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Hollister Hills SVRA Sediment Budget: Water Year 2010- 2011

FALL 2011

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Publication No. WI-2011-04b is the same as Publication No. WI-2011-04, with the following corrections.
1) Standard units have been removed from Table 2 and 3.
2) The paragraph below Table 3 has a corrected value of sediment for Hudner gage.

Executive Summary

California State Parks operates eight State Vehicular Recreation Areas (SVRA) where off-road driving is encouraged and managed. A core value of the Hollister Hills SVRA mission is conservation leading to sustainable off-road vehicle use. To further their proactive conservation program, resource managers from the Hollister Hills SVRA have initiated a partnership with Faculty and students from the Cal State Monterey Bay Division of Science and Environmental Policy to calculate and interpret the sediment yield from the park watersheds. The information will be used to inform future restoration measures in the park.

In water year 2010-2011, telemetered YSI water quality sondes were installed in Bird Creek above and below the region with off-road vehicle use. The sondes measure pressure and turbidity. The sondes were deployed after the beginning of the winter runoff period, so this report does not include a full year of analysis. From this partial record we estimate that the watershed produced approximately 971,000 m^3 (790 acre-ft) of water. We measured 1.7 tonnes km^{-2} of sediment passing the gage located above the park, whereas the sonde downstream of the park yielded approximately 30.6 tonnes km^{-2}. The increased sediment yield is due in part to the earlier deployment of the downstream gage (12/23/10) relative to the upstream gage (2/15/11).

Parsing the sediment yield into component sources is difficult for a variety of reasons. While not all sediment sources will be evaluated in this study, we have begun to establish benchmarked cross sections, longitudinal profiles and bankpin arrays to estimate sediment contributed from in-stream sources. We have also collected baseline terrestrial LiDAR data in a few key locations to quantify local erosion and landslide rates. The survey and LiDAR data will be presented in the next annual report.

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1 Introduction

1.1 Background

As part of its ongoing effort to improve park resource management, Hollister Hills State Vehicular Recreation Area (HHSVRA) contracted the Watershed Geology Lab at California State University Monterey Bay (CSUMB) to monitor sediment discharge into Bird Creek. CSUMB will conduct a five-year watershed assessment of HHSVRA that will help the resource managers of the park understand and manage the erosion impacts of off-highway vehicles (OHVs). This report presents the data from water year 2010-2011, the first year of monitoring.

1.2 Study Area

The study area for this project is the Bird Creek watershed (Figure 1). Bird Creek drains an eastern slope of the Gabilan Mountain range down to the San Benito River. The Bird Creek watershed is located east of the Monterey-San Benito county line, approximately 20 km northeast of Salinas. The Bird Creek watershed is 39.1 km^2, and 16.5 km^2 are within the boundary of HHSVRA. The ridge defining the upper watershed has an elevation of approximately 750 m and the watershed drains down to 115 m, where there is a confluence with the San Benito River. A portion of HHSVRA also drains into Cienega Creek, which is the neighboring drainage to the north of Bird Creek. Cienega Creek was not assessed as part of this study.

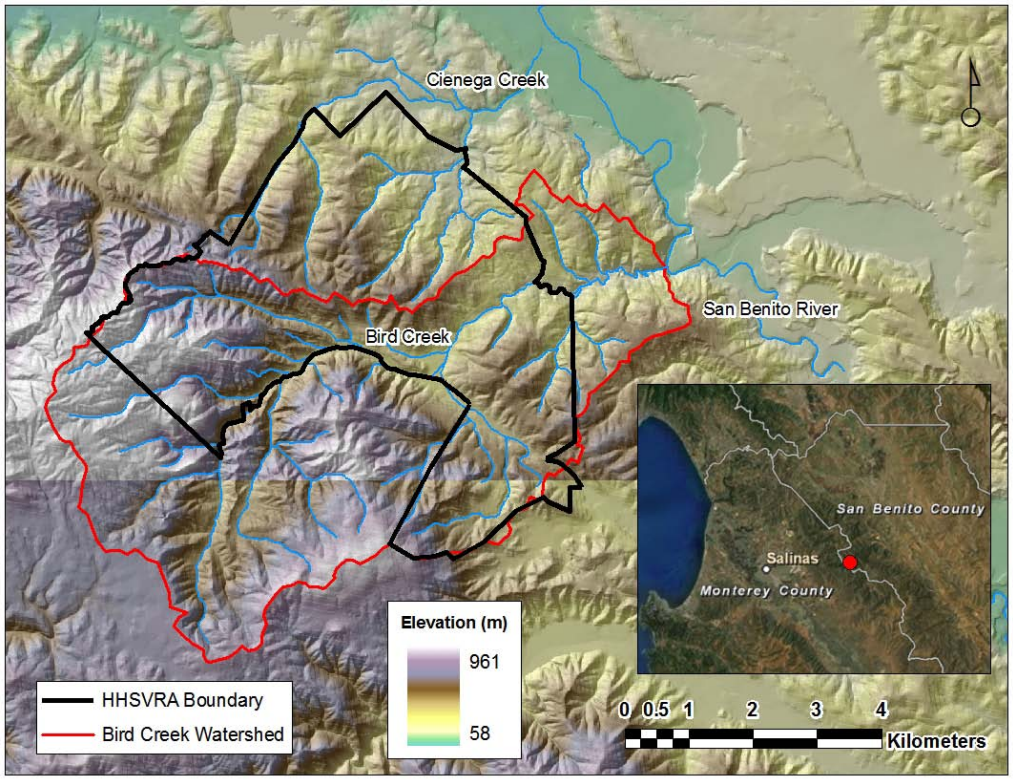

Figure 1. Location map for Hollister Hills State Vehicular Recreation Area and the Bird Creek watershed.

1.2.1 Geologic Setting

The geology of the study area may play a significant role in the sediment budget of Bird Creek. The San Andreas Fault, which forms the boundary between the Pacific and North American tectonic plates, runs through the center of the park (Figure 2). The Bird Creek channel and northern watershed divide are offset over 1000 m by the right-lateral motion of the San Andreas Fault. The presence of the fault creates two distinctly different geologic settings within the Bird Creek watershed and HHSVRA. We examined the documented soil units on either side of the fault (Figure 2), as well as a widely used erodibility factor (K) (Figure 3). In practical terms, K is a parameter defined as the average annual erosion potential of a given soil through hydrological processes (i.e. rain drop splash, overland flow, etc.; Romkins et al. 1998). Soils high in clay or sand content usually have low K values (0.05-0.15), while soils with moderate silt content such as silt-loams and high silt content have moderate to high K values (0.2-0.4 and >0.4, respectively; IWR 2002).

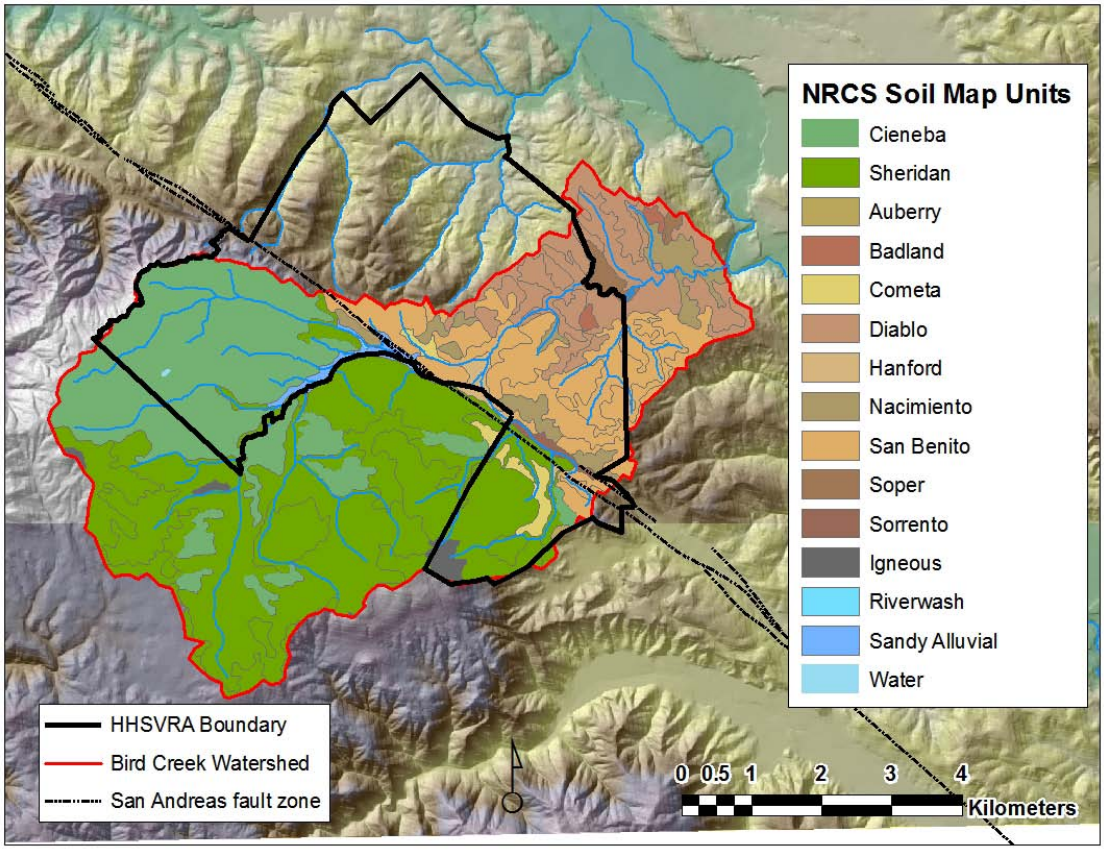

Figure 1. Soil map of the study watershed. Coloring is drawn to accentuate the complexity of soils on the northeast side of the San Andreas Fault (lower watershed), as compared with the southwest side (upper watershed).

To the southwestern side of the San Andreas fault, the bedrock is comprises dolomitic marble and Mesozoic granitic rocks (Harden et al. 2001). The marble from this area has been quarried for use in road construction, with at least one marble quarry still in operation. This area, comprising the upper half of Bird Creek watershed, is dominated by two soil units: the Cieneba and Sheridan units (NRCS 2011). When examining soil stability in terms of *K*, the area southwest of the San Andres (the upper watershed) has a midrange value of 0.17 (NRCS 2011). The relatively hard bedrock in this area weathers into coarse and highly permeable soil, and is susceptible to gullying, but is less prone to large landslide events (Harden et al 2001).

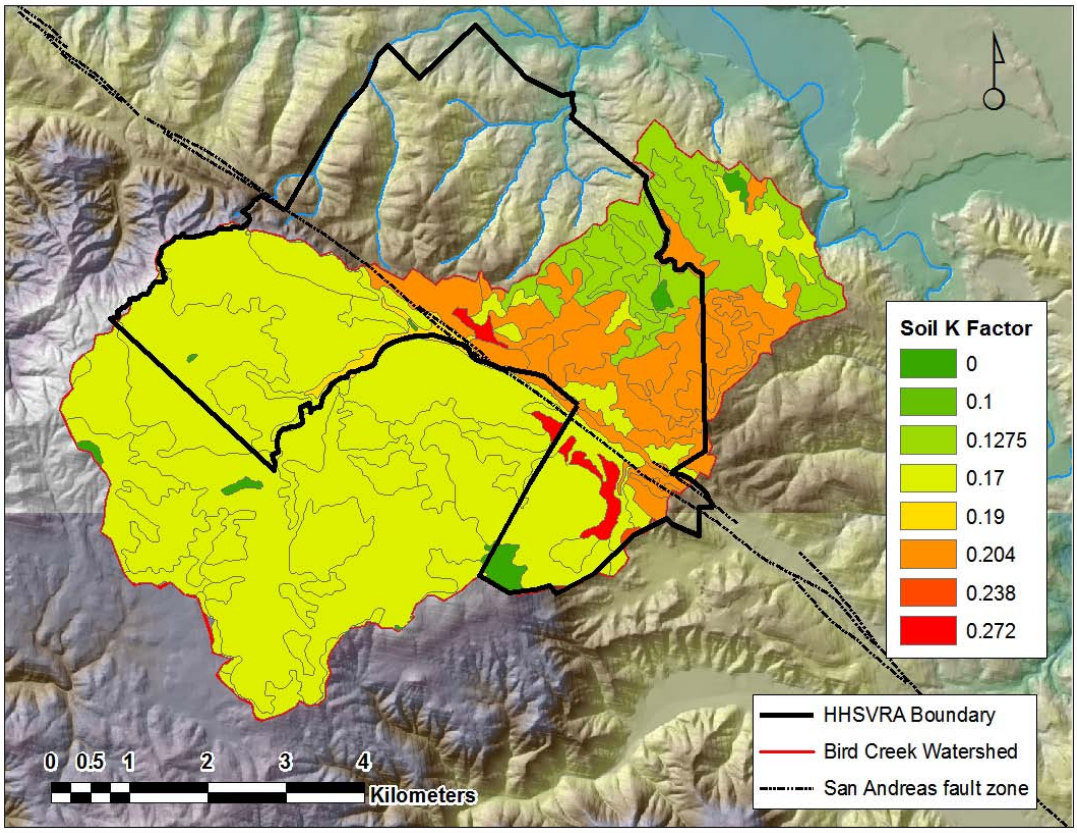

Figure 2. Soil erodibility factor (*K*) map. Nearly all of upper Bird Creek has a *K* factor of 0.17, while the soils in lower Bird Creek generally range from 0.1275 to 0.204.

On the northeastern side of the San Andreas Fault the landscape (lower watershed) is chiefly underlain by Pliocene sandstone and mudstone (Harden et al 2001). Marine invertebrate fossils are locally present in some of the sandstone outcrops in this area. The lower watershed has more soil variability than the upper watershed, and is composed of eight different types of soil (NRCS 2011). In terms of *K*, the lower watershed is composed of moderately to highly erodible soils. Soils in this area typically have much finer grain size, and are often impermeable. These soils are less susceptible to gully formation, but soils in this area are more susceptible to slumps and earthflows (Harden et al. 2001).

1.2.2 Hydrologic Setting

The hydrologic setting for Bird Creek is a Mediterranean climate in which most of the precipitation falls between October and April. The average annual precipitation for Bird Creek is 419 mm, ranging from 397 mm in the lower watershed to 491 mm at the ridge tops (Prism 2004). The rainfall in Central California is highlighted by rare, large rain events (such as El Nino winters), which can have dramatic and lasting impacts on landscapes and infrastructure.

Small streams in Central California often have a "flashy" hydrograph, in which short term large flow events account for a large portion of annual stream discharge. Most stormflows can be expected to last less than 24 hours, although multiple rain events within a short period of time may lead to longer lasting (and relatively higher) flows. Similarly, rain events late in the season will generate larger runoff events, as a wet antecedent moisture condition will not allow soils to absorb as much of the rainfall. Hot and dry summers typically lead to ephemeral streamflow in this region, including Bird Creek. Ephemeral streams typically have a period of baseflow between late spring and the start of the next rainy season. Baseflow is the condition when all streamflow originates from gradually declining groundwater reserves, which were recharged during the rainy season.

Bird Creek has several tributaries on both HHSVRA land and neighboring private land (Figure 4). Bird Creek exists in a managed landscape which has led to alterations in the natural hydrology of the area. Many of the tributaries on the HHSVRA property have sediment basins which store and moderate the release of stormwater, reducing the "flashiness" of the hydrograph (Figure 4).

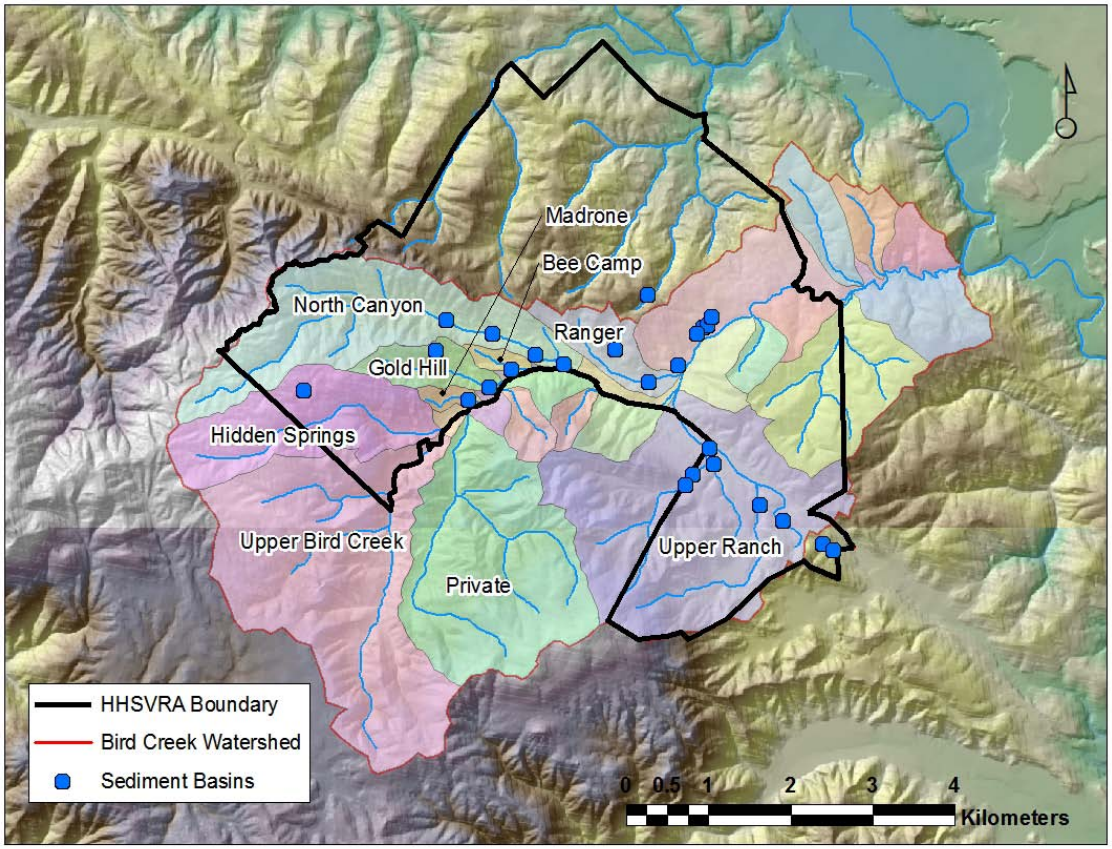

Figure 3. Area map showing sub-watersheds within the Bird Creek watershed and HHSVRA sediment basins.

1.3 Goals

Due to the five year duration of this project, the goals are split into an overall goal and annual goals for the current year of the project.

Overall Goal: Quantify the total volume of sediment entering Bird Creek from HHSVRA property, qualitatively document the sediment sources, and suggest strategies to reduce sediment input.

Goals for Water Year 2010-2011:

1. Establish and calibrate all monitoring equipment, and quantify sediment contribution to Bird Creek being generated in the reach running adjacent to and within HHSVRA.
2. Survey initial stream cross sections and longitudinal profiles, and set bank pins
3. Collect baseline terrestrial LiDAR at a few key erosion and landslide sites

2 Methods

The methods used to quantify the sediment discharge from Bird Creek can be broken down into two categories: continuous gaging and event based sampling. Continuous gaging yields surrogate parameters (water depth, turbidity) which are later converted into useful sediment discharge parameters (water discharge, suspended sediment discharge, bedload discharge). The continuous parameters are converted using event-based spot samples and a rating curve, which is a mathematical relationship between the continuous data and the event based data (See Appendix A for rating curves used in Water Year 2010-2011). Bedload and suspended sediment were rated with water discharge, which assumes a positive relationship between water discharge and sediment discharge. Additionally, suspended sediment was rated with turbidity, which assumes suspended particles that refract light are positively related to suspended sediment (Minella et al. 2008; Wass et al. 1997).

2.1 Continuous Gaging

To facilitate continuous monitoring of sediment discharge in Bird Creek, two telemetered YSI multi-parameter water quality sondes were deployed at two sampling sites (Figure 5). Each sonde records water pressure (which is converted to a depth/stage), temperature, dissolved oxygen, turbidity, and pH at 15 second sampling intervals. A Level Troll pressure transducer, which records stage, was also installed near the ranger housing at park headquarters.

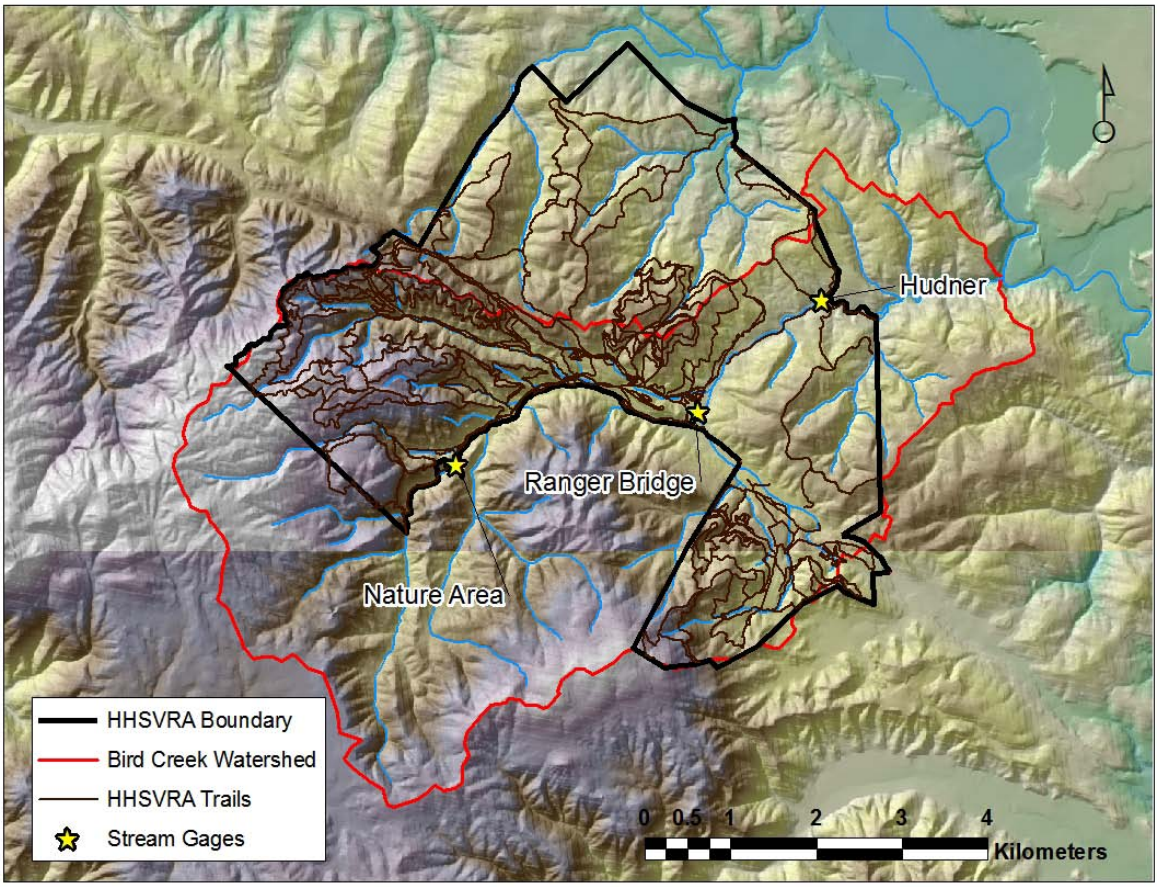

Figure 4. Map of the locations of the Nature Area, Ranger Bridge and Hudner gages. Note the Nature Area gage is upstream of nearly all OHV impact, and Hudner is downstream of nearly all OHV impact.

An above-and-below impact sampling design was used in order to quantify the amount of sediment that entered Bird Creek from HHSVRA. The "above impact" sampling site was located near the western park boundary at Nature Area. This location was selected because it was located upstream of all OHV impacts, it has a gage pool with good hydraulic control, and it was easily accessible for repeat sampling throughout the year. The "below impact" sampling site was located near the eastern park boundary at the Hudner special use area. This site was selected due to accessibility, and because it was located below all frequently used OHV trails. The pressure transducer was installed at the ranger housing because there is a bridge located just downstream, making the site very stable through time. Further, this site has a history of streamflow measurements that may aid in flow frequency analysis.

2.2 Event-based Sampling

Sediment discharge in a fluvial system often only happens during storm events, so the sampling design for this project was focused on flood events. Water discharge, suspended sediment, and bedload were measured over a wide range of flows to create robust rating curves.

Water discharge was measured using a Flowtracker Acoustic Doppler meter. Discharge was measured near the stream gage at all sites in order to minimize the variance between the water discharge recorded at the gage and the discharge at the location of the Doppler measurements. Discharge at each site was calculated using a modified version of the U.S. Geological Survey (USGS) guidelines as described by (Nolan and Shields 2000), The only significant modification to the USGS guidelines was when we sampled discharge measurements at fewer verticals across the stream due to the small cross-sectional width of Bird Creek.

Suspended sediment concentration was measured using a DH-48 depth integrated suspended load sampler, and bedload mass was measured using a Helley-Smith bedload sampler. Suspended sediment and bedload samples were each collected at even intervals across the stream channel in order to integrate spatial variation of sediment discharge within the cross section into the suspended sediment or bedload sample. Suspended sediment and bedload samples must be processed in the lab to yield a suspended sediment concentration (SSC) (mass/volume) and bedload discharge (mass/time). SSC must be combined with streamflow data (volume/time) in order to calculate suspended sediment discharge (mass/time).

2.3 Stream Surveys

Several stream cross sections were benchmarked with rebar rod and surveyed with autolevel or rotating laser. The surveys are generally precise to 2 cm vertical and 5 cm horizontal. Bank pins have been installed at many locations as well. Lastly, a few locations were surveyed with high precision mobile terrestrial LiDAR. These surveys are baseline measurements for determining erosion in subsequent years. The survey results will be presented in annual reports starting in the 2011-2012 water year.

3 Results

The sediment discharge data will be presented in three sections: hydrologic, bedload and suspended sediment data.

3.1 Hydrologic Data

Hydrologic data for this report consists of streamflow and rainfall data. Streamflow was monitored at the three gage locations (Figure 5) and rainfall data was downloaded from an existing HHSVRA weather station (Radio Ridge). During Water Year 2010-2011 there were 494 mm of rain, which is slightly above average. Due to late deployment dates, each stream gage recorded only a portion of the water year. Approximately 100,000 m^3 of water flowed past the longest running, and most downstream gage (Table 1).

Table 1. Summary of hydrology data from Water Year 2010–2011, which had slightly above average rainfall.

	Gaged Period	Total Precipitation		Total Q_w	
	mm/dd/yy	mm	in	m^3	acre-ft
WY 2010 - 2011	10/1/2010 - 10/1/2011	494	19.53	-	-
Nature Area	2/15/11 - 10/1/2011	261	10.32	330169	267.7
Ranger Bridge	2/2/11 - 10/1/2011	262	10.36	827070	670.5
Hudner	12/23/10 - 10/1/2011	352	13.91	971347	787.5

The "flashy" flood waves of Bird Creek can be seen in the plotted hydrographs (Figure 6). The peak discharge on the largest storm of the year (3/24/2011) ranged from 0.67 m^3/s in the Nature Area to 1.97 m^3/s at Hudner. Each gage site returned to baseflow approximately by May of 2011. The Nature Area gage was dry by the end of summer, but the Hudner gage site continued to have perennial running water. The gages were removed for maintenance in mid-summer.

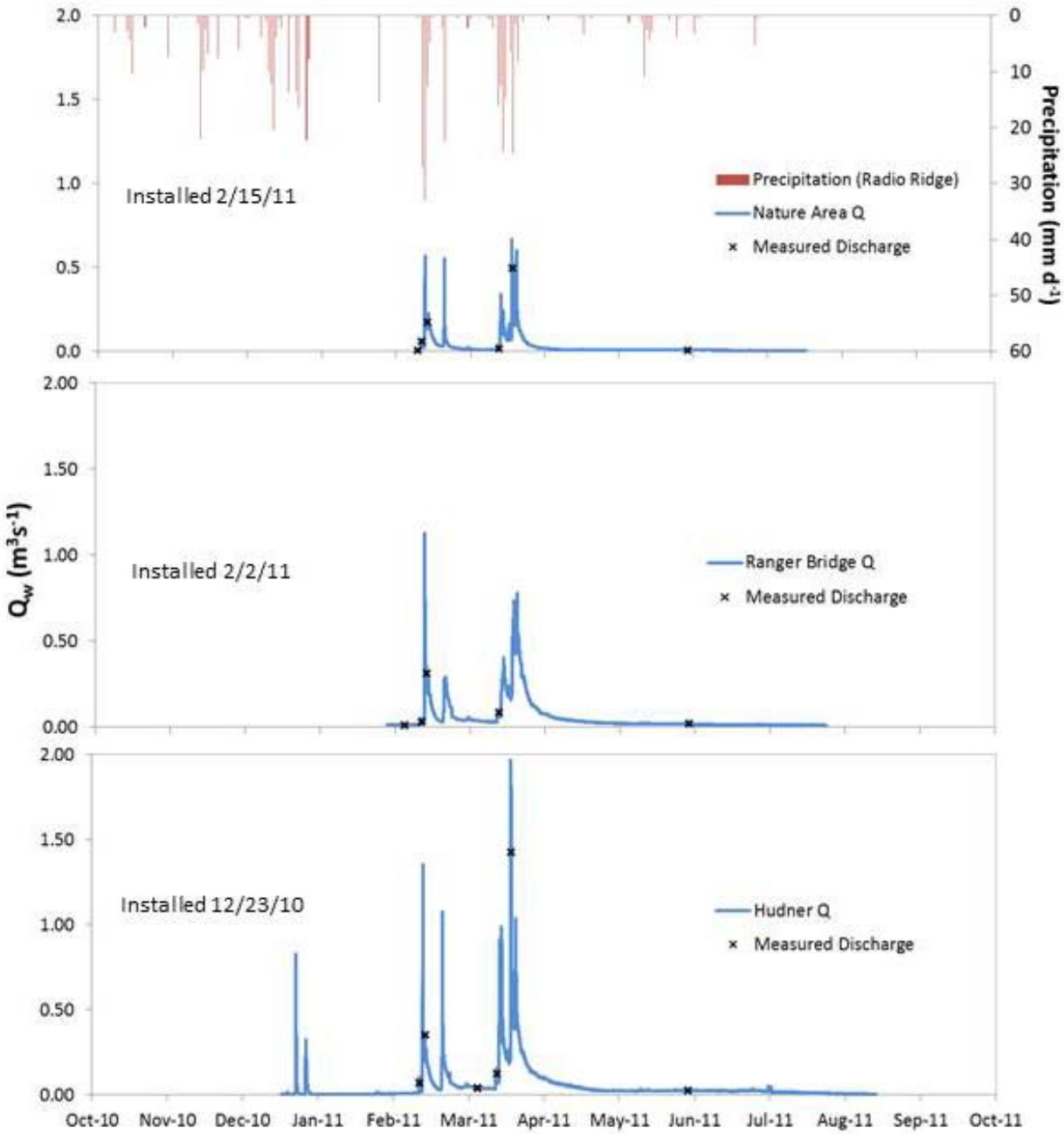

Figure 5. Hydologic data for water year 2010-2011. The magnitude of flood peaks and overall flood volume increases at gage sites lower in the watershed.

3.2 Bedload

Bedload was sampled at the Nature Area and Hudner gage locations for Water Year 2010-2011 (Table 2). As would be expected in a system with or without OHV use, bedload discharge (Q_{bed}) increased between the Nature Area and Hudner. No measurable bedload was moving when Bird Creek was flowing under approximately 0.06 and 0.05 m^3/s at the Nature Area and Hudner

gages, respectively. The peak Q_{bed} recorded at the Nature Area gage was 24.45 g/min and at the Hudner gage was 38.42 g/min. The total mass of bedload passing the gaged sites was approximately 21 kg at the Nature Area and 176 kg at Hudner.

Table 2. Summary of bedload data collected at the Nature Area and Hudner gage locations.

	Gaged Period	Threshold for bedload movement	Peak Q_{bed}	Total Bedload
	mm/dd/yyyy	$m^3 s^{-1}$	$g\ min^{-1}$	kg
Nature Area	2/15/2011 - 10/1/2011	0.0615	24	21
Hudner	12/23/2010 - 10/1/2011	0.052	38	176

The bedload movement during the gaged periods occurred during flood waves, with instantaneous bedload discharge rarely exceeding 30 g/min at either gage site (Figure 7).

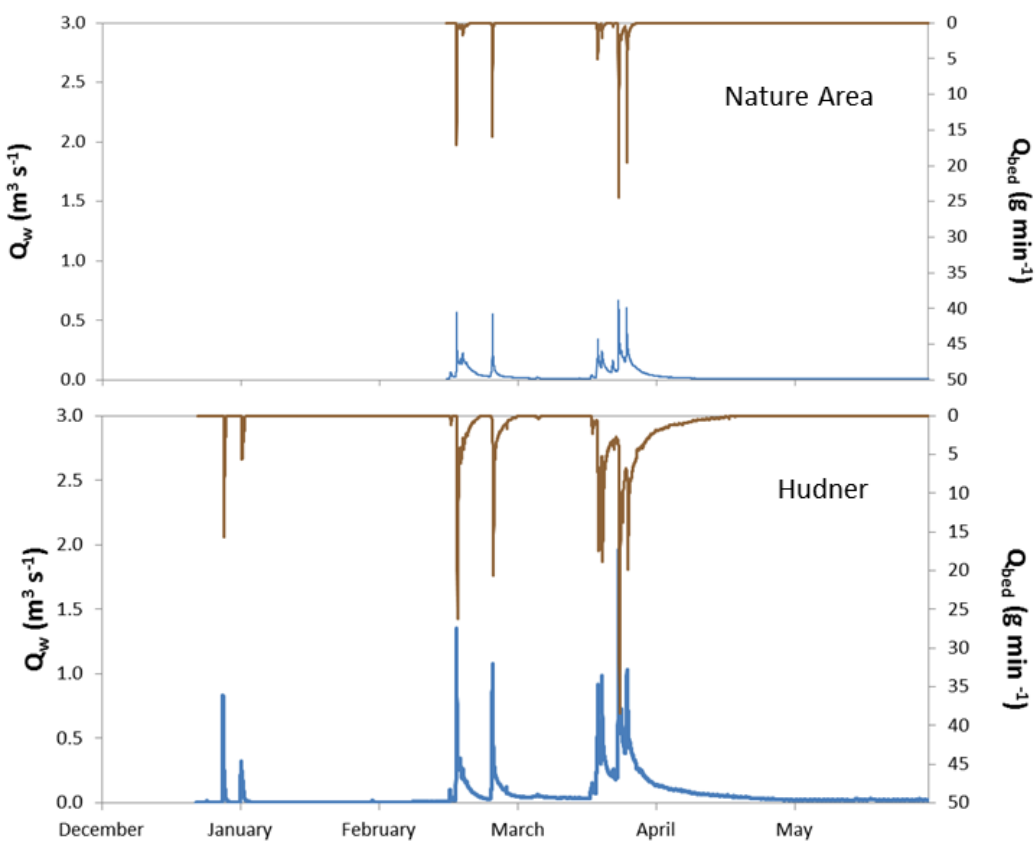

Figure 6 Gaging records for Q_w (blue) and Q_{bed} (brown) at the Nature Area and Hudner gage sites

3.3 Suspended Sediment

Suspended sediment was observed and sampled at the Nature Area and Hudner gages. In general, the water at both sites was clear except during storm events. Total suspended sediment mass was calculated in two independent ways. The first method used the continuous measure of Q_w rated by instantaneous field measurements of suspended sediment discharge (Q_{sus}). The second method was to rate a continuous record of turbidity with field measurements of Q_{sus}. Turbidity is a better surrogate than Q_w for Q_{sus}, but the turbidity meter on the YSI sondes does not have a high enough range to capture the peaks of turbidity during significant flow events.

3.3.1 *Suspended Sediment Rated to Q_w*

The threshold for Q_w under which there was no Q_{sus} was 0.13 m^3/s for the Nature Area and 0.052 m^3/s for Hudner. During storm events, there was a dramatic increase in suspended sediment discharge (Q_{sus}) between the two gages (Table 3). During the highest flows of the year on March 24th, Bird Creek experienced the annual peak Q_{sus} of 17 kg/min at the Nature Area gage and 586 kg/min at the Hudner gage.

Table 3. Summary of suspended sediment data collected at the Nature Area and Hudner gage locations. Note that Q_{bed} data were reported in g min^{-1} while Q_{sus} data are reported in kg min^{-1}.

	Gaged Period	Threshold for suspended sediment discharge	Peak Q_{sus}	Total Suspended Sediment
	mm/dd/yyyy	$m^3\ s^{-1}$	kg min^{-1}	kg
Nature Area	2/15/2011 - 10/1/2011	0.13	17	12342
Hudner	12/23/2010 - 10/1/2011	0.052	586	976519

The plots of Q_{sus} show the distribution of suspended sediment throughout the gaged period (Figure 8). Approximately 12,000 kg of suspended sediment passed the Nature Area gage. Nearly 1,000,000 kg of suspended sediment passed the Hudner gage between December 23rd, 2010 and the end of Water Year 2010–2011. Normalized to drainage area, we measured 1.7 tonnes km^{-2} of sediment passing the Nature Area gage and approximately 30.6 tonnes km^{-2} of sediment at the Hudner gage.

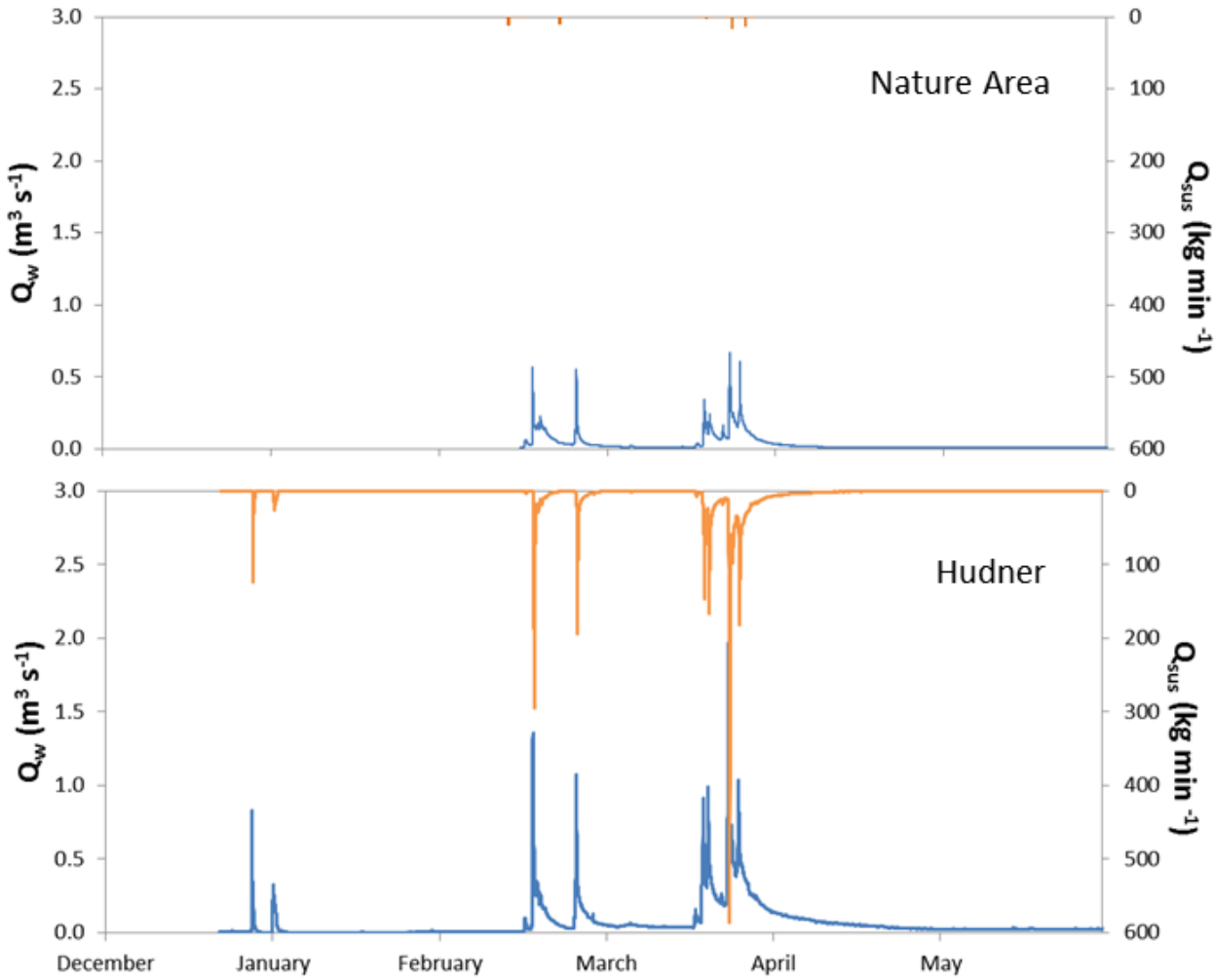

Figure 7. Gaging records for Q_w (blue) and Q_{sus} (orange) at the Nature Area and Hudner gage sites. Note the disparity in sediment discharge rates on the same storm events. Peak Q_{sus} at the Nature Area gage was 17 kg/min while the peak Q_{sus} at the Hudner gage site was 586 kg/min.

3.3.2 *Suspended Sediment Rated to Turbidity*

A continuous record of turbidity, rated to instantaneous field measurements of Q_{sus}, can be used to calculate total suspended sediment mass (Table 4). The turbidity at both the Nature Area and Hudner seemed to vary systematically with Q_w, with higher turbidity present at higher stream discharge (Figure 9). The total suspended sediment mass was calculated using the turbidity data. Despite short-lived anomalous turbidity response, these results corroborate the suspended sediment masses obtained through the continuous record of Q_w (Table 4).

Table 4. Comparison of the two techniques used rate suspended sediment in Bird Creek. Although there are anomalies in the turbidity data, the results of rating suspended sediment are similar with both techniques.

		Rated with Qw	*Rated with Turbidity*
	Gaged Period	**Total Suspended Sediment**	**Total Suspended Sediment**
	mm/dd/yyyy	kg	kg
Nature Area	2/15/2011 - 10/1/2011	12342	11892
Hudner	12/23/2010 - 10/1/2011	976519	1005917

The turbidity in the Nature Area has an anomalous shape in late March, while the turbidity at the Hudner gage site did not respond to a relatively large storm in late February (Figure 9). The Hudner turbidity sensor plateaued at 1200 NTU several times, which is the maximum turbidity the sensor can record.

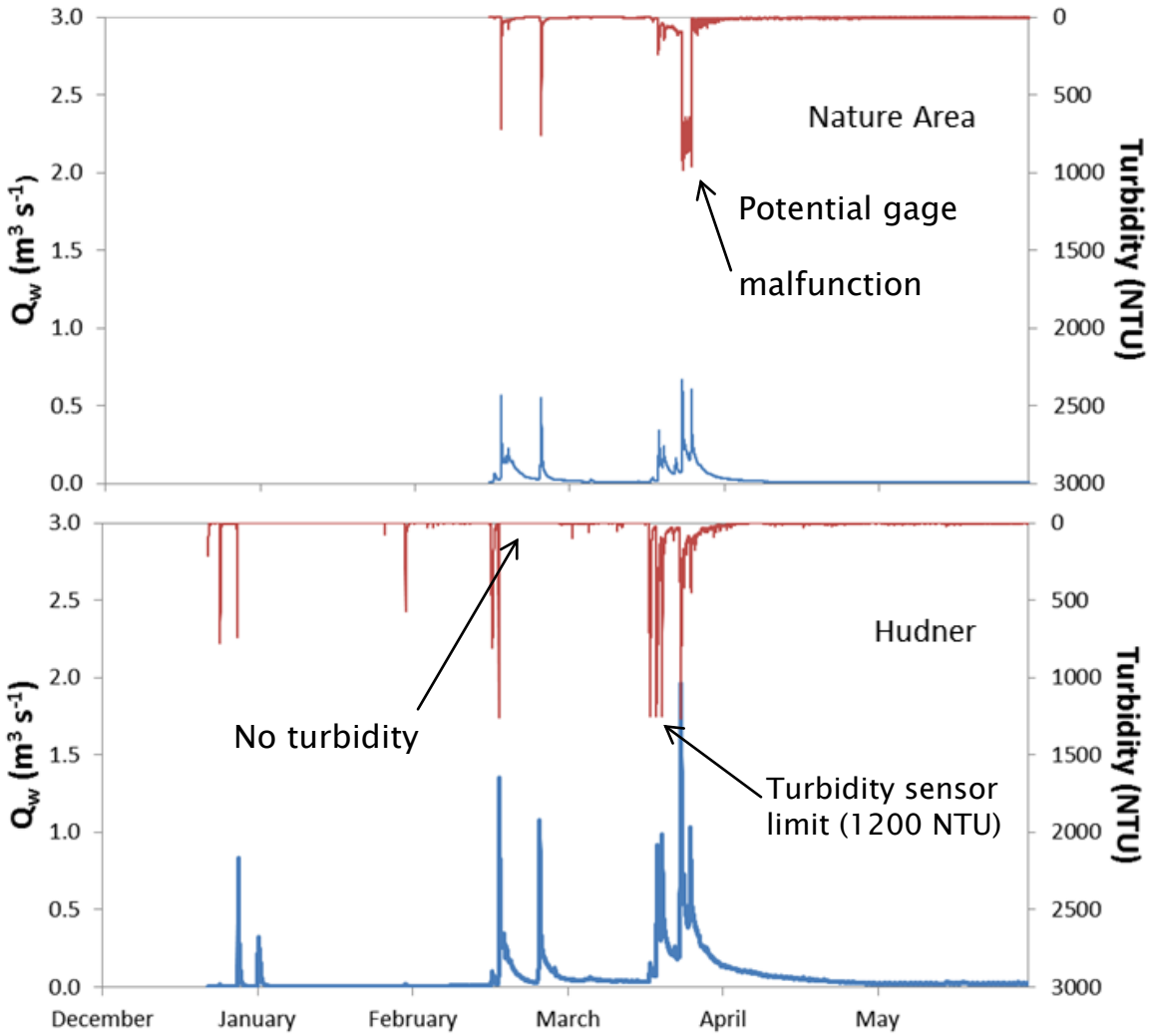

Figure 8. Gaging records for Q_w (blue) and turbidity (red) at the Nature Area and Hudner gage sites. A potentially anomalous periods of data are highlighted for each gage site.

4 Discussion

All data presented here are preliminary due to the short amount of time that the stream-gage monitoring program has been in place. The rating curves will change as more data are collected, so it will be necessary to frequently update the rating curves until enough data have been collected to produce reliable predictive models. While rating data are currently sparse, they span both low flows and the highest flow of the year (Appendix A), so these preliminary results should be relatively accurate.

When the Hudner and Nature gages are compared over the same time interval, there is clear increase in suspended sediment yield between the gages. Not all of that increase can be ascribed to OHV impacts, and it will difficult to parse the increased sediment load into component sources. The following factors contribute uncertainty.

1) The Bird Creek watershed drains private lands (grazed) as well as the park. Reconnaissance indicates that cattle have access to the creek and banks.
2) Streambank erosion, landslides, gullying, and other colluvial processes unrelated to OHV use are active in the watershed.
3) The geologic substrate is granodiorite above the Nature Area gage, but transitions to sandstone and mudstone across the San Andreas Fault, half-way through the park. Therefore, the Hudner gage is located downstream of highly erodible substrate that is not present at the upper gage.

Further study may be able to remove some of the uncertainty. The relative contributions of each sediment source and the specific subwatershed sources will be evaluated as this study continues. This year we determined that bedload transport is an insignificant fraction of the total sediment load of Bird Creek, so bedload will no longer be measured on a regular basis until future assessments indicate that bedload has increased. The lack of significant bedload is attributable to the existing array of sediment basins in the watershed (Figure 4).

5 References

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6 Appendix A – Rating Curves

Rating Q_w vs Stage

Continuous records of stream discharge (Q_w) at each gage are created from continuous records of stage through a model curve (rating curve) relating stage (m) to Q_w (m^3/s) (Figs. A1 to A3).

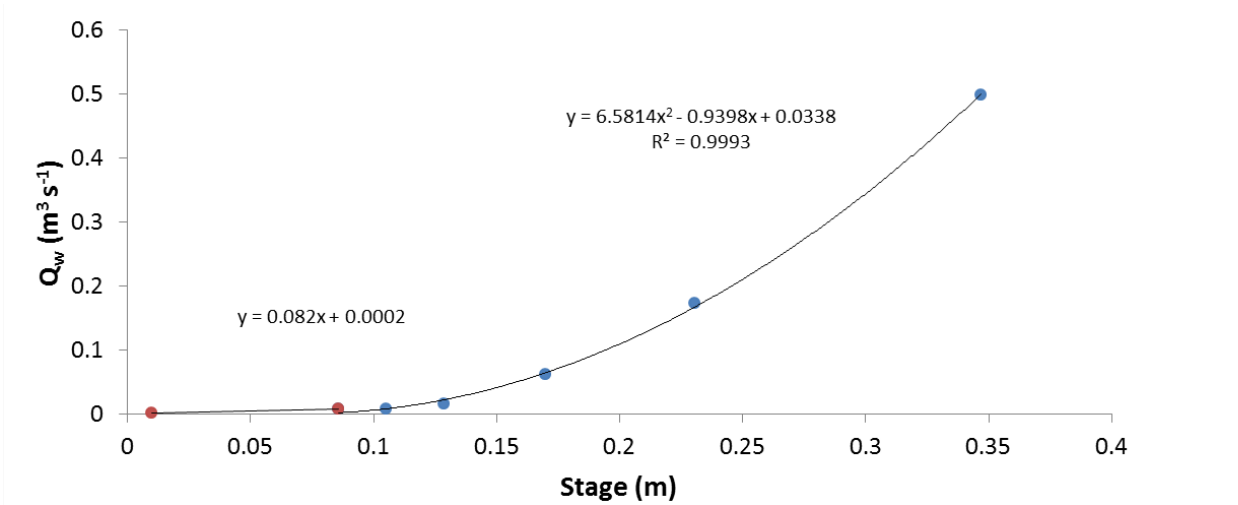

Figure 9. Rating curve for the Nature Area, relating continuously recorded stage to event based spot samples of Q_w.

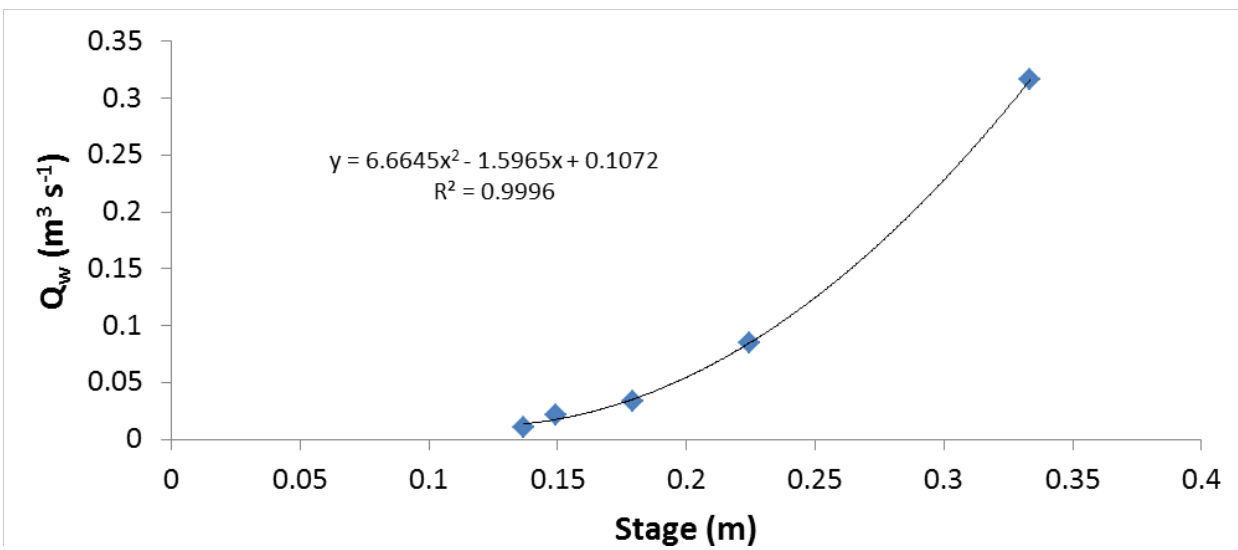

Figure 10. Rating curve for the Ranger Bridge, relating continuously recorded stage to event based spot samples of Q_w

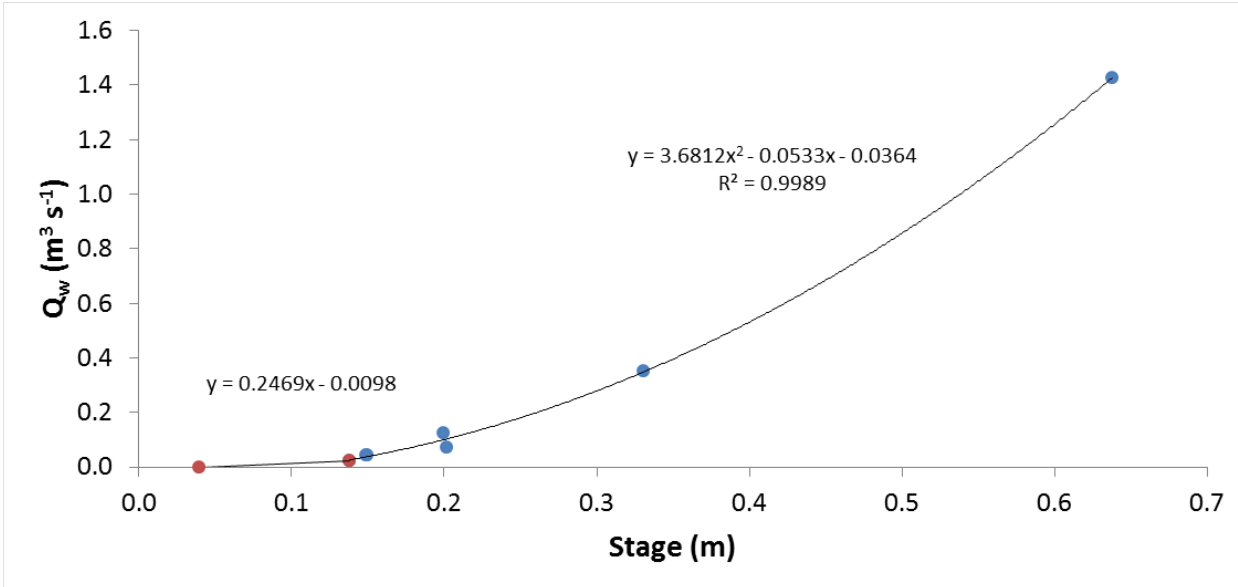

Figure A3. Rating curve for Huder, relating continuously recorded stage to event based spot samples of Q_w

Rating Q_{bed} vs Q_w

Continuous records of bedload discharge (Q_{bed}) and suspended sediment discharge (Q_{sus}) are developed with a rating curve relating Q_w (m^3/s) to Q_{bed} (kg/s) (Figs. A4 to A6).

Rating Q_{bed} vs Q_w

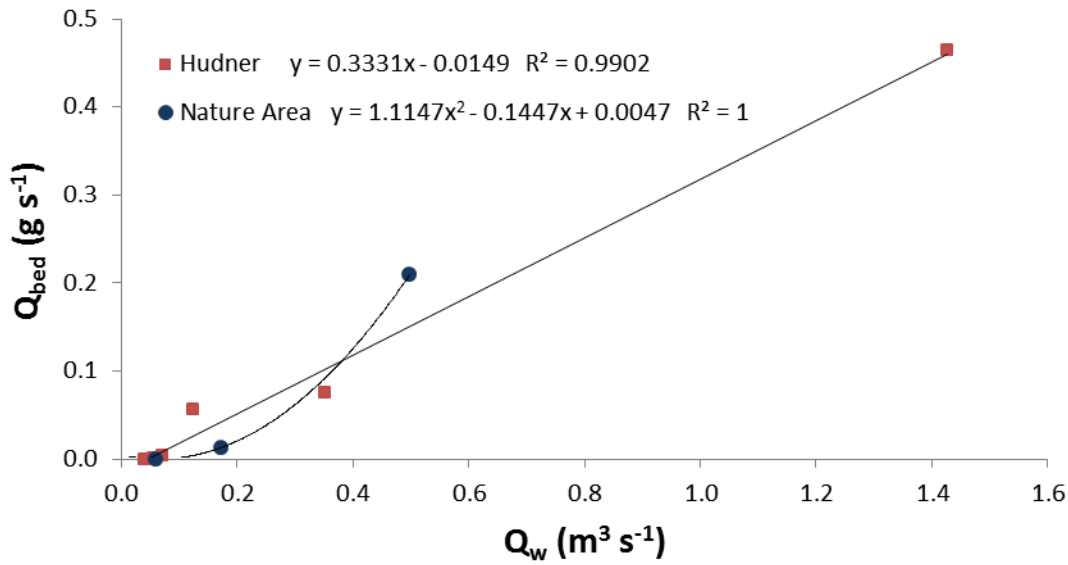

Figure A4. Rating curves to relate water discharge (Q_w) to bedload discharge (Q_{bed}).

Rating Q_{sus} vs Q_w

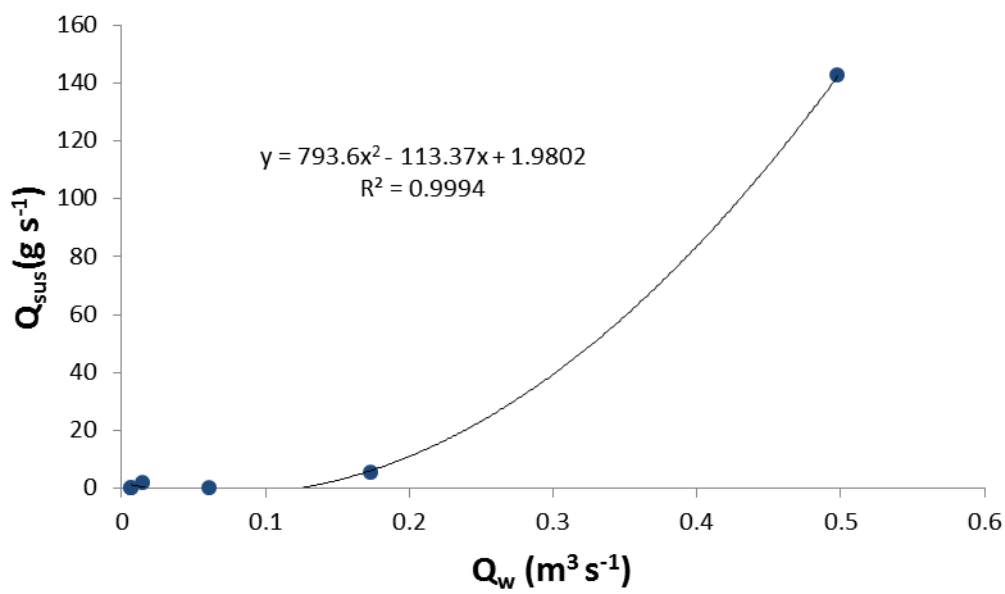

Figure A5. Rating curve for the Nature Area, relating water discharge (Q_w) to event based spot samples of Q_{sus}.

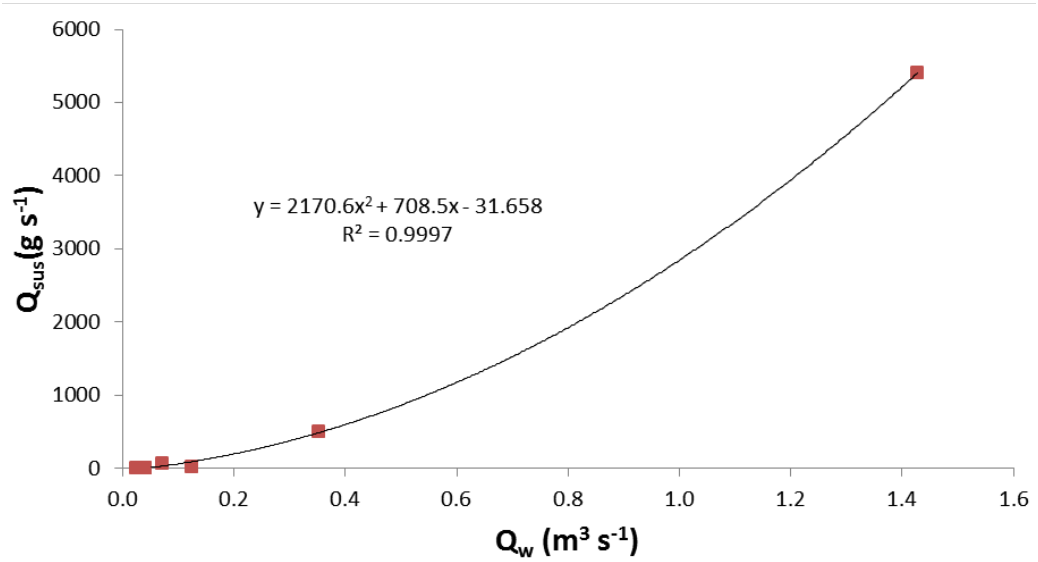

Figure A6. Rating curve for Huder, relating water discharge (Q_w) to event based spot samples of Q_{sus}.

Rating Q_{sus} vs Turbidity

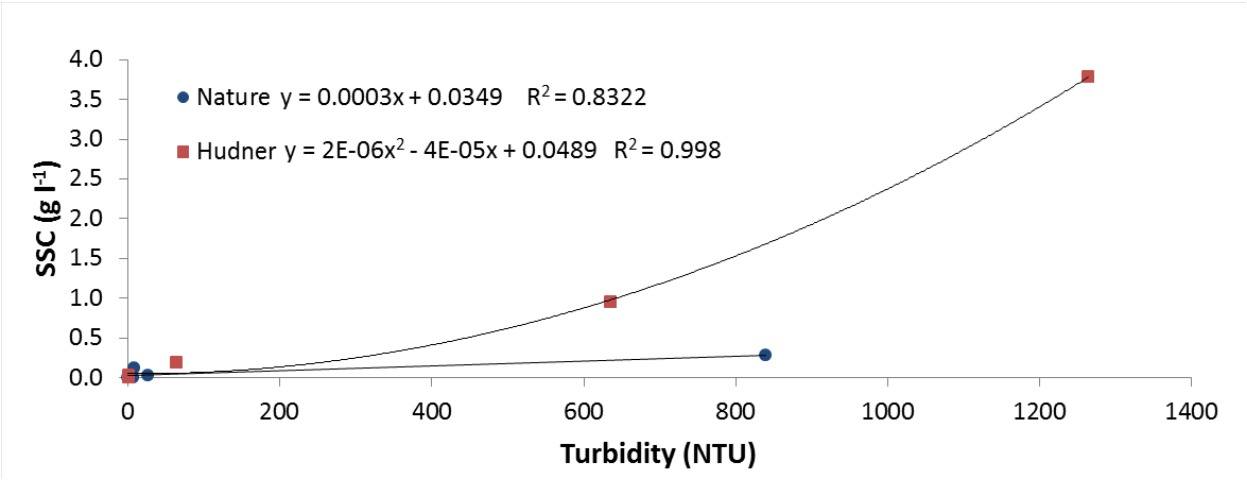

Figure A7. Rating curves for the Nature Area and Huder, relating turbidity (NTU) to event based spot.