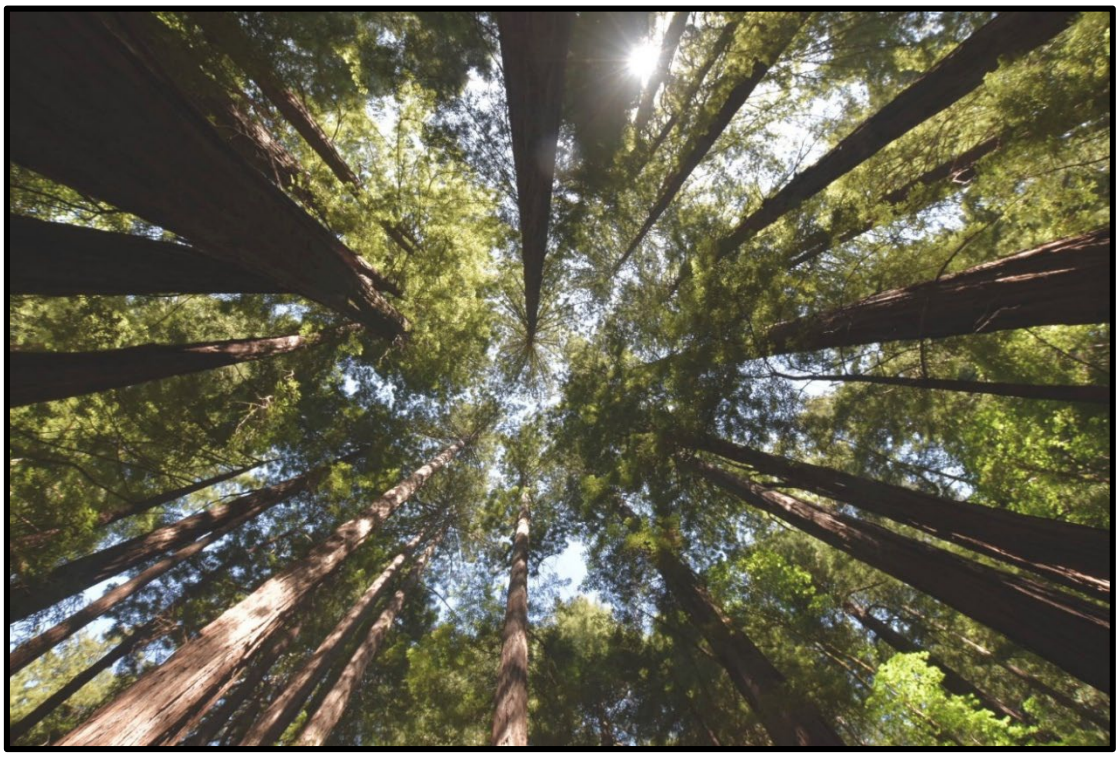
Pescadero-Butano Watershed Large Wood Monitoring Protocol



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Glossary of Key Terms

Bankfull Channel - portion of channel corridor that falls below bankfull elevation

Bankfull Elevation - relative elevation above the stream bed that defines the water level of frequent, channel forming flow (typically the 1.5- to 2-year flood event). Also referred to as bankfull depth.

Bankfull Width - width of channel from left to right bank, measured at the bankfull depth

Bar - elevated area of unconsolidated substrate deposited by flow, below bankfull elevation

Bole - trunk, or largest stem of tree

Bottom of Reach - farthest downstream point of survey reach

Channel Centerline - longitudinal line running through the center of the bankfull channel, equidistant from the right and left banks, not necessarily along the thalweg

Conifer - needle-leaved, cone-bearing, and evergreen tree species such as redwood, pine or fir.

Decay Class - level of decomposition of LW piece. Descriptions of each class can be found in Table 3.

Entrenchment Ratio - Flood prone width divided by bankfull width. This metric captures the degree of channel incision.

Flood Prone Area - area susceptible to inundation, defined here as the width of channel corridor at 2x bankfull elevation

Hardwood - broad-leaved tree species such as willow, alder, oak and maple.

Island - elevated area in channel, either depositional or a floodplain remnant, at or above bankfull elevation, and often vegetated

Key Piece - a piece of LW that is independently immobile and retains other pieces of LW or other organic matter.

Large Wood (LW) - piece of wood large enough to influence the characteristics and dynamics of a stream

Left bank - left side of the channel, *looking downstream* (i.e. river left)

Log - fallen, dead piece of wood

Log Jam - An accumulation of multiple pieces of LW that impedes a significant amount of flow, sediment, or organic matter. Jams are often established with key pieces.

Reach - segment of the channel with defined upstream and downstream points

Riffle - shallow, faster moving section of stream

Right bank - right side of the channel, *looking downstream* (i.e. river right)

Root wad - mass of roots (a.k.a. root ball) attached to the bole

Sediment wedge - mass of fine sediment, typically in a wedge shape, trapped behind a flow obstruction

Snag - standing dead tree

Spanner - fallen piece of wood that rests on both banks perched above bankfull elevation, spanning the channel

Thalweg - longitudinal line along the deepest point in the channel.

Top of Reach - farthest upstream point of survey reach

1. Introduction

The term “large wood” (LW) refers to pieces of timber within a channel or floodplain large enough to have hydrologic and geomorphic impacts on the system. LW provides numerous documented beneficial effects on rivers and river health including the development of deep pools for fish habitat (Bryant, 1983), providing refuge during seasonal high flows (Lisle, 1986), and trapping sediment and stabilizing banks (Montgomery, 2002). Specific benefits for salmonid species include harbors for juvenile fish and ideal spawning pools (Bryant, 1983). LW inputs can also impact nutrient cycling and provide consistent sources of dissolved organic carbon (Richardson, Bilby, & Bondar, 2007). LW pieces may form into log jams - immobile features that can arrest future incision and reverse adverse effects downstream by slowly releasing trapped sediment over time. Quantifying LW is crucial to understanding how river systems function as a whole.

This document provides a protocol for field-based techniques to quantify in-stream LW for Pescadero and Butano creeks and their tributaries in San Mateo County, California. The protocol presented herein was designed to capture multifaceted data. Initial surveys will capture a baseline level of LW loading in these rivers as required by the Sediment and Habitat Enhancement Total Maximum Daily Loading [TMDL] for this watershed (Frucht et. al., 2018). The protocol can be used to assess LW loading every 3-5 years for determining progress towards meeting established TMDL LW loading targets (≥300 m^3/ha for redwood forest channels and ≥100 m^3/ha hardwood forest channels). Additional analyses can yield key piece frequency, log jam structure and function, and possible loading and mobility insights. These factors are important for resource managers to understand the role of wood in the system at multiple spatial and temporal scales and ultimately to provide well-informed management recommendations. The protocol will aid in the improved health and management of the Pescadero-Butano watershed.

The methods in this protocol follow those of similar protocols developed for the region (e.g., Alford, 2013; Flosi, et. al., 2010) and draw from other published protocols and guidance from outside the region (e.g., Wohl, et. al., 2010; Ruiz-Villanueva, et. al., 2016; and Saunders, et. al., 2020). It is designed to provide a rapid assessment that maximizes the potential number of sites and length of streams surveyed. Due to the coordination of public and private land access and crew logistics needed for LW survey site selection, this protocol focuses solely on LW survey methods.

2. Site Description

Pescadero and Butano creeks combined drain 81 mi^2 (210 km^2) from the Santa Cruz mountains to the Pacific Ocean near the town of Pescadero (Frucht et. al., 2018, Figure 1). The majority of the watershed is characterized by redwood forest, with some reaches being hardwood dominated. Wood inputs from both forest types differ from large (sometimes massive) logs in redwood forests to smaller, more mobile pieces in hardwood areas. Channels are typically incised, few log jams or flow obstructions exist, and LW moves easily through the system during high flow events.

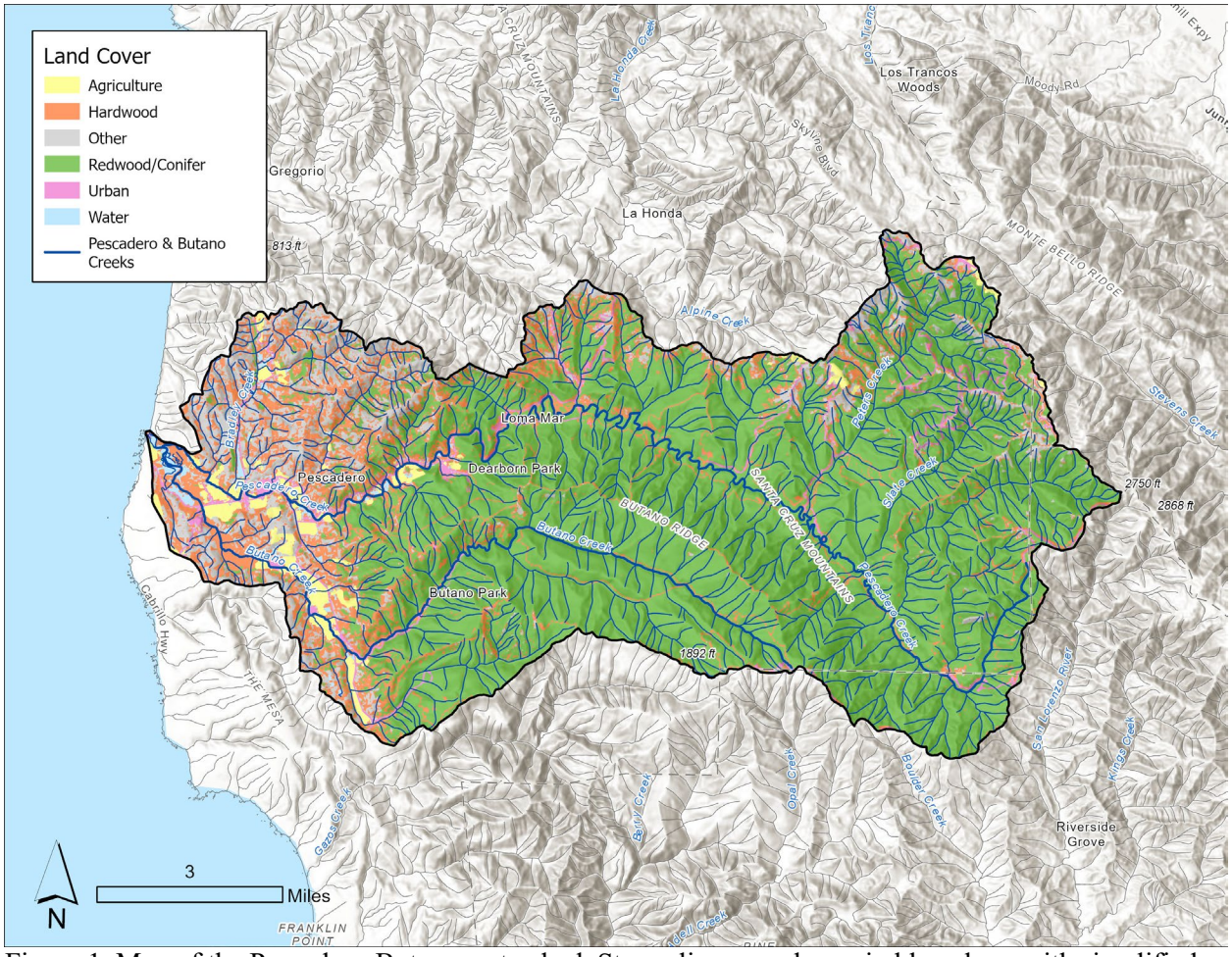

Figure 1. Map of the Pescadero-Butano watershed. Streamlines are shown in blue along with simplified land cover of the area.

3. In-Field Procedure

Safety and Field Equipment

Wading in creeks can be hazardous. Chest waders should be worn when working in creeks to remain dry and to prevent slipping. Precautions should be taken during high flows, and surveys should not be conducted during or immediately after storm events. Use conservative judgment when evaluating streamflow and avoid wading in moving water more than waist deep. If the water is deep or turbid, use a rod to probe before each step.

Wet logs can be extremely slippery, so take caution when walking on or around LW or log jams. Avoid walking on logs suspended above the channel, and note that log jams are often unstable. Estimates can be recorded when it is unsafe to measure a piece of wood.

Minimum equipment requirements used for this protocol:

- Field safety equipment, including first aid kit, wading equipment, and field shoes
- Field data sheets or electronic survey
- Pencil and permanent marker
- Clipboard
- Measuring tape (minimum 100 ft. or 30 m)
- Wading rod with hatch markings that denote every inch or centimeter
    - Alternate: yard stick
- Handheld GPS

3.1 Survey Procedure Summary

1. Collect bankfull and flood-prone width measurements in three locations along the survey reach. The watershed zone determines the height at which to make width measurements (Section 3.2).
2. Determine whether the channel is entrenched; this defines which width measurements define the survey boundaries (Section 3.2.1).
3. Measure the reach length along the channel centerline. This can be done at any time during the survey (Section 3.3).
4. Determine the minimum qualifying wood size for the survey reach based on average bankfull width and forest type (Section 3.4).
5. Measure and collect data related to all qualifying LW in the survey reach (Sections 3.5 - 3.7).
6. If log jams are encountered, collect additional information about the jams (Section 3.7).
7. Perform a qualitative assessment of the future loading potential of the survey reach (Section 3.8).

3.2 Defining Bankfull Channel

Each survey must quantify the aerial extent of the bankfull channel, so it is important to evaluate bankfull width. This will also set the boundary for qualifying LW, as pieces that fall outside of the bankfull channel will not be counted.

The bankfull width used in the LW survey will vary based on the reach's drainage area and entrenchment ratio. We identified five zones within the Pescadero-Butano watershed (Figure 2) and provided bankfull depths for each zone based on regional datasets (Table 1). This approach was preferred to field-based bankfull identification techniques in order to ensure survey accuracy, efficiency, and repeatability. Details about methods used to determine these metrics and specific reasoning can be found in Appendix A.

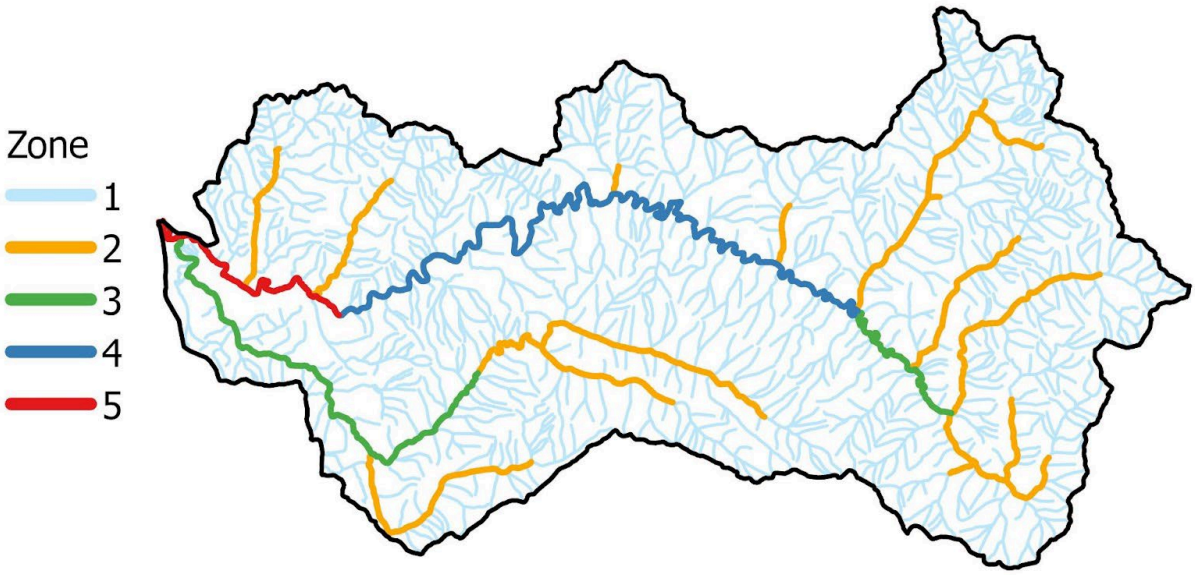

Figure 2. Map defining zones with different bankfull depth designations.

Table 1. Depth designations for each zone for typical and entrenched channels.

Zone	Drainage Area (mi^2)	Bankfull Depth (ft)	Flood-prone area depth (ft)
1	0-1	1.5	3
2	1-10	4.5	9
3	10-25	6.5	13
4	25-50	8.5	17
5	50-81	10.5	21

3.2.1 Bankfull Width and Entrenchment Ratio Procedure:

Measure and record three distinct width measurements spaced 50 ft (15 m) apart: the first at the Bottom of Reach, the second and third upstream at 50 ft intervals. Each measurement will consist of two widths: the width of the channel at the bankfull depth and the flood-prone width at 2x bankfull depth. Both depth values are found in Table 1. Be sure to measure width perpendicular to the channel. If obstructions exist or the measurement location falls in a deep pool, move upstream until three measurements are collected.

To measure bankfull width and evaluate entrenchment ratio:

1. Locate a straight section of channel, ideally in a riffle. Avoid deep pools.
2. Place a stadia rod in the thalweg to indicate bankfull depth.
3. Measure the width of the bankfull channel (from bank to bank) at bankfull depth (found in Table 1).
4. Measure the width of the flood-prone area (2x bankfull depth, found in Table 1).
5. Repeat this survey at three locations along the reach 50 ft (15 m) apart.
6. Calculate and record mean bankfull width and mean flood prone width.
7. Calculate and record the entrenchment ratio = $\frac{mean\ Flood\ Prone\ Width}{mean\ Bankfull\ Width}$ (See Table 2).

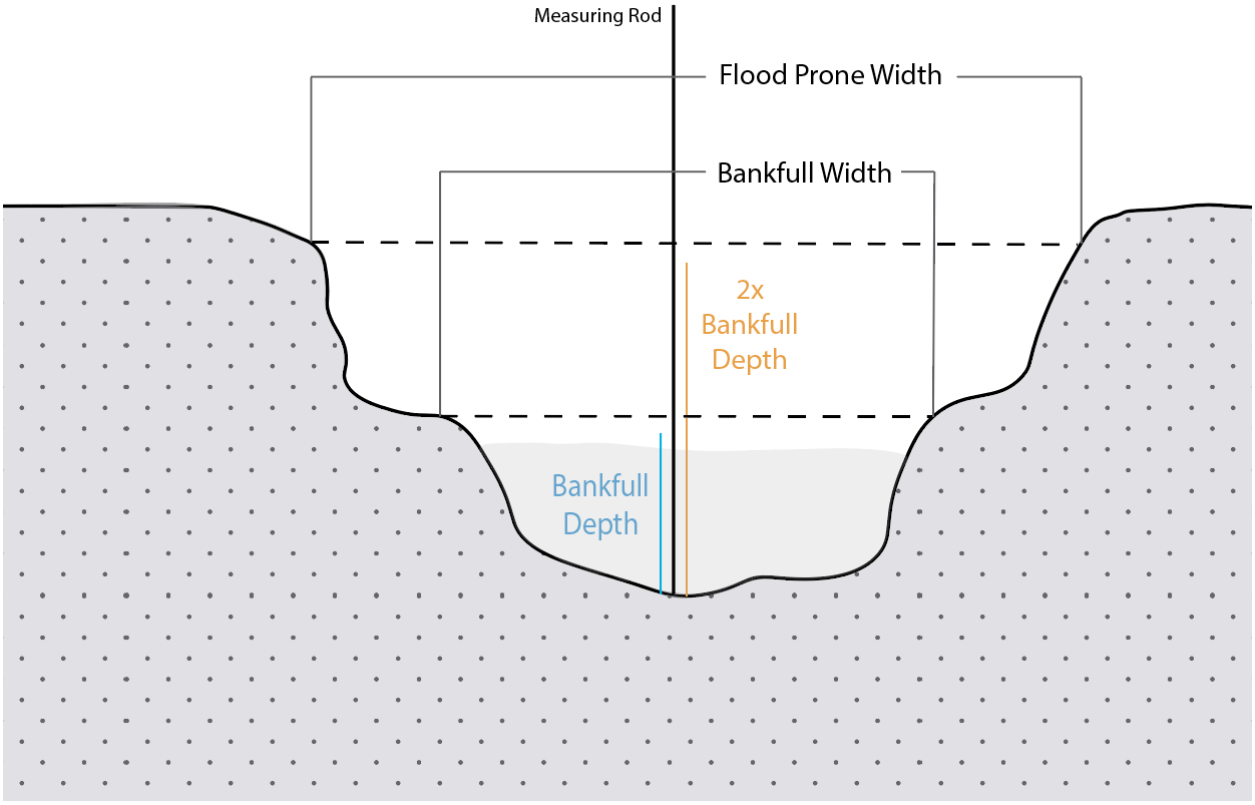

Figure 3. Conceptual diagram of bankfull and flood prone width measurements, used to calculate entrenchment ratio.

Table 2. Example measurements for a Zone 2 reach. The result is a non-entrenched channel with an average bankfull width of 21 ft.

	Bankfull Width	**Flood Prone Width**
1	20.1 ft.	45.8 ft.
2	19.6 ft.	56.9 ft.
3	23.2 ft.	48.3 ft.
Mean	**21.0 ft.**	**50.3 ft.**
Entrenchment ratio (mean FPW / mean BFW) = **2.4**		

The following are key points to consider when determining the channel boundary within which to quantify LW (see examples in Section 3.5).

- The bankfull depth or flood-prone area depth provided in Table 1 will be used to define the survey boundary. The survey will cover the portion of channel between left bank and right bank at and below the given depth.
- The bankfull depth is the default depth at which you determine this boundary. **If the entrenchment ratio is ≤ 1.4** (value based on Rosgen 1997)**, use the flood-prone depth to define the survey boundary.**
- Bankfull width varies along a reach, and at any given point it may need to be determined if LW falls within the survey boundary. In these instances, use the bankfull or flood-prone area depth from Table 1 to determine the width for qualifying LW at that point. Do not use the average width as the survey boundary.
- In the unusual case where the bankfull depth from Table 1 is obviously above the floodplain terrace, make a detailed note and adjust bankfull depth to correspond with the height of the terrace. This should only be done for unconfined channels where utilizing the bankfull depth from Table 1 would result in an unreasonably wide measurement. This is a possibility because bankfull depths in Table 1 are based on the largest drainage areas for each zone.

3.3 Defining a Survey Reach

A survey reach is defined as a stretch of river approximately 20x bankfull width and at minimum 500 ft. (150 m) long, with relatively uniform geomorphic shape, and characterized by a single forest type (hardwood or redwood). Survey locations should be chosen in a variety of channel sizes and distributed throughout the watershed network. **Record the length of each reach by measuring along the channel centerline.** A survey reach should not exceed 1600 ft. (~500 m). If this reach length is met, begin a new survey at or upstream of this point. Take new bankfull measurements for the new reach.

To allow for future repeat surveys, record the coordinates of the bottom and top of the reach and take an upstream- and downstream-facing photograph at each point. In the photos ensure a wading rod or other item of known height is in line with the survey boundary as a point of reference and scale of survey reach features, with both banks visible.

Relative continuity across a defined reach is critical. Before defining a survey reach, field crews should assess the reach to ensure there are no major changes along its length. They may include:

- A steep or abrupt elevation change such as a waterfall
- A tributary confluence
- Extreme narrowing or widening of the channel corridor
- Change in dominant forest type

If any of these are encountered, a new reach should be started at or upstream of the identified feature.

3.4 Measuring Qualifying Large Wood

This protocol has been developed for use in all stream reaches throughout the Pescadero-Butano watershed. The fluvial influence of wood differs in varying sized streams and the size of wood inputs differs between hardwood and redwood forests. Thus, for the purposes of this assessment, the size requirement for qualifying LW differs based on bankfull width and forest type. For this protocol, **bankfull width of > 16 ft. (5 m) defines a "main" channel, and bankfull width ≤ 16 ft. (5 m) defines a "tributary" channe**l. Forest type for a reach should be predetermined using the land cover shown in Figure 1, but if needed can be identified by the dominant trees in the riparian zone.

Large Wood Size Requirements

Hardwood main	- at least **6.5 ft. (2 m)** length and **4 in (10 cm)** diameter
Hardwood tributary	- at least **3 ft. (1 m)** length and **4 in (10 cm)** diameter
Redwood main	- at least **6.5 ft. (2 m)** length and **1 ft. (30 cm)** diameter
Redwood tributary	- at least **3 ft. (1 m)** length and **4 in (10 cm)** diameter

The length of each piece of LW should be measured to the tenth of a foot from one end to the other. The diameter of each piece of LW should be measured to the nearest inch one third (⅓) of the distance from the widest end of the piece. For pieces that extend beyond bankfull width, measure diameter within the bankfull channel one third of the distance from the widest point of the part of the piece that falls within the bankfull channel. This ensures an accurate quantification of the volume of wood within the bankfull channel.

In addition to the above size requirements, qualifying LW may be subject to additional requirements:

- Many pieces of wood may extend beyond bankfull width, however only measure the portion of each piece that is within bankfull width. Pieces whose main stem falls partially below the bankfull elevation should be counted. **(Figure 4)**
- Buried logs should be counted if the exposed section meets the length and diameter requirements. Do not quantify buried portions of wood that cannot be seen. **(Figure 5)**
- Record the presence of any spanners and estimate their dimensions (note: spanners will not be counted in the volumetric mass balance). **(Figure 5)**
- LW that falls below bankfull in side channels and backwater areas are counted, as well as pieces on point bars and in-channel bars. Wood found on islands or floodplains does not qualify. **(Figure 6)**
- Estimate the height of snags that stand within the bankfull channel. Measure the diameter at breast height.
- Root wads qualify as LW if the attached stem of the tree meets the diameter requirement of the reach. For these features, measure from the base of the root ball to the furthest extent of the bole (trunk) and measure diameter at the base of the bole where it meets the roots. There is often a bulge where the trunk and root ball meet; measure the diameter just above this bulge. **(Figure 7)**
- Broken pieces of wood are considered one piece if they are still touching at the break point. Once the pieces are no longer touching at the break, they are measured separately. **(Figure 7)**
- For instances of multi-stem pieces, measure only the largest stem.
- The majority of LW will be dead logs, but Fallen Live Trees (pieces with existing greenery) should be counted if the piece has the potential to be mobilized and/or is no longer rooted.
- In the instance of a milled board, the diameter measurement should be measured along the width of the board.

3.5 Examples of Qualifying Pieces of Wood

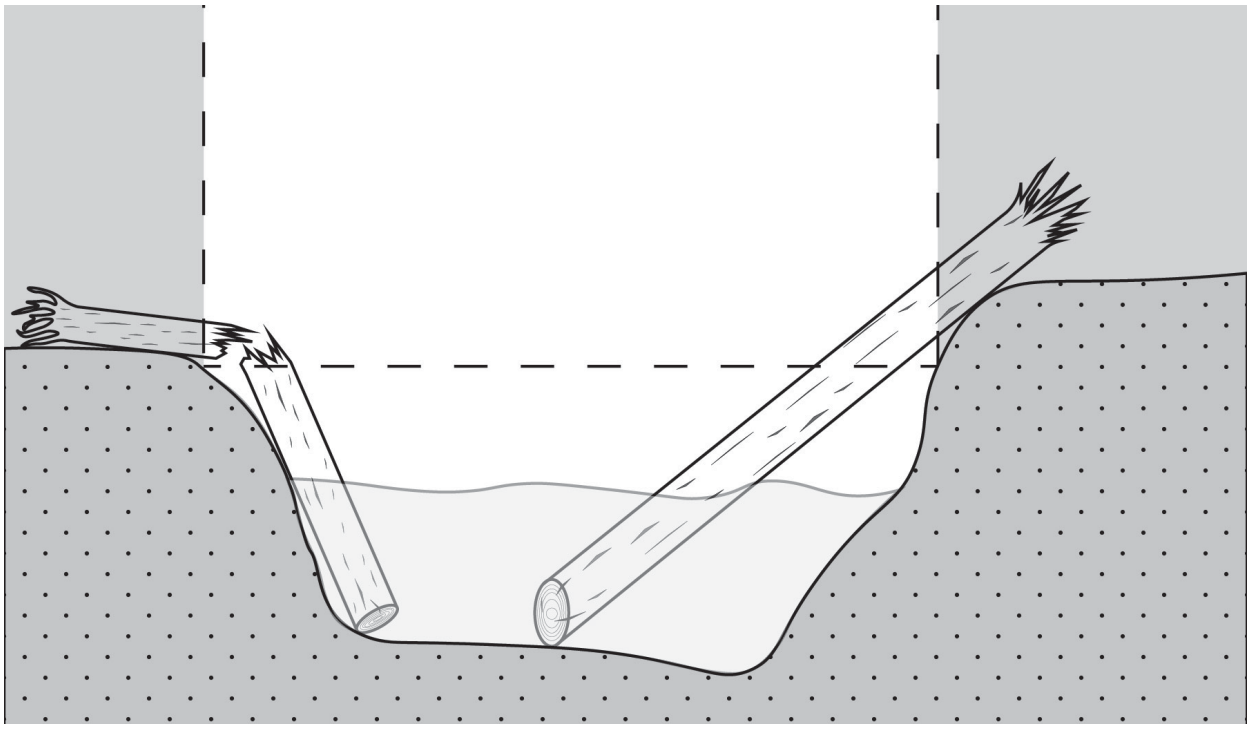

Figure 4. Example of an unconfined channel with attached floodplain. Pieces of wood will only be measured within bankfull width, including the portion of wood that extends above bankfull elevation. The extent of wood that goes beyond bankfull width will not be quantified (gray area).

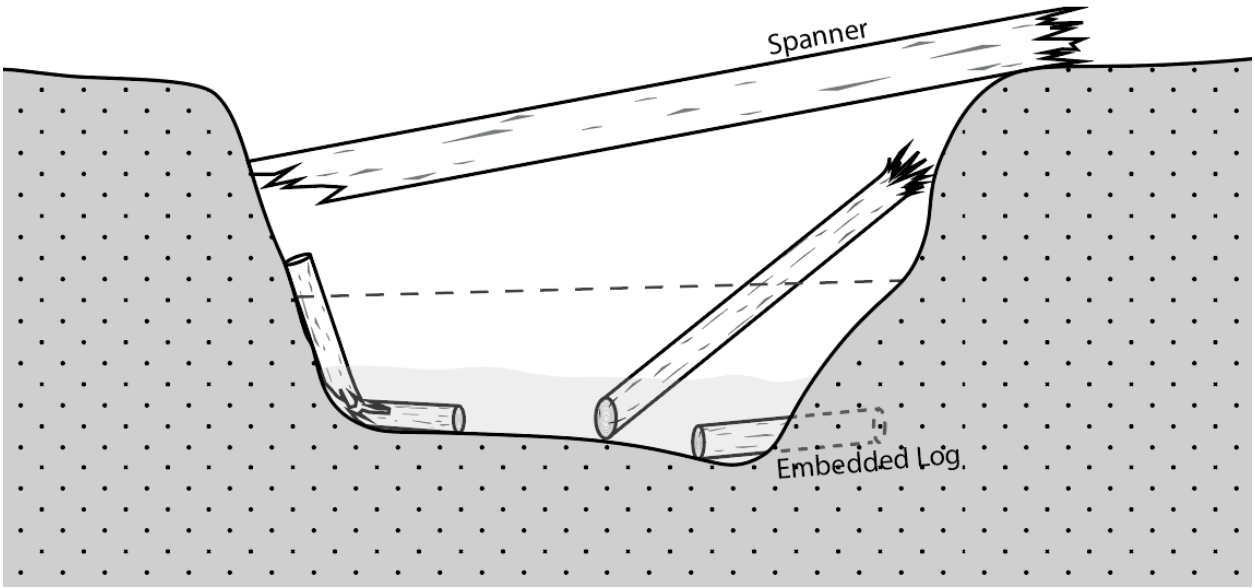

Figure 5. Example of a confined channel with steep banks. As in Figure 4, only measure LW within bankfull width. LW embedded in the bank should be measured only to the extent that is visible/exposed. Estimate the dimension of spanners and record "spanner" in the notes section of the data sheet.

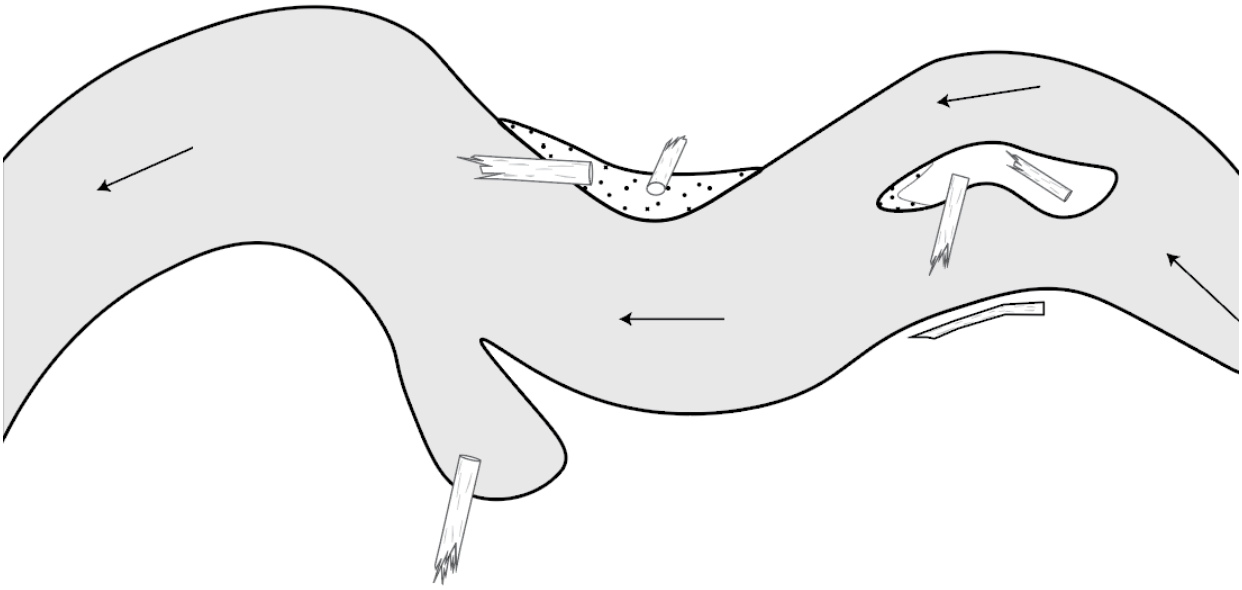

Figure 6. Plan view of stream reach. Measure the portion of LW that falls within bankfull width, including on bars and in backwaters. Pieces that fall above bankfull elevation on the bank or islands do not qualify.

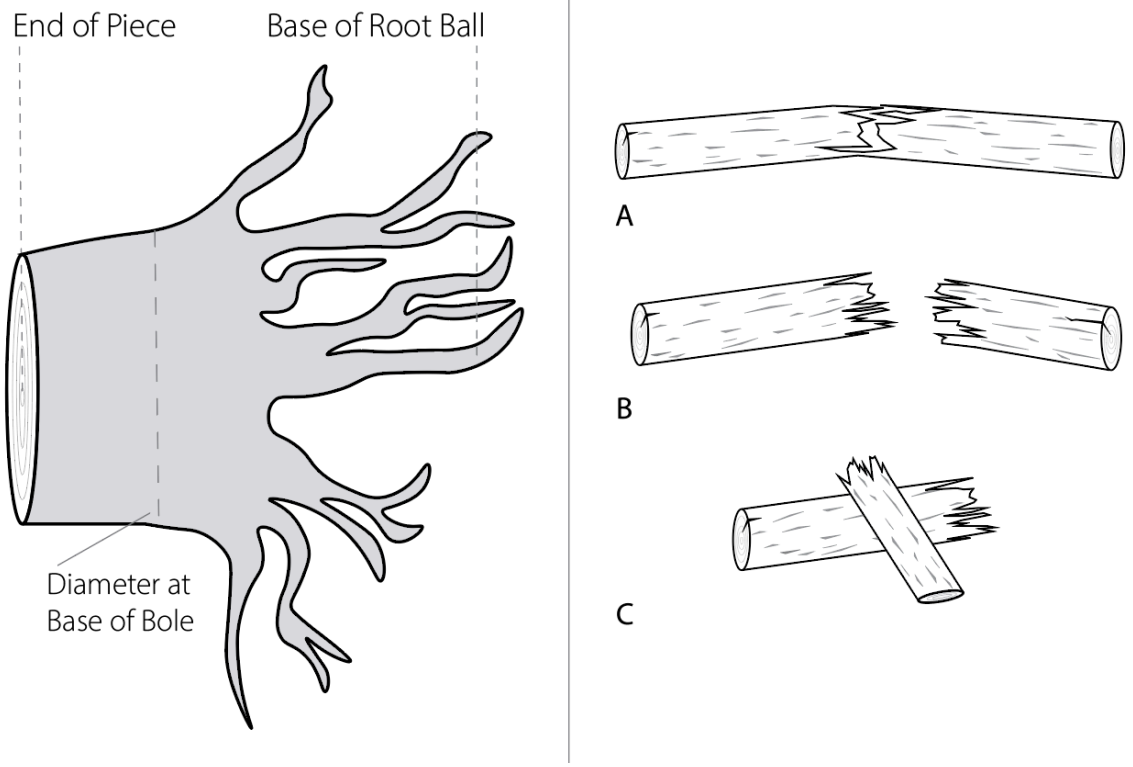

Figure 7. (Left) Points of measurement for stumps or pieces with attached root wads. (Right) A) broken sections are touching at the break point and considered one piece. B) broken sections are separate and considered two pieces. C) pieces are touching, but not at break point and considered two pieces.

3.6 Key Pieces and Log Jams

Key pieces and log jams are crucial components of any forested river system. They serve as areas of sediment deposition, fish habitat, and other river functions. Log jams can range in size from small clusters of wood to large features with hundreds of logs. When encountering log jams, several additional steps should be taken to completely characterize the extent of the jam and the geomorphic impact on the surrounding channel.

Key Pieces: Key pieces are independently stable pieces of wood that are likely to be stable during bankfull flow. They often capture sediment and can create log jams. Abbe and Montgomery (2003) define them as pieces with ratios of basal bole diameter (D_b) to bankfull depth (h) greater than 0.5, and log length (L) to bankfull width (w) greater than 0.5. Because this survey is designed to take diameter measurements at one third (⅓) of the length from the base of the bole, a narrower measurement, we have adjusted the Abbe and Montgomery (2003) qualification to:

$$D/h > 0.4 \text{ and } L/w > 0.5$$

Key pieces can therefore be identified in data post-processing to allow for rapid field surveys. However, if possible to identify in the field, additional data are important to collect for key pieces. Thorough notes about each key piece should be taken, including whether the root wad is attached, if it is forming pools or bars upstream or downstream, percentage of channel width it covers, orientation to flow, and any other relevant information to quantify the effect of the key piece on the channel.

> **Note:** because diameter is measured within the bankfull width, possibly far from the base of the bole (see Section 3.4), true key pieces with large diameters outside of the bankfull channel may not be identified. If obvious in the field, identify key pieces and provide an extra diameter measurement from outside the bankfull channel in the survey notes section.

Once the key pieces of a jam are sufficiently described, attention can be turned toward the jam itself. Quantifying LW in log jams will depend on their size. For this protocol, log jam size designation is as follows:

Small jam: consists of <10 pieces of LW
Large jam: consists of >10 pieces of LW

Small log jams: Small jams are treated similarly to other LW pieces - all individual logs should be counted and measured and recorded in the overall LW datasheet. Record if a piece is part of a log jam in the Log Jam column. A single set of coordinates representing the log jam location can be recorded for all pieces in the jam.

Large log jams: *Because of their geomorphic importance, large jams are treated differently than other LW within the watershed.* Rather than measuring each individual piece of the jam, quantify the volume of wood by estimating the length (upstream to downstream), width (bank to bank), and depth of the feature to the best of your ability. When possible, measure individual key pieces that are easily accessible or that can be estimated. Take photos of these features for reference.

Additional information should also be collected for all large log jams:

- The rough percentage of small pieces trapped by the large jam. Small pieces are simply pieces that would not be classified as LW if they were found independently from the large jam.
    - Example entry: 20% of the large log jam volume is small pieces
- The percent of bankfull channel width spanned by the jam.
    - Example entry: jam spans 80% of channel width

- The maximum storage potential of the jam. Sediment wedges can form upstream of log jams typically in steep, confined streams like those found in Zones 1 and 2. Storage potential is estimated by considering the height of the jam and the volume of sediment that may be stored in the channel upstream of the jam. Estimate the upstream potential length of a sediment wedge by including the area immediately behind a log jam before a change in slope or bend in the stream.
    - Example entry: max storage potential: 3 ft high, XX ft bankfull width, 10 ft of upstream channel

- Channel characteristics (e.g., are pools or bars formed by the jam? Is a channel step formed? Are there significant changes in channel grain size?).
    - Example entry 1: pool forms for 20 ft below jam, grain size decreases downstream of jam
    - Example entry 2: jam forms 2 ft step in channel

3.7 Other Metrics

Latitude & Longitude: Record the latitude and longitude of every piece of wood surveyed. If logs are directly adjacent to each other or part of a log jam, record the same coordinates.

Location: Record the location of each piece as one of the options: Left Bank (LB), Right Bank (RB), or in Channel (C). In addition, also record if the piece is in a Pool (P).

Wood Type: If possible, record the type of wood of each piece by indicating conifer or hardwood. This is not required information, but helpful if easily identified. Species expected to be found in Pescadero and Butano creaks include:

Conifer	Hardwood
Coast redwood (*Sequoia sempervirens*)	Alder (*Alnus sp.*)
Douglas fir (*Pseudotsuga menziesii*)	Ash (*Fraxinus sp.*)
Pine (*Pinus sp.*)	Bay Laurel (*Umbellularia californica*)
	Buckeye (*Aesculus californica*)
	Cottonwood (*Populus sp.*)
	Eucalyptus (*Eucalyptus sp.*)
	Maple (*Acer sp.*)
	Oaks (*Quercus sp.*)
	Willow (*Salix sp.*)

Burn Evidence: Record if a piece of wood has evidence of being burned.

Decay Class: Decay and burn status are visual assessments of each piece of wood that provide information on age, stability, and density of wood. Decay status should be categorized on a scale from 0 to 9, and 0.5 should be added to the decay class if the piece shows signs of having been cut or burned (Table 3).

Table 3. Decay Class definitions (adapted from Alford, 2013).

Decay Class Code	Decay Class (add 0.5 if cut or burned)
0	Live, rooted, and immobile
1	Live, mobile (indicated by green needles or leaves)
2	Bark intact, limbs, twigs, & needles or leaves present
3	Bark intact, limbs, & twigs present
4	Bark intact, limbs absent
5	Bark loose or absent
6	Bark absent, surface slightly rotted
7	Surface extensively rotted
8	Surface completely rotted, center solid
9	Rotted throughout

Loading Potential: Resource managers will benefit from an understanding of future loading potential in reaches surveyed. The term "loading" captures LW inputs to the bankfull channel via fluvial processes like bank erosion or remobilizing wood on floodplains, as well as other natural processes like toppling due to wildfire, windfall, and/or slope failure. When evaluating this metric, consider the floodplain, riparian area and adjacent hillslopes. Hillslope processes are primary wood recruitment drivers for steep, confined streams, while bank erosion and direct riparian inputs drive recruitment in larger, unconfined streams.

This metric will be defined by three classes: High, Medium, and Low. Descriptions of each class provide examples to use as guidance, but they do not include all possible characteristics that could lead to classification. Not all the examples in each class need to be met (e.g., your reach could have high loading potential, but not be located in a recent wildfire area).

- **High** - The reach has multiple snags, leaning trees, or spanners. There is a large amount of wood in the active floodplain or on the banks above the bankfull elevation. There are steep slopes with shallow soils, which could be indicated by wind-thrown trees. Bank erosion includes deep undercuts or large cutbanks with trees readily input into the channel. The riparian area or adjacent hillslope shows clear signs of recent widespread wildfire. Loading will likely occur frequently (1-2 years).

- **Medium** - There may be one or two snags and a spanner. There are a few pieces of wood in the active floodplain or on banks above bankfull elevation. Some bank undercuts exist under trees and small bank erosion features could provide inputs. Loading may be expected after large storm events, but no signs of frequent inputs are present. Possibly some indications of recent wildfire.

- **Low** - Riparian area is shrubby or sparsely forested, trees are young, healthy, and firmly rooted. Banks and hillslopes are stable. Little-to-no loading is expected or possible from the riparian area.

4. Data Processing, Analysis, and Reporting

4.1 Initial Data Processing

In addition to the paper field sheet templates below, we have also provided guidance for recreating the datasheets in a digital format using ESRI's Survey123 platform (Appendix C). If a digital survey tool was used to collect data (such as Survey123) the data should be user-ready for analysis. Any data or notes collected by hand should be converted to a digital format for processing and analysis.

Much of the analysis will depend on the makeup of data collected but several data processing and reporting steps are anticipated:

1. Wood lengths and diameters should be converted to volume measurements using a simple assumption of a cylinder; V= r2*h.
2. River area should be estimated using the measured length and average bankfull width of each reach investigated.
3. Unit density of LW should be classified by local dominant forest type, reported as volume of wood per hectare of river.
4. Maps should be created describing LW locations and concentrations, highlighting log jam frequency and distribution.

4.2 Bankfull assessment

Because we used the maximum bankfull depth for the largest drainage area of each zone, our protocol potentially overestimates bankfull width (Table 1). This was intentional in order to capture all wood in the channels and because requiring technicians to make visual estimates of bankfull in this watershed is not conducive to a rapid assessment of LW.

A follow-up study may be desired that assesses the accuracy of bankfull measurements. This would entail a handful of detailed bankfull surveys by professionals familiar with the identification of bankfull in incised reaches or specifically this watershed. A simple analysis of true bankfull width related to bankfull depth-derived width could help calibrate the rapid LW field surveys for increased accuracy.

4.3 Potential Investigations

Users of this protocol are also encouraged to investigate correlations such as:

- Decay class with position within the watershed
- Differences in log size by forest type
- Log jam density and size with position within the watershed
- Changes in LW density along reaches
- Differences in LW density between entrenched and non-entrenched reaches
- Any other apparent trends

After repeat surveys are conducted, analysts may be able to investigate:

- LW recruitment rates
- In-stream mobility of LW on the reach scale
- Burn zone recruitment rates
- Mobility of LW on a drainage scale (possibly based on burn status)

These processing and analysis steps should be documented in a report alongside the digitized field data. In addition, the report should also succinctly describe the reaches surveyed, data collected, and other relevant information.

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Appendix A. Bankfull Depth Determinations

Bankfull can be difficult to define in the field, especially considering factors in this watershed such as channel incision, wide ranging stream slopes, and varying flow regimes. Further, training technicians to consistently and rapidly identify bankfull using only physical indicators is impractical for the goals of this survey design. To decrease variability between practitioners and allow for rapid surveys, we developed standardized bankfull elevations to apply to the entire watershed.

We designated five stream zones based on drainage areas and that roughly align with stream order. Zone 1 includes streams with drainage areas less than 1 mi^2 (2.6 km^2), and captures all headwater reaches. Zone 2 is defined by reaches with drainage areas between 1 and 10 mi^2, including all major tributaries and upper reaches of Pescadero and Butano creeks. Zone 3 includes 10-25 mi^2 drainage areas, which captures the main stem of Butano Creek and the upper portion of Pescadero Creek where multiple tributaries join. Zone 4 has drainage areas from 25-50 mi^2, which includes the main stem of Pescadero Creek beginning upstream at the confluence of Peters Creek, a major tributary, and ending downstream at the hardwood/redwood transition point. Zone 5 captures the lower portion of Pescadero creek draining between 50 and 81 mi^2.

Each zone was assigned a standard bankfull depth, derived from the drainage area-mean bankfull depth regional curve developed for the Pescadero-Butano watershed by Collins & Leventhal (2017) and rounded to the nearest 0.5 ft. This standard depth was based on the largest drainage area for each zone, which could overestimate bankfull depth for reaches with smaller drainage areas. This was deemed an acceptable compromise in order to capture all wood in the system while ensuring a rapid and repeatable survey. A bankfull accuracy assessment is recommended in Section 4.

The regional curve provided mean bankfull depth based on drainage area, but the study design required maximum bankfull depth. A relationship between mean and maximum bankfull depths was developed by the same authors (2013) for wadeable streams in Marin and Sonoma Counties, also in Northern California. This relationship showed that maximum depth was approximately twice the mean depth, with a strong correlation. So, we doubled mean bankfull depths from the Pescadero-Butano regional curve for our maximum bankfull depth designations, using the following equation:

$$max\ bankfull\ depth = 2 \cdot 0.8412 \cdot drainage\ area^{0.4189}$$

Finally, we considered entrenchment ratio as an indicator to adjust the survey design for deeply incised channels. Entrenchment is important for sediment dynamics in river systems because more entrenched channels have less floodplain connectivity and therefore less potential to trap sediment (Pasternack & Wyrick, 2016). This may also have implications for LW recruitment and mobility. Rosgen (1997, 2001) considered entrenchment ratios below 1.4 to be entrenched channels, and we used this simple cutoff to determine when to use an elevated bankfull depth for defining the LW survey boundary in an entrenched reach.

Pescadero-Butano Large Wood Survey Survey Page __1__ of ____

Reach Survey

Date: _____ Technicians:_____ Reach ID:_____

Top of reach coordinates: Lat: _____ Long: _____ Reach Length: _____

Bottom of reach coordinates: Lat: _____ Long: _____ Bankfull Zone: _____

Bankfull width (ft): 1. _____ 2. _____ 3. _____ Flood Prone width (ft): 1. _____ 2. _____ 3. _____

BF Avg (ft): _____ Flood Prone Avg (ft): _____ Entrenchment ratio: _____

Reach Type: Hardwood / Redwood Stream Type: Main / Tributary Loading Potential: Low / Med / High
Notes:

Large Wood Sample

Technicians:_____ Reach ID:_____ Location: _____ Sample #: _____

Coordinates: Lat: _____ Long: _____

Wood Length (ft): _____ Diameter (in): _____ Decay Class: _____ Burn: Y / N Root Wad: Y / N Jam: N / S / L

Notes (if key piece / jams, add more information here):

Additional information (jams and key pieces only)

Percent small piece: _____ Channel-spanning width: _____ Maximum storage potential: _____

Channel Characteristics: _____

Large Wood Sample

Survey Page ____ of ____

Technicians:_____ Reach ID:_____ Location: _____ Sample #: _____

Coordinates: Lat: _____ Long: _____

Wood Length (ft): _____ Diameter (in): _____ Decay Class: _____ Burn: Y / N Root Wad: Y / N Jam: N / S / L

Notes (if key piece / jams, add more information here):

Additional information (jams and key pieces only)

Percent small piece: _____ Channel-spanning width: _____ Maximum storage potential: _____

Channel Characteristics: _____

Large Wood Sample

Technicians:_____ Reach ID:_____ Location: _____ Sample #: _____

Coordinates: Lat: _____ Long: _____

Wood Length (ft): _____ Diameter (in): _____ Decay Class: _____ Burn: Y / N Root Wad: Y / N Jam: N / S / L

Notes (if key piece / jams, add more information here):

Additional information (jams and key pieces only)

Percent small piece: _____ Channel-spanning width: _____ Maximum storage potential: _____

Channel Characteristics: _____

Appendix C. Survey123 Setup

Below are some brief instructions on how to recreate the paper field survey form in Esri's Survey123. Survey123 is ideal because of the spatial nature of the form (location data can automatically be collected with a GPS-enabled device). Other survey programs will also work (such as Qfield or Google Forms). As you begin creating your survey, you will be greeted with an empty page (Fig. C1). Feel free to set your survey title, description, and explore the different options available. The *Add* button adds new survey questions, the *Edit* button edits the selected survey questions. The Survey 123 platform has many different question types (Fig. C2). When creating a new survey, the user will drag question types into the survey. The question types most relevant to the Pescadero-Butano Large Wood survey are:

Singleline text - brief text answer
Multiline text - long text answer
Number - number only answer
Date and time - collects the date and time when the survey begins
Single select - multiple choice where one option is selected
Multiple select - checkboxes where multiple options can be selected
Map - collects the location of the entry
Image - take or upload photos to survey

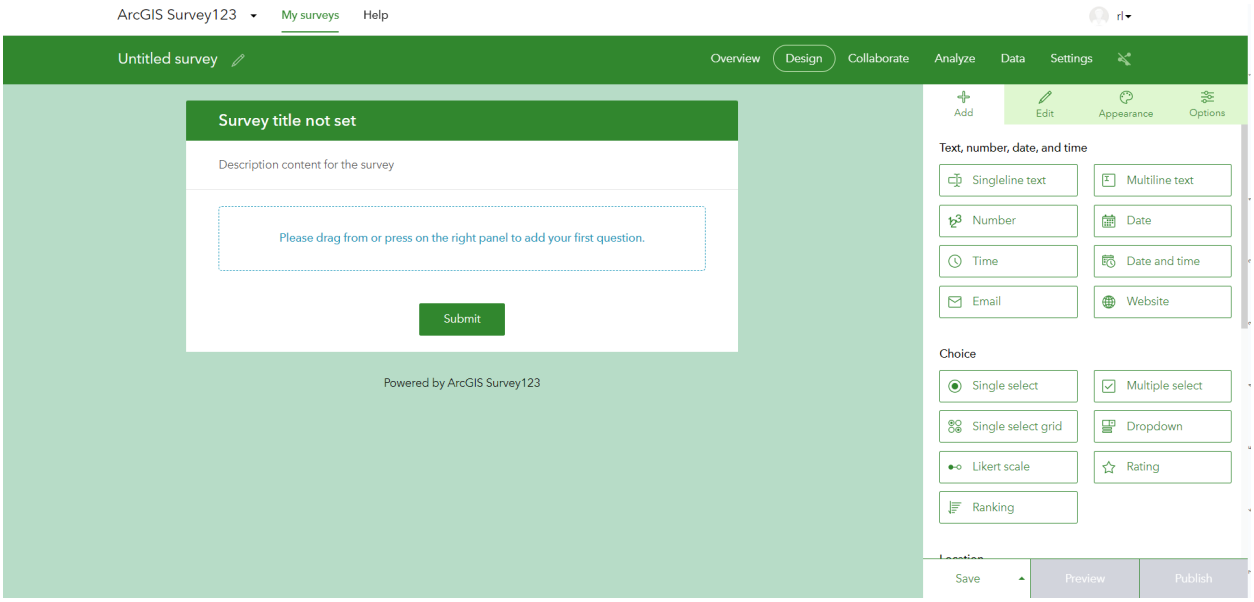

Figure C1: A blank Survey123 survey. Use Add and Edit to add new questions and to edit existing questions.

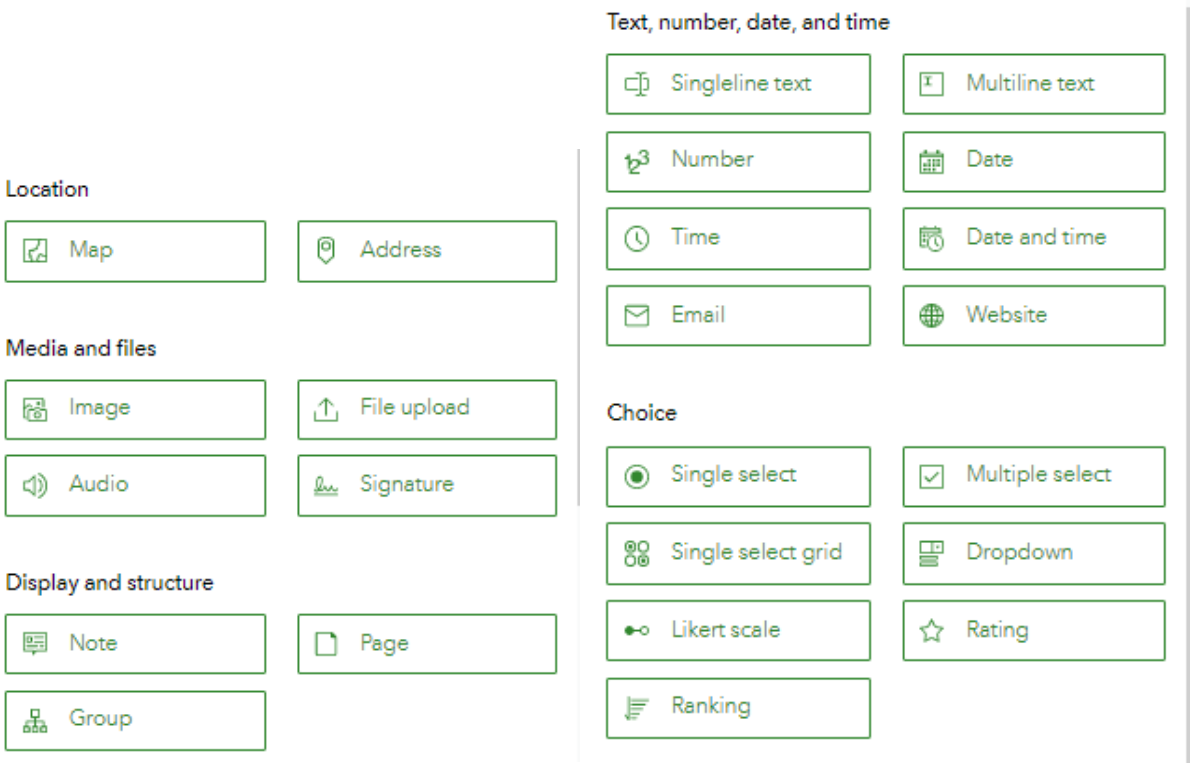

Figure C2: The question options available in Survey123.

It is recommended that two surveys be created, one for describing the reach characteristics and one for individual large wood pieces. An example of survey 1 (reach characteristics) is depicted in Fig. C3. General characteristics are described, and each bankfull measurement is grouped (using the *Group* function under Display and structure).

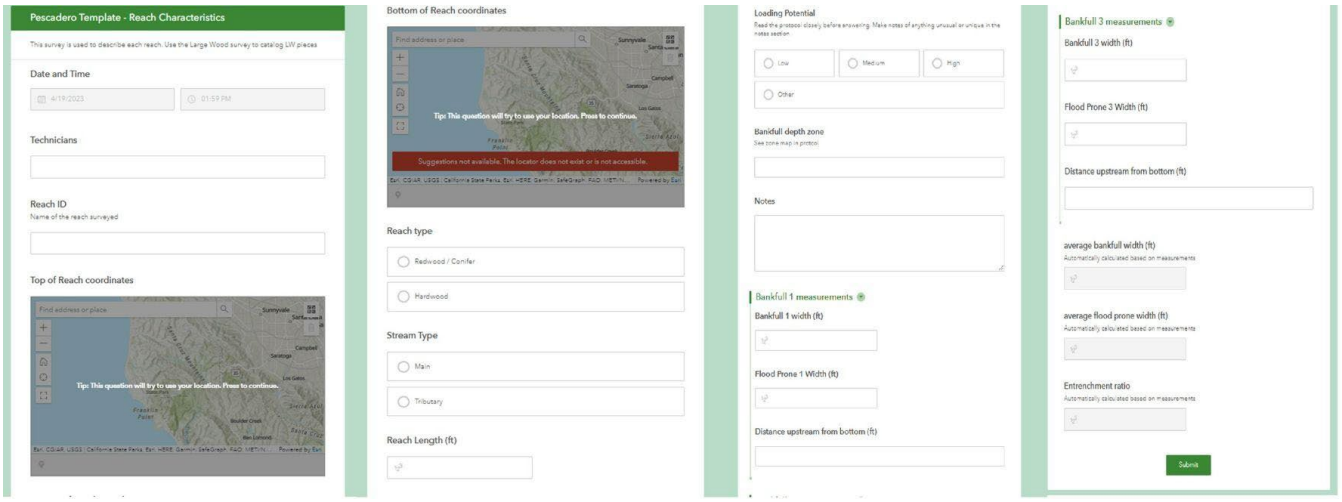

Figure S-3: Example questions for the reach survey.

An example of survey 2 (individual LW) is depicted in Fig. C4. Data are input in the order that they appear on the paper form. If the user identifies an entry as **Large Jam** a series of additional questions are promoted and asked.

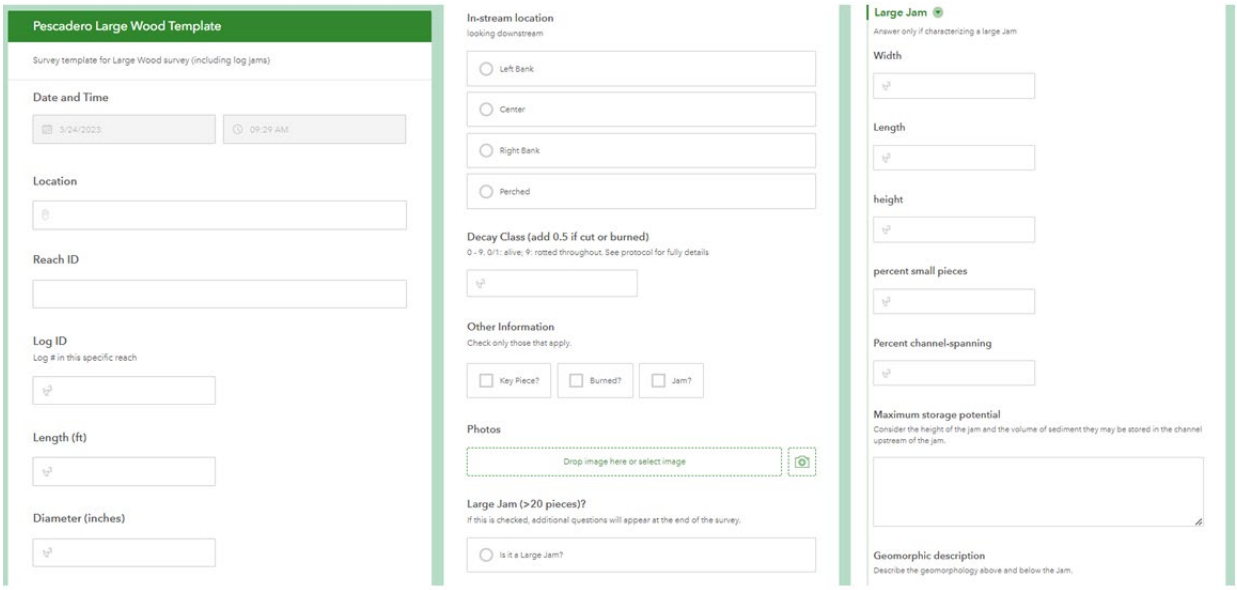

Figure C4: Example questions for the large wood survey.