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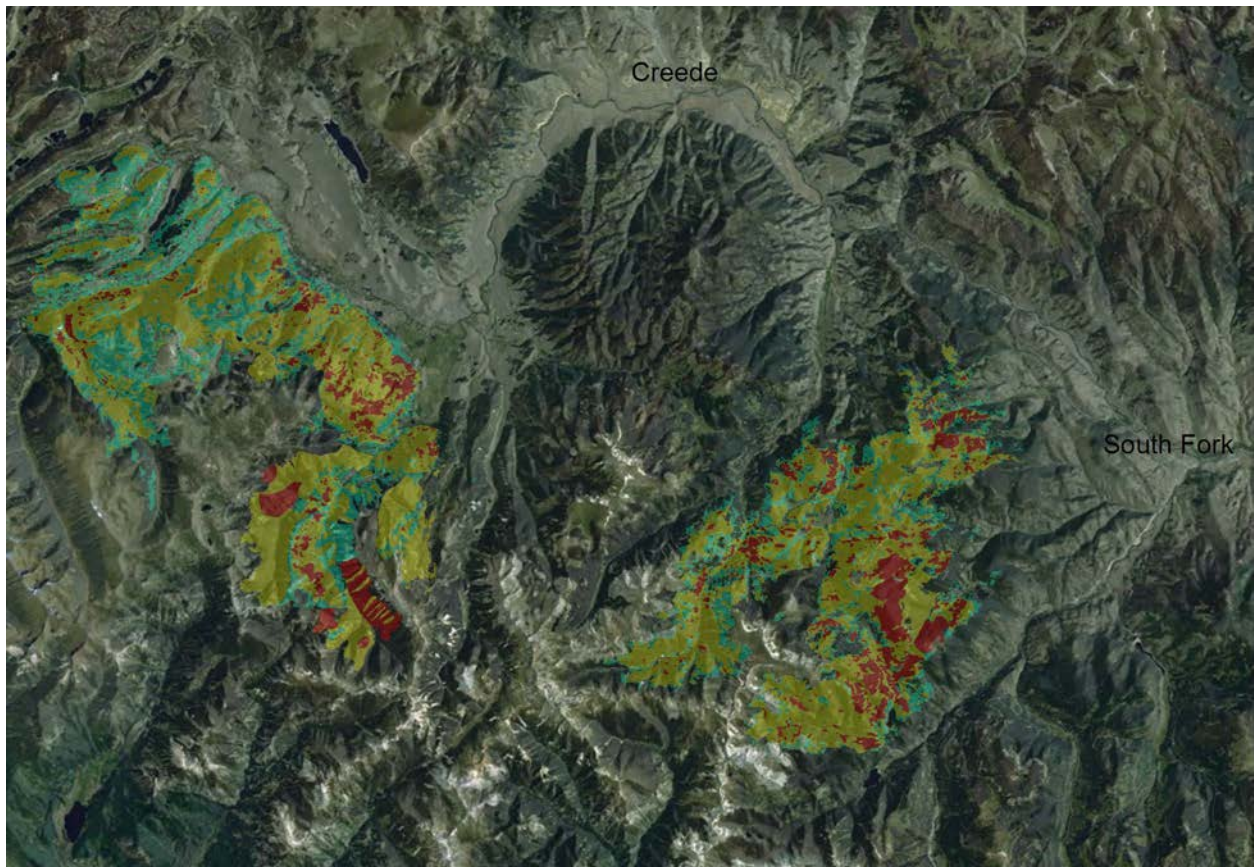
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# WEST FORK COMPLEX FIRE: Potential Increase in Flooding and Erosion

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January 2014



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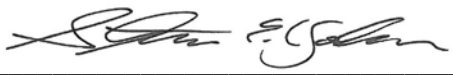
**WEST FORK COMPLEX FIRE:  
Potential Increase in Flooding and Erosion**

**Location:** Mineral and Hinsdale Counties, Colorado

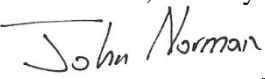
**Abstract:** The West Fork Complex Wildfire, in the San Juan Mountains West of South Fork, burned more than 109,000 acres between June 9<sup>th</sup> and July 12<sup>st</sup>, 2013. The fire area is composed of three separate fires: the Papoose Fire, in the Rio Grande watershed; the West Fork Fire, in the Rio Grande and San Juan watersheds; and the Windy Pass Fire, in the San Juan watershed. Together, these three fires are known as the West Fork Complex wildfire. For the next several years substantially increased flood peaks, flow volumes, sediment transport, and stream channel destabilization are expected in streams draining the fire areas.

The NRCS curve number (CN) technique was implemented for estimating direct runoff from rain events for both pre- and post-fire conditions, to develop estimates of flood hazard potential and potential threat to life and property. In addition, a model based on the Revised Universal Soil Loss Equation (RUSLE) was developed to estimate expected pre and post fire sediment yields. These results are best used as a relative value of flood and sediment release risk, for developing priorities. They can also provide approximate predictions for checking current infrastructure, as well as sizing new infrastructure.

In many catchments, post fire conditions are predicted to cause a 50- or 100-year (pre-fire) flood to result from a 10-year rain event, and 5 to 10 times the pre-fire runoff for the 25-year event. If it is assumed that the fire impacts on runoff in each of these catchments will be substantial for at least 5 years, the risk of a 10-year rain event over each individual point in these catchments over those 5 years of destabilization is 41 percent, with resulting (pre-fire) 50- and 100-year floods. The sediment analysis predicts that the Upper Rio Grande River will experience on average 130 times more sediment annually (1,030,000 tons/yr) than pre-fire conditions. The Papoose Wildfire accounts for 65% of the total sediment yields in the West Fork Complex while the West Fork Wildfire area has lower sedimentation rates overall. The highest yielding catchment (Hope Creek) accounts for about 18% of the total sediment yield of the entire West Fork Fire Complex Wildfire.

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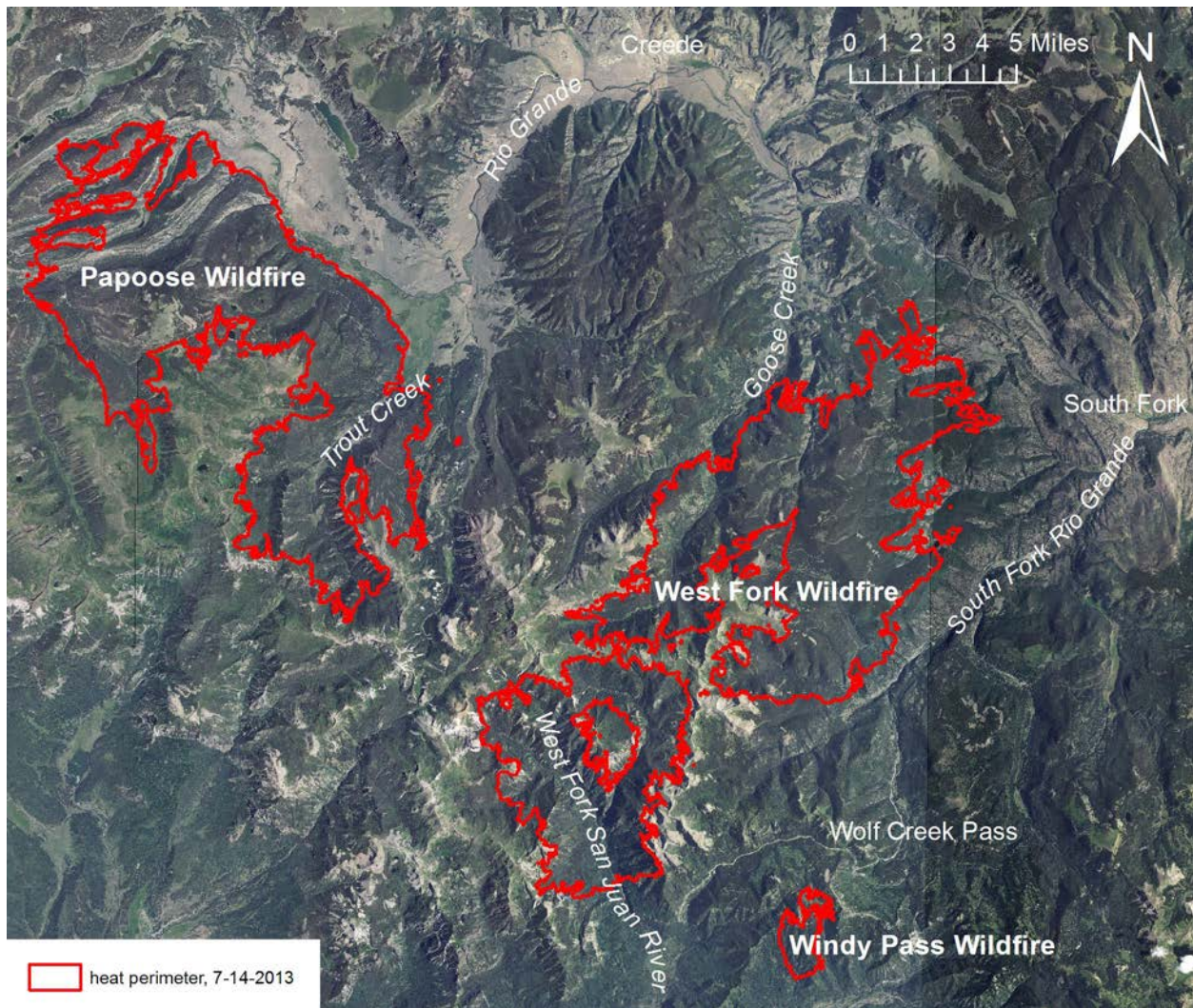
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## INTRODUCTION

The West Fork Complex Wildfire (Figure 1), in the San Juan Mountains West of the community of South Fork, burned more than 109,000 acres between June 9<sup>th</sup> and July 12<sup>st</sup>, 2013. The fire area is composed of three separate fires: the Papoose Fire, in the Rio Grande watershed; the West Fork Fire, in the Rio Grande and San Juan watersheds; and the Windy Pass Fire, in the San Juan watershed. Together, these three fires are known as the West Fork Complex fire. For the next several years substantially increased flood peaks, flow volumes, sediment transport, and stream channel destabilization are expected in streams draining the fire areas.

Wildfires cause hydrologic shifts for a number of years. Substantially increased runoff and

sediment production result from the loss of vegetation and soil cover, as well as from hydrophobicity, where the fire-induced vaporization of hydrophobic compounds causes water to collect on the soil surface and run off, instead of infiltrate. The lack of vegetation interception and soil infiltration, from the loss of surface roughness from ground litter and hydrophobicity, shifts the rainfall response from infiltration-dominated processes to surface runoff-dominated processes. For example, watershed impacts due to recent wildfire caused a Swiss catchment to produce 100-year to 200-year runoff discharges from a 10-year rainfall event due to changes in infiltration capacity (Conedera et al. 2003), though scale effects with greater runoff enhancement in smaller catchments and



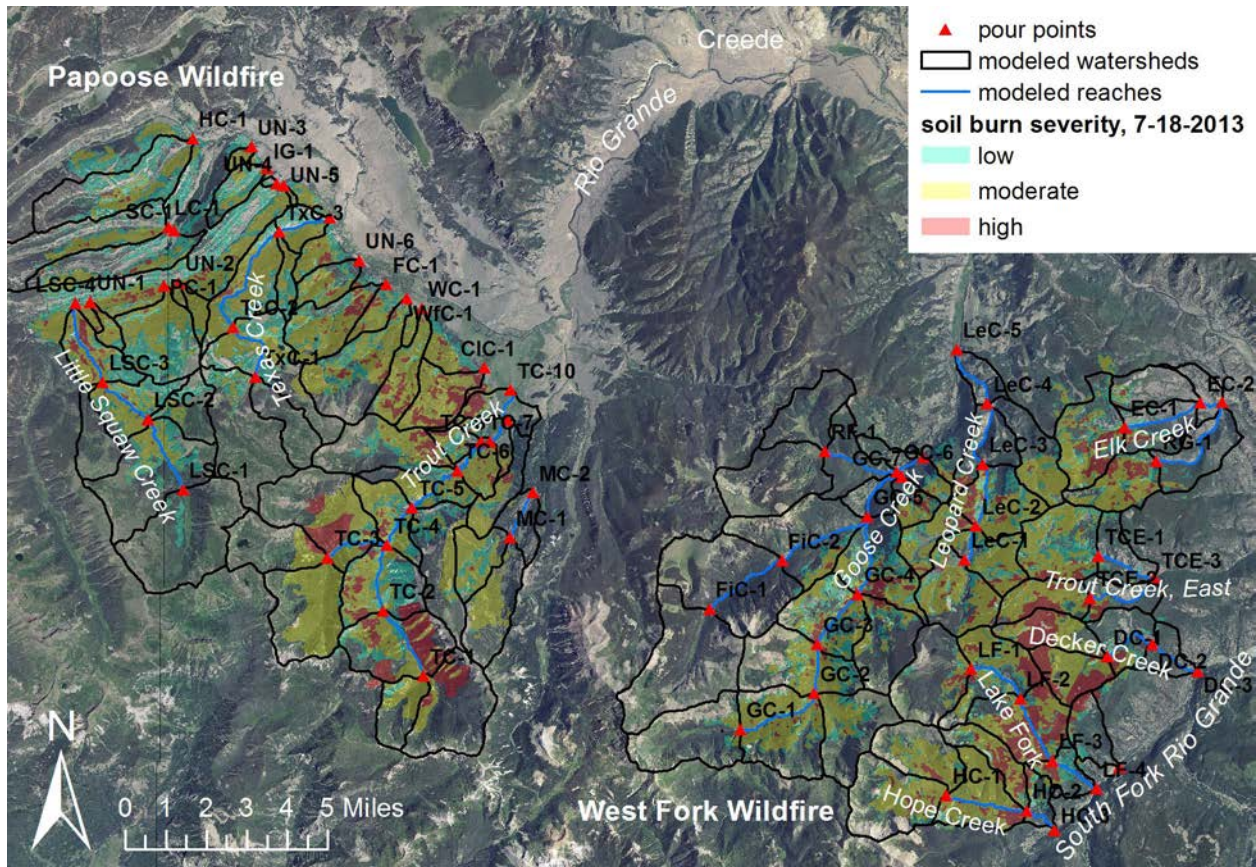
**Figure 1:** West Fork Complex Wildfire burn area extent.

tendencies towards overestimation in larger catchments have been noted (Stoof et al. 2011). Hydrophobicity, which tends to be more prevalent with increased sand content and lower soil water content, has been found to weaken within a few months of a fire but persist for at least 22 months in ponderosa and lodgepole pine forests of the Colorado Front Range (Huffman et al. 2001). Post-fire sediment yield is most dependent on ground cover, with percent ground cover explaining more than 80 percent of the variability in sediment yield (Benavides-Solorio and MacDonald 2001). Soil burn severity is hence fundamental for predicting sediment yield increases.

The West Fork Complex Wildfire Burned Area Emergency Response (BAER) report presented an initial hydrologic analysis of flood increases to be expected from the fire. However, this assessment was performed with a number of simplifications to meet the aggressive timeline

dictated by the BAER process. A more detailed peak flow analysis was performed to assess the variation and magnitude of increased flooding to be expected from the burned catchments. This analysis implemented the CN methodology.

Additionally, the potential increase in sediment yield due to the wildfire is relevant to prioritize locations where hillslope and riparian mitigation may be needed, to minimize impacts of the wildfire on such sensitive infrastructure as municipal water supply, irrigation diversions, and culvert conveyance. Predictions of post-fire sediment yield rely on mathematical models such as Revised Universal Soil Loss Equation RUSLE (Renard et al., 1997), Water Erosion Prediction Project WEPP (Elliot, 2004) and GeoWEPP (Renschler, 2003), as well as professional judgment (Robichaud et al., 2000). These methods have varying advantages and disadvantages for estimating the spatial distribution of post-fire soil loss, but all methods



**Figure 2:** Soil burn severity, with modeled pour points, watersheds and stream channels in the Rio Grande Basin.

can require large amounts of time and energy to estimate soil loss and its associated risks over large spatial extents. With wildfires becoming more pronounced in the wildland/urban interface, rapid watershed management actions to protect sociological concerns, water quality and ecosystem health are needed. This need for a rapid response to evaluate and manage post fire soil loss has increased the interest in using Geographic Information System (GIS) technology to spatially model post fire sediment yields. This has produced many toolsets that use the above models as engines to estimate soil loss rates spatially. Larsen et al., (2007) evaluated GIS versions of RUSLE and WEPP performance using established plots for fires on the Front Range of Colorado and found that the models performed poorly due to unaccountable variability not incorporated into the models. To address this weakness, it is preferred that sediment yield modeling focus on the magnitude of change in soil loss and not just to amount produced post fire. This method provides a good framework for managers to help prioritize and guide post-fire management activities.

This NRCS report details hydrologic analyses performed within the Rio Grande basin to assess the expected magnitude of flood increases in populated areas at risk of loss of life and property. Additionally, erosion modeling was performed to evaluate the expected increase in sediment to be expected from the burn areas. Together, these results are provided to assist with planning and prioritizing the recovery efforts.

## METHODS

Rainfall-runoff modeling was performed to simulate the expected flood response of the streams draining the wildfire areas. Additionally, predictions of post-fire sediment yield were also developed. The methods implemented to provide these predictions are presented below.

### Runoff Model

Hydrologic modeling for the West Fork Complex Fire was performed using the program HEC-HMS (version 3.5), a model developed by the U.S. Army Corps of Engineers' Hydrologic Engineering Center. The NRCS curve number (CN) technique for estimating direct runoff from rain events, combined with the NRCS dimensionless unit hydrograph method, was used in this analysis. Catchments and modeled stream channels and pour points are presented in Figure 2 and Appendix A.

As documented in NRCS (2004b), the NRCS method for estimating direct runoff from individual storm rainfall events is of the following form:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \quad \text{if } P > I_a \quad (1)$$

$$Q = 0 \quad \text{if } P \leq I_a \quad (2)$$

where  $Q$  is the depth of runoff (inches),  $P$  is the depth of rainfall (inches),  $I_a$  is the initial abstraction (inches), and  $S$  is the maximum potential retention (inches). The equation derivation is not physically based but does respect conservation of mass (NRCS 2004b).

The Curve Number (CN) is defined as:

$$CN = \frac{1000}{10 + S} \quad (3)$$

The initial abstraction was initially described and has traditionally been used as:

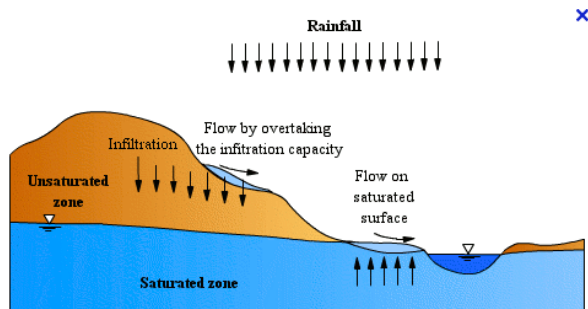
$$I_a = 0.2S \quad (4)$$

To reflect the decreased storage of a fire impacted soil surface (due to a reduction of depression storage from the elimination of soil litter), the initial abstraction was assumed to be 0.1S for post wildfire conditions in catchments that were substantially burned (>50% moderate + severe

soil burn severity). Catchments that were not substantially burned were modeled with the standard  $I_a$  of 0.2S. The impact of the  $I_a$  adjustment on CNs was ignored; for the high CN post wildfire conditions, smaller shifts in CN due to changes in  $I_a$  can be expected (Woodward et al. 2003).

The CN is a simple catchment-scale method that gives simplified results at a stream outlet, with more accurate results expected for larger, higher-intensity rain events. The method is documented in the NRCS National Engineering Handbook, Section 4, Hydrology, Chapters 9 and 10 (NRCS 2004a, NRCS 2004b), in Rallison (1980), as well as in numerous other publications. However, little quantitative information has been published of the database on which it was developed (Maidment 1992). In general, the method was developed for rural watersheds in various parts of the United States, within 24 states; was developed for single storms, not continuous or partial storm simulation; and was not intended to recreate a specific response from an actual storm (Rallison, 1980).

Fundamentally, the reliability of the CN method for predicting peak flow from forested, mountainous watersheds is questionable. Forested watersheds in unburned conditions may be dominated by saturation-excess overland flow (Figure 3), where runoff is produced from relatively small and variable portions of a catchment when rainfall depths exceed the soil capacity to retain water. Newly burned catchments, on the other hand, may be dominated by infiltration-excess (Hortonian) overland flow, where surface runoff is generated when rainfall intensity is greater than soil infiltration capacity, and flow runs down the hillslope surface. Evidence of this surface runoff is provided by such features as surface rilling on freshly-burned hillslopes. Rainfall-runoff modeling performed in the San Dimas Experimental Forest (Chen et al. 2013) found that pre-fire runoff predictions were more accurate using the CN method, while KINEROS2 performed better for post-fire conditions. These results suggest fundamental shifts in runoff mechanisms between pre- and post-fire conditions, complicating modeling strategies.



**Figure 3:** Hillslope section illustrating infiltration excess and saturation excess overland flow (Laboratory of Ecohydrology, EPFL).

Despite this shortcoming, due to its relative simplicity and achievable data requirements on large scales, as well as reasonable results when qualitatively compared to actual post-fire runoff events, the CN method is a preferred tool for predicting flow response of wildfire areas. Alternative approaches can be problematic, due to the need to quantify infiltration rates, the effects of soil litter and hydrophobicity on retention and infiltration for pre- and post-fire conditions, as well as vegetation canopy rainfall interception. This accounting would need to be performed at a spatial resolution appropriate for obtaining the needed flood predictions throughout the entire wildfire extent, which can be a very challenging task with the limited time and resources allotted to practitioners for prediction.

An additional complication arises from the peak rate factor imbedded in the NRCS dimensionless unit hydrograph method. Within HEC-HMS, this peak rate factor cannot be altered from the default value, despite an understanding that this factor tends to increase with steeper watersheds (Moore et al. 2014).

Considering the potentially problematic physical basis of the model application to these landscapes and conditions, an understanding of the potential accuracy of the modeling results is needed. In general, the greatest uncertainty in results is for frequent (shallow) rainfall events in pre-fire conditions and the best predictions are made for less frequent (deeper) rainfall events in post-fire conditions. However, post-fire conditions require use of CNs known with less certainty, complicating the situation. Additionally, spatial rainfall variability due to orographic forcing can lead to additional modeling uncertainty. Hence,

prediction error can be understood as variable depending upon rainfall depth, intensity, burn severity and catchment area. The best use of the modeling results is through comparison of different catchments flood response to identical rainfall events, for prioritization of areas of concern.

### CN

Curve numbers are values less than 100, with higher values corresponding to catchments with lower infiltration rates and higher runoff potential. In general, CN assignments are typically made using guidance provided in NRCS (2004a).

CNs were assigned throughout the modeled catchments according to hydrologic soil group, vegetative type, and soil burn severity. Soil burn severity is a dominant factor in CN assignments in burned areas. Hydrophobicity was assumed to be minimal, since the next rain events (after this analysis was performed) will occur a year after the fire.

The average catchment CN was computed using an aerial averaging methodology. Hence, catchment size was limited to areas that have similar runoff characteristics, to provide the most reliable results. As catchment size increased, CNs were computed for adjacent and serial catchments and flows were routed downstream and combined with lower catchments to predict flow at downstream points of interest. This was necessary due to the larger basins draining the fire areas, as well as to account for catchment shape and stream channel attenuation.

The methods used to quantify CN assignments are discussed in the following subsections.

#### *Soil Burn Severity*

Soil burn severity is the principle driver for increasing flow in runoff predictions. For this modeling, soil burn severity was measured using the BARC process from satellite data collected on 7/18/2013 (Figure 2).

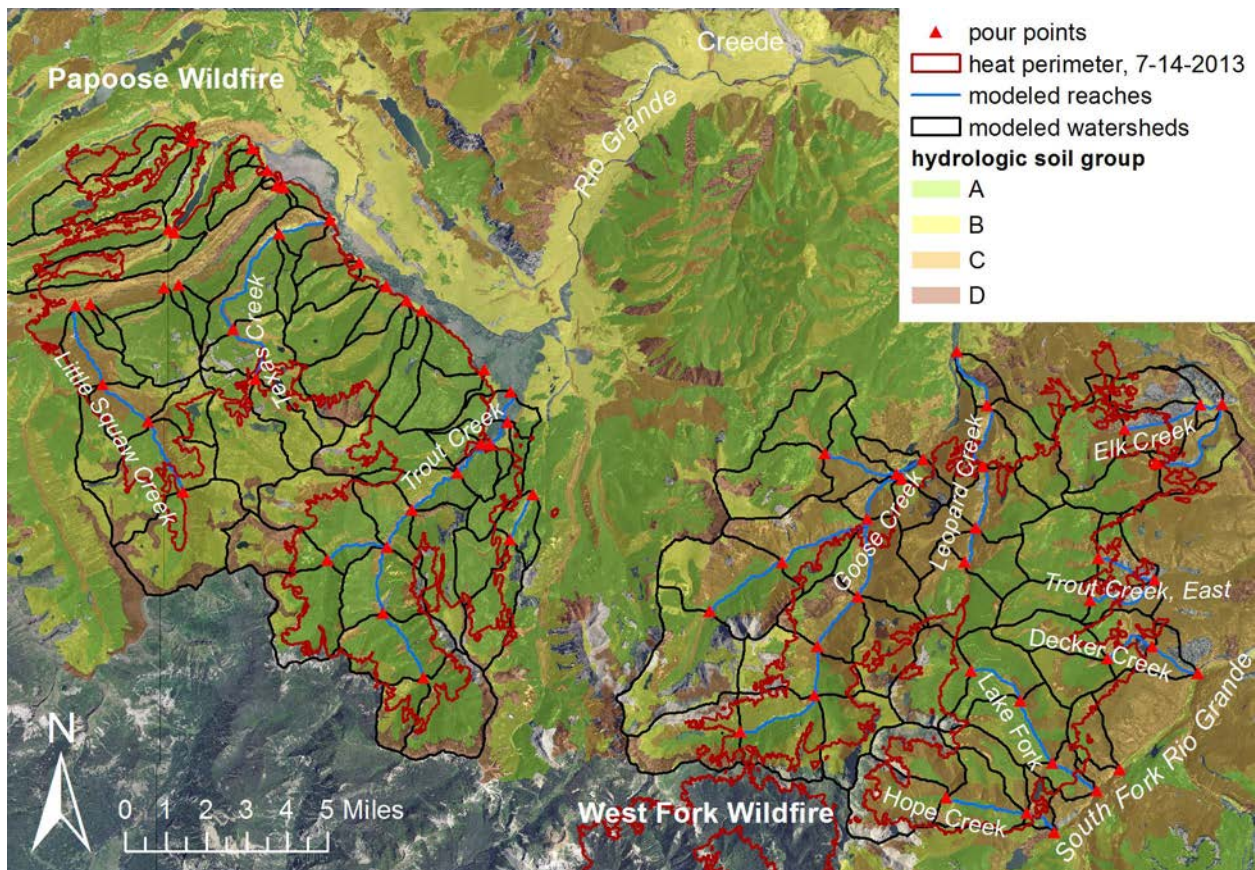
### Hydrologic Soil Groups

Hydrologic soil group (HSG) classification was selected using soils data published in the NRCS SSURGO (Soil Survey Geographic) database. Using this method, soil are classified as being either A, B, C, or D type, where A allows the most infiltration and least runoff and D allows the least infiltration and greatest runoff. The hydrologic soil groups of the modeled catchments are provided in Figure 4. A-type soils are prevalent in many areas of the fire.

Dual hydrologic groups (i.e. A/D, B/D) are indicated in portions of the catchments. These dual classifications are for certain wet soils that could be adequately drained, with the first letter indicating the wet condition and the second indicating the undrained condition. In these cases, an undrained condition was assumed.

### Vegetation Type

Vegetation type, from SWReGAP (Southwest Regional Gap Analysis Project) land cover mapping, was included in the CN assignments used for the modeling. The dominant vegetation types within the stream drainages draining the fire areas were spruce-fir, aspen, and alpine meadow and tundra.



**Figure 4:** Hydrologic soil group (HSG) classifications utilized in the modeling.

**Table 1:** CN assignments implemented in the West Fork Complex Fire hydrologic modeling. HSG: hydrologic soil group.

Cover Description	A HSG				B HSG				C HSG				D HSG			
	Unburned	Low	Moderate	High	Unburned	Low	Moderate	High	Unburned	Low	Moderate	High	Unburned	Low	Moderate	High
Herbaceous, Pasture, Alpine Meadow, Park	49	55	67	77	61	68	80	86	74	81	88	89	82	86	92	95
Oak-aspen—mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush	45	52	65	77	48	55	65	86	57	70	80	89	63	70	80	92
Ponderosa pine-juniper (grass understory)	49	57	65	77	58	65	75	86	73	78	83	89	80	85	90	92
Sagebrush (grass understory)	46	54	65	77	51	60	75	86	63	70	80	89	70	75	85	92
Lodgepole Pine Forest	49	57	65	77	60	65	70	86	73	78	83	89	79	83	87	92
Bare soil	77	77	77	77	86	86	86	86	91	91	91	91	94	94	94	94
Wetland	98	98	98	98	98	98	98	98	98	98	98	98	98	98	98	98

*CN Assignments*

Curve numbers were assigned by polygons that had unique values of hydrologic soil group, vegetation type, and soil burn severity. Using primarily a compilation modified from the values used in the High Park and Black Forest Wildfire analyses, the implemented CN values are provided in Table 1. A fair ground cover condition was generally assumed for the unburned values abstracted from NRCS (2004a), though a good ground condition was assumed for herbaceous/grassland. The CN values for burned conditions were primarily compiled from various grey literature and unpublished sources; they should be considered approximate.

**Rainfall**

Rainfall depths used in the modeling were extracted from NOAA Atlas 14, Vol 8 (Perica et al. 2013). 6-hour rainfall durations and NRCS Type II rainfall distributions were assumed.

Three rainfall depths were used in the analysis, reflecting the variable spatial and elevation extent of the catchments draining the fire area. However, for each specific watershed analyzed, identical rainfall depths were used for all catchments. The zones implemented in the modeling are as follows:

- Zone A (East, South): South Fork catchments, Upper Goose Creek,
- Zone B (East, North): Elk Creek, Leopard Creek,

- Zone C (West): Little Squaw Creek, Texas Creek, Trout Creek, Long and Sawmill Canyons

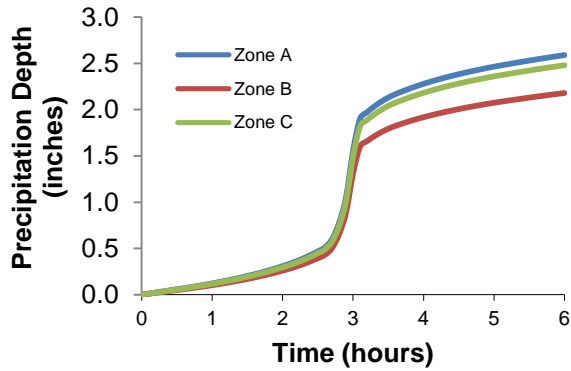
The specific rainfall depths for the 10-, 25-, 50- and 100-year floods are provided in Table 2.

**Table 2:** Rainfall depths (inches) implemented in the modeling.

	Return Interval			
	10-year	25-year	50-year	100-year
Zone A	2.17	2.59	2.93	3.28
Zone B	1.79	2.18	2.48	2.77
Zone C	1.99	2.48	2.91	3.40

The implemented rainfall distributions for the 25-year event are shown in Figure 5. Note that the majority of the rainfall is assumed to fall within a half hour of the 6-hour duration event.

For catchments with drainages areas > 11 mi<sup>2</sup> (<0.98 reduction), an areal reduction factor was applied as detailed in Miller et al. 1973. Reduction varied from 0.98 (Elk Creek) to 0.94 (Trout Creek). When applied, this area reduction was implemented in all catchments; flow may be underpredicted in the smaller, upper catchments of such drainages.



**Figure 5:** 25-year cumulative rainfall distributions implemented in modeling.

### Lag Time

Lag time ( $L$ ), which is required to generate a hydrograph using the NRCS unit hydrograph methodology, was computed using the watershed lag method (NRCS 2010). The lag equation is:

$$L = \frac{l^{0.8}(S + 1)^{0.7}}{1900Y^{0.5}} \quad (5)$$

, where  $l$  is the flow length (ft),  $Y$  is the average watershed land slope (%), and  $S$  is the maximum potential retention (in),

$$S = 1000 / cn' - 10 \quad (6)$$

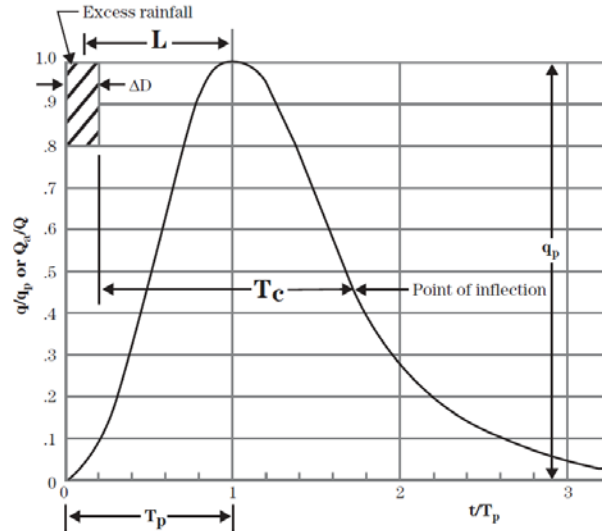
, where  $cn'$  is the retardance factor and is approximately equal to the  $CN$ . This method allows the rapid computation of differing lag times for pre- and post-fire conditions, reflecting actual physical mechanisms of more rapid flow response during post-fire conditions.

Lag time, and the related time of concentration, are shown on the dimensionless unit hydrograph schematic illustrated in Figure 6.

### Flow Routing

A Muskingum-Cunge procedure was used to route flow from upper catchments to the stream outlets. This 1-dimensional method, embedded in HEC-HMS, allows for flow attenuation in the computations but does not provide a numerical solution of the full unsteady flow routing equations, as provided in such computational models as HEC-RAS. In each reach, flow routing was estimated using a single simplified cross section, channel slope, and Manning's  $n$

roughness estimates. Manning's  $n$  was selected using a visual estimation procedure, with a quality control step to assure that to maintain subcritical or approximately critical velocity was maintained, reflecting an assumption that existing or new channel bedform development prevents reach-average supercritical flow.



**Figure 6:** Relationship of time of concentration and lag time to the dimensionless unit hydrograph (NRCS 2010).

### Sediment Bulking

A simple multiplication factor was applied to the post-fire flood predictions to account for sediment bulking in the debris flows. For burned catchments, this multiplication factor was assumed to be 1.25 if the severe + moderate (S+M) soil burn severity aerial extent was greater than 50%, and 1.1 for catchments with between 15 and 50 % S+M soil burn severity.

### Streamstats

As limited quality control, peak flows estimated using the USGS regression equations (Capesius and Stephens 2009), embedded in USGS Streamstats, were compared to the CN runoff results for unburned conditions.

## Erosion Modeling

The RUSLE model was chosen to estimate pre and post fire sediment related issues for the burn area because it's widely used, can be quick to execute with straight forward factors and has a large amount of supporting documentation. The RUSLE models (pre and post fire) are based on a spatial version of RUSLE outlined in the Assessment of Threats to Riparian Ecosystems in the Western U.S. (ATREW) [Theobald et al., 2010] report. The ATREW methods entail calculating RUSLE (Equation 7) the standard way using widely available fine resolution spatial datasets to approximate the 6 RUSLE factors. The ATREW report also provides guidance on parameterizing the RUSLE *C* and *P* factors based on commonly used landcover datasets (e.g., USGS National Landcover Dataset and USFS Existing Vegetation Dataset), as well as equations that scale GIS based terrain analysis for the *L* and *S* factors.

The advantages of the ATREW approach are (1) simple model parameterization using nationwide spatial datasets; (2) production of a soil loss raster (each raster cell has a soil loss value); and (3), evaluate the resulting sediment yield rasters spatially to help prioritize soil treatment zones and emergency resource allocation.

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P$$

**Equation 7:** The Revised Universal Soil Loss Equation (RUSLE) where *A* is the average annual unit-area (tons/ha/yr), *R* is the rain erosivity factor (Mj mm/(ha h yr)), *K* is the soil erosivity factor (tons ha h/(ha MJ mm)), *L* is the slope length factor (m), *S* is the slope steepness factor, *C* is the cover management factor ( $\geq 0$ ), and *P* representing the management factor ( $\geq 0$ ).

The sediment modeling entailed 5 general steps: (1) collection of Geospatial dataset for the greater burn area (Table 3); (2) development of spatial RUSLE factors for pre and post fire conditions; (3) calculate RUSLE for pre- and post-fire

**Table 3:** Spatial datasets used for the six RUSLE factors.

RUSLE factor	Website	Description
R	<a href="http://www.epa.gov/esd/land-sci/emap_west_browser/pages/wemap_mm_sl_table.htm#mapnav">http://www.epa.gov/esd/land-sci/emap_west_browser/pages/wemap_mm_sl_table.htm#mapnav</a>	EPA EMAP RUSLE factors summarized to HUC 8 units for the Western United States.
K	<a href="http://datagateway.nrcs.usda.gov">http://datagateway.nrcs.usda.gov</a>	NRCS SSURGO data downloaded for El paso County, Colorado
L and S	<a href="http://viewer.nationalmap.gov/viewer">http://viewer.nationalmap.gov/viewer</a>	10x10 meter elevation model downloaded for HUC 8 areas associated with the burn area
C	<a href="http://earth.gis.usu.edu/swgap/landcover.html">http://earth.gis.usu.edu/swgap/landcover.html</a>	30x30 meter landcover dataset for Nevada, Arizona, Utah and Colorado
P	Parameter not used in analysis due to lack of good spatial data	

scenarios (ArcGIS Raster Calculator); and (4) attribute computation points and values at risk with pre and post fire sedimentation rates. Pre and post fire sedimentation rate estimates were executed within a GIS using terrain analysis tools to calculate slope length ( $L$ ) and steepness ( $S$ ) factors with simple map algebra statements to compute Rain fall erosivity ( $R$ ), soil erodibility ( $K$ ) and cover management ( $C$ ) factors from ancillary spatial datasets. The soil/cover management ( $P$ ) factor was not incorporated in the analysis due to a lack of spatial information on management activity in the burn area. For each of the five RUSLE factors used, a 10 meter resolution raster dataset was generated. The five RUSLE factor rasters were multiplied together to calculate the local (cell level) sedimentation rate. The local sedimentation rate values were accumulated downslope via a flow direction raster (Figure 7) and averaged by the contributing area above each raster cell. This results in the final sedimentation rate raster with values representing the average cumulative sedimentation rate in tons per year for each scenario.

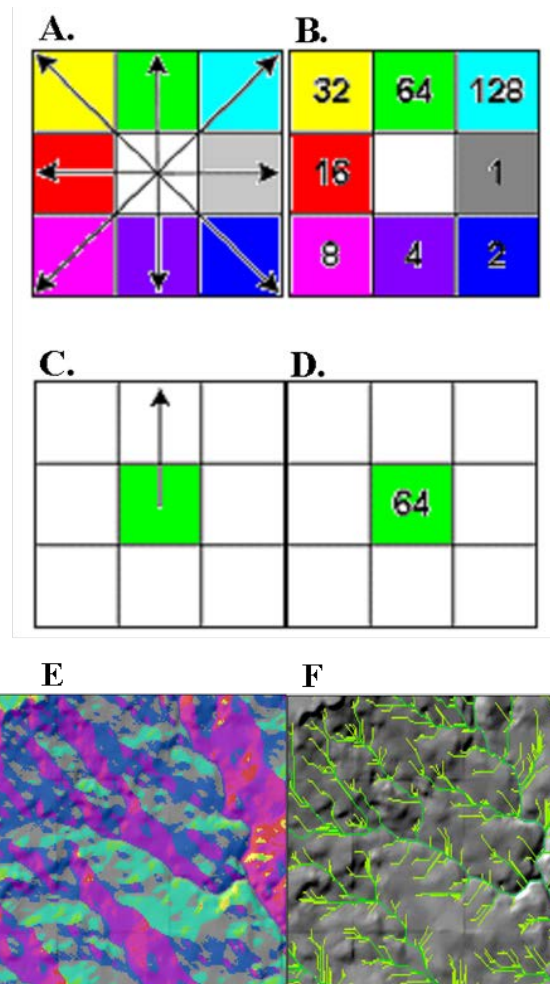
**Rainfall Erosivity ( $R$ ) Factor**

The rain erosivity ( $R$ ) factor raster was generated by rasterizing the EPA EMAP HUC 8 polygon shapefile to a raster containing  $R$  factor values. The  $R$  factor raster was held constant between the pre and post fire scenarios due to a lack of information about change in rain erosivity values and the EPA EMAP values are based on 30 year averages. The HUC 8  $R$  factor raster was masked out to match the cell size and processing extent (Figure 8).

**Soil Erodibility ( $K$ ) Factor**

The development of soil erodibility ( $K$ ) factor raster entailed summarizing KFFACT (SSURGO table attribute) to NRCS SSURGO map units and then rasterizing the map units in the same manner as the  $R$  factor. KFFACT (property of a soil horizon) was summarized to map unit delineations by calculating a depth/area weighted average based on horizon depths up to 15 centimeters and the component percent within a map unit. This was accomplished through queries developed in the SSURGO database downloaded from the USDA Geospatial Data Gateway

website. The  $K$  factor raster was held constant for both scenarios even though burn severity alters soil erodibility. Altering soil erodibility based on burn severity between scenarios could be incorporated in future models but would require additional research and parameterization.



**Figure 7:** Flow direction raster cell example. A) Demonstrates the eight directions of hydrologic flow from center cell; B) contains the direction coding system for the eight directions; C) Demonstrates the direction of flow from the center cell if flow direction is north; D) The coding scheme if the flow direction is north; E) raster with coded flow direction values (1,2,4,8,16,32,64,128) with coloring scheme that matches direction examples A and B; and F) accumulation analysis flow direction raster from example E with flow path values equaling accumulated drainage area.

**Slope Length (L) and Slope Steepness (S) Factors**

The *L* and *S* factor were calculated jointly (*LS*) using basic terrain analysis methods outlined in Theobald et al. (2010) using a 10 meter elevation model. These methods include calculating a percent slope, aspect (radians) and accumulated upslope length. The accumulated upslope length process entailed accumulating number of contributing raster cells to a given cell based on the overland flow paths from the flow direction raster. The resulting slope, aspect and upslope length rasters were transformed using equations developed by Winchell et al. (2008, Equation 8) and Nearing (1997, Equation 10). These equations scale the values derived from the above

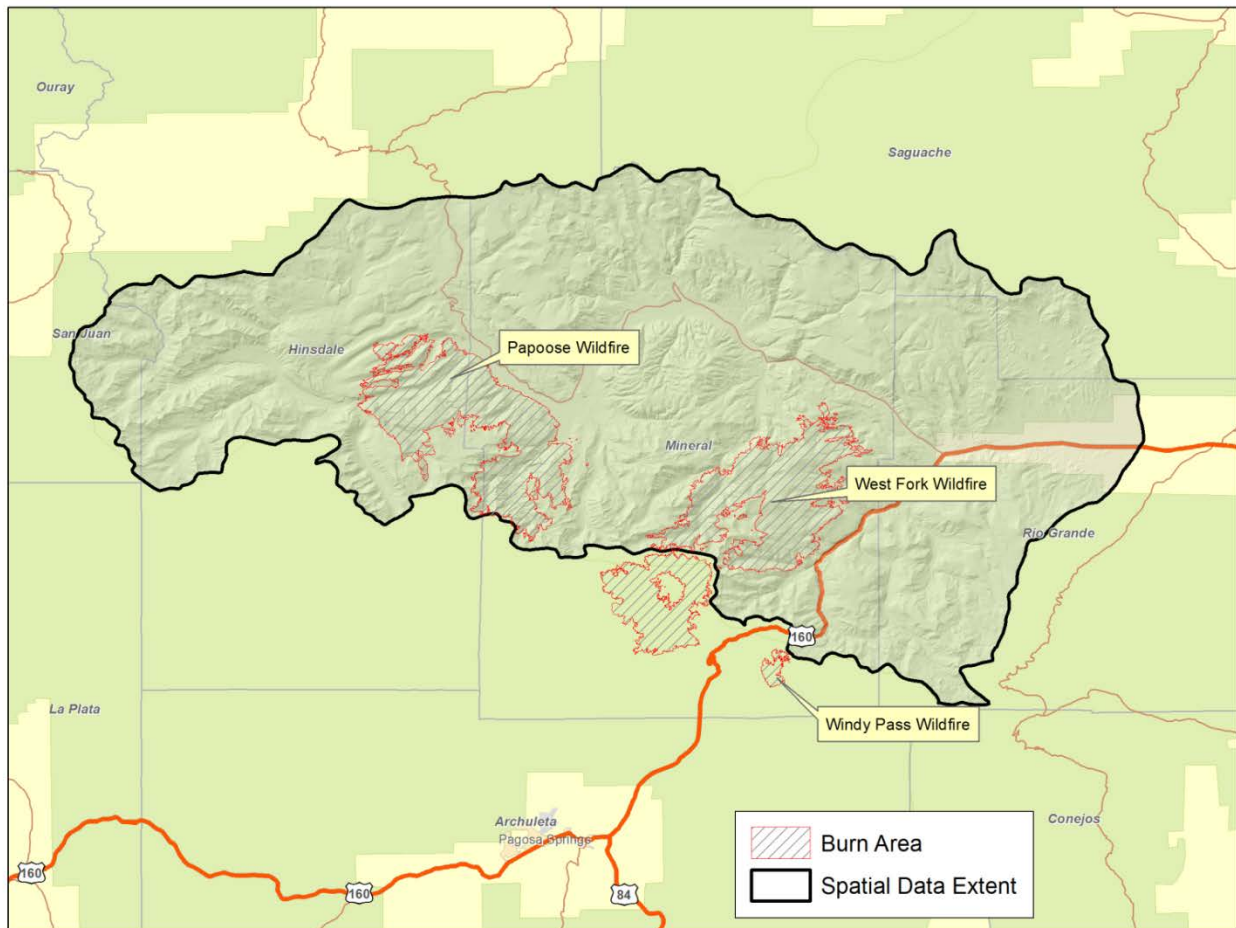
terrain analysis to better fit within the frame work of the RUSLE equation and ensure that the units are correct.

$$L_{ij} = \frac{(A_{ij} + D2)^{m+1} - A_{ij}^{m+1}}{x^m \cdot D^{m+2} \cdot 22.13^m}$$

**Equation 8:** Slope length scaling equation developed by Winchell et al. (2008), where  $L_{ij}$  is the transformed slope length,  $D$  is the cell size of the analysis (10 meters),  $X$  aspect transformation (Equation 9) and  $m$  percent slope transformation (Equation 10).

$$X_i = \sin \alpha_i + \cos \alpha_i$$

**Equation 9:** Aspect transformation where  $X_i$  is the transformed aspect values for raster cell  $I$  and  $\alpha$  is aspect (radians) for raster cell  $I$ .



**Figure 8:** Modeled area. The shaded area is the Upper Rio Grande River watershed that pre and post fire sediment yields were estimated for using RUSLE. This area was used to estimate impacts to the Upper Rio Grande River downstream of the burn area (red polygons).

$$\beta = \frac{\sin \theta}{3(\sin \theta + 0.56)}$$

**Equation 10:** Slope transformation to calculate *beta* with *theta* being percent slope. The *m* coefficient is calculated by taking the ratio between *beta* and one plus *beta* ( $\beta / 1 + \beta$ ).

The *S* factor was developed by first transforming percent slope using the Nearing (1997) equation (Equation 11) for slopes greater than 55% to create the *S* factor raster; second transform aspect (radians) using equations (1 and 2) to create variable *X* and coefficient *m* in equation 2; and third incorporating accumulated upslope length ( $A_{ij}$ ), the cell size of the analysis (*D*) (Equation 2) and the slope aspect transformations into equation 2 to create the *L* factor raster. As with the *R* and *K* factors the *L* and *S* factors were held constant between the pre and post fire models.

$$S = 1.5 + \frac{17}{1 + \exp(2.3 - 6.1 \sin\theta)}$$

**Equation 11:** *S* factor transformation with *theta* being percent slope.

### **Cover (C) Factor**

The *C* factor parameterization for the pre and post fire scenarios was developed using various source tables from different documents related to RUSLE. The pre fire scenario parameterization involved developing a lookup table that assigns the existing landcover types (Southwest ReGAP) within the greater burn area (Figure 8) its associated *C* factor (Table 4). Table 3 was compiled by Theobald et al., (2010) for the ATERW report and provides a broad spectrum of landcovers found in most landcover datasets and can be modified based on local knowledge. The post fire *C* factor parameterization entailed modifying the pre burn *C* factor raster based on burn severity classes derived from the Burned Area Reflectance Classification (BARC) image. This process consisted of assigning the BARC burn severity classes *C* factor values (low burn = 1.03, moderate burn = 2.25 and high burn 3.75) (Larsen et al., 2007) that were then used to modify the pre fire *C* factors by summing the two rasters together. Larsen et al., (2007) estimated

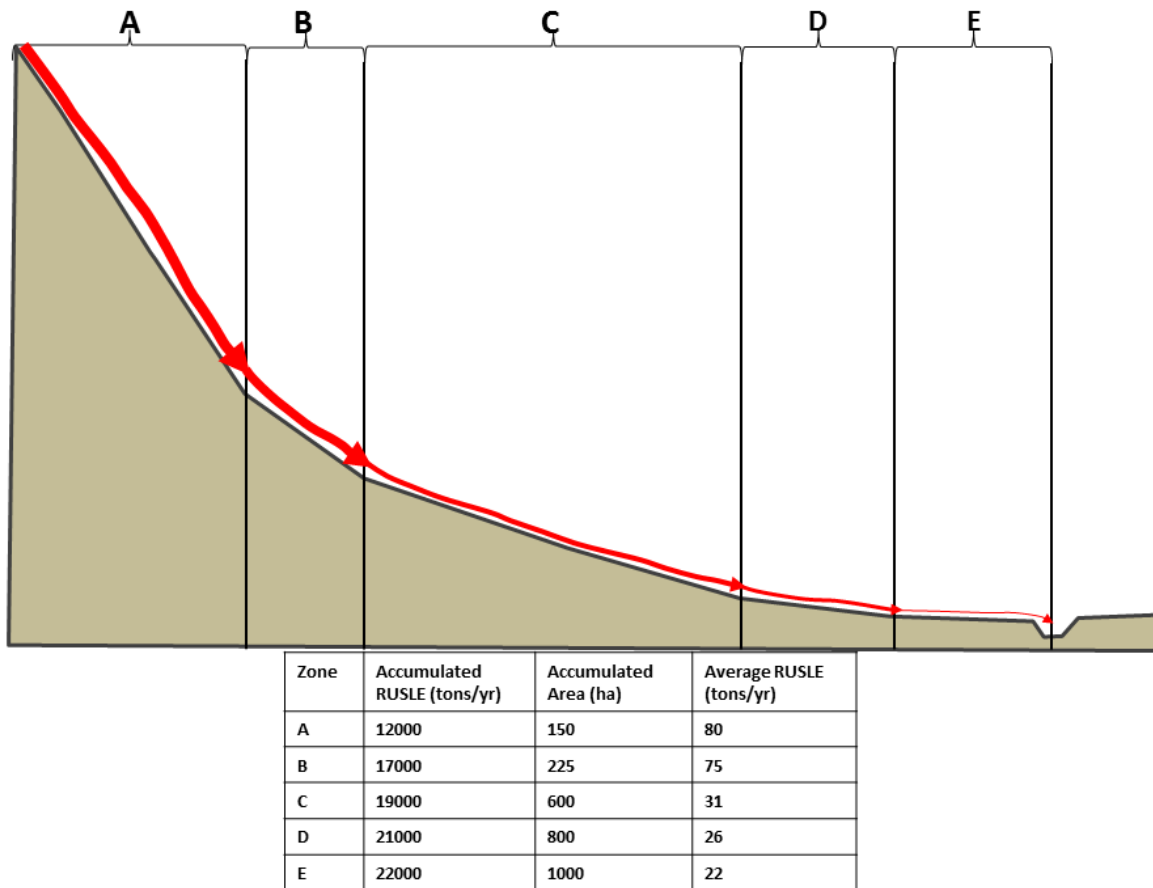
that high burn severity area *C* factors changed by four hundred percent but didn't estimate moderate and low burn severity changes. For these, *C* factors changes were estimated using professional judgment.

### **Generating Final Sedimentation Rate Raster**

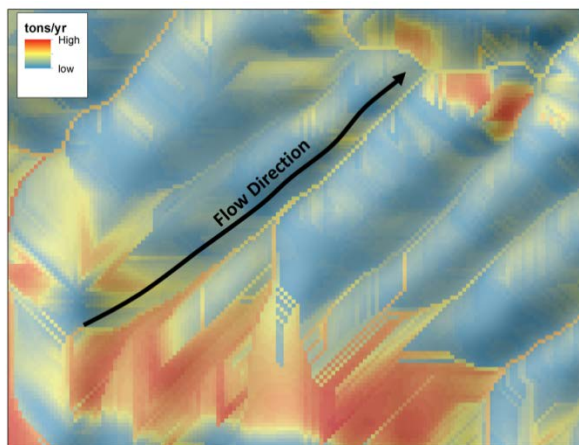
The final sedimentation rate models for the pre and post fire scenarios were generated by first multiplying the 5 factors, accumulating the multiplied values downslope via the flow direction raster, and calculating an area weighted sedimentation rate. The area weighted sedimentation rate is calculated by dividing the accumulated sedimentation rate by the total accumulated drainage area (Figure 9 and 10). This aspect approximates the transportation of sediment from areas where sediment originates (steep slopes or burned areas) to areas that dampen sediment transport due to decreases in slope, unburned areas or flow distance. This assumes that sediment yields decreases from source areas downslope as slope decreases and distance increase.

**Table 4:** C factors for common landcover that exist in most spatial landcover datasets.

<b>Land cover</b>	<b>C Factor</b>	<b>Citation</b>
Barren	1.0000	Toy and Foster 1998
Coniferous Forest	0.0020	Breiby 2006
Deciduous Forest	0.0010	Breiby 2006
Deciduous Shrubland	0.0250	Breiby 2006
Dense Grassland	0.0800	Dawen et al. 2003
Floodplain Forest	0.0100	Breiby 2006
Lowland Coniferous Forest	0.0025	Breiby 2006
Lowland Deciduous Forest	0.0015	Breiby 2006
Marsh/Riparian/Wetland	0.0010	Breiby 2006
Medium-tall grassland	0.0120	Breiby 2006
Mixed Forest	0.0010	Breiby 2006
Mixed Forest woodland	0.0020	Breiby 2006
Open Water/Exposed Rock	0.0000	Breiby 2006; McCuen 1998
Shrubland Other	0.0290	McQuen 1998
Snow field	0.0010	Dawen et al. 2003
Sparse Grassland	0.2000	Dawen et al. 2003
Aggregate mining	1.0000	Guobin et al. 2006
Asphalt	0.0001	Toy and Foster, 1998
Cultivated Crops Irrigated	0.2400	McCuen, 1998
Developed General	0.0030	Guobin et al. 2006
Developed Suburban	0.0020	Guobin et al. 2006
Developed Urban	0.0010	Guobin et al. 2006
Fallow	1.0000	McCuen, 1998
General Cropland	0.5000	Dawen et al., 2003
Gravel	0.2000	Toy and Foster, 1998
Industrial	0.0050	Guobin et al. 2006
Mixed Urban	0.0040	Guobin et al. 2006
Paddy field	0.1000	Dawen et al., 2003
Pasture Hay	0.1400	McCuen, 1998
Recreational Grasses	0.0080	McCuen, 1998
Small Grains	0.2300	McCuen, 1998



**Figure 9:** Conceptual diagram of how sediment yields are estimated at different positions on a hill slope by accumulating local sediment yields (many values to each zone brake) and then dividing by the accumulated area to compute the area weighted sediment yield at a given location.



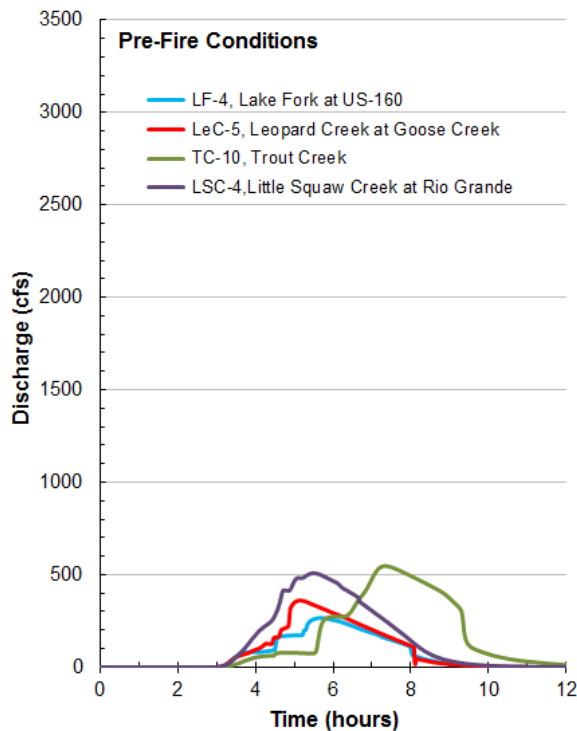
**Figure 10:** Example of area weighted RUSLE values for a drainageway. Notice that high loss areas (red) influence downslope areas but are dampened based on slope changes and travel distance. If for example, a hill slope with a high sediment yield is connected to a low yielding drainage way the sediment yields would be bumped to reflect the additional increase of sediment.

## RESULTS and DISCUSSION

The purpose of this modeling was to develop estimates of flood hazard and erosion potential due to the West Fork Complex Fire, to assist with evaluating potential threats to life and property along streams draining the fire area. These results are reasonable predictions for the determination of sufficiency of the current infrastructure for passing increased flood and sediment flows, as well as to assist with the design of new infrastructure. A summary of the runoff and sediment modeling results are provided in following sections. Results are illustrated in Appendix A (runoff) and Appendix B (sediment).

### Runoff Modeling

In many catchments, post fire conditions are predicted to cause a 50- or 100-year (pre-fire) flood to result from a 10-year rain event on burned landscapes, similar to actual measured fire runoff responses (Conedera et al. 2003). If it is assumed that the fire impacts on runoff in each of these catchments will be substantial for at least 5 years, the risk of a 10-year rain event over each individual point in these catchments over those 5 years of destabilization is 41 percent, with



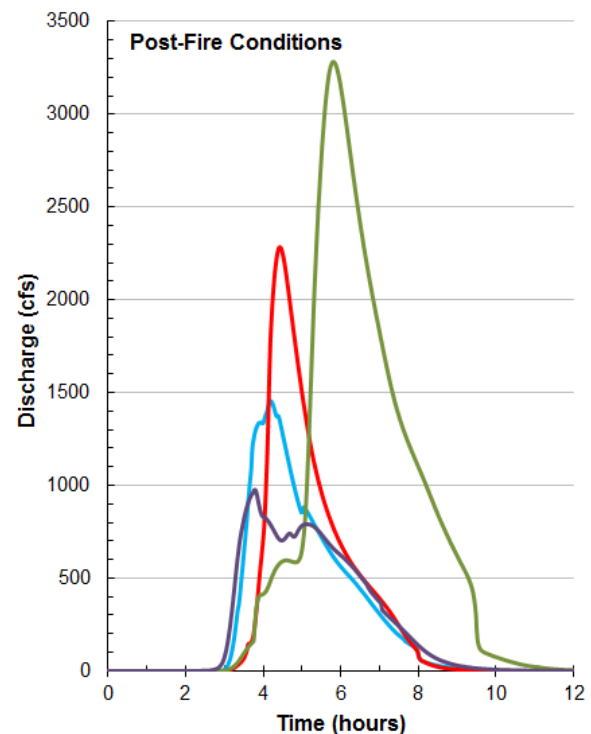
**Figure 11:** Selected pre-fire hydrographs, 10-year rain event.

resulting (pre-fire) 50- and 100-year floods. However, as catchment size increases the small spatial extent of typical convective storms will reduce the severity of the flood effects from these storms.

Peak flow predictions for the 25-year rainfall event are provided in the maps presented in Appendix A. Pre-fire and post-fire peak flows, estimates of the expected sediment-bulking flow, and post/pre fire peak flow ratios are presented for the 10-, 25-, 50-, and 100-year rain events (Tables 5 and 6). Soil burn severity is also shown on the mapping in Appendix A, along with modeled pour points and stream reaches.

### Example Hydrographs

Hydrographs are plots of flow versus time. For several key catchments draining the West Fork Complex Wildfire area, hydrographs are provided (Figures 11 and 12) that show the expected response to a 25-year rain event over each entire catchment for pre- and post- fire conditions. Substantially higher peak flows and flood volumes have been modeled for post-fire conditions.



**Figure 12:** Selected post-fire hydrographs, 10-year rain event.

**Table 5A:** Peak flow and time to peak estimates at pour points, for streams draining the West Fork Wildfire area. Bulking indicates estimated sediment bulking discharges. Refer to Appendix A mapping for point locations.

	Catchment or Pour Point	Drainage Area (mi <sup>2</sup> )	10-Year Rain Event				25-Year Rain Event			
			Predicted Peak Flow (cfs)			Post/Pre Flow	Predicted Peak Flow (cfs)			Post/Pre Flow
			Pre Fire	Post Fire	Bulking		Pre Fire	Post Fire	Bulking	
South Fork Rio Grande	HC-A	3.58	190	450	500	2.4	370	780	850	2.1
	HC-B	2.51	140	400	500	2.9	270	670	840	2.5
	HC-1	6.09	330	850	1100	2.6	630	1400	1800	2.3
	KC	1.53	48	460	580	9.6	100	650	820	6.3
	HC-2	10.20	430	1600	2100	3.9	860	2700	3300	3.1
	HC-3	11.04	450	1700	2200	3.8	910.0	2800	3500	3.1
	LF-1	3.34	52	91	91	1.8	140	210	210	1.5
	LF-2	6.27	59	300	380	5.1	170	510	630	3.0
	LF-3	9.50	83	870	1100	11	240	1400	1700	5.7
	LF-4	10.59	98	940	1200	10	270.0	1500	1800	5.5
	CbC-1	1.42	38	100	110	2.7	94.0	200	220	2.1
	DC-A	1.90	16	420	530	>15	44	610	760	>12
	DC-B	1.85	29	710	890	>15	77	1000	1200	>12
	DC-1	3.75	42	1100	1300	>15	110	1500	1900	>12
	DC-2	5.56	66	1100	1400	>15	170	1600	2100	9.8
	DC-3	6.63	90	1200	1500	13.1	210	1700	2200	8.2
TCE-1	3.28	15	400	500	>15	47.0	610	760	>12	
TCE-2	1.79	8.4	350	440	>15	26	510	640	>12	
TCE-3	8.06	83	870	1100	10	200	1300	1700	6.7	
Elk and Leopard Creeks	EC-1	3.19	19	420	530	>15	66	680	850	10.3
	EC-C	1.71	32	50	50	1.6	89	120	120	1.4
	EC-2	6.85	83	540	670	6.5	220	930	1200	4.2
	RG-1	2.18	9.1	290	360	>15	32	450	570	>12
	EC-3	12.22	150	890	1100	5.9	390	1500	1900	3.9
	LeC-1	2.99	8.7	340	420	>15	35	560	700	>12
	LeC-C	1.48	74	460	570	6.2	160	660	830	4.3
	LeC-2	6.45	78	970	1200	12.5	200	1500	1900	7.8
	LeC-3	9.16	96	1300	1600	13.7	270	2100	2600	7.9
	LeC-F	2.31	6.1	29	32	4.8	25	86	95	3.4
	LeC-4	13.29	110	1400	1700	12.0	330	2200	2800	6.7
LeC-5	14.26	130	1400	1700	10.8	360	2300	2900	6.3	
Upper Goose Creek	GC-1	3.83	120	150	150	1.2	280	330	330	1.2
	GC-C	2.94	28	78	86	2.8	82	190	210	2.3
	GC-2	10.83	180	700	760	3.9	450	1200	1400	2.7
	GC-3	14.49	240	910	1000	3.8	580	1600	1700	2.7
	GC-F	2.69	150	240	270	1.7	290	430	480	1.5
	GC-4	20.07	400	1300	1400	3.2	830	2100	2300	2.6
	FIC-1	6.05	73	73	73	1.0	190	190	190	1.0
	FIC-2	11.91	160	160	160	1.0	390	390	390	1.0
	GC-5	39.33	680	1600	1800	2.4	1400	2800	3100	1.9
	RF-1	6.15	27	27	27	1.0	84	84	84	1.0
GC-6	48.43	740	1600	1800	2.2	1600	2900	3200	1.9	
GC-7	0.96	54	390	480	7.1	120	550	690	4.5	
GC-8	50.81	740	1600	1800	2.2	1600	2900	3200	1.8	

**Table 5B:** Peak flow and time to peak estimates at pour points, for streams draining the West Fork Wildfire area. Bulking indicates estimated sediment bulking discharges. Refer to Appendix A mapping for point locations.

	Catchment or Pour Point	Drainage Area (mi <sup>2</sup> )	50-Year Rain Event				100-Year Rain Event			
			Predicted Peak Flow (cfs)			Post/Pre Flow	Predicted Peak Flow (cfs)			Post/Pre Flow
			Pre Fire	Post Fire	Bulking		Pre Fire	Post Fire	Bulking	
South Fork Rio Grande	HC-A	3.58	550	1100	1200	2.0	760	1400	1600	1.9
	HC-B	2.51	400	920	1200	2.3	560	1200	1500	2.1
	HC-1	6.09	940	2000	2500	2.1	1300	2600	3300	2.0
	KC	1.53	160	820	1000	5.0	240	1000	1200	4.2
	HC-2	10.20	1300	3600	4500	2.7	1900	4600	5800	2.5
	HC-3	11.04	1400	3800	4700	2.7	2000	4900	6100	2.5
	LF-1	3.34	240	340	340	1.4	360	500	500	1.4
	LF-2	6.27	310	660	820	2.1	500	940	1200	1.9
	LF-3	9.50	430	1800	2200	4.2	690	2300	2900	3.4
	LF-4	10.59	470	1900	2400	4.1	750	2500	3100	3.4
	CbC-1	1.42	160	300	330	1.9	240	420	460	1.8
	DC-A	1.90	81	770	970	9.6	130	960	1200	7.4
	DC-B	1.85	140	1200	1600	9.2	210	1500	1900	7.2
	DC-1	3.75	200	1900	2400	9.4	320	2300	2900	7.3
	DC-2	5.56	300	2100	2700	7.2	460	2600	3300	5.8
	DC-3	6.63	360	2300	2800	6.3	550	2900	3600	5.2
TCE-1	3.28	97	800	1000	8.2	170	1000	1300	5.9	
TCE-2	1.79	52	660	820	>10	90	820	1000	9.1	
TCE-3	8.06	350	1800	2200	5.1	530	2300	2900	4.3	
Elk and Leopard Creeks	EC-1	3.19	130	910	1100	6.9	220	1100	1400	5.3
	EC-C	1.71	150	200	200	1.3	230	290	290	1.3
	EC-2	6.85	410	1300	1600	3.2	590	1700	2100	2.9
	RG-1	2.18	64	600	750	9.4	110	750	940	7.0
	EC-3	12.22	650	2100	2700	3.3	970	2800	3500	2.9
	LeC-1	2.99	74	760	950	>10	140	960	1200	7.1
	LeC-C	1.48	240	840	1000	3.6	320	1000	1300	3.1
	LeC-2	6.45	350	2000	2500	5.8	520	2600	3200	4.9
	LeC-3	9.16	480	2800	3500	5.8	720	3500	4400	4.9
	LeC-F	2.31	53	150	170	2.8	95	230	260	2.4
Upper Goose Creek	LeC-4	13.29	610	3000	3800	5.0	930	3900	4900	4.2
	LeC-5	14.26	650	3100	3900	4.8	990	4000	5000	4.0
	GC-1	3.83	450	520	520	1.1	660	750	750	1.1
	GC-C	2.94	160	310	340	2.0	260	460	510	1.8
	GC-2	10.83	750	1700	1900	2.3	1100	2300	2500	2.0
	GC-3	14.49	940	2200	2400	2.4	1400	3000	3300	2.1
	GC-F	2.69	430	620	680	1.4	600	830	920	1.4
	GC-4	20.07	1300	3000	3300	2.4	1900	4000	4400	2.1
	FiC-1	6.05	330	330	330	1.0	500	500	500	1.0
	FiC-2	11.91	650	660	660	1.0	1000	1000	1000	1.0
	GC-5	39.33	2200	4000	4500	1.8	3300	5500	6000	1.7
	RF-1	6.15	170	170	170	1.0	290	290	290	1.0
GC-6	48.43	2400	4300	4700	1.8	3700	5900	6500	1.6	
GC-7	0.96	200	700	880	3.6	290	870	1100	3.1	
GC-8	50.81	2500	4200	4700	1.7	3700	5900	6500	1.6	

**Table 6A:** Peak flow and time to peak estimates at pour points, for streams draining the Papoose Wildfire area. Bulking indicates estimated sediment bulking discharges. Refer to Appendix A mapping for point locations.

	Catchment or Pour Point	Drainage Area (mi <sup>2</sup> )	10-Year Rain Event				25-Year Rain Event			
			Predicted Peak Flow (cfs)			Post/Pre Flow	Predicted Peak Flow (cfs)			Post/Pre Flow
			Pre Fire	Post Fire	Bulking		Pre Fire	Post Fire	Bulking	
Trout Creek	TC-A	3.99	21	65	72	3.1	85	220	240	2.6
	TC-B	1.60	12	62	68	5.2	49	170	190	3.5
	TC-1	5.59	32	120	130	3.7	130	370	410	2.9
	TC-2	9.30	37	570	710	>15	170	1100	1400	6.7
	TC-E	3.86	5.2	340	430	>15	38	620	770	>12
	TC-F	2.55	61	130	150	2.2	180	310	350	1.7
	TC-3	6.41	61	470	590	7.7	190	930	1200	4.9
	TC-4	23.34	100	1500	1800	14.3	440	2800	3500	6.4
	CC	3.01	4.5	21	23	5	31	75	83	2.4
	TC-5	28.19	110	1600	2000	14	500	3100	3800	6.2
TC-6	33.23	110	1700	2100	>15	530	3300	4100	6.2	
TC-J	0.65	1.2	110	140	93	7	200	240	>12	
TC-8	34.91	110	1700	2200	16	540	3300	4200	6.2	
TC-9	37.22	110	1800	2200	>15	550	3300	4200	6.1	
TC-10	38.60	110	1700	2200	15	550	3300	4100	6.0	
Upper Rio Grande	TxC-1	6.09	8.6	12	12	1.4	61	73	73	1.2
	TxC-2	9.89	22	67	74	3.0	120	210	230	1.7
	TxC-3	13.41	23	330	410	14	150	580	720	4.0
	TxC-4	14.40	23	380	470	>15	150	660	820	4.3
	LSC-1	5.55	58	62	62	1.1	200	210	210	1.1
	LSC-C	1.50	6.4	16	16	2.5	26	52	52	2.0
	LSC-2	12.02	100	150	170	1.5	360	490	540	1.4
	LSC-3	15.76	130	220	240	1.7	450	650	720	1.5
	LSC-4	17.73	150	520	570	3.4	510	980	1100	1.9
	LC-1	4.80	21	49	54	2.3	83	150	160	1.8
SC-1	2.89	17	66	73	3.9	62	170	190	2.8	

**Table 6B:** Peak flow and time to peak estimates at pour points, for streams draining the Papoose Wildfire area. Bulking indicates estimated sediment bulking discharges. Refer to Appendix A mapping for point locations.

Catchment or Pour Point	Drainage Area (mi <sup>2</sup> )	50-Year Rain Event				100-Year Rain Event				
		Predicted Peak Flow (cfs)			Post/Pre Flow	Predicted Peak Flow (cfs)			Post/Pre Flow	
		Pre Fire	Post Fire	Bulking		Pre Fire	Post Fire	Bulking		
Trout Creek	TC-A	3.99	210	430	480	2.1	410	760	830	1.8
	TC-B	1.60	110	310	340	2.7	220	500	550	2.3
	TC-1	5.59	310	710	780	2.3	620	1200	1300	1.9
	TC-2	9.30	410	1700	2100	4.1	840	2300	2900	2.8
	TC-E	3.86	98	910	1100	9.2	220	1300	1600	5.9
	TC-F	2.55	330	520	580	1.6	550	820	900	1.5
	TC-3	6.41	390	1400	1800	3.7	710	2100	2600	2.9
	TC-4	23.34	1000	4400	5500	4.4	1900	6400	8000	3.3
	CC	3.01	74	160	170	2.1	150	280	310	1.8
	TC-5	28.19	1100	4800	6000	4.2	2200	7000	8700	3.2
	TC-6	33.23	1200	5200	6500	4.3	2300	7600	9500	3.2
	TC-J	0.65	20	280	350	>10	49	390	490	7.9
	TC-8	34.91	1200	5200	6600	4.2	2400	7700	9600	3.2
TC-9	37.22	1300	5300	6600	4.2	2400	7700	9600	3.2	
TC-10	38.60	1300	5100	6400	4.0	2500	7400	9300	3.0	
Upper Rio Grande	TxC-1	6.09	140	160	160	1.1	280	310	310	1.1
	TxC-2	9.89	260	420	470	1.6	490	660	720	1.3
	TxC-3	13.41	320	820	1000	2.6	580	1200	1500	2.1
	TxC-4	14.40	330	940	1200	2.9	580	1300	1700	2.3
	LSC-1	5.55	410	430	430	1.1	740	770	770	1.0
	LSC-C	1.50	61	110	110	1.7	120	190	190	1.6
	LSC-2	12.02	750	950	1000	1.3	1300	1600	1800	1.2
	LSC-3	15.76	910	1200	1300	1.3	1600	2000	2100	1.2
	LSC-4	17.73	1000	1400	1500	1.4	1700	2200	2400	1.2
	LC-1	4.80	170	280	310	1.6	320	470	520	1.5
	SC-1	2.89	130	310	340	2.3	240	490	540	2.0

### ***Limitations in Modeling Accuracy***

As with all hydrologic modeling, the results provided by these simulations are approximate. Post fire runoff prediction using the CN technique is hampered by the very little available field data available to reliably select CN values from measured rainfall and runoff in burned catchments. Variability in the peak factor coefficient for the NRCS dimensionless unit hydrograph method further complicates this issue. Fundamentally, the reliability of the CN method for predicting peak flow from forested watersheds is questionable, due to questionable appropriateness of the CN method and shifting streamflow generation processes between and pre- and post-fire conditions.

Despite these shortcomings, the modeling performed for the West Fork Complex Wildfire area has substantial value for identifying areas of greatest threat to life, property and infrastructure. Peak flow ratios provide an excellent tool for communicating expected increases in runoff with agencies, first responders, and the public. These results are best used in a comparative manner, to help prioritize mitigation measures. Peak flow and runoff volume estimates are still required for sizing infrastructure improvements, though it needs to be understood that the use of these results in such a way is less dependable. Unknown uncertainties in the estimates needs to be effectively communicated to provide assurances that involved parties use the estimates with caution. Research and technical guidance is needed to develop and communicate more robust methods for flood prediction from wildfire-impacted landscapes.

### **Sediment Modeling**

The purpose of the sediment modeling is to provide estimated sediment magnification ratios at hydrologic pour points (Figure 2), as well as approximate sediment yield estimates. Sediment magnification ratios were calculated by taking the ratio between the predicted post- and pre-fire sediment flux values (tons/yr) to compute the magnitude of change. The true magnification ratios and quantities for the pre- and post-fire scenarios are unknown; these estimates are based on a lumped modeling approach (RUSLE) that provides values with substantial expected error.

However, these results do provide a reasonable framework for making management decisions.

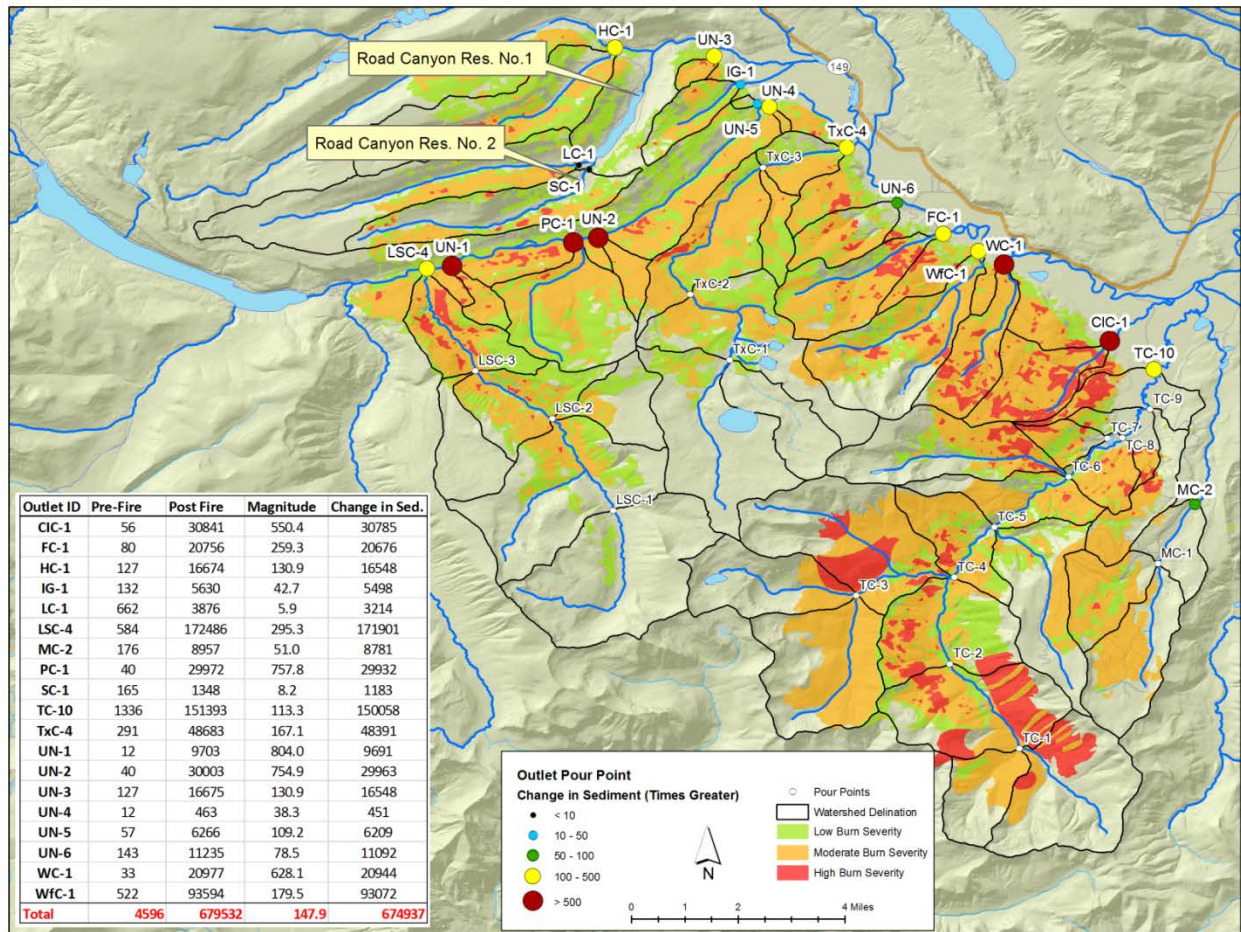
An overview of sediment magnification ratios is illustrated in the maps of Appendix B. The sedimentation analysis for the entire West Fork Complex Wildfire predicts that the Upper Rio Grande River will experience on average 130 times more sediment annually than pre-fire conditions (1,030,000 tons/yr). This is based on sediment rates estimated for the 27 outlet pour points (Figures 13 and 14) that are hydrologically connected to the burn area. These pour point estimates account for all sediment production and transport that occurs upstream of them. The Papoose Wildfire accounts for 65% of the total sediment yields in the West Fork Complex with 70% of its outlets having sediment magnification ratios greater than 100. The West Fork Wildfire area has lower sediment magnification ratios with 50% of its outlets having ratios higher than 100, but it has the highest yielding catchment (Hope Creek HC) which accounts for about 18% of the total sediment yield of the entire West Fork Fire Complex area.

The majority of sediment produced by the Papoose Wildfire area (Figure 13, Appendix B) is from two large catchments (Little Squaw Creek (LSC) and Trout Creek (TC)) which together account for about 50% of its total sediment yield. The other 17 outlet pour points don't account for as much sediment on an individual basis, but several (CIC-1, PC-1, UN-1, UN-2 and WC-1) have sedimentation magnification rates that exceed 500 times more sediment than pre-fire conditions. These catchments are small, but have steep slopes with high proportions of moderate and high burn severities which could pose a mass movement risk. The pour points that make up Trout Creek (Table 8) all have sediment magnification ratios greater than 100 with TC-6 having the highest sedimentation rate. The Little Squaw Creek catchment of the Upper Rio Grande (Table 8) has magnification ratios that increase dramatically downstream with a large bump in sediment yield at the outlet point (LSC-4). The Texas Creek catchment has magnification ratios that increase up to the midpoint of the catchment (TxC-3) and then decreases to the outlet point with sediment yields still increasing steadily downstream. The Road Canyon Reservoirs No. 1

and No. 2 (Figure 13) are connected to the LC and SC catchments that have low magnification ratios (less than 10) but the reservoirs could receive 4400 and 1300 tons of sediment annually.

The majority of sediment produced by the West Fork Wildfire (Figure 14, Appendix B) is dominated by two catchments (Goose Creek GC, and Hope Creek HC) that together produce 75% of the its total sediment yields. The pour points

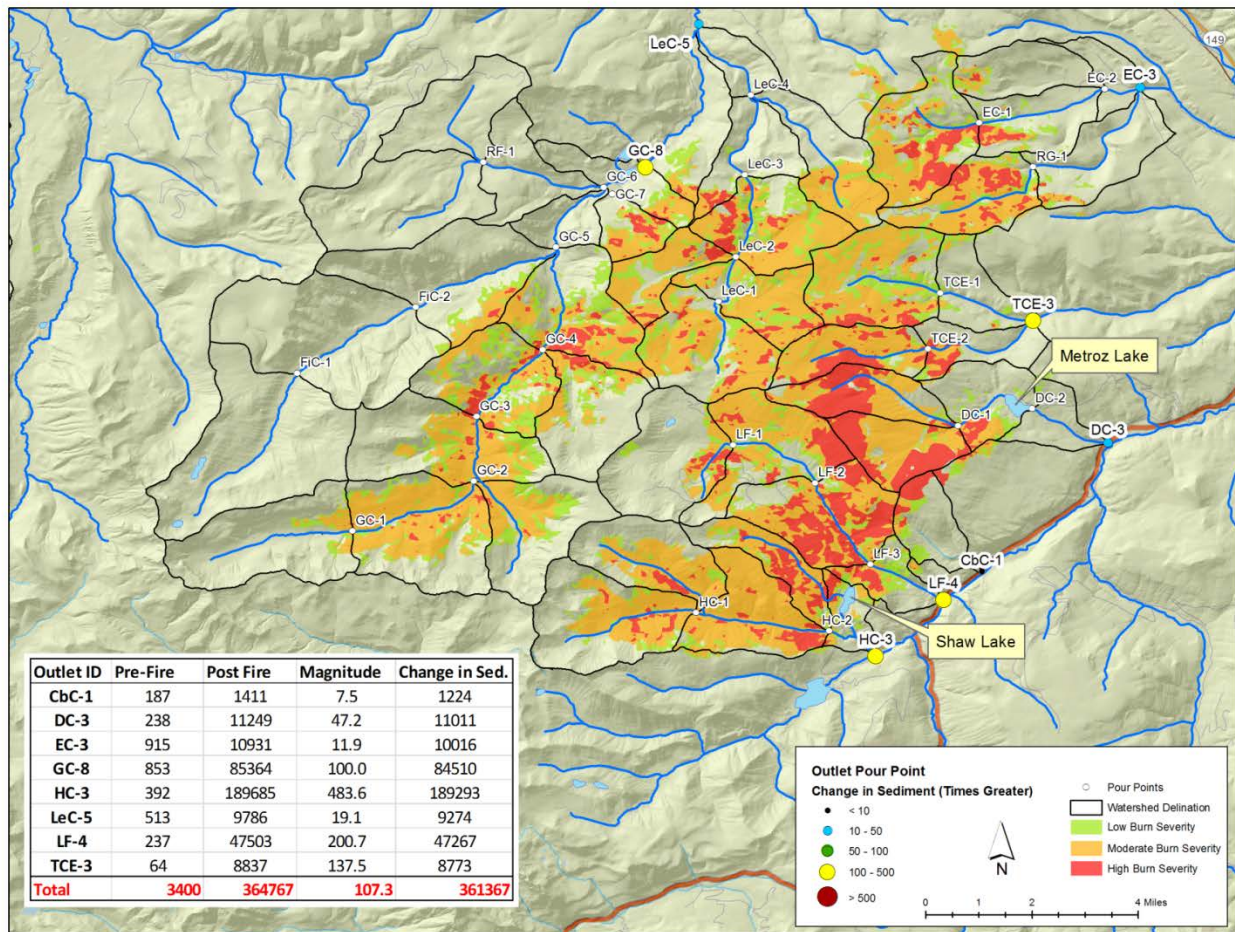
for Hope Creek (Table 7) predict that it will have sediment magnification ratios greater than 400 with a peak ratio of 605 at HC-2 and then dropping back to 483 at the outlet. This catchment along with LF-4, CbC-1 and DC-3 connect to the South Fork of the Rio Grande River which will increase its sediment yield by 250,000 tons annually.



**Figure 13:** Map of the Papoose Wildfire area with BARC burn severity classes and pour point outlets symbolized based on sedimentation rates with inset table listing outlet pre-fire sediment yield, post fire sediment yield, sedimentation rate (magnitude), and change in sediment yield between pre- and post-fire conditions. The red total values are the sum of outlets, except for the magnitude field which is an average

The Goose Creek pour points (Table 7) predict that sediment magnification ratios and yields increase dramatically to pour point GC-4 and then the ratios decrease by half at the outlet pour point at Lake Humphreys, where a post-fire sediment yield of 85,400 tons/year was simulated. The other four outlets DC-3, TCE-3, EC-3 and Lec-5 have moderately low sediment magnification ratios, with a total yield of 390,000 tons/year. Within the West Fork Wildfire area there are two additional lakes (Figure 14) that are connected to high sediment yielding catchments that dampen sediment yields to the South Fork of

the Rio Grande River, but could be at risk of sediment related issues. These lakes (Shaw Lake and Metroz Lake) are predicted to have magnification ratios 354 and 124, with average annual sediment yields of 770 and 13,500 tons, respectively.



**Figure 14:** Map of the West Fork Wildfire area with BARC burn severity classes and pour point outlets symbolized based on sedimentation rates with inset table listing outlet pre-fire sediment yield, post fire sediment yield, sedimentation rate (magnitude), and change in sediment yield between pre and post fire. The red total values are the sum of outlets, except for the magnitude field which is an average.

**Table 7:** Sediment magnification ratios and yields for the pour point associated with the West Fork Wildfire. The highlighted rows are the outlet pour points of a catchment.

	Pour point ID	Pre-Fire Sediment Yield (ton/yr)	Post Fire Sediment Yield (ton/yr)	Sediment Magnification Ratio (post-fire / pre-fire)	Change in Sediment Yield (tons/yr)
South Fork Rio Grande	HC-1	242	108493	448.7	108251
	HC-2	318	192365	605.1	192047
	HC-3	392	189685	483.6	189293
	LF-1	101	11314	111.7	11213
	LF-2	144	14614	101.3	14470
	LF-3	147	45762	310.9	45615
	LF-4	237	47503	200.7	47267
	CbC-1	187	1411	7.5	1224
	DC-1	62	14739	237.1	14677
	DC-2	109	13286	122.2	13178
	DC-3	238	11249	47.2	11011
	TCE-1	31	3781	122.8	3750
	TCE-2	27	20611	767.5	20584
	TCE-3	64	8837	137.5	8773
	Elk and Leopard Creeks	EC-1	57	27072	476.7
EC-2		115	15173	132.2	15058
EC-3		915	10931	11.9	10016
LeC-1		34	6707	195.8	6673
LeC-2		40	7597	190.6	7558
LeC-3		55	13183	239.2	13128
LeC-4		210	10126	48.3	9916
LeC-5		513	9786	19.1	9274
Upper Goose Creek	GC-1	455	3302	7.3	2847
	GC-2	360	55861	155.4	55502
	GC-3	405	120026	296.2	119620
	GC-4	519	190335	366.6	189816
	GC-5	622	109712	176.3	109090
	GC-6	880	88907	101.0	88028
	GC-7	27	7331	267.7	7304
	GC-8	853	85364	100.0	84510
	FiC-1	120	120	1.0	0
	FiC-2	292	292	1.0	0
	RF-1	432	432	1.0	0

**Table 8:** Sedimentation rates and yields for pour points associated with the Papoose Wildfire burn area. The highlighted rows are the outlet pour points of a catchment.

	Pour Point ID	Pre-Fire Sediment Yield (Tons/yr)	Post Fire Sediment Yield (tons/yr)	Sediment Magnification Ratio (post-fire / pre-fire)	Change in Sediment (tons/yr)
Trout Creek	TC-1	320	32013	100.0	31692
	TC-2	394	98607	250.5	98213
	TC-3	286	71096	248.7	70810
	TC-4	517	122817	237.4	122300
	TC-5	574	128868	224.4	128294
	TC-6	774	166480	215.2	165706
	TC-7	19	6912	360.0	6893
	TC-8	814	164859	202.6	164045
	TC-9	875	155689	178.0	154814
	TC-10	1336	151393	113.3	150058
Upper Rio Grande	TxC-1	94	239	2.5	145
	TxC-2	85	10509	123.4	10424
	TxC-3	197	47391	240.9	47194
	TxC-4	291	48683	167.1	48391
	LSC-1	577	585	1.0	9
	LSC-2	420	39152	93.2	38732
	LSC-3	508	90839	178.7	90331
	LSC-4	584	172486	295.3	171901
	LC-1	662	3876	5.9	3214
	SC-1	165	1348	8.2	1183

## CONCLUSIONS

Using the NRCS Curve Number method, peak flow predictions were made for streams draining the West Fork Complex Wildfire area, for both pre-fire and post-fire conditions. Watershed maps for each modeled catchment were developed, illustrating pour points locations and results, modeled reaches, and soil burn severity. Tables with expected pre- and post-fire peak flows, sediment bulking flows, and post/pre fire peak flow ratios were also provided in the results section of this report. The specific modeling accuracy is unknown, though predictions are likely to be more accurate in smaller catchments and for less-frequent (deeper) rain events.

Using the ATREW spatial RUSLE method, sedimentation rates were estimated for pre-fire and post-fire conditions for the West Fork

Complex Fire burn area. The pre-fire and post-fire rasters were used to attribute the pour points. The outlet pour points predict sedimentation rates and yields that flow into the Upper Rio Grande River and into lakes associated with the West Fork Complex fire. Sediment rate and yield accuracy is unknown, but the change in magnitude of sediment rates between pre-fire and post-fire provides information that planners can use to make informed prioritization decisions.

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**APPENDIX A:** Predicted West Fork Complex Wildfire Flood Response for Individual Drainages

- South Fork Rio Grande
- Leopard (Lower Goose) and Elk Creeks
- Upper Goose Creek
- Trout Creek
- Upper Rio Grande

**APPENDIX B:** Predicted West Fork Complex Wildfire Sediment Yield Response for Individual Drainages

- South Fork Rio Grande
- Leopard (Lower Goose) and Elk Creeks
- Upper Goose Creek
- Trout Creek
- Upper Rio Grande