COLORADO FRONT RANGE FLOOD OF 2013:

Peak Flow Estimates at Selected Mountain Stream Locations

December 2013

James Creek in Jamestown

North Fork of the Big Thompson River in Glen Haven

United States Department of Agriculture
Natural Resources Conservation Service

Helping People Help the Land

U.S. DEPARTMENT OF AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE
COLORADO STATE OFFICE

December 16, 2013

COLORADO FRONT RANGE FLOOD of 2013: Peak Flow Estimates at Selected Mountain Stream Locations

Location: Larimer and Boulder Counties, Colorado

Abstract: Peak flow estimates were developed in 15 mountain streams for the Front Range Flood of September 2013. These measurements were collected to inform resource managers of the flood severity, aid in the development of revised flow-frequency relationships, and quantify the flood response of key catchments burned during the 2012 High Park Fire. These stream reaches ranged from Jamestown in the South to catchments draining the High Park Fire area in the Poudre Canyon in the North, though are only a sample of the mountain streams impacted by the flooding. The critical depth method was used in this analysis, using replicate cross sections in channels with slopes greater than 1 percent. The highest peak flows were measured in the North Fork of the Big Thompson River upstream of Drake (18,400 cubic feet per second, cfs), the Little Thompson River at Pinewood Springs (14,600 cfs), West Creek upstream of Glen Haven (11,000 cfs) and Buckhorn Creek upstream of Masonville (11,000 cfs). The highest flow yields (peak flow normalized by drainage area) were measured in Fish Creek upstream of Lake Estes (442 cfs/mi^2), West Creek upstream of Glen Haven (477 cfs/mi^2), Little James Creek upstream of Jamestown (579 cfs/mi^2), Fox Creek upstream of Glen Haven (486 cfs/mi^2), and Skin Gulch upstream of Stove Prairie Road (720 cfs/mi^2). The streams with the highest flow yields correspond to the channels (and adjacent properties) that received a large amount of flood damage, with large disturbances to channel-stabilizing bank vegetation. The highest peak flow yield (Skin Gulch) flowed from a catchment with a substantial amount of high soil burn severity from the 2012 High Park Fire. Overall, the peak flows measured in these 15 reaches correspond to return intervals ranging from a 25-year flood event to approximately 5 times the 100-year flood.

PREPARED BY: ______________________________ **DATE:** 12/16/2013

STEVEN E. YOCHUM, PhD, PE
Hydrologist
970-295-5657, steven.yochum@co.usda.gov

PREPARED BY: ______________________________ **DATE:** 12/16/2013

DANIEL S. MOORE, PE
Hydraulic Engineer
503-414-3054, dan.moore@por.usda.gov

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

Appendix A: Cross Section Data

[This page is intentionally blank.]

INTRODUCTION

Peak flow estimates are provided for selected mountainous streams (Figure 1) impacted by the 2013 Colorado Front Range Flood. These measurement points were located where there were substantial threats to life and property during the flooding, and where high-quality high water marks were present. They represent some of the most severely-flooded mountain stream reaches. These measurements were collected in higher gradients steams (>1%) located in catchments primarily draining the northern portion of the extreme rainfall extent, in Larimer County. Measurements were collected in streams draining the High Park Fire area and the Estes Park area, including Glen Haven, Drake and Pinewood Springs. Additional measurements were collected in Boulder County, in the Jamestown area.

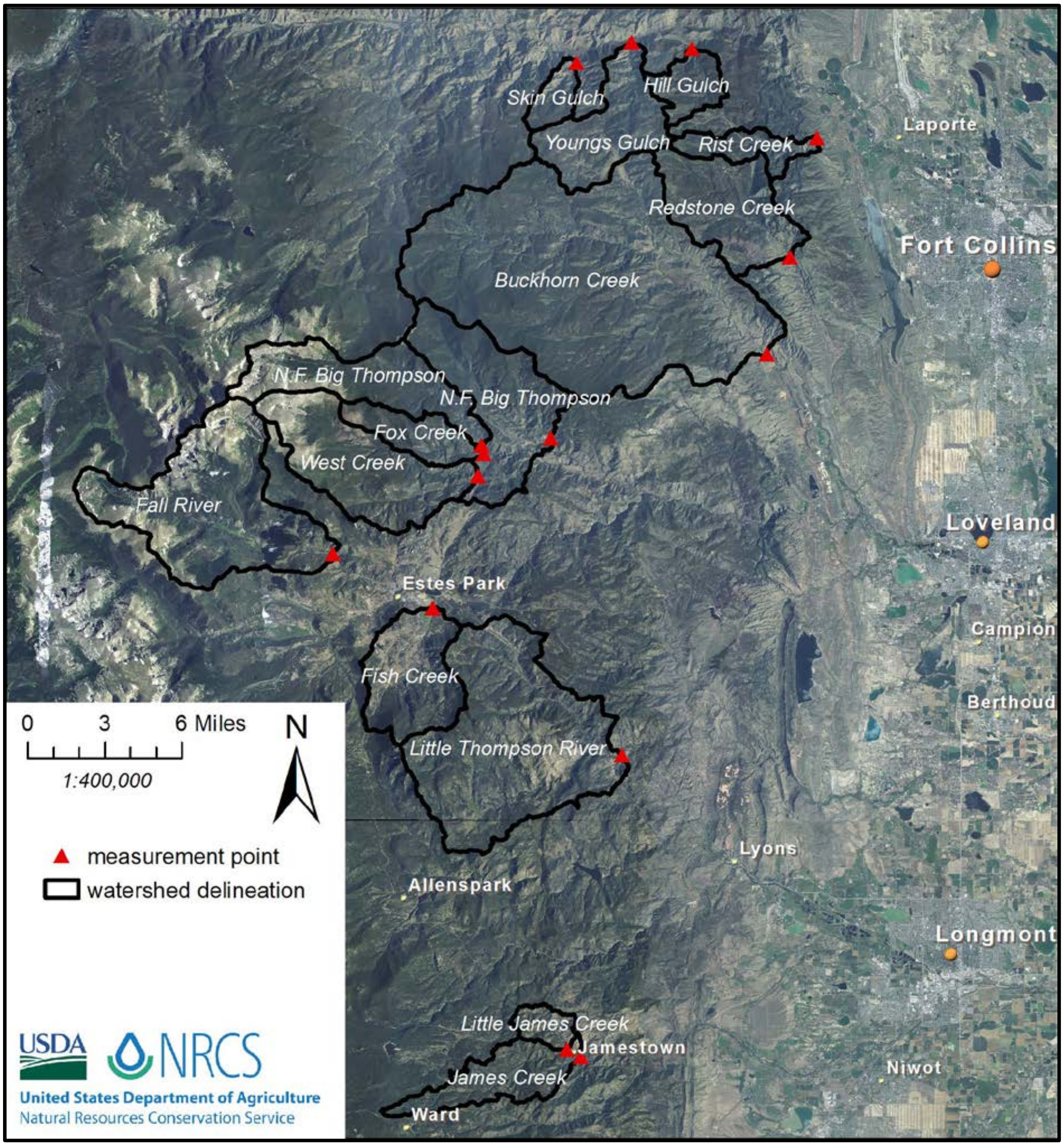

Figure 1: Peak flow estimate locations, Colorado Front Range Flood of 2013.

The measurements were collected and this was report was written to inform resource managers of the flood severity, aid in the development of revised flow-frequency relationships, and quantify the flood response of key catchments burned during the 2012 High Park Fire. This report details the methods implemented during the data collection and analysis processes, provides a summary and interpretation of results, and includes detailed information on each measurement. Additional documentation provides GPS locations, cross section data, and water surface elevations. ArcGIS shapefiles are also available, to provide spatial information to professionals and other interested parties.

METHODS

The critical depth method is frequently used to estimate peak flows from floods in mountain streams. This method has the key advantage of not requiring a roughness coefficient (Manning's *n*) estimate for the reach of interest. Manning's *n* can be notoriously difficult to estimate, especially since it varies by flow stage and debris loading (Limerinos, 1970; Bathurst, 1985; Lee and Ferguson, 2002; Wilcox and Wohl, 2006; Reid and Hickin, 2008; Ferguson, 2010; Yochum et al. 2012). Additionally, Manning's *n* has been found to vary in small headwater stream reaches from 0.05 to 0.30 for bankfull flow (slopes = 0.02 to 0.2 ft/ft, Yochum et al. 2012). As a result to this reach and stage variability, the step-backwater approach to peak flow prediction can be highly problematic in mountain stream channels, where flow resistance coefficients are likely to vary the greatest and the most appropriate Manning's *n* value for the flood condition in a specific reach unknown. The critical depth method avoids such pitfalls.

Using the critical-depth method, peak flow estimates are made using a single cross section (X-S, Figure 2), implementing high water marks at each location. This method is appropriate upstream of channel constrictions or drop-offs, and in channels with higher–gradient slopes (> ~1%). During floods, higher-gradient channels can flow at or near critical depth, where the Froude number (*Fr*) is unity and the following equation is applied to each cross section:

$$Fr = 1 = \frac{V}{\sqrt{gD}}$$

In this method, V is the average X-S velocity, D is the average flow depth ($D = A/T_w$), A is the flow area, T_w is the top width, and g is the acceleration due to gravity. Using the continuity equation, $Q = VA$, the Froude number equation can be reformulated to obtain estimates of flow rate:

$$Q = A\sqrt{\frac{gA}{T_w}}$$

where Q is the discharge in cubic feet per second (cfs). During substantial floods relatively long stretches of river can flow at or near critical depth, with replicate estimates of critical depth (3 to 6) providing estimates within +/- 15% of discharges measured using current meters (Jarrett and Tomlinson 2000; Webb and Jarrett 2002; Jarrett and England 2002).

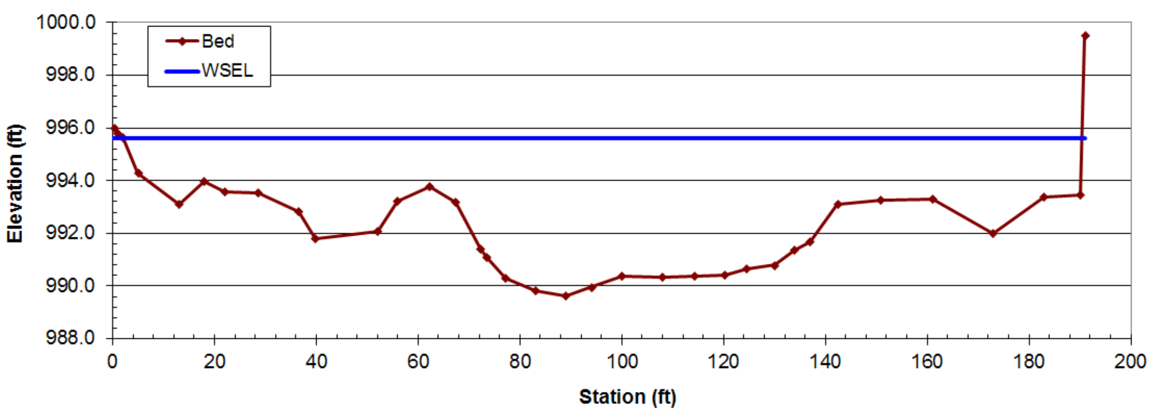

Figure 2: Example cross section (Buckhorn Creek, X-S 3)

Peak flow estimates documented in this report reply on the assumption that alluvial streams with slopes over 1 percent flow at about critical depth during large floods. Replicate measurements (separate flow estimates developed for several adjacent cross sections) were made for each reach of interest, to assess the reliability of the estimate. Consistency in the replicate measurements, as well as nested measurement locations in the Glen Haven area, indicate that the method is providing relatively precise estimates. Research assessing the accuracy of the method (Jarrett and Tomlinson 2000; Webb and Jarrett 2002; Jarrett and England 2002), combined with the precision seen in the estimates, supports the validity of the critical flow assumption.

All of the stream reaches measured in this report have slopes greater than 1%, and had discharge measured at three adjacent cross sections spaced about 1 flood-width apart. Average peak flow was computed from the replicate cross sections. Variations in the individual peak flow estimates provide a qualitative measure of prediction accuracy.

Each cross section was located in a reach that had uniform channel slope and width, did not have a substantial amount of debris that could induce local backwater effects, and, if possible, did not have substantial channel bank erosion. Where consistent high water marks were available between measured cross sections, a longitudinal profile of the water surface was measured. Flow was assumed to be dominated by water and that debris loading was not substantial enough to change the fluid dynamics of the flow. Field evidence did not indicate that debris flows and other types of mass movements were present at the measurement locations, though such mass movements have been documented in contributing areas (Figure 7).

If grouping was observed with the individual cross section flow peaks, and an outlier hence identified, the outlier was sometimes eliminated from the average. This elimination was contingent upon a reasonable mechanism identified that could explain the reason for the outlying point. Typical outlier causes include excessive bank erosion due to braiding during the flood, bank disturbance by heavy machinery during recovery efforts, or local backwater induced by a substantial amount of debris. While best practice avoids placing cross sections in such locations, some reaches were unavoidable due to extreme erosion, lack of quality high water marks, debris removal, infrastructure placement in the channel bottom, and reestablishment of roadway surfaces adjacent to the channels.

High Water Marks

Typical high water marks observed at the peak flow estimate locations include bent grass and slackwater deposits of fine sediment, organic material, and ash along the channel margins (Figure 3). Debris lines were ignored in mid-channel locations since these often reflect run up from high mid-channel velocities instead of actual peak water surface elevations. In contrast, velocities were at or near zero at the channel edges. If bent grass was observed, the banks above these locations were inspected for slackwater deposits within often still upright grasses. Multiple high water marks were searched for, since the flood event occurred over multiple days and multiple flood peaks were likely. Additionally, preference was given to high water marks that were part of a series of indicators along a channel edge, indicating a water surface profile in the measurement reach (Figure 4).

Figure 3: Typical slackwater deposit (Rist Creek, X-S 3).

Figure 4: Series of high water marks, providing a peak water surface profile (James Creek).

Flow Frequency Estimates

To provide an understanding of the flow frequency of the measured flood peak at each location, the peak flows are compared to flow frequency relationships developed for each site. These flow frequency values are approximate and are only intended to provide a basic level of understanding of the relative magnitude of the event.

In areas where sufficient streamgage data was available in the vicinity of the measurement location, peak flows were compared to the results of a logPearson Type 3 frequency analysis of the peak flow record. For this comparison, the 2013 flood peak was excluded from the flow-frequency analysis.

For areas draining the High Park Fire area, the peak flows were compared to the expected runoff predicted as a part of the High Park Fire recovery effort. The methods and results are presented in Yochum (2012).

For other areas, peak flows were compared to U.S. Geological Survey (USGS) peak flow predictions developed using regional regression equations (Capesius and Stephens 2009). The method was developed with separate equations for elevations below and above 7500 ft along the Front Range, the approximate elevation where convective rain events are assumed to cause annual peak flows. Since this rain event occurred at elevations both above and below 7500 feet, the equations developed for elevations less than 7500 feet (Plains Region) was applied for the comparisons. The implemented equation is:

$$Q_{100} = 10^{0.88} A^{0.63} P_{100}^{2.98}$$

, where Q is the peak flow estimate (cfs), the subscript is the recurrence interval (years), A is the drainage area (mi^2) and P_{100} is the 6-hour, 100-year precipitation depth (inches). The error bars associated with these predictions are substantial – typically about 140 percent.

RESULTS and DISCUSSION

Peak flood discharges were found to be substantially greater than the 100-year event in many of the streams, with substantial flows estimated for all 15 of the streams included in this effort (Table 1, Figure 5). Discharges ranged from 18,400 cubic feet per second (cfs, N.F. of the Big Thompson upstream of Drake) to 870 cfs (Hill Gulch). Peak flow yields ranged from 720 to 69 cfs/mi^2. The associated return intervals of the floods ranged from about 5 times the 100-year flood to between a 25- and 50-year flood. The highest flow yields and least frequent return interval typically corresponded to streams with the highest observed property damage and streambank disturbances.

Across this study extent, the highest peak flow yields are generally towards the south (Figure 5), though a northern catchment (Skin Gulch) is an important exception. Streams with the highest peak flow yield include Little James Creek upstream of Jamestown (579 cfs/mi^2), Fish Creek upstream of Lake Estes (442 cfs/mi^2), West Creek and Fox Creeks upstream of Glen Haven (477 and 486 cfs/mi^2, respectively) and Skin Gulch (720 cfs/mi^2). The high Skin Gulch flow is most likely the result of the 2012 High Park Fire, which burned much of this catchment to a high soil burn severity; large floods also occurred during the summers of 2012 and 2013 during local rain events. Catchments with larger drainage areas, such as the N.F of the Big Thompson River upstream of Drake and the Little Thompson River at Pinewood Springs, had large flows (18,400 and 14,600 cfs, respectively) but lesser yields. Peak yields occurred from smaller drainages, indicating spatial variability in rainfall depths, with greater rainfall depths over some of the smaller catchments. This yield variability indicates that while this storm event was large in area, substantial spatial variability in rainfall depths across the impacted area did occur.

Within the limits of this data collection effort, these peak flow data indicate that the highest rainfall appears to have occurred in the vicinity of Jamestown, Twin Sisters, and within the N. F. of the Big Thompson watershed. Lower yields in the Falls River and uppermost elevations of the N.F. of the Big Thompson indicate that the extreme rainfall was limited to points below the highest elevations, though substantial rainfall depths did occur at elevations above the 7500 feet rule of

Table 1: Peak flow estimates from the Colorado Front Range Flood (week of September 9th, 2013), organized from south to north and upstream to downstream. cfs = cubic feet per second, ft/s = feet/second, mi^2 = square miles.

Location Description	Peak Discharge (cfs)	Average Velocity (ft/s)	Peak Width (ft)	Catchment Area (mi^2)	Peak Yield (cfs/mi^2)	Return Interval or Multiples of 100-year flow
Little James Creek upstream of Jamestown	1,800	10.2	55	3.11	579	~3 * 100-year
James Creek in Jamestown	4,800	11.2	110	13.7	350	~3 * 100-year
Little Thompson River at Pinewood Springs	14,600	15.5	126	46.4	315	~3 * 100-year
Fish Creek upstream of Lake Estes	6,900	11.3	150	15.6	442	~5 * 100-year
Fall River upstream of Estes Park	3,800	9.3	153	36.5	104	~2 * 100-year
West Creek upstream of Glen Haven	11,000	14.2	125	23.1	477	~4 * 100-year
Fox Creek upstream of Glen Haven	3,500	10.9	88	7.2	486	~3 * 100-year
N.F. Big Thompson River upstream of Glen Haven	1,700	7.9	109	18.2	93	50- to 100-year
N.F. Big Thompson River upstream of Drake	18,400	16.7	127	70.9	260	~2.5 * 100-year
Buckhorn Creek upstream of Masonville	11,000	11.4	250	88.2	125	50- to 100-year
Redstone Creek at Happy Hollow Gulch	1,200	7.7	90	17.5	69	50- to 100-year
Rist Creek downstream of Whale Rock	1,000	9.3	41	5.48	182	50- to 100-year
Skin Gulch upstream of Stove Prairie Road	2,500	10.5	70	3.5	720	~5 * 100-year
Young Gulch upstream of CO-14	1,200	8.4	67	15.2	79	25- to 50-year
Hill Gulch upstream of CO-14	870	9.0	38	5.5	159	25- to 50-year

thumb used as a line of demarcation between convective- and snowmelt-dominated peak flow areas. Higher rainfall depths appear to have occurred at elevations as high as 8200 feet (Little James Creek), and 10,000 feet (Twin Sisters area). Two large mass movements occurred on both the East and West faces of the Twin Sisters (Figure 7), indicating high rainfall depths in these areas.

Impacts on Flow Frequency Relationships

Based on this new information, shifts in flow frequency relationships can be expected for many of the streams impacted by this flooding. For example, inclusion of the 2013 peak at the N.F. of the Big Thompson at Drake streamgage increases the expected 100-year flow from 7300 cfs to 24,000 cfs. This logPearson analysis also

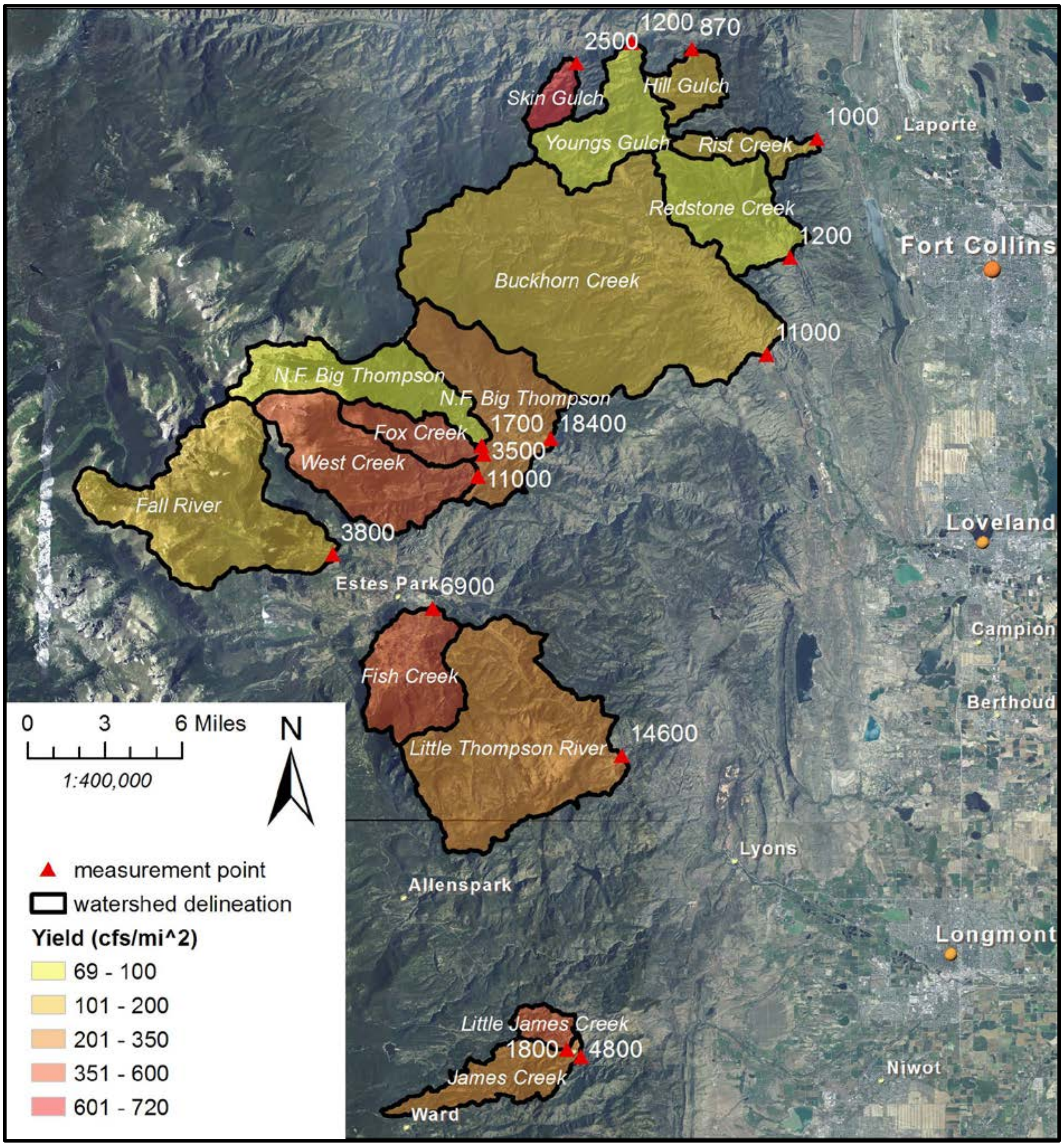

Figure 5: Peak flow (cfs) and yield (cfs/mi^2) estimates at selected locations, Colorado Front Range Flood of 2013.

includes the 1976 peak of 8700 cfs. Similarly, inclusion of the 2013 peak in the Fish Creek gage record increases the 100-year flow from 1500 cfs to 6600 cfs. In contrast, the Buckhorn Creek catchment has experienced multiple flows over 10,000 cfs prior to 2013, with prior flood events over 10,000 cfs in 1923, 1938 and 1951. Inclusion of the 2013 flow peak changes the 100-year flow from 14,000 to 22,000 cfs (with exclusion of the 1951 dam beach-impacted peak flow). While the channel prior to the 2013 flood was narrow (Figure 6), the channel is now on the order of 200 feet wide. The extensive riparian vegetation appears to have grown since the last large flood, indicating that this stream corridor shifts its form depending upon the time since the last large flood (alternate geomorphic states).

High Water Marks

In regard to the individual high water marks, most typically bent grass was observed at a measurement site, with slackwater flood deposits above these bent grasses within less-disturbed vegetation. Multiple (up to three) high water marks were observed at many locations, indicating the highest flow peak and lesser flow peaks that occurred during the multi-day flood event. In some areas high water marks were only indicated on one side of the cross section, due to cliff faces and erosion scars. However, where possible high water marks were measured on each side of the cross section and averaged.

Figure 6: Pre-flood Buckhorn Creek channel.

Individual Peak Flow Measurements

This section provides information on each of the individual peak flow measurements. Cross section and water surface elevation data are also provided in Appendix A, for reference. A site location map and typical condition photograph is also provided.

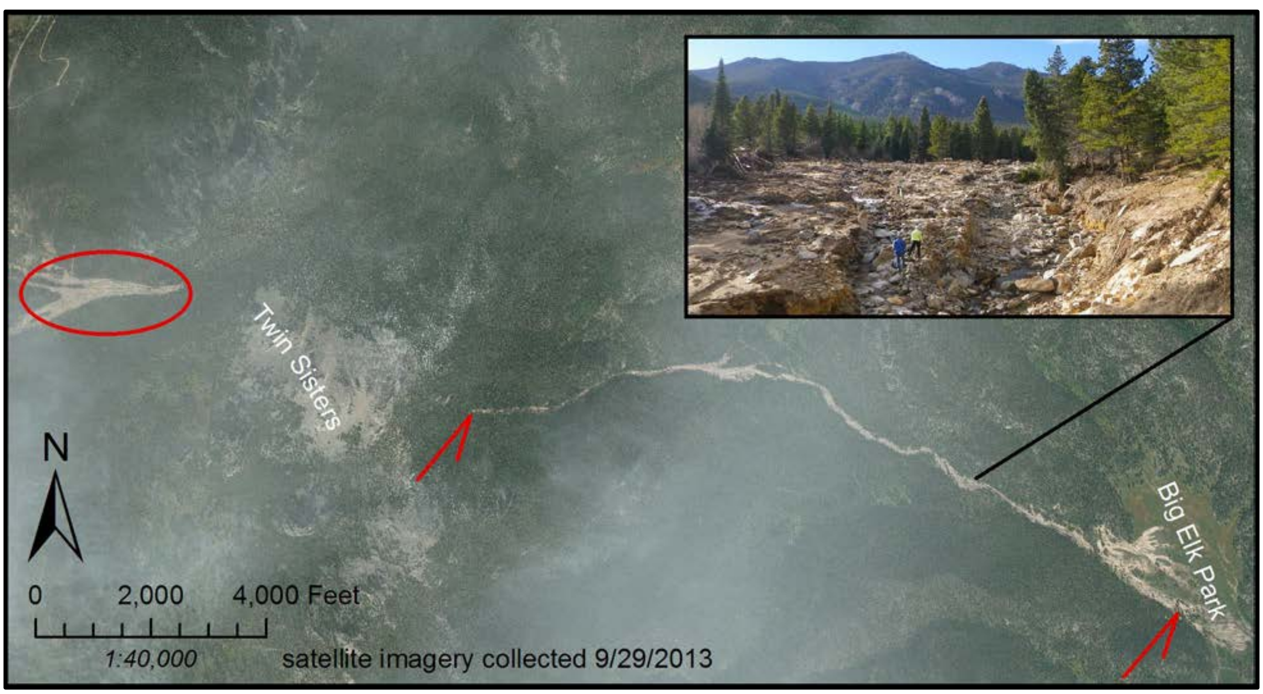

Figure 7: Twin Sisters' mass movements.

Little James Creek upstream of Jamestown

Discharge was measured at three adjacent sections on Little James Creek (Table 2, Figures 8 & 9, Table A-1), with peak flow computed to be **1,800 cfs**. Average channel slope is approximately 0.063 ft/ft in this reach. X-S 1 was eliminated in the average computations since it appears to have been too close to a waterfall, within the supercritical drawdown (resulting in a low estimate using the critical depth assumption). Consistency in the peak flow estimates at the more upstream sections supports this conclusion.

Table 2: Little James Creek cross section computations (measured 10/29/2013, data collection by J. Crane and S. Yochum).

	Velocity (ft/s)	Width (ft)	Max Depth (ft)	Discharge (ft^3/s)
X-S 1*	8.2	61	5.3	1,020
X-S 2	9.8	62	6.9	1,810
X-S 3	10.7	47	7.4	1,770

* not utilized in average

The average peak flow of 1,800 cfs is approximately 3 times the 100-year flow, as indicted by the USGS regression equations for peak flow prediction (Capesius and Stephens 2009).

The GPS point was measured on the left bank near X-S 1. X-S 2 was located about 1/2 flood width upstream of X-S 1. X-S 3 was located about 1/2 flood width upstream of X-S 2.

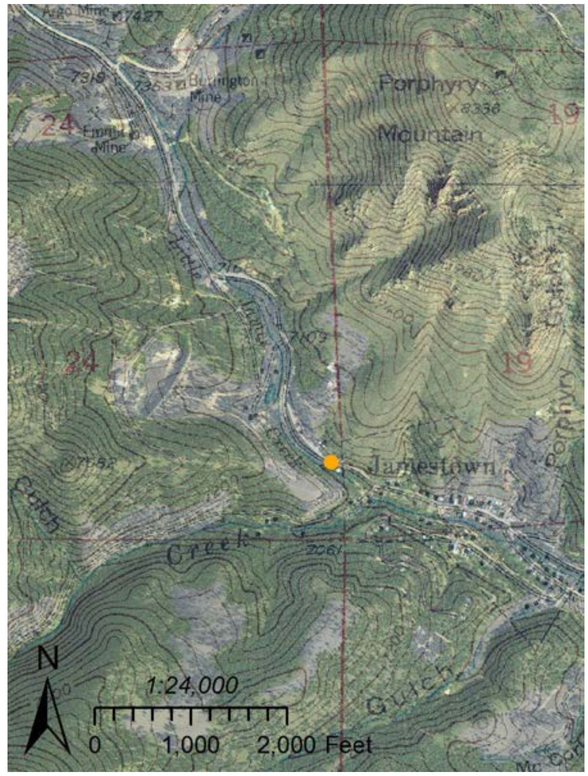

Figure 8: Little James Creek measurement location (Lat, Long = 40.117026, -105.392665)

Figure 9: Little James Creek, viewing downstream at X-S 2 (photo collected on 11/22/2013).

James Creek in Jamestown

Discharge was measured at three adjacent sections on James Creek (Table 3, Figures 10 & 11, Table A-2), with peak flow computed to be **4,800 cfs**. Average channel slope is approximately 0.033 ft/ft in this reach, with a water surface slope measured to be 0.025 ft/ft between X-S 1 and X-S 2. X-S 2 was eliminated in the average computations due to its location at a roadway failure and a compound channel.

Table 3: James Creek cross section computations (measured 10/29/2013, data collection by S. Yochum and J. Crane).

	Velocity (ft/s)	Width (ft)	Max Depth (ft)	Discharge (ft^3/s)
X-S 1	11.3	118	8.0	5,260
X-S 2*	12.7	119	9.0	7,580
X-S 3	11.2	100	8.2	4,360

* not utilized in average

The average peak flow of 4,800 cfs is approximately 3 times the 100-year flow, as indicted by the USGS regression equations for peak flow prediction (Capesius and Stephens 2009).

The GPS point was measured on the right bank at X-S 1. X-S 2 was located about 1 flood width downstream of X-S 1. X-S 3 was located about 1 flood width downstream of X-S 2.

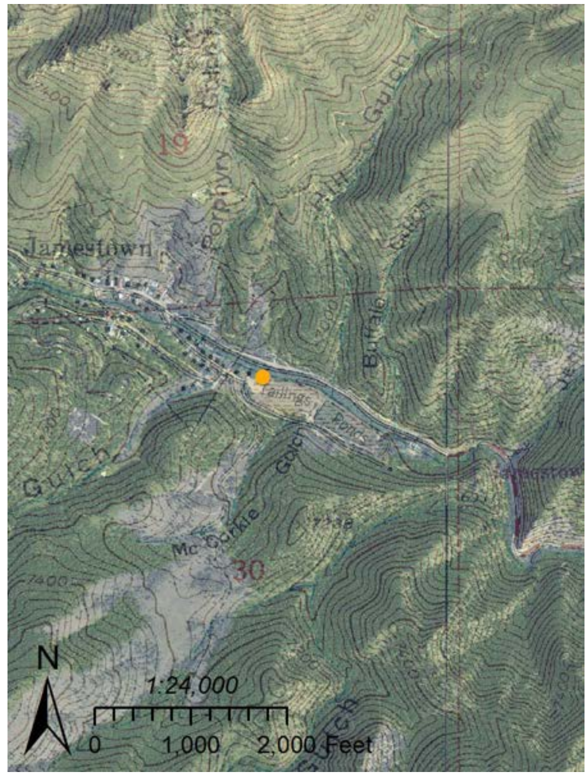

Figure 10: James Creek measurement location (Lat, Long = 40.113254, -105.382400)

Figure 11: James Creek, viewing downstream at X-S 2 and X-S 3.

Little Thompson River at Pinewood Springs

Discharge was measured at three adjacent sections on the Little Thompson River (Table 4, Figures 12 & 13, Table A-3), with peak flow computed to be **14,600 cfs**. Average channel slope is approximately 0.021 ft/ft in this reach. A number of small dams failed in the Big Elk Meadows community (5.3 miles upstream); the failure of these structures may have increased the peak flow at this location.

Table 4: Little Thompson River at Pinewood Springs cross section computations (measured 11/3/2013, data collection by D. Moore).

	Velocity (ft/s)	Width (ft)	Max Depth (ft)	Discharge (ft^3/s)
X-S 1	15.2	132	16.1	14,600
X-S 2	15.8	124	14.5	15,200
X-S 3	15.5	123	14.2	14,100

The average peak flow of 14,600 cfs is approximately 3 times the 100-year flow, as indicted by the USGS regression equations for peak flow prediction (Capesius and Stephens 2009).

The GPS point was measured on the right bank at X-S 2. X-S 1 was located about 1 flood width upstream of X-S 1. X-S 3 was located about 1 flood width downstream of X-S 2.

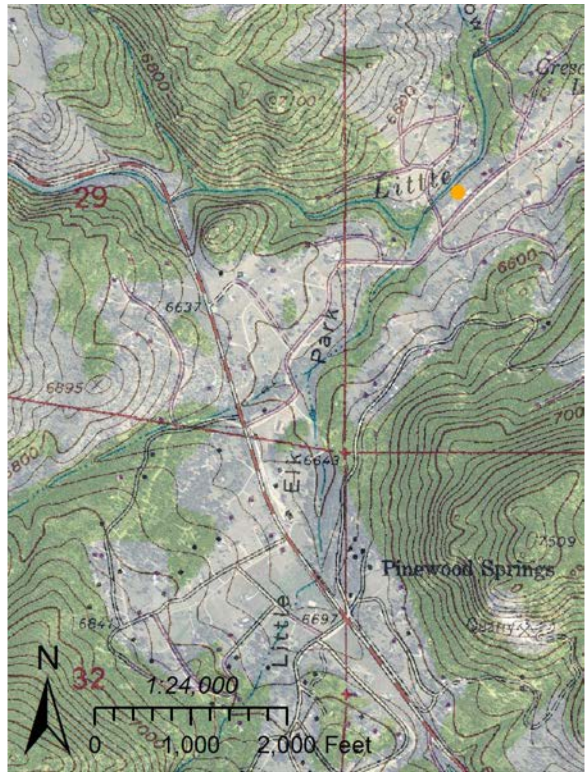

Figure 12: Little Thompson River at Pinewood Springs measurement location (Lat, Long = 40.283733, -105.352933)

Figure 13: Little Thompson River, viewing downstream at X-S 2.

Fish Creek upstream of Lake Estes

Discharge was measured at three adjacent sections on Fish Creek (Table 5, Figures 14 & 15, Table A-4), with peak flow computed to be **6,900 cfs**. The channel bed was disturbed to install a temporary sewer line; a site with minimal disturbance and quality high water marks was selected, though this disturbance may have negatively impacted the accuracy of the peak flow estimates. Average channel slope is approximately 0.015 ft/ft in this reach, with a water surface slope measured to be 0.011 ft/ft between X-S 1 and X-S 3.

Table 5: Fish Creek cross section computations (measured 10/29/2013, data collection by D. Moore).

	Velocity (ft/s)	Width (ft)	Max Depth (ft)	Discharge (ft^3/s)
X-S 1	11.2	163	9.4	7,100
X-S 2	10.8	159	9.6	6,300
X-S 3	11.8	141	9.4	7,200

The pre-flood channel was essentially obliterated during this flood, with the formally willow-lined banks destroyed in most locations. Channel width increased from approximately 10 ft to more than 60 ft, with an average flow width of 150 feet.

The average peak flow of 6,900 cfs is approximately 5 times the 100-year flow, as indicted by a logPearson flow frequency analysis of peak flow data from the Fish Creek near Estes Park streamgage (06734500), located just downstream of this measurement location. The gage record for this site is 33 years, with data collected from 1947 to 1979. Prior to 2013, the highest peak flow measured at this site was 1480 cfs (1951). The typical peak flow is between 5 and 60 cfs, with a 2-year flow of 26 cfs.

The GPS point was measured at X-S 2. X-S 1 was located 40 ft downstream of X-S 2. X-S 3 was located 150 upstream of X-S 2.

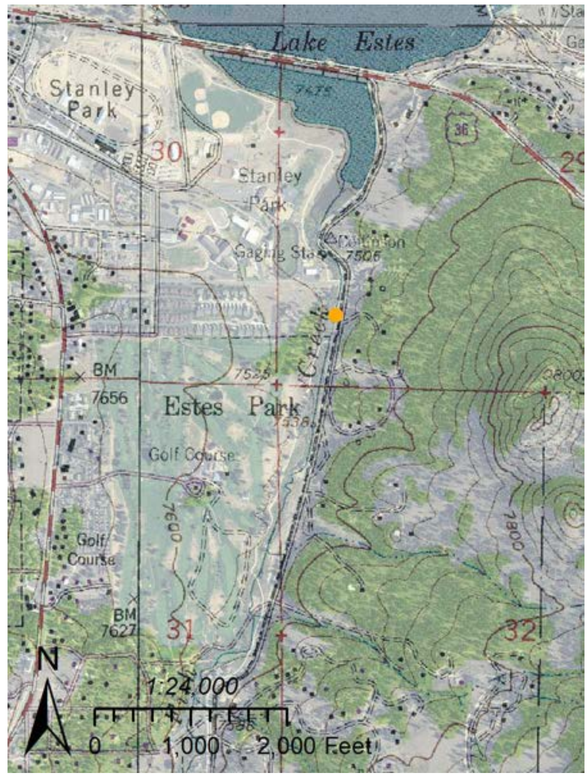

Figure 14: Fish Creek measurement location (Lat, Long = 40.366700, -105.493267)

Figure 15: Fish Creek, viewing downstream at X-S 3.

Fall River upstream of Estes Park

Discharge was measured at three adjacent sections on Fall River (Table 6, Figures 16 & 17, Table A-5), with peak flow computed to be **3,800 cfs**. Average channel slope is approximately 0.022 ft/ft in this reach.

Table 6: Fall River upstream of Estes Park cross section computations (measured 10/30/2013, data collection by D. Moore).

	Velocity (ft/s)	Width (ft)	Max Depth (ft)	Discharge (ft^3/s)
X-S 1	9.2	160	7.5	3,800
X-S 2	9.2	178	7.6	4,300
X-S 3	9.4	122	5.9	3,200

The average peak flow of 3,800 cfs is approximately 2 times the 100-year flow, as indicted by the USGS regression equations for peak flow prediction (Capesius and Stephens 2009).

The GPS point was measured at X-S 2. X-S 1 was located upstream of X-S 2 while X-S 3 was located downstream of X-S 2.

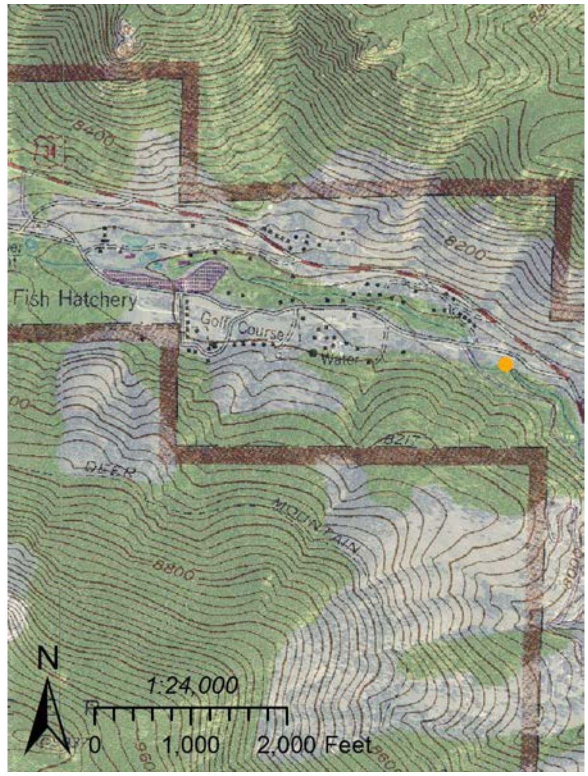

Figure 16: Fall River upstream of Estes Park measurement location (Lat, Long = 40.396683, -105.567317)

Figure 17: Fall River, viewing upstream at X-S 1.

West Creek upstream of Glen Haven

Discharge was measured at three adjacent sections on West Creek (Table 7, Figures 18 & 19, Table A-6), with peak flow computed to be **11,000 cfs**. Average channel slope is approximately 0.030 ft/ft in this reach.

Table 7: West Creek cross section computations (measured 10/28/2013, data collection by S. Yochum and D. Moore).

	Velocity (ft/s)	Width (ft)	Max Depth (ft)	Discharge (ft^3/s)
X-S 1	13.9	137	11.0	11,500
X-S 2	14.3	116	12.5	10,500
X-S 3	14.3	123	11.2	11,100

The average peak flow of 11,000 cfs is approximately 4 times the 100-year flow, as indicted by the USGS regression equations for peak flow prediction (Capesius and Stephens 2009).

The GPS point was measured on the left bank at X-S 1. X-S 2 was located about 1 flood width upstream of X-S 1. X-S 3 was located about 1 flood width downstream of X-S 2.

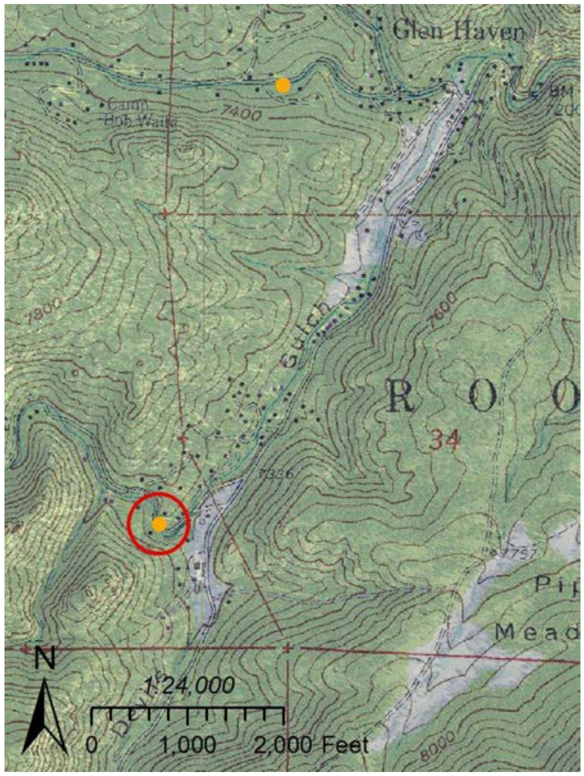

Figure 18: West Creek measurement location (Lat, Long = 40.441450, -105.460483).

Figure 19: West Creek, viewing upstream at X-S 1.

Fox Creek upstream of Glen Haven

Discharge was measured at three adjacent sections on Fox Creek (Table 8, Figures 20 & 21, Table A-7), with peak flow computed to be **3,500 cfs**. Average channel slope is approximately 0.029 ft/ft in this reach. X-S 3 was eliminated in the average computations due to being an outlier with a relatively wide compound channel.

Table 8: Fox Creek cross section computations (measured 10/31/2013, data collection by D. Moore).

	Velocity (ft/s)	Width (ft)	Max Depth (ft)	Discharge (ft^3/s)
X-S 1	11.6	77	9.9	3,700
X-S 2	10.3	98	8.6	3,300
X-S 3	11.5	112	8.7	5,300

* not utilized in average

The average peak flow of 3,500 cfs is approximately 3 times the 100-year flow, as indicted by the USGS regression equations for peak flow prediction (Capesius and Stephens 2009).

The GPS point was measured at X-S 2. X-S 1 was located upstream of X-S 2. X-S 3 was located downstream of X-S 2.

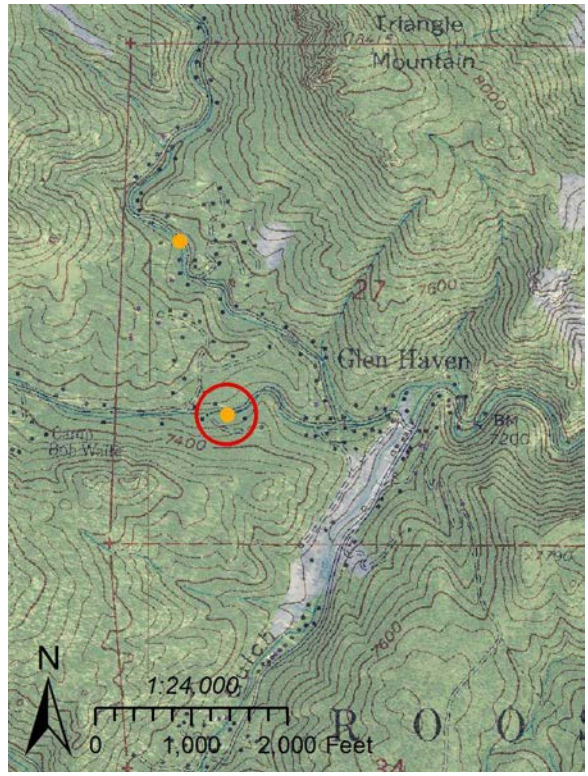

Figure 20: Fox Creek measurement location (Lat, Long = 40.454017, -105.455950).

Figure 21: Fox Creek, viewing downstream at X-S 2.

N.F. Big Thompson River upstream of Glen Haven

Discharge was measured at three adjacent sections on the N. F. of the Big Thompson River upstream of Glen Haven (Table 9, Figures 22 & 23, Table A-8), with peak flow computed to be **1,700 cfs**. Average channel slope is approximately 0.048 ft/ft in this reach.

Table 9: N.F. Big Thompson River upstream of Glen Haven cross section computations (measured 11/1/2013, data collection by D. Moore).

	Velocity (ft/s)	Width (ft)	Max Depth (ft)	Discharge (ft^3/s)
X-S 1	8.1	105	5.7	1,750
X-S 2	7.6	106	5.4	1,430
X-S 3	7.9	116	5.4	1,790

The average peak flow of 1,700 cfs is between a 50- and 100-year flow, as indicted by the USGS regression equations for peak flow prediction (Capesius and Stephens 2009).

The GPS point was measured near X-S 2. X-S 1 was located upstream of X-S 2. X-S 3 was located downstream of X-S 2.

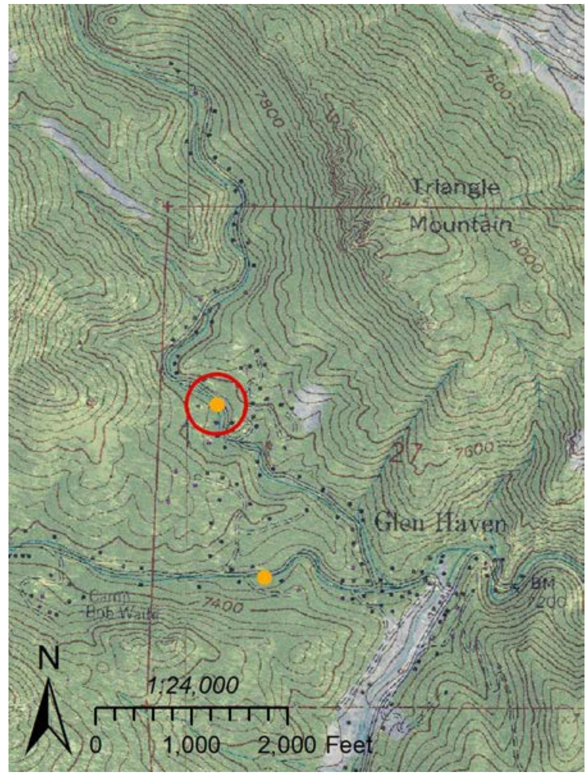

Figure 22: N.F. Big Thompson River upstream of Glen Haven measurement location (Lat, Long = 40.458967, -105.457767).

Figure 23: N. F. of the Big Thompson River upstream of Glen Haven, viewing upstream at X-S 2.

N.F. Big Thompson River upstream of Drake

Discharge was measured at three adjacent sections on the N.F. Big Thompson River upstream of Drake (Table 10, Figures 24 & 25, Table A-9), with peak flow computed to be **18,400 cfs**. Average channel slope is approximately 0.059 ft/ft in this reach. X-S 2 was eliminated in the average computations due to being an outlier with probable backwater influence from large boulders and woody debris.

Table 10: N.F. Big Thompson River upstream of Drake cross section computations (measured 11/3/2013, data collection by D. Moore).

	Velocity (ft/s)	Width (ft)	Max Depth (ft)	Discharge (ft^3/s)
X-S 1	16.6	129	17.7	18,500
X-S 2*	17.9	131	19.3	23,600
X-S 3	16.8	125	16.0	18,400

* not utilized in average

The average peak flow of 18,400 cfs is approximately 2.5 times the 100-year flow, as indicted by a logPearson flow frequency analysis of peak flow data from the N.F. Big Thompson River at Drake streamgage (06736000), ~4.5 miles downstream of this measurement location. This frequency analysis did not include the 2013 data point. The gage record for this site is 30 years, with data collected from 1947 to 1976. The peak flow measured at this location was 8710 cfs, in 1976.

The GPS point was measured at X-S 1. X-S 2 and X-S 3 were located downstream of X-S 1.

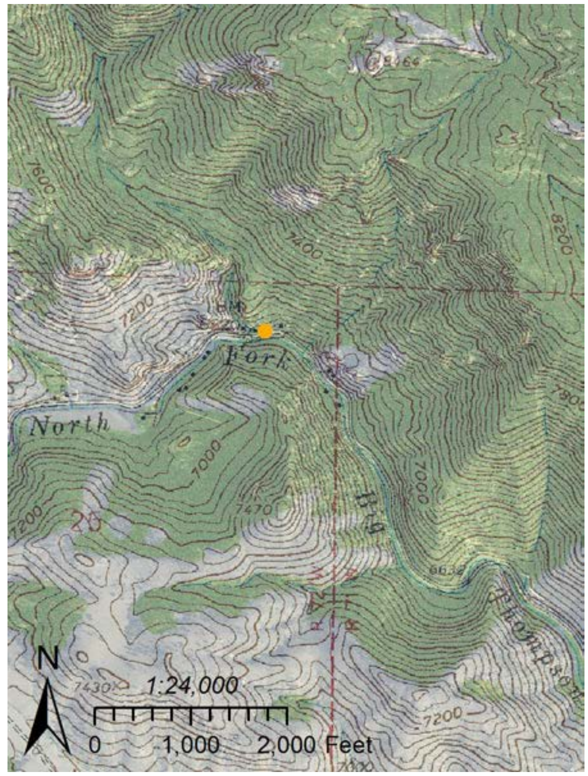

Figure 24: N.F. Big Thompson River upstream of Drake measurement location (Lat, Long = 40.463017, -105.406533)

This point is downstream of measurement locations at three contributing streams (West Creek, Fox Creek, and the upper N.F. of the Big Thompson). The summation of the peak flows at these sites is 16,200 cfs, which compares well with this measurement considering the additional runoff area downstream of Glen Haven.

Figure 25: N.F. Big Thompson River upstream of Drake, viewing downstream at X-S 1.

Buckhorn Creek upstream of Masonville

Discharge was measured at three adjacent sections on Buckhorn Creek (Table 11, Figures 26 & 27, Table A-10), with peak flow computed to be **11,000 cfs**. Substantial portions of this catchment burned during the High Park Fire in 2012, which most likely increased peak flow during this event. Average channel slope is approximately 0.013 ft/ft in this reach.

Table 11: Buckhorn Creek cross section computations (measured 9/26/2013, data collection by S. Yochum).

	Velocity (ft/s)	Width (ft)	Max Depth (ft)	Discharge (ft^3/s)
X-S 1	10.8	340	8.4	13,000
X-S 2	11.4	230	6.8	10,600
X-S 3	12.1	190	6.0	10,400

Flow was observed to have risen above the elevation of a high terrace at this location. A substantial about of stream bank was eroded, with a large amount of woody vegetation mobilized. Channel width increased from approximately 25 ft to more than 200 ft.

A streamgage installed for a High Park Fire emergency notification system indicated that stage increased more than 12 feet in 20 hours at that location 7 miles upstream of this site, peaking at 21:22 on 9/12/2013.

The average peak flow of 11,000 cfs is between a 50- and 100-year flow, as indicted by a logPearson flow frequency analysis of peak flow data from the Buckhorn Creek near Mansonville streamgage (06739500; BUCRMVCO), ~7 miles downstream of this measurement location. The gage record for this site is 29 years, with data primarily collected from 1947 to 1955 and 1993 to 2012. This site experienced flow of about 10,500 cfs (1923), 10,200 cfs (1938), and 14,000 cfs (1951, influenced by a dam failure), while relatively low annual peak flows have occurred in more recent years.

The GPS point was measured on the right bank at X-S 1. X-S 2 was located about 1 flood width downstream of X-S 1. X-S 3 was located about 1.5 flood widths downstream of X-S 2.

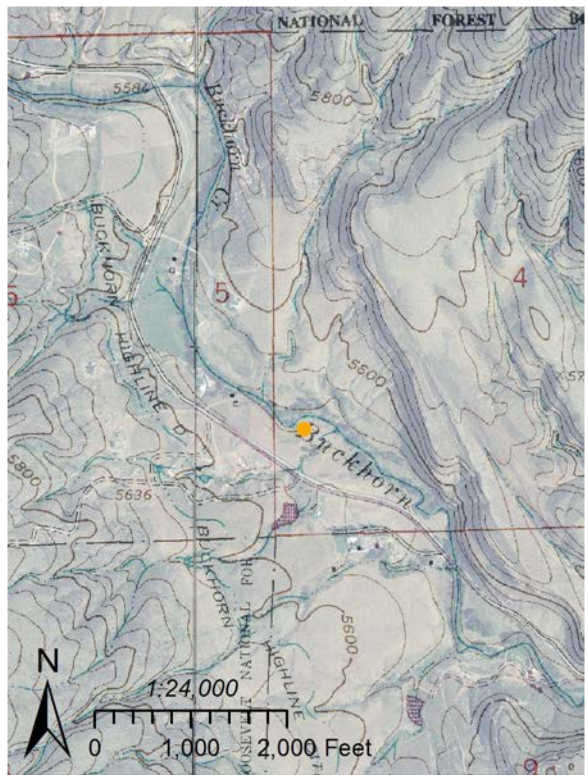

Figure 26: Buckhorn Creek measurement location (Lat, Long = 40.511138, -105.246466)

Figure 27: Buckhorn Creek, viewing upstream at X-S 2.

Redstone Creek at Happy Hollow Gulch

Discharge was measured at three adjacent sections on Redstone Creek (Table 12, Figures 28 & 29, Table A-11), with peak flow computed to be **1,200 cfs**. Substantial portions of this catchment burned during the High Park Fire in 2012, which most likely increased peak flow during this event. Average channel slope is approximately 0.024 ft/ft in this reach. X-S 3 was eliminated due to confluence and bridge influences.

Table 12: Redstone Creek cross section computations (measured 9/24/2013, data collection by S. Yochum).

	Velocity (ft/s)	Width (ft)	Max Depth (ft)	Discharge (ft^3/s)
X-S 1	7.4	110	4.2	1,370
X-S 2	8.0	69	4.6	1,100
X-S 3*	7.1	61	5.2	680

* not utilized in average

This reach had only minor bank erosion. Woody riparian vegetation was primarily not impacted by this event, though sediment deposition on the floodplain was evident.

A streamgage installed for a High Park Fire emergency notification system indicated that stage peaked on 9/12/2013 at 17:36, increasing from a base of 0.0 to 5.48 ft between the morning of 9/11 to the time of peak. Various lesser peaks were also recorded. The gage location is 1.3 miles upstream of this flow measurement site.

The average peak flow of 1,200 cfs is between the 50-year and 100-year peak flows for pre-fire conditions and between a 10-year and 25-year flood for post-fire conditions, as indicted by hydrologic modeling of 1-hour rainfall events for the High Park Fire area (Yochum 2012).

The GPS point was measured on the right bank at X-S 1. X-S 2 was located about 1 flood width upstream of X-S 1. X-S 3 was located about 1 flood width downstream of X-S 1.

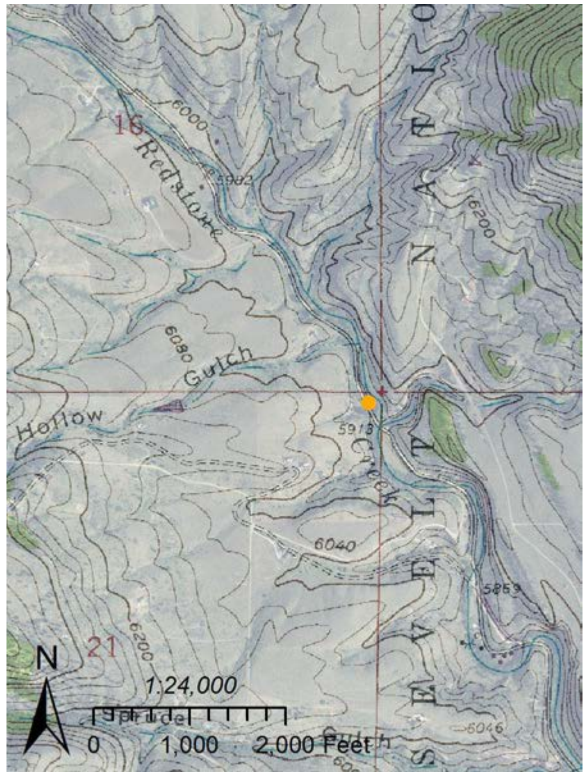

Figure 28: Redstone Creek measurement location (Lat, Long = 40.565932, -105.229426).

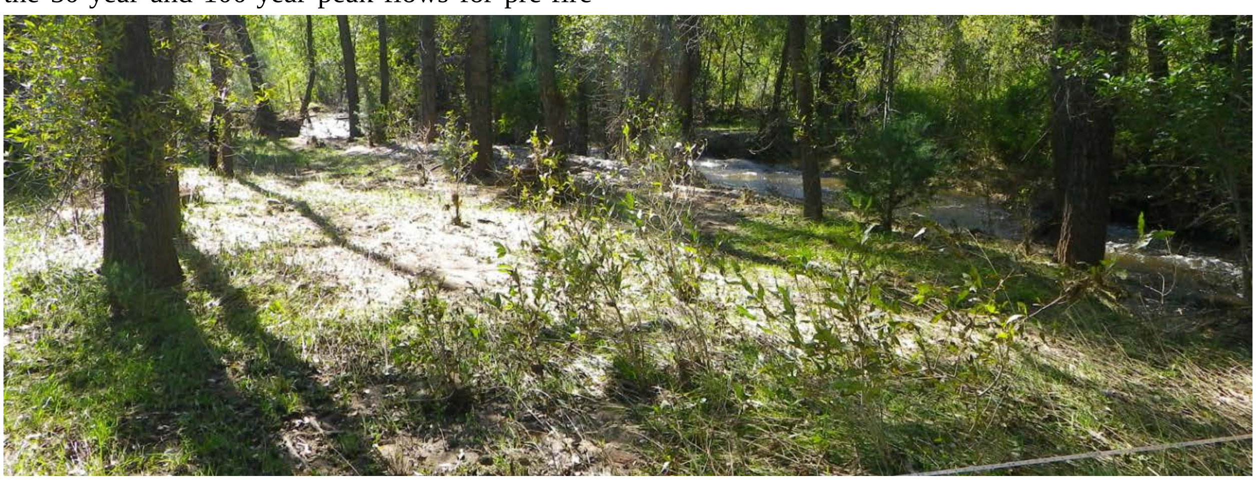

Figure 29: Redstone Creek, viewing downstream at X-S 2.

Rist Creek downstream of Whale Rock

Discharge was measured at three adjacent sections on Rist Creek (Table 13, Figures 30 & 31, Table A-12), with peak flow computed to be **1,000 cfs**. Substantial portions of this catchment burned during the High Park Fire in 2012, which most likely increased peak flow during this event. Average channel slope is approximately 0.040 ft/ft in this reach, with a water surface slope measured to be 0.029 ft/ft between X-S 1 and X-S 2.

Table 13: Rist Creek cross section computations (measured 9/25/2013, data collection by S. Yochum).

	Velocity (ft/s)	Width (ft)	Max Depth (ft)	Discharge (ft^3/s)
X-S 1	9.55	35.8	4.6	968
X-S 2	9.07	40.9	5.5	949
X-S 3	9.39	44.8	5.0	1,152

A streamgage installed 3.4 miles upstream of this site for a High Park Fire emergency notification system indicated that the stage peaked at 20:58 on 9/12/2013.

The average peak flow of 1,000 cfs is between a 50- and 100-year event (between 10- and 25-year post-fire event), as indicted by hydrologic modeling of 1-hour rainfall events for the High Park Fire area (Yochum 2012).

The GPS point was measured on the left bank at X-S 2. X-S 1 was located about 1 flood width upstream of X-S 1. X-S 3 was located about 1 flood width downstream of X-S 2.

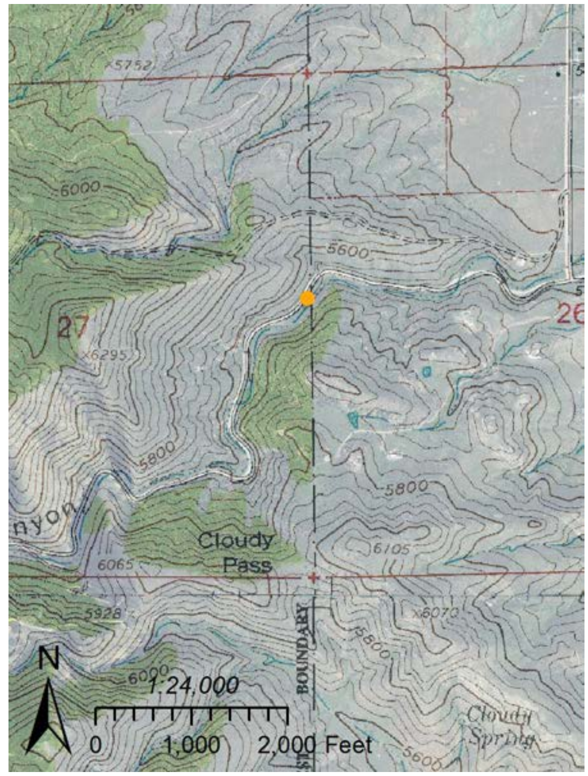

Figure 30: Rist Creek measurement location (Lat, Long = 40.633504, -105.209774)

Figure 31: Rist Creek, viewing downstream at X-S 3.

Skin Gulch upstream of Stove Prairie Road

Discharge was measured at three adjacent sections in Skin Gulch (Table 14, Figures 32 & 33, Table A-13), with peak flow computed to be **2,500 cfs**. Substantial portions of this catchment burned during the High Park Fire in 2012, which most likely increased peak flow during this event. Average channel slope is approximately 0.056 ft/ft in this reach.

Table 14: Skin Gulch cross section computations (measured 10/10/2013, data collection by S. Yochum).

	Velocity (ft/s)	Width (ft)	Max Depth (ft)	Discharge (ft^3/s)
X-S 1	10.5	81	6.2	2,900
X-S 2	10.5	72	4.8	2,500
X-S 3	10.5	56	5.0	2,000

The average peak flow of 2,500 cfs is approximately 5 times the 100-year event (1.5 times the 100-year post-fire event), as indicted by hydrologic modeling of 1-hour rainfall events for the High Park Fire area (Yochum 2012).

The GPS point was measured at X-S 1. X-S 2 was located about 2 flood widths upstream of X-S 1. X-S 3 was located about 1/2 flood width upstream of X-S 2.

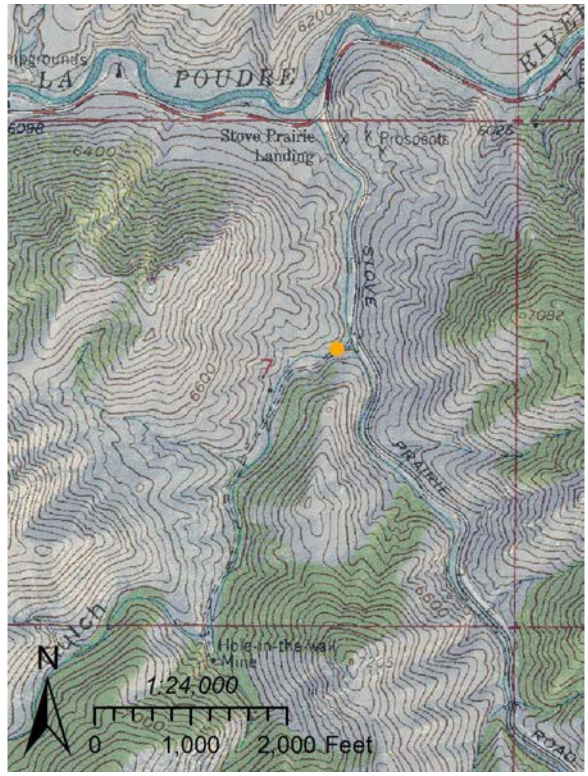

Figure 32: Skin Gulch measurement location (Lat, Long = 40.675912, -105.388637)

Figure 33: Skin Gulch, viewing upstream at X-S 2.

Young Gulch upstream of CO-14

Discharge was measured at three adjacent sections on Young Gulch (Table 15, Figures 34 & 3, Table A-14), with peak flow computed to be **1,200 cfs**. Substantial portions of this catchment burned during the High Park Fire in 2012, which most likely increased peak flow during this event. Average channel slope is approximately 0.035 ft/ft in this reach. X-S 3 was eliminated due to it being in a compound portion of the channel and its outlier status.

Table 15: Young Gulch cross section computations (measured 9/30/2013, data collection by S. Yochum).

	Velocity (ft/s)	Width (ft)	Max Depth (ft)	Discharge (ft^3/s)
X-S 1	8.1	66	3.1	1,100
X-S 2	8.7	68	3.7	1,400
X-S 3*	10.1	77	4.9	2,400

* not utilized in average

The average peak flow of 1,200 cfs is between the 25-year and 50-year peak flows for pre-fire conditions (between a 2-year and 10-year event for post-fire conditions), as indicted by hydrologic modeling of 1-hour rainfall events for the High Park Fire area (Yochum 2012).

The GPS point was measured on the right bank at X-S 1. X-S 2 was located about 1/2 flood width downstream of X-S 1. X-S 3 was located about 1 flood width downstream of X-S 2.

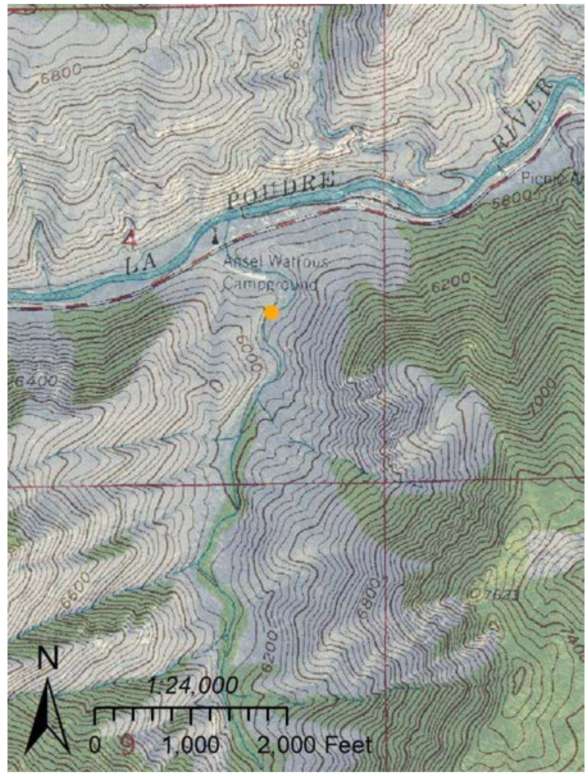

Figure 34: Young Gluch measurement location (Lat, Long = 40.687564, -105.347689).

Figure 35: Young Gulch, viewing upstream at X-S 3 and X-S 2.

Hill Gulch upstream of CO-14

Discharge was measured at three adjacent sections on Hill Gulch (Table 16, Figures 36 & 37, Table A-15), with peak flow computed to be **870 cfs**. Substantial portions of this catchment burned during the High Park Fire in 2012, which most likely increased peak flow during this event. Average channel slope is approximately 0.045 ft/ft in this reach.

Table 16: Hill Gulch cross section computations (measured 10/17/2013, data collection by S. Yochum).

	Velocity (ft/s)	Width (ft)	Max Depth (ft)	Discharge (ft^3/s)
X-S 1	8.7	40	5.2	800
X-S 2	8.8	41	4.8	880
X-S 3	9.5	34	5.0	930

The average peak flow of 870 cfs is between the 25-year and 50-year peak flows for pre-fire conditions (between a 2-year and 10-year event for post-fire conditions), as indicted by hydrologic modeling of 1-hour rainfall events for the High Park Fire area (Yochum 2012).

The GPS point was measured on the right bank at X-S 1. X-S 2 was located about 1/2 flood width downstream of X-S 1. X-S 3 was located about 1/2 flood width downstream of X-S 2.

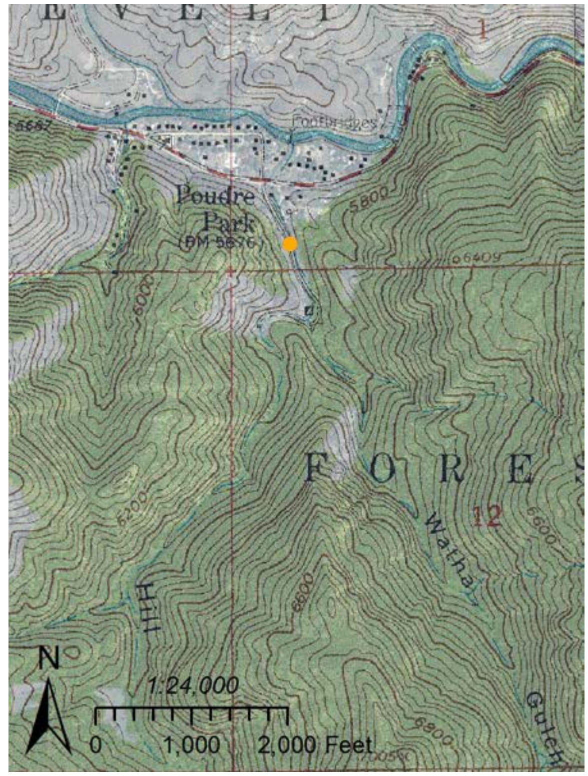

Figure 36: Hill Gulch measurement location (Lat, Long = 40.684103, -105.302884).

Figure 37: Hill Gulch, viewing downstream at X-S 2.

CONCLUSIONS

Peak flow estimates have been developed for a sample of the mountain streams where there were substantial threats to life and property during the September 2013 Front Range Flood. Many of the estimated peak flows are large to extreme, with up to approximately 5 times the 100-year flow experienced. Discharges ranged from 18,400 cfs (N.F. of the Big Thompson upstream of Drake) to 870 cfs (Hill Gulch). Peak flow yields ranged from 720 to 69 cfs/mi^2. This flood event caused loss of life, and substantial property and infrastructure damage. These peak flow measurements are provided as a service to inform resource managers of the flood severity, aid in the development of revised flow-frequency relationships, and quantify the flood response of key catchments burned in the 2012 High Park Fire.

Due to the requisite assumptions inherent in this approach, variability in individual cross section peak flow estimates and some high water mark elevations, and bank erosion and infrastructure rebuilding at some of the measurement locations, the accuracy of the predictions are considered to be “Fair” in quality.

ACKNOWLEDGEMENTS

The assistance of Jeffory Crane (Hydrologist with Crane Associates) with the flood peak predictions in the Jamestown area was appreciated. Additionally, review by Jon Fripp and Karl Visser of the NRCS National Design, Construction and Soil Mechanics Center was valuable for increasing the quality of this report.

REFERENCES

Bathurst, J.C., 1985. Flow resistance estimation in mountain rivers. Journal of Hydraulic Engineering 111(4), 625–643.

Capesius, J.P., Stephens, V.C. 2009. Regional Regression Equations for Estimation of Natural Streamflow Statistics in Colorado U.S. Department of Interior, U.S. Geological Survey, Scientific Investigations Report 2009-5136.

Ferguson, R., 2010. Time to abandon the Manning equation?. Earth Surface Processes and Landforms 35, 1873-1876. doi:10.1002/esp.2091.

Jarrett, R.D., England, J.F. 2002. Reliability of paleostage indicators for paleoflood studies. In Ancient Floods, Modern Hazards: Principles and Applications of Paleoflood Hydrology. American Geophysical Union, Water Science and Application Volume 5, 91-109.

Jarrett, R.D., Tomlinson, E.M. 2000. Regional interdisciplinary paleoflood approach to assess extreme flood potential. Water Resources Research 23(10), 2957-2984.

Lee, A.J., Ferguson, R.I., 2002. Velocity and flow resistance in step-pool streams. Geomorphology 46, 59–71.

Limerinos, J.T., 1970. Determination of the Manning Coefficient from Measured Bed Roughness in Natural Channels. U.S. Geological Survey Water-Supply Paper 1898-B.

Reid, D. E., Hickin, E.J., 2008. Flow resistance in steep mountain streams. Earth Surface Processes Landforms 33, 2211–2240.

Webb, R.H., Jarrett, R.D. 2002. One-dimensional estimation techniques for discharges of paleofloods and historical floods. In Ancient Floods, Modern Hazards: Principles and Applications of Paleoflood Hydrology. American Geophysical Union, Water Science and Application Volume 5, 111-125.

Wilcox, A.C., Wohl, E.E. 2006. Flow resistance dynamics in step-pool stream channels: 1. large woody debris and controls on total resistance. Water Resources Research 42, W05418. doi:10.1029/2005WR004277.

Yochum, S.E. 2012. High Park Fire: Increased Flood Potential Analysis. U.S. Department of Agriculture, Natural Resources Conservation Service, Colorado State Office.

Yochum, S.E., Bledsoe, B.P., David, G.C.L., Wohl, E. 2012. Velocity prediction in high-gradient channels. Journal of Hydrology 424-425, 84-98.

APPENDIX A: Cross Section Data

Table A-1: Little James Creek upstream of Jamestown (WSEL: water surface elevation, A: cross section area, V: average section velocity)

X-S 1		X-S 2		X-S 3	
WSEL (ft):	994.92	WSEL (ft):	997.15	WSEL (ft):	997.35
A (ft^2):	125	A (ft^2):	185	A (ft^2):	166
V (ft/s):	8.2	V (ft/s):	9.8	V (ft/s):	10.7
Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)
0.0	996.62	0.0	998.08	0.0	999.75
6.0	995.50	2.0	997.98	6.0	997.50
7.0	994.92	3.5	997.15	7.0	996.60
11.0	993.47	7.0	995.44	15.0	994.35
16.0	992.56	14.0	994.61	20.0	992.00
22.0	992.73	20.0	992.68	20.5	991.05
24.0	992.62	21.0	992.20	23.5	990.40
27.0	991.89	21.5	991.08	25.0	989.93
28.0	990.22	24.0	990.55	27.5	990.05
29.0	990.18	25.0	990.40	31.0	991.05
30.0	989.63	30.0	990.23	32.0	991.16
33.0	989.59	31.0	990.86	37.0	994.80
35.5	989.92	32.0	990.96	50.0	996.17
37.5	990.10	36.0	993.17	53.0	997.35
39.0	993.01	37.0	994.93	57.0	998.91
46.0	993.81	49.0	995.07		
62.0	994.01	58.0	995.87		
70.0	995.29	68.0	997.52		
74.0	996.77	70.0	999.09		

Table A-2: James Creek in Jamestown (WSEL: water surface elevation, A: cross section area, V: average section velocity)

X-S 1		**X-S 2**		**X-S 3**	
WSEL (ft):	995.8	WSEL (ft):	993.04	WSEL (ft):	985.88
A (ft^2):	466	A (ft^2):	596	A (ft^2):	390
V (ft/s):	11.3	V (ft/s):	12.7	V (ft/s):	11.2
Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)
0.8	999.49	0.0	996.25	0.0	989.74
6.0	996.84	1.0	996.00	1.0	989.00
9.0	992.85	19.0	985.01	8.0	985.88
16.6	992.04	32.0	984.94	21.0	983.64
28.0	993.15	41.0	989.47	36.0	983.92
33.0	993.94	46.5	988.79	50.0	982.19
43.0	989.93	48.0	987.08	56.0	981.04
49.0	988.75	52.7	985.12	62.0	980.85
54.0	988.00	55.0	984.57	64.0	979.04
59.0	987.85	59.4	984.04	66.0	978.75
64.0	987.93	62.4	984.03	69.0	978.93
70.0	988.40	67.6	984.48	75.5	977.64
72.6	988.83	70.7	985.68	80.0	978.59
78.6	991.78	75.5	990.41	84.0	980.82
83.5	992.48	90.0	990.62	96.0	981.29
90.0	994.14	101.5	988.29	105	983.51
103.0	993.88	110.5	988.68	108.4	985.88
107.0	992.23	116.0	990.95	116	996.35
116.0	994.20	124.3	993.04		
124.5	995.8	131	994.21		
134	997.72	137	996.27		
140	999.55				

Table A-3: Little Thompson River at Pinewood Springs (WSEL: water surface elevation, A: cross section area, V: average section velocity)

X-S 1		X-S 2		X-S 3	
WSEL (ft):	995.47	WSEL (ft):	994.66	WSEL (ft):	996.05
A (ft^2):	955	A (ft^2):	960	A (ft^2):	913
V (ft/s):	15.2	V (ft/s):	15.8	V (ft/s):	15.5
Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)
1.0	998.00	2.0	998.50	1.0	997.00
1.5	997.50	2.5	998.00	1.5	996.50
3.0	997.17	3.0	997.35	2.0	996.11
7.0	995.59	7.0	995.86	5.0	996.02
12.0	993.93	8.0	994.90	10.0	994.48
18.0	991.53	11.0	993.55	15.0	993.21
30.0	990.30	16.0	989.68	18.0	991.61
41.0	988.33	26.0	987.35	26.0	989.66
46.0	987.18	30.0	986.30	29.0	982.73
53.0	985.78	34.0	985.73	34.0	982.70
60.0	985.13	37.0	980.11	39.0	982.44
62.0	984.38	40.0	980.25	43.0	982.27
65.0	979.88	45.0	980.30	49.0	982.24
67.0	979.36	48.0	981.08	55.0	981.89
69.0	979.90	56.0	981.27	57.0	982.59
72.0	980.81	59.0	980.52	60.0	983.15
79.0	981.31	60.0	981.44	64.0	983.62
85.0	981.72	67.0	981.65	67.0	985.11
88.0	981.94	69.0	981.65	73.0	986.74
90.0	984.67	75.0	982.30	80.0	988.07
93.0	985.94	79.0	987.48	87.0	988.44
96.0	988.00	87.0	988.07	91.0	989.52
102.0	989.16	100.0	988.62	100.0	992.44
108.0	990.24	104.0	989.68	106.0	992.76
116.0	991.00	112.0	991.29	115.0	993.94
124.0	992.96	119.0	992.42	120.0	994.93
132.0	993.92	125.0	993.34	127.0	996.07
135.0	994.37	131.0	994.41	130.0	996.32
139.0	995.34	133.0	994.78	131.0	996.50
143.0	996.10	134.0	998.50	132.0	997.00
144.0	996.50				
145.0	997.00				
146.0	997.50				

Table A-4: Fish Creek upstream of Lake Estes (WSEL: water surface elevation, A: cross section area, V: average section velocity)

X-S 1		X-S 2		X-S 3	
WSEL (ft):	996.78	WSEL (ft):	997.05	WSEL (ft):	998.63
A (ft^2):	633	A (ft^2):	579	A (ft^2):	612
V (ft/s):	11.2	V (ft/s):	10.8	V (ft/s):	11.8
Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)
5.0	998.00	2.0	998.00	2.0	999.50
5.5	997.50	2.5	997.50	2.5	999.00
6.0	996.95	3.0	997.20	3.0	998.40
15.0	995.11	25.0	995.90	31.0	998.27
28.0	995.05	38.0	995.63	37.0	994.15
59.0	994.86	61.0	995.52	59.0	994.10
64.0	992.42	66.5	992.21	87.0	991.89
84.0	989.78	82.0	990.23	93.0	989.76
92.0	989.51	87.0	990.21	98.0	989.25
95.0	987.73	93.5	988.01	100.0	989.65
103.5	987.40	102.0	987.43	105.0	989.70
111.0	987.78	108.0	987.99	116.0	991.78
126.5	991.80	109.5	989.63	128.4	992.86
128.0	993.43	117.0	990.48	128.4	997.58
133.0	994.43	120.0	992.45	138.4	997.74
146.7	994.75	129.0	992.19	142.0	998.22
156.7	994.86	132.0	994.30	145.0	998.85
159.0	995.65	143.3	995.15	146.0	999.20
165.0	995.99	153.3	995.34	147.0	999.50
170.0	996.60	155.0	995.85		
171.0	997.50	164.0	996.90		
		165.0	997.50		
		166.0	998.00		

Table A-5: Fall River upstream of Estes Park (WSEL: water surface elevation, A: cross section area, V: average section velocity)

X-S 1		X-S 2		X-S 3	
WSEL (ft):	995.50	WSEL (ft):	996.51	WSEL (ft):	997.19
A (ft^2):	419	A (ft^2):	470	A (ft^2):	337
V (ft/s):	9.2	V (ft/s):	9.2	V (ft/s):	9.4
Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)
3.0	997.50	2.0	998.00	1.0	999.00
3.5	997.00	2.5	997.50	1.0	998.00
4.0	996.40	3.0	997.25	1.6	996.70
8.0	995.70	8.0	996.64	1.6	996.62
15.0	995.16	13.0	996.90	7.0	996.35
27.0	994.56	23.0	996.33	11.5	996.03
37.0	994.56	46.0	995.35	15.0	996.67
50.0	995.87	62.0	995.37	21.0	996.39
56.0	995.24	72.0	995.22	25.0	995.86
61.0	994.79	75.0	994.10	31.5	995.70
68.0	994.95	77.0	992.53	36.0	995.11
76.0	994.76	81.0	991.77	37.0	992.64
81.0	994.17	84.0	991.30	44.0	992.50
86.0	989.65	85.5	990.70	54.0	991.42
87.0	988.64	90.0	990.02	58.0	991.31
92.0	988.48	93.5	989.18	60.5	992.00
94.0	988.41	97.0	988.92	64.0	992.04
98.0	988.63	100.0	989.14	70.0	992.25
101.0	988.04	103.6	990.15	77.0	991.91
108.0	989.60	104.0	991.86	82.0	992.90
115.0	990.27	109.5	993.09	83.0	993.14
131.0	990.83	120.0	993.67	83.5	994.67
138.0	990.37	128.0	993.72	90.0	996.68
140.0	992.88	131.0	993.42	100.0	996.84
149.0	993.79	139.0	994.16	108.0	996.75
162.0	993.88	159.0	993.58	112.0	996.20
166.0	994.38	168.0	993.29	117.0	996.51
170.0	995.30	174.0	993.62	122.0	997.19
172.0	996.10	182.0	994.29	124.0	998.40
173.0	996.50	191.0	995.66	125.0	999.00
174.0	997.00	196	996.11		
		200	996.78		
		201	997.50		
		202	998.00		

Table A-6: West Creek upstream of Glen Haven (WSEL: water surface elevation, A: cross section area, V: average section velocity)

X-S 1		X-S 2		X-S 3	
WSEL (ft):	993.94	WSEL (ft):	996.03	WSEL (ft):	993.26
A (ft^2):	823	A (ft^2):	736	A (ft^2):	778
V (ft/s):	13.9	V (ft/s):	14.3	V (ft/s):	14.3
Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)
2.5	998.00	0.5	997.00	24.0	995.00
3.0	997.50	1.0	996.50	25.0	994.00
3.3	991.08	1.6	995.76	26.0	988.40
10.4	990.14	5.4	995.57	37.0	987.88
18.4	989.15	10.4	993.40	38.5	984.68
24.5	988.43	12.0	991.15	45.0	984.86
32.5	987.93	16.0	991.07	49.0	985.57
35.0	986.15	18.5	986.28	56.5	984.50
38.0	985.09	25.0	984.95	64.0	983.54
42.7	984.94	25.5	984.20	68.0	982.62
52.7	984.16	30.5	983.50	73.5	982.62
55.6	983.26	37.8	984.76	75.0	982.06
60.0	983.35	47.0	985.01	83.0	983.70
66.0	982.91	52.8	985.20	93.5	986.41
70.7	984.03	54.0	987.94	106.0	987.96
73.8	984.56	58.6	988.80	111.0	989.79
79.0	984.05	62.0	990.54	123.0	989.37
81.3	984.75	77.0	991.50	133.0	989.75
83.5	987.41	89.0	991.24	148.3	993.26
93.5	989.21	108.0	991.68	150.0	997.00
102.2	989.92	109.0	994.57		
109.0	990.73	114.0	995.24		
122.0	990.15	118.0	996.30		
132.0	992.25	120.0	997.00		
139.2	993.57				
146.8	996.80				
148.0	997.00				

Table A-7: Fox Creek upstream of Glen Haven (WSEL: water surface elevation, A: cross section area, V: average section velocity)

X-S 1		X-S 2		X-S 3	
WSEL (ft):	996.13	WSEL (ft):	995.74	WSEL (ft):	998.27
A (ft^2):	321	A (ft^2):	324	A (ft^2):	459
V (ft/s):	11.6	V (ft/s):	10.3	V (ft/s):	11.5
Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)
2.5	998.00	1.0	997.00	2.0	999.50
2.8	997.50	1.5	996.50	2.5	999.25
3.0	997.10	2.0	996.30	2.6	999.02
5.4	996.30	4.0	995.32	3.2	997.65
17.0	996.18	7.0	994.15	5.0	996.55
19.0	996.82	10.0	994.93	7.0	996.05
21.5	996.30	17.0	995.10	7.2	994.22
25.0	995.72	22.0	994.32	14.0	993.89
34.0	995.25	29.0	994.97	19.0	994.03
39.0	995.32	37.0	995.21	25.0	996.86
43.0	994.99	60.0	992.66	29.0	996.75
46.0	994.62	70.0	991.37	33.0	994.75
51.0	993.60	76.0	988.98	40.0	994.70
54.5	991.20	80.0	987.89	47.0	994.94
58.0	990.16	82.5	987.58	52.0	992.17
62.0	989.22	85.0	987.41	57.5	990.23
65.0	988.41	87.5	987.17	59.0	989.92
71.0	987.92	88.0	987.43	62.0	989.60
74.5	986.98	91.0	988.46	64.0	989.53
77.0	986.27	98.0	988.52	66.0	989.95
80.0	986.46	100.0	988.80	68.0	990.27
82.0	986.80	100.0	993.80	71.0	990.40
82.0	986.97	98.0	994.35	78.0	990.17
84.0	987.61	100.0	995.40	83.0	990.30
85.7	988.24	103.0	996.46	85.0	995.00
88.7	988.50	104.0	996.75	88.0	995.42
88.7	993.50	105.0	997.00	95.0	996.52
87.0	994.14			99.0	997.41
93.0	995.22			113.0	998.05
98.0	995.97			116.5	998.50
104.0	996.47			117.0	998.75
105.0	997.00			118.0	999.00
106.0	998.00				

Table A-8: N.F. Big Thompson River upstream of Glen Haven (WSEL: water surface elevation, A: cross section area, V: average section velocity)

X-S 1		X-S 2		X-S 3	
WSEL (ft):	996.26	WSEL (ft):	995.80	WSEL (ft):	996.78
A (ft^2):	216	A (ft^2):	189	A (ft^2):	226
V (ft/s):	8.1	V (ft/s):	7.6	V (ft/s):	7.9
Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)
1.0	998.00	1.0	997.50	2.0	998.00
1.5	997.50	1.5	997.00	2.5	997.50
3.0	997.25	2.0	996.58	3.0	997.06
6.0	996.50	5.0	995.86	4.0	996.78
7.0	996.14	9.0	994.50	5.0	996.25
10.0	994.58	10.0	993.12	10.0	995.61
11.0	991.79	16.0	993.46	19.0	995.26
14.0	991.47	19.0	992.47	23.0	993.71
16.0	991.20	22.0	991.52	25.0	992.64
19.0	990.86	26.0	991.30	27.0	991.45
21.0	990.71	29.0	991.06	31.0	991.63
23.0	990.52	31.5	990.64	32.5	991.33
24.0	991.22	33.0	990.35	35.5	991.79
28.0	991.39	35.5	990.78	38.0	991.64
31.0	991.59	41.0	991.69	44.0	992.73
33.0	992.00	42.0	991.75	45.0	994.33
37.0	992.38	46.0	994.74	48.0	994.90
38.5	993.92	55.0	994.99	57.0	995.87
42.5	994.60	64.0	995.05	67.0	994.80
63.0	994.85	71.0	994.92	77.0	995.30
71.0	994.87	78.0	995.54	87.0	995.67
76.0	996.20	95.0	995.68	99.0	996.21
90.0	996.06	98.0	994.60	102.0	995.32
94.0	994.70	109.0	994.52	113.0	995.46
105.0	994.94	111.0	995.74	116.0	996.39
108.0	995.89	112.0	996.00	120.0	996.70
113.0	996.38	113.0	997.00	121.0	997.00
114.0	997.00			122.0	997.50
115.0	998.00				

Table A-9: N.F. Big Thompson River upstream of Drake (WSEL: water surface elevation, A: cross section area, V: average section velocity)

X-S 1		X-S 2		X-S 3	
WSEL (ft):	995.91	WSEL (ft):	996.92	WSEL (ft):	996.27
A (ft^2):	1110	A (ft^2):	1313	A (ft^2):	1094
V (ft/s):	16.6	V (ft/s):	17.9	V (ft/s):	16.8
Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)
0.1	997.00	0.5	998.00	0.0	998.00
0.8	996.50	0.8	997.75	0.1	997.50
1.0	995.95	1.0	997.48	0.2	997.28
2.0	995.91	1.5	996.98	1.0	996.27
3.0	995.15	3.0	996.37	2.0	995.75
8.0	994.72	7.0	995.95	6.0	995.14
9.0	993.50	8.0	995.90	15.0	995.16
10.0	993.81	10.0	996.01	29.0	996.01
11.0	995.00	22.0	996.04	40.5	995.57
35.0	995.31	32.5	995.47	41.0	991.80
36.0	989.15	33.0	991.22	43.0	990.80
40.0	989.33	37.0	988.10	48.0	989.77
44.0	990.02	44.0	988.48	60.0	982.75
48.0	989.72	49.0	983.43	70.0	982.25
48.5	986.43	53.0	981.21	79.0	983.07
51.0	986.56	53.0	977.60	83.0	981.85
57.0	984.49	63.0	979.20	89.0	981.11
67.0	983.92	89.0	983.66	92.0	980.88
69.0	981.26	91.0	979.50	95.0	980.67
73.0	980.57	98.0	980.03	99.0	980.23
81.0	980.06	102.0	981.56	108.0	981.21
84.0	978.87	106.0	982.85	111.0	981.90
87.0	978.50	121.0	988.49	114.0	983.16
90.0	978.19	124.0	989.46	118.0	985.13
92.0	978.70	126.0	992.09	121.0	986.40
95.0	979.89	129.0	995.24	126.0	990.60
96.0	981.44	133.0	996.85	126.0	997.50
107.0	981.35	134.0	997.70	127.0	998.00
115.0	985.68	135.0	998.00	128.0	998.50
121.0	990.02	136.0	998.50		
131.0	995.80				
132.0	996.50				
133.0	997.00				

Table A-10: Buckhorn Creek upstream of Masonville (WSEL: water surface elevation, A: cross section area, V: average section velocity)

X-S 1		X-S 2		X-S 3	
WSEL (ft):	997.54	WSEL (ft):	995.29	WSEL (ft):	995.62
A (ft^2):	1206	A (ft^2):	931	A (ft^2):	859
V (ft/s):	10.8	V (ft/s):	11.4	V (ft/s):	12.1
Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)
1.0	997.70	1.0	996.00	0.5	996.00
2.0	997.60	2.0	995.50	1.0	995.80
2.5	997.54	2.5	995.29	2.0	995.62
20.0	997.38	13.0	994.52	5.0	994.30
33.0	997.24	16.5	988.45	13.0	993.11
33.5	993.95	25.0	988.72	18.0	993.97
37.0	990.64	34.0	988.83	22.0	993.58
44.0	989.13	42.0	989.37	28.5	993.55
53.0	989.77	50.0	989.57	36.5	992.83
62.0	989.96	60.0	990.24	39.8	991.79
73.0	990.53	72.0	990.22	52.0	992.06
80.0	990.95	88.0	990.07	56.0	993.23
86.0	991.26	100.2	989.76	62.3	993.77
97.0	992.36	109.5	989.81	67.4	993.17
112.0	990.68	118.5	990.77	72.3	991.39
132.5	994.53	127.0	990.08	73.4	991.07
149.0	994.18	139.0	989.75	77.2	990.31
159.0	993.27	148.5	990.23	83.0	989.81
166.0	992.14	155.0	991.03	89.0	989.62
174.0	993.11	166.0	991.50	94.2	989.96
180.5	992.63	172.0	990.51	100.0	990.37
184.5	992.33	180.5	992.22	108.0	990.35
188.5	991.75	190.0	992.93	114.4	990.36
194.5	993.65	202.5	994.63	120.3	990.40
209.5	994.33	221.0	995.10	124.5	990.66
222.0	995.70	234.0	995.30	130.0	990.79
245.0	995.90			134.0	991.35
263.0	995.50			137.0	991.67
280.0	993.93			142.4	993.10
294.0	994.04			150.8	993.26
307.0	996.54			161.0	993.30
340.0	997.60			173.0	992.01
				183.0	993.36
				190.0	993.46
				191.0	999.50

Table A-11: Redstone Creek at Happy Hollow Gulch (WSEL: water surface elevation, A: cross section area, V: average section velocity)

X-S 1		X-S 2		X-S 3	
WSEL (ft):	995.05	WSEL (ft):	993.98	WSEL (ft):	995.05
A (ft^2):	186	A (ft^2):	138	A (ft^2):	96
V (ft/s):	7.4	V (ft/s):	8.0	V (ft/s):	7.1
Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)
0.5	995.50	0.7	994.10	5.0	996.00
0.8	995.30	0.8	994.00	5.5	995.88
1.0	995.18	0.9	993.98	8.0	994.88
2.7	993.75	4.0	993.18	12.0	994.56
6.0	992.08	7.0	992.77	14.5	994.10
6.5	991.25	12.0	992.47	20.0	992.47
10.0	991.10	17.0	992.19	23.0	991.61
13.0	990.84	24.0	992.53	25.0	991.39
16.0	991.27	28.5	992.27	26.0	990.62
18.0	991.20	31.3	991.30	28.5	990.30
22.0	992.10	37.7	992.40	30.4	989.85
30.0	993.09	42.0	991.19	32.5	991.45
37.0	993.08	42.5	990.77	33.7	992.82
41.0	992.71	43.0	989.87	40.0	994.51
47.5	992.80	45.5	989.40	44.5	994.79
51.2	993.64	48.7	989.57	49.0	994.13
59.0	994.28	51.3	989.40	54.0	993.97
63.7	994.47	52.5	991.19	60.0	994.17
69.5	993.99	55.0	991.70	65.5	994.48
77.2	993.84	59.0	992.89	70.0	995.31
86.0	994.12	62.0	992.69	77.0	996.19
96.5	994.10	67.5	992.48	78.0	997.00
103.0	994.26	70.2	993.99		
110.5	995.05	70.5	994.50		
110.5	995.10				

Table A-12: Rist Creek downstream of Whale Rock (WSEL: water surface elevation, A: cross section area, V: average section velocity)

X-S 1		X-S 2		X-S 3	
WSEL (ft):	993.90	WSEL (ft):	992.40	WSEL (ft):	991.93
A (ft^2):	101	A (ft^2):	105	A (ft^2):	123
V (ft/s):	9.5	V (ft/s):	9.1	V (ft/s):	9.4
Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)
1.0	994.50	2.5	992.80	0.1	992.50
1.5	994.00	3.5	992.50	0.2	992.00
3.0	993.90	4.0	992.40	0.3	991.93
5.5	993.48	5.0	992.20	3.2	991.27
7.0	993.33	9.4	991.78	6.0	990.65
8.3	991.56	14.6	990.90	11.0	989.91
11.6	991.34	15.0	989.50	12.8	987.66
13.0	991.48	18.0	988.07	14.0	986.97
14.5	991.85	21.5	987.51	16.6	986.98
17.5	990.66	24.0	986.98	18.0	986.90
21.0	990.10	26.0	986.92	20.4	987.20
24.0	990.06	28.5	987.23	23.5	987.50
26.0	990.29	30.5	987.86	26.7	987.47
28.0	989.59	31.5	990.18	28.6	988.50
29.6	989.26	36.4	990.71	32.4	988.87
32.2	989.40	40.5	991.07	36.3	990.02
34.0	990.09	43.0	991.66	41.0	990.85
36.0	990.40	44.8	992.27	43.8	991.21
37.0	993.43	45.0	992.50	46.0	992.43
40.0	994.20	46.0	992.80		
41.0	994.50				
43.0	995.00				

Table A-13: Skin Gulch upstream of Stove Prairie Road (WSEL: water surface elevation, A: cross section area, V: average section velocity)

X-S 1		X-S 2		X-S 3	
WSEL (ft):	995.13	WSEL (ft):	992.68	WSEL (ft):	993.66
A (ft^2):	278	A (ft^2):	244	A (ft^2):	191
V (ft/s):	10.5	V (ft/s):	10.5	V (ft/s):	10.5
Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)
4.0	995.50	2.0	994.00	2.0	995.00
5.0	995.20	3.0	993.00	3.0	994.00
6.0	995.13	4.0	992.68	3.6	993.66
7.0	993.79	10.0	991.24	8.5	992.40
11.0	994.40	17.0	989.85	12.0	991.84
18.0	994.33	20.0	988.69	15.2	991.36
20.5	992.58	21.7	988.65	16.0	989.49
24.0	992.52	24.4	988.37	17.8	989.06
27.0	991.15	27.3	988.14	20.6	988.63
32.2	990.21	30.8	988.29	24.4	989.33
34.6	989.72	33.7	987.92	27.7	990.07
38.0	989.97	37.5	988.02	30.4	989.67
42.0	991.08	41.0	988.19	34.8	989.36
46.4	992.91	43.4	988.48	37.5	989.91
50.0	992.91	45.5	989.54	41.5	990.33
53.0	990.91	48.6	989.72	45.5	990.23
56.0	990.59	51.0	988.58	47.7	989.84
58.0	990.94	52.5	988.41	51.0	989.40
61.0	989.80	58.0	988.96	54.2	988.95
65.7	989.25	60.6	988.53	57.0	989.38
67.2	988.91	62.5	988.35	59.9	993.80
70.7	989.14	66.0	988.76		
75.0	990.48	69.1	988.99		
76.0	991.74	71.7	990.75		
79.0	992.55	74.7	992.00		
85.8	994.14	76.7	993.32		
87.0	995.20				

Table A-14: Young Gulch upstream of CO-14 (WSEL: water surface elevation, A: cross section area, V: average section velocity)

X-S 1		X-S 2		X-S 3	
WSEL (ft):	996.12	WSEL (ft):	997.52	WSEL (ft):	997.62
A (ft^2):	134	A (ft^2):	161	A (ft^2):	243
V (ft/s):	8.1	V (ft/s):	8.7	V (ft/s):	10.1
Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)
1.0	997.80	1.0	998.60	1.0	998.70
1.5	997.70	1.2	998.40	1.5	998.60
2.0	997.57	1.5	998.12	2.0	998.42
4.2	995.18	5.0	995.95	4.0	997.54
6.8	993.74	7.5	995.47	5.5	996.91
10.6	993.11	10.0	994.82	7.7	995.97
15.5	993.09	13.0	995.02	10.0	995.77
21.0	993.01	15.0	995.50	12.4	995.27
25.0	993.17	18.0	994.83	15.5	996.10
27.4	993.84	21.0	994.67	18.2	996.17
32.6	993.49	24.4	995.05	22.2	995.62
40.6	993.64	27.2	995.61	25.7	995.06
47.0	994.92	31.6	995.47	28.6	994.57
50.6	994.92	35.2	994.74	32.5	994.61
54.0	995.15	39.5	994.00	35.4	995.17
58.0	994.75	44.6	994.52	39.7	995.35
63.6	994.86	46.6	994.97	45.5	994.28
66.0	995.05	49.0	994.42	50.4	994.90
69.0	996.12	54.2	993.78	54.5	995.50
70.0	996.40	57.3	994.98	58.0	995.90
		61.3	995.90	61.0	995.37
		64.0	995.89	64.3	992.72
		67.0	996.60	67.6	992.36
		70.3	997.52	70.3	992.37
		71.0	998.00	71.6	993.79
				74.0	994.97
				77.0	997.62
				78.0	998.50

Table A-15: Hill Gulch upstream of CO-14 (WSEL: water surface elevation, A: cross section area, V: average section velocity)

X-S 1		X-S 2		X-S 3	
WSEL (ft):	991.95	WSEL (ft):	991.77	WSEL (ft):	992.89
A (ft^2):	92	A (ft^2):	100	A (ft^2):	97
V (ft/s):	8.7	V (ft/s):	8.8	V (ft/s):	9.5
Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)	Station (ft)	Elevation (ft)
0.5	997.00	1.0	996.00	0.5	999.00
1.0	996.00	2.0	994.74	1.0	998.00
1.4	995.00	4.4	989.97	2.0	996.62
1.7	993.76	10.0	989.35	7.0	994.18
5.7	991.84	16.0	988.19	11.5	992.78
9.5	990.56	18.8	988.11	14.2	991.57
12.8	990.27	20.7	987.21	15.9	990.53
15.4	989.49	23.0	986.97	21.0	990.07
17.2	988.39	26.0	987.39	23.4	990.01
18.7	987.04	26.5	987.65	26.0	988.91
19.2	986.79	27.8	988.21	27.3	988.59
22.8	986.89	31.7	989.43	28.3	988.23
23.7	987.16	33.3	991.08	31.0	987.90
24.9	987.95	36.0	991.49	33.3	988.15
27.0	988.21	38.0	991.02	34.5	988.62
29.3	989.43	41.5	991.33	36.5	989.15
33.3	989.87	44.5	991.45	38.2	990.26
37.0	990.87	44.7	991.77	40.7	991.61
42.0	991.12	46.0	993.00	44.3	991.65
43.3	991.31	48.0	994.00	45.6	992.89
45.0	991.95			47.0	994.00
46.0	993.00				
47.0	994.00				