Greater Santa Fe Fireshed Coalition

Wildfire Risk Assessment

Version 1.0 — March 22, 2018

Prepared for
The Greater Santa Fe Fireshed Coalition

by

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Executive Summary

The Greater Santa Fe Fireshed Coalition ("the Coalition") is developing a landscape resilience strategy for the forests in the Sangre de Cristo Mountains near Santa Fe. Resilience to wildfire is one of the primary concerns of the Coalition. This risk assessment supports development of that strategy by identifying areas that are most at-risk of losing value if burned by a wildfire. Following the wildfire risk assessment framework established by the U.S. Forest Service (Scott et al. 2013), the spatial distribution of risk was mapped for the area surrounding Santa Fe.

The forests around Santa Fe have been shaped by fire. Both the patterns of forest we see today and the species of plants and animals that live in these forests are a result of past fires. Historically, a combination of low-severity fire in the low to mid elevations, followed by mixed severity and high-stand replacing fire created a mosaic of forest types and patterns (Margolis and Balmat 2009). Areas with frequent low-severity fires were dominated by open stands of ponderosa pine. This transitioned at around 8,500–9,000 feet to a combination of conifer species and a mix of low and small patches — less than 100 acres — of high-severity fire. Only the highest elevation forests burned with large patches of high-severity stand replacing fire (Margolis et al. 2007) and only during the driest years (Margolis and Swetnam 2013).

Human impacts have been greatest in the lower elevation ponderosa pine forests, where the fire regime has changed from a series of frequent low-severity fires to one where fire is absent. This lack of fire has allowed flammable material to accumulate for over a century. There is sizable evidence for this conversion, much of it from tree-rings found in the Fireshed and northern New Mexico (Touchan et al. 1996, Allen et al. 2002, Margolis and Balmat 2009, Margolis et al. 2011). Other lines of evidence include aerial photos, historical descriptions, and accounts from local pueblos (Swetnam et al. 1999, Allen 2002).

The plants and animals of the Fireshed are adapted to these historical regimes so they are not resilient to the current, higher-intensity fire regime (Keane et al. 2002). Additionally, the homes, roads, campgrounds, and municipal and agricultural source watersheds within the Fireshed are generally more susceptible to damage by this new high-intensity fire regime (Table 2).

Historical human use of this landscape including grazing, firewood gathering, and fire suppression have changed the composition and structure of the forests around Santa Fe. Aerial photos from 1935 to 2016 show these changes in low-elevation forest over time (Figure 1). Much of the anthropogenic landscape change occurred prior to 1935. Antecedent forest conditions in this area — particularly historical fire regimes — are useful, ecologically-based means for planning implementation of fuels reduction and resilience treatments, though in this assessment, only the current condition of the landscape is considered.

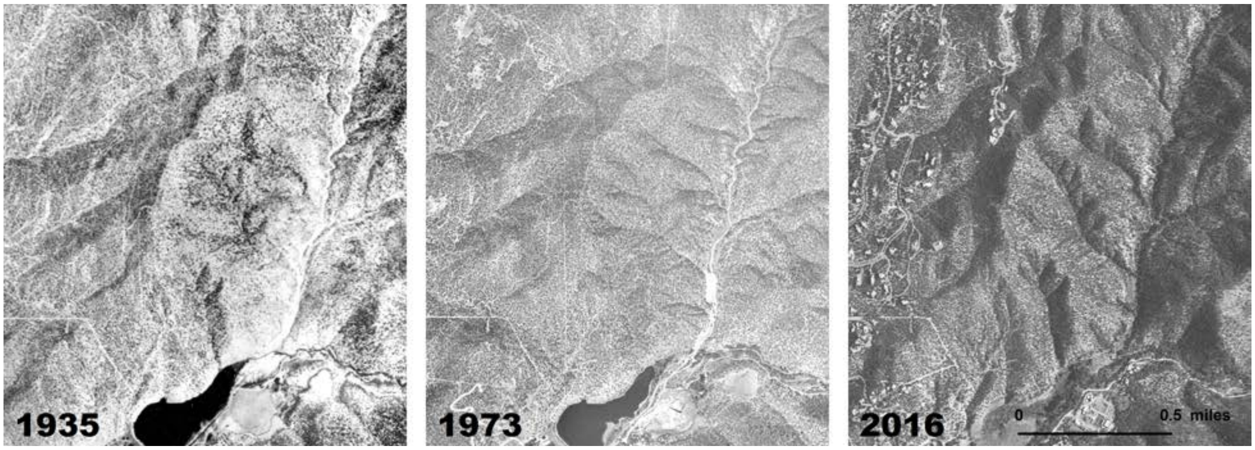

Figure 1. Changes in development and forest structure are visible in historical aerial photographs. This series of images shows tree growth, construction of houses, and other land use changes over 81 years in Santa Fe Canyon near Cerro Gordo and Aztec Springs. Much of the anthropogenic landscape change caused by grazing and firewood gathering occurred prior to 1935.

Wildfires pose a threat to valued resources and assets (VRAs). VRAs are the reason wildfire risk exists; if there is not something of value that could be damaged by fire, then there would not be a reason to consider the threat of wildfire. VRAs vary widely, ranging from tangible assets like homes, to abstract concepts like the flood mitigation potential of a stand of trees. Within the Coalition strategy area there are innumerable VRAs. Analyzing risk to all VRAs was infeasible with the time and resources available for this assessment, so risk was analyzed for a representative set of VRAs identified by interviewing subject matter experts within the Coalition (Table 1).

Table 1. Valued resources and assets (VRAs) included in this wildfire risk assessment.

Category	VRA	Sub-VRA
Private Investment	Private Land	
	Structures	
Watershed Function	Water for Irrigation	
	Water for People	
	Erosion Mitigation	Erosion Hazard Class
	Debris Flow Mitigation	Debris Flow Hazard Class
	Flood Control	
Infrastructure	Roads	Erosion Hazard Class
	Powerlines	
Recreation and Cultural Use	Developed Recreation Area	
	Trails	Erosion Hazard Class
Ecosystem Function	Spruce-Fir Forest	
	Mixed Conifer - Frequent Fire Forest	
	Ponderosa Pine Forest	
	PJ Grass	
	PJ Woodland	
	Juniper Grass	
	Colorado Plateau / Great Basin Grassland	
	Other Vegetation	

VRAs are inherently spatial. Some VRAs are tangible assets like structures which can be readily mapped. More abstract VRAs like flood mitigation potential require additional analysis to map. For ecosystem services and other abstract VRAs, the source of value as well as the relative benefit derived from that resource are combined to model the overall value of that VRA. Throughout this report, the spatial distribution of each value is mapped as the combination of a “provisioning index” and a “beneficiary index”. The provisioning index is a measure of supply, and the beneficiary index is a measure of demand. The highest value of a resource occurs where both the provisioning and beneficiary indexes are closest to one.

The post-fire flood mitigation VRA is an excellent illustration of the distinction between provisioning and beneficiaries (Figure 2). Any given watershed can produce a post-fire flood, though certain characteristics of a burned watershed increase the likelihood that a flood will occur. By mapping the relative contribution to post-fire flood hazard of each stand, the value of each stand to mitigate post-fire floods can be determined. The relative post-fire flood hazard mitigation potential is then converted to a “provisioning index” with values ranging from 0 to 1. Post-fire flood mitigation potential is most valuable in places where there are downstream values that would be impacted by a flood. To map the relative number of beneficiaries of post-fire flood risk mitigation in each drainage, downstream flood hazard areas that are developed were mapped and related back to the watersheds that would produce the flood. These values were also indexed to create a “beneficiary index” with values ranging from 0 to 1. Multiplying the provisioning and beneficiary indexes results in a measure of the relative value of flood mitigation, incorporating both the source and the beneficiaries of the VRA.

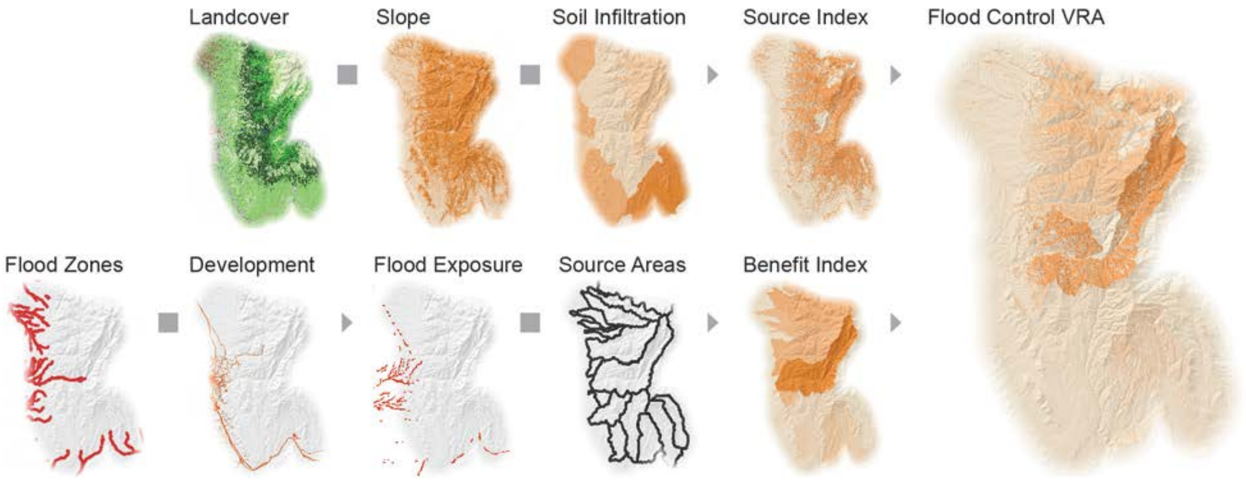

Figure 2. Process used to produce the map of post-fire flood mitigation value. Arrows indicate processing leading to output, boxes indicate inputs.

The VRAs included in this risk assessment are susceptible to wildfire. Susceptibility is a measure of the value lost or gained when burned. Most VRAs decrease in value when burned, especially when burned by high-intensity fire. A fire burning through a campground is likely to have negative outcomes, with the outcomes being more negative where the intensity of fire is the highest. On the other hand, fire is ecologically beneficial to the fire-adapted forests near Santa Fe, therefore the ecological value of the forest increases when burned at some intensity levels. This characterization of whether fire has a negative or positive effect is modeled as a “response function”.

Response functions were modeled as an expected change in value if exposed to fire at varying levels of fire intensity. Fire intensity describes the energy produced by a flaming front, the greater the energy produced, the higher the intensity. Flame length is a common analog for fire intensity and is easier to conceptualize than measures of energy released per unit area. Seven classes of fire intensity were delineated, each class representing a fire intensity level (FIL). The expected change of a VRA, if burned at each FIL, defines the response function (Table 2).

Table 2. Response functions that characterize how the value of each VRA changes when burned at each fire intensity level (FIL). Values represent percent value change. Total loss of value is represented by -100, half value loss is characterized by -50. Doubling of value is represented by 100, 150% value increase is represented by 50. Note that high fire intensity levels have a more negative effect on VRA value than lower fire intensity levels for 28 of 30 VRAs and sub-VRAs.

	Fire Intensity Level	**FIL 1**	**FIL 2**	**FIL 3**	**FIL 4**	**FIL 5**	**FIL 6**	**FIL 7**
VRA	**Flame length (feet)**	**< 2**	**2 – 4**	**4 – 6**	**6 – 8**	**8 – 10**	**10 – 12**	**> 12**
Private Land		10	0	0	-20	-40	-40	-40
Structures		-10	-20	-30	-40	-60	-80	-90
Water for Irrigation		50	30	10	0	-10	-20	-30
Water for People		50	30	10	0	-10	-20	-30
Erosion Mitigation								
Erosion Hazard: Very Severe		-10	-20	-40	-60	-80	-100	-100
Erosion Hazard: Severe		0	-10	-20	-40	-60	-80	-100
Erosion Hazard: Moderate		0	0	-10	-20	-40	-60	-80
Erosion Hazard: Slight (and null)		0	0	0	-10	-20	-40	-60
Debris Flow Mitigation								
Debris Flow Hazard: Very Severe		0	0	-20	-40	-60	-80	-100
Debris Flow Hazard: Severe		0	0	0	-20	-40	-60	-80
Debris Flow Hazard: Moderate		0	0	0	0	-20	-40	-60
Debris Flow Hazard: Slight (and null)		0	0	0	0	0	-20	-40
Flood Control		-10	-10	-20	-40	-60	-80	-100
Roads								
Erosion Hazard: Very Severe		-10	-10	-10	-20	-40	-50	-80
Erosion Hazard: Severe		0	-10	-10	-10	-20	-40	-50
Erosion Hazard: Moderate		0	0	-10	-10	-20	-40	-50
Erosion Hazard: Slight (and null)		0	0	0	-10	-20	-40	-50
Powerlines		-10	-20	-40	-80	-100	-100	-100
Developed Rec. Area		0	-10	-20	-55	-75	-75	-75
Trails								
Erosion Hazard: Very Severe		-10	-10	-10	-20	-40	-50	-80
Erosion Hazard: Severe		0	-10	-10	-10	-20	-40	-50
Erosion Hazard: Moderate		0	0	-10	-10	-20	-40	-50
Erosion Hazard: Slight (and null)		0	0	0	-10	-20	-40	-50
Spruce-Fir Forest		10	30	50	70	100	100	100
Mixed Conifer - Frequent Fire		100	100	70	30	-20	-50	-100
Ponderosa Pine Forest		100	100	70	30	-20	-50	-100
PJ Grass		100	100	70	30	-20	-50	-100
PJ Woodland		70	90	100	100	100	100	100
Juniper Grass		100	100	70	30	-20	-50	-100
Colorado Plateau / Great Basin Grassland		100	100	70	50	10	-10	-50
Other Vegetation		0	0	0	0	0	0	0

Susceptibility is just one factor considered when evaluating risk. Mapping susceptibility of VRAs with response functions explicitly defines how the landscape will respond to fire of different intensities. To understand where that value change is likely to occur, susceptibility data must be combined with data describing the expected likelihood and intensity of fires. Wildfire risk is defined as the combined influence of fire likelihood, fire intensity, and susceptibility of values (Figure 3).

Figure 3. Illustration of risk as the combined influence of the likelihood, intensity, and susceptibility of values to a hazard. Risk is highest when each component is maximized. This triangle has been used to illustrate wildfire risk in a similar format to the fire triangle which illustrates the "ingredients" required for combustion. In this wildfire risk assessment, the spatial interaction of wildfire likelihood, wildfire intensity, and susceptibility of VRAs were evaluated and combined to estimate the expected change in values following wildfire throughout the study area.

While susceptibility was mapped through consultation with land managers and other members of the Coalition, wildfire likelihood and intensity were mapped using simulated wildfires. Wildfire simulation is a common component of land management and is useful to inform planning at multiple temporal and spatial scales. Fire simulations are used to help fire managers allocate resources during wildfire incidents (e.g. Finney 1998). Simulations are also used to evaluate the effectiveness of forest restoration and fuels reduction treatments (e.g. Schmidt, Taylor, and Skinner 2008). As in this wildfire risk assessment, fire simulation can also be used to evaluate how fire is expected to spread across the landscape including the likelihood and intensity of expected fires (Thompson et al. 2017).

The fire simulation software used for this assessment was developed by the U.S. Forest Service (USFS) and uses industry standard models of fire behavior and spread to simulate individual fires (Finney 2006). Inputs required by the software to run these models are canopy characteristics, surface fuels characteristics, topography, and weather. Model inputs were created for the study area from multiple data sources (Table 3).

Table 3. Fire simulation inputs with description and source information.

Fire Model Input	Description and Source
Canopy Height	Canopy characteristics and surface fuels were derived from LANDFIRE [version 1.4.0] with modifications to more accurately match the current condition of the landscape. Poorly predicted surface fuels and canopy characteristics in piñon-juniper forest and recently treated areas where modified to reflect current conditions based on field data.
Canopy Base Height	
Canopy Bulk Density	
Canopy Cover	
Surface Fuel Model	
Elevation	Topographic data from LANDFIRE [version 1.4.0] were used without modification.
Slope	
Aspect	
Wind Speed and Direction	Wind speed and direction and fuel moisture observed at the Pecos Remote Automated Weather Station (RAWS) between 1986 and 2016 were used to create frequency distributions of observed weather intensity.
Fuel Moisture	

Fires were simulated on the "fuelscape" comprised of the canopy, surface fuels and topographic data. The fuelscape extends beyond the delineated boundary of the Coalition to include the area between where a fire could start and possible reach the VRAs identified by the Coalition. This larger analysis area could be considered the "fireshed" for the valued landscape identified by the Coalition and delineated by the official Coalition boundary. The fuelscape used for fire simulation reflects the current condition of the study area as nearly as possible. Data from LANDFIRE was modified using local information to remove artifacts of LANDFIRE production, and to update the fuels located within recently treated and burned areas.

Fires were simulated on the fuelscape under a range of wind and fuel moisture conditions to capture the variation in fire behavior that occurs under varying weather conditions. To measure the relative probability of a given weather condition occurring, historically observed daily weather conditions were ranked by intensity, and assigned percentiles. The lower quartile was assigned to the 25th percentile, the median weather intensity to the 50th percentile, the upper quartile was assigned to the 75th percentile, and so on, for the historically observed range of weather. Percentile weather distributions were created for the approximate fire season observed historically in the study area (March 1 through July 31). Sixty-four combinations of wind direction and fuel moisture were used to simulate fires with resulting burn probability and fire intensity metrics scaled for frequency at which those conditions historically occurred.

During fire simulation, 640,000 fires were started randomly across the landscape. Conditional burn probability where conditions exceed the 80th percentile for fire season weather were produced from the fires that started under conditions that exceeded the 80th percentile conditions (Figure 4). Burn probability is the percent of fires that burned each pixel, calculated as the number of fires that burned that pixel divided by the total number of fires that burned. FIL distribution when conditions exceed the 80th percentile were produced from the frequency of each FIL occurring in each pixel during simulations (Figure 5).

Risk is a function of likelihood, intensity, and susceptibility. Multiplying simulated burn probability and FIL distribution, with susceptibility of each VRA generates a prediction of the expected value change in a hypothetical year from wildfire. Summing the expected value change of all VRAs produces the expected net value change (eNVC) for the entire landscape (Figure 6).

Areas of high risk are present throughout the study area. Mixed conifer and ponderosa pine forest in the middle elevations of the study area have high risk in areas that are coincident with VRAs, especially the VRAs within the Watershed Function category. Structures and private land in the wildland urban interface (WUI) are also some of the highest risk areas irrespective of forest type. High wildfire risk occurs on both private and public lands so mitigating this risk is a shared responsibility.

High risk areas identified in this assessment are candidates for implementing wildfire risk reduction treatments. Risk reduction treatments can target any of the three components of risk. Reducing susceptibility of VRAs to fire or “hardening” them changes the VRA’s response function so fire is less likely to have a negative impact on that VRA. Decreasing the intensity of fire requires removal or alteration of the fuels through which fire spreads which can be accomplished through thinning and prescribed fire in dry conifer forests. Burn probability is the least straightforward to mitigate, though ignitions can be reduced with regulatory changes (i.e. fire restrictions and area closures during periods of high fire danger), and decreasing the homogenous nature of forests through which fires can rapidly spread.

While this report focuses on the highest risk areas, knowing where wildfire is less likely to cause damage can also be useful when managing fire in the study area. Prescribed fires typically occur under weather conditions below the 80th percentile conditions used to evaluate risk in this risk assessment. Areas that have a negative eNVC in this assessment can have a positive eNVC under less intense weather conditions.

This assessment can be a useful tool for planning wildfire risk reduction treatments. While investments should be prioritized in higher-risk areas, maintaining lower-risk areas such as recently treated areas, or opportunistically mitigating risk in areas with fewer constraints (such as support from local communities and available funding), may enable a faster pace of risk mitigation.

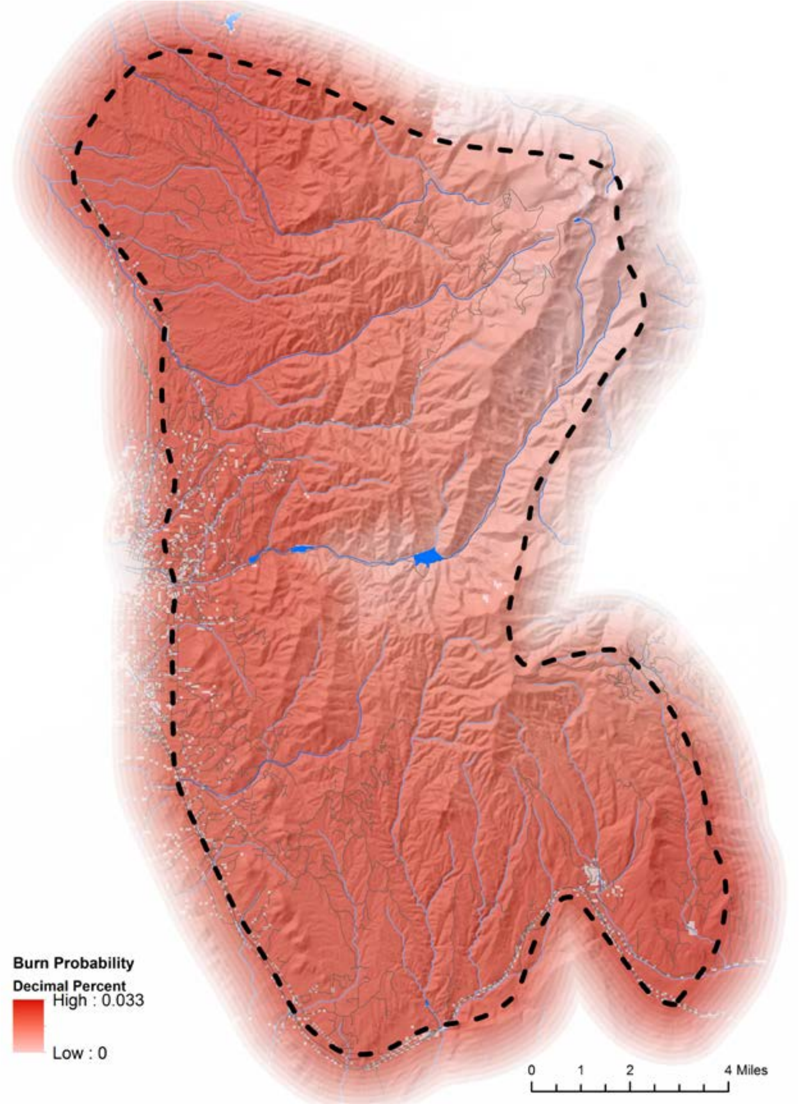

Figure 4. Burn probability under conditions exceeding 80th percentile conditions. High-elevation areas have lower likelihood of burning because they are generally wetter and less conducive to fire spread. Recently treated areas in the Santa Fe watershed also have lower burn probabilities.

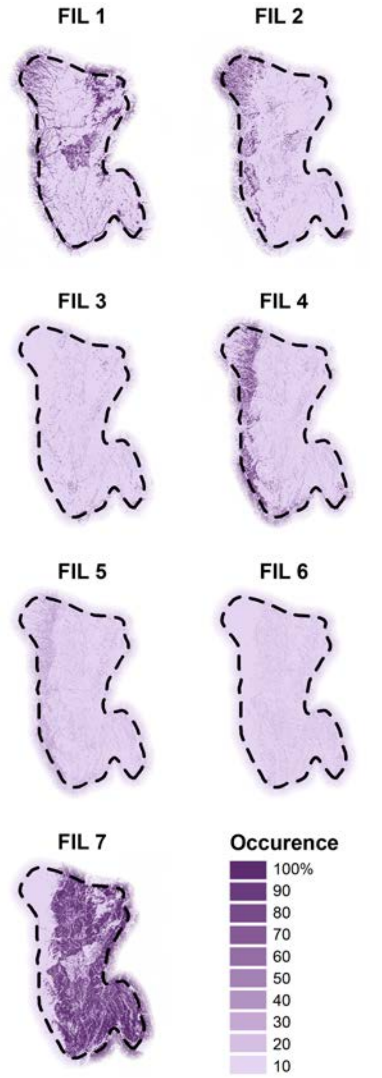

Figure 5. Fire intensity represented as probability of occurrence of each FIL derived from fires simulated above 80th percentile conditions

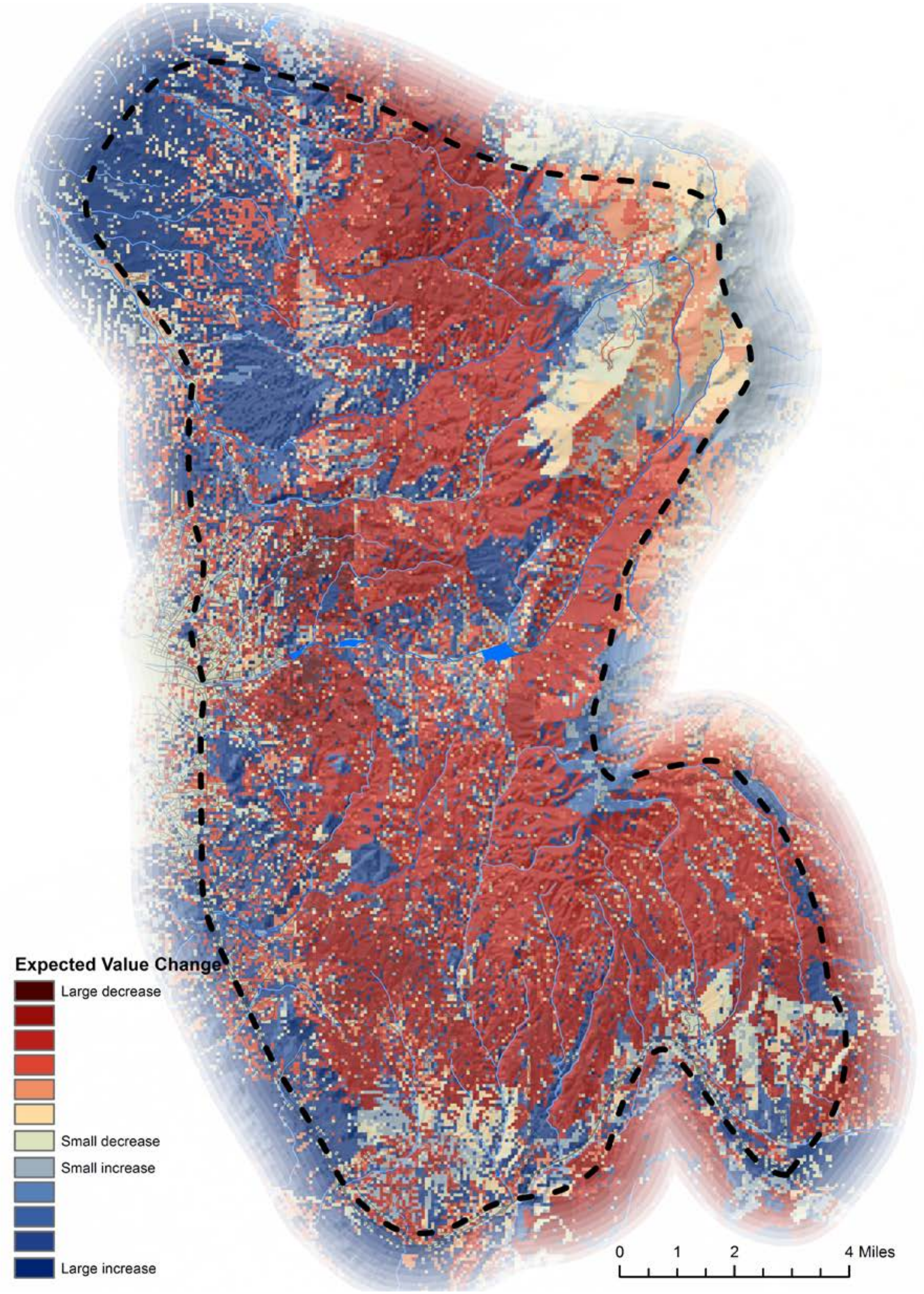

Figure 6. Overall wildfire risk in the Greater Santa Fe Fireshed Coalition area. Expected Net Value Change (eNVC) represents the relative value change expected on the landscape. Blue areas are expected to increase in value and red areas decrease in value when burned by wildfire.

Introduction

The Greater Santa Fe Fireshed Coalition ("the Coalition") seeks to improve the health and long-term resilience of forested watersheds and communities by addressing wildfire risk using a proactive, collaborative approach. The Coalition is based on a shared interest in the long-term resilience of the forests, watersheds, and communities of the Southern Sangre De Cristo Mountains. This landscape includes many land managers and stakeholders with diverse interests, though all are united by shared intent to prepare for and mitigate the negative impacts of future wildland fires. This wildfire risk assessment identifies areas most likely to experience a loss in value following a wildfire. Areas of high risk identified in this assessment can be prioritized for investment in risk mitigation including restoring and maintaining fire adapted forests and increasing and maintaining preparedness, mitigation, and planning at multiple levels so that communities are prepared for, can respond to, and recover from wildfire.

This wildfire risk assessment is based on an analytical framework developed by the U.S. Forest Service (USFS) (Scott et al. 2013), that has been widely used in the western U.S (Warziniack and Thompson 2013, e.g. Haas et al. 2014, USFS 2015a, Thompson et al. 2016) and has been applied at scales ranging from the continental United States (Calkin et al. 2011), to multi-state forest service regions (USFS 2015b), to states (Johnson et al. 2015), to individual national forests (Scott et al. 2013), and to smaller landscapes (Bassett 2016, Mimiaga 2017). The risk assessment framework uses spatially explicit information about the expected likelihood and intensity of wildfire and the location and susceptibility of valued resources and assets to identify the expected change in value of those resources following a fire. In addition to the fire hazards specified in the framework, this assessment includes post-fire hazards like flooding, erosion, and debris flow.

The Fireshed area has been included in national and regional risk assessment analyses, though the scale of interactions between fire and the resources and assets valued by the Coalition is too large to be accurately captured in these relatively coarse existing wildfire risk assessments. Additionally, these existing assessments are limited to including data that is consistent across the study area, which precludes the rollup of data collected by the Collaborative into these broader assessments.

Defining Wildfire Risk

Wildfire risk is the spatial interaction between expected fire intensity, fire likelihood, and the susceptibility of valued resources and assets to the expected fire intensity (Figure 7). All components of risk must be present for risk to exist; for example, if high-intensity fire is expected within a stand, but no value will be lost because of it, risk is low.

Figure 7. Illustration of risk as the combined influence of the likelihood, intensity, and susceptibility of values to a hazard. Risk is highest when each component is maximized. This triangle has been used to illustrate wildfire risk in a similar format to the fire triangle which illustrates the "ingredients" required for combustion. In this wildfire risk assessment, the spatial interaction of wildfire likelihood, wildfire intensity, and susceptibility of VRAs were evaluated and combined to estimate the expected change in values following wildfire throughout the study area.

How to Use this Risk Assessment

The information contained in this risk assessment can be used to prioritize investments in reducing risk, either through reducing the intensity or likelihood of fire, or by “hardening” the valued resources and assets to lose less value when burned. When overlaid with information about the cost-of or constraints-on treatments, relatively low-cost treatment opportunities can be identified. Once the easiest to implement treatments in high-risk areas are complete, the information generated in this risk assessment can be used to identify areas where the added higher cost of treatment (either in planning or implementation) is justified by the high risk posed by those areas.

Care should be taken when interpreting the results of this risk assessment. While individual homes or other resources and assets of importance to you may not appear to be in high risk areas, local factors under your control should be evaluated such as building materials, debris in gutters, and woodpiles near homes, that may increase your susceptibility to fire at a scale that is not evaluated in this assessment.

The relationship between areas that burn, and the values that flow from those areas have been captured in this assessment. While this assessment will show areas that if burned will produce a negative benefit, the areas that are negatively impacted do not have to be spatially coincident; they can be downstream, downhill, or downwind. A key example of this would be a structure appearing in a low-risk area; while that structure is in a low risk area, it could be negatively impacted by neighboring higher-risk areas through flooding, debris flow, or ember production.

Wildfire is just one of many hazards that exist in the Fireshed (Santa Fe County 2016). Only wildfire and post-fire hazards are included in this assessment.

Study Area

The Santa Fe Fireshed boundary was delineated to encompass the Santa Fe watershed, the Santa Fe Ski Basin, and communities in the foothills of the Sangre De Cristo Mountains (Figure 8). Bounded on the north by the area burned by the Pacheco Fire, on the east by the Pecos River drainage and the South and West by interstates and major highways, the Fireshed boundary is a rough approximation of the area where valued resources and assets of the Greater Santa Fe Fireshed Coalition overlap with areas of perceived fire hazard. Because firesheds are defined by the sources of fire that can impact valued resources and assets (Bahro et al. 2007), the analysis area used in this assessment extends beyond the official boundary of the Santa Fe Fireshed.

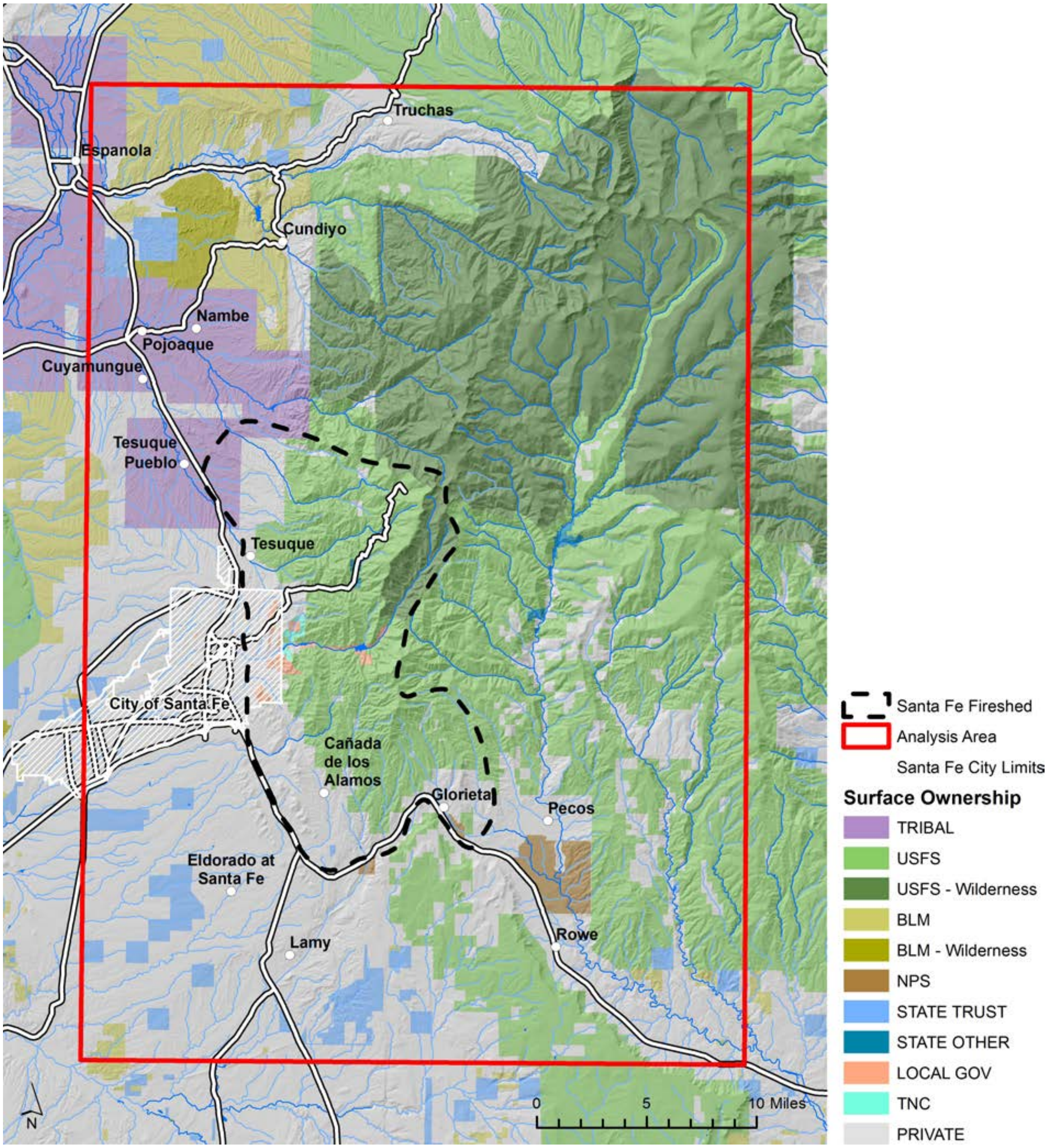

Figure 8. The analysis area used in this wildfire risk assessment (red line, 853,899 acres) extends beyond the official boundary of the Santa Fe Fireshed (black dashed line, 107,626 acres). The analysis area is larger to accommodate fires that begin outside but spread into the official boundary.

Methods

This risk assessment is built on a framework that has been widely used to understand the distribution of wildfire risk across large landscapes (Scott et al. 2013).

Wildfire Simulation

Fires were simulated on the fuelscape under a range of wind and fuel moisture conditions to capture the variation in fire behavior that occurs under varying weather conditions. Percentile weather distributions were created for the approximate fire season observed historically in the study area (March 1 through July 31). Sixty-four combinations of wind direction and fuel moisture were used to simulate fires with resulting burn probability and fire intensity metrics scaled for frequency at which those conditions historically occurred.

Burn probability was simulated with the FConstMTT software application which is functionally a command-line version of FlamMap (Finney 2006). Simulations were conducted for 640,000 fire starts; 10,000 starts under 64 different weather scenarios. FConstMTT has been used for several recent fire analyses (Kalabokidis et al. 2014, Ager et al. 2017). FConstMTT uses the Minimum Travel Time (MTT) algorithm (Finney 2002), which is the most commonly used method to model fire spread and analyze burn probability because it has been incorporated into all fire simulation software applications recently developed by the USFS including FSim (Finney et al. 2010b), FlamMap (Finney 2006), and WFDSS (Finney et al. 2010a).

Fire behavior was also simulated using FConstMTT which implements the Rothermel (1983) fire spread model and the Scott and Reinhardt (2001) crown fire models to predict fire behavior based on a range of inputs. Initially FlamMap was planned to be used for fire behavior simulation, though the ability to batch process fire simulations using FConstMTT expedited the running of 64 simulations with varying inputs.

Both FConstMTT and FlamMap require the same inputs. Spatial datasets representing topography, surface fuels, and canopy characteristics parameterize the fire behavior models at the pixel level. Wind direction and speed and fuel moisture parametrize the models for the whole simulated area. Each simulation run keeps these inputs constant, varying only the ignition location in FConstMTT.

Topography, Fuel Model, and Canopy Characteristics

Spatial topographic and fuel data is required for parameterization of fire spread and behavior models. The fire models require this data be formatted as a “landscape file” with file extension LCP. Landscape files characterize Elevation, Slope, Aspect, Fire Behavior Fuel Model, Canopy Cover, Canopy Height, Crown Base Height, and Crown Bulk Density for discrete stands within the modeled area which are represented by pixels (Finney 2006). In the risk assessment framework used for this assessment, this landscape file is said to represent the “fuelscape”(Scott et al. 2013).

A national program to develop this data nationwide has been underway since 2001 with the most recent release in 2017 reflecting landscape condition in 2014 (Nelson et al. 2016, LANDFIRE 2017). Datasets from LANDFIRE version 1.4.0 were used for the fire simulation conducted for this risk assessment. LANDFIRE data was modified to match local conditions following guidance from the USFS and LANDFIRE Program (Stratton 2006, Helmbrecht and Blankenship 2016). Details about the modification of LANDFIRE data are included in Appendix A.

Historical Weather

Weather is a critical control on fire spread and intensity. Wind speed, wind direction, and fuel moisture influence direction, rate of spread, and intensity of fire. Given sufficient fuel to carry fire, these are the controls on the behavior of the fire. When wind and fuel moisture conditions are not conducive to fire (high fuel moisture, low wind speed), fire spread is slow, and intensity is low. Alternatively, given low fuel moistures and high wind speeds, fire behavior is intense, and spread is fast.

These conditions can be described by the frequency that the conditions occur. Given a sufficient record of weather data, the frequency of weather events can be used to predict the probability of certain conditions occurring. For example, if 25 miles per hour (mph) wind speeds are exceeded only 3 percent of the time in the weather records, 25 mph wind speeds would be given a 97th percentile ranking.

Both the FConstMTT and FlamMap require wind speed, wind direction and fuel moisture as input parameters. The observed frequency of weather was used to parametrize the fire spread and behavior models for this assessment. The historical distribution of fire weather is commonly used to approximate future weather conditions and is suggested for the Wildfire Risk Assessment Framework followed for this risk assessment (Scott et al. 2013).

Throughout the Western U.S., Remote Automated Weather Stations (RAWS) are maintained by federal agencies to enable calculation and forecasts of fire danger (Zachariassen et al. 2003). Records of surface weather recorded at RAWS stations are also routinely used to parameterize fire simulations in addition to evaluating daily fire danger ratings.

The Pecos RAWS was used for this assessment. While the Santa Fe Watershed RAWS station is within the Fireshed, the Pecos station was selected because the station has been in operation longer, and is more representative of the expected weather in the Fireshed because the recorded windspeed and direction is less influenced by the surrounding topography (Figure 9 and Figure 10).

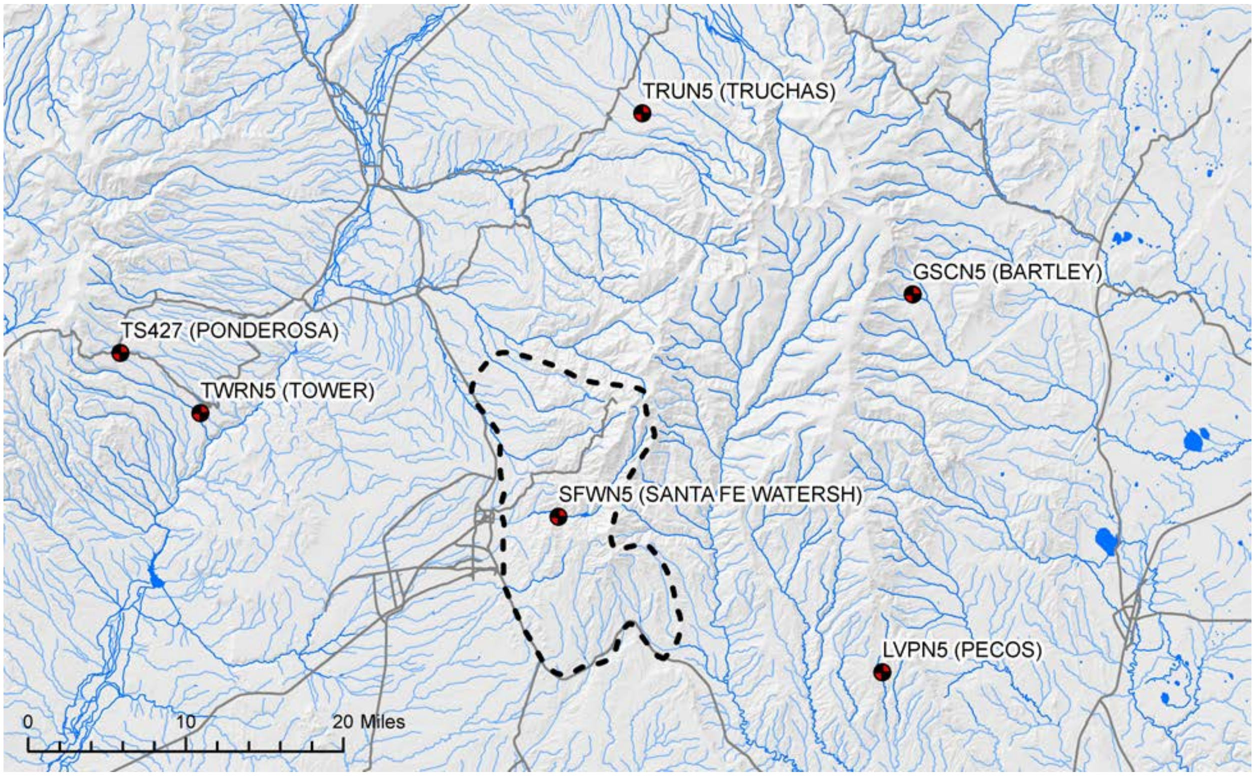

Figure 9. Remote Automated Weather Stations (RAWS) near the Santa Fe Fireshed.

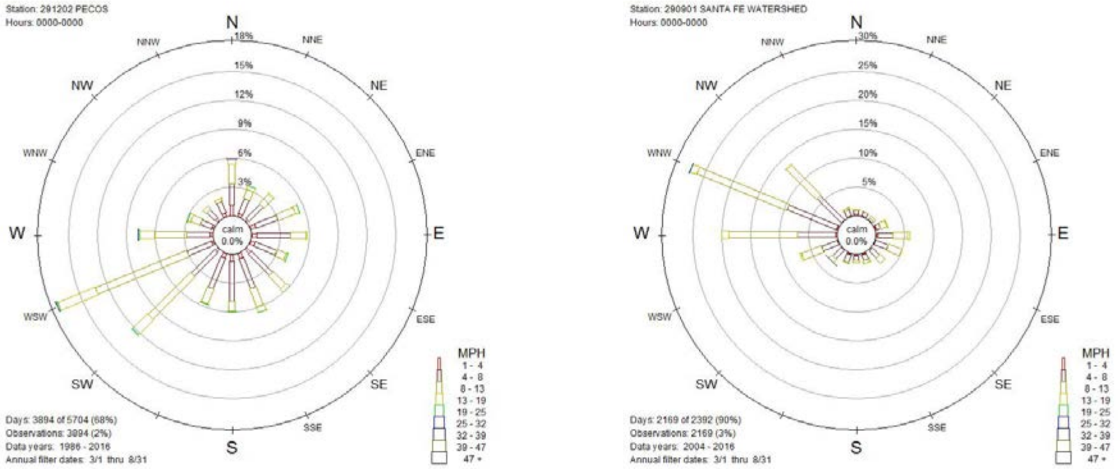

Figure 10. Wind rose graphs of the distribution of wind speed and direction that has been observed historically at the two RAWS stations closest to the Fireshed. Note the wind direction distribution at the Santa Fe Watershed RAWS is primarily up- and down-valley which indicates wind speed are also likely impacted. FireFamily Plus was used to analyze the wind data and produce the graphs (Bradshaw 2013).

Historical daily observations of weather at the Pecos RAWS were summarized and analyzed in the FireFamily Plus software application version 4.1 (Bradshaw 2013). The period from 1986-2016 was analyzed to identify percentile weather conditions using the Energy Release Component (ERC) measure of fire hazard. The historical data was further constrained to the fire season, defined in this assessment as March 1 through July 31.

The fuel model selected as representative of the Pecos reporting area was switched to G in FireFamily Plus as is commonly done because fuel model G includes all fuel components and size classes and thus is able to model both short and long-term changes in fuel moisture following precipitation or fluctuations in humidity and temperature (Finney et al. 2011).

Following the guidance in the Risk Assessment Framework, observed 20-foot wind speeds were modified from the 10-minute average wind speed recorded at each RAWS station to the "probable maximum 1-minute speed" using the relationship established by the USFS (Crosby and Chandler 2004). One-minute wind speeds were used because they are more representative of the conditions that drive changes in fire behavior. See Appendix D for additional details of this wind speed modification.

An analysis of area burned in New Mexico indicates most fires that have burned large areas have occurred between March 1 through July 31 (Figure 11). While fire seasons are growing longer throughout the world (Jolly et al. 2015), the historical fire season observed in New Mexico was used to capture the variability in weather observed during the observed fire seasons. Future changes in climate that change the fire season length will move the distribution of year-round weather, closer to the conditions observed during the historically observed fire season.

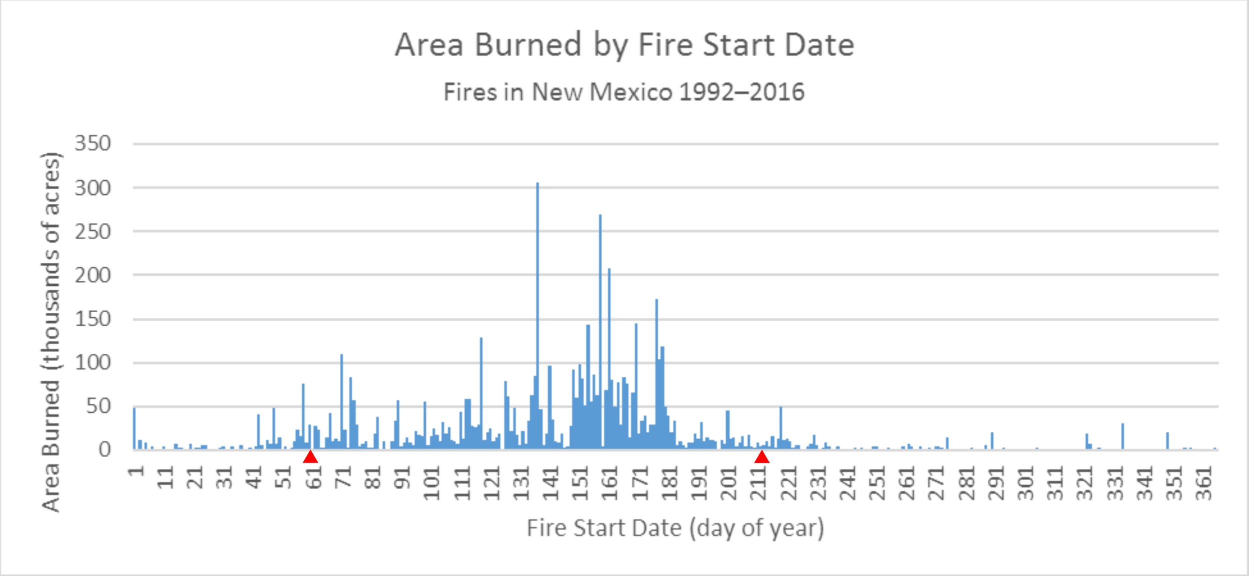

Figure 11. Total area burned by fire start date for most fires in New Mexico, 1992–2015. Data from Short (2017). Recent extreme fire events are responsible for much of the area burned. Day 60 through day 212 (March 1 through July 31) are the approximately the start and end of fire season (indicated with red arrows).

Weather during this period was distilled down to 64 representative weather conditions: eight fuel moisture and wind speed scenarios representing key fire danger percentiles, combined with eight wind directions (Table 4). Percentile conditions are representative of all observed fire season weather, from low fire severity weather to high severity fire weather.

Table 4. Sixty-four combinations of wind speed, fuel moisture and wind direction with the weighted probability of these conditions being representative of the fire weather during each fire simulation. These values were developed from an analysis of the Pecos RAWS for fire season (March through July) using the weather observations between 1986 and 2016. Wind direction (WD) is recorded in azimuth from north. Values sum to 100 to capture all variation in observed weather conditions.

Percentile	WD45	WD90	WD135	WD180	WD225	WD270	WD315	WD360	Fuel Moisture	Wind Speed
01	0.43	0.43	2.30	0.94	0.43	0.94	0.94	5.62	33 33 26 33 60	3 mph
25	2.49	4.21	4.15	4.76	2.07	2.21	1.66	3.45	8 9 13 46 89	10
50	0.85	1.88	2.40	2.56	4.87	2.52	0.53	1.39	5 6 10 30 74	12
60	0.50	1.11	1.41	1.50	2.86	1.48	0.31	0.82	4 5 9 24 69	13
70	0.50	1.11	1.41	1.50	2.86	1.48	0.31	0.82	4 5 8 27 67	14
80	0.27	0.11	1.17	0.51	4.17	2.90	0.08	0.80	3 4 7 29 66	17
90	0.24	0.10	1.05	0.46	3.76	2.61	0.07	0.72	3 3 6 25 62	19
97	0.06	0.00	0.71	0.06	2.74	2.74	0.06	0.63	2 2 5 27 60	22

Historical classifications of wind speed and direction were pulled from the FRISK file produced by FireFamily Plus (Table 5). These values were used to scale the percentile wind speeds for each weather condition. The nearest wind speed was used to assign directional probabilities to each scenario. For example, the 20 mph wind probabilities were used for the 90th percentile scenario, which has a wind speed of 19 mph.

Table 5. Probabilities of wind direction by wind speed generated by FireFamily plus in the FRISK file for the Pecos RAWS. Wind direction (WD) is recorded in azimuth from north.

	WD45	WD90	WD135	WD180	WD225	WD270	WD315	WD360
5 mph	0.05	0.05	0.27	0.11	0.05	0.11	0.11	0.66
10	1.97	3.33	3.28	3.77	1.64	1.75	1.31	2.73
15	2.62	5.79	7.37	7.86	14.96	7.75	1.64	4.26
20	0.55	0.22	2.4	1.04	8.57	5.95	0.16	1.64
25	0.05	0	0.55	0.05	2.13	2.13	0.05	0.49
30	0	0	0.11	0	0.22	0.22	0	0.05

Fires were simulated with a burn time of 72 hours. While most large fires burn for much longer and small fires for much shorter periods due to conditions that inhibit fire spread or suppression, 72 hours is long enough to allow fire spread across the landscape and burn through available fuels, even in areas with low rates of spread. Increasing the number of simulations could decrease the need for long simulation times because the rate of spread across each pixel would be captured.

Summary Scenarios

Three summary scenarios were used to aggregate the outputs of this assessment to simplify interpretation of the results. The all-weather scenario includes fires simulated under the distribution of all weather observed during fire season, defined in this study as March 1 through July 31st. A subset of this period is used for the problem-weather and near-worst-case-weather scenarios. The problem-weather scenario includes all weather at or above the 80th percentile. The near-worst-case scenario includes all fires that occur when simulated conditions exceed the 97th percentile of observed conditions.

Because the distribution of weather used in this assessment only includes fire season, the results of this analysis are not directly comparable to the results of FSim-based risk assessments which use the 80th percentile weather conditions for the entire year (Finney et al. 2011).While not directly comparable to the distribution of weather used during FSim simulations, the problem-weather summary scenario is an approximation of the FSim distribution. Additionally, suppression is modeled with FSim, which was not implemented in this assessment.

The problem-weather (80th percentile and up) “large fires” scenario is most similar to the FSim products produced during other risk assessments because FSim assumes ignitions that occur under conditions less extreme than the 80th percentile do not spread or are suppressed (Finney et al. 2011). The other scenarios are useful for planning for near-worst-case conditions and also for less intense average fire season conditions. It is important to note that prescribed fires are only conducted under very low-intensity conditions, which were not evaluated in this assessment.

Wildfire Behavior

Fire behavior was simulated with the FConsMTT tool. The resulting fire intensity from each of the 64 scenarios was weighted by the probability of that scenario occurring, and then combined to create a conditional flame length probability for seven fire intensity levels (Figure 12).

The Scott and Reinhart (2001) method was used for fire simulation (crown fire option) which also influences flame length (Scott and Reinhardt 2001). This method has been used on most recent fire risk assessments (Scott et al. 2013, Haas et al. 2014, Tillery and Haas 2016).

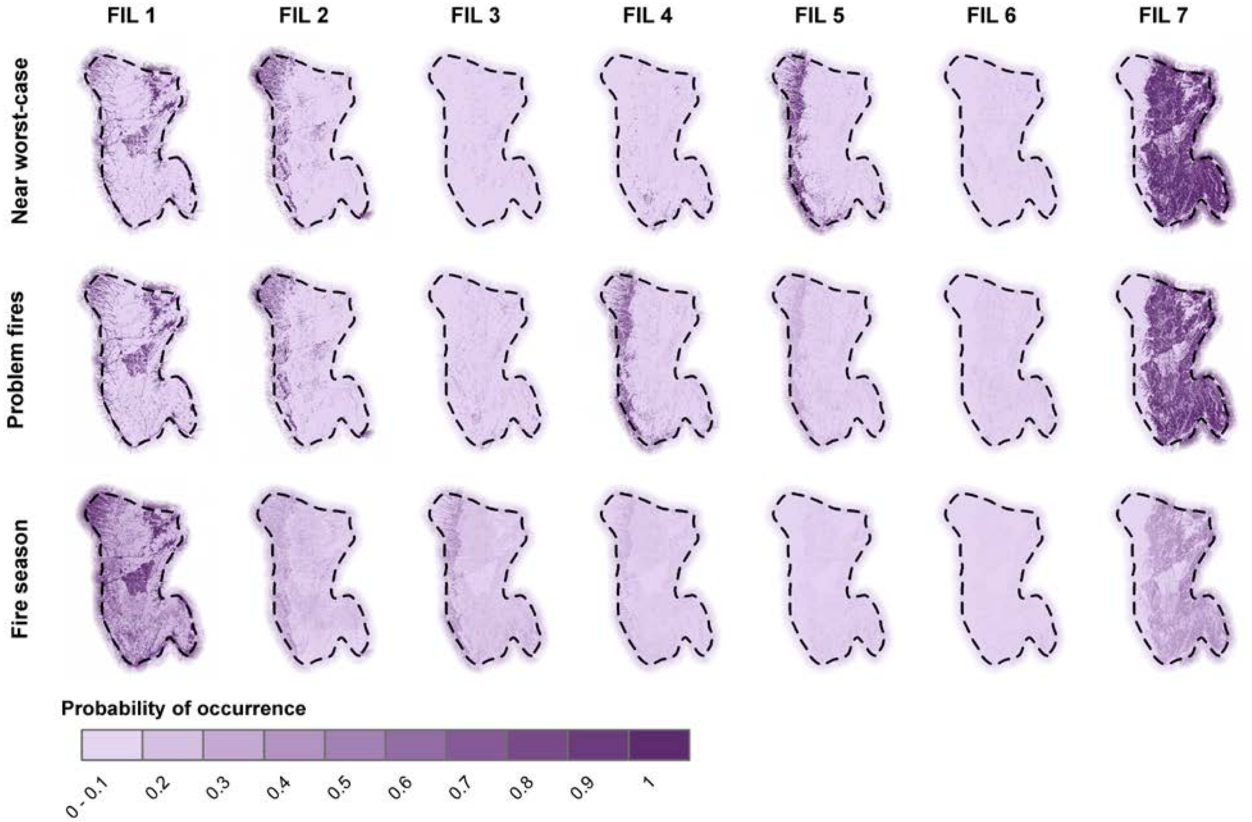

Figure 12. Probability of each fire intensity level (FIL) occurring under three weather scenarios. Also known as conditional flame length (CFL), outputs are summarized into three scenarios: all conditions (all fire season conditions), problem-fires (80th percentile conditions and up), and near-worst-case conditions (97th percentile and up). Additional summaries are possible given the intermediate products created during analysis.

Wildfire Likelihood

Burn probability was evaluated using FConstMTT. Ten thousand fires were simulated for each of the 64 weather scenarios. Burn probability was evaluated at a resolution of 90 meters to decrease time required for fire simulations to run. While the results are coarser, the broader patterns of fire spread and resulting burn probability are captured.

This burn probability is conditional on the weather conditions of the scenario, as well as the presence of an ignition. When an ignition occurs under each summary scenario conditions, this is the expected probability of a pixel burning. Most risk assessments calibrate the results of the risk assessment with previously observed fires to create an annual burn probability, however this step was not taken in this analysis.

Following the MTT simulations, output from each of the 64 simulations was weighted by the likelihood of that scenario happening. As with wildfire behavior, outputs are summarized into three scenarios: all conditions (all fire season conditions), problem-fires (80th percentile conditions and up), and near-worst-case conditions (97th percentile and up). Outputs were scaled so the burn probability percentage is conditional on the weather distribution selected (Figure 13).

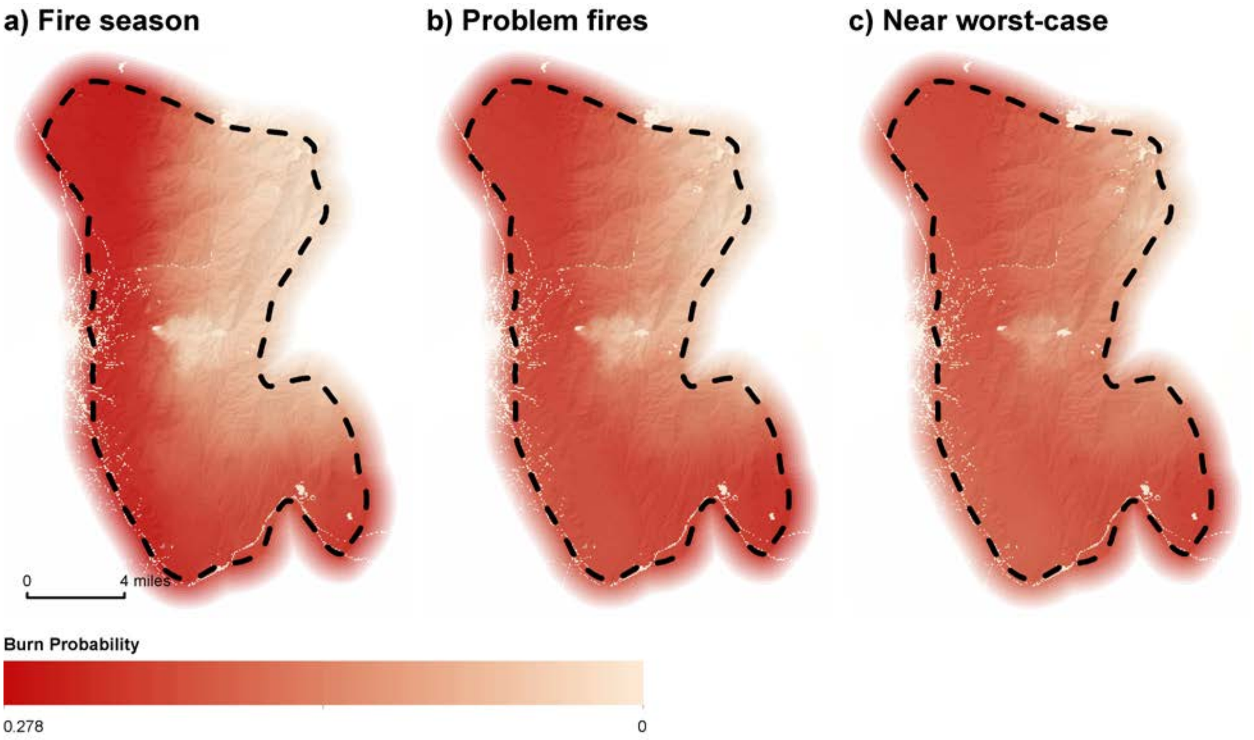

Figure 13. Burn probability under the three weather condition scenarios. a) Burn probability under the historical distribution of fire weather and fuels moisture conditions during fire season (March 1 through July 31. All fires are captured in this dataset, even fires that are easily suppressed or would burn out on their own. Low elevation areas have a relatively higher burn probability than lower areas because they can burn under less extreme conditions. b) Burn probability for fires that start during conditions above the 80th percentile of fire season ERC. Note the treatments in Santa Fe canyon that have reduced burn probability within the treated area. c) Burn probability under 97th percentile conditions. The flatter appearance of the near max burn probability layer is caused by the relatively homogenous fire spread behavior under extreme conditions. While under the eightieth percentile and up scenario lower drier area burn more readily than higher wetter types.

Fire Hazard

Fire hazard is the result of combining the probability and intensity data. Hazard is highest where intensity and probability are both high. Hazard is lowest when either intensity or probability is low. Hazard is converted into risk by including the exposure and susceptibility of valued resources and assets.

Characterization of Valued Resources and Assets

Much like fire hazard, the distribution of valued resources and assets is not uniform across the study area. Assets like homes and roads are easy to see on the landscape, others like watershed function or cultural use may be harder to discern. While Santa Fe Fireshed landscape has intrinsic value as a whole, the constituent VRAs are useful for identifying the concentrations of value and risk to that value. Full details of VRA delineation and characterization are included in Appendix B.

Identification and Mapping of VRAs

The Fireshed contains numerous assets and provides many resources that are valued by the members of the GSFFC and the community at large. An infinite list of valued resources and assets (VRAs, “things people care about”) could be generated, but with the limited time and resources available for this assessment, a limited set of VRAs were evaluated. Workshops were held with GSFFC members to identify VRAs within their specific jurisdiction. Forty VRAs were initially identified, though many were consolidated into a list of twelve for inclusion in this assessment (Table 6).

Table 6. Valued Resources and Assets (VRAs) included in this wildfire risk assessment. Appendix B contains much more detail about the VRAs included in this assessment.

Category	VRA	Sub-VRA
Private Investment	Private Land	
	Structures	
Watershed Function	Water for Irrigation	
	Water for People	
	Erosion Mitigation	Erosion Hazard Class
	Debris Flow Mitigation	Debris Flow Hazard Class
	Flood Control	
Infrastructure	Roads	Erosion Hazard Class
	Powerlines	
Recreation and Cultural Use	Developed Recreation Area	
	Trails	Erosion Hazard Class
Ecosystem Function	Spruce-Fir Forest	
	Mixed Conifer - Frequent Fire Forest	
	Ponderosa Pine Forest	
	PJ Grass	
	PJ Woodland	
	Juniper Grass	
	Colorado Plateau / Great Basin Grassland	
	Other Vegetation	

While not all VRAs that were originally identified are included, much of the value on the landscape is captured, either explicitly by a VRA or as an external association to the VRA. For example, structures are explicitly included, while fish and wildlife habitat is included only by association. As fish and wildlife quality depends on a functioning ecosystem, terrestrial habitats are included in the forest ecosystem VRA and aquatic habitats are included in the watershed function VRA category. The VRAs included in this assessment are not exhaustive and other resources and assets will be evaluated during project planning and implementation.

VRA Characterization

High intensity fire could occur in some parts of the landscape and produce positive effects, in other places a low intensity fire could have negative effects. Independent of fire hazard, VRA response is the theoretical expected change in value following a fire at each intensity level. This is a measure of the susceptibility to fire at different intensity levels.

Because different VRAs take different amounts of time to return to their pre-fire value, the timeframe for VRA response must be held constant when characterizing response functions. For this assessment, a timeframe of 5-years was used to capture the responses to fire that will persist beyond the first year or two following the fire. Some VRAs require a very long time to return to their pre-fire value, if ever; this distinction is not included in this assessment.

Expected Risk

Risk map is produced by multiplying the net value change assuming a fire occurs by burn probability. This risk measure shows the expected net value change (eNVC) of each VRA. The eNVC of all VRAs was summed by category and with all VRAs to produce summaries that can be used by the Collaborative and individual stakeholders to prioritize invests in risk mitigation that are most relevant to the VRAs or categories of VRAs they are most concerned about.

Results

Negative expected net value change following the next fire is high throughout the study area, though there are areas where the next expected fire will not have a negative outcome (Figure 14). In these risk maps, each, risk is classified into bins that represent a doubling of wildfire risk. The transition between colors represents a doubling of risk.

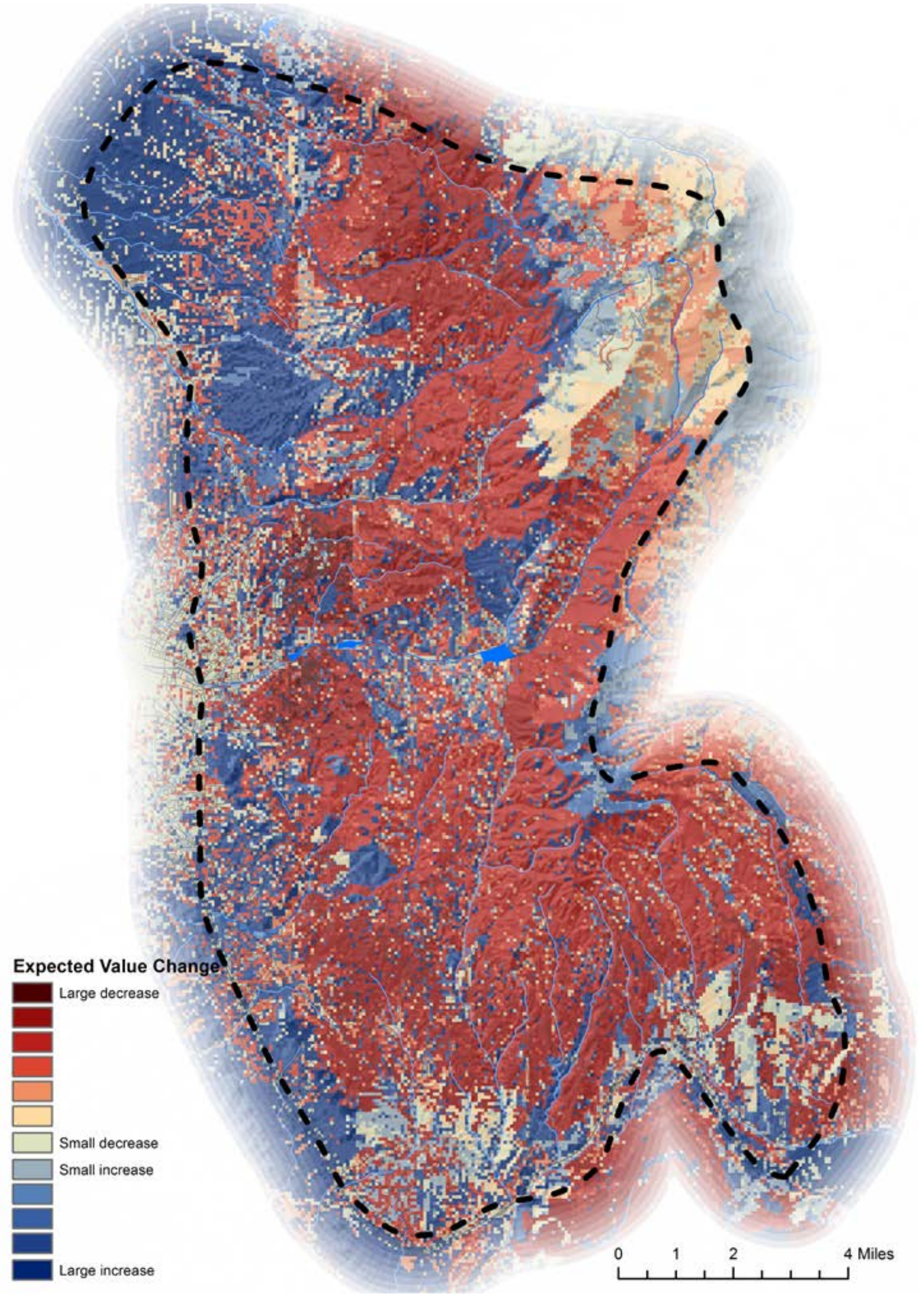

Figure 14. Expected net value change (eNVC) for all VRAs included in this wildfire risk assessment. Dark red areas are expected to lose the most value relative to other areas. Dark blue areas are expected to increase in value relative to other areas. Investments in reducing wildfire risk (including reducing the intensity and likelihood of wildfire through forest restoration and fuels reduction treatments, and decreasing the susceptibility of VRAs through hardening resources and assets to the effects of fire) should be prioritized in the highest risk areas. Investments in maintaining low risk areas through prescribed fire and re-treatment may be necessary to prevent low risk (blue) areas from becoming high-risk (red).

The data produced by this risk assessment can be used to derive additional valuable information. As an example: if investments are to be prioritized only on private or public lands, the highest risk areas can be identified with overlay analysis (Figure 15).

Risk was assessed for each VRA so if stakeholders are particularly concerned about one VRA, VRA-specific risk can be used to inform priorities and investment. Risk has also been summarized by VRA category. Larger maps of risk for individual VRAs are included in Appendix C.

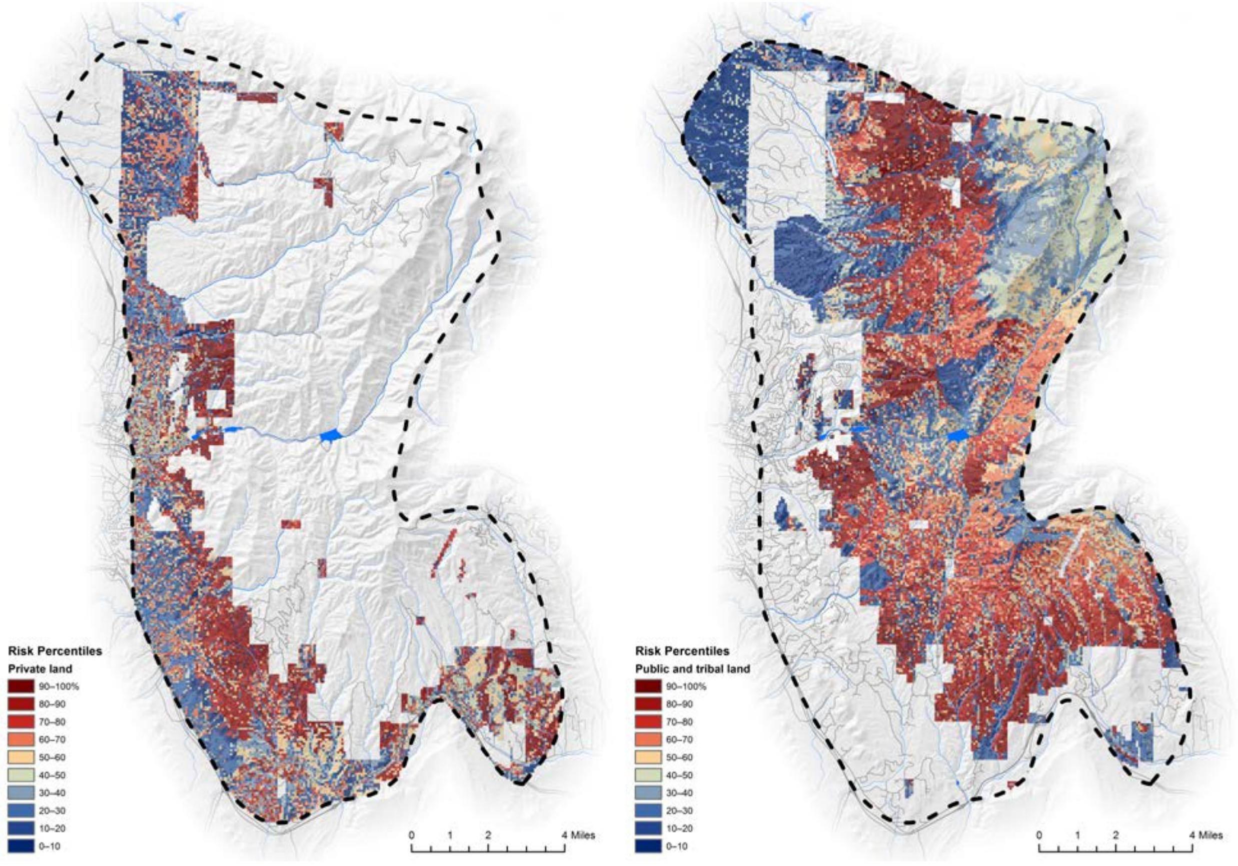

Figure 15. Wildfire risk within the GSFFC boundary symbolized in 10th percentile classes. The left map shows risk percentiles on private lands within the Fireshed. The right map shows percentile risk on public and tribal lands. Symbolizing risk by percentile on different land ownership types allows identification of risk reduction priorities by different land management agencies. Risk is highest (expected value change is most negative) in red areas. Blue areas are lower risk and have a positive, or relatively small negative expected value change.

For many stakeholders, the concern is not if a valued resource or asset burns but when. The maps of net value change assuming a fire occurs can be helpful for evaluating the hazard posed regardless of the probability of a fire occurring coincident with the VRA.

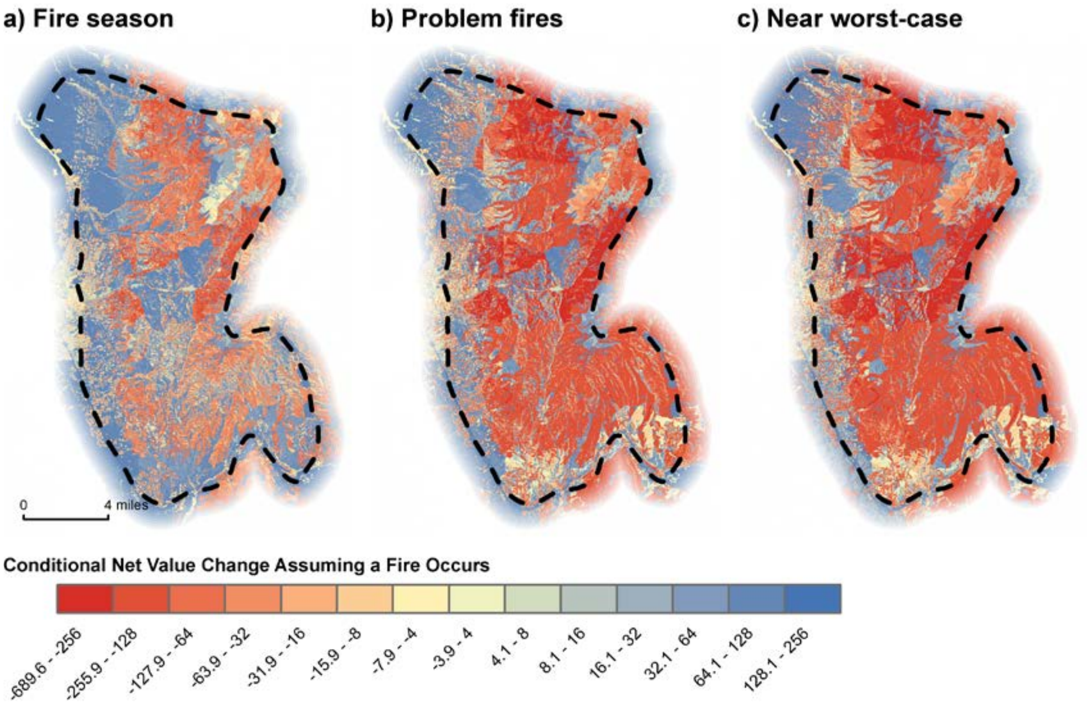

Figure 16. Conditional net value change assuming a fire occurs under the all conditions, problem-fires, and near worst-case conditions. Assuming a fire occurs, this is how the VRAs in the landscape are likely to change in value. a) Net Value Change (NVC) assuming each pixel burns under the fire intensity expected under the distribution of fire weather observed historically during fire season, even low intensity fires that would be relatively easy to suppress or would burn out on their own. b) Hazard to VRAs evaluated under the problem-fire scenario (80th percentile conditions and up). c) NVC expected under near-worst-case conditions (97th percentile). Larger maps are included in Appendix C.

Discussion

Relative risk maps produced during this assessment offer a powerful tool for prioritizing investment in wildfire risk reduction. While this assessment follows well-established protocols and produces results comparable to other regional and national assessments, care should be taken when interpreting the results of this assessment. When drawing conclusions from this assessment, the relative scope and scale of the assumptions should match the scope and scale of this assessment.

While the fire simulation components of this wildfire risk assessment were completed for a large landscape that extends beyond the official boundary of the Collaborative, most VRA delineations end at the Fireshed boundary, this is not a problem when comparing hazard and risk within the boundary, the problem arises when attempting to compare areas inside the Fireshed boundary to areas outside of it. While the fire hazard and risk data extend beyond the boundary, the VRAs do not. This results in an inaccurate assessment of hazard posed to VRAs outside the boundary.

This risk assessment is just one component of the overall prioritization of investments in risk mitigation. Operational constraints are essential to include when using this data. While risk can be high, there are places in the Fireshed where risk mitigation is limited by management intent, accessibility, and site-specific constraints (archaeological sites, steep slopes, etc.).

Relative importance and weighting of VRAs are commonly included in risk assessments (Scott et al. 2013). The relative importance of individual VRAs was not established in this assessment because individual members of the Collaborative have different priorities for risk mitigation. If only one agency or funder was to conduct a risk assessment, the relative importance of values would be relatively easy to implement. In the context of this landscape with stakeholders who have a wide variety of interests, VRAs are additional, not in competition.

Historically observed weather data used to parameterize the models is unlikely to be perfectly representative of the future. Observed and expected changes in climate will change the distribution of fire weather occurrence and resulting fire behavior. Projected future climate data was not incorporated into this assessment. Based on recent studies of the influence of climate change on weather and fire behavior, the percentile weather distribution used to simulate and summarize fire behavior will depreciate over time as previously rare extreme events become more common. As new climate projections and downscaled data becomes available, this assessment could be updated to evaluate how hazards change under new expected conditions.

Just as this analysis will become less accurate as the current distribution of weather conditions deviates from historically observed distribution, the fuelscape used to describe the fireshed will become less representative of reality as the actual fuelscape is modified by fires, treatments or other fuel disturbance.

As spatial data was compiled for use in this assessment, care was taken to include the best available data. In some cases, the data used to describe the fuelscape or delineate VRAs may be incomplete or inaccurate so care should be taken when interpreting the results of this assessment.

The percentile weather scenarios used in this assessment capture the overall distribution of expected fire weather, but in future assessments it would be better to use a higher resolution distribution with more bins that are better representative of actual weather distributions. FSim does not use bins for simulations and would offer the best representation of the expected distribution of weather. The current distribution is representative with most fuel moistures within 4% of their assigned value.

Patch size is not included in this assessment and is critical to consider; just because a stand will respond positively to disturbance does not mean the effect of burning all positive disturbance areas at once will have positive outcomes.

This assessment does not evaluate the tradeoffs between the costs associated with implementing treatments to reduce wildfire risk and the costs of high intensity fire burning if treatments are not implemented. Additionally, this assessment does not evaluate the change in value of VRAs due to treatments, though the reduction in value following a treatment is unlikely to be in the same order of magnitude as the loss in value following a wildfire.

Conclusion

The forests surrounding Santa Fe are valued for many reasons. Wildfire and post-fire hazards threaten these valued resources and assets (VRAs). The VRAs mapped and characterized in this assessment describe the spatial distribution and susceptibility of some of the phenomena that make these forests valuable. By exposing these VRAs to simulated wildfire, this assessment will help the communities and land managers of the Fireshed understand the patterns of susceptibility, hazard, and risk across the landscape. Using the data produced during this assessment, investments in resource hardening, forest restoration, fuels treatments, and other mitigation measures can be targeted in areas of high fire hazard and risk. While the output of this assessment is based on hypothetical fires, the patterns observed in the data reflect the real world and can be used to reduce the damage caused by future wildfires.

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Appendix A: Fireshed Fuelscape Critique and Improvement

Data from the LANDFIRE program was used as the foundation for the fire simulations completed as part of this assessment. LANDFIRE is an initiative of U.S. Department of Agriculture Forest Service and U.S. Department of the Interior that generates high-resolution vegetation, fuel, and fire regime data for United States to accelerate cross-boundary planning (Reeves et al. 2006, Nelson et al. 2016). Several guides have been published for utilizing LANDFIRE data for local analysis (Stratton 2006, Helmbrecht and Blankenship 2016, Beauchaine et al. 2017, Blankenship et al. 2017), these methods were used to modify the fuelscape to match local conditions.

Incorporating Recent Treatments and Fires

Preliminary inspection of the original fuelscape file revealed that it did not accurately reflect recently treated areas including the Santa Fe Municipal watershed project and thinning in the La Cueva area, Hyde Memorial State Park, and on Pueblo of Tesuque lands. Thinning in dry forests alters the structure of the forest canopy and prescribed fire including burning piles of excess biomass reduces surface fuels (Hunter et al. 2007, Evans et al. 2011).

Treatment outcomes have been monitored to detect changes in fuels at the treatment scale, but data has not been collected to detect changes at the sub-treatment pixel scale. Locations of treatments and burn blocks are generally known, but it is common for less than 100% of each block to be treated, and modern prescriptions are intended to be heterogeneous so monitoring is most effective at the treatment and project level. Prescriptions for treatments are also known, though rarely are treatments prescribed in terms that can easily be converted into fuel loadings and ultimately fuel model classification. To include the effects of these treatments on fire behavior, a range of possible post-treatment fuel models were used as the basis for fire simulation (Table A1 and Table A2).

Table A1. Fuel dataset modifications to reflect treatments.

Fuel Model	CBH	CBD	CH	CC
188 replaced with 181	original * 1.5	original * 0.8	original	original * 0.8
183 replaced with 181	original * 1.5	original * 0.8	original	original * 0.8
165 replaced with 161	original * 1.5	original * 0.8	original	original * 0.8
147 replaced with 181	original * 1.5	original * 0.8	original	original * 0.8
186 replaced with 181	original * 1.5	original * 0.8	original	original * 0.8
185 replaced with 181	original * 1.5	original * 0.8	original	original * 0.8

Table A2. Fuel dataset modifications to reflect recent wildfires.

Fuel Model	CBH	CBD	CH	CC
all replaced with 121	0	0	0	0

Only treatments in the last 10 years (2006–2016) were collected and used to modify the fuelscape (2008 was the earliest year with treatment data, earlier treatments may exist, but they are not captured in the current reports). Fires in the last 20 years — back to 1996 — were used to modify the fuelscape. The Monument Fire that burned in 2000 was the earliest fire in the records used to update to fuels dataset. Older treatments and fires are captured in the base LANDFIRE datasets or are assumed to no longer functioning as treated forest or recently burned area.

Observations of fuels following treatments have been recorded and provide anecdotal evidence that the corrections made during this fuels layer calibration are correct in direction of change, and conservative in the magnitude of change (Armstrong and Carril 2015).

The expected effective period following treatment is assumed to be 10 years. Because all of the treatments in the study area are less than ten years old, no regrowth was modeled. Future monitoring could improve the pixel-level assumptions of fuel changes following treatments.

Eliminating Ecoregion Boundary Artifacts

The fireshed encompasses three different modeling zones and edge artifacts are readily visible, especially in the fuel model and EVT datasets. After running a preliminary fire simulating, unexpected low intensity fire was observed along a band of consistent elevation in the western and southern foothills of the Sangre De Cristo Mountains.

Ensemble Consensus on Vegetation Type

All available vegetation type datasets were overlain to produce an ensemble consensus dataset, where each dataset "voted" for the vegetation type that it mapped for that area (Figure A1). Most areas were easily classified based on this method. In the few areas where no vegetation type captured more than 50 percent of the votes, the vegetation type that received the most votes (plurality) was given the classification.

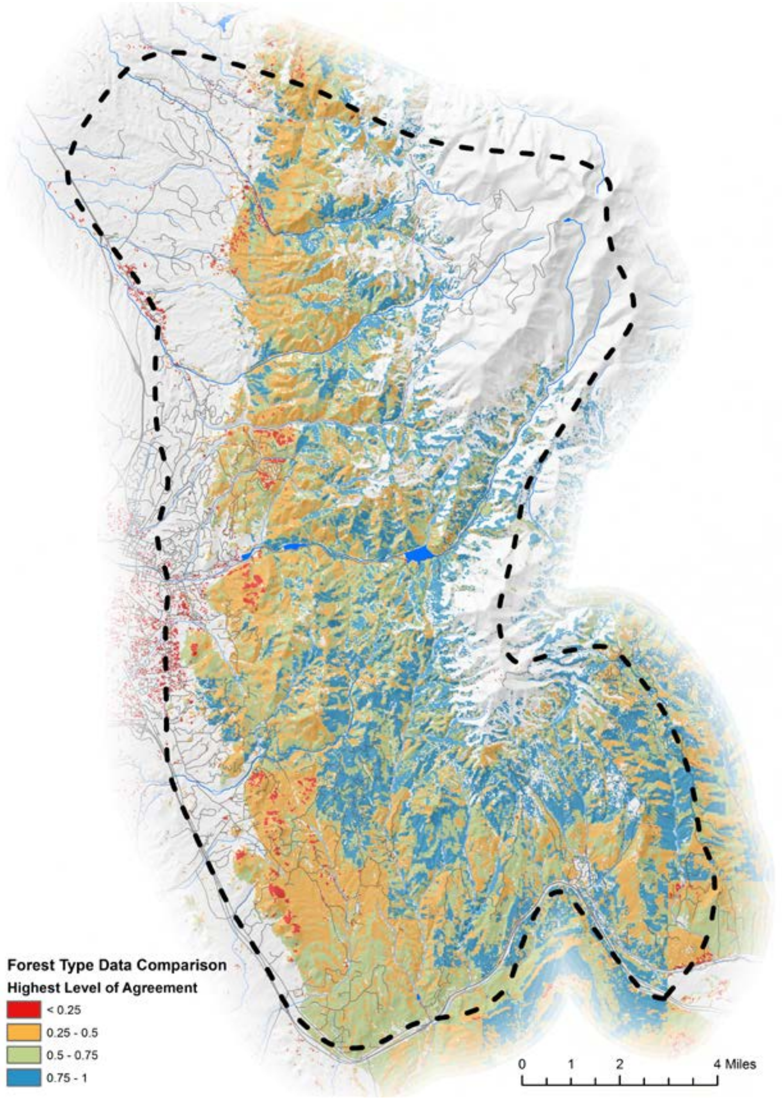

Figure A1. Level of agreement between spatial datasets depicting mixed conifer, ponderosa pine, and piñon-juniper forest types.

Field Validation

Due to the uncertainty about vegetation type and fuel model in a few areas, limited validation was attempted using quick visual fuel model classification protocol, conducted in the field and from photograph. Photographs used for the spot-validation of fuel model classification were taken during the “Google Trekker” Street View mapping of the Dale Ball trails by TOURISM Santa Fe in August 2015 (TOURISM Santa Fe 2015). The Google Trekker camera generates 360-degree panoramas at multiple points along a trail. Photo quality was relatively high, and consensus was reached by at least two analysts on the FBFM fuel model in each photo (Figure A2). This spot-checking demonstrated an 80-percent error rate (Table A3).

Figure A2. Sample image taken from Google Street View that is representative of the images used for spot-checking the LANDFIRE fuel model classification. This image is from photo point GSV_08 (35.6691988, -105.8906725) and was classified as fuel model SH7. This image is a subset of an image taken with a Google Trekker camera on the Atalaya Mountain Trail during August 2015.

Table A3. Confusion matrix of fuel types with analyst determined FBFM on one axis and Corrected Land fire on the other. Sites with correctly classified

Photo Classification		***Modified LANDFIRE***							
		GR1	**GS2**	**NB1**	**SH1**	**SH7**	**TL3**	**TU1**	**TU5**
	SH7	2	7	2	1	9	3	10	11
	TU5	0	2	0	0	0	0	2	1

With the significant amount of confusion or misclassification between the modeled and observed fuel models, I investigated the behavior of the confused models by comparing flame lengths under a range of scenarios. While the overall confusion rate was high for the SH7 and TU5 types, the underlying difference in modeled fire behavior is small. A sensitivity analysis indicates that simulated fire intensity levels are consistent between the frequently confused types, with a one FIL class difference at higher wind speeds.

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Appendix B: Valued Resources and Assets

Wildfires pose a threat to valued resources and assets (VRAs). VRAs are the reason wildfire risk exists; if there is not something of value that could be damaged by fire, then there would not be a reason to even consider the threat of wildfire. VRAs vary widely, ranging from tangible assets like homes, to abstract concepts like the flood mitigation potential of a stand.

While high intensity fires are portrayed negatively, intense fire behavior is not “bad” by itself; it is when those high intensity fires occur in places that are susceptible (will lose value) when burned by high intensity fire, that high intensity fires are bad. This appendix describes the process of mapping the presence of resources and assets that will be affected by fire, as well as the process of characterizing the response of those resources and assets to different intensities of fire.

Fifty-three VRAs were identified by GSFFC Coalition members during workshops during the fall of 2016. Of those identified VRAs, many had insufficient data or were dependent on other distinct VRAs. Nineteen VRAs are included in this assessment. These VRAs are classified in to five categories for ease of analysis and communicating risk.

This appendix is organized with a section for each VRA. Within each VRA section, the process for delineating and characterizing the VRA is described. Some VRAs such as structures and private land are straightforward to delineate (map), because the value of the VRA is coincident with the footprint of the structure. Other VRAs like water yield are continuous with variation in value across the landscape. These continuous VRAs are assigned value based on the combined relative value of the supply of the resource as well as the relative value of consumption of the resource (the benefit). For example, water yield is highest at higher elevations, these higher elevation areas have the same response function as lower elevation areas, but since runoff is higher in some places, the source index is higher. On the beneficiary side, the runoff from some watersheds are diverted to irrigate fields or provide drinking water. Because not all watersheds are equally relied upon for irrigation and drinking water, a beneficiary index is used to describe the relative importance of each watershed to downstream beneficiaries.

The risk assessment framework outlined in GTR-315 (Scott et al. 2013a), specifies that the relative importance of each VRA should be determined. Relative importance is a useful measure for individual stakeholders when determining where priorities exist on the landscape, but for a multi-stakeholder risk assessment can decrease the usefulness of the output. Agencies and organizations that are only interested in one VRA or category of VRAs would see their area of concern weighted less than other areas of concern. For example, the downstream water users that rely on these forested watersheds are only concerned with the watershed function VRAs and to demote them to be less important than structures would decrease the usefulness of the report. In this assessment, VRAs are considered equal, where the 100 percent loss of value of each VRA is considered equivalent. Therefore, in areas where multiple VRAs overlap, no VRA is given preference.

VRA Category: Private Investments

This VRA category describes all physical structures and privately owned real estate within the Fireshed.

This category of VRAs does not have a distinction between source and benefit. While there are other places and organizations that benefit from having private lands and residents within the fireshed, the value to those other beneficiaries are not included in this assessment. Examples of external beneficiaries that aren’t explicitly included are Santa Fe County programs that depend on the property tax of the private land in the fireshed, and the businesses that are dependent on the residents that live in the fireshed.

Private Land

Public land was derived from the Protected Area Database of the United States (PAD-US) version 1.3 (U.S. Geological Survey 2016b). All non-public lands are assumed to be private. Private lands are included as a VRA because wildfire has been shown to decrease the value of private land, in addition to the hazard posed to improvements made to the land. All private lands are given the same value; essentially if the land is privately owned this value exists. While variation in property value exists, this VRA does not include any variation, it is either private or it is not.

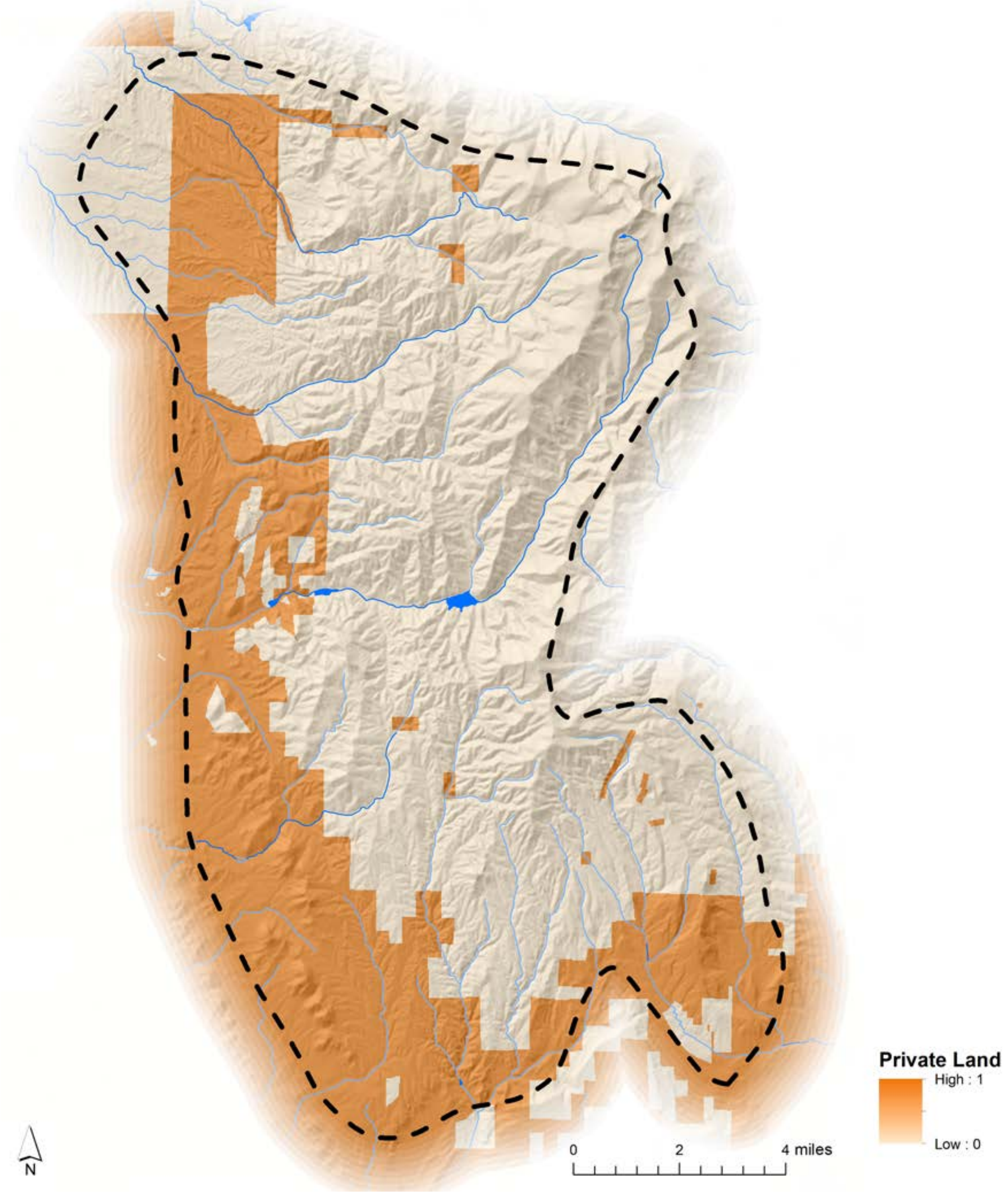

Figure B1. Public land was derived from the Protected Area Database of the United States (PAD-US) version 1.3 (U.S. Geological Survey 2016). All non-public lands are assumed to be private. Private lands are included as an VRA because wildfire has been shown to decrease the value of private land, in addition to the hazard posed to improvements made to the land. All lands are given the same value, essentially if the land is privately owned this value exists. While variation in property value exists, this VRA doesn't include any variation, it's either private or it isn't.

Structures

Structures were mapped from multiple sources. In areas where structures were not mapped by the City of Santa Fe GIS Department (City of Santa Fe 2016) or the Santa Fe County WUI Program (Wildfire Network 2016), aerial imagery was used to map structures (USDA 2014). All structures are given the same weight despite variation in property value, because structure value data wasn't readily available, and because homes frequently represent more than an investment.

Response functions for structures are based on those used in existing risk assessments (Scott et al. 2013b). While some structures have been "hardened" to resist fire, all structures are given the same response functions assuming limited structural hardening (Table B1).

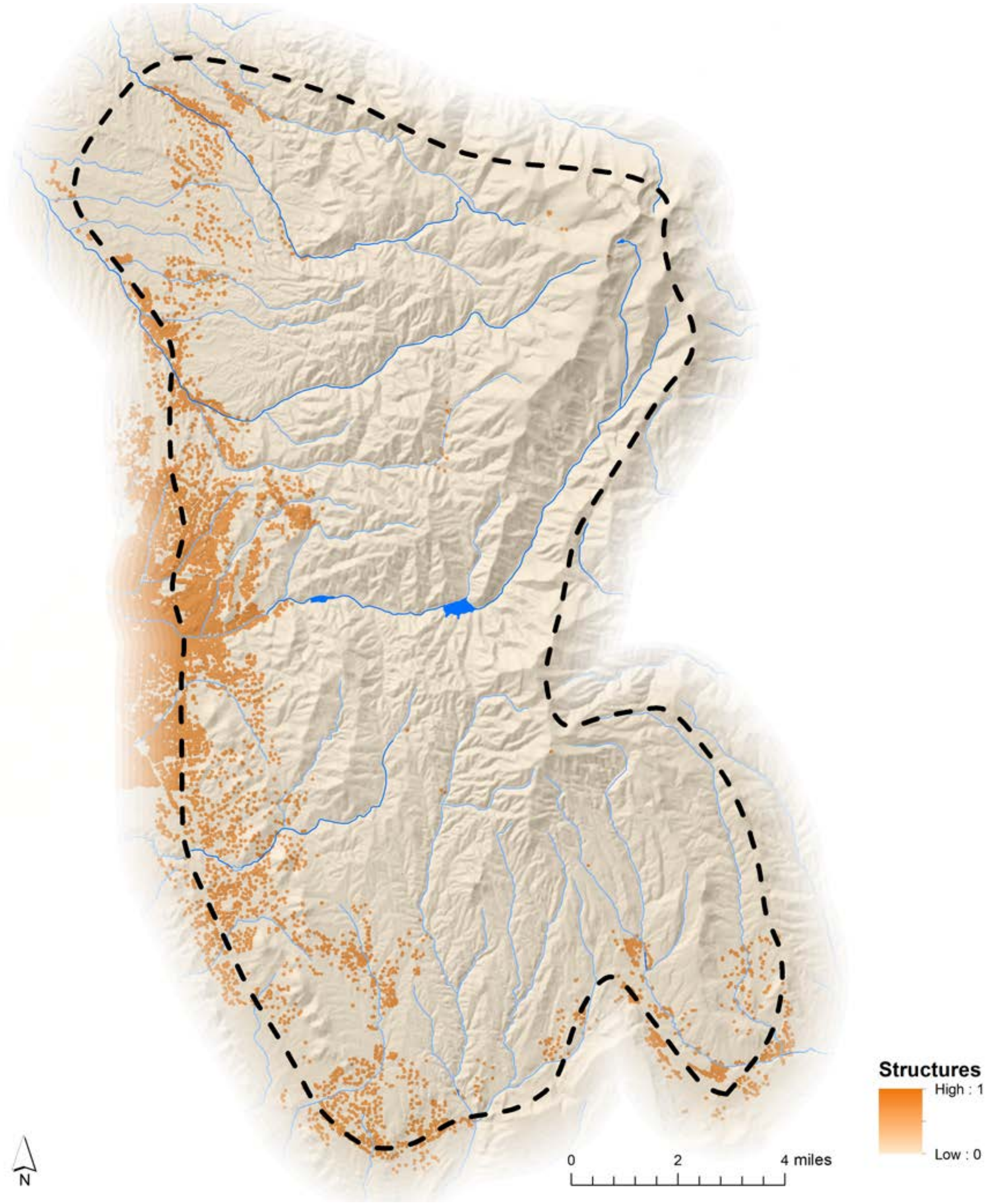

Figure B2. Structures in the Santa Fe fireshed. Structures were mapped from multiple sources. In areas where structures were not mapped by the City of Santa Fe GIS Department or the Santa Fe County WUI Program, aerial imagery was used to map structures (USDA 2014). All structures are given the same weight despite variation in property value, because structure value data wasn't readily available, and because homes frequently represent more than an investment.

Table B1. Private investment response functions.

VRA	Sub-VRA	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	FIL7
Private Land		10	0	0	-20	-40	-40	-40
Structures		-10	-20	-30	-40	-60	-80	-90

VRA Category: Watershed Function

This VRA category encompasses the areas that contribute value to watersheds. Watershed function has value for small local watershed (like the Santa Fe River Watershed) and to larger watersheds (e.g. the source watershed for compact obligations at Elephant Butte). Watersheds have many overlapping valued functions including snow retention, water yield, erosion and sediment control, flood control, and debris flow control. The source area for these VRAs is upstream in the watersheds. The beneficiaries of these VRAs are downstream from the source areas; some beneficiaries are within the collaborative area and others are far downstream.

Water for Ag

Elevation and aspect are important controls on snow accumulation and runoff (Spiegel and Baldwin n.d., Gillan et al. 150AD, Hunsaker et al. 2012, Zheng et al. 2016). An aspect northness index (after Zheng et al. 2016) and an elevation index were used to create a rough index of annual runoff. The spatial seasonal or annual precipitation data available for this study area isn't of sufficient resolution, so elevation us used as a proxy indicator for observed modeled precipitation.

Equation B1. Northness index after Zheng et al. (2016).

$$NorthnessIndex = (Con(\text{us\_asp2010} == -1\,, 0, cos("us\_asp2010" * 3.14159\ /\ 180)) + 1\ )\ /\ 2$$

Equation B2. Water yield index including factors for northness and elevation. Elevation is included as a proxy for precipitation and temperature. Indexes have a value that range from 0 to 1, in this case the higher the elevation or more north-facing, the closer to 1.

$$WaterYieldIndexA = NorthnessIndex * ElevationIndex$$

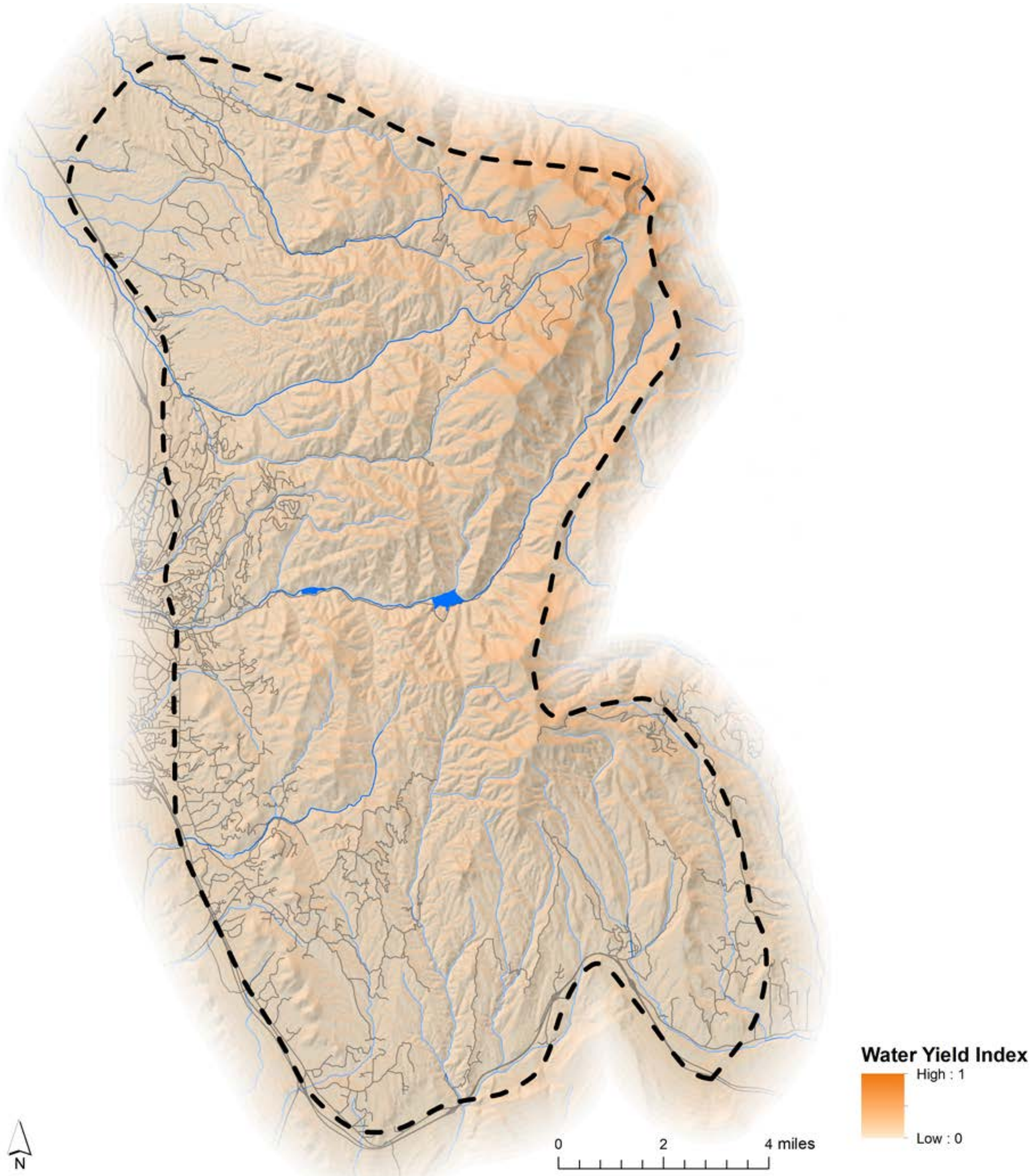

Figure B3. Elevation and aspect are important controls on snow accumulation and runoff (Zheng et al. 2016). An aspect northness index (after Zheng et al. 2016) and an elevation index were used to create a rough index of annual runoff. The spatial precipitation data available for this study area isn't of sufficient resolution so elevation was used as a proxy. This data is used to weight the supply side of the Water for People and Water for Ag VRAs.

The total area irrigated in each watershed was selected as the metric for relative number of beneficiaries because while the individual parciante or irrigator would feel the greatest disruption, the per-acre productivity would decrease more directly than the per-farmer productivity. Additionally, the cost of remedying decreases in water yield would likely be borne on a per-irrigated-acre basis.

Because spatial data describing the irrigated area in each watershed is incomplete for the study area, spatial datasets of cultivated acres were evaluated for use to distinguish between the level of benefit provided by each watershed (e.g. USDA 2018), as were reports of irrigated area (New Mexico Office of the State Engineer 2017a). Cultivated area data was limited by the lack of segmentation for surface and groundwater sources of irrigation, the small size of many fields that didn't appear in the data. Reported irrigated areas from the (New Mexico Office of the State Engineer 2017b) were similarly incomplete or out of date. Because these measures of the benefit of irrigation water had significant drawbacks, water right were a uniform measure of the relative level of beneficiaries in each watershed (New Mexico Office of the State Engineer 2017c) (Figure B4).

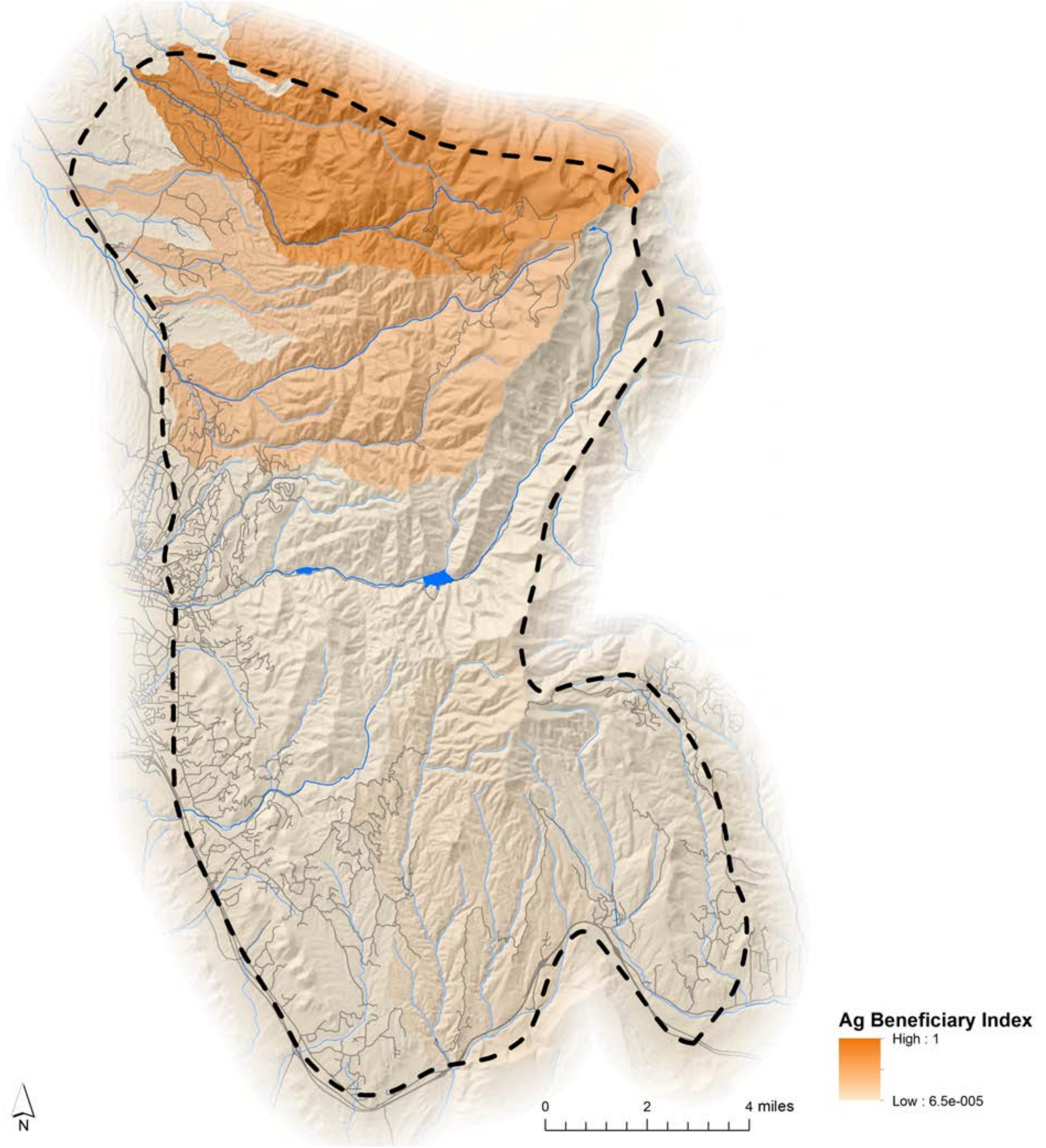

Figure B4. This beneficiary index is an index of the acre feet water right downstream from each watershed. Those water rights (and their holders) are impacted proportional to the right to water. Irrigated land was initially considered for this measure of beneficiaries but data was lacking. Many of the subtleties of water rights are not captured in this dataset, but generally the relative magnitude of downstream reliance on each watershed is captured in this measure.

Water for People

The same water yield index that was used to quantify the source of value for the Water for Agriculture VRA was also used for the Water for People VRA (Figure B3). Basins with more downstream drinking water users were rated higher in the beneficiary index (Figure B5).

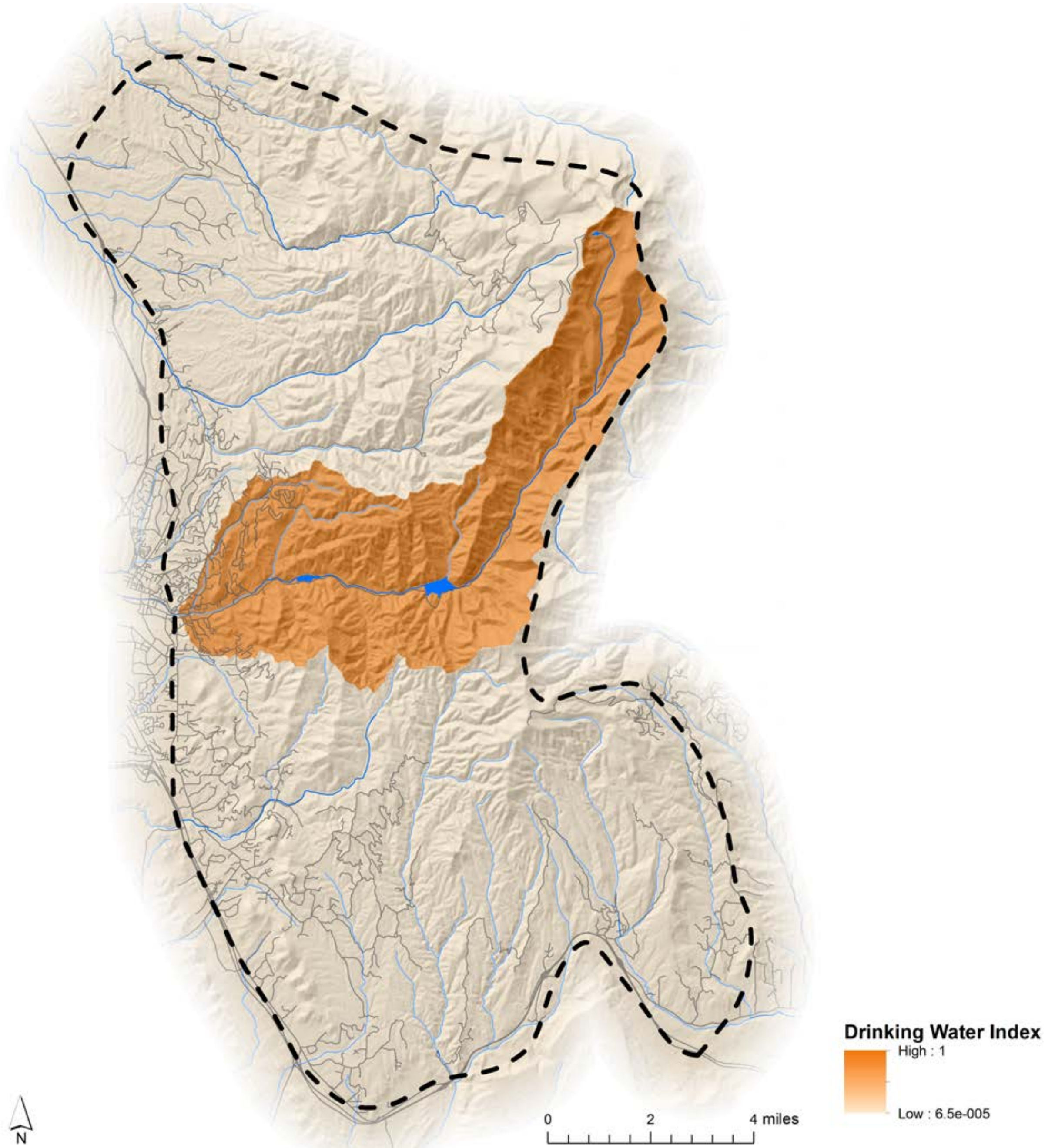

Figure B5. Downstream population served with surface water for domestic purposes. As an index of water use, only drinking water users unique to this study area were included because downstream water users cancel out during indexing. The Buckman Direct Diversion (BDD) was inadvertently omitted from the analysis, areas north of the Santa Fe River watershed also benefit the BDD customers.

Erosion Mitigation

Value for erosion and sediment control is highest in areas where post-fire erosion hazard is highest. Areas with the highest potential erosion hazard were identified using soil rating criteria published by the NRCS (1998). NRCS SSURGO data for Santa Fe County had already calculated Potential Erosion Hazard (Off-Road/Off-Trail) so the Santa Fe National Forest Data was the only are where it was calculated from slope and K-factor. The slope parameter of the erodibility factor was derived from the 30-meter National Elevation Dataset (NED) (U.S. Geological Survey 2016a).

Table B2. Soil Rating Criteria for Potential Erosion Hazard: Off-Road/Off-Trail (after Exhibit 537-3, NRCS 1998)

Soil Erodibility Factor (K-factor)			**Slope (%)**	
K_w <0.35	0–14	15–35	36–50	>50
K_w >= 0.35	0–9	10–25	26–40	>40
Potential Erosion Hazard:	*Slight*	*Moderate*	*Severe*	*Very Severe*

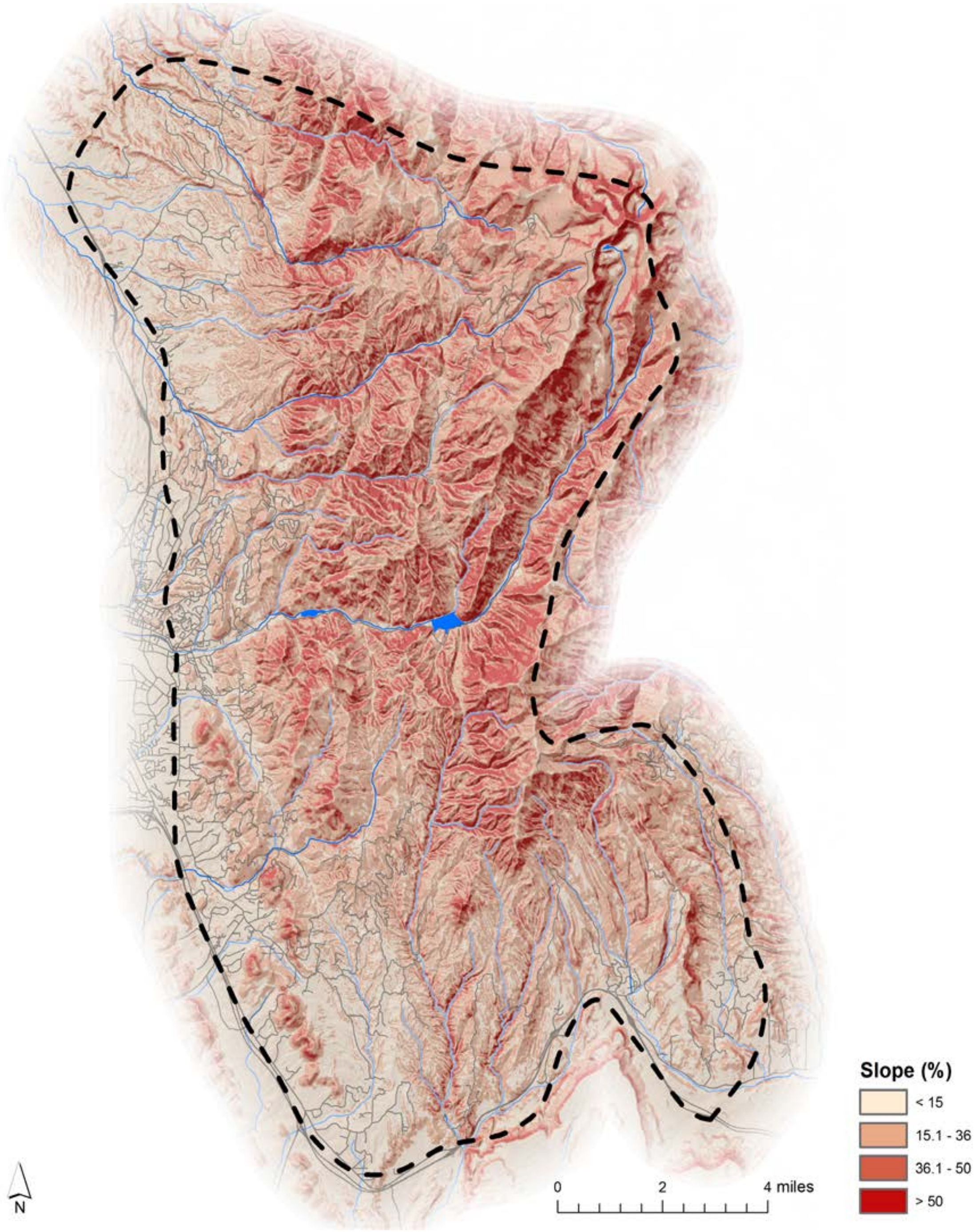

Figure B6. Slope was derived from the 30 meter National Elevation Dataset (NED) (U.S. Geological Survey 2016a).

K-factor

Soils data from the USFS and NRCS was used to determine K_w-factor for each stand (30-meter pixel). In areas where K-factor was not already determined, generalizations based on soil texture were made with guidance from the NRCS (Brewer 2012) (Table B3). From the range of factors given, the mid-point was used to approximate K_w-factor. Medium texture soils are the only class that could change based on the assumption about K_w-factor.

Table B3. Generalized determination of K_w-factor based on soil texture (Brewer 2012).

Texture	**K_w-factor Range**	**Generalized K_w-factor**
Fine textures (clays)	0.05–0.15	0.1
Coarse textures (sands)	0.05–0.20	0.125
Medium textures (loams)	0.25–0.45	0.35
Silts	0.45–0.65	0.55

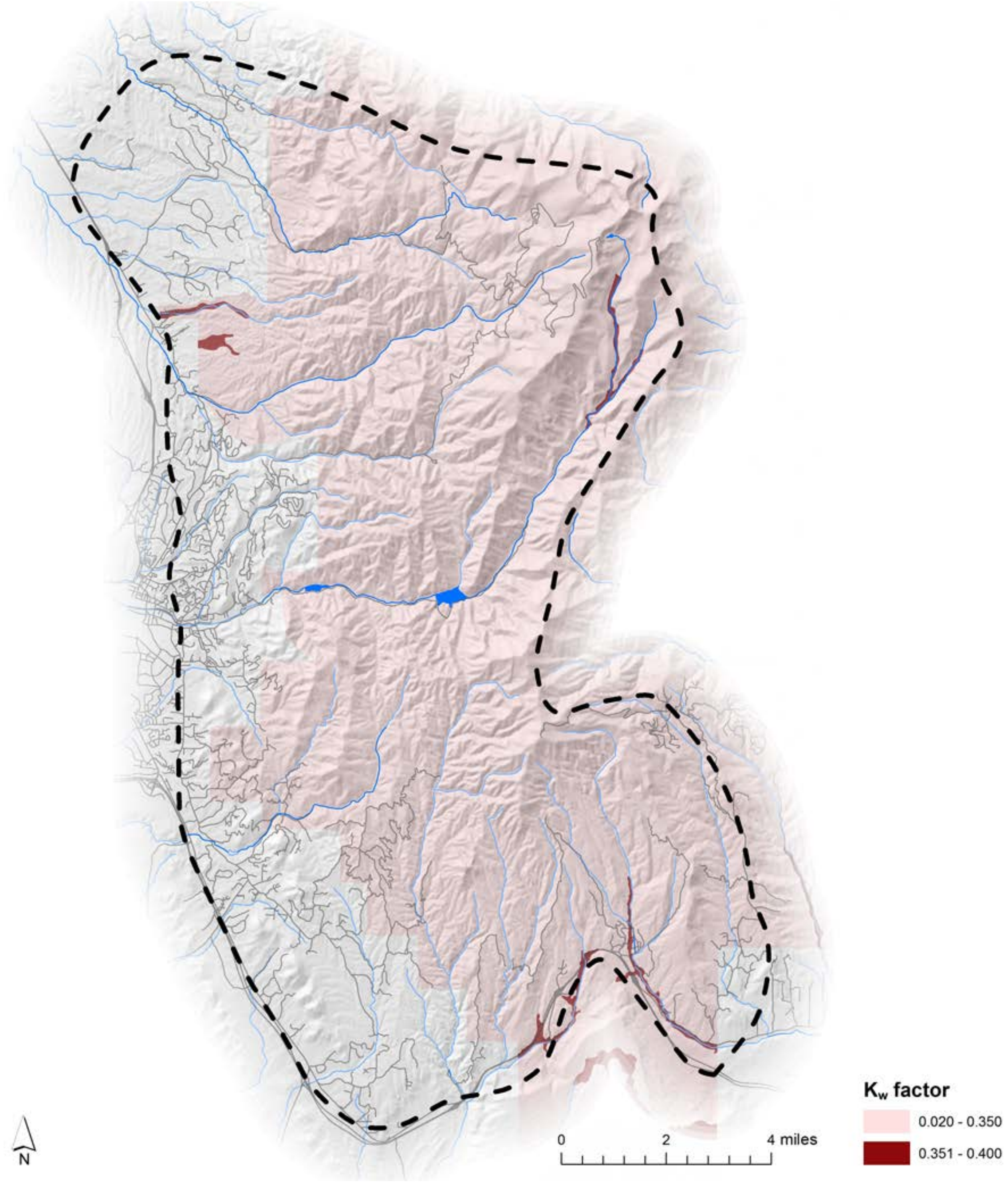

Figure B7. RUSLE K-factor for USFS areas from TEU data.

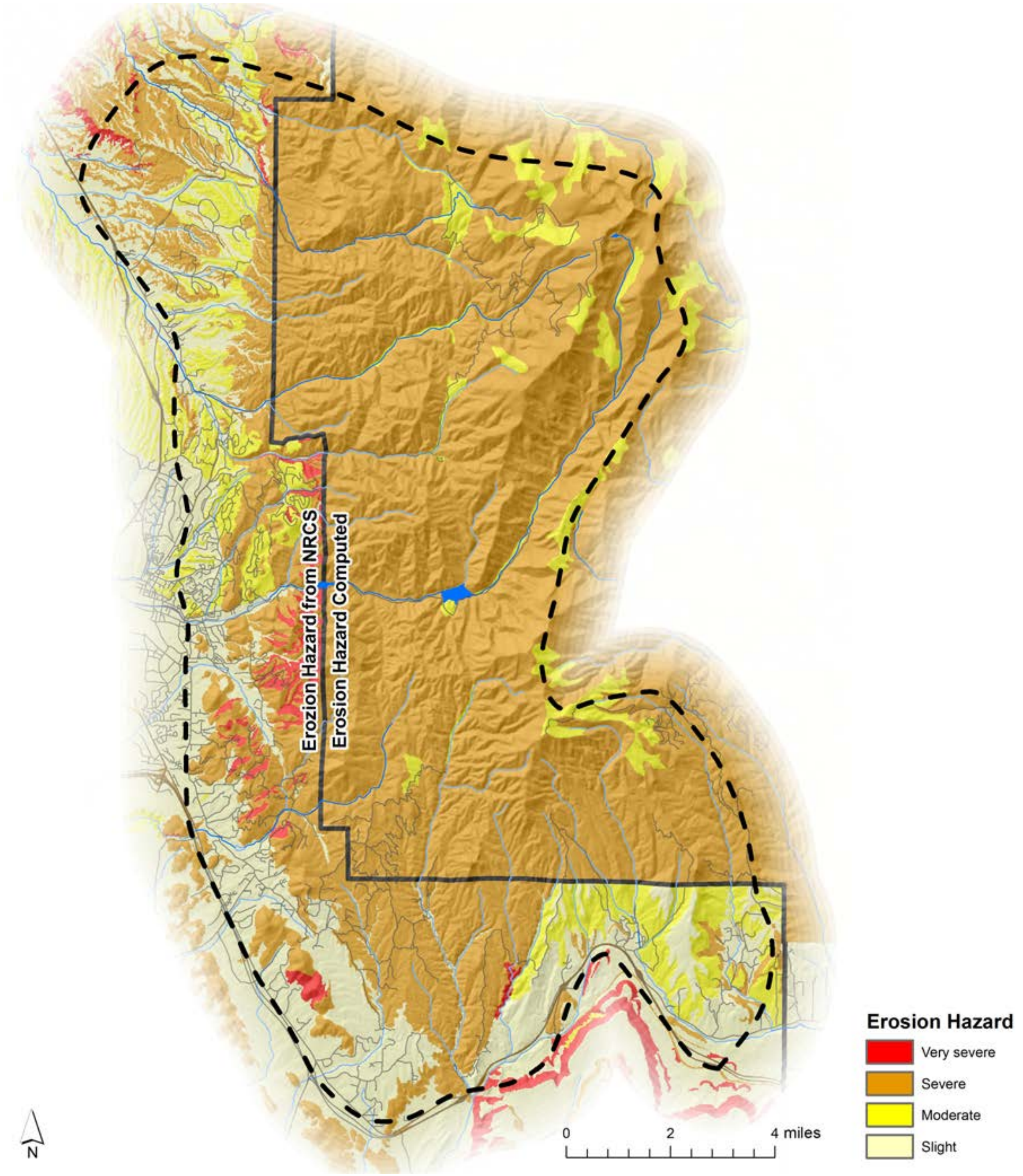

Figure B8. Erosion hazard computed by the NRCS on non-USFS lands and calculated using USFS TEU soils data and USGS elevation data on USFS lands. Erosion hazard is used to characterize sub-VRAs for several VRAs for which post-fire erosion is the mechanism for value change.

Erosion Hazard Mitigation Benefit Index

Number of diversions was considered as the metric for relative number of beneficiaries of erosion mitigation because while the magnitude of disruption would vary depending on the number of acres irrigated by that diversion or the number homes receiving drinking water, the cost of remedying the loss of the diversion is more significant than the cost of the disruption. This was rejected because not all diversions are comparable, for example the city of Santa Fe Drinking water diversion on the Santa Fe River and any given acequia with a small water right. These two diversions differ in both the repercussions of sedimentation or other service disruption (diversions ceased, reservoir capacity lost, etc.)

as well as the resources available for recovery. A benefit index was created capturing all water users (beneficiaries of erosion hazard mitigation) by summing and indexing the people and ag benefit index layers.

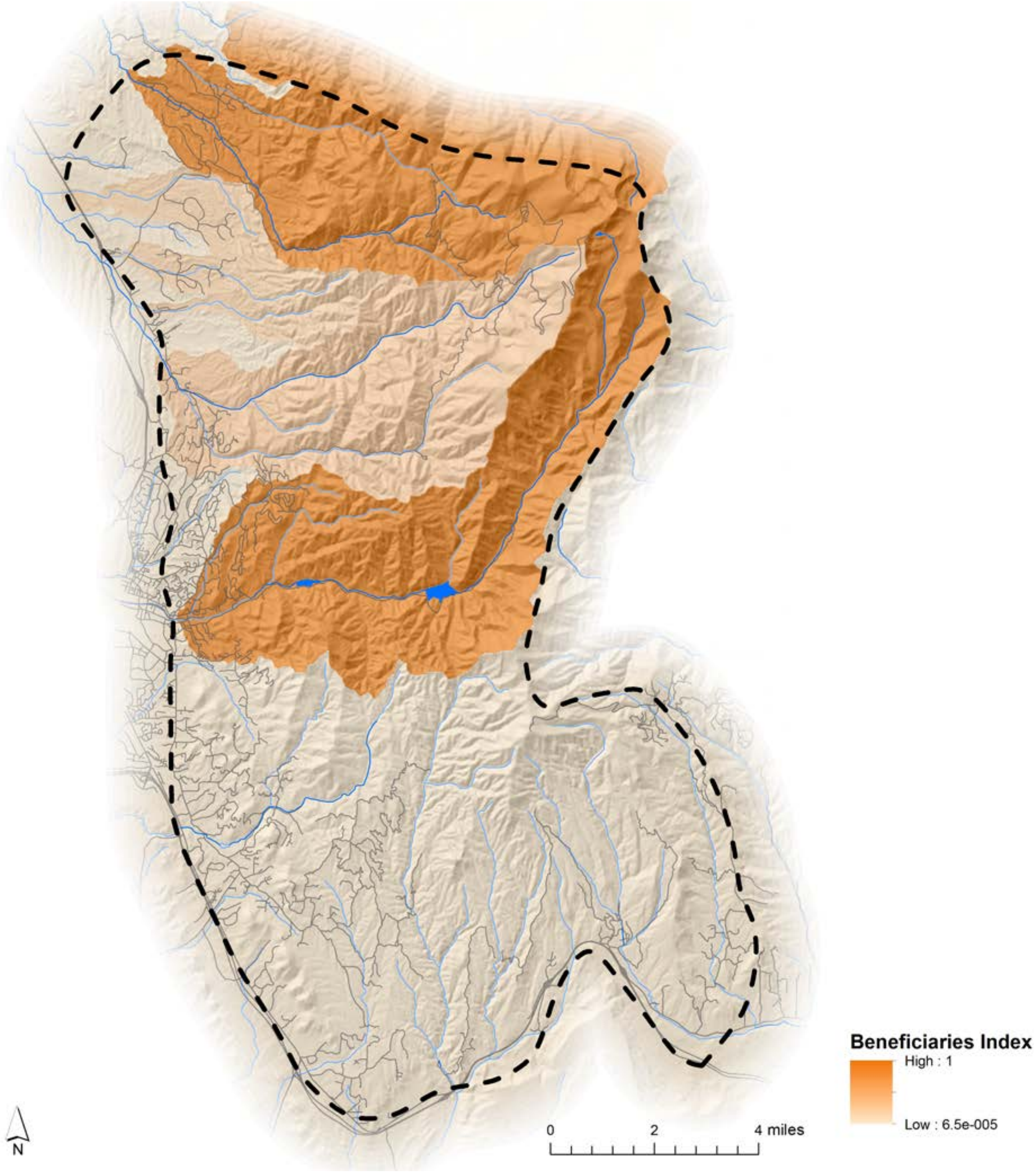

Figure B9. Combined index of agricultural and drinking water beneficiaries of water provisioning. This index is used to quantify relative impacts from postfire erosion and debris flow. Ag water beneficiaries and domestic water beneficiaries are summed and indexed to create this overall beneficiary index. The inadvertent omission of the Buckman Direct Diversion in the Water for People VRA beneficiaries index is replicated in this beneficiaries index, meaning the watersheds north of the Santa Fe watershed have a higher beneficiary index than is indicated in this map.

Erosion Hazard Mitigation Footprint

Because post-fire erosion is usually identified as a negative impact, labeling erosion as a valued resource or asset would be inconsistent. For consistency with other VRAs the capacity of a stand to mitigate erosion is used. Stands have value not because they produce erosion and sedimentation but because they limit its occurrence.

Post-fire Debris Flow Hazard Mitigation

Debris flows are commonly produced by recently burned areas, causing extensive damage to property and threatening lives (Cannon and Gartner 2005). Debris flows can be produced when any precipitation falls on bare soil (DeGraff et al. 2015). Unlike flash floods or sediment laden floods, debris flows carry considerable volumes of debris, traveling with the destructive energy of a landslide and the fluid movement of a flood (Pierson 2005). Models have been developed by the U.S. Geological Survey to predict the incidence of debris flows following fires (Cannon et al. 2010, Staley et al. 2016). These models were initially used to coordinate response to recently burned areas (DeGraff et al. 2007, Tillery et al. 2012), but have since been used in conjunction with simulated fire behavior to model debris flow hazards before the fire (Tillery et al. 2014, Tillery and Haas 2016).

To evaluate the hazard of post-fire debris flows in the Fireshed, crown fire behavior under problem-fire conditions was simulated with FlamMap and used as the burn severity parameter in the debris flow hazard model (Figure B10).

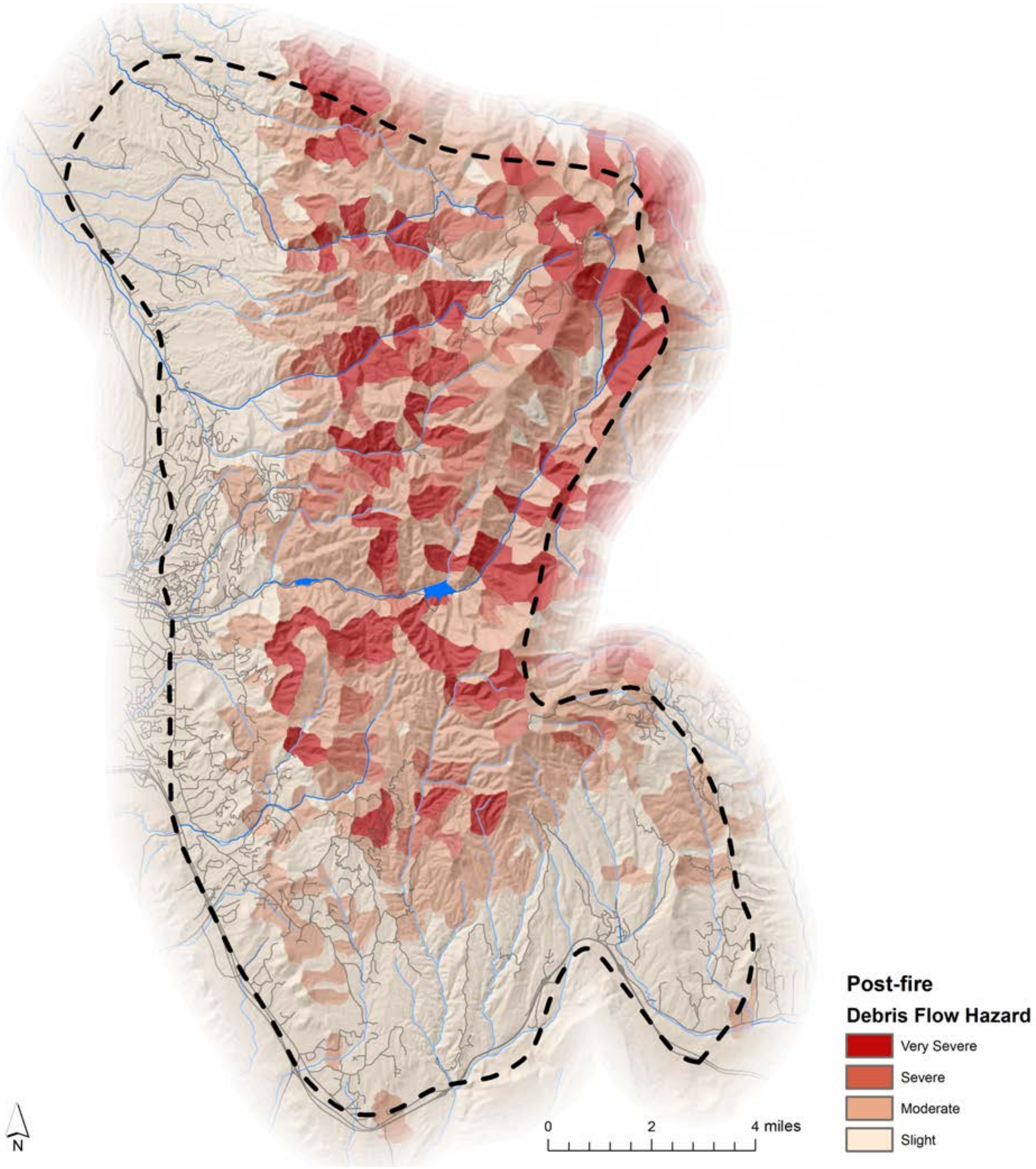

Figure B10. Post-fire debris-flow hazard calculated using a model developed by the USGS (Staley et al. 2016).

Post-fire Debris-flow Hazard Benefit Index

The benefit index that was developed for erosion hazard mitigation beneficiaries was also used for debris flow hazard mitigation beneficiaries. While the mechanism of debris flow is different than erosion, the beneficiaries are roughly the same. Future iterations could include downstream culverts as a measure of beneficiaries to debris flow mitigation.

Flood Control

The Flash Flood Potential Index (FFPI) commonly used by the National Weather Service to predict flooding was adapted for use in this assessment to predict post-fire flood generation (Zogg and Deitsch 2013). When combined with downstream flood zones, and the values within those flood zones, the relative value threatened by post-fire flooding from each watershed were tabulated. This flood hazard index was used to evaluate relative post-fire hazard of each watershed. Dammed reaches were considered as a mitigating factor for flood hazard but were not included due to concerns that the dams in the study area may exacerbate flooding (A. Hook personal communication, May 2017).

Flood Control Source Index

The FFPI protocol was selected because it has been used in similar assessments and the data inputs were readily available (Zogg and Deitsch 2013). The FFPI model uses topography, soils characteristics, and land-cover data classification to predict the relative likelihood of a basin producing a flash flood. Elevation data from the LANDFIRE program was converted to a slope index (Rollins 2009), soils data from the NRCS was converted into percent clay and percent sand indexes (NRCS 2014), and landcover data from the National Land Cover Dataset (NLCD) was reclassified in to a canopy index (Homer et al. 2015). The canopy index was modified to reflect post-fire conditions assuming shrub and forest types lost their cover. This is later tied to intensity of fire by having the value of the flood control VRA decrease more in areas that burn more intensely.

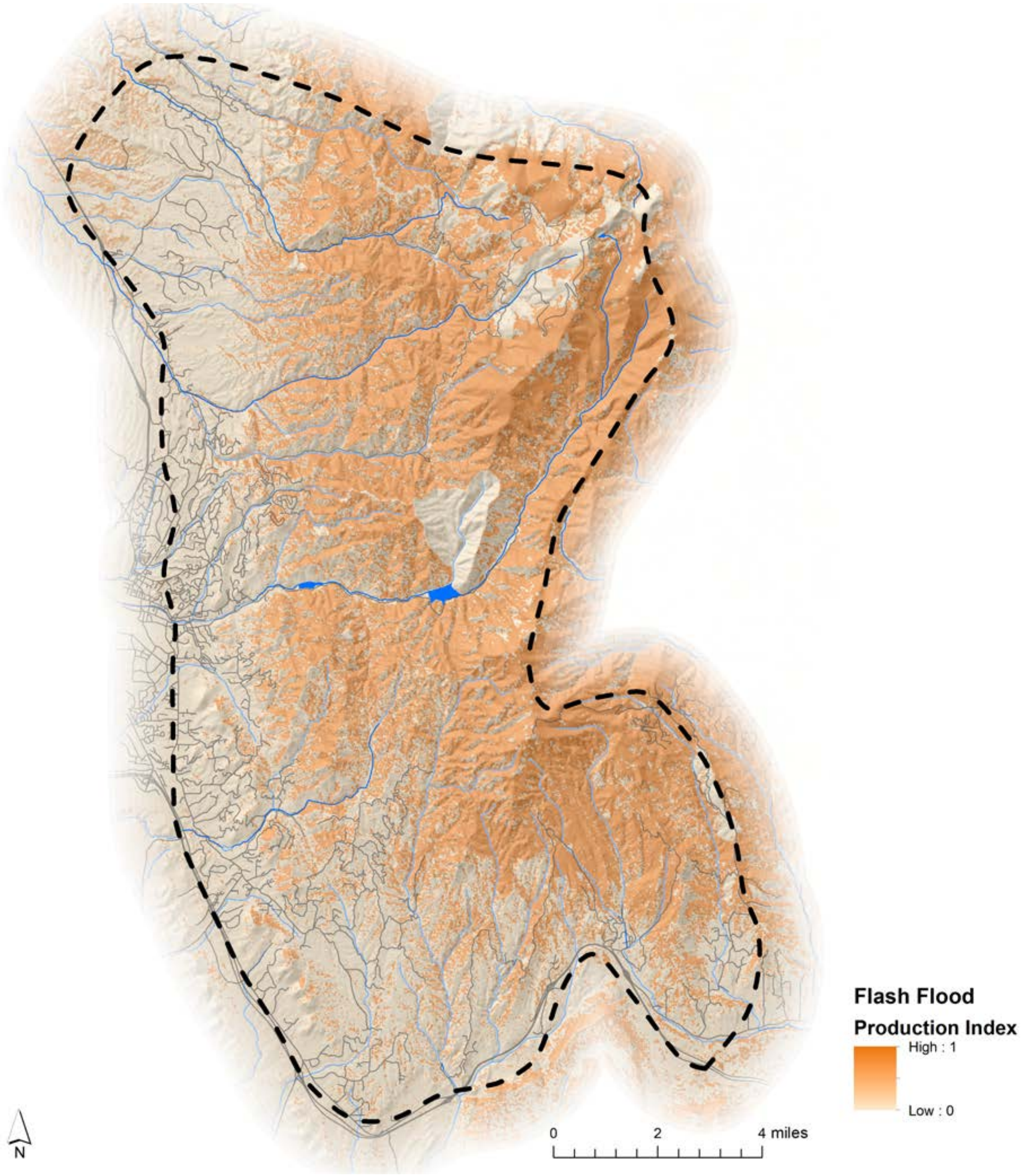

Figure B11. The flash flood production index (FFPI) for the study area shows that nearly all upland slopes are expected to produce flashfloods when burned by a wildfire. The large low FFPI hazard area in the Santa Fe watershed north of McClure reservoir reflects the most recent treatments, adjacent areas that have been treated also have lower FFPI hazard than is indicated in this map because thinning and prescribed fire were not included in the fuels data used to model the wildfire component of FFPI.

Flood Control Benefit Index

In this landscape there is a 5–20 percent probability of occurrence of a 500-year flood event in the first year following a fire that burns the majority of any watershed (USFS 2001). Flood hazard areas delineated in the National Flood Hazard Layer (NFHL) by the Federal Emergency Management Agency (FEMA) were used to identify areas at risk of post-fire flooding (FEMA 2013). The 100-year flood hazard zone was used because 500-year floodplain has not been developed for the entire study area.

Significant increases in runoff beyond 100-year events are commonly observed in recently burned areas (Benavides-Solorio and Macdonald 2001, Moody and Martin 2001).

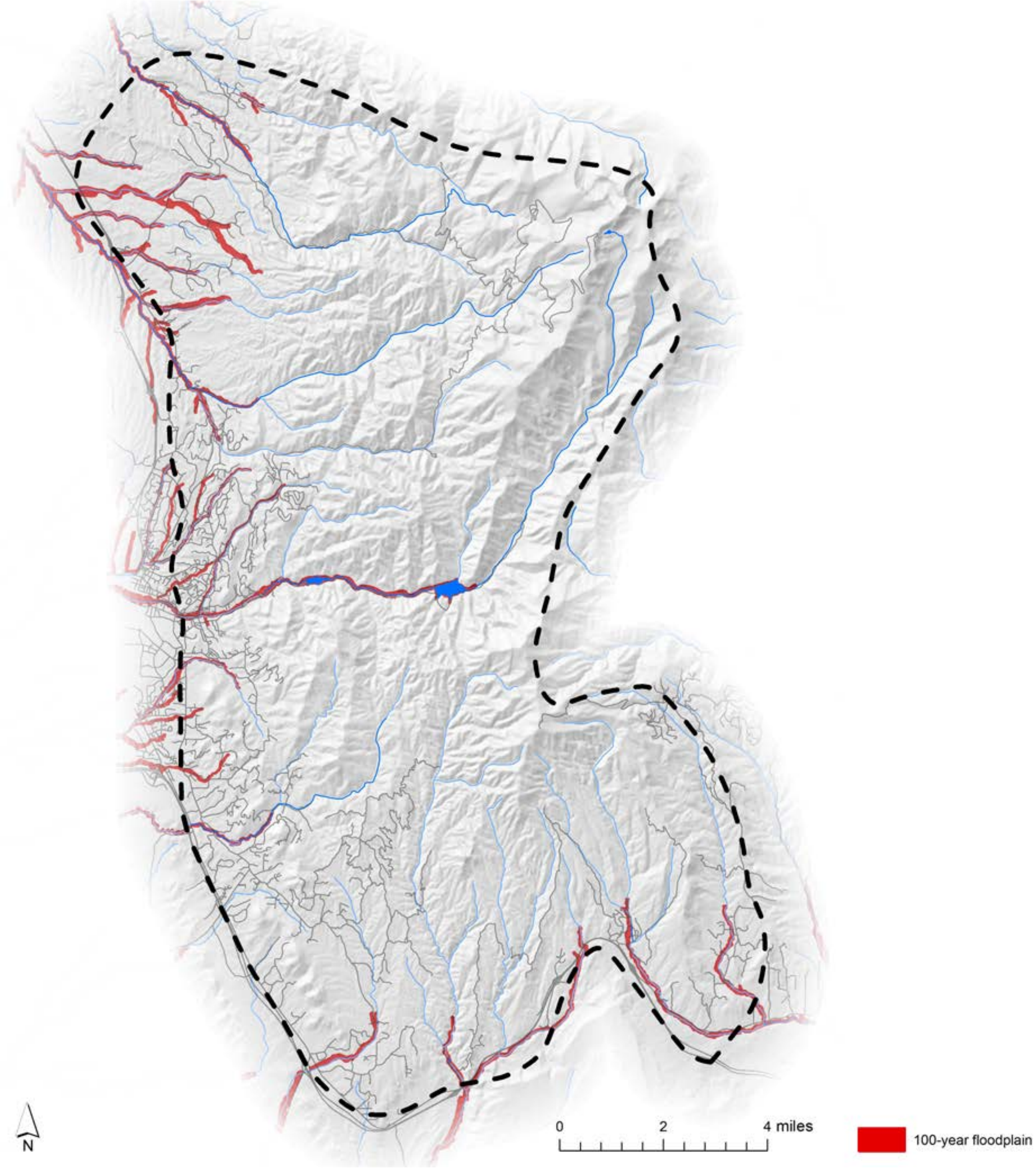

Figure B12. 100-year flood hazard zones were used to identify downstream development at risk because significant increases in runoff are commonly observed from recently burned areas.

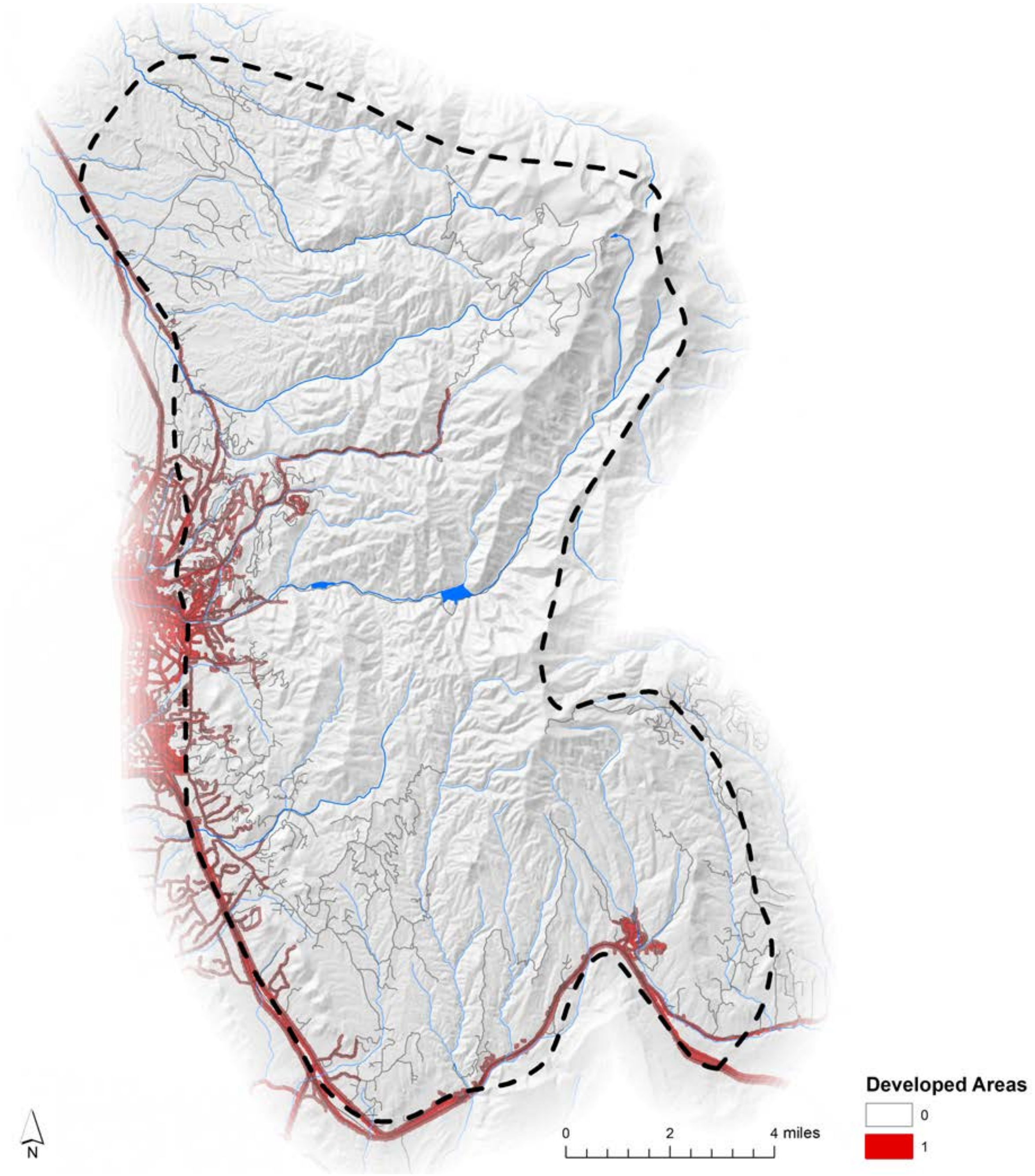

Figure B13. Developed areas from the NLCD

The developed area downstream of each watershed was used as a representation for the resources and assets threatened by post-fire flooding. Developed areas from the NLCD were intersected with the 100-year flood hazard zones to calculate the total area threatened by floods. This value was converted into an index to describe relative hazard between basins by dividing the total developed threatened by each basin, by the highest hazard.

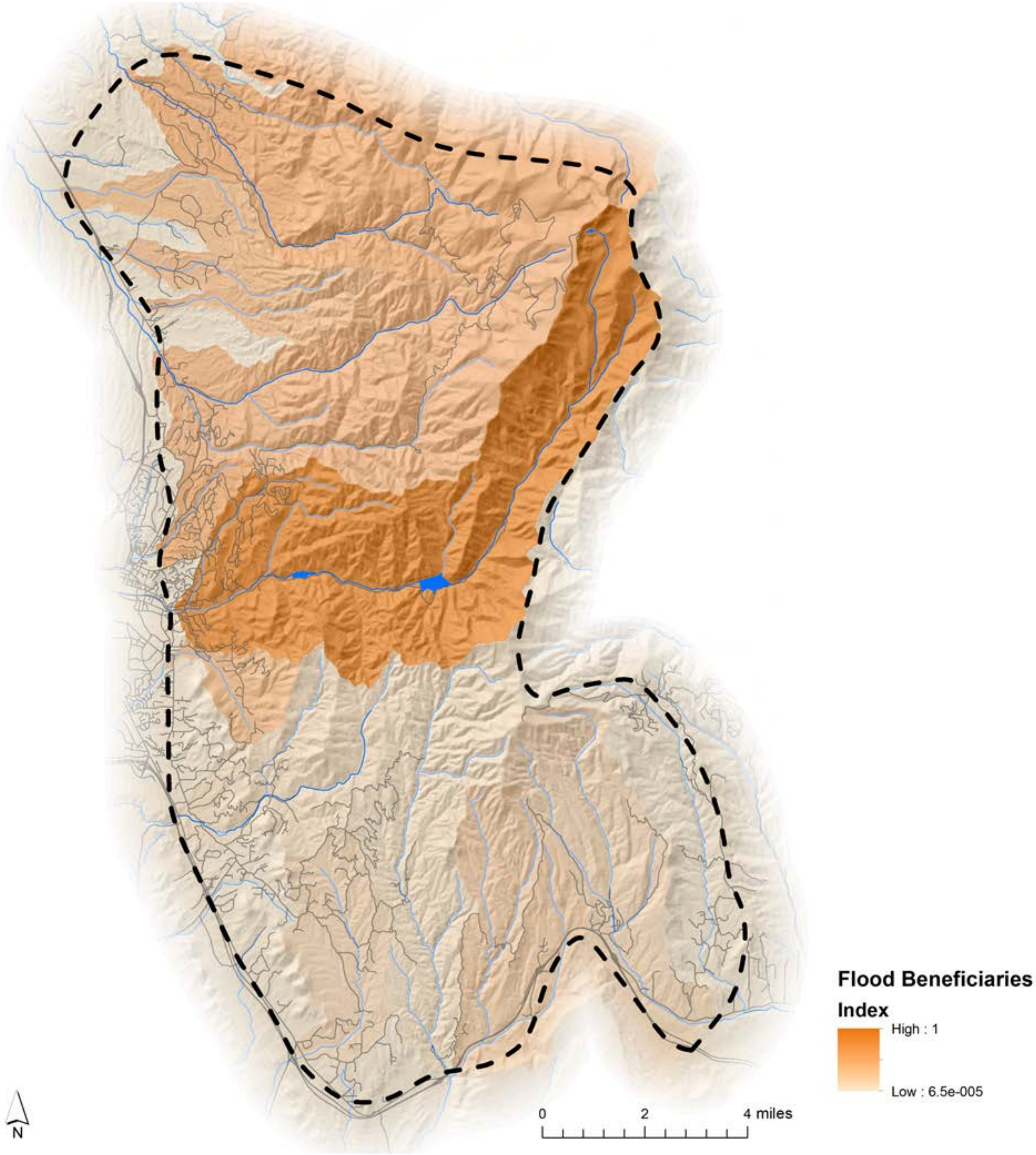

Figure B14. Flood hazard index calculated from the intersection of upstream erosion hazard and downstream values at risk.

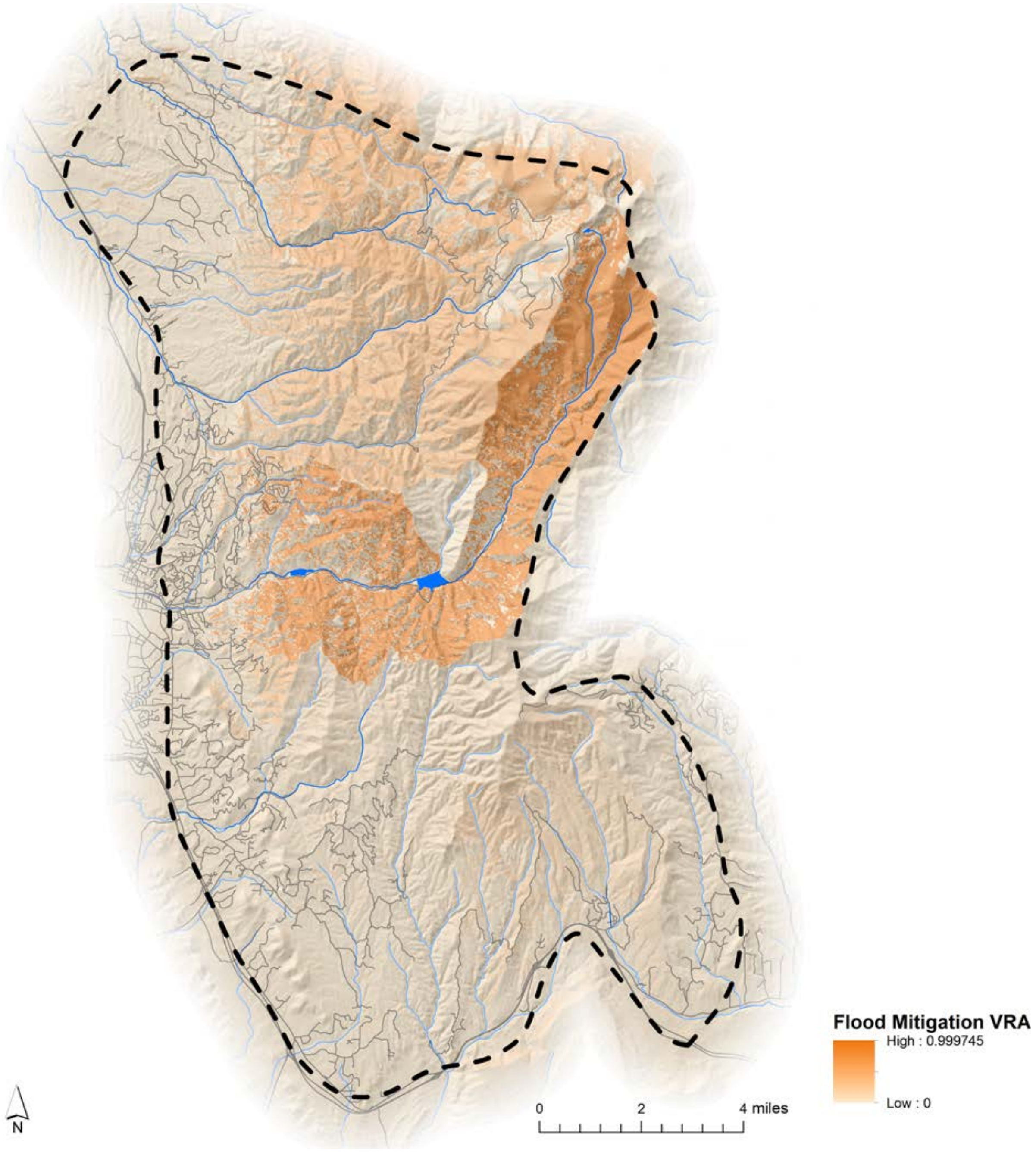

Figure B15. Flood hazard mitigation VRA footprint. Flood control is most valuable where the likelihood of a flood is high and where there are VRAs downstream. Multiplying the source index by the benefit index produces an overall representation of the value of flood control from each stand.

Response Functions

Table B4. Watershed function response functions.

VRA	sub-VRA	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	FIL7
Water Yield: Ag		50	30	10	0	-10	-20	-30
Water Yield: People		50	30	10	0	-10	-20	-30
Erosion Mitigation	Erosion Hazard: Very Severe	-10	-20	-40	-60	-80	-100	-100
Erosion Mitigation	Erosion Hazard: Severe	0	-10	-20	-40	-60	-80	-100
Erosion Mitigation	Erosion Hazard: Moderate	0	0	-10	-20	-40	-60	-80
Erosion Mitigation	Erosion Hazard: Slight	0	0	0	-10	-20	-40	-60
Debris Flow Mitigation	Debris Flow Haz.: Very Severe	0	0	-20	-40	-60	-80	-100
Debris Flow Mitigation	Debris Flow Haz.: Severe	0	0	0	-20	-40	-60	-80
Debris Flow Mitigation	Debris Flow Haz.: Moderate	0	0	0	0	-20	-40	-60
Debris Flow Mitigation	Debris Flow Haz.: Slight	0	0	0	0	0	-20	-40
Flood Control		-10	-10	-20	-40	-60	-80	-100

VRA Category: Recreation and Cultural Use

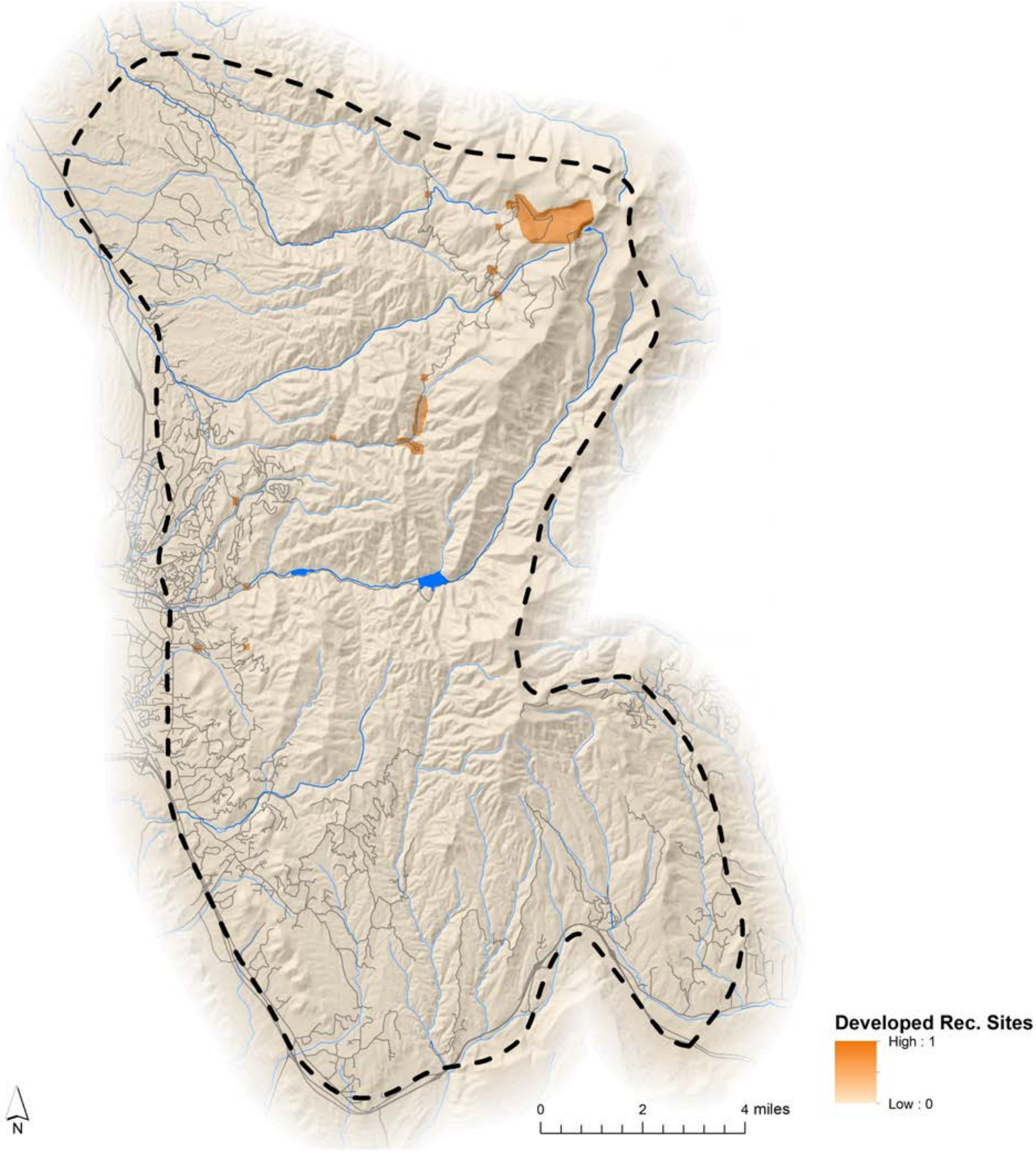

Figure B16. Developed Recreation Areas from USFS, City and County of Santa Fe.

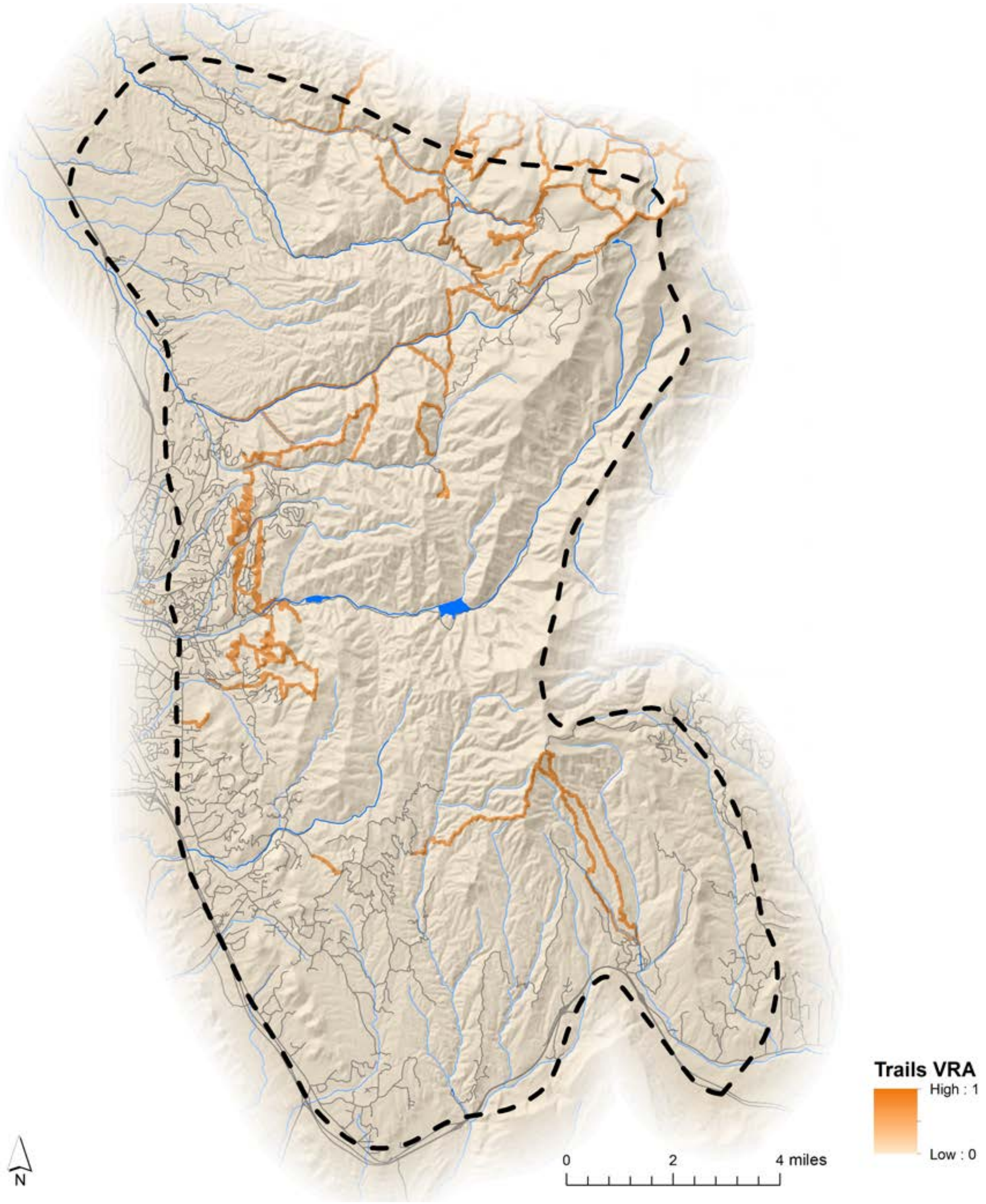

Figure B17. Trails from USFS, City of Santa Fe, and Santa Fe County.

Table B5. Recreation and Cultural Use response functions.

VRA	sub-VRA	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	FIL7
Dev. Rec. Area		0	-10	-20	-55	-75	-75	-75
Trails	Erosion Haz.: Very Severe	-10	-10	-10	-20	-40	-50	-80
Trails	Erosion Haz.: Severe	0	-10	-10	-10	-20	-40	-50
Trails	Erosion Haz.: Moderate	0	0	-10	-10	-20	-40	-50
Trails	Erosion Haz.: Slight	0	0	0	-10	-20	-40	-50

VRA Category: Infrastructure

Roads

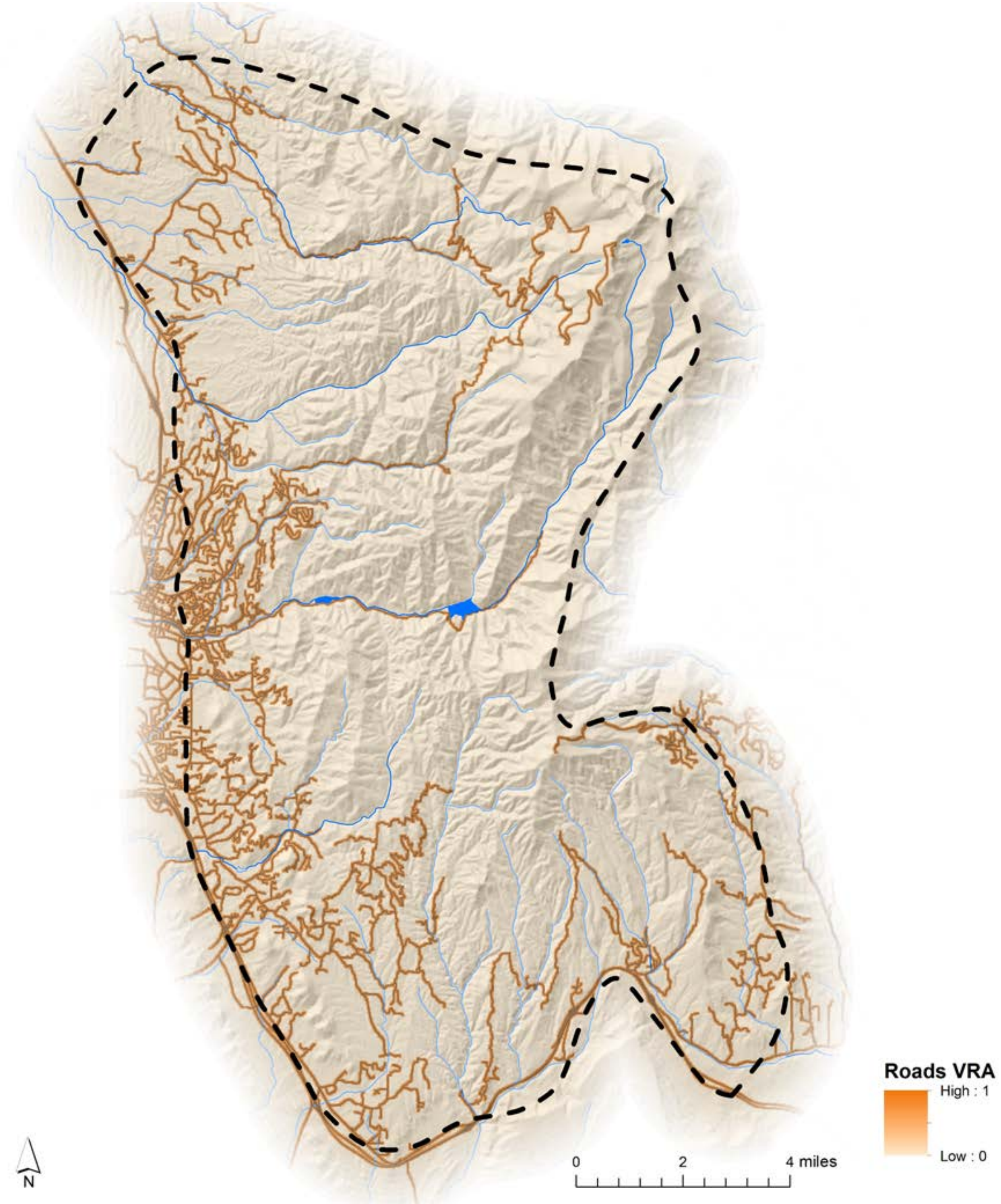

Figure B18. Roads within the fireshed area from multiple sources including the USFS, City and County of Santa Fe, and digitized from aerial photos.

Powerlines

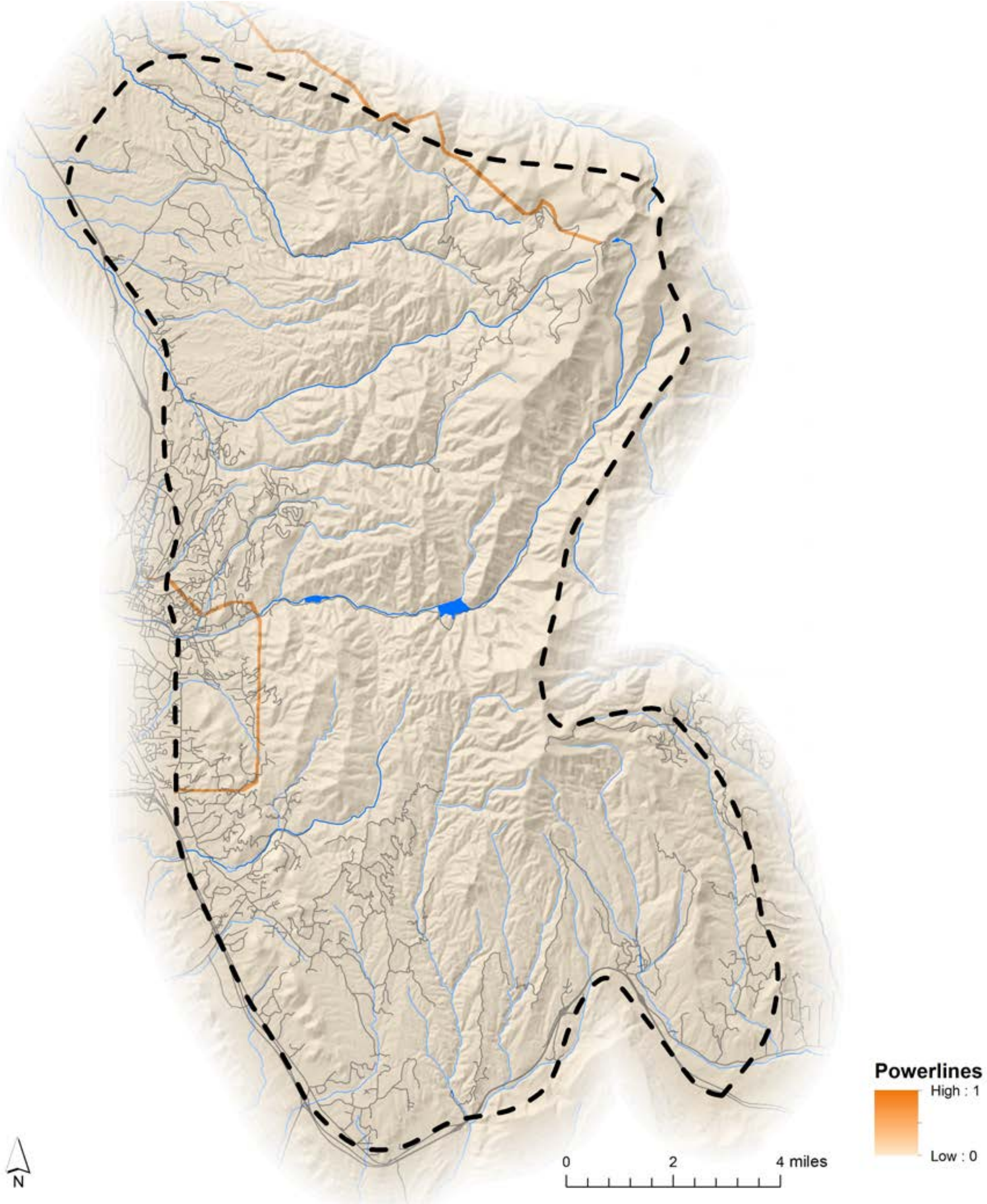

Figure B19. Medium voltage distribution powerlines.

Response Functions

Table B6. Infrastructure response functions.

VRA	sub-VRA	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	FIL7
Roads	Erosion Haz.: Very Severe	-10	-10	-10	-20	-40	-50	-80
Roads	Erosion Haz.: Severe	0	-10	-10	-10	-20	-40	-50
Roads	Erosion Haz.: Moderate	0	0	-10	-10	-20	-40	-50
Roads	Erosion Haz.: Slight (and null)	0	0	0	-10	-20	-40	-50
Powerlines		-10	-20	-40	-80	-100	-100	-100

VRA Category: Forest Type

The forests of the fireshed provide many additional values beyond what has already been included as VRAs in this assessment. Wildlife habitat, carbon storage, traditional use, and viewsheds are just a few of the intrinsic benefits of the forests. To capture the value of the forest, the ecological response units (ERUs) delineated by Region 3 of the USFS, were used to characterize the susceptibility of each forested pixel. ERUs classify the expected response to disturbance and pattern of growth and succession within each pixel. Forests that are resilient to wildfire are expected to provide more value over time. In areas where the forest is not currently resilient to the expected fire intensity, wildfire risk to the forest is highest.

Patch size wasn’t included in this assessment, so response functions are accurate for the majority of fires, though events that burn a high percentage of a forest type VRA would have more negative or less positive outcomes due to multiple factors including loss of seed sources.

Table B7. Forest type response functions.

sub-VRA	FIL1	FIL2	FIL3	FIL4	FIL5	FIL6	FIL7
Spruce-Fir Forest	10	30	50	70	100	100	100
Mixed Conifer - Frequent Fire	100	100	70	30	-20	-50	-100
Ponderosa Pine Forest	100	100	70	30	-20	-50	-100
PJ Grass	100	100	70	30	-20	-50	-100
PJ Woodland	70	90	100	100	100	100	100
Juniper Grass	100	100	70	30	-20	-50	-100
Colorado Plateau / Great Basin Grassland	100	100	70	50	10	-10	-50
Other	0	0	0	0	0	0	0

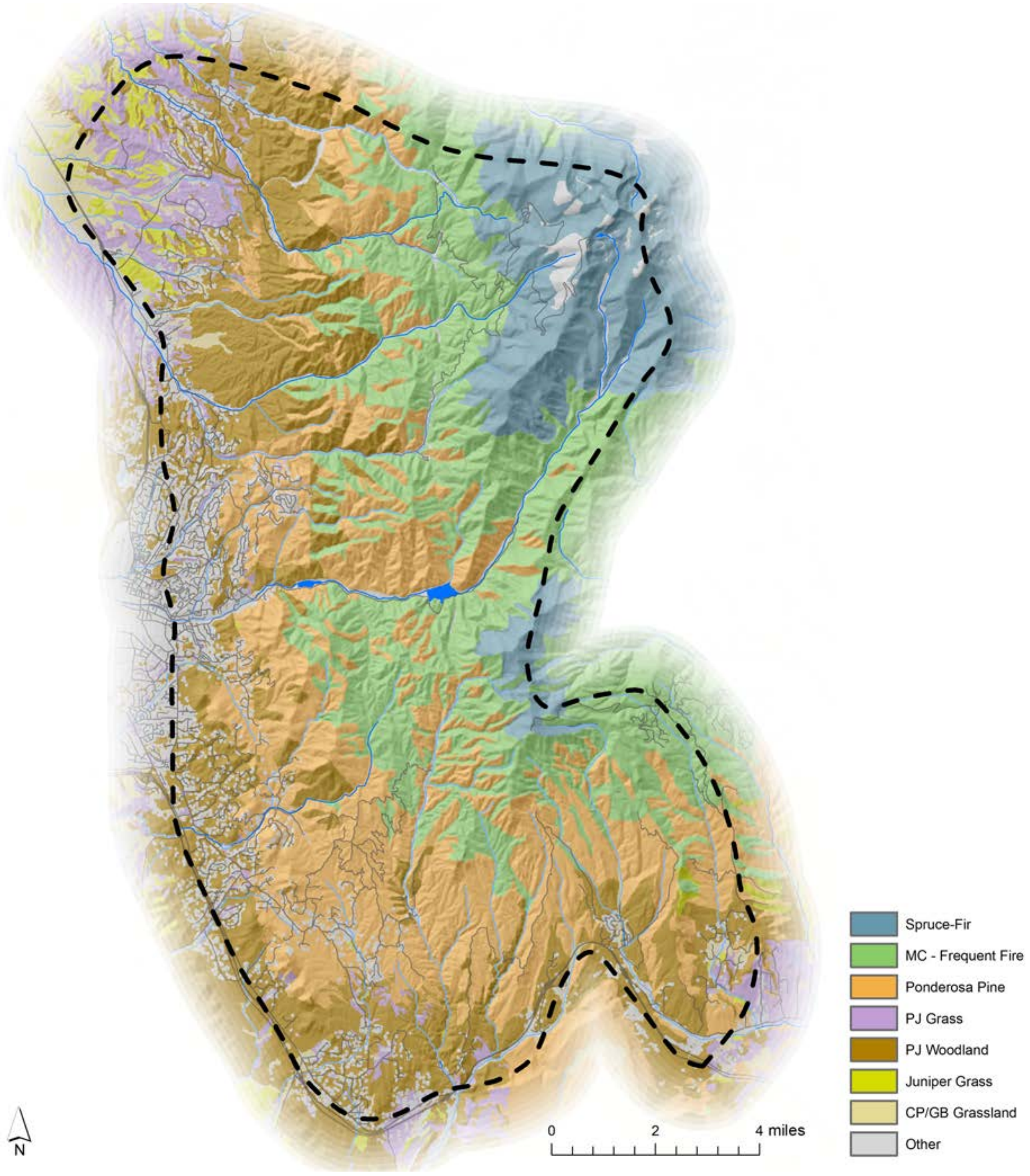

Figure B20. Ecological response units (ERUs) classify the expected response to disturbance and pattern of growth and succession within each pixel.

VRAs Identified but Not Evaluated

During the elicitation of VRAs from Fireshed members, 53 VRAs were identified in 10 categories. These were distilled in to 19 VRAs in 5 categories. Many of the originally identified VRAs were redundant or lacked needed data. An example of redundancy is the originally identified “Campgrounds” VRA identified in the “Economic Use” category, being duplicated in the “Developed Recreation Areas” VRA in the “Recreation and Cultural Use” category. Insufficient data limited the inclusion of many suggested VRAs including species-specific habitats and archaeological resources. While data is insufficient to include some VRAs in the landscape scale risk assessment, the omitted VRAs may be appropriate to include in project level planning.

Wilderness

Designated Wilderness and other protected areas have been considered for inclusion in several wildfire risk assessments. These protected areas are not included in this risk assessment because while delineation of the VRA would be relatively simple, the characterization of response functions would result in neutral response to fire, or be dependent on the overlying ERU.

Archaeological Resources

Archaeological resources are not included in this risk assessment because the delineation of this VRA would be incomplete and also complicated by regulations governing the distribution of data delineating sensitive resources. The ethnographic assessment of traditional and cultural ways of life in the area currently contracted out by the USFS will provide data that can be included in project level planning, or incorporated in future versions of this risk assessment.

Tourism and Economic Activity

Tourist attractions, infrastructure required for tourism, and existing businesses located within the fireshed were suggested for inclusion in this risk assessment. Resorts, hotels, museums, short-term vacation rentals, businesses, and recreational facilities were identified as VRAs in this category. Data was unavailable for many of these datasets, with structures identified as a surrogate for most commercial businesses, and developed recreation areas and trails for recreation-based economic activity.

Game and fish habitat

Habitat for individual species was considered for inclusion in the risk assessment, though do to restrictions on data use and inconsistencies in data collection across the landscape, these species-specific VRAs were not included. The forest type VRA can be used as a proxy for wildfire risk to habitat.

Acequias

Acequias and other irrigation infrastructure were considered for inclusion in this assessment, btu were omitted because the characterization of susceptibility of these resources and attribute to direct wildfire effects were not available. While wildfire risk to irrigation infrastructure was not evaluated, indirect wildfire risk to acequias is captured in the watershed function VRA category.

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Appendix C: Risk Maps

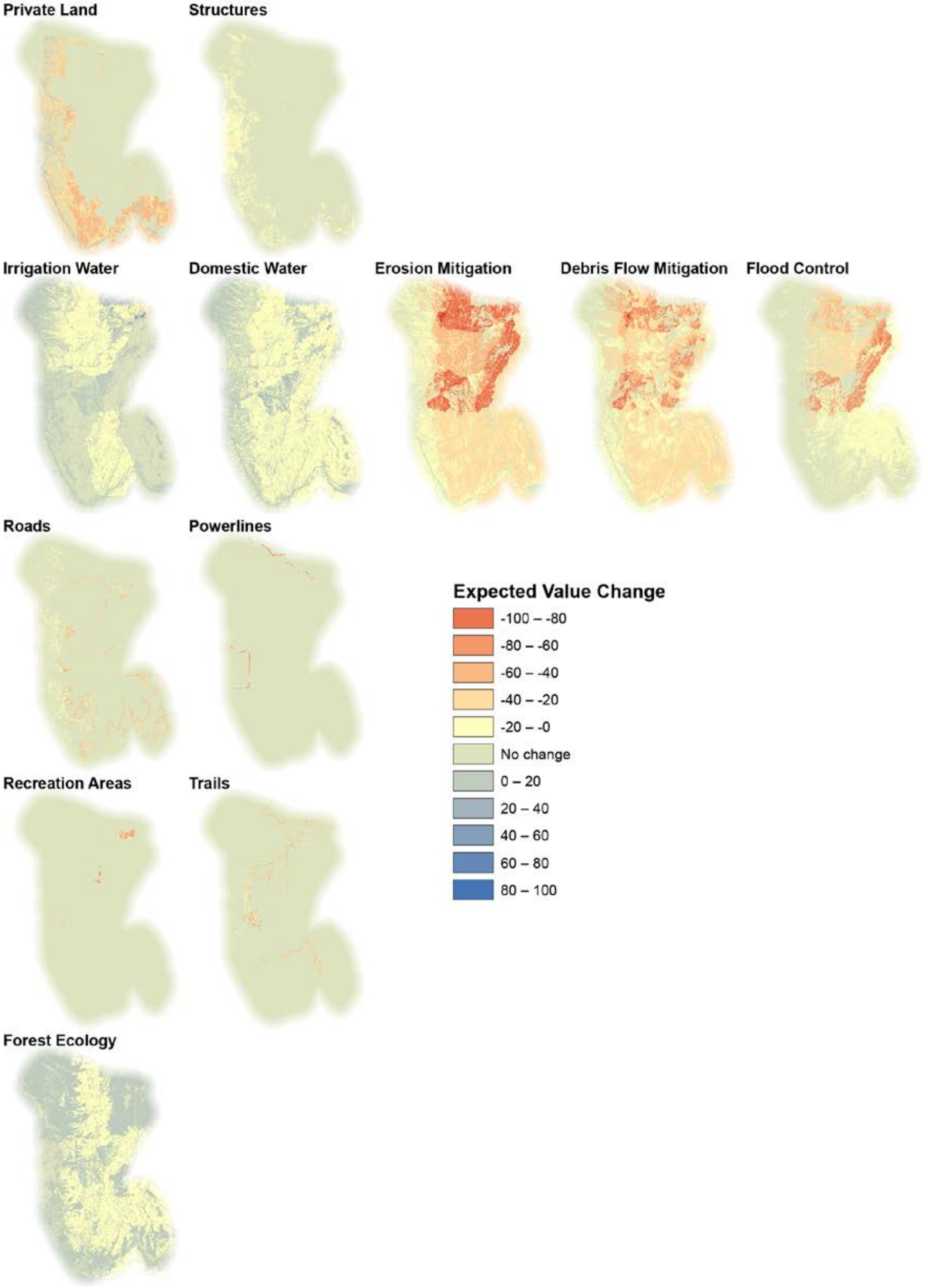

Figure C1. VRA response (percent value change) assuming every pixel burns under 80th percentile conditions.

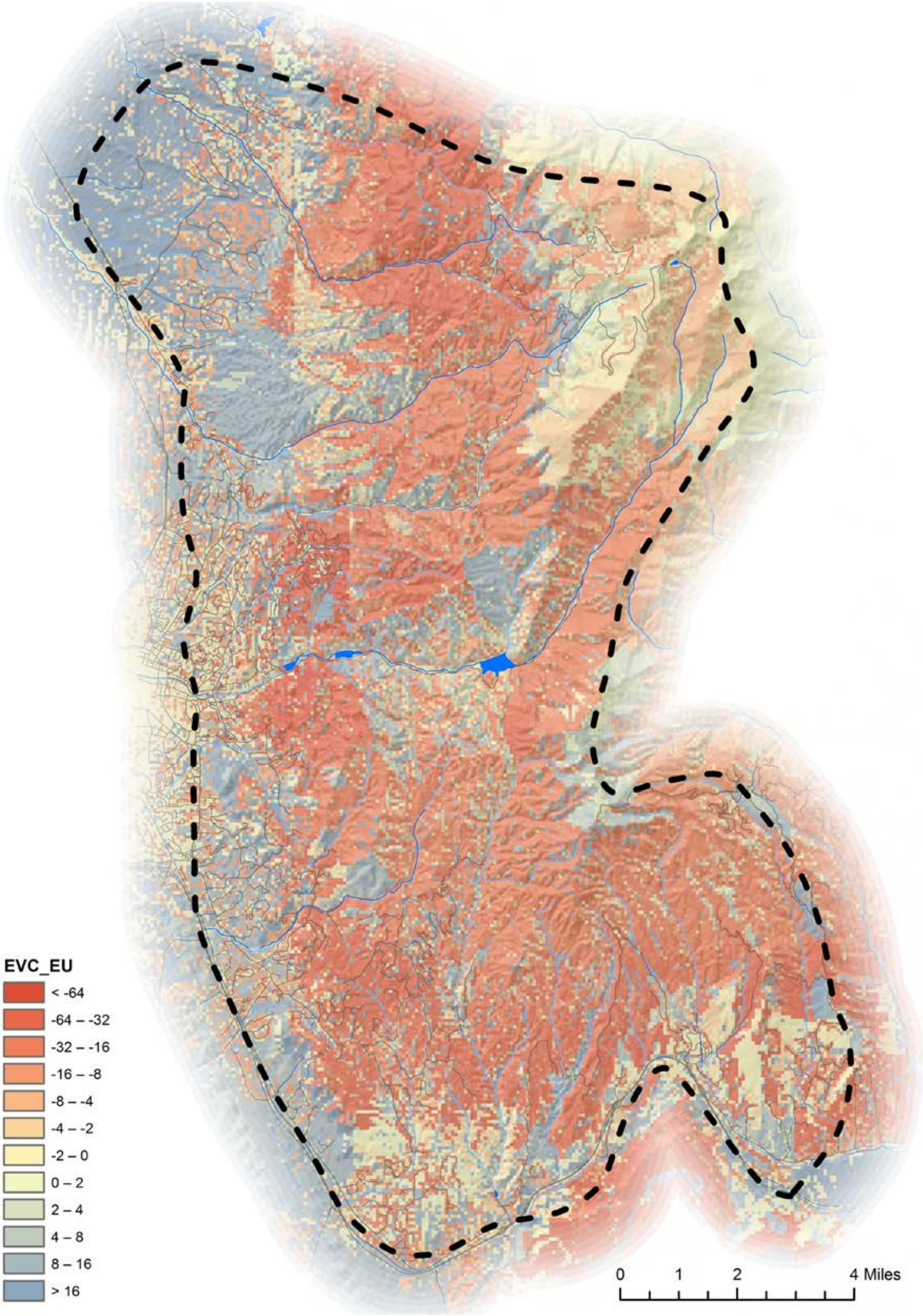

Figure C2. Expected value change on an annual basis from fires burning above the eightieth percentile of fire weather.

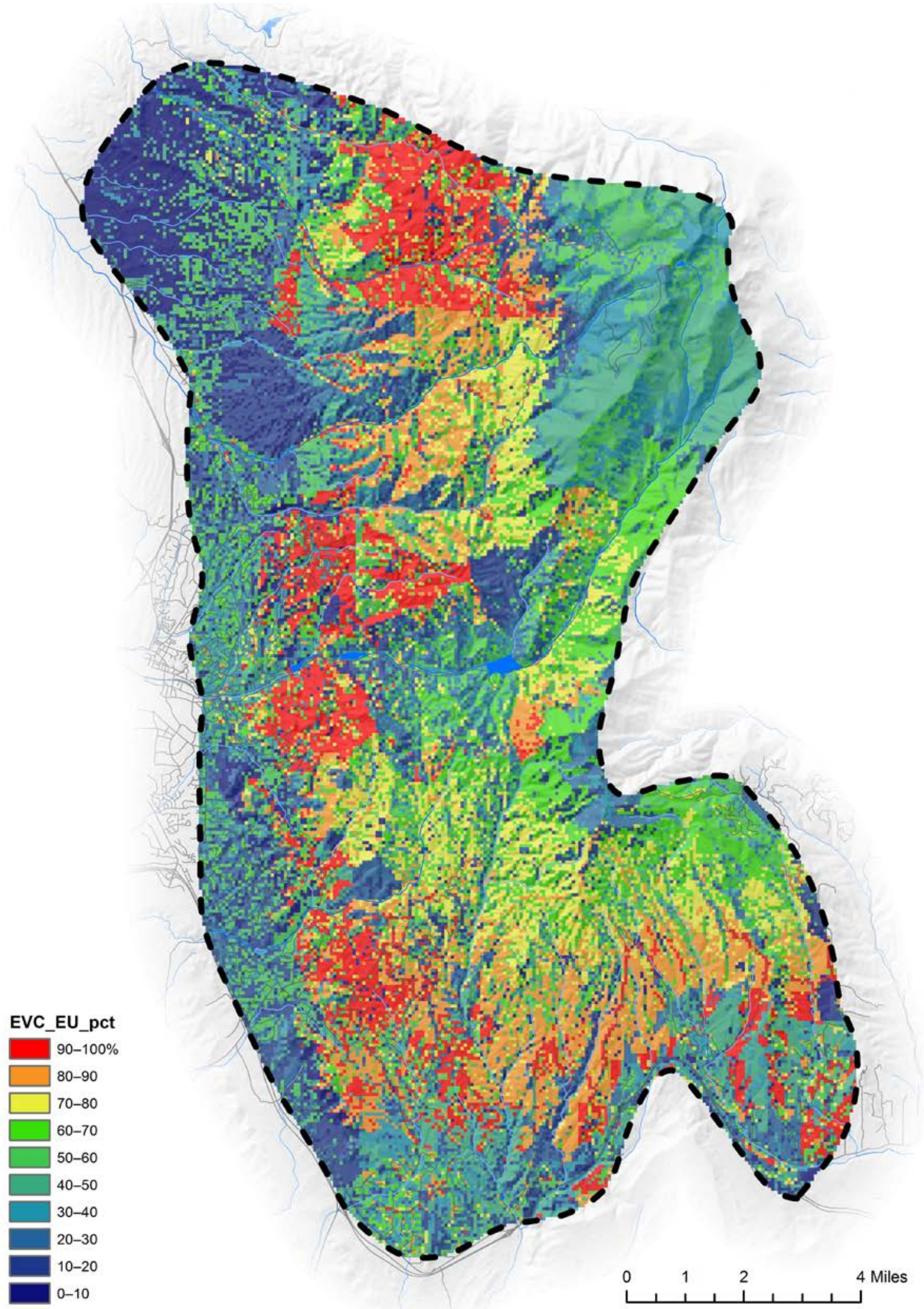

Figure C3. Percentile value change calculated for area within fireshed boundary.

Appendix D: Wind and Fuel Moisture Data

The equation used to modify windspeed values in the FireFamilyPlus database from the 10-minute average wind speed to the probable maximum 1-minute wind speed was based on the work of Crosby and Chandler (2004) (Equation E1).

Equation E1. Function used to change 20-foot wind speed 10-minute averages to probable maximum 1-minute speed values in the FireFamilyPlus database based on the relationship established by the USFS (Crosby and Chandler 2004)*; where* WS_{600} *is the 10-minute average speed recorded at the RAWS station and* WS_{60} *is the probable maximum 1-minute speed. [IIf([WS]=0,0,IIf([WS]=1,[WS]+2,IIf(([WS]>=2 AND [WS]<4),[WS]+3,IIf(([WS]>=4 AND [WS]<=11),[WS]+4,IIf([WS]>=12,[WS]+5,"error")))))]*

$$\mathrm{WS}_{60} = \mathrm{IIf}([\mathrm{WS}_{600}] = 0{,}0, \mathrm{IIf}([\mathrm{WS}_{600}] = 1, [\mathrm{WS}_{600}] + 2, \mathrm{IIf}(([\mathrm{WS}_{600}] \geq 2 \text{ AND } [\mathrm{WS}_{600}] < 4), [\mathrm{WS}_{600}] + 3, \mathrm{IIf}(([\mathrm{WS}_{600}] \geq 4 \text{ AND } [\mathrm{WS}_{600}] \leq 11), [\mathrm{WS}_{600}] + 4, \mathrm{IIf}([\mathrm{WS}_{600}] \geq 12, [\mathrm{WS}_{600}] + 5, \text{"error"})))))$$

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