BATTLE CREEK WATERSHED ASSESSMENT:
DATA COLLECTION PLAN

PREPARED BY TERRAQUA, INC.

FOR

THE BATTLE CREEK WATERSHED CONSERVANCY

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INTRODUCTION AND BACKGROUND

In recent years, there has been an observed increase in sediment production in the Battle Creek watershed (in Tehama and Shasta counties, California). Erosion has caused damage to roads (RWQCB 2015) and fine sediment has been delivered to stream channels. Fine sediment has degraded fish habitat where it has filled interstitial spaces in spawning gravel, and filled adult salmon holding pools (USFWS 2015). The routing of fine sediment downstream has also caused damage to infrastructure, including at the Coleman National Fish Hatchery (RWQCB 2015).

It has been hypothesized that recent events in the watershed have contributed to the increase in the sediment load in the stream network. In August 2012, the Ponderosa Fire burned approximately 27,600 acres of mid-elevation deciduous and coniferous forest. Following the wildfire, salvage logging took place on private lands. During the winter of 2014/2015, several storms brought high intensity precipitation and caused flooding in Battle Creek and its tributaries.

To address the recent increase in sediment load and concomitant impacts to fish habitat and infrastructure in the watershed, the Battle Creek Watershed Conservancy (BCWC), in coordination with the California Water Resources Control Board, is developing a Watershed-Based Plan (WBP; USEPA 2008) that will describe and make recommendations for how to manage the water quality problems that may be attributed to sediment.

The Battle Creek WBP will be based on an assessment of the sediment dynamics of the watershed. This watershed assessment will identify sediment sources and factors influencing sediment production, and quantify the relative contribution of each sediment source to overall sediment production. The results from this assessment will inform many of the nine elements of the WBP (USEPA 2008), but will be critical to the development of Elements 1, 2, and 3, listed below.

1. Identify causes and sources of pollution.
2. Estimate pollutant loading into the watershed and the expected load reductions.
3. Describe management measures that will achieve load reductions and target critical areas.

In support of Element 1 and Element 2, we will quantify the rate of sediment production from 1) hillslope sources of sediment, 2) floodplain sources of sediment, and 3) unpaved roads. Given the short time frame of the study and the available resources, it will not be possible to estimate erosion rates for each hillslope process that occurs in the watershed. Instead, we will combine the several types of hillslope erosion into three groups: soil erosion (including soil creep, sheetwash, and rills); channelization (including gullies and ravines); and landslides (slides and debris flows). Our three groups of hillslope sediment sources (Table 1) overlap with the five landscape process classes that Henkle et al. (2016) used in the spatially explicit landscape process model that they developed for Battle Creek, which was based on the five landscape process regimes modeled by Dietrich et al. (1992).

TABLE 1. — Three hillslope sediment source types used in this watershed assessment compared to the five landscape process regimes used by Henkle et al. (2016) and Dietrich et al. (1992).

Hillslope Sediment Source Type (Terraqua)	Landscape Process (Henkle et al. 2016)	Landscape Process Regime (Dietrich et al. 1992)
Soil Erosion (sheet wash, soil creep, and rills)	Soil Creep	Stable, diffusive erosion
	Sheet wash	Saturation overland flow without erosion
Channelization (gullies and ravines)	Channelization	Saturation overland flow with erosion
Landslides (slides and debris flows)	Landsliding (wet)	Saturation overland flow with erosion and landsliding
	Landsliding (dry)	Landslide erosion

Floodplains are a natural source and sink of sediment. Stream bank erosion is the dominant process that transfers sediment from floodplains to active channels, and it occurs when the force of the river is greater than the resistance provided by the bank. To determine if floodplains are a significant source of sediment to the total sediment load in the Battle Creek watershed, we will quantify bank erosion rates using a planform analysis described in the Methods section.

Sediment production in the Battle Creek watershed may not be restricted to natural sources: unpaved roads in the watershed may be a contributing source. We will estimate the production of sediment from the extensive unpaved road network using a modeling approach developed by the U.S. Forest Service.

In total, we plan to quantify erosion rates for five sources of sediment: soil erosion, channelization, landslides, floodplains, and unpaved roads. Further analysis of these results will allow us to rank the relative contribution of each source. We will couple the erosion rates that we generate with the Battle Creek landscape process model (Henkle et al. 2016) to estimate the relative contribution of each of the potential sources of sediment production in the watershed.

The watershed assessment will contribute to Element 1 not only by identifying and quantifying sediment sources, but also by determining what factors influence sediment production in the watershed. For example, our assessment will examine the roles that natural processes and human impacts have in the production of sediment. Natural factors that may influence sediment production include geology, slope, vegetation cover, climate, soil characteristics, and wildfire. Land management actions such as logging, agriculture, or road building may also contribute to the sediment production in Battle Creek. To examine the relative influence of these factors, we have structured our sampling designs to explore hypothesized relationships between wildfire, logging, and soil types on sediment production.

Other influences will be examined by collecting auxiliary data (e.g., slope characteristics, vegetation cover, etc.) at sediment sources, and quantifying historical changes in land use and land cover.

In this watershed assessment, we will quantify changes in vegetation and land cover during the last 30 years by analyzing a time series of Landsat data. Through the identification of the causes of the sediment production and attributing rates of the sediment production to either natural processes or land management actions, we will provide insight into how sediment production may have changed in recent decades.

Additionally, we present a sampling design for the implementation of the California Surface Water Ambient Monitoring Program (SWAMP) protocol in the Battle Creek watershed. The BCWC and State Water Board will use data collected using the SWAMP protocol in 2017 and future years to monitor the future implementation of the WBP. This sampling design meets several key goals: 1) conformation with the state-wide SWAMP sampling design that uses probabilistic and targeted sampling within perennial/fish bearing streams; 2) the ability to detect changes resulting from future disturbances and future implementation of the WBP; and 3) the ability to examine temporal signals or trends using data that were previously collected at sites that were sampled in previous watershed assessments.

Ultimately, results from our assessment will help land managers identify how much of a sediment load reduction is needed, define treatment extents (e.g., road length, landscape area, number of landslides, or the length of stream bank), and inform expectations about the amount of sediment that can be reduced from particular management actions (WBP Element 2). Managers will also be able to use our results with the SWAMP channel monitoring data that will be collected to determine how to meet water quality standards in the Battle Creek watershed (WBP Element 3).

In the Methods section, below, we describe the techniques that we will use to quantify erosion rates and identify causes of sediment production. However, we do not describe all of the analyses and interpretation that will be included in our assessment. For example, in this document we do not explain in depth how we will account for the uncertainty in each of our methods, although this will be an essential component of our assessment and will be included in the final report. Rather, we focus on the description of the methods that we will use to collect the new data that will be used to estimate erosion rates.

METHODS

In total, we plan to quantify erosion rates for five sources of sediment: soil erosion, channelization, landslides, floodplains, and unpaved roads. This section describes the methods that we will use to quantify erosion rates for each of the five sediment sources, and describes the procedures that will be used to select sites that will be sampled for each method. We also describe the methods that we will use to quantify changes in land use and land cover. Finally, we describe the site selection for the data that will be collected using the SWAMP protocol, which will be used to monitor the implementation of the WBP.

Soil Erosion

A variety of methods are available to measure soil erosion rates, including erosion pins, erosion traps, short-lived radionuclide tracers, chrono-stratigraphy, and topographic differencing.

There are benefits and drawbacks to each of these methods. For instance, radionuclide tracers can be used to quantify soil redistribution and erosion rates at multiple temporal scales including annual and decadal scales. Use of any other method would require the establishment of a long-term monitoring framework to estimate erosion rates at a decadal scale. Because this watershed assessment must be completed within one year (2017), the application of radionuclide tracers is the most suitable method for assessing soil erosion.

Short-lived radionuclides have been used successfully in many countries to measure soil loss and soil redistribution. The most commonly used isotope is fallout caesium-137 (^{137}Cs), but natural lead-210 (^{210}Pb) and cosmogenic beryllium-7 (^{7}Be) also offer considerable potential for use in soil erosion studies. ^{137}Cs is produced by nuclear fission, and atomic weapons testing in the 1950s and 1960s distributed it globally. Once delivered to the stratosphere, ^{137}Cs returns to the troposphere, falls to the ground with rain, and quickly adsorbs to clay particles in the surface soil or sediment. The highest concentrations of ^{137}Cs typically occur in the top 10 cm of the soil profile and decrease exponentially with depth. When the fine particles move downslope, the ^{137}Cs also moves with the fine particles, thus making the tracer extremely useful for estimating soil redistribution. Furthermore, when coupled with fluvial suspended sediment samples, ^{137}Cs can be used to identify the relative contribution of particular sediment sources, such as shallow or deep sediment.

Other radionuclides such as ^{210}Pb and ^{7}Be are useful in soil erosion studies, especially when analyzed in conjunction with ^{137}Cs. The isotope ^{210}Pb is a product of the uranium-238 (^{238}U) decay series and is derived from the decay of the radon gas isotope ^{222}Rn, which is a daughter of ^{226}Ra. Similar to ^{137}Cs, when ^{210}Pb is released into the atmosphere it falls back to the earth's surface with rain and adsorbs to fine particles. Because this is a naturally occurring process, the supply of ^{210}Pb is constant over time. The difference in the timing of deposition between ^{137}Cs and ^{210}Pb provides complementary information to understanding soil erosion history at a site. Furthermore, because the half-life of ^{7}Be (53.3 days) is short compared to that of ^{137}Cs and ^{210}Pb (30.12 years and 22.26 years, respectively), it can provide additional information about the erosional history at a site. For example, because ^{7}Be is typically found only in the upper 0.5 cm of the soil profile, it can be used to determine if sediment transport is due to shallow processes such as sheet wash or rill erosion.

Studies have shown that disturbances (especially logging and wildfire), soil characteristics, land cover, position on the hillslope, aspect of the hillslope, and climate, among other factors, influence soil erosion. Of these factors influencing erosion, logging and wildfire, and soil characteristics are particularly important to managers of the Battle Creek watershed. Therefore, we have chosen to stratify our sampling of radionuclide concentrations by elevation (a proxy with climate and a correlate with land cover, logging, and wildfire prevalence), the area burned by the Ponderosa fire, the area logged in the last 20 years, and soil type. The remaining factors influencing erosion will be accounted for with auxiliary data that we collect at each sample site.

Sample Site Selection

Soil erosion sampling sites will be allocated with a spatially-explicit stratified probabilistic disproportionate sampling design. The probabilistic component of this approach will allow us to choose sites without bias, thereby facilitating our ability to extrapolate soil erosion rates measured at sites to the entire domain of inference (i.e., the Battle Creek watershed). Stratification of the watershed will allow us to better partition the variability likely to be observed in empirical soil erosion rates as well as quantify the relative contribution of different sediment sources.

The first level of stratification is based on elevation: land surface elevations in Battle Creek range from 340 ft to 10,400 ft above sea level (asl). We divided the watershed into low (< 2,000 ft), mid (2,000 ft to 6,000 ft), and high (> 6,000 ft) elevation areas. Sample density will be highest in the mid elevation areas where logging, wildfire, and unpaved roads are most prevalent and have been hypothesized to have the greatest influence on watershed-wide sediment production. Sampling density will be low in low elevation areas because these areas have been less affected by the Ponderosa Fire, logging, and road placement, and because these areas receive relatively less precipitation than mid elevation areas. Sampling density will also be low in high elevation areas because these areas, which include Lassen National Park as well as steep terrain, have been rarely logged, did not experience the Ponderosa Fire, have few unpaved roads, and where snow is the dominant form of preciptiation, which introduces spatial variability in the fallout receipt of ^{137}Cs.

The mid-elevation areas are further stratified as: 1) burned/not burned, 2) logged/not logged, and 3) by lithology. For the purpose of this study, we defined "burned" as the area of the Ponderosa Fire. Conversely, we define "unburned" as the area that was not burned in the Ponderosa Fire. We classified an area as "logged" if it was logged sometime since 1996. Logged areas include both private and public lands that have been logged and include all of the types of logging activities. Some of the types of activities in the "logged" class include selective cut, sanitation cut, patch clear-cut, stand clear-cut, seed-tree cut, shelterwood removal, and salvage cut. We used Timber Harvest Plan data that is available at the CAL FIRE website (http://www.fire.ca.gov/resource_mgt/resource_mgt_forestpractice_gis), as well as the data that is available on the USFS geospatial data clearinghouse (https://data.fs.usda.gov/geodata/edw/datasets.php) to classify the watershed as either logged or not logged.

We combined the six major rock types that are present in the Battle Creek watershed including rhyolite, pyroclast, basalt, andesite sedimentary and metasedimentary rocks (KRIS 2004) into three groups based on suspected differences in erodibility. We combined the basalt, andesite, sedimentary, and metasedimentary rocks into one strata class ("hard rock"). Pyroclast is the second geologic strata class and rhyolite is the third geologic strata class.

A combination of the three strata that we have chosen results in 12 individual classes within 2,000 ft and 6,000 ft elevation asl (Figure 1). Class 4 (not burned, not logged, basalt/andesite/sedimentary class) covers the largest area of the watershed (231 km^2) and is approximately 38% of the total frame (Table 2). Class 10 covers the smallest area of the watershed (3.1 km^2) and is just 0.5 % of the frame (Table 2).

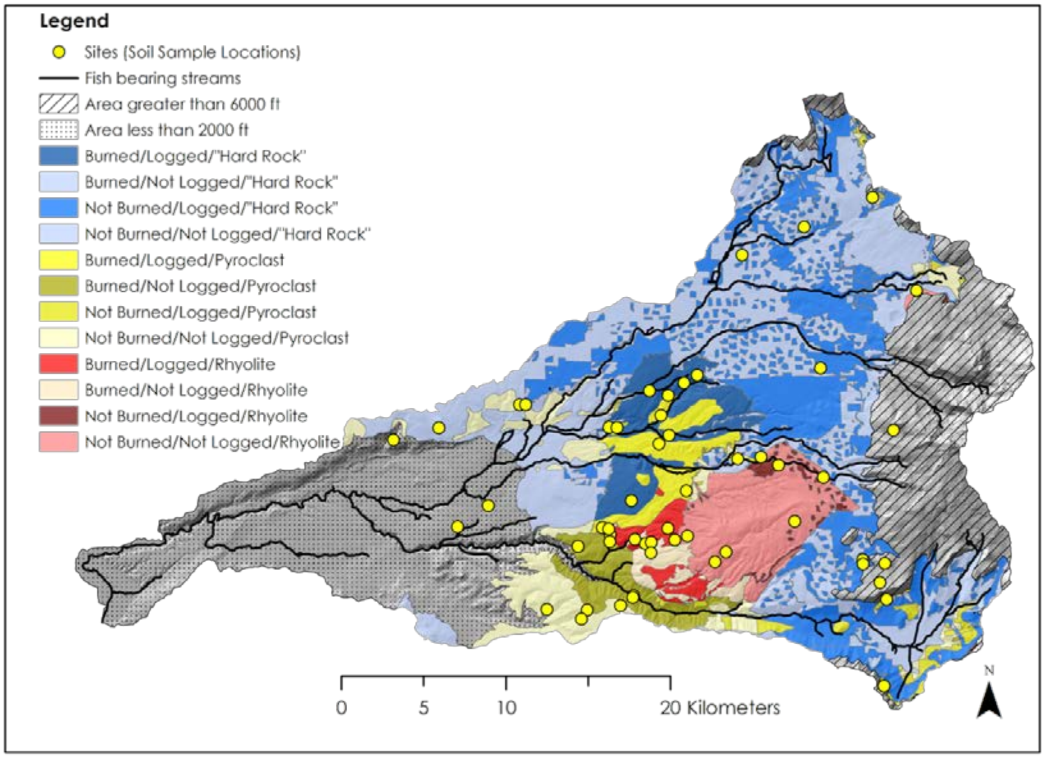

FIGURE 1. — Map of the 12 strata classes that occur in the mid-elevation area between 2,000 ft and 6,000 ft, and proposed soil erosion sampling sites.

TABLE 2. — Strata classes, total frame area covered by each class, and the percent of the total watershed area for each class.

Class	Class name	Area (km^2)	Percent of Watershed Area
1	Area greater than 6000 ft elevation asl	141.2	14.8
2	Area less than 2000 ft elevation asl	202.6	21.2
3	Burned/Logged/”Hard Rock”	37.2	3.9
4	Burned/Logged/Pyroclast	23.3	2.4
5	Burned/Logged/Rhyolite	11.6	1.2
6	Burned/Not Logged/”Hard Rock”	3.1	0.3
7	Burned/Not Logged/Pyroclast	23.0	2.4
8	Burned/Not Logged/Rhyolite	11.0	1.2
9	Not Burned/Logged/”Hard Rock”	152.4	15.9
10	Not Burned/Logged/Pyroclast	9.2	1.0
11	Not Burned/Logged/Rhyolite	6.0	0.6
12	Not Burned/Not Logged/”Hard Rock”	234.9	24.6
13	Not Burned/Not Logged/Pyroclast	49.3	5.2
14	Not Burned/Not Logged/Rhyolite	51.2	5.4
	Total	956.0	

Sample Collection

We will collect a combination of bulk samples and depth increment samples at 48 randomly chosen sites (four sites per each of 12 strata classes). At 12 sites (one per strata class), we will collect samples along a transect that is oriented perpendicular to a hillslope, in order to capture the soil redistribution patterns at various positions along a hillslope and to characterize "within site" measurement variability. Each transect will extend from the ridge top to the toe of the slope and may vary in length from 150 m to 1000 m. Along each transect, we will collect samples at approximately six evenly spaced points. At one of these six samples in each of the 12 Catena transects, we will collect a depth increment sample. The depth increment sample may vary in depth from 30 to 60 cm depending on the soil depth. At every 3-5 cm along the depth of the soil profile, we will collect samples for analysis of radionuclide concentration and grain size. At the other 36 randomly chosen sites (three per strata class), we will collect bulk samples. The depth of the bulk samples will vary depending on the depth of the soil. We will estimate the volume of the soil that was sampled in order to calculate bulk density. At a subset of the 36 sites (one per strata), we will analyze samples for grain size distribution. For all samples, we will analyze the size fraction that is less than 63 μm for concentrations of ^{137}Cs, ^{210}Pb, and ^{7}Be.

It is important to sample reference sites in order to determine the fallout concentration for the study area (i.e., at the watershed scale). We will collect at least three reference samples, using the depth incremented soil profile sampling technique. Reference locations will be chosen where there has not been a fire or change in land management since the 1950s and where the slope is less than 5%. Quantitative estimates of soil erosion can be derived when the soil sample isotope concentrations are compared to the reference inventory.

Auxiliary data that will be collected at each soil sampling site will include latitude and longitude, an estimation of vegetation cover, slope measurement, and information about the type of natural or anthropogenic disturbance (if any).

In total, we will collect approximately 252 samples at 57 sites, including bulk samples depth increment samples.

Channelization

Studies have shown that gullies can contribute significant amounts of sediment to the stream channel (Poesen et al. 1996). Gullies are formed by both channel and hillslope processes (Gao 2013) through a sequence of events that begins with downward scour of the soil, upslope head-ward erosion, rapid enlargement, and finally stabilization. Unlike rills, which tend to fill in and last only a few years, gullies are permanent once formed. Ravines are enlarged gullies predominantly formed by fluvial processes such as flash floods or debris flows. Often, ravines have near vertical head cuts and can act as both a source and a sink of sediment. Steep ravine walls frequently contain gullies.

We plan to use photogrammetric techniques to analyze the changes in gully and ravine morphology, and quantify rates of gully retreat and filling, as well as changes in the elevation of the floor of the gullies (DeRose et al. 1998; Martinez-Casasnovas 2003).

First, we will interpret stereo pairs of aerial photographs to aid in the identification of gullies and ravines, and map these features across the watershed in a GIS. Given the time constraints of the study, it may not be feasible to map all of the gullies and ravines; therefore, we will subsample the watershed. Once we have identified and mapped the gullies and ravines, we will measure the volumes of a subset of these features from digital terrain models that we will generate for each of the two series of aerial images that we will analyze: the 1952 series and the 2014 series. We selected the 1952 photo series because results from our inquiry to National Archives and Records Administration (NARA) indicate that while some earlier images (1938 and 1941) are available, only the 1952 series covers the entire watershed.

After we generate digital terrain models for both series of aerial images, we will use Geomorphic Change Detection (GCD) 6 software (Wheaton et al. 2010), which contains a suite of tools to rigorously account for the uncertainty associated with quantifying change, to difference the volumes of the analyzed features. We will validate our photogrammetric analyses by collecting field measurements at a subset of gullies and ravines. These measurements will allow us to generate estimates of slope, volume, and sediment grain size. Our gully and ravine inventory and photogrammetric analysis will begin in the fall of 2016 and continue into 2017. We will collect validation measurements in the summer of 2017.

Sample Site Selection

The frame for the channelization sample design is the entire watershed. We will subsample the watershed using a probabilistic design. For this design, we divided the watershed into a grid of 2 km by 2 km squares. We randomly ordered the squares such that the Digger Creek 12 digit Hydrologic Unit (United States Watershed Boundary Dataset) and the Lower South Fork Battle Creek 12 digit Hydrologic Unit will contain twice as many samples as the rest of the watershed. We will map gullies and ravines in as many squares as we can, given study time and budget constraints. Figure 2 shows the location of the first 50 samples sites (2 km by 2 km square) in the watershed that we will map. If time and budget allow, we will map additional squares based on the random order in which they are drawn.

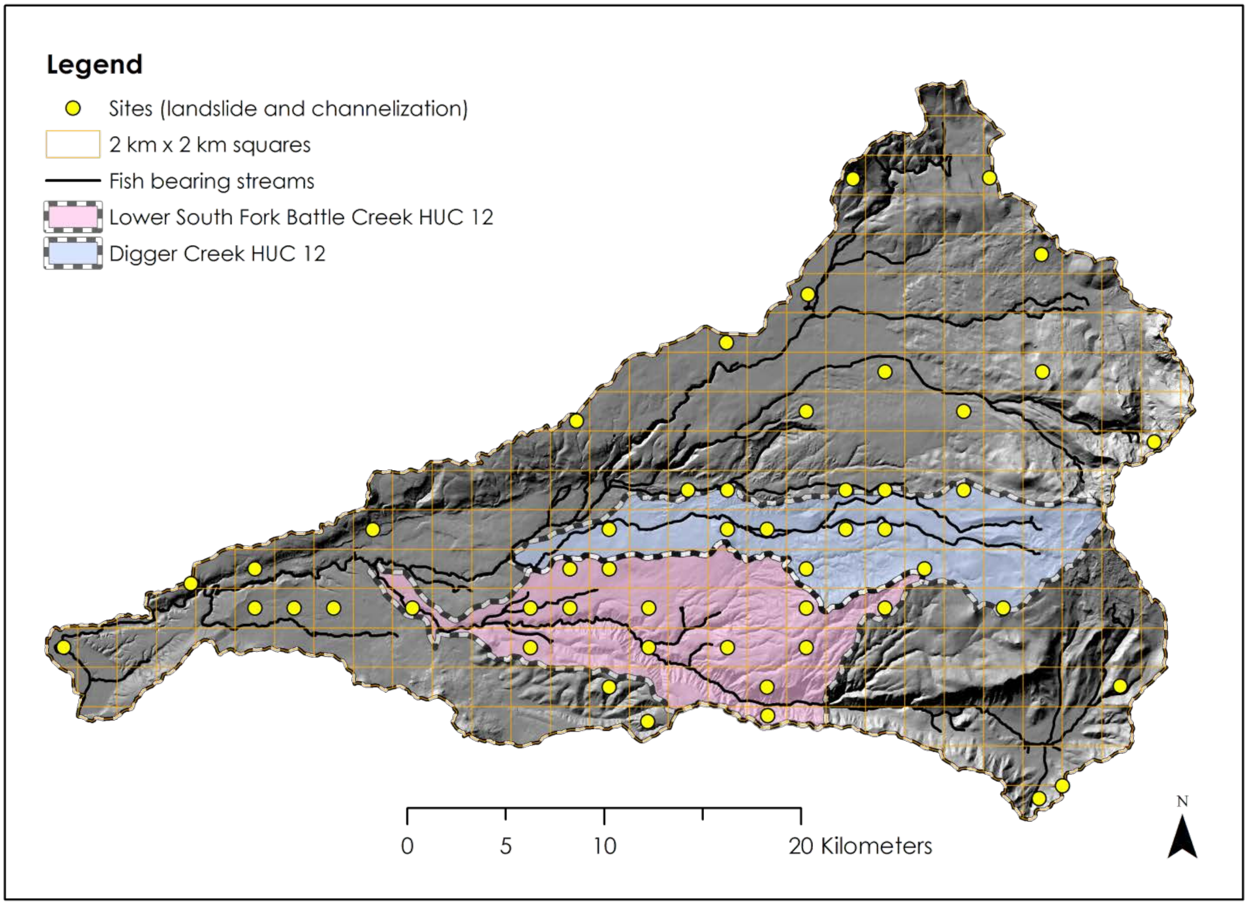

FIGURE 2. — The Battle Creek watershed, channelization sample design grid, and locations of the top 50 sample sites in relation to Lower South Fork Battle Creek and Digger Creek.

Landslides

Landslides are potential sources of sediment pollution. When slides deliver sediment to the stream channel, the response can be localized or translate far distances downstream, depending on the amount and the size of the sediment that is delivered, and the capacity of the stream channel to transport the delivered sediment. An increase in sediment supply from landslides can affect the stage-discharge relationship thereby increasing the risk of floods. An increase in sediment from slides may also have a negative impact on fish habitat if fine sediment fills the interstitial space of spawning gravels. Thus, it is important to account for landslides in our sediment assessment in Battle Creek.

There are several types of landslides. Varnes (1978) classified landslides into five types based on the kind of movement and material that is transported. The five types include falls, topples, slides, spreads, and flows. Slides originate along a slip surface, which is often where less porous material underlies a more porous surface layer. According to Varnes (1978), the two main types of slides are rotational and translational, and these differ based on the shape of the slip surface. Rotational slides are displaced along a concave surface, whereas translational slides are displaced along a planar or undulating surface. Debris flows usually begin as slides but then transform into a slurry of sediment and water that typically transports all of the material that is available, and as a result can be very destructive to downslope infrastructure (Davies et al. 2013). Debris flows usually form their own channels by constructing levees. When debris flows lose energy due in part to a decrease in slope, they deposit material usually in a lobate landform shape (i.e., an alluvial fan).

To quantify the rate of erosion of both slides and debris flows, we plan to use photogrammetry methods similar to those proposed to quantify erosion rates for gullies and ravines. We will map slides and debris flows in a GIS using aerial photograph interpretation techniques. Specifically, we will interpret stereo pairs of aerial photographs using visual analysis and heuristic techniques, which include using the shape, size, color, tone, mottling, texture, and pattern of the photographs to identify the location of slides and debris flows (Ray 1960; Miller 1961; Allum 1966; Rib and Liang 1978; van Zuidam 1985). We will delineate the perimeter of a landslide on both the historic (1952) and current (2014) series of aerial photographs.

Depending on the number of slides in the watershed, it may not be feasible to map all of the slides. Therefore, we will subsample the watershed using the same design that we will use to subsample gullies and ravines. Please refer to the channelization section for a description of this sample design.

We will calculate changes in the volume of a subset of the slides and debris flows that we map by using photogrammetric techniques. For each slide and debris flow that we analyze, we will generate a digital terrain model from the 1952 photographs and 2014 photographs. We will use the GCD 6 software (Wheaton et al. 2010) to difference the digital terrain models. By leveraging the functionality that is built into this software, we will be able to distinguish which changes are real, report volumes of change, and quantitatively and rigorously account for uncertainty.

For each slide and debris flow, we will collect information about its attributes including landslide type, active or non-active, whether it is connected to a stream channel, slope, land use type at initiation point (e.g., road, timber harvest, agriculture, etc.) and geomorphic landform association (e.g., inner gorge, swale, headwall, etc.). We will record this information in a GIS attribute table for each slide and flow. We will collect field measurements of slide geometry, erosion depth, etc. to validate a subset of these sites.

If there is some uncertainty about the factors that have caused a landslide, then we may decide to map landslides on additional series of aerial photographs. For example, we may want to inspect the 2012 photographs to determine if a particular landslide occurred prior to or following the Ponderosa Fire and subsequent salvage logging. The LiDAR data that were acquired in 2011 will be useful for identifying and mapping landslides that have occurred within a 200 m buffer of the stream channel. The 2011 data cover the portions of the North Fork Battle Creek, South Fork Battle Creek, and the mainstem Battle Creek stream network that are classified as anadromous. We may also use the LiDAR data to calculate sediment production and sediment delivery for particular landslides.

To determine if precipitation contributed to the initiation of the landslides that we map, we will analyze radar data as well as precipitation measurements from local rain gages. We intend to compute rainfall accumulation at the location of landslides by coupling the precipitation gage data with the radar reflectivity scans, which occur at 10-minute intervals (Nyman et al. 2011).

Floodplains

We will quantify the amount of sediment accessed from near channel sources by using a planform analysis method. In a GIS, we will delineate the active channel on two series of aerial photographs, 1952 and 2014. To measure rates of change in channel width and meander migration, we will use a method that is similar to the method that was used in Belmont et al. (2011), which they modified from Lauer and Parker (2008). This method computes the net local bank erosion rate as a function of measured meander migration rate and the difference in elevation between opposite channel banks. We will convert volumetric bank erosion rates to mass flux using an appropriate bulk density for the appropriate grain size. We will estimate bank erosion rates in each of the different geomorphic reach types that occur in the area of interest, as well as in areas affected or unaffected by the Ponderosa Fire and recent salvage logging.

In order to determine which portions of the stream network act as sediment sinks, we will derive longitudinal profiles for all major tributaries. We will use the stream profiler tool, which previous studies have used to extract longitudinal profiles (Stout et al. 2013). We will use a 10 m digital elevation mode**l** (DEM) or LiDAR, where available, to run the stream profiler tool. By analyzing the results, we will then be able to identify knick zones, or breaks in slope, which will aid in the determination of discontinuities in the sediment routing pathway.

Unpaved Roads

In many forested watersheds in the western United States, studies have identified unpaved roads as a source of sediment. We will survey rural roads of native surface throughout the Battle Creek Watershed using the GRAIP-Lite model (Black et al. 2013) to estimate the sediment production and sediment delivery from the unpaved road network. The GRAIP-Lite model, which runs in ArcGIS software, requires several inputs. These include a road network, stream network, DEM, and a calibration dataset that includes information about the vegetation cover on road surfaces and the probability of connection between the road network and the stream network. Model simulation results can be used to prioritize where to focus road rehabilitation, as well as conduct future road inventories. GRAIP-Lite differs from the full GRAIP model in several ways, one of which is that it only models road surface sediment contributions and not fill erosion and gully and landslide risks. The full GRAIP model produces more accurate estimates of sediment production and sediment delivery than what is generated using GRAIP-Lite, but it requires data from detailed road inventories, which is beyond the scope of this study.

Existing road inventories, sediment data, and modeling that has been conducted or is planned in the Battle Creek watershed can be used to improve the accuracy of the GRAIP-Lite model. Sources for such information include but may not be limited to Sierra Pacific Industries, the U.S. Forest Service, the Central Valley Regional Water Quality Control Board, and Lassen National Park.

We plan to run GRAIP-Lite for the entire network of unpaved roads that are present in the watershed. This includes roads that are located on public and private land. We will divide the road network into segments defined as the length of road between drain points, and predict sediment production for each individual road segment. Validation of the GRAIP-Lite model predictions will take place in 2017 at a subset of the road segments that we will model.

Elements of the model that we will validate include the location of drain points, and sediment production and sediment delivery prediction.

Vegetation and Land Cover Mapping

Determining the causes of sediment production in the Battle Creek watershed will help inform decisions about how to reduce the sediment load. One likely cause of sediment production is the lack of vegetation cover in some places. Specifically, vegetation influences the partition of water runoff across the landscape, and influences whether precipitation flows across the land surface or infiltrates into the ground and becomes subsurface flow. Because soil erosion takes place through the detachment of soil particles, often due to water runoff and subsequent downslope transport, vegetation (or lack thereof) exerts a strong influence on sediment transport rates (Kirkby 1995).

Natural and anthropogenic disturbances may alter the pattern and density of vegetation cover, which may lead to an increase in surface runoff and erosion. For example, studies have shown that the loss of vegetation and organic litter on the ground surface during wildfires leads to an increase in surface erosion (Morris and Moses 1987; Cerdà 1998a; Prosser and Williams 1998; Robichaud and Brown 1999; Benavides-Solorio and MacDonald 2001, 2005; Johansen et al. 2001; Larsen et al. 2009). Agriculture can also alter the natural vegetation cover of the land surface and result in an increase in soil erosion rates (Garcia-Ruiz 2010).

Since 1984, the U.S. Geological Survey has been collecting multi-spectral images with a 30 m resolution from at least one and up to three different satellites: Landsat 5, 7, and 8. We will survey and quantify changes in vegetation, as well as other land use and land cover attributes during the last 30 years, by analyzing the Landsat satellite imagery to yield insight into how soil erosion rates may have changed over time. We will quantify changes in forest, wildfire area, grassland and barren land, infrastructure, and other features. Our domain of inference (i.e., frame) is the watershed; therefore, we will analyze Landsat images that cover this entire area. Our analysis of land use and land cover will include both supervised and unsupervised classification of the data (Figure 3).

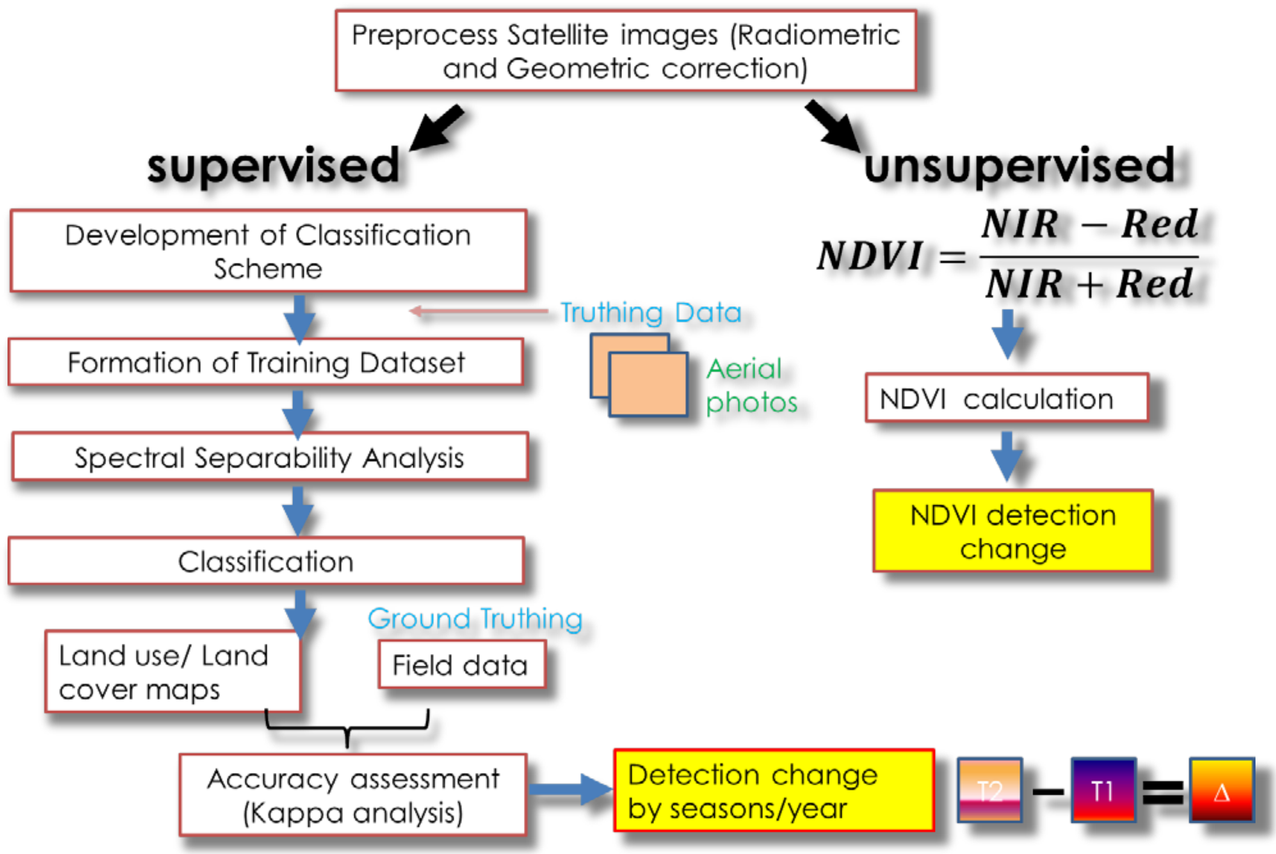

FIGURE 3. — Proposed work flow for the classification of land use and land cover attributes using Landsat imagery.

Channel Monitoring (SWAMP)

Part of Element 1 of the WBP includes setting goals to reduce the threat of impairment to the physical, chemical, or biological condition of the watershed. Studies have shown that benthic macroinvertebrates (BMIs) can be used to assess the ecological condition of streams. For example, BMI taxa respond differently to environmental stressors such as fine sediment, nutrients, contaminants, and stream flow alteration. The SWAMP protocol, developed by the state of California, includes a suite of methods that can be used to generate multi-parameter indices of ecological condition, such as the Index of Biological Integrity (IBI) and the California Stream Condition Index (CSCI). Specifically, IBI and CSCI can be used to determine the effects of recent natural disturbances and land management practices. Because the SWAMP protocol is compatible with previous data collection efforts in the watershed (i.e., the channel monitoring data that were collected in 2001, 2006, 2012, 2013, and 2014 using the Aquatic and Riparian Effectiveness Monitoring Plan (AREMP) protocol), we will able to quantify changes in the ecological condition of Battle Creek and its tributaries over a period of 15 years. The results from the analysis of channel monitoring data will assist managers in establishing water quality targets.

Sample Site Selection

The BCWC will collect SWAMP data in the summer of 2017 at 21 sites distributed across the perennial portion of the stream network. The sites will be chosen using a combined probabilistic and target sample design (Rehn and Ode 2009). The top 18 sites that were randomly chosen and sampled in 2001 will be resampled in 2017. In addition, we chose three sites lower in the 2001 use-order list so that previously sampled sites above and below the Ponderosa Fire would be included. These sites are use-order 31, 41, and 51. Figure 4 shows the location of the proposed sites where water chemistry, physical characteristics, and biological community will be measured, and historic data collection sites.

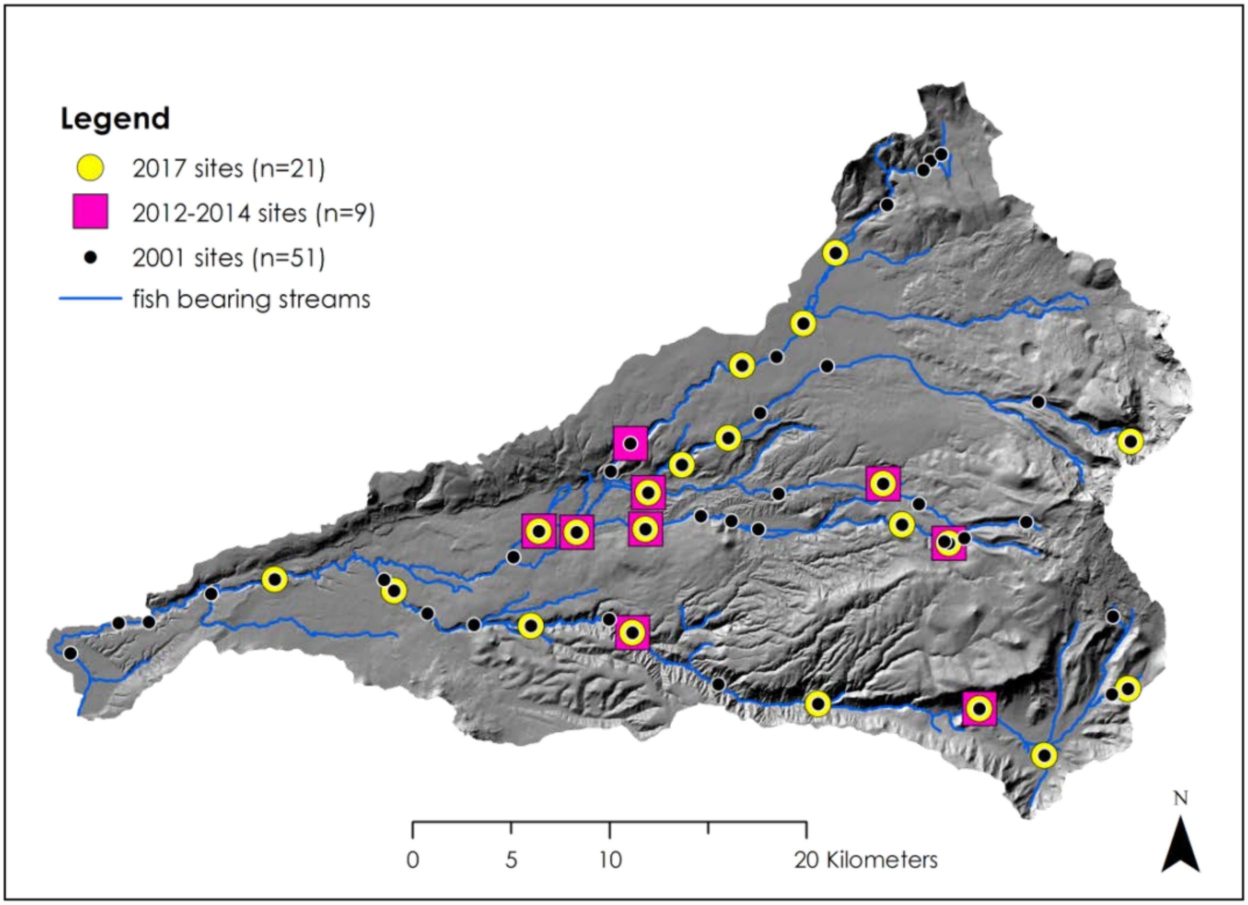

FIGURE 4. — Location of historic and future channel monitoring sites in the Battle Creek watershed.

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APPENDIX A. SUMMARY OF EXISTING DATA

INTRODUCTION

This appendix summarizes the existing data sets that will be used in the Battle Creek watershed assessment. As mentioned in the body of this Data Collection Plan, the aim of the assessment is to map sediment sources, identify causes of erosion, and quantify rates of erosion to support the development of a Watershed Based Plan (WBP) for Battle Creek. Information presented herein is intended to meet the deliverable requirements of Item B.3.5 - Summary of Existing Data - of the California State Water Resources Control Board grant agreement No. D1513502.

In the sections that follow, we present only the data sets that existed prior to the start of our assessment and which are necessary to complete each of the methods described in the body of this document. In our final report, we will present a synthesis of the other data sources that we will analyze, but do not describe in this appendix. For information on many of these data sets, we refer the reader to the 2015 Battle Creek Watershed Hydrology and Sediment Assessment (Henkle et al. 2016). This report contains an extensive review of the data sets that are relevant to the sediment dynamics in Battle Creek, including data related to geology, soils, hydrology, land use, wildfire, sediment, and biology. Some of the data presented in Henkle et. al (2016) were generated as part of studies that were specific to Battle Creek, while other data were generated by public agencies at broader scales, such as the state of California or the United States of America. Thus, to avoid repeating information contained in Henkle et al. (2016), we provide only brief descriptions of the existing data that will be used to complete each of the methods that we will implement, along with attributes of the data sets, in a concise tabular format.

It is important to note that some of the existing data that others have generated for the Battle Creek watershed are either proprietary or may not have been screened using a rigorous quality control and quality assurance procedure. Therefore, our ability to obtain and leverage such information in our analyses may be limited.

The following section, “Existing Data Sets”, is organized according to each method that we describe in the main document. Under each method heading, we identify the existing data sets that will be essential to the implementation of the method, and present several important attributes of each data set, including the source of the data, the type of the data, how we will utilize the data, and the status of the data. We present these attributes in a tabular format. For the attribute “status”, we assigned each data source one of three types: Possess, Acquire, Unknown. “Possess” refers to data that Terraqua currently has. “Update” refers to data that Terraqua possess but that are only partially complete. For example, we have downloaded timber harvest data from CAL FIRE’s website, but this data set does not include the areas that were salvage logged following the Ponderosa Fire in 2012. Therefore, the timber harvest data set that we possess is incomplete. “Unknown” refers to the data sets that may or may not be available for Battle Creek watershed and for which we need to conduct further research to determine if they exist. For example, we possess roads shapefiles that were acquired from several sources including the KRIS database and the U.S. Census TIGER database; however, these layers may not be entirely accurate and additional research and or work may be needed to update them.

EXISTING DATA SETS

Soil Erosion

As mentioned in the DCP, we are using a stratified probabilistic design to guide our identification of soil sample sites for radiogenic isotope analysis. We will stratify the watershed by three categories: natural disturbance, anthropogenic disturbance, and geology. The natural disturbance stratum contains two classes: the area that burned in 2012 during the Ponderosa Fire and the area that was not burned in 2012. The anthropogenic disturbance stratum contains two classes as well: the areas that have been logged since 1996 and the areas that have not been logged since 1996. The geology stratum consists of three classes: basalt/andesite/sedimentary/metasedimentary deposits ("hard rock"), rhyolite deposits, and pyroclast deposits. In Table 1, we list the data sets that comprise our strata and the two data sets that will be helpful during our site selection process, including the Henkle et al. (2016) landscape process model and the NRCS soils database. We will incorporate results from the landscape process model in our analysis of the soil sampling results, specifically when extrapolating from a sampling site to the broader scale such as the subwatershed (HUC 12) or the entire watershed.

TABLE 1. — Data sets that will be used to choose the sites for soil sampling.

Dataset/Tool	Source(s)	Type	Description	Purpose	Status
Landscape process model	Henkle et al. (2016)	Geo-spatial	Model predictions of dominant landscape processes	site selection and hypothesis testing	Possess
Geology	California Geologic Survey data that were digitized by Chico State University	Geo-spatial	Surficial Geologic Map of the watershed	site selection and identification of the causes of erosion	Possess
Soils	NRCS	Geo-spatial	SSRGO certified soils data	site selection and identification of causes of erosion	Possess
Timber harvest	USFS and CAL FIRE	Geo-spatial	Perimeters of timber harvest plans on both public and private lands that have occurred back to 1996	site selection and identification of causes of erosion	Possess and Update
Wildfire	CAL FIRE	Geo-spatial	Perimeters of wildfires that have occurred in the watershed back to 1878	site selection and identification of causes of erosion	Possess

Channelization (gullies and ravines) and Landslides

To map the location of and analyze gullies and ravines, we will use two types of data: aerial photographs and LiDAR (where it is available). We will interpret stereo pairs of two series of aerial photographs including the most recent series that are available (2014), as well as the oldest series of photographs that cover the entire watershed, the 1952 series. The digital terrain models (DTMs) that we generate from the aerial photographs will be helpful for identifying and mapping gullies and ravines. We will also use the DTMs in a change detection analysis of a subset of the gullies and ravines that we map.

TABLE 2. — Data sets that will be used in the inventory and analysis of gullies and ravines

Dataset	Source(s)	Type	Description	Purpose	Status
Aerial photographs	National Archives and Records Administration	Geospatial	1952; entire watershed	Identification and analysis	Acquire
Aerial photographs	Hexagon Geospatial	Geospatial	2014; entire watershed	Identification and analysis	Possess
LiDAR	USFWS	Geospatial	2011; anadromous extent of stream	Identification and analysis	Possess

Floodplains

We will analyze the oldest aerial photographs (1952) and the most recent aerial photographs (2014) in a GIS to quantify the amount of sediment accessed from near channel sources. For at least one occurrence of each type of geomorphic reach that exists in the perennial portion of the stream network, we will delineate the active channel width on both series of aerial photographs. We will analyze these active channel polygons to estimate the net local sediment contribution from both channel width changes and meander migration changes. In addition, we will acquire information on bank height, which is an input to the equations that we will use to calculate the net local sediment contribution, from whichever data set is available. Suitable candidates include the channel monitoring data that was collected in 2001, 2006, and 2012-2014 using the AREMP protocol; channel cross section data that collected in the 1990s during an Instream Flow Incremental Methodology (IFIM) work; and LiDAR. We will use the results from the channel planform analysis to assist in the identification of the reaches that are acting as sediment sources or sediment sinks.

We will augment the results from the channel planform analysis with an analysis of the longitudinal profiles of the main trunk streams in the watershed to identify the sediment routing dynamics. To generate longitudinal profiles, we will use the stream profiler tool (Whipple et al. 2007), which has been created to run in ArcGIS and Matlab. The only input to the stream profiler tool is an elevation raster. We plan to use the USGS 10-m digital elevation model and LiDAR, where available, to run the stream profiler tool. We will identify Knick zones, which are breaks in slope, to aid in the determination of discontinuities in the sediment routing pathway.

TABLE 3. — Data sets that will be used in the quantification of near channel sediment supply.

Dataset	Source(s)	Type	Description	Purpose	Status
Aerial photographs	National Archives and Records Administration	Geospatial	1952; entire watershed	Active channel width	Acquire
Aerial photographs	Hexagon Geospatial	Geospatial	2014; entire watershed	Active channel width	Possess
LiDAR	USFWS	Geospatial	2011; anadromous extent of stream	Active channel width and bank height calculation	Possess
Channel monitoring data	Terraqua BCWC surveys	Tabular data	Surveys conducted in 2001, 2006, and 2012-2014 using the AREMP protocol	Bank height calculation	Possess
Cross-section data	IFIM analysis	Tabular data	Surveyed cross sections	Bank height calculation	Acquire
Digital elevation model	USGS National Elevation Data (NED)	Geospatial	10 m resolution raster data	Longitudinal profile analysis	Possess

Unpaved Roads

We will run GRAIP-Lite, the Geomorphic Road Analysis Inventory model (Black et al. 2013), to predict the amount of sediment that is produced and delivered to streams from unpaved roads. Model data inputs include a road network, stream network, digital elevation model, and a calibration dataset that includes information about the vegetation cover on road surfaces and the probability of connection between the road network and the stream network. We will leverage existing road sediment and modeling data, where available. Road inventories and calibration data that may be available for use include work conducted by Sierra Pacific Industries, the U.S. Forest Service, Central Valley Regional Water Quality Control Board, and Lassen National Park.

TABLE 4. — Data sets that will be used to parameterize the GRAIP-Lite model.

Dataset	Source(s)	Type	Description	Purpose	Status
Digital elevation model	USGS National Elevation Data (NED)	Geospatial	10 m resolution raster data	Analysis	Possess
Stream network	USGS National Hydrography Data (NHD)	Geospatial	Stream flow polylines	Analysis	Possess
Road network	TIGER U.S. Census Bureau; USFS; Shasta and Tehama Counties; KRIS database	Geospatial	Unpaved road segments	Analysis	Update
Calibration data sets	USFS, SPI, CVRWQB, NPS	Geospatial	Road condition information	Analysis	Unknown

Land use and land cover mapping

To quantify changes in vegetation as well as other land cover and land use attributes to help determine the causes of sediment production, we will rely on the Landsat imagery that is available for the Battle Creek watershed. Since 1972, Landsat satellites have acquired images of the Earth's surface. Landsat 5 launched in 1984 and acquired imagery for 28 years before it was retired. Landsat 7 launched in 1999 and continues to collect images, and Landsat 8 launched in 2013 and continues to collect images. Images from the Landsat 5, 7, and 8 satellites contain several bands including the visible, near infrared, and shortwave infrared. The resolution of each Landsat image is 30 meters.

TABLE 5. — Existing data sets that will be used to quantify changes in land use and land cover during the last 30 years.

Dataset	Source(s)	Type	Description	Purpose	Status
Landsat	USGS	Geospatial	30 meter resolution. Collected every year from 1980s to the present	Analysis	Update

Channel monitoring

In 2017, the BCWC will use the SWAMP protocol to conduct sampling under California State Water Resources Control Board grant agreement No. D1513502. We will analyze the new instream measurements of water chemistry, physical characteristics, and biological communities to determine if the recent erosional events have affected the ecological condition of streams in Battle Creek. Specifically, we will analyze select metrics and indicators such as the Index of Biological Integrity (IBI) and the California Stream Condition Index (CSCI), along with data collected 2001, 2006, 2012, 2013, and 2014 using the Aquatic and Riparian Effectiveness Monitoring Plan (AREMP) protocol. In addition to a pre- and post-disturbance analysis, we will perform a trend analysis and watershed scale analysis of ecological conditions using metrics and indicators generated from the time series of channel monitoring data.

TABLE 6. — Data sources that will be used in the analysis of channel conditions.

Dataset	Source(s)	Type	Description	Purpose	Status
Channel monitoring data	Terraqua Inc., Battle Creek Watershed Conservancy, CVRWCQB	Tabular	Measurements of physical, biological parameters, and water quality	Analysis of ecological condition	Possess

APPENDIX B. RESPONSE TO COMMENTS ON THE DRAFT DATA COLLECTION PLAN

Comments from Dr. Andrew Gray

Dr. Gray's review was compiled as a standalone document and included as an attachment to an email that was sent to Stephen Fortney, Terraqua Inc., on October 18, 2016.

Data Variability and Uncertainty

In a review of Terraqua's Data Collection Plan (DCP; working version 1.0), Dr. Gray described the importance of accounting for the uncertainty associated with sediment load estimates. We concur with Dr. Gray that accounting for uncertainty is important. For example, in order to make well-informed decisions about how to address erosion in the watershed, managers and decision makers need to understand the inherent uncertainty in the erosion estimates. We plan to account for the uncertainty that is associated with each of the methods that we will use to estimate erosion rates, when possible. The new version of the Data Collection Plan describes how we will use GCD 6.0 to account for uncertainty in the measurement of erosion from gullies and ravines and landslides. We may be able to account for uncertainty in soil erosion estimates by comparing the erosion rate that we will generate from the radionuclide tracer method to the empirical estimates of erosion that Sierra Pacific Industries generated from 10 swales in the North Fork Battle Creek watershed. In the future, there may be additional opportunities to perform this type of comparison in Battle Creek. We will describe the uncertainty in our estimates of erosion rates in the final report.

Diversification in Methodologies

In light of the conversations that we had with Dr. Gray, the comments contained in his review of our Data Collection Plan, and the recommendations that we received from the Central Valley Regional Water Quality Control Board (CVRWQCB), we changed the methods for estimating rates of soil erosion that we previously described in the DCP (working version 1.0). Instead of using a topographic differencing method that leverages Structure from Motion technology, we intend to use radionuclide tracer methods to estimate soil erosion rates. Although topographic differencing would have enabled us to generate estimates of soil erosion at the event time scale and the annual time scale, estimates at the decadal time scale would have been infeasible given the length of time allocated for our assessment. Therefore, we will estimate soil erosion at the decadal time scale by analyzing soil samples for concentrations of radionuclides. Because we intend to generate estimates of erosion from nearly all of the other sources in the watershed (i.e., near-channel sources, landslides, gullies and ravines) at the decadal time scale, our new approach will better align the temporal scale of our soil erosion estimates with the scale used for other estimates. In addition, when coupled with an analysis of radio nuclide concentrations in suspended sediment samples, we will be able to estimate the relative contribution of sediment supply from various sources of erosion (e.g., shallow vs. deep soil erosion, or near channel vs. upslope).

Modern Fluvial Sediment Data

In October 2016, the CVRWQCB revealed that they have the capacity to collect grab samples of suspended sediment at multiple locations in Battle Creek and tributaries to Battle Creek during the 2016/2017 wet season. We are working with the CVRWQCB to identify the locations, timing, and the frequency of the grab samples. Analysis of the grab samples for the same radionuclide tracers that we plan to analyze in hillslope and floodplain sources will aid in the determination of the relative contribution of the various sources of sediment in the watershed.

Comments from the Central Valley Regional Water Quality Control Board

These comments were included in an email that was sent to Stephen Fortney and cc'd to Ben Letton on October 6, 2016.

"If the SfM technology is to be used, the plots should take into account soil type and herbicide/no herbicide conditions."

In light of the conversations that we had with Dr. Gray and his review of our Data Collection Plan, as well as the recommendations that we received from the CVRWQCB, we intend to replace the topographic differencing method, which leverages Structure from Motion technology to estimate soil erosion rates, with radionuclide tracer methods. We intend to collect sediment samples for isotope analysis on hillslopes that vary in parent material and thus soil type, as well as on hillslopes that vary in disturbance.

"Please add some sort of field verification to the GRAIP-Lite modeling results to ensure the model matches ground conditions."

In the Data Collection Plan, we added a description of the fieldwork that will be conducted to validate the GRAIP-Lite model outputs and predictions.

"It is preferred radioisotopes are used to quantify small scale erosional processes instead of SfM technology."

See response to comment #1, above.

"If budgeting requires some elements of the plan to be cut out, the near channel sources analysis is the lowest priority portion of the project."

Thank you for this comment. At the moment, we project that we will have the budget to complete the analysis of near channel erosion, and will proceed with completing this analysis.

Comments from Marily Woodhouse, Battle Creek Alliance

These comments were included in an email sent to Stephen Fortney and Steve Tussing, BCWC, on October 3, 2016.

"Regarding the soil plots on page 5-6: Could you tell me more about how you will determine the locations? I know access can be a problem. My land on Digger Creek burned in 2005. I left it alone to recover, so it's had no "treatment". We can discuss if you would like to put a plot here."

Thank you for the offer to collect soil erosion data on your property. We are finishing a revision of the data collection plan that takes into account Andy Gray's review. A strategy for selecting soil erosion sites will be part of our plan. I will keep in mind your offer as we polish our site selection strategy

"Regarding the slide section on pages 8-9: Over the years I've seen several slides which originated above the roadways, which were cleaned up pretty quickly. Because images aren't taken regularly or close together in time, I'm wondering if slides like that will be detectable with your methodology?"

The temporal resolution of our slide inventory and analysis is determined by the availability of aerial photographs or other remote sensing data sets. We are proposing to map slides on the most current aerial photographs that are available, as well as the oldest photographs that are available. In some areas we may want to interpret additional series of photographs in order to constrain the time of activation or initiation of a particular slide. In recent decades, aerial photographs are taken nearly every other year. We can take advantage of this higher temporal resolution of aerial photographs in targeted areas. Prior to the 1990s, aerial photographs were taken on average once every 8 to 10 years. In general, we are limited by the time frame of the project, and believe that we can get the most amount of useful information by analyzing just two series of photographs at the watershed scale.

"Lastly, in the first Terraqua document prepared from 2001 data, SPI asked for info to be removed, and it was. In our experience, and in evidence from PRA requests, we have found many instances where they have been allowed to alter CDF official responses and documents. Will they be allowed to alter this assessment?"

Response by Steve Tussing (BCWC): As project manager, I am trying to foster an assessment and planning process that is transparent, inclusive and data driven. If a stakeholder has a technical opinion about methodology or data interpretation, they can share that with the TAC for consideration. I think this approach will make for a better assessment and plan as we can draw on the broader range of expertise that the TAC members can provide, and build broad support for implementing high priority projects that can address sediment sources. In my opinion, to allow any stakeholder the opportunity to "alter" the assessment behind closed doors runs contrary to what we are trying to achieve here. I appreciate your time and participation in the TAC.