Appendix A: Design Flow Runoff Response

Waldo Canyon Fire

Pike and San Isabel National Forest, Cimarron and Comanche National Grasslands (PSICC),

Pikes Peak Ranger District, July 16, 2012

Mary Moore (LTBMU) and Dave Park (PSICC)

The hydrologic cycle represents the process and pathways by which water is circulated from land and water bodies to the atmosphere and back again. Precipitation inputs (rain and snow, etc.) to a watershed are affected little by a wildfire. However, interception, infiltration, evapotranspiration, soil moisture storage, and the overland flow of water can be significantly affected by fire. Interception is the hydrologic process by which vegetative canopies and accumulation of litter and other decomposed organic matter on the soil surface interrupt the fall of precipitation from the atmosphere to the soil surface. After a wildfire there often is a minor to significant loss of vegetation and the duff layer. Therefore, the soil surface is no longer protected from the energy of falling raindrops. The mineral surface can become compacted or dislodged by raindrop splash.

Precipitation that reaches the soil surface moves slowly down through the soils and then laterally to the stream channels. If more water is supplied to the site than can be infiltrated, the excess water flows on the surface as overland flow. Infiltration properties of the soil are altered when fire destroys vegetation and litter cover on a watershed. The soils can be affected by varying degrees, often resulting in decreased infiltration, and increased overland flows. Overland flow is a major contributor to many stream flow systems and the main contributor to most intermittent channels. This increase in overland flows is a major factor in increased stream flows and flood peakflows post wildfire. Changes in the hydrologic cycle caused by fires can affect the rate of soil erosion and the subsequent transport and deposition of eroded soil as sediment into streams, lakes, and reservoirs. (For Change in Sediment Rates See Soils Specialist Report)

Image 1: Picture of overland flows above pour point E

Table 1: Summary of changes in hydrologic process produced by wildfires

Hydrologic Process	Type of Change	Specific effects
Interception	Reduced	Moisture storage smaller Greater runoff in small storms Increased water yield
Litter storage of water	Reduced	Less water stored Overland flow increased
Transpiration	Temporary Elimination	Streamflow increased Soil moisture increased
Infiltration	Reduced	Overland flow increased Stormflow increased
Streamflow	Changed	Increased in most ecosystems

(USDA Forest Service: "Wildland Fire in Ecosystems." RMRS-GTR-42vol. 4. 2005)

Wildfires result in increased runoff and sediment yield commensurate with burn severity. The concern with increases in annual flood peakflows is that the increase could lead to channel instability and degradation, and to increased property damage in flood-prone urban areas. Burn Area Emergency Rehabilitation (BAER) teams use burn severity to estimate runoff and sediment increases resulting from fires. These increases are calculated as adjusted design flow and sediment potential. Adjusted design flow is the flow increase expected to occur as a result of decreased infiltration and interception following a wildfire. Sediment potential is the estimated potential sediment delivered to channels. (For Change in Sediment Rates See Soils Specialist Report) Together these values are utilized to evaluate the need to increase capacity for flow or drainage structures such as culverts and bridges. Values also provide an estimate of flooding and sedimentation potential to downstream communities. Pour points and subwatersheds or sub-basins were established in order to get a better understanding of specific areas, especially those that are related to areas at risk. The pour points represent a sampling of the fire and are not exclusive to all of the values at risk (i.e. not all values at risk have a pour point). Most of the pour points are closer to the fire perimeter, yielding much greater post fire flows.

Image 2: Drainage area of pour point "N"

Design Storm

Burned watersheds respond to rainfall faster, producing more "flashy floods". Precipitation inputs (rain and snow, etc.) to a watershed are affected little by a wildfire. Based on historic precipitation patterns, it can be expected that high-intensity monsoon storms have a high probability of occurring in the weeks following the fire. Intense short duration storms that are

characterized by high rainfall intensity and short durations have been associated with high stream peakflows and significant erosion events after fires.

The design storm selected to evaluate pre and post fire hydrology for watersheds within the burned perimeter is the 10-year, 1-hour storm and relates to 1.75 inch/hour. The design storm of 10 years has a 10% chance of occurring in any given year. Experience with other natural and prescribed fires indicate that while storms of 0.5 inches or greater will cause erosion, elevate floods, and sediment loading, it is typically 1 inch or greater high intensity storms that produce significant damage. Watersheds in the region have been shown to recover over a period of 7 to 10 years (Hayman 2002), water repellency in soils has been shown to persist for up to five years (Dyrness, 1976), and monsoon storms tend to have relatively short durations with a localized geographic distribution (Sheppard et al., 2002). A storm distribution was developed based on local rainfall storm distribution. The custom distribution represents the typical front range thunderstorm where the intensity is highest at the start of the storm and then tapers off at the end of the storm. Table 2 illustrates the distribution of the design storm, which is typical for a summer thunderstorm in this region. **The storm distribution is limited to a ground area of 5 mi2.** (Arkell and Richards, 1986, Hayman Hydrology Report 2002, and contact with High Park BAER 2012). This design storm distribution was applied to the larger "sub-watershed" during this rapid assessment.

Table 2. Distribution of 10 year one hour storm (1.75 inch in 1 hour).

% Time	% Storm
0	0
8.83	33
16.67	51
25	62
50	83
100	100

Distribution based on information in Arkell and Richards (1986).

Utilizing the "Precipitation-Frequency Atlas of the Western United States, Volume III – Colorado" estimated frequencies was determined for each sub-watershed or pour point.

South Platte, Republican, Arkansas, and Cimarron River Basin (1) equations:

Y2 = 0.218+0.709 (X1(X1/X2))
X1 = P,2yr,6hr X2 = P,2yr,24hr

Y100 = 1.897+0.439 (X3(X3/X4)) -0.008*Z
X3 = P,100yr,6hr X4 = P,100yr,24 hr

6 hour and 24 hour depths were calculated for each latitude and longitude of the pour point at NOAA's Hydrometerlogical Design Studies Center.[1] Y2 and Y100 values were plotted on a nomogram. The desired return-period of 5 and 10 year were pulled off the nomogram. The ratios in Table 12 (NOAA Atlas) were applied for estimates for less than 1 hour.

[1] http://hdsc.nws.noaa.gov/hdsc/pfds/

Table 3. Storm Precipitation average in inches based on Return Period

Duration	Average recurrence interval (years)			
	2	5	10	100
5-min	0.32	0.44	0.51	0.68
10-min	0.50	0.68	0.79	1.06
15-min	0.63	0.86	1.00	1.34
30-min	0.88	1.19	1.38	1.86
60-min	1.11	1.50	**1.75**	2.35

***Design Storm**

-Source: NOAA Atlas 2 Volume III, Region 1, Colorado Springs, Colorado

Maximum elevation was 9240 feet and minimum elevation was 7120 feet. The sub-watersheds analyzed are delineated and shown on the watershed map. (See Image 3)

Design Flow Runoff Response

Before an adjusted design flow can be determined, pre-fire design flow must be calculated. This is the flow expected to occur prior to the fire. This is the flow responsible for forming present day channel conditions and flows used to estimate proper performance of culverts and other drainage structures. Design flow estimates have been based on existing gage station information and streams surveyed within or adjacent to the immediate fire area. These estimates assume pre-fire ground infiltration and ground cover conditions.

Table 4: Acres by Burn Severity in 6th Field Watershed in the burn area.

6th Field Watershed	Burn Severity in Acres				**Total**
	High	**Mod**	**Low**	**Unb.**	
Cascade Creek-Fountain Creek	496	951	834	22	2304
Garden of the Gods	1046	3504	1470	3	6024
Headwaters Fountain Creek	358	1097	931	0	2386
Lower Monument Creek	619	1204	1443	67	3333
West Monument Creek	854	525	2820	3	4201
Grand Total	**3373**	**7281**	**7498**	**94**	**18247**

Adjusted design flow is calculated using the same relationships as design flow however runoff response is estimated by assuming an increased runoff commensurate with burn severity in terms of recurrence interval. This recurrence interval estimates the response of the newly burnt landscape to

an average annual storm. Runoff from the burned area is expected to respond to an average rainfall event, an event usually associated with the 2-year storm, In high and moderate severity of burned areas it is expected the landscape would respond as if the discharge were associated with a 5 or 10-year event, respectively. The unburned lands within the fire would respond as the unburned lands outside the fire and would have a discharge associated with the 2-year return interval. Increases in discharge associated with predicted recurrence intervals are prorated across watersheds by burn severity to yield post-fire discharge or the adjusted design flow. Samplings of sub-watersheds were established to determine the effects at the small-scale watershed level. This data is representative of the entire fire area. Tables 4, 5, and 6 display the amount of burned lands by severity for the affected 6thfield watersheds and include established pour points and sub-watersheds.

Image 3: Waldo Canyon Burn Severity Map with Pour Points

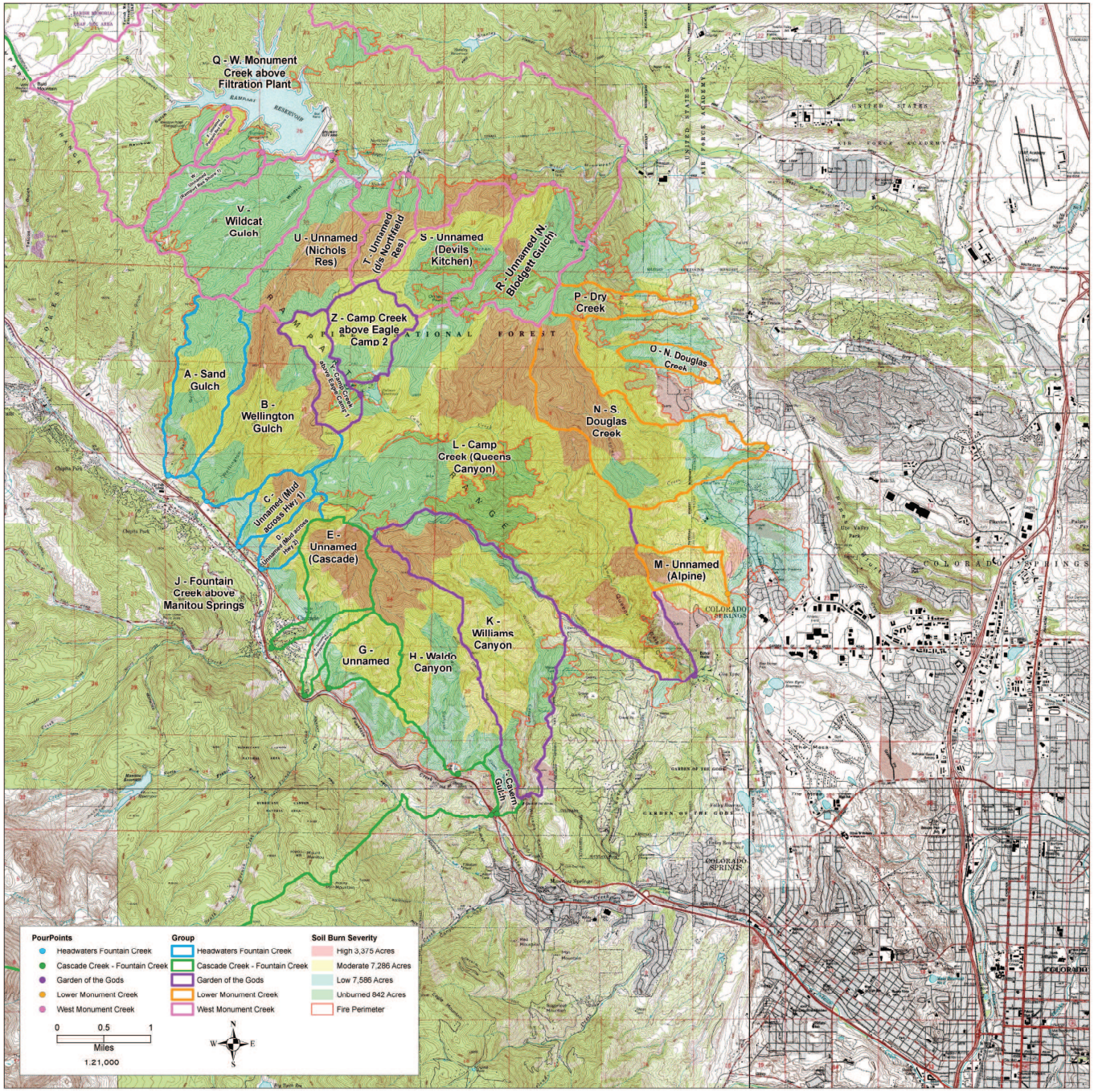


Table 5: Burn Severity by Pour Point Affected by the Waldo Canyon Fire	Burn Severity (acres)				Watershed Area (acres)
Sub-basins for Headwaters Fountain Creek	**High**	**Moderate**	**Low**	**Unburned**	
A - Sand Gulch	1.0	260.9	391.2	48.9	702.0
B - Wellington Gulch	273.4	560.4	266.7	6.2	1106.6
C - Unnamed (Mud across Hwy1)	72.9	90.5	58.9	1.2	223.4
D - Unnamed (Mud across Hwy2)	10.4	105.4	29.6	9.5	154.9
Sub-basins for Cascade Creek-Fountain Creek	**High**	**Moderate**	**Low**	**Unburned**	
E - Unnamed (Cascade)	254.7	142.8	47.3	43.0	487.8
F - Unnamed (Marygreen Pines)	2.6	33.8	41.4	34.9	112.8
G - Unnamed	0.5	274.3	57.9	0.0	332.8
H - Waldo Canyon	236.0	472.8	403.7	9.8	1122.4
I - Cavern Gulch			60.6	37.2	97.8
J - Fountain Creek above Manitou Spgs	851.5	2032.8	1707.8	39027.0	43619.1
Sub-Basins for Garden of the Gods	**High**	**Moderate**	**Low**	**Unburned**	
K - Williams Canyon	214.3	807.9	338.7	163.9	1524.8
L - Camp Cr (Queens Canyon)	838.6	2618.0	1027.8	686.3	5170.6
Y - Camp Creek above Eagle Camp 1	64.0	160.1	53.1	26.9	304.1
Z - Camp Creek above Eagle Camp 2		323.4	100.1	11.5	435.0
Sub-Basins for Lower Monument Creek	**High**	**Moderate**	**Low**	**Unburned**	
M - Unnamed (Alpine)	59.7	177.9	0.7	0.2	238.5
N - S. Douglas Creek	490.9	410.9	220.0	136.2	1257.9
O - N. Douglas Creek		0.2	130.4	21.5	152.1
P - Dry Creek	3.6	37.9	68.4	136.5	246.4
Sub-Basins for West Monument Creek	**High**	**Moderate**	**Low**	**Unburned**	
Q - W. Monument Creek above Filtration Plant	854.6	529.5	2596.3	5848.2	9828.6
R - Unnamed (N. Blodgett Gulch)	33.3	154.2	395.1	126.3	708.9
S - Unnamed (Devils Kitchen)	116.8	234.0	168.9	151.9	671.6
T - Unnamed (Northfield Res)	197.2	26.6	43.4	23.6	290.8
U - Unnamed (Nichols Res)	376.8	21.5	367.5	0.0	765.9
V - Wildcat Gulch			882.2	67.3	949.5
W - Unnamed (Rampart Res Shore 1)			255.6	6.4	262.0
X - Unnamed (Rampart Res Shore 2)		41.0	17.9	1.4	60.3

Table 6: % Burn Severity by Pour Point Affected by the Waldo Canyon Fire	% of Watershed by Burn Severity				Watershed Area (acres)
Sub-basins for Headwaters Fountain Creek	**High**	**Moderate**	**Low**	**Unburned**	
A - Sand Gulch	0.1	37.2	55.7	7.0	702.0
B - Wellington Gulch	24.7	50.6	24.1	0.6	1106.6
C - Unnamed (Mud across Hwy1)	32.6	40.5	26.3	0.5	223.4
D - Unnamed (Mud across Hwy2)	6.7	68.0	19.1	6.2	154.9
Sub-basins for Cascade Creek-Fountain Creek	**High**	**Moderate**	**Low**	**Unburned**	
E - Unnamed (Cascade)	52.2	29.3	9.7	8.8	487.8
F - Unnamed (Marygreen Pines)	2.3	30.0	36.7	30.9	112.8
G - Unnamed	0.1	82.4	17.4	0.0	332.8
H - Waldo Canyon	21.0	42.1	36.0	0.9	1122.4
I - Cavern Gulch	0.0	0.0	61.9	38.1	97.8
J - Fountain Creek above Manitou Spgs	2.0	4.7	3.9	89.5	43619.1
Sub-Basins for Garden of the Gods	**High**	**Moderate**	**Low**	**Unburned**	
K - Williams Canyon	14.1	53.0	22.2	10.7	1524.8
L - Camp Cr (Queens Canyon)	16.2	50.6	19.9	13.3	5170.6
Y - Camp Creek above Eagle Camp 1	21.0	52.6	17.5	8.9	304.1
Z - Camp Creek above Eagle Camp 2	0.0	74.3	23.0	2.6	435.0
Sub-Basins for Lower Monument Creek	**High**	**Moderate**	**Low**	**Unburned**	
M - Unnamed (Alpine)	25.0	74.6	0.3	0.1	238.5
N - S. Douglas Creek	39.0	32.7	17.5	10.8	1257.9
O - N. Douglas Creek	0.0	0.1	85.8	14.1	152.1
P - Dry Creek	1.4	15.4	27.8	55.4	246.4
Sub-Basins for West Monument Creek	**High**	**Moderate**	**Low**	**Unburned**	
Q - W. Monument Creek above Filtration Plant	8.7	5.4	26.4	59.5	9828.6
R - Unnamed (N. Blodgett Gulch)	4.7	21.8	55.7	17.8	708.9
S - Unnamed (Devils Kitchen)	17.4	34.8	25.1	22.6	671.6
T - Unnamed (Northfield Res)	67.8	9.2	14.9	8.1	290.8
U - Unnamed (Nichols Res)	49.2	2.8	48.0	0.0	765.9
V - Wildcat Gulch	0.0	0.0	92.9	7.1	949.5
W - Unnamed (Rampart Res Shore 1)	0.0	0.0	97.5	2.5	262.0
X - Unnamed (Rampart Res Shore 2)	0.0	68.0	29.7	2.3	60.3

The runoff curve number (RCN) model "WILDCAT5" (Hawkins and Greenberg, 1990) was used to estimate pre-fire and post-fire runoff by small watersheds. The model uses NRCS (formerly SCS) Curve Numbers to predict runoff "in a timed pattern from design rainstorms, and uses triangular unit hydrographs to route the rainfall excess to make hydrographs. There is no channel routing involved" (Hawkins and Greenberg, 1990).

Time of concentration (T_c) was calculated with the following equation (Dunne and Leopold 1978):

$$T_c = \frac{\text{Channel length}^{1.15}}{7700 * (\text{elevation difference})^{0.38}}$$

Soil types delineated by Carlton (1991) were utilized to determine hydrologic soil groups. The hydrologic soil group-burn severity combination was calculated for each watershed and each combination was assigned a corresponding runoff curve number.

The curve numbers utilized in this analysis were derived after consulting multiple sources (Hawkins and other USFS BAER experts). These numbers were modeled with an antecedent moisture condition II or average soil moisture conditions. Hydrologic changes from the loss of soil cover and soil water repellency from burning (USDA Forest Service 2005) were modified by increasing the curve number. The curve numbers for each burn severity-hydrologic group combination are shown in Table 8. The soil types were modeled as hydrologic soil groups A, B, C and D. The removal of ground cover and increased hydrophobicity will produce flashier flood response and increased peak flows in the area affected by the Waldo Canyon Fire.

Table 7. Curve numbers utilized

	Hydrologic Soil Group			
Burn Severity	**A**	**B**	**C**	**D**
Unburned	30	55	70	77
Low	55	66	77	83
Moderate	77	86	91	94
High	77	86	91	94

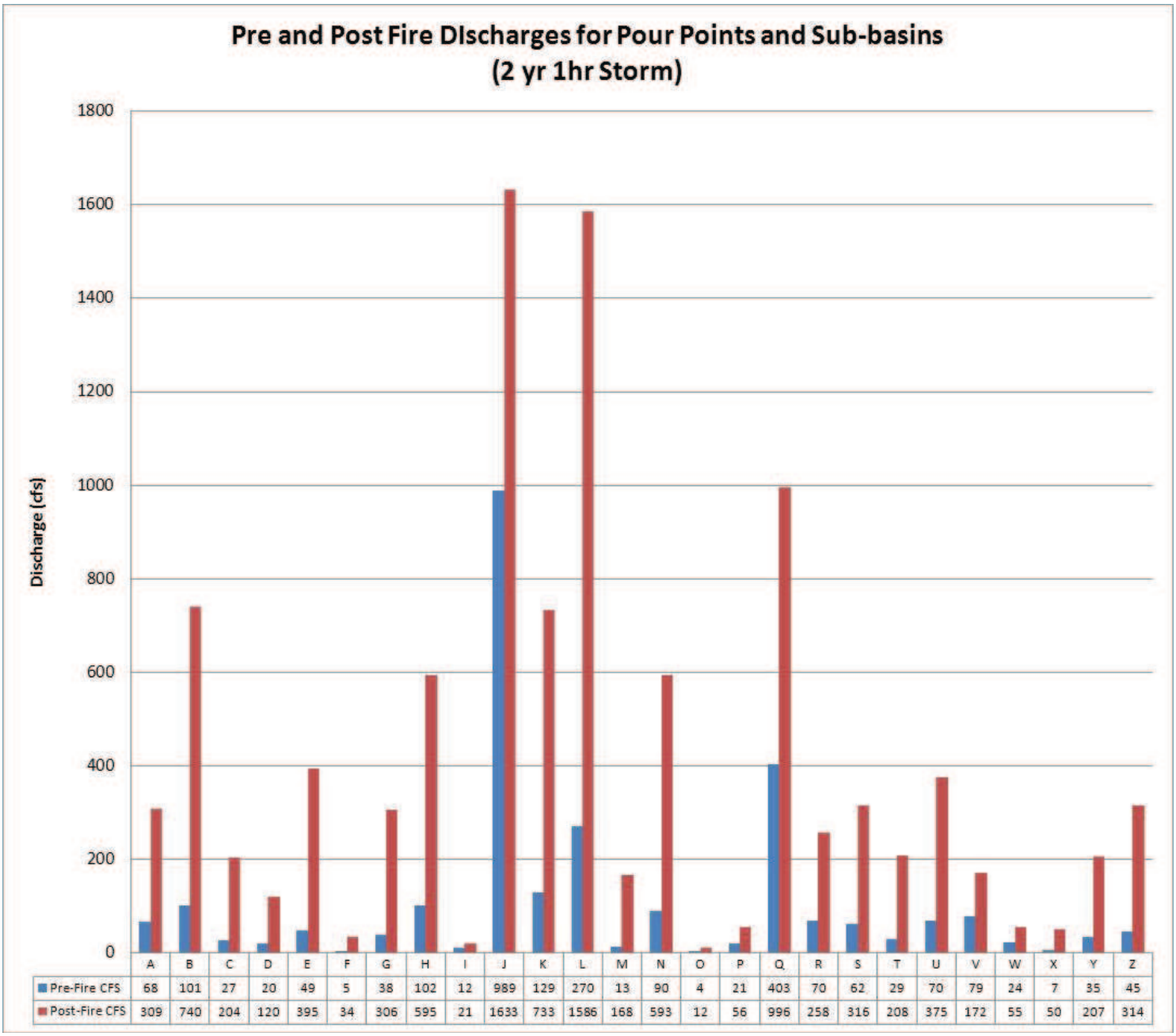
These curve numbers along with the acres corresponding to those curve numbers and the projected precipitation received from a 2, 5, and 10 year 1 hour storm were entered into the Wildcat 5 hydrologic model. The projected runoff identified by the Wildcat 5 model was compared with pre-fire projections to predict the increase in runoff due to the fire. Field reconnaissance found that while impacts to the soils were only moderate over a large percent of the burn there was little coverage left on the forest floor and minimal vegetation left to intercept rainfall. For this reason hydrologic response is expected to be similar between areas of moderate and high burn severity.

The model is limited to a ground area of 5 mi^2**.** Due to the rapid assessment, three larger sub-basins were greater than 5 mi^2. **They were run through Wildcat5 to determine the % of change between pre and post fire conditions.**

Table 8: Post Fire Discharge for the 2 year 1 hour storm.

Subwatershed	Drainage Area (mi2)	Design storm (2 year 1 hr.)		% Increase	Magnitude of post fire increase (post fire/pre-fire cfs)
		Pre-Fire CFS	Post-Fire CFS		
A - Sand Gulch	1.11	67.7	308.9	356.6%	4.56x
B - Wellington Gulch	1.73	101.3	739.9	630.5%	7.3x
C - Unnamed (Mud across Hwy1)	0.35	26.7	203.6	661.7%	7.6x
D - Unnamed (Mud across Hwy2)	0.24	20.2	119.8	492.5%	5.9x
E - Unnamed (Cascade)	0.77	49.4	394.8	698.6%	7.9x
F - Unnamed (Marygreen Pines)	0.18	4.9	33.7	595.5%	7.0x
G - Unnamed	0.52	38.0	306.2	705.0%	8.1x
H - Waldo Canyon	1.76	102.2	594.5	481.8%	5.8x
I - Cavern Gulch	0.15	12.1	21.3	76.2%	1.8x
J - Fountain Creek above Manitou Spgs*	68.3	988.7	1632.7	65.1%	1.7x
K - Williams Canyon	2.38	128.6	733.4	470.3%	5.7x
L - Camp Cr (Queens Canyon*	8.07	270.3	1586.3	486.8%	5.9x
M - Unnamed (Alpine)	0.37	13.5	167.8	1144.1%	12.4x
N - S. Douglas Creek	1.97	89.6	593.2	562.0%	6.6x
O - N. Douglas Creek	0.19	4.4	11.9	166.9%	2.7x
P - Dry Creek	0.39	21.0	55.9	166.0%	2.6x
Q - W. Monument Creek above Filtration Plant*	15.4	403.4	996.1	146.9%	2.5x
R - Unnamed (N. Blodgett Gulch)	1.12	70.2	257.7	267.2%	3.7x
S - Unnamed (Devils Kitchen)	1.09	61.6	316.4	413.3%	5.1x
T - Unnamed (Northfield Res)	0.46	29.3	207.7	608.0%	7.1x
U - Unnamed (Nichols Res)	1.21	70.1	374.8	434.3%	5.3x
V - Wildcat Gulch	1.48	79.0	172.4	118.2%	2.2x
W - Unnamed (Rampart Res Shore 1)	0.41	23.8	55.3	132.9%	2.3x
X - Unnamed (Rampart Res Shore 2)	0.09	7.4	50.2	577.2%	6.7x
Y - Camp Creek above Eagle Camp 1	0.48	35.5	207.0	483.6%	5.8x
Z - Camp Creek above Eagle Camp 2	0.68	44.9	314.3	599.5%	7.0x

Figure 1: Pre and Post Waldo Canyon Fire Discharge displayed for the 2 yr 1 hr storm event.

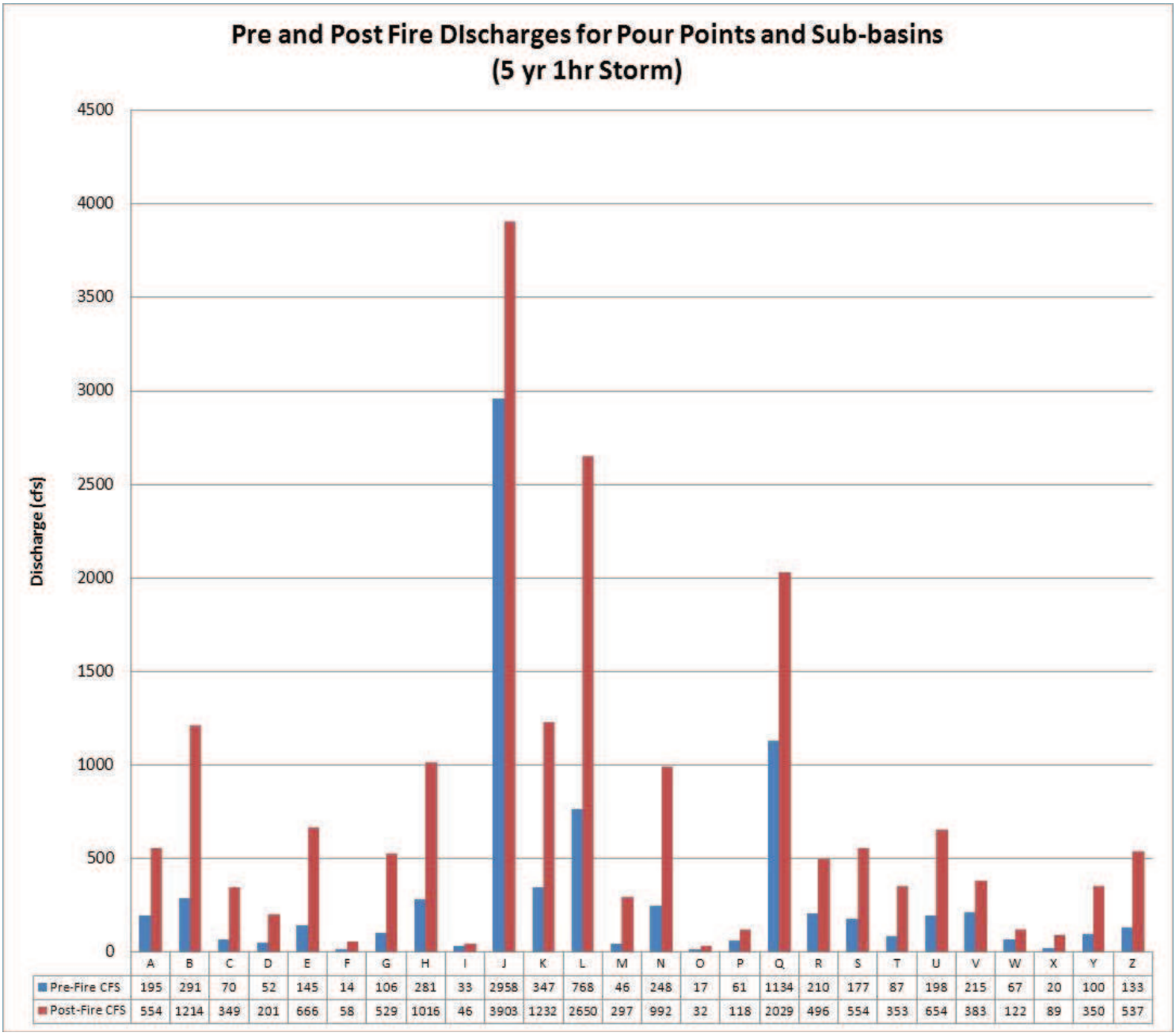


	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
Pre-Fire CFS	68	101	27	20	49	5	38	102	12	989	129	270	13	90	4	21	403	70	62	29	70	79	24	7	35	45
Post-Fire CFS	309	740	204	120	395	34	306	595	21	1633	733	1586	168	593	12	56	996	258	316	208	375	172	55	50	207	314

Table 9: Post Fire Discharge for the 5 year 1 hour storm.

Subwatershed	Drainage Area (mi2)	Design storm (5 year 1 hr.)		% Increase	Magnitude of post fire increase (post fire/pre-fire cfs)
		Pre-Fire CFS	Post-Fire CFS		
A - Sand Gulch	1.11	194.6	554.1	184.7%	2.8x
B - Wellington Gulch	1.73	291.0	1213.8	317.1%	4.2x
C - Unnamed (Mud across Hwy1)	0.35	70.0	348.9	398.2%	4.9x
D - Unnamed (Mud across Hwy2)	0.24	52.4	201.4	284.3%	3.8x
E - Unnamed (Cascade)	0.77	144.6	666.4	360.8%	4.6x
F - Unnamed (Marygreen Pines)	0.18	14.1	58.4	314.9%	4.1x
G - Unnamed	0.52	105.8	528.6	399.8%	5.0x
H - Waldo Canyon	1.76	281.0	1016.2	261.6%	3.6x
I - Cavern Gulch	0.15	33.1	46.3	39.8%	1.4x
J - Fountain Creek above Manitou Spgs*	68.3	2957.7	3902.8	32.0%	1.3x
K - Williams Canyon	2.38	346.8	1231.8	255.3%	3.6x
L - Camp Cr (Queens Canyon)*	8.07	767.7	2649.8	245.2%	3.5x
M - Unnamed (Alpine)	0.37	46.3	296.9	540.6%	6.4x
N - S. Douglas Creek	1.97	248.3	991.6	299.3%	4.0x
O - N. Douglas Creek	0.19	17.0	31.8	87.3%	1.9x
P - Dry Creek	0.39	61.2	117.9	92.5%	1.9x
Q - W. Monument Creek above Filtration Plant*	15.4	1133.6	2028.8	79.0%	1.8x
R - Unnamed (N. Blodgett Gulch)	1.12	209.6	496.4	136.9%	2.4x
S - Unnamed (Devils Kitchen)	1.09	177.2	554.2	212.7%	3.1x
T - Unnamed (Northfield Res)	0.46	87.2	352.6	304.2%	4.0x
U - Unnamed (Nichols Res)	1.21	198.4	653.7	229.5%	3.3x
V - Wildcat Gulch	1.48	215.1	382.6	77.8%	1.8x
W - Unnamed (Rampart Res Shore 1)	0.41	67.1	121.8	81.4%	1.8x
X - Unnamed (Rampart Res Shore 2)	0.09	20.3	89.1	339.3%	4.4x
Y - Camp Creek above Eagle Camp 1	0.48	100.0	350.1	250.2%	3.5x
Z - Camp Creek above Eagle Camp 2	0.68	133.5	537.5	302.6%	4.0x

Figure 2: Pre and Post Waldo Canyon Fire Discharge displayed for the 5 yr 1 hr storm event.

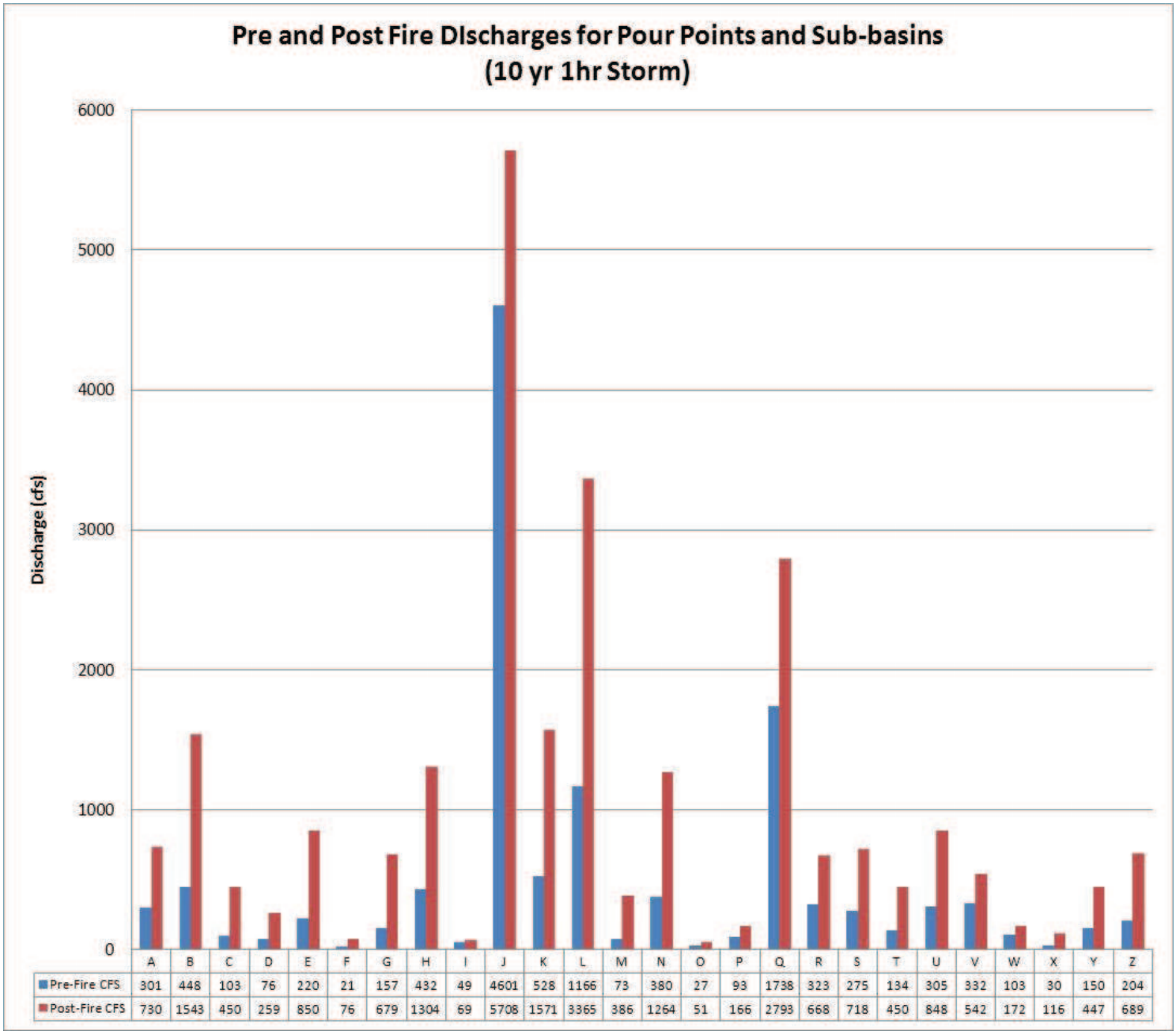


	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
Pre-Fire CFS	195	291	70	52	145	14	106	281	33	2958	347	768	46	248	17	61	1134	210	177	87	198	215	67	20	100	133
Post-Fire CFS	554	1214	349	201	666	58	529	1016	46	3903	1232	2650	297	992	32	118	2029	496	554	353	654	383	122	89	350	537

Table 10: Post Fire Discharge for the 10 year 1 hour storm

Subwatershed	Drainage Area (mi2)	Design storm (10 year 1 hr.)		% Increase	Magnitude of post fire increase (post fire/pre-fire cfs)
		Pre-Fire CFS	Post-Fire CFS		
A - Sand Gulch	1.11	301.3	730.5	142.4%	2.4x
B - Wellington Gulch	1.73	447.8	1542.5	244.5%	3.4x
C - Unnamed (Mud across Hwy1)	0.35	102.5	450.0	338.9%	4.4x
D - Unnamed (Mud across Hwy2)	0.24	76.4	258.9	238.8%	3.4x
E - Unnamed (Cascade)	0.77	219.9	850.4	286.7%	3.9x
F - Unnamed (Marygreen Pines)	0.18	21.3	76.0	256.8%	3.6x
G - Unnamed	0.52	156.8	679.0	332.9%	4.3x
H - Waldo Canyon	1.76	431.8	1303.6	201.9%	3.0x
I - Cavern Gulch	0.15	48.8	69.2	41.7%	1.4x
J - Fountain Creek above Manitou Spgs*	68.3	4601.4	5707.5	24.0%	1.2x
K - Williams Canyon	2.38	528.1	1571.3	197.5%	3.0x
L - Camp Cr (Queens Canyon)*	8.07	1165.6	3365.0	188.7%	2.9x
M - Unnamed (Alpine)	0.37	73.2	386.2	427.9%	5.3x
N - S. Douglas Creek	1.97	380.3	1264.4	232.5%	3.3x
O - N. Douglas Creek	0.19	27.4	51.3	86.8%	1.9x
P - Dry Creek	0.39	92.7	166.0	79.0%	1.8x
Q - W. Monument Creek above Filtration Plant*	15.4	1737.9	2792.7	60.7%	1.6x
R - Unnamed (N. Blodgett Gulch)	1.12	322.6	668.3	107.2%	2.1x
S - Unnamed (Devils Kitchen)	1.09	274.5	718.4	161.7%	2.6x
T - Unnamed (Northfield Res)	0.46	134.2	450.2	235.4%	3.4x
U - Unnamed (Nichols Res)	1.21	305.2	847.9	177.8%	2.8x
V - Wildcat Gulch	1.48	331.7	541.8	63.3%	1.6x
W - Unnamed (Rampart Res Shore 1)	0.41	103.2	171.5	66.2%	1.7x
X - Unnamed (Rampart Res Shore 2)	0.09	29.8	115.9	288.5%	3.9x
Y - Camp Creek above Eagle Camp 1	0.48	149.6	447.4	199.0%	3.0x
Z - Camp Creek above Eagle Camp 2	0.68	203.9	689.3	238.0%	3.4x

Figure 3: Pre and Post Waldo Canyon Fire Discharge displayed for the 10 yr 1 hr storm event.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
Pre-Fire CFS	301	448	103	76	220	21	157	432	49	4601	528	1166	73	380	27	93	1738	323	275	134	305	332	103	30	150	204
Post-Fire CFS	730	1543	450	259	850	76	679	1304	69	5708	1571	3365	386	1264	51	166	2793	668	718	450	848	542	172	116	447	689

Pour points and subwatersheds were established in order to get a better understanding of specific areas, especially those that are related to areas at risk. Not all values at risk have a pour point. Most of the pour points are closer to the fire perimeter, yielding much greater post fire flows.

The pour points are a sampling of the sub-watersheds within in the burn area. Average data can be applied to the entire area. The smaller watershed scale, 7th field, indicates approximately 3 to 4x greater increase in water yield. Pour points: J - Fountain Creek above Manitou Spgs, and W. Monument Creek above Filtration Plant watersheds have less increase because a large size of the point is predominantly outside of the burn perimeter.

The 7th field watersheds provide a more detailed evaluation of the fire as it reduces the amount of unburned lands and smaller watersheds. Thus this analysis provides a more pronounced increase in water yields by watershed. Pour Point M experienced the most significant increase with 5.3x greater than pre-fire discharges. On average 7th field watersheds with more than 50% burned high and moderate indicated a 3 to 4x greater increase in water yield. 7th field watersheds with less than 50% burned high and moderate indicated a 1 to 2x greater increase in water yield. Note: the model used seemed to over predict the pre-fire flows. On average there is a 250-350% increase based on the models predictions. Due to the over predictions of pre-fire flows there is probably a 350-450% increase in post fire flows.

Due to the change in watershed conditions an increase in peak flows is most applicable during the first year of recovery even during smaller precipitation events. Hydrologic response will decrease in subsequent years. The early precipitation events fill in available slope detention storage and create the rill and gully networks that are necessary to fully induce the expected increase in flood response from short duration high intensity rainstorms. Predicted post-fire peak flows show an increase of about one to two orders of magnitude. The peak flow values highlight the post-fire effects on the Waldo Canyon Fire, with the most increase reflected in subwatersheds where burn severity is moderate and high and where the most susceptible soils are affected.

Post-fire conditions have been assessed to determine how fire-induced changes to hillslope hydrology and soil conditions will impact the values at risk. Key to this assessment is the burn severity mapping.

Table 11. Hydrologic design factors

A. Estimated Vegetative Recovery Period	5-7 years
B. Design Chance of Success	50 %
C. Equivalent Design Recurrence Interval	10 years
D. Design Storm Duration	1 hours
E. Design Storm Magnitude	1.75 inches
F. Design Flow	112.4 cfs / mi^2
G. Estimated Reduction in Infiltration	60%
H. Adjusted Design Flow	237.3 cfs / mi^2

The results of a peak flow analysis show that pre-fire area weighted flows were on average 112.4 cfs / mi^2 for a 10 year, 1 hour storm, and 237.2 cfs / mi^2 for post-fire flows. As previously

mentioned, the post-fire flows could lead to plugged culverts, flow over road surfaces, rill and gully erosion of cut and fill slopes, erosion and deposition along road surfaces and relief ditches, loss of long-term soil productivity, and threats to human safety. Some sedimentation of the ephemeral channels is likely to occur at an accelerated rate until vegetation establishes itself and provides ground cover.

To examine the validity of the pre-fire and post-fire runoff predictions, USGS stream gage records were examined in the vicinity of the fire. Two gages were operated near the Rampart Range from 1958 to 2012. Mean monthly streamflow data is available from these records; however, the peak flows modeled in this analysis are not directly comparable to mean monthly flows. Furthermore, the condition of the watersheds is not known for long periods or whether these gages are representative of long-term streamflow trends. These relationships should be interpreted with caution.

Percent of increase from WILCAT5 for each pour point was applied to StreamStats (USGS) pre-fire flows. StreamStats[2] is a web-based application that implements regression equations for estimating instantaneous peak flows with probabilities of occurring in any given year of 50, 20, 10, 4, 2, 1, 0.5, and 0.2 percent based on gage data for the region. The mountainous region has very few gages representative of the Colorado Springs greater area. It was determined that **Streamstats under estimates post fire flows for all of the subwatersheds or pour points.**

WILDCAT5 model has limitation of a 5 mi^2 drainage area. Additionally, this model was applied to the 3 larger subwatershed greater than 5 mi^2 drainage area: J - Fountain Creek above Manitou Spgs, L - Camp Cr (Queens Canyon), and W. Monument Creek above Filtration Plant. **WILDCAT5 appears to over predict the pre-fire flows**. Post Fire flows from WILDCAT5 for subwatersheds of less than 10 mi^2 were plotted on regression lines from Bob Jarrett, retired USGS Paleohydrologist based on true post fire flows for several front range fires from 1996-2010. Post Fire flows from WILDCAT5 plotted within the range of variability. (See Attachment 1)

<u>Sediment Rate Calculations:</u>

See Soils Specialist Report

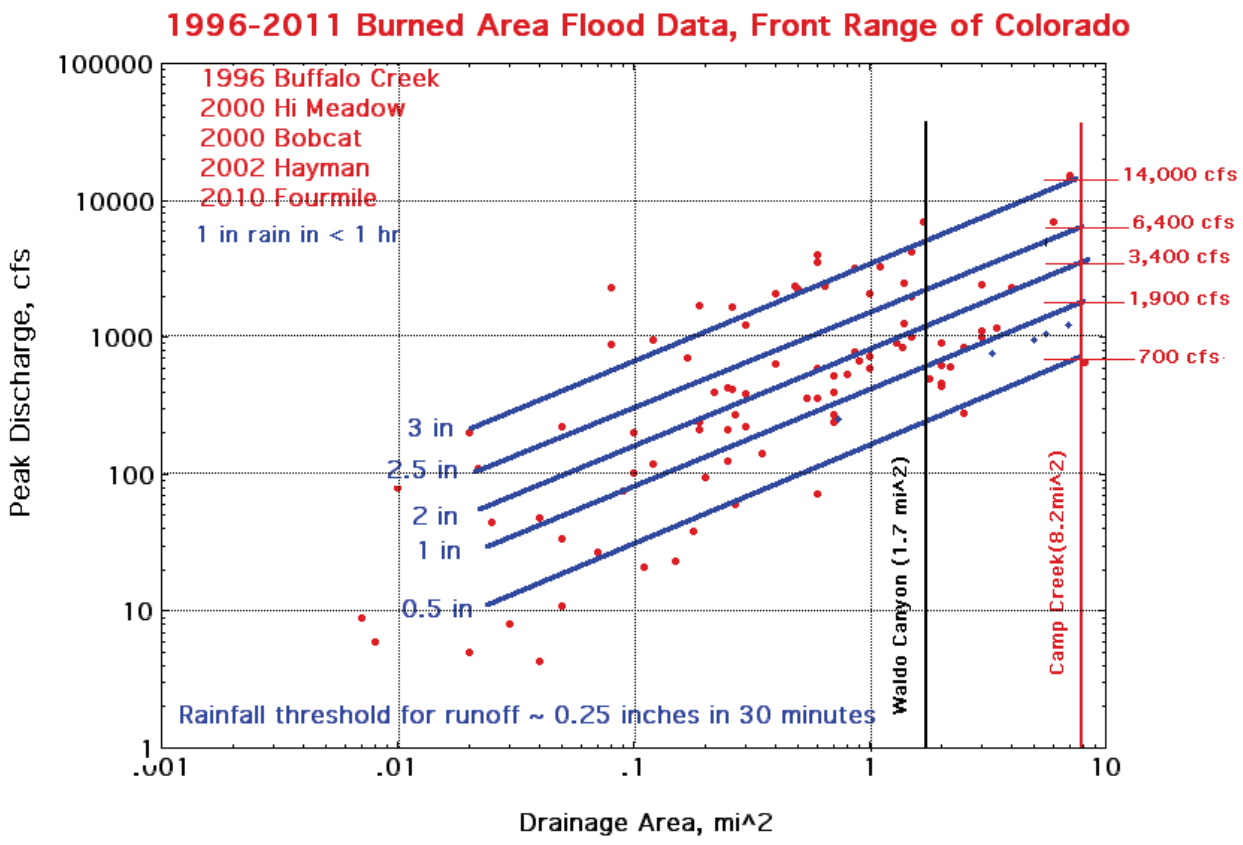
[2] http://streamstats.usgs.gov/colorado.html

Image 5: Drainage area of pour point "M"

Image 6: Sediment Basin at pour point "M" pre-rain

Image 7: Sediment Basin at pour point "M" post-rain (7/6-7/9 1.21 inches from Rampart RAWS)

Attachment 1: Post Fire Flood Estimates from Bob Jarrett, USGS.



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