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Hollister Hills SVRA Sediment Budget: Water Year 2011- 2012

FALL 2012

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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 (HHSVRA) 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 (WY) 2011 (October 1, 2011 to September 30, 2012), a telemetered YSI water quality sonde was installed in Bird Creek at Hudner special use area (Hudner), below the region with off-road vehicle use. The sonde measured pressure and turbidity. The sonde was deployed to capture the major runoff events of the water year. It successfully captured all events that were important for sediment transport. Data recorded by the sonde do not include the entire period of summer baseflow.

Hydrologic parameters of streamflow and sediment transport are highly variable through time. It is common to revise estimates of streamflow and sediment yield as more information becomes available. We present preliminary results in this report. These values may be revised in future reports.

The Radio Ridge rain gage in HHSVRA captured 271 mm (10.67 in) of rain in WY 2011, which is below the 419 mm (16.50 in) average. This rainfall produced approximately 91,600 m^3 (74 acre-ft) of water and 21,600 kg (23.8 tons) of suspended sediment that passed by the Hudner gage. The sediment yield was approximately 1000 kg km^{-2} (0.004 tons/acre). This very low yield is expected in a low rainfall year when a small proportion of the watershed area is actually contributing sediment to the streams. In a low rainfall year, only sediment very close to the channel network would be expected to move.

A correction in calculations is presented here for WY 2010 (Nicol et al., 2011). The yield for the Hudner gage was reported as 30.6 tonnes km^{-2} (30,600 kg km^{-2}). This value was reported to be approximately correct for both turbidity-rated and discharge-rated methods. A corrected turbidity-rated value indicates that the WY 2010 yield is 6.7 tonnes km^{-2} (6670 kg km^{-2} or 0.03 tons/acre). The yield for WY 2010 is much higher than for WY 2011 because rainfall was higher than average, and the creek was fully flowing for several months.

The values of sediment yield include contributions from all stakeholders and activities in the watershed. Approximately 50% of the watershed is not part of HHSVRA. Initial efforts were made this year to parse the sediment load into contributions from specific subwatersheds.

This effort was compromised by low rainfall. Analysis of 76 grab samples of suspended sediment at the gage sites and around various tributaries allowed us to effectively plan the WY 2013 sampling strategy.

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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 results of Water Year 2011, from October 1, 2011 to September 30, 2012 (WY 2011), and provides a correction for the 2010 water report (Nicol et al. 2011).

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. 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 in this study.

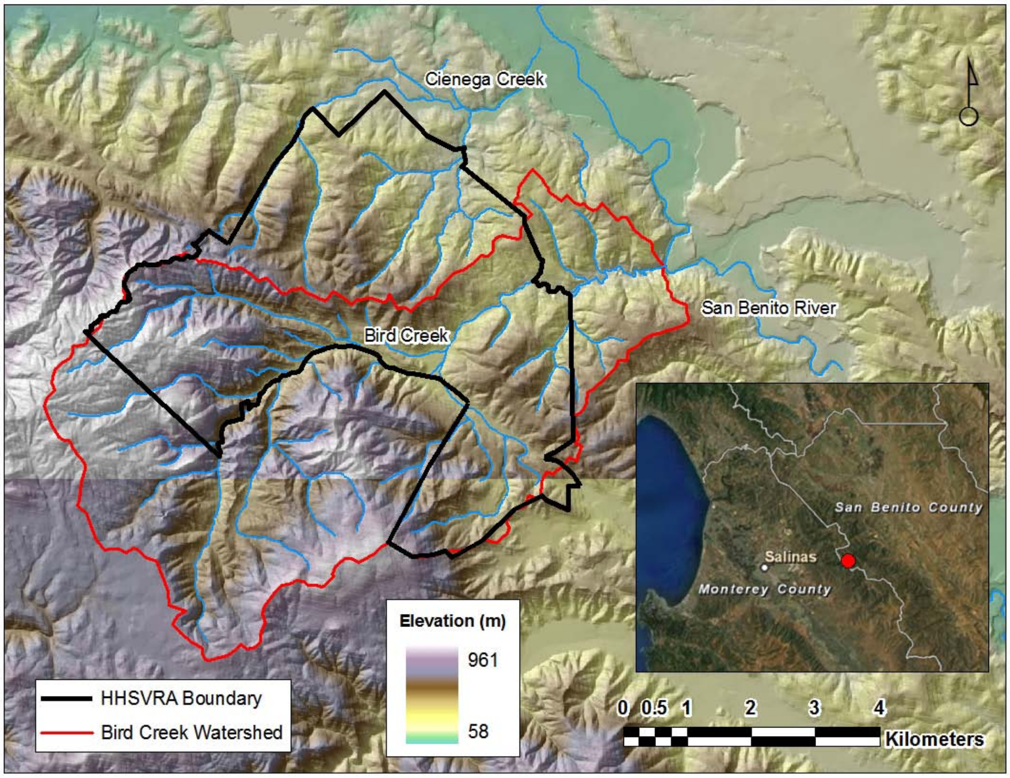

Figure 1. Location map for Hollister Hills State Vehicular Recreation Area and the Bird Creek watershed.

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. There is great variability in the 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).

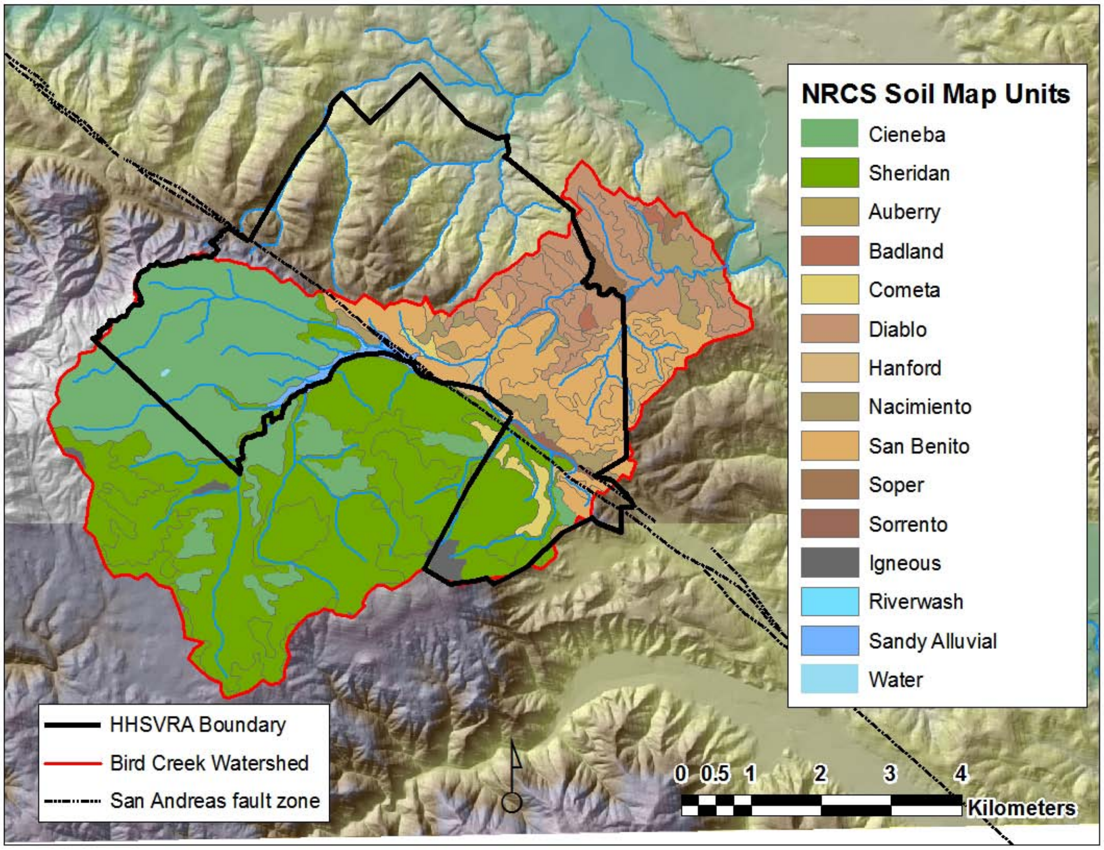

Figure 1. Soil map of the Bird Creek watershed. Note the change in soil type across the San Andreas Fault.

Southwest of the San Andreas fault, the bedrock 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--the upper half of Bird Creek watershed-- is dominated by two soil units: the Cieneba and Sheridan units (NRCS 2011; Figure 2). 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; it is susceptible to gullying, but is less prone to large landslide events (Harden et al. 2001).

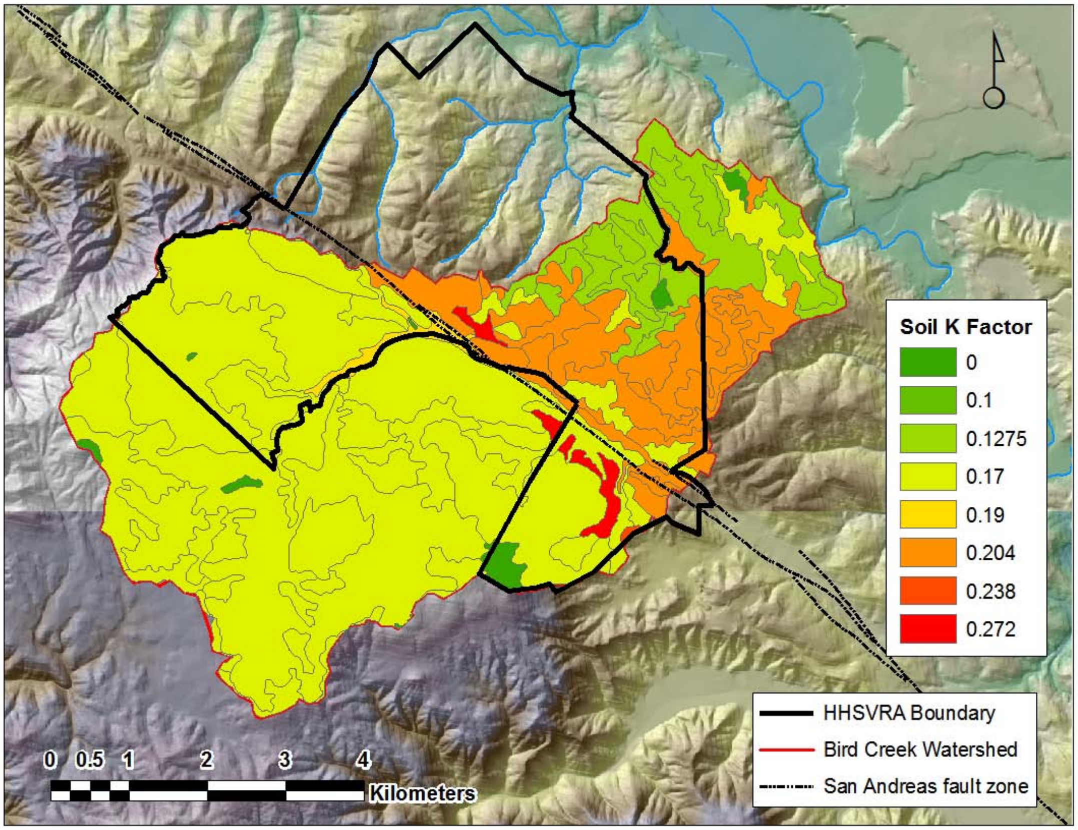

Figure 2. Soil erodibility factor (*K*) map. Nearly all of upper Bird Creek has a *K* factor of 0.17, while the soils in lower Bird Creek generally range from 0.1275 to 0.204.

Northeast 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 comprises 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 (16.5 in), ranging from 397 mm (15.6 in) in the lower watershed to 491 mm (19.3 in) at the ridge tops (Prism 2004). The rainfall in Central California is highlighted by rare, large rain events (such as El Niño 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. This behavior is present in Bird Creek except in two short reaches that have nearly perennial flow because of local active springs.

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 HHSVRA property have sediment basins which store and moderate the release of stormwater, reducing the “flashiness” of the hydrograph (Figure 4).

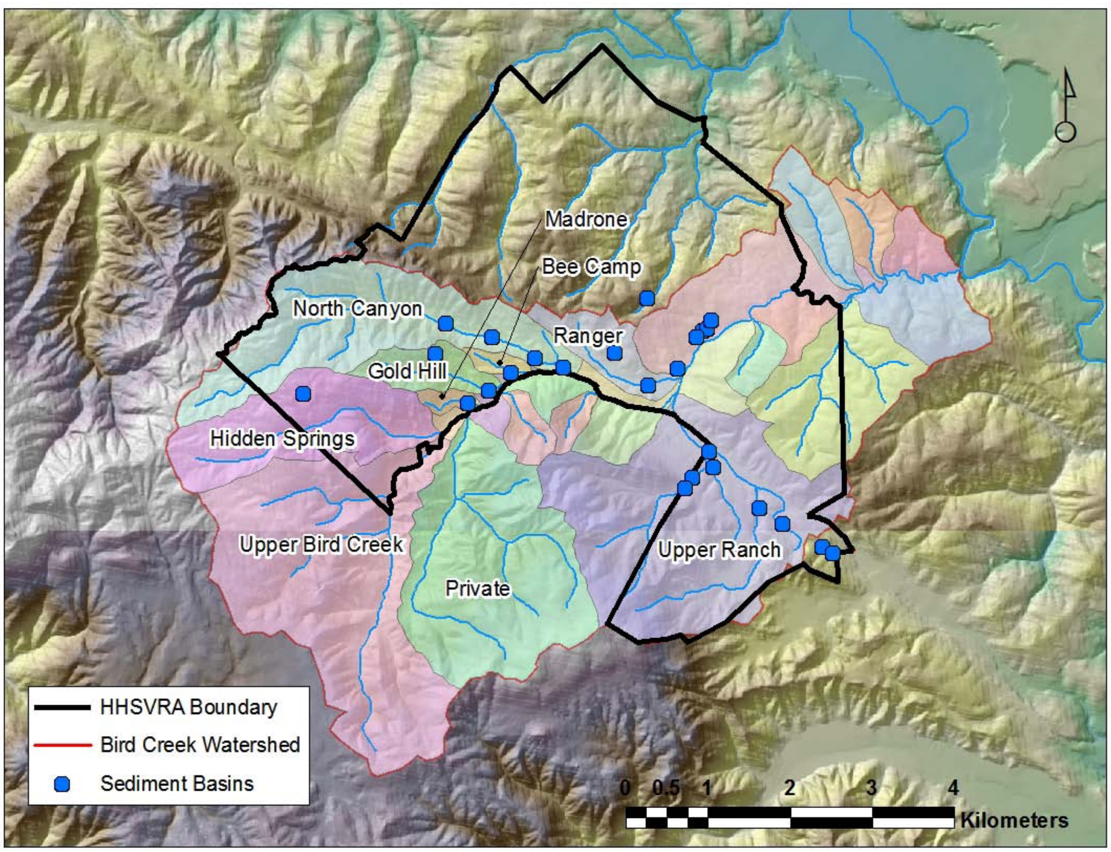

Figure 3. Area map showing sub-watersheds within the Bird Creek watershed and HHSVRA sediment basins.

1.3 Goals

The five year duration of this project allows us to split the project goals into an overall goal and annual goals for each 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 WY 2010:

1. Create long-term gage sites on Bird Creek.
2. Install and calibrate all monitoring equipment.
3. Quantify sediment discharge in Bird Creek above the Park and near where Bird Creek exits the Park.
4. Survey initial stream cross sections and longitudinal profiles, and set bank pins for bank erosion measurements.
5. Collect baseline terrestrial LiDAR at a few key erosion and landslide sites.

Goals for WY 2011:

1. Reinstall all monitoring equipment once baseflow returns to Bird Creek.
2. Quantify suspended sediment discharge in Bird Creek above the Park and near where Bird Creek exits the Park.
3. Re-survey stream cross sections and longitudinal profiles, and reset bank pins
4. Collect the second year terrestrial LiDAR at the same locations as in 2010.
5. Begin strategic grab sampling to determine if specific tributaries are disproportionately adding sediment to Bird Creek.

2 Methods

Sediment monitoring in 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. Suspended sediment was 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). Bedload sediment transport was measured in addition to suspended sediment in the WY 2010. In that year bedload was found to be a tiny fraction of the total sediment load (Nicol et al. 2011), so we have discontinued bedload monitoring until conditions indicate that bedload transport becomes important. Visual inspection of the bed during the peak flows of the current water year confirmed the lack of bedload transport during WY 2011. Our future work will continue to focus on suspended sediment transport.

2.1 Continuous Gaging

In WY 2010, a telemetered YSI multi-parameter water quality sonde was deployed at the Nature area (upstream of HHSVRA) and at the Hudner Ranch (at the downstream edge of HHSVRA) (Figure 5). In WY 2011, the reach of Bird Creek at the Nature Area never achieved winter base flow conditions, so a sonde was not deployed there. The Hudner sonde provided continuous monitoring of sediment leaving HHSVRA starting on November 9, 2011, at the onset of winter baseflow. The sonde records water pressure (which is converted to a depth/stage), temperature, dissolved oxygen, turbidity, and pH at 15 minute sampling intervals. A vented Level Troll pressure transducer, which records stage, was installed upstream of a small bridge near the ranger housing at park headquarters in the 2010 water year (Figure 5). The "Ranger" gage remained in service for WY 2011 as well.

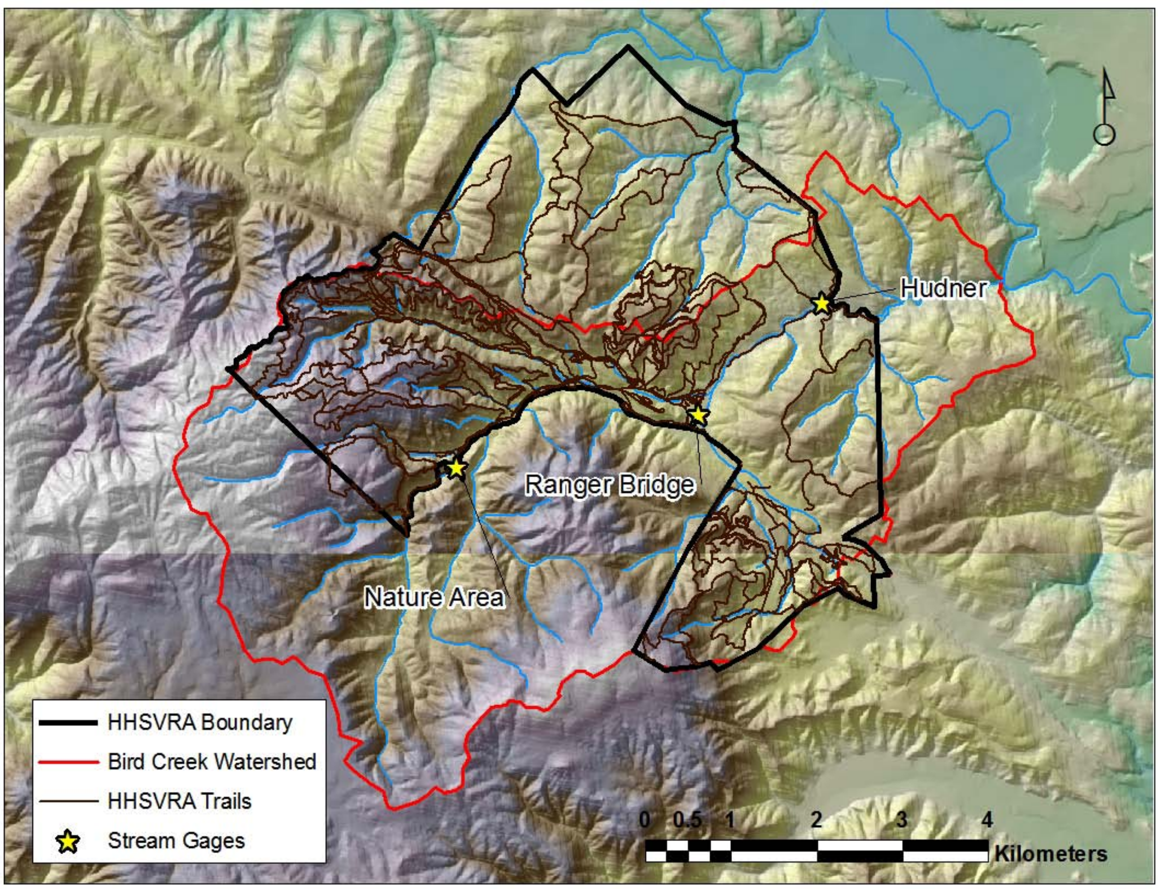

Figure 4. Map of the locations of the Nature Area, Ranger Bridge and Hudner gages. Note the Nature Area gage is upstream of nearly all OHV impact, and Hudner is downstream of nearly all OHV impact.

An above-and-below impact sampling design was used to quantify the amount of sediment that entered Bird Creek from HHSVRA. In WY 2011, the "above impact" sediment input was unmeasured, but negligible, because Bird Creek channel at the upstream site (Nature) never achieved continuous winter base flow. 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 "Ranger Bridge" pressure transducer was installed at the ranger housing where the geology changes from granitic rocks to sedimentary rocks. The site is a hydraulically sable because there is a concrete box culvert located just downstream. 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 and suspended sediment were measured over a wide range of flows to create robust rating curves.

Water discharge was measured using a Flowtracker Acoustic Doppler meter and a three-inch Parshall flume at low flow conditions. 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 discharge 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 samples were collected using a DH-48 depth integrated suspended load sampler. Suspended sediment samples were collected at even locations across the stream channel in order to integrate spatial variation of sediment discharge within the cross section. Suspended sediment samples were processed in the CSUMB lab to yield a suspended sediment concentration (SSC) (mass/volume). Suspended sediment concentrations were multiplied by instantaneous water discharge (volume/time) to calculate suspended sediment discharge (mass/time). The turbidity of each sample was measured with a Lamotte 2020 turbidity meter.

The sediment and turbidity values were used to rate the gages so that annual yield of suspended sediment mass could be calculated from the continuous gage records of stage and turbidity.

2.3 Sediment Source Analysis

This year we began taking suspended sediment samples at a variety of locations along bird Creek to determine if specific tributaries, campgrounds, or parking lots were adding a disproportionate amount of suspended sediment to the creek.

2.4 Stream Surveys

Several benchmarked stream cross sections established in 2010 were resurveyed in the current year. Bank pins installed in 2010 were measured and reset. Lastly, a few locations were resurveyed with mobile terrestrial LiDAR. The results of these surveys will be presented in a future report.

3 Results

The watershed data are presented in three sections: hydrology, suspended sediment yield, and source analysis.

3.1 Hydrologic Data

Hydrologic data for this report consists of rainfall and streamflow data. Rainfall data were downloaded from an existing HHSVRA weather station (Radio Ridge). WY 2011 produced 271 mm (10.67 in) of rain, which is below the 419 mm (16.50 in) average, and much drier than the previous year with 494 mm (19.44 in). WY 2011 was a low flow year and much of Bird Creek remained ephemeral throughout the winter. Bird Creek at Hudner (Figure 5) had enough base flow by November 9, 2011 to warrant deployment of the YSI sonde. It remained operational until it was removed June 12, 2012 because of low flow conditions. The flow was never consistent enough to deploy the gage in the Nature Area.

Table 1. Summary of hydrology data from Water Year 2011-2012, which had below average rainfall.

	Gaged Period	Precipitation		Total Q_w	
	mm/dd/yy	mm	in	m^3	acre-ft
WY 2010-2011	10/1/2011-9/30/2012	271	10.67	-	-
Hudner	11/9/2011-6/12/2012	223.5	8.8	91,600	74.26

Approximately 90,000 m^3 of water flowed past the Hudner gage (Table 1). Peak discharge of the year occurred on April 13, 2012 and peaked at 0.12 m^3s^{-1} (4.2 cfs) (Figure 6). This peak flow occurred on the only significant runoff event of the year (Figure 6). There were several small runoff events earlier in the winter, but discharge quickly receded to winter baseflow conditions following the storms. The April storm brought the first lasting shift in baseflow volume (Figure 6). For comparison, the peak flow in WY 2010 winter was 1.97 m^3s^{-1} (69 cfs), over 16 times the peak flow of WY 2011 (Figure 7).

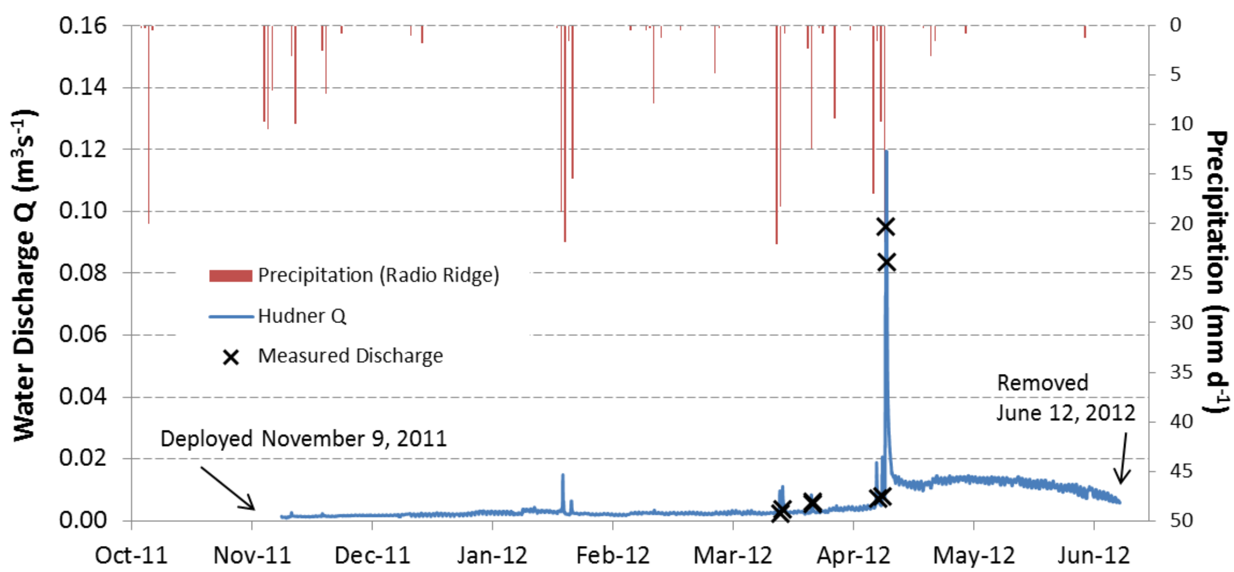

Figure 6. Hydologic data for Water Year 2011-2012. There was only one significant runoff event during this winter.

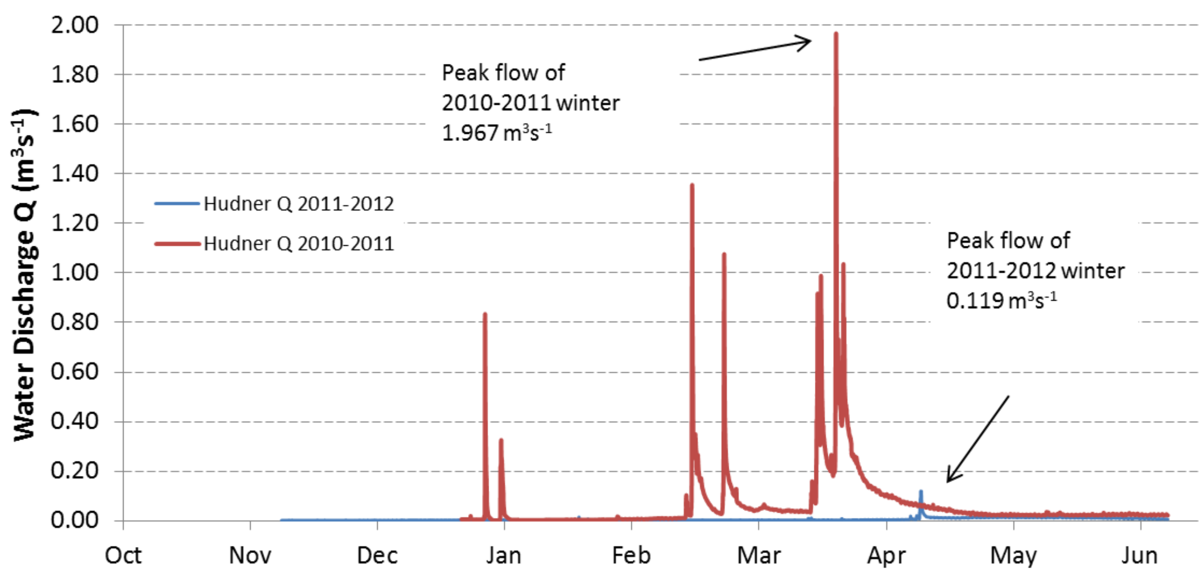

Figure 7. Comparison of the discharge at the Hudner gage site in Water Year 2010-2011 and Water Year 2011-2012.

3.2 Suspended Sediment

The low rainfall and runoff conditions resulted in relatively low suspended sediment transport in the 2011 water year. Total suspended sediment mass was calculated in two independent ways. The first method used the continuous measure of water discharge rated by instantaneous field measurements of suspended sediment discharge (Q_{sus}). The second method used the continuous record of turbidity rated by field measurements of SSC. These two independent methods are common in watershed studies, but provide significantly different estimates of sediment discharge.

3.2.1 *Suspended Sediment Rated to Q_w*

The first method for calculating the sediment discharge from HHSVRA used water discharge (Q_w) to rate continuous suspended sediment discharge (Q_{sus}) (Figure 8). Using Q_w to rate suspended sediment discharge produces one spike in sediment discharge and a small tail of sediment discharge as the baseflow is receding after the initial spike. The estimate of total sediment discharged from the park using this method is 41,500 kg (46 tons).

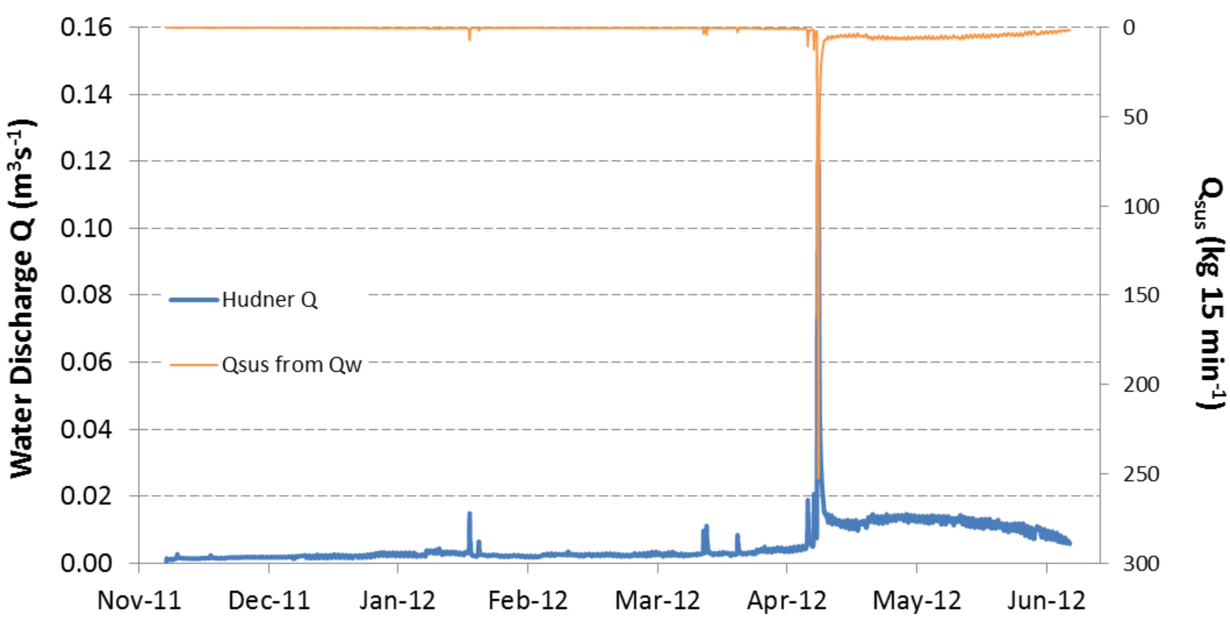

Figure 5. Gaging records for Q_w (blue) and Q_{sus} (orange) at the Hudner gage site. Suspended sediment was calculated using SSC.

3.2.2 *Suspended Sediment Rated to Turbidity*

Another method for calculating the suspended sediment discharge is to determine a relationship between turbidity and SSC, then calculate SSC for every turbidity reading in the continuous gage record. The Q_{sus} record is then the product of SSC and Q_w (Figure 9). Q_{sus} Using turbidity to estimate Q_{sus} produces a similar result to rating with Q_w, with the exception that the sediment discharge in the baseflow after the large storm peak is slightly less (Figure 10). The total sediment discharge at the Hudner gage using turbidity to estimate Q_{sus} is 21,600 kg (24 tons).

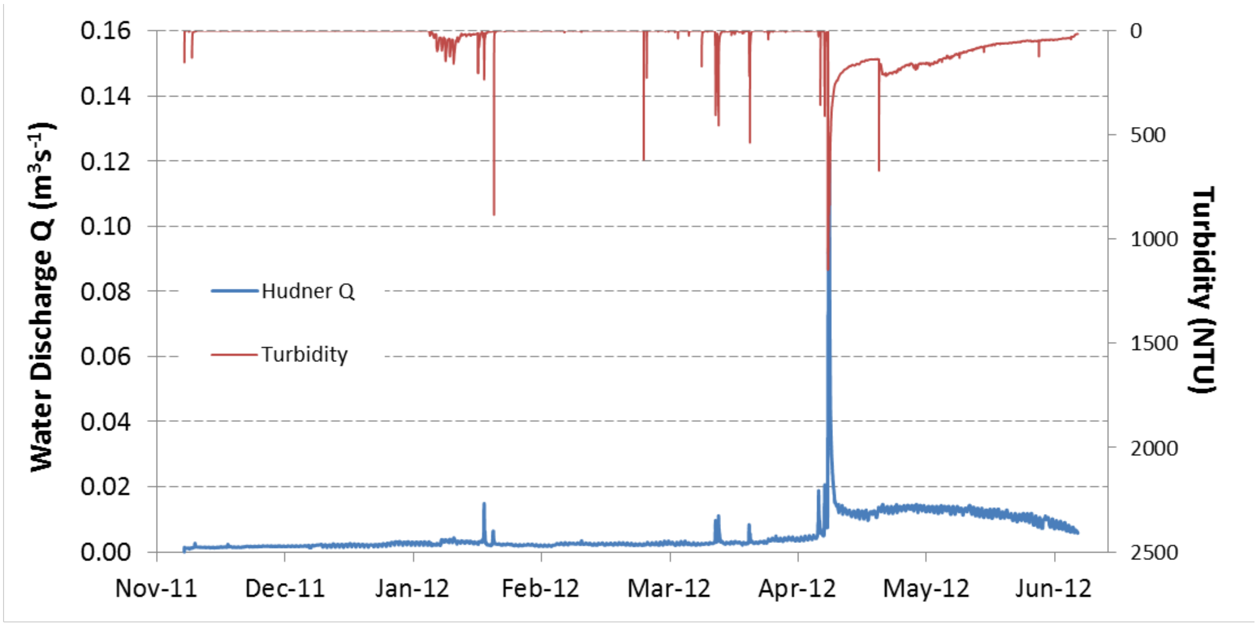

Figure 9. Gaging records for Q_w (blue) and turbidity (red) at the Hudner gage site.

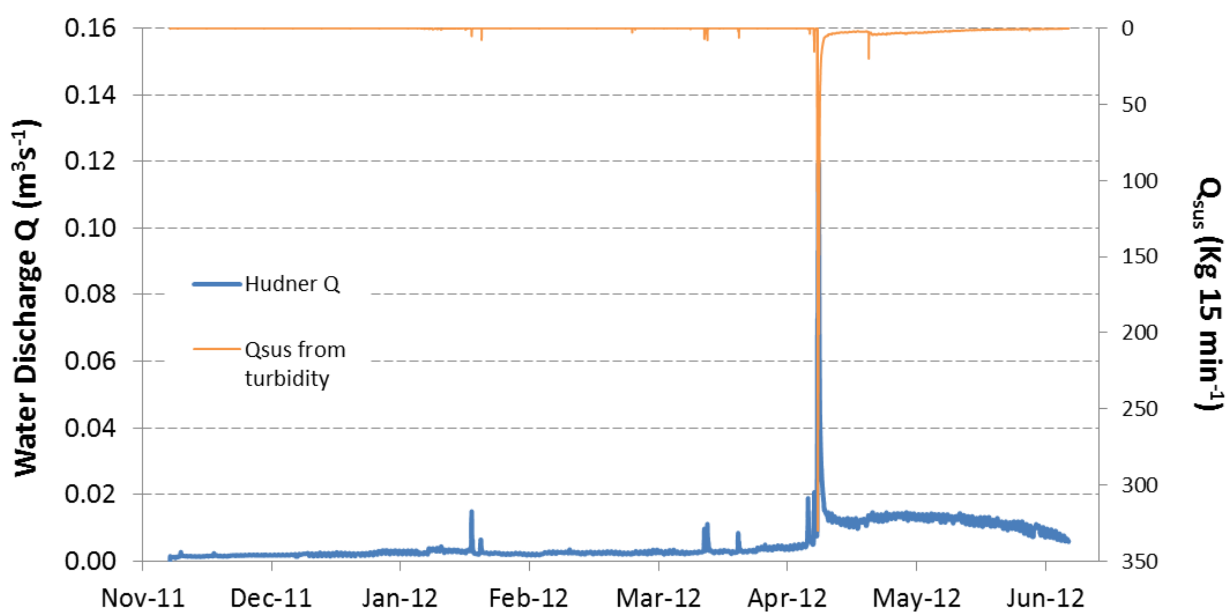

Figure 10. Gaging records for Q_w (blue) and Q_{sus} (orange) at the Hudner gage site. Suspended sediment was calculated using continuous turbidity.

3.2.3 *Sources of Suspended Sediment*

As part of the sampling methods in WY 2011, suspended sediment was sampled along Bird Creek above and below tributaries. As this year was a very low flow year, surface water was commonly flowing only locally--along discontinuous sections of Bird Creek. Sediment sampled in the upper reaches did not necessarily flow out of the watershed this water year.

Examining SSC values along the creek should be done with care. A high concentration of sediment under very low flow conditions can contribute less sediment to the system than a low concentration under high flow conditions. As the flow in Bird Creek during WY 2011 was sporadic and disconnected between upstream and downstream reaches, the SSC values should simply be treated as a guide to more effective sampling for Water Year 2012.

In general, during storm runoff there was moderate flow with very low SSC flowing into the Nature Area. At Hidden Springs often more turbid water could be observed flowing into Bird Creek, representing the first major input of sediment from HHSVRA. Downstream of the Nature Area flow would drop significantly by infiltration to groundwater, and the remaining surface water would be much more turbid and have a high SSC. The growth of several gullies in the campgrounds adjacent to Bird Creek was observed throughout the rainy season, and these gullies may be contributing significant amounts of sediment to Bird Creek in this reach. Below Lodge camp flow would often increase and SSC would decrease, most likely from the input of cleaner water from North Canyon tributary, which diluted SSC in Bird Creek (Figure 11).

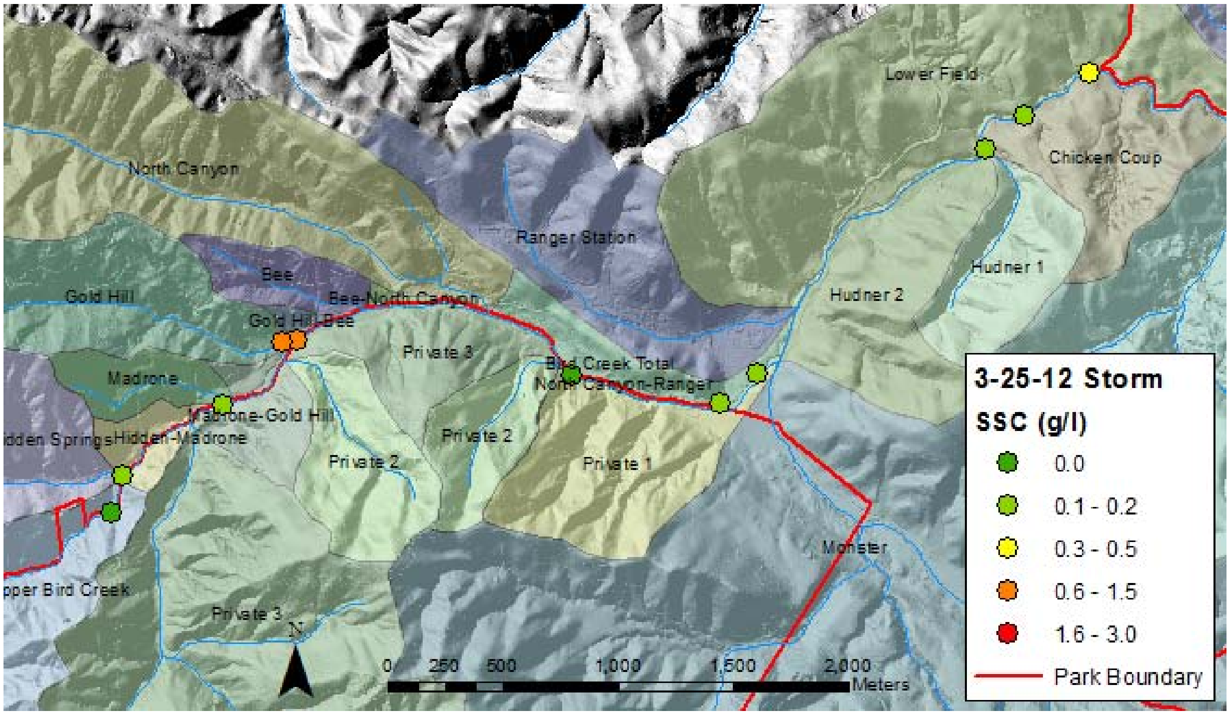

Figure 11. Suspended sediment concentrations along Bird Creek during the 3-25-12 storm. Turbid water was observed flowing from the Gold Hill tributary through the Whoop-de-Doo basin and into Bird Creek.

Each tributary has at least one sediment basin, but fine, suspended sediment may be flowing past some of these basins. On 4/13/12 turbid water was observed flowing directly into Bird from the Whoop-de-Doo sediment basin, which was the only basin observed to be contributing directly to Bird Creek (Figure 12). Under higher flow conditions it is likely more basins connect to Bird Creek, but it is unclear how often this occurs. Next year during storm events flow inputs from sediment basins (Madrone, Whoop-de-Doo, Bee, Turtle, and Ranger Basin) should be monitored with special attention around the outlet of Whoop-de-Doo.

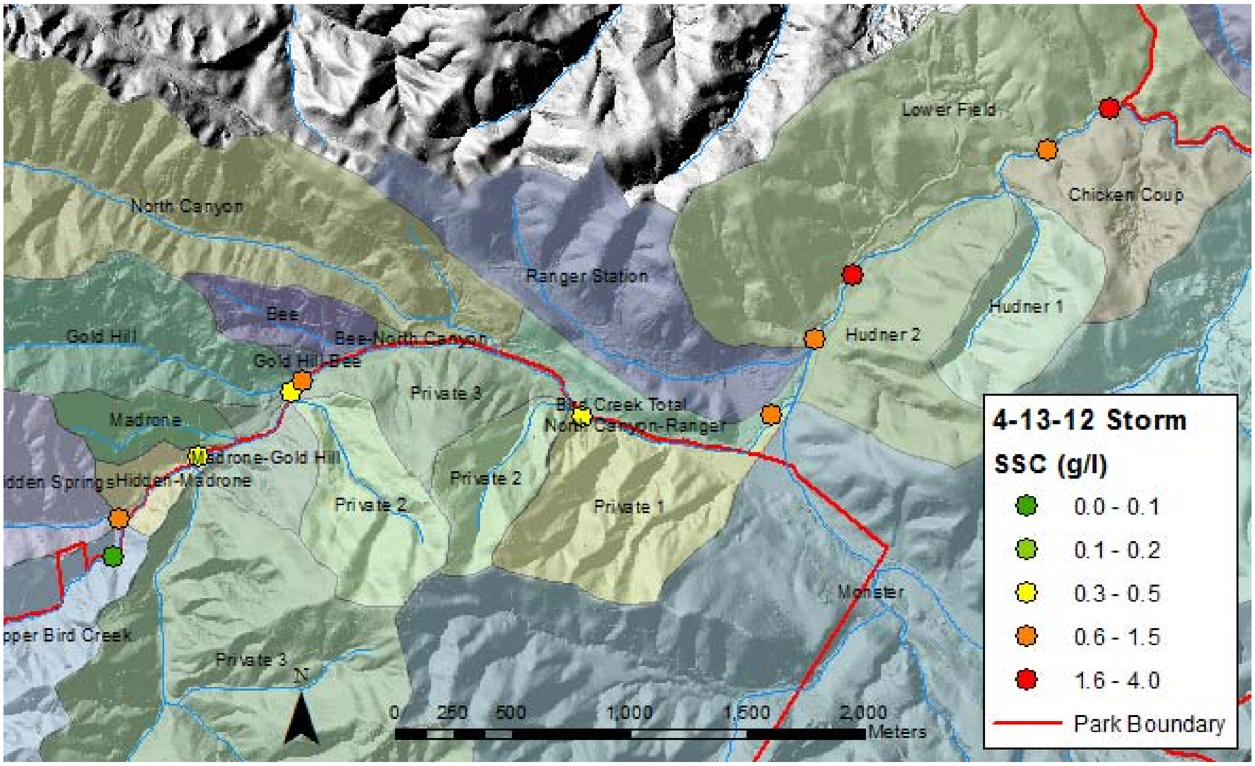

Figure 12. Suspended sediment concentrations along Bird Creek during the 4-13-12 storm. This storm saw the largest peak flow of the winter, and the SSC along the creek has an expected rise moving downstream.

4 Discussion

Suspended sediment enters Bird Creek from a variety of sources including erosion in HHSVRA, cattle impacts, and uncontrolled runoff from public roads. Two types of uncertainty are evident in this study; the first is the true amount of suspended sediment generated and the second is the relative contribution from various sources inside and outside the Park.

We have employed two independent bases for calculating suspended sediment transport. "Method 1" is based upon a continuous record of water discharge rated to sporadic SSC samples. "Method 2" is based upon a continuous record of turbidity and a field-determined relationship between turbidity and SSC. Method 1 gives consistently greater sediment load than Method 2. The chief reason for this is that storm runoff is typically muddier at the beginning of the storm, but is much cleaner as the storm runoff wanes. This effect is directly captured by Method 1, but is ignored by Method 2 (Figure 13). An example of this effect is present immediately following the April 2012 storm. Figure 8 shows the sediment transport function exactly mirroring the shape of the water discharge hydrograph (method 1). Figure 10, using Method 2, shows the water clarifying more rapidly because it is driven by the real-time turbidity (Figure 9). We see benefits in both techniques, and have presented both sets of results.

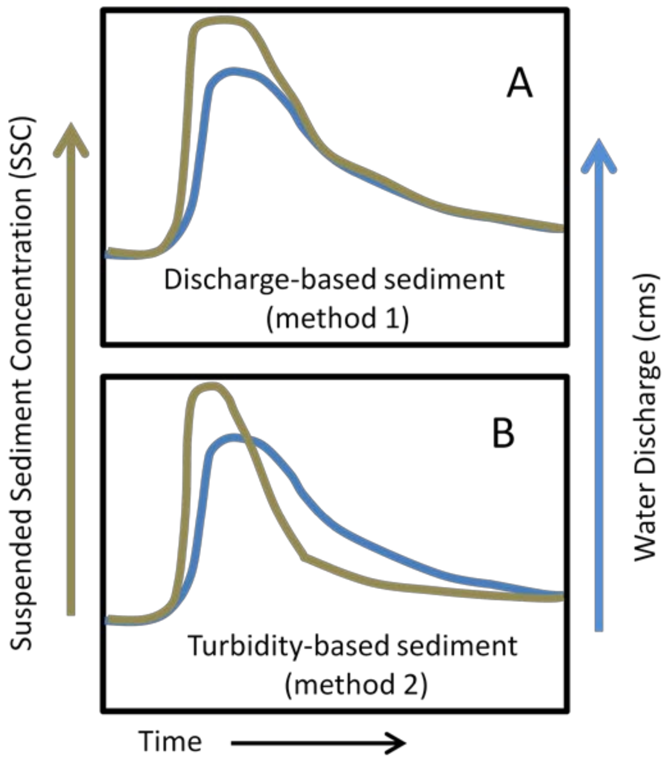

Figure 13. Schematic comparison of suspended sediment concentration modeled using two methods. Figure 13A shows the sediment modeled on method 1, while 13B shows method 2.

We revisit the results of WY 2010, using turbidity-rated sediment and corrected calculations (Table 2). WY 2010 had several months of continuous flow from Nature to Hudner. The input of suspended sediment to the Nature gage was 23,300 kg, and the output from the Hudner gage was 173,200 kg (Table 2).

Table 2. Summary of hydrology data from Water Years 2010 and 2011.

	Gaged Period	Precipitation	Q_w	Suspended Sediment	
				Rated with Qw	*Rated with Turbidity*
	mm/dd/yy	mm	m^3	kg	kg
WY 2011-2012	10/1/2011 - 9/30/2012	271	-	-	-
Hudner	11/9/2011 - 6/12/2012	223	91,600	41,500	21,600
WY 2010-2011	10/1/2010 - 9/30/2011	494	-	-	-
Nature Area	2/15/2011 - 9/30/2011	261	330,170	12,300	23,300
Range Bridge	2/2/2011 - 9/30/2011	262	827,070	-	-
Hudner	12/23/2011 - 9/30/2011	352	971,350	976,500	173,200*

* Value updated from 2010-2011 report

The difference between these values is an approximation of the sediment added to Bird Creek from all sources in the Bird Creek watershed between the Nature and Hudner gages. That value is 150,000 kg (165 tons). The sediment "yield" for this part of the watershed is the sediment mass per unit of watershed area lying between Nature and Hudner. The watershed area between the gages is between 19 km^2 (4773 acre) and 26 km^2 (6488 acre), depending upon whether the Upper Ranch (Figure 4) subwatershed is contributing flow. The Upper Ranch only contributes flow during very large storms, and the proportion of annual contribution is unknown. Given that total range in watershed area, the yield in WY 2010 may have ranged from 5780 kg km^{-2} (0.026 ton/acre) to 7860 kg km^{-2} (0.035 ton/acre) (using turbidity-based sediment transport). These values are much lower than reported in Nicol (2011) because of a calculation error in determining turbidity-based sediment load.

In contrast to WY 2010, in WY 2011 only on select occasions was there flow along the entire length of Bird Creek. The sparse rainfall transported almost no sediment past the Nature site, and transported 21,600 kg (23.8 tons) past the Hudner gage. Taking that value as the amount sourced between the gages, the yield for WY 2011 lies somewhere between 832 kg km^{-2} (0.0037 ton/acre) and 1131 kg km^{-2} (0.005 ton/acre).

These values of sediment yield apply to the entire watershed between the Nature and Hudner gages. Approximately 50% of the watershed between Nature and Hudner is utilized by HHSVRA and the other half is in private ownership. Parsing the sediment yield between the watershed stakeholders will require more focused subwatershed monitoring, as was initiated this year.

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