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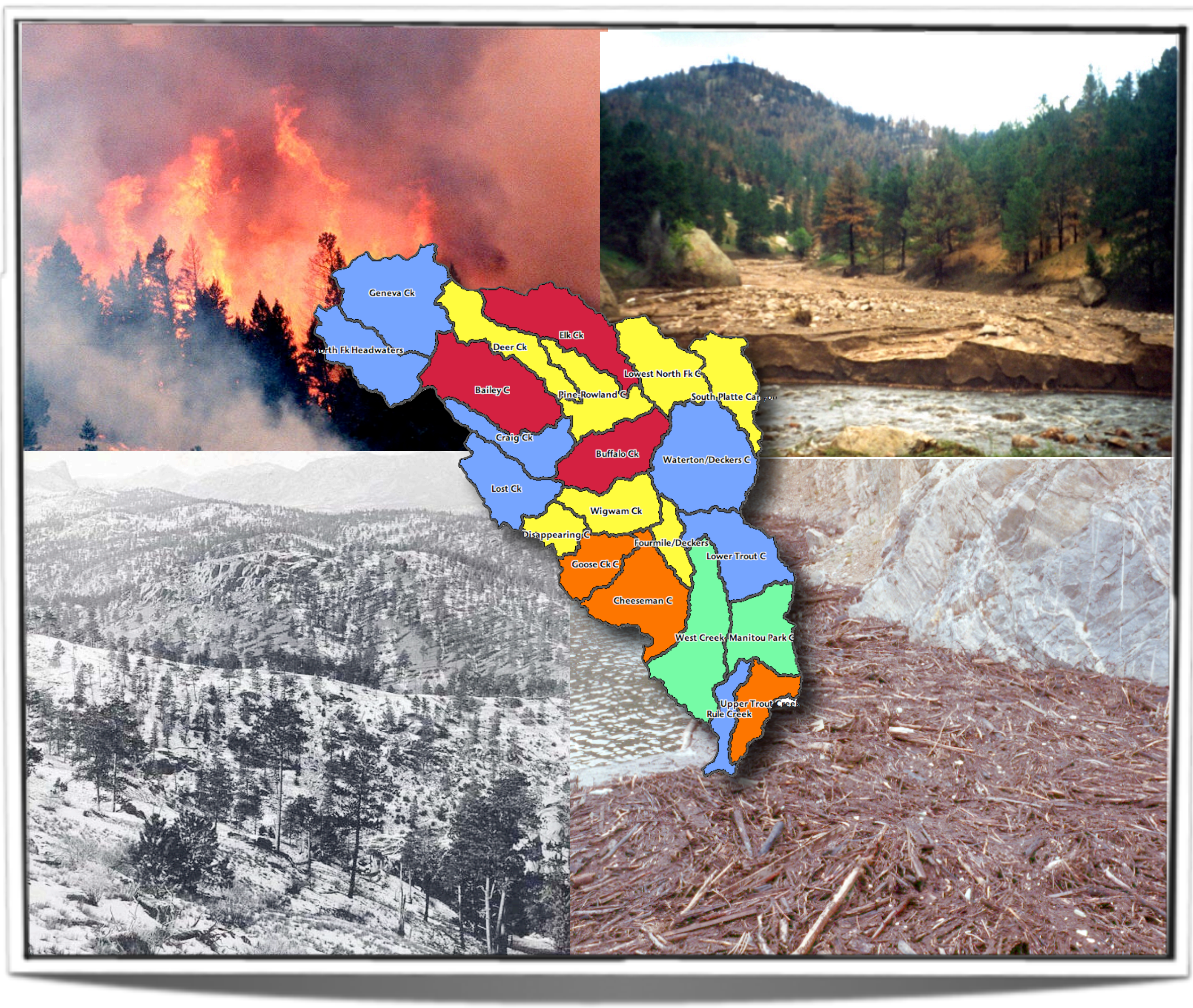
PROTECTING CRITICAL WATERSHEDS IN COLORADO FROM WILDFIRE: A TECHNICAL APPROACH TO WATERSHED ASSESSMENT AND PRIORITIZATION



FINAL VERSION - REVISED AUGUST 2009

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Introduction

The seven major Front Range water providers – Aurora, Boulder, Colorado Springs, Denver Water, Fort Collins, Northern Colorado and Westminster – draw their water supplies from 10 watersheds in the mountains that collectively provide more than two-thirds of Colorado's population with drinking water. Many cities, towns and villages in the mountains also depend on these watersheds for drinking water.

The Front Range of Colorado experienced major impacts on municipal water supplies as a result of flooding, erosion and sediment deposition after the 1996 Buffalo Creek Fire, 2000 Bobcat Fire, and 2002 Hayman and Schoonover fires. In July 2007, the Pinchot Institute for Conservation released an assessment report titled, "Protecting Front Range Forest Watersheds from High-Severity Wildfires," which was funded by the Front Range Fuels Treatment Partnership. The study concluded that climate factors and forest conditions place Front Range source watersheds at high risk from severe wildfires that threaten water supplies and the integrity of reservoirs due to erosion and flood damage. General areas of wildfire hazards and water supplies at risk were identified.

Spring Creek after Buffalo Creek Fire

Strontia Springs Reservoir

Hayman Fire

In August 2007, the Colorado State Forest Service and U.S. Forest Service hosted a meeting with Front Range water providers to discuss the report's findings and explore opportunities for joint action. In September 2007, the agencies and water providers met again and crafted the structural outlines of a partnership effort to protect Front Range watersheds from severe wildfires. As a result, the Front Range Watershed Wildfire Protection Working Group was formed to develop and implement a strategy to protect critical Front Range Watersheds from high-severity wildfires. The working group consulted with the Front Range Fuels Treatment Partnership Roundtable, which is composed of members from more than 40 participating organizations.

Organizations participating in the Front Range Watershed Wildfire Protection Working Group include:

Agencies - Bureau of Land Management, Colorado Division of Emergency Management, Colorado Division of Public Health and Environment, Colorado State Forest Service, Colorado Water Conservation Board, Douglas County Public Works, U.S. Forest Service (Rocky Mountain Region, Arapaho and Roosevelt National Forests and Pawnee National Grasslands, and Pike and San Isabel National Forests and Cimarron and Comanche National Grasslands), Natural Resources Conservation Service and U.S. Geological Survey

Water Providers - Aurora Water, Boulder Public Works, Colorado Springs Utilities, Denver Water, Loveland Water & Power, Northern Colorado Water Conservancy District, Pueblo Water, Westminster Utilities and Farmers Reservoir & Irrigation Company

Others - American Water Works Association, Colorado Watershed Network, The Nature Conservancy and The Wilderness Society

Purpose

The Front Range Watershed Protection Data Refinement Work Group (hereafter termed the Work Group) is one of three sub-work groups formed to implement the strategy of the Front Range Watershed Wildfire Protection Working Group. The members of the Work Group are listed at the end of this document. The purpose of this Work Group is to develop a methodology to identify and prioritize those watersheds that provide or convey water used by communities and municipalities. This identification of priority watersheds will, in turn, assist in prioritizing watersheds for hazard reduction treatments or other watershed protection measures. The Work Group adapted and refined the methods used by the Pinchot Institute for Conservation to assess individual watersheds within the 10-county area served by the Front Range Fuels Treatment Partnership and Roundtable. The Work Group also reviewed additional information and created a template for watershed assessments to identify critical watersheds that supply community or municipal water. The Work Group envisions that the template can be used in fourth-level watersheds in Colorado or the western United States.

Goals

The primary goal of the Work Group was to develop and adopt a clear and common methodology to identify sixth-level watersheds (defined below) that are critical for public water supplies; to develop criteria and processes and recommend data that can be used to determine hazards/effects associated with fire and treatment potential for sixth-level watersheds; and to use the results of the analysis to help determine treatment priorities. A second goal was to apply the watershed assessment approach to a test case to help adapt and refine the approach.

The Work Group completed the following tasks:

1. Created a basic approach to the assessments and prioritization process.

2. Created a technical approach to the components of the assessment, and identified and evaluated data to be used for each technical component.

3. Created an overall technical approach to watershed assessments.

4. Created a watershed assessment report format.

5. Tested and validated the results of the assessment method using a test watershed.

This document is the result of the Work Group's approach to the above tasks. The test watershed in Task 5 is provided in Appendix A (Upper South Platte Watershed Assessment Test Case). A review of the test case is helpful in understanding the watershed assessment approach described below.

Analysis Units

The Work Group used the existing national network of delineated watersheds in their approach. They chose to analyze and prioritize sixth-level (12-digit) watersheds, typically 16-63 square miles or 10,000-40,000 acres (Federal Geographic Data Committee 2004). A wide range of data generally is available at this scale, and this is an appropriate size for watershed analysis and planning for landscape-level fuels treatment. Sixth-level watersheds are the standard analysis unit recommended for the watershed assessments.

The Work Group chose the Upper South Platte Watershed, a fourth-level watershed that is approximately 649,694 acres in area and contains 22 sixth-level watersheds, as its test case because 1) it is well known and studied; 2) a previous prioritization exists to which results can be compared, and; 3) soils data for the area are challenging.

There are 10 fourth-level/8-digit watersheds in the 10-county area (Table 1 and Figure 1). The watershed assessment method is intended to prioritize critical watersheds within each fourth-level watershed, but does not compare fourth-level watersheds to each other. A consistent analysis should be completed for all sixth-level watersheds within the fourth-level watersheds. Typically, data are available at a resolution that is finer than the size of a sixth-level watershed. These finer scale data are amalgamated for each sixth-level watershed to produce a single value for the factor under consideration.

TABLE 1. FOURTH-LEVEL WATERSHEDS IN THE 10-COUNTY AREA[1]

WATERSHED NAME	HUC CODE
Arkansas Headwaters	11020001
Big Thompson	10190006
Cache La Poudre	10190007
Clear Creek	10190004
Colorado Headwaters	14010001
Fountain	11020003
South Platte Headwaters	10190001
St. Vrain	10190005
Upper Arkansas	11020002
Upper South Platte	10190002

[1] The Chico watershed was not included because it has a limited amount of forest land.

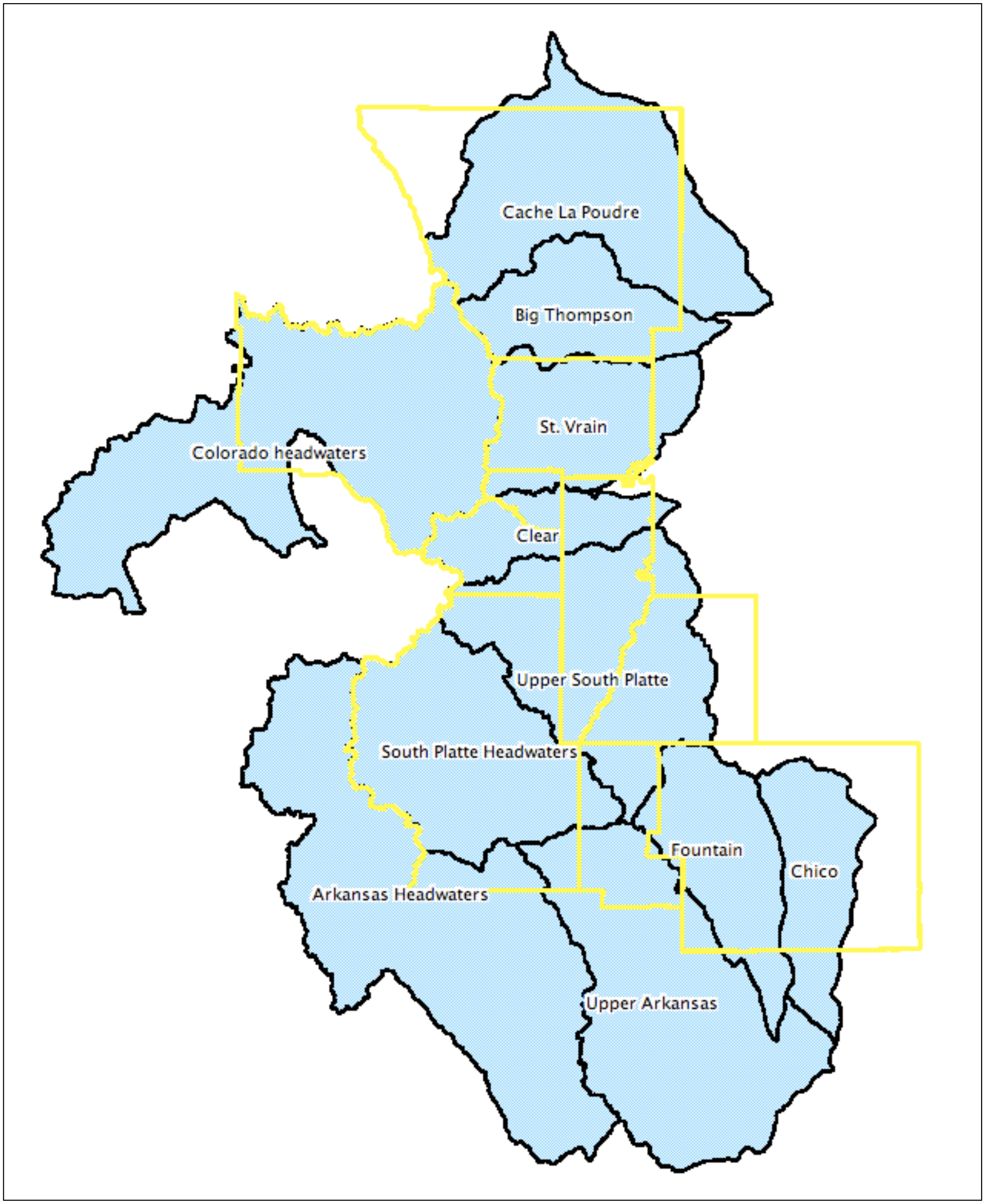

FIGURE 1. FOURTH-LEVEL WATERSHEDS IN THE 10-COUNTY AREA

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 Watershed Assessment considers four components that are integral in evaluating hazardous watershed conditions: wildfire hazard, flooding or debris flow risk, soil erodibility and water uses ranking. This section of the report presents the watershed assessment approach that results in prioritization of sixth-level watersheds. It also discusses the technical approach for each component and the process used to assemble the watershed ranking. A list of the geographic information systems (GIS) data sources are provided in Appendix B.

Component 1 - Wildfire Hazard

The forest conditions that are of concern for the assessments are the wildfire hazard based on existing forest conditions. Two data sets provide wildfire hazard categories for the Front Range Counties. The Pinchot Institute for Conservation wildfire hazard rating provides a data set that is simple and ready to use. The advantage of the Colorado Fire Risk Assessment System is that it covers all of western Colorado. It also is more robust, but is more complex to implement. Either data set can be used for watershed assessments. A careful comparison of how well each represents wildfire hazard for each fourth-level watershed should be completed during the watershed assessment process for individual watersheds. The following is a description of a suggested approach to implement each data set.

Pinchot Institute for Conservation

In 2007, the Pinchot Institute for Conservation evaluated the wildfire hazard for the 10 Front Range counties based on data provided by the Colorado State Forest Service. The results of this analysis were used to assess wildfire hazards in the Upper South Platte Watershed test case (Appendix A). The wildfire hazard assessment presented in that document was determined by using the following formula developed by the Colorado State Forest Service (2002):

$$\text{Wildfire Hazard} = \text{Fuel Hazard}*0.40 + \text{Disturbance Regime}*0.35 + \text{Aspect}*0.10 + \text{Slope}*0.15$$

The Pinchot Institute for Conservation (2007) analysis resulted in five categories of wildfire hazard ranging from low (Category 1) to high (Category 5). A large portion of the forested area was rated as Category 4 (Figure 2). This analysis is available in GIS for the entire 10-county area. The analysis presented in the Pinchot Institute for Conservation Report (2007) appears to be valid for the purposes of this assessment process. Because large portions of the area are covered by Category 3 (Figure 2), Categories 4 and 5 would be used as indicators of high and severe wildfire hazard, respectively. Sixth-level watersheds can be rated for wildfire hazard based on the following formula.

$$\text{Wildfire Hazard} = \frac{\text{Area in Category 4} * 1 + \text{Area in Category 5} * 2}{\text{Watershed Area}}$$

Colorado Fire Risk Assessment System

The Colorado Fire Risk Assessment System was developed by Sanborn for the Colorado State Forest Service in 2008. The result is a robust fire risk assessment map and subcomponents that together form a map called the Wildland Fire Susceptibility Index (WFSI) for western Colorado. The WFSI is used to determine the probability that an acre will burn. The WFSI consists of three components:

1. Probability of fire occurrence by percentile weather category

2. Fire behavior (rate of spread)

3. Fire suppression effectiveness

The probability of fire occurrence analysis includes historic fire locations and weather. As a result, the analysis is biased toward areas that have geospatial fire occurrence data. The model developers stated that areas close to population centers and within the jurisdictions of fire departments that record latitude/longitude data are over-represented. An examination of the data shows that grasslands generally are rated high in certain parts of the state.

The fire behavior prediction portion of the WFSI is based on weather, topography (slope, aspect and elevation), a surface fuel model, canopy closure and canopy attributes (canopy base height, canopy bulk density and stand height). The surface fuel model is based on LANDFIRE data, with some adjustments. The adjustments primarily were found in areas that had recently burned and were greater than 1,000 acres in size. The adjustments were only done where GIS burn-severity data were available.

Fire suppression effectiveness calculations were based on fire occurrence data, and final data on fire sizes from 2002-2006. A relationship between rate of spread and final fire size was calculated for each weather zone.

The most appropriate application of the WFSI is the fire behavior portion of the analysis, which can be used for the wildfire hazard component of the watershed assessment approach described in this report. The other two components contain probabilities that appear to skew the results toward grasslands and areas around population centers.

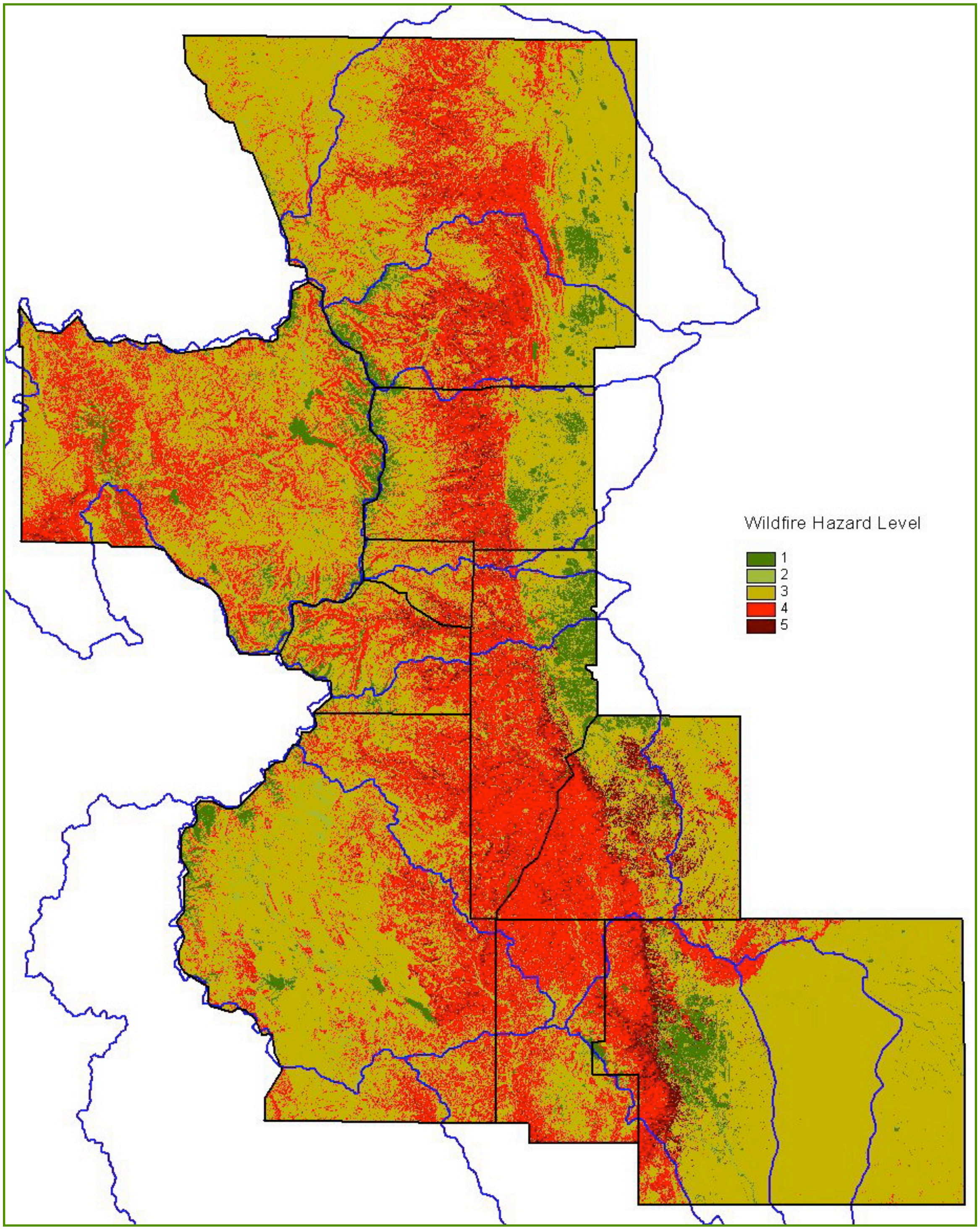

FIGURE 2. WILDFIRE HAZARD FROM PINCHOT INSTITUTE FOR CONSERVATION REPORT (2007)

Wildfire Hazard Ranking

The formula for the raw ranking calculation developed by the Colorado State Forest Service (2002) and used in the Pinchot Institute report appears on page 5. That formula is calculated for each sixth-level watershed and results are expressed as a percentage. If the WFSI ranking is used, a similar rating scheme would be used. The results are then separated into five numeric categories. The calculation of ranking for each sixth-level watershed is completed as follows:

1. Use the formula on page 5 to calculate the raw ranking number for each sixth-level watershed, or apply a similar approach when using the WFSI.
2. Scale the results so that they fall within five categories.
3. Round the scaled result to the nearest whole number (retain the actual number for use in the combined ranking).
4. Create a map of the results using the following scheme:

   Category 1 – Low

   Category 2 – Moderate

   Category 3 – Moderate-High

   Category 4 – High

   Category 5 – Very High

COMPONENT 2 - FLOODING OR DEBRIS FLOW RISK

A combination of slope, road density (miles of road per square mile of watershed area), and other data were used to assess the flooding or debris flow risk portion of the analysis.

Slope

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) defines ruggedness, R, as;

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

Where A_b is basin area and H_b is basin height measured from the point of highest elevation (or average elevation) along the discharge divide to the outlet. These data can be easily extracted from GIS data and the calculations then can be completed in a spreadsheet.

Road Density

Roads can convert subsurface runoff to surface runoff and then route the surface runoff to stream channels, increasing peakflows (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 will be used as an indicator of flooding risk. Roads data need to be consistent within the fourth-level watershed to allow for appropriate comparisons during prioritization. Therefore, the Work Group recommends using the U.S. Census Bureau's Tiger database for a consistent roads layer. The Tiger database can be downloaded for individual counties at: http://www.census.gov/geo/www/tiger/tgrshp2007/tgrshp2007.html.

Flooding or Debris Flow Risk Ranking

The Work Group determined that slope should have a higher value than road density in this ranking. In this assessment, the effect of road density on post-wildfire effects was determined to be more variable than slope. For example, an area with a shallow slope and high road density would have little influence on post-wildfire erosion. The determination that slope would have a higher value than road density was based on professional judgment, experience and the results of the Upper South Platte Watershed Assessment Test Case (Appendix A). The ranking calculation is determined by following these steps:

1. Complete the ruggedness calculation above for each sixth-level watershed.

2. Categorize the ruggedness results using Steps 2 thru 3 from the wildfire hazard ranking; for best results, do not round.

3. Calculate the road density in miles of road per square mile of watershed area for each sixth-level watershed.

4. Categorize the road density results using Steps 2 thru 3 from the wildfire hazard ranking; for best results, do not round.

5. Multiply the result of Step 2 by 2 and add it to the result of Step 4.

6. Scale the results so that they fall within five categories. Round the result to the nearest whole number (retain the actual number for use in the combined ranking).

7. Create a map of the results using the following scheme:

    Category 1 – Low

    Category 2 – Moderate

    Category 3 – Moderate-High

    Category 4 – High

    Category 5 – Very High

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).

The soils analysis that was completed by the Pinchot Institute for Conservation (2007) revealed that large portions of the 10-county area were not assessed because soils data were not available. Two soils data sources were reviewed to fill the gaps or create a consistent soils data layer for each fourth-level watershed. The two data sets that were evaluated were the U.S. Department of Agriculture - Natural Resources Conservation Service (NRCS) STATSGO and SSURGO soils data. STATSGO soils data is available for the entire 10-county area. STATSGO data is relatively coarse soils data, created at a scale of 1:250,000. The STATSGO data results in large-scale soils polygons that might not be useful for prioritization. However, they do provide a consistent soils data layer that can be used in the absence of more site-specific data. When combined with the K-factor and the completed slope analysis, the STATSGO data can provide reasonable soil erodibility polygons that are useful for prioritization.

SSURGO soils data does not cover all the fourth-level watersheds in the 10-county area, though efforts by the NRCS currently are under way to produce an updated soils data layer. The SSURGO data is available at a scale that generally ranges from 1:12,000 to 1:63,360, which is more appropriate than STATSGO data for this analysis.

To complete a meaningful prioritization, the soils data for each fourth-level watershed must be consistent. Therefore, a decision to use either STATSGO or SSURGO data should be made for each fourth-level watershed. If SSURGO data is not available for the entire fourth-level watershed, then STATSGO data is recommended.

The soil analysis used a combination of two standard erodibility indicators: the inherent susceptibility of soil to erosion (K factor) and land slope derived from USGS 30m digital elevation models. The K factor data (kwfact or Kw) from the STATSGO or SSURGO spatial databases was combined with a slope grid using Natural Resources Conservation Service (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. 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

Soil scientists have observed that K factor does not adequately identify soil erodibility on granitic soils. Therefore, where substantial areas of granitic soils exist, a geology layer should be used to identify areas of granitic soils and increase the erodibility rating for those soils. In areas with identified granitic soils, or granite geology, the soils potential erodibility rating (Table 2) would be increased by a factor of one. Other soils and/or geology types may be identified within fourth-level watersheds that would use a similar approach to increase their potential erodibility rating due to specific geology. These would be determined through a combination of local knowledge, expert opinion and scientific research.

Soil Erodibility Ranking

The soil erodibility ranking result is a numeric ranking obtained from the analysis shown above in Table 2. The ranking calculation is determined by following these steps:

1. Complete the GIS analysis shown in Table 2.

2. Calculate the area of each category in Table 2 for each sixth-level watershed.

3. Add the percentages of Severe and Very Severe rankings for each sixth-level watershed.

4. Categorize the soil erodibility results using Steps 2 thru 3 from the wildfire hazard ranking.

5. Apply any adjustments based on local geology, but do not increase the Very Severe ranking to a higher level.

6. Create a map of the results using the following scheme:

    Category 1 – Low

    Category 2 – Moderate

    Category 3 – Moderate-High

    Category 4 – High

    Category 5 – Very High

Component 4 - Water Uses Ranking

The water infrastructure discussion from the Pinchot Institute for Conservation Report (2007) does a good job of summarizing the situation.

"As noted above, the seven major providers serving Front Range communities get their water from eleven watersheds, and eight have been designated as critical because they are mostly or wholly contained in the ten Front Range counties. The major providers deliver water through nine conveyances, which include pipelines, canals, tunnels, aqueducts, and ditches, as well as existing channels of streams and rivers. Six of the seven water providers — Westminster being the exception — get some or all of their water from west of the continental divide. Substantial distances are involved. Colorado Springs reportedly brings water from one source located 200 miles away. On its journey from west to east, water is stored in multiple reservoirs of various kinds and sizes.

Most of the conveyances flow through forests at some point and for extended distances. Similarly many of the reservoirs are surrounded by forests. High-severity wildfires can have a catastrophic impact on watershed values, water conveyances, and reservoirs. As noted earlier, sediment from post-fire flooding, landslides, and organic debris flow can put water conveyances and reservoirs out of operation. Rehabilitation, which often requires construction of physical structures such as sediment dams, involves large expenditures of money, time, and effort." (Page 25)

Surface water intakes, diversions, conveyance structures, storage reservoirs and streams are all susceptible to the effects of wildfires. Risks to water uses are evaluated using several suggested mapping tools. The tools can be applied based on the judgment of stakeholders in the watershed. Suggested tools are listed below.

Water Supply 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 define which sixth-level watersheds contain water nodes that are critical components of the public water supply infrastructure. For the purpose of this methodology, water nodes were defined as coordinate points corresponding to surface water intakes, upstream diversion points and classified drinking water reservoirs. The process involves mapping the sixth-level watersheds that contain water supply nodes. The water node ranking will be based on the presence of one or more nodes within the sixth-level watersheds. If a sixth-level watershed contains a node, it will have a higher risk ranking due to its proximity to water supply nodes.

Source Water Assessment Areas

Source water assessment areas (SWAAs) were developed by the SWAP program and can be obtained from the Colorado Department of Public Health and Environment. The SWAAs can be used to assess the upstream wildfire hazard to water supply nodes. If three (3) or more public water systems (PWS) SWAAs overlap in a common sixth-level watershed, the associated risk ranking for that sixth-level watershed will increase.

Reservoirs without SWAAs

Nodes will not be identified for some drinking water supply reservoirs that do not have associated direct surface water intakes. Source water assessment areas could be created for these important water-use features by identifying the watershed areas above the reservoirs.

Overall Watershed Ranking

The overall watershed ranking was determined by following the steps described below:

1. Create a Composite Hazard Ranking.
2. Create a Final Watershed Prioritization map by adding the Water Uses Ranking to the Composite Hazard Ranking map.
3. Decide what approach to use for the Zones of Concern and add them to the Final Watershed Prioritization map.

Composite Hazard Ranking

The Composite Hazard Ranking combines the first three components (Wildfire Hazard, Flooding/Debris Flow Risk and Soil Erodibility) by averaging their rankings for each sixth-level watershed. A Composite Hazard Ranking map of the results is then created using the following scheme:

Category 1 – Low

Category 2 – Moderate

Category 3 – Moderate-High

Category 4 – High

Category 5 – Very High

The Work Group believed it was valuable to create this Composite Hazard Ranking map to compare relative watershed hazards based solely on physical factors (See Appendix A for the Upper South Platte Watershed Composite Hazard Map).

Final Watershed Prioritization

The Final Watershed Prioritization involves combining the Composite Hazard Ranking map and the Water Uses Ranking. The Water Uses Ranking would result in a numeric ranking between zero and two, depending on what portions of that ranking are used. Combining the Composite Hazard Ranking and Water Uses Ranking would involve increasing the hazard categories for each sixth-level watershed from the Composite Hazard Ranking map by one category for each Water Uses Ranking value. For example, a sixth-level watershed with a high Composite Hazard Ranking (numeric value of 4.3) and a Water Uses Ranking of one would have a Final Watershed Prioritization ranking of 5.3. That numeric result would then be scaled to fit into the five categories used in all the rankings. The result would be mapped as the Final Watershed Prioritization map.

Zones of Concern

The Work Group identified an important risk factor for water uses related to transport of debris and sediment from upstream source water areas. The source water areas above important surface water intakes, upstream diversion points and classified drinking water supply reservoirs that have a higher potential for contributing significant sediment or debris are called the Zones of Concern. These zones also could be used by stakeholders to further define project areas that focus on watershed protection actions. The portions of sixth-level watersheds within that distance are considered to be within the Zone of Concern. The boundaries for the Zones of Concern are drawn and overlaid on the Final Watershed Prioritization map.

The following list provides some options for identifying Zones of Concern:

1. A 5-mile stream distance upstream of the node based on Colorado State Statute 31-15-707.

2. An 11-mile stream distance upstream based on experience following the Buffalo Creek Fire in 1996 (Moody and Martin 2001). Sediment and debris from the burned area were transported this distance along the stream course downstream to a critical water supply reservoir, Strontia Springs Reservoir.

3. A 15-mile radial distance using the SWAP (CDPHE 2004) data.

4. A distance determined by application of some analytical tools such as RiverSpill. RiverSpill is a GIS-based real-time transport model for source water protection (Samuels et al. 2002). RiverSpill can estimate travel time of water for specific streamflow conditions. Post-fire streamflow conditions could be assumed and travel times modeled for those conditions. A travel time of 24 hours would be a reasonable assumption for developing the Area of Concern using the RiverSpill model. The databases required for RiverSpill include the Enhanced River Reach File (ERF1), USGS real-time streamflow measurements and the EPA Safe Drinking Water Information System (SDWIS), along with the Arcview Network Analyst extension. These tools would provide a more quantitative approach in determining the Areas of Concern.

5. Other distances can be determined through modification of the above methods, or new methods, supported by scientific research, site-specific evidence and/or professional judgment.

6. Another approach would be to identify the Areas of Concern upstream of drinking water reservoirs and diversions by stakeholder agreement. This approach would be site-specific to each reservoir or water node.

Integration of Critical Community Watershed Wildfire Protection Plans

For each surface water intake, upstream diversion point, classified drinking water supply reservoir or other water infrastructure component, there is a set of stakeholders interested or involved in its operation and maintenance. In some cases, this may be a single water provider or community. In other cases, multiple communities and water providers may have an interest.

In addition, some existing Community Wildfire Protection Plans (CWPPs) may cover portions of the watershed(s) in which planning will occur. Existing CWPPs should be inventoried, and the stakeholders involved in the planning efforts should be invited to participate in the development of expanded watershed or source-water protection plans. Specific treatment areas and priorities identified in existing plans also should be reviewed for their contribution to the watershed protection effort and incorporated into the expanded plan.

In a similar manner, other existing land and vegetation management plans, fuels treatment plans, source water protection plans, watershed restoration plans or prescribed fire or fire-use plans may exist that cover portions of the watersheds in which planning will occur. The stakeholders involved in these other efforts also should be invited to participate. A final check should then be made to see if any other interest group or individual ought to be brought into the planning effort. Time spent early in the process to bring all possible stakeholders to the table will facilitate efficient planning and implementation. After the stakeholder list is complete and existing treatment plans are inventoried, the planning effort may begin in earnest.

The stakeholders for the infrastructure element in question need to arrive at some consensus on the relative priority for conducting such planning. Several options are available:

- Conduct planning efforts in the final priority order resulting from the analysis.
- Conduct planning efforts in the final priority order resulting from the Composite Hazard Map.
- Conduct planning efforts in some other logical order agreeable to the stakeholders.

Stakeholders may be tempted to begin planning for all watersheds at once. Certain parts of the planning process for the various watersheds encompassed by a Zone of Concern can, in fact, begin and take place at the same time, but one effort must take precedence over the others because the decisions, results, specific treatment areas and treatment priorities for that first watershed will dictate similar actions and decisions in follow-up planning efforts. Indeed, the process should become easier and smoother as the various watershed plans are developed.

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Appendix A

Upper South Platte Watershed Assessment Test Case

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Introduction

One of the tasks of the Front Range Watershed Protection Data Refinement Work Group was to apply the watershed assessment approach to a test case to help adapt and refine the approach. The Work Group chose the Upper South Platte Watershed for the following reasons;

1. It is well known and studied.
2. There is a previous prioritization to which results can be compared.
3. Some soils data challenges exist.

Background

The Upper South Platte Watershed provides the City of Denver with 75 percent of its drinking water supply. Because of its close proximity to Denver, it provides easy accessibility to fishing, hiking and other outdoor experiences. The watershed also is home to portions of two wilderness areas (Lost Creek and Mt. Evans). Portions of the South Platte River are designated as a gold medal trout fishery.

In 1996, an intense wildfire in the Buffalo Creek drainage resulted in the loss of several houses and forest cover on nearly 12,000 acres. This fire was a wind-driven (up to 70 miles per hour) crown fire that burned more than 10,000 acres in one day. Two large summer storms in the burn area caused catastrophic erosion and deposition of sediment in the watershed's streams, and tragically contributed to two human deaths. The Denver Water Board and the City of Aurora are planning extensive dredging of Strontia Springs Reservoir due to sediment from the Buffalo Creek Fire that was transported and deposited into the water-supply reservoir.

In 2000, the Hi Meadow Fire burned more than 10,000 acres near the Buffalo Creek burn area. Unlike the Buffalo Creek Fire, this fire burned in a mosaic pattern, although many areas experienced intense crown fire. Some erosion and sedimentation problems were associated with runoff following the fire.

In 2002, three wildfires occurred in the Upper South Platte Watershed. The Snaking Fire burned about 2,500 acres near Bailey. Although relatively small, the fire lead to evacuations in the Town of Bailey and surrounding populated areas. The Schoonover Fire burned nearly 3,500 acres near Deckers and the Hayman Fire, the largest fire in Colorado history, burned 137,000 acres. The Hayman Fire burned the entire area around Cheesman Lake, which has experienced substantial erosion and deposition as a result.

Watershed Characterization

The Upper South Platte Watershed is a fourth-level watershed that is approximately 649,694 acres in area and contains 22 sixth-level watersheds (Table A-1). The sixth-level watersheds in the Upper South Platte Watershed are shown on Figure A-1.

TABLE A-1. SIXTH-LEVEL WATERSHEDS IN THE UPPER SOUTH PLATTE WATERSHED

WATERSHED NAME	HYDROLOGIC UNIT CODE (HUC)	WATERSHED AREA (ACRES)
Bailey	101900020303	46,464
Buffalo Creek	101900020404	30,861
Cheesman	101900020101	39,603
Craig Creek	101900020304	21,644
Deer Creek	101900020402	27,150
Disappearing Creek	101900020103	11,943
Elk Creek	101900020403	40,430
Fourmile/Deckers	101900020105	10,963
Geneva Creek	101900020302	49,679
Goose Creek	101900020104	19,382
Lost Creek	101900020102	28,204
Lower Trout Creek	101900020804	31,980
Lowest North Fork	101900020405	29,900
Manitou Park	101900020803	28,043
North Fork Headwaters	101900020301	31,446
Pine-Rowland	101900020401	27,092
Rule Creek	101900020801	12,726
South Platte Canyon	101900020501	24,016
Upper Trout Creek	101900020802	18,585
Waterton/Deckers	101900020107	51,673
West Creek	101900020805	44,224
Wigwam Creek	101900020106	23,686

FIGURE A-1. SIXTH-LEVEL WATERSHEDS IN THE UPPER SOUTH PLATTE WATERSHED

Watershed Assessment

The Upper South Platte Watershed Assessment is divided into four components that focus on the technical aspects of the issues that have been defined as most critical to the protection of watershed conditions. The watershed's ability to deliver sediments following catastrophic wildfire depends on forest and soil conditions, and the physical configuration of those watersheds. These conditions then are evaluated relative to the locations of water uses.

Component 1 - Wildfire Hazard

Forest conditions that are of concern for the assessments are wildfire risk or hazard based on existing forest conditions. In 2007, the Pinchot Institute for Conservation evaluated the wildfire hazard for the 10 Front Range counties. The wildfire hazard assessment presented in the report was determined by using the following formula (Colorado State Forest Service 2002).

Wildfire Hazard = Fuel Hazard*0.40 + Disturbance Regime*0.35 + Aspect*0.10 + Slope *0.15

The analysis presented in the Pinchot Institute for Conservation Report (2007) was used to assess the wildfire hazard for the Upper South Platte Watershed. Because large portions of the area are covered by Category 3, Categories 4 and 5 were used as indicators of high and severe wildfire hazard, respectively. Sixth-level watersheds were rated for wildfire hazard based on the following formula.

$$\text{Wildfire Hazard} = \frac{\text{Area in Category 4} * 1 + \text{Area in Category 5} * 2}{\text{Watershed Area}}$$

The results of the wildfire hazard ranking and categorization are shown in Table A-2 and Figure A-2.

TABLE A-2. UPPER SOUTH PLATTE WATERSHED WILDFIRE HAZARD RANKING

WATERSHED NAME	WILDFIRE HAZARD CALCULATION	WILDFIRE HAZARD RANKING
Bailey	70.77%	Moderate-High
Buffalo Creek	90.69%	High
Cheesman	93.75%	Very High
Craig Creek	40.80%	Moderate
Deer Creek	46.02%	Moderate
Disappearing Creek	50.52%	Moderate
Elk Creek	73.19%	High
Fourmile/Deckers	101.93%	Very High
Geneva Creek	22.41%	Low
Goose Creek	81.91%	High
Lost Creek	19.63%	Low
Lower Trout Creek	101.16%	Very High
Lowest North Fork	94.88%	Very High
Manitou Park	87.94%	High
North Fork Headwaters	24.26%	Low
Pine-Rowland	100.68%	Very High
Rule Creek	53.47%	Moderate-High
South Platte Canyon	101.87%	Very High
Upper Trout Creek	68.54%	Moderate-High
Waterton/Deckers	101.63%	Very High
West Creek	93.81%	Very High
Wigwam Creek	90.71%	High

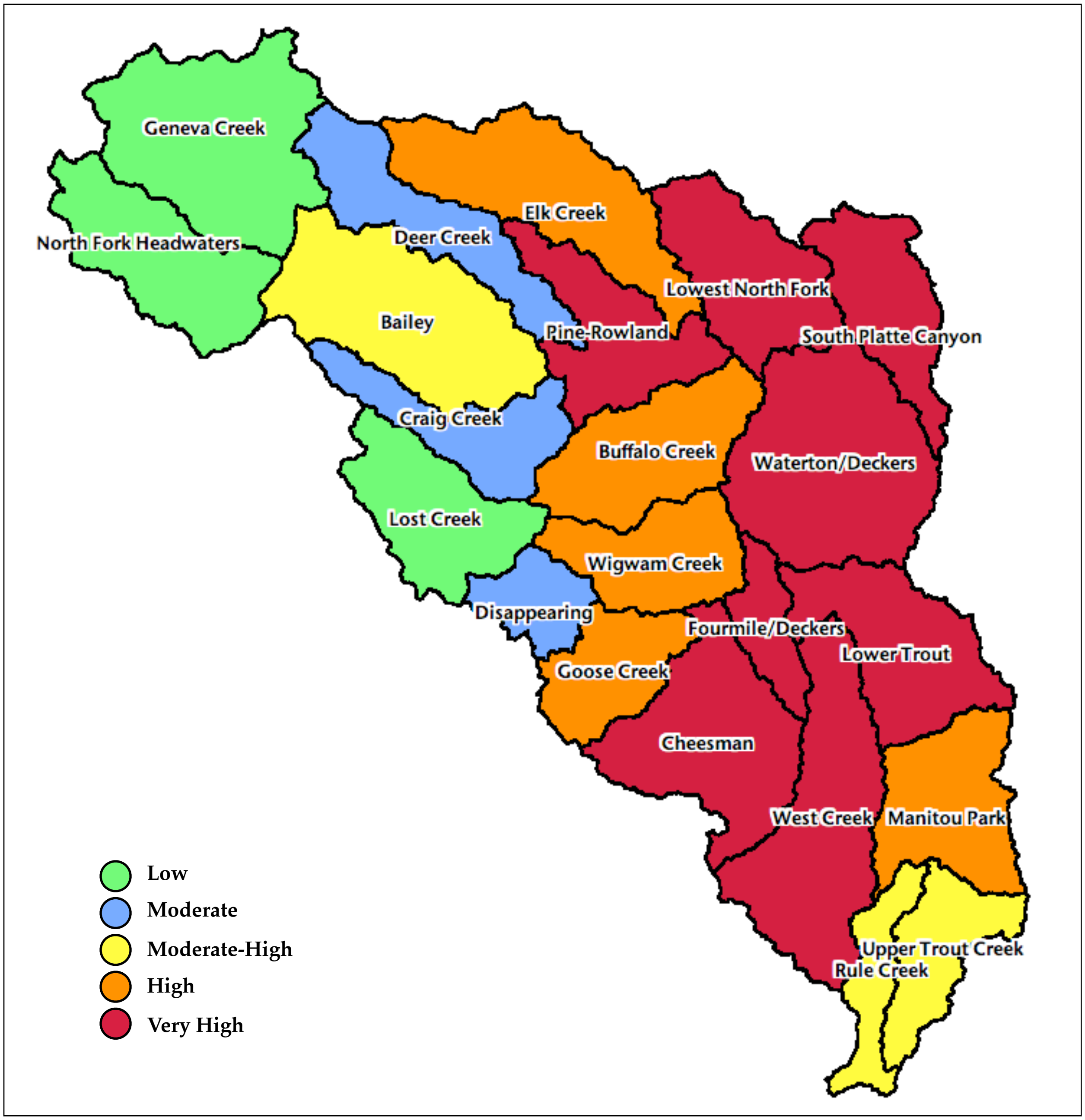

FIGURE A-2. UPPER SOUTH PLATTE WATERSHED WILDFIRE HAZARD RANKING MAP

Component 2 - Flooding or Debris Flow Risk

Slope

Watershed steepness or ruggedness can be 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) defines ruggedness, R, as;

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

where A_b is watershed area and H_b is watershed height measured from the point of highest elevation along the watershed divide to the outlet. These data were extracted from GIS data and the calculations are presented in Table A-3 along with the ranking for slope. A slope ranking map is presented as Figure A-3.

TABLE A-3. UPPER SOUTH PLATTE WATERSHED SLOPE RANKING

WATERSHED NAME	RUGGEDNESS CALCULATION	SLOPE HAZARD RANKING
Bailey	0.1180	Moderate-High
Buffalo Creek	0.1606	High
Cheesman	0.0978	Moderate
Craig Creek	0.1565	High
Deer Creek	0.1859	Very High
Disappearing Creek	0.1754	High
Elk Creek	0.1303	Moderate-High
Fourmile/Deckers	0.1568	High
Geneva Creek	0.1221	Moderate-High
Goose Creek	0.1675	High
Lost Creek	0.0794	Low
Lower Trout Creek	0.0767	Low
Lowest North Fork	0.0940	Moderate
Manitou Park	0.0552	Low
North Fork Headwaters	0.1202	Moderate-High
Pine-Rowland	0.0782	Low
Rule Creek	0.1149	Moderate-High
South Platte Canyon	0.1005	Moderate
Upper Trout Creek	0.0930	Moderate
Waterton/Deckers	0.0722	Low
West Creek	0.0732	Low
Wigwam Creek	0.1554	High

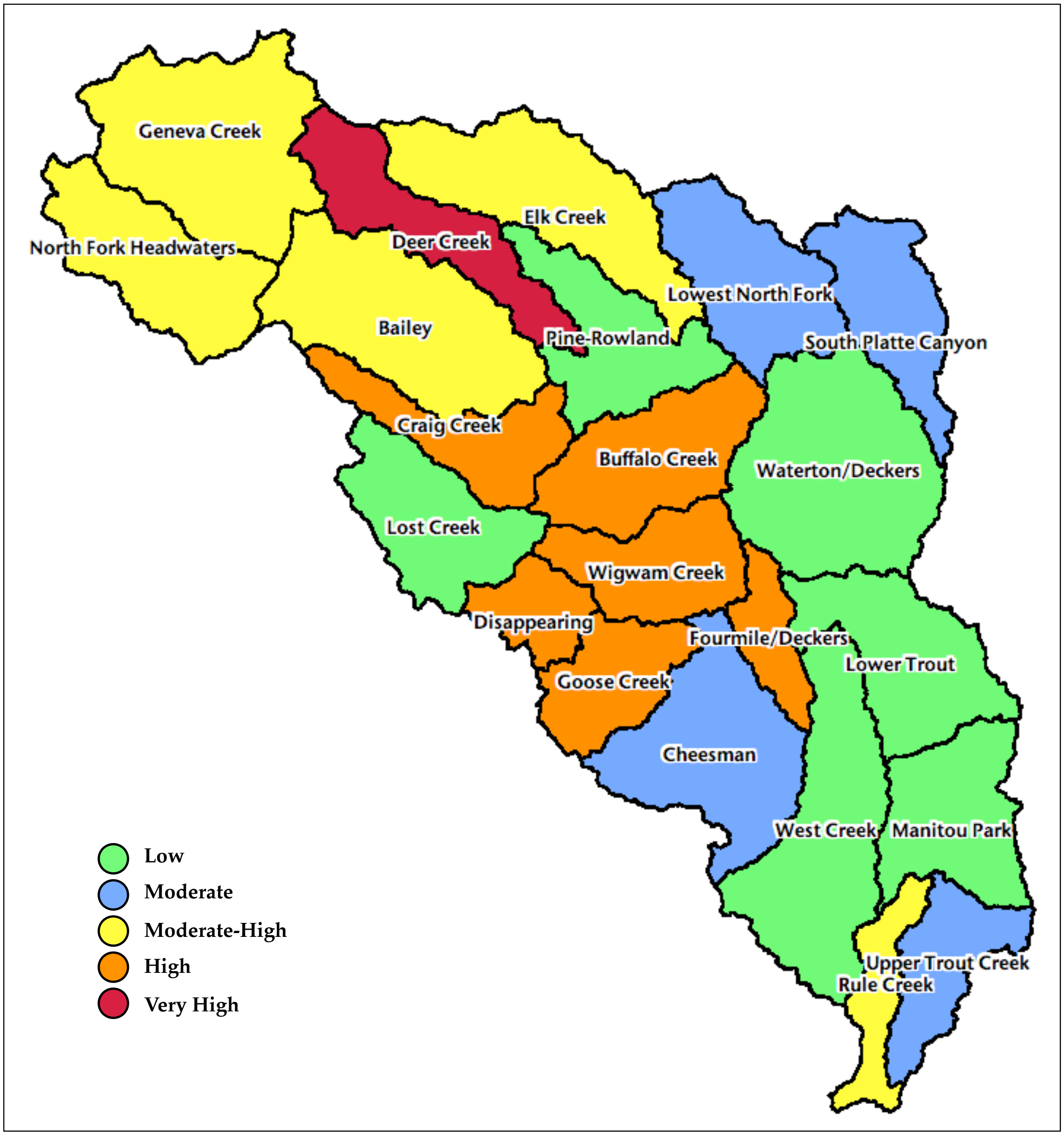

FIGURE A-3. UPPER SOUTH PLATTE WATERSHED SLOPE RANKING MAP

Road Density

Roads can convert subsurface runoff to surface runoff and then route the surface runoff to stream channels, increasing peakflows (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 will be used as an indicator of flooding risk. The U.S. Census Bureau's Tiger database was used as a consistent roads layer for the entire Upper South Platte Watershed. The Tiger database was downloaded from; http://www.census.gov/geo/www/tiger/tgrshp2007/tgrshp2007.html. The road-density data are presented in Table A-4 along with the ranking for road density. A road-density ranking map is presented as Figure A-4.

TABLE A-4. UPPER SOUTH PLATTE WATERSHED ROAD-DENSITY RANKING

WATERSHED NAME	ROAD DENSITY (MILES/SQ. MILE)	ROAD DENSITY HAZARD RANKING
Bailey	1.3	Moderate
Buffalo Creek	0.9	Low
Cheesman	1.5	Moderate
Craig Creek	0.2	Low
Deer Creek	3.1	High
Disappearing Creek	0.0	Low
Elk Creek	3.1	High
Fourmile/Deckers	1.0	Low
Geneva Creek	0.4	Low
Goose Creek	0.9	Low
Lost Creek	1.1	Low
Lower Trout Creek	1.7	Moderate
Lowest North Fork	2.4	Moderate-High
Manitou Park	2.1	Moderate-High
North Fork Headwaters	1.2	Low
Pine-Rowland	2.9	High
Rule Creek	3.3	High
South Platte Canyon	1.0	Low
Upper Trout Creek	3.9	Very High
Waterton/Deckers	1.0	Low
West Creek	1.7	Moderate
Wigwam Creek	1.0	Low

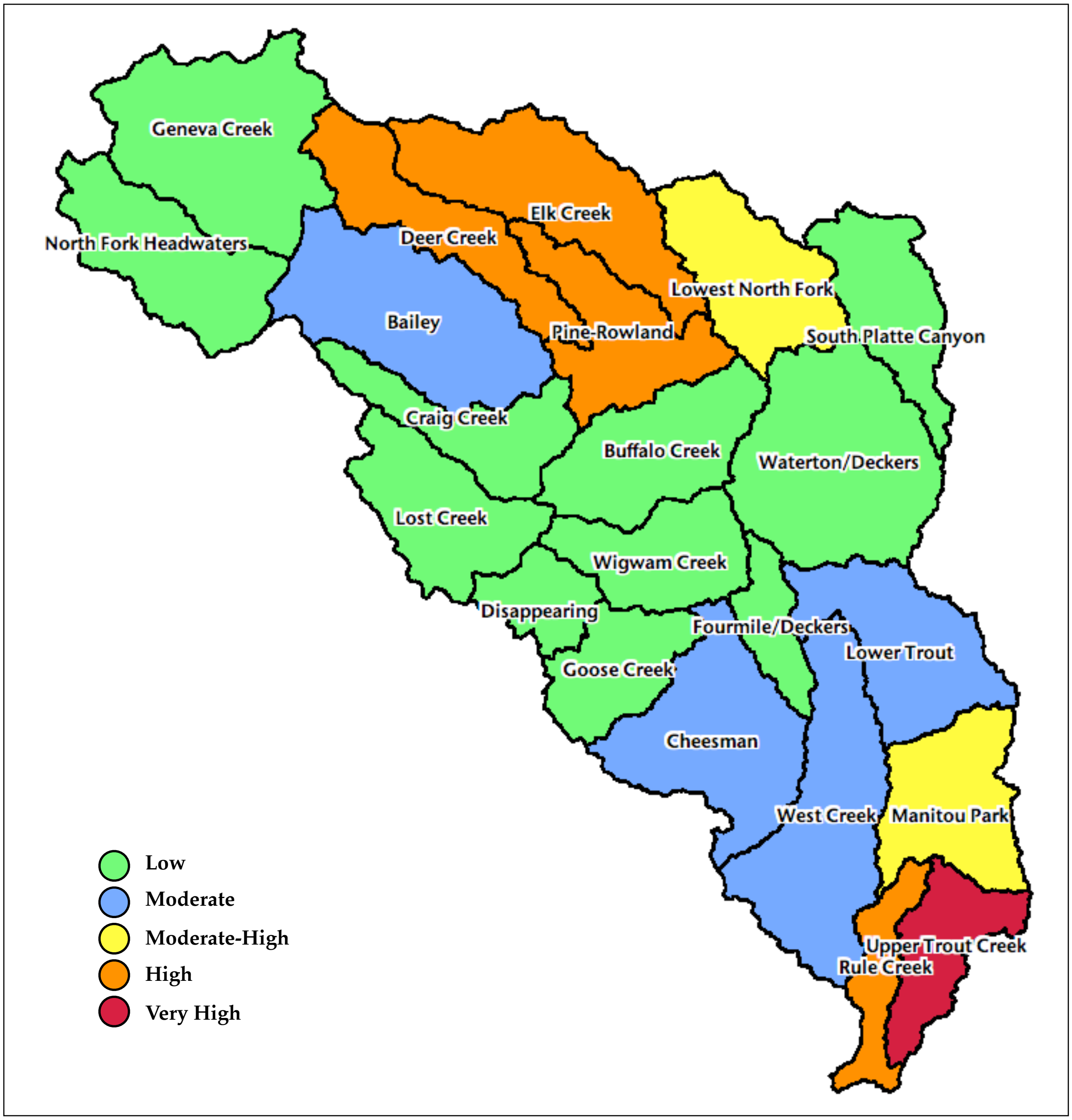

FIGURE A-4. UPPER SOUTH PLATTE WATERSHED ROAD DENSITY RANKING MAP

Flooding or Debris Flow Risk Combined Ranking

The Front Range Watershed Protection Data Refinement Work Group determined that slope should have a higher value than road density in this ranking. This determination was followed in the Upper South Platte Watershed Assessment Test Case with ruggedness, or slope, having twice the value as road density in the combined ranking. The individual rankings and the combined flooding or debris flow risk rankings are presented in Table A-5, and the combined ranking map is presented as Figure A-5.

TABLE A-5. UPPER SOUTH PLATTE WATERSHED FLOODING/DEBRIS FLOW RANKING

WATERSHED NAME	SLOPE HAZARD RANKING	ROAD DENSITY HAZARD RANKING	FLOODING OR DEBRIS FLOW HAZARD RANKING
Bailey	Moderate-High	Moderate	Moderate-High
Buffalo Creek	High	Low	High
Cheesman	Moderate	Moderate	Moderate
Craig Creek	High	Low	Moderate-High
Deer Creek	Very High	High	Very High
Disappearing Creek	High	Low	Moderate-High
Elk Creek	Moderate-High	High	High
Fourmile/Deckers	High	Low	High
Geneva Creek	Moderate-High	Low	Moderate
Goose Creek	High	Low	High
Lost Creek	Low	Low	Moderate
Lower Trout Creek	Low	Moderate	Moderate
Lowest North Fork	Moderate	Moderate-High	Moderate-High
Manitou Park	Low	Moderate-High	Moderate
North Fork Headwaters	Moderate-High	Low	Moderate-High
Pine-Rowland	Low	High	Moderate-High
Rule Creek	Moderate-High	High	High
South Platte Canyon	Moderate	Low	Moderate
Upper Trout Creek	Moderate	Very High	Moderate-High
Waterton/Deckers	Low	Low	Low
West Creek	Low	Moderate	Moderate
Wigwam Creek	High	Low	High

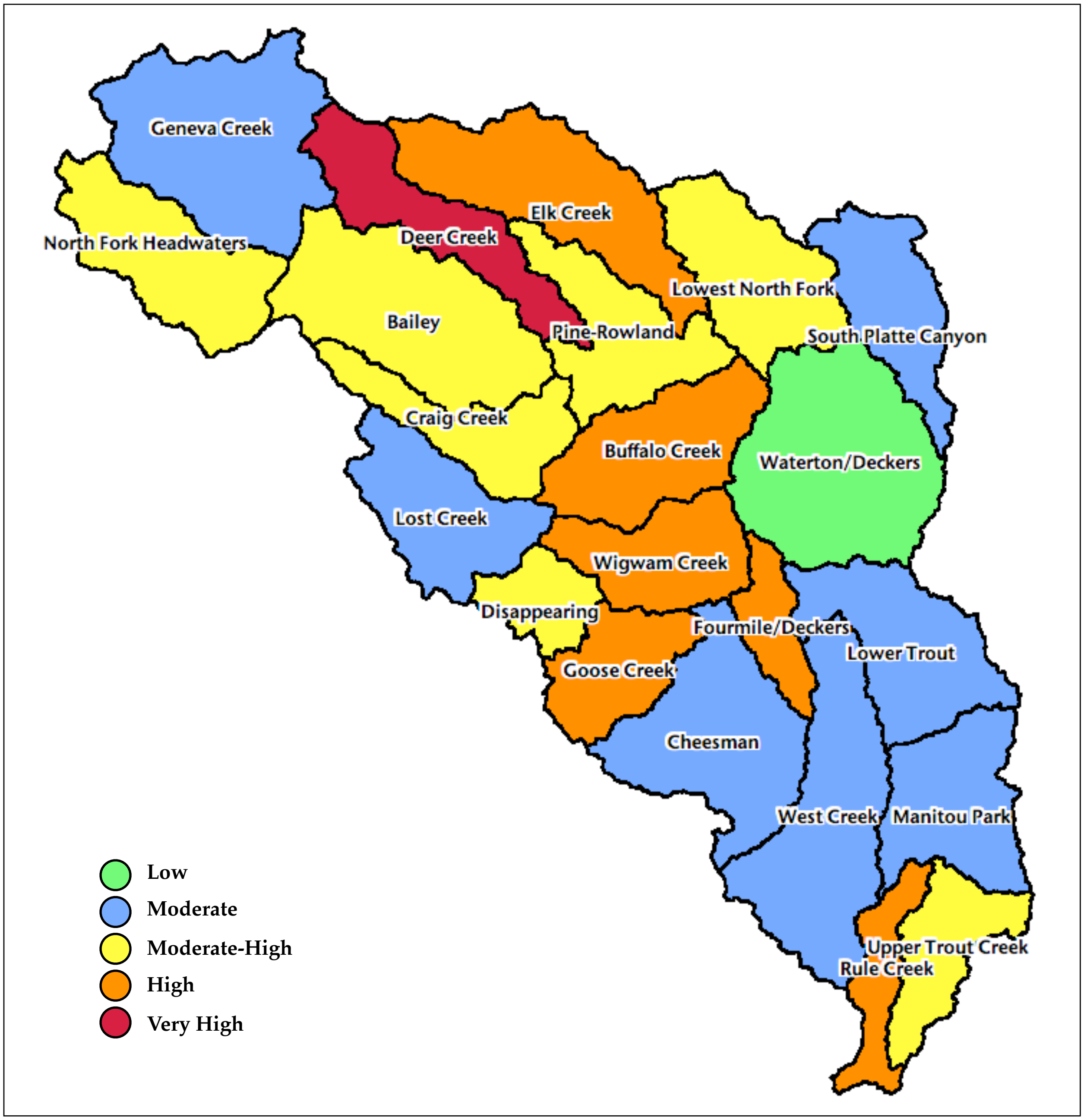

FIGURE A-5. UPPER SOUTH PLATTE WATERSHED FLOODING/DEBRIS FLOW RANKING MAP

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 as a result of soil heating (Hungerford et al. 1991).

The U.S. Department of Agriculture - Natural Resources Conservation Service (NRCS) STATSGO soils data were used for this analysis because the SSURGO data were not available. The potential for soil loss following a wildfire was determined by using a combination of two standard erodibility indicators. The base predictions of post-fire soil erosion hazard used a combination of the soil's inherent susceptibility to erosion (K factor) and land slope derived from USGS 30m digital elevation models. The K factor data (kwfact or K_w) from the STATSGO spatial database were combined with a slope grid using Natural Resources Conservation Service (USDA NRCS 1997) slope-soil relationships (Table A-6) to create a grid classified into slight, moderate, severe and very severe erosion hazard ratings.

TABLE A-6. 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

Soil scientists have observed that K factor in the Upper South Platte Watershed does not adequately identify soil erodibility on granitic soils. Therefore, where substantial areas of granitic soils exist, a geology layer was used to identify areas of granitic soils, and the erodibility rating was increased for those soils. The soils erodibility analysis was extracted from the 1999 Upper South Platte Landscape Assessment (Foster Wheeler Environmental), which is presented in Table A-7 and mapped on Figure A-6.

TABLE A-7. UPPER SOUTH PLATTE WATERSHED SOIL ERODIBILITY RANKING

WATERSHED NAME	SOIL ERODIBILITY SCORE	SOIL ERODIBILITY HAZARD RANKING
Bailey	88	Very High
Buffalo Creek	59	High
Cheesman	36	Moderate
Craig Creek	87	Very High
Deer Creek	61	High
Disappearing Creek	63	High
Elk Creek	87	Very High
Fourmile/Deckers	55	Moderate-High
Geneva Creek	71	High
Goose Creek	63	High
Lost Creek	63	High
Lower Trout Creek	38	Moderate
Lowest North Fork	88	Very High
Manitou Park	31	Moderate
North Fork Headwaters	65	High
Pine-Rowland	88	Very High
Rule Creek	31	Moderate
South Platte Canyon	55	Moderate-High
Upper Trout Creek	31	Moderate
Waterton/Deckers	55	Moderate-High
West Creek	22	Low
Wigwam Creek	55	Moderate-High

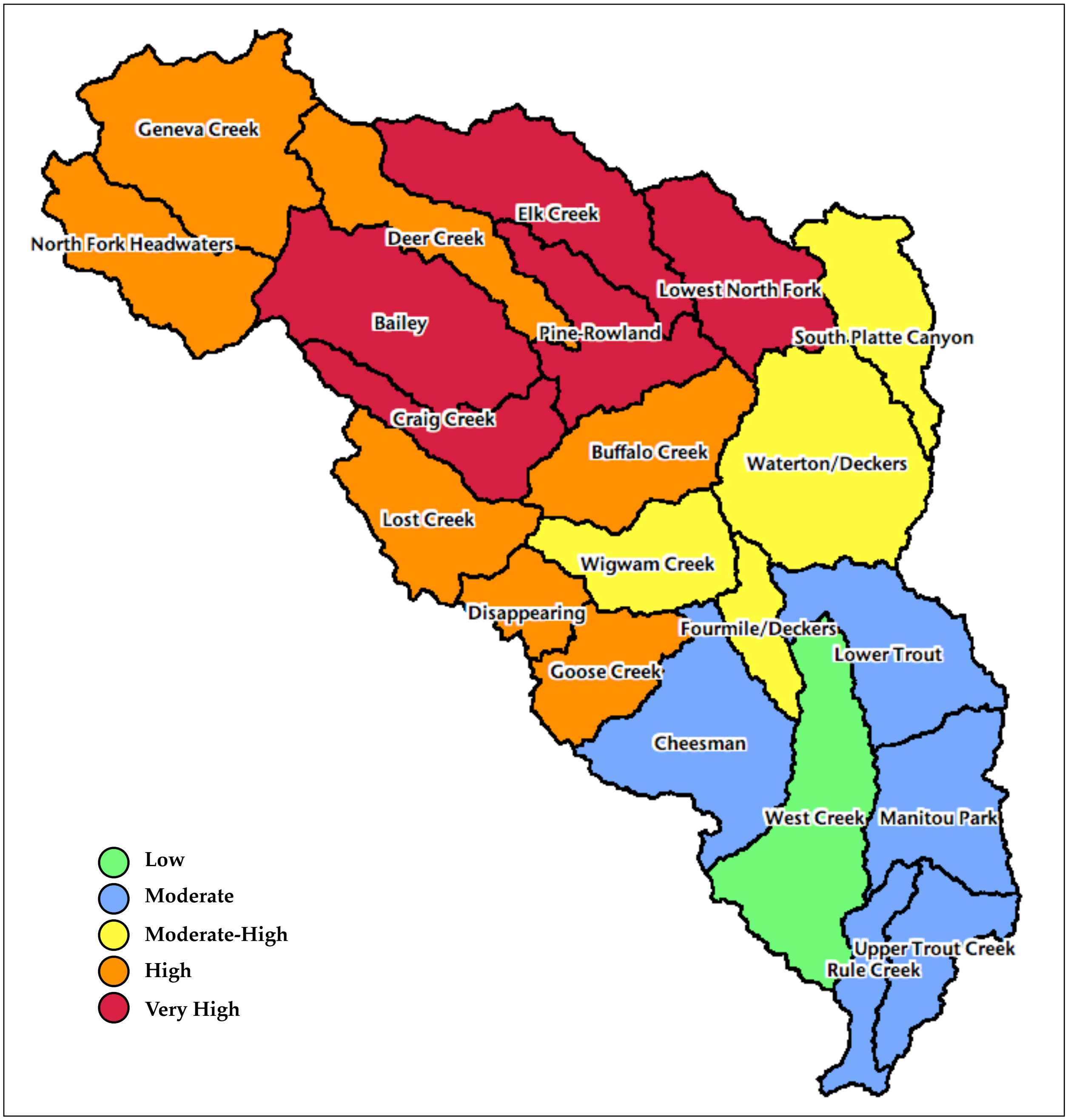

FIGURE A-6. UPPER SOUTH PLATTE WATERSHED SOIL ERODIBILITY RANKING MAP

Component 4 - Water Uses Ranking

Water intakes, diversions and storage reservoirs, and streams that are used as conveyances are more susceptible than pipelines to the effects of wildfires. These structures have been identified for the Colorado Source Water Assessment phase completed by the Colorado Department of Public Health and Environment. The water locations of the surface drinking water supply collection points, from the Source Water Assessment and Protection (SWAP) Program, in the Upper South Platte Watershed were used to define the sixth-level watersheds that contain water supply nodes. Risks to water uses were evaluated using the Water Supply Nodes tool. This test case did not use the source water assessment areas (SWAAs) developed by the SWAP Program in the Water Uses Ranking. The SWAAs did not supply additional separation between sixth-level watersheds than that supplied by the water nodes themselves in this watershed. However, the SWAAs are a valuable tool that likely will be useful in other watersheds.

The sixth-level watersheds that contain water supply nodes were identified based on data from the Colorado Department of Public Health and Environment SWAP Program. The water node ranking was based on the presence of one or more nodes within each sixth-level watershed (Table A-8). If a sixth-level watershed contained one or more nodes, it was given a "yes" in Table A-8.

TABLE A-8. UPPER SOUTH PLATTE WATERSHED WATER SUPPLY NODE PRESENCE

WATERSHED NAME	WATER SUPPLY NODE PRESENCE
Bailey	Yes
Buffalo Creek	Yes
Cheesman	Yes
Craig Creek	No
Deer Creek	No
Disappearing Creek	No
Elk Creek	Yes
Fourmile/Deckers	No
Geneva Creek	No
Goose Creek	No
Lost Creek	No
Lower Trout Creek	No
Lowest North Fork	No
Manitou Park	No
North Fork Headwaters	No
Pine-Rowland	No
Rule Creek	No
South Platte Canyon	Yes
Upper Trout Creek	Yes
Waterton/Deckers	No
West Creek	No
Wigwam Creek	No

OVERALL WATERSHED RANKING

Composite Hazard Ranking

The Composite Hazard Ranking is the combination of the rankings of the first three components (Wildfire Hazard, Flooding/Debris Flow Risk and Soil Conditions). They were combined by averaging the numerical ranking values of the Wildfire Hazard, Flooding or Debris Flow Risk and Soil Erodibility for each sixth-level watershed into a Composite Hazard Ranking (Table A-9) and was mapped (Figure A-7).

TABLE A-9. UPPER SOUTH PLATTE WATERSHED COMPOSITE HAZARD RANKING

WATERSHED NAME	WILDFIRE HAZARD RANKING	FLOODING OR DEBRIS FLOW HAZARD RANKING	SOIL ERODIBILITY HAZARD RANKING	COMPOSITE HAZARD RANKING
Bailey	Moderate-High	Moderate-High	Very High	High
Buffalo Creek	High	High	High	High
Cheesman	Very High	Moderate	Moderate	Moderate-High
Craig Creek	Moderate	Moderate-High	Very High	High
Deer Creek	Moderate	Very High	High	High
Disappearing Creek	Moderate	Moderate-High	High	Moderate-High
Elk Creek	High	High	Very High	Very High
Fourmile/Deckers	Very High	High	Moderate-High	Very High
Geneva Creek	Low	Moderate	High	Moderate
Goose Creek	High	High	High	High
Lost Creek	Low	Moderate	High	Low
Lower Trout Creek	Very High	Moderate	Moderate	Moderate-High
Lowest North Fork	Very High	Moderate-High	Very High	Very High
Manitou Park	High	Moderate	Moderate	Moderate
North Fork Headwaters	Low	Moderate-High	High	Moderate
Pine-Rowland	Very High	Moderate-High	Very High	Very High
Rule Creek	Moderate-High	High	Moderate	Moderate
South Platte Canyon	Very High	Moderate	Moderate-High	High
Upper Trout Creek	Moderate-High	Moderate-High	Moderate	Moderate-High
Waterton/Deckers	Very High	Low	Moderate-High	Moderate-High
West Creek	Very High	Moderate	Low	Moderate
Wigwam Creek	High	High	Moderate-High	High

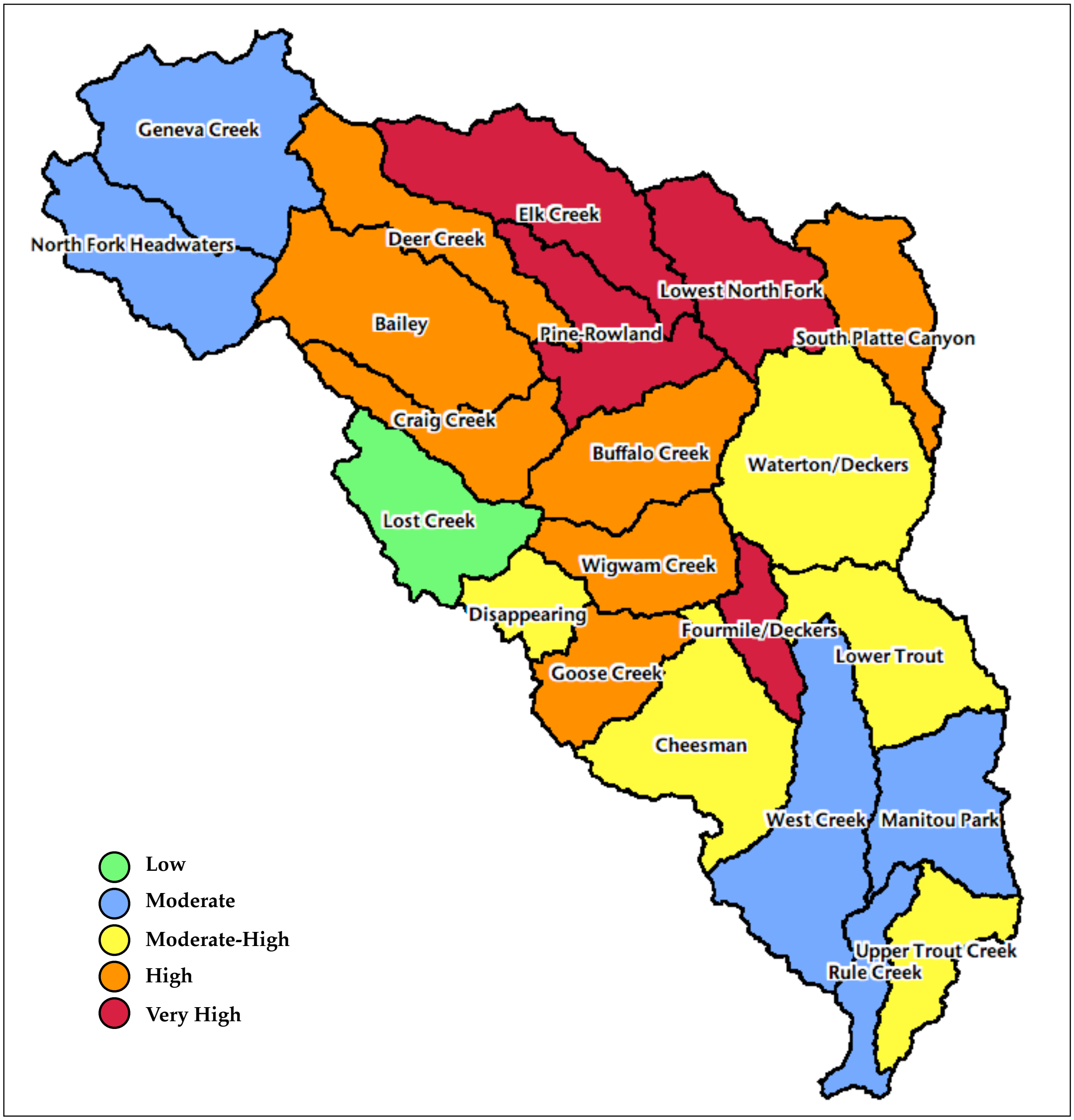

FIGURE A-7. UPPER SOUTH PLATTE WATERSHED COMPOSITE HAZARD MAP

Final Watershed Prioritization

The Final Watershed Prioritization involves combining the Composite Hazard Ranking map and the Water Uses Ranking from above. The Water Uses Ranking resulted in a numeric ranking of either zero or one. Combining the Composite Hazard Ranking and Water Uses Ranking involved increasing the hazard categories for each sixth-level watershed from the Composite Hazard Ranking map by one category for each watershed with a Water Uses Ranking value of one. The result was mapped as the Final Watershed Prioritization map (Figure A-8).

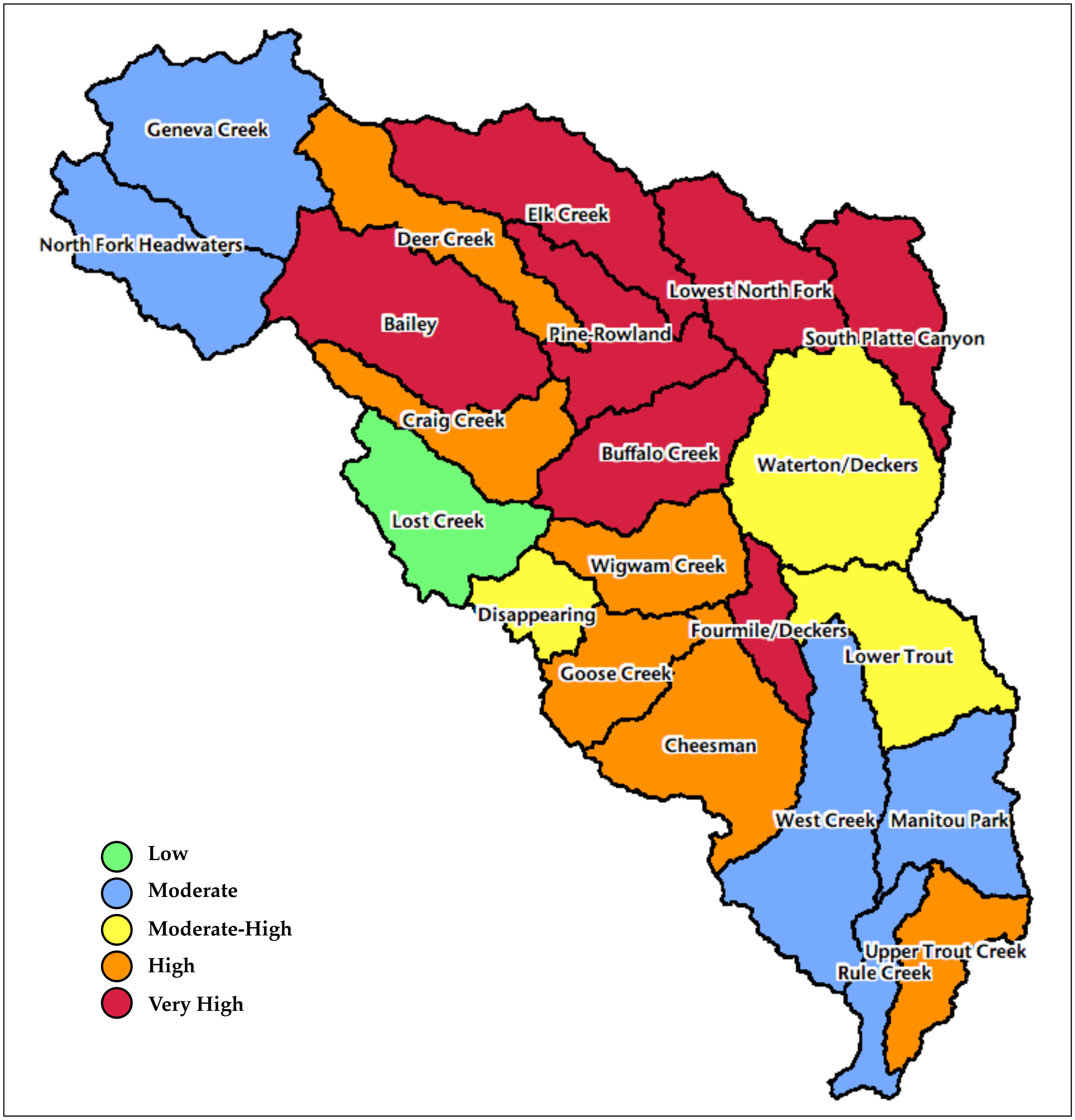

FIGURE A-8. UPPER SOUTH PLATTE FINAL WATERSHED PRIORITIZATION MAP

Zones of Concern

The Work Group identified an important risk factor for water uses related to transport of debris and sediment from upstream sources. The area upstream of important water supply reservoirs or diversions that have a higher potential for contributing significant sediment or debris is called the Zone of Concern. These Zones of Concern can be used to define project areas for stakeholders on which to focus watershed protection actions. The sixth-level watersheds within that distance are considered to be within the Zone of Concern.

The Upper South Platte Watershed Assessment used the Zones of Concern based on an 11-mile stream distance upstream based on experience following the Buffalo Creek Fire in 1996 (Moody and Martin 2001). Sediment and debris from the burned area were transported this distance along the stream course downstream to a critical water supply reservoir, Strontia Springs Reservoir. Ten Zones of Concern were identified (Table A-10), the boundaries were determined by GIS analysis (Figure A-9) and were overlaid on the Final Watershed Prioritization map (Figure A-10).

TABLE A-10. UPPER SOUTH PLATTE WATERSHED ZONES OF CONCERN

ZONES OF CONCERN
Bailey
Elk Creek
Cheesman
High Line Canal
Moore Dale Ranch
Santa Maria
Shawnee
Strontia
Windy Peaks
Woodland Park

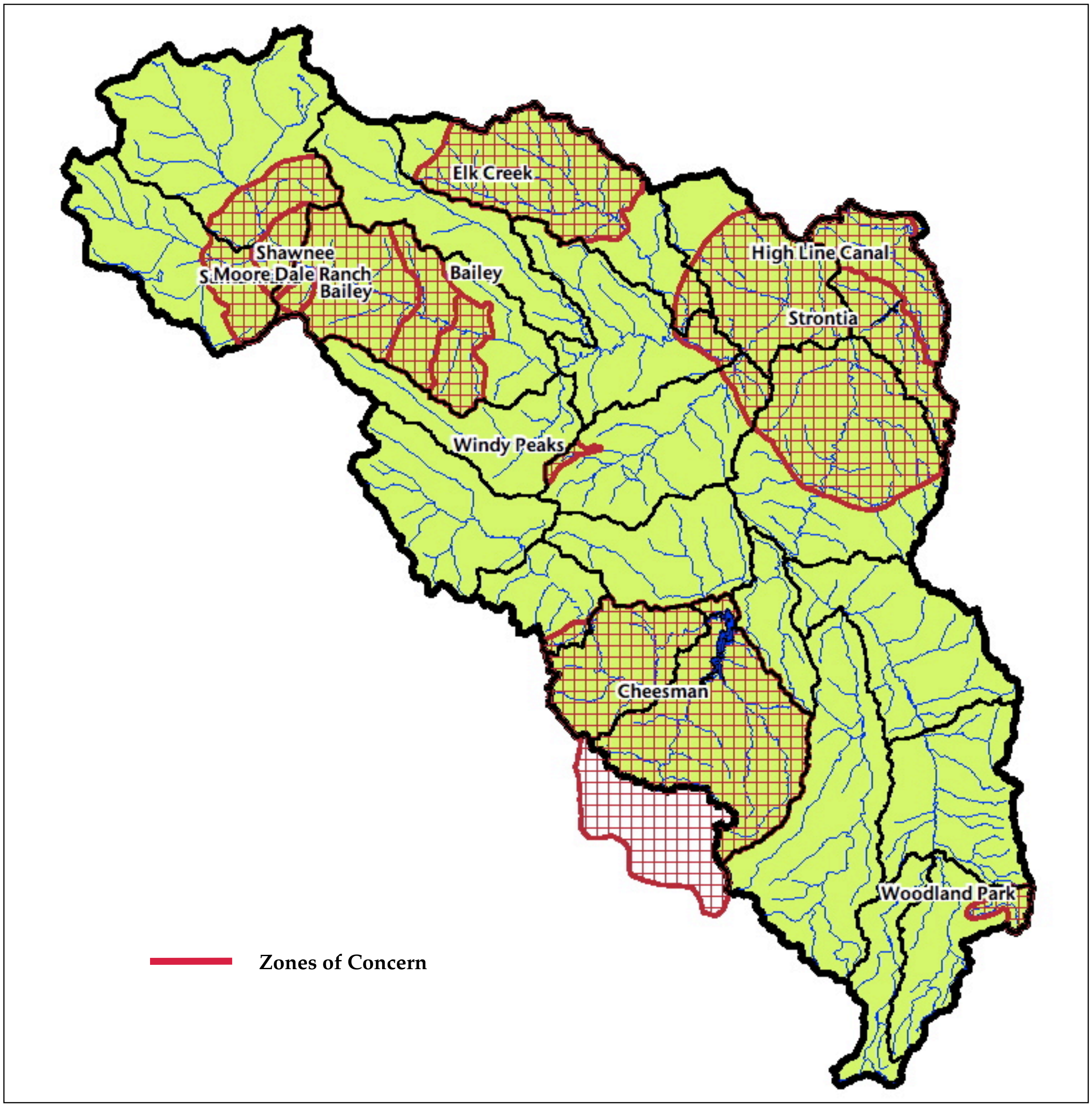

FIGURE A-9. UPPER SOUTH PLATTE WATERSHED ZONES OF CONCERN

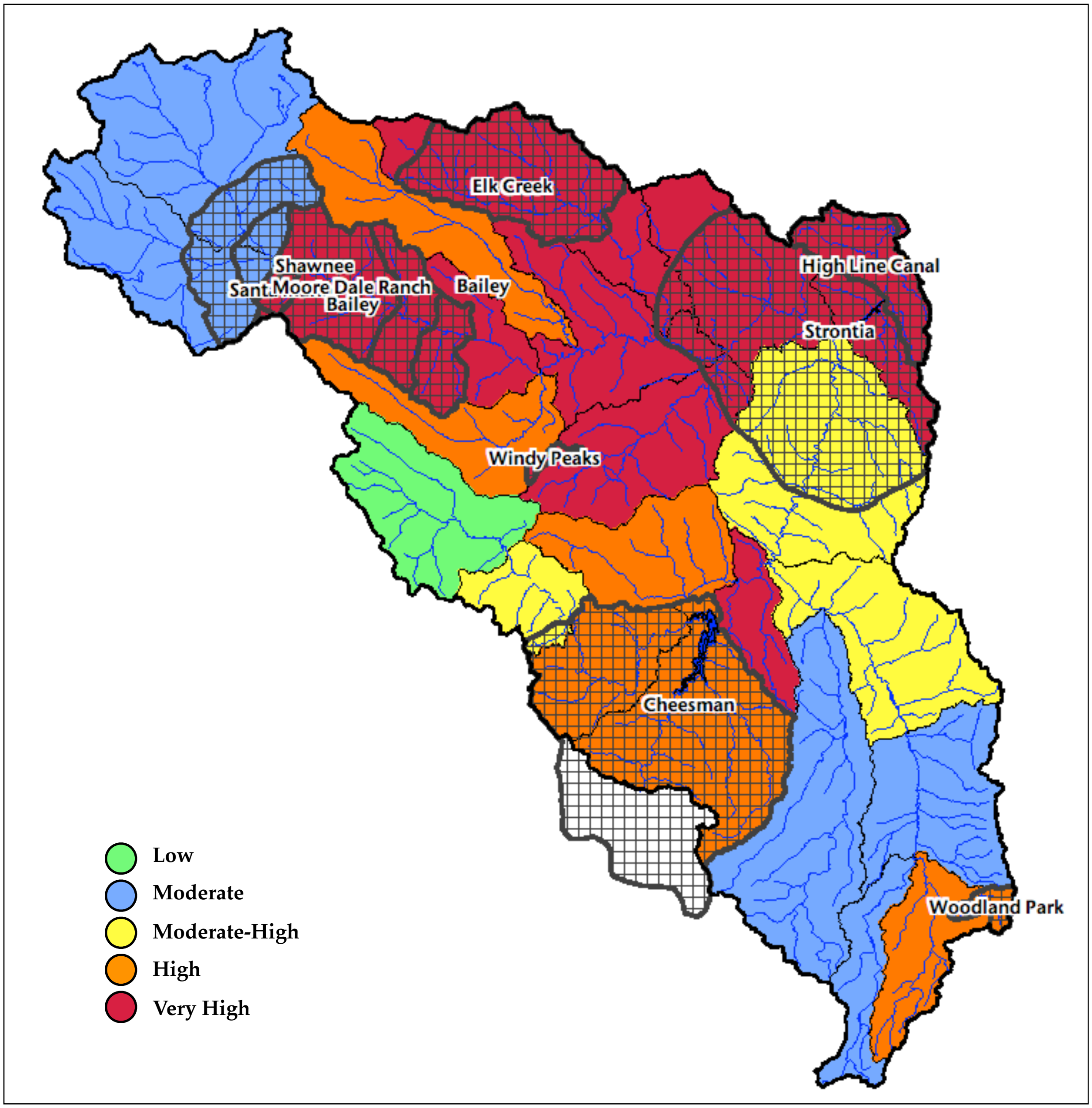

FIGURE A-10. UPPER SOUTH PLATTE ZONES OF CONCERN WITH FINAL WATERSHED PRIORITIZATION MAP

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Appendix B

GIS Data Sources

TABLE B-1. GIS DATA SOURCES

WATERSHED ASSESSMENT COMPONENT	DATA TYPE	DATA SOURCE
Wildfire Risk		
	Pinchot Institute (2007)	Colorado State Forest Service
	Colorado Fire Risk Assessment System	Colorado State Forest Service
Flooding/Debris Flow Risk		
- Elevations	Digital Elevation Model (DEM)	http://datagateway.nrcs.usda.gov/
- Watershed Boundaries	Fourth and sixth level watersheds	http://datagateway.nrcs.usda.gov/
- Roads	U.S. Census Bureau's Tiger database	http://www.census.gov/geo/www/tiger/tgrshp2007/tgrshp2007.html
Soil Conditions		
- Land Slope	Digital Elevation Model (DEM)	http://datagateway.nrcs.usda.gov/
- Soil Erodibility (K factor)	NRCS SURRGO soils data	http://soils.usda.gov/survey/geography/ssurgo/
- Soil Erodibility (K factor)	NRCS STATSGO soils data	http://soildatamart.nrcs.usda.gov
Water Uses		
- Water supply diversions & reservoirs	Colorado Department of Health and Environment (CDPHE)	http://www.cdphe.state.co.us/wq/sw/swaphom.html Note that a data-sharing agreement with CDPHE is required to acquire these data