Upper White 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

This report was prepared by:

PO Box 3759

Breckenridge, Colorado 80424

and

JG Management Systems, Inc.

336 Main Street, Suite 207

Grand Junction, Colorado 81501

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Upper White 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.

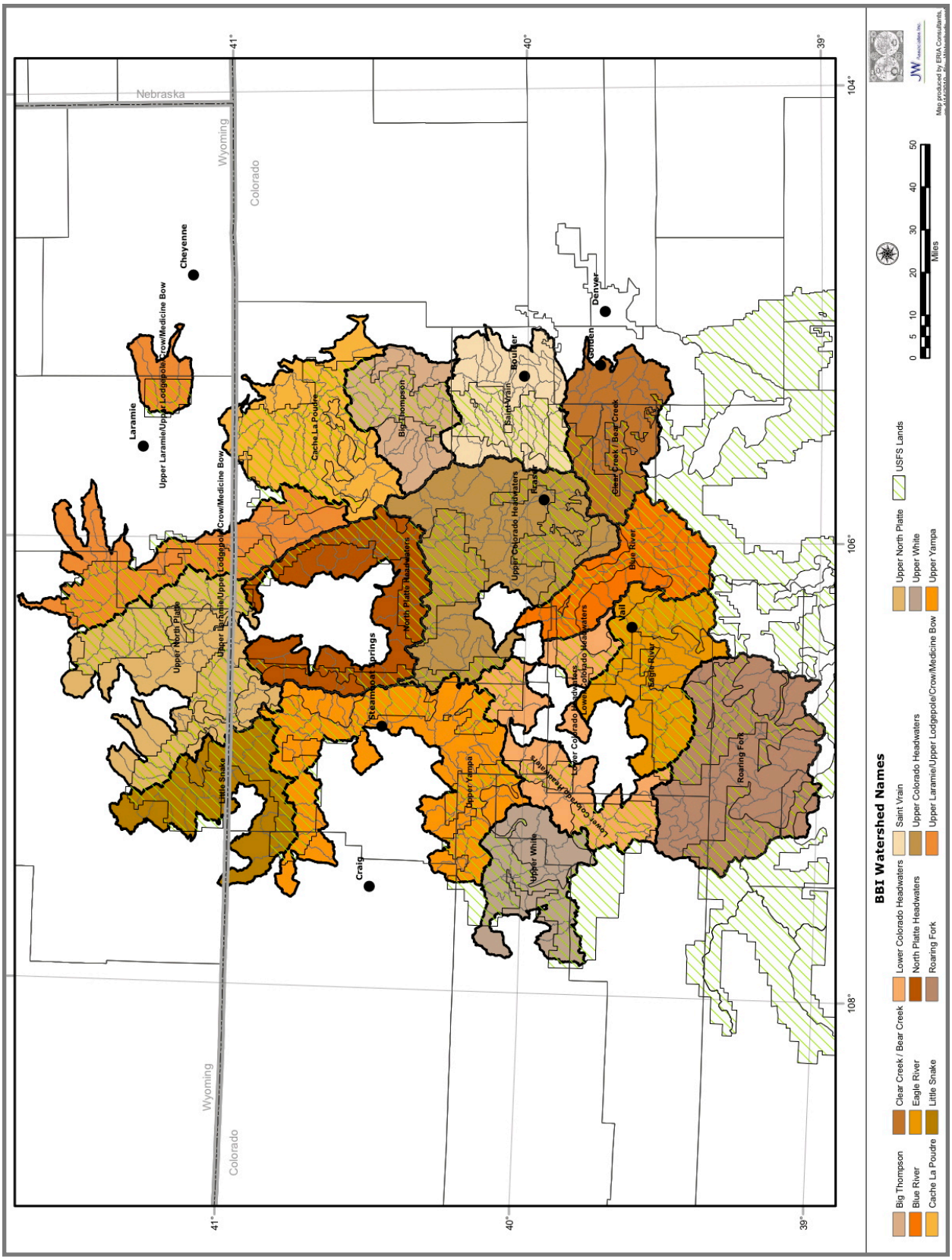

Figure 1. Bark Beetle Incident Phase 1 Watersheds

WATERSHED DESCRIPTION

The Upper White watershed is located in the Colorado Plateau country in northwestern Colorado. The Upper White flows west into Utah an joins the Green River. This watershed assessment is designed to assess hazards from forest fires to water supply. Therefore, the subwatersheds that are mostly non-forested were eliminated from this watershed assessment.

The Upper White Watershed is approximately 868,091 acres in area and is one fourth-level[1] (eight-digit) watershed (HUC 14050005). For this watershed assessment, 20 sixth-level watersheds were eliminated based upon their wildfire hazard, ruggedness, and an examination of how well they fit into this assessment. The Upper White watershed used in this analysis is 412,015 acres, contains three fifth-level watersheds and 18 sixth-level watersheds, which are the analysis units for this watershed assessment (Front Range Watershed Protection Data Refinement Work Group 2009). The Upper White 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.

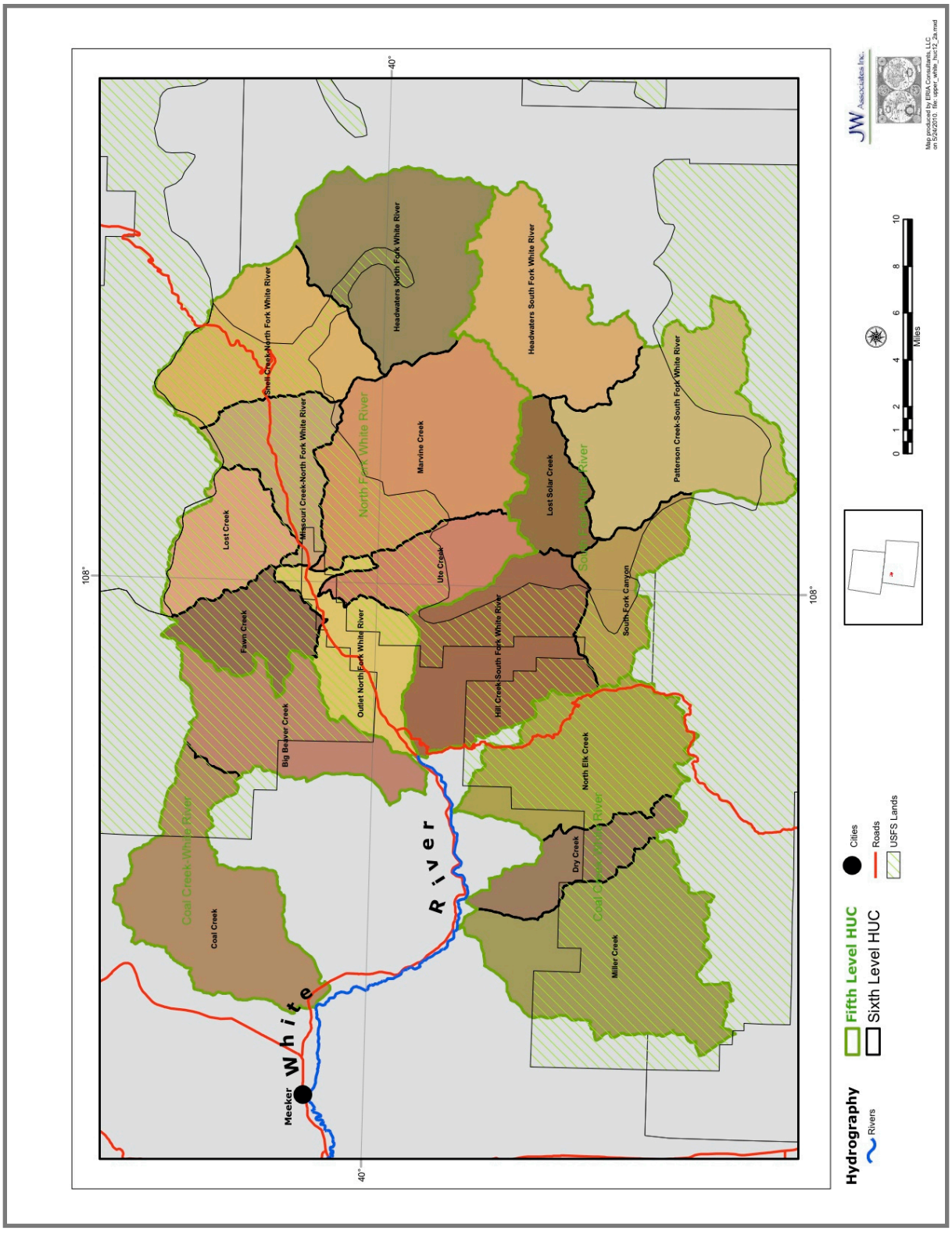

Figure 2. Upper White Watershed Analysis Area[2]

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

Table 1. Fifth-level and Sixth-level Watersheds in Upper White Watershed[3]

Fifth-level Watershed	Sixth-level Watershed	Watershed Area (acres)	Hydrologic Unit Code (HUC)	Map #
North Fork White River HUC 1405000501	Headwaters North Fork White River	32,635	140500050101	200
	Snell Creek-North Fork White River	25,873	140500050102	201
	Lost Creek	13,834	140500050103	202
	Marvine Creek	38,344	140500050104	203
	Missouri Creek-North Fork White River	14,505	140500050105	204
	Ute Creek	13,315	140500050106	205
	Fawn Creek	12,062	140500050107	206
	Outlet North Fork White River	16,317	140500050108	207
North Fork White River HUC 1405000502	Headwaters South Fork White River	25,211	140500050201	208
	Lost Solar Creek	10,417	140500050202	209
	Patterson Creek-South Fork White River	36,372	140500050203	210
	South Fork Canyon	13,209	140500050204	211
	Hill Creek-South Fork White River	30,190	140500050205	212
Coal Creek-White River HUC 1405000503	Big Beaver Creek	21,886	140500050301	213
	North Elk Creek	28,375	140500050302	214
	Dry Creek	11,446	140500050303	215
	Miller Creek	37,567	140500050304	216
	Coal Creek	30,457	140500050307	217
	Total Area	**412,015**		

[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 - Upper White 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 Upper White 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: Snell Creek-North Fork White River, Ute Creek, and Lost Solar Creek. Four watersheds were ranked as Category 4, which is the next highest category (see Table B-1 in Appendix B).

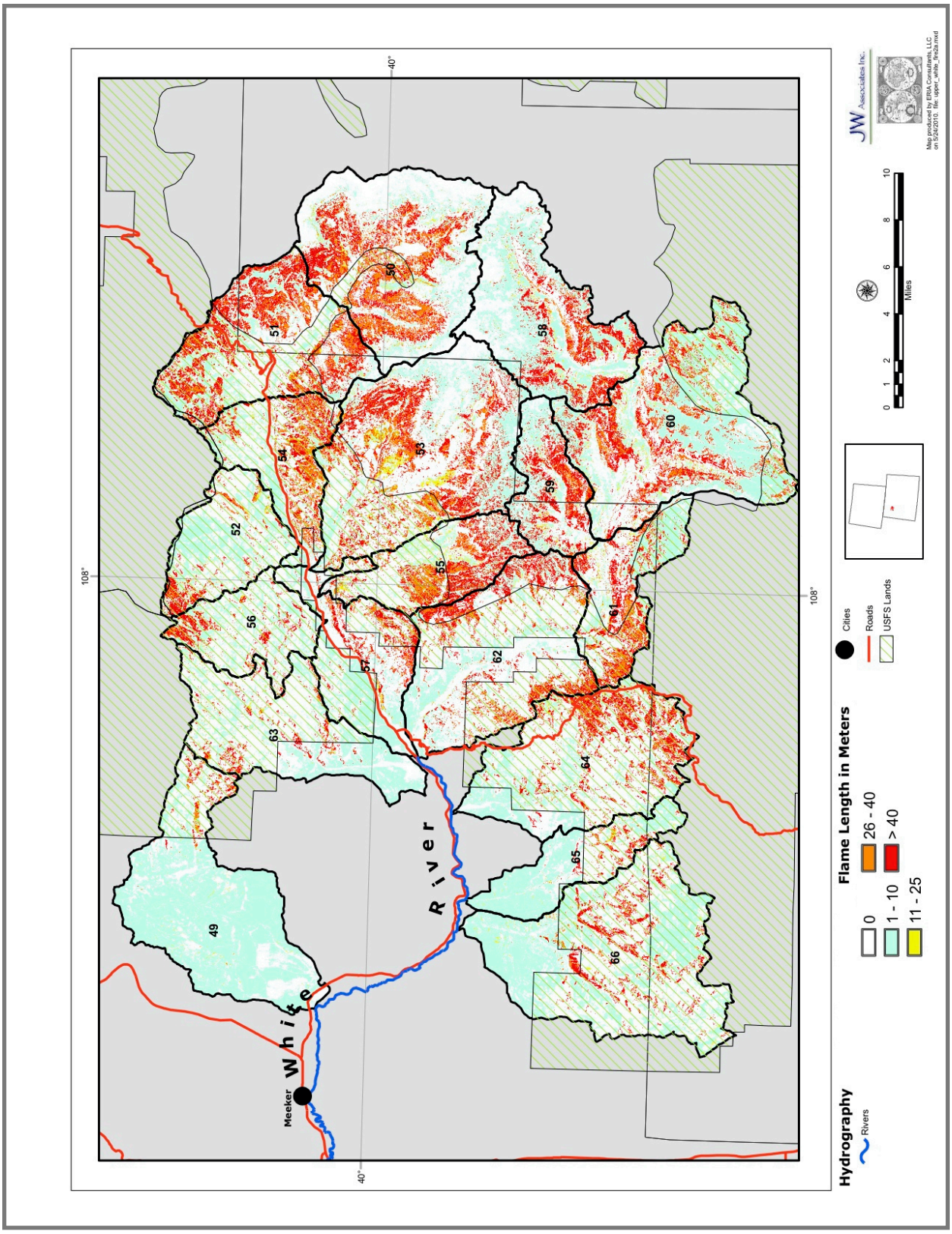

Figure 3. Upper White Watershed Wildfire Hazard Modeling Results

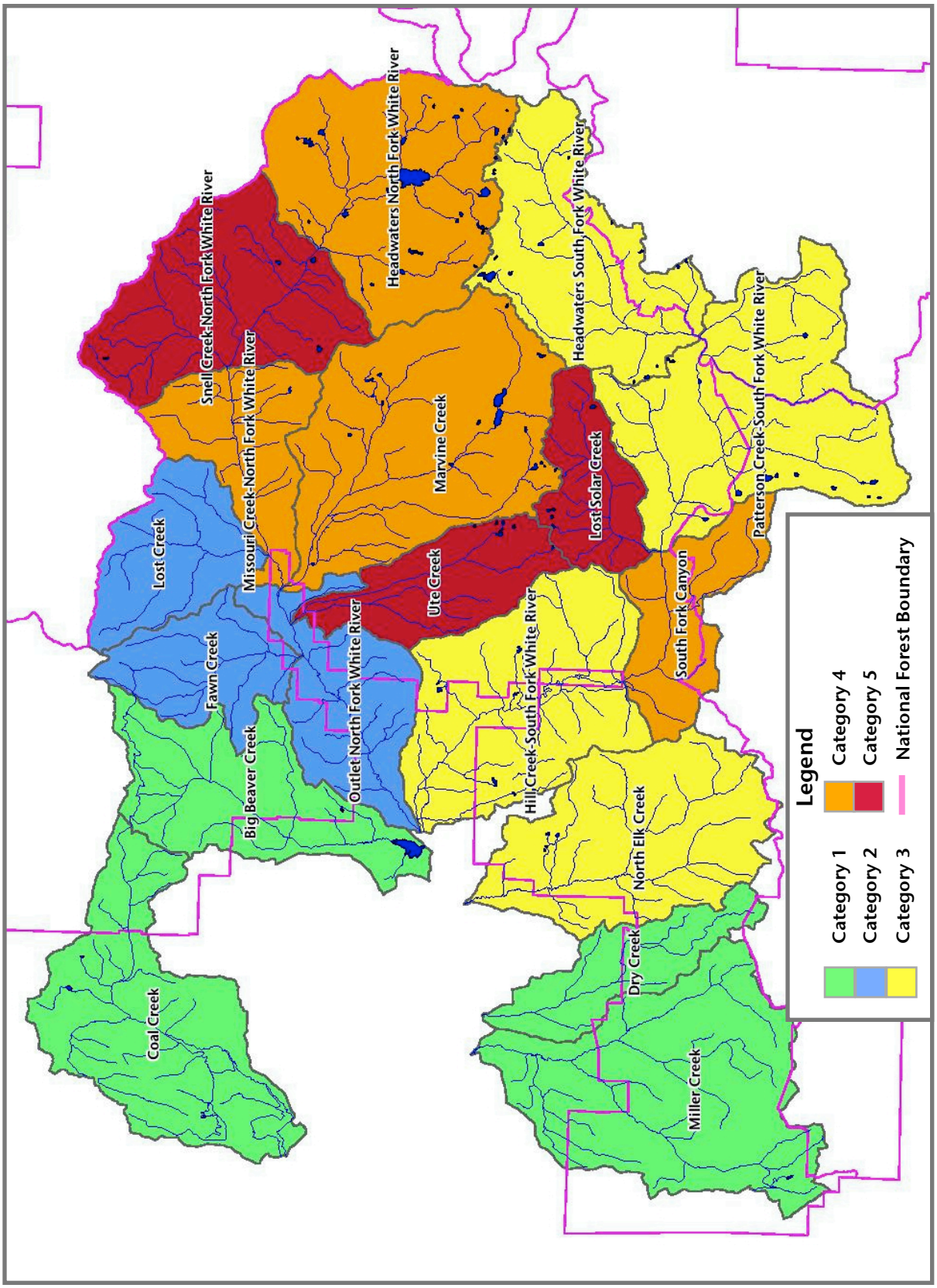

Figure 4. Upper White Watershed Wildfire Hazard Ranking

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 not completed on any watersheds in the Upper White watershed.

Figure 5 displays the categorized ruggedness for the Upper White 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 Lost Solar Creek, South Fork Canyon, Missouri Creek-North Fork White River, Fawn Creek, and Ute Creek.

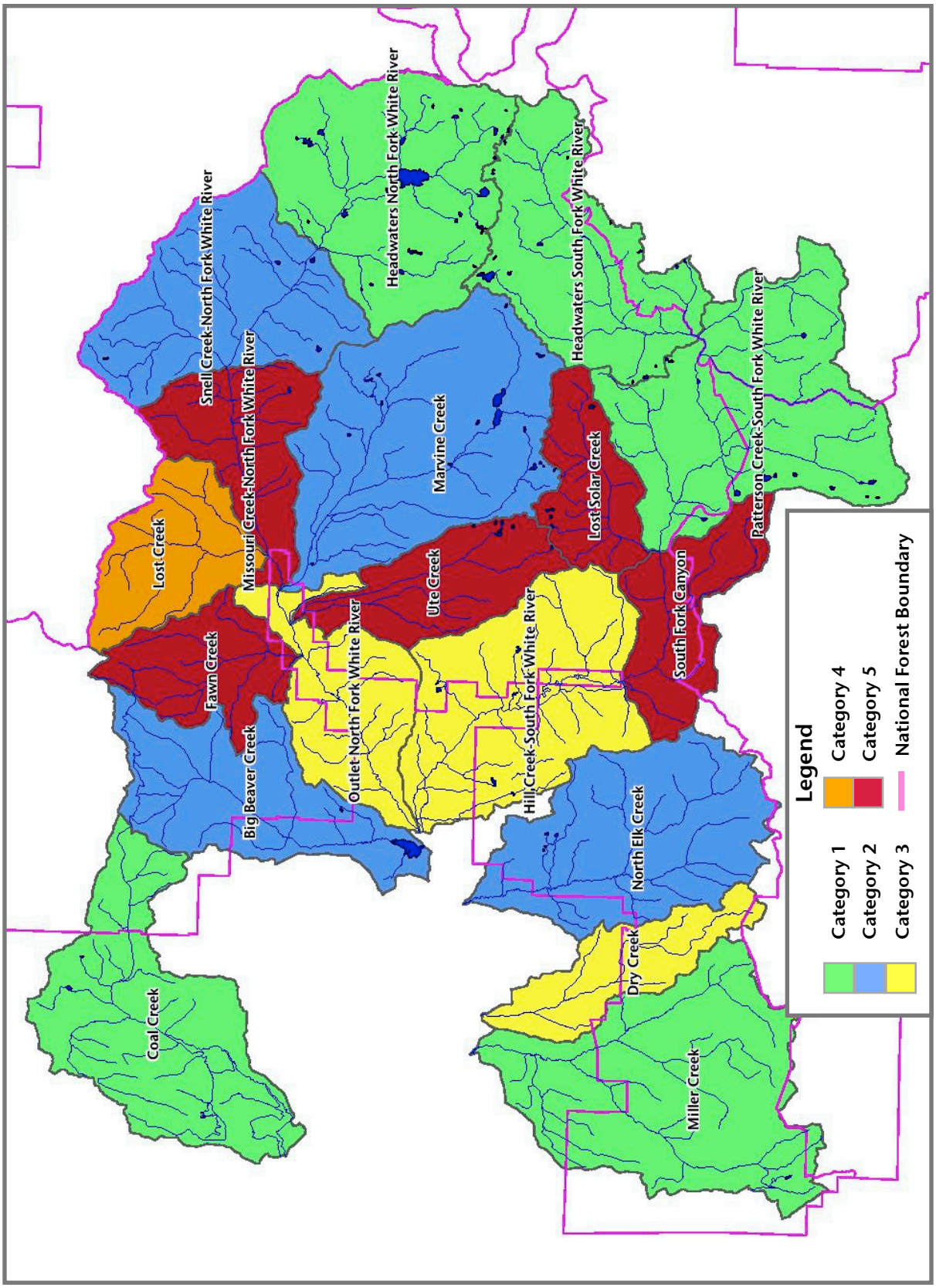

Figure 5. Upper White Watershed Ruggedness Ranking

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 was not adjusted in the Upper White Watershed. Figure 7 displays the categorized road density for the Upper White Watershed and tabular results are presented in Appendix B (Table B-3). Figure 7 shows that the highest rankings are in Outlet North Fork White River, and Miller Creek.

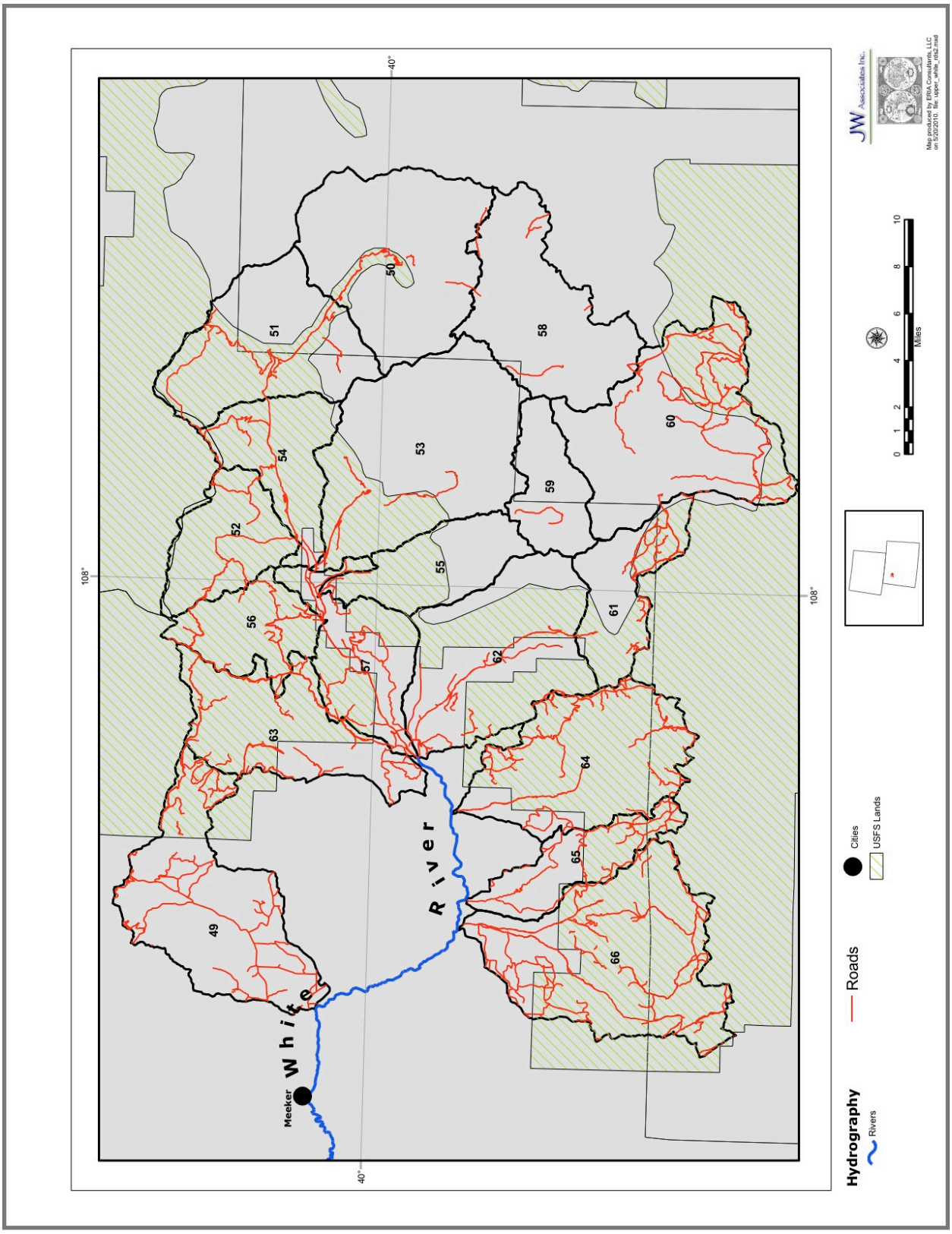

Figure 6. Upper White Watershed Roads Map

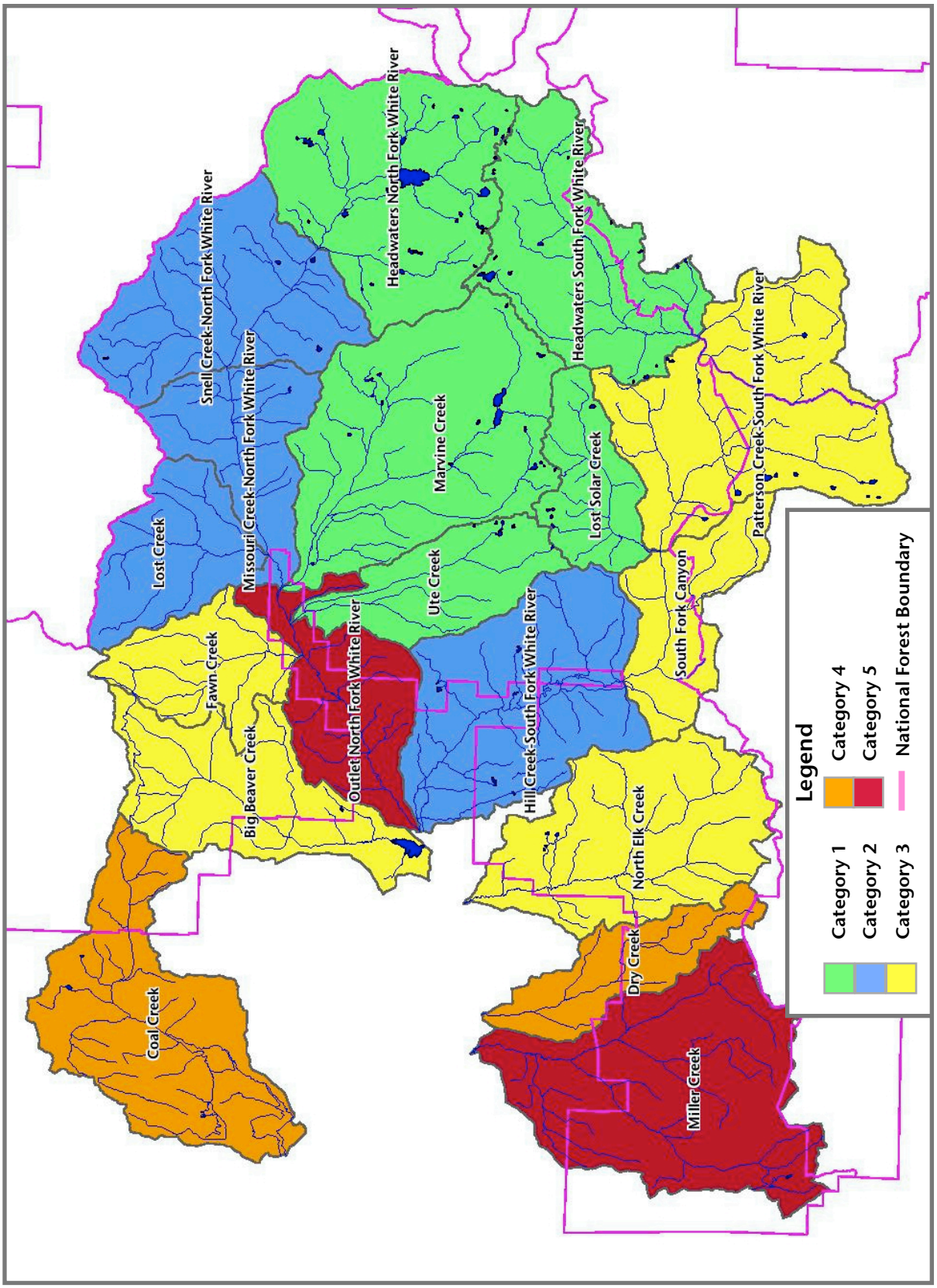

Figure 7. Upper White Watershed Road Density Ranking

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 Upper White 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 South Fork Canyon, Fawn Creek, Missouri Creek-North Fork White River, and Lost Solar Creek.

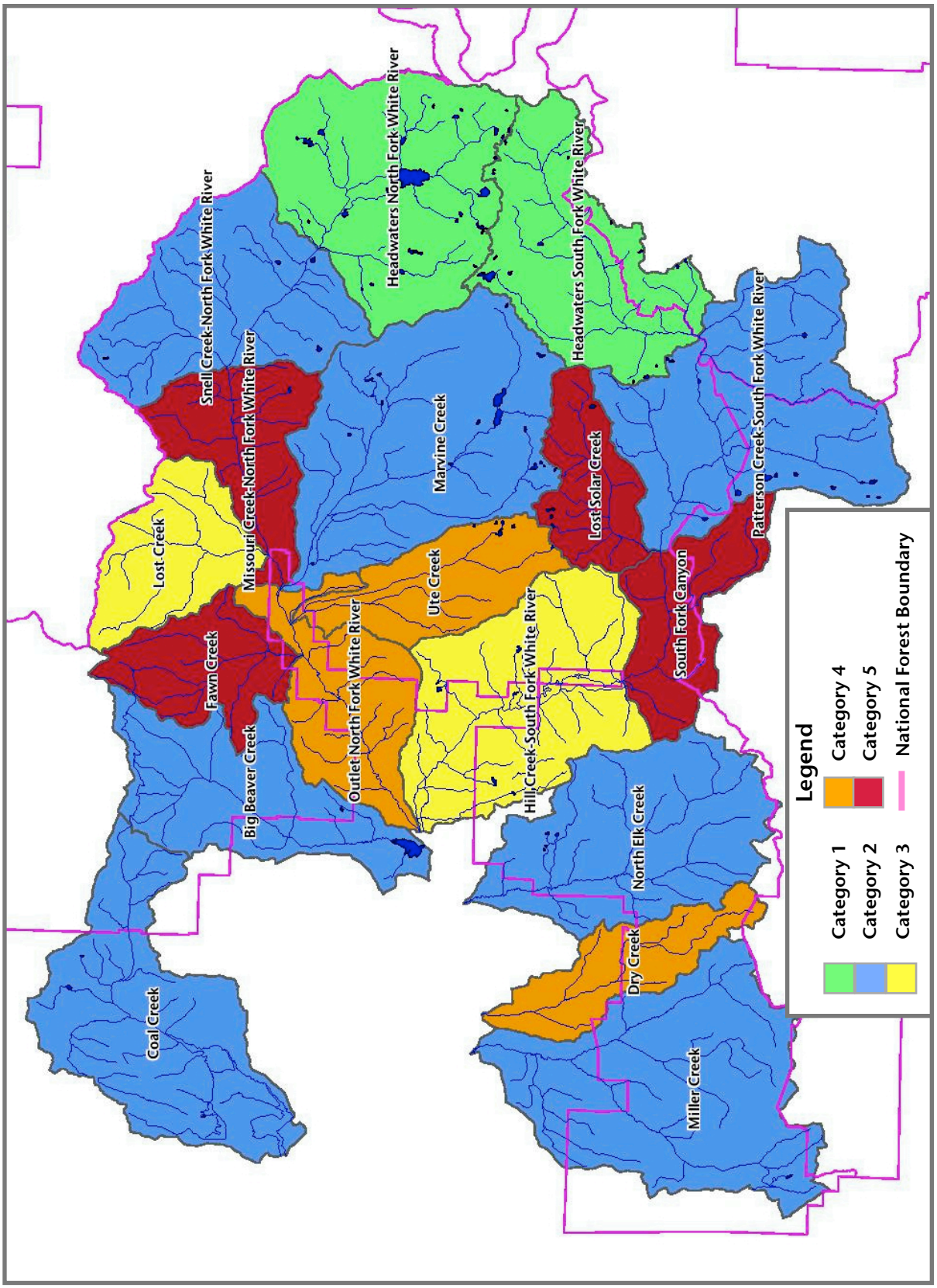

Figure 8. Upper White Watershed Flooding/Debris Flow Hazard Ranking

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 Lost Solar Creek, and South Fork Canyon.

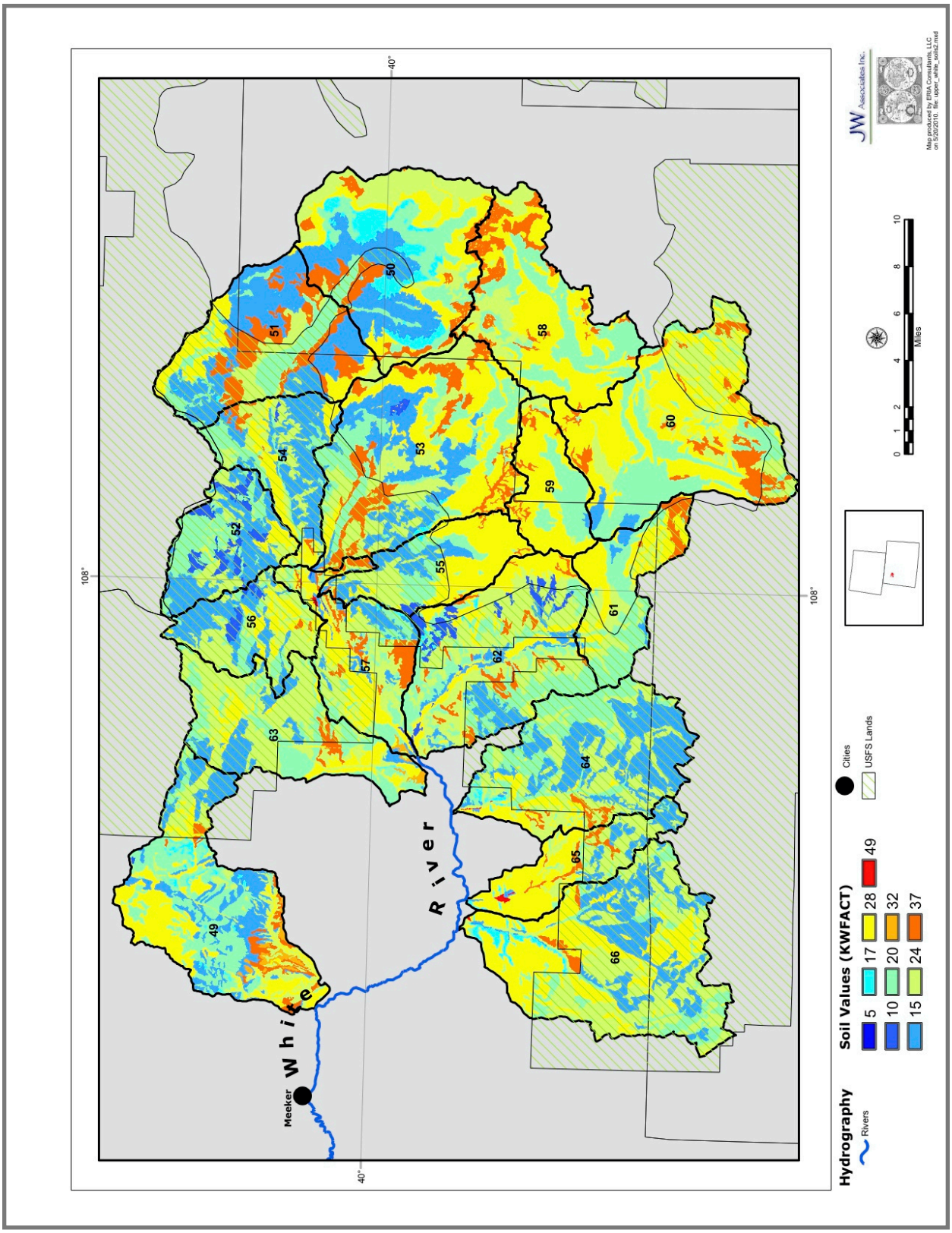

Figure 9. Upper White Watershed Soils K-Factor Map

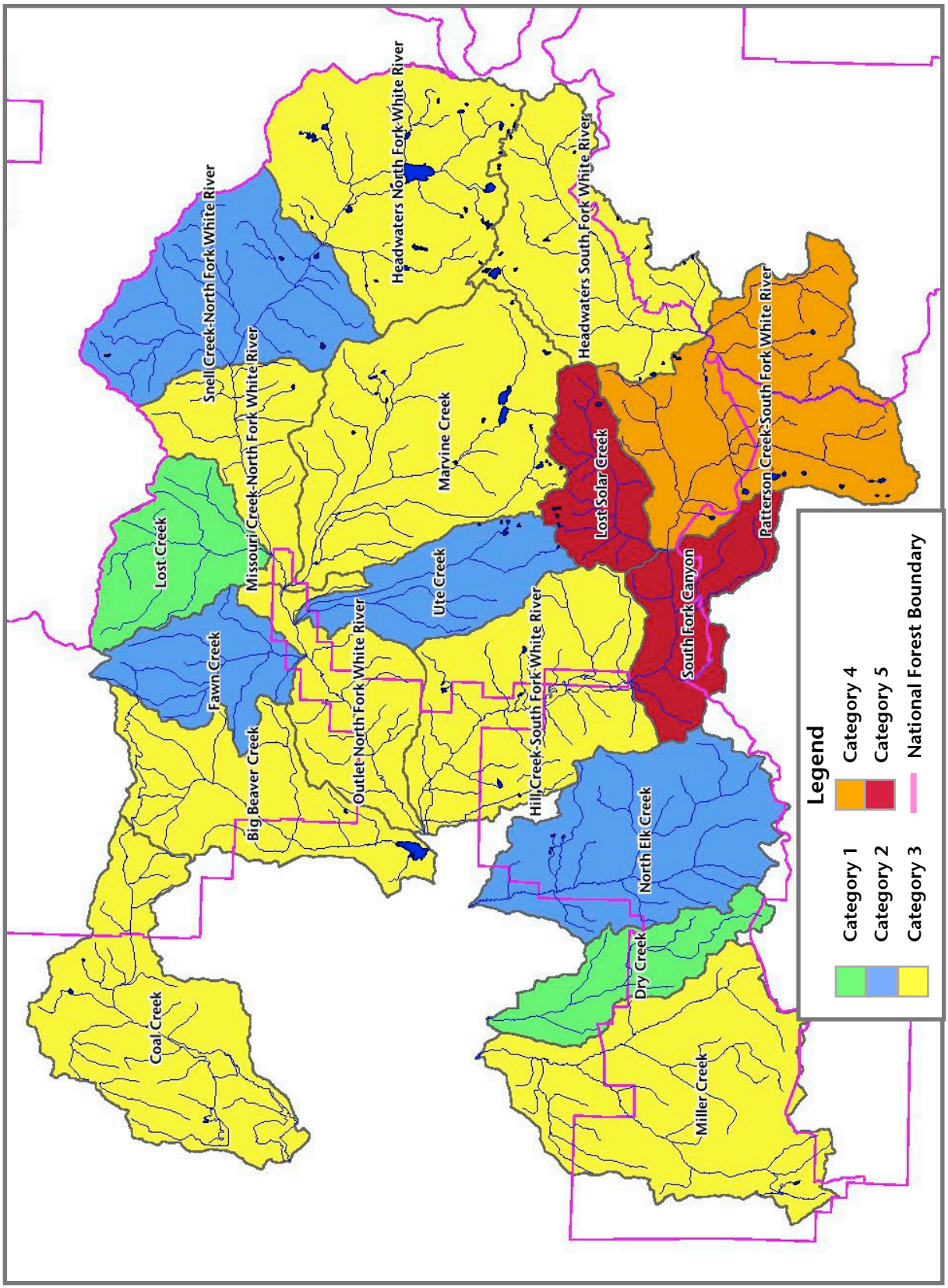

Figure 10. Upper White Watershed Potential Soil Erodibility Hazard Ranking

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 Upper White 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 South Fork Canyon, and Lost Solar Creek.

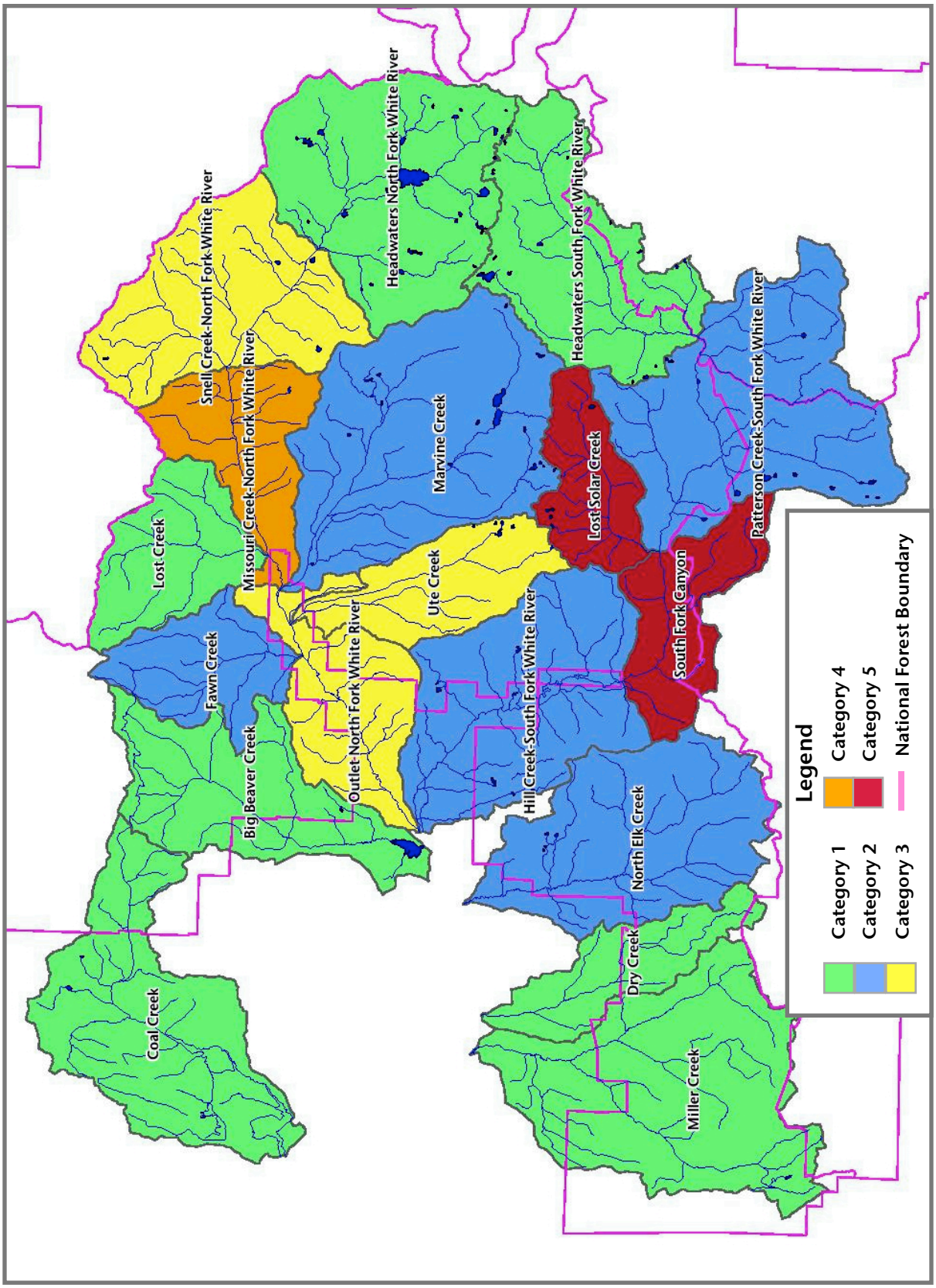

Figure 11. Upper White Watershed Composite Hazard Ranking

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.

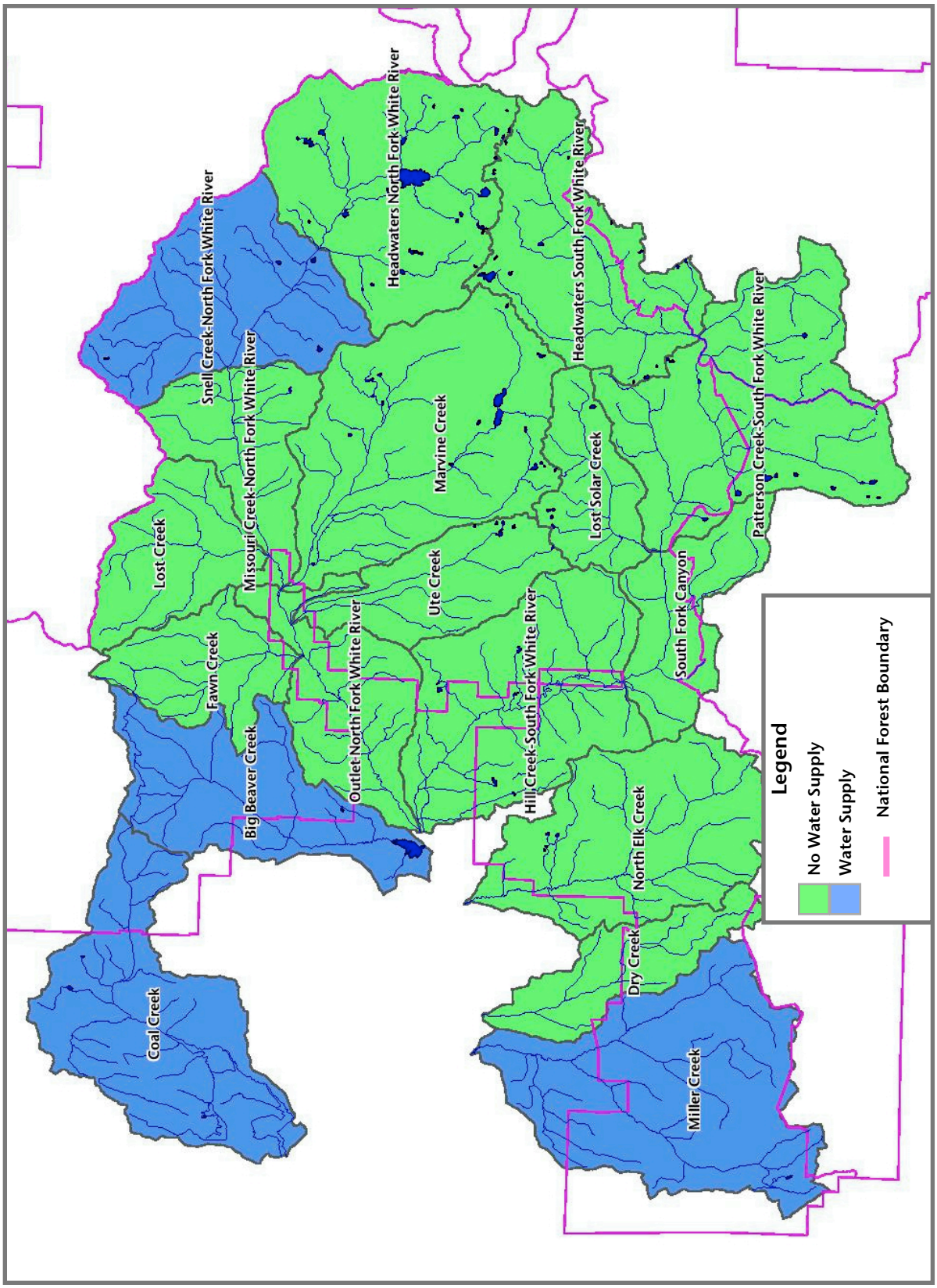

Figure 12. Upper White Watershed Water Supply Map

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APPENDIX A

UPPER WHITE 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 UPPER WHITE WATERSHED ASSESSMENT RESULTS

Table B-1. Upper White Watershed Wildfire Hazard Ranking

Sixth-level Watershed Name	Watershed Area (acres)	Wildfire Hazard Calculation	Wildfire Hazard Rank
Snell Creek-North Fork White River	25,873	59.2%	*5.5*
Ute Creek	13,315	53.9%	*5.0*
Lost Solar Creek	10,417	52.4%	*4.9*
South Fork Canyon	13,209	47.8%	*4.5*
Missouri Creek-North Fork White River	14,505	43.0%	*4.0*
Headwaters North Fork White River	32,635	41.6%	*3.9*
Marvine Creek	38,344	38.9%	*3.7*
Patterson Creek-South Fork White River	36,372	32.9%	*3.1*
Headwaters South Fork White River	25,211	30.4%	*2.9*
North Elk Creek	28,375	30.1%	*2.9*
Hill Creek-South Fork White River	30,190	30.0%	*2.9*
Outlet North Fork White River	16,317	21.6%	*2.1*
Fawn Creek	12,062	20.3%	*2.0*
Lost Creek	13,834	17.4%	*1.7*
Miller Creek	37,567	13.0%	*1.4*
Big Beaver Creek	21,886	10.0%	*1.1*
Dry Creek	11,446	9.6%	*1.0*
Coal Creek	30,457	3.6%	*0.5*

Table B-2. Upper White Watershed Ruggedness Ranking[1]

Sixth-level Watershed Name	Maximum Elevation	Minimum Elevation	Difference Elevation	Ruggedness	Ruggedness Rank
Lost Solar Creek	11,336	7,905	3,431	0.1611	*5.5*
South Fork Canyon	11,375	7,537	3,838	0.1600	*5.4*
Missouri Creek-North Fork White River	11,352	7,459	3,893	0.1549	*5.1*
Fawn Creek	10,824	7,318	3,506	0.1530	*5.0*
Ute Creek	11,008	7,370	3,638	0.1510	*4.9*
Lost Creek	10,749	7,557	3,191	0.1300	*3.6*
Dry Creek	9,364	6,645	2,719	0.1218	*3.1*
Outlet North Fork White River	9,997	6,931	3,067	0.1150	*2.7*
Hill Creek-South Fork White River	11,008	6,924	4,084	0.1126	*2.6*
Snell Creek-North Fork White River	11,788	8,118	3,670	0.1093	*2.4*
Marvine Creek	11,926	7,459	4,467	0.1093	*2.4*
Big Beaver Creek	9,988	6,986	3,001	0.0972	*1.6*
North Elk Creek	10,165	6,793	3,372	0.0959	*1.5*
Patterson Creek-South Fork White River	11,454	7,875	3,578	0.0899	*1.2*
Headwaters South Fork White River	11,962	9,033	2,929	0.0884	*1.1*
Headwaters North Fork White River	11,936	8,672	3,264	0.0866	*1.0*
Coal Creek	9,453	6,340	3,113	0.0855	*0.9*
Miller Creek	9,791	6,599	3,191	0.0789	*0.5*

[1] Ruggedness is based on Melton (1957)

Table B-3. Upper White Watershed Road Density Ranking

Sixth-level Watershed Name	Roads (miles)	Roads Adjusted (miles)	Watershed Area (sq. mi.)	Road density (miles per sq. mi.)	Road Density Rank
Outlet North Fork White River	37.0	37.0	25.50	1.45	*5.5*
Miller Creek	68.6	68.6	58.70	1.17	*4.5*
Dry Creek	20.3	20.3	17.88	1.14	*4.4*
Coal Creek	53.9	53.9	47.59	1.13	*4.4*
North Elk Creek	38.3	38.3	44.34	0.86	*3.5*
Big Beaver Creek	28.8	28.8	34.20	0.84	*3.4*
Patterson Creek-South Fork White River	45.4	45.4	56.83	0.80	*3.2*
Fawn Creek	12.0	12.0	18.85	0.64	*2.7*
South Fork Canyon	12.4	12.4	20.64	0.60	*2.6*
Hill Creek-South Fork White River	24.0	24.0	47.17	0.51	*2.3*
Snell Creek-North Fork White River	19.5	19.5	40.43	0.48	*2.2*
Missouri Creek-North Fork White River	10.2	10.2	22.66	0.45	*2.1*
Lost Creek	7.4	7.4	21.62	0.34	*1.7*
Ute Creek	3.2	3.2	20.80	0.15	*1.0*
Headwaters North Fork White River	6.7	6.7	50.99	0.13	*0.9*
Marvine Creek	7.4	7.4	59.91	0.12	*0.9*
Headwaters South Fork White River	0.8	0.8	39.39	0.02	*0.6*
Lost Solar Creek	0.0	0.0	16.28	0.00	*0.5*

Table B-4. Upper White Watershed Flooding/Debris Flow Hazard Ranking[2]

Sixth-level Watershed Name	Ruggedness Ranking	Road Density Ranking	Combined Ranking	Rank
South Fork Canyon	5.4	2.6	13.44	5.5
Fawn Creek	5.0	2.7	12.71	5.2
Missouri Creek-North Fork White River	5.1	2.1	12.30	5.0
Lost Solar Creek	5.5	0.5	11.50	4.6
Outlet North Fork White River	2.7	5.5	10.90	4.3
Ute Creek	4.9	1.0	10.81	4.3
Dry Creek	3.1	4.4	10.63	4.2
Lost Creek	3.6	1.7	8.91	3.4
Hill Creek-South Fork White River	2.6	2.3	7.35	2.7
Snell Creek-North Fork White River	2.4	2.2	6.86	2.4
Big Beaver Creek	1.6	3.4	6.63	2.3
North Elk Creek	1.5	3.5	6.55	2.3
Coal Creek	0.9	4.4	6.19	2.1
Marvine Creek	2.4	0.9	5.63	1.9
Patterson Creek-South Fork White River	1.2	3.2	5.59	1.8
Miller Creek	0.5	4.5	5.52	1.8
Headwaters North Fork White River	1.0	0.9	2.88	0.6
Headwaters South Fork White River	1.1	0.6	2.73	0.5

[2] Combined Ranking is Ruggedness Ranking times 2 plus the Road Density Ranking

Table B-5. Upper White Watershed Soil Erodibility Ranking[3]

Sixth-level Watershed Name	Severe (%)	Very Severe (%)	Soil Erodibility Value	Soil Erodibility Rank
Lost Solar Creek	19.8%	18.7%	0.572	*5.5*
South Fork Canyon	14.8%	21.0%	0.568	*5.5*
Patterson Creek-South Fork White River	13.9%	16.2%	0.463	*4.2*
Missouri Creek-North Fork White River	16.5%	10.5%	0.375	*3.2*
Outlet North Fork White River	18.3%	9.4%	0.372	*3.2*
Hill Creek-South Fork White River	17.6%	9.2%	0.359	*3.0*
Miller Creek	17.1%	9.0%	0.352	*2.9*
Marvine Creek	15.1%	10.0%	0.351	*2.9*
Headwaters South Fork White River	14.1%	10.3%	0.348	*2.9*
Coal Creek	16.9%	8.0%	0.328	*2.6*
Big Beaver Creek	15.6%	8.5%	0.326	*2.6*
Headwaters North Fork White River	13.4%	9.5%	0.325	*2.6*
Snell Creek-North Fork White River	16.4%	7.0%	0.305	*2.4*
North Elk Creek	15.4%	6.9%	0.291	*2.2*
Ute Creek	11.5%	6.6%	0.247	*1.7*
Fawn Creek	10.1%	7.0%	0.242	*1.6*
Dry Creek	11.0%	5.0%	0.210	*1.2*
Lost Creek	7.6%	3.6%	0.147	*0.5*

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

Table B-6. Upper White Watershed Composite Hazard Ranking[4]

Sixth-level Watershed Name	Wildfire Hazard Rank	Flooding/ Debris Flow Rank	Soil Erodibility Rank	Composite Hazard Rank
South Fork Canyon	4.5	5.5	5.5	5.5
Lost Solar Creek	4.9	4.6	5.5	5.3
Missouri Creek-North Fork White River	4.0	5.0	3.2	3.9
Ute Creek	5.0	4.3	1.7	3.3
Snell Creek-North Fork White River	5.5	2.4	2.4	3.0
Outlet North Fork White River	2.1	4.3	3.2	2.6
Patterson Creek-South Fork White River	3.1	1.8	4.2	2.4
Fawn Creek	2.0	5.2	1.6	2.2
Hill Creek-South Fork White River	2.9	2.7	3.0	2.1
Marvine Creek	3.7	1.9	2.9	2.1
North Elk Creek	2.9	2.3	2.2	1.5
Headwaters North Fork White River	3.9	0.6	2.6	1.4
Dry Creek	1.0	4.2	1.2	1.1
Headwaters South Fork White River	2.9	0.5	2.9	1.0
Miller Creek	1.4	1.8	2.9	0.9
Big Beaver Creek	1.1	2.3	2.6	0.9
Lost Creek	1.7	3.4	0.5	0.7
Coal Creek	0.5	2.1	2.6	0.5

[4] 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).