BAER SPECIALIST REPORT

Resource Specialty: **Hydrology**
Fire Name: **Hayden Pass**
Month and Year: **July 2016**
Author Name and Home unit Name: **Jamie Krezelok, Pike/San Isabel National Forests and Cimarron/Comanche National Grasslands**

I. Potential Values at Risk

The BAER team conducted a review of potential values at risk that might be present on National Forest System (NFS) lands within and downstream of the Hayden Pass Fire. The potential critical values were selected using the agency direction contained in FSM 2523.1, Exhibit 01, "Critical Values to be Considered During a Burned Area Emergency Response." The following potential critical values impacted by the Hayden Pass Fire include:

- Human life, safety, and property
  - Increased risk for human life and safety within and downstream from the burned area due to increased potential for flooding and debris flows
  - Roads and recreation facilities including trails, campgrounds, and trailheads, irrigation ditches, reservoirs, and a fish barrier within and downstream of the burn area
  - Land survey monuments along the forest boundary
- Natural Resources
  - Municipal water supplies, source water areas, and water for agricultural uses.
  - Hydrologic function
  - Water quality
  - Habitat for threatened greenback cutthroat trout
- Cultural and Heritage Resources
  - Historic cabins and the historic Hayden Pass Road

II. Resource Condition Assessment

Resource Setting

As of July 20, 2016 the Hayden Pass Fire burned approximately 16,520 acres along the Sangre de Cristo Mountains 20 miles southeast of Salida, CO. The fire burned the eastern side of the mountain range and is bordered by the Hayden Pass Road on the north and the Lake Creek Road on the south. Table 1 summarizes the acres burned by land ownership.

Table 1: Area and percent of land burned by ownership

Land ownership	Acres burned	Percent of burned area
NFS	15,065	91%
BLM	912	6%
State of Colorado	358	2%
Private	185	1%

The majority of the NFS lands that burned are managed by the Salida Ranger District of the Pike & San Isabel National Forests and Cimarron & Comanche National Grasslands (PSICC) with a small

portion of the San Carlos Ranger District at the southern end of the fire. Portions of six HUC 12 (6th field) sub-watersheds were affected by the fire (Figure 1, Table 2). All of these are a part of the larger Arkansas River watershed. Only watersheds with more than 5% burned area were included in this analysis.

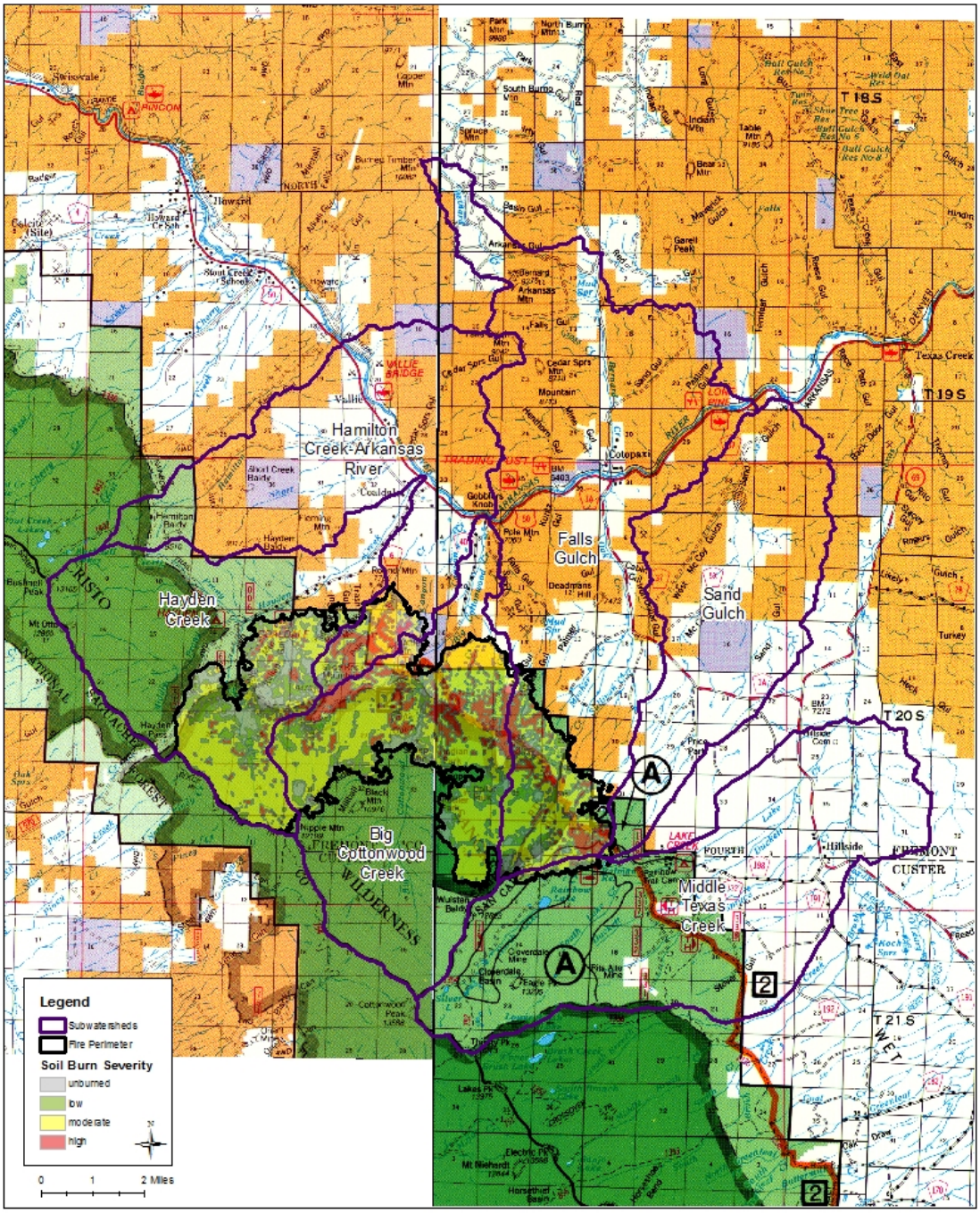

Figure 1: Map of Soil Burn Severity within the 6th field sub-watersheds affected by the Hayden Pass Fire.

Table 2: Sixth field sub-watersheds and named streams within burned area

6th field sub-watershed	HUC	Named streams in the fire perimeter	Total acres	Acres burned	Percent burned
Hayden Creek	110200010905	South Prong Hayden Creek, Italian Gulch, Spring Gulch	14,130	4,567	32%
Hamilton Creek-Arkansas River	110200010907	Pole Gulch, Fox Canyon Creek	15,774	1,259	8%
Big Cottonwood Creek	110200010906	Wolf Creek, Foots Gulch, Millball Gulch, Big Cottonwood Creek, Rattler Gulch, Indian Creek, Butter Creek, Little Cottonwood Creek	15,723	7,305	46%
Falls Gulch	110200011403	Mud Gulch, Deep Gulch, Mosher Creek, Oak Creek, Sullivan Creek	24,748	3,140	13%
Middle Texas Creek	110200011003	None	19,734	210	1%
Sand Gulch	110200011404	None	12,455	31	0.2%

Within these 6th field sub-watersheds, multiple drainages were delineated to evaluate the potential values at risk. A pour point was identified at the mouth of each of each of these drainages, and this point was utilized to delineate the drainage area above that point. Table 3 and Figure 2 show the modeled drainages within each of the larger 6th field sub-watersheds.

Table 3: Sub-watersheds within the 6th level watersheds

6th field sub-watershed	Modeled drainage	Total acres	Percent of 6th field sub-watershed
Hayden Creek	South Prong Hayden Creek	3,434	24%
	Italian Gulch	1,245	9%
Hamilton Creek-Arkansas River	Pole Gulch	1,317	8%
Big Cottonwood Creek	Wolf Creek	2,399	15%
	Big Cottonwood Creek	8,360	53%
	Butter Creek	1,017	6%
	Little Cottonwood Creek	2,379	15%
Falls Gulch	Deep Gulch	804	3%
	Mosher Creek	1,686	7%
	Oak Creek	1,252	5%
	Sullivan Creek	2,009	8%

The main streams within the fire perimeter are listed in Table 2 above. These are bedrock, cobble and gravel dominated stream systems. There is approximately 24 miles of perennial stream and miles of intermittent stream within the fire perimeter.

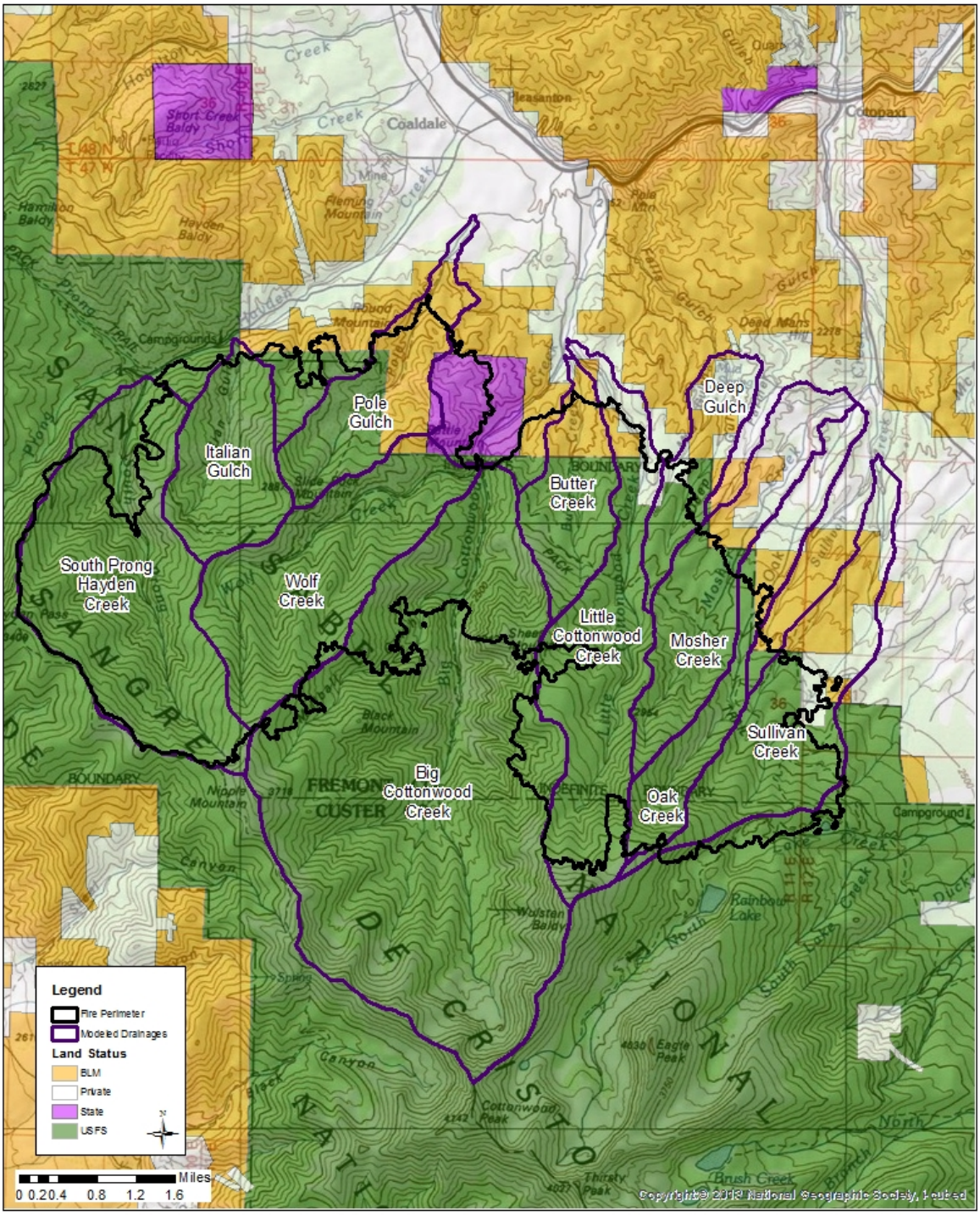

Figure 2: Modeled drainages in the Hayden Pass Fire.

Elevation within the burned area perimeter ranges from approximately 11,900 feet near Wulsten Baldy to approximately 7,060 feet along Pole Gulch at the northern end of the fire. Annual precipitation ranges from 15 to 27 inches throughout the fire perimeter and is comprised of snowfall in the higher elevations during the winter and high intensity rainfall events in the late summer when the area is impacted by monsoonal flow patterns.

Summary of Findings of the On-the-Ground Survey

Resource Condition Resulting From the Fire

The BAER team performed a rapid ground and air reconnaissance of the burned area to verify the validity of the burned area reflectance map. The criteria for soil burn severity can be found in the soil scientist's report. The BAER team assessment identified the overall soil burn severity for the Hayden Pass Fire as 26% low/unburned, 56% moderate, and 18% high. The team conducted soil hydrophobicity tests and found that both moderate and high burn severity areas had increased hydrophobicity from baseline conditions. Table 4 shows the burn severity by sub-watershed.

Hydrologic conditions in the burned watersheds have changed significantly as compared to pre-fire conditions. Under pre-fire conditions vegetation and underlying organic matter slows runoff and protects soils from direct raindrop impact, assists with water infiltration to soil, and releases runoff at slower rates.

Table 4: Burn severity and percent of watershed in each severity class by sub-watershed

6th field watershed	Unburned acres (%)	Low acres (%)	Moderate acres (%)	High acres (%)
South Prong Hayden Creek	812 (24%)	548 (16%)	1,841 (54%)	197 (6%)
Italian Gulch	298 (24%)	297 (24%)	482 (39%)	168 (13%)
Pole Gulch	264 (20%)	116 (9%)	501 (38%)	436 (33%)
Wolf Creek	136 (6%)	259 (11%)	1,507 (63%)	497 (21%)
Big Cottonwood Creek	7,135 (85%)	373 (4%)	758 (9%)	298 (4%)
Butter Creek	68 (7%)	13 (1%)	610 (60%)	326 (32%)
Little Cottonwood Creek	605 (25%)	285 (12%)	1,229 (52%)	260 (11%)
Deep Gulch	540 (67%)	41 (5%)	89 (11%)	134 (17%)
Mosher Creek	734 (46%)	142 (8%)	592 (35%)	218 (13%)
Oak Creek	627 (50%)	173 (14%)	405 (32%)	47 (4%)
Sullivan Creek	989 (49%)	136 (7%)	605 (30%)	279 (14%)

As a result of the altered hydrologic function associated with burned soils and vegetation the primary threat to values at risk for hydrology are associated with flooding, debris flows, and sedimentation. Consumption of organic material and high soil heating can promote the formation of water repellent layers, at or near the soil surface, which can result in increased overland flow and hillslope erosion resulting in significant amounts of soil loss. The strength and depth of water repellency varies greatly by the duration and intensity of soil heating, type of organic matter consumed by the wildfire, and soil texture and moisture content. A water repellent layer was observed at the surface to a depth of approximately 1/8th inch in moderate burn severity areas and

was deeper in areas with high burn severity. Due to the Hayden Pass Fire the hydrologic function has been adversely affected and rates of runoff and sediment outputs are expected to increase, particularly for the first one to two years after the fire.

These increased flows are expected to result in sedimentation and/or scour of channels and are likely to occur at an accelerated rate until vegetation establishes itself and provides ground cover. With intense rainfall and the expected increase in runoff, the slope materials could easily move into drainages, accumulate and move downstream, and increase exponentially further down the watershed. Along with sediment bulking, it is expected that burned wood and other organic materials in the watersheds will be entrained in the flows. If a sustained and intense runoff event occurs, it is likely that debris flows may initiate in the upper basins and accumulate in steeper tributary channels and move downstream.

Initial erosion of ash and surface soil during the first storm events will reduce slope roughness by filling depressions above rocks, logs, and remaining vegetation. The ability of the burned slopes to detain water and sediment will be reduced accordingly. This will increase the potential for flash floods and will increase the distance that eroded materials are transported. However, several factors favor a quick recovery in terms of normal hydrologic response of some hillslopes. The existence of fine roots in the low and moderate severity burn areas just below the surface will likely aid plant recovery and will serve as a seed source for natural vegetation recovery. The major factor in hydrologic recovery is development of ground cover and vegetative recovery in the moderate and high soil burn severity areas.

If channel capacities are limited along these reaches due to channel constriction points areas of dense in-channel vegetation and sediment deposits are large enough, peak flow runoff and debris may be able to overwhelm channel banks and flow out of the channel. The post-fire flows could lead to plugged culverts, flow over road and trail surfaces, rill and gully erosion, and threats to human safety.

Modeling Summary

The Wildcat Rainfall-Runoff Hydrograph Model (Hawkins and Greenberg 2013) was used to predict increases in peak flows resulting from the fire. Two separate design storms were used in this analysis. The 10-year 1-hour storm was chosen to represent a high intensity monsoonal storm and a 2-year, 30 minute storm was used to represent a more general rainstorm. The design storm magnitudes found using the NOAA Precipitation Frequency Data Server were 1.01 inches and 0.6 inches, respectively (Perica et al. 2013). Experience with other natural and prescribed fires indicates that while storms of 0.5 inch or greater will cause erosion and elevated floods and sediment loads, it is typically 1 inch or greater high intensity storms that produce significant damage.

A custom storm distribution based on Arkell and Richards (1986) was used in this analysis. This distribution represents the typical thunderstorm where the intensity is highest at the start of the storm then tapers off at the end of the storm. Table 5 shows the storm distribution used for both storms.

Table 5: Rainfall storm distribution used in hydraulic modeling

Time (%)	Rain (%)
0	0
8.3	30
16.7	50
25	63
50	83
100	100

Soil types were utilized to determine hydrologic soil groups. The hydrologic soil group-burn severity combination was calculated for each watershed and each combination was assigned a corresponding curve number. The curve numbers used in this analysis were based on the curve numbers in WILDCAT5 for Woods in fair condition. Pre-fire curve numbers were assigned with the assumption of good condition or an intact forest floor. Hydrologic changes from the loss of soil cover and soil water repellency from burning were modified by increasing the curve number. Curve numbers utilized are shown in Table 6 below.

Table 6: Curve numbers used in analysis

	Hydrologic Soil Group	
Burn Severity	**B**	**D**
Unburned	60	79
Low	65	84
Moderate	85	85
High	90	90

Watersheds were delineated using the on-line USGS StreamStats program (Cooper 2005). Basin characteristics and regression equation approximations of peak flows were generated using the web-based utility and exported as shapefiles.

Using these curve numbers and the delineated watersheds pre and post-fire runoff were estimated using the Wildcat 5 (ver. July 2013) hydrologic model using a simple triangular unit hydrograph.

Inputs necessary for Wildcat 5:

- Acres of each CN based on soil burn severity and hydrologic group
- Time of Concentration calculated using Dunne and Leopold's equation (1978)
    - Length of longest channel (ft) – measured using measuring tool in ArcMap
    - Basin Relief - calculated by subtracting the basin outlet from the highest ridge elevation
- Storm intensity and duration

The following tables contain the hydrologic factors used in the analysis and a comparison of pre to post-fire flow projections for the modeled precipitation events by watershed.

Table 7: Hydrologic design factors used in this analysis

Estimated Vegetative Recovery Period	3 to 5 years
Design Chance of Success	80%
Equivalent Design Resource Interval	2 years and 10 years
Design Storm Duration	30 minutes and 1 hour
Design Storm Magnitude	0.6 inches and 1.01
Design Flow	0 and 13 cfs/mi^2
Estimated Reduction in Infiltration	74%
Adjusted Design Flow	22 and 76 cfs/mi^2

The runoff numbers from the 10-year storm event modeled in Wildcat were comparable to the 2-year peak flows calculated through StreamStats, indicating that the Wildcat model results were within the expected range of variability. The Big Cottonwood Creek drainage was too large to be run through Wildcat, which is only accurate for watersheds under 3,200 acres, therefore a smaller subwatershed that contained the majority of the burned area within that drainage was run under both pre and post-fire conditions. The average flow from StreamStats was used as the pre-fire flow under the 10-year storm event. The percent difference between pre and post fire was then applied to this value to get the post-fire peak flow. The 2-year flow was also determined as a percent difference from the 10-year event based on the modeled flow values.

The results of the pre and post-fire hydrologic modeling are shown in Table 8 below. Increases in flows are expected within the modeled drainages as a result of the two design storms simulated. None of the drainages generates measurable runoff from the pre-fire 2-year storm. In this case the initial abstraction is greater than the depth of rainfall from the design storm, which results in no runoff. These results should be interpreted with caution as numerous assumptions and simplifications of physical processes are embodies in the output. While absolute flow magnitudes may contain considerable uncertainty, relative increases in peak flow are intended to provide a more useful guide for understanding the general extent of alteration of a drainages soil hydrologic function. The post-fire peak flows do not include a sediment bulking factor; therefore, the actual post-fire peak flows are expected to be higher than predicted. Overall, basins where the majority of the watershed burned as moderate or high severity showed the greatest increase in flows. It is expected that flash floods and debris flows are likely to occur if sufficient rainfall and intensity occurs. A general rule of thumb, based on anecdotal information from previous fires, is that burned areas, greater than a half inch of rain in less than 1-hour is sufficient to initiate debris flows.

Table 8: Pre and post-fire peak flow predictions from Wildcat Rainfall-Runoff Hydrograph Model

Sub-Watershed	Percent NFS land	2-year, 30 minute event		10-year, 1-hour event	
		Pre-fire estimated discharge (cfs)	Post-fire estimated discharge (cfs)	Pre-fire estimated discharge (cfs)	Post-fire estimated discharge (cfs)
South Prong Hayden Creek	100%	0	120	35	465
Italian Gulch	100%	0	71	35	225
Pole Gulch	49%	0	93	45	282
Wolf Creek	98%	0	137	32	468
Big Cottonwood Creek	100%	0	55	89	220
Butter Creek	74%	0	97	53	288
Little Cottonwood Creek	85%	0	86	114	365
Deep Gulch	41%	0	27	6	77
Mosher Creek	62%	0	57	33	202
Oak Creek	59%	0	26	29	109
Sullivan Creek	58%	0	74	23	238

Consequences of the Fire on Values at Risk

There are multiple threats to municipal, domestic, or agricultural supply to water quality and hydrologic function within and downstream of the burned area. The magnitude of post-fire impacts to water quality are dependent on the size, intensity, and severity of the fire. In general the following effects are observed in post wildfire conditions:

- Accelerated rates of erosion and channel scouring can deliver large amounts of sediment to neighboring water bodies. As a result, suspended sediment concentrations and turbidity will increase in surrounding rivers and lakes. Post-fire increases in suspended sediment and turbidity are expected to be most evident in the first year following the fire, and to return to levels similar to pre-fire conditions within 3-5 years.

- Sediment delivery is largely a function of hill slope and channel gradient, with steeper hill slopes delivering more sediment to water bodies, and steep streams acting as transportation conduits to lower gradient depositional areas. The steep gradients of many of the smaller tributaries in the burned area indicate that substantial transport and deposition will occur in depositional areas downstream of the burned area in lower gradient areas.

- Increased concentrations (in water bodies) of nitrogen, phosphorus, sulfur, chloride, bicarbonate, and heavy metals all have the potential to occur following fire events.

However, documented cases of exceeding National Primary and Secondary Drinking Water Standards are rare (Neary et al. 2005).

III. Emergency Determination

Upon completion of the BAER survey and analysis, the BAER team completed a review of threats to the previously identified critical values at risk. This was done using the Values at Risk matrix contained in FSM 2531.1, Exhibit 2. Through this process a probability of loss or damage is assigned along with a magnitude of the consequence to determine the level of risk that is present. The calculated risk level is then used to determine whether or not an emergency exists and what treatments are necessary to mitigate the emergency on NFS lands. The following is a summary of the BAER team's emergency determination for the previously identified critical values that are directly and indirectly related to the hydrology resource area.

Human Life and Safety

The flood hazard is predicted to increase dramatically within and immediately downstream of the burn area for forest visitors and workers on NFS lands. An emergency for flood hazard was determined for the following reasons:

- Runoff is predicted to increase significantly following the fire.
- There is substantial risk to life and property resulting from the increased flood risk, especially at roads, trails, and campgrounds located within the floodplain.

It was determined that the risk to NFSR 40, the Coaldale Campground, and the Rainbow Trail was very high. An emergency exists and response actions have been proposed by the BAER team engineering and recreation resource specialists.

Property

Threats to property and infrastructure on NFS lands within and downstream of the burned area exist along the road and trail network. These threats are an indirect effect of the expected post-fire watershed response to storm events. It was determined that the risk along NFSR 40, the Coaldale Campground, the Rainbow Trail, and to the fish barrier on South Prong Hayden Creek was very high. An emergency exists and response actions have been proposed by the BAER team engineering, recreation, and fisheries resource specialists.

Spring Development for Livestock and Wildlife Water on NFS Allotment

The Sullivan Spring and Pipeline is located on NFS lands within the burned area near the northeast edge of the fire. The condition of this water development is unknown at this time, but it is in an area of high burn severity and may be at risk for impacts from erosion and sediment input. Since the site was not visited a risk assessment was not done for this value at risk. The water development will be visited as soon as possible to determine if any work needs to be done to protect this development.

Diversion Ditches and Mosher Reservoir

The Mosier and Little Cottonwood Ditches and Mosher Reservoir appear to be under a right of way agreement with the Forest Service and therefore are considered NFS property. The two ditches are located within the burned area and flow into Mosher Reservoir, which is also within the burned area on NFS land. Due to the steepness of the terrain and likelihood of ash and sediment laden flows coming into the ditch it is likely that these two ditches will need increased maintenance to ensure

they remain functional and do not cause resource damage if they fail. The reservoir is in fairly good condition; however the spillway is currently clogged with trees that could block high flows and debris increasing the risk of dam failure.

The probability of damage or loss is likely. This determination is a result of the burned area upstream causing sediment, ash, and other burned material to fill in the ditch and clog the reservoir spillway. The magnitude of consequences is moderate. Therefore, the risk level is high.

Natural Resources-Water Quality

Threats to waters used for agricultural supply on NFS lands exist within the Hayden Pass Fire area. Threats to critical habitat and suitable occupied habitat for federally listed threatened or endangered aquatic species exists within the South Prong of Hayden Creek. Large sediment increases from moderate and high burn severity areas are possible during and immediately after storm events. This is expected to be a short-term effect that will persist for the next three to five years.

Irrigation Water Quality

Impacts to irrigation water quality could occur downstream of the burned area off NFS lands. These impacts would occur in direct response to heavy rain events and subside quickly following storm generated peak flows. Irrigation water providers and users may need to test periodically to ensure water quality meets standards for irrigation or livestock watering.

The probability of damage or loss is possible. This determination is a result of high intensity storms often occuring before or after the irrigation season, and the ability to close off ditches before high intensity storms to minimize impacts. The magnitude of consequences is moderate. Therefore, the risk level is intermediate. An emergency does not exist.

Municipal/Domestic Drinking Water Quality

Post-fire water quality is not anticipated to impact municipal or domestic water supply significantly, due primarily to usage of wells rather than surface supply intakes. The closest surface water supply out takes are approximately 35 miles downstream, near Canon City, CO and 43 miles downstream to Florence, CO.

The probability of damage or loss is unlikely. This determination is due to the fact that water supply in the areas adjacent to the fire is from groundwater rather than surface water. In addition, the water treatment plant in Canon City is able to shut down their system for a few days if necessary and the Florence has the ability to take water from another source if necessary. The magnitude of consequences is major. Therefore, the risk level is intermdiate, and an emergency does not exist.

Natural Resources-Hydrologic Function

Threats to hydrologic function on NFS lands within the burned area exist on areas of moderate and high burn severity. The presence of hydrophobic soils, loss of canopy cover, loss of ground cover, and loss of channel stabilizing riparian vegetation all have the potential to contribute to altered hydrologic function and watershed response to precipitation events within burned watersheds. This is expected to be a short-term effect. The probability of hydrologic function impairment is likely and the magnitude is minor. An emergency does not exist.

IV. Treatment Proposals to Mitigate the Emergency

Proposals including closure, storm-proofing, signing, and monitoring are included for the Coaldale Campground, multiple foot bridges, the Rainbow Trail, dispersed campsites, roads, and the fish barrier on South Prong Hayden Creek. These values and treatments are discussed in detail in other resource reports, including engineering, recreation, and fisheries.

Mosher and Little Cottonwood Ditches

A. Treatment Type: Assessment of the ditches, and storm patrol and clean out after thunderstorms.
B. Treatment Objective: To ensure the ditches have enough capacity to transport water to the Mosher Reservoir without failing.
C. Treatment Description: The treatment will involve an assessment of the condition of the ditches and headgates to determine the risk of failure. Headgates will be closed if it appears a thunderstorm is moving over the area to reduce the risk of sediment and ash laden flows getting into the ditch. Monitoring and cleanout of the ditches with hand tools will occur after thunderstorms.

V. Discussion/Summary/Recommendations

Wildfires result in increased runoff and sediment yield commensurate with soil burn severity. Minor precipitation could now produce runoff that would not have occurred previously, and moderate or major precipitation could produce extreme runoff events, particularly in steep drainages. Streams in the analysis area have peak flows in response to summer thunderstorms. Post-fire peak flows will vary depending on the amount of vegetative recovery and the degree that hydrophobic soil layers are broken up before the next high-intensity storm.

Areas that have the highest potential for increased flows resulting from the fires include drainages with large amounts of high and moderate burn severity. Debris flows in these areas are a risk to life and safety for forest visitors and workers, and to property including roads, trails, and campgrounds. Treatments to mitigate hazards on NFS lands include: safety signs, campground closure, road drainage improvements, bridge removal, trail storm-proofing and storm patrol, and protection of the fish barrier. These treatments are described in the engineering, recreation, and fisheries specialist reports.

VI. References

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