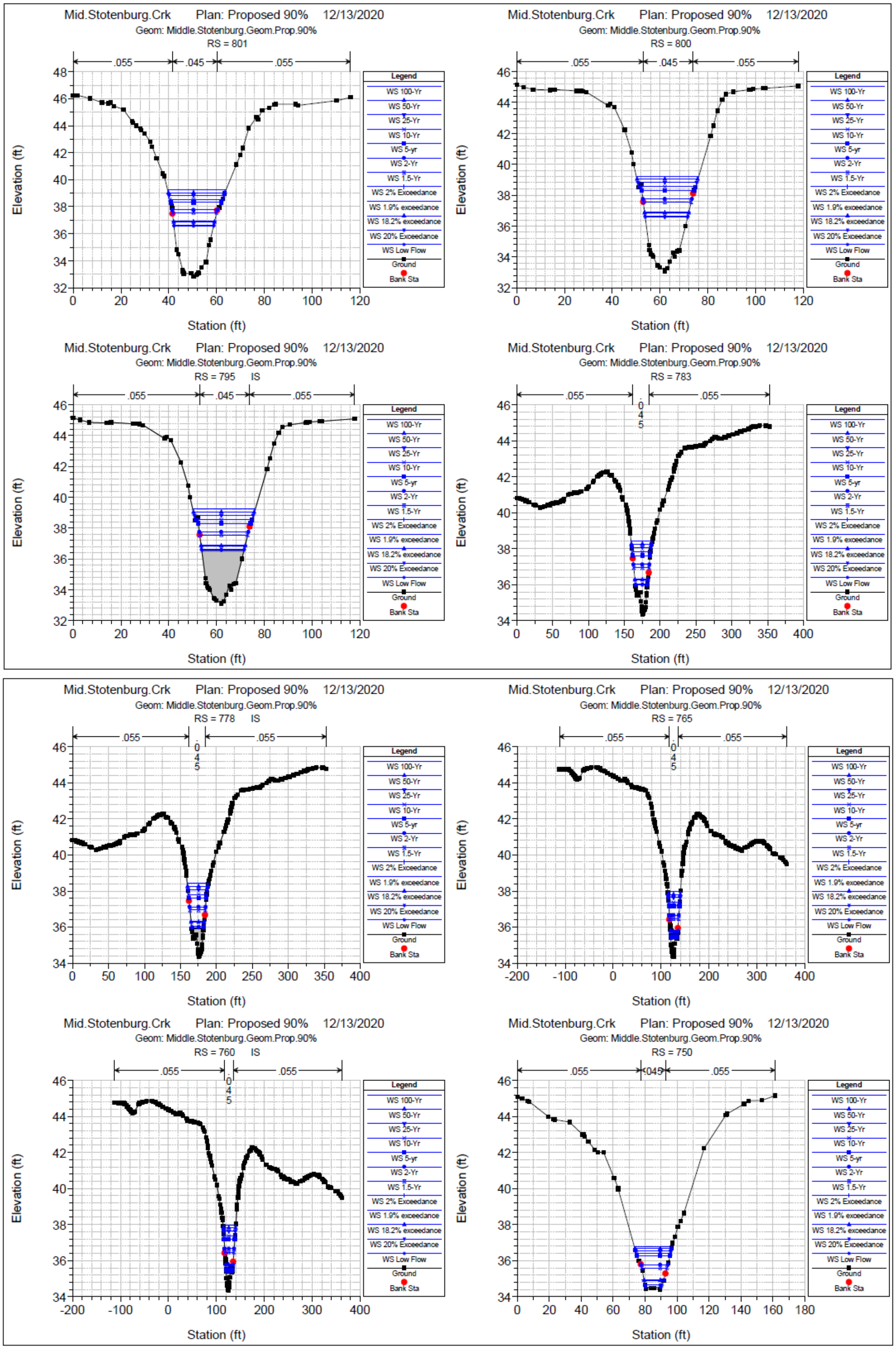


Figure C-2 (cont.). HEC-RAS model sections for proposed conditions – 90% design.

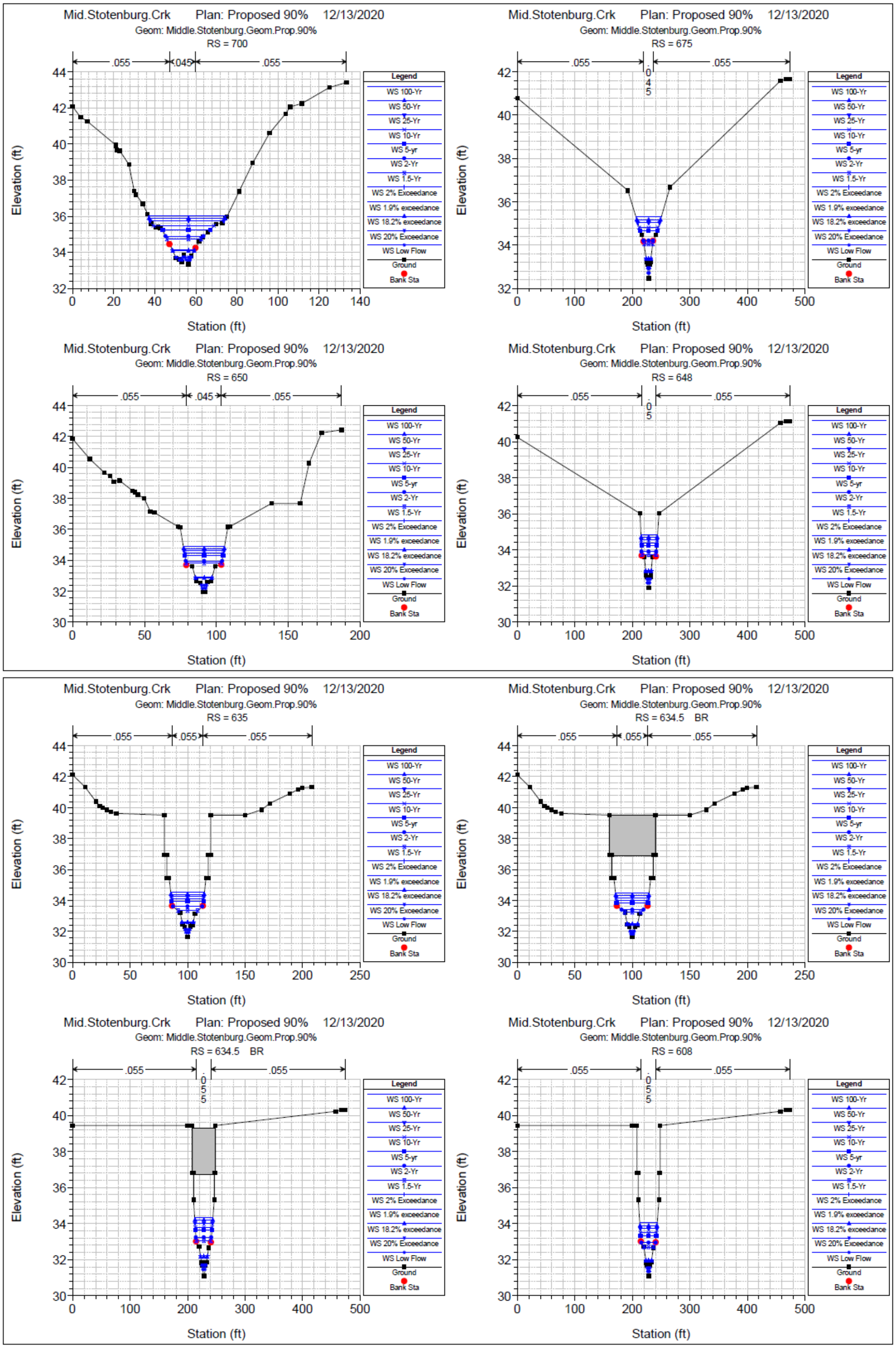


Figure C-2 (cont.). HEC-RAS model sections for proposed conditions – 90% design.

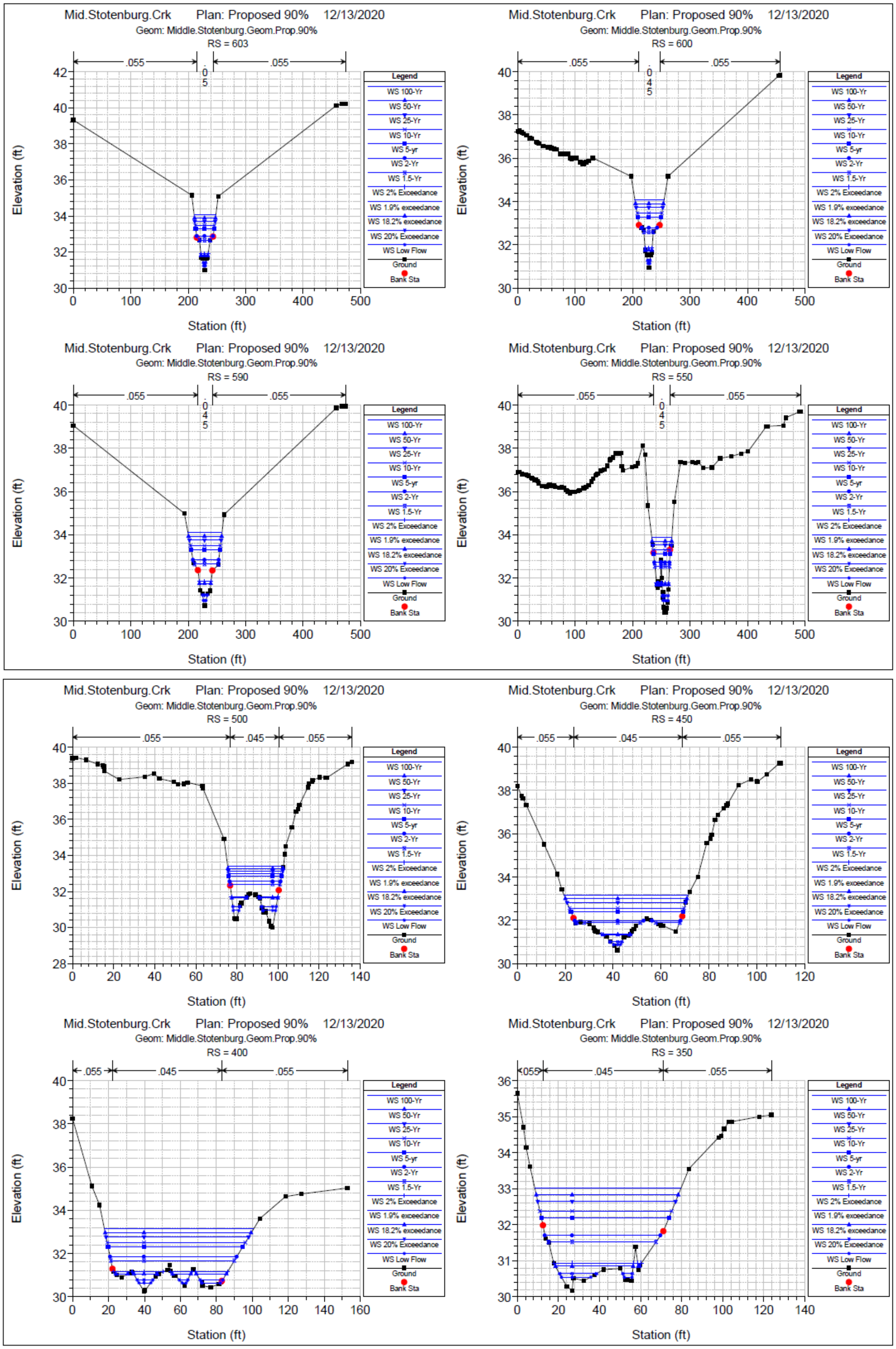


Figure C-2 (cont.). HEC-RAS model sections for proposed conditions – 90% design.

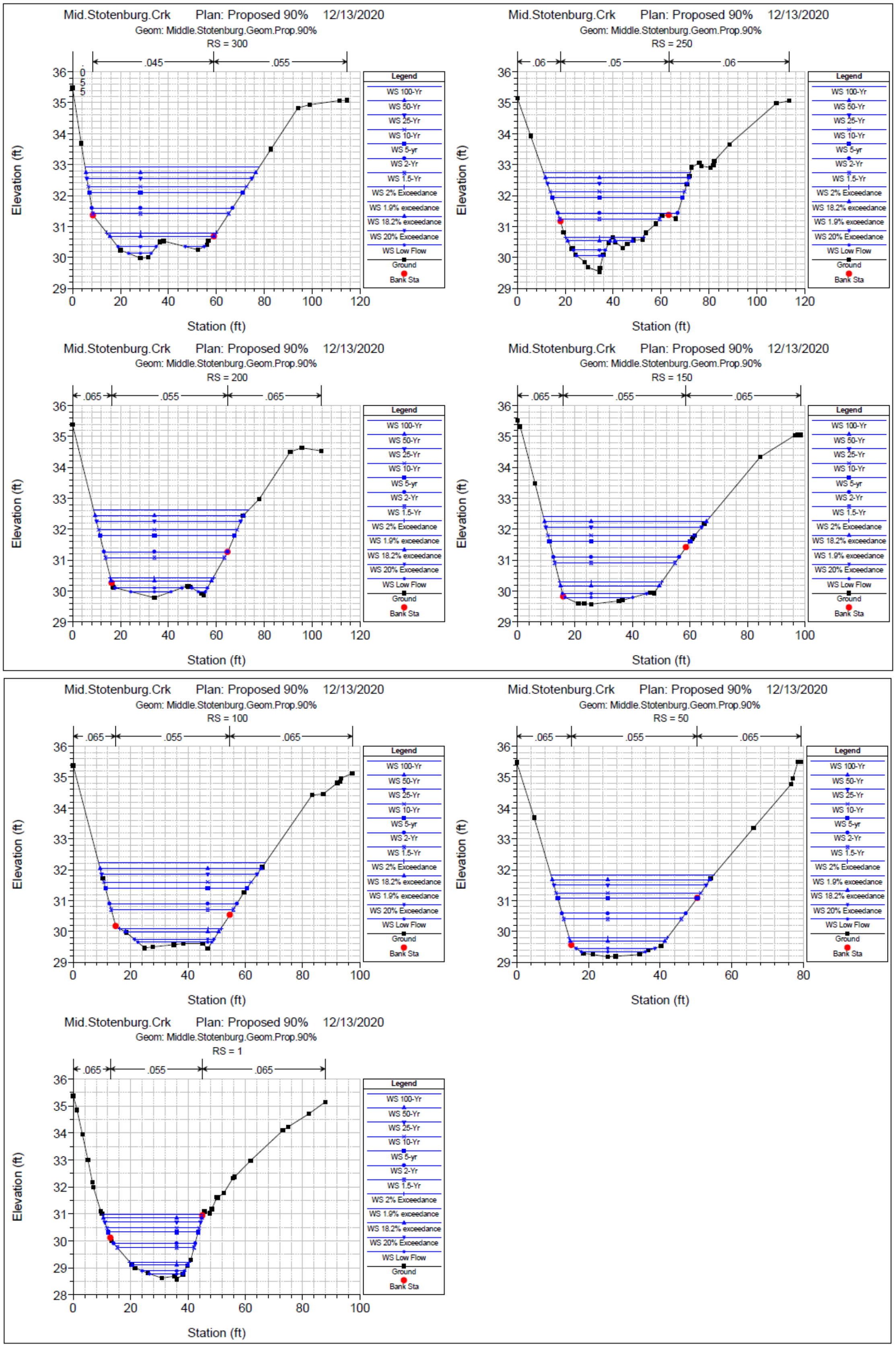


Figure C-2 (cont.). HEC-RAS model sections for proposed conditions – 90% design.

Appendix D

Large Wood Stability Analyses

Middle Stotenburg Creek Habitat Enhancement

Large Wood Structure Stability Analysis

TABLE OF CONTENTS

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Date of Last Revision: January 7, 2016

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Large Wood Structure Stability Analysis Spreadsheet was developed by Michael Rafferty, P.E.
Version 1.1

Reference for Companion Paper:
Rafferty, M. 2016. *Computational Design Tool for Evaluating the Stability of Large Wood Structures.* Technical Note TN-103.1. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, National Stream & Aquatic Ecology Center. 27 p.

Middle Stotenburg Creek Habitat Enhancement
Factors of Safety and Design Constants

Spreadsheet developed by
Michael Rafferty, P.E.

Symbol	Description	Value
FS_V	Factor of Safety for Vertical Force Balance	**2.00**
FS_H	Factor of Safety for Horizontal Force Balance	**1.50**
FS_M	Factor of Safety for Moment Force Balance	**1.50**

Symbol	Description	Units	Value
C_{Lrock}	Coefficient of lift for submerged boulder (D'Aoust, 2000)	-	0.17
C_{Drock}	Coefficient of drag for submerged boulder (Schultz, 1954)	-	0.85
g	Gravitational acceleration constant	ft/s^2	32.174
DF_{RW}	Diameter factor for rootwad ($DF_{RW} = D_{RW}/D_{TS}$)	-	**2.50**
LF_{RW}	Length factor for rootwad ($LF_{RW} = L_{RW}/D_{TS}$)	-	1.50
SG_{rock}	Specific gravity of quartz particles	-	2.65
γ_{rock}	Dry unit weight of boulders	lb/ft^3	165.0
γ_w	Specific weight of water at 50ºF	lb/ft^3	62.40
η	Rootwad porosity from NRCS Tech Note 15 (2001)	-	0.20
ν	Kinematic viscosity of water at 50ºF	ft/s^2	1.41E-05

Middle Stotenburg Creek Habitat Enhancement
Hydrologic and Hydraulic Inputs

Spreadsheet developed by
Michael Rafferty, P.E.

Average Return Interval (ARI) of Design Discharge: 100 yr

Site ID	Proposed Station	Design Discharge, Q_{des} (cfs)	Maximum Depth, d_w (ft)	Average Velocity, u_{avg} (ft/s)	Bankfull Width, W_{BF} (ft)	Wetted Area, A_W (ft^2)	Radius of Curvature, R_c (ft)
Single log	28+00	337	2.90	3.73	33.0	90	900

Middle Stotenburg Creek Habitat Enhanc
Stream Bed Substrate Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Stream bed D_{50} (mm)	Stream Bed Substrate Grain Size Class	Bed Soil Class	Dry Unit Weight[1], γ_{bed} (lb/ft^3)	Buoyant Unit Weight, γ'_{bed} (lb/ft^3)	Friction Angle, ϕ_{bed} (deg)
Single log	28+00	0.50	Medium sand	7	94.2	58.7	30

Source: Compiled from Julien (2010) and Shen and Julien (1993); soil classes from NRCS Table TS14E–2 Soil classification

[1] γ_{bed} (kg/m^3) = 1,600 + 300 log D_{50} (mm) (from Julien 2010)

1 kg/m^3 = 0.062 1 lb/ft^3

Middle Stotenburg Creek Habitat E
Bank Soil Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Bank Soils (from field observations)	Bank Soil Class	Dry Unit Weight, γ_{bank} (lb/ft^3)	Buoyant Unit Weight, γ'_{bank} (lb/ft^3)	Friction Angle, ϕ_{bank} (deg)
Single log	28+00	**Gravel/sand**	5	111.7	69.5	39

Middle Stotenburg Creek Habitat Enhancement
Large Wood Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Project Location: West Coast

Timber Unit Weights			Air-dried[1]	Green[2]
Selected Species	**Common Name**	**Scientific Name**	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Tree Type #1:	Redwood, Coast (young)	Sequoia sempervirens	24.5	50.0
Tree Type #2:				
Tree Type #3:				
Tree Type #4:				
Tree Type #5:				
Tree Type #6:				
Tree Type #7:				
Tree Type #8:				
Tree Type #9:				
Tree Type #10:				

[1] **Air-dried unit weight,** γ_{Td} = Average unit weight of wood after exposure to air on a 12% moisture content volume basis. Air-dried unit weight is used in the force balance calculations for the portion of wood that is above the proposed thalweg elevation (assuming unsaturated conditions).

[2] **Green unit weight,** γ_{Tgr} = Average unit weight of freshly sawn wood when the cell walls are completely saturated with water. Green unit weight is used in the force balance calculations as a conservative estimate of the unit weight for the portion of wood that is below the proposed thalweg elevation (assuming saturated conditions). For comparison, Thevenet, Citterio, & Piegay (1998) determined wood unit weight typically increases by more than 100% after less than 24 hours exposure to water.

Source for timber unit weights:

U.S. Department of Agriculture, U.S. Forest Service. (2009) Specific Gravity and Other Properties of Wood and Bark for 156 Tree Species Found in North America. Research Note NRS-38. Table 1A.

Middle Stotenburg Creek Habitat Enhancement

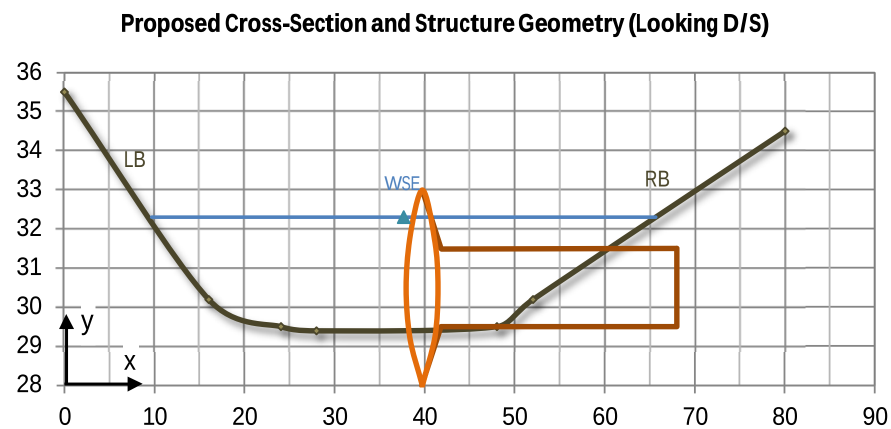
Spreadsheet developed by
Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Single log	Log Vane	Right bank	Straight	28+00	2.90	27.27	3.73

Multi-Log Structures	Layer	Log ID
	Wracked	1

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	0.00	35.50
Top LB	16.00	30.20
Toe LB	24.00	29.50
Thalweg	28.00	29.40
Toe RB	48.00	29.50
Top RB	52.00	30.20
Fldpln RB	80.00	34.50

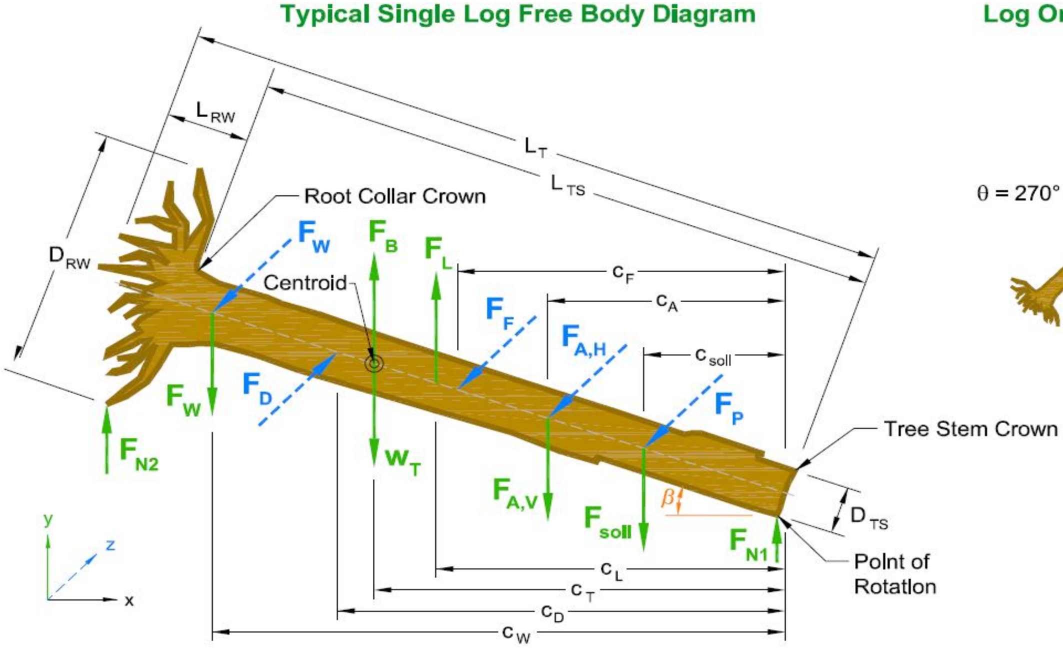


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Redwood, Coast (young)	Yes	40.0	2.00	3.00	5.00	24.5	50.0

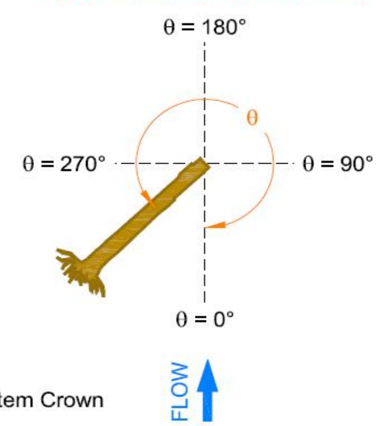
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	225.0	0.0	Stem tip: Bottom	68.00	29.50	27.99	32.99	38.00

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Medium sand	94.2	58.7	30.0	7	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	10.67	1.16	0.58

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.7	0.7	17	0
↓WS↑Thw	116.2	20.0	136.2	3,333	8,502
↓Thalweg	0.0	3.8	3.8	189	236
Total	116.2	24.5	140.7	3,539	8,738

Lift Force

C_{LT}	0.16
F_L (lbf)	80

Vertical Force Balance

F_B (lbf)	8,738	↑
F_L (lbf)	80	↑
W_T (lbf)	3,539	↓
F_{soil} (lbf)	908	↓
$F_{W,V}$ (lbf)	13,440	↓
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	9,070	↓
FS_V	2.03	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	1.2	11.2	12.4	908
Total	1.2	11.2	12.4	908

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.42	0.46	1.10	0.43	4.72	2,421

Horizontal Force Balance

F_D (lbf)	2,421	→
F_P (lbf)	1,996	←
F_F (lbf)	0	
$F_{W,H}$ (lbf)	9,286	←
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	8,861	←
FS_H	4.66	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	3.00	0	3.40	0.58	0
Bank	4.40	1,996	28.30	0.81	0
Total	-	1,996	31.70	-	0

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
22.5	34.9	25.4	22.5	5.3	0.0	7.1

*Distances are from the stem tip

Point of Rotation: Stem Tip

Moment Force Balance

M_d (lbf)	261,018	↻
M_r (lbf)	541,768	↺
FS_M	2.08	✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Middle Stotenburg Creek Habitat Enhancement

Spreadsheet developed by
Michael Rafferty, P.E.

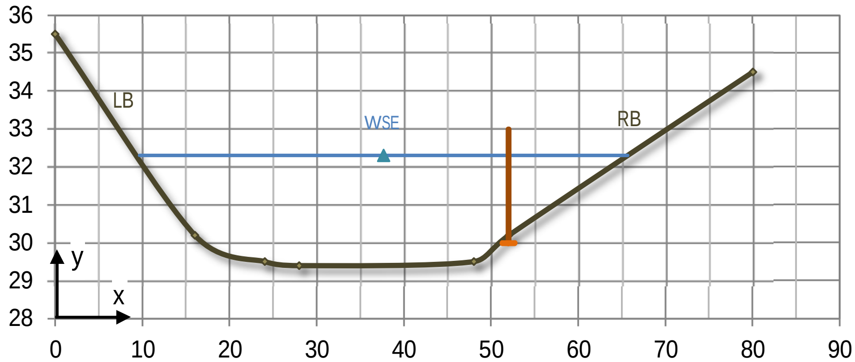
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Single log	Log Vane	Right bank	Straight	28+00	2.90	27.27	3.73

Multi-Log Structures	Layer	Log ID
	Footer	Piling Typ.

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	0.00	35.50
Top LB	16.00	30.20
Toe LB	24.00	29.50
Thalweg	28.00	29.40
Toe RB	48.00	29.50
Top RB	52.00	30.20
Fldpln RB	80.00	34.50

Proposed Cross-Section and Structure Geometry (Looking D/S)

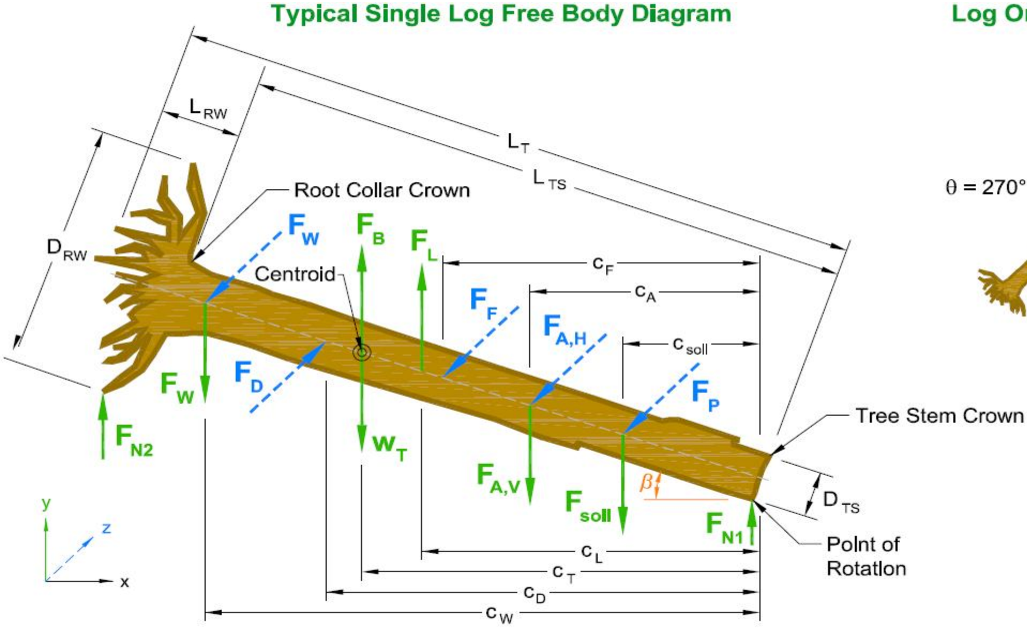


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Redwood, Coast (young)	No	3.0	1.25	-	-	24.5	50.0

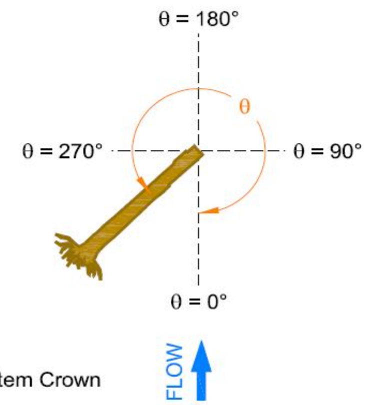
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	1.0	89.0	Stem tip: Crown	52.00	33.00	29.98	33.00	0.05

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Medium sand	94.2	58.7	30.0	7	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	0.20	0.20	0.10

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.8	0.0	0.8	21	0
↓WS↑Thw	2.8	0.0	2.8	69	177
↓Thalweg	0.0	0.0	0.0	0	0
Total	3.7	0.0	3.7	90	177

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	177	↑
F_L (lbf)	0	
W_T (lbf)	90	↓
F_{soil} (lbf)	2	↓
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
Σ F_V (lbf)	85	↑
FS_V	0.52	✗

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	2
Total	0.0	0.0	0.0	2

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.00	0.59	1.07	0.00	1.06	1

Horizontal Force Balance

F_D (lbf)	1	→
F_P (lbf)	4	←
F_F (lbf)	0	
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
Σ F_H (lbf)	3	←
FS_H	5.28	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	3.00	0	2.00	0.58	0
Bank	4.40	4	0.22	0.81	0
Total	-	4	2.22	-	0

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F&N}$ (ft)	c_P (ft)
1.5	0.0	1.7	1.5	2.9	0.0	2.9

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	5
M_r (lbf)	2
FS_M	0.51 ✗

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

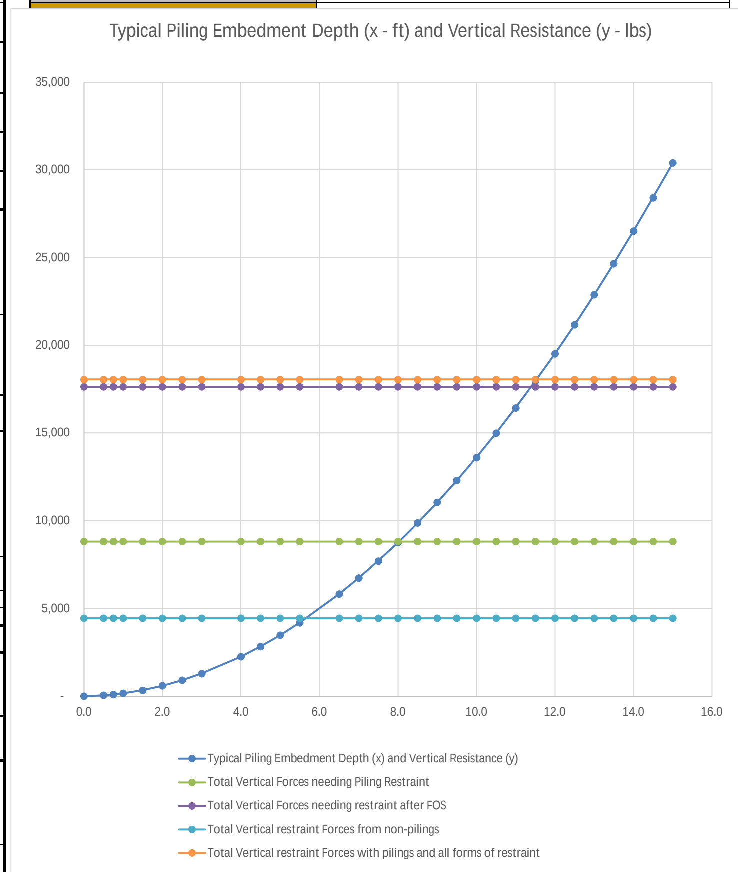
Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Pilings within Stream Bank Soils			
Vertical net resistance of pile group to vertical uplift forces of LWD (buoyancy and coefficient of lift vs piling resistance)			
Description	Value	Symbol	Units
saturated specific weight of wood (from sheet 5, green spec gravity. Note, hard coded location, will need adjustment if this sheet is altered.)	50.0		
specific weight of water (from sheet 2 Note, hard coded location, will need adjustment if this sheet is altered.)	62.4		
saturated specific weight of soil (from sheet 4 Note, hard coded location, will need adjustment if this sheet is altered.)	131.9		
dry specific weight of soil (from sheet 4 Note, hard coded location, will need adjustment if this sheet is altered.)	111.7		
Number of piles in group	2	N_{piles}	
Diameter of piles	1.25	d_{piles}	
Max assumed scour	0.50		
Nominal Embedded length of piles (do not include added depth for scour protection, those values are added below. This is not the depth to specify, look below for total embed depth for specification).	10	L_{piles}	
h_{load} - distance from pin/anchor down to bed (after installation)	1.50		
h_{load}' - distance from pin/anchor down to bed (after install and scour)	2.00		
L_{pile}^3 - intermediate term for application in eqtn 36 of USBR	1,000		
Coefficient of Lateral Earth Pressure - Used for Calculations. This a judgement call. The actual lateral earth pressure will engage some amount of the passive maximum, but in friction the upwards resistance from this sideways leverage is not that significant (the horiz is); therefore, this value should be some amount greater than the resting and active coeffs b/c as soon as it obstructs flow it will engage some of the passive potential, but it can never really reach its full passive potential (in the vertical). use the types of earth pressures below to determine the appropriate choice. Adopt 0.5 here as recommended minimum. do not exceed 1.0.	0.50	k_s'	
$k_{passive}$ - **Passive Earth Pressure** - The passive state occurs when a soil mass is externally forced laterally and inward (towards the soil mass) to the point of mobilizing its available full shear resistance in trying to resist further lateral deformation. That is, the soil mass is at the point of incipient failure by shearing due to loading in the lateral direction. It is the maximum lateral resistance that a given soil mass can offer to a retaining wall that is being pushed towards the soil mass.	4.40	$k_{Passive}$	
$k_{resting}$ - **At Rest Earth Pressure** - condition of soil relaxing to its passive "slouched" state, but not getting squeezed.	0.37	$k_{resting}$	
k_{Active} - **Active Earth Pressure** - The active state occurs when a retained soil mass is allowed to relax or deform laterally and outward (away from the soil mass) to the point of mobilizing its available full shear resistance (or engaging its shear strength) in trying to resist lateral deformation. That is, the soil is at the point of incipient failure by shearing due to unloading in the lateral direction. It is the minimum theoretical lateral pressure that a given soil mass will exert on a retaining that will move or rotate away from the soil until the soil active state is reached (not necessarily the actual in-service lateral pressure on walls that do not move when subjected to soil lateral pressures higher than the active pressure).	0.23	k_{Active}	
Internal angle of friction of soils (from sheet 4.Note, hard coded location, will need adjustment if this sheet is altered.)	39.00	(theta)	
Intermediate pressure calculation	1.63		
σ' (sigma prime) as defined in eqtn 16, CH6, USBR	695.18	σ'	
Final Total Embedment of pilings	**10.50**		
$F_{piles-v}$ - Skin Friction for group of piles. This is the vertical resistance contributed from the piling group. Is represents a purely vertical max resistance force the piers can produce. Per eqtn 15 of CH6 USBR	**-13,611**	**$F_{piles-v}$**	
FOS_{vert} - Vertical Factor of Safety given Piling configuration and all other inputs from Rafferty.	2.03	FOS_{vert}	
$F_{piles-h}$ - Lateral resistance provided by piles. This is the max horizontal resistance that the pilings can produce against drag forces of the river. This eqtn assumes full passive development in the soils on the DS face of the pilings (eqtn 38). Per eqtn 36 and 37 of CH6 USBR	**-9,280**	**$F_{piles-h}$**	
FOS_{horiz} - Horizontal Factor of Safety given by Piling configuration and all other inputs from Rafferty.	4.66	FOS_{horiz}	

Shear resistance of pile group - Resistance to being swept off surface of stream bank due to catastrophic transverse (perpendicular) failure of a pilings based on NDS methods with ADS load Factors			
Nominal Total cross-sectional area of all piles	2.45	sqft	
Nominal Total cross-sectional area of all piles	353	sqin	
NDS - ASD C_D - Load Duration Factor (permanent condition per NDS Table 2.3.2)	0.90	coeff	
NDS - ASD C_t - Temperature Factor (typical exposure <100 deg F per NDS Table 2.3.3)	1.00	coeff	
NDS - ASD C_{ct} - Condition Treatment Factor (moist/steaming - max reduction per NDS page 74, adjustment factors for Table 6A/6B)	0.74	coeff	
F_v - Nominal shear capacity of piles (cross-sectional resistance to shear off at ground surface), Pacific coast Douglas fir per NDS Table 6B	160	psi	F_V
F_V'adjusted value for design purposes - this is the working strength of douglas fir after the adjust factors have been made. The sis the shear (psi) that would represent a reduced prediction of strength, NDS Table 6.3.1.	107	psi	F_V'
Nominal Depth of Log Piling (diameter, in) for use w/ NDS	15	in	d
depth of log behind (outside) of connection (% of total depth), this is the amount the bolt would embed into the piling log in a worst-case tension loading. Using this value on pilings on the DS side of the structure is conservative	0.10		
Adjusted Nominal Depth (d_e) of the piling. Accounts for the embed and "lost" gross area that is behind it. For use w/ NDS eqtns	13.5		d_e
V' - Adjusted design shear capacity - Total amount of horiz force (lbs) that would be resisted given NDS methods. Compare to the Drag and lift forces on the Large wood.	**18,294**	**lbs**	V'
FOS_{shear} - Shear Factor of Safety given Piling configuration and all other inputs from Rafferty.	7.56	FOS_{shear}	

Cell Format	Directions
Dropdown List	Select value from dropdown list
User Input	Type value into cell
User Verify	Verify value in cell (edit if necessary)
Heading	Table Heading (Scroll over sample heading for description of comments)
Key Value	Verify value of force calculation
Solution	Verify value of force balance or factor of safety calculation
Background Value	Optional - Verify value of background calculation (outside of print area)
COMPUTED VALUE	



Interaction Forces with Adjacent Logs					
Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)
Piling Typ.	Behind	Pinned	20.0	-6,720	-4,643
Piling Typ.	In front	Pinned	19.0	-6,720	-4,643

Greek Symbols

Symbol	Description	Unit
β	Tilt angle from stem tip to vertical	deg
γ_{bank}	Dry specific weight of bank soils	lb/ft^3
$\gamma_{bank,sat}$	Saturated unit weight of bank soils	lb/ft^3
γ'_{bank}	Effective buoyant unit weight of bank soils	lb/ft^3
γ_{bed}	Dry specific weight of stream bed substrate	lb/ft^3
γ'_{bed}	Effective buoyant unit weight of stream bed substrate	lb/ft^3
γ_{rock}	Dry unit weight of boulders	lb/ft^3
γ_s	Dry specific weight of soil	lb/ft^3
γ'_s	Effective buoyant unit weight of soil	lb/ft^3
γ_{Td}	Air-dried unit weight of tree (12% MC basis)	lb/ft^3
γ_{Tgr}	Green unit weight of tree	lb/ft^3
γ_w	Specific weight of water at 50ºF	lb/ft^3
η	Rootwad porosity	-
θ	Rootwad (or large end of log) orientation to flow	deg
μ	Coefficient of friction	-
ν	Kinematic viscosity of water at 50ºF	ft/s^2
Σ	Sum of forces	-
ϕ_{bank}	Internal friction angle of bank soils	deg
ϕ_{bed}	Internal friction angle of stream bed substrate	deg

Units

Notation	Description
cfs	Cubic feet per second
ft	Feet
lb	Pound
lbf	Pounds force
kg	Kilograms
m	Meters
mm	Millimeters
s	Seconds
yr	Year

Abbreviations

Notation	Description
ARI	Average return interval
Avg	Average
DBH	Diameter at breast height
deg	Degrees
Dia	Diameter
Dist	Distance
D/S	Downstream
ELJ	Engineered log jam
Ex	Example
Fldpln	Floodplain
H&H	Hydrologic and hydraulic
ID	Identification
i.e.	That is
LB	Left bank
LW	Large wood
Max	Maximum
MC	Moisture content
Min	Minimum
ML	Multi-log
SL	Single log
N/A	Not applicable
no	Number
Pt	Point
rad	Radians
RB	Right bank
RW	Rootwad
SL	Single log
Thw	Thalweg (lowest elevation in channel bed)
Typ	Typical
U.S.	United States
WS	Water surface
WSE	Water surface elevation
↑	Above
↓	Below

Middle Stotenburg Creek Habitat Enhancement
Notation, Units, and List of Symbols

Notation

Symbol	Description	Unit
A_W	Wetted area of channel at design discharge	ft^2
A_{Tp}	Projected area of wood in plane perpendicular to flow	ft^2
c_D	Centroid of the drag force along log axis	ft
c_{Am}	Centroid of a mechanical anchor along log axis	ft
c_{Ar}	Centroid of a ballast boulder along log axis	ft
c_{Asoil}	Centroid of the added ballast soil along log axis	ft
$c_{F\&N}$	Centroid of friction and normal forces along log axis	ft
c_L	Centroid of the lift force along log axis	ft
c_P	Centroid of the passive soil force along log axis	ft
c_{soil}	Centroid of the vertical soil forces along log axis	ft
$c_{T,B}$	Centroid of the buoyancy force along log axis	ft
$c_{T,W}$	Centroid of the log volume along log axis	ft
c_{WI}	Centroid of a wood interaction force along log axis	ft
C_{Lrock}	Coefficient of lift for submerged boulder	-
C_{LT}	Effective coefficient of lift for submerged tree	-
C_{Di}	Base coefficient of drag for tree, before adjustments	-
C_D^*	Effective coefficient of drag for submerged tree	-
C_{Di}	Base coefficient of drag for tree, before adjustments	-
C_W	Wave drag coefficient of submerged tree	-
$d_{b,avg}$	Average buried depth of log	ft
$d_{b,max}$	Maximum buried depth of log	ft
d_w	Maximum flow depth at design discharge in reach	ft
D_{50}	Median grain size in millimeters (SI units)	mm
D_r	Equivalent diameter of boulder	ft
D_{RW}	Assumed diameter of rootwad	ft
D_{TS}	Nominal diameter of tree stem (DBH)	ft
DF_{RW}	Diameter factor for rootwad ($DF_{RW} = D_{RW}/D_{TS}$)	-
e	Void ratio of soils	-
$F_{A,H}$	Total horizontal load capacity of anchor techniques	lbf
$F_{A,HP}$	Passive soil pressure applied to log from soil ballast	lbf
$F_{A,Hr}$	Horizontal resisting force on log from boulder	lbf
F_{Am}	Load capacity of mechanical anchor	lbf
$F_{A,V}$	Total vertical load capacity of anchor techniques	lbf
$F_{A,Vr}$	Vertical resisting force on log from boulder	lbf
$F_{A,Vsoil}$	Vertical soil loading on log from added ballast soil	lbf
F_B	Buoyant force applied to log	lbf
F_D	Drag forces applied to log	lbf
$F_{D,r}$	Drag forces applied to boulder	lbf
F_F	Friction force applied to log	lbf
F_H	Resultant horizontal force applied to log	lbf
F_L	Lift force applied to log	lbf
$F_{L,r}$	Lift force applied to boulder	lbf
F_P	Passive soil pressure force applied to log	lbf
F_{soil}	Vertical soil loading on log	lbf
$F_{W,H}$	Horizontal forces from interactions with other logs	lbf
$F_{W,V}$	Vertical forces from interactions with other logs	lbf

Notation (continued)

Symbol	Description	Unit
F_V	Resultant vertical force applied to log	lbf
Fr_L	Log Froude number	-
FS_V	Factor of Safety for Vertical Force Balance	-
FS_H	Factor of Safety for Horizontal Force Balance	-
FS_M	Factor of Safety for Moment Force Balance	-
g	Gravitational acceleration constant	ft/s^2
K_P	Coefficient of Passive Earth Pressure	-
$L_{T,em}$	Total embedded length of log	ft
L_{RW}	Assumed length of rootwad	ft
L_T	Total length of tree (including rootwad)	ft
L_{Tf}	Length of log in contact with bed or banks	ft
L_{TS}	Length of tree stem (not including rootwad)	ft
$L_{TS,ex}$	Exposed length of tree stem	ft
LF_{RW}	Length factor for rootwad ($LF_{RW} = L_{RW}/D_{TS}$)	-
M_d	Driving moment about embedded tip	lbf
M_r	Driving moment about embedded tip	lbf
N	Blow count of standard penetration test	-
p_o	Porosity of soil volume	-
Q_{des}	Design discharge	cfs
R	Radius	ft
R_c	Radius of curvature at channel centerline	ft
SG_r	Specific gravity of quartz particles	-
SG_T	Specific gravity of tree	-
u_{avg}	Average velocity of cross section in reach	ft/s
u_{des}	Design velocity	ft/s
u_m	Adjusted velocity at outer meander bend	ft/s
V_{dry}	Volume of soils above stage level of design flow	ft^3
V_{sat}	Volume of soils below stage level of design flow	ft^3
V_{soil}	Total volume of soils over log	ft^3
V_{RW}	Volume of rootwad	ft^3
V_S	Volume of solids in soil (void ratio calculation)	ft^3
V_T	Total volume of log	ft^3
V_{TS}	Total volume of tree	ft^3
V_V	Volume of voids in soil	ft^3
V_{Adry}	Volume of ballast above stage of design flow	ft^3
V_{Awet}	Volume of ballast below stage of design flow	ft^3
$V_{r,dry}$	Volume of boulder above stage of design flow	ft^3
$V_{r,wet}$	Volume of boulder below stage of design flow	ft^3
W_{BF}	Bankfull width at structure site	ft
W_r	Effective weight of boulder	lbf
W_T	Total log weight	lbf
x	Horizontal coordinate (distance)	ft
y	Vertical coordinate (elevation)	ft
$y_{T,max}$	Minimum elevation of log	ft
$y_{T,min}$	Maximum elevation of log	ft

Middle Stotenburg Creek Habitat Enhancement

Large Wood Structure Stability Analysis

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Date of Last Revision: January 7, 2016

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Large Wood Structure Stability Analysis Spreadsheet was developed by Michael Rafferty, P.E.
Version 1.1

Reference for Companion Paper:
Rafferty, M. 2016. *Computational Design Tool for Evaluating the Stability of Large Wood Structures.* Technical Note TN-103.1. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, National Stream & Aquatic Ecology Center. 27 p.

Middle Stotenburg Creek Habitat Enhancement
Factors of Safety and Design Constants

Spreadsheet developed by
Michael Rafferty, P.E.

Symbol	Description	Value
FS_V	Factor of Safety for Vertical Force Balance	**1.50**
FS_H	Factor of Safety for Horizontal Force Balance	**1.50**
FS_M	Factor of Safety for Moment Force Balance	**1.50**

gn - Decem

Symbol	Description	Units	Value
C_{Lrock}	Coefficient of lift for submerged boulder (D'Aoust, 2000)	-	0.17
C_{Drock}	Coefficient of drag for submerged boulder (Schultz, 1954)	-	0.85
g	Gravitational acceleration constant	ft/s^2	32.174
DF_{RW}	Diameter factor for rootwad ($DF_{RW} = D_{RW}/D_{TS}$)	-	**2.50**
LF_{RW}	Length factor for rootwad ($LF_{RW} = L_{RW}/D_{TS}$)	-	1.50
SG_{rock}	Specific gravity of quartz particles	-	2.65
γ_{rock}	Dry unit weight of boulders	lb/ft^3	165.0
γ_w	Specific weight of water at 50ºF	lb/ft^3	62.40
η	Rootwad porosity from NRCS Tech Note 15 (2001)	-	0.20
ν	Kinematic viscosity of water at 50ºF	ft/s^2	1.41E-05

Middle Stotenburg Creek Habitat Enhancement
Hydrologic and Hydraulic Inputs

Spreadsheet developed by
Michael Rafferty, P.E.

Average Return Interval (ARI) of Design Discharge: 100 yr

Site ID	Proposed Station	Design Discharge, Q_{des} (cfs)	Maximum Depth, d_w (ft)	Average Velocity, u_{avg} (ft/s)	Bankfull Width, W_{BF} (ft)	Wetted Area, A_W (ft^2)	Radius of Curvature, R_c (ft)
Log weir	34+78	255	3.70	3.86	29.6	70	450

Middle Stotenburg Creek Habitat Enhanc
Stream Bed Substrate Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Stream bed D_{50} (mm)	90% Design - December, 2020	Bed Soil Class	Dry Unit Weight[1], γ_{bed} (lb/ft^3)	Buoyant Unit Weight, γ'_{bed} (lb/ft^3)	Friction Angle, ϕ_{bed} (deg)
Log weir	34+78	**100.00**	Small Cobble	4	137.3	85.5	41

Source: Compiled from Julien (2010) and Shen and Julien (1993); soil classes from NRCS Table TS14E–2 Soil classification

[1] γ_{bed} (kg/m^3) = 1,600 + 300 log D_{50} (mm) (from Julien 2010)

1 kg/m^3 = 0.062 1 lb/ft^3

Middle Stotenburg Creek Habitat E
Bank Soil Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Bank Soils (from field observations)	Bank Soil Class	Dry Unit Weight, γ_{bank} (lb/ft^3)	Buoyant Unit Weight, γ'_{bank} (lb/ft^3)	Friction Angle, ϕ_{bank} (deg)
Log weir	34+78	**Gravel/cobble**	4	137.0	85.3	41

Middle Stotenburg Creek Habitat Enhancement
Large Wood Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Project Location: West Coast

90% Design - December, 2020

Timber Unit Weights			Air-dried[1]	Green[2]
Selected Species	**Common Name**	**Scientific Name**	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Tree Type #1:	**Redwood, Coast (young)**	Sequoia sempervirens	24.5	50.0
Tree Type #2:				
Tree Type #3:				
Tree Type #4:				
Tree Type #5:				
Tree Type #6:				
Tree Type #7:				
Tree Type #8:				
Tree Type #9:				
Tree Type #10:				

[1] **Air-dried unit**

[2] **Green unit weight, γ_{Tgr}** = Average unit weight of freshly sawn wood when the cell walls are completely saturated with water. Green unit weight is used in the force balance calculations as a conservative estimate of the unit weight for the portion of wood that is below the proposed thalweg elevation (assuming saturated conditions). For comparison, Thevenet, Citterio, & Piegay (1998) determined wood unit weight typically increases by more than 100% after less than 24 hours exposure to water.

Source for timber unit weights:

U.S. Department of Agriculture, U.S. Forest Service. (2009) Specific Gravity and Other Properties of Wood and Bark for 156 Tree Species Found in North America. Research Note NRS-38. Table 1A.

Middle Stotenburg Creek Habitat Enhancement

Spreadsheet developed by
Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

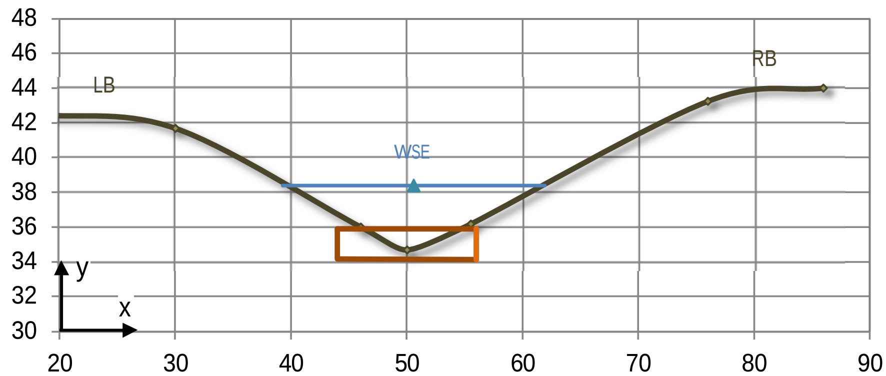
90% Design - December, 2020

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Log weir	Log Weir	Full span	Straight	34+78	3.70	15.22	3.86

Multi-Log Structures	Layer	Log ID
	N/A	1

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	18.00	42.50
Top LB	30.00	41.70
Toe LB	46.00	36.00
Thalweg	50.00	34.70
Toe RB	55.50	36.20
Top RB	76.00	43.25
Fldpln RB	86.00	44.00

Proposed Cross-Section and Structure Geometry (Looking D/S)

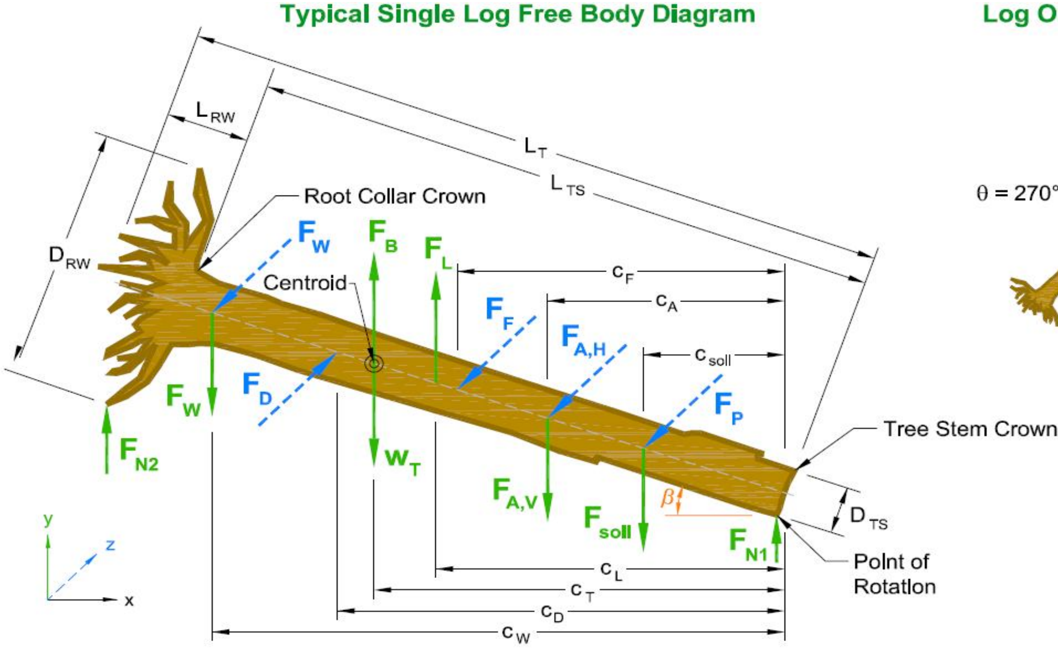


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Redwood, Coast (young)	No	12.0	1.75	-	-	24.5	50.0

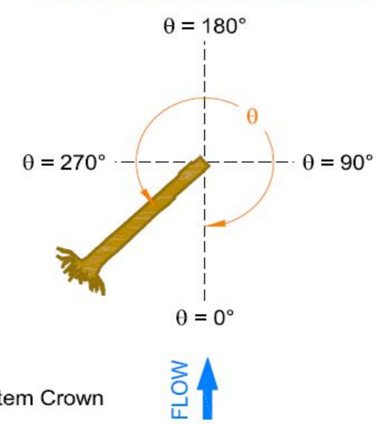
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	90.1	0.0	Stem tip: Crown	44.00	35.90	34.15	35.90	4.74

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Small Cobble	137.3	85.5	41.0	4	1.42	0.29	0.13
Bank	Gravel/cobble	137.0	85.3	41.0	4	2.50	0.81	0.45

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	21.1	0.0	21.1	516	1,315
↓Thalweg	7.8	0.0	7.8	389	486
Total	28.9	0.0	28.9	905	1,801

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	1,801
F_L (lbf)	0
W_T (lbf)	905
F_{soil} (lbf)	193
$F_{W,V}$ (lbf)	6,200
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	5,496
FS_V	4.05

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.3	0.3	27
Bank	0.0	1.9	1.9	166
Total	0.0	2.3	2.3	193

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.07	0.51	0.90	0.43	1.53	105

Horizontal Force Balance

F_D (lbf)	105
F_P (lbf)	464
F_F (lbf)	4,778
$F_{W,H}$ (lbf)	21,824
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	26,960
FS_H	257.79

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.81	64	11.48	0.87	3,918
Bank	4.81	399	2.52	0.87	860
Total	-	464	14.00	-	4,778

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
6.0	0.0	6.4	6.0	5.3	6.0	6.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	11,399
M_r (lbf)	155,225
FS_M	13.62

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Middle Stotenburg Creek Habitat Enhancement

Spreadsheet developed by
Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

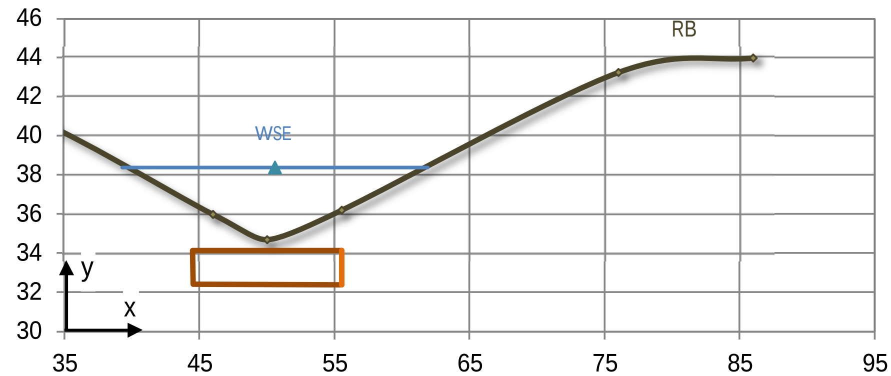
90% Design - December, 2020

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Log weir	Log Weir	Full span	Straight	34+78	3.70	15.22	3.86

Multi-Log Structures	Layer	Log ID
	Stacked	2

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	18.00	42.50
Top LB	30.00	41.70
Toe LB	46.00	36.00
Thalweg	50.00	34.70
Toe RB	55.50	36.20
Top RB	76.00	43.25
Fldpln RB	86.00	44.00

Proposed Cross-Section and Structure Geometry (Looking D/S)

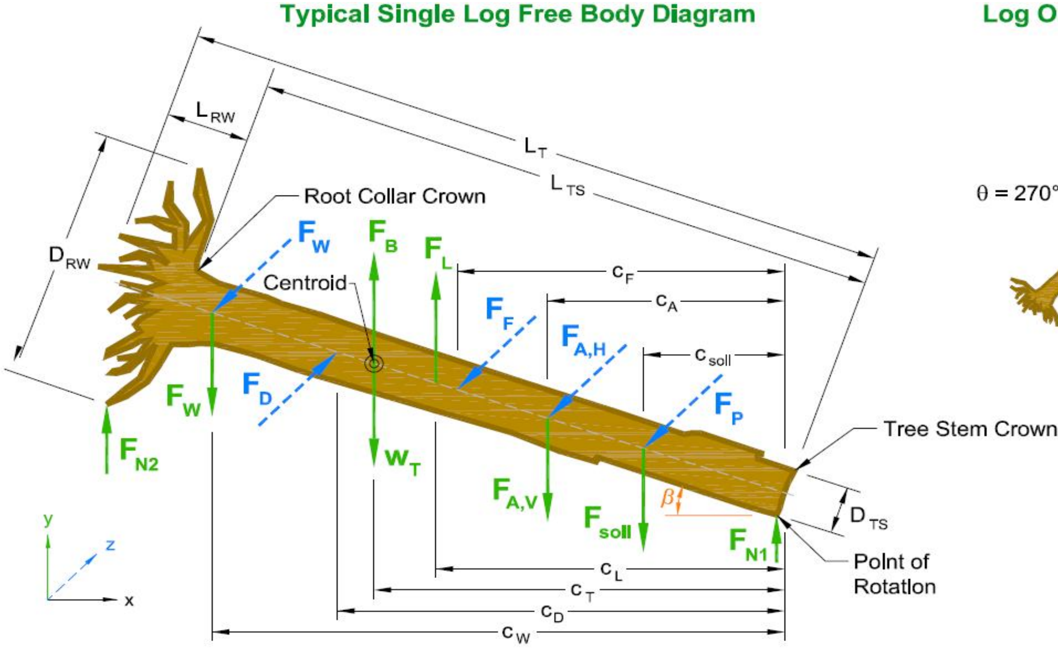


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Redwood, Coast (young)	No	11.00	1.75	-	-	24.5	50.0

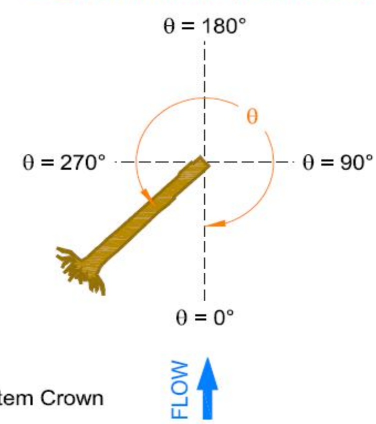
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	90.1	0.0	Stem tip: Crown	44.50	34.15	32.40	34.15	0.00

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Small Cobble	137.3	85.5	41.0	4	9.50	2.05	1.26
Bank	Gravel/cobble	137.0	85.3	41.0	4	1.50	2.38	2.12

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	0.0	0.0	0.0	0	0
↓Thalweg	26.5	0.0	26.5	1,323	1,651
Total	26.5	0.0	26.5	1,323	1,651

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	1,651
F_L (lbf)	0
W_T (lbf)	1,323
F_{soil} (lbf)	2,264
$F_{W,V}$ (lbf)	3,560
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	5,496
FS_V	4.33

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	20.9	20.9	1,786
Bank	0.0	5.6	5.6	478
Total	0.0	26.5	26.5	2,264

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.00	0.51	0.90	0.00	0.90	0

Horizontal Force Balance

F_D (lbf)	0
F_P (lbf)	5,450
F_F (lbf)	4,778
$F_{W,H}$ (lbf)	15,069
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	25,297
FS_H	50,604.64

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.81	4,301	11.49	0.87	4,222
Bank	4.81	1,150	1.51	0.87	556
Total	-	5,450	13.00	-	4,778

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
5.5	0.0	0.0	5.5	5.5	5.5	5.5

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	10,493
M_r (lbf)	144,880
FS_M	13.81

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Middle Stotenburg Creek Habitat Enhancement

Spreadsheet developed by
Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

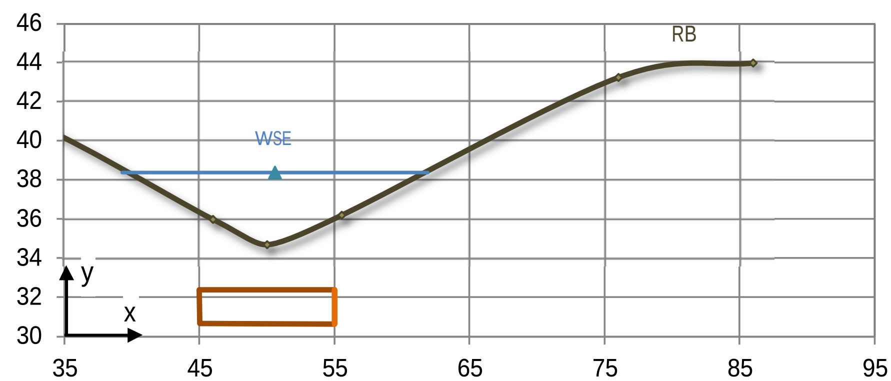
90% Design - December, 2020

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Log weir	Log Weir	Full span	Straight	34+78	3.70	15.22	3.86

Multi-Log Structures	Layer	Log ID
	Footer	3

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	18.00	42.50
Top LB	30.00	41.70
Toe LB	46.00	36.00
Thalweg	50.00	34.70
Toe RB	55.50	36.20
Top RB	76.00	43.25
Fldpln RB	86.00	44.00

Proposed Cross-Section and Structure Geometry (Looking D/S)

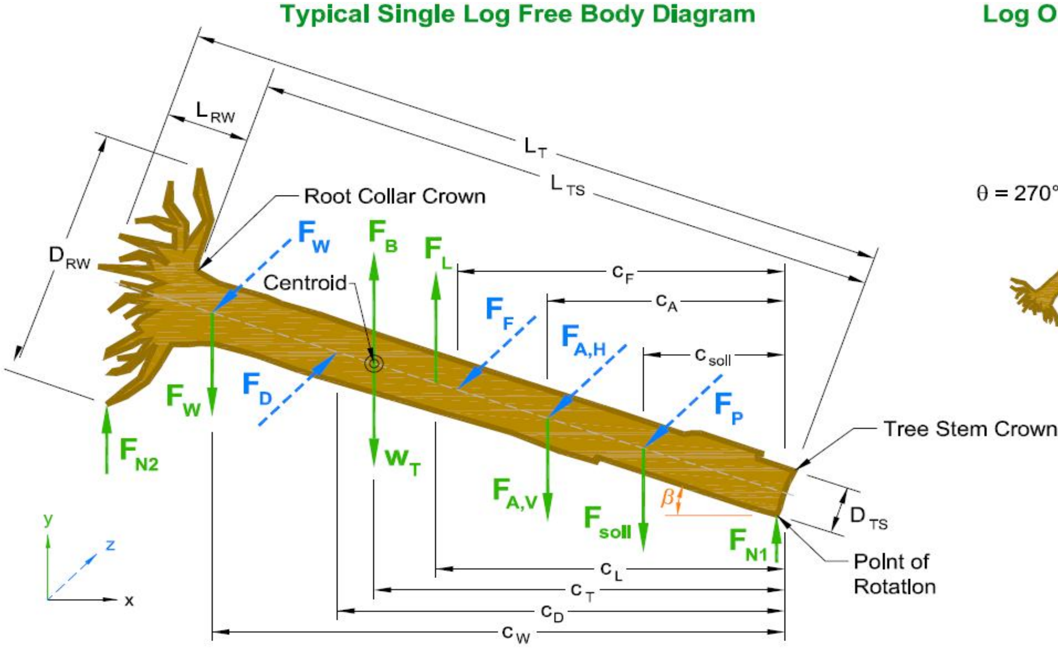


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Redwood, Coast (young)	No	10.00	1.75	-	-	24.5	50.0

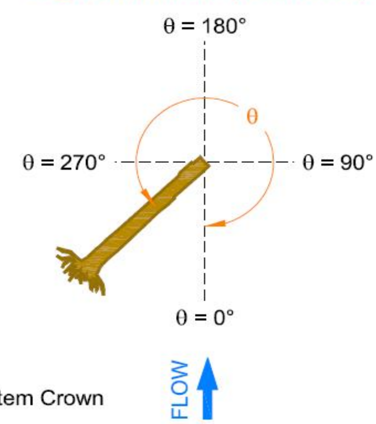
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	90.1	0.0	Stem tip: Crown	45.00	32.40	30.65	32.40	0.00

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Small Cobble	137.3	85.5	41.0	4	9.00	3.67	2.97
Bank	Gravel/cobble	137.0	85.3	41.0	4	1.00	3.96	3.78

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	0.0	0.0	0.0	0	0
↓Thalweg	24.1	0.0	24.1	1,203	1,501
Total	24.1	0.0	24.1	1,203	1,501

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	1,501	↑
F_L (lbf)	0	
W_T (lbf)	1,203	↓
F_{soil} (lbf)	4,562	↓
$F_{W,V}$ (lbf)	1,232	↓
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	5,496	↓
FS_V	4.66	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	46.6	46.6	3,985
Bank	0.0	6.8	6.8	577
Total	0.0	53.4	53.4	4,562

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.00	0.51	0.90	0.00	0.90	0

Horizontal Force Balance

F_D (lbf)	0	
F_P (lbf)	10,984	←
F_F (lbf)	4,778	←
$F_{W,H}$ (lbf)	7,512	←
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	23,273	←
FS_H	46,556.17	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	µ	F_F (lbf)
Bed	4.81	9,593	10.98	0.87	4,370
Bank	4.81	1,390	1.03	0.87	408
Total	-	10,984	12.00	-	4,778

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
5.0	0.0	0.0	5.0	5.0	5.0	5.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	8,213
M_r (lbf)	144,562
FS_M	17.60 ✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Middle Stotenburg Creek Habitat Enhancement
Notation, Units, and List of Symbols

Notation

90% De

Symbol	Description	Unit
A_W	Wetted area of channel at design discharge	ft^2
A_{Tp}	Projected area of wood in plane perpendicular to flow	ft^2
c_D	Centroid of the drag force along log axis	ft
c_{Am}	Centroid of a mechanical anchor along log axis	ft
c_{Ar}	Centroid of a ballast boulder along log axis	ft
c_{Asoil}	Centroid of the added ballast soil along log axis	ft
$c_{F\&N}$	Centroid of friction and normal forces along log axis	ft
c_L	Centroid of the lift force along log axis	ft
c_P	Centroid of the passive soil force along log axis	ft
c_{soil}	Centroid of the vertical soil forces along log axis	ft
$c_{T,B}$	Centroid of the buoyancy force along log axis	ft
$c_{T,W}$	Centroid of the log volume along log axis	ft
c_{WI}	Centroid of a wood interaction force along log axis	ft
C_{Lrock}	Coefficient of lift for submerged boulder	-
		-
C_{Di}	Base coefficient of drag for tree, before adjustments	-
C_D*	Effective coefficient of drag for submerged tree	-
C_{Di}	Base coefficient of drag for tree, before adjustments	-
C_W	Wave drag coefficient of submerged tree	-
$d_{b,avg}$	Average buried depth of log	ft
$d_{b,max}$	Maximum buried depth of log	ft
d_w	Maximum flow depth at design discharge in reach	ft
D_{50}	Median grain size in millimeters (SI units)	mm
D_r	Equivalent diameter of boulder	ft
D_{RW}	Assumed diameter of rootwad	ft
D_{TS}	Nominal diameter of tree stem (DBH)	ft
DF_{RW}	Diameter factor for rootwad ($DF_{RW} = D_{RW}/D_{TS}$)	-
e	Void ratio of soils	-
$F_{A,H}$	Total horizontal load capacity of anchor techniques	lbf
$F_{A,HP}$	Passive soil pressure applied to log from soil ballast	lbf
$F_{A,Hr}$	Horizontal resisting force on log from boulder	lbf
F_{Am}	Load capacity of mechanical anchor	lbf
$F_{A,V}$	Total vertical load capacity of anchor techniques	lbf
$F_{A,Vr}$	Vertical resisting force on log from boulder	lbf
$F_{A,Vsoil}$	Vertical soil loading on log from added ballast soil	lbf
F_B	Buoyant force applied to log	lbf
F_D	Drag forces applied to log	lbf
$F_{D,r}$	Drag forces applied to boulder	lbf
F_F	Friction force applied to log	lbf
F_H	Resultant horizontal force applied to log	lbf
F_L	Lift force applied to log	lbf
$F_{L,r}$	Lift force applied to boulder	lbf
F_P	Passive soil pressure force applied to log	lbf
F_{soil}	Vertical soil loading on log	lbf
$F_{W,H}$	Horizontal forces from interactions with other logs	lbf
$F_{W,V}$	Vertical forces from interactions with other logs	lbf

Notation (continued)

Symbol	Description	Unit
F_V	Resultant vertical force applied to log	lbf
Fr_L	Log Froude number	-
FS_V	Factor of Safety for Vertical Force Balance	-
FS_H	Factor of Safety for Horizontal Force Balance	-
FS_M	Factor of Safety for Moment Force Balance	-
g	Gravitational acceleration constant	ft/s^2
K_P	Coefficient of Passive Earth Pressure	-
$L_{T,em}$	Total embedded length of log	ft
L_{RW}	Assumed length of rootwad	ft
L_T	Total length of tree (including rootwad)	ft
L_{Tf}	Length of log in contact with bed or banks	ft
L_{TS}	Length of tree stem (not including rootwad)	ft
$L_{TS,ex}$	Exposed length of tree stem	ft
LF_{RW}	Length factor for rootwad ($LF_{RW} = L_{RW}/D_{TS}$)	-
M_d	Driving moment about embedded tip	lbf
M_r	Driving moment about embedded tip	lbf
N	Blow count of standard penetration test	-
p_o	Porosity of soil volume	-
Q_{des}	Design discharge	cfs
R	Radius	ft
R_c	Radius of curvature at channel centerline	ft
SG_r	Specific gravity of quartz particles	-
SG_T	Specific gravity of tree	-
u_{avg}	Average velocity of cross section in reach	ft/s
u_{des}	Design velocity	ft/s
u_m	Adjusted velocity at outer meander bend	ft/s
V_{dry}	Volume of soils above stage level of design flow	ft^3
V_{sat}	Volume of soils below stage level of design flow	ft^3
V_{soil}	Total volume of soils over log	ft^3
V_{RW}	Volume of rootwad	ft^3
V_S	Volume of solids in soil (void ratio calculation)	ft^3
V_T	Total volume of log	ft^3
V_{TS}	Total volume of tree	ft^3
V_V	Volume of voids in soil	ft^3
V_{Adry}	Volume of ballast above stage of design flow	ft^3
V_{Awet}	Volume of ballast below stage of design flow	ft^3
$V_{r,dry}$	Volume of boulder above stage of design flow	ft^3
$V_{r,wet}$	Volume of boulder below stage of design flow	ft^3
W_{BF}	Bankfull width at structure site	ft
W_r	Effective weight of boulder	lbf
W_T	Total log weight	lbf
x	Horizontal coordinate (distance)	ft
y	Vertical coordinate (elevation)	ft
$y_{T,max}$	Minimum elevation of log	ft
$y_{T,min}$	Maximum elevation of log	ft

Greek Symbols

Symbol	Description	Unit
β	Tilt angle from stem tip to vertical	deg
γ_{bank}	Dry specific weight of bank soils	lb/ft^3
$\gamma_{bank,sat}$	Saturated unit weight of bank soils	lb/ft^3
γ'_{bank}	Effective buoyant unit weight of bank soils	lb/ft^3
γ_{bed}	Dry specific weight of stream bed substrate	lb/ft^3
γ'_{bed}	Effective buoyant unit weight of stream bed substrate	lb/ft^3
γ_{rock}	Dry unit weight of boulders	lb/ft^3
γ_s	Dry specific weight of soil	lb/ft^3
γ'_s	Effective buoyant unit weight of soil	lb/ft^3
γ_{Td}	Air-dried unit weight of tree (12% MC basis)	lb/ft^3
γ_{Tgr}	Green unit weight of tree	lb/ft^3
γ_w	Specific weight of water at 50ºF	lb/ft^3
η	Rootwad porosity	-
θ	Rootwad (or large end of log) orientation to flow	deg
μ	Coefficient of friction	-
ν	Kinematic viscosity of water at 50ºF	ft/s^2
Σ	Sum of forces	-
ϕ_{bank}	Internal friction angle of bank soils	deg
ϕ_{bed}	Internal friction angle of stream bed substrate	deg

Units

Notation	Description
cfs	Cubic feet per second
ft	Feet
lb	Pound
lbf	Pounds force
kg	Kilograms
m	Meters
mm	Millimeters
s	Seconds
yr	Year

Abbreviations

Notation	Description
ARI	Average return interval
Avg	Average
DBH	Diameter at breast height
deg	Degrees
Dia	Diameter
Dist	Distance
D/S	Downstream
ELJ	Engineered log jam
Ex	Example
Fldpln	Floodplain
H&H	Hydrologic and hydraulic
ID	Identification
i.e.	That is
LB	Left bank
LW	Large wood
Max	Maximum
MC	Moisture content
Min	Minimum
ML	Multi-log
SL	Single log
N/A	Not applicable
no	Number
Pt	Point
rad	Radians
RB	Right bank
RW	Rootwad
SL	Single log
Thw	Thalweg (lowest elevation in channel bed)
Typ	Typical
U.S.	United States
WS	Water surface
WSE	Water surface elevation
↑	Above
↓	Below

Interaction Forces with Adjacent Logs					
Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)
1	Above	Pinned	9.0	704	-379
2	Above	Pinned	9.0	-1,936	-7,133
3	Below	Pinned	9.0	-4,264	-14,690

Middle Stotenburg Creek Habitat Enhancement

Large Wood Structure Stability Analysis

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Date of Last Revision: January 7, 2016

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Large Wood Structure Stability Analysis Spreadsheet was developed by Michael Rafferty, P.E.
Version 1.1

Reference for Companion Paper:

Rafferty, M. 2016. *Computational Design Tool for Evaluating the Stability of Large Wood Structures.* Technical Note TN-103.1. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, National Stream & Aquatic Ecology Center. 27 p.

Middle Stotenburg Creek Habitat Enhancement
Factors of Safety and Design Constants

Spreadsheet developed by
Michael Rafferty, P.E.

Symbol	Description	Value
FS_V	Factor of Safety for Vertical Force Balance	**1.50**
FS_H	Factor of Safety for Horizontal Force Balance	**1.50**
FS_M	Factor of Safety for Moment Force Balance	**1.50**

Symbol	Description	Units	Value
C_{Lrock}	Coefficient of lift for submerged boulder (D'Aoust, 2000)	-	0.17
C_{Drock}	Coefficient of drag for submerged boulder (Schultz, 1954)	-	0.85
g	Gravitational acceleration constant	ft/s^2	32.174
DF_{RW}	Diameter factor for rootwad ($DF_{RW} = D_{RW}/D_{TS}$)	-	**2.50**
LF_{RW}	Length factor for rootwad ($LF_{RW} = L_{RW}/D_{TS}$)	-	1.50
SG_{rock}	Specific gravity of quartz particles	-	2.65
γ_{rock}	Dry unit weight of boulders	lb/ft^3	165.0
γ_w	Specific weight of water at 50ºF	lb/ft^3	62.40
η	Rootwad porosity from NRCS Tech Note 15 (2001)	-	0.20
ν	Kinematic viscosity of water at 50ºF	ft/s^2	1.41E-05

Middle Stotenburg Creek Habitat Enhancement
Hydrologic and Hydraulic Inputs

Spreadsheet developed by
Michael Rafferty, P.E.

Average Return Interval (ARI) of Design Discharge: **100** yr

Site ID	Proposed Station	Design Discharge, Q_{des} (cfs)	Maximum Depth, d_w (ft)	Average Velocity, u_{avg} (ft/s)	Bankfull Width, W_{BF} (ft)	Wetted Area, A_W (ft^2)	Radius of Curvature, R_c (ft)
Log weir	35+00	255	4.53	2.67	26.1	70	450

Middle Stotenburg Creek Habitat Enhanc
Stream Bed Substrate Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Stream bed D_{50} (mm)	Stream Bed Substrate Grain Size Class	Bed Soil Class	Dry Unit Weight[1], γ_{bed} (lb/ft^3)	Buoyant Unit Weight, γ'_{bed} (lb/ft^3)	Friction Angle, ϕ_{bed} (deg)
Log weir	35+00	100.00	Small Cobble	4	137.3	85.5	41

Source: Compiled from Julien (2010) and Shen and Julien (1993); soil classes from NRCS Table TS14E–2 Soil classification

[1] γ_{bed} (kg/m^3) = 1,600 + 300 log D_{50} (mm) (from Julien 2010)

1 kg/m^3 = 0.062 1 lb/ft^3

Middle Stotenburg Creek Habitat E
Bank Soil Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Bank Soils (from field observations)	Bank Soil Class	Dry Unit Weight, γ_{bank} (lb/ft^3)	Buoyant Unit Weight, γ'_{bank} (lb/ft^3)	Friction Angle, ϕ_{bank} (deg)
Log weir	35+00	**Gravel/cobble**	4	137.0	85.3	41

Middle Stotenburg Creek Habitat Enhancement
Large Wood Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Project Location: West Coast

Timber Unit Weights			Air-dried[1] γ_{Td} (lb/ft^3)	Green[2] γ_{Tgr} (lb/ft^3)
Selected Species	**Common Name**	**Scientific Name**		
Tree Type #1:	**Redwood, Coast (young)**	Sequoia sempervirens	24.5	50.0
Tree Type #2:				
Tree Type #3:				
Tree Type #4:				
Tree Type #5:				
Tree Type #6:				
Tree Type #7:				
Tree Type #8:				
Tree Type #9:				
Tree Type #10:				

[1] **Air-dried unit weight, γ_{Td}** = Average unit weight of wood after exposure to air on a 12% moisture content volume basis. Air-dried unit weight is used in the force balance calculations for the portion of wood that is above the proposed thalweg elevation (assuming unsaturated conditions).

[2] **Green unit weight, γ_{Tgr}** = Average unit weight of freshly sawn wood when the cell walls are completely saturated with water. Green unit weight is used in the force balance calculations as a conservative estimate of the unit weight for the portion of wood that is below the proposed thalweg elevation (assuming saturated conditions). For comparison, Thevenet, Citterio, & Piegay (1998) determined wood unit weight typically increases by more than 100% after less than 24 hours exposure to water.

Source for timber unit weights:

U.S. Department of Agriculture, U.S. Forest Service. (2009) Specific Gravity and Other Properties of Wood and Bark for 156 Tree Species Found in North America. Research Note NRS-38. Table 1A.

Middle Stotenburg Creek Habitat Enhancement

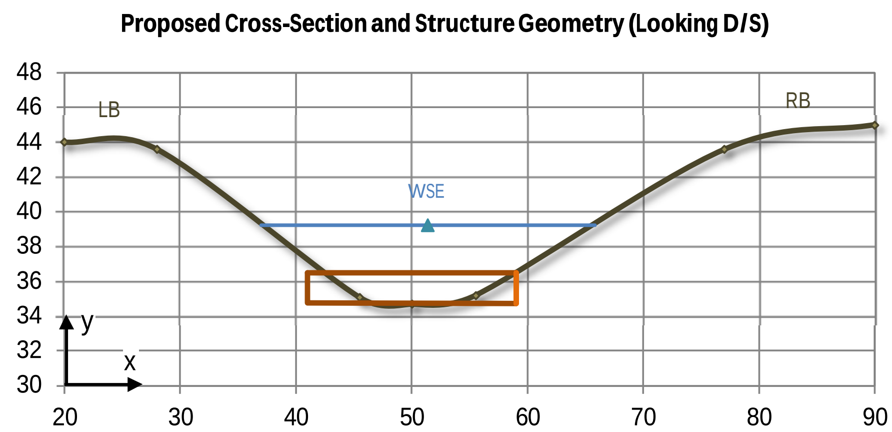
Spreadsheet developed by
Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Log weir	Log Weir	Full span	Straight	35+00	4.53	17.24	2.67

Multi-Log Structures	Layer	Log ID
	N/A	1

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	20.00	44.00
Top LB	28.00	43.60
Toe LB	45.50	35.07
Thalweg	50.00	34.70
Toe RB	55.50	35.20
Top RB	77.00	43.60
Fldpln RB	90.00	45.00

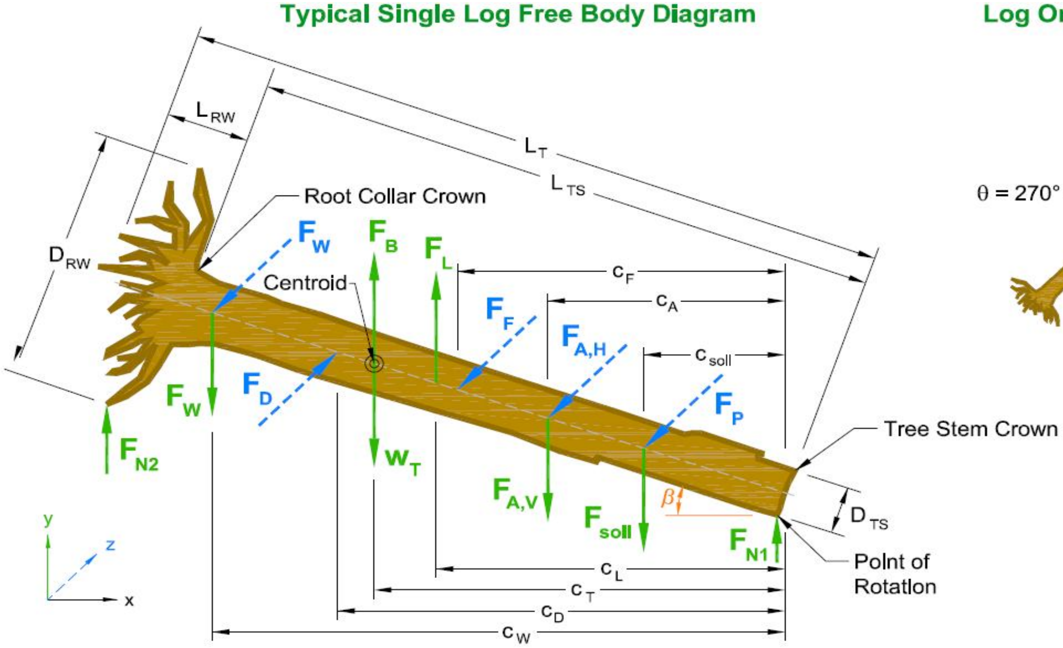


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Redwood, Coast (young)	No	18.0	1.75	-	-	24.5	50.0

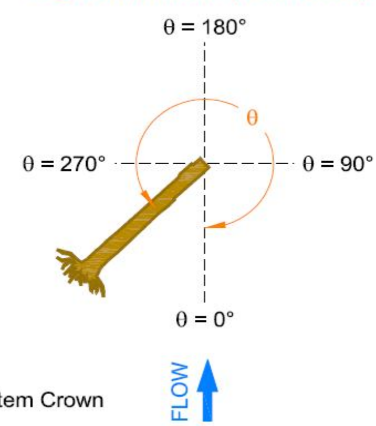
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	90.1	0.0	Stem tip: Crown	41.00	36.50	34.75	36.50	19.84

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Small Cobble	137.3	85.5	41.0	4	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	1.75	0.76	0.34

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft³)	V_{RW} (ft³)	V_T (ft³)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	43.3	0.0	43.3	1,059	2,702
↓Thalweg	0.0	0.0	0.0	0	0
Total	43.3	0.0	43.3	1,059	2,702

Lift Force

C_{LT}	0.03
F_L (lbf)	4

Vertical Force Balance

F_B (lbf)	2,702	↑
F_L (lbf)	4	↑
W_T (lbf)	1,059	↓
F_{soil} (lbf)	90	↓
$F_{W,V}$ (lbf)	5,736	↓
$F_{A,V}$ (lbf)	0	
Σ F_V (lbf)	4,180	↓
FS_V	2.54	

Soil Ballast Force

Soil	V_{dry} (ft³)	V_{sat} (ft³)	V_{soil} (ft³)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	1.1	1.1	90
Total	0.0	1.1	1.1	90

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.28	0.36	0.90	0.04	1.87	257

Horizontal Force Balance

F_D (lbf)	257	→
F_P (lbf)	217	←
F_F (lbf)	3,633	←
$F_{W,H}$ (lbf)	20,697	←
$F_{A,H}$ (lbf)	0	
Σ F_H (lbf)	24,291	←
FS_H	95.64	

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.81	0	10.91	0.87	2,095
Bank	4.81	217	8.01	0.87	1,538
Total	-	217	18.92	-	3,633

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
9.0	9.0	9.7	9.0	3.2	9.0	9.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	26,487
M_r (lbf)	321,013
FS_M	12.12

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft³)	V_{Awet} (ft³)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft³)	$V_{r,wet}$ (ft³)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Middle Stotenburg Creek Habitat Enhancement

Spreadsheet developed by
Michael Rafferty, P.E.

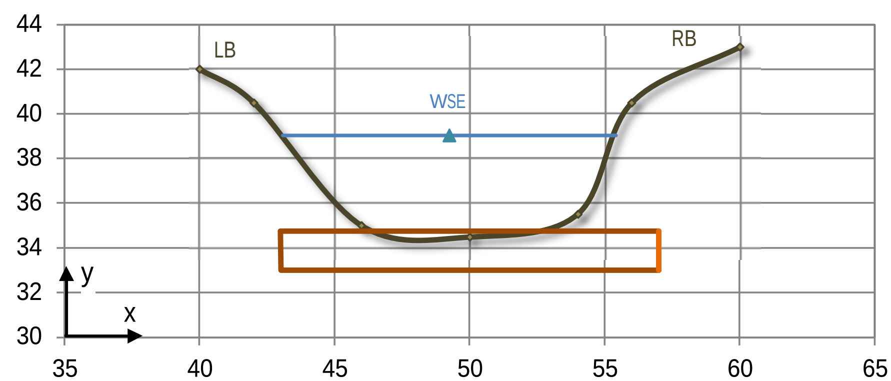
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Log weir	Log Weir	Full span	Straight	35+00	4.53	17.24	2.67

Multi-Log Structures	Layer	Log ID
	Stacked	2

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	40.00	42.00
Top LB	42.00	40.50
Toe LB	46.00	35.00
Thalweg	50.00	34.50
Toe RB	54.00	35.50
Top RB	56.00	40.50
Fldpln RB	60.00	43.00

Proposed Cross-Section and Structure Geometry (Looking D/S)

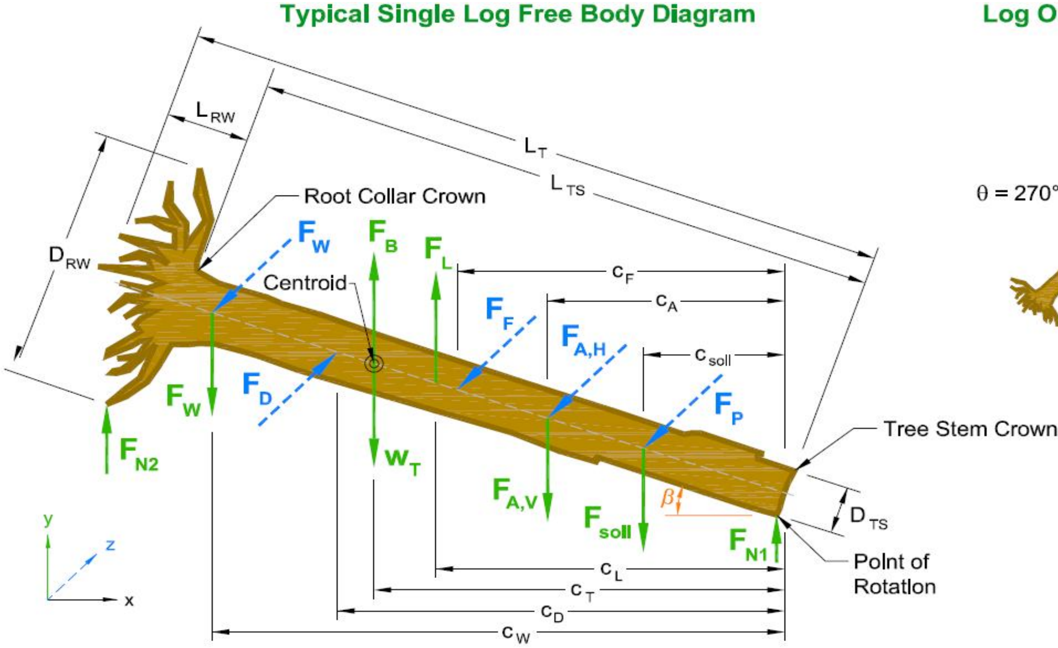


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Redwood, Coast (young)	No	14.00	1.75	-	-	24.5	50.0

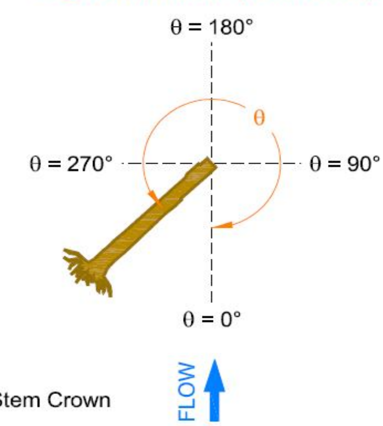
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	90.1	0.0	Stem tip: Crown	43.00	34.75	33.00	34.75	0.25

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Small Cobble	137.3	85.5	41.0	4	5.01	0.75	0.28
Bank	Gravel/cobble	137.0	85.3	41.0	4	6.00	6.38	3.30

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	2.9	0.0	2.9	72	183
↓Thalweg	30.7	0.0	30.7	1,537	1,918
Total	33.7	0.0	33.7	1,609	2,101

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	2.5	2.5	210
Bank	3.9	30.2	34.1	3,109
Total	3.9	32.7	36.6	3,319

Vertical Force Balance

F_B (lbf)	2,101
F_L (lbf)	0
W_T (lbf)	1,609
F_{soil} (lbf)	3,319
$F_{W,V}$ (lbf)	1,353
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	4,180
FS_V	2.99

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.00	0.36	0.90	0.00	0.91	2

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	µ	F_F (lbf)
Bed	4.81	507	10.05	0.87	2,282
Bank	4.81	7,485	5.95	0.87	1,351
Total	-	7,992	16.00	-	3,633

Horizontal Force Balance

F_D (lbf)	2
F_P (lbf)	7,992
F_F (lbf)	3,633
$F_{W,H}$ (lbf)	10,210
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	21,833
FS_H	13,992.32

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
7.0	0.0	6.5	7.0	7.1	7.0	7.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	22,698
M_r (lbf)	210,478
FS_M	9.27

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Middle Stotenburg Creek Habitat Enhancement

Spreadsheet developed by
Michael Rafferty, P.E.

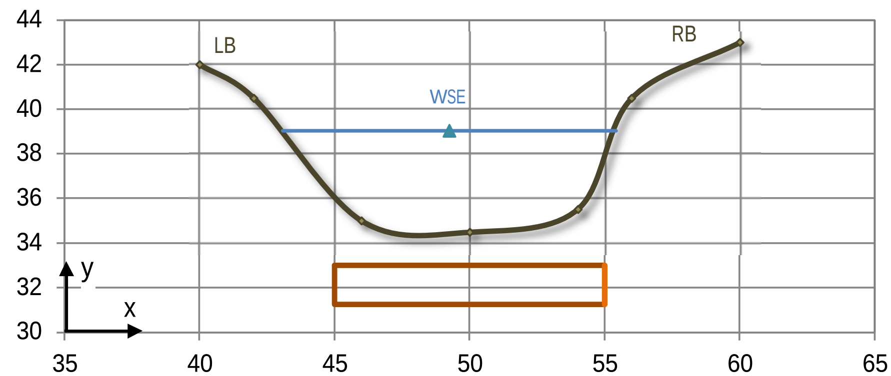
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Log weir	Log Weir	Full span	Straight	35+00	4.53	17.24	2.67

Multi-Log Structures	Layer	Log ID
	Footer	3

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	40.00	42.00
Top LB	42.00	40.50
Toe LB	46.00	35.00
Thalweg	50.00	34.50
Toe RB	54.00	35.50
Top RB	56.00	40.50
Fldpln RB	60.00	43.00

Proposed Cross-Section and Structure Geometry (Looking D/S)

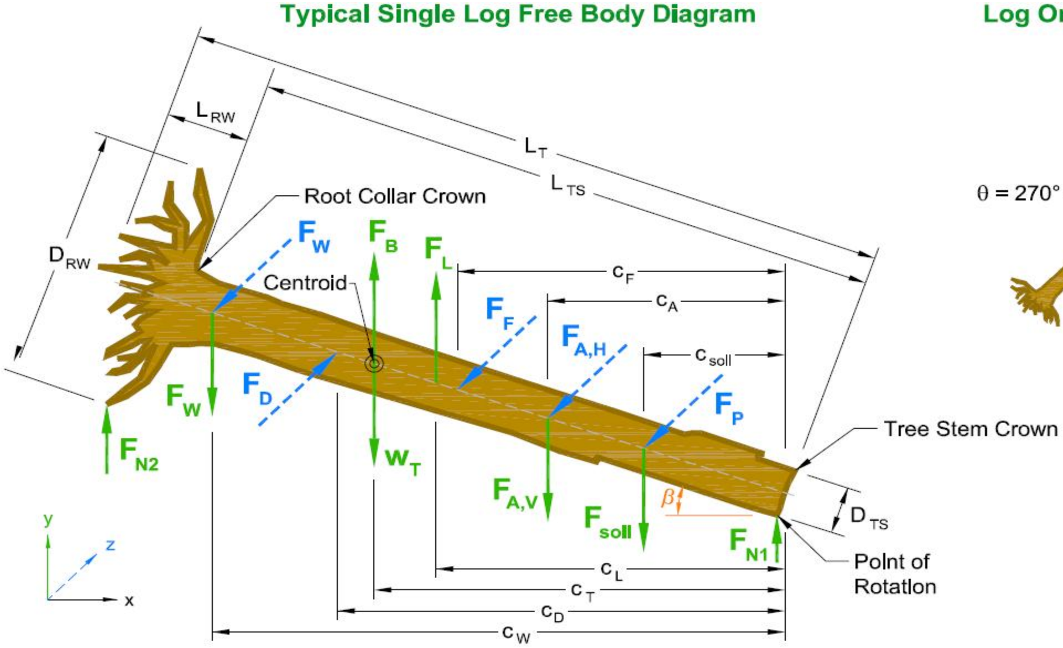


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Redwood, Coast (young)	No	10.00	1.75	-	-	24.5	50.0

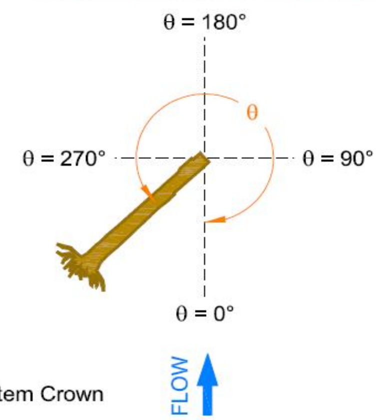
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	90.1	0.0	Stem tip: Crown	45.00	33.00	31.25	33.00	0.00

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Small Cobble	137.3	85.5	41.0	4	8.00	2.50	1.88
Bank	Gravel/cobble	137.0	85.3	41.0	4	2.00	5.00	3.24

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	0.0	0.0	0.0	0	0
↓Thalweg	24.1	0.0	24.1	1,203	1,501
Total	24.1	0.0	24.1	1,203	1,501

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	1,501	↑
F_L (lbf)	0	
W_T (lbf)	1,203	↓
F_{soil} (lbf)	3,207	↓
$F_{W,V}$ (lbf)	1,271	↓
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	4,180	↓
FS_V	3.78	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	26.3	26.3	2,248
Bank	0.0	11.2	11.2	959
Total	0.0	37.5	37.5	3,207

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.00	0.36	0.90	0.00	0.90	0

Horizontal Force Balance

F_D (lbf)	0	
F_P (lbf)	7,721	←
F_F (lbf)	3,633	←
$F_{W,H}$ (lbf)	10,408	←
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	21,762	←
FS_H	43,533.59	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.81	5,411	10.00	0.87	3,028
Bank	4.81	2,310	2.00	0.87	606
Total	-	7,721	12.00	-	3,633

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
5.0	0.0	0.0	5.0	5.0	5.0	5.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	9,105	
M_r (lbf)	112,992	
FS_M	12.41	✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Middle Stotenburg Creek Habitat Enhancement
Notation, Units, and List of Symbols

Notation

Symbol	Description	Unit
A_W	Wetted area of channel at design discharge	ft^2
A_{Tp}	Projected area of wood in plane perpendicular to flow	ft^2
c_D	Centroid of the drag force along log axis	ft
c_{Am}	Centroid of a mechanical anchor along log axis	ft
c_{Ar}	Centroid of a ballast boulder along log axis	ft
c_{Asoil}	Centroid of the added ballast soil along log axis	ft
$c_{F\&N}$	Centroid of friction and normal forces along log axis	ft
c_L	Centroid of the lift force along log axis	ft
c_P	Centroid of the passive soil force along log axis	ft
c_{soil}	Centroid of the vertical soil forces along log axis	ft
$c_{T,B}$	Centroid of the buoyancy force along log axis	ft
$c_{T,W}$	Centroid of the log volume along log axis	ft
c_{WI}	Centroid of a wood interaction force along log axis	ft
C_{Lrock}	Coefficient of lift for submerged boulder	-
C_{LT}	Effective coefficient of lift for submerged tree	-
C_{Di}	Base coefficient of drag for tree, before adjustments	-
C_D*	Effective coefficient of drag for submerged tree	-
C_{Di}	Base coefficient of drag for tree, before adjustments	-
C_W	Wave drag coefficient of submerged tree	-
$d_{b,avg}$	Average buried depth of log	ft
$d_{b,max}$	Maximum buried depth of log	ft
d_w	Maximum flow depth at design discharge in reach	ft
D_{50}	Median grain size in millimeters (SI units)	mm
D_r	Equivalent diameter of boulder	ft
D_{RW}	Assumed diameter of rootwad	ft
D_{TS}	Nominal diameter of tree stem (DBH)	ft
DF_{RW}	Diameter factor for rootwad ($DF_{RW} = D_{RW}/D_{TS}$)	-
e	Void ratio of soils	-
$F_{A,H}$	Total horizontal load capacity of anchor techniques	lbf
$F_{A,HP}$	Passive soil pressure applied to log from soil ballast	lbf
$F_{A,Hr}$	Horizontal resisting force on log from boulder	lbf
F_{Am}	Load capacity of mechanical anchor	lbf
$F_{A,V}$	Total vertical load capacity of anchor techniques	lbf
$F_{A,Vr}$	Vertical resisting force on log from boulder	lbf
$F_{A,Vsoil}$	Vertical soil loading on log from added ballast soil	lbf
F_B	Buoyant force applied to log	lbf
F_D	Drag forces applied to log	lbf
$F_{D,r}$	Drag forces applied to boulder	lbf
F_F	Friction force applied to log	lbf
F_H	Resultant horizontal force applied to log	lbf
F_L	Lift force applied to log	lbf
$F_{L,r}$	Lift force applied to boulder	lbf
F_P	Passive soil pressure force applied to log	lbf
F_{soil}	Vertical soil loading on log	lbf
$F_{W,H}$	Horizontal forces from interactions with other logs	lbf
$F_{W,V}$	Vertical forces from interactions with other logs	lbf

Notation (continued)

Symbol	Description	Unit
F_V	Resultant vertical force applied to log	lbf
Fr_L	Log Froude number	-
FS_V	Factor of Safety for Vertical Force Balance	-
FS_H	Factor of Safety for Horizontal Force Balance	-
FS_M	Factor of Safety for Moment Force Balance	-
g	Gravitational acceleration constant	ft/s^2
K_P	Coefficient of Passive Earth Pressure	-
$L_{T,em}$	Total embedded length of log	ft
L_{RW}	Assumed length of rootwad	ft
L_T	Total length of tree (including rootwad)	ft
L_{Tf}	Length of log in contact with bed or banks	ft
L_{TS}	Length of tree stem (not including rootwad)	ft
$L_{TS,ex}$	Exposed length of tree stem	ft
LF_{RW}	Length factor for rootwad ($LF_{RW} = L_{RW}/D_{TS}$)	-
M_d	Driving moment about embedded tip	lbf
M_r	Driving moment about embedded tip	lbf
N	Blow count of standard penetration test	-
p_o	Porosity of soil volume	-
Q_{des}	Design discharge	cfs
R	Radius	ft
R_c	Radius of curvature at channel centerline	ft
SG_r	Specific gravity of quartz particles	-
SG_T	Specific gravity of tree	-
u_{avg}	Average velocity of cross section in reach	ft/s
u_{des}	Design velocity	ft/s
u_m	Adjusted velocity at outer meander bend	ft/s
V_{dry}	Volume of soils above stage level of design flow	ft^3
V_{sat}	Volume of soils below stage level of design flow	ft^3
V_{soil}	Total volume of soils over log	ft^3
V_{RW}	Volume of rootwad	ft^3
V_S	Volume of solids in soil (void ratio calculation)	ft^3
V_T	Total volume of log	ft^3
V_{TS}	Total volume of tree	ft^3
V_V	Volume of voids in soil	ft^3
V_{Adry}	Volume of ballast above stage of design flow	ft^3
V_{Awet}	Volume of ballast below stage of design flow	ft^3
$V_{r,dry}$	Volume of boulder above stage of design flow	ft^3
$V_{r,wet}$	Volume of boulder below stage of design flow	ft^3
W_{BF}	Bankfull width at structure site	ft
W_r	Effective weight of boulder	lbf
W_T	Total log weight	lbf
x	Horizontal coordinate (distance)	ft
y	Vertical coordinate (elevation)	ft
$y_{T,max}$	Minimum elevation of log	ft
$y_{T,min}$	Maximum elevation of log	ft

Greek Symbols

Symbol	Description	Unit
β	Tilt angle from stem tip to vertical	deg
γ_{bank}	Dry specific weight of bank soils	lb/ft^3
$\gamma_{bank,sat}$	Saturated unit weight of bank soils	lb/ft^3
γ'_{bank}	Effective buoyant unit weight of bank soils	lb/ft^3
γ_{bed}	Dry specific weight of stream bed substrate	lb/ft^3
γ'_{bed}	Effective buoyant unit weight of stream bed substrate	lb/ft^3
γ_{rock}	Dry unit weight of boulders	lb/ft^3
γ_s	Dry specific weight of soil	lb/ft^3
γ'_s	Effective buoyant unit weight of soil	lb/ft^3
γ_{Td}	Air-dried unit weight of tree (12% MC basis)	lb/ft^3
γ_{Tgr}	Green unit weight of tree	lb/ft^3
γ_w	Specific weight of water at 50ºF	lb/ft^3
η	Rootwad porosity	-
θ	Rootwad (or large end of log) orientation to flow	deg
μ	Coefficient of friction	-
ν	Kinematic viscosity of water at 50ºF	ft/s^2
Σ	Sum of forces	-
ϕ_{bank}	Internal friction angle of bank soils	deg
ϕ_{bed}	Internal friction angle of stream bed substrate	deg

Units

Notation	Description
cfs	Cubic feet per second
ft	Feet
lb	Pound
lbf	Pounds force
kg	Kilograms
m	Meters
mm	Millimeters
s	Seconds
yr	Year

Abbreviations

Notation	Description
ARI	Average return interval
Avg	Average
DBH	Diameter at breast height
deg	Degrees
Dia	Diameter
Dist	Distance
D/S	Downstream
ELJ	Engineered log jam
Ex	Example
Fldpln	Floodplain
H&H	Hydrologic and hydraulic
ID	Identification
i.e.	That is
LB	Left bank
LW	Large wood
Max	Maximum
MC	Moisture content
Min	Minimum
ML	Multi-log
SL	Single log
N/A	Not applicable
no	Number
Pt	Point
rad	Radians
RB	Right bank
RW	Rootwad
SL	Single log
Thw	Thalweg (lowest elevation in channel bed)
Typ	Typical
U.S.	United States
WS	Water surface
WSE	Water surface elevation
↑	Above
↓	Below

Interaction Forces with Adjacent Logs					
Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)
1	Above	Pinned	9.0	1,556	39
2	Below	Pinned	9.0	-2,827	-10,448
3	Below	Pinned	9.0	-2,909	-10,249

Appendix E

Historical Aerial Photographs

Appendix F

Ecological Cost-Benefit Analysis

Appendix G

Construction Specifications