Appendix F Fire Behavior Modeling: Methods and Assumptions

F.1 Models Used

Two fire behavior prediction models were used, FLAMMAP and FARSITE, by the AMSET Team to model predicted fire behavior under each alternative. FlamMap portrays fire behavior in each landscape location (pixel) if it burned under specified weather conditions. FARSITE has similar underlying algorithms as FLAMMAP, but incorporates fire spread across the landscape over time, given a set of fire weather conditions (that change over time). Details on model settings and weather inputs were included in Chapter 4.

F.2 Fuel Modeling

AMSET used three data sources to characterize park fuels for use in potential fire behavior modeling, 1) surface fuel model layer developed by GRCA fire staff, 2) crown fuel layers from LANDFIRE, and 3) the GRCA vegetation type layer. The base surface fuel layer was not modified from what GRCA fire staff provided, except in some areas of piñon-juniper vegetation types. AMSET extensively investigated crown fuel layers provided by GRCA, but determined that layers were not comprehensive enough (areas missing), not updated for fires as was the surface fuel layer, had apparent inconsistencies, and were difficult to understand. AMSET tried to correct inconsistencies and update data for fires, but, in the end, a reasonable layer could not be constructed for the analysis area, thus testing and revision of LANDFIRE data for fires since 2000 begun from scratch.

<u>Surface Fuels</u> The surface fuel model layer developed by GRCA fire staff incorporates new fuel models found in the Standard Fire Behavior Fuel Models: A Comprehensive Set for Use with Rothermel's Surface Fire Spread Model (Scott and Burgan 2005). The layer was informally ground-truthed by GRCA fire staff. Changes in surface fuel layer were made by GRCA fire staff for post-fire conditions based on a set of developed rules (Table F-2). Criteria include pre-fire surface fuel model type, vegetation type, and post-fire severity. These rules have been applied since 2000, when post-fire severity maps were available. GRCA fire staff evaluated rule effectiveness in the field over the past several years.

AMSET modified the base layer in piñon-juniper woodlands in some places to incorporate crown fuels and better characterize bi-polar behavior observed in piñon-juniper vegetation. Previously, modeling the piñon-juniper type in the western U.S. has been problematic. Under very high weather conditions, such as 97^{th} percentile or high wind conditions, crowning will occur. Typically, a surface model that depicts tall, dense shrub type has been used to depict these conditions. However, this leads to overprediction of fire behavior during less extreme weather conditions. Since the time GRCA fire staff assigned surface fuel model types to piñon-juniper, fire behavior analysts and fuel modeling experts have shifted to use of combined crown fuels and dynamic surface fuel models with reduced loading and fire behavior. Dynamic models change characteristics with level of fuel moisture. In piñon-juniper, this allows a more accurate portrayal of observed surface fire behavior during most weather conditions, but a high likelihood of crown fire during very windy and dry weather conditions. Areas modeled as Type 147 (portrays a tall shrub fuel type with heavy loading and intense fire behavior during most weather conditions, Scott and Burgan 2005) in piñon-juniper were changed to a grass or shrub-grass models, and crown fuels were applied from the LANDFIRE data.

AMSET made changes to treated areas in the surface fuel model layer using an ARCGIS GRID[1] program, and used criteria based on rules provided by GRCA fire staff that incorporated years since treatment or fire, fire severity level, and pretreatment surface fuel model. AMSET predicted severity levels based on analysis of fire severity patterns by dominant vegetation type for prescribed fires mapped for post-fire

[1] ARCGIS GRID stands for ArcView Geographic Information System Grid Program

severity since 2000. Mean acres per severity class per vegetation type were calculated, but in some cases the sample size was low, and levels were adjusted. The modeled levels are shown in Table F-1.

Table F-1 Percent of Area by Dominant Vegetation Type Assigned to Different Post-treatment Severity Levels

Percent of Fire Severity Class by Dominant Vegetation Type					
Severity	Shrub/Barren	Piñon-Juniper	Spruce/Fir	Ponderosa Pine	Mixed-Conifer
unburned	19	36	30	16	20
low	50	47	10	51	20
low/moderate	22	10	20	23	30
moderate/high	6	4	20	7	20
high	3	3	20	3	10
TOTAL	100	100	100	100	100

Levels were developed from fire severity mapping of recent prescribed fires. Severity refers to composite burn index levels, as defined by FIREMON (http://www.landfire.org/media/la_final.pdf).

Since some areas received more than one treatment over the ten-year period, a dynamic model was created. The individual assignment rules are shown in Table F-2.

Crown Fuels AMSET used the crown fuel model layer from LANDFIRE. The existing GRCA crown fuel layer did not cover the entire park, and the canopy cover layer had been inconsistently updated. AMSET reviewed and compared the LANDFIRE data set with other published data and available Forest Inventory and Analysis (FIA) plot data on crown fuels for GRCA and nearby areas. Since the LANDFIRE data was from 2000 imagery, it was updated for changes through 2005 using fire severity maps.

In late December 2006, LANDFIRE staff recommended systematic modifications to LANDFIRE crown fire data based on review by Fire Behavior Analysts (FBAN) during the 2006 fire season.

Modifications included reducing canopy cover and decreasing canopy base height. AMSET tested effects of these modifications on fire behavior prediction modeling and concluded modifications would result in more accurate fire behavior predictions based on review by GRCA fire staff and an experienced FBAN, and data on fuels and fire behavior measured in the nearby Warm Fire during 2006 (Fites et al. 2006).

F.3 Data Limitations and Uncertainty

AMSET did not perform formal accuracy assessments on the GRCA-generated surface fuel layer nor the LANDFIRE crown fuel data. However, surface fuel layers have been informally ground-truthed by visiting sites and comparing predicted fire behavior with expected fire behavior using the fuels data.

AMSET did not model changes in fuels in untreated areas for the years encompassed by proposed fire management plan alternatives. Undoubtedly accumulations of fuels will occur at various rates, depending on vegetation type and density. The Forest Vegetation Simulator (FVS) model provides predictions of surface and crown fuel accumulations over time, but this part of the model is limited due to the data it is based on, and results are uncertain, particularly for surface and ladder fuels. Therefore, fuel conditions changes in untreated areas are discussed qualitatively. They were not incorporated in FARSITE and FLAMMAP fire behavior predictions. Expected changes in fire behavior due to qualitative predictions in fuels are described qualitatively.

Table F-2 Rules to Modify Surface Fuel Model

One Year Post-fire severity	Pre-fire Surface Fuel Model Type	Other conditions	Years Since Fire	Post-fire Fuel Model Type
1 low	5	PP in stand desc.	1-2	181
1 low	5	PP in stand desc.	3+	5
1 low	5	No PP	1-2	181
1 low	5	No PP	3+	5
2 low-mod	5	PP in stand desc.	1-4	181
2 low-mod	5	PP in stand desc.	5+	142
2 low-mod	5	No PP	1-4	141
2 low-mod	5	No PP	5+	142
3 mod-hi	5	PP in stand desc.	1-6	181
3 mod-hi	5	PP in stand desc.	7+	122
3 mod-hi	5	No PP	1-5	101
3 mod-hi	5	No PP	6-7	102
3 mod-hi	5	No PP	7+	122
4 hi	5	PP in stand desc.	1-3	99
4 hi	5	PP in stand desc.	4-12	101
4 hi	5	No PP	1-3	99
4 hi	5	No PP	4-12	101
4 hi	5	ALL	12+	121
1 low	101		1+	101
2 low-mod	101		1+	101
3 mod-hi	101		1+	101
4 hi	101		1+	101
1 low	102		1-2	101
1 low	102		3+	102
2 low-mod	102		1-2	101
2 low-mod	102		3+	102
3 mod-hi	102		1-2	101
3 mod-hi	102		3+	102
4 hi	102		1-2	101
4 hi	102		3+	102
1 low	121		1+	121
2 mod	121		1+	121
3 mod-hi	121		1 to 4	101
4 mod-hi	121		5+	121
4 hi	121		1 to 4	101
5 hi	122		5+	121
1 low	122		1+	122
2 mod	122		1 to 4	121
3 mod	122		5+	122
3 mod-hi	122		1 to 4	101

One Year Post-fire severity	Pre-fire Surface Fuel Model Type	Other conditions	Years Since Fire	Post-fire Fuel Model Type
4 mod-hi	122		5+	121
4 hi	122		1 to 4	101
4 hi	122		5+	121
1 low	141		1+	141
2 low-mod	141		1+	141
3 mod-hi	141		1+	141
4 hi	141		1-4	99
4 hi	141		5+	141
1 low	142		1-2	141
1 low	142		3+	142
2 low-mod	142		1-4	141
2 low-mod	142		5+	142
3 mod-hi	142		1-6	141
3 mod-hi	142		7+	142
4 hi	142		1-4	99
4 hi	142		5+	141
1 low	147		1	141
1 low	147		2+	147
2 low-mod	147		1-4	141
2 low-mod	147		5-9	142
2 low-mod	147		10+	145
3 mod-hi	147		1-4	141
3 mod-hi	147		5-9	142
3 mod-hi	147		10+	145
4 hi	147		1-4	99
4 hi	147		5+	142
1 low	161		1+	161
2 low-mod	161		1+	161
3 mod-hi	161		1+	161
4 hi	161		1-4	99
4 hi	161		5-8	181
4 hi	161		9+	161
1 low	165		1 to 4	188
2 low	165		5+	165
2 mod	165		1 to 4	188
3 mod	165		5+	165
3 mod-hi	165		1 to 4	181
4 mod-hi	165		5+	188
4 hi	165		1 to 4	181
5 hi	165		5+	188
1 low	181		1+	181

One Year Post-fire severity	Pre-fire Surface Fuel Model Type	Other conditions	Years Since Fire	Post-fire Fuel Model Type
2 low-mod	181		1+	181
3 mod-hi	181		1+	181
4 hi	181		1-4	99
4 hi	181		5+	181
1 low	182		1	181
1 low	182		2+	182
2 low-mod	182		1-4	181
2 low-mod	182		5+	182
3 mod-hi	182		1-4	181
3 mod-hi	182		5+	182
4 hi	182		1-4	99
4 hi	182		5-10	181
4 hi	182		11+	187
1 low	183		1-4	181
1 low	183		5+	183
2 low-mod	183		1-8	181
2 low-mod	183		9+	183
3 mod-hi	183		1-8	181
3 mod-hi	183		9+	183
4 hi	183		1-4	99
4 hi	183		5-10	181
4 hi	183		11+	187
1 low	185		1-2	181
1 low	185		3+	183
2 low-mod	185		1-4	181
2 low-mod	185		5+	183
3 mod-hi	185		1-6	181
3 mod-hi	185		7+	183
4 hi	185		1-4	99
4 hi	185		5-10	181
4 hi	185		11+	187
1 low	186		1	181
1 low	186		2-8	182
1 low	186		9+	186
2 low-mod	186		1-2	181
2 low-mod	186		3-8	182
2 low-mod	186		9+	186
3 mod-hi	186		1-6	181
3 mod-hi	186		7-10	182
3 mod-hi	186		11+	186
4 hi	186		1-4	99
4 hi	186		5-10	181

One Year Post-fire severity	Pre-fire Surface Fuel Model Type	Other conditions	Years Since Fire	Post-fire Fuel Model Type
4 hi	186		11+	187
1 low	187		1-2	181
1 low	187		3+	183
2 low-mod	187		1-5	181
2 low-mod	187		6+	183
3 mod-hi	187		1-6	181
3 mod-hi	187		7+	183
4 hi	187		1-4	99
4 hi	187		5-10	181
4 hi	187		11+	187
1 low	188		1	181
1 low	188		2-4	182
1 low	188		5-15	186
1 low	188		16+	188
2 low-mod	188		1-2	181
2 low-mod	188		3-7	182
2 low-mod	188		8-15	186
2 low-mod	188		16+	188
3 mod-hi	188		1-6	181
3 mod-hi	188		7-10	182
3 mod-hi	188		11-15	186
3 mod-hi	188		16+	188
4 hi	188		1-4	99
4 hi	188		5-10	181
4 hi	188		11+	187

These rules are based on the pre-burn surface model, post one year fire severity, years since fire and, in some cases, other criteria such as ponderosa pine presence. The data in this table were provided by GRCA fire staff, except for surface fuel model types 121, 122 and 165, which were not present in the original file. PP refers to ponderosa pine.

F.4 Results of Fire Behavior Prediction Modeling

AMSET conducted modeling for baseline conditions and after changes from all prescribed fire and manual/mechanical treatments.

Modeling was conducted for baseline conditions, assuming fuel conditions prior to proposed treatments (Tables F-4 through 7). These data were used as a partial basis for assumptions on wildland fire-use or supression fire behavior. Qualitative discussion of how these potentials might change relative to location and treatment amount proposed for each alternative was included in each alternative's impact analysis.

Effects of treatments on changes in potential fire behavior using FlamMap are displayed as cumulative change from all proposed treatments (prescribed fire and manual/mechanical) in Figures F-1 through 7. There was no feasible way to model spatial patterns of wildland fire-use or suppression fires, and thus potential changes in spatial patterns of potential fire behavior. These changes were addressed non-spatially and qualitatively.

Table F-3 Rules Used to Modify Crown Fuels Post-fire and Crown Fuels in Piñon-Juniper Stands with 147 Surface Fuel Type

Surface Fuel Model	One-year Post Fire Severity	Fire	Canopy Bulk Density	Canopy Base Height (feet)	Canopy Cover (Landfire Class)	Canopy Height (feet)
	Low	Outlet	No change	8	No change	No change
	Moderate/low	Outlet	No change	8	No change	No change
	Moderate/high	Outlet	0.05	1	85	6
	High	Outlet	0.05	1	85	6
	Unburned	Outlet	No change	No change	No change	No change
	Low	Other fires	No change	8	No change	No change
	Moderate/low	Other fires	No change	8	No change	No change
	Moderate/high	Other fires	10% original	20	10% original	No change
	High	Other fires	No values	No values	10% original	No values
	Unbur ned	Other fires	No change	No change	No change	No change
147			No data	No data	No data	No data

These data were used extensively in analysis displayed in the impact analysis in chapter 4. Although emphasis of the analysis displayed was on fire type, fireline intensity, flamelength and rate of spread were also modeled.

For several representative locations selected by GRCA fire staff, AMSET modeled FARSITE fire behavior predictions (Figures F-6 and 7). These include changes due to prescribed fire and manual/mechanical treatments but not wildland fire-use or suppression fires. Changes in fuels and potential fire behavior were addressed qualitatively. Results vary by ignition location. On North Rim (Figure F-6), fire spread rapidly and primarily as crown fire through the large block of previously unburned and untreated mixed-conifer and spruce-fir from ignition in Thompson Canyon depicted for Alternative 3. The display for Alternative 4 shows that planned treatments on the park's north border did modify and reduce progression of fire to the north. For other North Rim ignition locations, differences between simulations shown for Alternative 3 and 4 illustrate effects of treatments in Alternative 4. In the simulation for Alternative 4, ignition occurred in a treatment unit; the fire moved very slowly and did not grow very large compared to the Alternative 3 simulation where fire moved through an untreated area and spread much more rapidly.

Simulations results for South Rim ignition are less straightforward. For all simulations, fire spread primarily as surface fire, reflecting past prescribed fire and other treatments (Figure F-7). Although more treatments immediately around South Rim park headquarters are modeled for Alternatives 2, 3, and 4 than Alternative 1, spread toward headquarters is least in Alternative 1. This is an artifact of the fuel model choice used to portray post-treatment conditions that has a higher rate of spread characteristic than prior to treatment. As stated in chapter 4, on limitations of fuels data and fire behavior predictions, there is not an optimal set of fuel models to characterize post-treatment conditions, and no existing fire behavior model that adequately depicts fire behavior in a WUI. Therefore, changes due to treatments around structures are dealt with qualitatively in the impact section for WUI.

Table F-4 Potential Fire Behavior for Baseline Conditions, Prior to Proposed Treatments

Ponderosa Pine				
Fire Type	**Weather Percentile**			
	50th	80th	90th	97th
Active crown	0%	0%	0%	11%
Passive crown	2%	4%	5%	9%
Surface	98%	96%	95%	80%

Data is from FlamMap run with different weather percentile conditions

Table F-5 Potential Fire Behavior for Baseline Conditions, Prior to Proposed Treatments

Mixed Conifer				
Fire Type	**Weather Percentile**			
	50th	80th	90th	97th
Active crown	1%	1%	1%	22%
Passive crown	23%	37%	39%	25%
Surface	76%	62%	60%	53%

Data is from FlamMap run with different weather percentile conditions

Table F-6 Potential Fire Behavior for Baseline Conditions, Prior to Proposed Treatments

Spruce/Fir				
Fire Type	**Weather Percentile**			
	50th	80th	90th	97th
Active crown	0%	0%	0%	25%
Passive crown	31%	43%	46%	26%
Surface	69%	57%	54%	49%

Data is from FlamMap run with different weather percentile conditions

Table F-7 Potential Fire Behavior for Baseline Conditions, Prior to Proposed Treatments

Piñon-Juniper				
Fire Type	**Weather Percentile**			
	50th	80th	90th	97th
Active crown	0%	1%	1%	7%
Passive crown	5%	6%	6%	3%
Surface	95%	93%	93%	90%

Data is from FlamMap run with different weather percentile conditions

Figure F-1 Results of FlamMap Fire Behavior Modeling for Alternative 1

This incorporates changes due to proposed prescribed fire and manual treatments; it does not include potential changes due to wildland fire-use or suppression fires. These were addressed non-spatially.

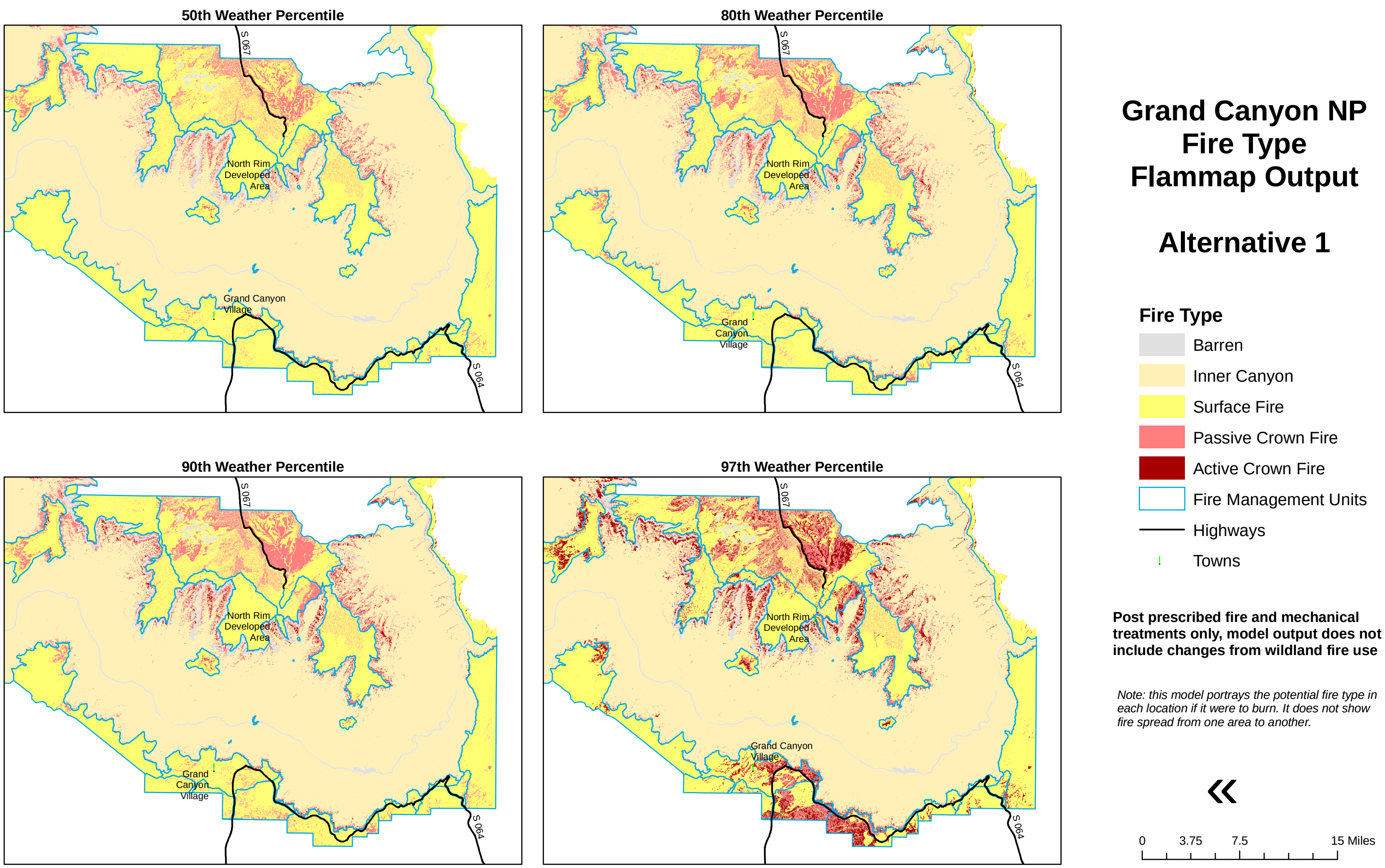

Figure F-2 Results of FlamMap Fire Behavior Modeling for Alternative 2

This incorporates changes due to proposed prescribed fire and manual treatments; it does not include potential changes due to wildland fire-use or suppression fires. These were addressed non-spatially.

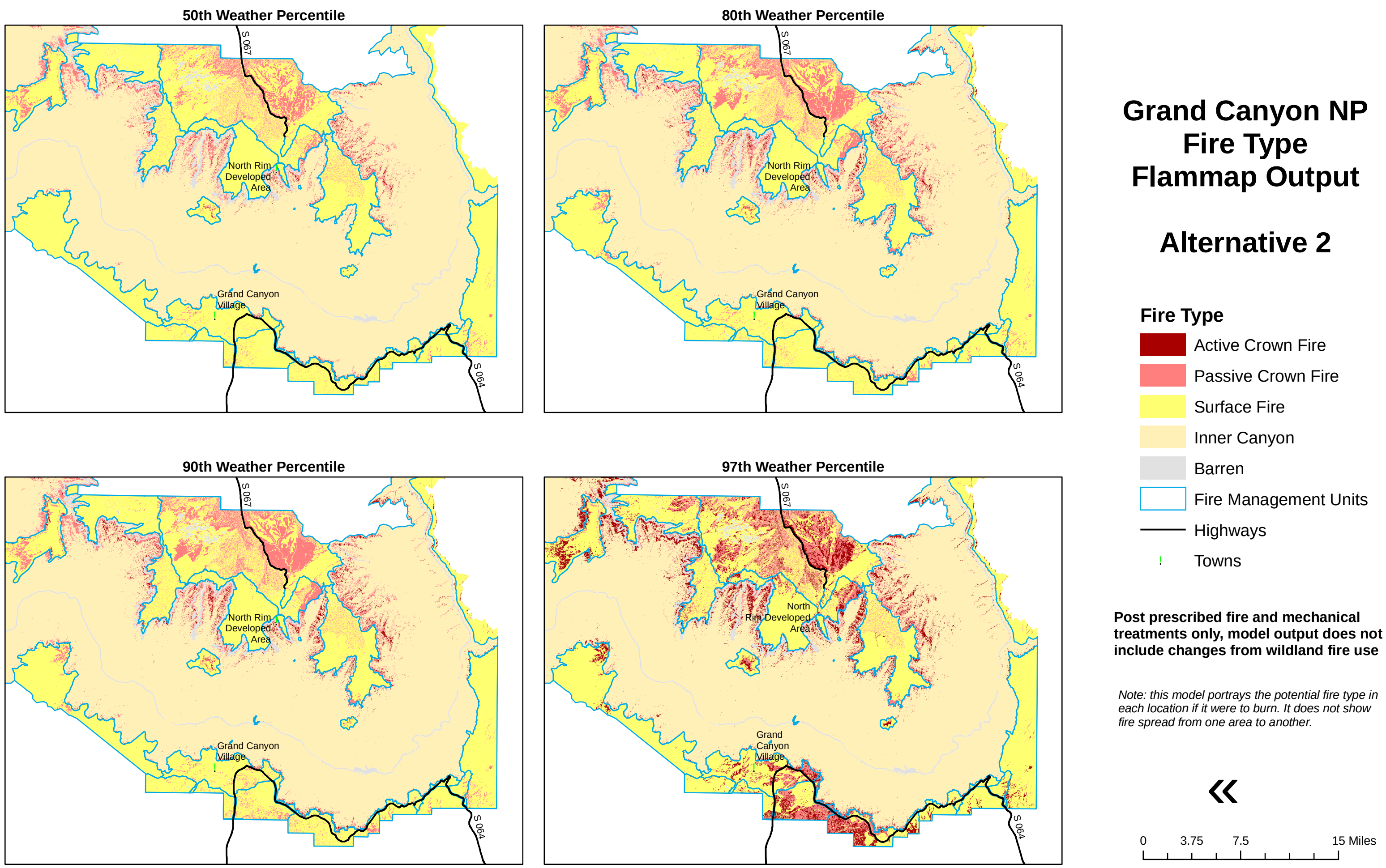

Figure F-3 Results of FlamMap Fire Behavior Modeling for Alternative 3

This incorporates changes due to proposed prescribed fire and manual treatments; it does not include potential changes due to wildland fire-use or suppression fires. These were addressed non-spatially.

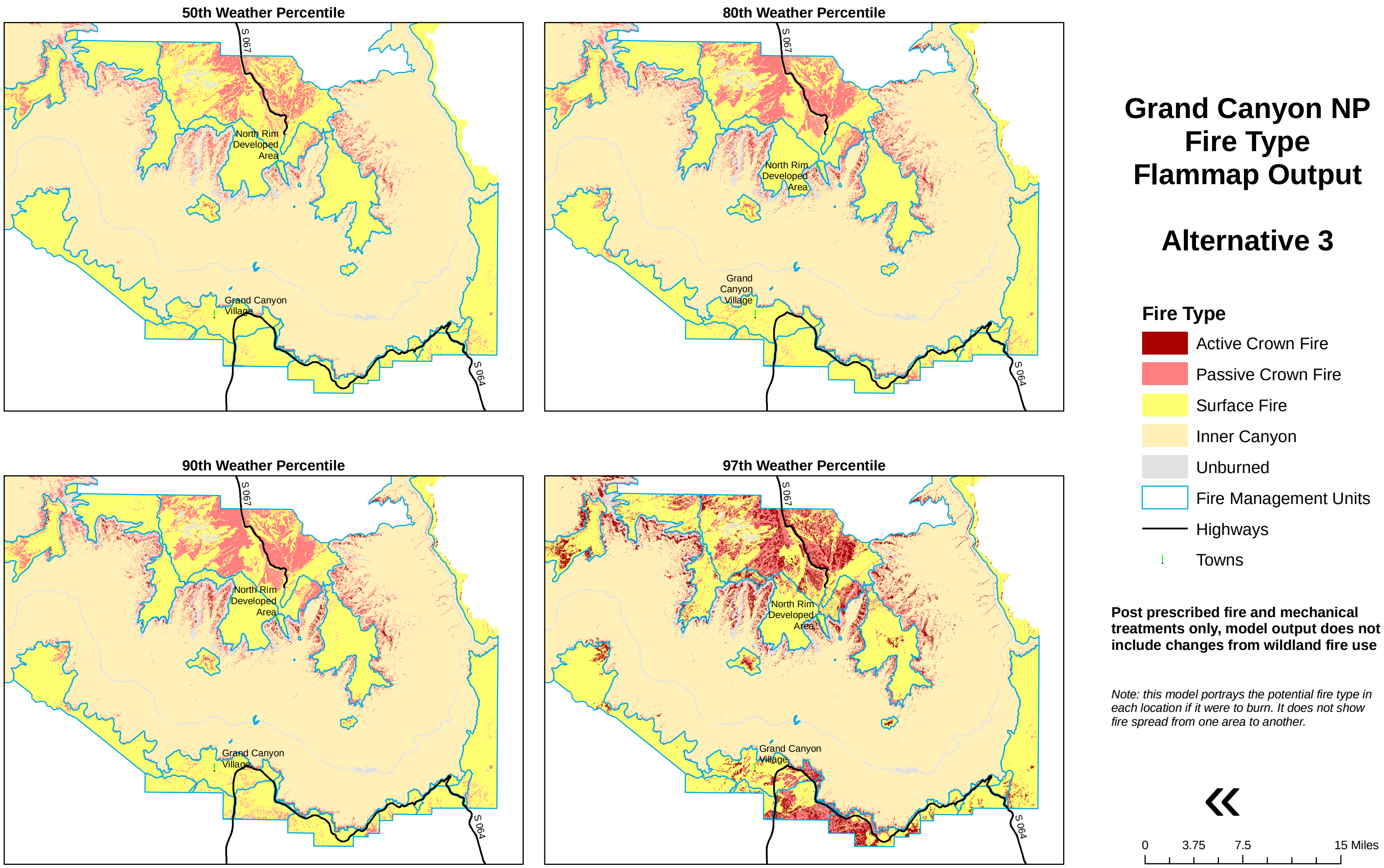

Figure F-4 Results of FlamMap Fire Behavior Modeling for Alternative 4

This incorporates changes due to proposed prescribed fire and manual treatments; it does not include potential changes due to wildland fire-use or suppression fires. These were addressed non-spatially.

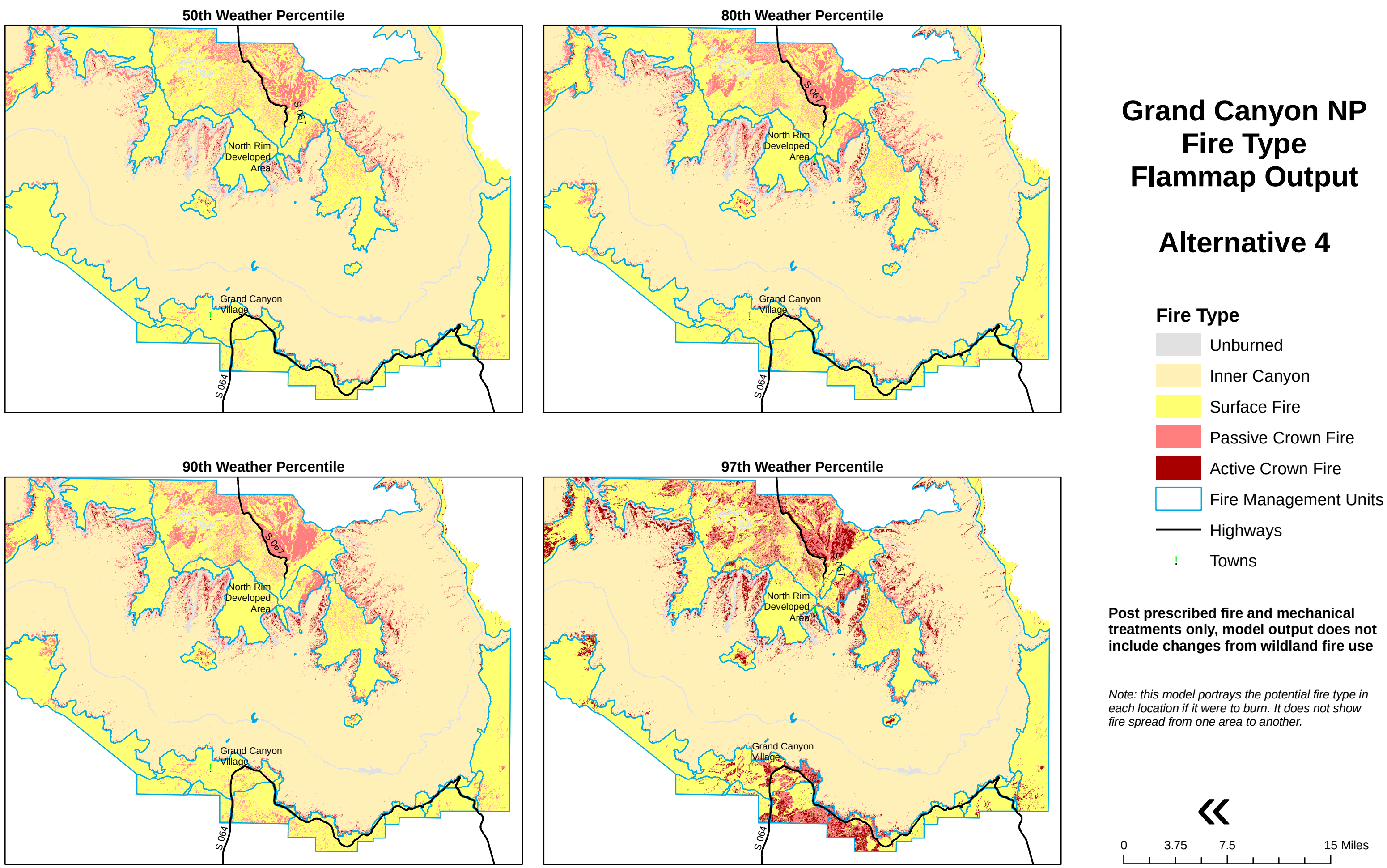

Figure F-5 Results of FlamMap Fire Behavior Modeling for Alternative 5

This incorporates changes due to proposed prescribed fire and manual treatments; it does not include potential changes due to wildland fire-use or suppression fires. These were addressed non-spatially.

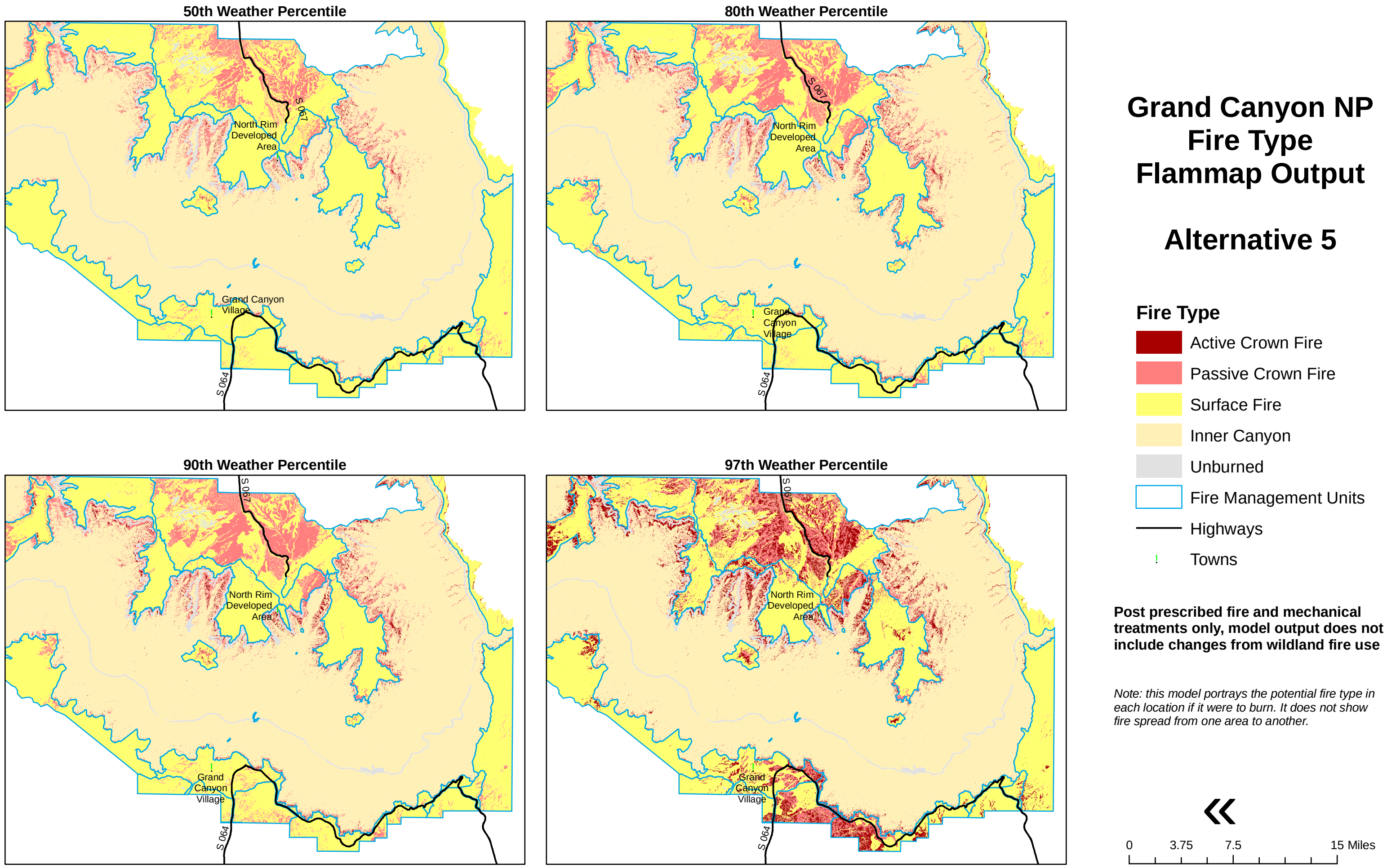

Figure F-6 Results of Farsite Potential Fire Behavior Modeling
This incorporates changes due to proposed prescribed fire and manual treatments; it does not include potential changes due to wildland fire-use or suppression fires. These were addressed non-spatially.

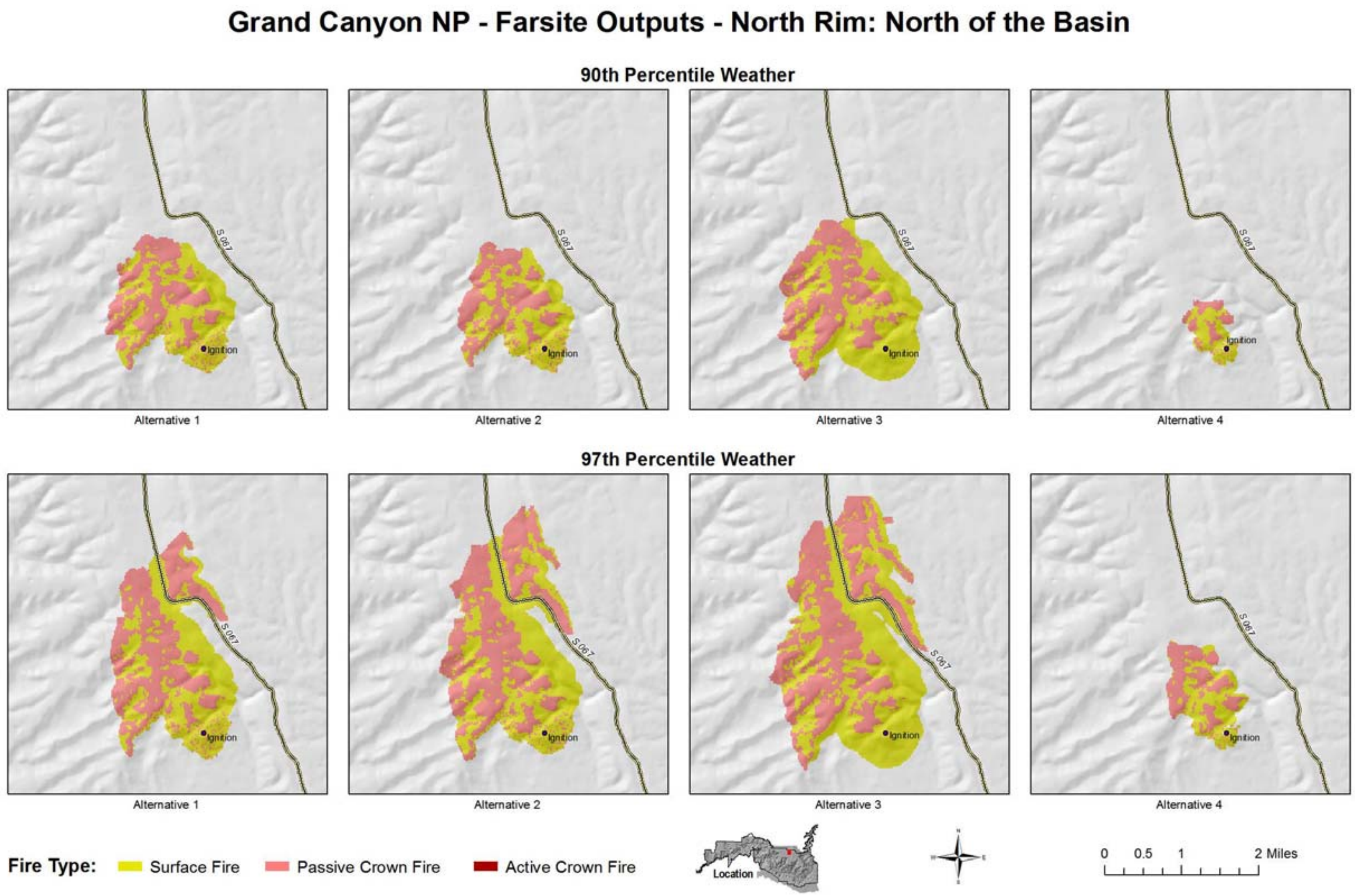

Figure F-7 Results of Farsite Potential Fire Behavior Modeling

This incorporates changes due to proposed prescribed fire and manual treatments; it does not include potential changes due to wildland fire-use or suppression fires. These were addressed non-spatially.