Hayden Pass Wildfire Hydrologic Analysis

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1. Introduction and Background

The Hayden Pass Wildfire started in the San Isabel National Forest (Fremont and Custer Counties, Colorado) about 20 miles southeast of Salida, Colorado on June 11, 2016, as shown in Figure 1. As of August 10, 2016, the U.S. Forest Service Pike and San Isabel National Forest's final posting of the Daily Update for the Hayden Pass Wildfire, the wildfire burned over 16,754 acres along the northeast face of the Sangre De Cristo Mountains extending into and beyond the headwaters of Big Cottonwood Creek within the Sangre De Cristo Wilderness. The Hayden Pass Wildfire burn area is bound by the Hayden Pass Road to the northwest and Lake Creek Road to the southeast. In the valley below the burn area, US Highway 50 runs east to west along the south bank of the Arkansas River. This report summarizes the hydrologic analysis for the Hayden Pass Wildfire burn area.

1.1 U.S. Forest Service Hayden Pass BAER Assessment Report Summary

The U.S. Forest Service released the Hayden Pass Post-Fire Burned Area Emergency Response (BAER) Assessment Report in August 2016. The report identifies the following critical values impacted by the Hayden Pass Wildfire:

- Human life, safety, and property
  - Increased risk for human life and safety within and downstream of the burned area as a result of increased flooding and debris flow potentials
  - Roads and recreation facilities including trails, bridges, water diversion/conveyance/storage infrastructure, campgrounds, and trailheads, and a fish barrier downstream of the burn area
  - Land survey monuments along the forest boundary
- Natural Resources
  - Public water supplies, source water areas, and water for agricultural uses.
  - Temporary loss of watershed hydrologic function
  - Water quality
  - Critical habitat for the threatened and endangered Colorado Greenback Cutthroat Trout
  - Recovery of native vegetation due to increased risk for establishment and/or spread of noxious weeds
- Cultural and Heritage Resources
  - Historic cabins and the historic Hayden Pass Road

The U.S. Forest Service report identified the burn area percentages based on land ownership and on 6th Field Hydrologic Unit Codes (HUC), as shown below in **Table 1** and **Table 2**.

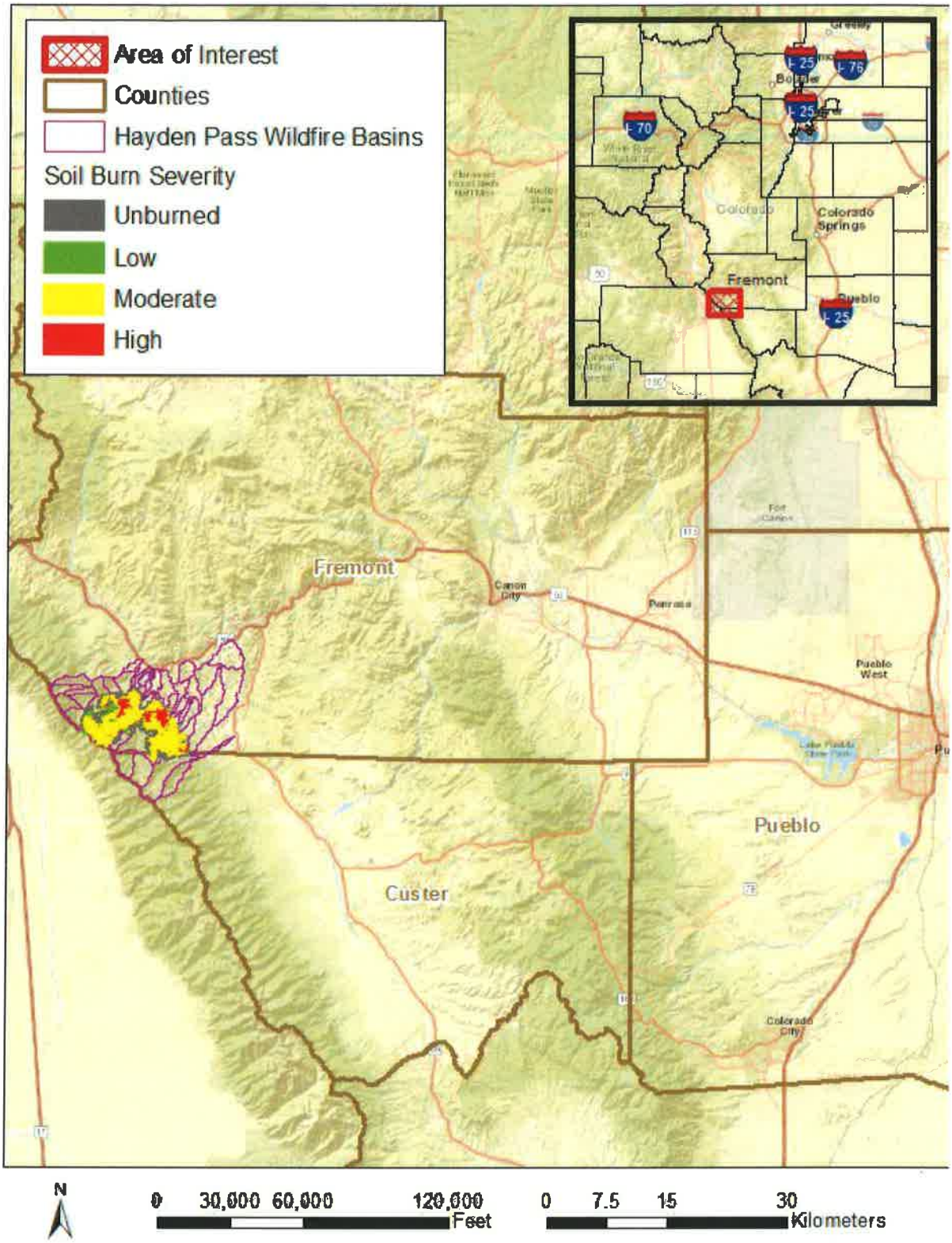


Figure 1 – Vicinity Map

Table 1: Percent Area Burned by Land Ownership

Land Ownership	Land Ownership	Percentage of Burned Area
U.S. Forest Service	15,065	91%
Bureau of Land Management	912	6%
State of Colorado	358	2%
Private	185	1%

Table 2: 6th Field Hydrologic Unit Code Watershed Burn Percentages

6th Field Sub-Watershed	HUC	Total Area (Acres)	Burned Area (Acres)	Percent Burned (%)
Hayden Creek	110200010905	14,130	4,567	32%
Hamilton Creek-Arkansas River	110200010907	15,774	1,259	8%
Big Cottonwood Creek	110200010906	15,723	7,305	46%
Falls Gulch	110200011403	24,748	3,140	13%
Middle Texas Creek	110200011003	19,734	210	1%
Sand Gulch	110200011404	12,455	31	0.2%

The majority of the U.S. Forest Service lands that were burned are managed by the Salida Ranger District of the Pike & San Isabel National Forests and the Cimarron & Comanche National Grasslands (PSICC). A small portion of the U.S. Forest Service lands that were burned, at the southern end of the fire, are managed by the San Carlos Ranger District.[1]

The Pole Gulch drainage basin within the Hamilton Creek-Arkansas River 6th field sub-watershed and the Oak Creek drainage basin within the Falls Gulch 6th field sub-watershed were delineated to evaluate the potential values at risk; consequently, eight drainage basins (i.e., Hayden Creek, Pole Gulch, Fox Canyon, Big Cottonwood Creek, Falls Gulch, Oak Creek, Sand Gulch, and Lake Creek) were initially considered in this analysis. Watersheds with less than 5% burned area (i.e., Sand Gulch, and Lake Creek) were excluded from this analysis; hence, only six drainage basins (i.e., Hayden Creek, Pole Gulch, Fox Canyon, Big Cottonwood Creek, Falls Gulch, and Oak Creek) were included in this analysis. The Sand Gulch and Lake Creek basins have 0.0% and 0.1% of high, 0.1% and 1% of moderate, 0.0% and 0.4% low burn severity areas, respectively. The low percentage of burned area, which was very close to 1%, was not classified

[1, 2] Hayden Pass Fire BAER Hydrology Report, U.S. Forest Service

as high severity burn for either the Sand Gulch or Lake Creek basins and in both cases the burn areas were located near the headwaters of the watersheds. Therefore, only minimal to no impacts are expected within the Sand Gulch and Lake Creek basins. All of these drainage basins are part of the larger Arkansas River watershed, and each basin was modeled separately within HEC-HMS to obtain peak flow rates for each respective basin.[2]

The BAER Team's Burn-Area Report[3] states "The soil burn severity (SBS) map shows approximately 74% burned at high and moderate soil burn severity. The rest of the fire was either low soil burn severity or unburned. Large contiguous areas of high and moderate soil burn severity occur throughout the burned area. Increased post fire soil erosion, runoff, and debris flows within and downstream from these areas are likely to cause flooding, scouring and/or deposition of materials."

"High intensity summer thundershowers are the precipitation events of primary concern. Based on historic precipitation patterns, thunderstorms are likely to occur in the weeks and months following the Hayden Pass Fire. The risk of flooding and erosional events has increased as a result of the fire, creating hazardous conditions within and downstream of the burned area."

1.2 Study Area Description

The Hayden Pass Wildfire burn area is primarily located in Fremont County, Colorado. A small portion of the burn area extends southward into Custer County, Colorado as shown in Error! Reference source not found.. The Hayden Pass Wildfire burn area transects the Hayden Creek, Pole Gulch, Fox Canyon, Big Cottonwood Creek, Falls Gulch, and Oak Creek drainage basins. All of the drainage basins outfall directly into the Arkansas River. US Highway 50 parallels the south bank of the Arkansas River; consequently, the downstream ends of all of these drainage basins intersect US Highway 50. Hayden Creek drains to the northeast towards Coaldale, Colorado. Oak Creek drains to the northeast towards Cotopaxi, Colorado.

The Sangre de Cristo Mountains to the south of Coaldale, Colorado contains the headwaters of the watersheds affected by the Hayden Pass Wildfire. Elevations range from over 13,500 feet in the headwaters to under 6,420 feet at watershed pour points along the Arkansas River as illustrated in Figure 2.

. Agricultural, mining, residential, commercial, and recreational development is light and widely dispersed throughout the watersheds. Land cover is illustrated in Error! Reference source not found..

"Forest cover types that are present across the burn area are spruce-fir, mixed conifer, aspen, lodgepole pine, pinon juniper and Gambel oak. Tree species represented on the landscape include: Ponderosa Pine (Pinus ponderosa), Douglas-fir (Pseudotsuga menziesii), Limber Pine (Pinus flexilis), Bristlecone pine (Pinus aristata), Lodgepole pine (Pinus contorta), White fir (Abies concolor), Sub-alpine fir (Abies lasiocarpa), Engelmann spruce (Picea engelmanii), Aspen (Populus tremuloides). Shrub species include Pinon pine (Pinus edulis), Juniper (Juniperus scopulorum), and Gambel Oak (Quercus gambelii)."[4]

[3] Hayden Pass Fire Burned-Area Report, USDA Forest Service
[4] Hayden Pass Fire BAER SPECIALIST REPORT - Forestry

A key topographic feature in the study area is the downslope, which extends from the Sangre de Cristo Mountain ridgeline northeastward to the middle of the watersheds that is characterized by densely-forested steep-sided canyons with sandy and gravelly loam soils. Although tabular and spatial data is not currently available for the soils in the Sangre de Cristo Wilderness (i.e., Sangre de Cristo Area, Colorado, Parts of Alamosa, Custer, Fremont, Huerfano, and Saguache Counties[5]), the following soil characteristics and geologic type descriptions were included in the *Summary of Findings* within the "*Soils Report for the Hayden Pass Fire, July 2016, San Isabel National Forest*"[6]:

"***Dominant Soils**: Leadville, Perfrin, Mollic Cryonoralfs-Lithic Cryoboralfs, Bowen, and Leighcan. Soils within the burn area generally have moderate and deep, well-drained, sandy loam and loamy-skeletal characteristics with a gravel and sand component. The granular, sand, and fine particle structure accommodates organic components concentrated at the surface layer. Soils are dominantly a sandy loam texture, containing more nutrients, moisture and humus in pre-fire and low burned conditions. Ground cover, critical for soil stabilization, is lacking throughout most areas mapped as moderate and high soil burn severity. These soils are sensitive to fire effects, and soil productivity is likely impacted where heavy surface fuels were consumed. High rates of erosion are expected in moderate and high burn soil severity where ground cover was burned."*

"***Geologic Types**: Marine Limestone – Minturn – Belden Formation, Arkosic Sandstone and Conglomerate – Sangre de Cristo Formation, Lahar, Soda Granite, Boulder Alluvium – Santa Fe Formation, Glacial Till, Slocum Alluvium, Bull Lake Deposits, Pinedale Deposits and Landslide Deposits. The geology in the area lends to pebble, cobble, and sandy soils, mixed with finer organic material. Landslide deposits, dated to the Holocene epoch (current geologic time period), are boulder and derived from bedrock with a hummocky surface."*

1.3 Study Objectives

Hydrologic analysis of the Hayden Pass Wildfire burn area is necessary to estimate the effects of the wildfire on the magnitude of flood frequency events. The study estimates the magnitude of flood events both pre-and post-wildfire for the Hayden Creek, Pole Gulch, Fox Canyon, Big Cottonwood Creek, Falls Gulch, and Oak Creek drainage basins. The Sand Gulch and Lake Creek drainage basins were not included in this analysis because less than 5% of these drainage basins were burned, and the burn severity was mostly classified as moderate to low. Therefore, little to no impact to peak flows are expected for Sand Gulch and Lake Creek basins. The study also identifies locations with elevated flood risk within the Hayden Pass Wildfire burn area.

[5] Sangre de Cristo Area, Colorado, Parts of Alamosa, Custer, Fremont, Huerfano, and Saguache Counties (CO634), NRCS Web Soil Survey

[6] Hayden Pass Fire BAER SPECIALIST REPORT - Soils

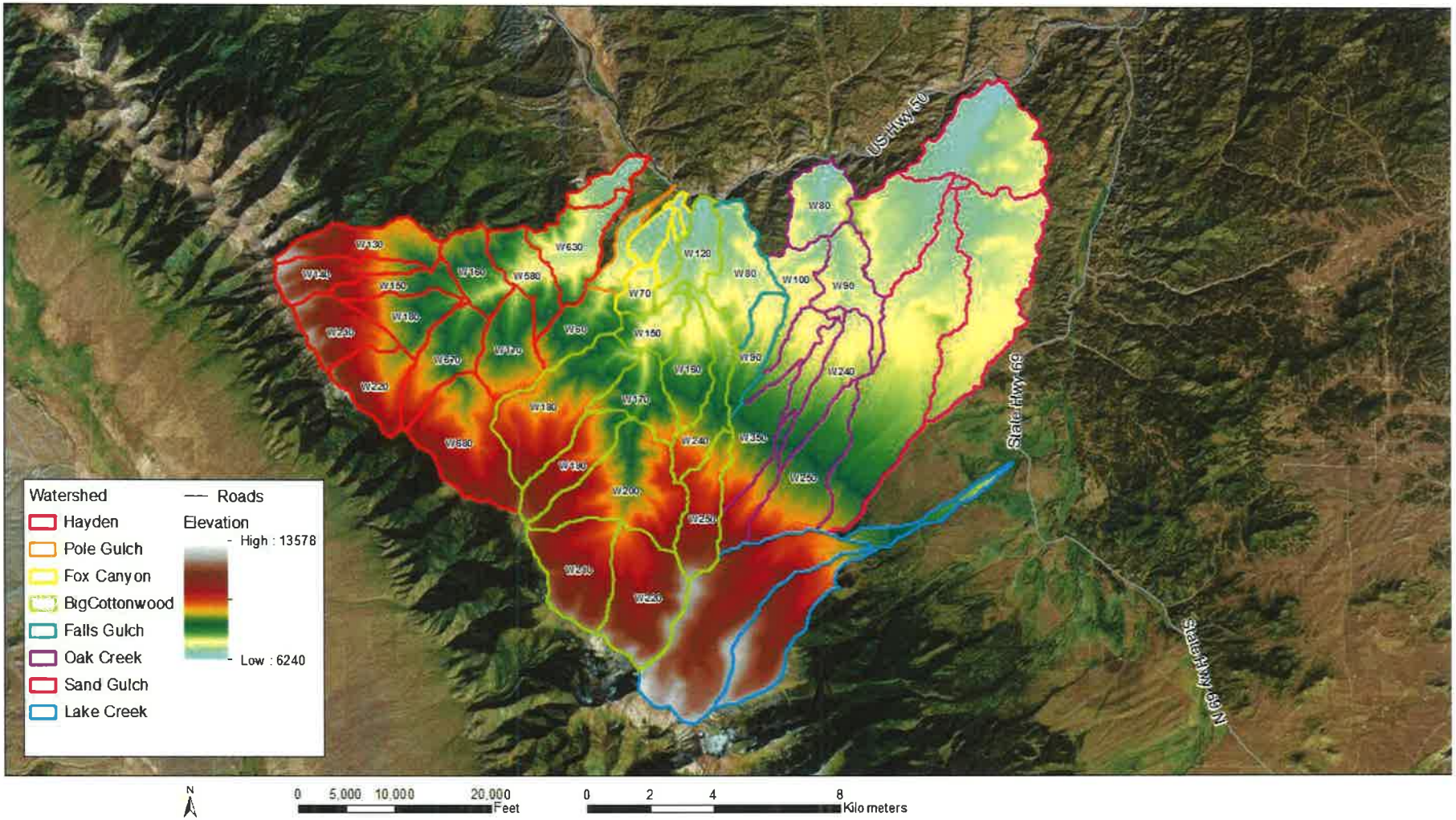


Figure 2 – Hayden Pass Watershed Elevations

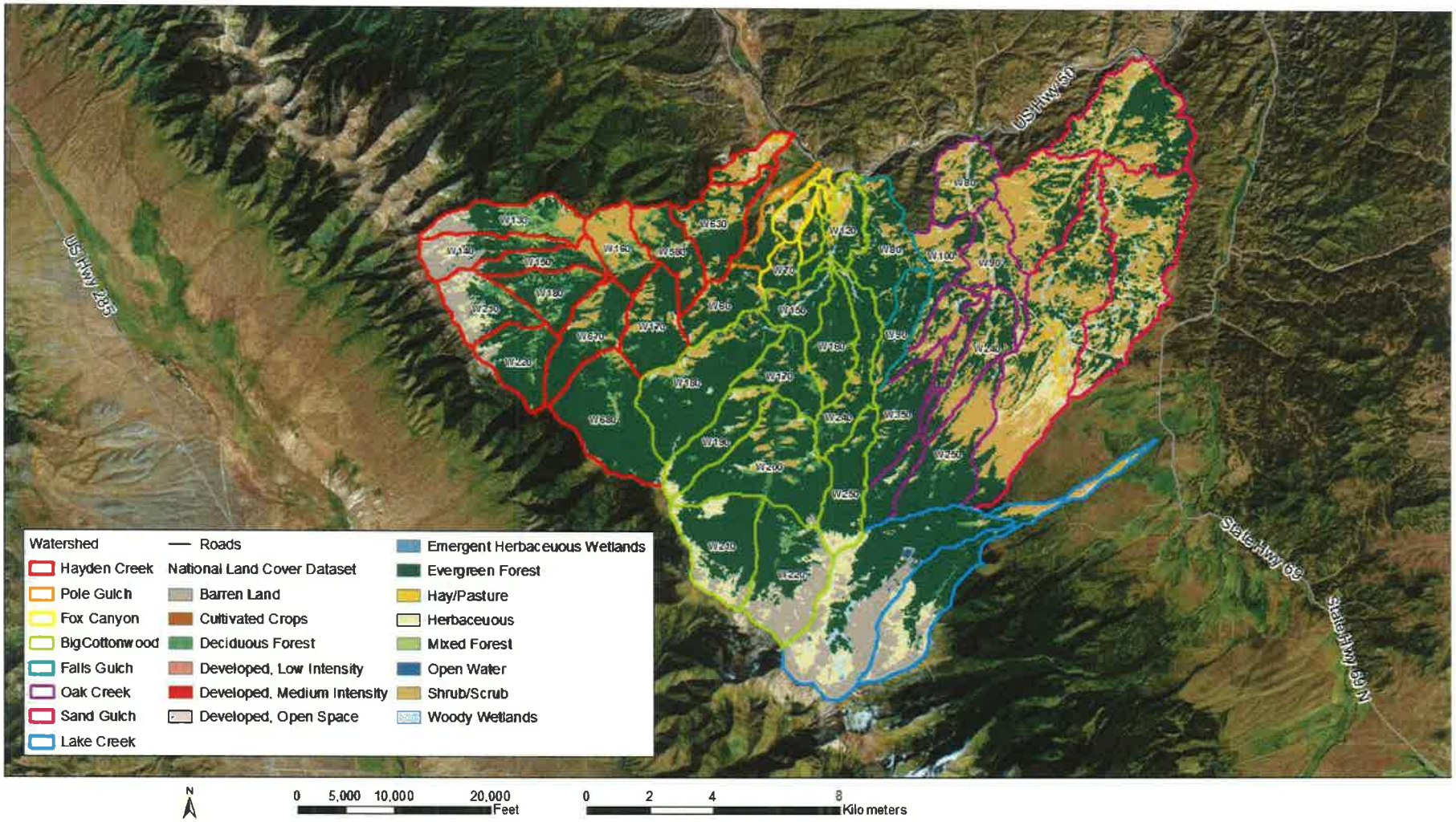


Figure 3 – United States Geological Survey Land Cover

2. Hydrologic Analysis

The hydrologic analysis was conducted using the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center (HEC) Hydrologic Modeling System (HMS) version 4.2 to numerically simulate the watershed. HEC-HMS simulates the precipitation-to-runoff process while accounting for storage (i.e. canopy and soil) and attenuation throughout a watershed. The watershed model contains multiple sub-basins that were delineated using HEC-GeoHMS version 10.2, along with other tools contained within the ArcGIS Spatial Analyst Toolbox. The HEC-GeoHMS tool was run within ESRI ArcGIS ArcMap Version 10.2. HEC-GeoHMS is a pre-processing tool specifically designed by USACE to aid in the delineation of watersheds and sub-basin parameters. ArcGIS was also utilized, with Microsoft Excel, to process and analyze the soils, national land cover dataset, and soil burn severity data.

2.1 Data Sources

Intermap Technologies, Inc. used Interferometric Synthetic Aperture Radar (IFSAR) in 2009 to create 5-meter grid cell resolution Digital Elevation Model (DEM). The topographic data was utilized for the hydrologic analysis for the Hayden Pass Wildfire burn area. Publically available U.S. Geological Survey (USGS) land cover and U.S. Department of Agriculture Natural Resources Conservation Service (NRCS) soils data were also utilized in the hydrologic analysis of the Hayden Pass Wildfire area. The national land cover dataset resolution is 30-meters and it was created in 2011 by the Multi-Resolution Land Characteristics (MRLC) Consortium. The Soil Survey Geographic (SSURGO) and Digital Soil Map of the U.S. (STATSGO2) data published in 2015 and 2016, respectively, were utilized to characterize the subbasin soils. SSURGO was the primary source of soils and the STATSGO2 dataset was used to supplement gaps in the SSURGO dataset.

2.2 Precipitation

Statistical frequency-based storms were used to simulate precipitation for the study area. National Oceanic and Atmospheric Administration (NOAA) Atlas 14 Volume 1 Version 5.0 point precipitation frequency estimates for the region were queried at the minimum and maximum elevations as well as the centroid of each watershed to determine precipitation variability. Precipitation depths varied less than 0.2 inches for all queried locations. Due to the lack of spatial variability, a single representative point located at the centroid of the Big Cottonwood Creek watershed was used for all precipitation inputs. The centroid coordinates of Big Cottonwood Creek Watershed are Latitude 38.2852° and Longitude -105.7594°. HEC-HMS meteorological models were created for each of the seven Annual Exceedance Probabilities (AEP) or recurrence intervals: 50%AEP (2 year), 20%AEP (5 year), 10%AEP (10 year), 4%AEP (25 year), 2%AEP (50 year), 1%AEP (100 year), 0.2%AEP (500 year) storm events. The rainfall totals used to generate the HEC-HMS meteorological model are shown in **Table 3**.

Table 3: Precipitation Estimates used in meteorological model

Duration	Precipitation Frequency Estimates (in)						
	50%	20%	10%	4%	2%	1%	0.2%
5-min:	0.25	0.29	0.35	0.45	0.55	0.67	1.02
15-min:	0.44	0.52	0.62	0.80	0.98	1.19	1.82
60-min:	0.79	0.92	1.07	1.38	1.67	2.02	3.05
2-hr:	0.94	1.09	1.28	1.62	1.96	2.36	3.55
3-hr:	1.01	1.18	1.37	1.73	2.07	2.48	3.66
6-hr:	1.18	1.39	1.61	1.99	2.34	2.74	3.88
12-hr:	1.45	1.73	1.99	2.40	2.77	3.17	4.26
24-hr:	1.78	2.12	2.43	2.90	3.30	3.72	4.84

2.3 Meteorological Model

The 'Frequency Storm' method was used to simulate the representative storm pattern for the watershed to reflect the probabilistic nature of the NOAA Atlas 14 precipitation estimates. This method also gives the modeler the ability to select an intensity position (25, 33, 50, 67 or 75%) in which the peak intensity or greatest incremental change in precipitation will occur. The position chosen by this analysis placed the largest incremental change in the 33% position to simulate the rapid and intense rainfall events that typically correspond with summertime monsoon weather. Monsoon storms typically occur between June and September, when most of the snow has already melted. Therefore, no rain on snow simulations have been included as part of this analysis. The storm duration analyzed in this study is 6 hours, using the 33% intensity position places the peak intensity at the 2.0-hour position. A storm duration of 6-hours was selected to simulate the short duration and high intensity nature of typical monsoon rainfall events.

Four sets of meteorological models were created for each flood recurrence interval to capture the varying sizes of the watersheds. Big Cottonwood Creek, Hayden Creek, and Oak Creek all populated the storm area fields to more accurately simulate precipitation falling over the entire watershed. The storm areas for Big Cottonwood Creek, Hayden Creek, and Oak Creek were 24.5, 22.2, and 13.9 square miles respectively. Populating the storm area allows HEC-HMS to automatically compute the depth-area reduction factor for precipitation simulations over large watersheds. All of the other watersheds do not have a total storm area populated because they were relatively small drainage areas ranging from 1.8 square miles to 3.4 square miles.

2.4 Soils

Sub-basins from the HEC-GeoHMS process were used along with the STATSGO2 and SSURGO soils datasets to determine the dominant hydrologic soil groups for each of the sub-basins illustrated in **Figure 4.** Hydrologic soil groups for **Table 4** below summarizes the analysis results for each of the sub-basins within each watershed. Dominant soil hydrologic groups are B and D for a majority of the area. Hydrologic soil group D soils are characterized as having low soil infiltration, whereas hydrologic group B soils have moderate infiltration. Rock outcrops exist within the study area, particularly in the watershed headwaters along the hydrologic soil group D areas. If additional information regarding the rock outcrop coverage for all the watersheds is acquired, a change to the percent impervious for the sub-basins should be applied.

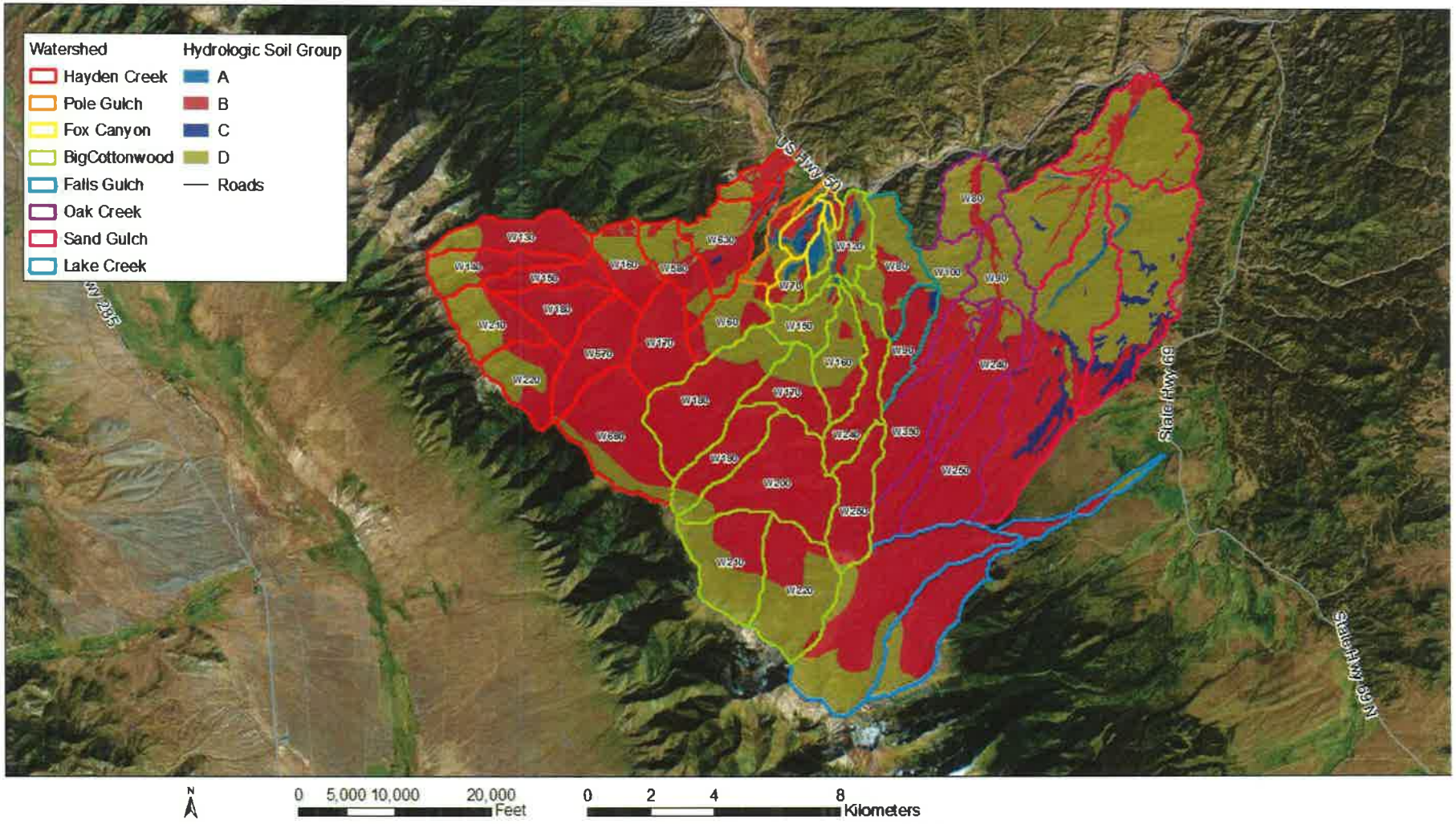


Figure 4 – Natural Resource Conservation Service Hydrologic Soil Groups

Table 4: Sub-basin Hydrologic Soil Group Composition

Sub-basin Name	Hydrologic Soil Group Composition (%)			
	A	**B**	**C**	**D**
Big Cottonwood Creek				
W120	24%	16%	0%	60%
W130	47%	4%	0%	49%
W150	1%	7%	0%	92%
W160	0%	34%	4%	62%
W170	0%	50%	17%	33%
W180	0%	58%	19%	23%
W190	2%	65%	24%	9%
W200	1%	67%	24%	8%
W210	9%	42%	25%	24%
W220	9%	42%	25%	24%
W240	0%	70%	8%	22%
W250	0%	70%	23%	7%
Falls Gulch				
W80	1%	32%	1%	66%
W90	0%	88%	5%	7%
Fox Canyon				
W70	11%	34%	0%	55%
W100	38%	52%	0%	10%
W120	57%	28%	5%	11%
W140	56%	10%	0%	33%
W160	62%	0%	0%	37%
Hayden Creek				
W130	3%	60%	23%	14%
W140	8%	47%	25%	21%
W150	0%	70%	24%	6%
W160	0%	44%	8%	48%
W170	0%	76%	18%	6%
W180	0%	70%	24%	6%
W190	0%	70%	24%	6%
W210	10%	41%	25%	25%
W220	7%	49%	24%	19%
W580	3%	37%	1%	58%
W620	25%	36%	0%	39%
W630	14%	32%	1%	53%
W670	0%	73%	20%	6%
W680	3%	60%	24%	12%
Oak Creek				
W100	0%	25%	0%	75%
W110	0%	53%	0%	47%
W240	2%	84%	1%	13%
W250	7%	85%	6%	2%
W290	0%	92%	0%	8%
W310	5%	72%	19%	5%
W340	0%	87%	0%	13%
W350	1%	86%	8%	5%
W80	5%	12%	0%	84%
W90	2%	18%	0%	80%
Pole Gulch				
W50	21%	38%	0%	41%
W60	0%	33%	4%	63%

2.5 Initial Loss, Constant Loss Rates, and Percent Impervious

Initial and constant loss rates were estimated using the Natural Resources Conservation Service (NRCS) Dominant Hydrologic Soil Groups which are shown in **Figure 4**. The watersheds in the study area are sparsely populated or open space and undeveloped and consist mainly of hydrologic soil groups B and D. Constant losses were estimated using Table 11 of the HEC-HMS Technical Reference Manual, which has been summarized below in **Table 5**.

Initial losses were estimated to be 0.5 inches based on Engineer Manual (EM) 1110-2-1417 Flood-Runoff Analysis. The manual states that research shows typical initial losses within forests range from 10-20% of total precipitation with a maximum of 0.5 inches. Precipitation within the study area for the 1% AEP (100-yr) 6-hour event is 2.7 inches, which corresponds to a range of 0.27 to 0.54 for initial losses. Since the maximum initial loss value is capped at 0.5 inches, 0.5 inches was selected as the initial loss value for all sub-basins in the study area.

Pre-wildfire initial loss, constant loss rates, and percent impervious were left unchanged for the post-wildfire simulations. Post-wildfire changes to losses within HEC-HMS were handled through canopy interception and surface detention losses. The burnt soils will become hydrophobic immediately following a wildfire, usually subsiding within one to two years. The initial loss, constant loss rates, and percent impervious values used in both the pre and post wildfire HEC-HMS simulations are included in **Table 6**.

Table 5: Soil Loss Rates Based on HEC-HMS Technical Reference Manual

Hydrologic Soil Group	Range of Loss Rates (in/hr)
A	0.30-0.45
B	0.15-0.30
C	0.05-0.15
D	0.00-0.05

Table 6: Pre-Wildfire and Post Wildfire Initial and Constant Loss Parameters

Basin Name	Initial Losses (in.)	Composite Infiltration Losses (in/hr)	% Impervious
Big Cottonwood Creek			
W120	0.5	0.14	6
W130	0.5	0.20	5
W150	0.5	0.04	9
W160	0.5	0.10	6
W170	0.5	0.14	3
W180	0.5	0.15	2
W190	0.5	0.18	1
W200	0.5	0.18	1
W210	0.5	0.16	2

W220	0.5	0.16	2
W240	0.5	0.17	2
W250	0.5	0.18	1
Falls Gulch			
W80	0.5	0.09	7
W90	0.5	0.20	1
Fox Canyon			
W100	0.5	0.26	1
W120	0.5	0.28	1
W140	0.5	0.24	3
W160	0.5	0.24	4
W70	0.5	0.13	5
Hayden			
W130	0.5	0.17	1
W140	0.5	0.16	2
W150	0.5	0.18	1
W160	0.5	0.12	5
W170	0.5	0.19	1
W180	0.5	0.18	1
W190	0.5	0.18	1
W210	0.5	0.16	2
W220	0.5	0.17	2
W580	0.5	0.11	6
W620	0.5	0.18	4
W630	0.5	0.14	5
W670	0.5	0.19	1
W680	0.5	0.17	1
Oak Creek			
W100	0.5	0.08	7
W110	0.5	0.13	5
W240	0.5	0.20	1
W250	0.5	0.22	0
W290	0.5	0.21	1
W310	0.5	0.20	0
W340	0.5	0.20	1
W350	0.5	0.21	1
W80	0.5	0.06	8
W90	0.5	0.07	8
Pole Gulch			
W50	0.5	0.17	4
W60	0.5	0.09	6

2.6 Canopy Interception and Depression Storage

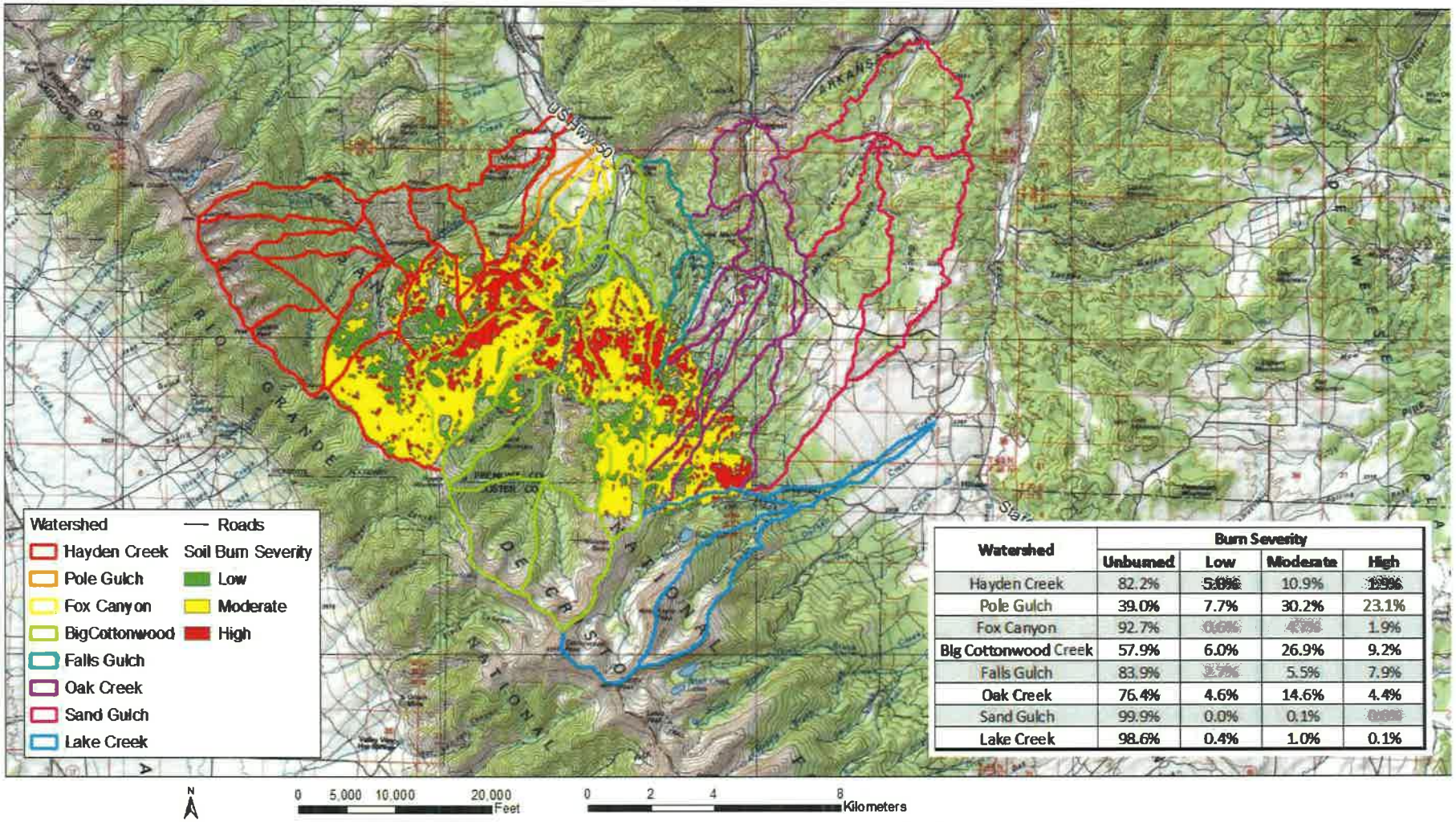
The USGS land cover dataset was used to estimate canopy interception and depression storage parameters based on the associated land cover of each basin. ArcGIS was used to compute the percent of land use coverage for each individual basin. Then each land use category in the USGS land cover dataset was associated with a canopy interception value and depression storage value. The initial canopy interception and depression storage value ranges were taken from Table 6-1 of the Engineer Manual (EM) 1110-2-1417 Flood-Runoff Analysis and are summarized in **Table 7** for each of the land use categories. Excel was used to compute a composite canopy interception or surface depression value based on the percent of land use coverage and associated loss value. The thick organic horizon layer was included in consideration when evaluating the surface detention values and correlating land use with loss values.

Post-Fire canopy interception and depression storage parameters were estimated based on Burned Area Emergency Response (BAER) soil burn severity maps for each of the watersheds. The soils burn severity maps are included below as **Figure 5** through **Figure 13**. ArcGIS was utilized to determine each sub-basins burn severity percentage relating specifically within four categories: unburned, low, moderate and high soil burn severity. Then the original canopy interception and surface depression values were reduced by the multipliers listed in Table 8.

All of the canopy interception and depression storage parameters for each sub-basin can be found in **Table 9**. As mentioned above the surface detention accounts for the thick organic horizon layer, which is why the multiplier is lower for lower soil burn severity.

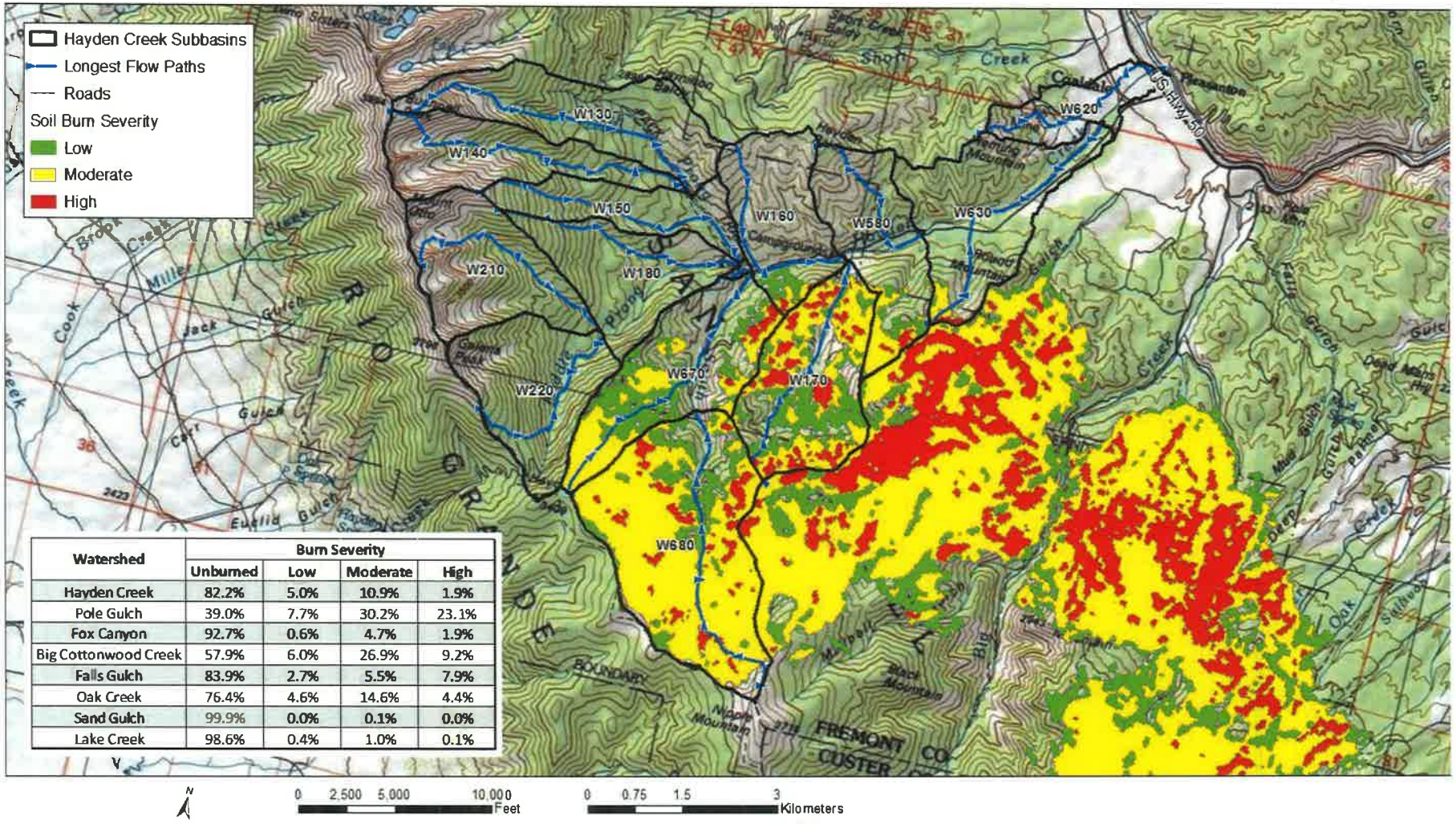
Table 7: USGS Land Use Categories and Associated Canopy Interception and Depression Storage Values

Land Use Category	Canopy Interception (in.)	Depression Storage (in.)
Developed, Open Space	0.10	0.50
Developed, Low Intensity	0.05	0.30
Developed, Medium Intensity	0.00	0.20
Barren Land	0.00	0.30
Deciduous Forest	0.40	1.20
Evergreen Forest	0.50	1.50
Mixed Forest	0.45	1.35
Shrub/ Scrub	0.15	1.00
Herbaceous	0.20	0.50
Hay/Pasture	0.25	0.80
Cultivated Crops	0.25	0.80
Woody Wetlands	0.30	1.00
Emergent Herbaceous Wetlands	0.25	0.60



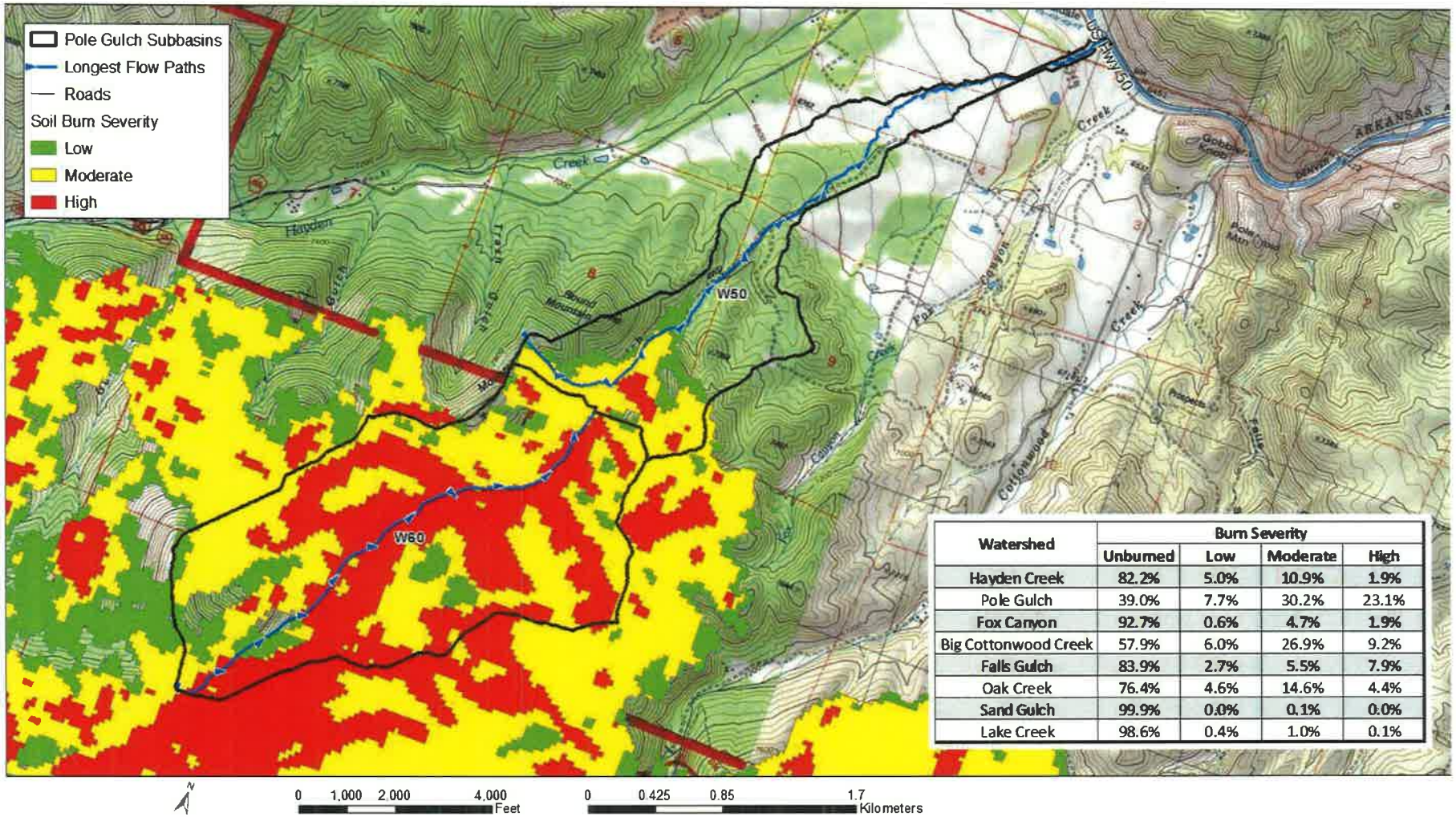
Watershed	Burn Severity			
	Unburned	Low	Moderate	High
Hayden Creek	82.2%	5.0%	10.9%	1.9%
Pole Gulch	39.0%	7.7%	30.2%	23.1%
Fox Canyon	92.7%	0.6%	4.7%	1.9%
Big Cottonwood Creek	57.9%	6.0%	26.9%	9.2%
Falls Gulch	83.9%	2.7%	5.5%	7.9%
Oak Creek	76.4%	4.6%	14.6%	4.4%
Sand Gulch	99.9%	0.0%	0.1%	0.0%
Lake Creek	98.6%	0.4%	1.0%	0.1%

Figure 5 – Hayden Pass Watersheds BAER Soil Burn Severity Map



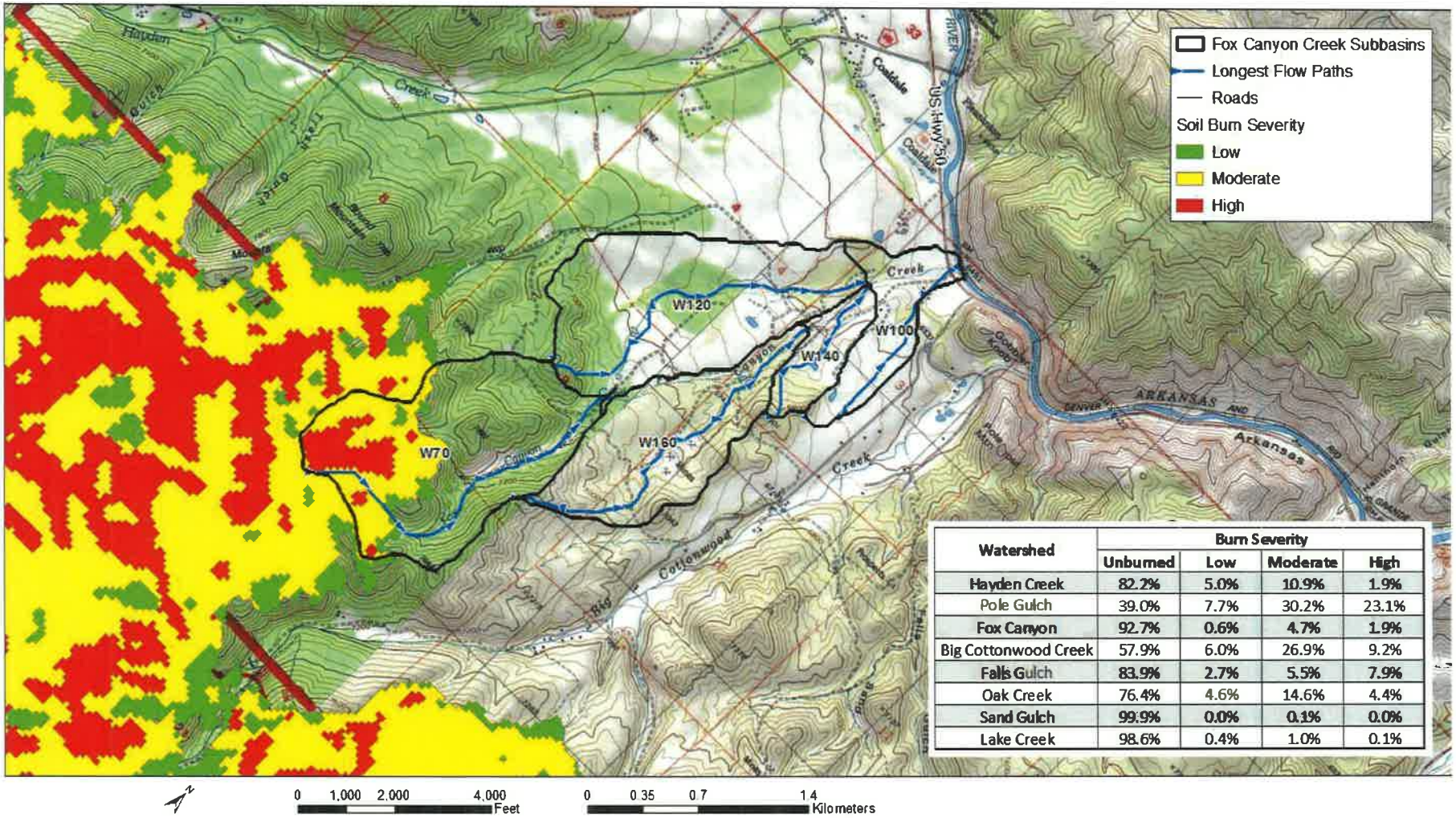
Watershed	Burn Severity			
	Unburned	Low	Moderate	High
Hayden Creek	82.2%	5.0%	10.9%	1.9%
Pole Gulch	39.0%	7.7%	30.2%	23.1%
Fox Canyon	92.7%	0.6%	4.7%	1.9%
Big Cottonwood Creek	57.9%	6.0%	26.9%	9.2%
Falls Gulch	83.9%	2.7%	5.5%	7.9%
Oak Creek	76.4%	4.6%	14.6%	4.4%
Sand Gulch	99.9%	0.0%	0.1%	0.0%
Lake Creek	98.6%	0.4%	1.0%	0.1%

Figure 6 – Hayden Creek BAER Soil Burn Severity Map



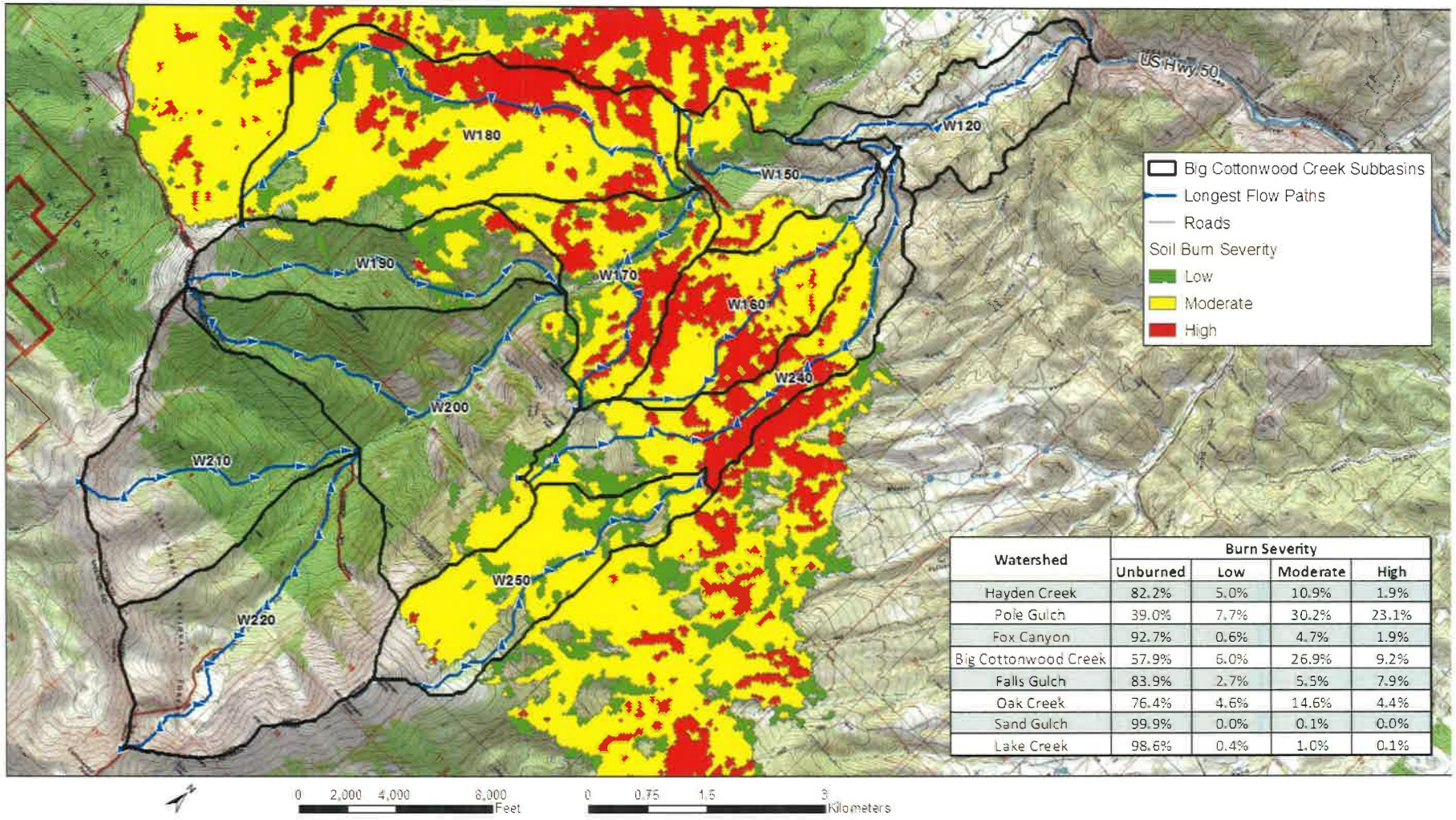
Watershed	Burn Severity			
	Unburned	Low	Moderate	High
Hayden Creek	82.2%	5.0%	10.9%	1.9%
Pole Gulch	39.0%	7.7%	30.2%	23.1%
Fox Canyon	92.7%	0.6%	4.7%	1.9%
Big Cottonwood Creek	57.9%	6.0%	26.9%	9.2%
Falls Gulch	83.9%	2.7%	5.5%	7.9%
Oak Creek	76.4%	4.6%	14.6%	4.4%
Sand Gulch	99.9%	0.0%	0.1%	0.0%
Lake Creek	98.6%	0.4%	1.0%	0.1%

Figure 7 – Pole Gulch BAER Soil Burn Severity Map



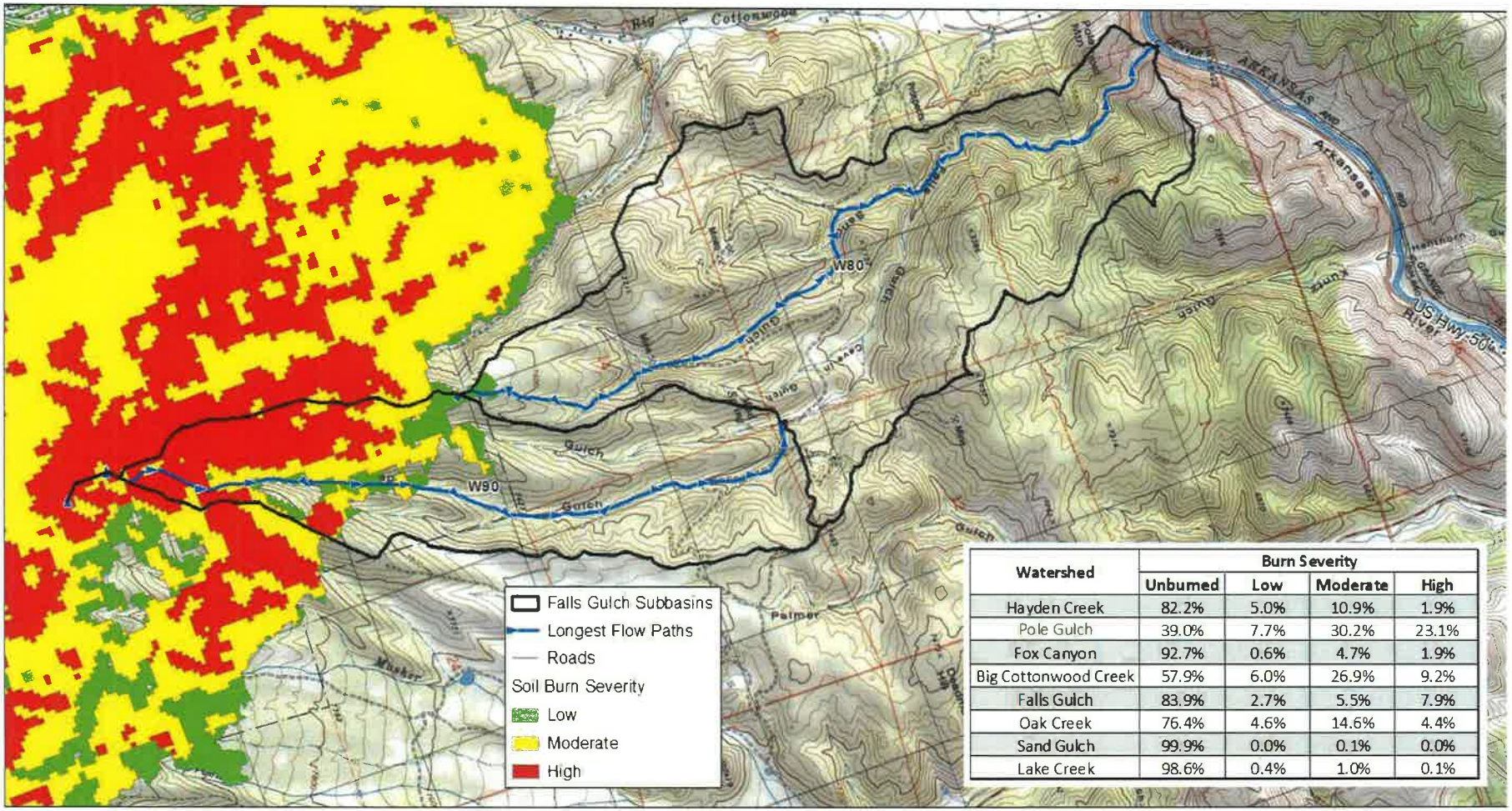
Watershed	Burn Severity			
	Unburned	Low	Moderate	High
Hayden Creek	82.2%	5.0%	10.9%	1.9%
Pole Gulch	39.0%	7.7%	30.2%	23.1%
Fox Canyon	92.7%	0.6%	4.7%	1.9%
Big Cottonwood Creek	57.9%	6.0%	26.9%	9.2%
Falls Gulch	83.9%	2.7%	5.5%	7.9%
Oak Creek	76.4%	4.6%	14.6%	4.4%
Sand Gulch	99.9%	0.0%	0.1%	0.0%
Lake Creek	98.6%	0.4%	1.0%	0.1%

Figure 8 – Fox Canyon BAER Soil Burn Severity Map



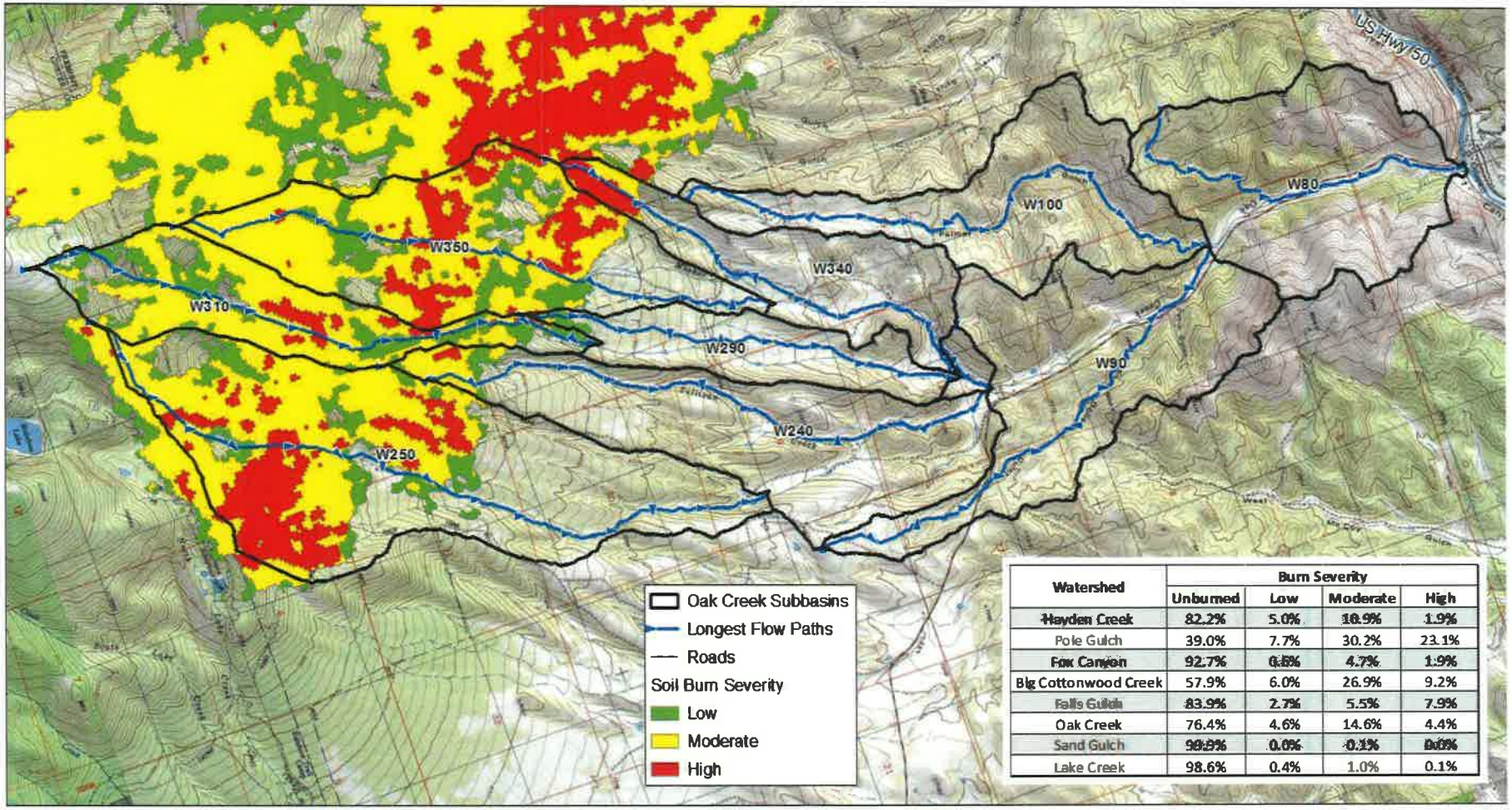
Watershed	Burn Severity			
	Unburned	Low	Moderate	High
Hayden Creek	82.2%	5.0%	10.9%	1.9%
Pole Gulch	39.0%	7.7%	30.2%	23.1%
Fox Canyon	92.7%	0.6%	4.7%	1.9%
Big Cottonwood Creek	57.9%	6.0%	26.9%	9.2%
Falls Gulch	83.9%	2.7%	5.5%	7.9%
Oak Creek	76.4%	4.6%	14.6%	4.4%
Sand Gulch	99.9%	0.0%	0.1%	0.0%
Lake Creek	98.6%	0.4%	1.0%	0.1%

Figure 9 – Big Cottonwood Creek BAER Soil Burn Severity Map



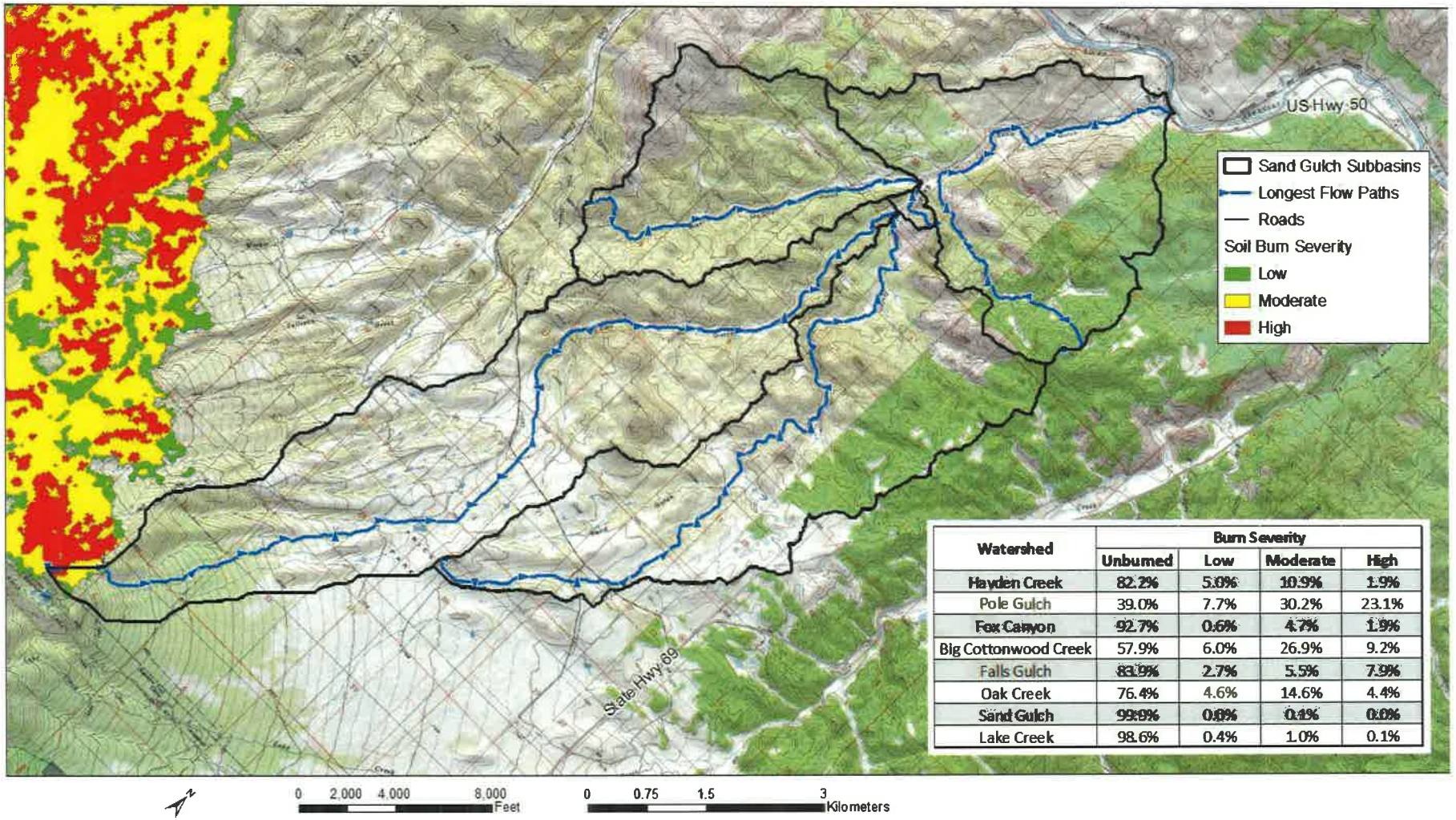
Watershed	Burn Severity			
	Unburned	Low	Moderate	High
Hayden Creek	82.2%	5.0%	10.9%	1.9%
Pole Gulch	39.0%	7.7%	30.2%	23.1%
Fox Canyon	92.7%	0.6%	4.7%	1.9%
Big Cottonwood Creek	57.9%	6.0%	26.9%	9.2%
Falls Gulch	83.9%	2.7%	5.5%	7.9%
Oak Creek	76.4%	4.6%	14.6%	4.4%
Sand Gulch	99.9%	0.0%	0.1%	0.0%
Lake Creek	98.6%	0.4%	1.0%	0.1%

Figure 10 – Falls Gulch BAER Soil Burn Severity Map



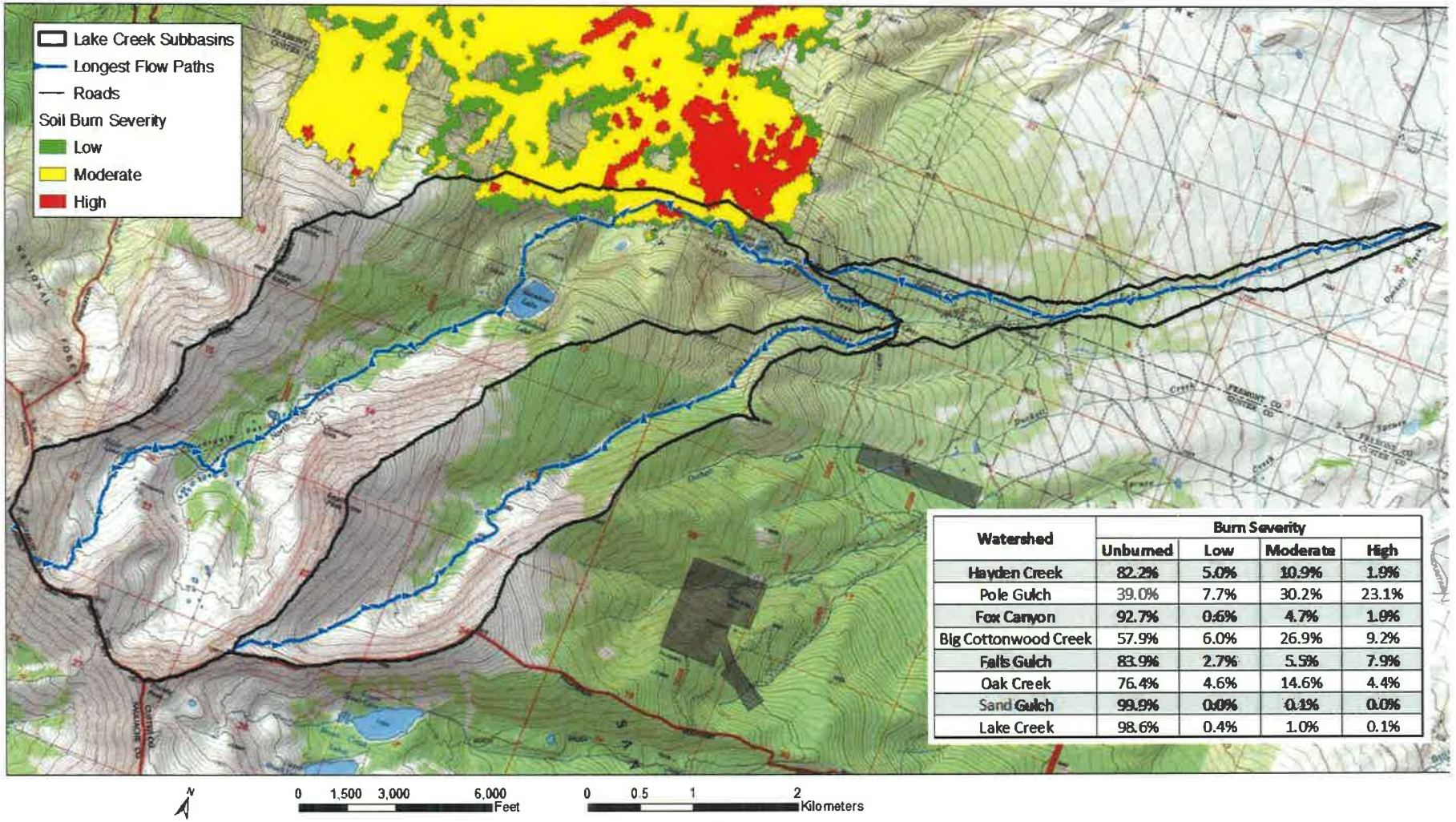
Watershed	Burn Severity			
	Unburned	Low	Moderate	High
Hayden Creek	82.2%	5.0%	10.9%	1.9%
Pole Gulch	39.0%	7.7%	30.2%	23.1%
Fox Canyon	92.7%	0.5%	4.7%	1.9%
Big Cottonwood Creek	57.9%	6.0%	26.9%	9.2%
Falls Gulch	83.9%	2.7%	5.5%	7.9%
Oak Creek	76.4%	4.6%	14.6%	4.4%
Sand Gulch	99.8%	0.0%	0.1%	0.0%
Lake Creek	98.6%	0.4%	1.0%	0.1%

Figure 11 – Oak Creek BAER Soil Burn Severity Map



Watershed	Burn Severity			
	Unburned	Low	Moderate	High
Hayden Creek	82.2%	5.0%	10.9%	1.9%
Pole Gulch	39.0%	7.7%	30.2%	23.1%
Fox Canyon	92.7%	0.6%	4.7%	1.9%
Big Cottonwood Creek	57.9%	6.0%	26.9%	9.2%
Falls Gulch	83.9%	2.7%	5.5%	7.9%
Oak Creek	76.4%	4.6%	14.6%	4.4%
Sand Gulch	99.9%	0.0%	0.1%	0.0%
Lake Creek	98.6%	0.4%	1.0%	0.1%

Figure 12 – Sand Gulch BAER Soil Burn Severity Map



Watershed	Burn Severity			
	Unburned	Low	Moderate	High
Hayden Creek	82.2%	5.0%	10.9%	1.9%
Pole Gulch	39.0%	7.7%	30.2%	23.1%
Fox Canyon	92.7%	0.6%	4.7%	1.9%
Big Cottonwood Creek	57.9%	6.0%	26.9%	9.2%
Falls Gulch	83.9%	2.7%	5.5%	7.9%
Oak Creek	76.4%	4.6%	14.6%	4.4%
Sand Gulch	99.9%	0.0%	0.1%	0.0%
Lake Creek	98.6%	0.4%	1.0%	0.1%

Figure 13 – Lake Creek BAER Soil Burn Severity Map

Table 8: Post Wildfire Burn Severity Multipliers

	Burn Severity Multiplier			
Loss Value	Low	Moderate	High	Unburned
Canopy	0.99	0.75	0.10	1.00
Surface	0.90	0.50	0.10	1.00

Table 9: Pre and Post-Wildfire Canopy Interception and Storage Depression Parameters

Basin Name	Fire Burn Intensity %				Canopy Interception (in.)		Surface Detention (in.)	
	Low	Moderate	High	Unburned	Pre-Fire	Post-Fire	Pre-Fire	Post-Fire
Big Cottonwood Creek								
W120	0%	0%	0%	100%	0.38	0.38	0.90	0.90
W130	0%	0%	0%	100%	0.35	0.35	0.75	0.75
W150	6%	30%	5%	59%	0.46	0.40	1.28	1.02
W160	1%	61%	31%	7%	0.47	0.27	1.37	0.56
W170	13%	51%	28%	8%	0.46	0.28	1.21	0.58
W180	11%	63%	21%	6%	0.45	0.30	1.25	0.61
W190	13%	11%	2%	74%	0.44	0.42	1.20	1.09
W200	4%	6%	0%	90%	0.44	0.44	1.15	1.11
W210	0%	0%	0%	100%	0.38	0.38	1.00	1.00
W220	0%	0%	0%	100%	0.29	0.29	0.72	0.72
W240	10%	40%	21%	28%	0.46	0.32	1.26	0.75
W250	14%	61%	1%	24%	0.45	0.38	1.26	0.85
Falls Gulch								
W80	0%	0%	0%	100%	0.41	0.41	1.37	1.37
W90	5%	11%	16%	68%	0.46	0.38	1.43	1.14
Fox Canyon								
W100	0%	0%	0%	100%	0.25	0.25	0.20	0.20
W120	0%	0%	0%	100%	0.32	0.32	0.50	0.50
W140	0%	0%	0%	100%	0.34	0.34	0.60	0.60
W160	0%	0%	0%	100%	0.43	0.43	0.90	0.90
W70	3%	24%	10%	64%	0.45	0.39	0.98	0.78
Hayden								
W130	0%	0%	0%	100%	0.34	0.34	0.53	0.53
W140	0%	0%	0%	100%	0.24	0.24	0.53	0.53
W150	0%	0%	0%	100%	0.43	0.43	1.01	1.01

W160	5%	3%	1%	91%	0.28	0.27	0.40	0.38
W170	24%	39%	13%	24%	0.44	0.35	1.21	0.80
W180	0%	0%	0%	100%	0.47	0.47	1.10	1.10
W190	0%	0%	0%	100%	0.48	0.48	1.35	1.35
W210	0%	0%	0%	100%	0.26	0.26	0.51	0.51
W220	0%	0%	0%	100%	0.45	0.45	1.19	1.19
W580	5%	12%	1%	82%	0.39	0.38	0.94	0.87
W620	0%	0%	0%	100%	0.25	0.25	0.34	0.34
W630	1%	3%	1%	96%	0.39	0.38	1.00	0.98
W670	22%	28%	2%	48%	0.45	0.41	1.17	0.96
W680	12%	69%	8%	11%	0.48	0.37	1.36	0.78
Oak Creek								
W100	0%	0%	0%	100%	0.31	0.31	0.66	0.66
W110	0%	0%	0%	100%	0.34	0.34	0.71	0.71
W240	1%	5%	0%	94%	0.34	0.34	0.78	0.76
W250	8%	33%	15%	44%	0.39	0.30	0.97	0.67
W290	2%	1%	0%	97%	0.37	0.36	0.89	0.88
W310	22%	55%	6%	18%	0.48	0.38	1.34	0.88
W340	0%	4%	6%	90%	0.33	0.31	0.72	0.66
W350	13%	50%	16%	21%	0.45	0.33	1.28	0.76
W80	0%	0%	0%	100%	0.28	0.28	0.55	0.55
W90	0%	0%	0%	100%	0.28	0.28	0.53	0.53
Pole Gulch								
W50	7%	16%	3%	75%	0.40	0.38	1.04	0.93
W60	9%	44%	44%	3%	0.43	0.21	1.18	0.44

2.7 Unit Hydrograph Transform Method

The Clark unit hydrograph method was used in HEC-HMS as the transform method. Hydrologic parameter guidelines provided by the State of Colorado Dam Safety Bureau in 2008 found that the Clark Unit hydrograph was an acceptable method for the Rocky Mountains and the Great Plains. The Clark transform method requires two inputs to translate precipitation Time of Concentration (T_c) and the Storage Coefficient (R) for the Rocky Mountain, and Great Plains areas. The time of concentration is defined as the amount of time it takes for a flood wave to travel from the most hydraulically distant point in the basin to the outlet of the basin. The storage coefficient is used to relate the basin runoff storage to the unit hydrograph shape.

The time of concentration equation is:

$$T_c = 2.4A^{0.1}L^{0.25}{L_{ca}}^{0.25}S^{-0.2}$$

where, A – basin area in square miles; L – longest flowpath from the outlet to the most hydraulically distant point in the basin in miles; Lca – length measured along the longest flowpath from the outlet to a point along the longest flowpath that is perpendicular to the basin centroid in miles; and S – longest flowpath slope in feet per mile. This results in a time of concentration in hours.

The storage coefficient equation is:

$$R = 0.37T_c^{1.11}L^{0.80}A^{-0.57}$$

where, the variables are the same as for the time of concentration and the storage coefficient is reported in hours. Transform values were consistent for both pre and post wildfire simulations and are summarized in **Table 10**.

Table 10: Clark Unit Hydrograph Transform Parameters

Basin Name	Time of Concentration Tc (hrs)	Storage Coefficient R (hrs)
Big Cottonwood Creek		
W120	1.08	0.839
W130	0.26	0.242
W150	0.78	0.496
W160	1.04	0.771
W170	0.79	0.470
W180	1.36	0.930
W190	0.99	0.738
W200	1.07	0.560
W210	0.87	0.381
W220	1.01	0.509
W240	1.32	1.272
W250	1.01	0.748
Falls Gulch		
W80	1.30	0.898
W90	1.01	0.833
Fox Canyon		
W70	0.62	0.429
W100	0.49	0.472
W120	0.70	0.487
W140	0.40	0.397
W160	0.67	0.602
Hayden		
W130	0.91	0.655

W140	0.99	0.820
W150	0.84	0.730
W160	0.92	0.550
W170	0.89	0.490
W180	0.78	0.487
W190	0.20	0.225
W210	0.82	0.479
W220	0.68	0.318
W580	0.61	0.280
W620	0.87	0.768
W630	1.08	0.668
W670	0.92	0.568
W680	1.00	0.483
Oak Creek		
W100	1.23	1.154
W110	0.33	0.298
W240	1.19	0.974
W250	1.26	0.899
W290	0.95	0.960
W310	1.00	0.997
W340	1.00	0.922
W350	1.08	0.817
W80	0.97	0.552
W90	1.13	0.790
Pole Gulch		
W50	1.07	1.154
W60	0.78	0.420

2.8 Reach Routing Parameter Methods

Muskingum-Cunge routing was selected as the routing method for flood simulations. With the Muskingum-Cunge method several cross-section representations can be selected and assigned to each individual routing reach. All of the routing reaches utilize the 8-point cross section. ArcGIS was utilized to cut cross sections from the IFSAR data at key representative locations within each of the watersheds. One cross section was cut per watershed since each routing reach within a watershed was relatively similar based on aerial imagery and topography. The cross sections used are included in Appendix A. The routing parameters of each reach are shown in **Table 11**. No post-wildfire adjustments were made to the reach routing parameters based on the assumption that any potential decrease in roughness as a result of burned areas may be offset by the presence of additional in-channel sediment and debris.

Reach length and slope were determined from the terrain model. Channel Manning's n coefficients of 0.040 and 0.050, and Left Bank/Right Bank Manning's n coefficients of 0.080 and 0.100 were used to represent the simulated reaches. All reaches within the Fox Canyon Watershed and R10 in the Big Cottonwood Creek watershed were assigned Manning's n coefficients of 0.040 for the main channel and 0.080 for the left and right banks to simulate the flatter terrain with less forest vegetation in the overbanks.

Table 11: Muskingum-Cunge 8-Point Reach Routing Parameters

Watershed	Reach	Length (FT)	Slope (FT/FT)	Channel Manning's n	L.B./R.B. Manning's n
Hayden Creek	R110	8,571	0.0840	0.050	0.100
Hayden Creek	R30	5,881	0.0250	0.050	0.100
Hayden Creek	R40	4,576	0.1048	0.050	0.100
Hayden Creek	R50	853	0.0664	0.050	0.100
Hayden Creek	R590	4,780	0.0431	0.050	0.100
Hayden Creek	R60	5,190	0.0603	0.050	0.100
Hayden Creek	R650	12,229	0.0386	0.050	0.100
Hayden Creek	R90	9,429	0.1061	0.050	0.100
Pole Gulch	R10	14,655	0.0592	0.050	0.100
Fox Canyon	R110	2,354	0.0314	0.040	0.080
Fox Canyon	R130	6,458	0.0565	0.040	0.080
Fox Canyon	R150	1,709	0.0540	0.040	0.080
Big Cottonwood Creek	R10	11,218	0.0381	0.040	0.080
Big Cottonwood Creek	R20	1,142	0.0439	0.050	0.100
Big Cottonwood Creek	R40	8,367	0.0503	0.050	0.100
Big Cottonwood Creek	R60	7,845	0.0698	0.050	0.100
Big Cottonwood Creek	R80	18,154	0.0893	0.050	0.100
Big Cottonwood Creek	R90	11,750	0.1029	0.050	0.100
Falls Gulch	R10	13,568	0.0485	0.050	0.100
Oak Creek	R10	9,182	0.0338	0.050	0.100
Oak Creek	R30	8,574	0.0398	0.050	0.100
Oak Creek	R300	11,690	0.0714	0.050	0.100
Oak Creek	R40	1,074	0.0483	0.050	0.100
Oak Creek	R60	7,228	0.0585	0.050	0.100
Oak Creek	R70	8,112	0.0607	0.050	0.100

2.9 Computation Interval

A time interval of 5 minutes was selected for the control specifications. The simulation was run for 48 hours to ensure the complete hydrographs routed through the entire watersheds.

$$Q_{0.2} = 10^{-2.04} A^{0.95} P^{2.02}$$

$$Q_{0.1} = 10^{-1.55} A^{0.93} P^{1.80}$$

$$Q_{0.04} = 10^{-1.01} A^{0.91} P^{1.55}$$

$$Q_{0.02} = 10^{-0.66} A^{0.89} P^{1.39}$$

$$Q_{0.01} = 10^{-0.19} A^{0.87} P^{1.17}$$

$$Q_{0.005} = 10^{-0.03} A^{0.86} P^{1.11}$$

$$Q_{0.002} = 10^{-0.52} A^{0.84} P^{0.85}$$

where, $Q_{0.5}$ = Peak flow for annual exceedance probability of 0.5, similar to other annual exceedance probabilities (ft^3/s), A = Drainage area (mi^2), P = Mean annual precipitation (in)

3.3 USGS Regression Equation Results

USGS regression equation discharge estimates for the affected Hayden Pass Wildfire watersheds are shown in **Table 12**. The results were acquired using StreamStats 4.0 and are included in Appendix B. Peak flow values are split when using StreamStats 4.0 based on percent coverage for watersheds that were within both the Rio Grande and Foothills regions. For example, Big Cottonwood Creek watershed is split 37% to 63% between the Foothills and Rio Grande Regions respectively, and the peak flow is computed using the entire watershed size before the percent coverage is applied.

The 0.01 AEP USGS Regression peak flowrates for Big Cottonwood Creek were 806 cfs and 297 cfs for the Foothills and Rio Grande Regions respectively and once the 37% and 63% reductions are applied results in peak flowrates of 298 cfs and 187 cfs for the Foothilss and Rio Grande Regions respectively, resulting in a total peak flowrate of 485 cfs. Note that the estimates are for an un-burned watershed condition as the regression equations do not have a separate variable to account for burned conditions.

Regional regression equations come with limitations and standard errors. Standard error of predictions (SEP) are reported in the generalized-least square (GLS) and weighted least-square regional regression analyses as outlined in the USGS reports. SEP measures the GLS regression model's prediction of annual exceedance probability (AEP) discharge at ungagged sites. The SEP within the Foothills region ranges from 80 to 117 percent with a mean SEP of 92 percent for the eight annual exceedance probabilities. SEP for the Rio Grande region ranges from 51 to 67 percent with a mean SEP of 55 percent for the eight annual exceedance probabilities. Less frequent events have a higher standard error due to the lack of observed data and resulting extensive extrapolation.

Table 12: USGS Peak Discharges for all Watersheds Affected by the Hayden Pass Wildfire

Drainage Basin	Annual Exceedance Probability Peak Discharges (ft^3/s)							
	0.5 (50%)	0.2 (20%)	0.1 (10%)	0.04 (4%)	0.02 (2%)	0.01 (1%)	0.005 (0.5%)	0.002 (0.2%)
Big Cottonwood	50	111	171	269	357	485	593	833
Falls Gulch	24	58	91	143	191	249	313	410
Fox Canyon	15	37	59	93	123	160	201	263
Hayden Creek	49	114	177	281	374	504	625	862
Lake Creek	33	68	101	154	199	270	323	456
Oak Creek	53	124	192	305	406	533	670	887
Pole Gulch	18	43	67	106	141	183	230	302
Sand Gulch	81	193	303	485	651	855	1080	1430

4. HEC-HMS Results and Discussion

4.1 HEC-HMS Results

The pre-wildfire, post-wildfire, change in cubic feet per second and percent at each of the watershed outlets have been summarized in **Table 13**.

Table 13: HEC-HMS Pre and Post Wildfire Simulation Results

		Big Cottonwood Creek	Falls Gulch	Fox Canyon	Hayden Creek	Oak Creek	Pole Gulch
0.5 AEP (2 year)	Pre-Wildfire (cfs)	95	32	17	90	82	36
	Post-Wildfire (cfs)	104	32	18	94	83	47
	Change (cfs)	9	0	1	4	0	12
	Change (%)	9	0	8	4	0	33
0.2 AEP (5 year)	Pre-Wildfire (cfs)	126	41	23	119	103	46
	Post-Wildfire (cfs)	135	41	24	123	104	57
	Change (cfs)	9	0	1	4	0	11
	Change (%)	7	0	6	3	0	24
0.1 AEP (10 year)	Pre-Wildfire (cfs)	161	52	38	153	128	59
	Post-Wildfire (cfs)	170	52	40	157	128	148
	Change (cfs)	10	0	2	4	0	90
	Change (%)	6	0	5	3	0	153
0.04 AEP (25 year)	Pre-Wildfire (cfs)	228	71	129	710	525	82
	Post-Wildfire (cfs)	464	71	131	717	526	479
	Change (cfs)	236	0	2	7	0	397
	Change (%)	104	0	2	1	0	486
0.02 AEP (50 year)	Pre-Wildfire (cfs)	624	89	305	1820	1172	103
	Post-Wildfire (cfs)	1610	89	327	1829	1453	806
	Change (cfs)	985	0	22	9	282	703
	Change (%)	158	0	7	1	24	682
0.01 AEP (100 year)	Pre-Wildfire (cfs)	1868	148	622	3747	2374	380
	Post-Wildfire (cfs)	4443	261	766	3795	3301	1276

	Change (cfs)	2575	113	144	48	927	896
	Change (%)	138	76	23	1	39	236
0.002 AEP (500 year)	Pre-Wildfire (cfs)	12858	1565	1935	14940	7590	1738
	Post-Wildfire (cfs)	15988	1764	2062	15264	8891	2661
	Change (cfs)	3130	199	127	324	1300	923
	Change (%)	24	13	7	2	17	53

4.2 HEC-HMS Model Parameter Variability Discussion

Vegetation recovery and stream geomorphology will affect the loss rates. Grass, shrub, and tree growth within the burn region will cause increased canopy and forest floor litter interception of rainfall for post-fire rainfall events, reducing the runoff from the basins into the channels. As the watersheds heal the parameters used in this HEC-HMS analysis should be re-evaluated for appropriateness, particularly within the burned areas. Additionally, high intensity storms in the first few years after a wildfire may cause rilling, gully formation, and channel widening. This process creates more efficient conveyance channels and increases sediment transport potential in some reaches, while simultaneously establishing reaches for sediment deposition with flatter slopes. Changes in geomorphology that are expected to occur within the affected watersheds are not captured in this HEC-HMS model, and consideration should be given to re-evaluating model parameters as changes to vegetation and geomorphology are observed.

4.3 Calibration

USGS stream gages within 75 miles of the Hayden Pass Wildfire in the Sangre de Cristo Mountains having drainage areas close to the size of the study area watersheds, and with more than 30 years of record were selected to determine regional trends in observed discharge. Two gages were discovered fitting the selection criteria. North Crestone Creek near Crestone, Co. (08227500) and Trinchera C AB Turners Ranch near Ft. Garland, Co. (08240500) with 12.9 and 52.7 square mile drainage areas and 45 and 58 years of record, respectively. Annual max monthly mean and monsoon mean discharge values were investigated. The Monsoon Mean Baseflow (Monsoon Mean) uses the mean values from May through August, the months with the highest regional flows. The Annual Max Monthly Baseflow (Monthly Max) is based on month with the highest mean flow. The means were plotted against basin area producing a linear regression used to fit the watershed simulated in HEC-HMS.

Simulated 0.5 AEP (50%) discharges from HEC-HMS should be roughly twice the values from the USGS Mean analysis. Column 7 in Table 14 shows the ratio of HEC-HMS 0.5 AEP to Monthly Max. Study watersheds, Big Cottonwood Creek, Hayden Creek, and Oak Creek are all within the discharge area limits of the regression analysis. The average HMS/Monthly Max ratio is 1.9 indicating a close calibration for high frequency flows.

Table 14: High Frequency Flow Calibration

Watershed	Total Area (mi^2)	Monsoon Mean (cfs)	Monthly Max (cfs)	HMS 0.5 AEP Flow (cfs)	HMS / Monsoon Mean	HMS / Monthly Max
1	2	3	4	5	6	7
Big Cottonwood Creek	25	31	51	95	3.0	1.9
Falls Gulch	3	18	32	32	1.7	1.0
Fox Canyon	2	18	30	17	1.0	0.6
Lake Creek	9	22	37	n/a	n/a	n/a
Hayden	22	30	49	90	3.0	1.8
Oak Creek	14	25	41	82	3.3	2.0
Pole Gulch	2	18	31	36	2.0	1.2
Sand Gulch	19	28	46	n/a	n/a	n/a

Stream stage and/or flow gauging for watersheds impacted by the Hayden Pass wildfire do not exist, therefore, no calibration data is available to verify the results of the HEC-HMS analysis or the USGS Regression Equations or to fully calibrate the HEC-HMS analysis. Therefore, while the HEC-HMS analysis incorporates considerations for soil infiltration, canopy interception, and surface detention and precipitation losses within the watershed the HEC-HMS analyses can differ from actual precipitation and runoff events.

As gage or indirect survey discharge and ecosystem recovery data is collected the HEC-HMS analysis should be calibrated to the observed data to improve simulation prediction error. Events more frequent than the 0.01 AEP should be calibrated separately as additional precipitation, vegetation, soil, and geomorphology data become available. The higher frequency flows will vary greatly during the first decade of watershed recovery. As the vegetation recovers and geomorphology evolves, model accuracy will benefit from current condition optimization.

5. Recommendations

5.1 Installation of Precipitation and Stream Gages

The USGS regression equations for the study area are statistical approximations with potential standard errors discussed in the USGS Regression section. The study area falls partially within the Rio Grande and the Foothills Regions as established by the USGS and is entirely on the eastern face of the Sangre de Cristo Mountains, which may contribute additional uncertainty. Installation of automated streamflow and precipitation gages with a planned operation of at least five years (preferably ten or more) will provide real-time reliable data with which the hydrologic model can be calibrated.

5.2 Sediment Monitoring

Sediment inflows towards the bridges and conduit locations are likely to increase. Routine monitoring of the watersheds and drainage structures after each significant rainfall event for the next five years is recommended. Monitoring and regular maintenance of the culverts and bridges will minimize the chance of structure overtopping or being bypassed.

5.3 Vegetation Monitoring

One of the most critical components of post-wildfire watershed recovery is vegetation development. Conducting bi-annual ground based ecosystem surveys combined with remotely sensed vegetation analysis (NVDI) using USDA National Agriculture Imagery Program (NAIP) as the data collected.

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APPENDIX D