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MEMORANDUM

DATE: May 12, 2016

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SUBJECT: Soquel Creek Large Woody Debris Habitat Complexity and Streambank/Road Repair Projects, 2015 Annual Physical Monitoring Report

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County: Santa Cruz

Description: T10S, R1E, Section 7 - MDB&M.

Quadrangles: Laurel (1994) United States Geological Survey 7.5 minute Quadrangle Series (Topographic):

References: See Appendix A

Introduction

At the request of the California Department of Forestry and Fire Protection (CAL FIRE), staff of the California Geological Survey (CGS) provided on-site technical support and direction for a Large Woody Debris and Habitat Complexity project which involved the installation of ten, large wood (LW) elements in four project reaches in the East Branch of Soquel Creek, within the Soquel Demonstration State Forest (SDSF). CGS also provided on-site technical support and direction for a Streambank/Road Repair project which involved the installation of a rootwad based revetment structure along the East Branch of Soquel Creek. This memorandum presents the 2015 annual physical monitoring record for those elements, which include the four reaches referred to as Sites 1, 2, 4, and 5 and also for the Streambank/Road Repair site (Figure 1). Site 1 was completed in September of 2012 and Sites 2, 4, and 5 were constructed in August and September of 2013. The Streambank/Road Repair site was constructed in July and August 2014. Originally, seven potential sites were identified and after a detailed field survey in 2011, Sites 1, 2, 4, and 5 were ultimately selected for the Large Woody Debris Habitat Complexity project implementation. The Streambank/Road Repair project (Site 7) was done as a separate project implementation.

Background

Large Woody Debris and Habitat Complexity Project

The Large Woody Debris and Habitat Complexity Project is located along the East Branch of Soquel Creek, within the boundaries of Soquel Demonstration State Forest (SDSF). The 2,681 acre forest is managed by CAL FIRE. Previous work has found that Soquel Creek has declining populations of steelhead and previously once supported populations of coho salmon (Santa Cruz County RCD, 2003; National Marine Fisheries Service, 2012). An overview of the 2004 extent and distribution of salmonids in Santa Cruz County can be found in a map prepared by the County of Santa Cruz (2004).

Typical of many suburban watersheds, Soquel Creek was gleaned of all woody debris, large or otherwise, as both a fisheries management approach and a flood management tactic between approximately the early 1970s and the late 2000s (Lassettre and Kondolf, 2011). Since then, the critical role of Large Woody Debris (LWD) in providing fish habitat and promoting watershed and stream stability has been recognized and well documented (Triska and Cromack, 1980; Sedell et al, 1988).

With the recognition that salmonid fish populations were declining in the Soquel Creek Watershed, various studies (Balance Hydrologics, 2003; Santa Cruz County RCD, 2003) were undertaken to describe the condition of the Soquel Creek watershed and identify factors that could be affecting the fish populations. These studies identified various factors including a severe shortage of large wood and pool habitat in Soquel Creek and geomorphic evidence within certain reaches where the channel structure was observed to be highly influenced by the presence of large wood and bedrock (Balance Hydrologics, 2003; Santa Cruz County RCD, 2003). Additionally, Soquel Creek was identified by the National Oceanic and Atmospheric (NOAA) Fisheries Service as a “focus” watershed in their Recovery Plan for the Evolutionarily Significant Unit of Central California Coast Coho Salmon, and also identified low amounts of large wood as a stressor for the recovery of coho salmon in Soquel Creek (National Marine Fisheries Service, 2012).

SDSF’s Large Woody Debris and Habitat Complexity Project was undertaken in an effort to help address the shortage of LWD within Soquel Creek, and to increase overall stream quality from a biological standpoint.

The SDSF large wood placement project includes the following components:

(1) Installation of large wood along a 0.7 mile stretch of the East Branch of Soquel Creek in four, discrete reaches, and

(2) Monitoring the large wood elements to document changes in channel geomorphology, movement of large wood, modifications to aquatic habitat, and resultant response of biotic (for example salmonid) communities.

The project design and installation details are described in “as-built” reports prepared for Site 1 (CGS, 2013) and Sites 2, 4, and 5 (CGS, 2014a).

Streambank/Road Repair Project

The Streambank/Road Repair was undertaken in order to preserve Hihn's Mill Road, the main access road through SDSF. At this location, Hihn's Mill Road is adjacent to the channel of the East Branch of Soquel Creek and over several years the stream bank had been retreating into the road prism to the point of rendering the road impassable to logging trucks. Continued streambank retreat would have ultimately made the road impassable for administrative and emergency vehicle access also.

The SDSF Streambank/Road Repair project includes the following components:

(1) Installation of nine rootwad-footer log pairs for a rootwad-rock wall revetment along 140 feet of stream bank, and

(2) Monitoring the revetment site to document performance of the rootwad revetment and changes in channel morphology.

The project design and installation details are described in the "as-built" report (CGS, 2014b).

Project Description

Presented below is a general description of the large wood elements installed or constructed at the four project reaches (Sites 1, 2, 4, and 5) and the Streambank/Road Repair site. A summary of the quantity of wood introduced to the creek as a result of the Large Woody Debris and Habitat Complexity project is also included. The "as-built" configuration of the large wood elements at each site are provided in the attachments as Plates 1-5. More specific details pertaining to the large wood metrics at each project reach (Sites 1, 2, 4, and 5) are provided in Appendix B.

Site 1

Site 1 is an approximately 300-foot long reach with three large wood (LW) elements comprised of multi-stemmed redwood trees with attached rootwads. The three LW elements are identified as Site 1a, Site 1b, and Site 1c, upstream to downstream, respectively. The rootwad fans were placed facing upstream with the stems oriented in the downstream direction. Installation took place in September 2012. The primary Site 1 structures consist of:

- Site 1a – two (2) rootwads that are 5.5 and 10.5 feet in diameter with three stems ranging from 19 to 30 inches diameter and 110 to 111 feet long.
- Site 1b – one (1) rootwad that is 12 feet in diameter with four stems that range from 14 to 51 inches diameter and 44 to 86 feet long.
- Site 1c – one (1) rootwad with a diameter of 12.5 feet and three stems that range from 24 to 39 inches in diameter and 85 to 87 feet in length.

Site 2

Site 2 consists of three LW elements within an approximately 300-foot reach. The three LW elements are identified as Site 2a, Site 2b, and Site 2c, upstream to downstream, respectively. The rootwad fan at Site 2a was placed upstream at an angle with the attached stem placed up on the left bank.

Site 2b contains a rootwad cover log adjacent to the left bank facing the stream channel and oriented generally parallel to the flow direction. The rootwad fans at Site 2c were placed facing downstream with the stems oriented in the upstream direction. Installation took place in August 2013. The primary Site 2 structures consist of:

- Site 2a - a log cluster comprised of three logs ranging from 32-34 inches in diameter and 58.5-65.5 feet in length, and a log with an attached 7-foot diameter rootwad and a 32-inch diameter and 27-foot long stem.
- Site 2b - a 28 inch diameter and 69-foot long log vane placed with a rootwad cover log that is 10.6 feet in diameter with a stem that is 42 inches diameter and 35-feet long.
- Site 2c - a rootwad “backstop” structure consisting of three rootwads, one of which is multi-stemmed. The rootwads are 4.5 to 11 feet in diameter and the various stems range from 19 to 36 inches in diameter and 48 to 93 feet long.
- In addition to the primary stems, broken or trimmed tops from the large wood elements were incorporated into the clusters. Several alders and a few sycamores that were broken and pinned by the clusters are also included in the placement. These additional wood elements range from 14 to 30 inches in diameter and 24 to 64.5 feet long.

Site 4

Site 4 consists of three large wood elements within an approximately 300-foot reach. The three LW elements are identified as Site 4a, Site 4b, and Site 4c, upstream to downstream, respectively. The Site 4b rootwad “backstop” structure was placed in the roughly 2/3 bankfull width position from the left bank with the rootwad fan facing upstream and the stem oriented in the downstream direction. The Site 4c rootwad cover log was placed with the rootwad fan adjacent to the left bank facing the stream channel and oriented generally parallel to the stream flow direction. Installation took place in September 2013. The primary Site 4 structures are:

- Site 4a - a log cluster comprised of 9 interlaced logs ranging in diameter from 12 to 33 inches and in length from 25.6 feet to 63.3 feet.
- Site 4b - a rootwad “backstop” structure consisting of a large single redwood stem 48 inches in diameter and 57 feet long and the attached 9-foot diameter rootwad.
- Site 4c - a 20 inch diameter and 60-foot long log vane with a rootwad cover log. The rootwad diameter is 8.5 feet and the stem is 53 inches in diameter and 16 feet long.

Site 5

Large wood at Site 5 was limited to a single log cluster. Installation took place in September 2013. Rootwad fans were placed facing upstream with stems oriented in the downstream direction. The primary Site 5 structure consists of:

- Site 5 – two (2) 12-foot diameter Douglas-fir rootwads with 48 and 53 inch diameter stems, and lengths of 53 and 116 feet. The Douglas –fir rootwads are augmented with a 32-inch diameter and 61-foot long redwood log, and a 30-inch diameter and 43.5 foot long Douglas-fir log. In addition an 18-inch diameter and 50-foot long alder and a 12-inch diameter and 56-foot long sycamore were broken and pinned during the installation and are incorporated in the structure.

Streambank/Road Repair Site

The Streambank/Road Repair site was constructed in July and August 2015 and consists of nine redwood rootwad-footer log pairs obtained from the Fern Gulch timber harvest. Footer logs ranged from 20 to 27 feet in length, rootwads 25 to 28 feet (including rootwad). The rootwads and footer logs were placed in a lattice formation (each footer log supports its immediate rootwad fan and the bole of the next upstream rootwad) extending into the road fill. The road fill between and above the rootwads was reinforced with a rock revetment which extends from below the channel scour depth to an elevation of 492 feet which corresponds to the elevation of the right bank and adjacent flood plain and is approximately two feet above the estimated height (stage) of a ten-year event (storm).

Large Wood Metrics Summary (Sites 1, 2, 4, and 5)

The total amount of wood introduced into Soquel Creek at the four sites includes 45 stems and 10 rootwads. The stems range from 10 to 54 inches diameter and 26 to 116 feet long. The rootwads range from 8.5 to 12.5 feet in diameter. The total calculated volume of wood added is 11,528 cubic feet (Appendix B).

In-stream Wood Loading (Site 1, 2, 4, and 5)

The total amount of LWD wood introduced into Soquel Creek for all four project reaches calculates to 412ft^3/100ft (LWD volume versus channel length) or 0.27ft^3/ft^2 (LWD volume versus channel area). This is similar to amounts described in nine studies of disturbed but recovering watersheds of the Pacific Northwest (Keller and MacDonald, 1983; Long, 1987; Swanson et al, 1987; Fausch and Northcote, 1992; McHenry et al, 1998; Benda, Bigelow, and Worsley, 2002; Benda, Bigelow, and Andras, 2003; Faustini and Jones, 2003; and Wooster and Hilton, 2004) where median LWD values of about 486ft^3/100ft or 0.28ft^3/ft^2 of channel are reported. See Appendix C for more detailed information on in-stream wood loading.

Monitoring

Hydrology

2012/2013 Winter Rains: Two significant rain events occurred producing peak stream flows in Soquel Creek of roughly 950 cubic feet per second (cfs) (an approximately 4-year return interval) and 1260 cfs (an approximately 8-year return interval) on December 2, 2012 and December 23, 2012, respectively. Since Site 1 was installed in September 2012, the LWD at this location experienced these 2012/2013 peak flows. These events did not move the Site 1 rootwads from their installation point, but the stems attached to the rootwads did rotate from their original position oriented across the creek to an orientation more in line with the flow direction. Figure 2 shows the change in stem orientation at each of the Site 1 structures.

2013/2014 and 2014/2015 Winter Rains: The winter season of 2013/2014 and the early part of the 2014/2015 winter season did not produce major storm events. The largest event over this period occurred on December 12, 2014 producing a peak flow of 221 cfs (approximately a 1.4-year return interval storm) in the vicinity of the project sites. The minor storm events were not significant enough to alter the LW elements substantially from their initial placement location.

2014/2015 and 2015/2016 Winter Rains: The winter season of 2014/2015 and the early part of the 2015/2016 winter season (through December 2, 2015) did not produce major storm events. The largest event over this period occurred on February 8, 2015, producing a peak flow of 345 cfs (approximately a 1.7-year return interval storm) in the vicinity of the project sites. The minor storm events were not significant enough to alter the LW elements substantially from their initial placement location, with the exception of rotating several of the logs in the log cluster sites at Sites 2a, 4a, and 5, and the mobilization of one of the logs from Site 2a. The mobilized log from 2a was entrained downstream in the Site 2c structure.

Streamflows are extrapolated from the gage located in the town of Soquel (USGS 11160000).

Surveys

Because storm events that occurred since the installation of all four project sites have not altered the location or position of the large wood elements to any great significance, the annual physical monitoring effort conducted in 2015 consisted of thalweg surveys at each site to document changes in channel morphology. The thalweg surveys were completed using an optical level at each site to record distance and relative elevation measurements. The data was processed to correlate distances and elevations with previous surveys performed at each site. Elevation control at Site 1 was determined by correlating a bank survey pin placed at the site with an elevation control determined by Cal Fire surveyors in 2010 based on a benchmark located on the right bank upstream bridge abutment on the Hihn's Mill Bridge (elevation of 495.10 feet above mean sea level). Elevation control for Sites 2, 4, and 5 were tied into the Site 1 bank survey pin during the 2015 survey. Elevations at these sites were previously established by GPS locations collected at each site, which was later found to be inaccurate in the elevation readings. Although the GPS determined elevations were inaccurate with respect to the elevations determined during a February 2011 survey using the Hihn's Mill Bridge abutment benchmark, they provided a useful relative elevation comparison. Based on this 2015 survey, elevations throughout Sites 2, 4, and 5 were adjusted using stable, previously surveyed locations that were re-populated during this survey to provide a control point for the adjustments to be made. The elevation control for the Streambank/Road Repair site is the benchmark on the Hihn's Mill bridge abutment.

Thalweg surveys conducted at Site 1 include a post-installation survey completed in November 2012 and monitoring surveys conducted in February 2013, December 2014, and December 2015. Thalweg surveys represented for Sites 2, 4, and 5 include the post-installation surveys completed in October 2013 and monitoring surveys conducted in December 2014 and December 2015. Thalweg surveys conducted at the Streambank/Road Repair site include the November 2014 As-Built survey, a December 2014 post-installation survey, and the December 2015 monitoring survey. A baseline thalweg survey was conducted in February 2011. Thalweg surveys are shown in Figures 3-7.

In addition to the thalweg surveys, a pebble count (after the Wolman Pebble Count technique, [Wolman, 1954]) was conducted at each of the four large wood sites in October 2013, providing baseline streambed particle size data for Sites 2, 4, and 5. The pebble count at Site 1 was completed the year following LWD installation and should not be considered as baseline data, but will be useful for monitoring streambed particle size as the project matures. The pebble count results are provided below at the end of the results discussion and are illustrated in Figures 8 and 9.

Photo Monitoring

Soquel Demonstration State Forest Staff have established photographic monitoring points at the large wood sites and are responsible for conducting the photo monitoring. Photo documentation collected by SDSF staff is being submitted as a separate report and is not included within this annual monitoring report. For purposes of illustrating the large wood sites, photo documentation of the four sites, along with the Streambank/Road Repair Site, including a photo from the year of installation and a photo from after the first winter rainy season from installation and/or near the date of this annual monitoring event, has been provided as Appendix D.

Results

This section presents the results of the physical monitoring that has occurred at each of the large wood sites and the Road/Stream Bank Repair Site since installation. A pre-project long-profile thalweg survey was conducted in February 2011. The 2011 survey data is shown in Figures 3-7 to illustrate pre-project channel conditions.

Site 1

November 2012 Survey. Site 1 LWD was installed in September 2012. The Site 1 post-installation survey profile reflects a uniform channel with one incipient pool. An incipient pool, for the purpose of the large wood monitoring, is defined as a bed roughness element less than 1-foot in residual depth, meaning the depth calculated from the low point of the roughness element to the top of the next downstream riffle crest or high point, irrespective of water depth. A pool is defined as a bed roughness element having a residual depth of 1-foot and greater.

February 2013 Survey. This survey was conducted after placement of LWD at Site 1 and prior to placement of LWD at sites 2, 4, and 5. This survey reflects significant changes to channel morphology relative to the previous survey (CGS, 2013) after the occurrence of an approximately 4-year return interval storm and an approximately 8-year return interval storm that occurred in December 2012. The most significant change was an increase from 0 to 2 pools (1.01 and 1.23 feet deep) and 1 incipient pool to 4 incipient pools with depths ranging from approximately 0.42 to 0.98 feet. In addition to the increase in pools and bed roughness, it appears that approximately ½ to 1 ½ feet of channel aggradation occurred primarily at the area immediately upstream of the upstream end of each large wood element.

The storm flows also had an effect on the orientation of the large wood elements. Each of the three rootwad structures with stems were rotated during the higher flows, aligning more with the downstream flow path than at the angle originally installed. While the stems rotated, the overall large elements remained in place, performing as designed to remain meta-stable during 5-year return interval events. Several smaller logs incorporated into the large wood elements shifted and one 31-inch diameter, 42-foot long redwood log dislodged from where originally pinned at Site 1b and was found approximately 1,100 feet downstream lodged against a large boulder near Site 2c. The rotation of the large wood elements is shown in Figure 2.

December 2014 Survey. The December 2014 survey indicates two pools (1.18 and 1.03 feet deep) remain, although their locations within the reach have shifted. There also appears to be the development of an additional incipient pool, increasing the number of incipient pools to 5, with depths of approximately 0.11 to 0.79 feet. Nearly the entire reach has locally aggraded with channel elevations increased approximately 1 ½ feet from the previous survey (February 2013) and nearly 3 feet when compared to the February 2011 pre-installation survey.

December 2015 Survey. The December 2015 survey indicates the presence of one pool (1.15 feet deep) and four incipient pools (0.16 to 0.78 feet deep). The thalweg profile appears to have smoothed out compared to the previous survey (CGS, 2015) with fewer pools and incipient pools. While there may have been a reduction in the number of pools and incipient pools, the larger pool and incipient pool appear to be increasing in size. The pools and incipient pools in near proximity to the large wood structures appear to be relatively stable features with minor fluctuations in depth and position. Additionally, the thalweg profile has degraded approximately ½ foot to 2 1/2 feet within the reach since the previous survey (CGS, 2015), and appears to be returning to pre- and immediately post-installation levels. These channel changes are represented in Figure 3.

Site 2

October 2013 and December 2014 Surveys. Site 2 LWD installation occurred in August 2013. Comparison of the October 2013 and December 2014 surveys indicate the thalweg profile at Site 2 has changed relatively dramatically following installation of the large wood elements even though the largest storm was only a 1.4-year return interval. The number of pools increased from 3 incipient pools (0.36 to 0.61 feet deep) present at the time of installation to 3 pools (1.16 to 2.28 feet deep) and 5 incipient pools (0.54 to 0.86 feet deep) post installation. Immediately upstream of the Site 2c rootwad backstop structure, channel elevation locally increased approximately 2 ½ feet with aggraded stream gravels. The aggraded material appears to extend upstream from the rootwad backstop a distance of approximately 200 feet. At Site 2b a 2.3-foot deep scour pool was measured at the location of the rootwad cover for the vane log. Scour pools appear to have increased in depth, ranging from less than 1-foot in depth before installation to approximately 0.5 to 2.3 feet deep after installation. For example, at Site 2a (location of the log cluster structure) a scour pool has deepened by approximately 0.5 feet when compared to the previous survey.

December 2015 Survey. The December 2015 thalweg survey indicates the presence of three pools (1.03 to 2.41 feet deep) and three incipient pools (0.28 to 0.78 feet deep). The number of pools remained from the previous survey and there was a slight decrease in incipient pools from five to three when compared to the 2014 survey. The pools associated with large wood structures 2b and 2c appear to be generally stable in terms of their location. The thalweg profile appears to remain dynamic through this reach with locations of both relative aggradation and degradation with respect to the December 2013 survey. Overall, the channel remains aggraded throughout the center of the reach in comparison to pre- and immediately post-installation surveys. Both the log vane structure (2b) and the rootwad backstop structure (2c) appear to be effectively retaining gravels resulting in localized aggradation. Though not reflected in the thalweg survey, a large gravel bar was observed to have built up along the right bank upstream of Site 2b and one of the logs from the Site 2a log cluster mobilized and moved downstream where it was entrained in the Site 2c rootwad backstop structure. The remaining three logs at Site 2a have been rotated and repositioned within that site location. This reach seems to have the most fluctuation with regard to both thalweg adjustments and site adjustments in comparison to the other three large wood sites (1, 4, and 5) even though the flow events have remained relatively low with a maximum of a 1.7 year return interval since installation. These channel changes are represented in Figure 4.

Site 4

October 2013 and December 2014 Surveys. Site 4 LWD installation was conducted in September 2013. Site 4 exhibited relatively modest changes in post channel morphology following installation when comparing the October 2013 and December 2014 surveys, recognizing that the largest storm over this period had a 1.4-year return interval. The number of incipient pools increased from four (0.20 to 0.76 feet deep) to six (0.32 to 0.58 feet deep). Channel elevation appears to have locally increased (via aggradation) approximately ½ to 1 foot through most of the reach distance.

December 2015 Survey. The December 2015 survey appears relatively consistent with the 2014 survey. There are still six incipient pools (0.19 to 0.97 feet deep), although the deepest one has increased in depth and is nearly a pool. The survey through this reach extended farther than it did the previous year and captured one pool downstream of Site 4c (2.51 feet deep) that was also present in 2011 and partially captured in the 2013 survey. This larger pool appears to be relatively stable with regard to depth and location. There does not appear to be any significant aggradation or degradation through the reach when compared to 2014. These channel changes are represented in Figure 5.

Site 5

October 2013 and December 2014 Surveys. Site 5 LWD installation was conducted in September 2013. A comparison of the Site 5 surveys indicates only slight changes in channel morphology since LWD installation, recognizing that the largest storm over this period had a 1.4-year return interval. At the time of installation, the channel was fairly uniform with only two incipient pools (0.13 and 0.27 feet deep). The December 2014 survey indicates an increase to three incipient pools (ranging from 0.36 to 0.71 feet deep) and channel elevation appears to have locally increased (via aggradation) approximately ½ to 1 foot over a distance of more than 25 feet upstream of the log cluster. An exhumed stump is represented in Figure 6 that was used as an elevation control point between the two surveys. Several stumps appear in and adjacent to the channel at Site 5 and appear to have been previously buried by valley infill of sediment and then subsequently exhumed by modern Soquel Creek channel lowering.

December 2015 Survey. Within the survey distance of the 2014 survey, it appears that the thalweg profile has smoothed a bit and that there was a decrease in the number of incipient pools from three to two. However, the 2015 survey extended beyond the 2014 survey in both the upstream and downstream directions and covered a similar distance as the 2013 survey. Within the distance encompassing both the 2013 and 2014 surveys, the 2015 survey indicates the presence of six incipient pools ranging from 0.19 to 0.66 feet deep. No significant aggradation or scour appears to have occurred since 2014. The local aggradation since 2013 in the vicinity of the wood structure appears to remain in place. Additionally, as can be seen in the Appendix D Photos, a log in the structure has rotated from parallel to the bank to spanning the channel. The channel changes are represented in Figure 6.

Road/Stream Bank Repair Site

November 2014 As-Built and December 2014 Surveys. Thalweg surveys were conducted in November 2014 for the post-installation As-Built documentation and again in December 2014 as part of the monitoring event for the large wood sites, though it was not considered a monitoring event for this site. At the time of installation, the thalweg was re-constructed at a relatively uniform two percent grade downstream along the left bank, at the edge of the rootwads, similar to the original pre-construction thalweg position and gradient. Therefore, the post-installation channel bed appears fairly uniform. Thalweg readjustment appears to have taken place in the form of up to approximately a foot of scour downstream of the A-A' cross-section location, forming a stepped morphology.

December 2015 Survey. Within the year after installation, the Road/Bank Repair site experienced an approximately 1.7-year return interval storm event that appears to have caused up to approximately 1 ½ feet of scour upstream of the A-A' cross-section line and some localized aggradation downstream. Two incipient pools (0.32 and 0.78 feet deep) have formed within the project reach and one incipient pool (minimum depth of 0.62 feet) was logged approximately 50 feet upstream of the farthest upstream rootwad location. Although not observable in the thalweg survey, the thalweg has been pushed out toward the center of the channel and finer sandy sediments have been deposited behind the rootwads. These channel changes are represented in Figure 7.

Pebble Counts (Sites 1, 2, 4, and 5)

Pebble count data is obtained to conduct comparison of changes to the size of bed materials at each site (1, 2, 4 and 5) over time. Currently there is only one measurement at each site (collected in October 2013) and therefore comparisons cannot be made. The pebble count was conducted in a "Z" configuration through the majority of each reach. The initial pebble count data are provided in graphic form as Figures 8 and 9. Based on the initial data it appears all four sites are gravel dominated (2 millimeters to <64 millimeters) with boulders (over 256 millimeters) comprising the next major component of the streambed particle size. The exception is Site 4 which appears to have a significant sand component (<2 millimeters). Comparatively it appears that Site 2 contains the coarsest substrate, Site 5 appears to have a somewhat finer gravel component, and Site 4 contains more of a sand component. The particle size classification is based on the Wentworth scale (Wentworth, 1922).

Summary

The purpose of introducing wood elements into Soquel Creek is to create aquatic habitat complexity, such as increased pools, low velocity refuge areas, and cover, which occur from the interaction of the streamflow and associated mobile channel substrate around the wood elements. Although there have not been significant flows since installation (with the exception of Site 1), the following responses were observed at the large wood sites following installation:

- Increase in the number of pools or incipient (less than 1-foot deep) pools;
- Localized channel aggradation (typically retained gravels) and scour;
- Development of low velocity areas (indicated by observations of finer bed material; not quantified);
- Increase in vegetative cover from the wood structures themselves (not quantified);
- Stability through a design stormflow event (Site 1)

Table 1 provides a summary of the large wood metrics and channel characteristics for each site along with a summary of peak stormflows experienced during the winter season.

It is important to note that Site 1 experienced a storm event producing peak flows in excess of the storm event it was designed to be capable of withstanding while remaining relatively stable. The Site 1 key large wood elements, which were designed to be metastable through a 5-year return interval storm event, rotated during the high flows, but the rootwads anchoring the structures maintained their position and their geomorphic functionality within the channel. This is important because during project planning one of the desired outcomes was for the key large structures to remain in a state of metastable equilibrium for at least 5 years to provide biological habitat benefits. In terms of biological habitat benefits and geomorphic processes, a key structure remaining in metastable equilibrium means that the structure largely remains within a project reach or even downstream a modest distance in a location where it continues to interact with the watercourse at various flow levels and continues to perform its geomorphic function (in this case meter sediment and create habitat for salmonids). The intent of key structures are to remain in the general placement location through the design event, with the understanding that some movement, particularly at higher than design flows, will likely occur. With the Site 1 structures remaining metastable through an approximately 7-8 year return interval storm event, it appears that properly designed large wood structures for particular watercourse attributes can lead to successful project effects that include beneficial changes to watercourse ecology.

Annual physical monitoring will continue for five years after project installation. Future physical monitoring will continue to include thalweg surveys and may include pebble counts and more extensive reach surveys depending on the occurrence of larger storm events or observed significant alterations to the large wood elements. The next annual physical survey is planned for summer 2016.

Original Signed By
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Attachments:
- Table 1
- Figures 1 - 9
- Plates 1 - 5
- Appendix A – References
- Appendix B – LWD Metrics
- Appendix C – LWD Loading
- Appendix D – Photos

TABLES

Table 1: Large Wood Project Summary

	Site 1	Site 2	Site 4	Site 5
Key Wood Installation Metrics	1a: Primary RW (10.5 foot diameter), two attached stems (length 110 feet, diameter 26-30 inches); Secondary RW (5.5 foot diameter), one attached stem (length 111 feet, diameter 19 inches) 1b: One RW (12 foot diameter), four attached stems (length 44-87 feet, diameter 14-51 inches) 1c: One RW (12.5 foot diameter), three attached stems (length 85-87 feet, diameter 24-39 inches)	2a: Three stems (length 58.5-65.5 feet, diameter 32-34 inches); One stem with RW (RW diameter 7 feet, stem length 27 feet, stem diameter 32 inches) 2b: Vane log (length 69 feet, diameter 28 inches); RW cover log (RW diameter 10.6 feet, bole length 35 feet, bole diameter 42 inches) 2c: Primary RW (diameter 11 feet), one attached stem (length 70 feet, diameter 36 inches); Secondary RW (diameter 10.5 feet), two attached stems (length 48-93 feet, diameter 19-30 inches); Tertiary RW (diameter 4.5 feet), one attached stem (length 57 feet, diameter 30 inches); 6 unattached stems (length 24-64.5 feet, diameter 14-28 inches)	4a: Nine stems (length 25.6-63.3 feet, diameter 12-33 inches) 4b: One RW (diameter 9 feet), one attached stem (length 57 feet, diameter 48 inches) 4c: Vane log (length 60 feet, diameter 20 inches); RW cover log (RW diameter 8.5 feet, bole length 16 feet, bole diameter 53 inches)	One RW (diameter 12 feet), one attached stem (length 116 feet, diameter 53 inches); One RW (diameter 12 feet), one attached stem (length 53 feet, diameter 48 inches); One RW (diameter 4 feet), one attached stem (length 50 feet, diameter 18 inches); Three unattached stems (length 43.5-61 feet, diameter 12-32 inches)
Pools, number and depth	November 2012: 1 incipient pool (0.43 feet deep) February 2013: 2 pools (1.01 and 1.23 feet deep), 4 incipient pools (0.42 to 0.98 feet deep) December 2014: 2 pools (1.03 and 1.18 feet deep), 5 incipient pools (0.11 to 0.79 feet deep)	N/A October 2013: 3 incipient pools (0.36 to 0.61 feet deep) December 2014: 3 pools (1.16 to 2.28 feet deep), 5 incipient pools (0.54 to 0.86 feet deep)	N/A September 2013: 4 incipient pools (0.20 to 0.76 feet deep) December 2014: 6 incipient pools (0.32 to 0.58 feet deep)	N/A September 2013: 2 incipient pools (0.13 and 0.27 feet deep) December 2014: 3 incipient pools (0.36 to 0.71 feet deep)
Pebble Count Summary	Sand (8%), Gravel (49%), Cobble (23%), Boulder (20%)	Sand (5%), Gravel (47%), Cobble (24%), Boulder (24%)	Sand (12%), Gravel (50%), Cobble (18%), Boulder (20%)	Sand (9%), Gravel (65%), Cobble (10%), Boulder (17%)

Storm Data Summary

Winter 2012/2013: 2 significant events (950 cfs, 4-year storm; and 1260 cfs, 8-year storm)

Winter 2013/2014: 1 minor event (63 cfs, 1.3-year storm)

Winter 2014/2015: 1 minor event (345 cfs, 1.7-year storm)

Winter 2015/2016 (through December 1, 2015): 1 minor event (9 cfs, 1.2-year storm)

FIGURES

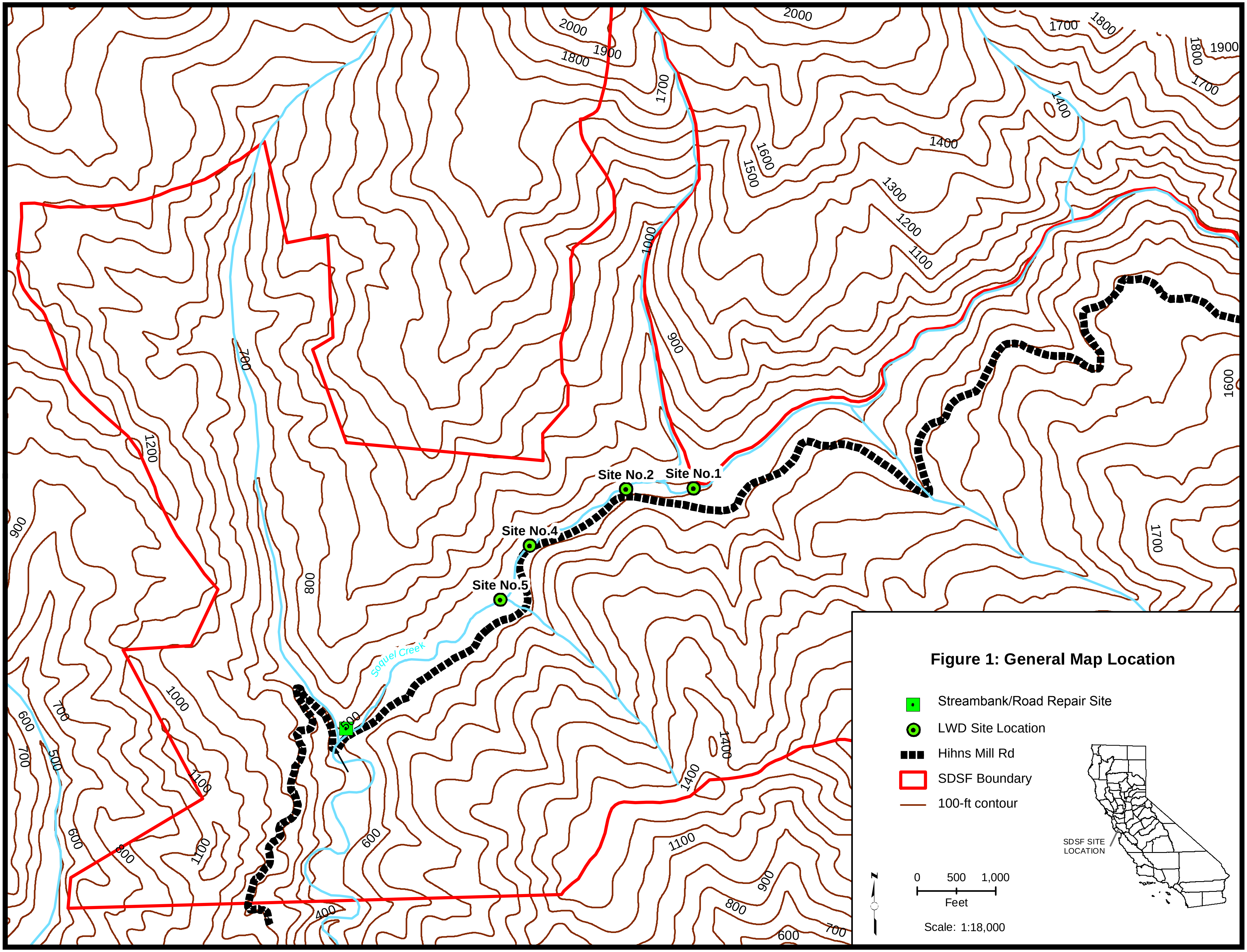


Figure 1: General Map Location
Streambank/Road Repair Site
LWD Site Location
Hihns Mill Rd
SDSF Boundary
100-ft contour
0 500 1,000
Feet
Scale: 1:18,000
SDSF SITE LOCATION
Site No.1
Site No.2
Site No.4
Site No.5
Soquel Creek

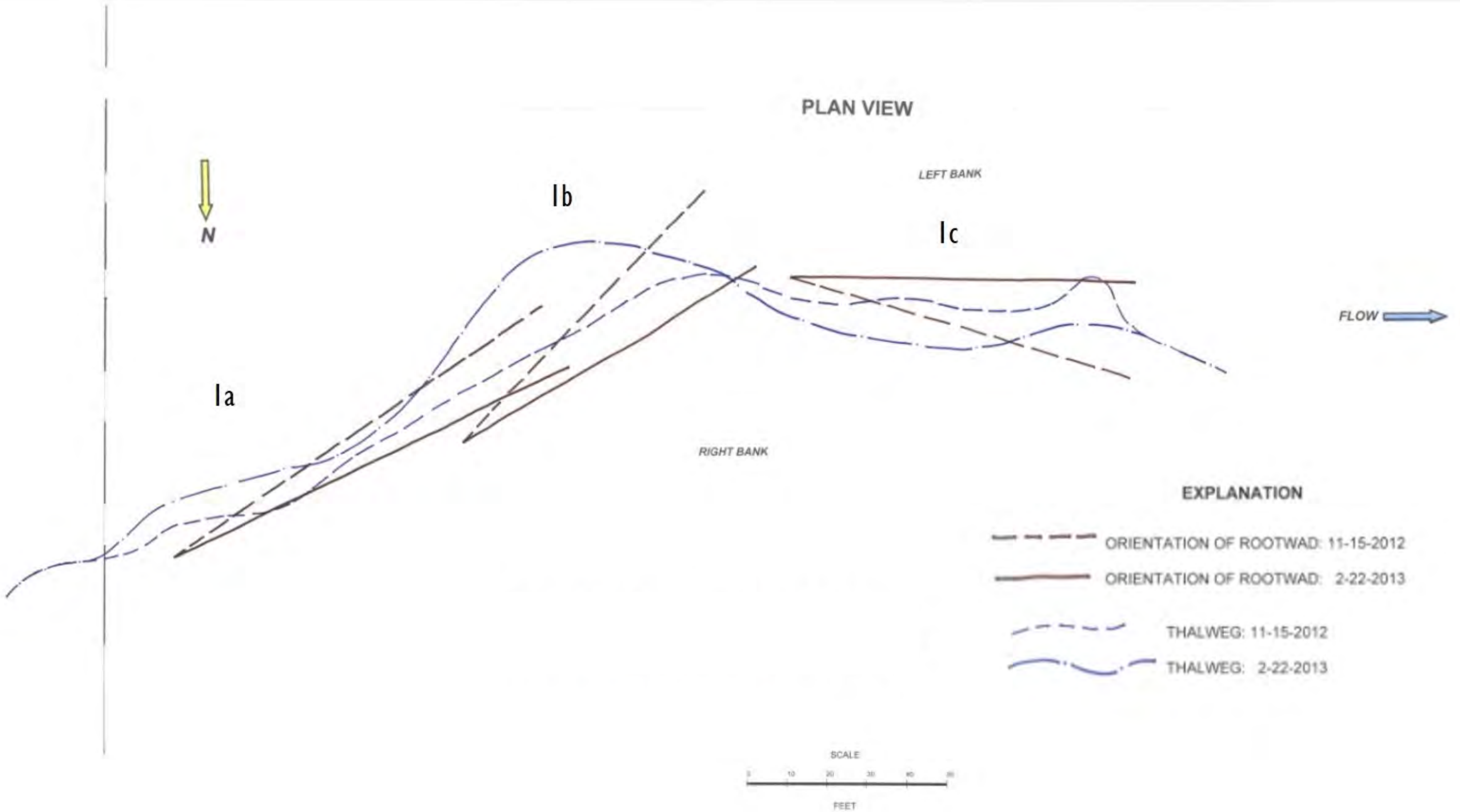


Figure 2: Site 1 Rootwad Monitoring

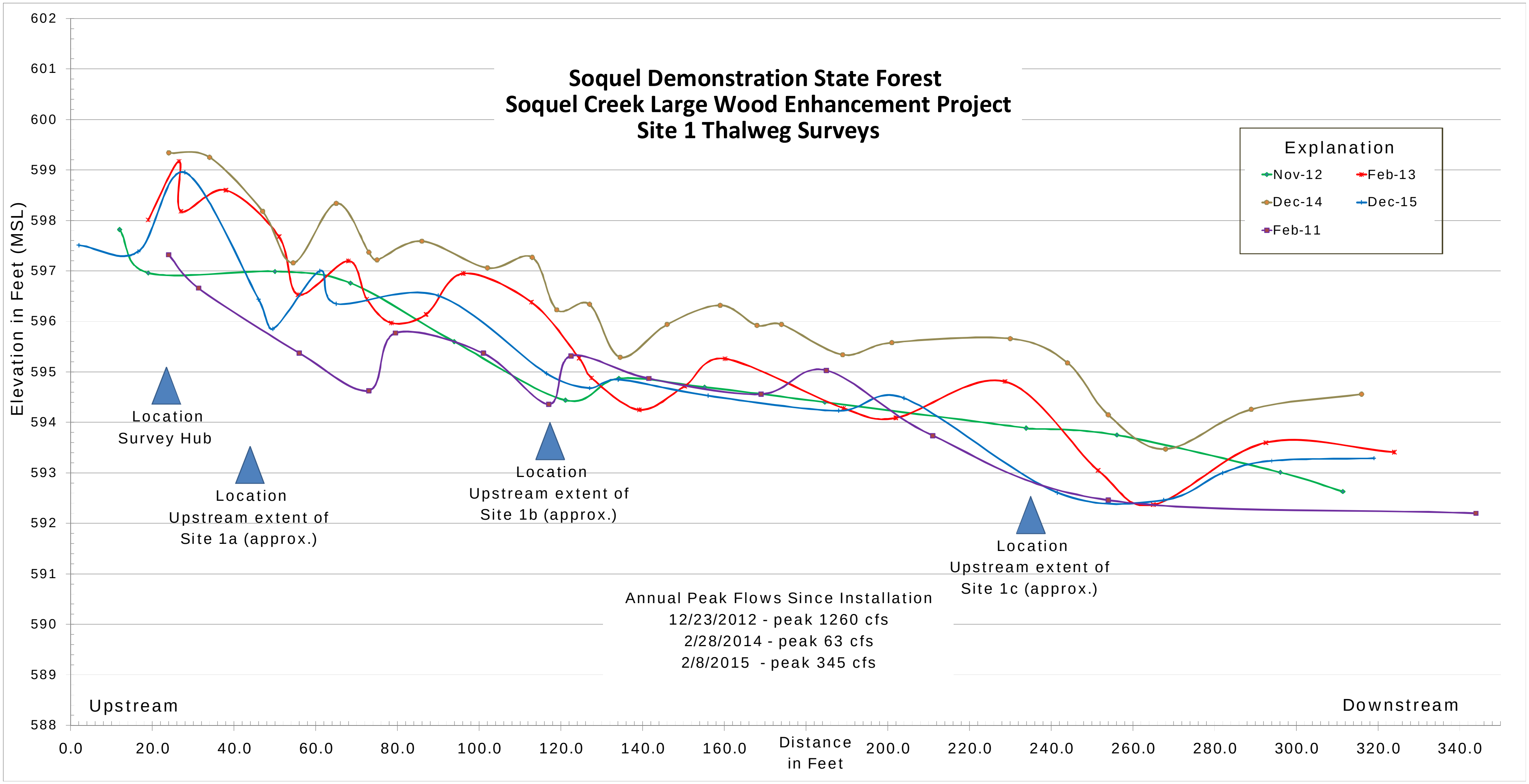


Figure 3: Site 1 Thalweg Profile

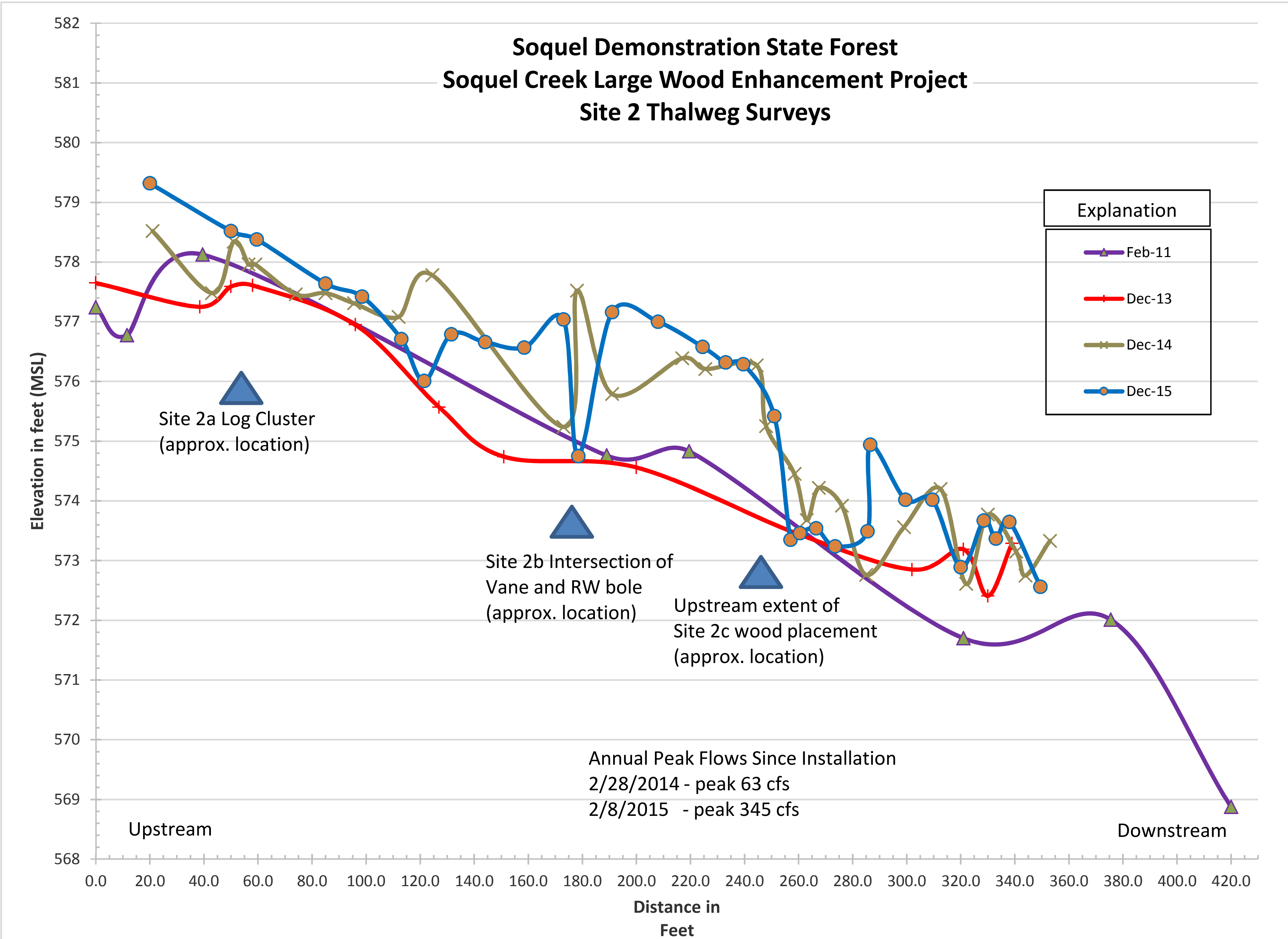


Figure 4: Site 2 Thalweg Profile

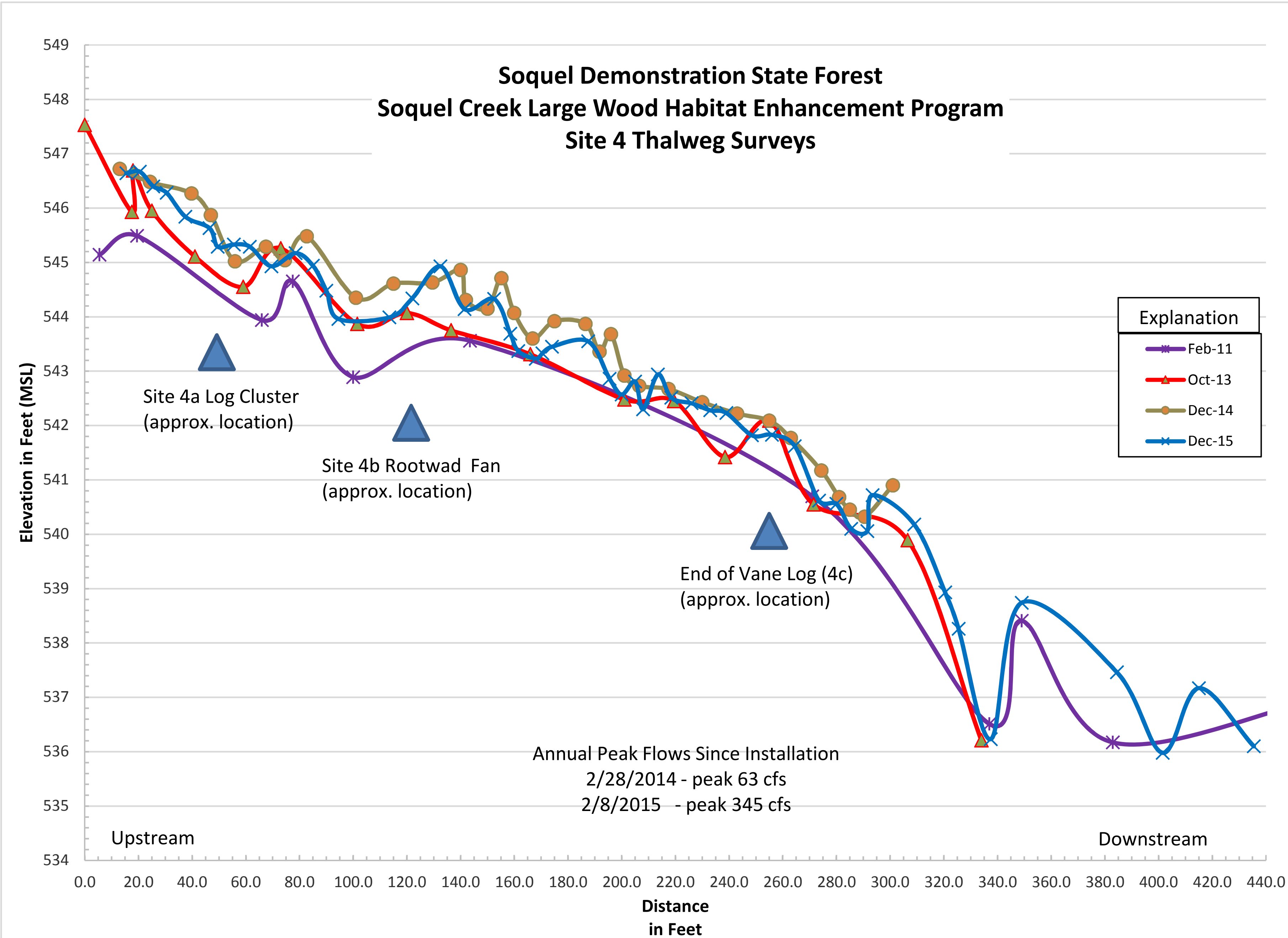


Figure 5: Site 4 Thalweg Profile

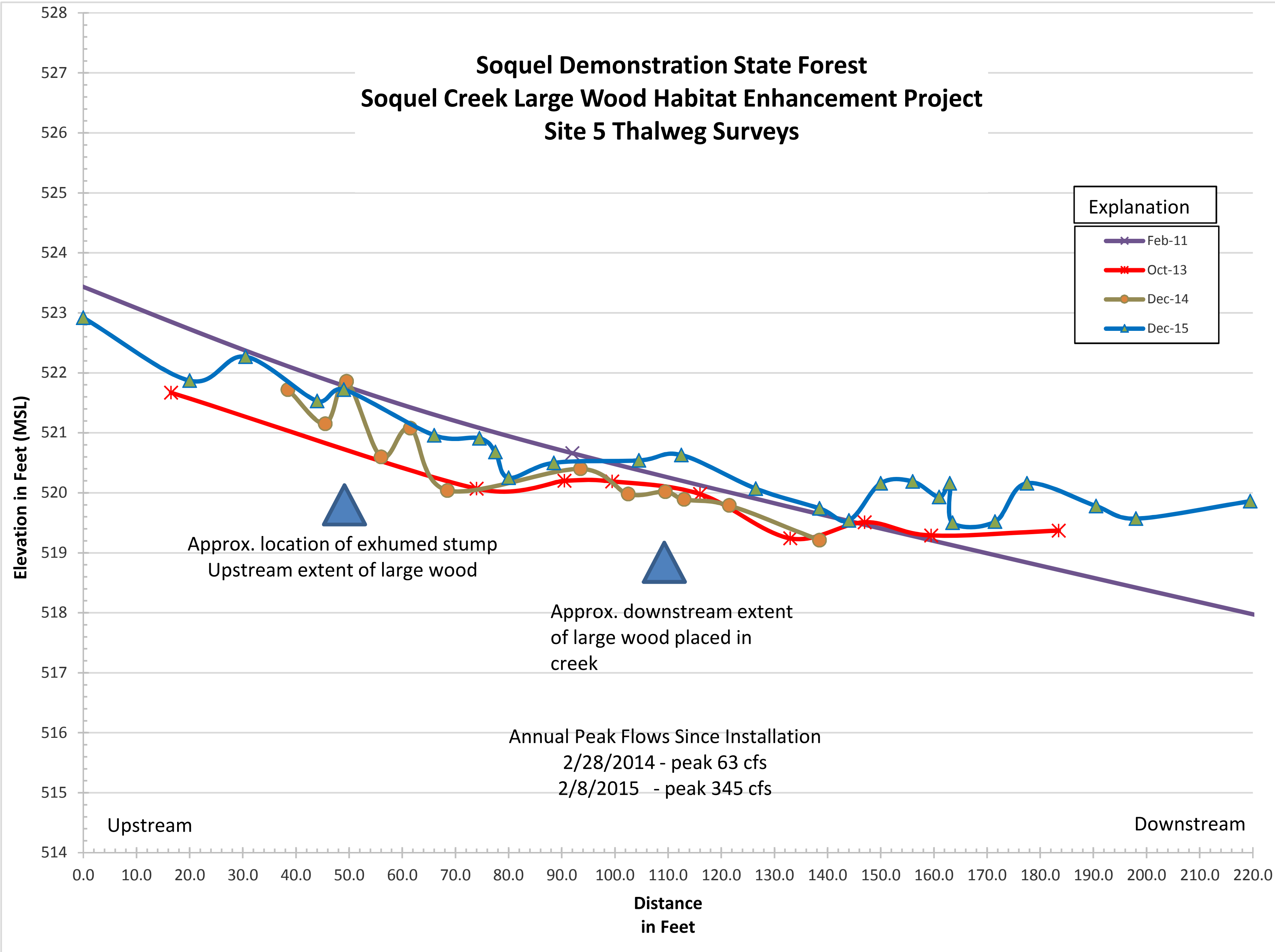


Figure 6: Site 5 Thalweg Profile

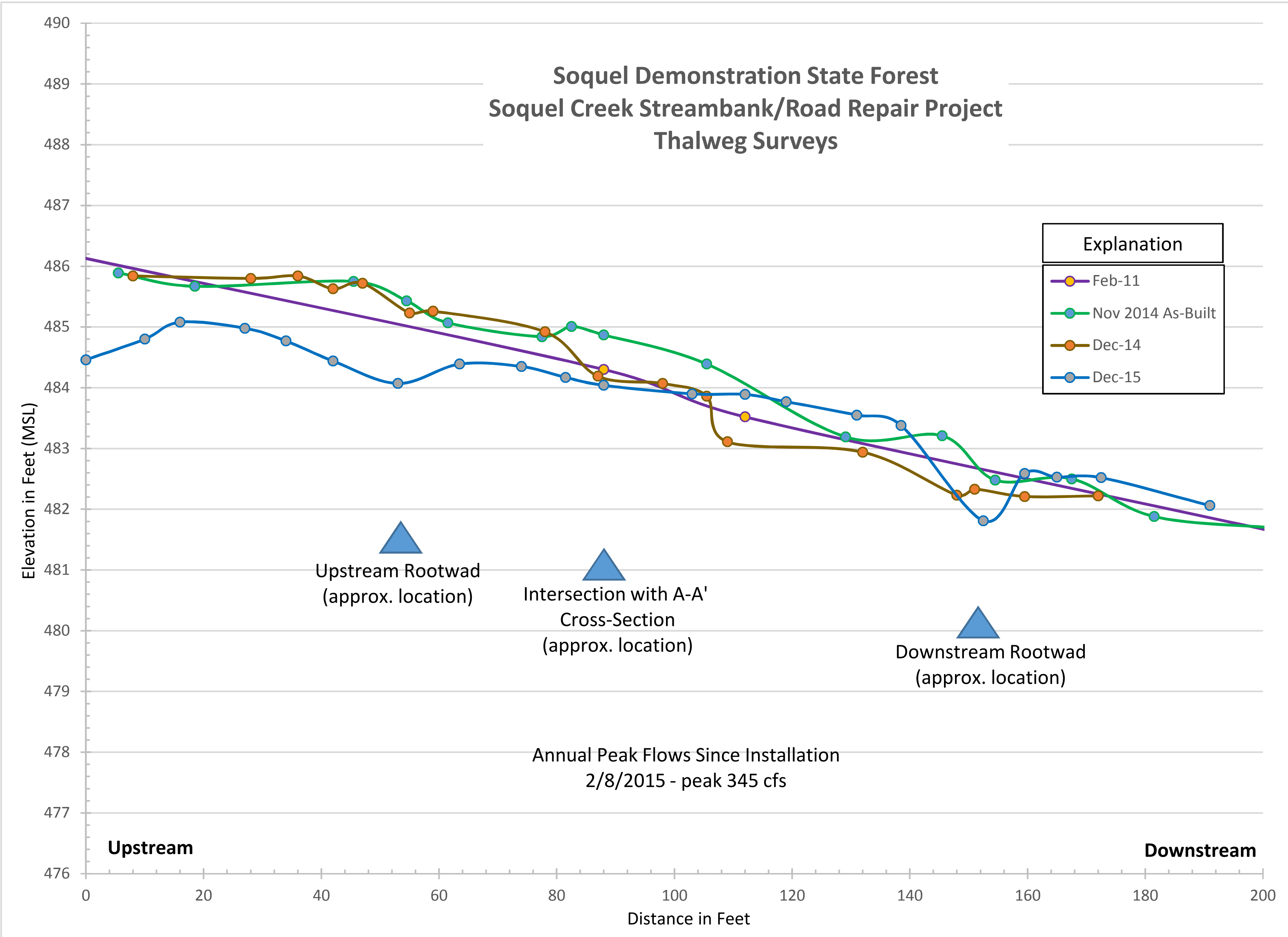


Figure 7: Streambank/Road Repair Thalweg Profile

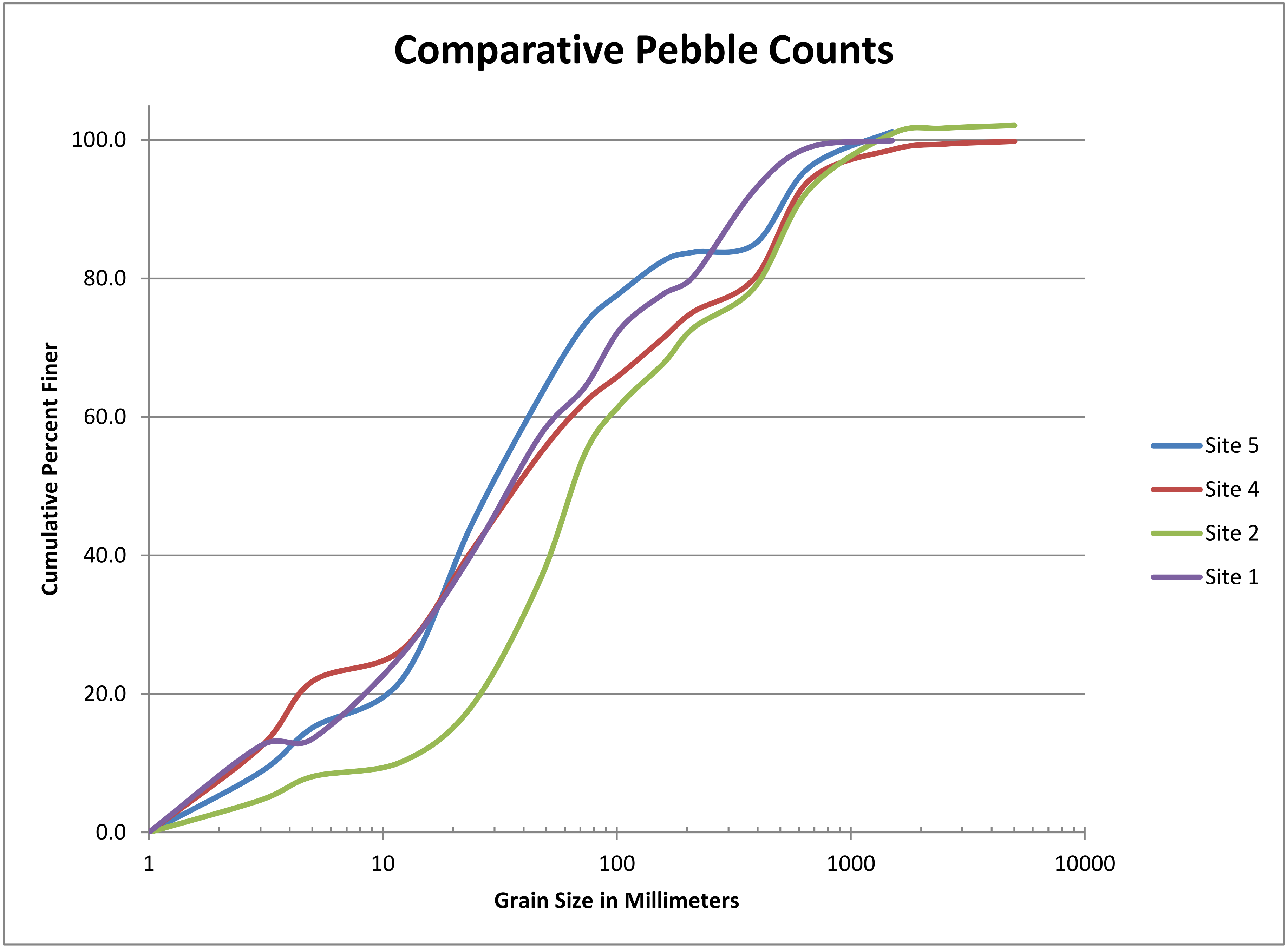


Figure 8: Cumulative Percent Finer Pebble Count Grain Size Distribution

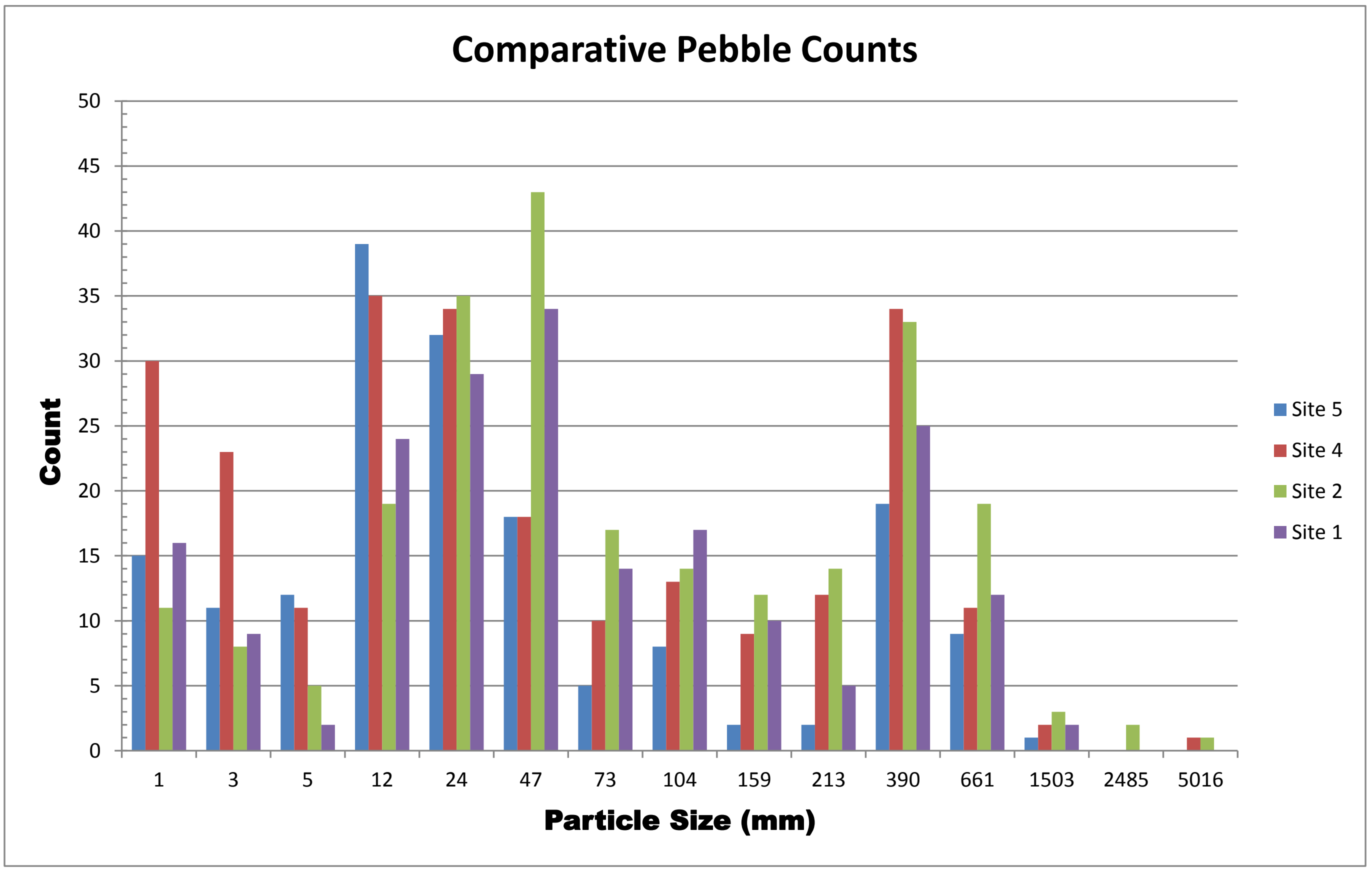


Figure 9: Pebble Count Particle Size Distribution

PLATES

Plate 1
GEOMORPHIC SKETCH MAP
SOQUEL DEMONSTRATION STATE FOREST
SITE 1 LARGE WOODY DEBRIS ENHANCEMENT PROJECT

Stephen D. Reynolds, CHG and Cheryl A. Hayhurst, PG

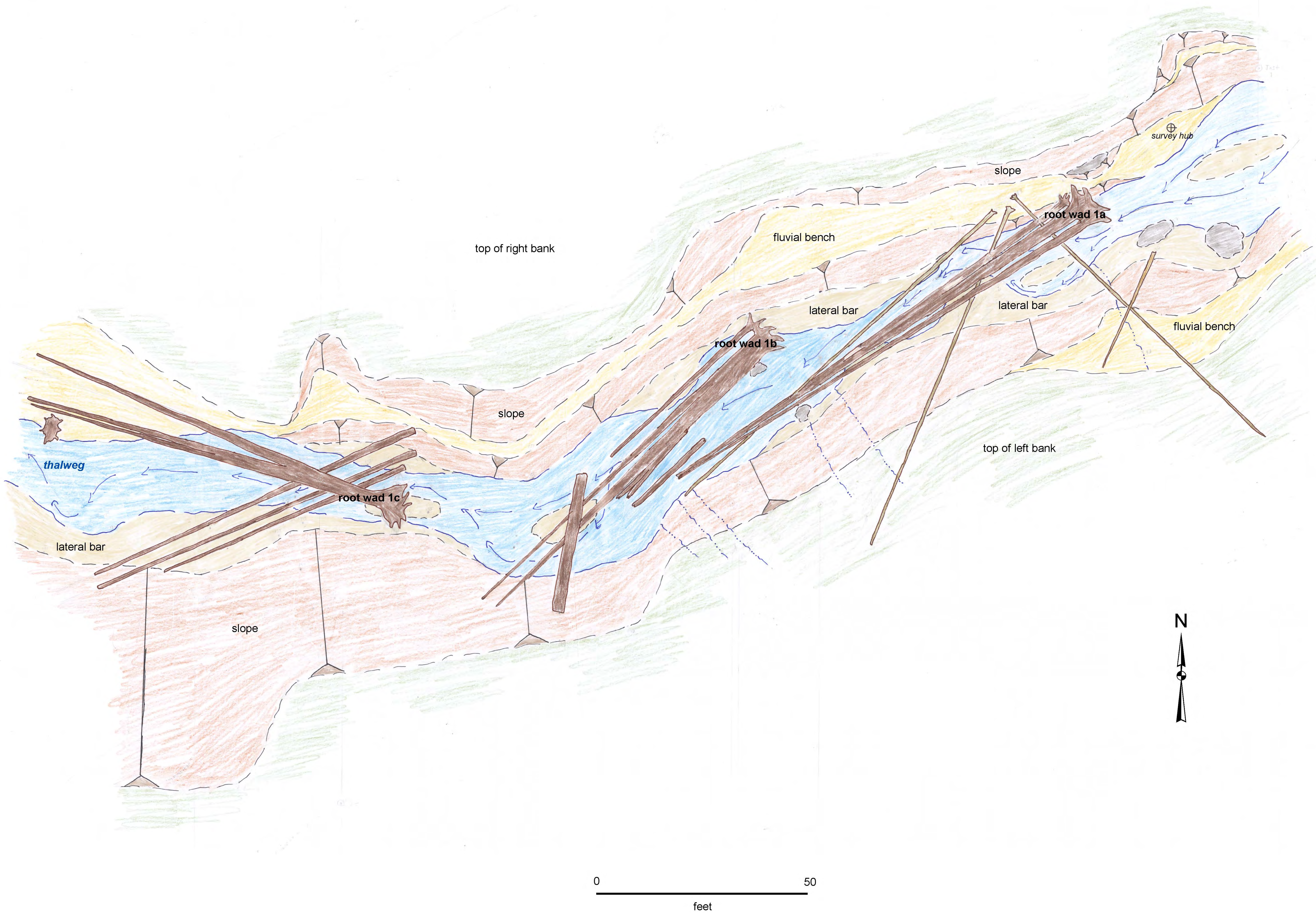


Plate 2
GEOMORPHIC SKETCH MAP
SOQUEL DEMONSTRATION STATE FOREST
SITE 2 LARGE WOODY DEBRIS ENHANCEMENT PROJECT

Stephen D. Reynolds, CHG and Cheryl A. Hayhurst, PG

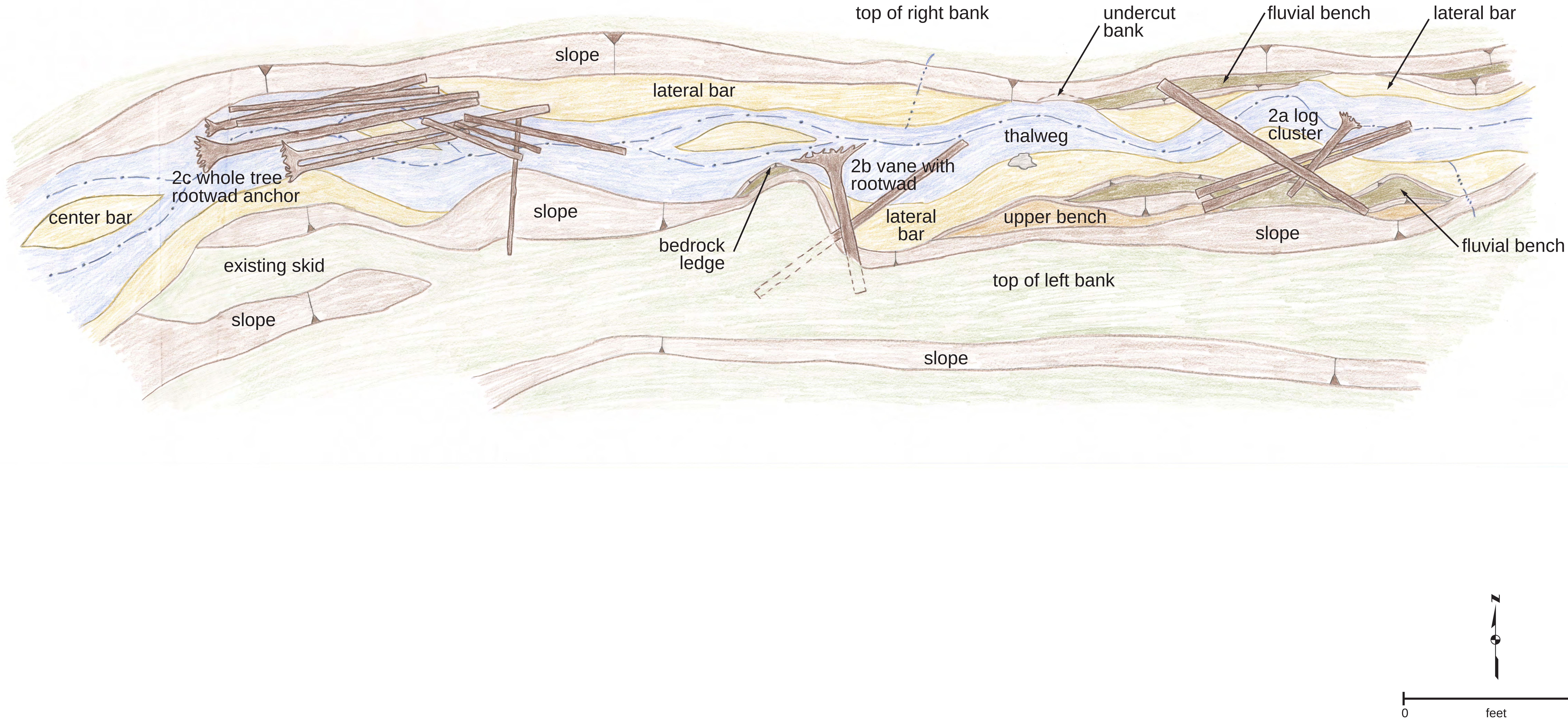


Plate 3
GEOMORPHIC SKETCH MAP
SOQUEL DEMONSTRATION STATE FOREST
SITE 4 LARGE WOODY DEBRIS ENHANCEMENT PROJECT

Stephen D. Reynolds, CHG and Cheryl A. Hayhurst, PG

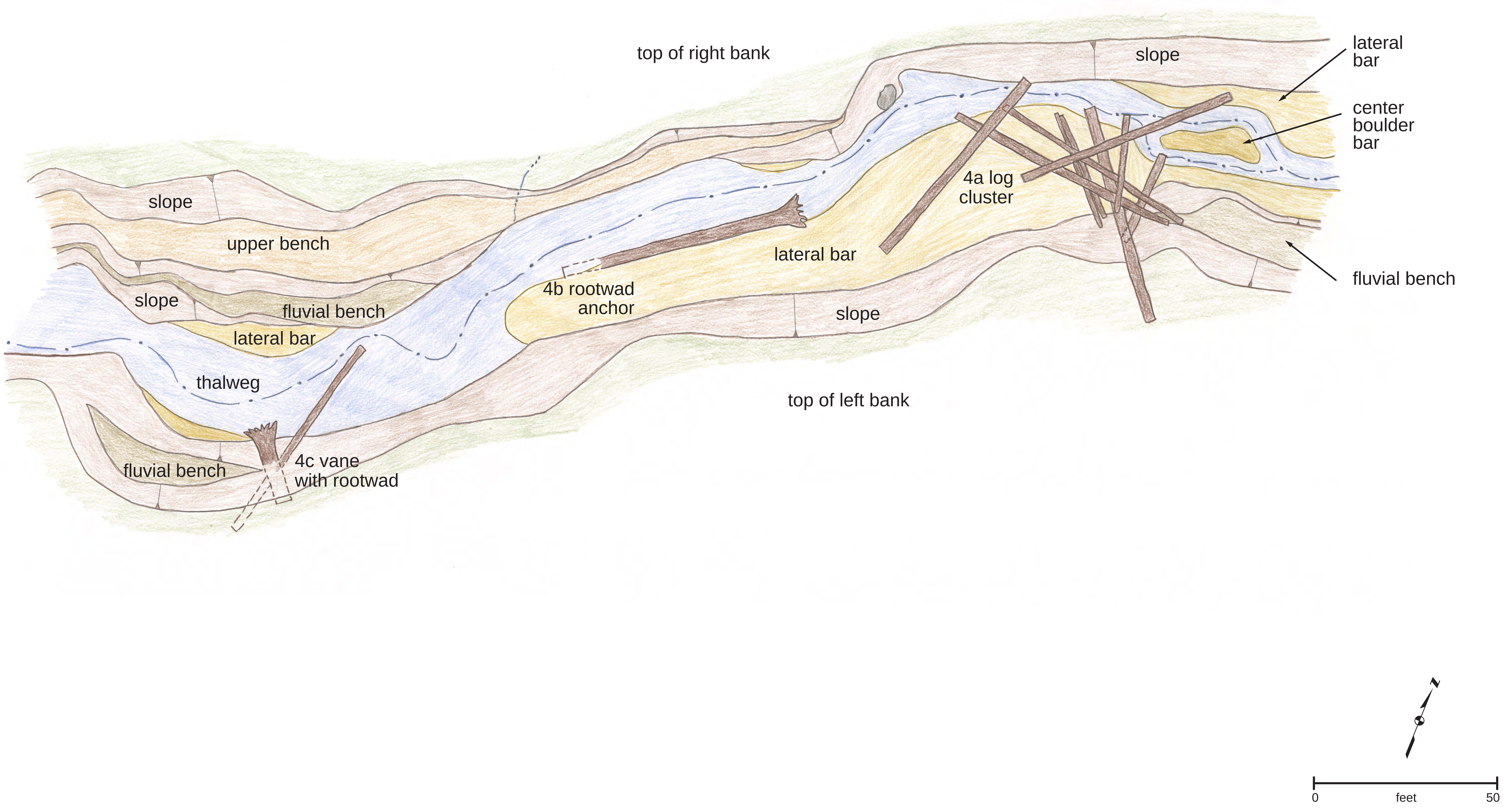
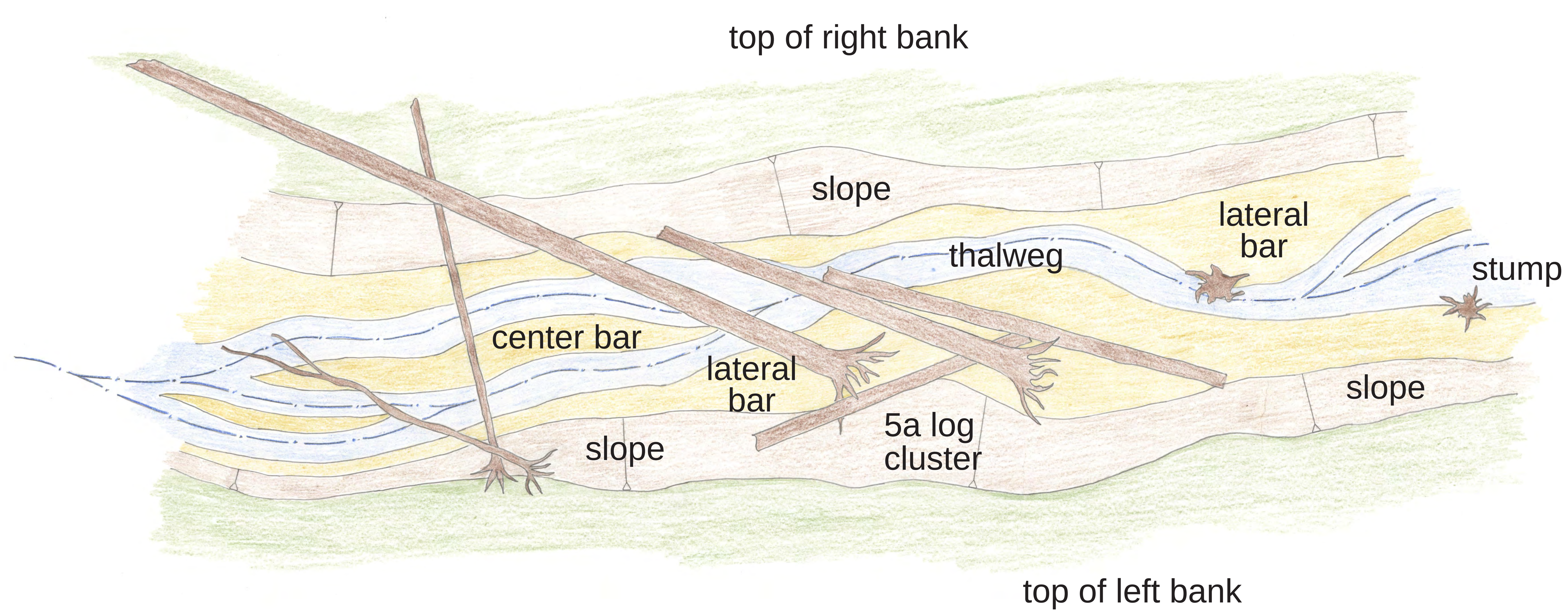


Plate 4
GEOMORPHIC SKETCH MAP
SOQUEL DEMONSTRATION STATE FOREST
SITE 5 LARGE WOODY DEBRIS ENHANCEMENT PROJECT

Stephen D. Reynolds, CHG and Cheryl A. Hayhurst, PG



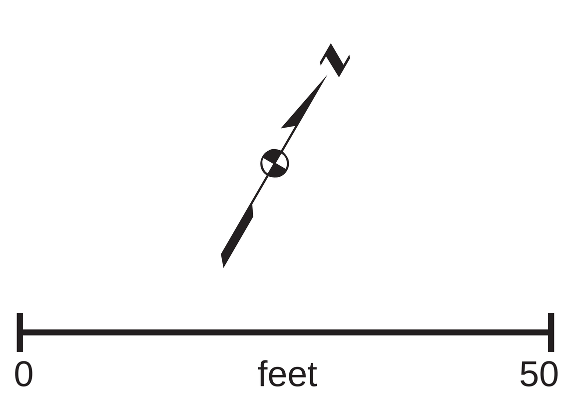
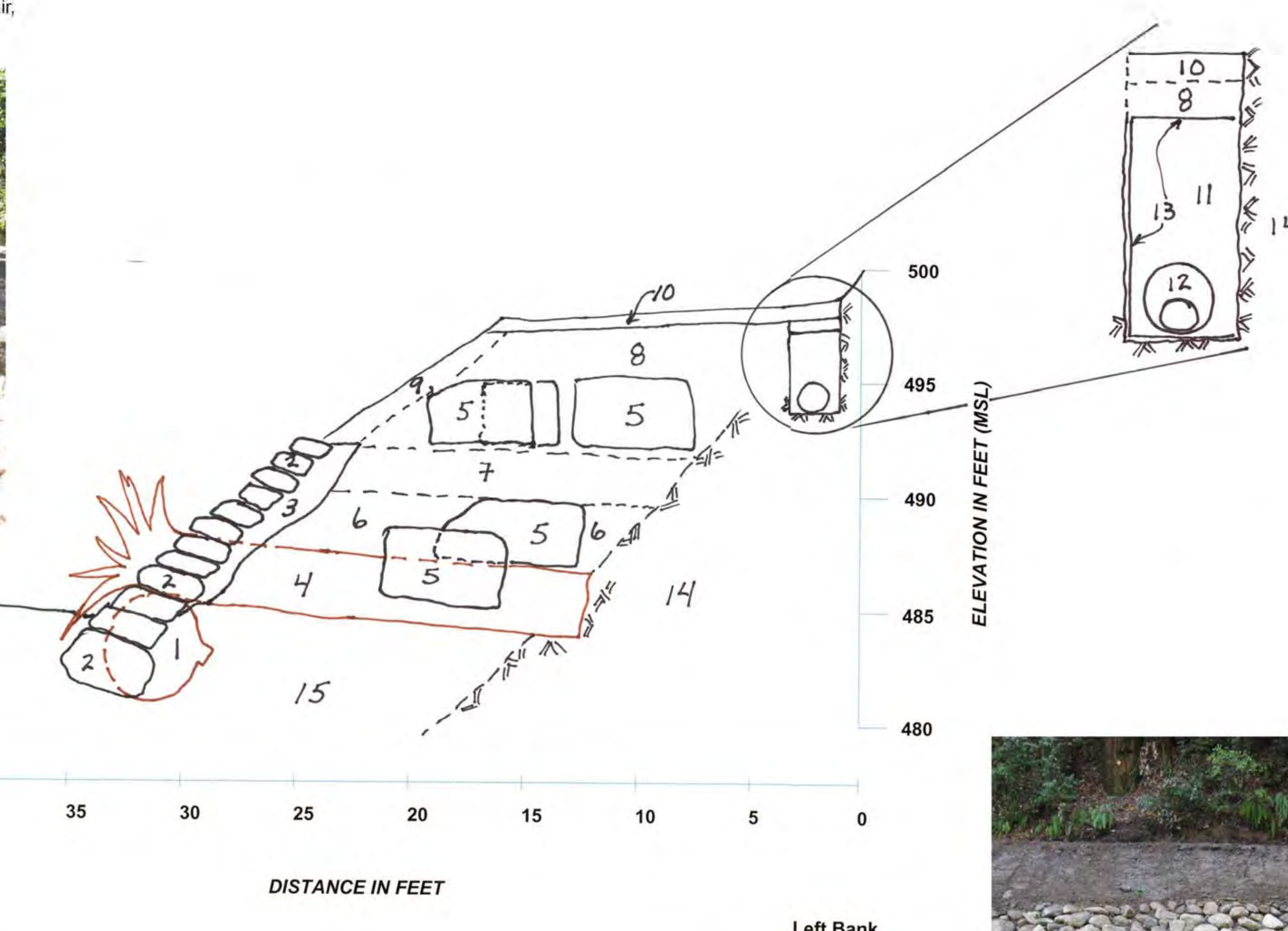


Plate 5: Typical As-Built Section (A-A')

Soquel Demonstration State Forest, Hihns Mill Streambank/Road Repair,
Section Prepared by California Geological Survey



EXPLANATION

1-Footer Log
2-Rock Revetment
3-Drain Blanket
4-Rootwad w/ Bole
5-Concrete Block
6-Mixed channel Material and Soil Backfill
7-Compacted Soil Transition Layer
8-Compacted Soil
9-Loosely Compacted Rooting Layer
10-Road Base, ¾-inch Crushed Rock
11-Washed ¾-inch Crushed Drain Rock
12-Prefabricated Drain Pipe w/ Filter Media
13-Plasitc Liner
14-Purisima Formation Sandstone
15-In-place Channel Deposits; Boulders thru Silty Sand

APPENDIX A
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APPENDIX B
LWD METRICS

SITE 1

1A Primary Root Wad

Diameter – H: 9 feet (108 inches) V: 10.5 feet (126 inches)
Thickness 4 feet (48 inches)

Stem 1; Diameter Breast Height (DBH) – 30inches
Length – 110 feet
Orientation – 228 ^{o}
Pitch – 15 percent
Height above thalweg – 5.7 feet

Stem 2; Diameter Breast Height (DBH) – 26inches
Length – 110 feet
Orientation – 228 ^{o}
Pitch – 13 percent
Height above thalweg – 3.3 feet

Secondary Root Wad (broke off main stump)
Diameter – H: 5.5 feet (66 inches) V: 4.5 feet (54 inches)
Thickness 3 feet (36 inches)

Stem 1; Diameter Breast Height (DBH) – 19 inches
Length – 111 feet
Orientation – 230 ^{o}
Pitch – 13 percent
Height above thalweg – 3.3 feet

Additional Wood:
Three Alders brought down during falling of main root wad
Diameter Breast Height (DBH) – 8, 9, 13 inches
Length – 80, 84, 96 feet
Orientation – 135, 196, 214^{o}
Pitch – 10, 11, 13 percent
Height above thalweg – 0.5, 1.1, 1.3 feet

1B Primary Root Wad

Diameter – H: 9.5 feet (114 inches) V: 12 feet (144 inches)
Thickness 4 feet (48 inches)

Stem 1; Diameter Breast Height (DBH) – 51 inches
Length – 86 feet
Orientation – 228^{o}
Pitch – 5 percent
Height above thalweg – 3.3 feet

1B Primary Root Wad - continued

Stem 2; Diameter Breast Height (DBH) – 19 inches
Length – 86 feet
Orientation – 228°
Pitch –3 percent
Height above thalweg – 1.0 feet

Stem 3; Diameter Breast Height (DBH) – 24 inches
Length – 87 feet
Orientation – 228°
Pitch –3 percent
Height above thalweg – 2.4 feet

Stem 4; Diameter Breast Height (DBH) – 14 inches
Length – 44 feet
Orientation – 228°
Pitch –7 percent
Height above thalweg – 6.6 feet

Additional Wood: Top of 51-inch DBH stem
Diameter - 31 inches
Length – 42 feet
Orientation – 204°
Pitch – 20 percent
Height above thalweg – 0.8 feet

1C Primary Root Wad

Diameter – H: 12.5 feet (150 inches) V: 12.5 feet (150 inches)
Thickness 4.5 feet (54 inches)

Stem 1; Diameter Breast Height (DBH) – 32 inches
Length – 87 feet
Orientation – 290°
Pitch – 5 percent
Height above thalweg – 2.6 feet

Stem 2; Diameter Breast Height (DBH) – 24 inches
Length – 85 feet
Orientation – 285 °
Pitch –5 percent
Height above thalweg – 6.1 feet

1C Primary Root Wad – continued

Stem 3; Diameter Breast Height (DBH) – 39 inches
Length – 86 feet
Orientation – 285 ^{o}
Pitch –5 percent
Height above thalweg – 7.0 feet

Additional Wood: Three stem tops
Diameter – 13, 19, 19 inches
Length – 60, 79, 80 feet
Orientation – 248 ^{o}, 248 ^{o}, 248 ^{o}
Pitch – 1-, 1-, 1- percent
Height above thalweg – 0.8, 1.0, 1.1 feet

SITE 2

2A Log Cluster

Stem 1
Length: 65.5feet
Diameter: 32inches
Bearing: 300 ^{o}

Stem 2 (Root Wad)
Length - 27feet
Diameter: 32inches
Bearing: 35 ^{o}
RW Diameter - V: 7 feet (84 inches) H: 6 feet (72 inches)
RW thickness: 2.5feet (30 inches)

Stem 3
Length: 60feet
Diameter: 32inches
Bearing: 77 ^{o}

Stem 4
Length: 58.5feet
Diameter: 34inches
Bearing: 70 ^{o}

2B Vane with Root Wad

Vane
Length: 69feet
Diameter: 28inches
Bearing: 50 ^{o}
Intersection with center of RW: 39.1feet
East end of vane in thalweg

Root Wad
Bole Length: 35feet
Diameter: 42inches
Bearing: 345 ^{o}
Unballasted bole length: 10feet
Diameter – H: 10.6 feet (127 inches) V: 8 feet (96 inches)
Thickness: 3.5feet (42 inches)

2C Root Wad Anchor

Primary Root Wad
Diameter – H: 9 feet (108 inches) V: 11 feet (132 inches)
Thickness 4 feet (48 inches)

Stem 4 (main stem attached to RW)
Length: 70feet
Diameter: 36inches
Bearing: 82 ^{o}

Secondary Root Wad
Diameter – H: 10.5 feet (126 inches) V: 8.5 feet (102 inches)
Thickness 3 feet (36 inches)

Stem 5
Length: 93feet
Diameter: 30inches
Bearing: 78 ^{o}

Stem 6
Length: 48feet
Diameter: 19inches
Bearing: 77 ^{o}

2C continued

Tertiary Root Wad

Diameter – H: 4 feet (48 inches) V: 4.5 feet (54 inches)
Thickness 3.5 feet (42 inches)

Stem 1

Bole Length: 57feet
Diameter: 30inches
Bearing: 80 ^{o}

Unattached Logs

Stem 2

Length: 56feet
Diameter: 22inches
Bearing: 85 ^{o}

Stem 3

Length: 64.5feet
Diameter: 28inches
Bearing: 84^o

Stem 7

Length: 44feet
Diameter: 24inches
Bearing: 105^o

Stem 8

Length: 24feet
Diameter: 19inches
Bearing: 112 ^{o}

Stem 9

Length: 28feet
Diameter: 16inches
Bearing: 120 ^{o}

Stem 10 (alder/tan oak?)

Length: 38feet
Diameter: 14inches
Bearing: 10 ^{o}

SITE 4

4A Log Cluster

Stem 1
Length: 25.6feet
Diameter: 24inches
Bearing: 358 ^{o}

Stem 2
Length: 26feet
Diameter: 21inches
Bearing: 341^{o}

Stem 3
Length: 59.5feet
Diameter: 33inches
Bearing: 318 ^{o}

Stem 4
Length: 30feet
Diameter: 18inches
Bearing: 315 ^{o}

Stem 5
Length: 33.5feet
Diameter: 12inches
Bearing: 317 ^{o}

Stem 6
Length: 60feet
Diameter: 26inches
Bearing: 44 ^{o}

Stem 7
Length: 58feet
Diameter: 28 inches
Bearing: 101 ^{o}

Stem 8
Length: 63.3feet
Diameter: 21inches
Bearing: 90 ^{o}

4A continued

Stem 9

Length: 60feet
Diameter: 30inches
Bearing: 15 º
Distance to intersection with Stem 7: 9feet

4B Root Wad Anchor

Bole length: 57feet
Diameter (dbh): 48 inches
Bearing: 50 º
Inclination: 15%
Approximate distance of buried bole: 11feet
RW Diameter vertical axis: 8feet
RW Diameter horizontal axis: 9feet
RW thickness: 5feet

4C Vane with Root Wad

Vane

Length: 60feet
Diameter: 20inches
Bearing: 19 º
Distance to center of RW: 38feet

Root Wad

Bole length: 16feet
Unballasted bole length: 4.5feet
Bole diameter: ~ 53inches
RW Diameter vertical axis: 8feet
RW Diameter horizontal axis: 8.5feet
RW thickness: 4.5feet
RW Bearing: 321º

SITE 5

5A Log Cluster

Stem 1 – Fir with root Wad
- Bole Length 116 feet
- Bole Diamter (DBH) 53 inches
- Bole Diameter Small end 26 inches
- Root Wad diameter H: 12 feet (144 inches) V: 10 feet (120 inches)
- Root Wad Thickness 4 feet (48 inches)
- Bearing 89^{o}

Stem 2– Fir with Root Wad
- Bole Length 53 feet
- Bole Diamter (DBH) 48 inches
- Bole Diameter Small end 26 inches
- Root Wad diameter – H: 12 feet (138 inches) V: 9 feet (108 inches)
- Root Wad Thickness 4 feet (48 inches)
- Bearing 85^{o}

Stem 3– Redwood
- Bole Length 61 feet
- Bole Diamter (DBH) 32 inches
- Bole Diameter Small end 20 inches
- Bearing 74^{o}

Stem 4– Fir
- Bole Length 43.5 feet
- Bole Diamter (DBH) 30 inches
- Bole Diameter Small end 26 inches
- Bearing 42^{o}

Stem 5– Sycamore
- Bole Length 56 feet
- Bole Diamter (DBH) 12 inches
- Bole Diameter Small end 10 inches
- Bearing 143^{o}

Stem 5– Alder with Root Wad
- Bole Length 50 feet
- Bole Diamter (DBH) 18 inches
- Bole Diameter Small end 8 inches
- Root Wad diameter – H: 4 feet (48 inches) V: 3.5 feet (42 inches)
- Root Wad Thickness 1.5 feet (18 inches)
- Bearing 94^{o}

APPENDIX C
LWD INSTREAM WOOD LOADING

DEPARTMENT OF CONSERVATION

CALIFORNIA GEOLOGICAL SURVEY

801 K STREET • Suite 1324 • SACRAMENTO, CALIFORNIA 95814
PHONE 916 / 327-0791 • **FAX** 916 / 323-9264 • **TDD** 916 / 324-2555 • **WEBSITE** conservation.ca.gov

To: Angela Bernheisel
California Department Forestry and Fire Protection
Forest Manager Soquel State Demonstration Forest
4750 Soquel-San Jose road
Soquel, CA 95073

From: Stephen D. Reynolds
Sr. Engineering Geologist
California Geological Survey
801 K Street, Suite 1324
Sacramento, CA 95814

Date: October 11, 2013 Updated December 18, 2013

Subject: Soquel Creek LWD Project – “Background” LWD Loading Rates

County: Santa Cruz

Description: T10S, R1E, Section 7 - MDB&M.

Quadrangles: Laurel (1994) United States Geological Survey 7.5 minute Quadrangle Series (Topographic):

References: See Appendix A

Introduction

At the request of California Department Forestry and Fire Protection (CDF), staff of the California Geological Survey (CGS) developed quantitative criteria for large woody debris (LWD) loading in Soquel Creek. This memorandum presents CGS findings in the context of Soquel Demonstration State Forest’s (SDSF) recently completed Large Woody Debris and Habitat Complexity Project. If you have any questions, please feel free to contact Stephen Reynolds at (916) 322-6968 or Stephen.Reynolds@ conservation.ca.gov.

Background

Typical of suburban watersheds, Soquel Creek was gleaned of all woody debris, large or otherwise, as both a fisheries management approach and a flood management tactic. Since then, the critical role of Large Woody Debris (LWD) in providing fish habitat and promoting watershed and stream stability has been recognized and well documented. SDSF ’s Large Woody Debris and Habitat Complexity Project was undertaken in an effort to begin to address Soquel Creek’s severe LWD shortage (13,14).

The project involved installing LWD along a 0.7 mile stretch of the East Branch of Soquel Creek in four, discrete reaches of approximately 300 feet in length, Figure 1. As part of long-term project monitoring and evaluation of the project, LWD accumulation (loading) within the treatment sites will be measured and evaluated. In order to provide a baseline for LWD loading, CGS conducted a comprehensive literature search, finding 20 LWD studies that either directly provided LWD loading data or from which loading data could be developed. These studies were further parsed based upon geographic location (Pacific Northwest), similarity of watershed aspect (westerly), and physiography (upwards of 1000 feet relief). The remaining nine studies were used to develop LWD loading metrics. Complete citations are provided in Appendix A.

Eight of the nine studies provided data on LWD loading for undisturbed watersheds (Table 1) and all nine studies provided data on logged watersheds (Table 2). The data were extracted from the studies and standardized into two metrics; cubic meters of LWD per 100 meters ($m^3/100m$) of stream channel and cubic meters of LWD per square meter (m^3/m^2) of stream channel. Once the data was converted to a uniform measure, the next step was to normalize the data to Soquel Creek. Bankfull width of Soquel Creek is larger than those of the cited studies, thus the metric cubic meters of LWD per 100 meters ($m^3/100m$) of stream channel would be erroneous without correcting for the difference in bankfull width, i.e. surface area of 100 meters of Soquel Creek is larger. This is addressed in Table 1 through the use of a bankfull normalization factor which is the ratio of Soquel Creek bankfull width to study bankfull width. The metrics were converted to English units and adjusted to a 100-foot interval since that was one of the demarcations used in the Soquel LWD project. This correction then allows direct comparison of LWD loading by reach.

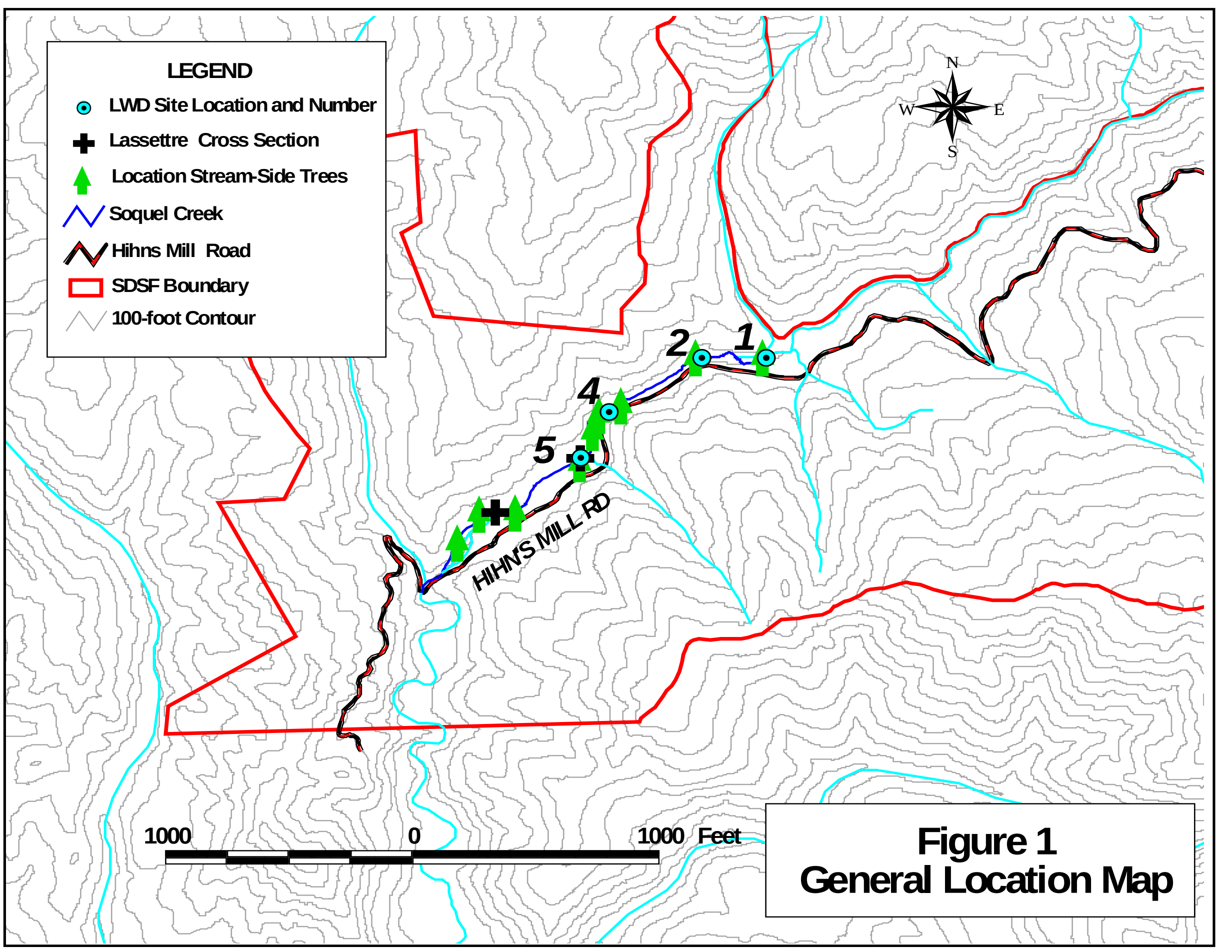

Figure 1
General Location Map

SDSF LWD Loading Methods
LWD loading at SDSF utilized three approaches; 1) introduction of whole trees, including root wad, 2) unanchored log clusters consisting of 4 to 6 large[1] redwood logs with and without root wad, and 3) anchored vane structure consisting of two large logs, one with a root wad and one without.

Site 1 was treated solely by dropping three large, multi-stem redwoods with root wad, the remaining three treatment reaches contained one of each type of LWD structure.

Findings
Table 1 is a summary of LWD loading data for unlogged watersheds contrasted against that for SDSF LWD project reaches. The data indicates that project LWD loading rates are roughly half what would be expected for an undisturbed watershed. However, when compared to other logged (clear-cut), but recovering, watersheds (Table 2), the LWD project loading rates compare favorably, essentially matching LWD loading rates for recovering watersheds.

Another key finding was that of the three approaches used for the LWD loading project, dropping whole trees proved most effective. LWD loading rate at Site 1 was on average 40 percent higher than sites with mixed loading techniques.

The data indicates that dropping whole trees is the most effective method of LWD loading based upon total wood loading, cost, and intrusiveness (collateral damage). Wood loading by dropping whole trees was 40 percent higher than the other methods. Cost for dropping whole trees was on-the-order of \$11 per ft^3 of LWD placed in channel, while constructed LWD features cost approximately \$36 per ft^3 of LWD placed. Dropping whole trees does not require channel dewatering, electro-fishing, or in-channel work, thus greatly reducing environmental disturbance.

Discussion
In evaluating the data an important consideration is that the east branch of Soquel Creek is larger than streams in the reviewed studies, i.e. larger watershed. As such Soquel Creek experiences higher flows than the studied streams. Higher flows would result in the removal of LWD that would have remained in the study streams. The stream closest to Soquel Creek in general dimension was that in the study by Faustini and Jones (2003) involving both logged and unlogged stream reaches. In that study the LWD loading rate for the logged stream reach was approximately 1/7th that of the Soquel Creek project. This suggests that the level of LWD loading done in the Large Woody Debris and Habitat Complexity Project is appropriate and provides a good foundation from which natural processes can build.

An additional consideration is how the various researchers defined LWD. In general, the working definition of LWD included material as small as 3 inches in diameter and 5 feet in length. The basis for defining material this small as LWD is unclear. None of the researchers provided either a physical or biological basis for LWD sizing, e.g. sufficient size to provide substrate for biological effect or large enough to induce geomorphic effect. This author proposes a working definition of LWD be limited to material of sufficient mass or dimension

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[1] *1.5 – 2 times bankfull width in length and up to 4.5 times mean bankfull depth in diameter*

such that it cannot be mobilized by the annual storm, i.e. residence time of at least two years. For Soquel Creek that is material on the order of 16 inches mean diameter and 45 – 50 feet long. This is consistent with observations made at Site 1over the winter of 2012-2013, which is now devoid of material smaller than the aforementioned calculated piece size.

While it is clear that dropping whole trees is the most efficient approach to introducing LWD to Soquel Creek, the analysis does not look at the biological component. The concept behind dropping whole trees is that it most closely emulates natural processes as compared to constructed LWD features. As such, dropping whole trees should result in LWD features most closely resembling natural ones. However, current data does not address biological efficacy. That will be addressed through post-project monitoring, both geomorphic and biologic.

Recommendations
It is recommended that future LWD loading projects focus on dropping whole trees.

In order to optimize the dropping of whole trees, the original fluvial geomorphic map developed by CGS should be updated and expanded to include more reaches suitable[2] for introduction of LWD. Updating of the map would include mapping of suitable trees within 30 feet of the stream bank[3].

Original Signed By
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Senior Engineering Geologist
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cc: Cheryl Hayhurst

Attachments: Tables 1 & 2
Appendix A

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[2] *Criteria include stream gradient less than 3 percent, entrenchment ratio greater than 1.5, mean channel armor less than 12 inches, and accessible by excavator with minimal potential damage to riparian zone.*

[3] *During Soquel LWD project, found 30 feet to be upper limit of working distance for dropping at least part of the tree in the channel and moving large, whole-tree into channel on relatively flat ground. Also see reference 19.*

Table 1: Summary of LWD Loading Rates Minimally Disturbed Watersheds Coastal Pacific Northwest, United States

Study Date	Author	Geographic Area	Forest	Bankfull Width (m)	LWD Loading $m^3/100$ m	LWD Loading m^3/m^2	Soquel Bankfull Channel Nomalization Factor	LWD Loading $ft^3/100$ ft	LWD Loading ft^3/ft^2
1983	Keller & Mac Donald	Northern California Coast	Conifer	7	119	0.17	2.14	2,754	1.20
1986	Harmon, etal	Northern California Coast	Conifer	7	109	0.155	2.14	2,523	1.10
1987	Swanson, etal	Coastal Oregon	Conifer	12	38.4	0.032	1.25	518	0.13
1992	Fausch & Northcote	Coastal British Columbia	Conifer	5.4	43	0.08	2.78	1,290	0.73
1998	McHenry, etal	Olympic Pennisula, Washington	Conifer	11	51.7	0.047	1.36	761	0.21
2002	Benda, Bigelow & Worsley	Northern California Coast	Conifer	8	137	0.21			
2003	Faustini & Jones	Western Cascade, Oregon	Conifer	13	134	0.1	1.15	1,670	0.38
2004	Wooster & Hilton	Northern California Coast	Conifer	8.3	59	0.084	1.81	1,152	0.50
							Mean	***1523.97***	***0.61***
							Median	***1290.00***	***0.50***
2013	Reynolds & Hayhurst (in press)	Site 1	Conifer	15	43.1	0.09	1.00	465	0.31
2013	Reynolds & Hayhurst (in press)	Site 2	Conifer	15	33.3	0.07	1.00	360	0.24
2013	Reynolds & Hayhurst (in press)	Site 4	Conifer	15	25.0	0.05	1.00	270	0.18
2013	Reynolds & Hayhurst (in press)	Site 5	Conifer	15			1.00	585	0.39
							Mean	***420.00***	***0.28***
							Median	***412.50***	***0.28***

Table 2: Summary of LWD Loading Rates for Historically Logged Watersheds Coastal Pacific Northwest, United States

Study Date	Author	Geographic Area	Forest	Bankfull Width (m)	LWD Loading m^3/100 m	LWD Loading m^3/m^2	Soquel Bankfull Channel Nomalization Factor	LWD Loading ft^3/100 ft	LWD Loading ft^3/ft^2
1983	Keller & MacDonald	Northern California Coast	Conifer	7	91	0.13	2.14	2,106	0.92
1987	Long	Coastal Oregon	Conifer	4.4	13.2	0.03	3.41	486	0.34
1987	Swanson, etal	Coastal Oregon	Conifer	12	38.4	0.032	1.25	518	0.13
1992	Fausch & Northcote	Coastal British Columbia	Conifer	5.4	14.9	0.03	2.78	447	0.28
1998	McHenry, etal	Olympic Pennisula, Washington	Conifer	11	23.9	0.022	1.36	352	0.10
2002	Benda, Bigelow & Worsley	Northern California Coast	Conifer	7.5	115	0.15	2.00	2,484	0.99
2003	Benda, Bigelow, & Andros	Southern Cascade, Klamath	Conifer	11	31	0.028	1.36	457	0.13
2003	Faustini & Jones	Western Cascade, Oregon	Conifer	13	4	0.003	1.15	50	0.01
2004	Wooster & Hilton	Northern California Coast	Conifer	7.5	37	0.05	2.00	799	0.33
				Mean	***40.93***	***0.05***	***Mean***	***855.44***	***0.36***
				Median	***31.00***	***0.03***	***Median***	***486.00***	***0.28***
2013	Reynolds & Hayhurst (in press)	Site 1	Conifer	15	43.1	0.09	1.00	465	0.31
2013	Reynolds & Hayhurst (in press)	Site 2	Conifer	15	33.3	0.07	1.00	360	0.24
2013	Reynolds & Hayhurst (in press)	Site 4	Conifer	15	25.0	0.05	1.00	270	0.18
2013	Reynolds & Hayhurst (in press)	Site 5	Conifer	15			1.00	585	0.39
							Mean	***420.00***	***0.28***
							Median	***412.50***	***0.28***

Appendix A - References

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APPENDIX D
PHOTOS

Site 1a November 2012 – View looking downstream


Site 1a December 2014 – View looking downstream


Site 1a April 2015 – View looking downstream

Site 1b September 2012 – View looking downstream


Site 1b December 2014 – View looking downstream

Site 1b April 2015 – View looking upstream

Site 1c November 2012 – View looking downstream

Site 1c December 2014 – View looking upstream

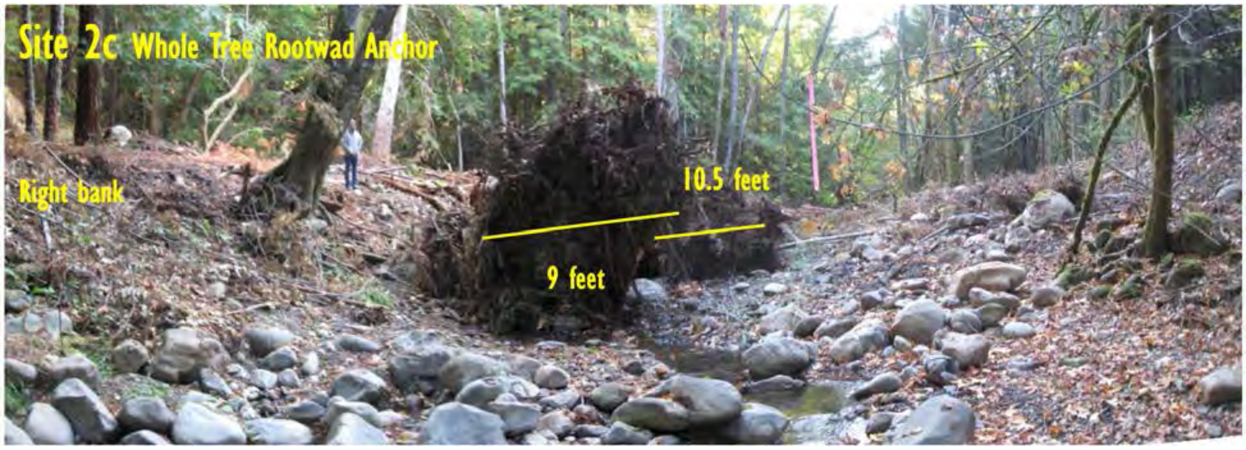
Site 2a August 2013 – View looking upstream


Site 2a December 2014 – View looking upstream

Site 2a April 2015 – View looking downstream

Site 2b October 2013 – View looking downstream


Site 2b December 2014 – View looking downstream



Site 2c October 2013 – View looking upstream


Site 2c December 2014 – View looking downstream


Site 2c April 2015 – View looking upstream

Site 4a September 2013 – View looking upstream


Site 4a March 2015 – View looking downstream


Site 4a April 2015 – View looking downstream

Site 4b October 2013 – View looking downstream


Sit3 4b March 2015 – View looking upstream

Site 4c September 2013 – View looking downstream


Site 4c March 2015 – View looking downstream


Site 4c April 2015 – View looking downstream

Site 5 October 2013 – View looking downstream


Site 5 December 2014 – View looking downstream


Site 5 April 2015 – View looking downstream


Streambank/Road Repair Site August 2014 – View looking downstream


Streambank/Road Repair Site April 2015 – View looking downstream