Fast Response to Fast-Forwarding Nature: Instream Large Wood Habitat Restoration[1]

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Abstract

How quickly and in what way does a channel bed respond when large wood elements are introduced in a way that imitates natural wood loading processes (un-anchored or anchored by burial)? Using a design streamflow threshold for determining the size of key large wood elements, what changes in channel bed and habitat complexity occur after streamflow events above and below the threshold? These are questions we are currently trying to answer with a large wood habitat enhancement project on the East Branch of Soquel Creek within Soquel Demonstration State Forest in Santa Cruz County, California. This project also aims to address a lack of instream habitat complexity that was identified in the National Marine Fisheries Service 2012 Central California Coast Coho Salmon Recovery Plan.

Large wood elements were placed in four project reaches (sites) along East Branch Soquel Creek in 2012 and 2013. These large wood elements consist of a combination of large key pieces (whole or nearly whole redwood trees with rootwads), log vanes with rootwad covers, and loosely racked wood structures. The large key elements were selected based on a size calculated to remain meta-stable through a 5-year return interval streamflow event and consist of single or multi-stem redwood trees with rootwads. The rootwad diameters range from 2.7 m to 3.81 m (9 ft to 12.5 ft) and the stems range from 0.8 m (30 inches) diameter at breast height (DBH; 1.37 m) to 1.3 m (51inches) DBH (largest stems on multi-stemmed structures). In all, 45 stems and 10 rootwads were introduced.

Monitoring observations have been conducted on four separate occasions at Site 1 (installed in 2012) and three times for the remaining three sites (2, 4, and 5) installed in 2013. Site 1 large wood elements experienced an event approximating the 7-year return interval the first winter after installation, which rotated the elements in place. Channel changes occurred the first winter after installation of sites 2, 4, and 5 in response to streamflow events below the design threshold. Thalweg profiles indicate increased complexity in the form of pool formation and localized aggradation and scour through the project reaches. On March 5 and 6, 2016, these structures experienced an approximately 10-year streamflow event which visibly affected the geometry and positioning of the structures along with generally increasing the number, and in some cases the size, of pools. The extent of thalweg changes and the position and orientation of large wood elements will be included as part of the physical monitoring of the four reaches that continues for 5 years after installation.

Keywords: channel morphology, Coho salmon, geomorphology, large wood, salmonids, stream restoration, wildlife habitat

Introduction

At the request of the California Department of Forestry and Fire Protection (CAL FIRE), staff of the California Geological Survey (CGS) completed the design and provided on-site technical support and direction for a Large Woody Debris and Habitat Complexity project. The project design included a large wood restoration literature review, geomorphic assessment, and hydrologic analysis. The installation included 10, large wood (LW) elements in four project reaches (referred to as Sites 1, 2, 4, and 5) along a 1.1 km (0.7 mile) stretch of the East Branch of Soquel Creek, within the Soquel Demonstration State Forest (SDSF) (fig.1). The SDSF is a 1,085 ha (2,681 ac) forest managed by CAL FIRE. Site 1 consists of three elements (1a, 1b, and 1c) within an approximately 91 m (300 ft)

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reach and was completed in September of 2012. Sites 2 and 4 also consist of three elements each within an approximately 91 m (300 ft) reach, while Site 5 consists of one element in an approximately 30.5 m (100 ft) reach. Sites 2, 4, and 5 were constructed in August and September of 2013. Site 3 was not constructed due to funding constraints.

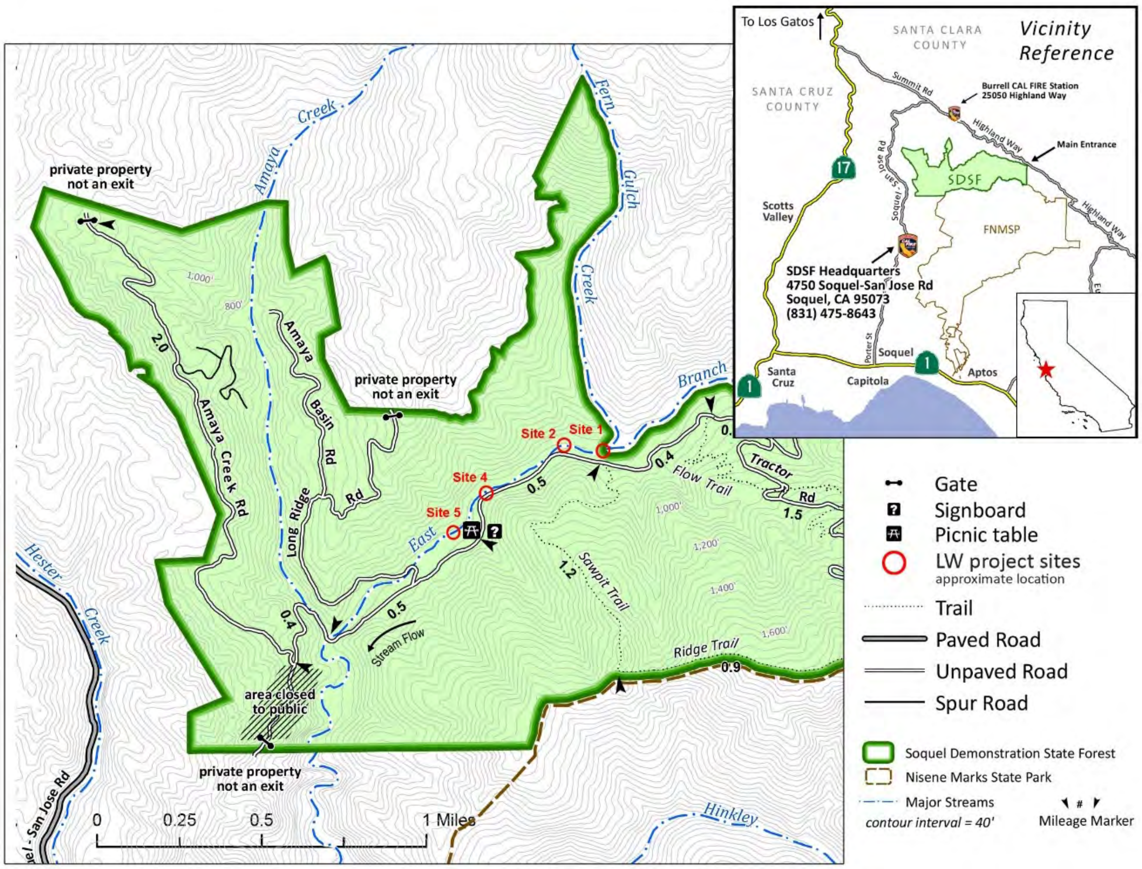

Figure 1—Site location map showing the LW sites within the SDSF boundary.

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, on the basis of low amounts of large wood being a stressor for the recovery of Coho salmon in Soquel Creek (National Marine Fisheries Service 2012).

The SDSF’s Large Woody Debris and Habitat Complexity Project was undertaken in an effort to help address the shortage of LW within Soquel Creek, and to increase overall stream quality from a biological standpoint. Lack of wood can cause simplification of channel characteristics and the wood emplacement is meant to increase channel complexity such as increasing the number and/or depth of pools, storing gravel, and providing high flow refugia areas.

The underlying concept of the project is to emulate natural LW features as closely as possible, including dropping of bank-side trees with rootwad, placement of log vanes and log clusters, and avoiding the use of cables, bolts, and other artificial means of achieving LW stability. The approach to the design process involved the basic steps of 1) geomorphic mapping of potential stream reaches, 2) selection of project reaches, 3) selection of design flow, 4) sizing LW elements. and 5) configuration of LW elements. A summary of the project design and installation details are described below. Additional details are described in "as-built" reports prepared for Site 1[4] and Sites 2, 4, and 5[5].

Methods and Materials

Hydrology and Large Wood Design Considerations

Initial design surveys (including longitudinal profiles, cross-sections, bankfull geometry, and bank heights) indicated that for East Branch Soquel Creek, bankfull channel width varies from 14 m (45 ft) to 17 m (55 ft), bankfull maximum depth varies from 0.6 m (2.2 ft) to 0.8 m (2.6 ft), and bankfull mean depth varies from 0.2 m (0.8 ft) to 0.4 m (1.2 ft). East Branch Soquel Creek was determined to have a bank height ratio (BHR) that is typically on the order of 1.4 and was found generally incised. Bank height ratio is defined as the height of the lowest bank divided by the maximum bankfull depth.

In order to achieve the desired stability for the LW elements, a key piece of information necessary for the project design and sizing of the LW elements was the design streamflow threshold. The design flow was determined in consultation with fisheries biologists from the California Department of Fish and Wildlife, National Marine Fisheries Service, and private consultants, who were asked to provide bounding values for desired LW longevity. A minimum threshold time frame of 5 years was agreed upon for LW features to have a significant biological benefit. That opinion provided a minimum or base-line design flow, i.e., a flow with a recurrence interval of at least 5 years.

The 5-year return interval design flow was calculated by annual-flood frequency analysis using a flow transference method (Waananen and Crippen 1977) from United States Geological Survey (USGS) gage No. 11160000 (USGS 2016) on Soquel Creek located downstream in the town of Soquel, California. A correction factor developed by a local hydrologist for the East Branch of Soquel Creek was used to refine the analysis (B. Kreager, personal communication). A flow of 28 cms (990 cfs) and a stage height of 1.5 m (5 ft) were used in the design.

To form stable LW accumulations Key Logs (typically a complete tree with rootwad attached) were sized to withstand the forces generated at the design flow by conducting a stability analysis that takes into account various forces due to buoyancy, gravity, and flow, among others. The stability analysis indicated that a Key Log of a minimum 24 m (80 ft) length, 1 m (40 inches) DBH, and a 3 m (10 ft) diameter rootwad would remain meta-stable through a 5-year return interval event. Single-stem trees of sufficient mass to be stable through a 5-year streamflow event, were not available. However, several complexes consisting of a single rootwad with two to four stems were available. These clumps were of sufficient height and mass to conform to the LW design parameters.

Large Wood Elements

The LW features installed at SDSF are of two primary types, mobile and anchored. Mobile wood is comprised of features that rely solely on the mass and shape (bole plus rootwad) to provide stability; anchored wood features rely on secondary elements, in this case boulders and burial, to achieve stability. LW elements involving mobile wood were Key Logs dropped into the creek, with rootwads facing both up- and down-stream (Sites 1a, 1b, 1c, and 2c, see fig. 2), and loose-stacked arrays of logs referred to as log clusters (Sites 2a, 4a, and 5). These two features were used in conjunction, the Key Logs having sufficient mass to be stable at the design flows and the log clusters sized to slowly disaggregate and move downstream. This allows the desegregated logs to become entangled with the downstream key logs, thus emulating the natural process of log jam formation. Two types of anchored

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[4] California Geological Survey. 2013. Soquel Creek LWD Project – Site 1 As-Built Report. Unpublished memorandum to Angela Bernheisel, Forest Manager, Soquel Demonstration State Forest, California Department of Forestry and Fire Protection; dated January 18, 2013.

[5] California Geological Survey. 2014. Soquel Creek LWD Project – Site 2, 4, & 5 As-Built Report. Unpublished memorandum to Angela Bernheisel, Forest Manager. Soquel Demonstration State Forest, California Department of Forestry and Fire Protection; dated April 4, 2014.

wood elements were employed. The first is a variant of the dropped whole tree. In places where access was limited, a single large bole with rootwad attached was placed downstream of a log cluster (Site 4b). In order to achieve the requisite stability, 3.7 m to 4.6 m (12 ft to 15 ft) of the bole was buried in the stream bed with large rock (ballast) being used as backfill. The other anchored structure was a simple log vane, a large log that is buried in the bank and partially buried in the channel (Sites 2b and 4c). The logs project upstream from the bank at approximately a 30 degree angle and plunges at approximately 5 degrees. The function of this feature is to reduce pressure and erosive forces on a stream bank by locally reducing stream gradient and thus encourage deposition of bed load leading to the formation of a lateral bar. A secondary benefit is that typically downstream of the vane a pool will form. To enhance the biological value of the pool, a rootwad cover log was added to the vane. Like the vane, the rootwad is buried in the bank. In addition to the primary LW elements, broken or trimmed tops and alders or other smaller trees that came down with the falling of the primary LW elements were incorporated into the structures.

Figure 2—Site 1b Key Log.

All LW elements consist of redwood (*Sequoia sempervirens* (D. Don) Endl.) or Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) trees either from the adjacent banks or from a recent timber harvest within SDSF. Rock for ballast was derived onsite, generally within the reach vicinity. The total amount of wood introduced into Soquel Creek at the four sites includes 45 stems and 10 rootwads. The stems range from 0.25 m (10 inches) to 1.37 m (54 inches) diameter and 7.9 m (26 ft) to 35.4 m (116 ft) long. The rootwads range from 2.6 m (8.5 ft) to 3.8 m (12.5 ft) in diameter. The total calculated volume of wood added is 326.4 cubic meters (m^3) (11,528 cubic feet [ft^3]). The total amount of LW introduced into Soquel Creek for all four project reaches calculates to 11.7 m^3/30.5 m (412 ft^3/100 ft) (LW volume versus channel length) or 0.0076 m^3/m^2 (0.27 ft^3/ft^2) (LW volume versus channel area). This is similar to amounts described in nine studies of disturbed but recovering watersheds of the Pacific Northwest (Benda et al. 2002, Benda et al. 2003, Fausch and Northcote 1992, Faustini and Jones 2003, Keller and MacDonald 1983, Long 1987, McHenry et al. 1998, Swanson et al. 1987, Wooster and Hilton 2004) where median LW values of about 13.3 m^3/30.5 m (486 ft^3/100 ft) or 0.0079 m^3/m^2 (0.28 ft^3/ft^2) of channel are reported.

Monitoring

Annual monitoring primarily consists of thalweg surveys at each site to document changes in channel morphology. The thalweg surveys are completed using a rod and level survey at each site to record distance and relative elevation measurements. Thalweg surveys conducted at Site 1 include a post-installation survey completed in November 14-15, 2012, and monitoring surveys conducted February 22, 2013, December 22-23, 2014, December 1-2, 2015, and June 21-23, 2016. Thalweg surveys represented for Sites 2, 4, and 5 include the post-installation surveys completed October 22-23, 2013, and monitoring surveys noted above conducted in 2014, 2015, and 2016. A baseline thalweg survey was conducted February 4, 2011. Streamflow data from the downstream USGS gage were also used to summarize peak streamflows experienced at the project sites between the annual monitoring events.

Results

LW Response to Hydrologic Events

2012/2013 Winter Rains

Two significant rain events occurred producing peak stream flows in Soquel Creek of roughly 26.9 cms (950 cfs), an approximately 4-year return interval, and 35.7 cms (1260 cfs), an approximately 7-year return interval, on December 2, 2012 and December 23, 2012, respectively. Since Site 1 was installed in September 2012, the LW at this location experienced these 2012/2013 peak flows. These events did not move the Site 1 rootwads from their installation point, however the stems attached to the rootwads rotated from their original position oriented across the creek to an orientation more in line with the flow direction. Several of the smaller wood pieces incorporated into the large wood elements, such as broken tops, did dislodge and either moved downstream out of the reach, or readjusted positions within the reach. Figure 3 shows the change in stem orientation at each of the Site 1 structures.

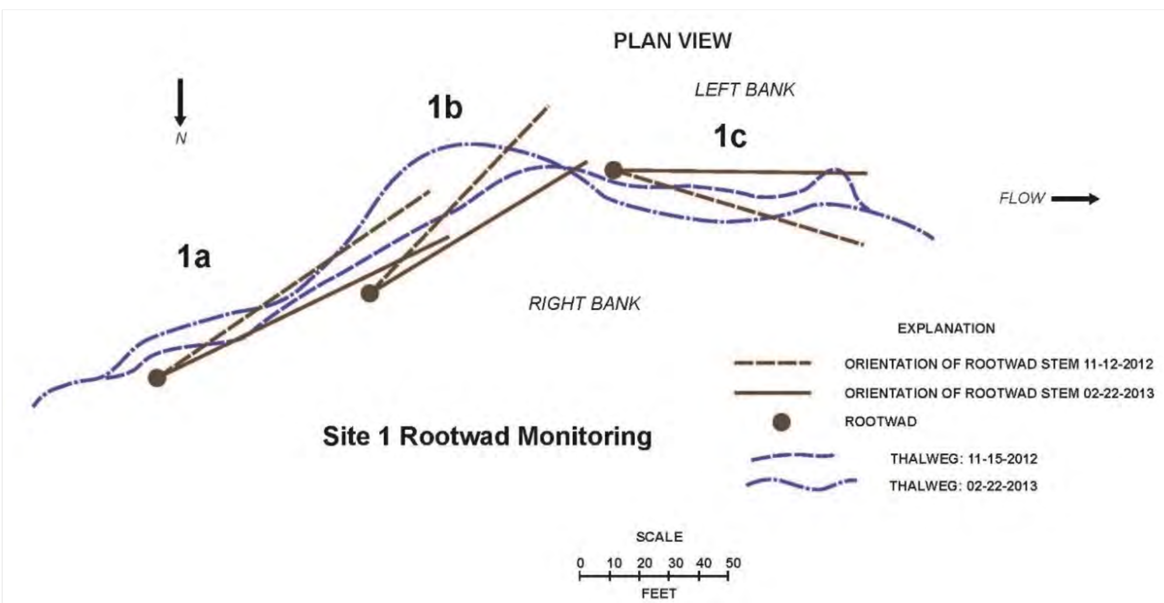

Figure 3—Rotation of Site 1 Key Logs after approximately 7-year return interval streamflow event.

2013/2014 and 2014/2015 Winter Rains

The winter season of 2013/2014 and the early part of the 2014/2015 winter season (though December 20, 2014) did not produce significant storm events. The largest event over this period occurred on

December 12, 2014 producing a peak flow of 6.26 cms (221 cfs), approximately a 1.4-year return interval streamflow, in the vicinity of the project sites. The minor streamflow 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 significant streamflow events. The largest event over this period occurred on February 8, 2015, with a peak flow of 9.8 cms (345 cfs), an approximately 1.7-year return interval streamflow, in the vicinity of the project sites. The minor streamflow 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.

2015/2016 Winter Rains (Dec 3, 2015 – July 1, 2016)

A significant streamflow event occurred on March 5, 2016, producing a peak flow of 39.8 cms (1405 cfs), an approximately 10-year return interval event. This event had a more substantial impact on the LW project sites. The Key Logs at 1a and 1b both moved downstream approximately 21.8 m (71.5 ft) and 48.8 m (160 ft), respectively, with 1b now farther downstream than the 1c Key Log, though all three elements have remained within the project reach vicinity. At the Site 2a log cluster only one of four logs remains. The Site 2c Key Log moved approximately 113 m (370 ft) downstream of the project reach to create a new log jam where it hung up. At the 4a log cluster, four of nine logs mobilized downstream and have formed a new log jam just downstream of Site 4c. The 4b anchored rootwad backstop mobilized and the rootwad hung up on the 4c vane log. The log cluster at Site 5 had several pieces rotate and has entrained additional wood, including a large stump that appears to have eroded out of the right bank just upstream of the structure.

Channel Bed Response

Site 1

Through the Site 1 reach, baseline 2011 and 2012 post-installation surveys show a generally uniform channel profile with only one incipient pool present after the installation of the three Key Log structures. An incipient pool, for the purpose of the LW monitoring, is defined as a bed roughness element less than 0.3 m (1 ft) 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 0.3 m (1 ft) and greater. During the winter following installation, Site 1 experienced an approximately 7-year return interval streamflow event that exceeded the design peak streamflow for the Key Logs. As noted above, the Key Log structures rotated in the streamflow event, but remained in their general installation locations. The channel response included the formation of two pools and three incipient pools for a total of four incipient pools. Based on the survey data localized aggradation occurred just upstream of each of the Key Log sites. During the next 2 years (2014 and 2015) the largest streamflow events were approximately 1.4-year and 1.7-year return intervals. Even with the minimal streamflow events, the channel profile remained dynamic with localized aggradation and scour. In comparison to the other sites, Site 1 was installed prior to the 7-year event in 2012, which may account for the increased aggradation observed at Site 1 relative to the other sites, which were installed the following summer after that event. In March 2016, Site 1 experienced an approximately 10-year return interval streamflow event. The Key Log structures at 1a and 1b both mobilized downstream a short distance, though they remained within the general project reach area. Site 1c remained in its previous position. In addition to the relocation of Key Log structures at Sites 1a and 1b, there are now four pools and seven incipient pools present in the project reach. These channel changes are represented in fig. 4.

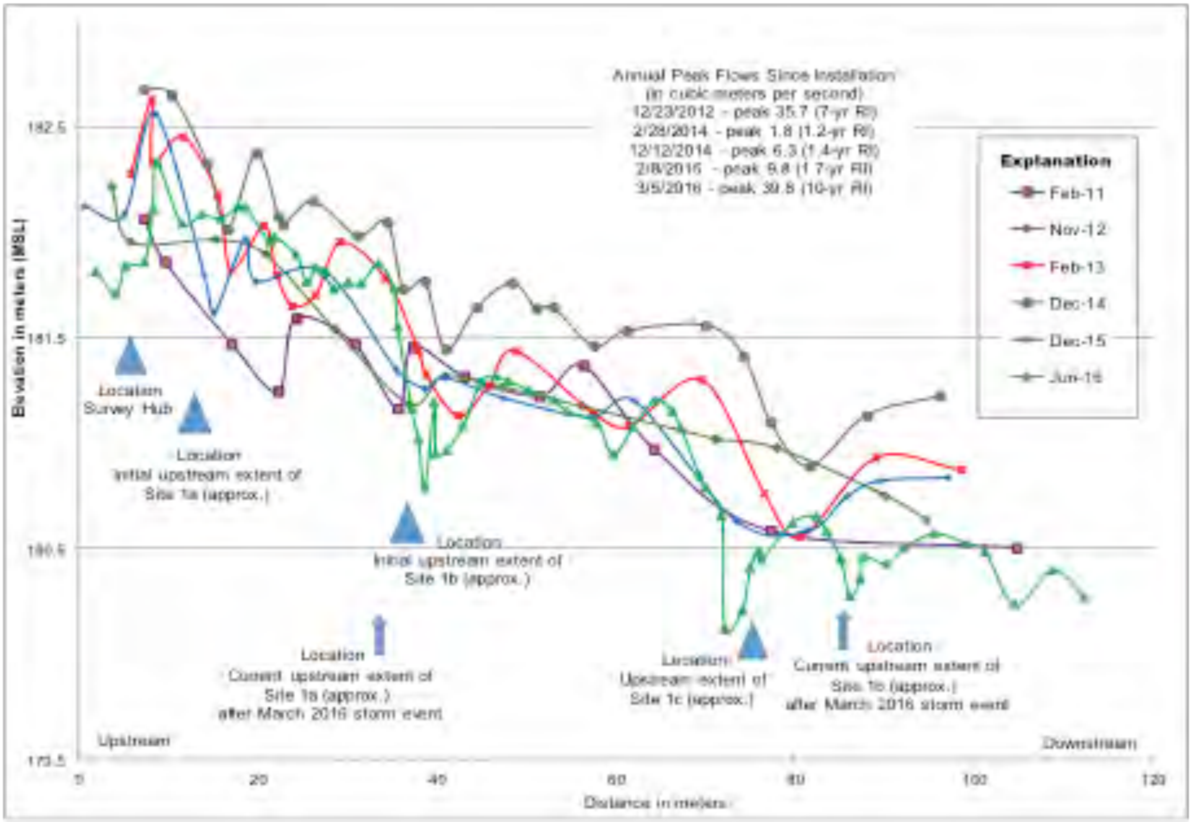

Figure 4—Site 1 thalweg surveys.

Site 2

Site 2 has been one of the more dynamic sites since installation. Although the profiles differ some, both the 2011 baseline survey and the 2013 post-installation survey show a fairly uniform channel profile with up to three incipient pools. In the 2 years following the LW installation (peak flows of 1.4- and 1.7-year return intervals), the channel elevation immediately upstream of the Site 2c Key Log structure increased by approximately 0.76 m (2.5 ft) with aggraded stream gravels. The aggraded material extended upstream from the 2c structure a distance of approximately 61 m (200 ft). At Site 2b a 0.7 m (2.3 ft) deep scour pool was measured at the location of the rootwad cover for the vane log. In that 2-year timeframe, three pools were scoured and the incipient pools varied in number from three to five. In 2016, after the 10-year streamflow event, the entire 2c Key Log structure mobilized downstream out of the project reach. With the 2c structure no longer present to retain bed material, up to approximately 1.2 m (4 ft) of vertical channel scour occurred upstream of the initial 2c location. The scour response was most significant between the 2b and 2c structures, but did continue upstream through the 2a structure. The resulting thalweg profile contained nine incipient pools and no pools. These channel changes are represented in fig. 5.

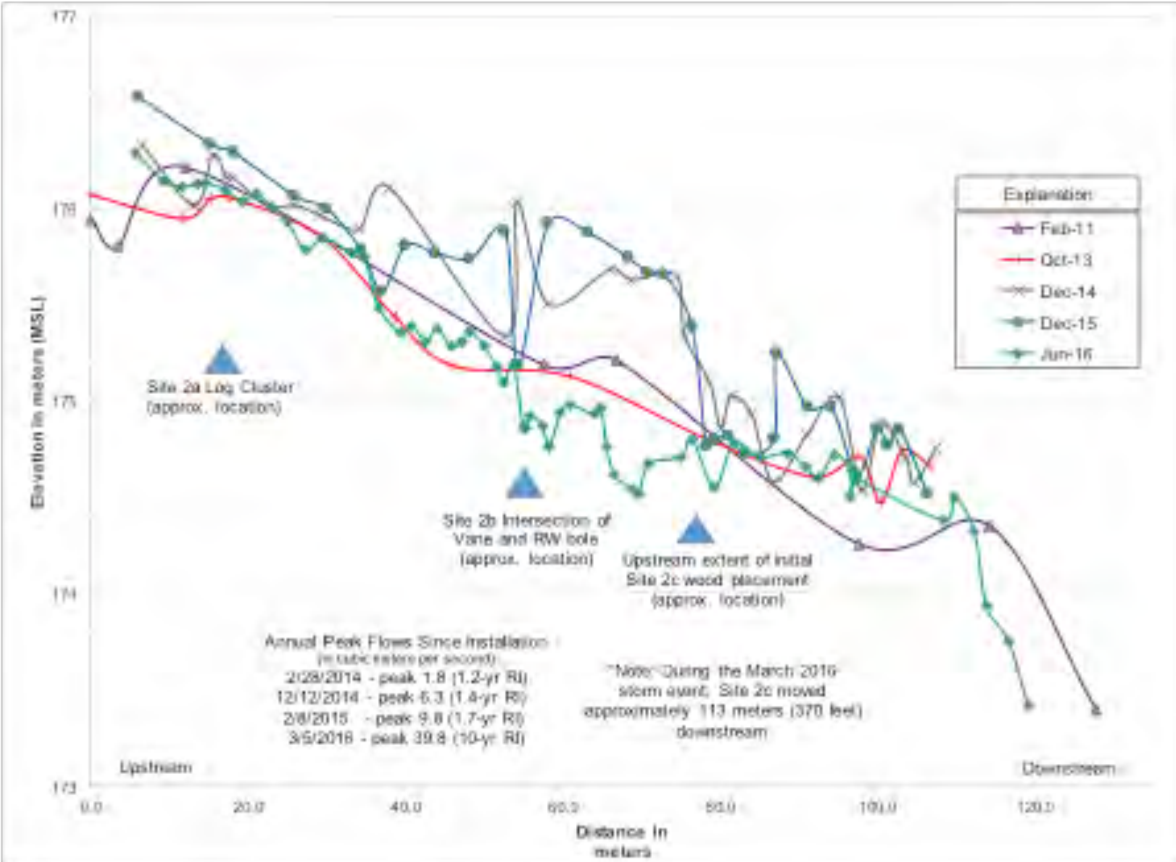

Figure 5—Site 2 thalweg surveys.

Site 4

The 2011 baseline survey through Site 4 shows a relatively uniform channel profile with two incipient pools and one large pool just downstream of the site. The post-installation survey in 2013 reflects a similar channel condition to 2011 with four incipient pools and the large pool downstream. Thalweg changes over the next 2 years (peak flows of 1.4- and 1.7-year return intervals) were generally modest, though incipient pools increase to six in 2014 and remained through 2015. Thalweg complexity also appears to increase during this time with localized scour and aggradation throughout the reach on the order of approximately 0.2 m to 0.3 m (0.5 ft to 1 ft) through most of the reach distance. During the 10-year streamflow event the anchored LW structure at 4b dislodged and traveled downstream where its rootwad hung up on the vane log at the 4c structure. This is where the most significant channel changes occurred. Vertical channel scour of approximately 0.8 m (2.5 ft) occurred at the 4c structure downstream of the vane log and the large downstream pool that had been relatively stable since at least 2011 filled with sediment. Overall, the 2016 survey shows similar channel complexity upstream of the 4c structure and the presence of five incipient pools and three pools within the reach. These channel changes are represented in fig. 6.

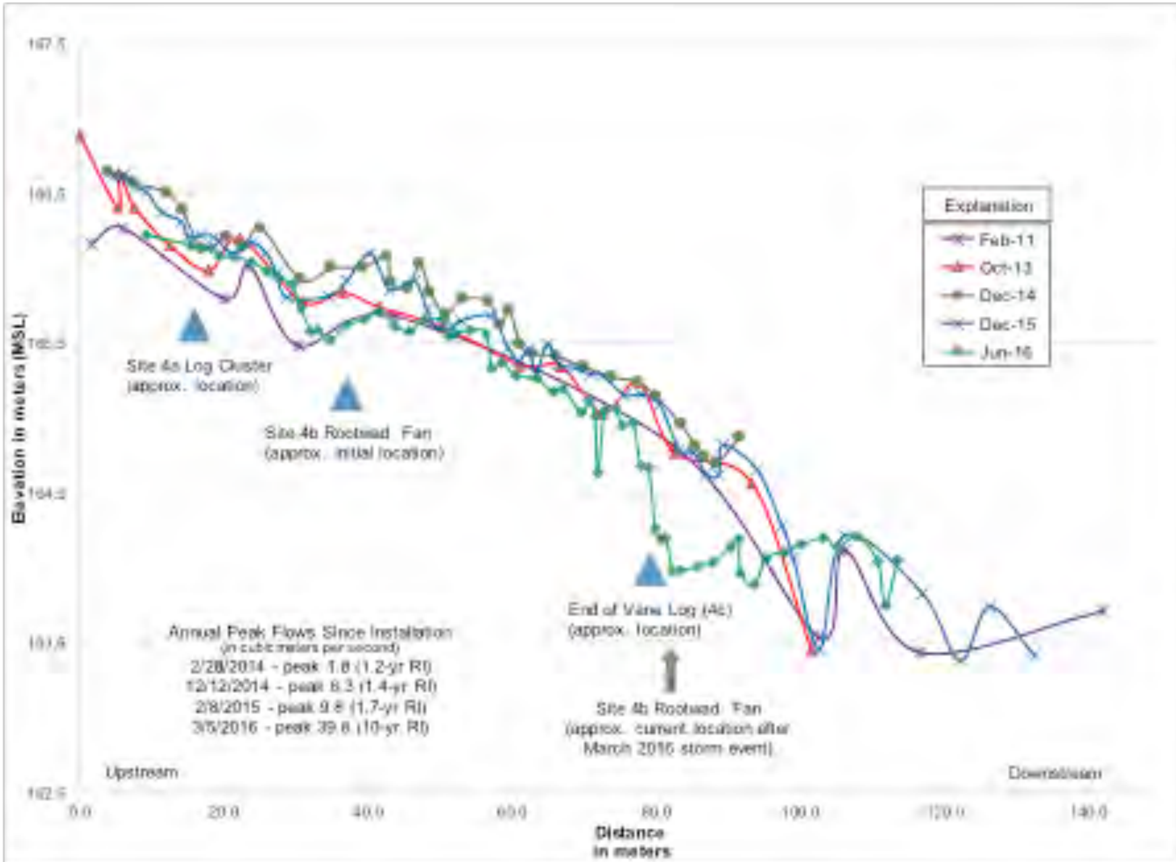

Figure 6—Site 4 thalweg surveys.

Site 5

The baseline 2011 survey shows a uniform channel profile through Site 5, however few data points were collected at that time. The post-installation survey in 2013 shows the presence of two incipient pools. Over the next 2 years (2014 and 2015), the number of incipient pools grew to three and then six, respectively, through the project site and channel elevation appears to have locally increased (via aggradation) approximately 0.2 m to 0.3 m (0.5 ft to 1 ft) over a distance of more than 7.6 m (25 ft) upstream of the log cluster. These channel changes occurred with relatively low annual peak flows corresponding to approximately 1.4-year and 1.7-year return interval events. The 2016 survey reflects significant changes that occurred in response to the 10-year streamflow event and the formation of a log jam at the LW structure. Five incipient pools remain in the reach and a large pool with a residual depth of 0.97 m (3.17 ft) was scoured at the log jam. Additionally, channel aggradation of an average of approximately 0.30 m (1 ft) occurred upstream of the new log jam. The channel changes are represented in fig. 7.

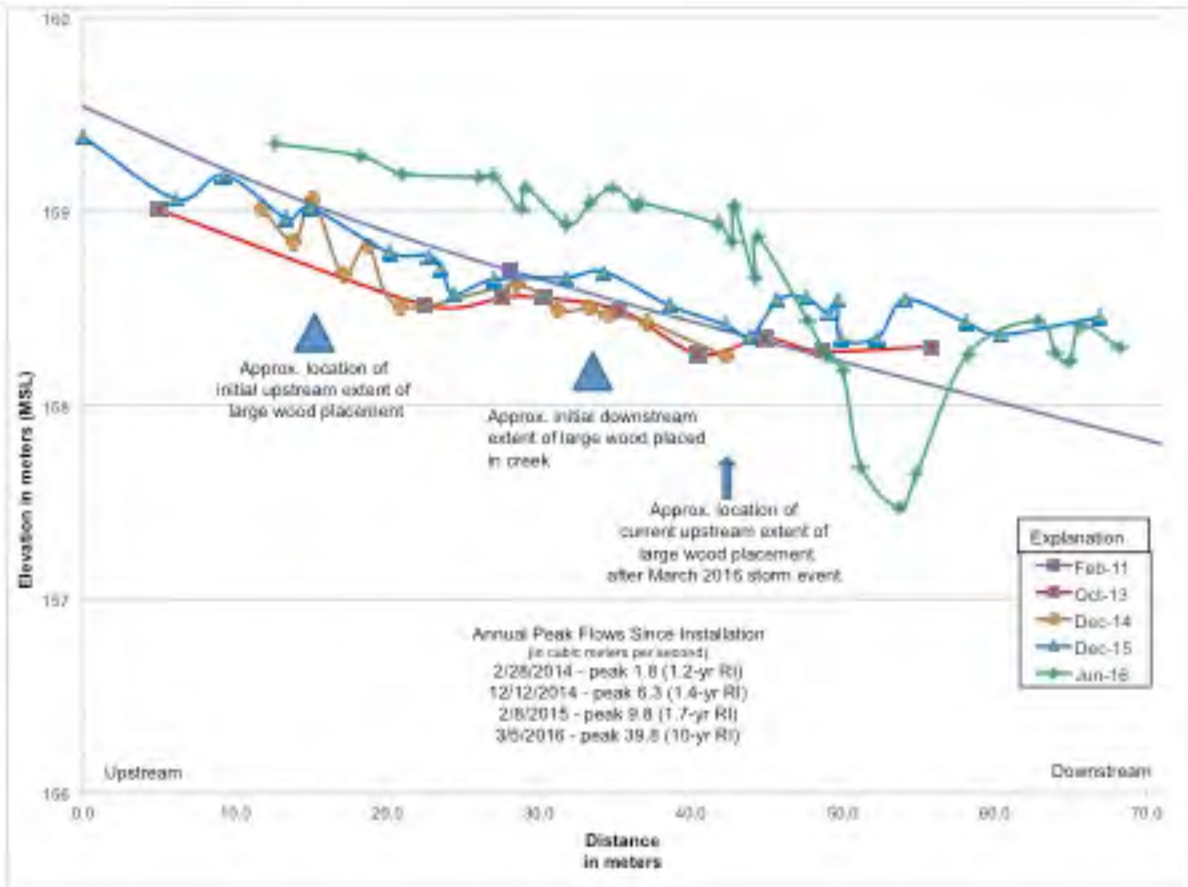

Figure 7—Site 5 thalweg surveys.

Discussion

Instream habitat restoration at Soquel Creek utilized Key Logs in LW structures sized to remain meta-stable through a 5-year streamflow event to provide a habitat benefit and increase geomorphic complexity within each reach for a period of time (5 years) deemed significant by the fisheries biologists. In the 4 years since installation, the Site 1 structures have experienced an approximately 7-year recurrence interval streamflow event and a 10-year recurrence interval streamflow event (fig. 8). Sites 2, 4, and 5 have been in place for 3 years and experienced a 10-year streamflow event. With the exception of one of the Key Log structures, Site 2c, all of the Key Log structures remained within the general project reach vicinity and remain interacting with the stream channel. Though Site 2c mobilized downstream out of the project reach, it has lodged in a new location and will continue to add a positive benefit to the overall health and functionality of the stream. Within our monitoring reaches at Soquel Creek, we demonstrated that the channel profiles respond relatively quickly to constructed LW structures that imitate natural wood loading. All four of the sites showed increased thalweg profile complexity within the first year of installation. These changes included the development of incipient pools (less than 0.3 m [1 ft] deep) and pools (0.3 m [1 ft] and greater depth, summarized in table 1), localized aggradation and scour (particularly aggradation upstream of the wood structures), and the formation of lateral gravel bars (though not represented in the thalweg surveys; see fig. 9). What was particularly interesting is the increase in complexity at Sites 2, 4, and 5 occurred within the first year or two after installation during an extended drought characterized by low rainfall and small peak flows (1.4-year and 1.7-year events).

Figure 8—Site 1 showing 10-year flow features (March 17, 2016).

Table 1—Summary of the number of pools and pool depths at each site

Site 1	Site 2	Site 4	Site 5
November 2012: 1 incipient pool (0.13 m [0.43 ft] deep)	N/A	N/A	N/A
February 2013: 2 pools (0.31 m and 0.37 m [1.01 and 1.23 ft] deep), 4 incipient pools (0.13 m to 0.30 m [0.42 to 0.98 ft] deep)	October 2013: 3 incipient pools (0.11 m to 0.19 m [0.36 to 0.61 ft] deep)	September 2013: 4 incipient pools (0.06 m to 0.23 m [0.20 to 0.76 ft] deep)	September 2013: 2 incipient pools (0.04 m and 0.08 m [0.13 and 0.27 ft] deep)
December 2014: 2 pools (0.31 m and 0.36 m [1.03 and 1.18 ft] deep), 5 incipient pools (0.03 m to 0.24 m [0.11 to 0.79 ft] deep)	December 2014: 3 pools (0.35 m to 0.69 m [1.16 to 2.28 ft] deep), 5 incipient pools (0.16 m to 0.26 m [0.54 to 0.86 ft] deep)	December 2014: 6 incipient pools (0.10 m to 0.18 m [0.32 to 0.58 ft] deep)	December 2014: 3 incipient pools (0.11 m to 0.22 m [0.36 to 0.71 ft] deep)
December 2015: 1 pools (0.35 m [1.15 ft] deep), 4 incipient pools (0.05 m to 0.24 m [0.16 to 0.78 ft] deep)	December 2015: 3 pools (0.31 m to 0.73 m [1.03 to 2.41 ft] deep), 3 incipient pools (0.09 m to 0.24 m [0.28 to 0.78 ft] deep)	December 2015: 6 incipient pools (0.06 m to 0.30 m [0.19 to 0.97 ft] deep)	December 2015: 6 incipient pools (0.06 m to 0.20 m [0.19 to 0.66 ft] deep)
June 2016: 4 pools (0.41 m to 0.63 m [1.33 to 2.06 ft] deep), 7 incipient pools (0.06 m to 0.30 m [0.21 to 0.97 ft] deep)	June 2016: 0 pools, 9 incipient pools (0.06 m to 0.27 m [0.20 to 0.87 ft] deep)	June 2016: 3 pools (0.31 m to 0.42 m [1.02 to 1.39 ft] deep), 5 incipient pools (0.07 m to 0.22 m [0.23 to 0.72 ft] deep)	June 2016: 1 pool (0.91 m [3.17 ft] deep), 5 incipient pools (0.11 m to 0.21 m [0.37 to 0.70 ft] deep)

Figure 9—Site 2b gravel bar (December 23, 2014).

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