Blue River Phase 1 Watershed Assessment

Prioritization of watershed-based hazards to water supplies

Report Prepared for:

USDA Forest Service

Rocky Mountain Region

Bark Beetle Incident

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INTRODUCTION

This Phase 1 Watershed Assessment is designed to be the first phase of a process to identify and prioritize sixth-level watersheds based upon their hazards of generating flooding, debris flows and increased sediment yields following wildfires that could have impacts on water supplies. It is intended to expand upon current wildfire hazard reduction efforts by including water supply watersheds as a community value. The watershed assessment follows the ranking procedure for each of the four integral components as prescribed by the Front Range Watershed Protection Data Refinement Work Group (2009).

This Phase 1 Watershed Assessment is one of 15 that are being completed for the Bark Beetle Incident team in the Rocky Mountain Region (Region 2) of the USDA Forest Service (Figure 1). The Bark Beetle Incident team covers the following three National Forests:

1. White River National Forest
2. Medicine Bow-Routt National Forests
3. Arapaho-Roosevelt National Forests

Phase 2 of the Watershed Assessment process would be to gather the key water supply stakeholders to communicate the suggested process, show them the results of Phase 1, listen to any suggested changes, make appropriate changes and build collaborative support for the assessment process. The stakeholder process is critical to local support for the results of the assessment, and the effectiveness of implementing recommendations that would come out of the assessment process.

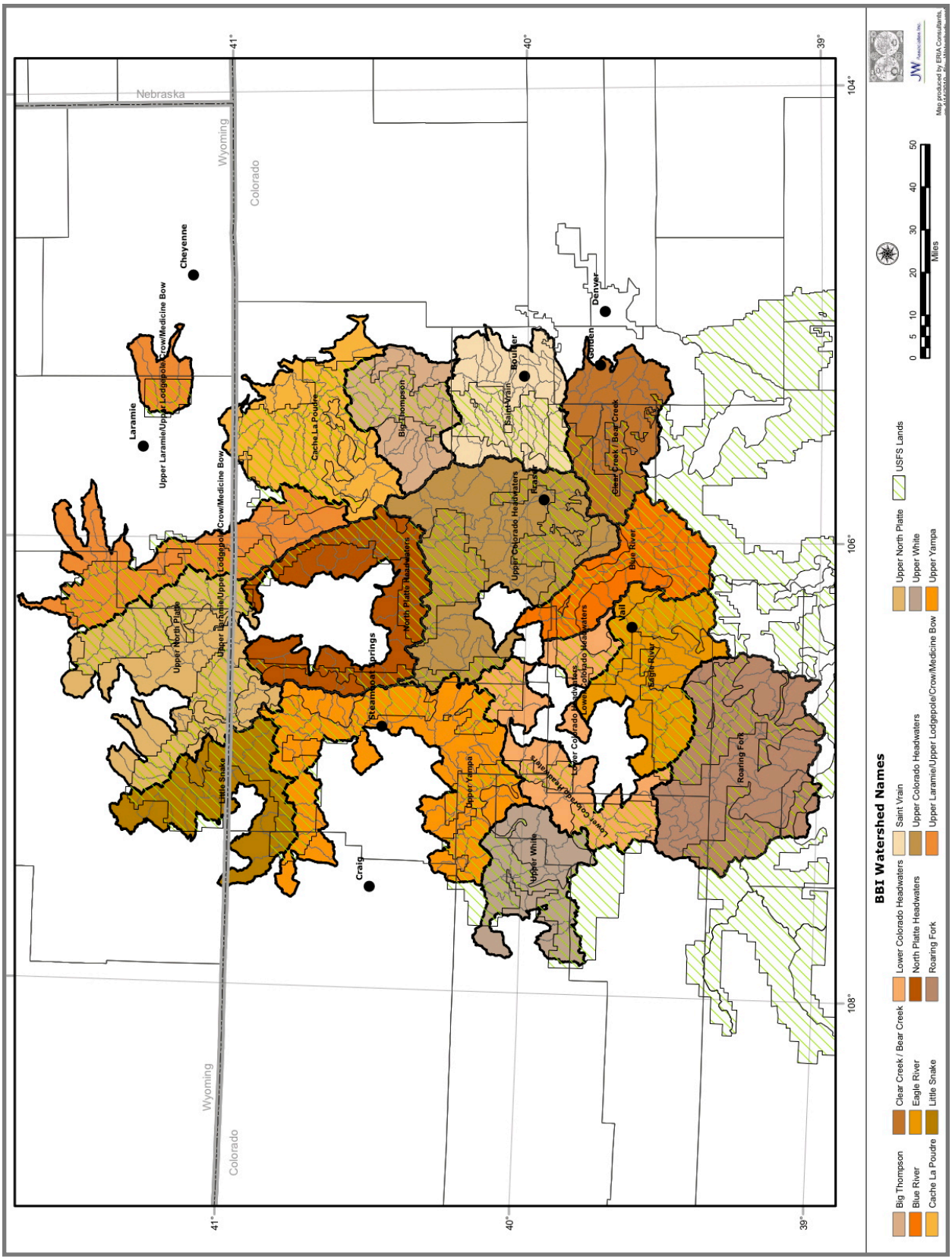

Figure 1. Bark Beetle Incident Phase 1 Watersheds

WATERSHED DESCRIPTION

The Blue River watershed is a high Rocky Mountain headwaters watershed. The Blue River flows into the Colorado River when it emerges from this watershed. The Blue River watershed assessment is designed to assess hazards from forest wildfire to water supply. Therefore, the subwatersheds that are mostly or entirely outside of the forest were examined closely because they can skew the results of the assessment because they are relatively flat, have higher road densities and very different fire regimes.

The Blue River watershed is one fourth-level[1] (eight-digit) watershed (HUC 14010002) that is 436,970 acres in size and contains 25 sixth-level watersheds. For this watershed assessment, one sixth-level watershed was eliminated based upon its wildfire hazard, ruggedness, and an examination of how well it fit into this assessment. The Blue River watershed used in this analysis is 422,634 acres, contains six fifth-level watersheds and 24 sixth-level watersheds, which are the analysis units for this watershed assessment (Front Range Watershed Protection Data Refinement Work Group 2009). The Blue River watershed and its fifth-level and sixth-level watersheds are shown on Figure 2 and listed in Table 1.

[I] The watersheds that were used are part of the existing national network of delineated watersheds. Hydrologic Unit Codes (HUCs) are nested watersheds and are designated numerically by levels (Federal Geographic Data Committee 2004). Sixth-level HUCs or watersheds, use the 11th and 12th digits in the HUC code. Fifth-level HUCs use the ninth and 10th digits in the HUC code.

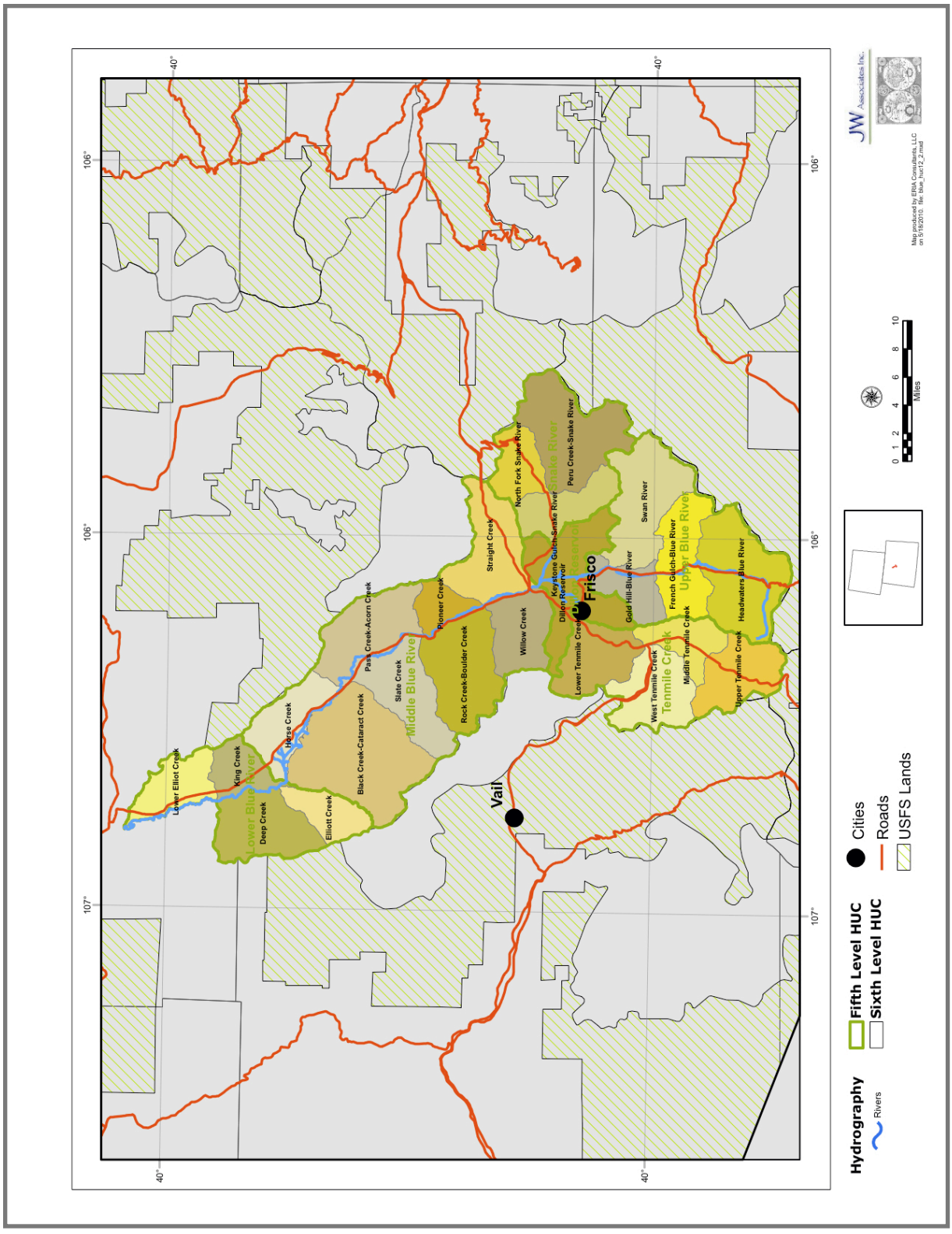

Figure 2. Blue River Watershed Analysis Area[2]

[2] The fifth-level watersheds are shown in Figure 2.

Table 1. Fifth-level and Sixth-level Watersheds in Blue River Watershed[3]

Fifth-level Watershed	Sixth-level Watershed	Watershed Area (acres)	Hydrologic Unit Code (HUC)	Map Number
Upper Blue River HUC 1401000201	Headwaters Blue River	27,034	140100020101	331
	French Gulch-Blue River	17,341	140100020102	333
	Swan River	24,059	140100020103	343
	Gold Hill-Blue River	10,424	140100020104	344
Snake River HUC 1401000202	North Fork Snake River	10,232	140100020201	342
	Peru Creek-Snake River	26,667	140100020202	341
	Keystone Gulch-Snake River	12,841	140100020203	338
Tenmile Creek HUC 1401000203	Upper Tenmile Creek	15,804	140100020301	335
	West Tenmile Creek	17,538	140100020302	334
	Middle Tenmile Creek	10,413	140100020303	339
	Lower Tenmile Creek	15,655	140100020304	345
Dillon Reservoir HUC 1401000204	Dillon Reservoir	25,623	140100020401	340
Middle Blue River HUC 1401000205	Straight Creek	20,818	140100020501	337
	Willow Creek	14,723	140100020501	351
	Pioneer Creek	6,651	140100020502	336
	Rock Creek-Boulder Creek	23,347	140100020502	350
	Pass Creek-Acorn Creek	19,242	140100020503	332
	Slate Creek	19,756	140100020503	349
	Black Creek-Cataract Creek	39,423	140100020504	329
	Horse Creek	14,983	140100020504	348
Lower Blue River HUC 1401000206	Elliot Creek	9,610	140100020601	328
	Deep Creek	19,142	140100020602	330
	King Creek	8,937	140100020602	347
	Lower Elliot Creek	12,372	140100020603	346
Total Area		422,634		

[3] Map numbers are used in Figures 3, 6 and 9

WATERSHED ASSESSMENT

The potential of a watershed to deliver sediments following wildfire depends on forest and soil conditions, the physical configuration of the watersheds, and the sequence and magnitude of rain falling on the burned area. High-severity fires can cause changes in watershed conditions that are capable of dramatically altering runoff and erosion processes in watersheds. Water and sediment yields may increase as more of the forest floor is affected by fire.

This Phase 1 - Blue River Watershed Assessment provides the analysis for the first three components specified in the Front Range Watershed Protection Data Refinement Work Group (2009) procedure. It provides the analysis for: wildfire hazard, flooding or debris flow hazard, and soil erodibility. This Phase 1 assessment then combines those three components into a composite hazard ranking. This report discusses the technical approach for each component and the process used to assemble the watershed ranking.

The categories used in the prioritization are numbered one though five, with one being the lowest ranking and five being the highest. The numeric ranges for each category are as follows;

Category 1 - 0.5 to 1.49
Category 2 - 1.5 to 2.49
Category 3 - 2.5 to 3.49
Category 4 - 3.5 to 4.49
Category 5 - 4.5 to 5.49

The categories are used in this analysis for the purpose of comparing watersheds to each other within the Blue River watershed. Comparisons with other watershed assessments are not valid because this approach prioritizes watersheds by comparing them to the other sixth-level watersheds only in this watershed assessment area.

Component 1 - Wildfire Hazard

The forest conditions that are of concern for the assessments are the wildfire hazard based on existing forest conditions. The wildfire hazard (Flame Length) was determined using the Fire Behavior Assessment Tool (FBAT) (http://www.fire.org) which is an interface between ArcMap and FlamMap. The input spatial data were collected from LANDFIRE project (http://www.landfire.gov/).

After a mountain pine beetle outbreak there are substantial increases in the amount of fine dead fuels in the canopy. The majority of these fuels remain in the canopy for 2-3 years post outbreak (Knight 1987, Schmid and Amman 1992). Therefore, certain input spatial data sets were updated based on Mountain Pine Beetle (MPB) mortality conditions using USDA Forest Service, Rocky Mountain Region Aerial Detection Survey (ADS) Data from the years 2002-2007 (http://www.fs.fed.us/r2/resources/fhm/aerialsurvey/). The assumptions used in the FBAT model are presented in Appendix A.

The flame length results were divided into five categories of wildfire hazard ranging from lowest (Category 0) to highest (Category 4). The flame length categories that were used are;

Flame Length Category 0 - 0 meters

Flame Length Category 1 - 1 to 10 meters

Flame Length Category 2 - 11 to 25 meters

Flame Length Category 3 - 26 to 40 meters

Flame Length Category 4 - >40 meters

Figure 3 shows the results of the wildfire hazard modeling. The results were categorized by sixth-level watershed into five categories that are used throughout the analysis (see Table B-1 in Appendix B) using the following formula.

Wildfire Hazard Ranking = (Percentage in Category 3 + Percentage in Category 4 * 2)

The categorized wildfire hazard by sixth-level watershed was mapped (Figure 4). The map shows that the highest hazards are in the following sixth-level watersheds: Elliot Creek, Swan River, Gold Hill-Blue River, Lower Tenmile Creek, Willow Creek, and Keystone Gulch-Blue River. Six watersheds were ranked as Category 4, which is the next highest category (see Table B-1 in Appendix B).

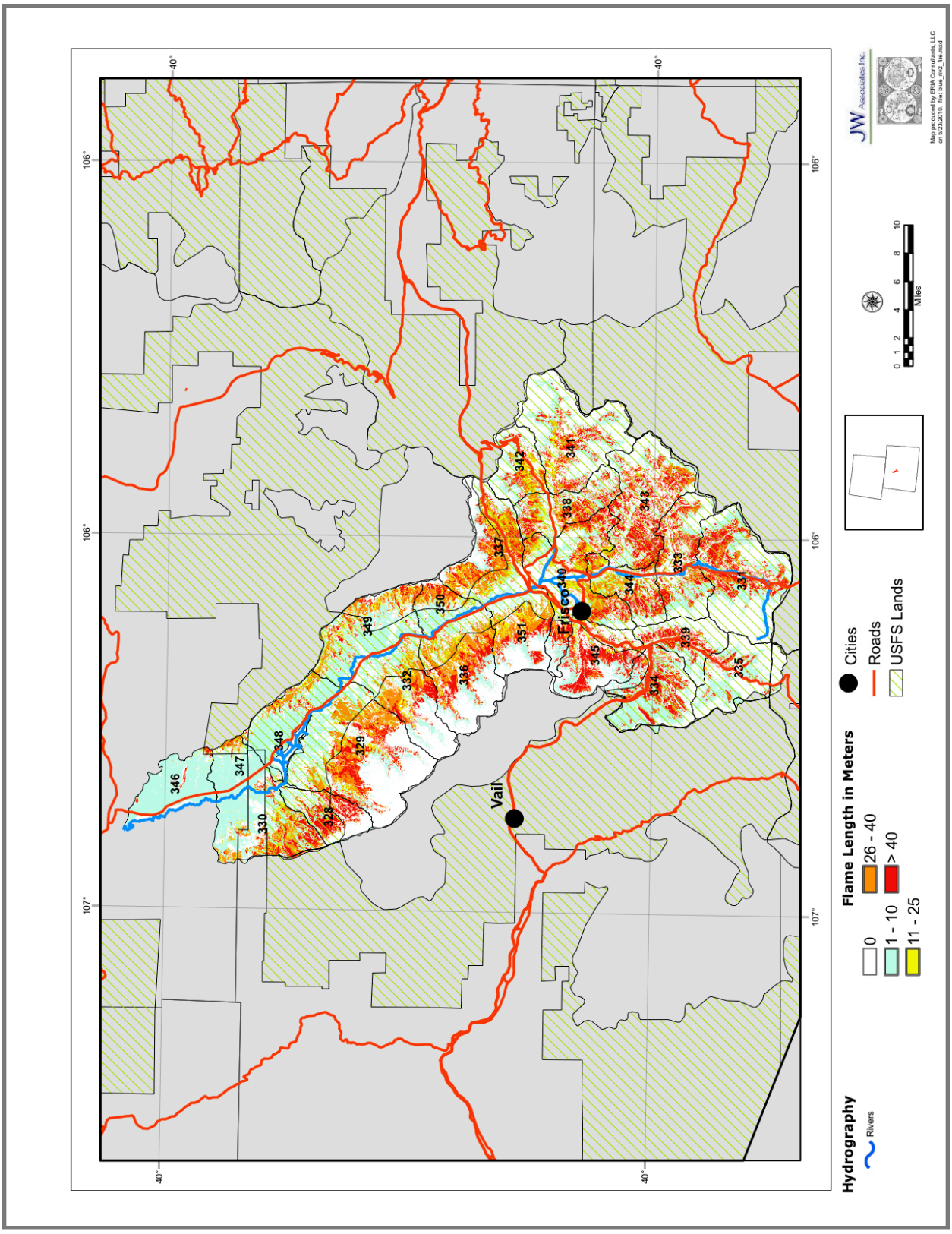

Figure 3. Blue River Watershed Wildfire Hazard Modeling Results

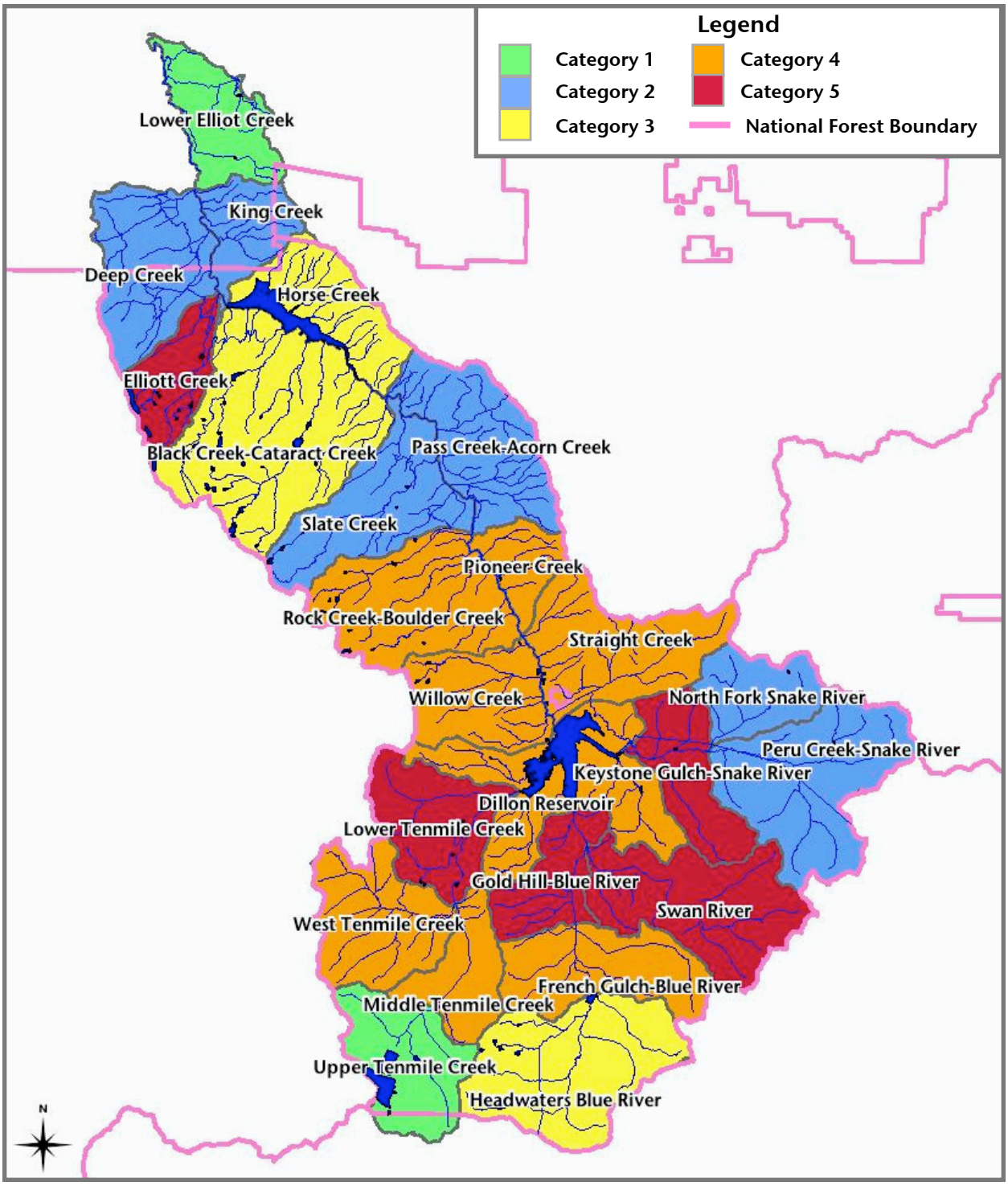

Figure 4. Blue River Watershed Wildfire Hazard Ranking

Component 2 - Flooding or Debris Flow Hazard

A combination of ruggedness and road density (miles of road per square mile of watershed area) was used to assess the flooding or debris flow hazard portion of the analysis. The two components, ruggedness and road density, are described below.

Ruggedness

Watershed steepness or ruggedness is an indicator of the relative sensitivity to debris flows following wildfires (Cannon and Reneau 2000). The more rugged the watershed, the higher its sensitivity to generating debris flows following wildfire (Melton 1957). The Melton ruggedness factor is basically a slope index.

Melton (1957) defines ruggedness, R, as;

$$R = H_b A_b^{-0.5}$$

Where A_b is basin area (square feet) and H_b is basin height (feet) measured from the point of highest elevation along the watershed divide to the outlet.

The ruggedness result in some watersheds was adjusted because they do not accurately reflect the slope in those watersheds. Those situations are most common in composite watersheds because they are disconnected from their headwaters. These watersheds can have a high hazard for debris flows because they contain a main stem of a creek or river with several steep first order streams as tributaries. In those situations, the ruggedness calculation was adjusted up by reducing the watershed area. These adjustments were completed on the following watersheds; Headwaters Blue River, French Gulch-Blue River, Swan River, North Fork Snake River, Peru Creek-Snake River, Keystone Gulch-Snake River, Upper Tenmile Creek, West Tenmile Creek, Lower Tenmile Creek, Straight Creek, Rock Creek-Boulder Creek, Pass Creek-Acorn Creek, Slate Creek, Black Creek-Cataract Creek, Horse Creek, and Deep Creek.

Figure 5 displays the categorized ruggedness for the Blue River Watershed. The tabular results are presented on Table B-2 in Appendix B. The map (Figure 5) shows that the most rugged sixth-level watersheds are Pioneer Creek, North Fork Snake River, Headwaters Blue River, Rock Creek-Boulder Creek, French Gulch-Blue River, Slate Creek, and Black Creek-Cataract Creek.

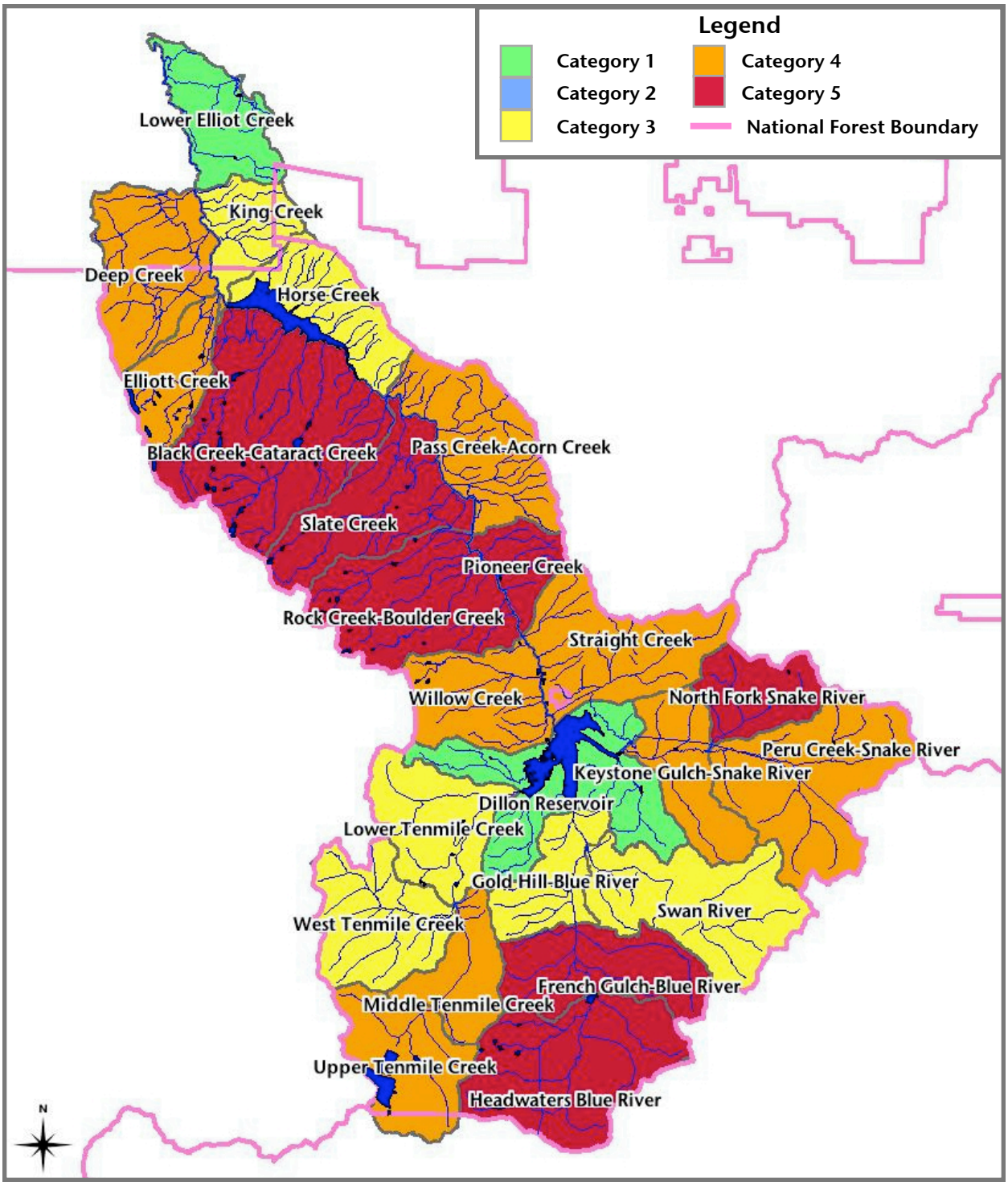

Figure 5. Blue River Watershed Ruggedness Ranking

Road Density

Roads can convert subsurface runoff to surface runoff and then route the surface runoff to stream channels, increasing peak flows (Megan and Kidd 1972, Ice 1985, and Swanson et al. 1987). Therefore, watersheds with higher road densities have a higher sensitivity to increases in peak flows following wildfires. Road density in miles of road per square mile of watershed area was used as an indicator of flooding hazard. The U.S. Forest Service roads data was used on National Forest System (NFS) lands because it is the most accurate roads data for those roads in the forest. On all other lands the U.S. Census Bureau's Tiger database was used because it is a consistent roads data layer (Figure 6).

Road densities were adjusted in some watersheds for two separate reasons. One reason for adjusting the road density was the situation where a watershed had a much higher road density than the next highest value, so that watershed was skewing the categorization. In that situation, the watershed was manually given a road density slightly higher than the next highest score.

The other situation where road density was adjusted is where some of the roads within a watershed were within towns, developed areas, or outside the forested areas of the watershed. The roads that are of interest in this analysis are those roads that would increase the risk of flooding or debris flows following wildfires in forested areas. The watersheds were all examined by looking at the roads data overlain on digital images and vegetation mapping. If it was found that there were significant lengths of road outside forested areas, the road density in those watersheds was adjusted down based on ocular estimates.

Road density in the French Gulch-Blue River, Swan River, Keystone Gulch-Snake River, and Dillon Reservoir watersheds were all adjusted down. The adjustments are displayed on Table B-3 in Appendix B.

Figure 7 displays the categorized road density for the Blue River Watershed and tabular results are presented in Appendix B (Table B-3). Figure 7 shows that the highest rankings are in French Gulch-Blue River, Gold Hill-Blue River, Willow Creek, and Upper Tenmile Creek.

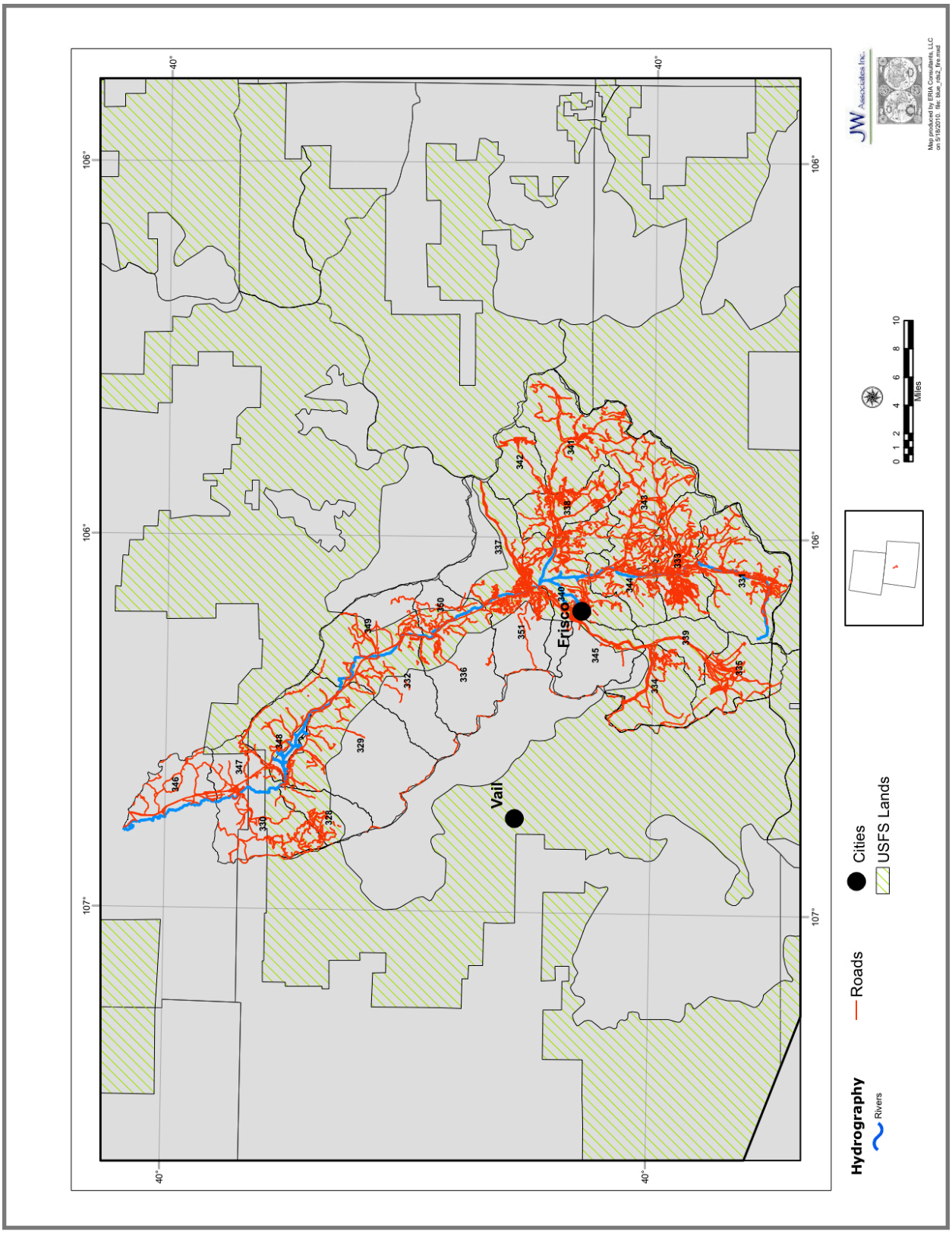

Figure 6. Blue River Watershed Roads Map

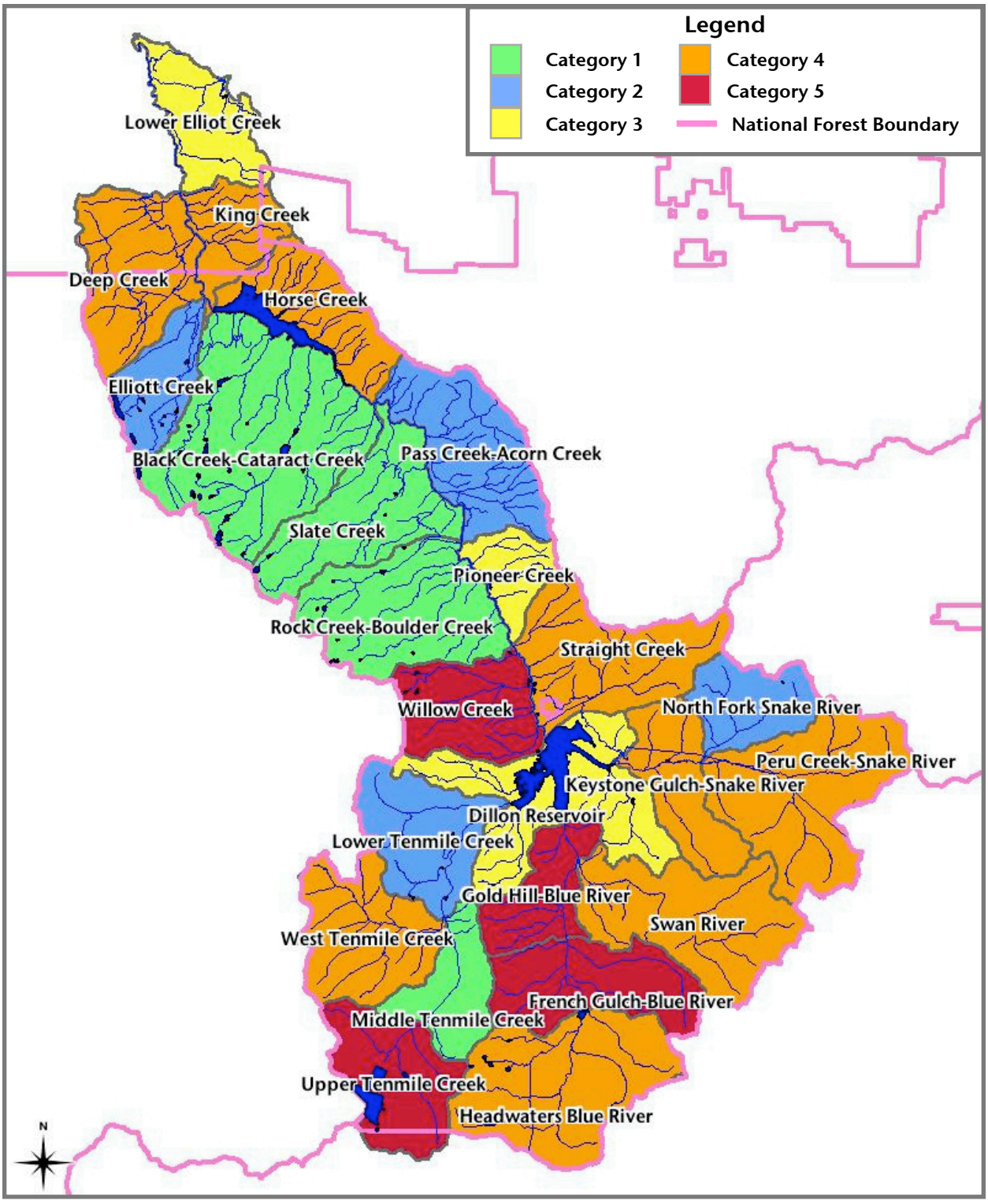

Figure 7. Blue River Watershed Road Density Ranking

Flooding or Debris Flow Hazard Ranking

The Flooding or Debris Flow Hazard is the combination of ruggedness and road density. The procedure from the Front Range Watershed Work Group (2009) assigned ruggedness a higher value than road density in this ranking. While ruggedness is the most important factor, an increase in road density will magnify the effects of ruggedness on the flooding/debris flow hazard. Accordingly, the analysis for flooding or debris flow hazard for the Blue River Watershed used the following formula. The results of this calculation were then re-categorized into five hazard rankings.

Flooding or Debris Flow Hazard Ranking = (Road Density Ranking + Ruggedness Ranking * 2)

Figure 8 shows that areas of the watershed with high road densities and high ruggedness rank high in this combined factor. The best way to look at this map is to look at a single watershed on the ruggedness and road density maps, noting the rankings on each. Then look at this map and see how they result in the final ranking for this component. The tabular results are presented in Table B-4 in Appendix B.

The highest ranked sixth-level watersheds are French Gulch-Blue River, Headwaters Blue River and Pioneer Creek. Dillon Reservoir and Lower Elliot Creek were skewing the categorization because of their low combined numeric scores for Flooding or Debris Flow Hazard Ranking. The combined numeric scores for Dillon Reservoir and Lower Elliot Creek watersheds was manually given a score slightly less than the next lowest score (Table B-4 in Appendix B).

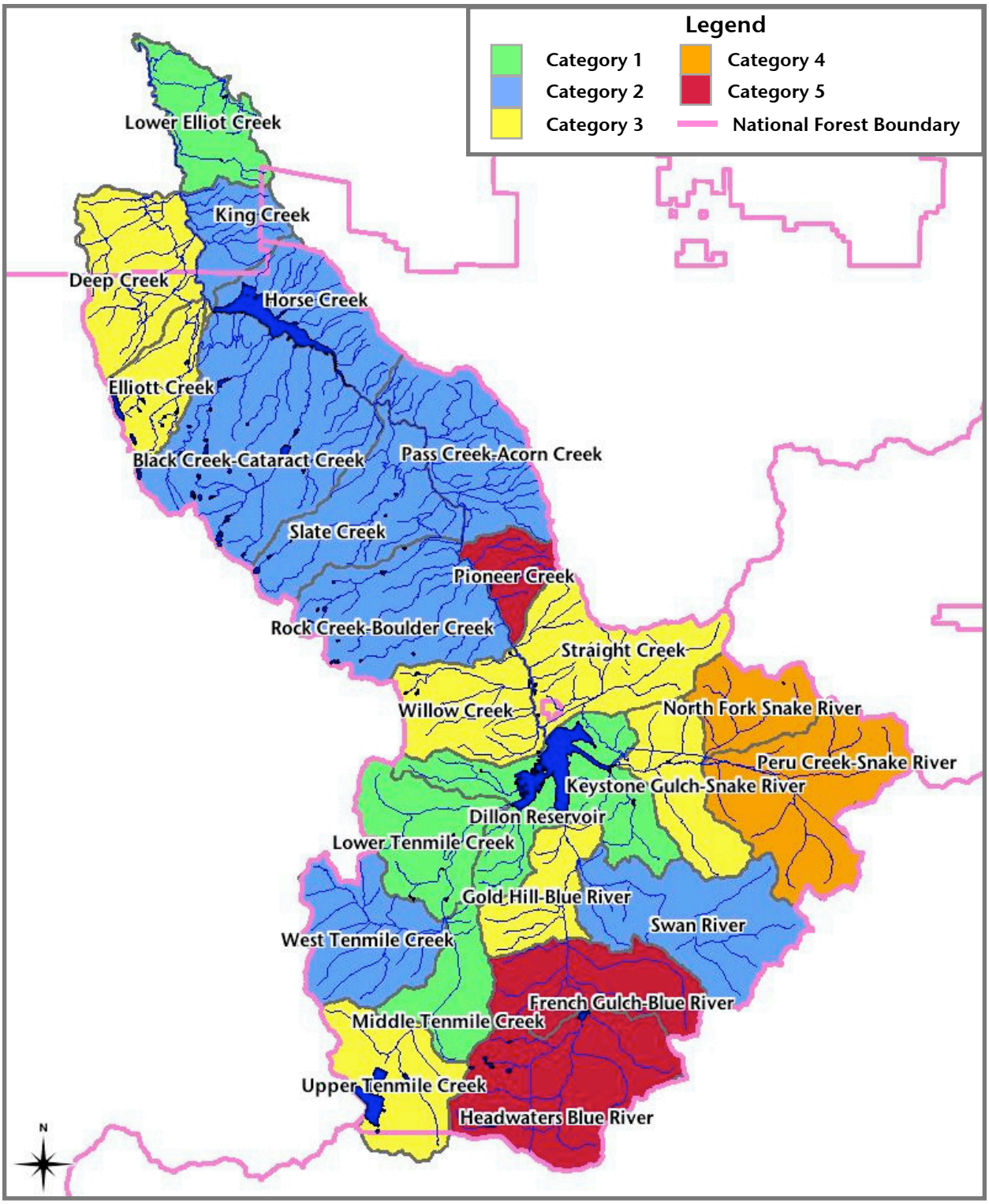

Figure 8. Blue River Watershed Flooding/Debris Flow Hazard Ranking

Component 3 - Soil Erodibility

High-severity fires can cause changes in watershed components that can dramatically change runoff and erosion processes in watersheds. Water and sediment yields may increase as more of the forest floor is consumed (Wells et al. 1979, Robichaud and Waldrop 1994, Soto et al. 1994, Neary et al. 2005, and Moody et al. 2008) and soil properties are altered by soil heating (Hungerford et al. 1991).

Two soils data sets were evaluated for use in this analysis. They were the U.S. Department of Agriculture - Natural Resources Conservation Service (NRCS) STATSGO and SSURGO soils data. STATSGO data are relatively coarse soils data, created at a scale of 1:250,000 and are available for the entire watershed assessment area. SSURGO soils data do not cover all the watershed assessment area, though efforts by the NRCS are currently under way to produce an updated soils data layer.

The data used in this analysis is the U.S. Department of Agriculture - Natural Resources Conservation Service (NRCS) SSURGO soils data combined with the U.S. Forest Service soils data. SSURGO data does not cover all the watershed but is available at a preferable scale (generally ranges from 1:12,000 to 1:63,360) than STATSGO data. The U.S. Forest Service soils data is comparable with the SSURGO data in scale and quality. Areas without SSURGO data were filled in with U.S. Forest Service soils data (Figure 9).

The soil erodibility analysis used a combination of two standard erodibility indicators: the inherent susceptibility of soil to erosion (K factor) and land slope derived from Unites States Geological Survey (USGS) 30-meter digital elevation models. The K factor data from the SSURGO spatial database was combined with a slope grid using NRCS (USDA NRCS 1997) slope-soil relationships (Table 2) to create a classification grid divided into slight, moderate, severe and very severe erosion hazard ratings.

Table 2. NRCS Criteria for Determining Potential Soil Erodibility

Percent Slope	K Factor <0.1	K Factor 0.1 to 0.19	K Factor 0.2 to 0.32	K Factor >0.32
0-14	Slight	Slight	Slight	Moderate
15-34	Slight	Slight	Moderate	Severe
35-50	Slight	Moderate	Severe	Very Severe
>50	Moderate	Severe	Very Severe	Very Severe

The potential soil erodibility hazard rankings are shown on Figure 10 and the tabular results are presented in Table B-5 in Appendix B. The map shows areas of high soil erodibility in the assessment area. The highest ranked sixth-level watersheds based on soil erodibility are Pioneer Creek, Middle Tenmile Creek, Keystone Gulch-Snake River, and Lower Tenmile Creek. The soil erodibility value for Straight Creek was adjusted up due to the presence of large quantities of highway sand that increase the concern for soil erosion. Middle Tenmile Creek and Pioneer Creek were skewing the categorization because of their high soil erodibility values and were manually given a score slightly more than the next highest score (Table B-5 in Appendix B).

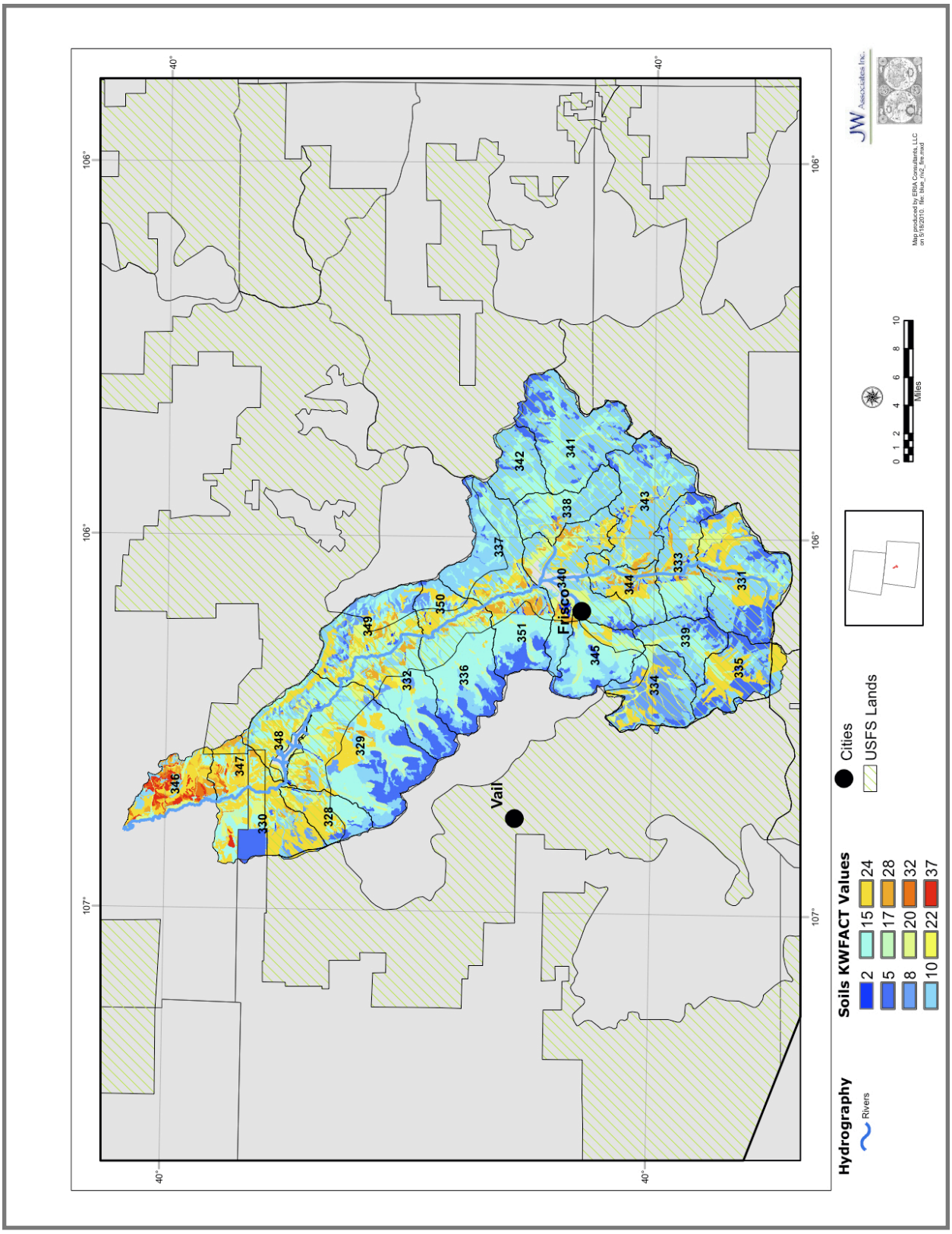

Figure 9. Blue River Watershed Soils K-Factor Map

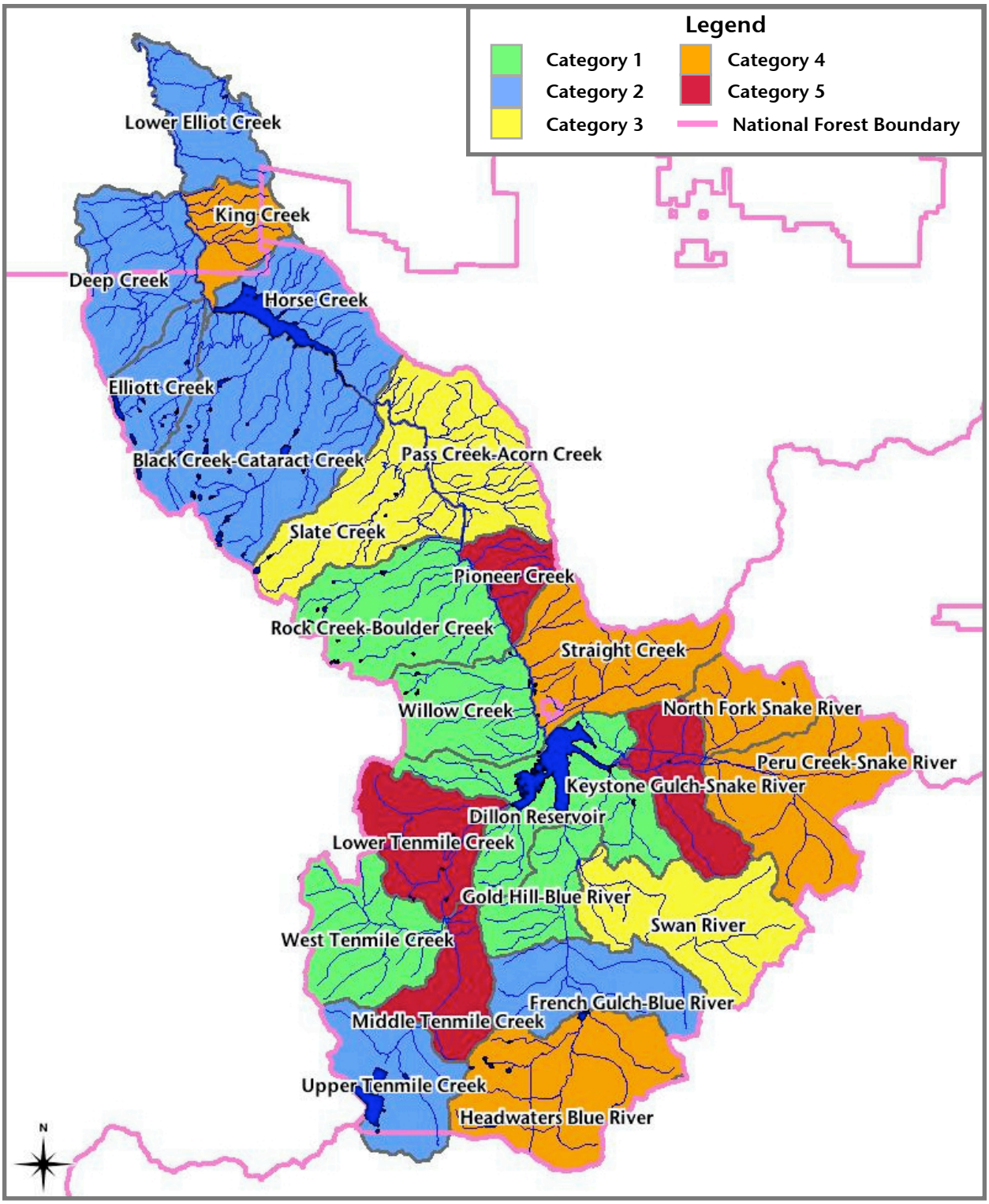

Figure 10. Blue River Watershed Potential Soil Erodibility Hazard Ranking

Composite Hazard Ranking

The Composite Hazard Ranking combines the first three components (Wildfire Hazard, Flooding/Debris Flow Hazard and Soil Erodibility) by numerically combining their rankings for each sixth-level watershed and then re-categorizing the results. The Composite Hazard Ranking map is useful in comparing relative watershed hazards based solely on environmental factors. Figure 11 shows the Composite Hazard Ranking for the Blue River Watershed. The tabular results that display the rankings for Wildfire Hazard, Flooding/ Debris Flow Hazard and Soil Erodibility, as well as the composite rankings are presented in Table B-6 in Appendix B. The highest ranked sixth-level watersheds are Pioneer Creek, Keystone Gulch-Snake River, and Headwaters Blue River. Additionally, there are five watersheds in Category 4.

Lower Elliot Creek was skewing the categorization because of it low score for the Composite Numeric Rank. The Composite Numeric Rank for Lower Elliot Creek was manually given a score less than the next lowest score (Table B-6 in Appendix B).

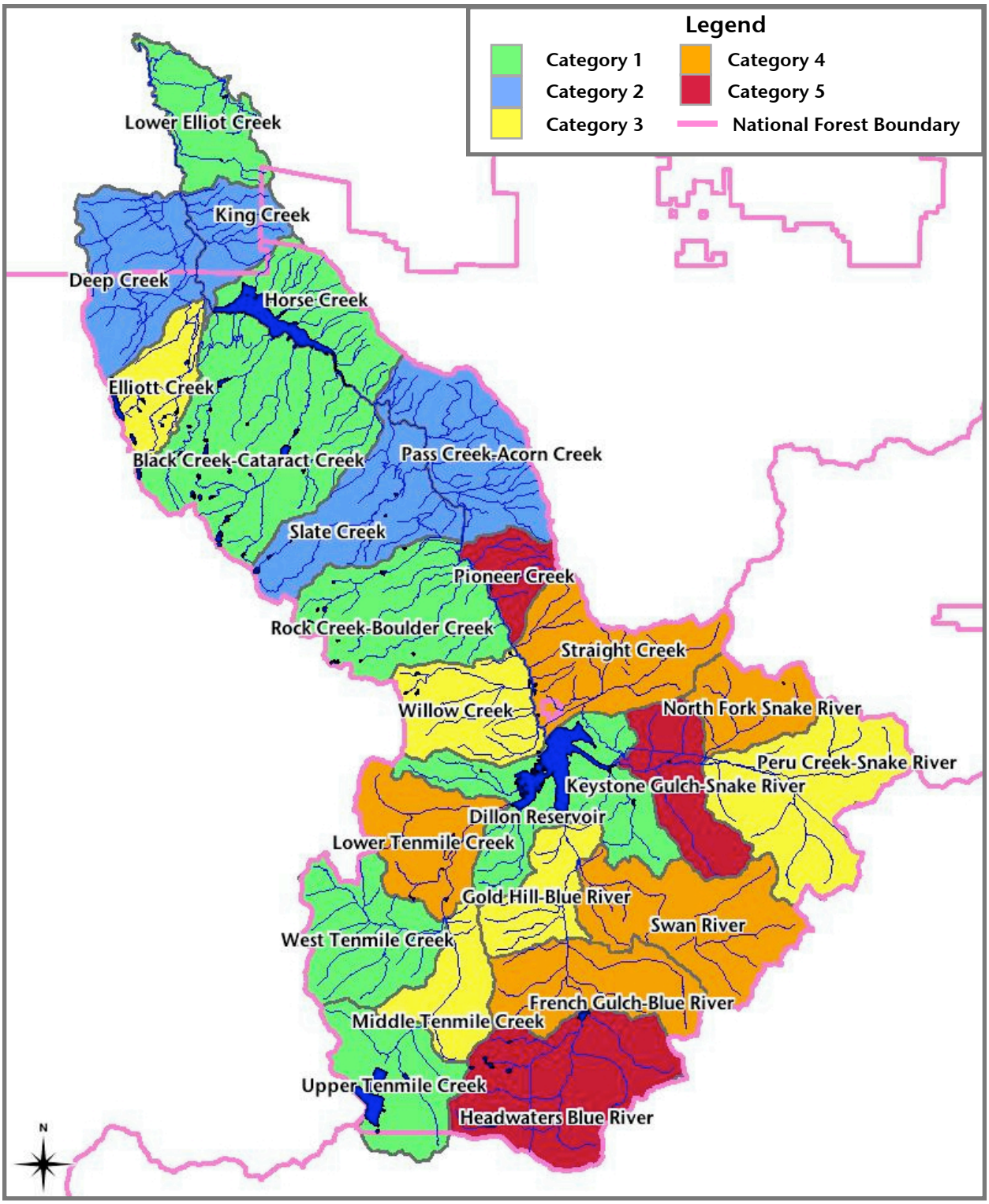

Figure 11. Blue River Watershed Composite Hazard Ranking

Component 4 - Water Supply Ranking

Surface water intakes, diversions, conveyance structures, storage reservoirs and streams are all susceptible to the effects of wildfires. The suggested approach from the procedure prescribed by the Front Range Watershed Protection Data Refinement Work Group (2009) is to first rank watersheds based upon the presence of water nodes.

Surface drinking water supply collection points from the Source Water Assessment and Protection (SWAP) Program (see http://www.cdphe.state.co.us/wq/sw/swaphom.html for basic information on the SWAP Program) were used to identify which sixth-level watersheds contain critical components of the public water supply infrastructure in Colorado. For this assessment, water nodes were defined as coordinate points corresponding to surface water intakes, upstream diversion points and classified drinking water reservoirs.

Water supply locations may not be identified in the state's database for some drinking water supply reservoirs that do not have associated direct surface water intakes. Also, some water supply reservoirs may not be identified in the SWAP database. The Water Supply map was modified to include these features by including all named reservoirs.

Figure 12 shows the sixth-level watersheds that have water supply locations in blue and those without water supply locations in green.

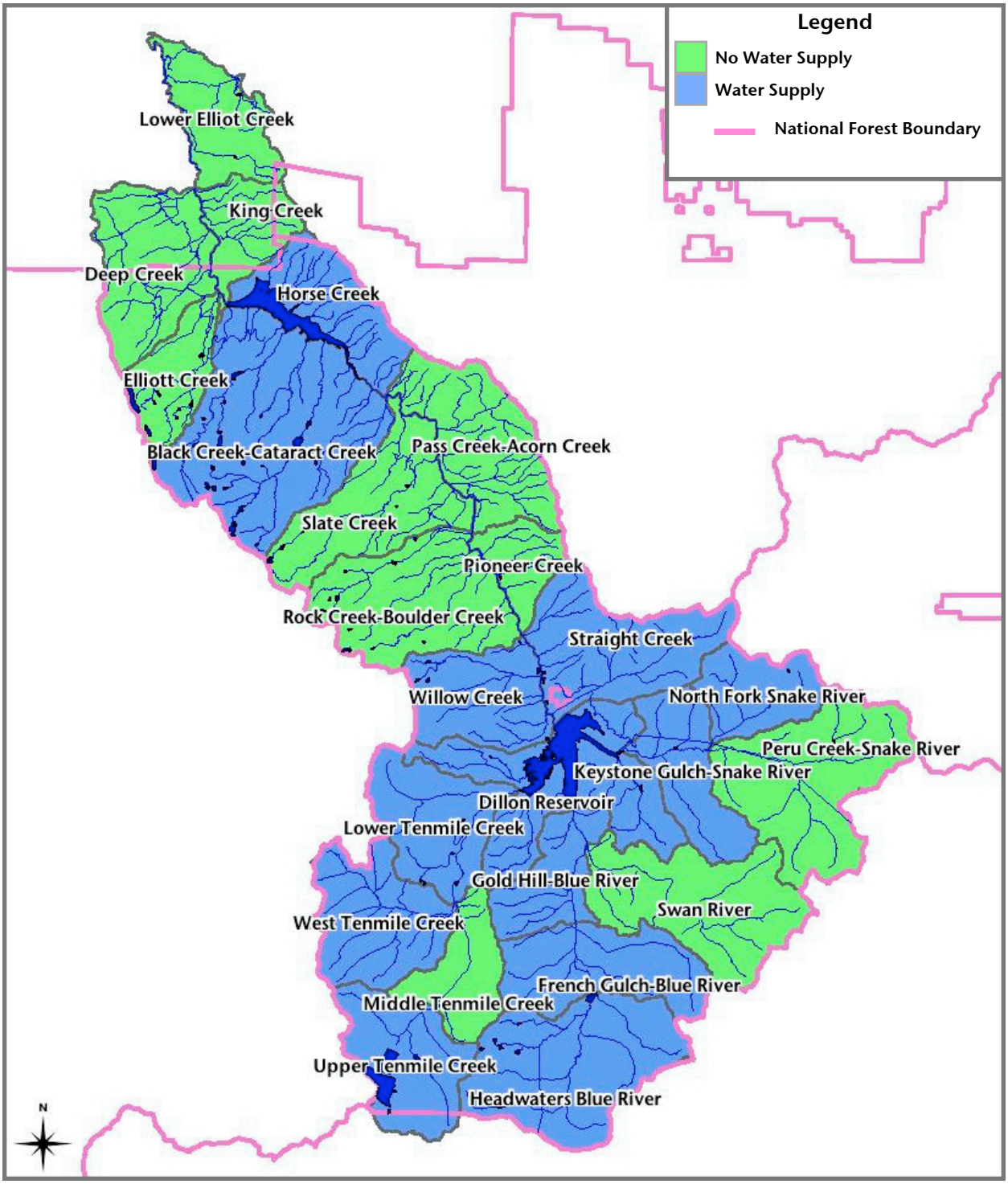

Figure 12. Blue River Watershed Water Supply Map

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APPENDIX A

BLUE RIVER WILDFIRE HAZARD MODELING METHODOLOGY

The forest conditions that are of concern for the assessments are the wildfire hazard based on existing forest conditions. The wildfire hazard (Flame Length) was determined using the Fire Behavior Assessment Tool (FBAT) (http://www.fire.org) which is an interface between ArcMap and FlamMap. The input spatial data were collected from LANDFIRE project (http://www.landfire.gov/).

After a mountain pine beetle outbreak there are substantial increases in the amount of fine dead fuels in the canopy. The majority of these fuels remain in the canopy for 2-3 years post outbreak (Knight 1987, Schmid and Amman 1992). Therefore, certain input spatial data sets were updated reflecting Mountain Pine Beetle (MPB) mortality conditions using USDA Forest Service, Rocky Mountain Region Aerial Detection Survey (ADS) Data from the years 2002 - 2007 (http://www.fs.fed.us/r2/resources/fhm/aerialsurvey/). The following modeling settings and spatial data modification were used:

Modeling Setting

1. Scott and Burgan (2005) Fire Behavior Model (Fuel Moisture is shown in Table A-1)
2. Uphill wind direction
3. Scott & Reinhardt (2001) crown fire calculation
4. Foliar Moisture at 100%

Spatial Data Modifications

1. Canopy Cover was assigned a value of 10% when coincident with MPB mortality from ADS for years 2002-2007.
2. Canopy Base Height (CBH) was reduced by 25% for MPB mortality derived from ADS for the years 2002-2006.
3. CBH was reassigned a value of 0 for MPB mortality from ADS for the year 2007.
4. Canopy Bulk Density (CBD) was reduced by 50% for MPB mortality derived from ADS for the years 2002-2006

Table A-1. Fuel Moisture (percent) used in FBAT Model Runs

Scott and Burgan (2005) fuel model	1-Hour Fuel	10-Hour Fuel	100-Hour Fuel	Live Herbaceous	Live Woody
1	4	5	8	200	95
2	4	5	8	150	95
3	4	5	8	85	95
4	4	5	8	85	95
5	4	5	8	85	150
6	4	5	8	85	95
7	4	5	8	85	95
8	4	5	8	85	95
9	4	5	8	85	95
10	4	5	8	85	95
11	4	5	8	85	95
12	4	5	8	85	95
13	4	5	8	85	95
14	3	4	8	85	95
15	3	4	8	85	95
16	3	4	8	85	95
17	3	4	8	85	95
18	3	4	8	85	95
19	3	4	8	85	95
20	3	4	8	85	95
21	3	4	8	85	95
22	3	4	8	85	95
23	3	4	8	85	95
24	3	4	8	85	95
25	3	4	8	85	95
26	3	4	8	85	95
27	3	4	8	85	95
28	3	4	8	85	95
29	3	4	8	85	95
30	3	4	8	85	95
31	3	4	8	85	95
32	3	4	8	85	95
33	3	4	8	85	95
34	3	4	8	85	95
35	3	4	8	85	95
36	3	4	8	85	95
37	3	4	8	85	95
38	3	4	8	85	95
39	3	4	8	85	95
40	3	4	8	85	95
41	3	4	8	85	95
42	3	4	8	85	95
43	3	4	8	85	95
44	3	4	8	85	95
45	3	4	8	85	95
46	3	4	8	85	95
47	3	4	8	85	95
48	3	4	8	85	95
49	3	4	8	85	95
50	3	4	8	85	95

Weather Data

The weather data used comes from the Colorado Wildfire Risk Assessment Statewide (CRA) dataset prepared by Sandborn under contract to the Colorado State Forest Service. For the Colorado Fire Risk Assessment nine weather influence zones (WIZ) were developed for analysis purposes. A WIZ is an area where for analysis purposes the weather on any given day is uniform. Within each WIZ, daily weather data was gathered for the years 1980-2006. Where not available, the weather data was gathered from the earliest year through 2006. Several weather stations were analyzed within each WIZ. From this analysis, one representative weather station was selected for each WIZ. From this data set, percentile weather was developed for each WIZ using the Fire Family Plus software package.

For this watershed assessment the percentile weather for WIZ CO 02 (Dowd 1986-2006) was used for all watersheds on the west side of the continental divide and WIZ CO 03 (Coral Creek 1980-2006) was used for all watersheds on the east side of the continental divide. The 20-foot wind speeds for the "High" case was used in the modeling runs (Table A-2).

In addition the wind direction was assumed to be uphill (parallel with slope) in all instances. This setting encourages crown fire initiation and establishes a common baseline for the evaluation of areas within the landscape based upon the fuels hazard represented by vegetation conditions.

Table A-2. Wind Speed (Miles per Hour) used in FBAT Model Runs

Watershed Name	Wind Speed (mph)	Probable Momentary Gust Speed (mph)
North Platte	15	29
Upper North Platte	15	29
Crow/Medicine Bow/Upper Laramie/Upper Lodgepole	12	25
Clear/Bear Creek	12	25
Big Thompson	12	25
Cache la Poudre	12	25
Blue River	15	29
Eagle River	15	29
Upper Yampa	15	29
Little Snake	15	29
Upper White	15	29
Lower Colorado	15	29
Upper Colorado	15	29
Saint Vrain	12	25
Roaring Fork	15	29

Categorization of Results

The FBAT model results were divided into five categories of flame length. These values range from lowest (Category 0) to highest (Category 4) based upon flame length. The flame length categories that were used are:

Flame Length Category 0 - 0 meters

Flame Length Category 1 - 1 to 10 meters

Flame Length Category 2 - 11 to 25 meters

Flame Length Category 3 - 26 to 40 meters

Flame Length Category 4 - >40 meters

APPENDIX B

DETAILED BLUE RIVER WATERSHED ASSESSMENT RESULTS

Table B-1. Blue River Watershed Wildfire Hazard Ranking

Sixth-level Watershed Name	Watershed Area (acres)	Wildfire Hazard Calculation	Wildfire Hazard Rank
Elliott Creek	9,610	66.7%	*5.5*
Swan River	24,059	66.3%	*5.5*
Gold Hill-Blue River	10,424	61.1%	*5.0*
Lower Tenmile Creek	15,655	59.0%	*4.8*
Willow Creek	14,723	46.2%	*4.8*
Keystone Gulch-Snake River	12,841	58.0%	*4.8*
French Gulch-Blue River	17,341	51.0%	*4.2*
Dillon Reservoir	25,623	48.2%	*3.9*
West Tenmile Creek	17,538	47.3%	*3.9*
Straight Creek	20,818	46.2%	*3.8*
Pioneer Creek	6,651	43.3%	*3.5*
Rock Creek-Boulder Creek	23,347	43.3%	*3.5*
Middle Tenmile Creek	10,413	42.9%	*3.5*
Headwaters Blue River	27,034	42.2%	*3.4*
Black Creek-Cataract Creek	39,423	31.1%	*2.5*
Horse Creek	14,983	31.1%	*2.5*
Deep Creek	19,142	30.8%	*2.5*
King Creek	8,937	30.8%	*2.5*
Pass Creek-Acorn Creek	19,242	30.4%	*2.5*
Slate Creek	19,756	30.4%	*2.5*
North Fork Snake River	10,232	30.3%	*2.4*
Peru Creek-Snake River	26,667	26.7%	*2.1*
Upper Tenmile Creek	15,804	13.8%	*1.1*
Lower Elliot Creek	12,372	7.2%	*0.5*

Table B-2. Blue River Watershed Ruggedness Ranking[1, 2]

Sixth-level Watershed Name	Maximum Elevation	Minimum Elevation	Difference Elevation	Ruggedness	Ruggedness Rank
Pioneer Creek	12,339	8,403	3,936	0.2312	*5.5*
North Fork Snake River	13,314	9,334	3,980	0.2309	*5.5*
Headwaters Blue River	14,261	9,887	4,374	0.2208	*5.0*
Rock Creek-Boulder Creek	13,330	8,393	4,938	0.2190	*5.0*
French Gulch-Blue River	13,677	9,463	4,214	0.2168	*4.9*
Slate Creek	13,191	7,998	5,193	0.2168	*4.9*
Black Creek-Cataract Creek	13,555	7,943	5,612	0.2141	*4.8*
Elliott Creek	11,948	7,687	4,261	0.2082	*4.5*
Pass Creek-Acorn Creek	12,234	8,000	4,234	0.2068	*4.4*
Peru Creek-Snake River	14,249	9,337	4,912	0.2038	*4.3*
Deep Creek	11,476	7,462	4,014	0.1966	*4.0*
Middle Tenmile Creek	13,852	9,687	4,166	0.1956	*3.9*
Straight Creek	12,984	8,589	4,395	0.1931	*3.8*
Upper Tenmile Creek	13,901	10,331	3,570	0.1924	*3.8*
Keystone Gulch-Snake River	12,420	9,031	3,389	0.1896	*3.7*
Willow Creek	13,314	8,591	4,723	0.1865	*3.5*
Lower Tenmile Creek	12,907	9,035	3,871	0.1816	*3.3*
Swan River	13,301	9,155	4,146	0.1811	*3.3*
West Tenmile Creek	13,188	9,684	3,504	0.1793	*3.2*
Gold Hill-Blue River	12,842	9,023	3,819	0.1792	*3.2*
Horse Creek	11,611	7,943	3,667	0.1758	*3.1*
King Creek	10,889	7,467	3,422	0.1734	*3.0*
Lower Elliot Creek	10,131	7,333	2,797	0.1205	*0.7*
Dillon Reservoir	12,905	9,008	3,897	0.1166	*0.5*

[1] Ruggedness is based on Melton (1957)

[2] These watersheds were manually adjusted because they do not accurately reflect the ruggedness in those watersheds. The original values were; Headwaters Blue River (0.1275), French Gulch-Blue River (0.1533), Swan River 0.1281), North Fork Snake River 0.1885), Peru Creek-Snake River (0.1441), Keystone Gulch-Snake River (0.1433), Upper Tenmile Creek (0.1361), West Tenmile Creek (0.1268), Lower Tenmile Creek (0.1483), Straight Creek (0.1459), Rock Creek-Boulder Creek (0.1548), Pass Creek-Acorn Creek (0.1462), Slate Creek (0.1770), Black Creek-Cataract Creek (0.1354), Horse Creek (0.1435), and Deep Creek (0.1390).

Table B-3. Blue River Watershed Road Density Ranking[3]

Sixth-level Watershed Name	Roads (miles)	Roads Adjusted (miles)	Watershed Area (sq. mi.)	Road density (miles per sq. mi.)	Road Density Rank
French Gulch-Blue River	178.3	89.1	27.09	3.29	*5.5*
Gold Hill-Blue River	53.6	53.6	16.29	3.29	*5.5*
Willow Creek	70.7	70.7	23.00	3.07	*5.0*
Upper Tenmile Creek	71.8	71.8	24.69	2.91	*4.7*
Straight Creek	89.5	89.5	32.53	2.75	*4.3*
Headwaters Blue River	114.1	114.1	42.14	2.71	*4.2*
Swan River	133.5	100.2	37.59	2.66	*4.1*
Keystone Gulch-Snake River	104.7	52.4	20.06	2.61	*4.0*
King Creek	36.3	36.3	13.96	2.60	*4.0*
Peru Creek-Snake River	108.1	108.1	41.67	2.60	*4.0*
Horse Creek	51.2	51.2	20.23	2.53	*3.9*
West Tenmile Creek	68.7	68.7	27.40	2.51	*3.8*
Deep Creek	74.8	74.8	29.91	2.50	*3.8*
Dillon Reservoir	157.7	78.8	35.15	2.24	*3.2*
Pioneer Creek	22.6	22.6	10.39	2.17	*3.1*
Lower Elliot Creek	39.4	39.4	19.33	2.04	*2.8*
North Fork Snake River	28.9	28.9	15.99	1.81	*2.3*
Elliott Creek	26.5	26.5	15.02	1.76	*2.2*
Pass Creek-Acorn Creek	52.7	52.7	30.07	1.75	*2.2*
Lower Tenmile Creek	39.4	39.4	24.46	1.61	*1.8*
Slate Creek	34.7	34.7	30.87	1.13	*0.8*
Middle Tenmile Creek	18.3	18.3	16.27	1.12	*0.8*
Rock Creek-Boulder Creek	38.6	38.6	36.48	1.06	*0.6*
Black Creek-Cataract Creek	61.2	61.2	61.60	0.99	*0.5*
Totals	1675.6	1421.9	660.37	2.15	

[3] The road density was adjusted based upon the procedure discussed in the report (p. 12). The original road density values were; French Gulch-Blue River (6.58), Swan River (3.55), Keystone Gulch-Snake River (5.22), and Dillon Reservoir (4.49).

Table B-4. Blue River Watershed Flooding/Debris Flow Hazard Ranking[4]

Sixth-level Watershed Name	Ruggedness Ranking	Road Density Ranking	Combined Numeric Rank	Combined Ranking
French Gulch-Blue River	*4.9*	*5.5*	15.24	*5.5*
Headwaters Blue River	*5.0*	*4.2*	14.32	*4.8*
Pioneer Creek	*5.5*	*3.1*	14.07	*4.7*
North Fork Snake River	*5.5*	*2.3*	13.25	*4.1*
Peru Creek-Snake River	*4.3*	*4.0*	12.60	*3.6*
Upper Tenmile Creek	*3.8*	*4.7*	12.28	*3.4*
Willow Creek	*3.5*	*5.0*	12.13	*3.3*
Straight Creek	*3.8*	*4.3*	12.00	*3.2*
Gold Hill-Blue River	*3.2*	*5.5*	11.96	*3.1*
Deep Creek	*4.0*	*3.8*	11.76	*3.0*
Keystone Gulch-Snake River	*3.7*	*4.0*	11.38	*2.7*
Elliott Creek	*4.5*	*2.2*	11.17	*2.6*
Pass Creek-Acorn Creek	*4.4*	*2.2*	11.02	*2.5*
Swan River	*3.3*	*4.1*	10.76	*2.3*
Rock Creek-Boulder Creek	*5.0*	*0.6*	10.57	*2.1*
Slate Creek	*4.9*	*0.8*	10.53	*2.1*
West Tenmile Creek	*3.2*	*3.8*	10.27	*1.9*
Horse Creek	*3.1*	*3.9*	10.02	*1.7*
Black Creek-Cataract Creek	*4.8*	*0.5*	10.01	*1.7*
King Creek	*3.0*	*4.0*	9.95	*1.7*
Middle Tenmile Creek	*3.9*	*0.8*	8.67	*0.8*
Lower Tenmile Creek	*3.3*	*1.8*	8.51	*0.7*
Dillon Reservoir	*0.5*	*3.2*	8.40	*0.6*
Lower Elliot Creek	*0.7*	*2.8*	8.30	*0.5*

[4] Dillon Reservoir and Lower Elliot Creek watersheds were skewing the categorization because of their low Combined Numeric Rank values (originally 4.22 and 4.11 respectively) and were manually given a score slightly lower than the next lowest score

Table B-5. Blue River Watershed Soil Erodibility Ranking[5, 6, 7]

Sixth-level Watershed Name	Severe (%)	Very Severe (%)	Soil Erodibility Value	Soil Erodibility Rank
Pioneer Creek	40.9%	2.0%	0.300	*5.5*
Middle Tenmile Creek	22.6%	6.9%	0.290	*5.3*
Keystone Gulch-Snake River	11.4%	8.1%	0.276	*5.0*
Lower Tenmile Creek	24.4%	1.2%	0.269	*4.9*
Peru Creek-Snake River	23.7%	0.2%	0.242	*4.4*
North Fork Snake River	23.5%	0.0%	0.236	*4.2*
King Creek	11.2%	6.2%	0.235	*4.2*
Headwaters Blue River	15.5%	3.8%	0.231	*4.1*
Straight Creek	17.5%	0.0%	0.226	*4.0*
Pass Creek-Acorn Creek	12.8%	3.3%	0.193	*3.4*
Slate Creek	16.7%	1.2%	0.190	*3.3*
Swan River	12.8%	1.3%	0.154	*2.6*
Horse Creek	12.5%	0.6%	0.137	*2.3*
Black Creek-Cataract Creek	11.6%	1.0%	0.136	*2.3*
Deep Creek	6.1%	3.5%	0.131	*2.2*
Elliott Creek	4.9%	4.0%	0.129	*2.1*
Upper Tenmile Creek	11.5%	0.2%	0.119	*1.9*
Lower Elliot Creek	11.7%	0.0%	0.117	*1.9*
French Gulch-Blue River	9.4%	0.7%	0.108	*1.7*
Dillon Reservoir	8.8%	0.4%	0.096	*1.5*
Willow Creek	7.9%	0.4%	0.086	*1.3*
Gold Hill-Blue River	5.8%	0.2%	0.062	*0.8*
West Tenmile Creek	5.6%	0.0%	0.057	*0.7*
Rock Creek-Boulder Creek	4.3%	0.1%	0.046	*0.5*

[5] Soil Erodibility Value is percentage of Severe plus 2 times the percentage of Very Severe.

[6] The soil erodibility value for Straight Creek was adjusted up (original value of 0.176) due to the presence of large quantities of highway sand that increase the concern for soil erosion.

[7] Middle Tenmile Creek and Pioneer Creek watersheds were skewing the categorization because of their high soil erodibility values (originally 0.364 and 0.449 respectively) and were manually given a score slightly higher than the next highest score.

Table B-6. Blue River Watershed Composite Hazard Ranking[8, 9]

Sixth-level Watershed Name	Wildfire Hazard Rank	Flooding/ Debris Flow Rank	Soil Erodibility Rank	Composite Numeric Rank	Composite Hazard Rank
Pioneer Creek	3.5	4.7	5.5	13.7	5.5
Keystone Gulch-Snake River	4.8	2.7	5.0	12.5	4.8
Headwaters Blue River	3.4	4.8	4.1	12.4	4.8
French Gulch-Blue River	4.2	5.5	1.7	11.4	4.2
Straight Creek	3.8	3.2	4.0	11.0	3.9
North Fork Snake River	2.4	4.1	4.2	10.7	3.8
Lower Tenmile Creek	4.8	0.7	4.9	10.4	3.6
Swan River	5.5	2.3	2.6	10.4	3.6
Elliott Creek	5.5	2.6	2.1	10.2	3.5
Peru Creek-Snake River	2.1	3.6	4.4	10.1	3.4
Middle Tenmile Creek	3.5	0.8	5.3	9.6	3.1
Willow Creek	4.8	3.3	1.3	9.3	3.0
Gold Hill-Blue River	5.0	3.1	0.8	9.0	2.8
King Creek	2.5	1.7	4.2	8.4	2.5
Pass Creek-Acorn Creek	2.5	2.5	3.4	8.3	2.4
Slate Creek	2.5	2.1	3.3	7.9	2.2
Deep Creek	2.5	3.0	2.2	7.6	2.0
Horse Creek	2.5	1.7	2.3	6.5	1.4
Black Creek-Cataract Creek	2.5	1.7	2.3	6.5	1.4
West Tenmile Creek	3.9	1.9	0.7	6.5	1.4
Upper Tenmile Creek	1.1	3.4	1.9	6.4	1.3
Rock Creek-Boulder Creek	3.5	2.1	0.5	6.2	1.2
Dillon Reservoir	3.9	0.6	1.5	6.0	1.1
Lower Elliot Creek	0.5	0.5	1.9	5.0	0.5

[8] The Composite Hazard Rank is the average of the Wildfire Hazard Rank, Flooding/Debris Flow Rank, and Soil Erodibility Rank that is re-categorized into 5 categories using the procedure described in Front Range Watershed Protection Data Refinement Work Group (2009).

[9] Lower Elliot Creek watershed was skewing the categorization because of its low Composite Numeric Rank value (2.9) and was manually given a score slightly lower than the next lowest score