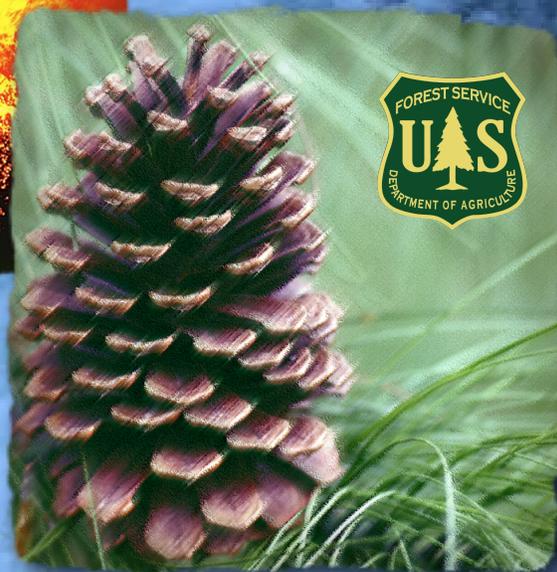

Big Thompson Phase 1 Watershed Assessment

Prioritization of watershed-based hazards to water supplies



Report Prepared for:

**USDA Forest Service
Rocky Mountain Region
Bark Beetle Incident**

Final Report • May 2010

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Big Thompson - Phase 1 Watershed Assessment

Prioritization of watershed-based hazards to water supplies

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.

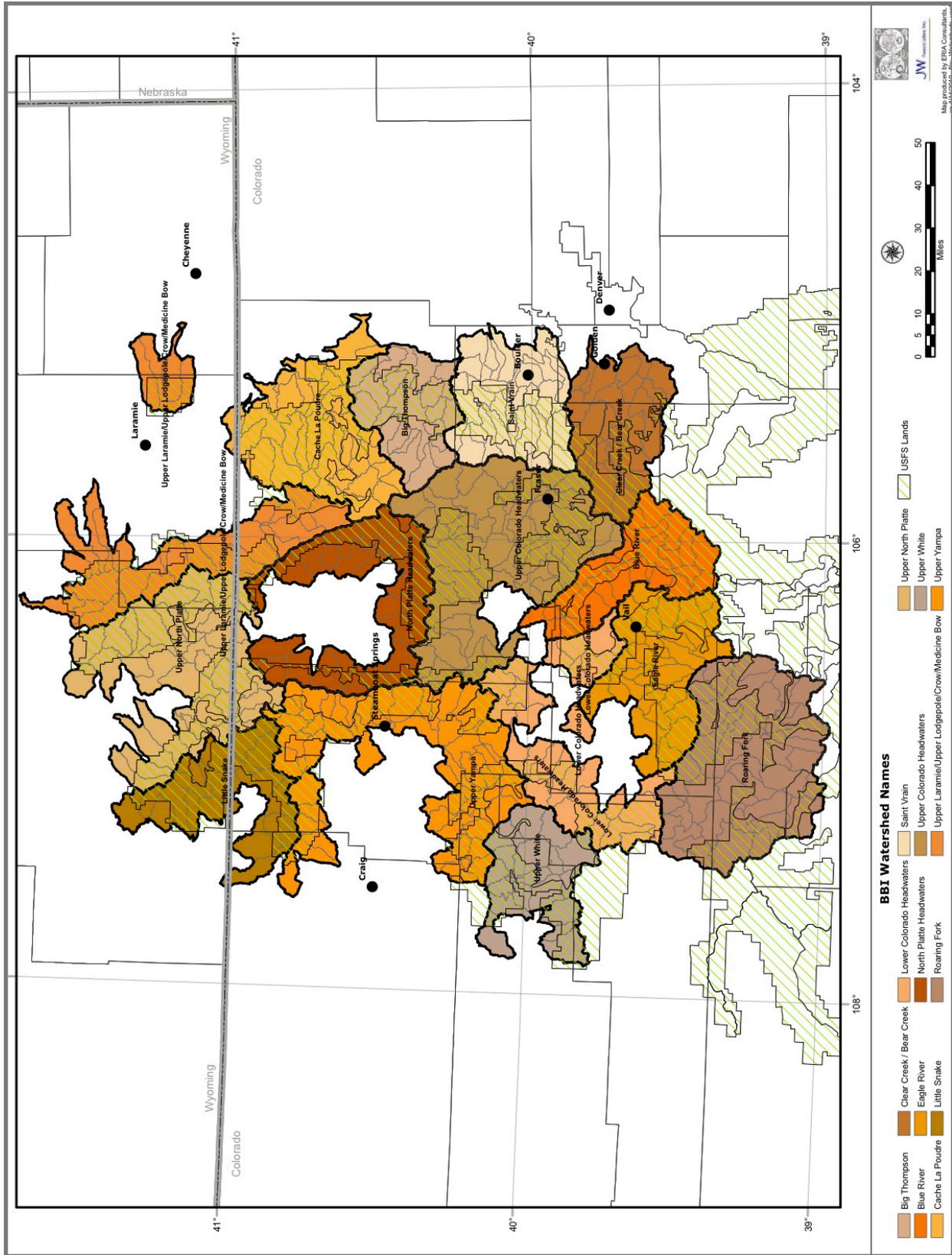


Figure 1. Bark Beetle Incident Phase 1 Watersheds

WATERSHED DESCRIPTION

The Big Thompson watershed is a Front Range watershed that typically begins at the continental divide and ends at the start of the western edge of the plains. It is a tributary to the South Platte River. This watershed assessment is designed to assess hazards from wildfire to water supply. Therefore, the subwatersheds that are entirely on the plains to the east were eliminated from this watershed assessment. The plains watersheds would have skewed the results of the assessment because they are relatively flat, have higher road densities and very different fire regimes.

The Big Thompson watershed is one fourth-level¹ (eight-digit) watershed (HUC 10190006) that is 532,032 acres in size and contains 30 sixth-level watersheds. For this watershed assessment, eight sixth-level watersheds were eliminated based upon their wildfire hazard, ruggedness, and an examination of how well they fit into this assessment. The Big Thompson watershed used in this analysis is 386,813 acres, contains five fifth-level watersheds and 22 sixth-level watersheds, which are the analysis units for this watershed assessment (Front Range Watershed Protection Data Refinement Work Group 2009). The Big Thompson watershed and its fifth-level and sixth-level watersheds are shown on Figure 2 and listed in Table 1.

¹ 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.

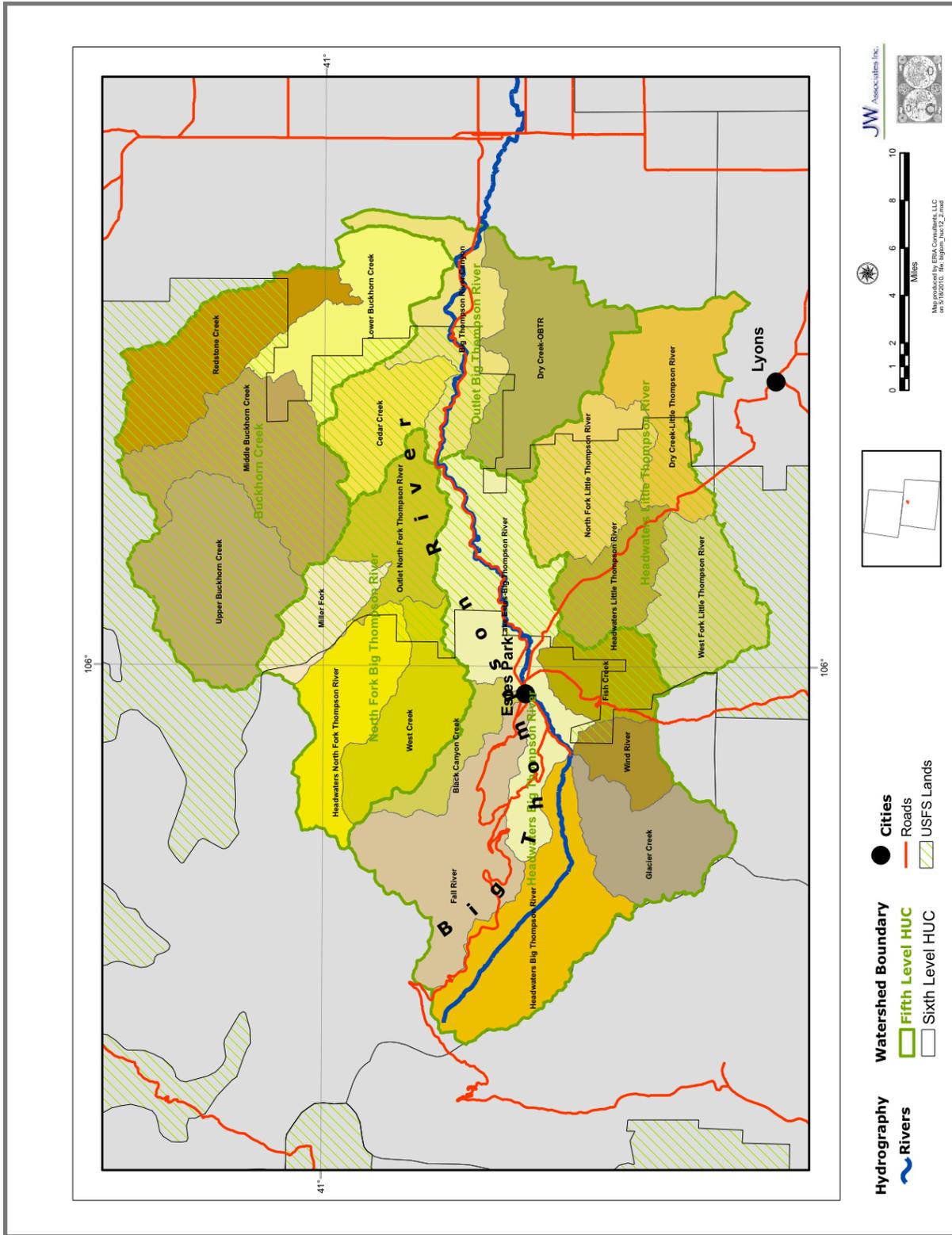


Figure 2. Big Thompson Watershed Analysis Area²

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

Table 1. Fifth-level and Sixth-level Watersheds in Big Thompson Watershed ³

Fifth-level Watershed	Sixth-level Watershed	Watershed Area (acres)	Hydrologic Unit Code (HUC)	Map Number
North Fork Big Thompson River	West Creek	15,809	101900060101	354
HUC 1019000601	Headwaters North Fork Thompson River	16,417	101900060102	355
	Miller Fork	8,933	101900060103	356
	Outlet North Fork Thompson River	13,344	101900060104	357
Headwaters Big Thompson River	Glacier Creek	16,117	101900060201	358
HUC 1019000602	Headwaters Big Thompson River	25,602	101900060202	359
	Wind River	6,532	101900060203	360
	Fall River	25,504	101900060204	361
	Black Canyon Creek	6,410	101900060205	362
	Fish Creek	9,982	101900060206	363
	Lake Estes-Big Thompson River	31,867	101900060207	364
Buckhorn Creek	Upper Buckhorn Creek	27,367	101900060301	365
HUC 1019000601	Middle Buckhorn Creek	25,358	101900060302	366
	Redstone Creek	19,848	101900060303	367
	Lower Buckhorn Creek	19,953	101900060304	368
Headwaters Little Thompson River	West Fork Little Thompson River	16,241	101900060401	369
HUC 1019000601	Headwaters Little Thompson River	11,369	101900060402	370
	North Fork Little Thompson River	17,806	101900060403	371
	Dry Creek-Little Thompson River	18,638	101900060404	372
Outlet Big Thompson River	Cedar Creek	12,099	101900060601	373
HUC 1019000601	Dry Creek - OBTR	23,922	101900060602	352
	Big Thompson River Canyon	17,695	101900060603	353
	Total Area	386,813		

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 - Big Thompson 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 through 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 Big Thompson 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: Miller Fork and Upper Buckhorn Creek. Five watersheds were ranked as Category 4, which is the next highest category (see Table B-1 in Appendix B).

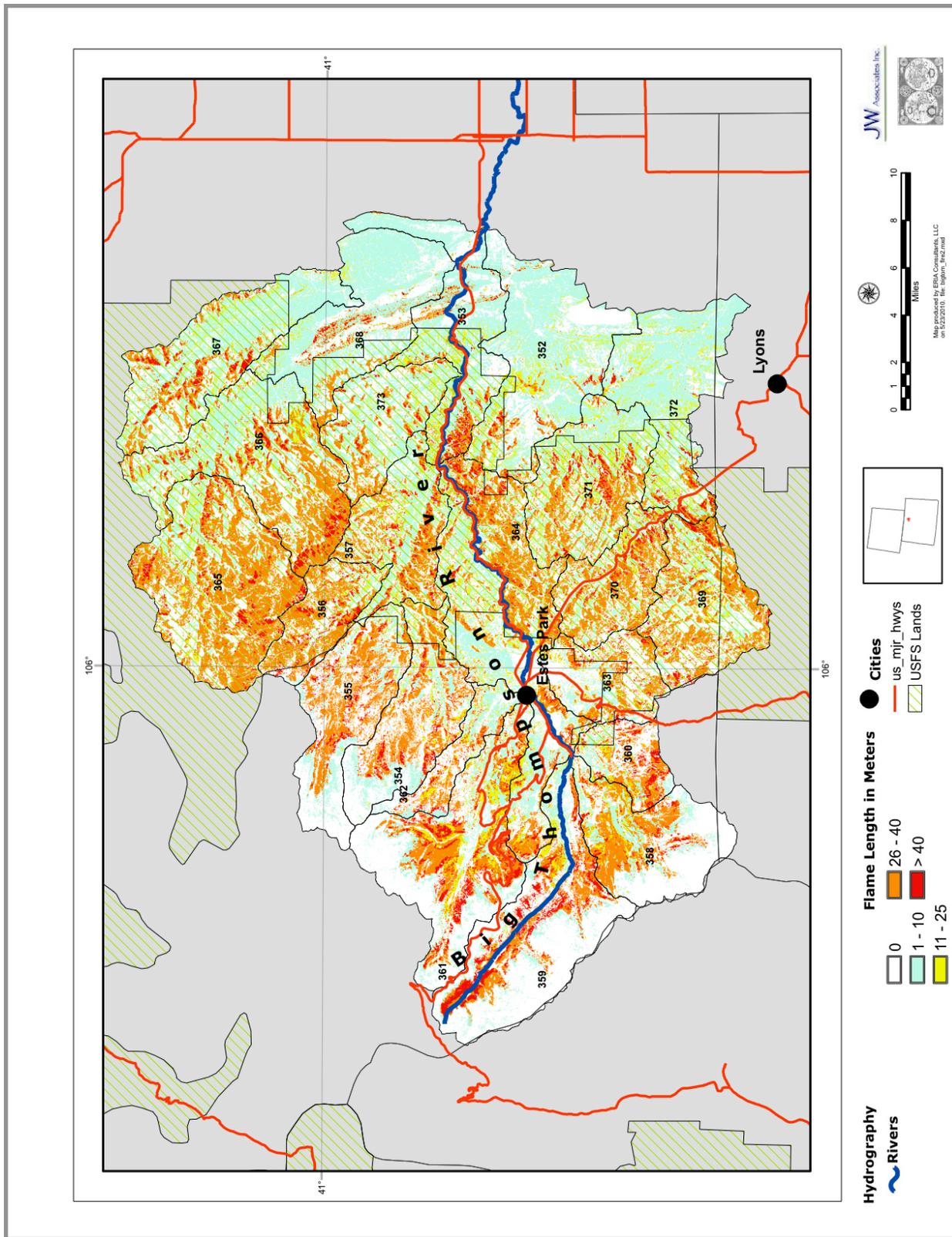


Figure 3. Big Thompson Watershed Wildfire Hazard Modeling Results

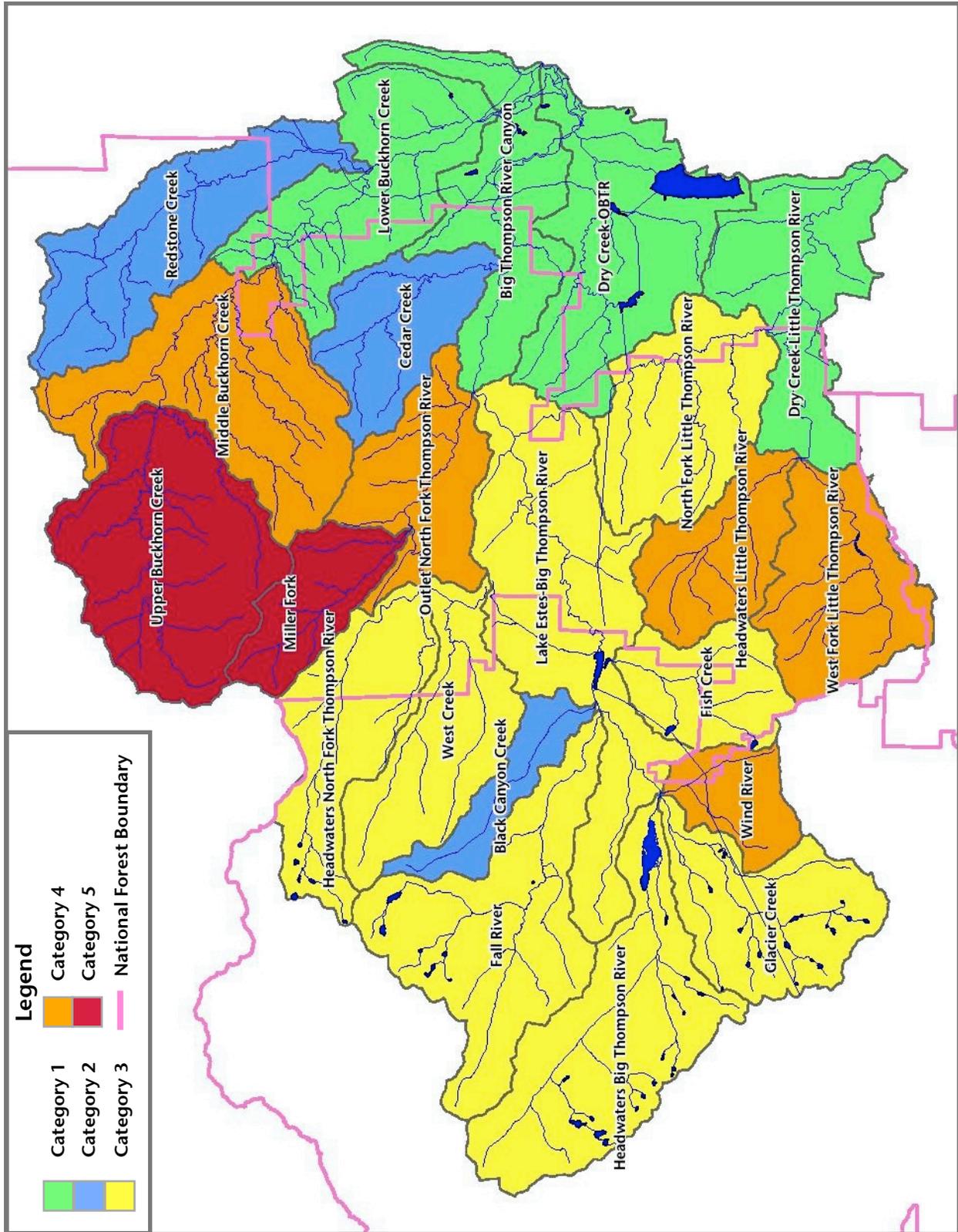


Figure 4. Big Thompson Watershed Wildfire Hazard Ranking

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; Dry Creek-Little Thompson River, and Big Thompson River Canyon.

Figure 5 displays the categorized ruggedness for the Big Thompson 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 Black Canyon Creek, Wind River, Headwaters North Fork Thompson River, Glacier Creek, West Creek and Miller Fork. Black Canyon Creek watershed was manually adjusted because it was skewing the results of the categorization because of its high value.

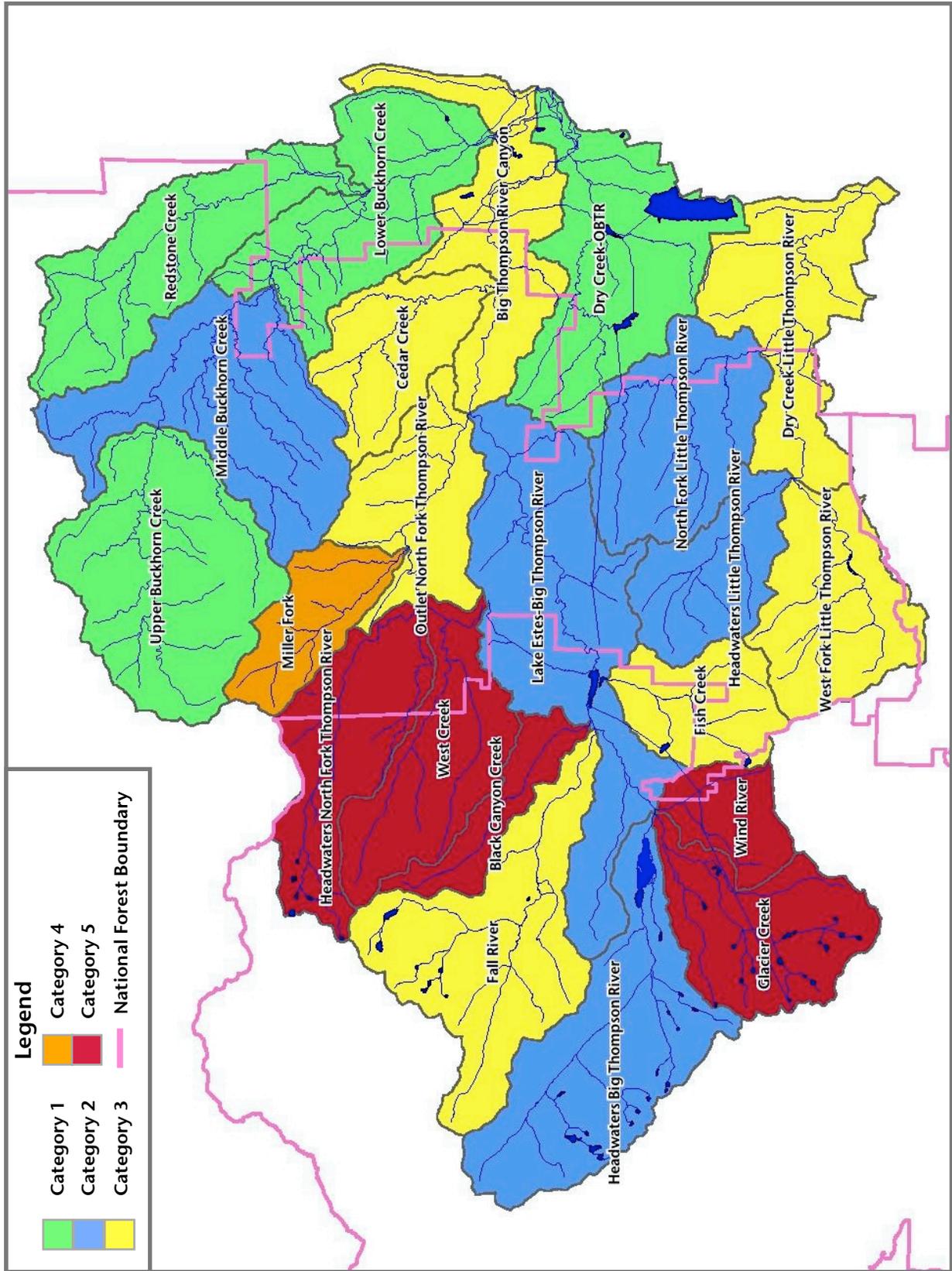


Figure 5. Big Thompson Watershed Ruggedness Ranking

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 Wind River, Fall River, Black Canyon Creek, Fish Creek, and Lake Estes-Big Thompson River watersheds were all adjusted down because they contain towns or housing developments that display very high road density or have road systems outside of the forest. The adjustments are displayed on Table B-3 in Appendix B.

Figure 7 displays the categorized road density for the Big Thompson Watershed and tabular results are presented in Appendix B (Table B-3). Figure 7 shows that the highest rankings are in Fish Creek, Lower Buckhorn Creek, Lake Estes-Big Thompson River, Dry Creek - OBTR and Dry Creek-Little Thompson River.

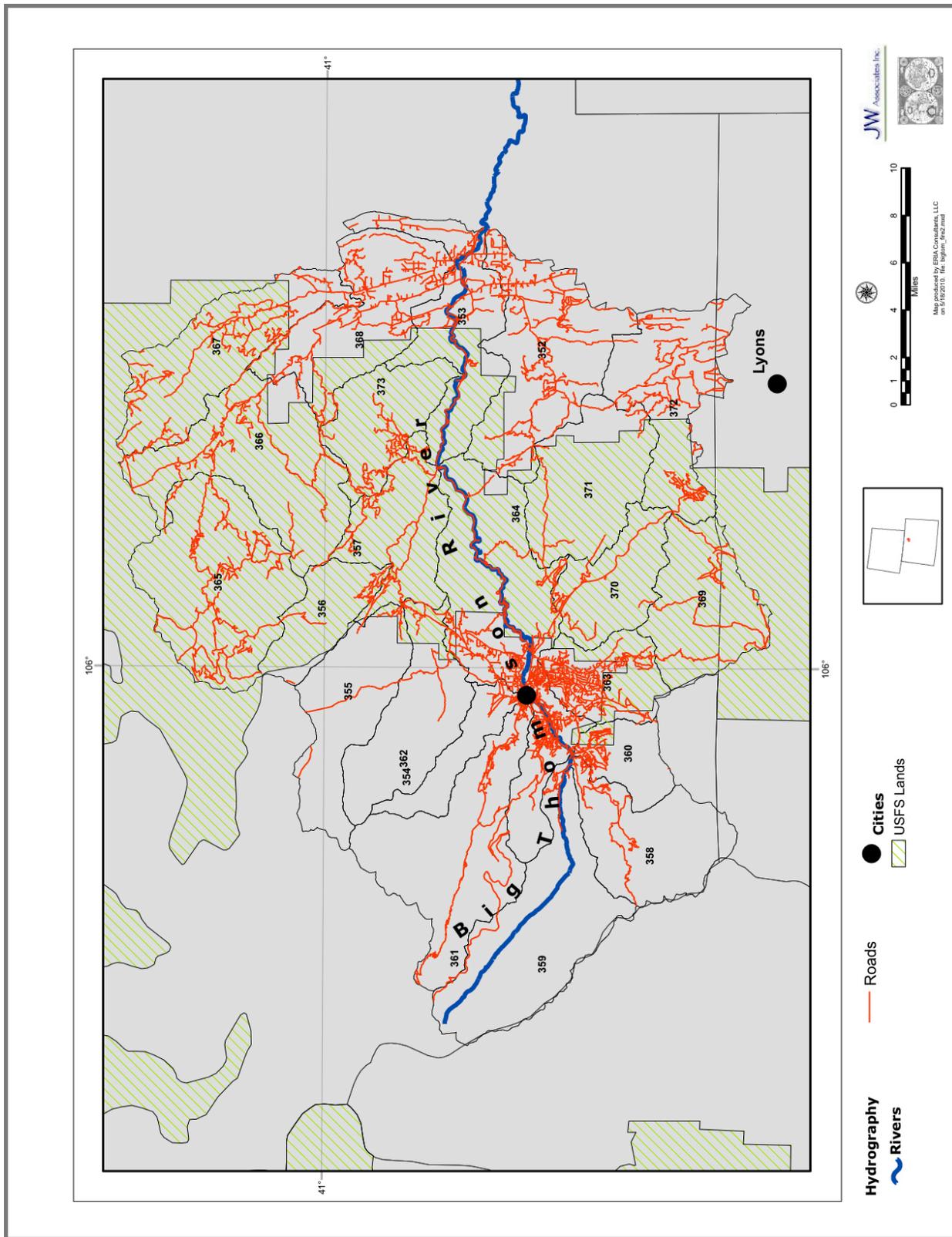


Figure 6. Big Thompson Watershed Roads Map

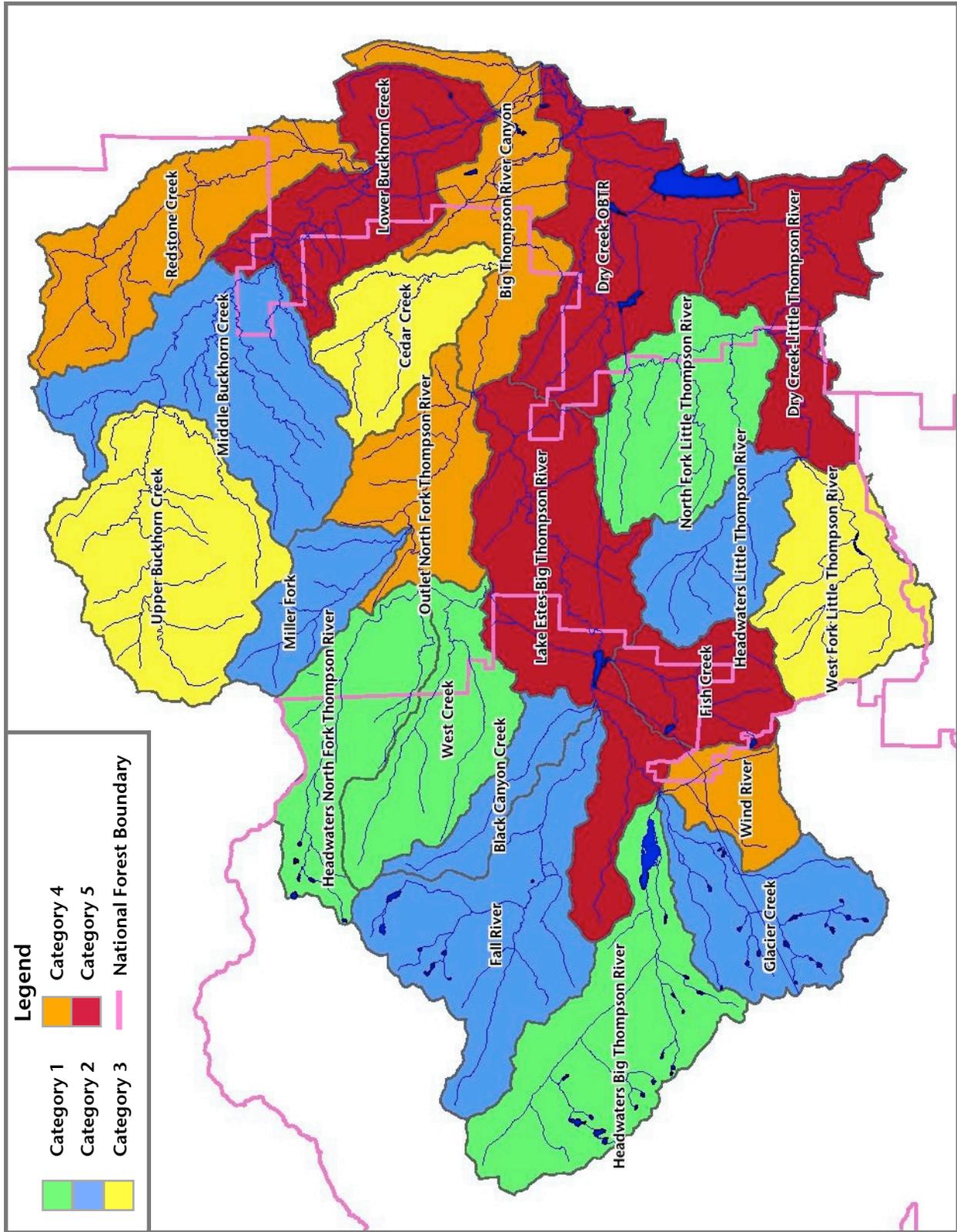


Figure 7. Big Thompson Watershed Road Density Ranking

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 Eagle 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 Wind River and Black Canyon Creek.

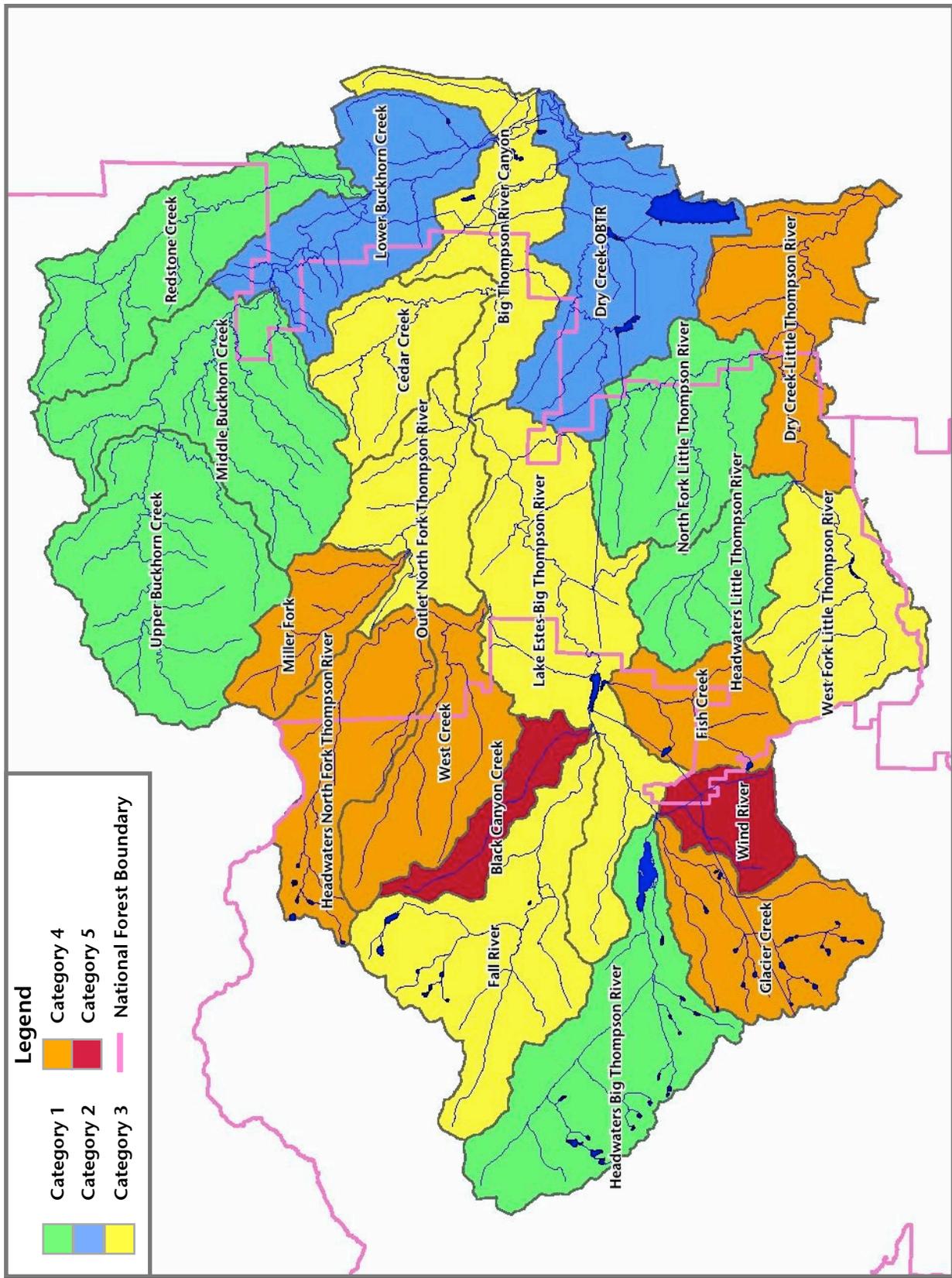


Figure 8. Big Thompson Watershed Flooding/Debris Flow Hazard Ranking

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 United 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 Headwaters Big Thompson River, Fall River, Glacier Creek, and Black Canyon Creek. Glacier Creek, Headwaters Big Thompson River, and Fall River watersheds were skewing the categorization because of their high soil erodibility values and were manually given a score slightly higher than the next highest score (Table B-5 in Appendix B).

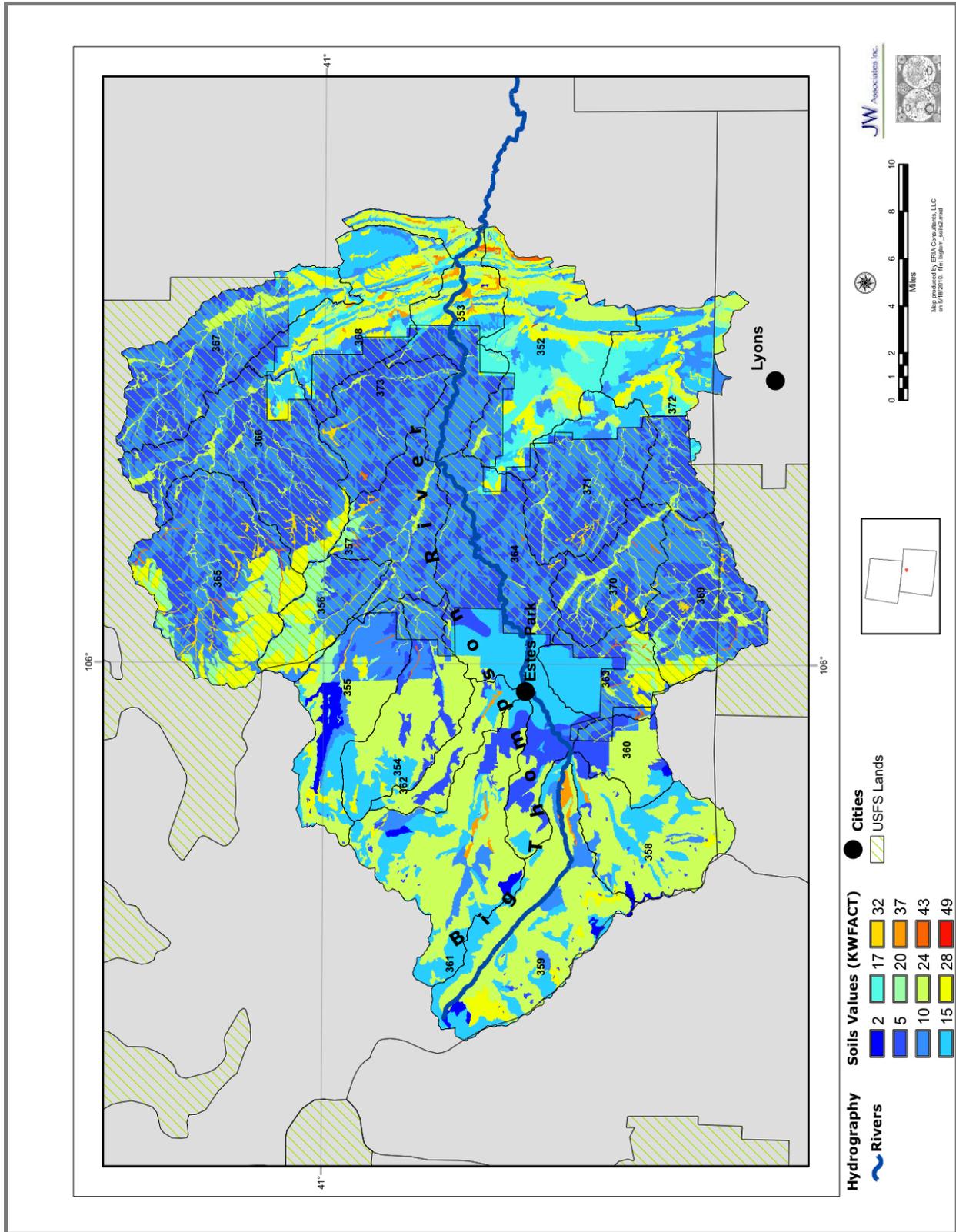


Figure 9. Big Thompson Watershed Soils K-Factor Map

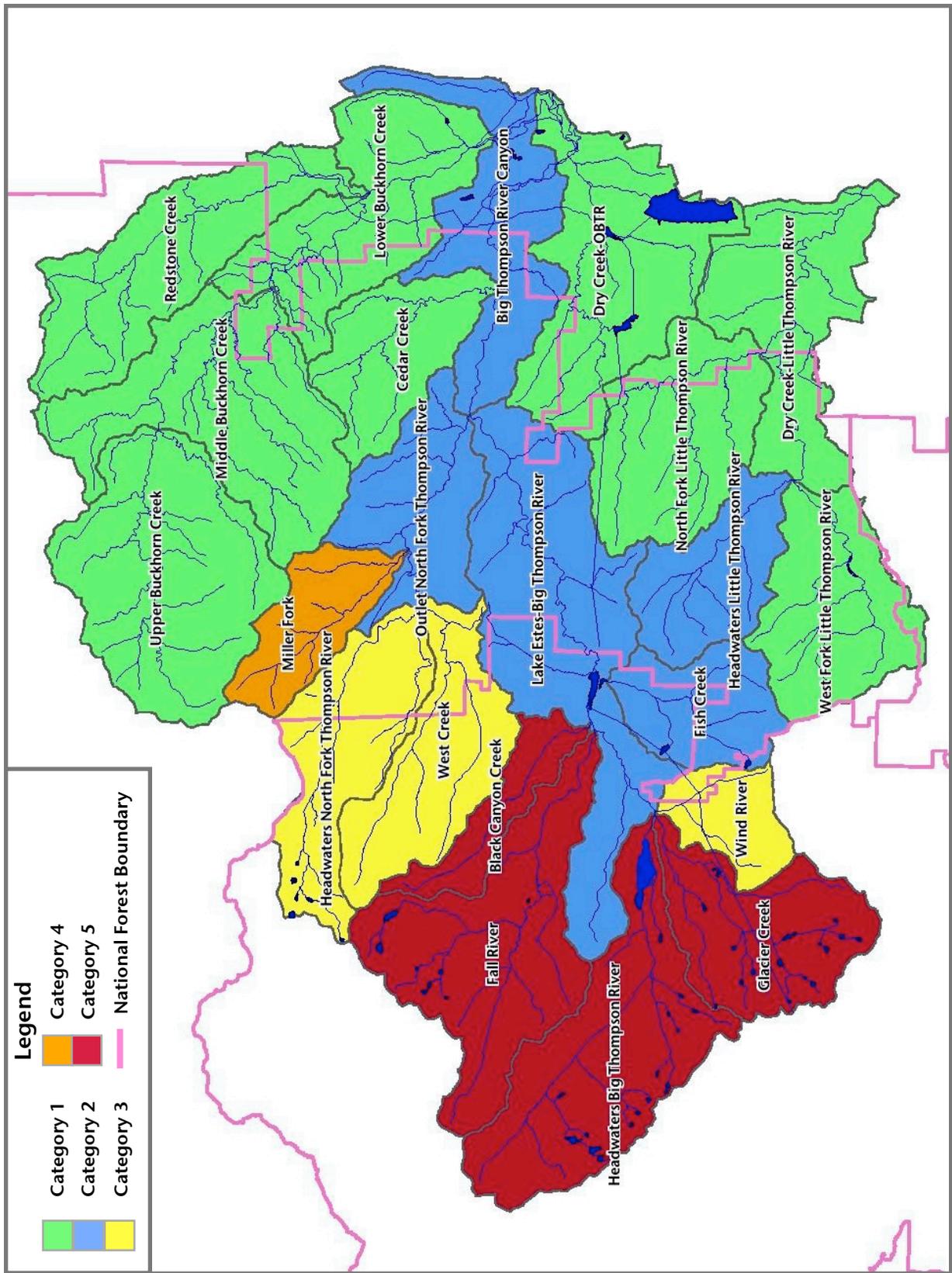


Figure 10. Big Thompson Watershed Potential Soil Erodibility Hazard Ranking

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 Big Thompson 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 Wind River, Miller Fork, Black Canyon Creek, Glacier Creek and Fall River. Additionally, there are three watersheds in Category 4.

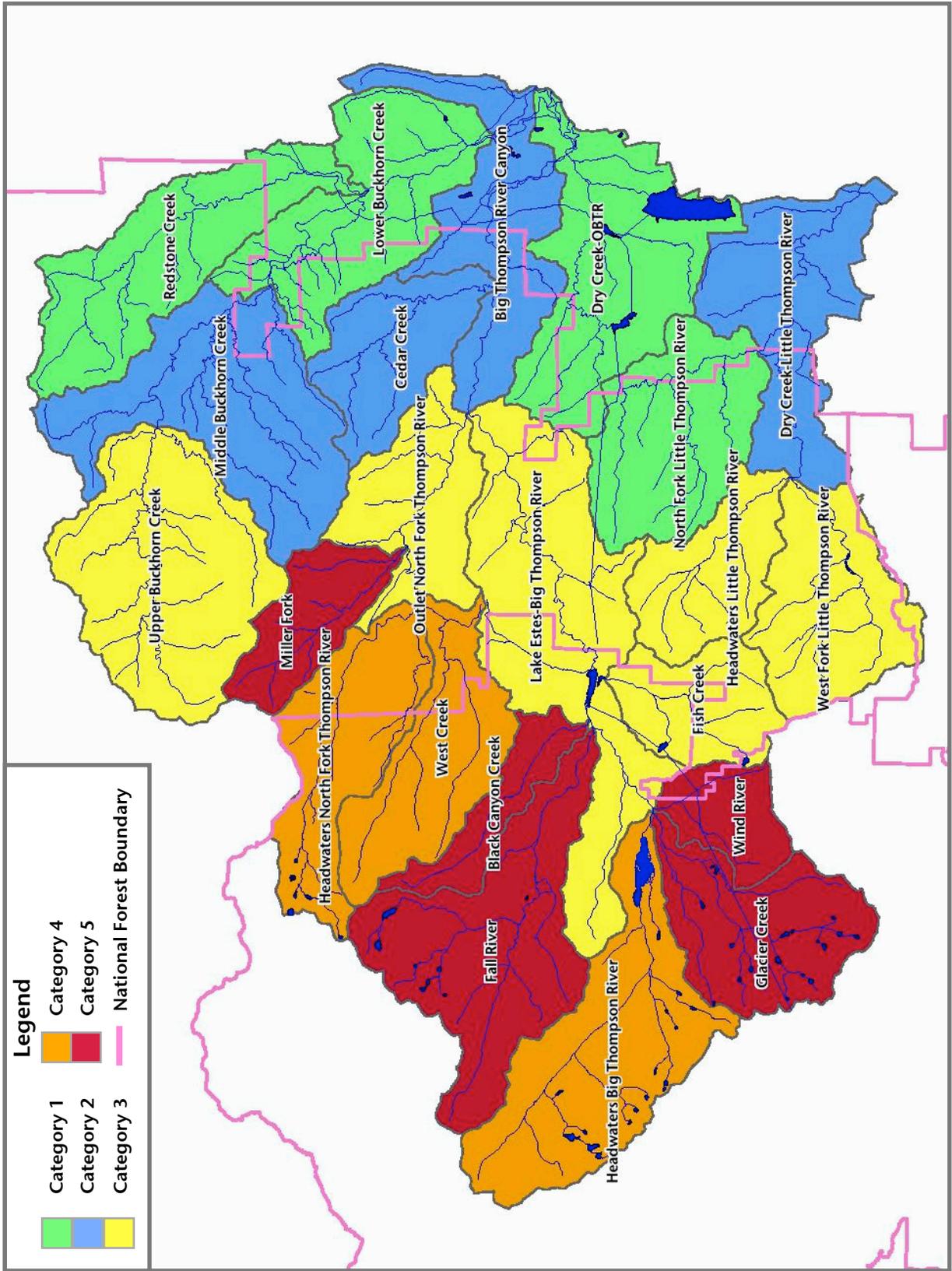


Figure 11. Big Thompson Watershed Composite Hazard Ranking

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.

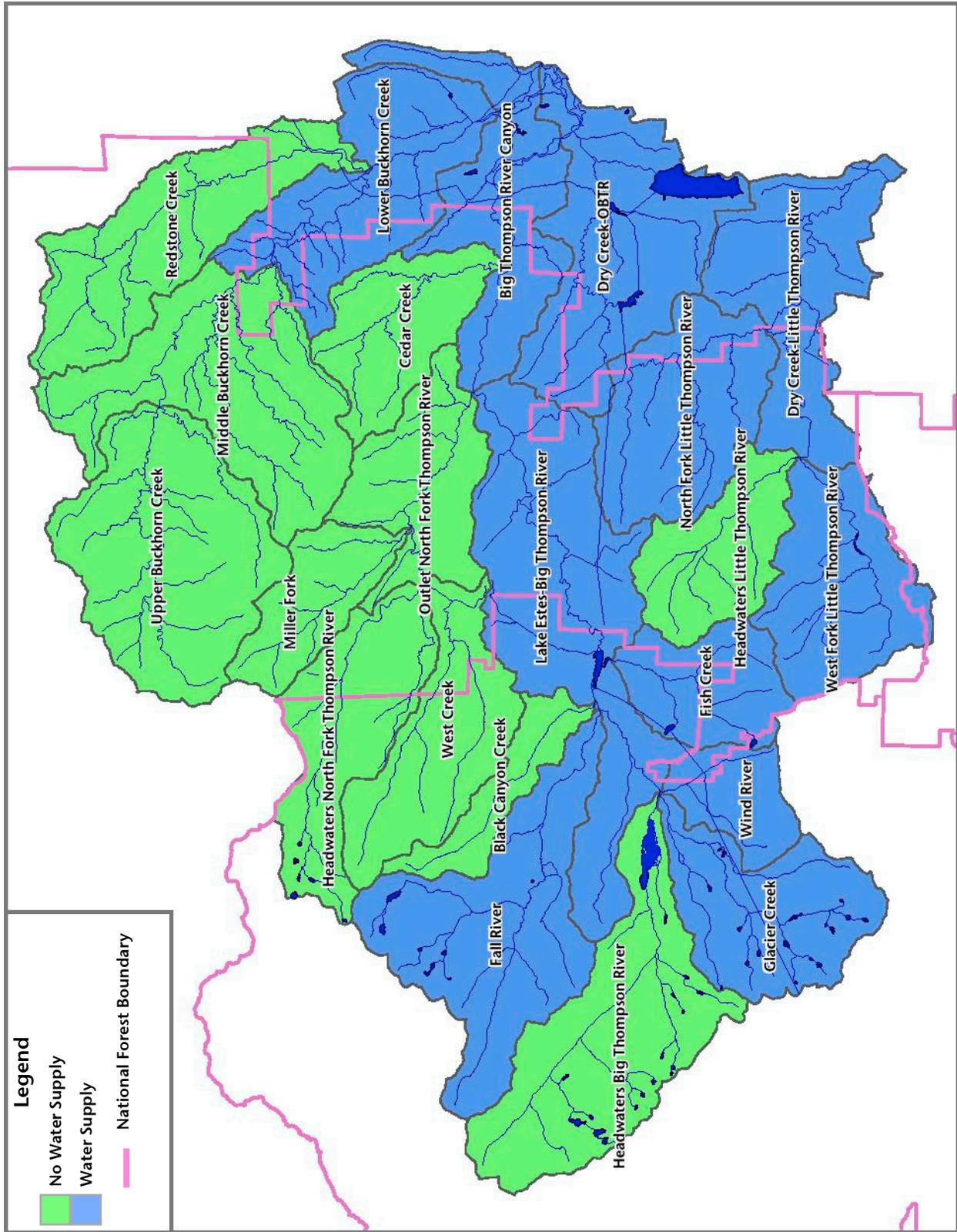


Figure 12. Big Thompson Watershed Water Supply Map

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APPENDIX A

BIG THOMPSON 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
Big Thompson	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 BIG THOMPSON WATERSHED ASSESSMENT RESULTS

Table B-1. Big Thompson Watershed Wildfire Hazard Ranking

Sixth-level Watershed Name	Watershed Area (acres)	Wildfire Hazard Calculation	Wildfire Hazard Rank
Miller Fork	8,933	59.7%	5.5
Upper Buckhorn Creek	27,367	57.2%	5.3
Headwaters Little Thompson River	11,369	48.7%	4.4
Wind River	6,532	47.9%	4.4
West Fork Little Thompson River	16,241	44.3%	4.0
Middle Buckhorn Creek	25,358	39.9%	3.6
Outlet North Fork Thompson River	13,344	38.8%	3.5
Headwaters North Fork Thompson River	16,417	37.2%	3.3
West Creek	15,809	35.5%	3.2
Lake Estes-Big Thompson River	31,867	34.7%	3.1
Fall River	25,504	34.1%	3.0
North Fork Little Thompson River	17,806	33.0%	2.9
Headwaters Big Thompson River	25,602	31.3%	2.8
Fish Creek	9,982	30.1%	2.7
Glacier Creek	16,117	30.0%	2.7
Black Canyon Creek	6,410	26.4%	2.3
Redstone Creek	19,848	21.8%	1.9
Cedar Creek	12,099	21.3%	1.8
Big Thompson River Canyon	17,695	15.1%	1.2
Lower Buckhorn Creek	19,953	10.1%	0.8
Dry Creek-Little Thompson River	18,638	9.3%	0.7
Dry Creek - OBTR	23,922	7.5%	0.5

Table B-2. Big Thompson Watershed Ruggedness Ranking^{1, 2, 3}

Sixth-level Watershed Name	Maximum Elevation	Minimum Elevation	Difference Elevation	Ruggedness	Ruggedness Rank
Black Canyon Creek	13,146	7,554	5,592	0.2500	5.5
Wind River	11,667	7,757	3,910	0.2318	4.9
Headwaters North Fork Thompson River	13,396	7,272	6,124	0.2290	4.8
Glacier Creek	13,704	7,797	5,907	0.2229	4.7
West Creek	13,002	7,180	5,822	0.2219	4.6
Miller Fork	11,247	6,990	4,257	0.2158	4.4
Fall River	13,563	7,557	6,006	0.1802	3.3
West Fork Little Thompson River	11,280	6,750	4,530	0.1703	3.0
Big Thompson River Canyon	8,318	5,035	3,283	0.1672	2.9
Fish Creek	10,949	7,472	3,477	0.1667	2.9
Dry Creek-Little Thompson River	8,564	5,228	3,336	0.1656	2.9
Cedar Creek	9,335	5,632	3,703	0.1613	2.7
Outlet North Fork Thompson River	9,886	6,170	3,716	0.1541	2.5
Headwaters Big Thompson River	12,907	7,918	4,989	0.1494	2.4
Lake Estes-Big Thompson River	11,182	6,143	5,038	0.1352	1.9
Middle Buckhorn Creek	10,004	5,684	4,320	0.1300	1.8
North Fork Little Thompson River	9,273	5,753	3,519	0.1264	1.6
Headwaters Little Thompson River	9,545	6,776	2,768	0.1244	1.6
Upper Buckhorn Creek	10,604	6,557	4,048	0.1172	1.4
Dry Creek - OBTR	8,453	5,028	3,424	0.1061	1.0
Redstone Creek	8,331	5,317	3,014	0.1025	0.9
Lower Buckhorn Creek	7,728	5,084	2,644	0.0897	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; Dry Creek-Little Thompson River (0.1171), and Big Thompson River Canyon (0.1183).

³ Black Canyon Creek watershed was manually adjusted because it was skewing the results of the categorization because of its high value (0.3347).

Table B-3. Big Thompson Watershed Road Density Ranking⁴

Sixth-level Watershed Name	Roads (miles)	Roads Adjusted (miles)	Watershed Area (sq. mi.)	Road density (miles per sq. mi.)	Road Density Rank
Fish Creek	83.6	41.8	15.60	2.68	5.5
Lower Buckhorn Creek	81.3	81.3	31.18	2.61	5.3
Lake Estes-Big Thompson River	161.7	121.3	49.79	2.44	5.0
Dry Creek - OBTR	88.4	88.4	37.38	2.36	4.8
Dry Creek-Little Thompson River	66.9	66.9	29.12	2.30	4.7
Redstone Creek	62.1	62.1	31.01	2.00	4.1
Big Thompson River Canyon	54.7	54.7	27.65	1.98	4.0
Wind River	25.9	19.4	10.21	1.90	3.9
Outlet North Fork Thompson River	36.5	36.5	20.85	1.75	3.5
Upper Buckhorn Creek	71.5	71.5	42.76	1.67	3.4
Cedar Creek	26.7	26.7	18.90	1.41	2.8
West Fork Little Thompson River	32.3	32.3	25.38	1.27	2.5
Fall River	50.3	50.3	39.85	1.26	2.5
Middle Buckhorn Creek	49.8	49.8	39.62	1.26	2.5
Black Canyon Creek	11.8	11.8	10.02	1.17	2.3
Headwaters Little Thompson River	19.5	19.5	17.76	1.10	2.1
Glacier Creek	23.6	23.6	25.18	0.94	1.8
Miller Fork	12.4	12.4	13.96	0.89	1.7
West Creek	15.4	15.4	24.70	0.62	1.1
North Fork Little Thompson River	14.8	14.8	27.82	0.53	0.9
Headwaters North Fork Thompson River	10.9	10.9	25.65	0.43	0.7
Headwaters Big Thompson River	12.8	12.8	40.00	0.32	0.5

⁴ The road density was adjusted based upon the procedure discussed in the report (p. 12). The original road density values were; Fish Creek (5.36), Lake Estes-Big Thompson River (3.25), and Wind River (2.54).

Table B-4. Big Thompson Watershed Flooding/Debris Flow Hazard Ranking

Sixth-level Watershed Name	Ruggedness Ranking	Road Density Ranking	Combined Numeric Rank	Combined Ranking
Wind River	4.9	3.9	13.72	5.5
Black Canyon Creek	5.5	2.3	13.31	5.3
Fish Creek	2.9	5.5	11.31	4.2
Glacier Creek	4.7	1.8	11.12	4.1
Miller Fork	4.4	1.7	10.57	3.8
Dry Creek-Little Thompson River	2.9	4.7	10.42	3.8
Headwaters North Fork Thompson River	4.8	0.7	10.41	3.8
West Creek	4.6	1.1	10.38	3.7
Big Thompson River Canyon	2.9	4.0	9.86	3.5
Fall River	3.3	2.5	9.14	3.1
Lake Estes-Big Thompson River	1.9	5.0	8.82	2.9
West Fork Little Thompson River	3.0	2.5	8.55	2.8
Outlet North Fork Thompson River	2.5	3.5	8.55	2.8
Cedar Creek	2.7	2.8	8.28	2.6
Dry Creek - OBTR	1.0	4.8	6.86	1.9
Lower Buckhorn Creek	0.5	5.3	6.34	1.6
Upper Buckhorn Creek	1.4	3.4	6.08	1.5
Middle Buckhorn Creek	1.8	2.5	6.00	1.4
Redstone Creek	0.9	4.1	5.87	1.4
Headwaters Little Thompson River	1.6	2.1	5.31	1.1
Headwaters Big Thompson River	2.4	0.5	5.22	1.0
North Fork Little Thompson River	1.6	0.9	4.24	0.5

Table B-5. Big Thompson Watershed Soil Erodibility Ranking^{5, 6}

Sixth-level Watershed Name	Severe (%)	Very Severe (%)	Soil Erodibility Value	Soil Erodibility Rank
Headwaters Big Thompson River	22.5%	26.1%	0.590	5.5
Fall River	26.2%	20.7%	0.580	5.4
Glacier Creek	18.3%	23.3%	0.570	5.3
Black Canyon Creek	22.0%	17.1%	0.561	5.2
Miller Fork	29.1%	5.8%	0.408	3.7
Wind River	20.2%	8.9%	0.381	3.4
Headwaters North Fork Thompson River	20.4%	8.6%	0.375	3.4
West Creek	19.1%	6.9%	0.328	2.9
Outlet North Fork Thompson River	17.8%	1.5%	0.209	1.8
Big Thompson River Canyon	16.4%	1.8%	0.200	1.7
Fish Creek	11.2%	4.1%	0.195	1.6
Headwaters Little Thompson River	13.2%	2.9%	0.190	1.6
Lake Estes-Big Thompson River	13.8%	2.3%	0.184	1.5
West Fork Little Thompson River	11.0%	3.1%	0.172	1.4
North Fork Little Thompson River	14.3%	1.2%	0.167	1.3
Upper Buckhorn Creek	13.0%	1.4%	0.158	1.3
Dry Creek-Little Thompson River	11.4%	1.9%	0.152	1.2
Redstone Creek	10.0%	1.2%	0.124	0.9
Dry Creek - OBTR	8.7%	1.0%	0.108	0.8
Middle Buckhorn Creek	8.7%	0.7%	0.102	0.7
Cedar Creek	7.2%	0.5%	0.082	0.5
Lower Buckhorn Creek	6.0%	1.1%	0.081	0.5

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

⁶ Glacier Creek, Headwaters Big Thompson River, and Fall River watersheds were skewing the categorization because of their high soil erodibility values (originally 0.648, 0.747 and 0.677 respectively) and were manually given a score slightly higher than the next highest score

Table B-6. Big Thompson Watershed Composite Hazard Ranking⁷

Sixth-level Watershed Name	Wildfire Hazard Rank	Flooding/Debris Flow Rank	Soil Erodibility Rank	Composite Numeric Rank	Composite Hazard Rank
Wind River	4.4	5.5	3.4	13.3	5.5
Miller Fork	5.5	3.8	3.7	13.0	5.4
Black Canyon Creek	2.3	5.3	5.2	12.8	5.3
Glacier Creek	2.7	4.1	5.3	12.1	4.9
Fall River	3.0	3.1	5.4	11.5	4.6
Headwaters North Fork Thompson River	3.3	3.8	3.4	10.5	4.1
West Creek	3.2	3.7	2.9	9.9	3.8
Headwaters Big Thompson River	2.8	1.0	5.5	9.3	3.6
Fish Creek	2.7	4.2	1.6	8.5	3.2
West Fork Little Thompson River	4.0	2.8	1.4	8.2	3.1
Outlet North Fork Thompson River	3.5	2.8	1.8	8.0	3.0
Upper Buckhorn Creek	5.3	1.5	1.3	8.0	3.0
Lake Estes-Big Thompson River	3.1	2.9	1.5	7.5	2.7
Headwaters Little Thompson River	4.4	1.1	1.6	7.1	2.5
Big Thompson River Canyon	1.2	3.5	1.7	6.4	2.2
Middle Buckhorn Creek	3.6	1.4	0.7	5.7	1.9
Dry Creek-Little Thompson River	0.7	3.8	1.2	5.6	1.8
Cedar Creek	1.8	2.6	0.5	5.0	1.5
North Fork Little Thompson River	2.9	0.5	1.3	4.8	1.4
Redstone Creek	1.9	1.4	0.9	4.2	1.1
Dry Creek - OBTR	0.5	1.9	0.8	3.1	0.6
Lower Buckhorn Creek	0.8	1.6	0.5	2.9	0.5

⁷ 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).