# EXHIBIT 13 - DESIGN FLOW RUNOFF RESPONSE

## 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<br>Greater runoff in small storms<br>Increased water yield |
| **Litter storage of water** | Reduced | Less water stored<br>Overland flow increased |
| **Transpiration** | Temporary Elimination | Streamflow increased<br>Soil moisture increased |
| **Infiltration** | Reduced | Overland flow increased<br>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. Most of the pourpoints 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 low volumes 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. The justification for using this design storm is that 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). Table 2 illustrates the distribution of the design storm, which is typical for a summer thunderstorm in this region. **The design storm is limited to a ground area of 5 mi2.** The distribution of rainfall intensities over the 1-hour is based on local information of short duration rainfall relations (Arkell and Richards, 1986, Hayman Hydrology Report 2002, and contact with High Park BAER 2012). This design storm distribution was applied 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 or pour points are delineated and numbered on the watershed map. (See Image 3)

## Design Flow Runoff Response

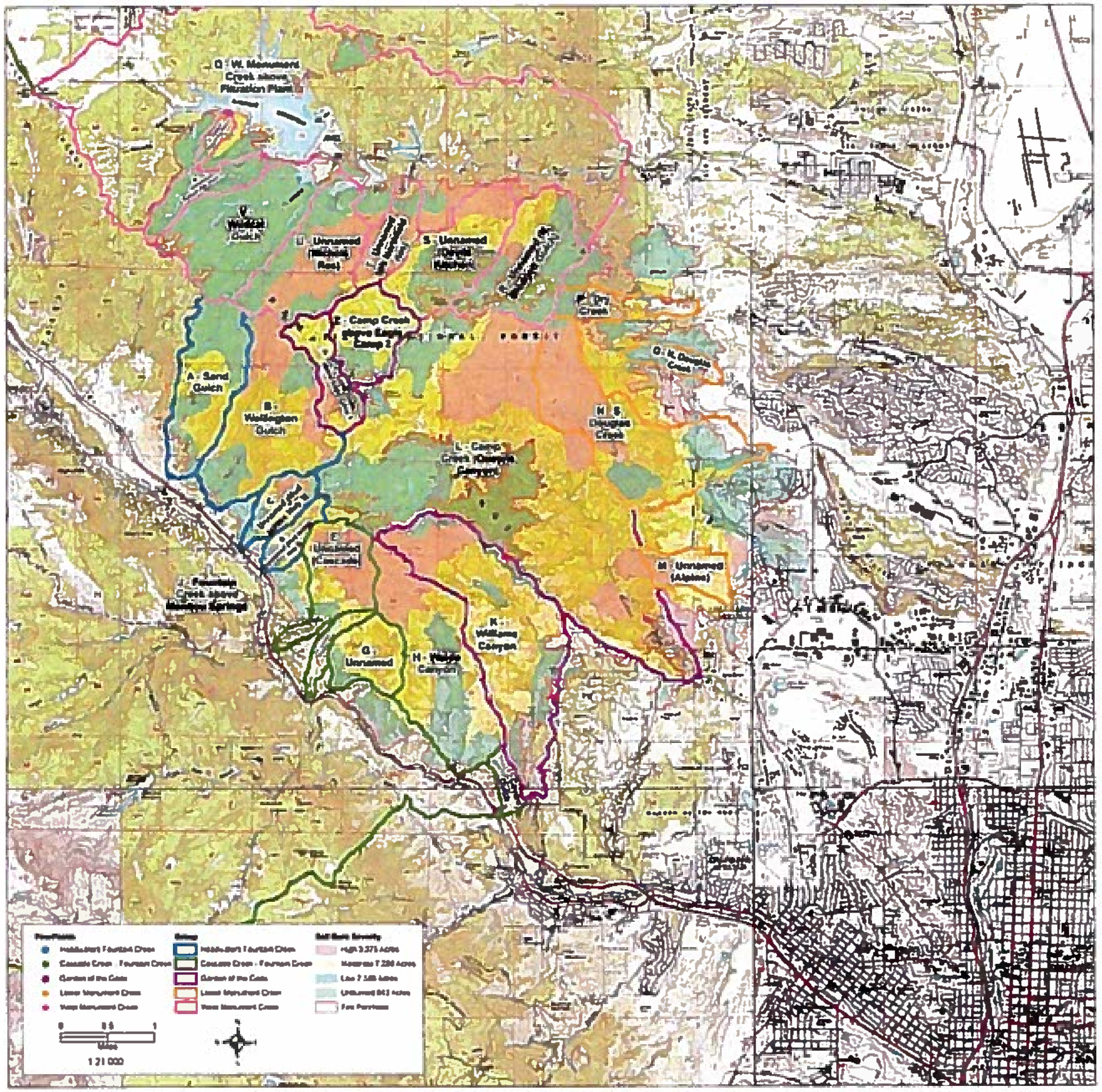
Before an adjusted design flow can be determined, pre-fire design flow must be calculated. This is the flow expected to occur prior to the fire. This is the flow responsible for forming present day channel conditions and flows used to estimate proper performance of culverts and other drainage structures. 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 | | 2282 |
| 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 | 72 | 18225 |

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 10-year storm, depending on severity of burned areas. It is expected the landscape would respond as if the discharge were associated with a 2 and 5-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 10-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 6$^{th}$field 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):

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

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 USFS). 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 |

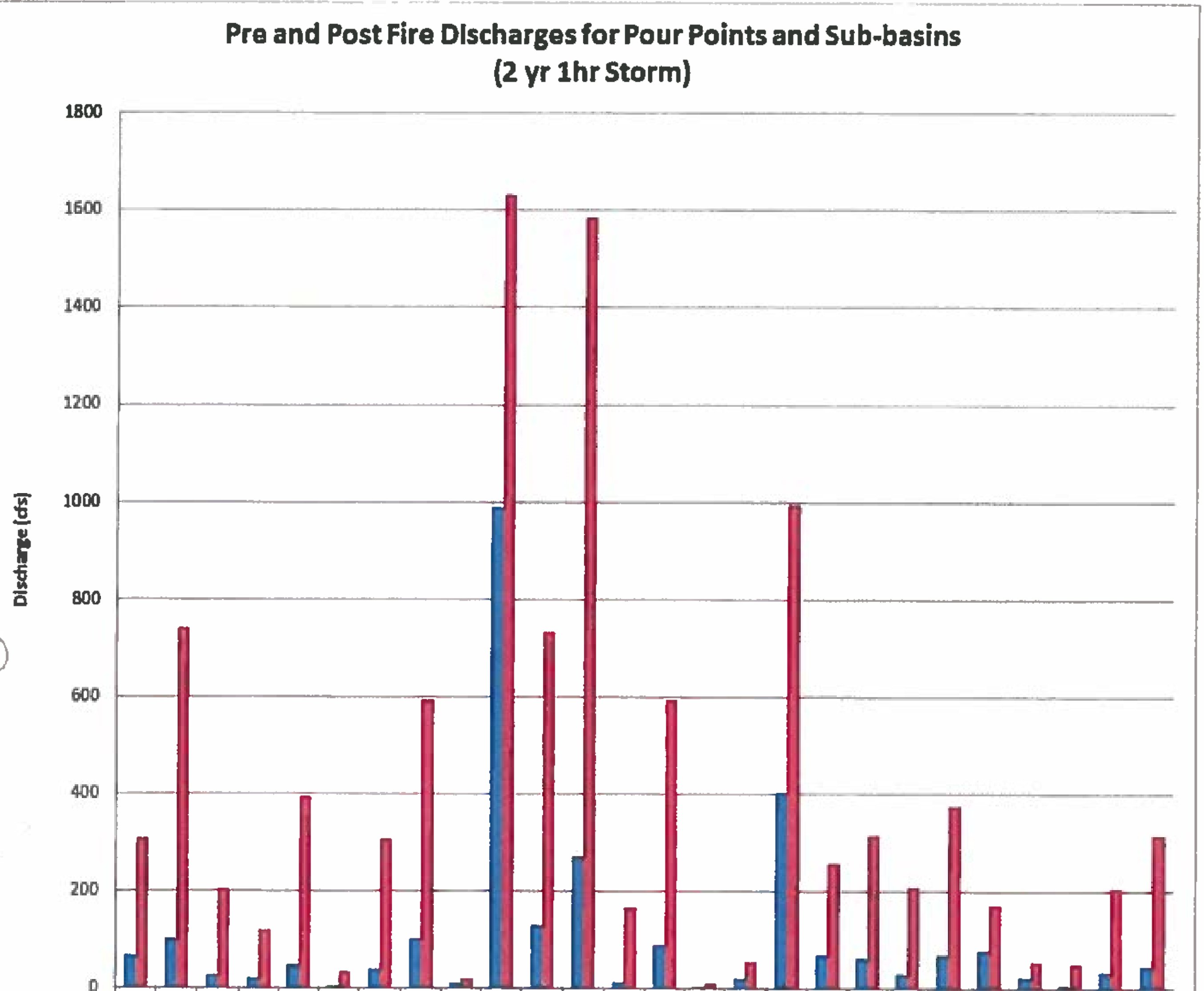
These curve numbers along with the acres corresponding to those curve numbers and the projected precipitation received from a 10 year 1 hour storm were entered into the Wildcat 5 hydrologic model. The projected runoff identified by the Wildcat 5 model was compared with pre-fire projections to predict 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 3: Pre and Post Waldo Canyon Fire Discharge displayed for the 2 yr 1 hr storm event.**

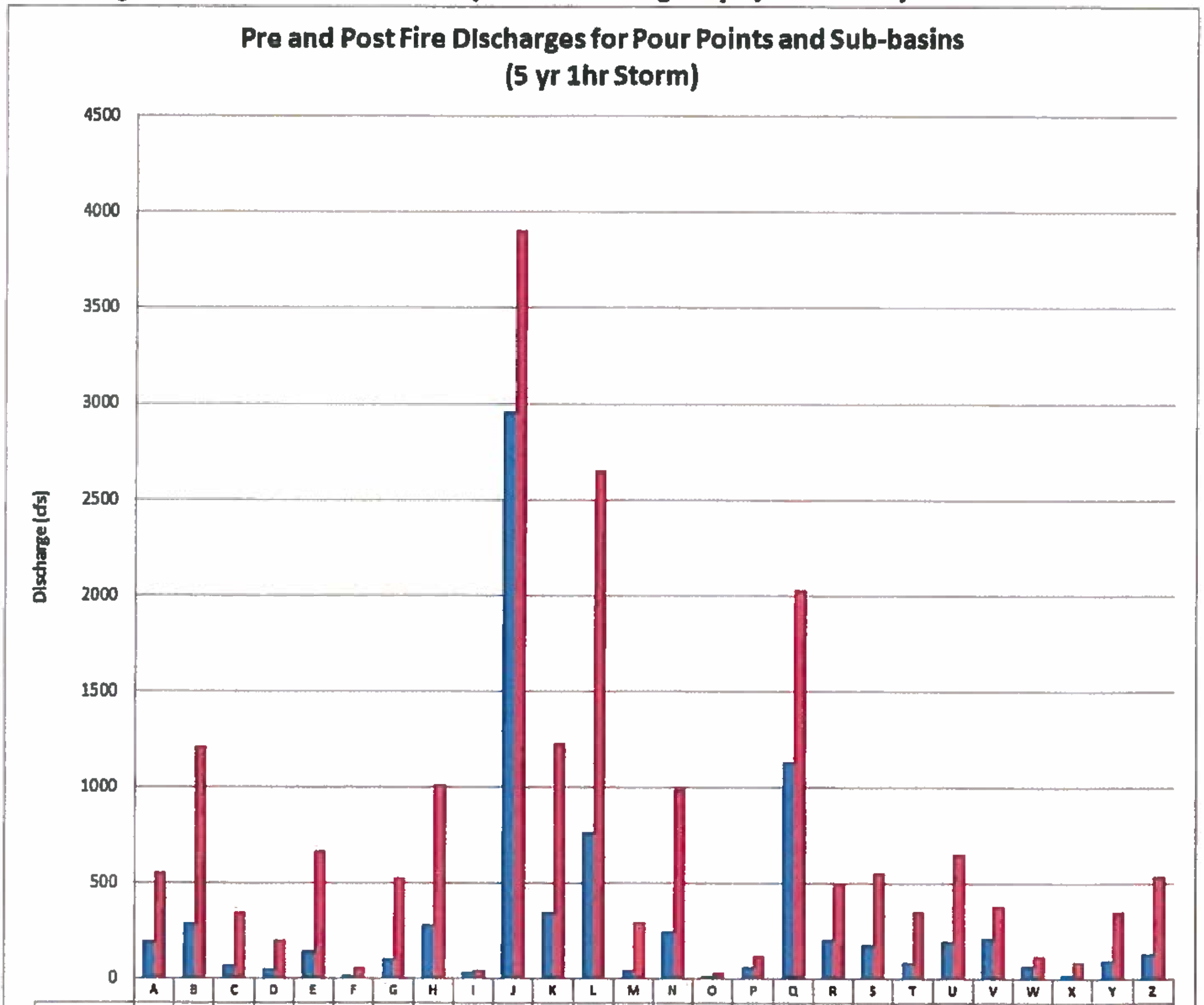



| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W | X | Y | Z |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pre-Fire CFS | 68 | 101 | 27 | 20 | 49 | 5 | 38 | 102 | 12 | 989 | 129 | 270 | 13 | 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 4: Pre and Post Waldo Canyon Fire Discharge displayed for the 5 yr 1 hr storm event.**

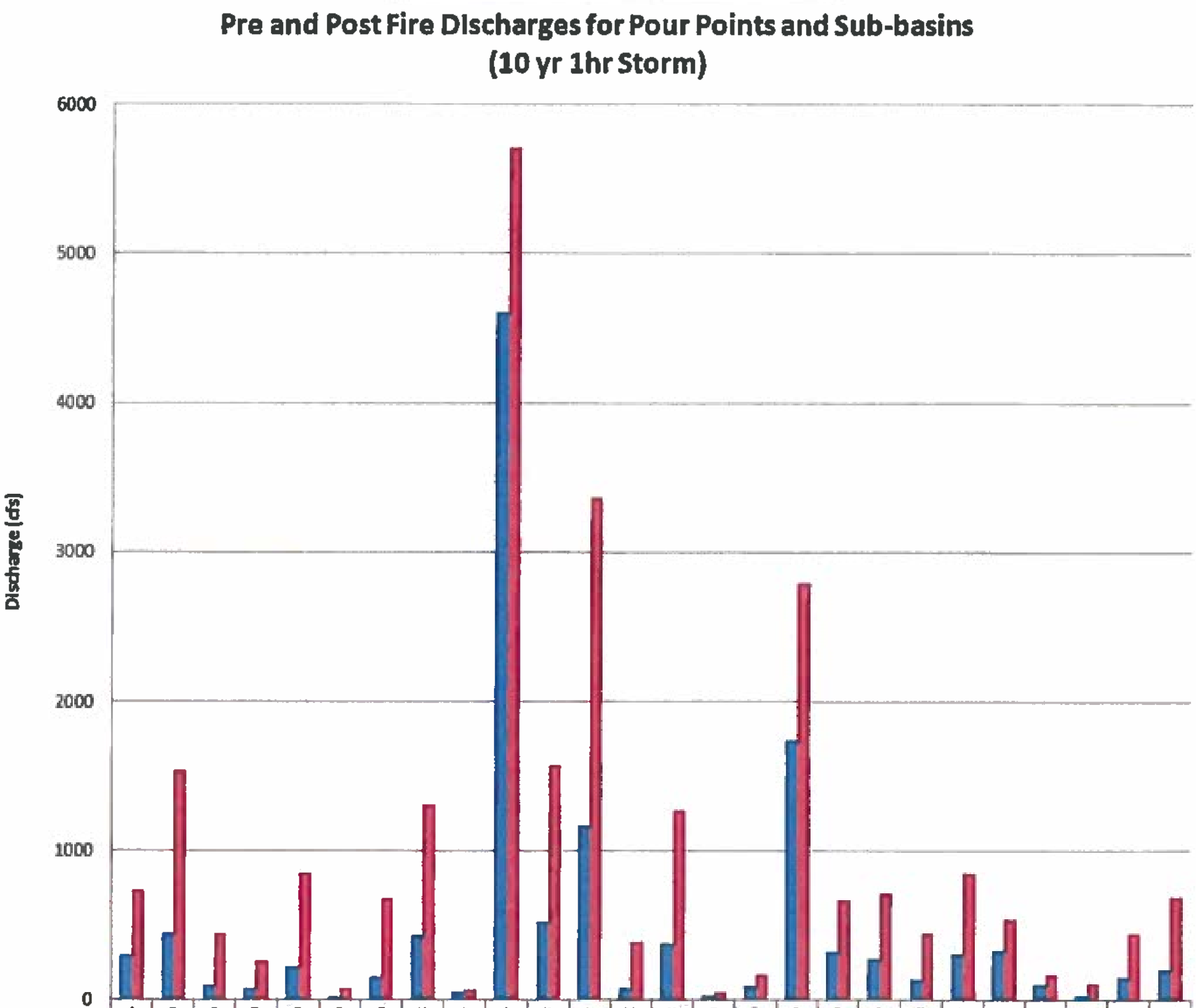



| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W | X | Y | Z |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pre-Fire CFS | 195 | 291 | 70 | 52 | 145 | 14 | 106 | 281 | 33 | 2958 | 347 | 768 | 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 5: Pre and Post Waldo Canyon Fire Discharge displayed for the 10 yr 1 hr storm**




| | 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 | 3363 | 386 | 1264 | 51 | 166 | 2793 | 668 | 718 | 450 | 848 | 542 | 172 | 116 | 447 | 689 |

event.

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. 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 subwatersheds 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 increases because there large size 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.

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 slope 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 | 70 % |
| 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. An example of this analysis is provided in Appendix F. 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 estimating post fire flows for all of the sub-basins or pour points.**

WILDCAT5 model has limitation of a 5 $mi^2$ drainage area. Additionally, this model was applied to the 3 larger sub-basins 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 sub-basins 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>**

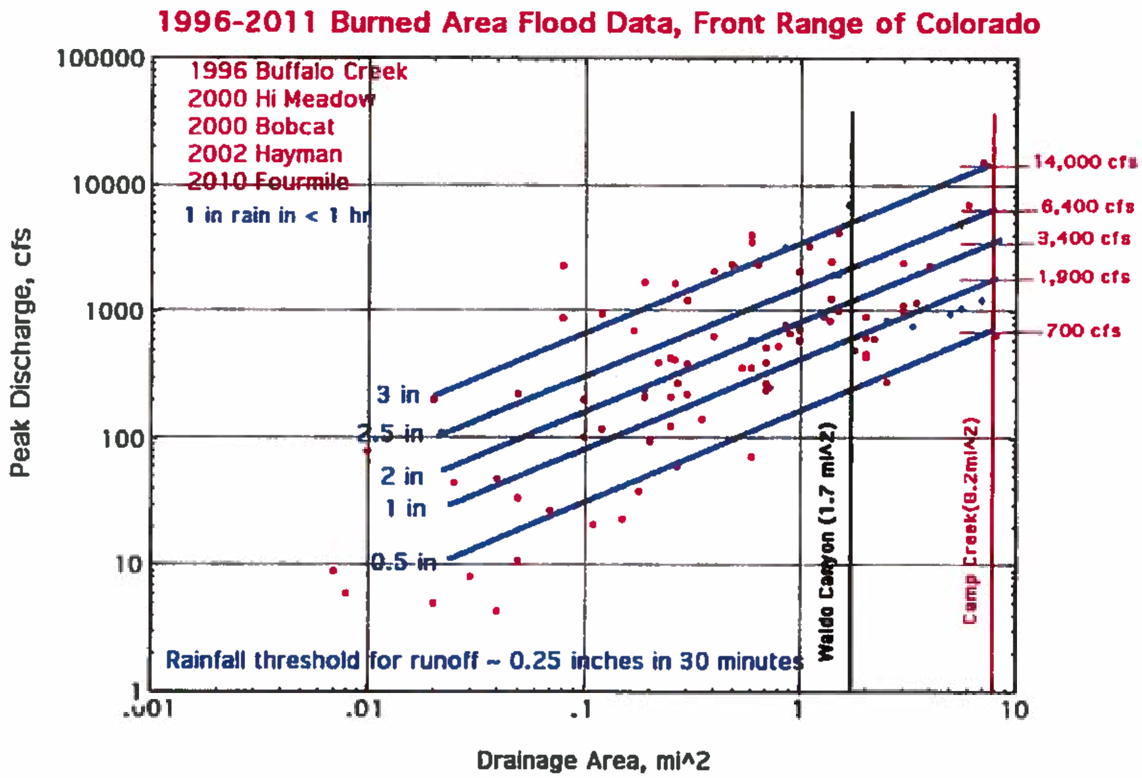
See Soils Specialist Report

[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.



## References Cited

Capesius, J.P., and Stephens, V.C., 2009, Regional Regression Equations for Estimation of Natural Streamflow Statistics in Colorado: U.S. Geological Scientific Investigations Report 2009-5136, 46 p.

Dunne, T. and Leopold, L.B. 1978. Water in Environmental Planning. W. H. Freeman and Company, New York, NY.

Dyrness, C., 1976: Effect of Soil Wettability in the High Cascades of Oregon. USDA Forest Service Research Paper PNW-202, 18 p.

Hawkins, R.H. and R.J. Greenberg, 1990. Wildcat5 Flow Model. School of Renewable Natural Resources, University of Arizona, Tucson, Arizona. BLM contact: Dan Muller, Denver, CO.

Jarrett, Robert (Bob). Personal Correspondence. Retired USGS Paleohydrologist. July 15, 2012.

NOAA. Hydrometerological Design Studies Center. http://hdsc.nws.noaa.gov/hdsc/pfds/. Accessed 28 June 2011.

climate of the US Southwest. Climate Research 21: 219-238.

USDA Natural Resources Conservation Service. 1986. Urban Hydrology for Small Watersheds. Conservation Engineering Division, Technical Release 55.

USDA Forest Service, "Details of Curve Number Methods," 20 June, 2011. http://forest.moscowfsl.wsu.edu/BAERTOOLS/ROADTRT/Peakflow/CN/supplement.html. Accessed 29 June 2011.