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Probability and Volume of Potential Postwildfire Debris Flows in the 2012 High Park Burn Area near Fort Collins, Colorado

Open-File Report 2012–1148

U.S. Department of the Interior
U.S. Geological Survey

Cover: Colorado Department of Transportation. The cover photograph was taken on July 7, 2012, in Poudre Canyon. The road shown is Colorado State Highway 14.

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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)
kilometer (km)	0.6214	mile (mi)
	Area	
square meter (m^2)	0.0002471	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	1.308	cubic yard (yd^3)
cubic meter (m^3)	0.0008107	acre-foot (acre-ft)
	Flow rate	
millimeter per year (mm/yr)	0.03937	inch per year (in/yr)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).
Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Probability and Volume of Potential Postwildfire Debris Flows in the 2012 High Park Burn Area near Fort Collins, Colorado

By Kristine L. Verdin, Jean A. Dupree, and John G. Elliott

Abstract

This report presents a preliminary emergency assessment of the debris-flow hazards from drainage basins burned by the 2012 High Park fire near Fort Collins in Larimer County, Colorado. Empirical models derived from statistical evaluation of data collected from recently burned basins throughout the intermountain western United States were used to estimate the probability of debris-flow occurrence and volume of debris flows along the burned area drainage network and to estimate the same for 44 selected drainage basins along State Highway 14 and the perimeter of the burned area. Input data for the models included topographic parameters, soil characteristics, burn severity, and rainfall totals and intensities for a (1) 2-year-recurrence, 1-hour-duration rainfall (25 millimeters); (2) 10-year-recurrence, 1-hour-duration rainfall (43 millimeters); and (3) 25-year-recurrence, 1-hour-duration rainfall (51 millimeters).

Estimated debris-flow probabilities along the drainage network and throughout the drainage basins of interest ranged from 1 to 84 percent in response to the 2-year-recurrence, 1-hour-duration rainfall; from 2 to 95 percent in response to the 10-year-recurrence, 1-hour-duration rainfall; and from 3 to 97 in response to the 25-year-recurrence, 1-hour-duration rainfall. Basins and drainage networks with the highest probabilities tended to be those on the eastern edge of the burn area where soils have relatively high clay contents and gradients are steep. Estimated debris-flow volumes range from a low of 1,600 cubic meters to a high of greater than 100,000 cubic meters. Estimated debris-flow volumes increase with basin size and distance along the drainage network, but some smaller drainages were also predicted to produce substantial volumes of material. The predicted probabilities and some of the volumes predicted for the modeled storms indicate a potential for substantial debris-flow impacts on structures, roads, bridges, and culverts located both within and immediately downstream from the burned area. Colorado State Highway 14 is also susceptible to impacts from debris flows.

Introduction

The objective of this report is to present a preliminary emergency assessment of the debris-flow hazards from basins burned by the 2012 High Park fire near Fort Collins in Larimer County, Colorado. Debris flows have been documented after many fires in the western United States (Cannon and others, 2010), and can threaten lives, property, infrastructure, aquatic habitats, and water supplies. Wildfires can denude hillslopes of vegetation and change soil properties that affect watershed hydrology and sediment-transport processes. Even small postwildfire rainstorms can increase overland runoff that erodes soil, rock, ash, and vegetative debris from hillslopes (Cannon and others, 2008). This increased runoff concentrates in stream channels and entrains the sediment that can lead to the generation of destructive debris flows. Debris flow hazards are most significant up to 3 years (yr) following wildfires (Susan Cannon, U.S. Geological Survey, written commun., 2010). Field inspection within the area burned by the High Park fire identified debris-flow deposits in several locations, indicating that the area is susceptible to debris flows. It is unknown, however, if these debris flows occurred postwildfire.

This report, done in cooperation with the Colorado Department of Transportation, presents an assessment of the debris-flow hazards from drainage basins burned in 2012 by the High Park wildfire west of Fort Collins, Colorado (Colo.). The High Park wildfire burned more than 65,000 acres within a burn perimeter of more than 90,000 acres (fig. 1). This report provides estimates of the predicted probability of debris-flow occurrence and volume of debris along the drainage network throughout the entire area, as well as estimates for drainage basins above 44 selected basin outlets in response to three design storms: (1) 2-year-recurrence, 1-hour duration rainfall of 25 millimeters (mm) (a 50-percent chance of occurrence in any given year); (2) 10-year-recurrence, 1-hour-duration rainfall of 43 mm (a 10-percent chance of occurrence in any given year); and (3) 25-year-recurrence, 1-hour-duration rainfall of 51 mm (a 4-percent chance of occurrence in any given year). These design events were defined from data and methods detailed in the National Oceanic and Atmospheric Administration's (NOAA) Precipitation-Frequency Atlas of the Western United States (Miller and others, 1973).

A set of empirical equations (models) documented in Cannon and others (2010) and derived from statistical evaluation of data collected from recently burned basins throughout the intermountain western United States were used to estimate the probability of debris-flow occurrence and volumes of debris flows along the drainage network and for selected drainage basins. The regression equation of debris-flow probability (eq. 1) is as follows:

$$P = e^{x} /(1 + e^{x}), \qquad (1)$$

where

P is the probability of debris-flow occurrence in fractional form; and

$x = -0.7 + 0.03(\%SG30) - 1.6(R) + 0.06(\%AB) + 0.07(I) + 0.2(\%C) - 0.4(LL),$

where

%SG30 is the percentage of the drainage-basin area with slope equal to or greater than 30 percent;

R is drainage-basin ruggedness: the change in drainage-basin elevation (meters) divided by the square root of the drainage-basin area (square meters) (Melton, 1965);

%AB is the percentage of drainage-basin area burned at moderate to high severity (data for this investigation from Amy Coe, U.S. Department of Agriculture Forest Service, written commun., 2012);

I is average storm intensity (calculated by dividing total storm rainfall [Miller and others, 1973] by the storm duration, in millimeters per hour);

%*C* is clay content of the soil (in percent) (National Soil Survey Center, 1991); and

LL is the liquid limit of the soil (percentage of soil moisture by weight) (National Soil Survey Center, 1991).

Cannon and others (2010) also developed an empirical model that can be used to estimate the volume of debris flow that would likely be produced from recently burned drainage basins:

$$\text{Ln } V = 7.2 + 0.6(\ln SG30) + 0.7(AB)^{0.5} + 0.2(T)^{0.5} + 0.3, \tag{2}$$

where

V is the debris-flow volume, including water, sediment, and debris (cubic meters);
SG30 is the area of drainage basin with slopes equal to or greater than 30 percent (square kilometers);
AB is the drainage basin area burned at moderate to high severity (square kilometers);
T is the total storm rainfall (millimeters); and
0.3 is a bias-correction factor that changes the predicted estimate from a median to a mean value (Helsel and Hirsch, 2002).

Values for both probability and volume were obtained along drainage networks using the continuous parameterization technique (Verdin and Greenlee, 2003; Verdin and Worstell, 2008). With this technique, estimates of debris-flow probability and volume (Cannon and others, 2010) were obtained for every 10-meter (m) pixel along the drainage network (plates 1 and 2) as a function of conditions in the drainage basin above each pixel. This technique was developed as an alternative to basin-characterization approaches used in the past (for example, Cannon and others, 2009), which require definition of outlets (pour points) at the beginning of the analysis, and their corresponding basins. The technique used here allows for a synoptic view of conditions throughout the entire study area, which can be used to identify specific 10-m cells or stream reaches that might be in danger; the technique also aids in sampling design and monitoring-site selection.

The base layer upon which the continuous-parameterization layers are built is the 1/3-arc-second National Elevation Dataset (Gesch and others, 2002). This digital elevation model (DEM) was projected into a Colorado-appropriate projection system (UTM, Zone 13) and processed using standard DEM-conditioning tools in ArcGIS (ESRI, 2009) and RiverTools (Rivix, 2012). Once the overland flow structure was derived (in the form of a flow-direction matrix) using the DEM, the independent variables driving the probability and volume equations were evaluated for every grid cell within the extent of the DEM. Input rainfall totals and rainfall intensities will vary over the extent of the burn; the highest rainfall amounts will be located near the eastern base of the foothills, and higher amounts will be located farther up the Poudre Canyon and higher in elevation (Nolan Doesken, Colorado State Climatologist, written commun., 2012). For this study, however, the maximum rainfall amounts for each storm were assumed to be uniform over the entire burn area, providing the most conservative estimate of the probability and volumes of potential debris flows. Values for all of the other independent variables driving the debris-flow and volume equations were obtained using the continuous-parameterization approach. Once the surfaces of the independent variables were developed, the probability and volume equations were solved using map algebra for each grid cell along the drainage network. Identification of the probability or volume of a debris flow at locations within the study area can be obtained by querying the derived surfaces.

Following calculation of debris-flow probabilities and volumes continuously along the drainage networks, 44 basins of interest along State Highway 14 and the burn perimeter were identified. Debris-flow probabilities and volumes were extracted from the probability and volume surface for these locations. These values are shown in plates 1 and 2 and summarized in table 1.

Probability and Volume of Potential Debris Flows

In response to the 2-year-recurrence, 1-hour-duration rainfall, three basins affected by the burn (basins 19, 20 and 21; table 1) were identified as having probabilities of debris-flow occurrence greater than 60 percent, and 2 basins (4 and 22) had probabilities between 40 and 60 percent. These are all relatively small basins with drainage areas ranging from 0.5 to 4.6 square kilometers (km^2). Estimated volumes of debris flows for these five basins ranged from 4,500 to 29,000 cubic meters (m^3). In addition, volumes greater than about 100,000 m^3 were calculated for 9 basins. These values indicate a substantial risk of debris flow in response to a storm with a 50-percent chance of impacting the area each year.

The 10-year-recurrence, 1-hour-duration rainfall resulted in more basins with a higher probability of debris flow (plate 1, table 1). Seven basins (4, 18, 19, 20, 21, 22, and 27) had probabilities of debris flow in excess of 60 percent with corresponding volume estimates from 6,200 m^3 to 39,000 m^3. These basins are located on the northern and eastern edge of the burned area and range in size from 0.5 to 4.6 km^2. The volume estimates displayed in plate 2 indicates 11 basins with potential yields in excess of 100,000 m^3 in response to the 10-year-recurrence/1-hour-duration rainfall event. The high volumes are produced by larger streams that drain the entirety of the burn area as well as being produced by large streams entering the burn areas from the east and north (South Fork Cache la Poudre River [43] and Hewlett Gulch [28]). While the volume equation predicts large volumes for these basins, the probability of a debris flow for several of the larger basins (South Fork Cache la Poudre River [43], Hewlett Gulch [28], and Bennett Creek [44]) is very low (only 3 to 6 percent) in response to the 10-year-recurrence, 1-hour-duration storm. However, several of the basins with volume estimates in excess of 100,000 m^3 also have corresponding probabilities in excess of 40 percent (Lewstone Creek [16], Poverty Gulch [42], Skin Gulch [40], Rist Canyon [3] and Watha Gulch [26]). The volumes and probabilities calculated for these basins indicate a substantial risk of debris flow in response to a storm with a 10-percent chance of occurring each year.

The additional detail provided by the continuous-parameterization technique can be seen in plate 1. For example, the estimated probabilities at the pour points for Redstone Creek (9) and Stove Prairie Creek (11) are 19 percent and 28 percent, respectively. Examination of the drainage network upstream of these two pour points reveals many drainage channels with estimated probabilities above 60 percent. The 25-year-recurrence,1-hour-duration storm shows additional basins with higher probabilities of debris flows (table 1), and significantly higher volumes are produced in response to this storm as well. Twelve basins show a probability of debris flow in excess of 60 percent and an additional seven basins have a probability between 40 and 59 percent. Only 13 basins are modeled as expected to produce debris-flow volumes less than about 10,000 m^3. These 13 basins are located on the periphery of the burn and all have drainage areas less than 1 km^2. Probabilities and volumes calculated in response to the 25-year-recurrence storm indicate that should this storm occur (there is a 4-percent chance each year), destructive debris flows can be expected from many of the drainage basins burned by the High Park fire. The predicted probabilities and volumes in response to the three storm varieties indicate a potential for substantial debris-flow effects to buildings, roads, bridges, culverts, and reservoirs located both within drainages and immediately downstream from the burned area. In addition, even small debris flows that affect structures at the basin outlets could cause considerable damage.

Use and Limitations of the Map

This assessment provides estimates of debris-flow probability and volume for drainage basins burned by the High Park fire in response to three design storms based on predictive models developed from data from burned areas throughout the western United States. The predictive models were not developed from data from basins burned by this fire. Larger, less-frequent storms are more likely to produce much larger debris flows. Because individual storms may not affect the entire area at any given time, debris flows may not be produced from all basins during storms. The estimates are meant to be valid for up to 3 yr after the fire (Susan Cannon, U.S. Geological Survey, written commun., 2010).

The plates may be used to prioritize areas where emergency-flood warnings or erosion mitigation may be needed prior to rainstorms within these basins, their outlets, or areas downstream from these basins. This assessment evaluates only postwildfire debris flows (Cannon and others, 2007). Substantial hazards from flash floods without debris flow may remain for many years after a fire.

This work is preliminary and is subject to revision. It is being provided owing to the need for timely “best science” information. The assessment is provided on the condition that neither the U.S. Geological Survey nor the United States Government may be held liable for any damages resulting from the authorized or unauthorized use of the assessment.

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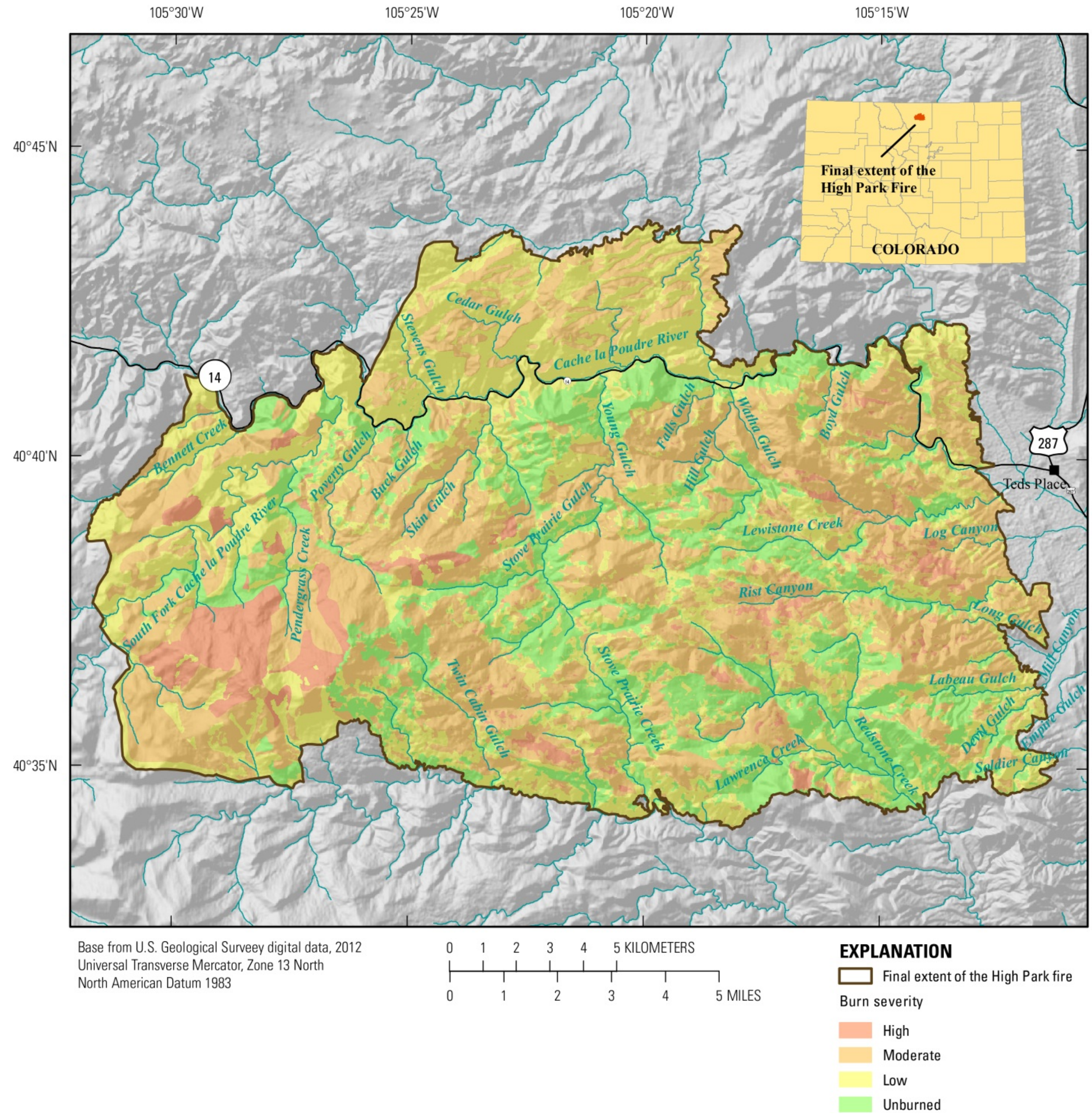

Figure 1. Location and severity of the 2012 High Park fire near Fort Collins, Colo.

Table 1. Estimated debris-flow probabilities and volumes for the 2012 High Park fire near Fort Collins, Colo.
(mm, millimeters; km^2, square kilometers; %, percent; m^3, cubic meters; >, greater than)

					2-year/1-hour precipitation		10-year/1-hour precipitation		25-year/1-hour precipitation	
		Basin Pour Point		Drainage	25.4 mm		43.2 mm		50.8 mm	
Basin	Description	Latitude	Longitude	Area km^2	Probability (%)	Volume (m^3)	Probability (%)	Volume (m^3)	Probability (%)	Volume (m^3)
1	Buck Gulch	40.6739	-105.4173	2.0	7	9,600	20	13,000	30	15,000
2	Unnamed Creek near Hwy 14. mile marker 97	40.6794	-105.4826	2.1	6	9,700	19	13,000	28	15,000
3	Rist Canyon	40.6457	-105.1951	16.5	26	>100,000	55	>100,000	67	>100,000
4	Log Canyon	40.6458	-105.1952	4.6	50	29,000	78	39,000	86	44,000
5	Mill Canyon	40.6175	-105.1838	9.2	9	44,000	25	60,000	37	67,000
6	Long Gulch	40.6176	-105.1839	6.8	25	44,000	53	60,000	66	67,000
7	Empire Gulch	40.6106	-105.1738	2.3	1	7,400	4	10,000	7	11,000
8	Soldier Canyon	40.5885	-105.1773	2.2	3	8,100	8	11,000	13	12,000
9	Redstone Creek	40.5728	-105.2360	38.8	6	>100,000	19	>100,000	29	>100,000
10	Unnamed Creek flowing to Buckhorn Creek near Deadman Hill	40.5666	-105.3128	1.6	5	7,200	15	9,800	23	11,000
11	Stove Prairie Creek flowing to Buckhorn Creek	40.5711	-105.3300	16.8	10	>100,000	28	>100,000	40	>100,000
12	Unnamed creek (Paradise Park) flowing to Buckhorn Creek	40.5719	-105.3512	4.3	17	18,000	42	24,000	55	27,000
13	Twin Cabin Gulch	40.5774	-105.3868	9.8	19	71,000	46	96,000	59	>100,000
14	Unnamed creek (East White Pine Mountain) flowing to Buckhorn Creek	40.5835	-105.4123	3.8	3	17,000	10	23,000	16	26,000
15	Unnamed creek near near Hwy 14. at mile marker 121 (west of Ted's Place)	40.6653	-105.2023	5.6	4	19,000	12	26,000	18	29,000
16	Lewstone Creek	40.6592	-105.2047	17.7	19	>100,000	44	>100,000	58	>100,000
17	Unnamed Creek near Hwy 14. west of mile marker 119	40.6709	-105.2367	1.7	26	11,000	55	14,000	67	16,000
18	Unnamed Creek near Hwy 14. northwest of mile marker 119	40.6727	-105.2389	3.0	39	19,000	69	25,000	79	28,000
19	Unnamed Creek near Hwy 14. northwest of mile marker 118	40.6844	-105.2379	0.7	84	6,300	95	8,600	97	9,600
20	Unnamed Creek near Hwy 14. northwest of mile marker 118	40.6851	-105.2395	0.5	77	4,500	92	6,200	95	6,900
21	Unnamed Creek near Hwy 14. between mile markers 115 and 116	40.6918	-105.2559	0.7	65	5,900	86	8,100	92	9,000
22	Boyd Gulch	40.6928	-105.2646	3.2	47	23,000	75	32,000	84	36,000
23	Unnamed Creek near Hwy 14. between mile markers 113 and 114	40.6953	-105.2822	0.2	2	1,600	6	2,200	9	2,500
24	Unnamed creek draining Greyrock Meadow	40.6950	-105.2872	3.3	3	9,300	10	13,000	16	14,000
25	Unnamed creek near Hwy 14. south of mile marker 113	40.6903	-105.2873	0.6	3	4,000	11	5,500	17	6,200

Table 1. Estimated debris-flow probabilities and volumes for the 2012 High Park fire near Fort Collins, Colo.—Continued

(mm, millimeters; km^2, square kilometers; %, percent; m^3, cubic meters; >, greater than)

					2-year/1-hour precipitation		10-year/1-hour precipitation		25-year/1-hour precipitation	
		Basin Pour Point		Drainage	25.4 mm		43.2 mm		50.8 mm	
Basin	Description	Latitude	Longitude	Area km^2	Probability (%)	Volume (m^3)	Probability (%)	Volume (m^3)	Probability (%)	Volume (m^3)
26	Watha Gulch/Hill Gulch	40.6872	-105.3027	14.4	28	>100,000	57	>100,000	69	>100,000
27	Falls Gulch	40.6877	-105.3089	3.5	32	24,000	62	32,000	74	36,000
28	Hewlett Gulch	40.6881	-105.3074	56.4	2	>100,000	6	>100,000	10	>100,000
29	Unnamed creek west of mile marker 111	40.6892	-105.3222	0.4	1	2,600	3	3,500	5	3,900
30	Unnamed creek between mile marker 110 and 111	40.6930	-105.3263	0.4	5	3,300	15	4,500	24	5,000
31	Unnamed creek just east of mile marker 110	40.6942	-105.3282	0.4	2	2,800	8	3,800	13	4,300
32	Unnamed creek east of mile marker 110 near Diamond Rock Picnic Area	40.6932	-105.3329	0.6	4	3,700	12	5,000	19	5,600
33	Unnamed creek west of mile marker 110	40.6942	-105.3369	0.3	3	2,400	8	3,200	13	3,600
34	Unnamed creek west of mile marker 110	40.6927	-105.3377	0.3	1	2,600	3	3,500	5	3,900
35	Unnamed creek between mile markers 109 and 110	40.6913	-105.3401	4.5	11	20,000	31	27,000	43	30,000
36	Young Gulch	40.6902	-105.3495	39.7	10	>100,000	27	>100,000	39	>100,000
37	Unnamed creek west of mile marker 109	40.6881	-105.3562	0.3	2	2,500	6	3,400	10	3,800
38	Unnamed creek near mile marker 108	40.6872	-105.3691	0.4	2	2,700	6	3,700	9	4,100
39	Cedar Gulch	40.6933	-105.3786	5.2	18	27,000	43	36,000	57	40,000
40	Skin Gulch (contains Stove Prairie Road)	40.6828	-105.3900	15.5	24	>100,000	53	>100,000	65	>100,000
41	Stevens Gulch	40.6840	-105.4094	4.5	6	17,000	17	23,000	26	26,000
42	Poverty Gulch	40.6746	-105.4290	11.2	19	85,000	45	>100,000	58	>100,000
43	South Fork Cache la Poudre River	40.6864	-105.4472	268.7	1	>100,000	4	>100,000	6	>100,000
44	Bennett Creek	40.6740	-105.4782	37.2	1	89,000	3	>100,000	5	>100,000