February 21, 2001

Stream Discharge and Sediment Production Following the Bobcat Fire

Bob Lange
Department of Earth Resources
Colorado State University

1.0 Introduction

The June 2000 Bobcat Fire may indicate an increasing risk of large high-intensity wildfires due to higher fuel loads in Front Range forests. The 10,600-acre Bobcat Fire was nearly four times the size of the 2,800-acre Grace Creek Fire. The 1988 Grace Creek Fire at had been the largest wildfire in the Arapaho Roosevelt National Forest since 1900. After the Bobcat Fire, the USDA Forest Service and the USDA Natural Resources Conservation Service implemented a number of treatments that included contour log felling, mulching, and seeding to encourage vegetation recovery, reduce runoff, and minimize erosion from the burned area. These treatments were targeted toward areas of concern such as potential dangers to property and water resources downstream. The cost of these treatments for the Bobcat Fire was almost $1.5 million (USDA, 2000). Evaluations on the watershed scale are required to assess the overall effect of the Bobcat Fire on runoff, erosion and sediment production and evaluate these treatments if possible.

The erosive impact of water on post-fire soils can be dramatic after even moderate precipitation events (Campbell et al., 1977; Helvey, 1980; Bolin and Ward, 1987; Williams, 1991; Keller et al., 1997). Fires can significantly alter soil properties due to soil heating, the removal of litter and duff layers, and the potential formation of a hydrophobic soil layer (Ralston, 1971). Fires can change rainfall interception, infiltration, evapotranspiration, and snow accumulation, while the loss of vegetation canopies, litter, and soil organic mater can greatly increase the raindrop erosivity and the potential for erosion. The changes in these processes can result in a large net change in runoff and erosion on the watershed scale.

For high severity wildfires, the peak streamflow discharge can be up to 60 times higher than what would be expected under pre-fire conditions or from comparable unburned watersheds (Tiedemann et al., 1979). Overland flow typically increases after

fires and can erode and transport sediment to stream channels (Chandler et al., 1983). This sediment can take the form of suspended and/or bedload sediment loads (Bartram and Balance, 1996). Suspended sediment is typically fine particles and organic material suspended in the water column. Bedload is material that is too heavy to stay suspended in the water column and moves in contact with the streambed (Novotny and Olem, 1994).

The objectives of this research project are to:

1) Measure runoff at the watershed scale and relate this to the amount and intensity of precipitation.
2) Sample suspended and bedload sediment and relate these to precipitation and discharge.
3) Interpret these data as related to the Bobcat Fire.

2.0 Methods

2.1 Site Description

The Bobcat Fire burned 10,600 acres northeast of Drake, Colorado in the Big Thompson watershed. The fire severity was rated at high to moderate in the high intensity burn areas that made up 45% of total acreage, and low in the other areas. The fire behavior was characterized as a fast-moving crown fire in dense Douglas fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*) stands (USDA, 2000).

Bobcat Gulch is located in the western portion of the burned area and drains into the North Fork of the Big Thompson River just above the confluence with the Big Thompson River. Jug Gulch and Dry Creek are located in the center of the burned area and drain into Cedar Creek, which joins the Big Thompson River above Viestenz Smith Mountain Park. The east side of the fire along Greenridge drains into Buckhorn Creek near Masonville, which joins the Big Thompson River west of Loveland (Figure 1). The Big Thompson River is a water source for Loveland and Greeley, and also transports water from the Colorado River Basin transmountain diversion as part of the Colorado-Big Thompson Project (Monroe, 2000).

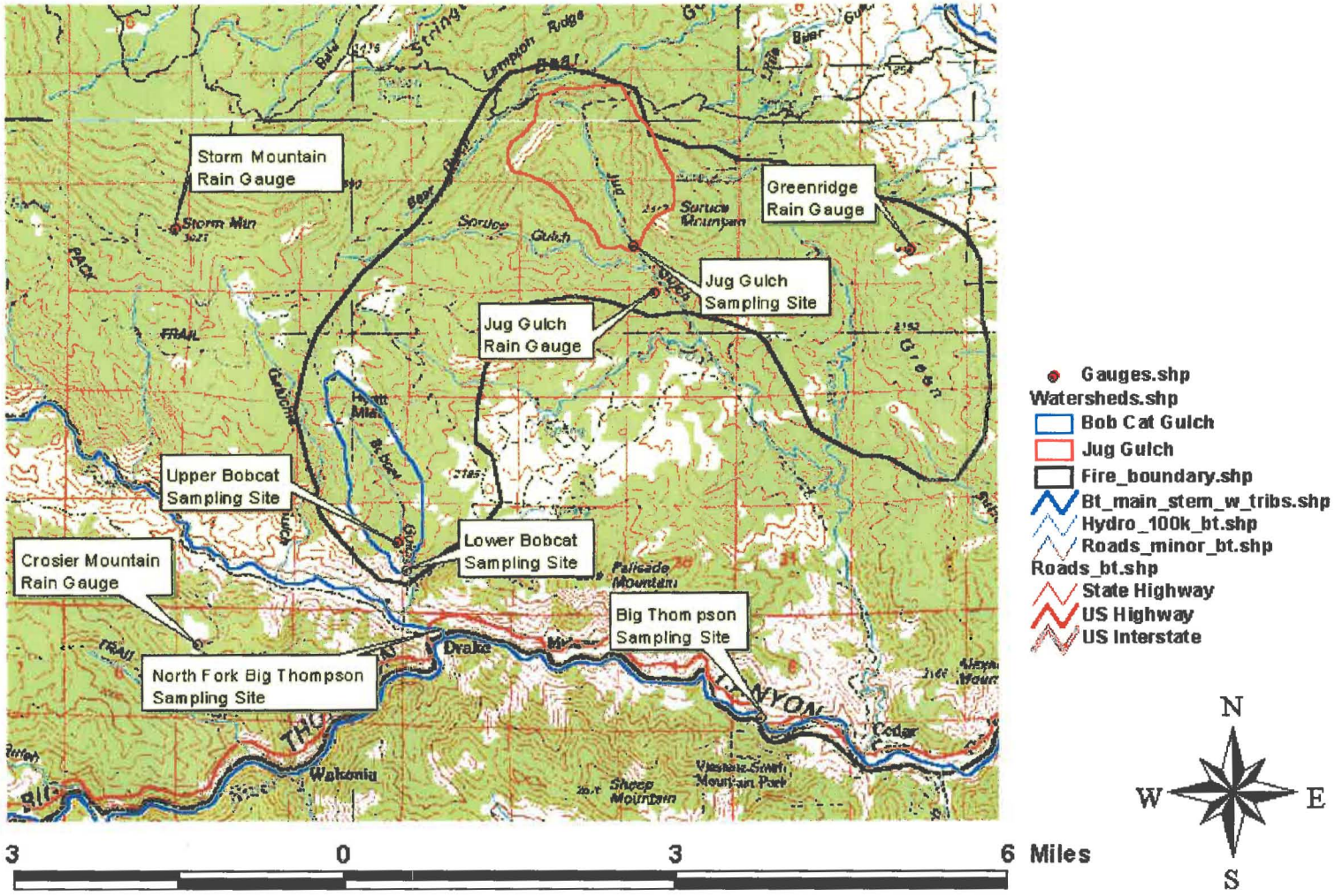


Figure 1: Bobcat Fire area with rainfall gauge and water quality sampling sites.

In order to monitor runoff and erosion from the burned area, precipitation and stream discharge were measured. Suspended sediment in post-fire runoff was measured by taking water quality samples at six locations. To measure bedload sediment, two small watersheds with similar vegetation and burn characteristics were selected for the installation of sediment traps. The drainage area above the sediment traps is 2.2 km^2 in Bobcat Gulch and 3.6 km^2 in Jug Gulch (Figure 1).

2.2 Precipitation

A rainfall gauge network was installed and data was collected from rain gauges located in or near the burned area. Crosier Mountain, Juan's Gauge, Joe's Gauge, Bobcat Gulch, and Jug Gulch are 8-inch diameter plastic tipping buckets attached to Onset Hobo Event loggers. The resolution of these gauges was either 0.2 mm or 0.01 inch. The Storm Mountain and Greenridge gauges were installed after the fire and had a resolution of 1 mm. The Storm Mountain and Greenridge gauges were equipped with radio transmitters as part of an early warning system for potential flooding. Runoff was sampled when the rain gauges indicated a storm with the potential to increase stream discharge. The threshold criterion was 0.2 inches in 30 minutes or 0.5 inches in one hour.

2.3 Stream Discharge

Water level was recorded from staff gauges in Buckhorn Creek near Masonville, the North Fork of the Big Thompson at Drake, and the Big Thompson River at Viestenz Smith Mountain Park (Figure 1). At each of these sites, the Colorado State Engineers Office monitors stream discharge. The stage-discharge relationships at each site were used to calculate discharge from water level observations. Preliminary stream discharge data were obtained from the State Engineers Office for the North Fork of the Big Thompson at Drake (NFBT) and the Big Thompson at Viestenz-Smith Mountain Park (BTVS) stations. The NFBT station had 15-minute records available for 1 August to 30 September 2000 and average daily values for 1999, and the BTVS gauge had average daily stream discharge records from 1 March to 31 October 2000.

Stream discharge at the Upper Bobcat Gulch and Jug Gulch sampling sites was estimated using 90° V-notch weirs during field visits (Figure 2). Discharge for the weirs was calculated using equation 1 (USBR, 1984).

$$Q = 2.49\ H^{2.48} \qquad (1)$$

where

Q = discharge over weir in cubic feet per second, and

H = head on the weir in feet.

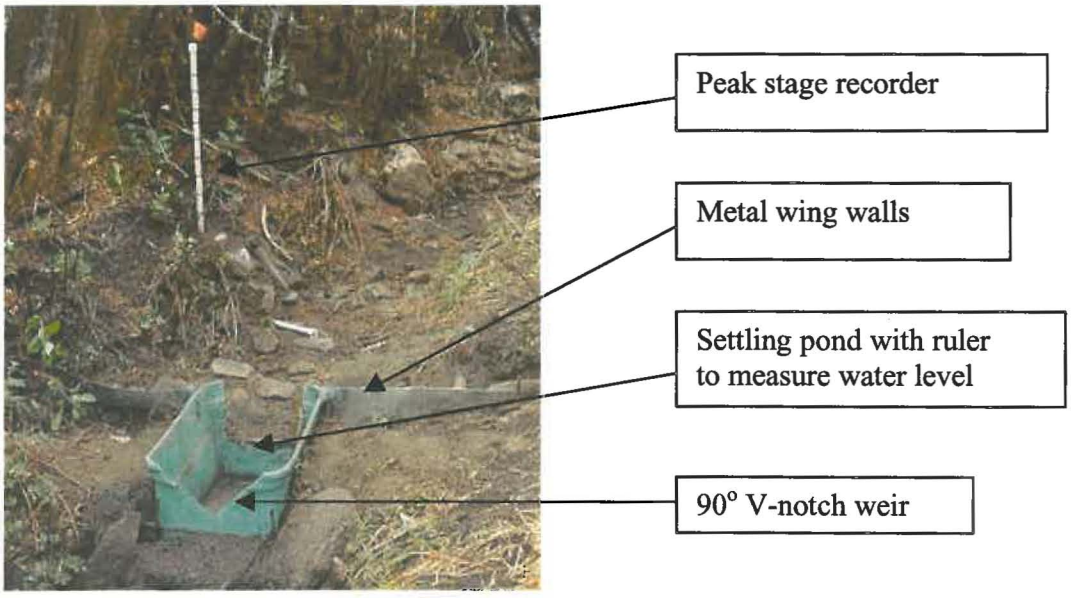


Figure 2: *Bedload sediment trap at located at Upper Bobcat Gulch.*

The maximum height of the V-notch is 0.58 ft, so the highest stream discharge that could be measured was 0.65 cfs. Peak stage recorders were installed at the same location as the weirs. These recorders used ground cork and a measuring stick inside a plastic pipe, but were ineffective due to the intakes clogging with ash and fine sediment. Therefore, sites were visited after high stream discharge events and the stage was determined based on flow indicators such as deposited debris and ash. Each water level was marked and labeled. The cross-section at the location was surveyed and the stream discharge was estimated using Mannings equation. Roughness coefficients were selected from Van Haveren (1986).

2.4 Suspended Sediment Sampling

MacDonald et al. (1991) recommends intensive sampling during high-flow events for suspended sediment with lower sampling intensity at lower flows, or a volumetric approach to sampling density. Suspended sediment in water samples was measured using

gravimetric analysis (Stednick, 1991). Since most sampling locations did not have depths over 30 cm, grab samples were taken in the thalweg. A total of 21 samples were taken at six different locations from June to September 2000.

2.5 Bedload Sampling

For bedload sediment, MacDonald et al. (1991) recommends intensive sampling during high flow events or establishing a sediment trap where sediment accumulation can be periodically measured. In this study, bedload was monitored using sediment traps at the Upper Bobcat Gulch and Jug Gulch sites (Figure 1). These traps were monitored from 8 August to 20 November 2000.

The sediment traps were constructed by inserting 250-L plastic storage containers into the stream bed. Each container had a 90° V-notch weir cut on the downstream side (Figure 2). Sediment traps were installed several weeks before the first measurements to allow time for the channel bed to adjust to the sediment trap. The opening of the sediment traps on the upstream side was at least 45 cm wide and served as the entry point to a 15 cm deep settling pond below the normal elevation of the channel bed. Metal wing walls were extended out from the bedload sediment trap into the stream banks approximately 1 m on either side. These walls extended at least 8 cm into the channel bed. The sediment trap was attached to rebar inserted into the stream channel.

Bedload sediment samples were removed from the settling pond using wire-framed hand-held fish catching nets. The coarser material was removed by using a 2 mm mesh net, and remaining material was removed with a fine cloth mesh net. Samples were dried at 105° C for 24 hours and weighed. In some cases samples were split in the lab using a sample splitter (Lewis and McConchie, 1994). The organic content of the bedload samples was determined by weight loss on ignition at 500°C in a muffle furnace (Radojevic and Bashkin, 1999). Particles with an intermediate axis greater than 16 mm were measured individually, while particle-size fractions from 0.04 mm to 16 mm were determined by dry sieving.

A common way to describe the distribution of particle size is to graphically evaluate the mean and standard deviation for the cumulative distribution when plotted on a $-\log_2$ (phi) scale against the size class (Lewis and McConchie, 1994). The cumulative

distribution was calculated base on the percentage finer than scale in millimeters (Wolman, 1954). The resulting graphs were used to determine the D_{50}, D_{16} and D_{84} values.

3.0 Results

3.1 Precipitation

The Storm Mountain rain gauge was triggered twice for rainstorms after the fire. These storms occurred on 16 August and 31 August 2000. The Greenridge rain gauge was only triggered on 1 September 2000. The Greenridge and Storm Mountain gauges were closed after the first snow storm on 18 September 2000. To monitor snowfall and increase the network density, the Bobcat Gulch and Jug Gulch gauges were installed on 4 November 2000 (Figure 3).

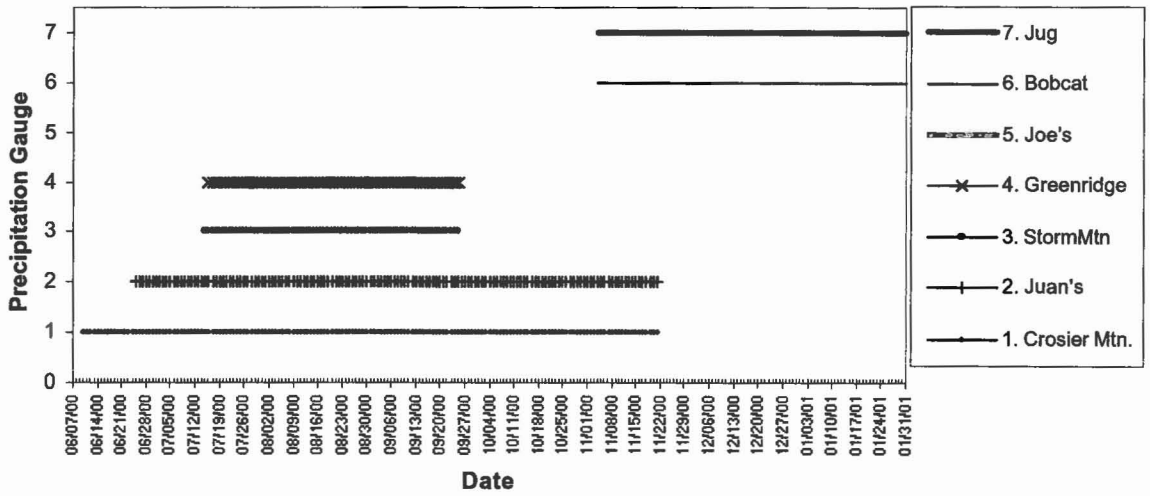


Figure 3: *Data availability for precipitation gauges in or near Bobcat Fire.*

A comparison of the daily precipitation for all the stations during 15 August through 2 September 2000 shows the spatial variability of rainfall in this area (Figure 4).

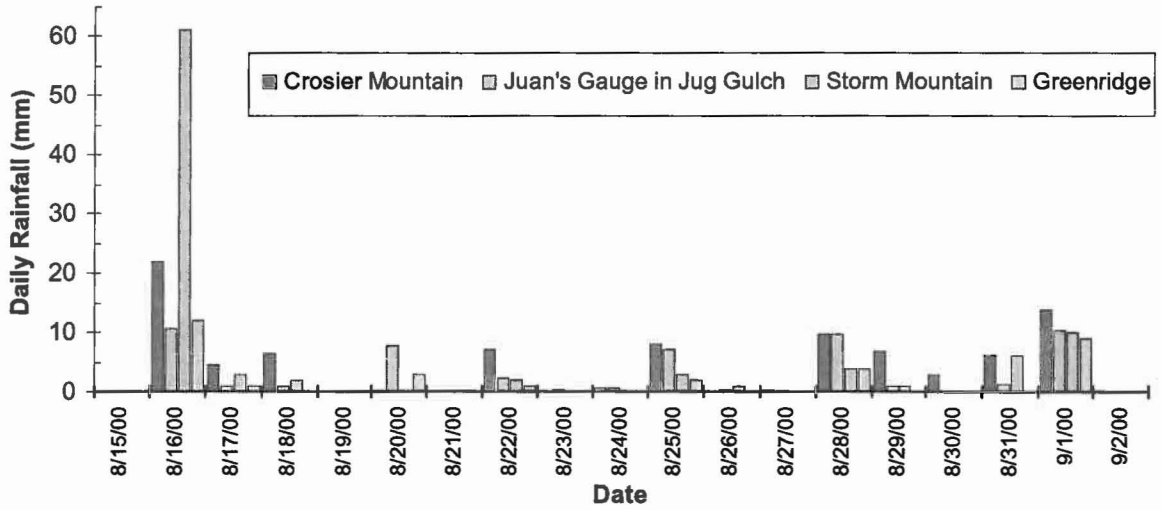


Figure 4: *Comparison of daily precipitation data from 15 August to 2 September 2000.*

The largest storm event was on 16 August 2000. The Storm Mountain gauge measured a total of 61 mm or 2.4 inches. The most intense portion of the rainfall was from 12:15 to 15:15, 54 mm or 2.2 inches fell in three hours (Figure 5).

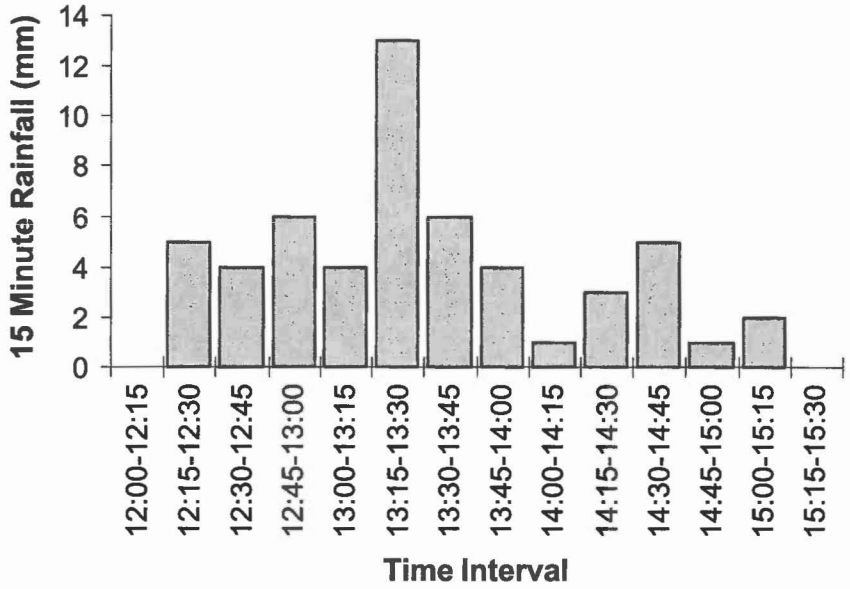


Figure 5: *15 -minute rainfall for Storm Mountain from 12:30 – 15:30 on 16 August 2000.*

3.2 Stream Discharge

Daily average discharge for the Big Thompson River at Viestenz Smith Mountain Park for 1 March to 31 October 2000 are shown in Figure 6. Preliminary 15-minute data for the North Fork of the Big Thompson at Drake from 8 August to 12 September 2000 are shown in Figure 7.

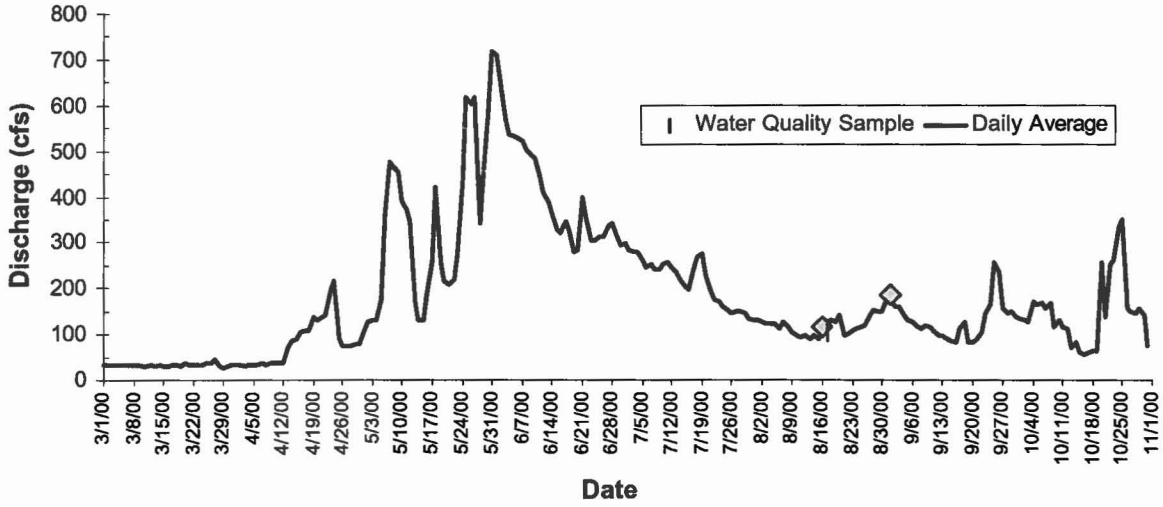


Figure 6: *Daily discharge for the Big Thompson River at Viestenz Smith Mountain Park, 1 March – 31 October 2000.*

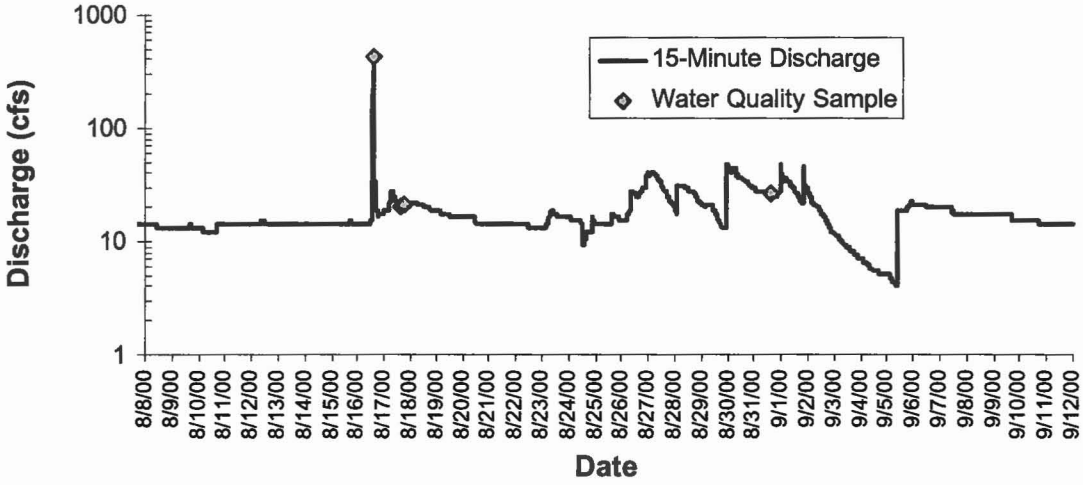


Figure 7: *15-minute discharge from the North Fork of the Big Thompson River near Drake, 8 August – 12 September 2000.*

For the storm on 16 August 2000 the gauging records at the North Fork of the Big Thompson showed a stream discharge value of 61 cfs from 1:30 to 3:00 p.m. A high water mark of 5.2 feet was observed during the rainstorm and was evident on the staff gauge the next day. According to this water level mark and the stage-discharge relationship, the peak flow must have been at least 430 cfs. More than likely the inlet to the gauge clogged with fine silt and cleared after the main pulse of water passed. Figure 7 shows the 15-minute stream discharge records from the gauge with the high stream discharge value added.

The peak stream discharge results for the major flow events for Bobcat and Jug Gulch are presented in Table 1 and the cross-section profiles are in the Appendix.

Table 1: *Peak stream discharge estimates.*

Site	Date	Estimated Time of Peak Discharge	Discharge (cfs)
Lower Bobcat	8/16/00	2:15 PM	220
Lower Bobcat	8/31/00	11:45 PM	60
Lower Bobcat	9/1/00	8:15 PM	30
Upper Bobcat	8/16/00	2:07 PM	150
Jug Gulch	9/1/00	8:00 PM	7

3.3 Suspended Sediment

The concentration of suspended sediments ranged from 1 to 310 mg/L. A comparison of the suspended sediment concentrations for Upper Bobcat Gulch and Jug Gulch is shown in Table 2. As can be seen from Table 2 the suspended sediment concentrations were generally higher with higher flows. The 27 June 2000 sample is the one exception. The discharge for this sample was measured using a current meter and not estimated from the cross section.

Table 2: Total suspended sediment for Upper Bobcat Gulch and Jug Gulch.

Location	Date	Time	Discharge (cfs)	Suspended Sediment (mg/L)
Jug Gulch	6/27/00	1:35 PM	0.07	40.0
Jug Gulch	8/17/00	5:35 PM	0.001	3.1
Jug Gulch	9/26/00	6:45 PM	0.10	8.8
Upper Bobcat	8/16/00	3:15 PM	0.25	50.0
Upper Bobcat	9/1/00	1:30 AM	0.12	22.0
Upper Bobcat	9/1/00	2:00 AM	0.10	24.0
Upper Bobcat	9/26/00	7:45 PM	0.05	1.5

The Lower Bobcat Gulch site had a total of four samples and the stream discharge was estimated from high water marks (Table 3). The relatively high values measured on 27 June 2000 and 1 September 2000 were both measured when it was raining and stream discharge levels were still rising.

Table 3: Suspended sediment at or near Lower Bobcat gauging station.

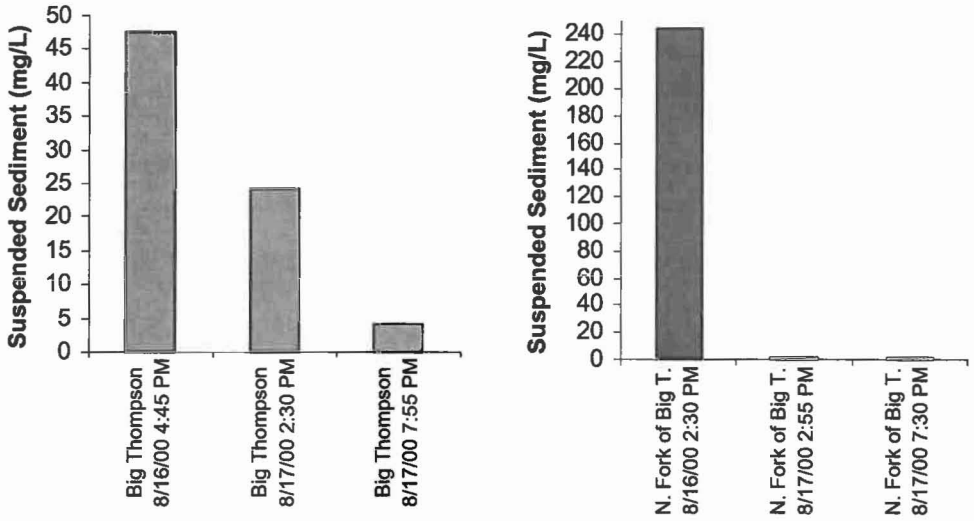
Location	Date	Time	Estimated Discharge (cfs)	Suspended Sediment (mg/L)
Lower Bobcat	6/27/00	11:15 a.m.	0.1	310
Lower Bobcat	8/16/00	4:00 p.m.	1.3	27
Lower Bobcat Near Road	9/1/00	12:00 a.m.	50	310
Lower Bobcat	9/1/00	1:00 a.m.	30	64

Suspended sediment was measured at three sites downstream from the burned area: North Fork of the Big Thompson at Drake, Big Thompson River at Viestenz Smith Mountain Park, and Buckhorn Creek (Table 4).

Table 4: Suspended sediment samples from sites downstream of the burned area.

Location	Date	Time	Discharge (cfs)	Suspended Sediment (mg/L)
N. Fork of Big T.	8/16/00	2:30 PM	430	245
N. Fork of Big T.	8/17/00	2:55 PM	20	2
N. Fork of Big T.	8/17/00	7:30 PM	21	2
N. Fork of Big T.	8/31/00	2:45 AM	35	7
Big Thompson	8/16/00	4:45 PM	114	48
Big Thompson	8/17/00	2:30 PM	102	24
Big Thompson	8/17/00	7:55 PM	109	4
Big Thompson	8/31/00	3:10 AM	185	8
Buckhorn	8/16/00	5:20 PM	1.1	0.6
Buckhorn	8/17/00	2:05 PM	1.3	1.4

The suspended sediment concentration drops off dramatically after the initial flush, which occurred at 2:30 p.m. at the North Fork of the Big Thompson near Drake gauge for 16 August 2000 storm (Figure 8).



(a) Big Thompson River at Viestenz Smith Mountain Park (b) North Fork Big Thompson Near Drake

Figure 8: *Suspended sediment concentrations after 16 August 2000 storm.*

Table 5 shows the estimated time from peak rainfall to when the sample was taken. The log of the suspended sediment concentrations from the North Fork of the Big

Thompson and the Bobcat Gulch sites were inversely related to the log of the time since peak rainfall (Figure 9).

Table 5: *Suspended sediment concentrations and time since peak rainfall.*

Location	Peak Rainfall Date/Time	Sample Date/Time	Time Since Peak (hr)	TSS (mg/L)
N. Fork of Big T.	8/16/00 1:30 p.m.	8/16/00 2:30 p.m.	1.00	245
Upper Bobcat	8/16/00 1:30 p.m.	8/16/00 3:15 p.m.	1.45	51
Lower Bobcat	8/16/00 1:30 p.m.	8/16/00 4:00 p.m.	2.50	27
N. Fork of Big T.	8/16/00 1:30 p.m.	8/17/00 3:00 p.m.	22.50	2
N. Fork of Big T.	8/16/00 1:30 p.m.	8/17/00 7:30 p.m.	30.00	2
Bobcat Road	8/31/00 11:30 p.m.	9/1/00 12:00 a.m.	0.50	312
Lower Bobcat	8/31/00 11:30 p.m.	9/1/01 1:00 a.m.	1.50	64
Upper Bobcat	8/31/00 11:30 p.m.	9/1/01 1:30 a.m.	2.00	22
Upper Bobcat	8/31/00 11:30 p.m.	9/1/01 2:00 a.m.	2.50	24
N. Fork of Big T.	8/31/00 11:30 p.m.	9/1/01 2:45 a.m.	3.25	7

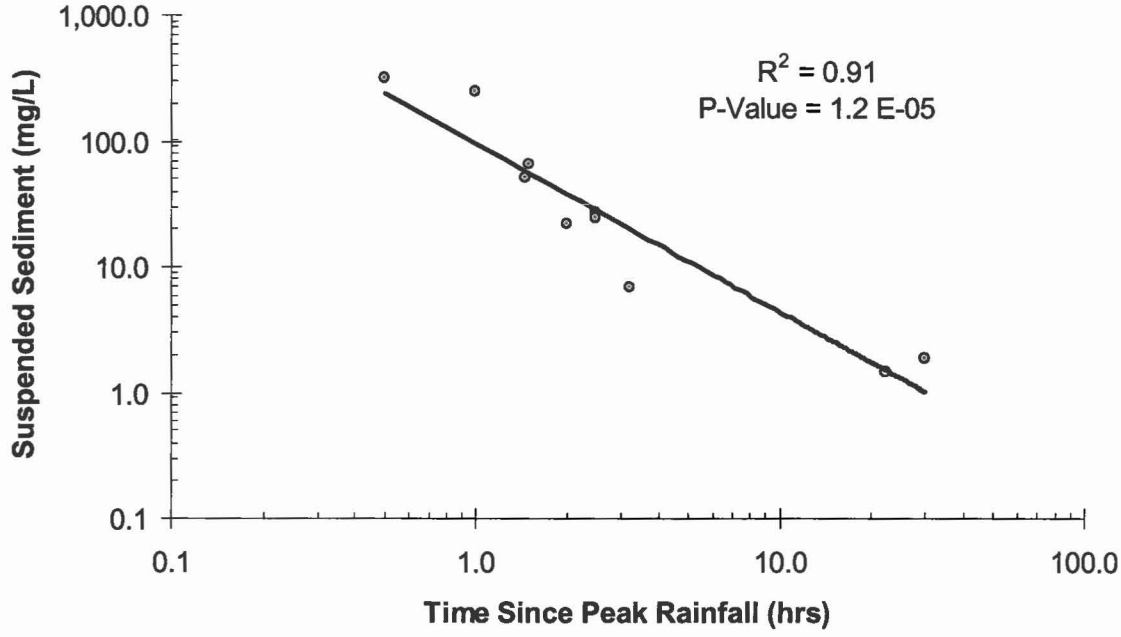


Figure 9: *Linear regression for suspended sediment samples from Bobcat Gulch and NFBT.*

3.4 Bedload Sediment

Bedload sediment was collected from 8 August to 20 November 2000. The record at Jug Gulch is continuous, although the structure was overtopped once during the storm on 1 September 2000. The peak stream discharge for the storm was estimated at 7 cfs and resulted in the largest deposit measured (Figure 10).

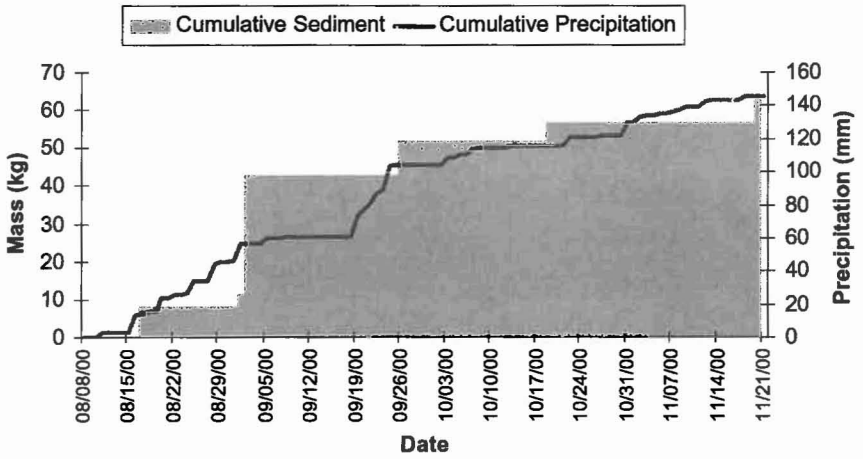


Figure 10: *Cumulative sediment and rainfall for Jug Gulch from 8 August to 20 November 2000.*

Particle size distribution was calculated individually for each sample and the mass of each size class was summed for all samples to produce a combined distribution for 8 August to 20 November 2000 (Figure 11).

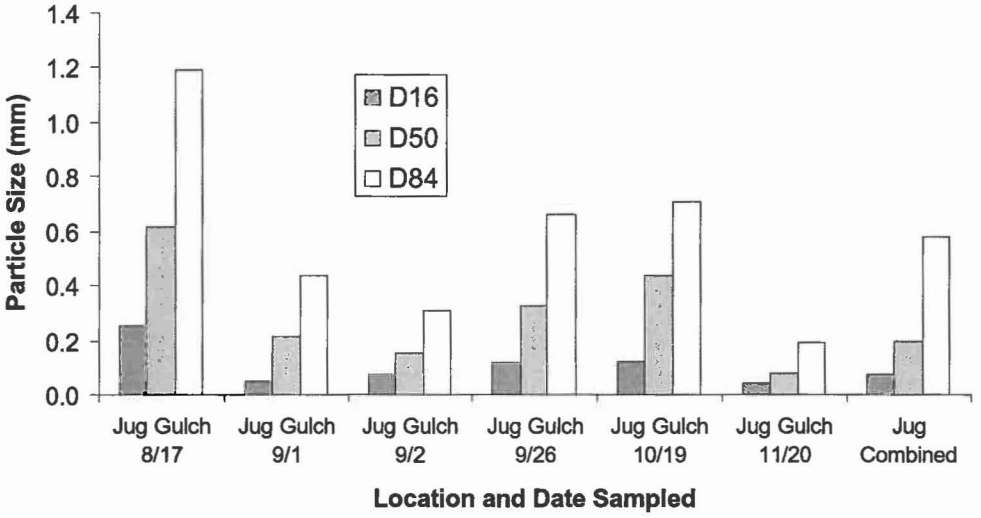


Figure 11: *Particle size distribution for bedload samples from Jug Gulch 8 August to 20 November 2000.*

The sediment trap at Upper Bobcat Gulch completely filled several times in response to rainfall events. The first time the sediment trap filled was during the 16 August 2000 storm and sediment particle sizes were much larger then measured at any other time or location (Table 6).

Table 6. *Bedload mass, percent organic matter, and particle sizes.*

Location	Begin	End	Total (kg)	kg/day	%Org	D_{84} (mm)	D_{50} (mm)	D_{16} (mm)
Jug	8/8/00	8/17/00	8.2	0.9	6.9%	0.25	0.62	1.19
Jug	8/17/00	9/1/00	3.1	0.2	40.3%	0.05	0.22	0.44
Jug	9/1/00	9/2/00	31.4	35.9	1.4%	0.08	0.15	0.31
Jug	9/2/00	9/26/00	9.1	0.4	2.3%	0.12	0.33	0.66
Jug	9/26/00	10/19/00	5.0	0.2	5.8%	0.13	0.44	0.71
Jug	10/19/00	11/20/00	6.1	0.2	37.6%	0.04	0.08	0.19
Bobcat	8/8/00	8/16/00	115.0	14.1	0.4%	0.57	27.86	112.21
Bobcat	9/23/00	9/26/00	104.5	34.0	0.9%	0.27	0.62	1.15
Bobcat	9/26/00	11/20/00	3.1	0.1	1.4%	0.18	0.57	1.74

The particle distribution shown in Figure 12 is the sum of all bedload particle sizes sampled from Upper Bobcat Gulch and Jug Gulch from 8 August to 20 November 2000. Each size class was summed for all samples before plotting.

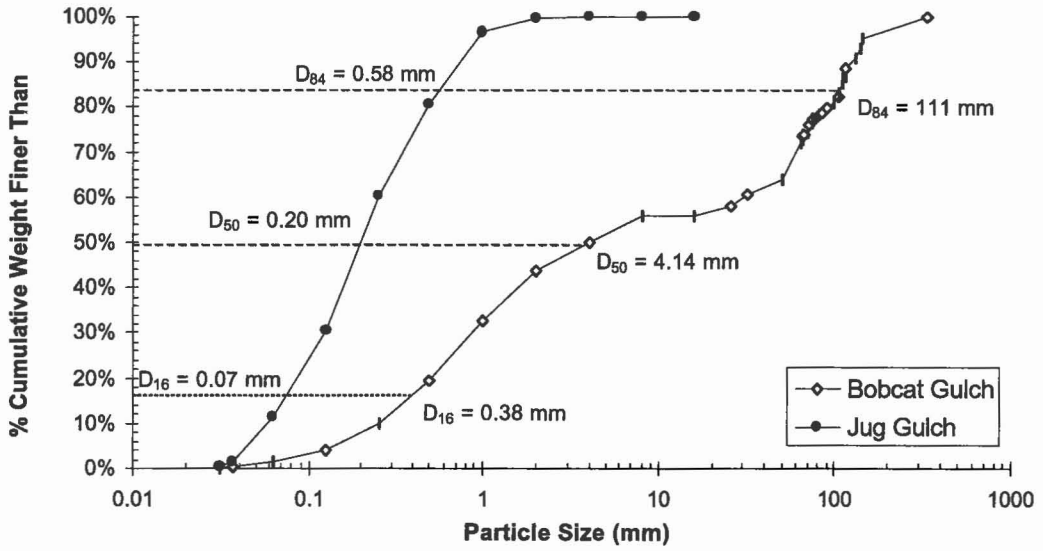


Figure 11. *Combined particle size distribution for Upper Bobcat Gulch and Jug Gulch.*

3.0 Discussion

The intense thunderstorm of 16 August 2000 produced 61 mm or 2.4 inches of rain in Bobcat Gulch and caused a tremendous amount of erosion. The maximum stream discharge in Bobcat Gulch after this storm was estimated to be 150 cfs. In contrast, Jug Gulch did not experience a similar storm during the monitoring period of 8 August to 20 November 2000. The maximum daily rainfall in Jug Gulch was only 12 mm measured at the Greenridge gauge on 16 August 2000. The largest discharge in Jug Gulch was 7 cfs on 1 September 2000 and the impact of 16 August 2000 storm in Jug Gulch was minimal. Therefore, the differences in sediment production from Bobcat Gulch and Jug Gulch cannot be used to evaluate treatments at the watershed scale due to differences in precipitation amounts for the two watersheds.

The maximum suspended sediment concentrations were measured while it was raining and stream discharge was rising (Tables 2 and 3). Even with the early warning system for potential high discharge events, all of the samples except for the 27 June 2000 sample were obtained after peak discharge. Future monitoring plans as early as Spring 2001 call for the installation of flow recorders and automatic sampling equipment at two locations in the burn area. This equipment will give a better picture of discharge and suspended sediment response and will allow a volumetric sampling design.

The bedload sediment traps functioned adequately during periods of moderate rainfall, but their capacity was exceeded during larger storm events. Sediment traps were also subject to flows higher than the top of the weir for some storm events. High bedload sediment production in Bobcat Gulch filled the trap to capacity for most of the major storms after 16 August 2000. The frequent filling may be due to the movement of sediment stored in the stream channel after the 16 August 2000 storm.

Jug Gulch's largest bedload sample was 31.4 kg on 2 September 2000. This value stems from one day of flow and represents over half of the sediment collected for the entire monitoring period. This was also the only time that the stream discharge exceeded the capacity of the V-notch weir. The estimated discharge for this event was 7 cfs, the highest observed during the monitoring period. Hence the measured bedload for this event is probably an underestimate of the bedload transported during this storm.

Cumulative precipitation and bedload for Jug Gulch is shown in Figure 10. This graph does not show a corresponding large increase in rainfall for the increase in bedload sampled on 2 September 2000. Daily rainfall for 1 September was 10 mm at both Juan's Gauge and the Greenridge Gauge. Since the highest discharge during the monitoring period occurred as a result of this storm, the precipitation was probably more than the amount measured at these two gauges. Juan's Gauge and Greenridge Gauge are probably not represnetative of the precipitation in Jug Gulch and additional rain gauges should be considered.

Figure 11 shows how different the bedload particle size distributions were for Bobcat Gulch and Jug Gulch. Bobcat Gulch had values of 0.38 mm, 4.14 mm, and 111 mm for the D_{16}, D_{50}, and D_{84}, respectively, while Jug Gulch had values of 0.07 mm, 0.20 mm, and 0.58 mm. Only the Bobcat sample after the 16 August 2000 storm had particles larger than 16 mm. This sample had a tremendous influence on the overall particle size distribution for Bobcat. However, since the sediment trap filled and overtopped after this storm and for subsequent samples, this distribution should not be assumed to represent the distribution of the whole period. It is most likely representative of the particle sizes during the first portion of the bedload pulse, since once it fills, the subsequent sediment would be transported over the top of the structure.

4.0 Conclusions

4.1 Rainfall is very localized and there is a need for at least one additional rain gauge in Jug Gulch to adequately characterize precipitation.

4.2 Comparison of treatment impacts on the watershed scale is not possible due to the high intensity thunderstorm on 16 August 2000 in Bobcat Gulch.

4.3 The majority of the bedload and suspended sediment movement was in reaction to thunderstorms.

4.4 Suspended sediment concentrations appear to be the highest when stream discharge increases in response to storm events and they decrease rapidly to background conditions after the stream discharge peak.

4.5 Bedload sediment moves in pulses in response to storm events. Sediment deposited by one storm in the bed can be remobilized by subsequent storms, but may not be mobilized during low flow conditions.

4.6 Jug Gulch bedload had generally smaller particle sizes then bedload sediment in Bobcat Gulch due to the 16 August 2000 storm.

5.0 References

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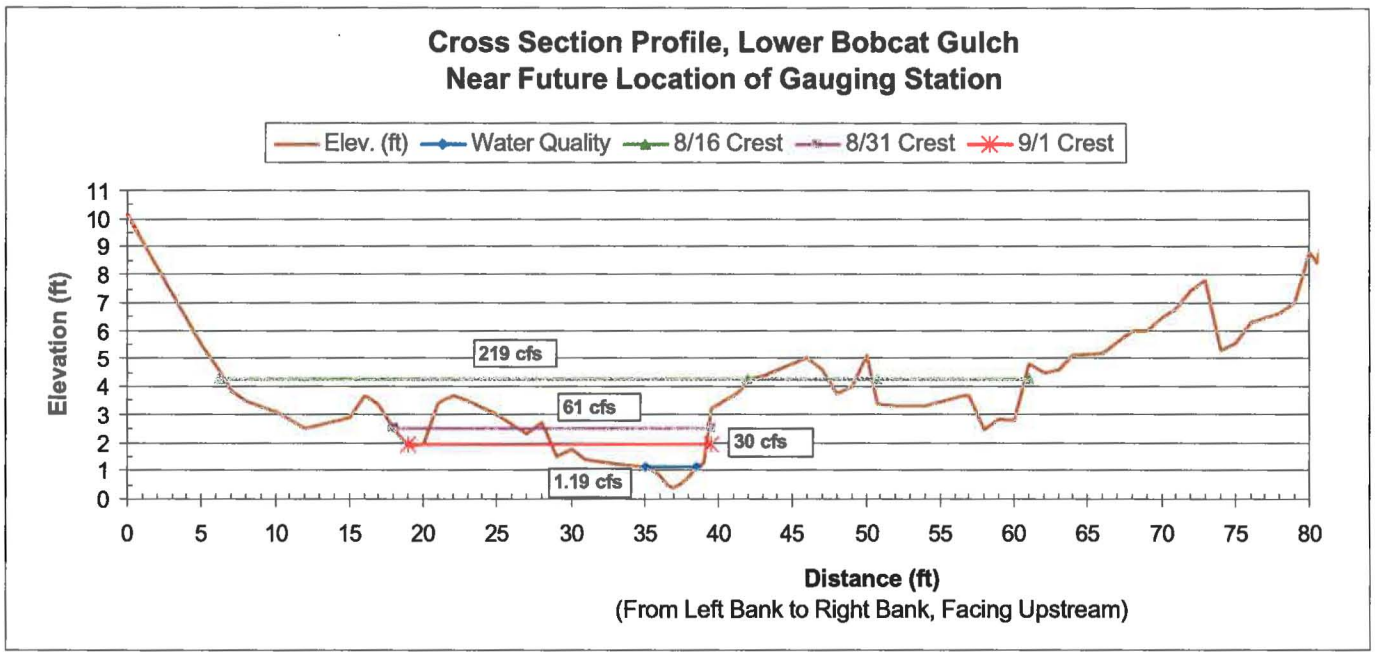
6.0 Appendix

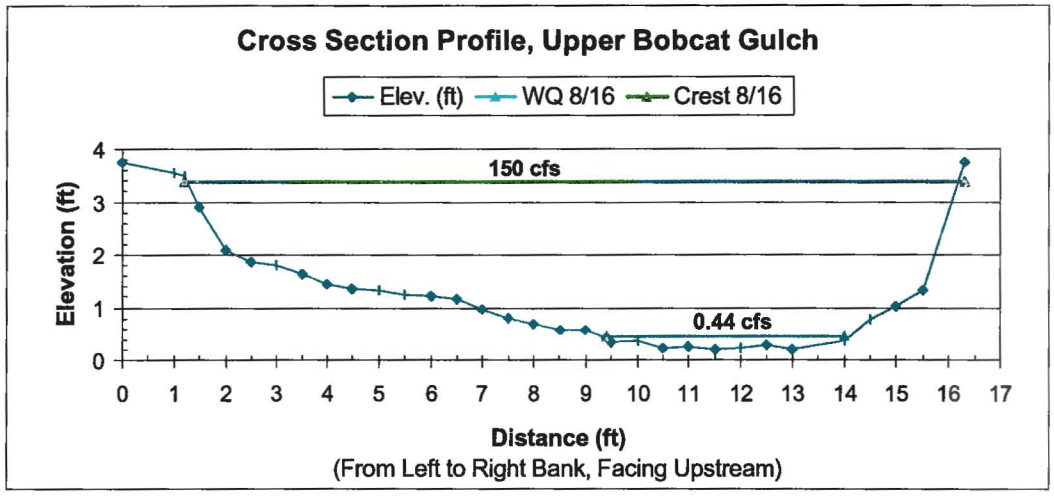
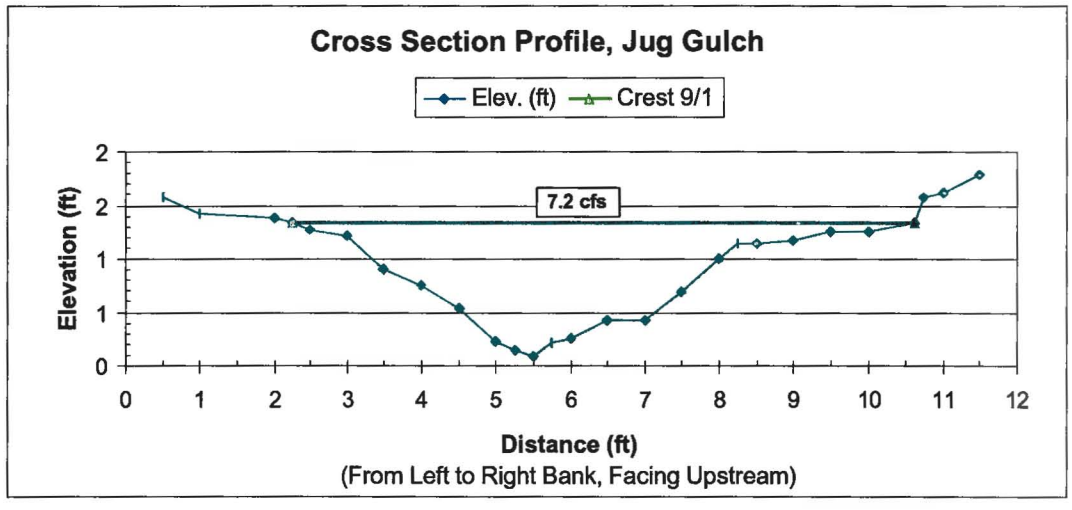
6.1 Lower Bobcat Gulch Cross Section



Parameters*		Mean Depths		Velocity Estimates		Area Estimates		Discharge Estimates	
1) Manning n Value =	0.07	8/16 Left =	1.91 ft	8/16 Left =	3.3 ft/s	8/16 Left =	64.36 ft^2	8/16 Left =	211 cfs
2) Manning n Value =	0.18	8/16 Right =	1.09 ft	8/16 Right =	0.9 ft/s	8/16 Right =	9.00 ft^2	8/16 Right =	8 cfs
Est. Slope =	0.01	8/31 Crest =	2.51 ft	8/31 Crest =	3.9 ft/s	8/31 Crest =	15.54 ft^2	8/16 Total =	219 cfs
		9/1 Crest =	2.55 ft	9/1 Crest =	4.0 ft/s	9/1 Crest =	7.66 ft^2	Est. Crest 8/31 =	61 cfs
		Water Quality =	0.29 ft	Water Quality =	0.9 ft/s	Water Quality =	1.29 ft^2	Est. Crest 9/1 =	30 cfs
								Est. WQ =	1.19 cfs

* Mannings values selected from Van Haven, B.P., 1986. Water Resource Measurements: American Water Works Association, 132 p.
- Mannings n for 8/16 uses the 1) value for the left portion of the cross-section and 2) for the right section. Discharges are calculated seperately and summed.

6.2 Upper Bobcat Cross-section



6.3 Jug Gulch Cross-section