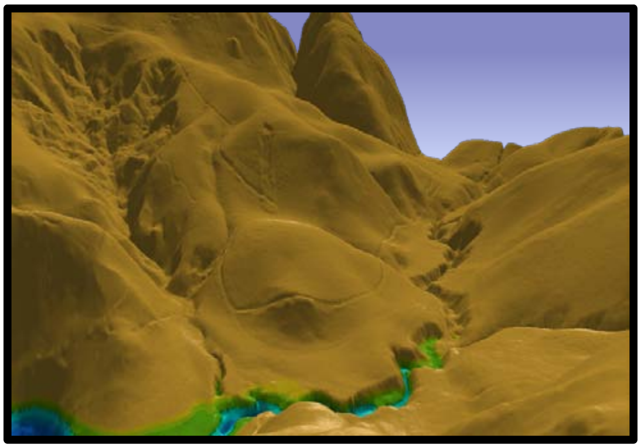

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Partitioning Sediment Sources at the Hollister Hills State Vehicular Recreation Area

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Disclaimer:

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Executive Summary

Hollister Hills State Vehicular Recreation Area (SVRA) is one of eight SVRAs operated by California State Parks. Resource managers at Hollister Hills have employed a wide range of erosion control and sediment retention strategies throughout the park. Assessing the efficacy of these overall conservation efforts is technically difficult. There are several sources of sediment that have to be considered in an overall sediment budget. This study begins to address the relative importance of potentially important sediment sources in the Bird Creek Watershed, which includes most of the SVRA and some private lands bordering the park. We used a combination of field research and literature review to assess the potential importance of the following sources of sediment in Bird Creek:

- Off-highway vehicle use
- Overland flow carrying dirt from unpaved parking lots and campgrounds
- Riparian cattle grazing
- Stream bank erosion
- Landslides.

Initial studies of sediment retention basin data at Hollister Hills indicates that watersheds with no off-highway use in this region will shed approximately 159 m^3/yr of sediment per km^2 of drainage area. Reconnaissance level studies of unpaved parking lots and campgrounds suggest that these regions are sediment sources for Bird Creek, and deserve in-depth study. Further work will lead to recommendations for erosion reduction. Riparian cattle grazing was shown to damage local creek banks, leading to increased fine sediment in the Bird Creek channel. Cattle exclusion from the riparian corridor would eliminate that impact. Bird Creek stream bank and bed were monitored for change using cross section surveys, bed particle counts, and bank pins. Analysis in the Hudner reach of Bird Creek indicates that there has been minor aggradation of mainly fine sediment, in keeping with cattle impacts described above. Bank pin analysis suggests that as much as 93,000 kg of fine sediment was generated from the Bird Creek banks between Hudner and the Park entrance in the 2011 water year. Only 24,000 kg were added during the winter of the 2012 water year, generally in keeping with the drier conditions. Landslides were active sometime between 2007 and 2009, based upon the presence of freshly exposed headwall scarps, sharp slope breaks between the scarp and undisturbed hill slopes, and aerial photo analysis. Analysis of potential triggering events (earthquakes and intense rainfall) failed to reveal any obvious external landslide triggers. Conversely, combined intense rainfall and earthquake clusters in 1995 and 2001 did not generate any discernible slope failure features. Longitudinal profiles, cross sections, and field reconnaissance indicate that landslides sporadically add considerable sediment to Bird Creek in a two-stage process. First, slope failure generates a displaced body of crushed rock that is easier to erode than bedrock. Second, over-steepened slopes at the landslide toes produces alluvial knick points that cut

steep “V” shaped gullies and ravines into the slide body. These steep features can efficiently transport sediment to Bird Creek in high-intensity rain events. Our work underscores the idea that sediment sources are technically difficult to partition in Bird Creek. Volumetrically important sediment transport events may vary considerably in both time and space. Therefore, accurate estimates of the various components in the sediment budget must be measured over many years. In the meantime, sediment control strategies will continue to improve as sediment erosion and transport processes are better understood and more precisely located.

Table of Contents

1 Introduction

1.1 Background

Hollister Hills State Vehicular Recreation Area (Fig. 1) is one of eight off-highway vehicle parks operated by California State Parks. Located in central California, Hollister Hills provides off-highway vehicle enthusiasts access to 185 kilometers of managed and patrolled dirt roads and trails, for an entrance fee. Soil erosion due to off-highway vehicle recreation at the Park could have a detrimental impact on water quality. Quantifying the relative impact of off-highway vehicle-related erosion requires us to balance that impact against other local sediment sources, such as cattle and natural background sedimentation processes. Quantifying regional sediment sources is problematic because they vary greatly in magnitude and timing, while scientific studies last a finite period. Observations over sub-decadal periods of time might not capture important, rare, high-magnitude natural sediment transport events. This paper describes initial attempts to partition the relative importance of sediment sources in the Bird Creek watershed, where most of the Hollister Hills State Vehicular Recreation Area is located.

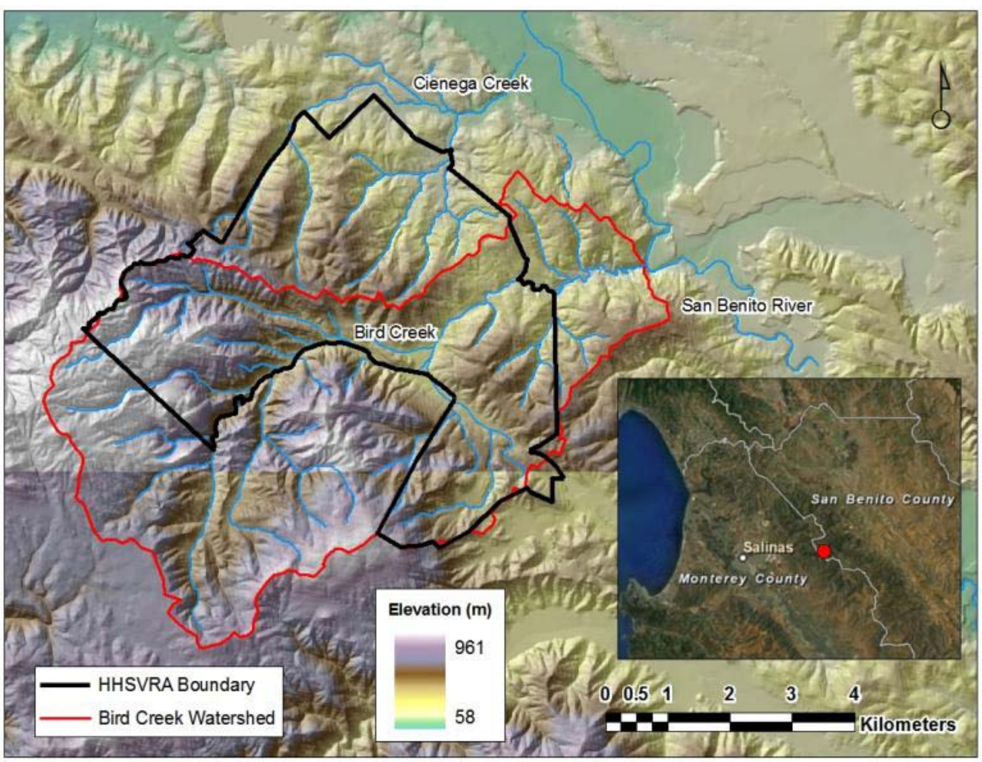


Figure 1. Location map for Hollister Hills State Vehicular Recreation Area and the Bird Creek watershed.

1.2 Clean Water Act

Degradation of water quality by various pollution sources was addressed by the Clean Water Act (CWA) of 1972. The CWA established regulatory procedures to enforce water quality standards for surface waters; pollution control and education programs are funded by federal grant money (USEPA 2011). Two mechanisms through which pollutants reach water supplies are point and non-point source pollution. Point source pollution has a clear origin and can be readily traced back to its source. Point source pollution is typically associated with discharge from industrial facilities and sewage treatment plants. Non-point source (NPS) pollution is often wide spread and difficult to track back to a single source, commonly originating from poorly defined diffuse sources that may occur over broad geographical scales (Ritter et al. 2002). Non-point source pollution includes chemical-laden runoff from rainfall and excess sediment in water supplies (USEPA 2011). The CWA originally addressed only point source pollution, but was later amended to also address NPS pollutants.

The Environmental Protection Agency (EPA) lists excess sediment as "the most common pollutant in rivers, streams, lakes and reservoirs" (EPA 2011). Excess sediment, both suspended and bedload, can alter stream geomorphology and negatively impact both lotic aquatic ecosystems and nearshore marine communities at the river mouth (Pye 1994; Thrush et al. 2004). A deep problem exists in the regulatory assessment of sediment pollution; it is difficult to quantify the level of sediment that constitutes "pollution" because sediment is a ubiquitous natural component of surface waters, and natural sediment concentrations vary enormously in both time and space. Our work addresses a range of natural and potential NPS sediment sources associated with the Hollister Hills SVRA.

1.3 State Vehicular Recreation Areas

The California Off-Highway Vehicle (OHV) Recreation program was created in 1971, when Governor Reagan signed the Chappie-Z'Berg Off-Highway Motor Vehicle Law as part of a state-wide effort to manage the environmental impacts of OHV recreation (Bedrossian and Reynolds 2007). The intent of the legislature was to ensure stewardship of the land, including erosion control, through maintenance and oversight while providing designated riding areas to serve a growing population of off-highway enthusiasts (Bedrossian and Reynolds 2007). State Vehicular Recreation Areas throughout California are managed by the Off-Highway Motor Vehicle Recreation (OHMVR) Division of California State Parks (CSP) (California State Parks 2009). The OHMVR Division was established by the OHMVR Act of 2003 to provide leadership and administer a guiding principle to meet legislative mandates; the Act is established to provide "education, conservation, and enforcement efforts that balance OHV recreation impacts with programs that conserve and protect natural resources" (California State Parks 2009).

In 1987, the California legislature mandated the development of a soil loss standard for OHV recreation (Bedrossian and Reynolds 2007). As a result, soil conservation standards and guidelines for OHV use in California were published in 1991. The 1991 soil conservation standards and guidelines required maintenance of OHV areas and trails, use of an erosion hazard rating system, and annual monitoring that would allow for "feasible rehabilitation by resource managers" (Bedrossian and Reynolds 2007). In response to an increase in OHV usage state-wide and decreased lands available for OHV recreation, the California Geological Survey (CGS) (contracted by California State Parks) worked with stakeholders, agencies, and other interest groups to update the standards in 2006 (Bedrossian and Reynolds 2007). Major changes included: a requirement that managers take regional soil, geology, vegetation, climate, hydrogeologic conditions, issues from past land use, and site-specific criteria into consideration when planning and designing any project; a requirement that (potential) off-site effects and mitigation options be identified; a tiered approach to assessment, maintenance, monitoring, project design, and construction which allows for the best management practices to be applied when specific conditions are taken into account; and modification of restoration timelines to allow for realistic compliance (Bedrossian and Reynolds 2007). The standards and guidelines apply "specifically to (1) the development and management of California's SVRAs, and (2) all acquisition, development, and trail and road maintenance projects on federal and local government lands that receive funding from the California OHV grants and Cooperate Agreements Program" (Bedrossian and Reynolds 2007). The updated soil conservation standards and guidelines prompted California's SVRAs to undertake research efforts to determine how much suspended sediment can be attributed to OHV recreation, and to determine whether more rigorous restoration efforts are required.

Serious opposition to OHV use in California has been documented in the form of A Writ of Mandate issued by Judge Frank Roesch of the Alameda County Superior Court to ensure compliance of Carnegie SVRA with the Porter-Cologne Water Quality Control Act (Writ of Mandate for Carnegie SVRA 2009; Stade K 2009). The OHMVR division had continued to make efforts in all SVRAs to ensure compliance with the Act and ensure proper stewardship of the environment and California's natural resources.

1.4 Hollister Hills SVRA

Hollister Hills SVRA (HH SVRA) is located in the Gabilan Range 8km south of the town of Hollister and is one of eight SVRAs managed by California State Parks (CSP OHMVR 2012). Off-highway vehicle use at Hollister Hills began in 1941 under the supervision of Howard Harris, the former owner of the property, and heavy OHV use by the public began in 1969 (Webb et al. 1978).

The 13km^2 park ranges from 660 feet to 2,425 feet (220-730m) in elevation and encompasses roughly 4,100 acres of motorcycle, all-terrain vehicle, and 4-wheel drive trails and campgrounds (Tuttle and Griggs 1987; CSP OHMVR 2012). The San Andreas Fault divides the park; chaparral grows in gravelly-sandy-loam soils atop granite to the Southwest of the fault and oak woodlands and grasslands grow in the clayey/loamy soil of the Purisima formation to the Northeast of the fault (Tuttle and Griggs 1987). Bird Creek and its tributaries are seasonal streams that experience highest flow during winter and spring storm events and low to dry conditions during summer (Tuttle and Griggs 1987). Annual precipitation is higher than the 33.3cm a year value reported by the Hollister California Department of Forestry Weather Station (Tuttle and Griggs 1987).

Natural resources, including vegetation and soil, were impacted by grazing, agriculture, and OHV recreation prior to the 1975 acquisition by State Parks (Tuttle and Griggs 1987). When "the physical properties of soil, slopes, vegetative cover, and climate" are impacted, soil erosion rates and sediment yield may exceed what is natural for the area (Tuttle and Griggs 1987).

Sediment management practices include the use of sediment catch basins, trail maintenance, gully control, vegetative restoration, and annual water sampling to produce estimates of sediment yields from watersheds disturbed by OHV use (CSP OHMVR 2012; Nicol et al. 2011). Ongoing investigations continue to monitor sediment yield (Nicol et al. 2011) and seek to partition sediment sources into "natural/background processes" and "anthropogenic/OHV recreation-related processes" by monitoring stream morphology and collecting water quality data from tributaries that may contribute excess sediment to Bird Creek.

Our study combines field research and literature review to assess the relative importance of the following potential sources of sediment in Bird Creek:

- Off-highway vehicle use
- Overland flow from dirt parking lots and campgrounds
- Riparian cattle grazing
- Stream bank erosion
- Landslides

The following sections introduce each of these potential sediment sources and outline how they were studied.

1.4.1 Erosion from OHV use

Unpaved dirt roads have the potential to significantly contribute excess sediment to surface water bodies (Smolen et al. 2009; Ramos-Scharron and MacDonald 2006). Studies from many geologic and climate settings around the world have determined that unpaved roads contribute a disproportionate amount of sediment runoff even though they occupy a small proportion of the watershed area (Smolen et al. 2009). A study in the Dominican Republic determined that a watershed had a small road area that contributed 30% of the total sediment runoff (Smolen et al. 2009). Another study in Issaquah Creek, Washington determined that while unpaved roads occupied only 2.6% of the watershed's area they contributed 15% of the sediment runoff (Smolen et al. 2009). Another study in Stillwater Creek, Oklahoma extrapolated that while roads in the watershed made up only 1.3% of the total area, they contributed 35% of the sediment load coming from the watershed (Smolen et al. 2009). The reasons for such high instances of erosion from dirt roads can be attributed to changes in vegetative cover, soil make-up, and slope brought about by the construction of a dirt road (Ramos-Scharron 2010). Vegetation along the ground helps to break up water as it hits the surface and makes the water move more slowly (Ramos-Scharron and MacDonald 2006). Plant roots can also act as a natural hold on soils, keeping them from washing away rapidly during a rain event (Bullard 1966; Amador et al. 2012). Removing the vegetative ground cover means that soils no longer have that natural anchor and are more easily removed by alluvial processes. In addition to removing plant cover, creating and using unpaved roads can also change the soil density in that area; constructing and driving on the dirt roads leads to compaction of the soil which creates a semi-impermeable layer (Amador et al. 2012). This denser soil layer leads to less infiltration and a higher runoff, resulting in a greater volume of water available to move sediment (Amador et al. 2012). It is also important to consider the slope at which a dirt road is being created; the slope of a road contributes greatly to the amount of sediment runoff because a greater slope increases the shear stress developed by water as it runs off of the road. The increase in water velocity results in increased sediment erosion and transport off of roads during storm runoff events (Amador et al. 2012).

Off-highway vehicle recreation exacerbates the impacts of unpaved roadways by increasing the rates at which skidding tires liberate sedimentary particles from soil and bedrock underlying the roads (Tuttle and Griggs 1987). Off-highway vehicles create a shear stress on the land, which physically de-vegetates and removes the topsoil leading to increased runoff and erosion. OHV use has also been shown to significantly compact the soil, decreasing permeability while increasing surface runoff (Webb et al. 1978). Increasing compaction and density of soil also creates a challenging environment for restoration efforts such as re-vegetation.

We address the erosion impact of OHV use by analyzing the relationship between the total length of OHV trails in a watershed and the amount of sediment removed from sediment basins at the mouths of the watersheds. Specifically we attempted to quantify exactly how much of the trapped sediment produced in Hollister Hills is due strictly to OHV use. Figure 2 shows an example of a sediment basin catching sediment eroded from the watershed that drains into it.

Figure 2. Sediment retention basin catches sediment generated from natural background sources and OHV roads.

1.4.2 Runoff from unpaved campgrounds and parking lots

Much like unpaved roads, unpaved campgrounds and parking lots in recreational areas are potential non-point source sediment sources for adjacent rivers and streams. Well established campground sites and parking lots usually feature losses of vegetation and compaction of the soil (Monz and Cole 2004). As a consequence of compaction, soil infiltration and permeability are reduced since increased compaction caused by cars and foot traffic leads to increased bulk density and decreased porosity (Ruserholz et al. 2009). The end result is increased runoff, accelerated erosion, and sedimentation of adjacent streams (Cole 2000). Specific impacts include higher peak stream flows, channel incision, bank erosion, increased sediment transport, less groundwater recharge, and lower base flows (Brattebo and Booth 2003).

There are a total of seven campgrounds along with seven parking lots at the Hollister Hills SVRA. The Lower Ranch has a total of five campgrounds, which are: Madrone, Bee, Lodge, Walnut, and Radio Ridge (CSP OHMVR 2012). Four of the campgrounds (Madrone, Bee, Lodge, and Walnut) in the Lower Ranch are close enough to the Bird Creek to contribute overland flow and rill runoff to the stream.

We addressed this potential sediment source by visually inspecting the unpaved areas during dry and rainy periods for active rills and channels leading to the Bird Creek channel.

1.4.3 Riparian cattle grazing

Cattle grazing can influence the stability of soil surfaces in terrestrial and riparian landscapes. Cattle are important geomorphic agents because hoof trampling and shearing reshape the landscape by locally compacting and loosening soil (Trimble and Mendel 1995). The force of cattle hooves reduces water infiltration and increases overland flow, leading to higher rates of water erosion and transport of fine-grained soils (Trimble and Mendel 1995). While much grazing is focused on uplands, cattle grazing in the western United States regularly occurs within the riparian corridor near streams to provide cattle access to shade and water (Meehan and Platts 1978).

Numerous studies have shown that cattle grazing near riparian zones can lead to myriad problems (Figure 3; McDowell and Magillian 1997). Grazing of riparian zones can remove up to 80% of the vegetation which can reduce stream bank resistance to erosion (Trimble and Mendel 1995). Trampling alongside and across streams flattens and erodes stream banks which leads to broader stream channel widths (McDowell and Magillian 1997). Stream banks impacted by cattle are quickly eroded and contribute higher inputs of excess sediment through natural stream process (Trimble and Mendel 1995). Furthermore, cattle trampling will directly loosen and dump sediment into streams (Bengeyfield). Sediment yields generated from cattle grazing consists of higher suspended, fine-grained sediment that can make the water muddy (Herbst et al. 2012). The EPA recognized long ago that a major outcome of cattle activity near streams is the input of excess suspended sediment which is classified as a water pollutant (Meehan and Platts 1978). Watersheds with cattle grazing can experience higher suspended sediment yields. For instance, cattle grazing within a watershed in Colorado, US experienced 30% higher sediment yields than a nearby watershed without cattle (Trimble and Mendel 1995). In a tributary in Montana, sediment yields increased from 3 tons/day to 15 tons/day during the grazing period (Bengeyfield). Riparian cattle grazing in the Bird Creek watershed is a potential source of excess in-stream sediment (Figure 4).

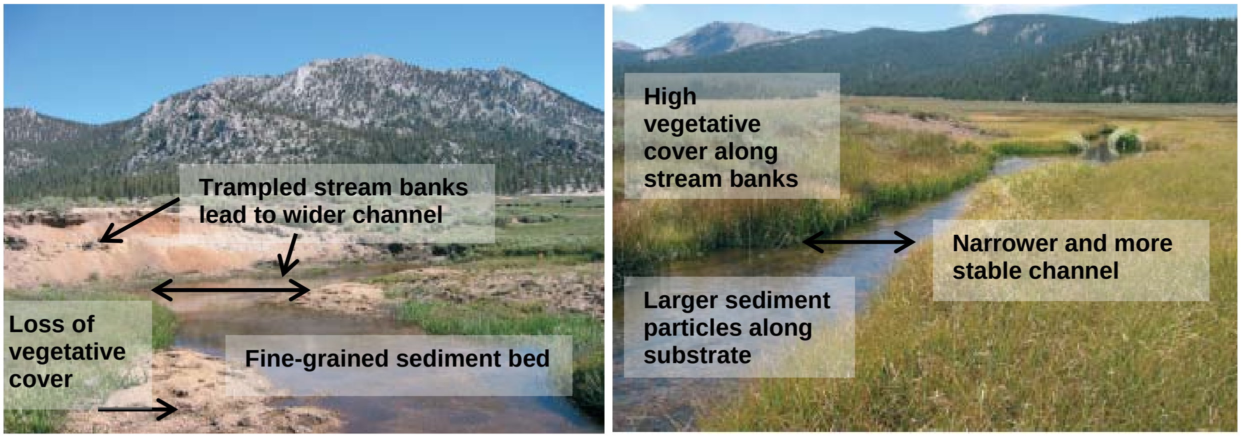


Figure 3. Cattle grazing impacts (left) along a stream in the Sierra Nevada include decreases in vegetative cover, increased erosion and fine-grained sediment input, and channel widening. The ungrazed portion of the stream (right) maintains riparian vegetative cover, narrower channels, and therefore greater channel stability (Herbst et al. 2012).

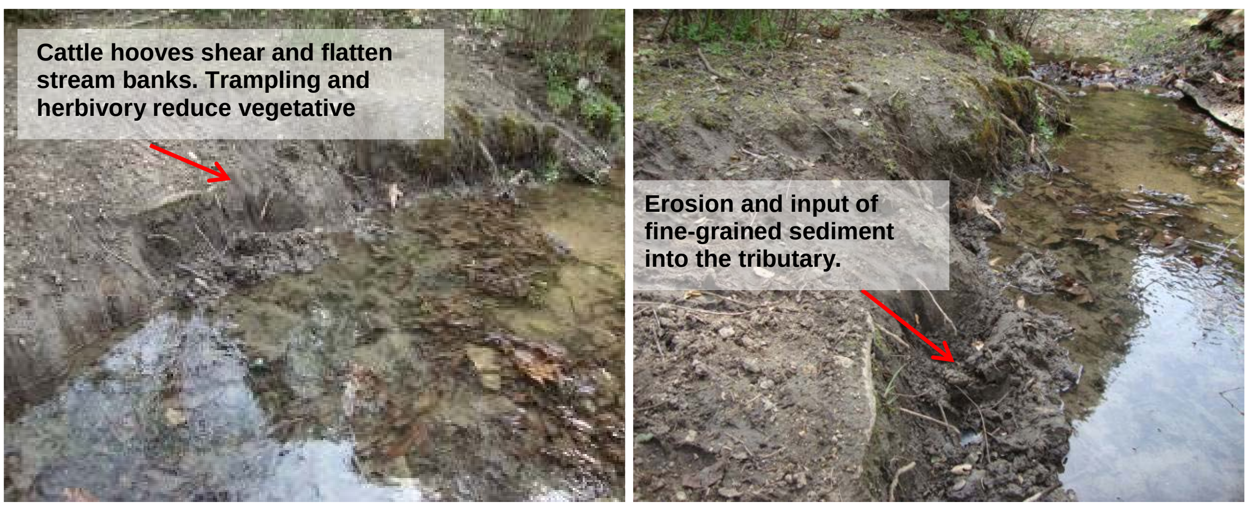


Figure 4. Stream banks sheared by cattle hooves.

As part of the Hollister Hills SVRAs land management plan, there is a concession contract with local ranchers to take cattle into certain areas in the watershed to remove perennial and invasive grasses (CDPR 2012). One of the areas where grazing is allowed is Hudner Ranch, an area located in the eastern end of the park boundary where the lower portion of Bird Creek flows. Cattle graze at Hudner Ranch from January through March. During grazing season, single-wire fences bar cattle from entering Bird Creek. However, these fences are temporary (CDPR 2012) and might not serve as effective barriers because they are easily breached. Cattle belonging to private ranches adjacent to the park also contribute to riparian impacts. The private grazing occurs along Bird Creek west of the San Andreas Fault, downstream of the Park east of the fault (Smith, Pers. Comm. 2012).

The management at HH SVRA recognizes seasonal cattle grazing as a disturbance at certain sites within the watershed (CDPR 2012). The presence of cattle can ultimately damage “special habitat” and “drainage infrastructures" (CDPR, 2012). However, the quantitative extent to which cattle induced erosion and sedimentation are affecting Bird Creek is unknown.

The purpose of this study is to assess the effects of cattle grazing on stream bank stability and sediment input into Bird Creek. This study will attempt to answer four questions:

1) Is the width of the stream channel wider where cattle graze?
2) Is the sediment particle size smaller where cattle graze?
3) Are stream banks at Hudner susceptible to cattle erosion?
4) Is cattle grazing near Bird Creek directly contributing sediment to the channel through hoof impacts?

Based on previous studies, we hypothesize: 1) The stream channel width is greater where there are cattle grazing and therefore the stream banks are unstable; 2) The sediment size is smaller along Bird Creek where cattle graze; 3) Stream banks at the Hudner Ranch are at risk of erosion due to cattle activity; and 4) Cattle grazing is contributing sediment to Bird Creek. To address the study questions cross sections of Bird Creek were established and surveyed in areas with and without cattle grazing activity. Geomorphic comparisons of these two sets of cross sections will provide a framework to compare stream channel stability, morphology, and sediment sizes in sites with and without cattle grazing. Analyzing stream channel cross sectional profiles through time will lead to preliminary estimations of the volume of sediment eroded due to cattle grazing.

1.4.4 Streambank Erosion

Sediment erosion, transport and retention are naturally occurring stream processes. These sedimentation processes are largely controlled by the size of the watershed, type of lithology, topography, grade, climate (Frissel et al. 1986), and condition (Rosgen 1997). All of these variables play a role in determining channel stability. In general, a channel that is in equilibrium is just able to transport the sediment supplied to it from upstream sources (Wynn, 2006). Although, even “stable” streams experience periods of equilibrium to periods of imbalance, over time they will maintain the same average morphological character (Fischenich and Marrow Jr. 2000). During stages of imbalance, channels will degrade (cut downward) or aggrade (fill up) depending on the transport potential of the stream at that time. Streams that have degraded are no longer in equilibrium and can contribute a very large quantity of sediment to the greater watershed (Judson, 1968).

The main factors that influence the rate of bank erosion are frequency and magnitude of storm events and the properties of bank material (Couper and Maddock, 2001). One significant property of bank material is its density, also known as bulk density. It can be defined as the mass of many particles of a material divided by the total volume those particles occupy; this includes particle volume, inter-particle void volume, and pore volume (Keller et al, 2010). Bulk density is used for characterization purposes and is one of the major factors when determining the soil erosion rate. Erosion along streambanks tends to decrease as bulk density increases (Wynn 2006). The more compact the streambanks are, the less likely they are to erode (Hanson and Robinson, 1993). Bulk density integrates multiple soil properties including, soil texture, soil chemistry, root density, and soil organic matter content (Wynn 2006). One essential property, organic matter, plays a leading role in the bulk density of soil due to it having a much lower density than mineral particles; commonly, the higher the organic matter, the lower the bulk density. The majority of mineral soils have bulk densities ranging from 1.0-2.0 (g/cm^3) (Keller et al, 2010), and can be determined by pushing a core sampler (of known volume) into the soil, retrieving samples of various lengths, oven drying those samples, and then weighing them.

Bulk density and other material properties determine the process by which erosion will occur. Sub-aerial erosion describes the cracking response a material may have to climatic wetting and drying. The process at work during large quick storm events is fluvial erosion. Fluvial erosion undercuts banks leading to mass failure of the material above. Flushing of the introduced sediments will depend on the load quantity and the transport potential of the flow conditions over time (Couper and Maddock, 2001).

Stream banks along Bird Creek vary greatly in height and material strength. For example, a marked change in geology occurs across the San Andreas Fault. West of the fault, in the granitic part of the watershed, the soil along Bird Creek is sandy alluvial loam. East of the fault, where the watershed is underlain by weaker sedimentary rocks, the Creek runs through diablo clay and gravelly loam (NRCS Website). Clay, having low bulk density, is not only a suspended sediment component but also prone to sub aerial erosion (Prosser et al. 2000).

As is true in all watersheds, a portion of the sediment load in Bird Creek is from stream bank erosion. We assess this source by measuring morphologic change at several cross sections located east and west of the San Andreas Fault. We also assess bank erosion more directly by analyzing bank pin exposure as well as bulk density. We will compare the results from the opposite sides of the fault to assess if and where stream bank restoration is recommended.

To investigate the sediment contribution from natural stream processes our study compares data from upper and lower bird creek sites. The following four questions were posed:

1) Is Bird creek aggrading or degrading?
2) Are their differences in erosion or aggradation between Upper and Lower Bird Creek?
3) How much of the sediment leaving the bird creek watershed can be attributed to bank erosion?
4) Are the actual bulk densities of the Upper and Lower Bird Creek stream bank materials what we expected to find?

1.4.5 Landslides

Landslides are defined as the downward and outward movement of a mass of rock, earth, or debris under the influence of gravity (Dikau 1996). The two main physical features of landslides are the main scarp, i.e. headwall scarp, and the toe (Figure 5). Landslide events can be triggered by earthquakes, heavy rain, pre-existing geologic conditions, and anthropogenic land disturbances such as building a road with poor grading (USGS 2005). The impact radius of the potential landslide triggering energy that earthquakes carry varies due to variation in bedrock, soil temperature, fault size, and location (Pers. Comm. Greg Durocher). The magnitude of earth displaced by landslides ranges from dry ravel to 100,000 cubic meters (Dikau 1996). Landslides can be a major source of excess sediment in rivers if they are hydraulically connected to a river channel (Davis 2004).

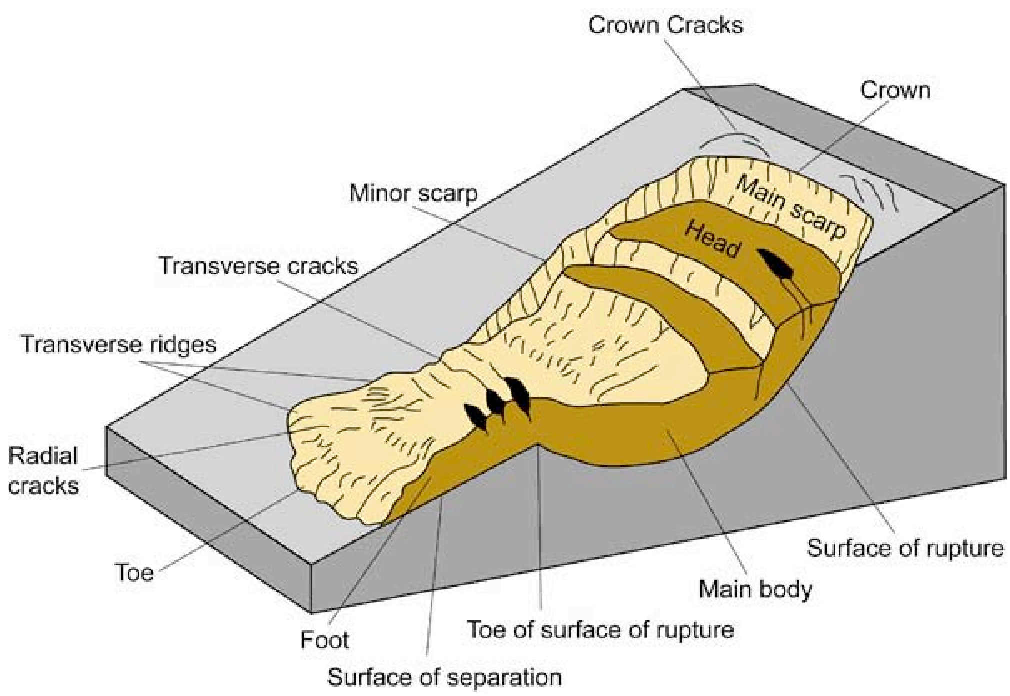


Figure 5: General landslide morphology and associated terms. (Image source: Idaho Geologic Survey [internet], date unknown).

Landslides are locally abundant within the Bird Creek watershed, but it is unknown if they are important sediment sources for Bird Creek, and their genesis is unclear. A landslide system near Hudner Pass has high potential to contribute sediment directly to Bird Creek. This landslide system lies within a valley partially filled with landslide debris and other colluvium reworked from the landslide bodies, called “Colluvial Valley” in this study (Figure 37).

An active gully system is cutting through the fill of Colluvial Valley and could be transporting landslide sediment to Bird Creek. Colluvial Valley has two knickzones, or relative changes in slope from high to low (Hayakawa and Oguchi 2006). One of the knickzones is the drop in base level from Colluvial Creek to Bird Creek. The second knickzone is the difference in slope between the naturally steep hillsides of Colluvial Valley and the generally low gradient landslide bodies.

We explored the potential causes of the landslides by analyzing nearby earthquake events, extreme rainfall events, and geologic maps. We placed and resurveyed wooden pegs in several landslide heads and analyzed historic satellite imagery in order to determine if the landslides are moving on a decadal-scale. We used cross sections of Colluvial Creek surveyed in October 2011, January 2012, and March 2012 to assess geomorphic changes of the valley. Morphological changes present in the cross sections will help us to assess the potential of these landslides to contribute sediment to Bird Creek.

1.5 Goals

The CWA as implemented by the OHMVR Divisions Soil Conservation Standards and Guidelines applies to “all SVRAs and all federal and local projects that receive state-funded OHV grants” (Bedrossian and Reynolds, 2007). The Clean Water Act regulates non-point source sediment, but does not outline a scientifically defensible way to separate sediment pollution from natural background sediment in any given watershed. The overall goal of this work is to investigate the relative importance of several common sediment sources in the Hollister Hills State Vehicular Recreation Area (HH SVRA). This work will eventually lead to better quantification of all sediment sources in the watershed.

2 Methods

The following methods were used to evaluate the importance of known or potential Bird Creek sediment sources:

- Off-highway vehicle use
- Overland flow from dirt parking lots and campgrounds
- Riparian cattle grazing
- Stream bank erosion
- Landslides

2.1 Off-highway vehicle use

We conducted a field and digital reconnaissance of the Hollister Hills SVRA property. A literature search provided background information on the typical impacts of OHV use and best management practices to prevent erosion or sediment transport. Historically, sediment catch basins have been used to study the total soil deposition coming from particular trails and sub-watersheds. ArcMap Software and GIS mapping techniques were employed to assess ten sediment retention basins throughout the park. For each sediment basin, we measured trail length (km) and contributing catchment area (km^2). The annual sediment caught in each basin was provided by Wes Gray (HH SVRA). Total trail length above each basin was the independent variable in a power-function regression of area-normalized annual sediment yield. The slope and intercept of the log-transformed data were tested for significance. The intercept was interpreted as the sediment yield expected in the absence of OHV trails.

2.2 Runoff from unpaved campgrounds and parking lots

Our assessment of unpaved recreational areas included field reconnaissance, GPS data collection, GIS map production, and literature review. Site reconnaissance of the campsites and parking lots at the Lower Ranch of the Hollister Hills SVRA occurred in early April 2012. Four campsites (Madrone, Bee, Lodge, and Walnut) and parking lots adjacent to Bird Creek were mapped for GIS using a Trimble GeoExplorer 2008 GPS unit. Presence or absence of sediment erosion and transport (rills, gullies, etc.) was noted and each erosional feature was mapped and photo documented. Once the UTM coordinates of each erosional feature were collected by GPS, the data were compiled into ESRIs ArcMap Suite for developing GIS maps of all the recreational areas and their sediment pathways. Other photos captured during runoff events were provided by Colin Nicol (CSUMB Watershed Geology Lab).

2.3 Riparian cattle grazing

Study Area

Field data were collected along two different reaches of Bird Creek 1) Bird Creek at Hudner and 2) Bird Creek at Hudner Culvert located in Hudner Ranch (Figure 5). These two reaches are generally similar, except that the Hudner reach has seasonal grazing whereas Hudner Culvert does not.

Bird Creek at Hudner (elevation: ~170m) experiences cattle activity normally between January through May. During this study, cattle were in Hudner from March 22 through April 15. The approximate channel length of interest is 400 m. The dominant vegetation species are *Quercus* spp. (oak) and *Salix* spp. (willow), including other shrubs and forbs commonly found in riparian-oak woodland plant communities. Non-native vegetation is also prevalent, including *Cirsium* spp. (thistle) and *Conium maculatum* (poision hemlock) (Figure 6).

Bird Creek at Hudner Culvert (elevation: ~184m) currently does not experience cattle activity. The approximate channel length of interest is 80 m. The canopy cover along this study reach is higher than the canopy cover along Bird Creek at Hudner. The tree density of *Quercus* spp., *Salix* spp., and *Plantanus racemosa* (sycamore) is higher and more abundant. Due to the canopy cover, light penetration is lower and much of the channel is shaded. Although it was not directly measured, there is a possibility that the temperature (air, soil, and/or water) is slightly lower than the temperatures at Bird Creek at Hudner. There is also higher leaf litter and cover along the channel floor.

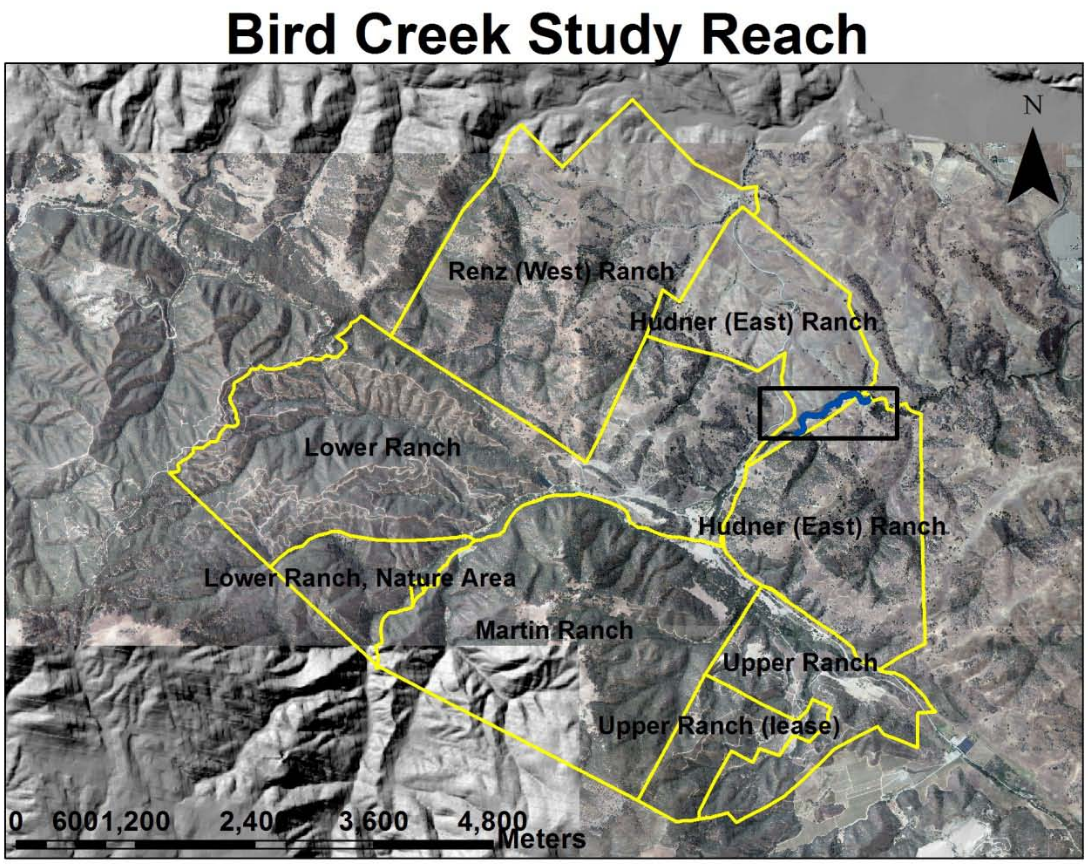


Figure 5. Bird Creek watershed (black outline) is divided into multiple ranches. To assess cattle impacts on Bird Creek, a particular reach of Bird Creek was chosen for the study located in Hudner Ranch (inside box). Cattle grazing at certain areas in Hudner Ranch was named a disturbance by the management at the HH SVRA.

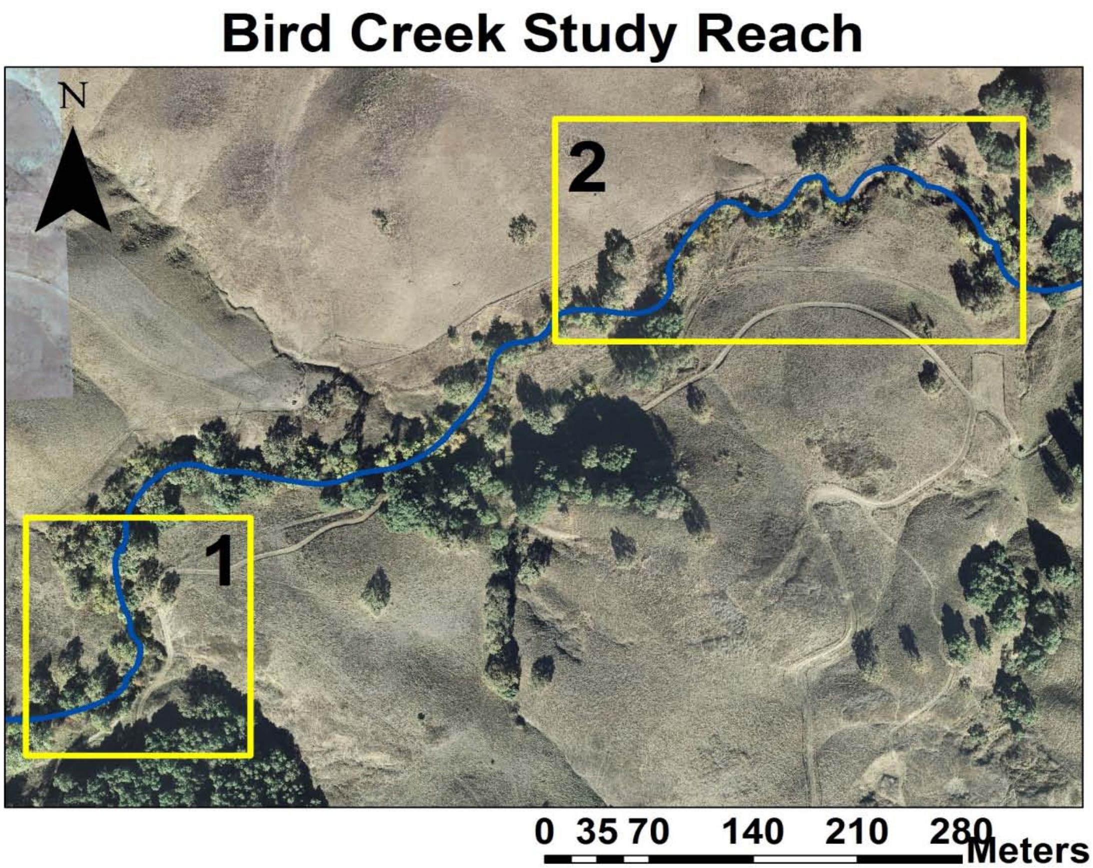


Figure 6. Bird Creek at Hudner Culvert (1) is ungrazed. Further downstream, ~ 0.5 kilometers, Bird Creek at Hudner (2) is grazed usually three months in a year.

Field Methods

Cross-sections

There are nine stream cross sections along Bird Creek at Hudner labeled A through I (Figure 7). The cross sections were established in Spring 2011 to analyze stream bank morphology and were selected based on equilibrium conditions and accessibility, equilibrium meaning that bankfull conditions can be approximately determined and there is no evidence of recent channel aggradation or degradation. Cross section I is the farthest upstream and cross section A is the farthest downstream. The right and left benchmarks (RBM and LBM respectively) of the cross section are positioned based on the downstream motion of Bird Creek.

Six new cross sections were established at Bird Creek at Hudner Culvert (Figure 8). Cross section 6 is farthest upstream and 1 is the farthest downstream. The location of the RBM and LBM of each cross section were captured using GPS.

Each stream cross section was surveyed based on standard survey methods (Harrison et al. 1994)

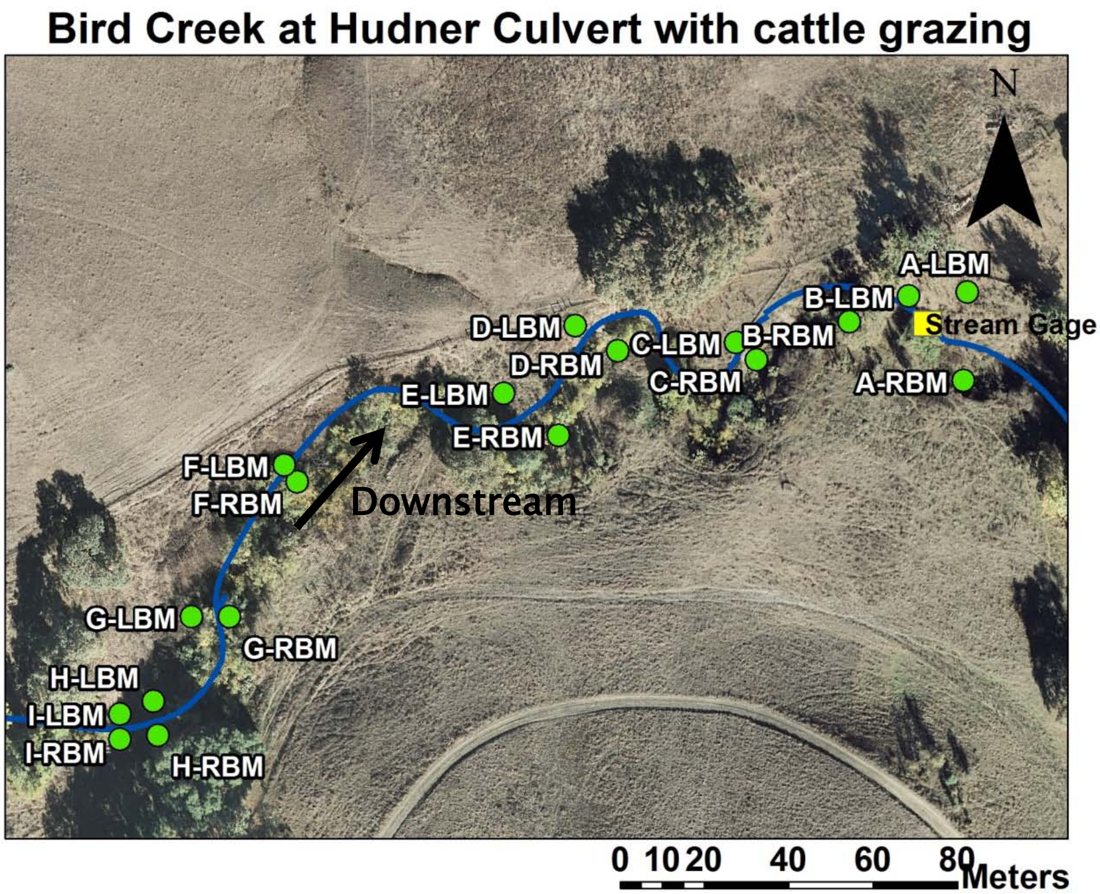


Figure 7. Locations of nine cross sections at Bird Creek at Hudner. The left and right benchmarks of each cross section are labeled.

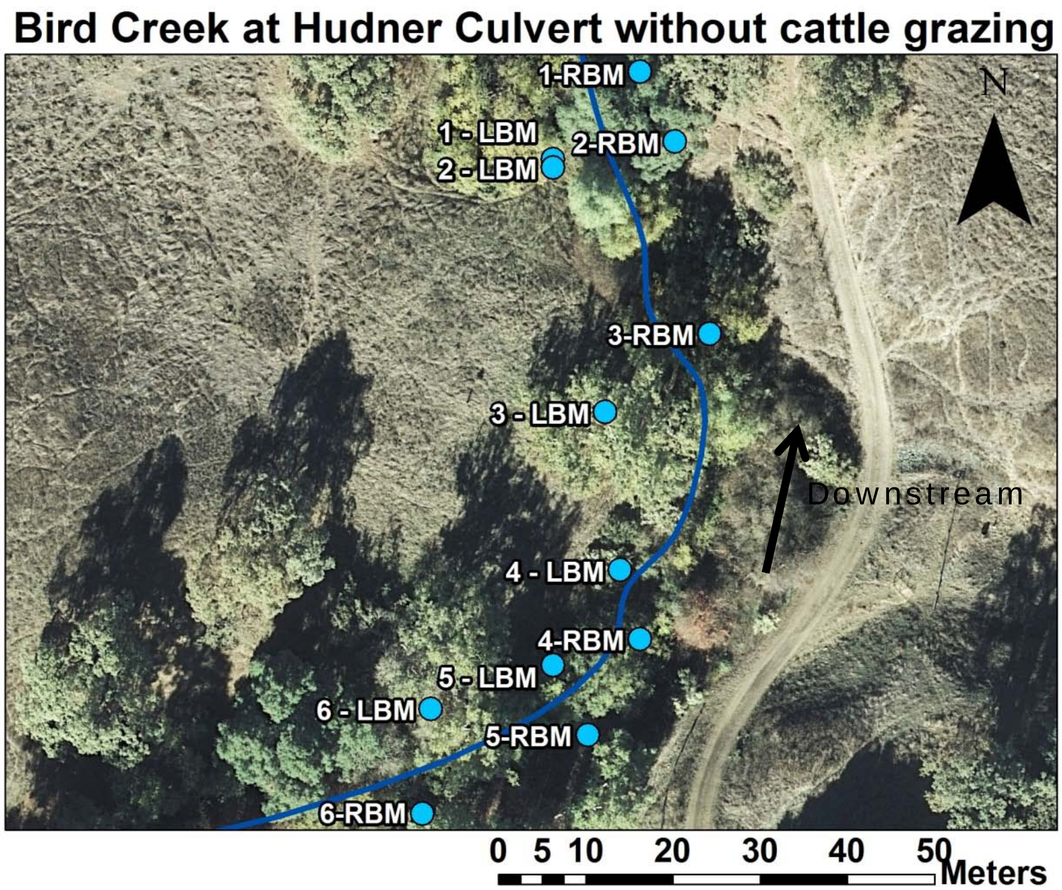


Figure 8. Locations of 6 cross sections at Bird Creek at Hudner Culvert. The left and right benchmarks of each cross section are labeled.

Pebble Count

A Wolman pebble count was conducted at each cross section at Hudner and Hudner Culvert in order to assess the bed material of grazed and ungrazed cross sections. The established cross sections A-I and 1-6 respectively are considered representative reaches at each site, as the cross sections include riffles, pools, and runs or glides. Pebble counts were conducted based on standard bank and bed material classification methods (Harrison et al. 1994).

Shear strength

The shear strength of a surface is a variable that can be used to assess stream bank stability and potential failure. Prior to this study, shear strength tests had not been performed at the

Hudner cross sections or at Hudner Culvert. However, it was important to establish a baseline to use for future studies of stream bank stability and cattle activity along Bird Creek.

Shear strength was sampled using a penetrometer which collects the relative strength ($ton*ft^{-2}$ or $kg*cm^{-2}$) that a soil surface can withstand before succumbing to the pressure exerted by the penetrometer. Samples were taken at random points along representative regions such as banks, walls, point bars, and floodplains along cross sections A-I at Bird Creek at Hudner. Beginning at the most downstream cross section A, the penetrometer was deployed at least four times at each cross section resulting in a total of 30 measurements.

Analysis Methods

<u>Bankfull Width-Depth (W/D) ratios</u>

Bankfull stage or discharge is defined as the flow that fills the main channel and just begins to spill into the active floodplain. The width-to-depth (W/D) ratio at bankfull conditions describes the shape of a river, shallow and wide, or deep and narrow.

To examine the effects of cattle on stream channel morphology, the bankfull width to depth ratios were determined for the 9 cross sections at Hudner (grazed) and the 6 cross sections at Hudner Culvert (ungrazed). The area and width of a cross section at bankfull conditions were calculated from survey plots. The bankfull depth at bankfull was determined by the quotient of area and width. Bankfull width divided by depth yields the width-to-depth (W/D) ratio.

Statistical analysis was carried out using the R Project for Statistical Computing. To test the hypothesis that cattle grazing increases the W/D ratio of stream banks, the W/D ratios of cross sections in Bird Creek at Hudner were compared to those in Bird Creek at Hudner Culvert. Variables satisfied standard parametric assumptions which led to the use of a one-way independent t-test.

<u>Particle size comparison</u>

Grain size percentiles were used to quantitatively compare the sediment sizes of Bird Creek at Hudner and Hudner Culvert. For the purposes of this study, the 84^{th} percentile particle size (d84) was selected.

The d84 value was determined by creating cumulative size distribution charts for qualitative comparison and histograms by size class and frequency for qualitative comparison. For each cross section at Hudner and Hudner Culvert, the particle size denoting the 84th percentile was extrapolated from the distribution charts. Using a straightedge, the d84 was ‘pinpointed’ using the 84% on the Y axis and the corresponding millimeters on the X axis. This method is illustrated in the Results.

2.4 Stream banks

Field Methods

Analysis of stream bank erosion was conducted by comparing time-serial cross sections at two reaches located on opposing sides of the San Andreas Fault. Bank pins were set in Spring 2011 and measured during the Fall 2011 and Spring 2012 geology class. Bulk density was also measured on both sides of the fault in 2012.

<u>Cross-sections</u>

Cross-sections were surveyed Fall 2011 and Spring 2012 to evaluate the significance of stream bank erosion as a sediment source to Bird Creek. These cross-section surveys were carried out along two reaches of Bird Creek, on opposing sides of the San Andreas Fault to determine if bank erosion rates vary with differing geologic settings. The lower Bird Creek cross-sections are on the North American Plate (east of the fault) while Upper Bird cross-sections are on the Pacific Plate (west of the fault; Figure 9). Cross section survey technique followed standard practices described by (Harrelson et al. 1994). Fall 2011 and spring 2012 cross sections were then graphed with left benchmarks aligned to evaluate net stream degradation or aggradation during this period.

Although bankfull elevations were not captured in the field, approximate bankfull geometry was calculated for each cross section from survey plots. Bankfull elevation was estimated by observing the major changes in slope adjacent to a floodplain as captured in the cross-section surveys of fall 2011 and spring 2012. Bankfull geometry calculations included: bankfull area, width at bankfull (Wbkf), wetted perimeter (WP), entrenchment ratio (ER), width to depth ratio (W/D), and flood plain width (W_{fp}).

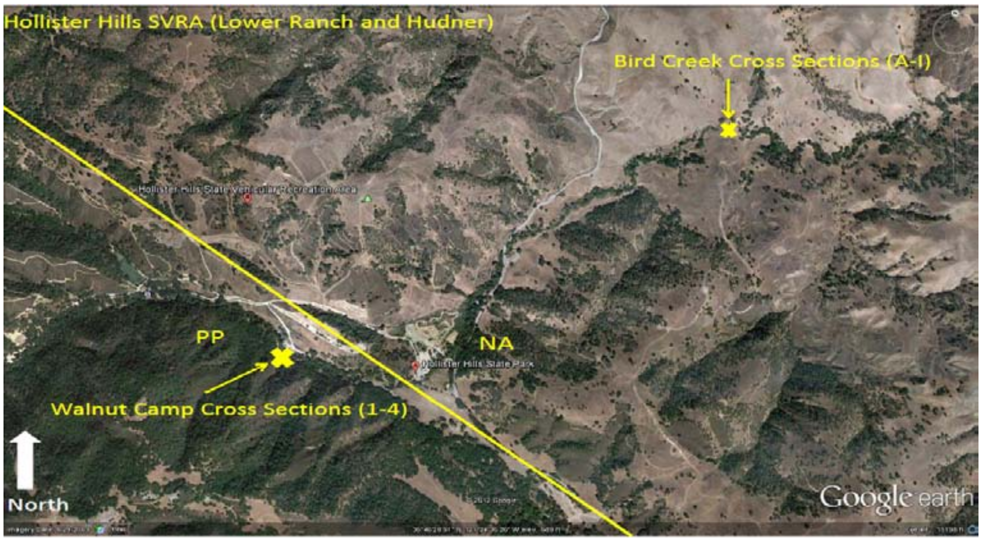


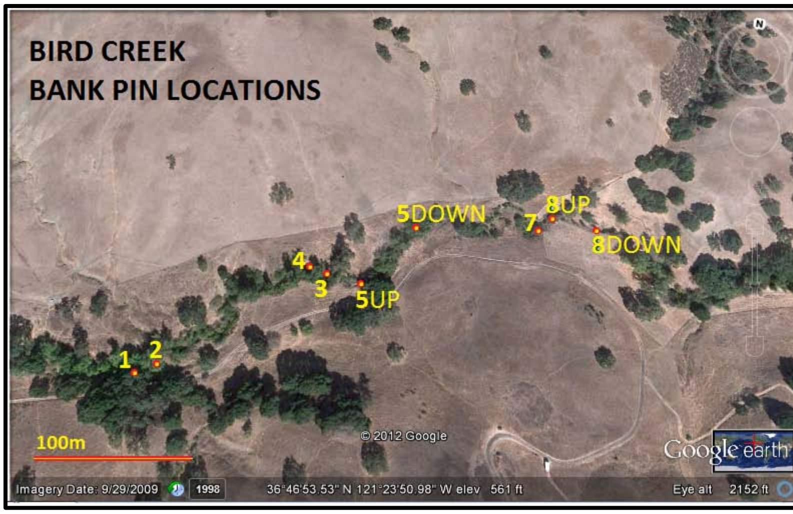
Figure 9. Stream survey locations relative to San Andreas Fault

<u>Bank Pins</u>

Bird Creek bank pins were installed at 8 locations along Lower Bird Creek in March 2011. Pin sets 5 and 8 have upstream and downstream sets (Figure 10). Each bank pin set consists of 2 to 3 rebar stakes inserted into the channel bank as illustrated in Figure 11. Pin exposure along Bird Creek has been recorded for spring 2011, fall 2011 and spring 2012. Measurements of pin exposure were taken in millimeters. Total mass of stream bank erosion was calculated using the average pin exposure, stream length measured using Google Earth, and the average bank height was calculated from bank measurements taken during the spring 2011 recording.

<u>Soil Bulk Density</u>

Bulk density samples were taken in Upper and Lower Bird Creek. Twenty random samples were collected from each site using a galvanized steel soil corer with a diameter of 28 mm. The soil corer was forced into the soil apron along the stream bank above the bedload. Soil cores were retrieved at various lengths and recorded. Soil density was calculated using the dry soil mass (g) and the sample volume (cm^3) (Carter and Gregorich 2008).



PIN #	UTM Coordinates Zone 10N
1	0642814E 4071710N
2	0642815E 4071715N
3	0642933E 4071797N
4	0642932E 4071809N
5 UP	0642961E 4071801N
5 DOWN	0642961E 4071801N
7	0643099E 4071887N
8 UP	0643112E 4071889N
8 DOWN	0643112E 4071889N

Figure 10. Bird Creek bank pin UTM locations plotted in Google Earth. Image courtesy of Google Earth.

Figure 11. (a) Demonstration of pin exposure measurement. (b) Red arrows point to the placement of set of 3 pins at Bird Creek bank pin site 4.

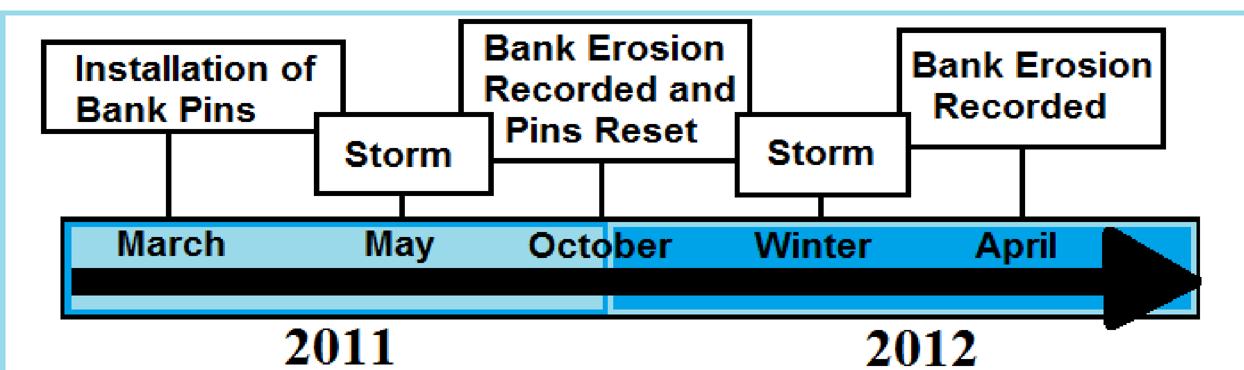


Figure 12. Bird Creek bank pin timeline from pin installation in wateryear 2011 to most recent recording in April 2012.

2.5 Landslides

Three questions will be addressed regarding the landslides in the Bird Creek watershed:

1) What causes and triggers the landslides?
2) Are they important to consider in the decadal-scale sediment budget of Bird Creek?
3) Are there clear sediment routes from the landslide bodies to Bird Creek?

The first question was addressed by looking for a correlation between potential landslide triggers and slope failure that occurred in the last 20 years. We identified earthquakes within 20km of the Park boundary with a magnitude of ≥4.0 (NCEDC) that occurred in the same year as 10-year 24-hour rain events (NOAA) to look for years in which major earthquakes corresponded with periods of soil saturation. We compared these triggers with changes in a landslide to the east of Colluvial Valley using historical satellite imagery. Geologic formations on both sides of the San Andreas Fault were analyzed to determine if particular bedrock types are associated with a higher risk of slope failure (USGS).

The second question was answered by monitoring the rate at which landslide colluvium is moving downslope. Eight cross sections located along Colluvial Creek were analyzed for evidence of sediment moving down the valley towards Bird Creek. These cross sections were surveyed in October 2011, January 2012, and March 2012. Changes in cross sectional morphology were quantified by lining up the left benchmarks of each cross section and measuring the vertical and horizontal changes in their graphs. Cross sections that had right benchmarks that did not line up were excluded from the analysis. Four wooden stakes were driven into five landslide heads as passive markers of landslide motion at Colluvial Creek. The stakes were surveyed using RTK GPS in October 2011 and again in March 2012.

The third question was addressed by using ArcGIS (ESRI v.10.1) to identify hydrologic pathways connecting the landslides to Colluvial Creek, and Colluvial Creek to Bird Creek.

3 Results

Study results are presented for each potential sediment source.

3.1 Erosion from OHV use

The exponetional regression model (Figure 13). arrives at the eqation $y=159.28e^{0.1561x}$ with an R^2 of 0.56. Total annual sediment removal from OHV trails/roads was found to be 20,736 yd^3 over 112 km of OHV trails & roads feeding the 10 catch basins in Table 1. The model found annual natural background sediment to be 159 yd^3 per km^2 on undisturbed land.

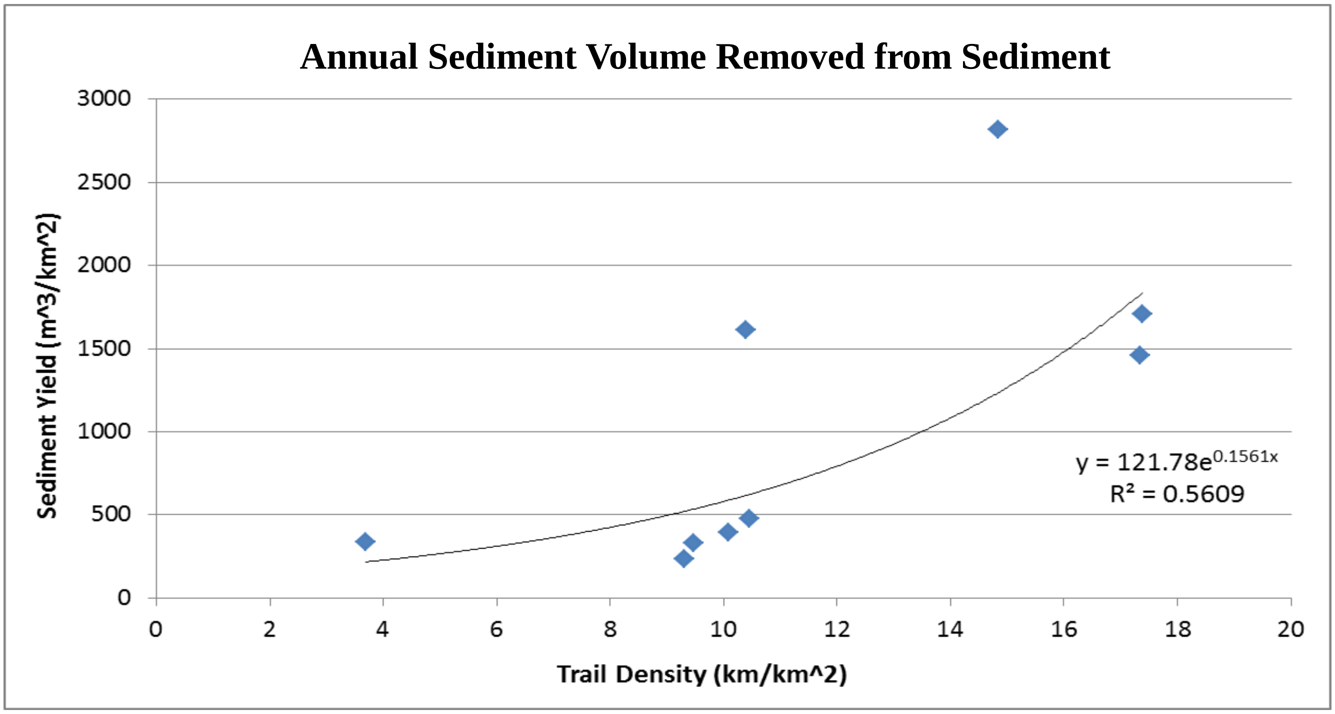


Figure 13: Exponential Regression Model of Area-normalized Annual Sediment Yield in Sediment basins as a function of area normalized trail length in the watershed feeding the sediment basin

Catch Basin	Trail Length (km)	Annual Removal (yd^3)
Tule Lake	11	8,473
Madrone	4	442
Woopie-do	10	2,112
Bee	15	3,687
Woodwardia	9	309
Sycamore	9	434
Lodge	10	517
Turtle	10	621
Day Use	17	1,908
Basin Lake	17	2,233
Totals	**112**	**20,736**

Table 1. Annual Sediment Removal per Catch Basin, normalized by area

3.2 Campgrounds and parking lots

To establish the locations of the possible sediment pathways, GIS/GPS technology was used to map visible channels and rills from the campsites and parking lots leading to Bird Creek. Once the GPS data was compiled, an overview of the various drainage pathways for the four Lower Ranch campgrounds and the entrance parking lot was generated (Figure 14).

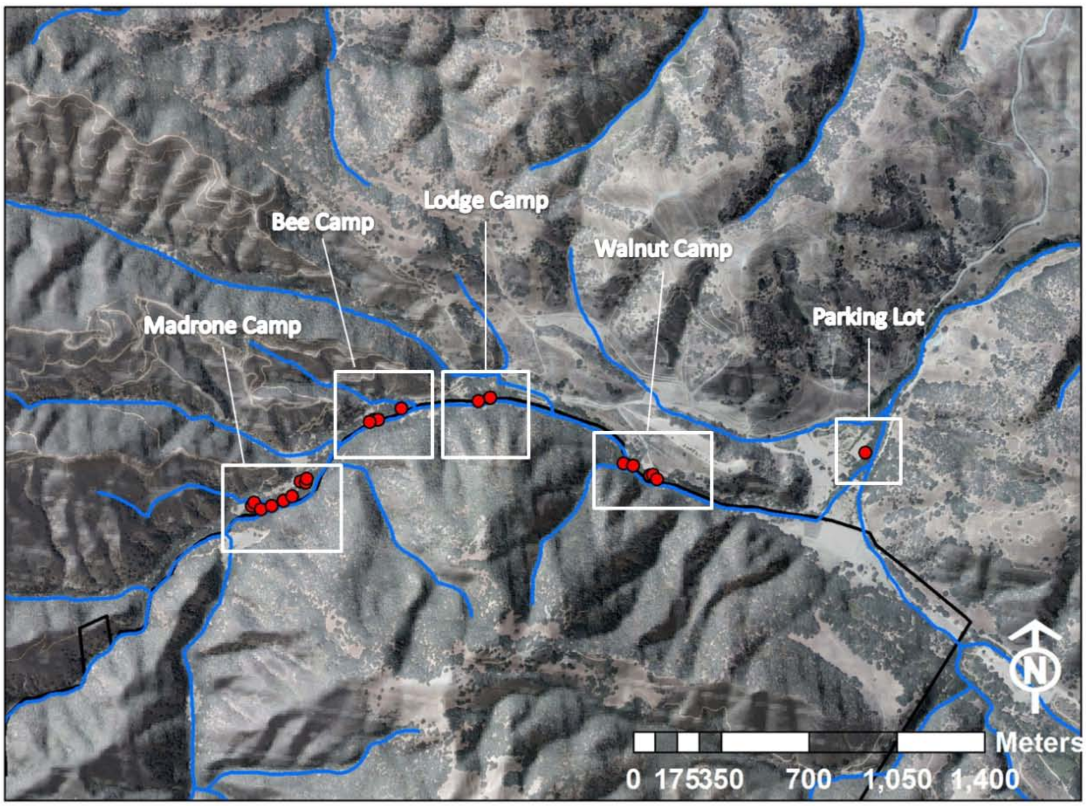


Figure 14. Locations of Drainage Pathways Relative to Lower Ranch Campgrounds & Parking lots at HHSVRA

Following the overview, an examination of each individual site revealed distinct rills that lead across each campground directly into Bird Creek. In particular, the Madrone and Bee campgrounds featured frequently disturbed landscapes with rolling terrain, heavy vehicular traffic, and deeply incised channels, which appear to be significant sediment contributors connected to the watershed (Figure 15).

Figure 15. Rill channel pathways at Madrone Camp (MC) & Bee Camp (BC)

The Lodge and Walnut campgrounds featured gentle slopes and long winding water pathways leading to Bird Creek. The most notable was a broad pathway dissecting the middle of the park leading to Bird Creek at Lodge Camp, and a disturbed rill formation flowing down a steep slope, connecting to a knick point at Bird Creek near Walnut Camp (Figure 16).

Figure 16. Rill channel pathways at Lodge Camp (LC) & Walnut Camp (WC)

3.3 Riparian cattle grazing

Stream channel morphology: width-to-depth ratios

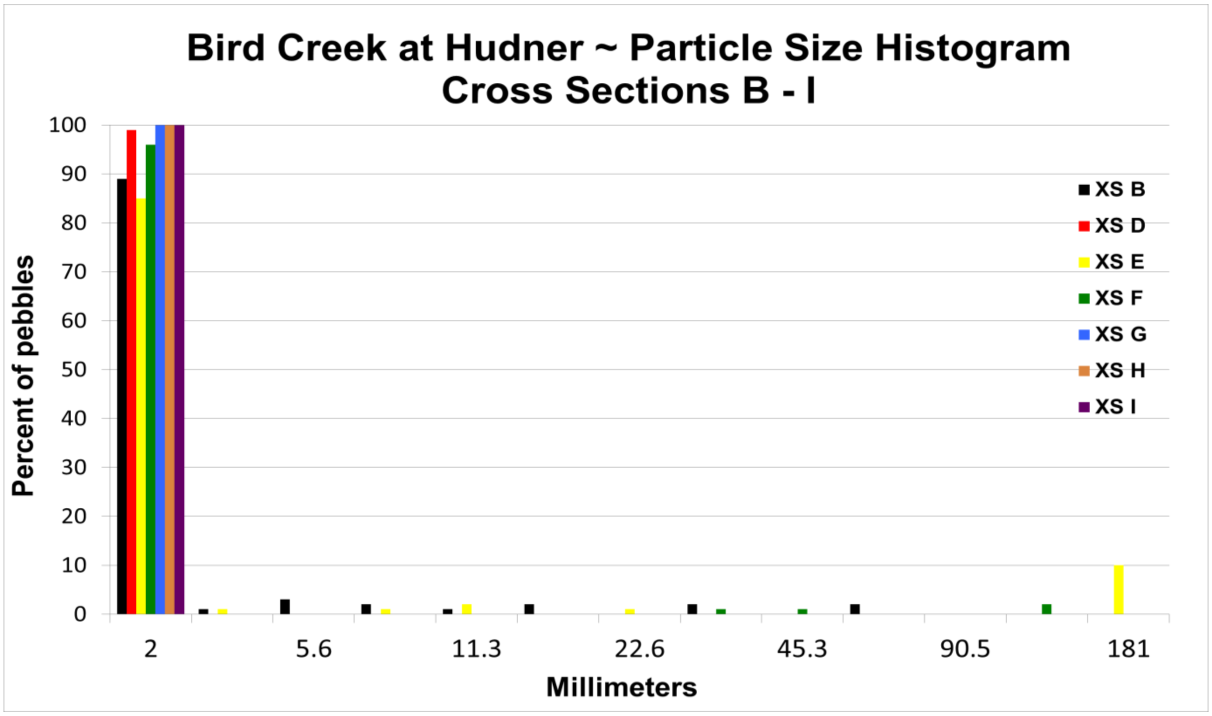
The width-to-depth ratio is a parameter with which to gage the effects of cattle on stream bank stability and morphology. We found that the mean W/D ratio of Bird Creek at Hudner is not significantly higher than at Bird Creek at Hudner Culvert ($p=0.98$, $n = 15$). This result indicates that cattle activity at Bird Creek at Hudner has not resulted in stream widening (Table 2) (McDowell and Magillian 1997). However, local hoof shearing and channel widening has been documented by direct observation of the banks and photo documentation.

Location	Cross Section (upstream to downstream)	Bankfull Width	Bankfull Depth	W/D	Average Particle Size
Bird Creek at Hudner (grazed)	I	2.9	0.38	7.560	<2mm
	H	3.9	0.49	7.96	<2mm
	G	3.8	0.24	16.04	<2mm
	F	2.2	0.15	14.58	<2mm
	E	2.3	0.4	5.87	<2mm
	D	2.2	0.28	7.75	<2mm
	C	2.6	0.24	11.01	*
	B	2.2	0.57	3.86	<2mm
	A	3.1	0.27	12.04	*
	Mean			9.630	
Bird Creek at Hudner Culvert (ungrazed)					
	6	2	0.10	19.70	53.4mm
	5	5.3	0.16	33.50	2mm
	4	3.27	0.18	17.86	49.1mm
	3	3.1	0.26	11.86	7.42 mm
	2	3.2	0.35	9.23	2 mm
	1	3	0.18	16.32	*
	Mean			18.07	
p-value				0.98	

Table 2. The width-depth ratios (W/D) and average particle size for the cross sections at Hudner and Hudner Culvert. * - pebble counts were not completed at cross sections A, C, and 1during this study.

Sediment particle size percentiles

There is fine-grained sediment along the reference reach at Hudner and Hudner Culvert (Table 2). However, the substrate at Hudner is dominated by fine-grained sediment (Figure 17). As a result, the water at Hudner is muddy as photo documented (Figure 3.3D). The substrate at Hudner Culvert has more variation in sediment size due to the presence of larger particles (Figure 18).



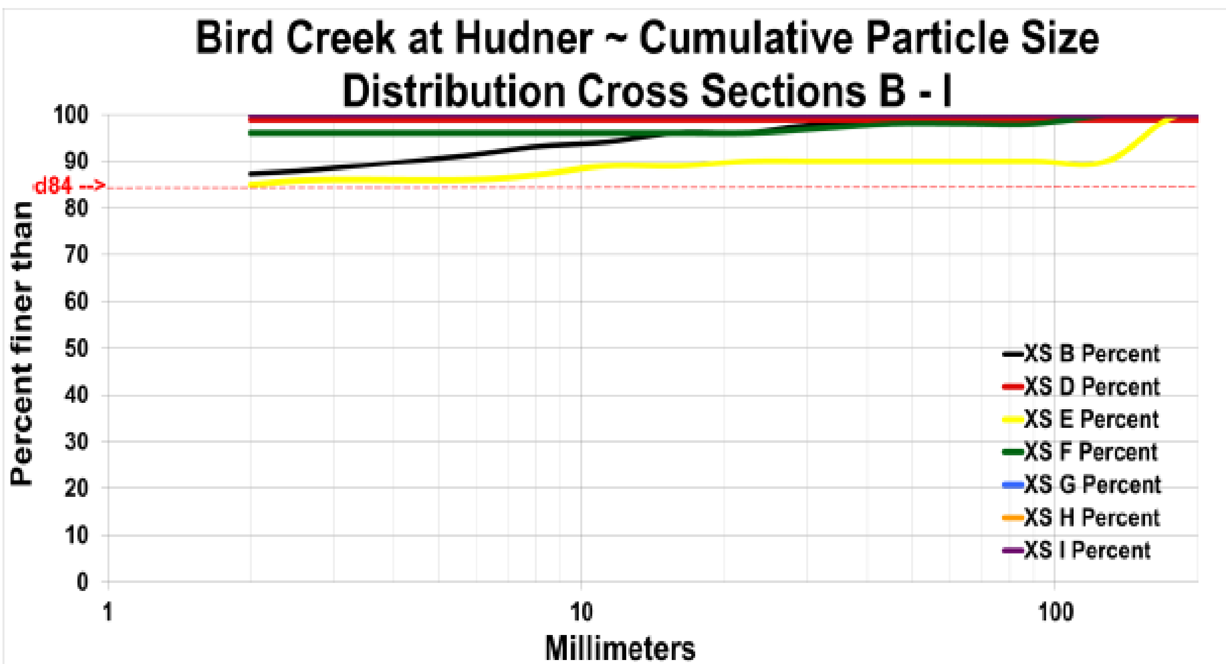
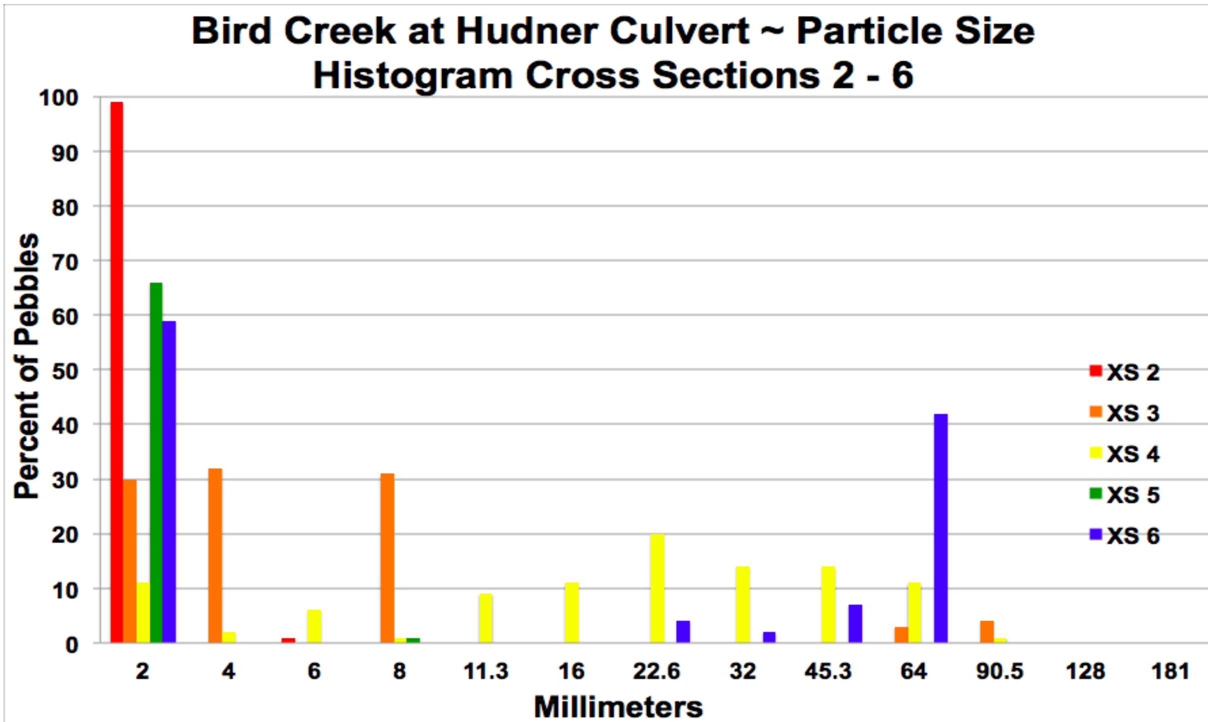


Figure 17. The Wolman particle frequency histogram and cumulative size frequency distribution charts for Bird Creek at Hudner. Pebble counts occurred at all cross sections except for A and C. All of the particle counts in this region have particles less than two millimeters in the 84th percentile or higher, so plotting the d84 line is ineffective. For a complete demonstration of finding 84th percentile particle size, please refer to Bird Creek at Hudner Culvert Cumulative Particle Size.



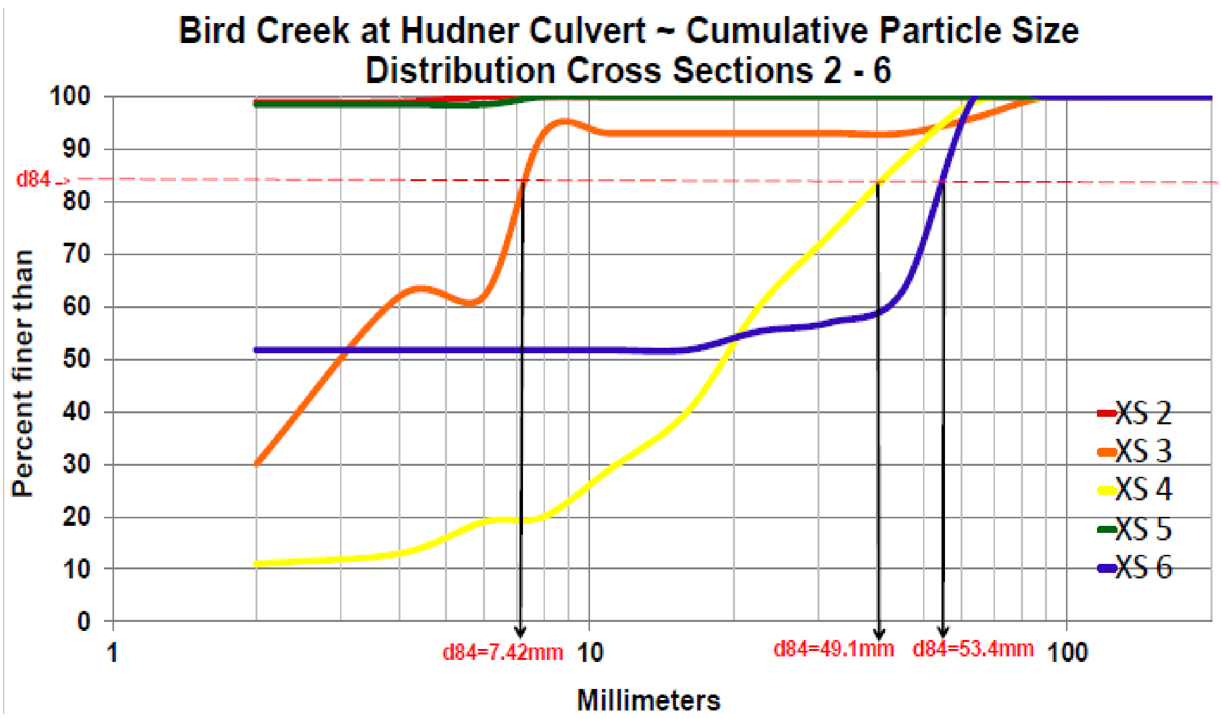


Figure 18. The Wolman frequency histogram and particle cumulative size frequency distribution charts for Bird at Hudner Culvert. Pebble counts occurred at all cross sections except for 1. To determine the d84 value (the value of the 84 percentile), the d84 line is added to the frequency chart. From this line, the point where each cross section intersects is the d84 for that data. Extrapolating to the x axis indicates the value of the particle size at the 84th percentile.

Photo documentation of cattle impacts

Photo monitoring that captures stability or changes through time can lead to more robust evaluations of impacts and recovery. This section describes a template for photo assessment of cross section sites of the Hudner (grazed) and Hudner Culvert (ungrazed) Bird Creek sites.

Cattle grazing at Hudner Culvert

The riparian buffer strip along the Bird Creek at Hudner has suffered severe impacts due to cattle. Such impacts include: broken riparian vegetation (e.g. willow trees with broken branches, larger branches littering the ground), shorter vegetation due to grazing or trampling (mostly grazed; stripped bare), caved-in banks, hoof prints, cow excrement on the banks and in the creek (Williams, Pers. Comm., 2012). Cattle induced erosion has led to local suspended sediment pollution therefore causing the water to be opaque and muddy.

Photo #	Position	Comments
Photo 1	Left Bank (C)	Dressed back banks with extensive hoof shear
Photo 2	Channel (C – D)	Excessive siltation, likely cattle-caused
Photo 3	Channel (G)	Trampled and denuded banks
Photo 4	Channel (H)	Sheared banks and mud filled channel

Table 3. Letters in the Position column denote cross-section where the photo was taken.

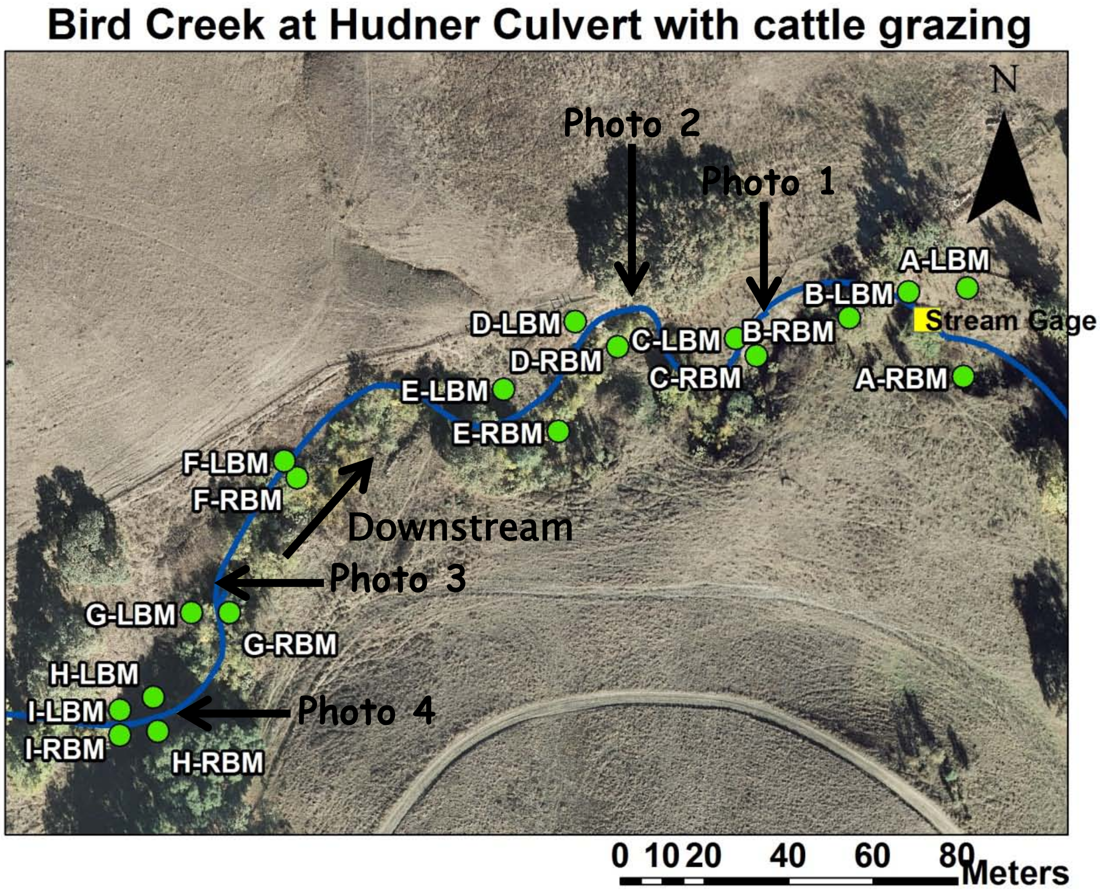


Figure 19. Approximate spatial location of each photo.

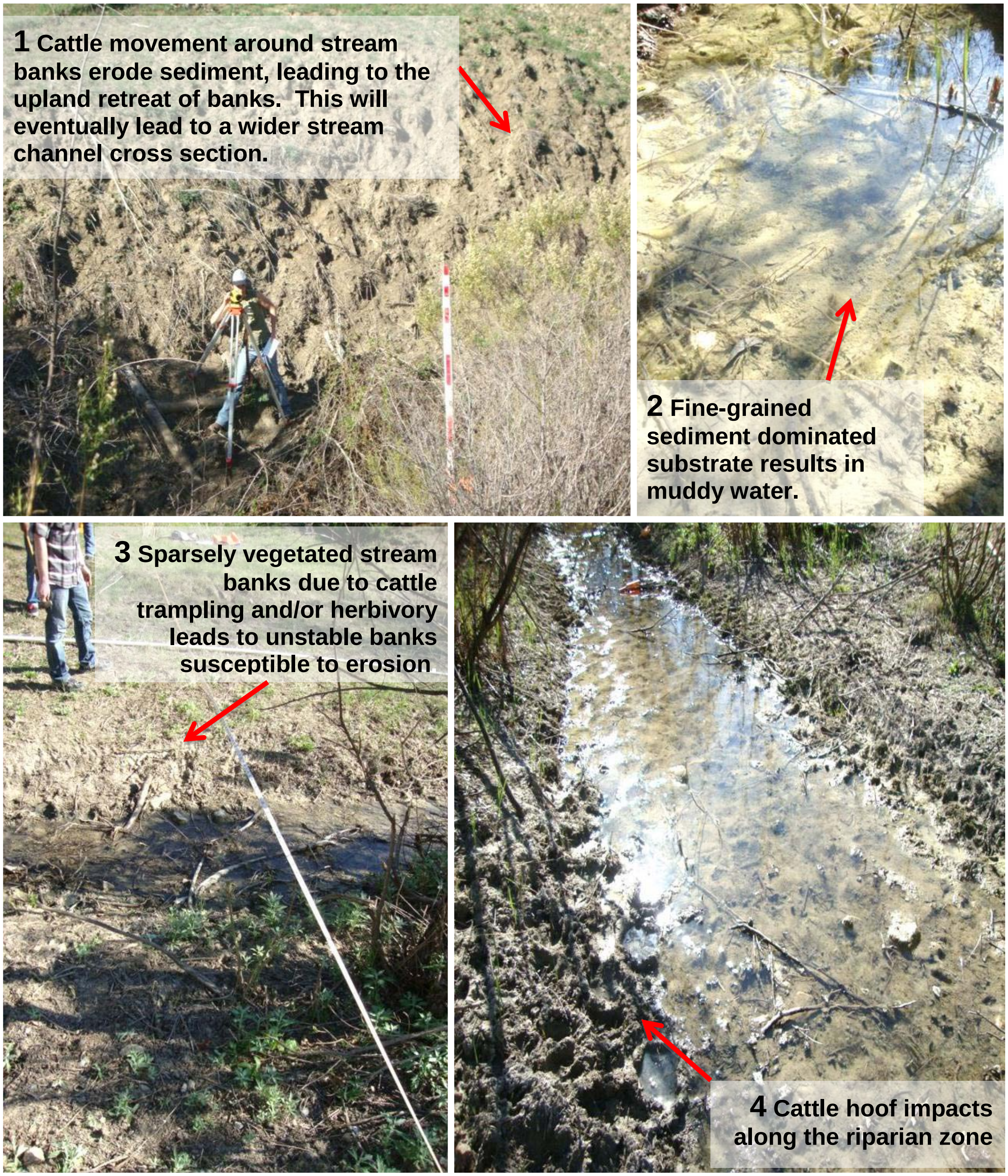


Figure 20. Refer to Table 3 for further photo comments.

Cattle grazing absent at Hudner Culvert

This study reach shows no evidence of cattle activity. The bank slopes leading into the stream channel are vegetated and cohesive, with gradual, no extreme bank slope angles. Vegetation surrounding and within the stream itself is unbroken, and there is new growth visible. Channel material grain size is noticeably larger than at Hudner (compare D84 values in Figures 17 and 18), contributing to the overall clarity of the water in this reach of stream.

Table 4. Letters in the Position column denote cross-section where the photo was taken.

Photo #	Position	Comments
Photo 1	Right Bank (2)	Untrammeled bank slopes
Photo 2	Left Bank (1)	Strong, dense bank walls resistant to erosion
Photo 3	Channel (6)	Undisturbed vegetation, clear water
Photo 4	Channel (3)	Clear water and large-particle substrate on bottom

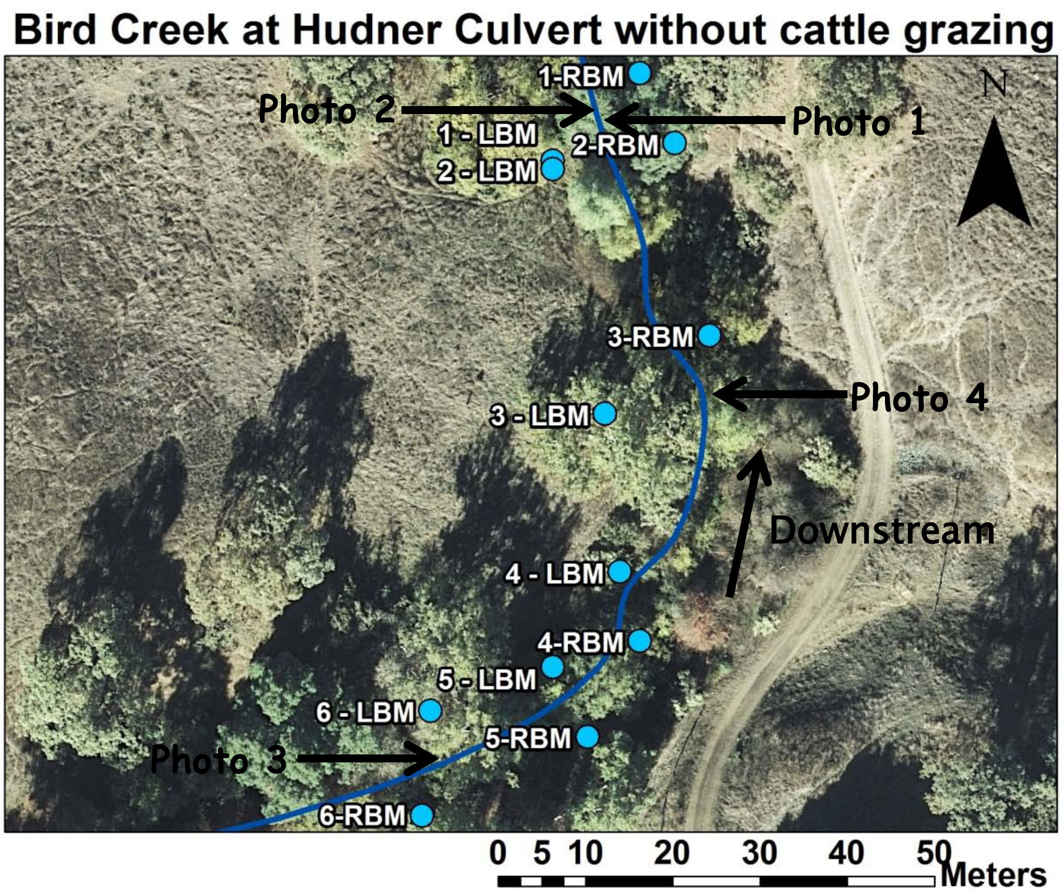


Figure 21. Approximate spatial location where each photo was taken.

Figure 22. Refer to Table 4 for further photo comments.

Shear strength as a determinate of stream bank susceptibility to cattle induced erosion

This study established a framework to analyze shear strength along Bird Creek. Cows can actively shear hoof-sized chunks of sediment from banks and reduce overall bank stability (Trimble and Mendel 1995). Therefore, weak and unstable stream banks are more susceptible to cattle induced erosion. Stronger stream banks can better withstand larger applications of pressure, including pressure from cattle hooves.

A graphical illustration of shear strength along Bird Creek at Hudner shows variation in shear strength (Figure 23). Variation in shear strength along Bird Creek is also reflected in the shear strength readings (values) in Table 5.

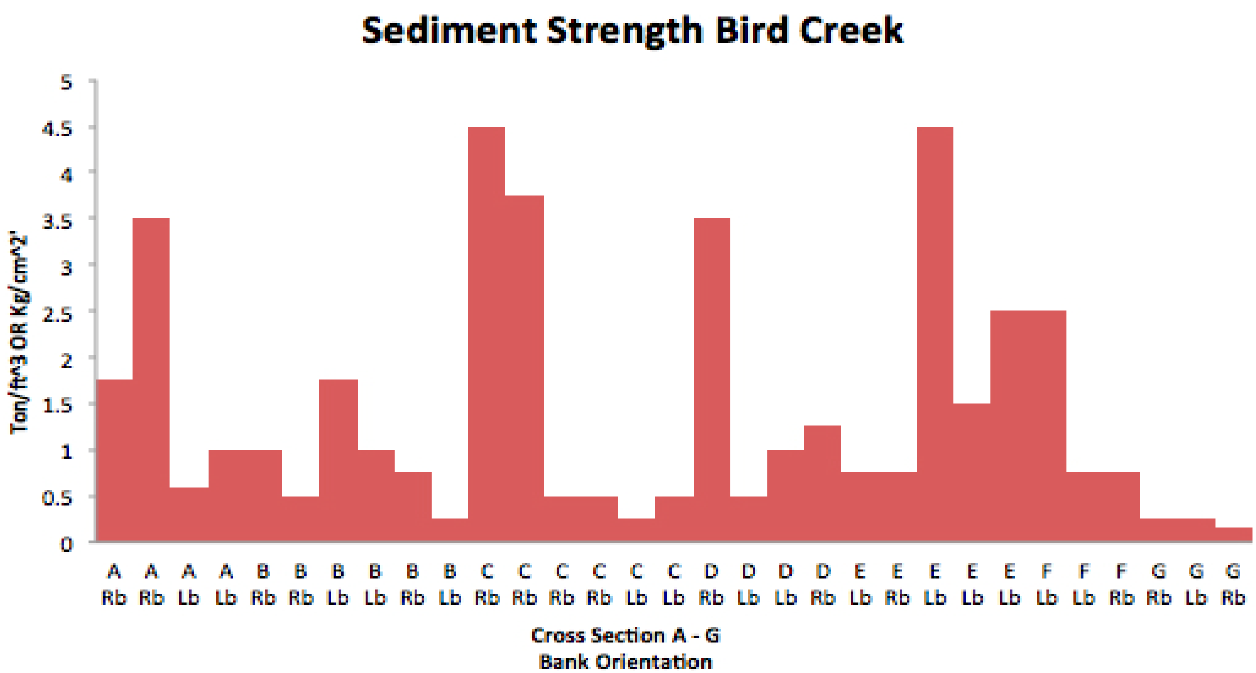


Figure 23. The penetrometer records the bank strength in tons per cubic foot and kilograms per square centimeter. The graph shows the measurements beginning at the farthest cross section downstream, A. Right and left banks are labeled as Rb and Lb respectively.

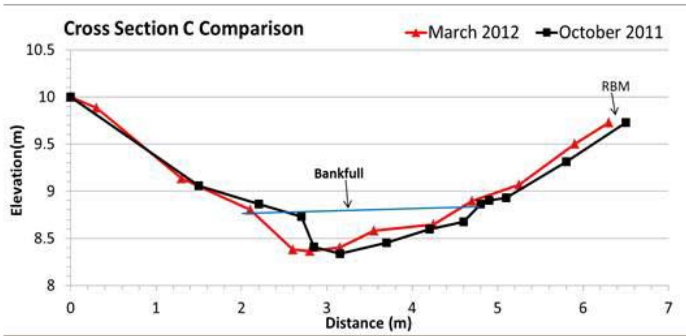
Table 5. Results of the shear strength measurements along Bird Creek at Hudner (cattle impacts).

Shot	Reading	Location (Between Cross Section and Bank Side)	Note
1	1.75	A Rb	
2	3.5	A Rb	
3	0.6	A Lb	Shore
4	1	A Lb	Terrace
5	1	B Rb	Shore
6	0.5	B Rb	Floodplain
7	1.75	B Lb	Bank
8	1	B Lb	Bank
9	0.75	B Rb	Bank
10	0.25	B Lb	Bank
11	4.5	C Rb	Bank
12	3.75	C Rb	Floodplain
13	0.5	C Rb	Bar
14	0.5	C Rb	Bank Wall
15	0.25	C Lb	Bank
16	0.5	C Lb	Bank
17	3.5	D Rb	Wall
18	0.5	D Lb	Bank
19	1	D Lb	Bank
20	1.25	D Rb	Bank
21	0.75	E Lb	Bar
22	0.75	E Rb	Wall Down Stream of Culvert
23	4.5	E Lb	Bar
24	1.5	E Lb	Bank
25	2.5	E Lb	Bank
26	2.5	F Lb	Wall
27	0.75	F Lb	Wall
28	0.75	F Rb	Bar
29	0.25	G Rb	Wall
30	0.25	G Lb	Bank
31	0.15	G Rb	Bar
Average Strength	1.39		

3.4 Stream banks

Bird Creek cross sections were compared to assess any changes that have occurred in stream channel morphology. The cross section benchmark positions are shown in Figure 7. Bankfull geometry is included for cross sections that show morphologic changes. Cross sections with little to no change are included at the end of the section without bankfull geometry. Cross section B was not assessed because there are no comparable surveys.

Bird Creek Cross Section C

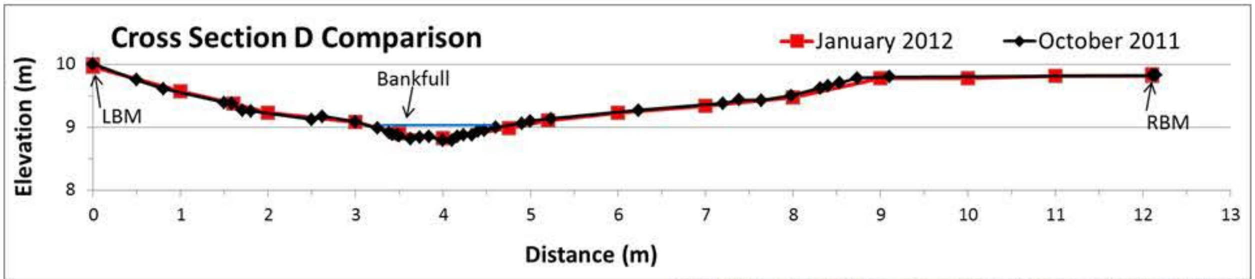


Bankfull Geometry						
Survey	Width (m)	Dbkf (m)	WP (m)	Wfp (m)	E.R.	Area (m^2)
October 2011	2	0.2	2.3	8.8	4.4	0.5
March 2012	2.7	0.2	2.9	8.8	3.2	0.6

Figure Above Right: Bird Creek Cross Section C during March 2012 survey. This picture was taken looking downstream
Table Left: Bankfull geometry calculated using bankfull points estimated post survey
Figure Above Left: Comparison of Cross section C surveys of October 2011 and March 2012

Figure 24. March 2012 survey shows degradation on the left bank and aggradation on the right bank. The right bench-marks of these surveys do not line up signifying horizontal error between surveys.

Bird Cross Section D

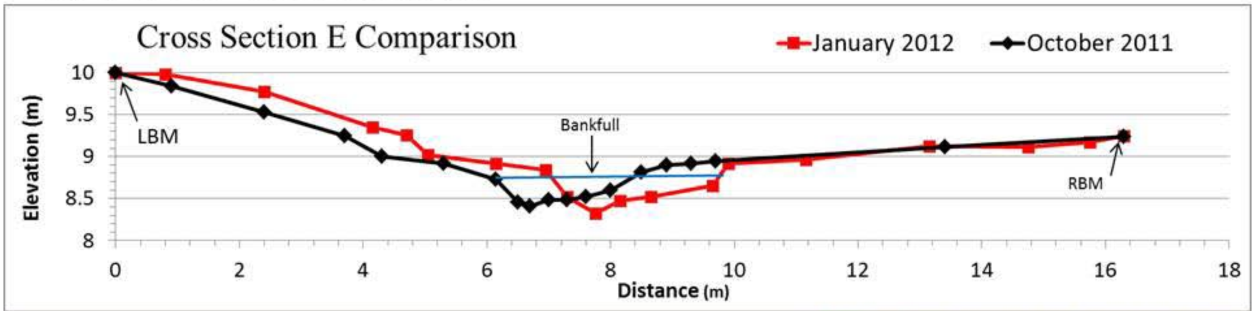


Bankfull Geometry						
Survey	Width (m)	Dbkf (m)	WP (m)	Wfp (m)	E.R.	Area (m^2)
October2011	2	0.3	2.1	5.9	2.9	0.3
January 2012	2.2	0.3	2.3	5.4	2.5	0.3

Figure Above: Comparison of Cross section C surveys of January 2012 and October 2011.
Table: Bankfull Geometry calculated using bankfull points estimated post survey.
Figure Right: Looking downstream at cross section D in March 2012.

Figure 25. The bench marks in these cross sections line up, suggesting low survey erro5. There was no significant change in cross section D between January and October 2011.

Bird Creek Cross Section E



Bankfull Geometry						
survey	Width (m)	Dbkf (m)	WP (m)	Wfp (m)	E.R.	Area (m^2)
October 2011	2.8	0.3	3.1	12.3	5	0.9
January 2012	2.8	0.4	2.5	14	5.6	0.9

Figure Above: Comparison of January 2012 and October 2011 surveys of Bird Creek cross section E.
Table: Bankfull geometry calculated from post survey estimated bankfull points.
Figure Right: Bird Creek cross section E during March 2012 Survey. Note access to floodplain.

Figure 26. The right benchmarks of both surveys line up precisely suggesting that between survey error is minimal. Aggradation of the left bank and an eroded and shifted right bank can be seen. The entrenchment ratios are high above 2.2. As the graph and photo above show, this section of Bird Creek has an accessible floodplain.

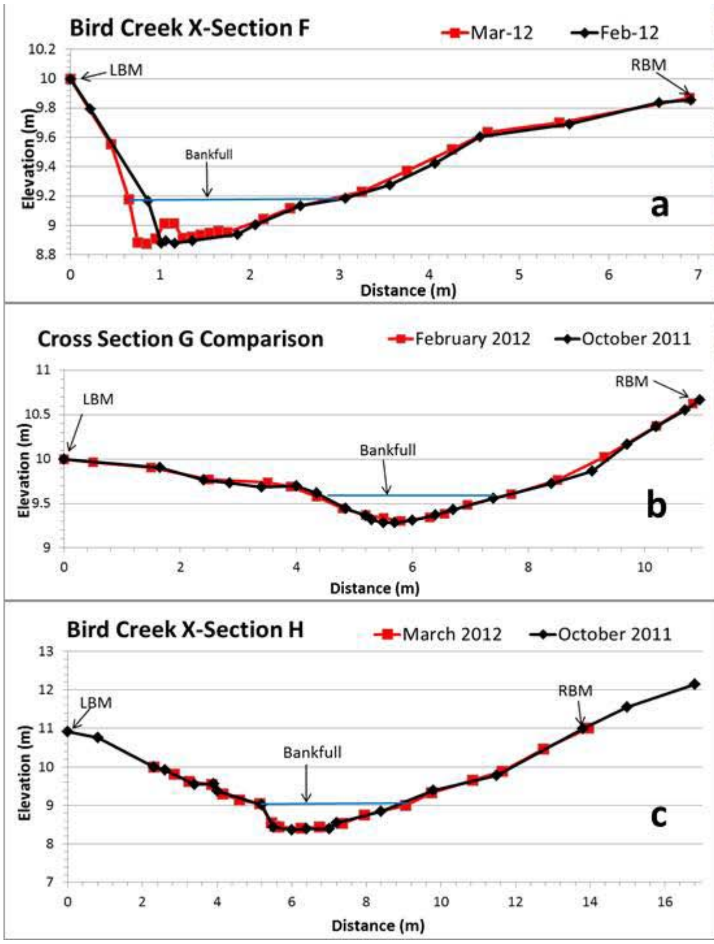


Figure Above: Cross section H in March 2012.

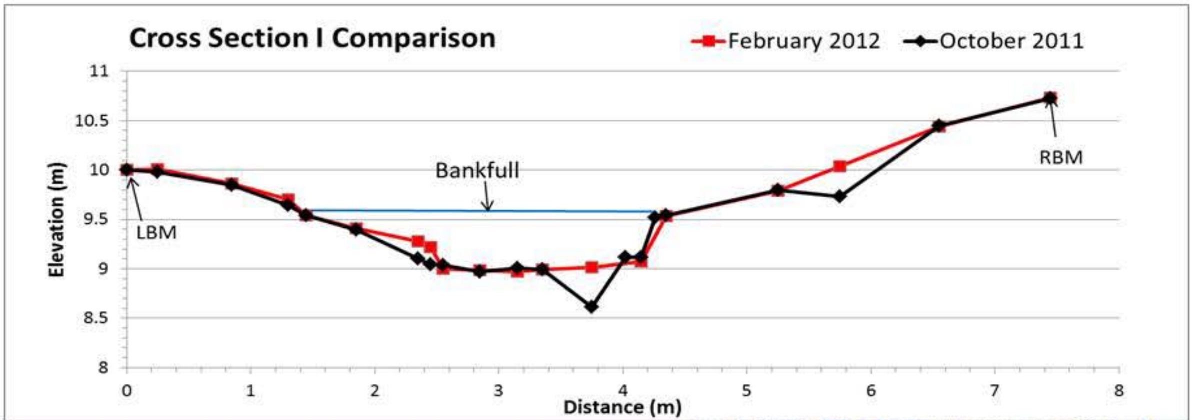
Figure a : Comparison of cross Section F surveys from March 2012 and February 2012.

Figure b : Comparison of February 2012 and October 2011 surveys of Cross Section G.

Figure c: : Comparison of March 2012 and October 2011 surveys of cross section H.

Figure 27. Lower Bird Creek Cross sections that had minimal change or survey error. The degradation seen in cross section F is possible error because the compared time periods are February and March of the same year (2012). Cross sections H and G had well aligned right benchmarks and do not show large changes between surveys.

Bird Creek Cross Section I

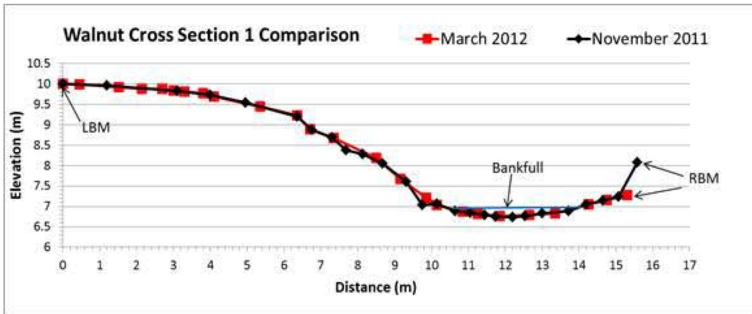


Bankfull Geometry						
Survey	Width (m)	Dbkf (m)	WP (m)	Wfp (m)	E.R.	Area (m^2)
October 2011	3.1	0.5	4	5.8	1.9	1.6
February 2012	2.9	0.4	3.4	5.8	2	1.1

Figure Above: Comparison of February 2012 and October 2011 surveys of Bird Cross section I.
Table: Bankfull geometry calculated from estimated bankfull as seen in figure _ above.
Figure Right: Looking downstream at Bird Creek Cross Section I during the March 2012 survey.

Figure 28. Cross section I. The right bench marks are well aligned allowing for between survey comparison. The right bank and the thalweg show aggradation. Both of the entrenchment ratios are below 2.2. As seen in the above photo the banks are nearly bare of vegetation in March of 2012.

Walnut Cross Section 1



Bankfull Geometry						
Survey	Width (m)	Dbkf (m)	WP (m)	Wfp (m)	E.R.	Area (m^2)
November 2011	1.95	0.06	1.96	3.08	1.58	0.12
March 2012	2.50	0.07	2.51	4.10	1.64	0.18

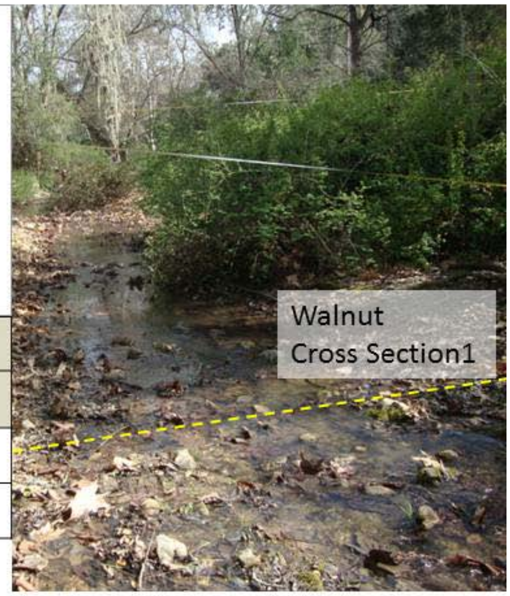
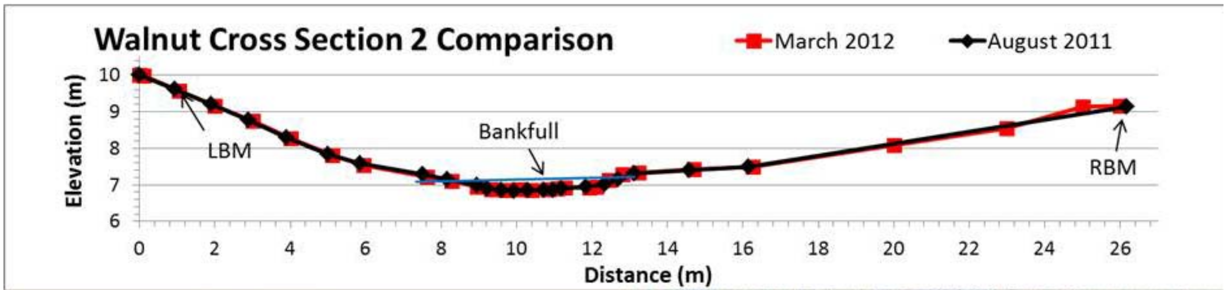


Figure Above: Comparison of survey data from March 2012 and November 2011.
Table: Bankfull geometry calculated from bankfull points that were chosen post survey for use as a comparison tool.
Figure Right: Yellow dotted line shows location of Walnut Cross section 1. Photo taken in March 2012.

Figure 29: Although the right bench marks are not alligned these surveys are still comparable. The allignment of many of the other survey points allows for this exception. There is minimal change between the November 2011 and March 2012 surveys.

Walnut Cross Section 2

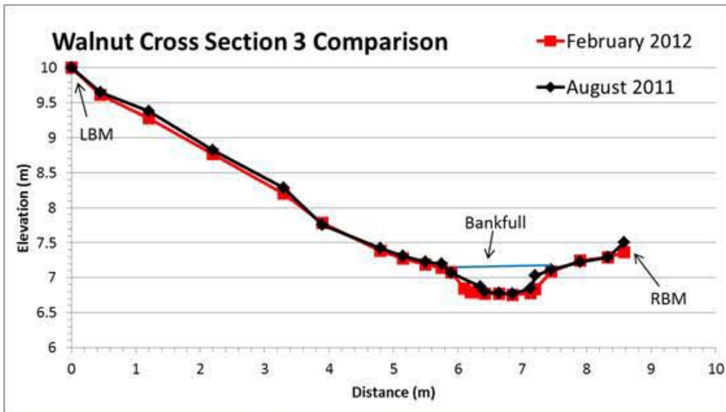


Bankfull Geometry						
Survey	Width (m)	Dbkf (m)	WP (m)	Wfp (m)	E.R.	Area (m^2)
August 2011	5.60	0.32	5.72	7.46	1.33	1.78
March 2012	5.60	0.38	6.15	7.50	1.34	2.10

Figure Above: Comparison of survey data from March 2012 and August 2011.
Table: Bankfull geometry calculated from bankfull points chosen post survey.
Figure Right: Yellow dotted line shows location of Walnut Cross section 2. Photo taken in March 2012.

Figure 30. The right benchmarks are aligned in both surveys of Walnut cross-section 2. The entrenchment ratios are above 2.2. The August 2011 photo (above on right) shows vegetation growing within the channel the March 2012 photo (above on left) show witing channel leaf litter and well vegetated banks.

Walnut Cross Section 3



Bankfull Geometry						
Survey	Width (m)	Dbkf (m)	WP (m)	Wfp (m)	E.R.	Area (m^2)
February 2012	3.20	0.22	3.05	4.90	1.53	0.71
August 2011	1.30	0.20	1.51	3.43	2.64	0.26

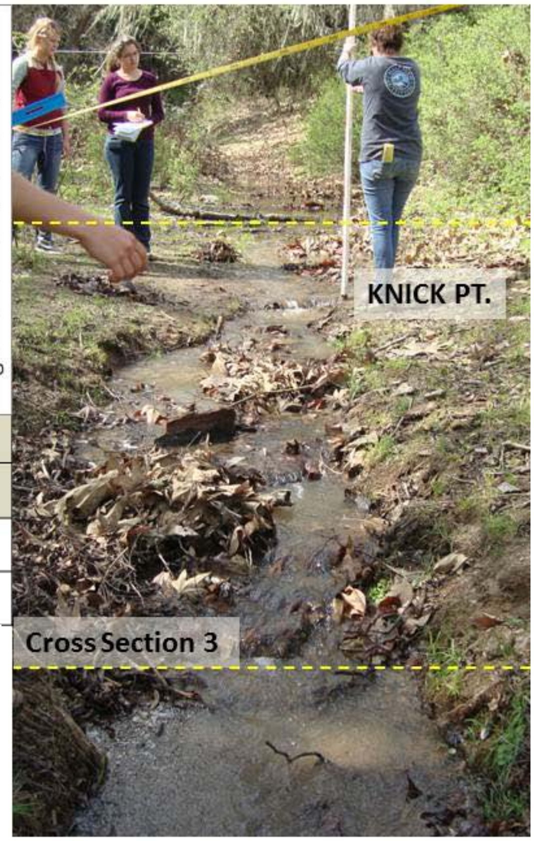
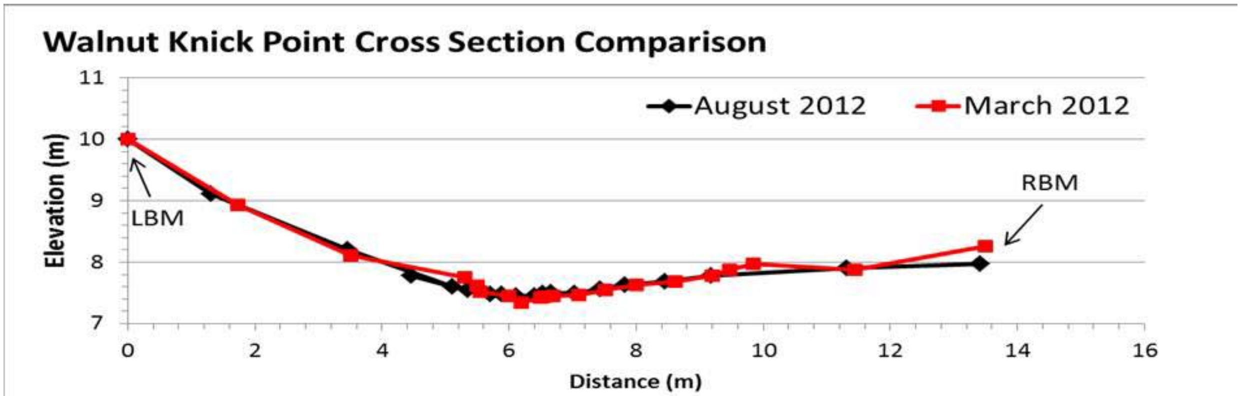


Figure Above: Cross section comparison between the February 2012 and August 2011 surveys.
Table: Post survey calculated bankfull geometry.
Figure Right: March 2012 view looking upstream at cross sections 3, and Knick Point.

Figure 31. In Walnut creek cross section 3 there was some vertical error. Overall there was no significant change from August 2011 to February 2012.

Walnut Knick Point



Bankfull Geometry						
Survey	Width (m)	Dbkf (m)	WP (m)	Wfp (m)	E.R.	Area (m^2)
August 2011	2.08	0.06	2.10	7.46	3.59	0.12
March 2012	1.98	0.09	2.05	7.63	3.85	0.18

Figure Above: Comparison of Walnut Knick point cross section surveys from August 2011 and March 2012

Table: Bankfull geometry calculated from bankfull points chosen post survey.

Figure Left: March 2012 looking across the channel.

Figure 32. Although the right benchmarks are not aligned the remaining points do match up, allowing for comparison. The March 2012 survey shows slight aggradation on the left bank.

Bulk Density Analysis Results

In 2012, 20 soil cores were taken with means to calculate average bulk density for streambanks at Walnut Camp and Lower Bird Creek. The bulk density for Lower Bird Creek was calculated to be 0.93 g/cm^3 while the bulk density for Walnut Camp came out a little higher at 0.98 g/cm^3 (Appendix C). The analysis for bulk densities obtained in Walnut Camp suggests that the true mean lies within 0.93 ($\pm$ 0.06). The analysis for bulk densities taken in Lower Bird Creek suggests that the true mean lies within 0.98 ($\pm$ 0.05).

Bank Pin Analysis Results

Bank pin exposure measurements were used to calculate the mass of sediment eroded from the banks of Bird Creek between Hudner and the San Andreas Fault in water years 2011 and 2012. The volume of banks eroded is the product of average bank pin exposure, average erodible bank height, and the length of erodible bank measured from Hudner to the SAF. The mass was calculated as the product of eroded bank volume and bank material density. The bank density was estimated as the average of 20 bank samples (Appendix C). The density for each sample was determined by finding the dry sample mass and dividing by the sample volume. The samples were cylinders of various length and a 14 mm radius. The resulting mass for 2011 is 93,662kg (Table 5) and 24,461kg for 2012 (as of April 25th) (Table 5).

Table 5. Total Mass of stream bank erosion calculated from 2011 water year bank pin exposure.

Water Year 2011 Bank Pin Exposure		
2800	m	Stream Length from San Andreas Fault (SAF) to below pin 8
1.2	m	Average bank height
0.028	m	Average pin exposure
95.57	m^3	Calculated bank erosion
0.98	$g*cm^3$	Average soil density
980	$kg*m^3$	Average soil density--unit conversion
93662	**kg**	Total **MASS** of stream bank erosion

Table 5. Mass of stream bank erosion calculated from 2012 water year as of 2012 bank pin erosion.

Water Year 2012 Bank Pin Exposure as of April 2012		
2800	m	Stream Length from San Andreas Fault (SAF) to below pin 8
1.2	m	Average bank height
0.007	m	Average pin exposure
24.96	m^3	Calculated bank erosion
0.98	$g*cm^3$	Average soil density
980	$kg*m^3$	Average soil density--unit conversion
24461	**kg**	Total **MASS** of stream bank erosion

3.5 Landslides

Landslide causes and triggers

In the past 20 years there were 15 earthquakes with a magnitude of ≥4.0 within 20km of the Colluvial Creek landslide system (Figure 33), and there were five 10-year 24-hour rainfall events. Major earthquake(s) and storm(s) co-occurred in 1995, 1998, and 2001 (Table 6). The magnitude 5.0 earthquake located closest to the park (~3km away) occurred in the same year as the 1998 El Niño event. Other years that contained potential landslide triggering conditions were 1995, when there was one ten-year rain event and three earthquakes, and 2001 when there were three ten-year rain events and six earthquakes.

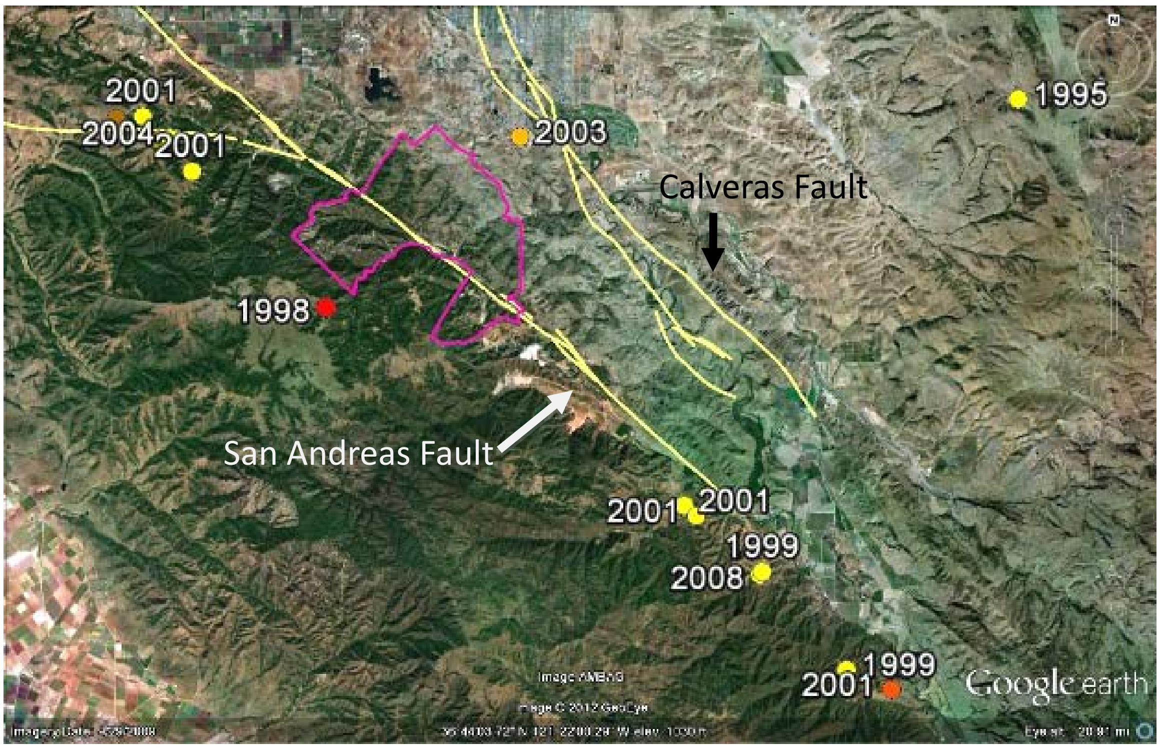


Figure 33. Earthquakes within 20 km of Hollister Hills SVRA between 1992 and 2012 with a magnitude of 4.0 or greater.

Table 6. Rainfall events that met the criteria for a 10-year 24-hour rain event (from 1994-2011) compared with earthquakes of magnitude ≥4.0 within a 20km radius of Hollister Hills SVRA.

Year	Number of Extreme Rainfall Events	Magnitude of Earthquake Events
1994	1	–
1995	1	4.2, 4.0, 4.2
1996	0	–
1997	0	–
1998	0	4.3, 5.1
1999	0	4.2, 4.0
2000	0	–
2001	3	4.01, 4.1, 4.1, 4.0, 4.0, 4.6
2002	0	–
2003	0	4.3
2004	0	4.25
2005	0	–
2006	0	4.34
2007	0	–
2008	0	4.0
2009	0	4.34
2010	0	4.0
2011	0	–

Major differences in geology on either side of the San Andreas Fault were identified using the geologic units map displayed in Google Earth (Figure 34). The east side of the SAF is predominantly weak sedimentary rock, and the west side of the SAF is predominantly metamorphic and plutonic rock.

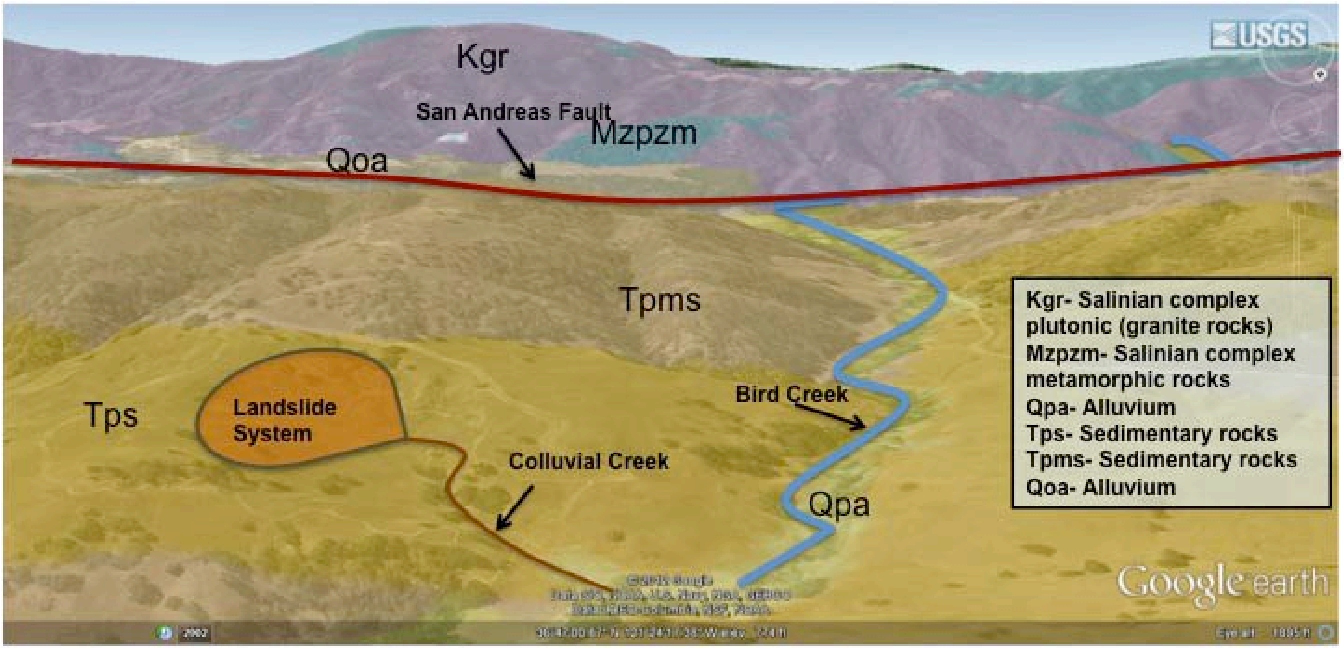


Figure 34. Differences in geologic formations of both sides of the San Andreas Fault.

Rate of landslide movement

Historic Google Earth imagery of a landslide located about 40 meters to the southeast of the Colluvial Creek watershed divide were analyzed to determine the relative age of the Colluvial Creek landslides. The headwall scarp length of this landslide increased between 2007 and 2009 (Figure 36).

Landslide movement was monitored by using RTK GPS to measure the change in elevation of the wooden pegs in the landslide bodies (Table 7). Three of the five landslide peg groups were excluded from our analysis because the pegs were displaced by cattle. The remaining two peg groups (one and two) moved downhill slightly (Table 7).

Figure 35. Photo of the landslide located near the Colluvial Creek watershed divide, but outside the Colluvial Creek watershed. Photo date March 12, 2012.

Figure 36. Historical Google Earth imagery of the landslide seen in Figure 35.

The morphology of Colluvial Creek changed very little between October 2011 and March 2012 (Appendix A).

Hydrologic connection from landslides to Bird Creek

GIS software was used to create a map of the landslide system in conjunction with topographic lines to determine if the landslide body has the potential to meet Bird Creek (Figure 37). The slope of 0.228 can be derived from Figure 37, which shows contours lines angling down towards Bird Creek from Colluvial Creek.

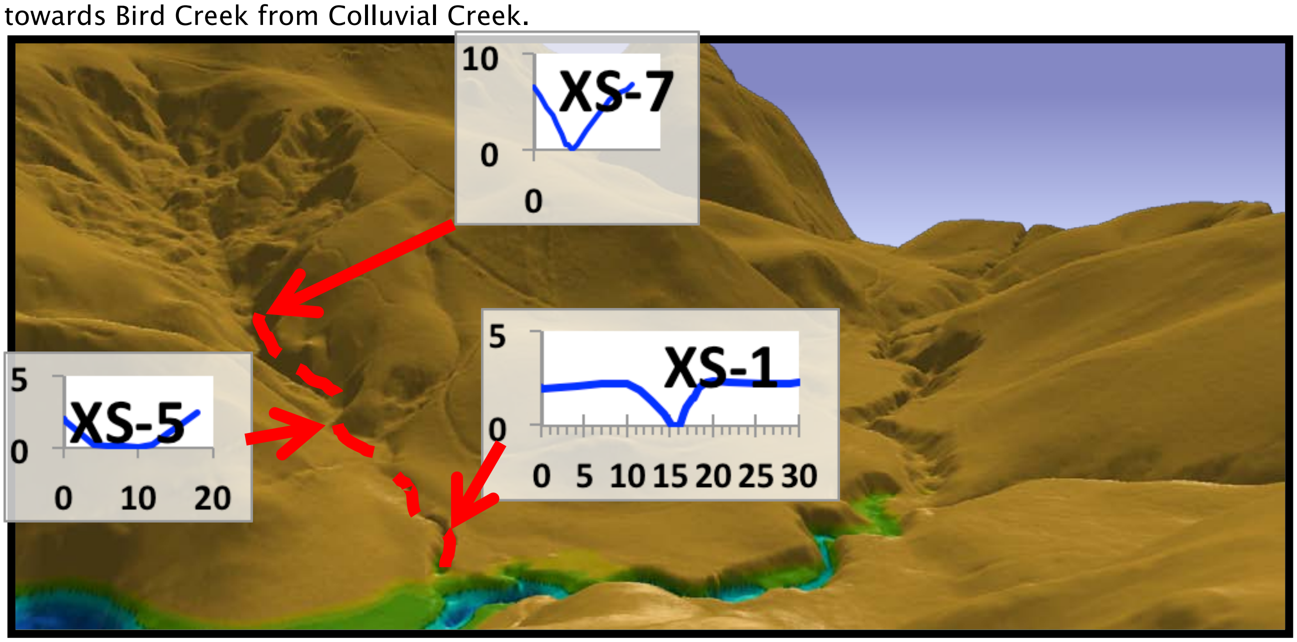


Figure 37. Digital terrain of landslides above Colluvial Creek cross-sections, leading to Bird Creek.

Table 7. RTK GPS data displaying movement in the landslide pegs.

Landslide 1	z	Notes
peg1a	0.005	LS1A
peg1b	0.011	LS1B
peg1c	-0.009	LS1C
peg1d	0.009	LS1D
	0.004	average change

Landslide 2	z	Notes
peg2a	0.039	LS2A
peg2b	0.003	LS2B
peg2c	0.009	LS2C
peg2d	0.020	LS2D
	0.018	average change

Landslide 3	z	Notes
peg3a*	0.302	LS3A - reset
peg3b	-0.008	LS3B
peg3c	-0.010	LS3C
peg3d	-0.013	LS3D
	-0.010	average change

Landslide 4	z	Notes
peg4a*	0.167	LS4A - loose
peg4a.1	-0.002	New LS4A
peg4b*	-0.016	LS4B - reset
peg4c	-0.007	LS4C
peg4d	0.001	LS4D
	-0.001	average change

Landslide 5	z	Notes
peg5a	-0.010	LS5A
peg5b*	0.024	LS5B - tilted 45°
peg5c	-0.007	LS5C
peg5d	-0.006	LS5D
	-0.003	average change

*Excluded from average change calculation.

NOTE: Positive z implies a decrease in elevation.

4 Discussion

4.1 Erosion from OHV use

There are several management solutions that can be implemented to reduce the amount of excess sediment that enters stream systems. Each road site is different and can require a variety of mitigating treatments based on its proximity to a stream or river system, the amount of sediment it contributes in runoff, how easily treatments can be applied to the road, and how much money can be allocated toward managing the roadway (Amador et al. 2012). Management options can vary in cost and complexity, and can include digging inside ditches to provide a specific path for sediment to travel, installing check damns to catch sediment along ditch paths, and digging out energy dissipaters like catchment basins to let sediment settle to pouring paved gutters and laying down wire mesh pavement (Amador et al. 2012).

Hollister Hills SVRA is already using sediment basins to catch as much of the sediment coming downhill from the trails as possible to keep it from getting into Bird Creek and its tributaries. In addition to the sediment basins, HH SVRA also uses techniques like sediment nets, hydro seeding, and re-vegetation as ways to reduce the erosion on the trails (California State Parks, 2012). Using data that was provided to us by the park, we determined that the sediment basins caught over twenty thousand m^3/yr of sediment coming down from the trails, using or exponential graph with the sediment basin and trail length data, we determined that there would be about 160 m^3/yr sediment per square kilometer of park coming off of the hillsides if there were no trials. It also means that with one hundred and twelve kilometers of trails there is almost 26,000 m^3/yr of sediment coming off of the trails. Since we do not yet know the total amount of sediment reaching Bird Creek, we cannot determine if the sediment basins and other management practices are successful at stopping sediment from the trails.

We recommend that since we have not determined the total amount of sediment reaching Bird Creek, or even the amount of sediment coming off of the trails, that Hollister Hills SVRA continue to use the management practices currently in place. We also recommend that HH SVRA update their Geographic Information Systems (GIS) data, because, while in theory the techniques we used to create our exponential graph with the sediment basin data, are good, without up to date, relevant data, we were only able to make of chart with fifty six percent of the sediment yield data. Because of our inability to answer our questions about the amount of sediment reaching Bird Creek from the trails, we also recommend that further study needs to be done on the trails and hillsides in the park to determine the amount of sediment that is eroding off of the trails.

4.2 Runoff from unpaved campgrounds and parking lots

We suggest that erosion control measures be implemented to mitigate each sites sediment contribution to Bird creek. Erosion control measures slow overland flow and trap small amounts of sediment from disturbed areas (USDA-NRCS [updated 2009]). Some erosion control treatments include hill slope management techniques designed to stabilize soils, such as vegetation manipulation, water spreading, pitting, and terracing, as well as structures such as detention dams designed to reduce sediment loads (Wohl 2003). One other option includes using permeable mulches such as straw and wood chips with gravel to protect bare soil (USDA-NRCS [updated 2009]). Low impact development (LID) practices involving pervious pavement and pervious asphalt have also shown to be effective in reducing the cumulative impact of runoff on down-stream water bodies (Dietz 2007). Since campsites and parking lots feature substantial vehicular traffic, water quality inlets and catch basins may be an effective Best Management Practice solution (Kent 2001). Directing remedial measures to these specific areas, as opposed to a more general aerial application of erosion control has been found to be effective and efficient in the past for both soil erosion, and nonpoint source pollution problems in watersheds with more rolling terrain (Wall et al. 1990).

Due to the variable topography at each of the recreational sites in the Hollister Hills SVRA, the following recommendations for Madrone, Lodge, Bee, and Walnut camps are suggested. Due to Madrone and Walnut being moderately sloped relative to the other sites, applying pervious pavement to the areas most incised is proposed. Alternatively, Lodge and Bee camps feature less inclined landscapes and will benefit more from sediment basins and re-vegetation of their outer perimeters. More research will be needed to properly assess whether or not LID use is appropriate for these sites, as conditions such as steep slopes, shallow depth to bedrock, and seasonal high water tables are unfavorable for LID use (Dietz 2007).

Currently there are no previous studies that have quantified the amount of sediment from these areas within the Hollister Hills SVRA. Some research could include conducting a soil analysis on the campgrounds and parking lots, measuring the total volume of suspended sediment concentrations downstream from the sites and comparing them to locations upstream without OHV recreation, examining bulk density and porosity at each parking lot and campsite, estimating the slopes of each site as well as their distance from Bird Creek, measuring the area of the campsites and parking lots in comparison to the rest of the park, and taking cross sections of the areas to monitor their change through time.

4.3 Riparian cattle grazing

We found that 1) cattle at Hudner are not currently causing stream channel widening but 2) the sediment at Hudner consists of a greater proportion of fine-grained, suspended sediment. Although this is a preliminary study, we believe that cattle grazing along lower Bird Creek at Hudner Ranch is a significant sediment source for Bird Creek. Primary evidence for this conclusion stems from sources such as photo documentation of cattle impacts at Hudner Ranch and results from other studies reported in research journals.

Although stream widening from riparian cattle grazing has been well documented (Herbst et al. 2012; Trimble and Mendel, 1995) apparently the grazing at Hudner has not reached a magnitude of impact detectable by repeated stream cross section surveys. Based on photos of local stream bank retreat at Hudner (Photo 1, Figure 20), more general widening will clearly result from more continuous grazing. Widening is commonly associated with reduced sediment transport, loss of riparian vegetation, and increased siltation (Trimble and Mendel, 1995).

This study revealed a trend of fine-grained sediment at Bird Creek at Hudner and Hudner Culvert. The presence of the sediment finer than 2mm at Hudner Culvert could be a natural geologic manifestation, or a buildup of silt could have resulted from a drier than normal year and therefore the inability to transport much sediment downstream. There was more mud-size sediment at Hudner, likely because of the local cattle impact. The observation of fine-grained sediment at Hudner is consistent with literature that states “grazed sites tend to be significantly dominated by fine-grained sediment less than 2mm in diameter (Herbst et al. 2012). Future studies in this area should include Wolman Pebble Counts at all sites, even when the substrate is all mud. These counts will increase the statistical sample size, thereby allowing for more in depth substrate analysis.

Shear strength at Hudner varied between geomorphic features along the reference reach at Hudner. Several highly compacted areas such as floodplains and point bars had readings of

3.5kg*cm^2 and higher, but other areas such as shorelines and bank walls returned readings as low as 0.5kg*cm^2. On average, the shear strength along the Bird Creek reach at Hudner was determined to be 1.39kg*cm^2. Background research indicated that a 530kg cow (average size) exerts 2.55kg*cm^2 of pressure (Trimble and Mendel, 1995). Since average cows can create pressure far exceeding the average shear strength of stream bank substrate at Hudner, cattle have the potential to displace sediment. Perhaps cattle can diminish shear strength over time, and therefore it would be beneficial to reproduce this experiment in future studies to detect changes to shear strength and/or compare shear strength results at Hudner to ungrazed study areas such as Hudner Culvert.

Additional studies are needed to determine the significance of cattle induced erosion and sediment deposition. This study did not examine impacts due to privately-grazed cattle, but that may be another significant sediment source in the Bird Creek watershed. Future studies should include a time log or record of cattle activity on a daily basis that would include information such as when the cattle grazing (date, time), how many, where, etc. A general map of where the cattle are taken during the grazing period would also be beneficial in order to gage at the spatial extent of cattle grazing and where it is most concentrated.

Disturbed stream channels have demonstrated the ability to regrow riparian vegetation and regain bank stability once cattle are excluded from riparian areas (Herbst et al. 2012). Complete removal of cattle at the HH SVRA might not be favored because of the land management services they provide. Here are options to reduce and mitigate cattle impacts along Bird Creek that are being used in cattle impacted watersheds throughout California:

- Relocate the cattle further upland.
- Reduce or exclude grazing near streams during heavy precipitation (bankfull conditions) when stream banks are most susceptible to erosion.
- Install permanent fencing or reinforce temporary fencing to prevent cattle from entering Bird Creek.
- Provide water troughs to discourage cattle from drinking out of Bird Creek.
- Rotational grazing: reduce the concentration and impacts of cattle grazing at one location such as Bird Creek at Hudner.

4.4 Streambank Erosion

If a stream is out of equilibrium is has the potential to be a significant sediment contributor. This preliminary study conducted in the Lower and Upper reaches of Bird Creek has found that 1) the channel is not eroding but 2) the channel has aggraded. In general, the cross sectional surveys in the Lower reaches of Bird Creek have shown aggradation. The Upper Bird Creek cross sections near Walnut camp have shown no significant change between surveys. The aggradation could be caused by the abnormally dry winter. Low winter flows would have failed to wash out the fine sediment deposited over the summer and fall. Since there are not enough time serial surveys it is hard to determine what constitutes as “normal” net aggradation or degradation. To further analyze stream bank erosion in the HHSVA, more time serial surveys are required.

Based on the bulk density analysis conducted along the stream channels at both sites, the aggradation seen in Lower Bird creek is not surprising. Lower Bird creek and Walnut Camp yielded relatively low average bulk densities (0.98 and 0.93 g/cm^3). These results indicate high porosity and low shear strength on the banks. Both cross section sites had average bulk densities below the representative densities proposed by Keller et al. (1.0– 2.0 g/cm^3). The low bulk density at Walnut Camp and Lower Bird could be attributed to indirect tillage from cattle disturbing compacted soil layers along the streambanks (USDA-NRCS, 2011).

This survey also measured bank pin exposure to determine how much sediment leaving Bird Creek is a direct effect of stream bank erosion. In the 2011 water year a total of 1,000,000 kg of sediment came out of the Bird Creek watershed (Nicol et al., 2011). The bank pin exposure measure in this survey accounts for 93,662 kg, a 9% contribution of the total Bird Creek sediment load for 2011. This small sediment contribution must be considered in the context of a low precipitation year because bank erosion rates are largely dependent on frequency and magnitude of storm events. This calculated contribution is representative of only the reach between the Lower Bird creek study site and the San Andreas Fault. It is recommended that more bank pins be set along Bird Creek to further refine the sediment load attributed to bank erosion.

In some areas of Lower Bird there is little to no vegetation on the stream banks. A passive restoration method is suggested to protect stream banks from future erosion. Passive restoration uses the principle that over time the river will heal itself and stream banks will stabilize (Wissmar and Bisson 2003). Limited stream access and the facilitation of a riparian buffer zone are also recommended.

4.5 Landslides

It is clear that the region near Colluvial Creek is seismically active. Some of these seismic events stand out because they correlate with major rain events. Together, the close proximity (in time) of the earthquakes and the heavy precipitation could have caused landslides or created minor scarps within larger, historical landslides. Along with heavy precipitation and earthquake magnitude, soil composition plays a role in landslides by providing a medium for earthquake energy to travel. The difference in geologic formations on the east and west side of the fault (sedimentary and metamorphic/plutonic respectively) is clearly a first-order control on landslide location, given the great number of landslides on the east side of the fault and the absence of detectable landslides on the west side.

Based on the historical images we can date one of the landslides in the area adjacent to the Colluvial Creek landslides. From the slight increase in headwall scarp length from 2007 to 2009, we can conclude that the landslides are somewhat active on a decadal timescale and can be a possible source of sediment. However, a more precise analysis of the landslides present on the east side of the San Andreas fault (which would require better quality imagery) would benefit future research.

The Colluvial Creek cross sections revealed that there is little geomorphic change in the channel from October 2011 to March 2012, possibly due to the lack of rain during those winter months. However, the channel geometry downstream indicates local incision by an active gully system, followed by net aggradation down valley where the slope is less severe. Therefore, the bottom of Colluvial Creek has the potential to transport the large amount of sediment stored via an extreme rainfall event. This hypothesis is supported by the topographic map that clearly displays a hydrologic connection from Colluvial Creek to Bird Creek (Figure 37). Therefore, it can be inferred that the landslide bodies are a possible source of sediment to Bird Creek in the event of major rainfall. However, continuing the monitoring of Colluvial Creek is recommended to provide additional data that could support this inference. Also, establishing cross sections downstream of where Colluvial Creek meets Bird Creek could provide more evidence for the hypothesis that Colluvial Creek (and therefore the landslide bodies) are contributing sediment to Bird Creek.

Only two of the average change in elevation (z) values were used for the analysis. However, given the very small scale of change, we can assume that no significant movement occurred in the landslide bodies. Recommendations for future research include a more sophisticated monitoring method including rebar instead of wooden pegs (so that they stay in place) and of course more years of data are needed to make decadal scale comparisons.

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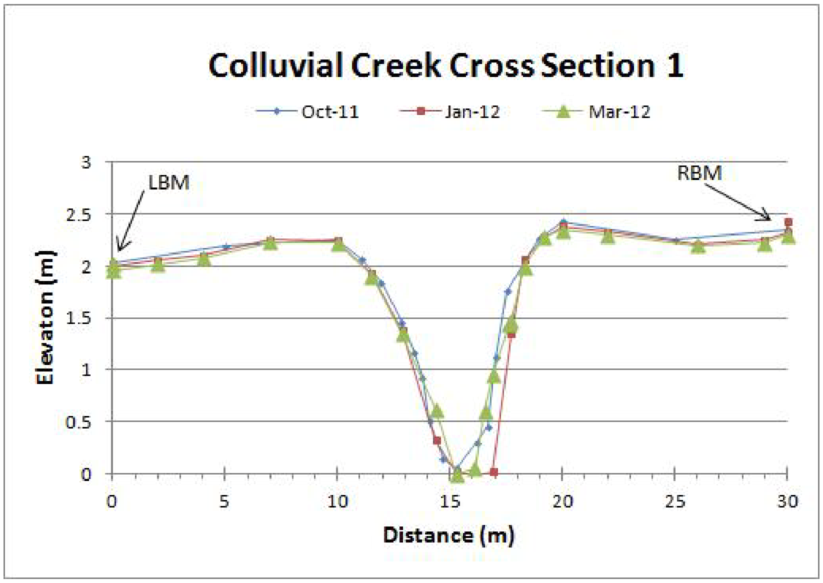
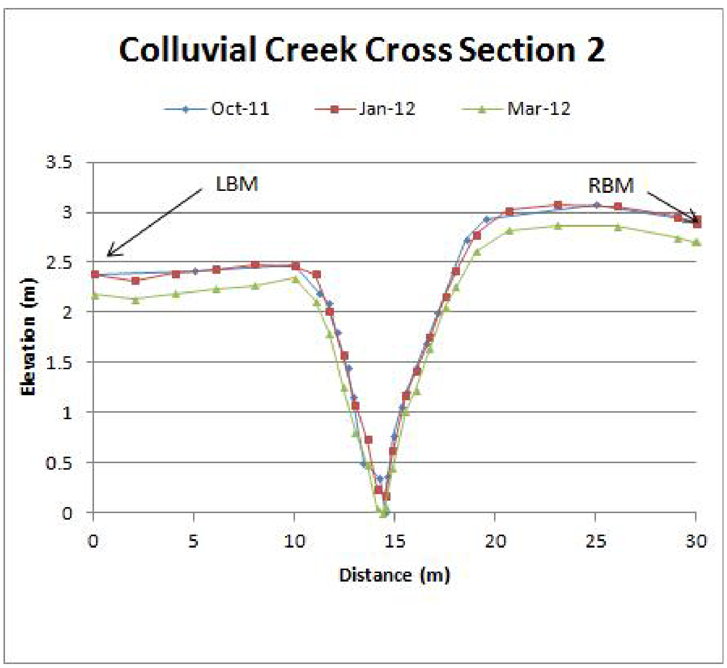
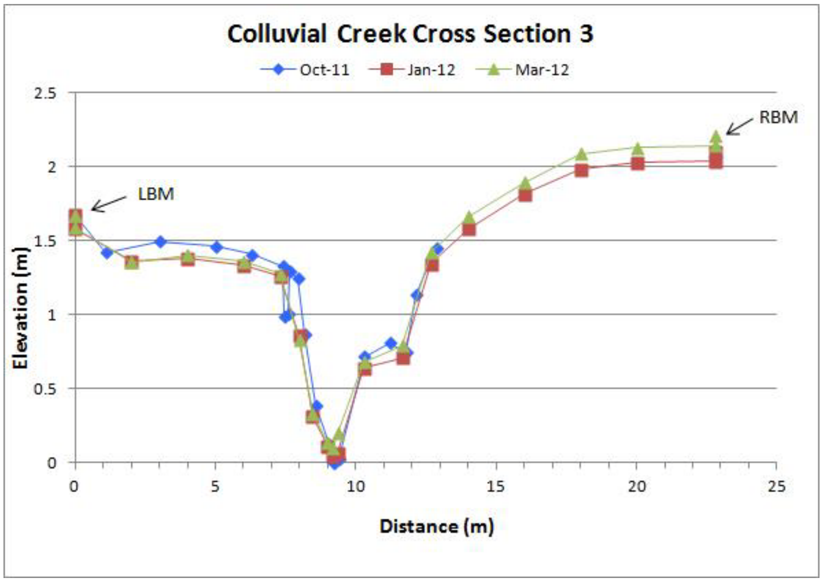
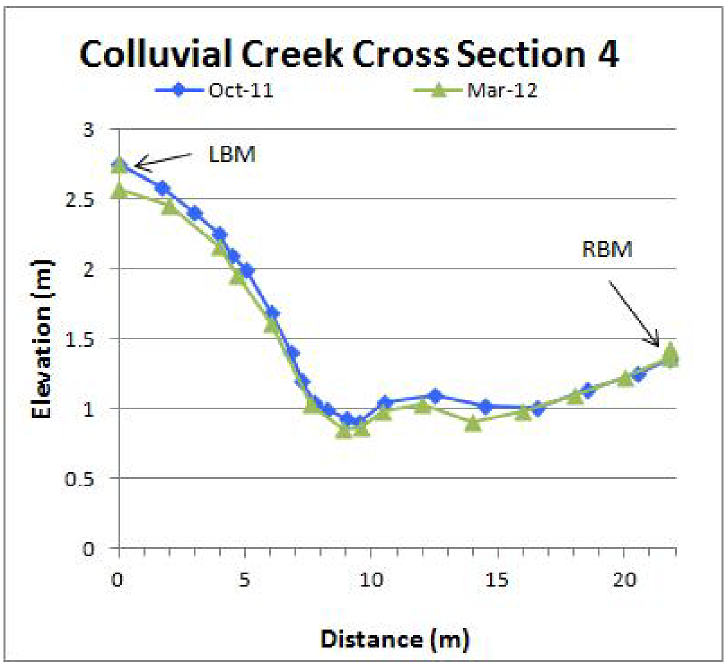
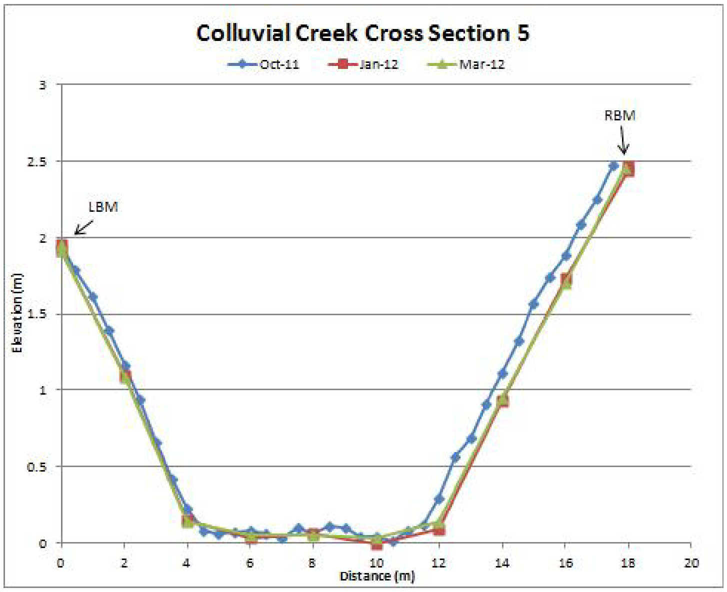
6 Appendix A – Colluvial Creek Cross Sections



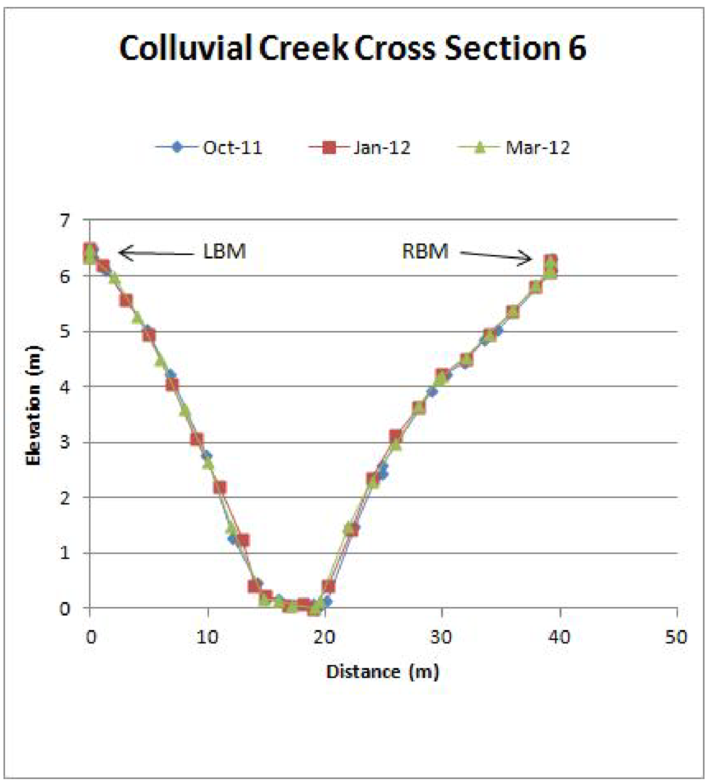



Colluvial Creek Cross Section 3
Oct-11
Jan-12
Mar-12
RBM
LBM
Elevation (m)
Distance (m)
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25

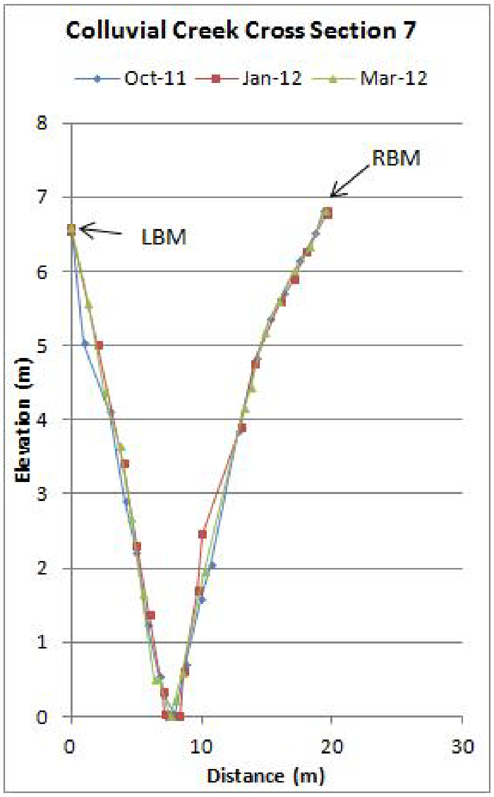

Colluvial Creek Cross Section 4
Oct-11
Mar-12
LBM
RBM
Elevation (m)
Distance (m)
3
2.5
2
1.5
1
0.5
0
0
5
10
15
20

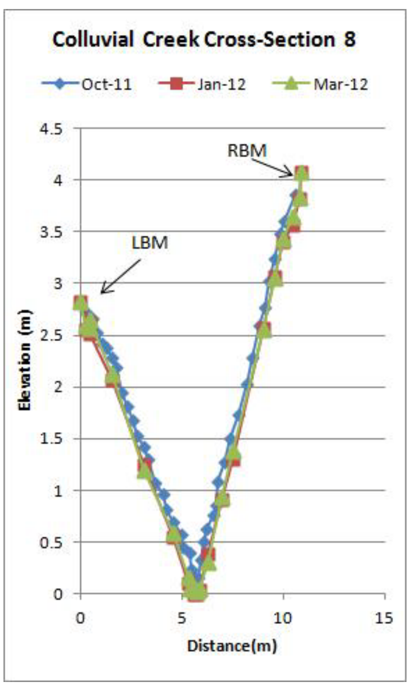


Colluvial Creek Cross Section 5
Oct-11
Jan-12
Mar-12
RBM
LBM
Elevation (m)
Distance (m)
0
0.5
1
1.5
2
2.5
3
0
2
4
6
8
10
12
14
16
18
20



Colluvial Creek Cross Section 6
Oct-11
Jan-12
Mar-12
LBM
RBM
Elevation (m)
Distance (m)
0
1
2
3
4
5
6
7
0
10
20
30
40
50


Colluvial Creek Cross Section 7
Oct-11
Jan-12
Mar-12
RBM
LBM
Elevation (m)
Distance (m)
0
10
20
30
1
2
3
4
5
6
7
8


Colluvial Creek Cross-Section 8
Oct-11
Jan-12
Mar-12
RBM
LBM
Elevation (m)
Distance(m)
0
5
10
15
0.5
1
1.5
2
2.5
3
3.5
4
4.5

7 Appendix B- Bulk Density

Bank Material Density **Lower Bird Creek** Tin Mass (g)							
A	B	C	D=C-A	E	F=E*π*(14mm)^2	G=F/1000	H=D/G
Empty	Full (wet)	Full (dry)	Soil Mass (g)	Core Length (mm)	Volume (mm^3)	Volume (cm^3)	Density (g/cm^3)
16.0		50.0	34.0	79.0	48644.4	48.6	0.70
15.6		50.9	35.3	57.0	35097.9	35.1	1.01
15.4		94.1	78.7	120.0	73890.3	73.9	1.07
13.5		69.5	56.0	80.0	49260.2	49.3	1.14
13.6		78.1	64.5	90.0	55417.7	55.4	1.16
13.6		73.5	59.9	116.0	71427.3	71.4	0.84
13.6		85.5	71.9	119.0	73274.5	73.3	0.98
15.6		73.9	58.3	100.0	61575.2	61.6	0.95
15.6		93.0	77.4	118.0	72658.8	72.7	1.07
16.1		111.6	95.5	138.0	84973.8	85.0	1.12
16.0		99.3	83.3	140.0	86205.3	86.2	0.97
16.0		83.7	67.7	114.0	70195.7	70.2	0.96
16.1		73.2	57.1	108.0	66501.2	66.5	0.86
16.1		98.3	82.2	130.0	80047.8	80.0	1.03
16.0		83.3	67.3	130.0	80047.8	80.0	0.84
16.0		89.8	73.8	150.0	92362.8	92.4	0.80
15.9		106.2	90.3	146.0	89899.8	89.9	1.00
16.1	66.0	61.5	45.4	75.0	46181.4	46.2	0.98
13.6	107.1	86.7	73.1	130.0	80047.8	80.0	0.91
16.0	157.4	135.2	119.2	170.0	104677.9	104.7	1.14
						average:	**0.98**

Bank Material Density Walnut Camp Tin Mass (g)							
A	B	C	D=C-A	E	F=E*π*(14mm)^2	G=F/1000	H=D/G
Empty	Full (wet)	Full (dry)	Soil Mass (g)	Length (mm)	volume (mm^3)	volume (cm^3)	Density (g/cm^3)
15.9	111.2	91.6	75.7	128	78816.3	78.8	0.96
13.6	120.7	86.0	72.4	141	86821.1	86.8	0.83
13.6	118.7	105.6	92.0	146	89899.8	89.9	1.02
13.6	143.6	110.4	96.8	156	96057.3	96.1	1.01
13.5	79.3	63.7	50.2	106	65269.7	65.3	0.77
15.4	86.5	72.9	57.5	139	85589.6	85.6	0.67
15.6	130.7	101.4	85.8	151	92978.6	93.0	0.92
16.0	154.2	124.0	108.0	162	99751.8	99.8	1.08
16.0	169.5	139.7	123.7	172	105909.4	105.9	1.17
16.1	79.5	69.2	53.1	105	64654.0	64.7	0.82
15.6	106.2	79.6	64.0	116	71427.3	71.4	0.90
15.6	100.7	77.6	62.0	127	78200.5	78.2	0.79
15.9	111.7	98.8	82.9	125	76969.0	77.0	1.08
16.0	102.9	95.7	79.7	140	86205.3	86.2	0.92
16.0	68.9	57.3	41.3	105	64654.0	64.7	0.64
16.1	116.9	110.8	94.7	153	94210.1	94.2	1.01
16.1	109.9	89.0	72.9	120	73890.3	73.9	0.99
13.5	127.8	109.3	95.8	163	100367.6	100.4	0.95
13.6	116.9	99.6	86.0	143	88052.6	88.1	0.98
13.6	117.3	96.9	83.3	129	79432.0	79.4	1.05
						average:	**0.93**