Appendix A

Rio Grande Water Fund Advisory Board – February 2014

Lesli Allison
Western Land Alliance

Arturo Archuleta
NM Land Grant Council

Will Barnes
NM State Land Office

Brian Burnett
Bohannan Huston

Rick Carpenter
City of Santa Fe

Janie Chermak
University of New Mexico

Terri Cole
Greater Albuquerque Chamber of Commerce

Dale Dekker
Dekker/Perich/Sabatini

Monique DiGiorgio
Chama Peak Land Alliance

Charles Easterling
NM Watershed and Dam Owners Coalition

Joy Esparsen
NM Association of Counties

Jeffrey Espenship
Lowe's Home Improvement

Alexander Evans
Forest Guild

Deborah Foley
US Army Corps of Engineers

John Franchini
NM Department of Insurance

Abe Franklin
NM Environment Department

Ron Gardiner
The Land and Water Clinic

Steve Glass
Ciudad Soil and Water Conservation District

Mark Gunn
USGS Water Science Center

Martin Haynes
NM Water Business Task Force

Mike Hightower
Sandia National Laboratory

Eileen Grevey Hillson
Kerry Howe
UNM Center for Water and Environment

Cal Joyner
USDA Forest Service, Southwest Region

John Kelly
Middle Rio Grande Conservancy District

Elaine Khorman
Cibola National Forest

Kim Kostelnik
SAYAK

Jerry Lovato
Albuquerque Metropolitan Arroyo Flood Control Authority

Hal Luedtke
Bureau of Indian Affairs

Mark Lautman
Lautman Economic Architecture

Beverlee McClure
NM Association of Commerce and Industry

Dan McGregor
Bernalillo County

Amy Miller
PNM Resources

Gael Minton
Acequia del Monte del Rio Chiquito Taos

Toner Mitchell
Trout Unlimited

Joe Norrell
Santa Fe National Forest

Robert Parmenter
Valles Caldera National Preserve

Page Pegram
NM Interstate Stream Commission

Brent Racher
Racher Restoration

Susan Rich
NM Dept. of Minerals, Energy and Natural Resources

Richard Rose
NM Office of the State Engineer

Buck Sanchez
Carson National Forest

Gilbert Sandoval
New Mexico Acequia Association

Mark Schuetz
Watershed Dynamics

Teresa Seamster
Northern NM Group, Sierra Club

Dan Shaw
Bosque Environmental Management Program

Terry Sullivan
The Nature Conservancy

Bruce Thomson
University of New Mexico

Michael Tupper
Bureau of Land Management

Jose Varela Lopez
NM Forest Industry Association

Scott Verhines
NM Office of the State Engineer

Charles Walter
NM Museum of Science and Natural History

Carrie Weitz
Intel

Katherine Yuhas
Albuquerque Bernalillo County Water Utility Authority

Appendix B: Debris Flow Study

Summary of Debris Flow Study

Information to identify the forested watersheds at greatest risk of a high severity burn and with the highest probability to experience debris flow after burning is central to this Comprehensive Plan. To develop this information, The Nature Conservancy convened a technical team of experts from the U.S. Geological Survey (USGS), USDA Forest Service (USFS), Rocky Mountain Research Station (RMRS), and a few Advisory Board members. The technical team was charged with developing a modeling approach to identify forested watersheds at highest risk of wildfire and water source damage from debris flow. The team used the FlamMap model developed by the RMRS, a debris flow model developed by Sue Cannon and others[i] at the USGS Landslide Hazards Program and a RMRS burn probability model system, the Large Fire Simulation system (FSIM) as the basis for their work.[ii]

The FlamMap model uses spatial information on topography and fuels along with fuel moisture and weather data to create output depicting the probability of crown fire[iii]. The crown fire output is translated to medium or high-severity burn and used as an input to the debris flow model (see below). The USGS post-fire debris flow model was used to characterize the potential probability and volume of material that could result from a post-fire debris flow. The FSIM model was used to estimate likelihood of wildfire or annual burn probability. Together the three models were used for estimating the spatial variation in burn probability, fire severity, and debris flow hazard and combined to represent the threat of debris flows in unburned watersheds.

The team conducted a detailed risk assessment for the East Mountains, which includes the Sandia and Manzanos Mountains, first. The results are in publication (available early August 2014) and include documentation of the methodology for linking FlamMap, FSIM, and the debris flow model. A sample output is shown in Figure 5.0 of this Plan (will replace with actual East Mt graphics when available). A second study is underway for the Jemez Mountains (available early 2015) and a third will be started for the western slope of the Sangre de Cristo Mountains (available late 2015). The results from the studies will be used to identify priority projects for forest treatments within each landscape.

The Nature Conservancy created a rapid assessment of wildfire and debris flow probability. The rapid assessment used FlamMap output of crown fire potential developed in 2012 for the New Mexico Department of Game and Fish (NMDGF), and data for the key predictors of debris flow as identified in the USGS post-fire model, such as percent slope, burn severity, soil type, and percent rainfall expected. The results of this rapid assessment are shown in Figure 5.1 of this plan. The rapid assessment was used to identify the four focal areas for the Rio Grande Water Fund as described later in this Plan. The assessment is intended for landscape comparison and not to identify projects within each focal area.

Appendix C: Summary of Watershed Runoff Study

Background

The purpose of this study is to evaluate the potential hydrologic impacts of forest thinning in tributary watersheds to the Rio Grande. This is an important factor to consider for landscape-scale forest treatments contemplated as part of the Rio Grande Water Fund ("water fund") because improved watershed hydrologic function will improve forest resilience to future fires and drought and protect source waters for downstream water users. In addition to estimating changes in hydrologic response to forest treatment, this initial study is also intended to provide guidance for future modeling efforts and assist water fund stakeholders prioritize restoration efforts. The Nature Conservancy's study is part of a broader effort to evaluate the potential changes in hydrologic response to forest treatments planned in water fund area. The broader effort has three objectives: 1) identify and summarize the results of previous studies related to the impacts of wildfires and forest treatments on western high altitude forest hydrology with special emphasis on snowpack dynamics, and runoff and hydrologic responses; 2) identify and evaluate existing hydrologic models that can inform restoration efforts and suggest alternatives for future model development based on a tiered approach; and 3) develop estimates of the range of potential changes in hydrologic processes in the water fund area resulting from forest treatments. This study involved a preliminary analysis using available models and data as part of Objective 3.

Building on work funded by United States Bureau of Reclamation Southern Rocky Mountains Landscape Conservation Cooperative grants, the New Mexico Interstate Stream Commission has contracted with University of New Mexico researcher Dr. Mark Stone to fulfill Objectives 1, 2 and part of 3; this work is expected to be completed by late 2014. Because there are few available models to estimate changes in hydrologic process resulting from forest treatments in the southwest, Objective 3 will be accomplished through a tiered approach for model development: a Level 1 approach to provide broad-brush estimates of changes in hydrologic processes for the water fund area using existing empirical relationships between watershed characteristics and forest treatments; a Level 2 modeling effort will involve a more detailed numerical investigation of changes in water and sediment yields as a function of watershed characteristics and forest conditions at the scale of the entire program area; and a Level 3 modeling effort using detailed process models applied at the catchment scale to guide specific restoration practices and optimize investments. In close coordination with UNM, The Nature Conservancy's contribution to this overall effort is to complete the Level 1 modeling effort described above for changes in runoff due to forest treatments. This chapter summarizes The Nature Conservancy's methodology, results and subsequent recommendations for future analyses.

Methodology

To estimate the increase in runoff resulting from forest treatments, this study used both the Baker-Kovnar model and a modification of this model by O'Donnell-Robles. The original Baker-Kovner model (Equation 1) predicts annual watershed runoff from ponderosa pine stands based on three independent variables: winter precipitation, stand basal area, and an insolation index[iv].

Northern Arizona University Researcher Francis O'Donnell and Marcos Robles of The Nature Conservancy's Arizona Chapter tested the ability of the Baker-Kovner model to predict the increase in runoff directly associated with forest treatments (e.g. the difference in runoff between control and treated watersheds). When they tested the model with data from another watershed not included in the original paired-basin study, they found that the model's ability to predict runoff changes was relatively poor. They concluded that the original regression model was relatively insensitive to the direct effect of forest treatments on runoff and that a modification of the model was necessary. The new model uses reduction in basal area, winter precipitation, and years since treatment to calculate increases in runoff due to thinning (Equation 2).

Equation 1: Pre-Treatment Runoff

$$R = -5.72 + (0.83 * P) + (0.42 * r) - (0.24 * r * P0.92) - (0.007 * P2 * (1 - e\text{-}BA/45))^3$$

where:
R = Annual Runoff in watershed in inches
P = Total Winter Precipitation (Oct-Apr) in inches
r = Insolation index as a decimal fraction
BA = Basal Area in ft^2/acre
R-squared: 0.69

Equation 2: Additional Runoff from Forest Treatments

$$R = -1.1206 + (0.14676 * P) + -(0.014896 * P * Y) + (-0.091779 * P * B)$$

where:
R = Increase in runoff attributed to treatment in inches
Y = Years since treatment (Y = 0, 1, 2...), Range: 0-7
P = Total winter precipitation (Oct-Apr) in in., Range: 6.8-44.2
B = Linear basal area term $(1-\exp(-BA_2/45))-(1-\exp(-BA_1/45))$, where BA_1 and BA_2 are the basal area before and after treatment in ft^2/acre.
R-squared: 0.67

For The Nature Conservancy's analysis, the Baker-Kovner model (Equation 1) was used to calculate base runoff from forests in their current condition, while the O'Donnell-Robles model (Equation 2) was used to calculate the increase in runoff associated with treatments.

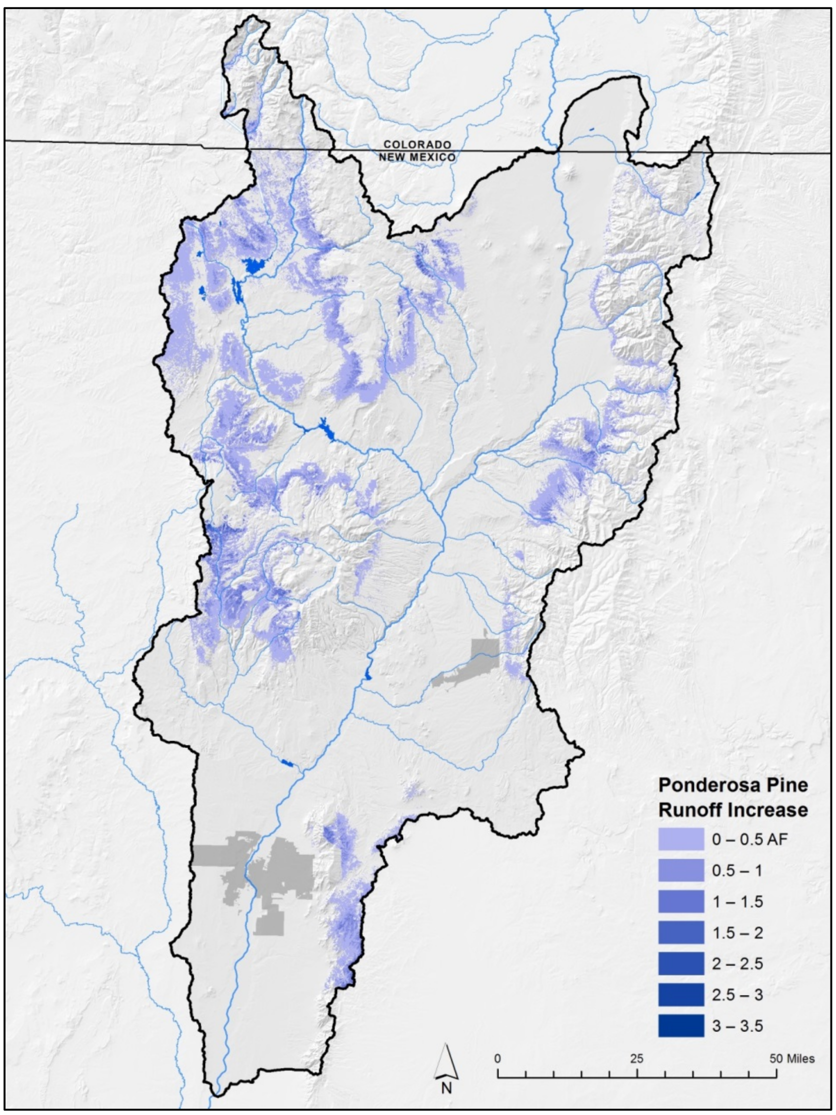
Existing vegetation type data from the LANDFIRE program was used to identify stands of ponderosa pine.[v] The 2012 USFS National Insect & Disease Risk Map provided seamless 30-meter resolution basal area statistics for the study area.[vi] Winter precipitation data was derived from long-term average datasets available from the PRISM Climate Group at Oregon State University.[vii] The insolation index was calculated from a 30-meter resolution raster elevation model. The insolation index is the percent of maximum direct radiation received at noon on February 23rd. Maximum radiation is the radiation received on a surface normal to solar radiation.

Both pre-treatment and post-treatment analyses were conducted using ArcGIS. A regular hexagonal grid was used to define analysis stands, each with an area of approximately 6.5 acres. These discrete processing units allowed stand level treatment simulation with spatially specific output. Post treatment "target" basal area was estimated based on historical forest conditions,[viii] and treatment guidelines used by the USFS when planning treatments in northern goshawk habitat.[ix] The average post-treatment basal area used for modeling was 54.5 ft^2/acre.

Both runoff models were only applied to stands that could be feasibly treated. To determine the total number of treatable acres to include in the hydrologic response analysis, designated wilderness, recently burned or treated areas, areas too steep to treat (>20%), and stands with existing basal area less than the target (<54.5ft^2/acre) were excluded. Runoff from 275,000 acres of ponderosa pine forest was modeled using both equations.

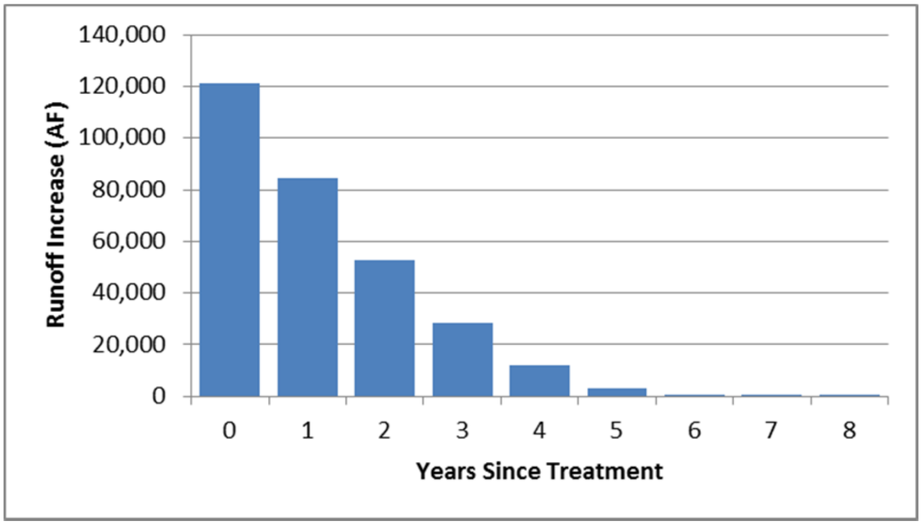
Results

Assuming the entire 275,000 acres are treated according to the target levels, the greatest impact to hydrologic response was at the highest elevations, in part because these areas receive higher levels of precipitation and because they had higher basal areas before treatment (Figure C1).



FigureC1: Total increase in runoff from thinned ponderosa pine stands.

Figure C2 illustrates increase in runoff if all 275,000 acres of Pondersoa pine forest were treated in one year. The runoff increase declines significantly over time and after eight years runoff returns to pre-treatment levels. The total increase in runoff over eight years is approximately 25,000 acre feet.



FigureC2: Additional water yield assuming all thinning treatments conducted in one year

As part of water fund planning, the annual treatment goal is 30,000 acres per year. Figure C3 illustrates the impact to hydrologic response on an annual basis through year 8, when most of the treatable forest has been treated. 5,000 acres are treated in year 9. Increases in runoff persist until year 17 when hydrologic response returns to pre-treatment levels. This analysis assumes a single pass of forest treatment through the entire 275,000 acres with no maintenance treatments to prevent forest regrowth. Under this scenario, the maximum annual increase in runoff is approximately 2,745 acre feet.

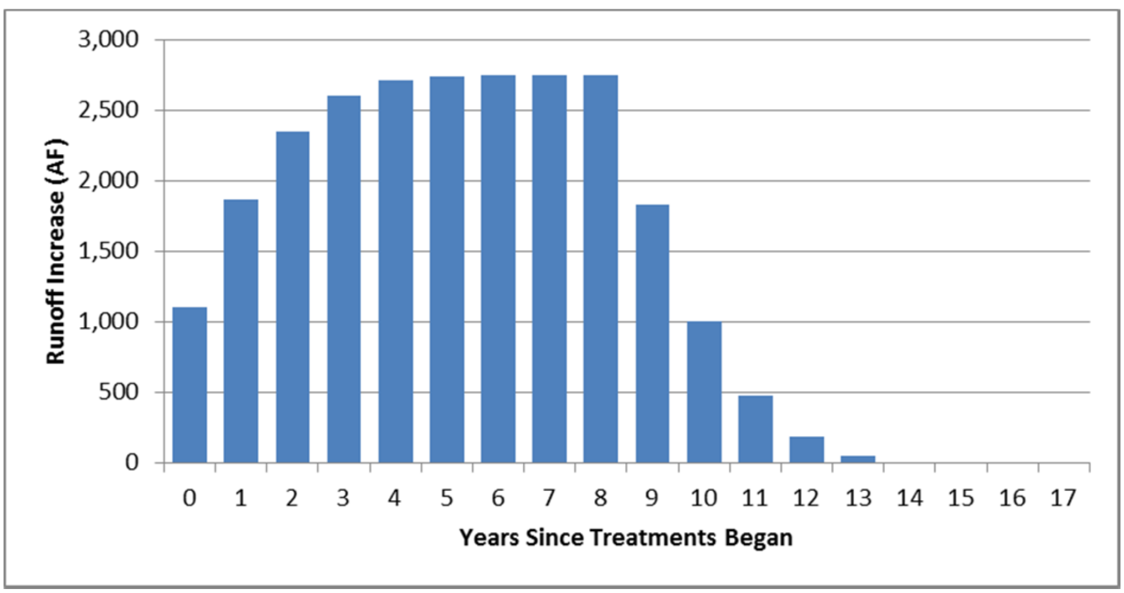


Figure C3: Runoff increase if 30,000 acres of ponderosa pine forest are treated annually

Recommendations for Future Analyses

Future water analyses should: 1) include projected precipitation estimates resulting from climate change; 2) consider soil type and underlying geology, stand runoff and in-stream-flow relationships, and field verified pre- and post-treatment basal area data; 3) exclude critical endangered species habitat, cultural sites, and erodible or otherwise sensitive soils from treatment areas; 4) include consideration of ongoing maintenance treatments in previously treated areas, which will help preserve improved hydrologic function; and 5) evaluate treatments in mixed conifer and aspen forest types.

Appendix D: Restoration Activities Eligible for Support

The Rio Grande Water Fund could pay for a variety of project-related expenses including:

- Planning, for example NEPA, archeological, species and other surveys;
- Restoration treatments, as described in table below; and
- Monitoring that contributes to the objectives of the Rio Grande Water Fund monitoring plan, Appendix G.

Actions and Activities	Description
Forest Thinning	Selectively cutting trees or shrubs with a focus on improving the structure, composition and function of the remaining forest and the health and vigor of the remaining trees or shrubs so that treated and adjacent forest stands are resilient to wildfires.
Biomass Disposal	Removal of woody material for subsequent use, yarding (pulling logs and trees partially or fully suspended above the ground) or skidding (dragging or carrying logs or trees) biomass to a road or landing point.
Biomass Disposal Mastication	Shredding (sometimes called masticating) or chipping and leaving the biomass on site; some equipment is capable of thinning and masticating trees simultaneously.
Controlled Burning or "Prescribed Fire"	Planned ignition of fire under prescribed environmental conditions to dispose of the biomass left after thinning; prescribed fire can be used alone to improve forest health and maintain previously thinned areas.
Road Closure and Decommissioning	Roadbed rehabilitation to promote natural revegetation. Activities may include placing mulch, creating drainage by shaping the alignment or installing culverts, and scarifying and seeding the alignment.
Road Maintenance and Repair	Maintenance on open roads. Activities include road grading, reconstruction of the road prism, and construction of drainage features such as lead-out ditches and the placement (or replacement) of culverts to protect streams and wetlands.
Riparian/wetland Restoration	Activities to protect or restore riparian and wetland vegetation or watershed function. Common activities are planting, placing sod, erecting fences or barriers, and placing structures to reduce the energy of flowing water. Heavy equipment may be used to remove man-made impoundments, restore previously diverted stream courses, or address localized erosion in stream riparian or upland environments.

Appendix E: Sample of Planned Restoration Treatments by Ownership

Agency	District/Subunit	Project Name	NEPA Status	Timeline	Planning Area acres	Thinning acres	Rx Fire acres	Stream Restoration miles	Road Decommission miles
Valles Caldera NP		SWJM Landscape Restoration Project		2014-2024	80,000	21,496	49,825		
Santa Fe NF	Jemez	SWJM Landscape Restoration Project	Draft EIS Published		110,000	29,900	77,000	24	100
Santa Fe NF	Espanola	Santa Fe Municipal watershed	Complete			TBD	2,900		
Santa Fe NF	Pecos	Gallinas watershed	Complete		8,000	8,000	8,000		
Cibola NF	Mountainair	Red Canyon	Complete	2014-2017		330	360		1
Cibola NF	Mountainair	Espinoso	Complete	2014-2018		40	2,400		1
Cibola NF	Mountainair	Isleta	Complete	2014-2018		2,700	5,700		11
Cibola NF	Mountainair	T-Bird	Complete	2014-2018		800	600		
Cibola NF	Sandia	Isleta	Complete	2014-2017			2,100		
Cibola NF	Sandia	Cedro	Complete	2014-2017		8,000	3,000		7
Cibola NF	Sandia	Tablezon	Complete	2014-2016		195	200		
Cibola NF	Sandia	Hondo	Complete	2014-2016		200	420		
Cibola NF	Sandia	Talking Talons	Complete	2014-2016			400		
Cibola NF	Sandia	Sulphur	Complete	2014-2017		800	500		
Cibola NF	Sandia	La Madera	Complete Fall of 2016		18,000				
Cibola NF	Sandia	La Madera	Once Complete	2016-2018		4,000	500		TBD
Carson NF	Canjilon	Canjilon WUI	Complete	2014-2018		500	500		
Carson NF	El Rito	Lower El Rito WUI	Complete	2014-2018		5,800	5,800		
Carson NF	Camino Real	Rio de Las Trampas		2014-2018		3,100	3,100	4	
Carson NF	Tres Piedras	Tusas- San Antonio	Starting	2014-2018		20,000	20,000		
Carson NF	Questa	Comanche Creek		2014-2018		2,800	2,800	11	
Carson NF		Other Landscapes		2014-2018			15,400		
Santa Ana Pueblo		Cottonwood Die-off Fuels Removal				23			
Santa Ana Pueblo		River Bar Cottonwood Planting						135 ac	

Appendix F: Road Maintenance and Restoration Costs

(Adapted from a memo of November 2013, from USDA Forest Service, Southwest Region, Engineering)

Transportation and Landscape-Scale Restoration Funding Shortages:

- Funding for transportation in USDA Forest Service Southwest Region has declined approximately $6.3 million (40%) since 2002.
- Reductions in funding have resulted in significantly less road maintenance and very little to no investments for much needed road reconstruction, road improvement, or road resurfacing projects. As a result, the condition of the entire road system has continued to decline.
- There is no long term plan to address funding shortages for transportation investments that are needed to implement restoration projects.
- The transportation needs on National Forests far exceed their budgets.

Current Road Conditions:

- Current condition of the transportation system is not adequate for implementation of restoration projects.
- Less than 7% of the High Clearance roads are maintained annually. A significant number of these roads are no longer passable by high clearance vehicles and/or are negatively impacting watershed health.
- Investments made on Passenger Car Roads are limited to surfacing blading. Many of these roads can no longer be maintained for moderate speeds due to the lack of surfacing material.

Estimated Road Needs:

The following unit costs can be used to estimate road maintenance and road improvements:

Road Category	Unit Cost	Description
High Clearance Roads - Single Lane Routine Maintenance	$3,500/mile	Spot surface maintenance and minor drainage maintenance.
High Clearance Roads - Single Lane Heavy Maintenance	$10,000/mile	Surface maintenance and drainage repair.
Passenger Car Roads - Double Lane Spot Surfacing	$10,000/mile	Spot surfacing w/ gravel or native material.
Passenger Car Roads - Double Lane Re-surfacing	$40,000/mile	Re-surface w/ 4 inches gravel.

Preliminary field reviews indicate that there is a significant backlog of high clearance road maintenance and that high clearance roads have seen the biggest impact from the reduced funding levels. High clearance roads often provide the only access to restoration treatment areas. Passenger car roads will be critical to movement of forest products.

The following are examples of typical existing road conditions on National Forests in the Southwest Region.

Passenger Car Roads

High Clearance Roads

Bridges/Culverts/Low Water Crossings

Appendix G: Focal Area Analysis

Why were these maps generated and what do they mean?

The focal area maps are the first attempt to illustrate important landscapes within the Rio Grande Water Fund (RGWF) where the risk to water supplies from wildfire and associated post-fire effects is significant. This mapping analysis covers all ownerships in New Mexico; it does not just cover forested lands or just areas within the water fund boundary. The focal areas are broad landscapes where restoration treatments and economic development will be focused. The establishment of focal areas is intended to aid in the efficient, strategic, and focused use of resources and funding created by the RGWF.

Data models representing wildfire risk, water quality and supply, potential for wood utilization, forest health conditions and fish and wildlife habitat were the basis for identifying focal areas. The data models depict five themes considered most important for identifying landscapes where additional project-level criteria will be used to prioritize projects. This appendix describes the data used in the model development. A weighted overlay analysis, which is a technique for applying a common scale of values to diverse and dissimilar inputs to create an integrated analysis, was used in creating each data model as well as in combining the five data models to produce focal area maps for the RGWF Comprehensive Plan. The methodology for the weighted overlay analyses are also described below.

Description of five key data models.

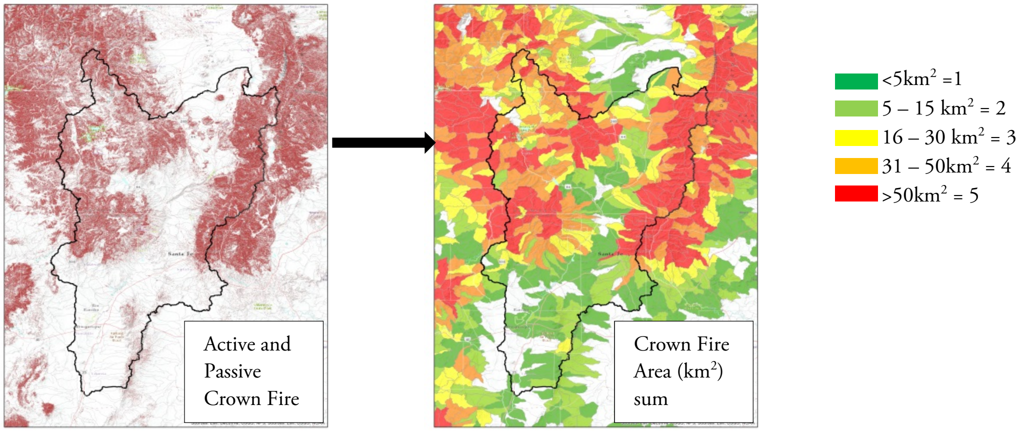
Wildfire Risk

The wildfire risk model identifies areas where severe wildland fires are predicted to occur or areas that are prone to extreme fire behavior. Five data layers were used as inputs: (1) crown fire potential, (2) flame length potential, (3) probability of ignition, (4) wildland urban interface, and (5) communities at risk from post-fire debris flow. The areas identified have large fuel loads that could result in large fires with extreme fire behavior, are near developments, and are "hotspots" of past wildland fire occurrences.

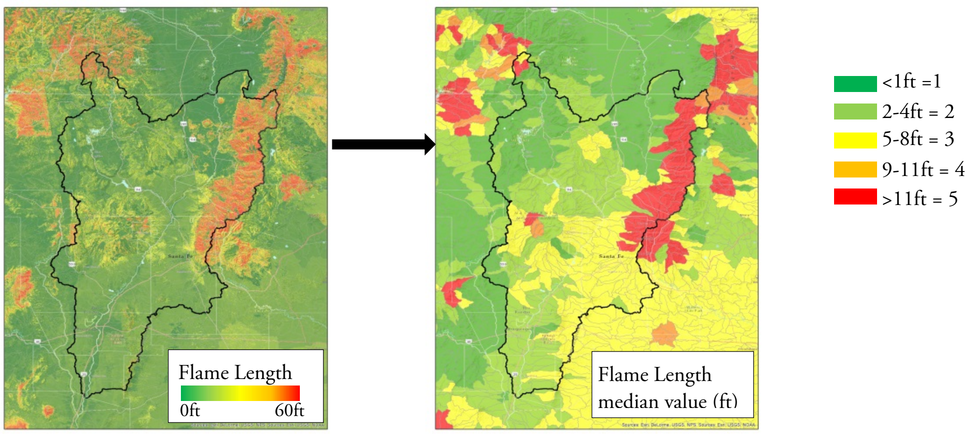
CROWN FIRE POTENTIAL AND PREDICTED FLAME LENGTH

Crown fire is the movement of fire into and through the canopy. Flame length is the distance from the base of the flame to the tip of the flame. Crown fire and flame length are both good indicators of the potential for extreme fire behavior. They were modeled using FlamMap, an interagency fire behavior mapping and analysis program developed by RMRS. FlamMap uses eight spatial layers created by LANDFIRE (2013) to represent biophysical conditions and weather parameters to simulate wind and fuel moisture conditions. Crown fire and flame length were modeled for each HUC 8 watershed using representative weather and fuel moisture inputs from a RAWS station within the watershed. The results were merged into one statewide layer in ArcGIS.

The FlamMap model results for crown fire potential classifies areas into four potential categories: active crown fire, passive crown fire, surface fire, and not modeled (no data). Pixels classified as active and passive crown fire crown were summed to the HUC 12 watershed level and converted into a predicted area (km^2) of extreme fire behavior using raster calculator (30m x 30m x number pixels). Each HUC 12 watershed was reclassified based on the total area of predicted crown fire as follows:" as follows:

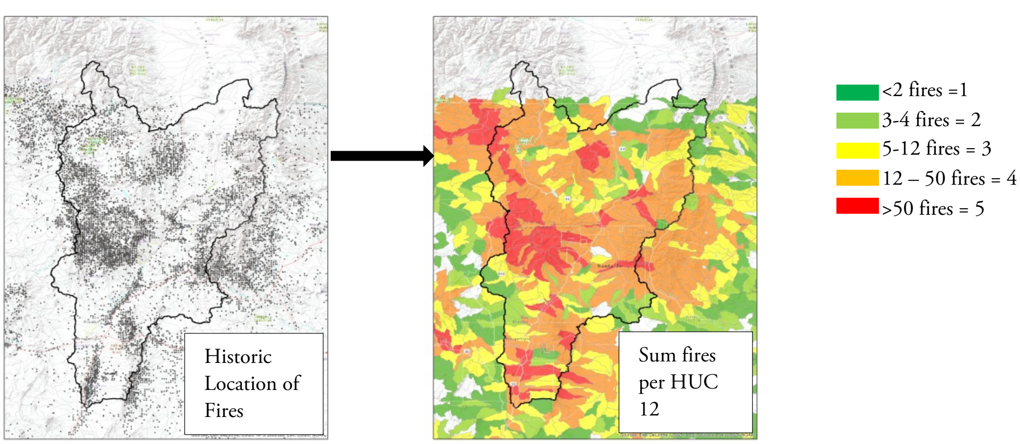


The FlamMap model results for flame length are reported as a distance measure. The median predicted flame length for each HUC 12 watershed was calculated. The median flame length value within each HUC 12 watershed was reclassified (see below) into 5 groups representing the expected difficulty of fire suppression efforts:



PROBABILITY OF IGNITION

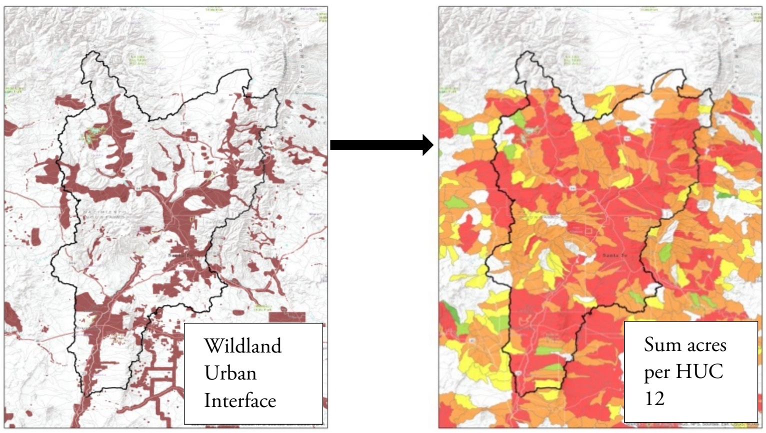
Many studies show that the spatial distribution of ignition locations, whether human-caused or natural, is not random. To assess locations where ignition probability to is greatest, we used historic locations of fires, assuming that there will be an increase in the probability of a fire occurring in areas where they have occurred in the past. Fire occurrence point data from the New Mexico Statewide Assessment was used as the sole input. The original data source for the fire occurrence data layers was USFS, State Forestry, BLM, and DOI fire occurrence from 1987 to 2008. The number of past fires occurring within a HUC 12 watershed was summed. The sum of fires within each watershed was reclassified using natural breaks in the frequency distribution of the number of ignitions per HUC 12 watershed as follows:



Transmission data was unavailable and is not incorporated as an input into the probability of ignition layer. Transmission data is being collected and will be incorporated when a statewide coverage has been developed.

WILDLAND URBAN INTERFACE (WUI)

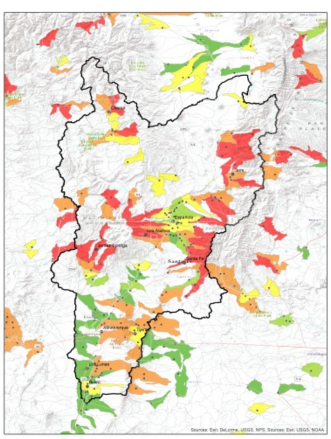
WUI commonly refers to areas where homes or other structures are built near lands prone to wildfire. WUI can also represent a set of conditions or values at risk from wildfire and are defined by a community. The WUI layer developed for the NM Statewide Natural Resource Assessment was used to represent WUI for this model. Metadata for original data can be found on the New Mexico State Forestry website http://www.emnrd.state.nm.us/SFD/statewideassessment.html. The total area of WUI for each HUC 12 watershed was summed and reclassified using a natural breaks system as follows:



- <4 acres =1
- 5 – 45 acres = 2
- 46 – 515 acres = 3
- 516 - 5815 acres = 4
- >5815 acres = 5

COMMUNITIES AT RISK OF POST-FIRE DEBRIS FLOW

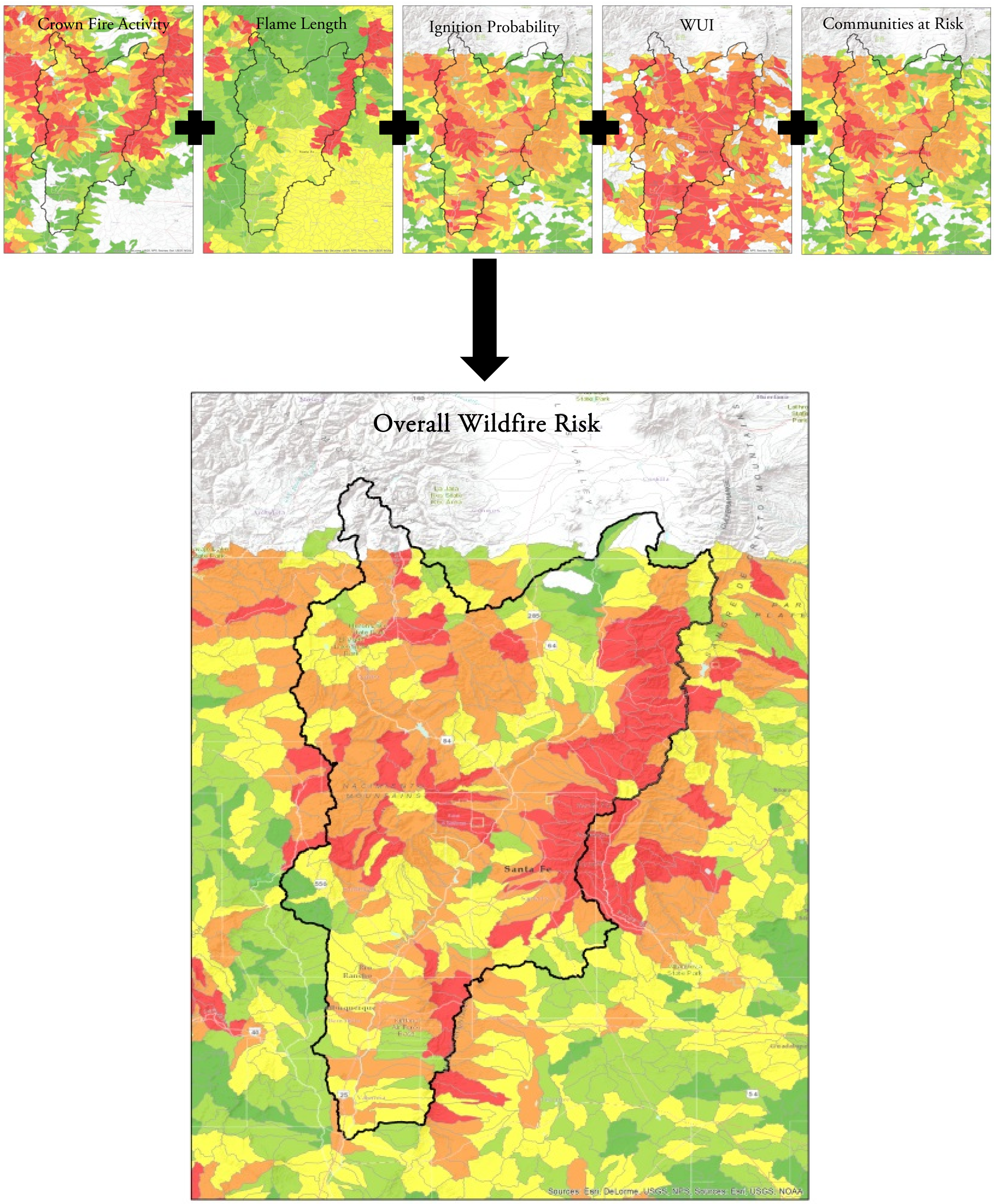
Communities at risk of post-fire debris flow depicts watersheds where a community is found AND where the TNC rapid debris flow assessment predicts an increase in volume of debris flow after a fire. The input layers were the 2010 census layer and the TNC rapid debris flow assessment, more fully described in the Water Quality and Supply section below. The sum of predicted debris volume within each HUC 12 watershed where a community is found was reclassified using a geometric interval classification as follows:



- <16m^3=1
- 17 – 203m^3 = 2
- 204 – 2,321m^3 = 3
- 2,322 – 26,347m^3 = 4
- >26,347m^3 = 5

OVERALL WILDFIRE RISK

An equal weight overlay analysis was used to create an overall wildfire risk model. The common scale of 1 to 5 created for each input layer was weighted equally and summed for each HUC 12 watershed. A natural breaks classification was used to scale overall risk from wildfire. Watersheds with rank of 5(shown in red) are those that have large fuel loads that could result in fires with extreme fire behavior, are near developments, and are "hotspots" of past wildland fire occurrences.



Water Quality and Supply

The water quality and supply model identifies areas where there is an increased risk of post-fire debris flows and areas with key risks to water supplies. Five data layers were used as inputs: (1) probability of a debris flow (2) volume of debris flow, (3) groundwater recharge areas, (4) watersheds with debris flow risk that contribute directly to the Rio Chama and Rio Grande, and (5) watersheds with debris flow risk that contain the only source of drinking water for a community. The areas identified are watersheds important for supplying sustainable, clean water supplies along with the potential risk of post-fire debris-flows to these supplies.

PROBABILITY AND VOLUME OF DEBRIS FLOW

Debris flows pose substantial threats to life, property, infrastructure, and water resources. Debris flows in burned areas may be of catastrophic proportions compared to debris flows occurring in unburned areas. These layers represent the relative measure of which watersheds might constitute the most serious debris flow hazards. The equation developed by Cannon and others (2009) to quantify the predicted probability of a debris flow was based on the study of 388 basins in the western United States. Multiple regression analysis allowed the creation of a predictive model for probability and volume of post wildfire debris flows.

Probability of a Debris Flow

Equation 1:

$$P = \frac{e^x}{1 + e^x}$$

where

P is the probability of debris-flow in fractional form; and

ex is the exponential function.

Equation 2:

$$x = -0.7 + 0.03(\%SG30) - 1.6(R) + 0.06(\%AB) + 0.07(I) + 0.2(\%C) - 0.4(LL)$$

where

%SG30 is the percent of the basin with slope greater than or equal to 30%;
R is the ruggedness of the basin as defined by Melton:the elevation range of the basin (in meters) divided by the square root of the basin area (in square meters);
%AB is the percentage of the area expected to experience active or passive crown fire;
I is the average storm intensity of the basin (in mm per hour);
%C is the average clay content of the soils in the basin (as percentage); and
LL is the average liquid limit of the soils in the basin (as percentage).

Volume of a Debris Flow

$$ln\,V = 7.2 + 0.6(ln\,SG30) + 0.7(AB)^{0.5} + 0.2(T)^{0.5} + 0.3$$

where

V is the debris flow volume (m^3);

ln is the natural log function;

SG30 is the area of the basin with slope greater than or equal to 30% (km^2);

AB is the area of the basin burned at moderate to high severity ; and

T is the total storm rainfall (mm).

The variables used in the model were derived from readily available, best available data for the study area and described below. Due to the large extent of the study area, the datasets used were regional and national in scale because higher resolution and more accurate datasets were unavailable.

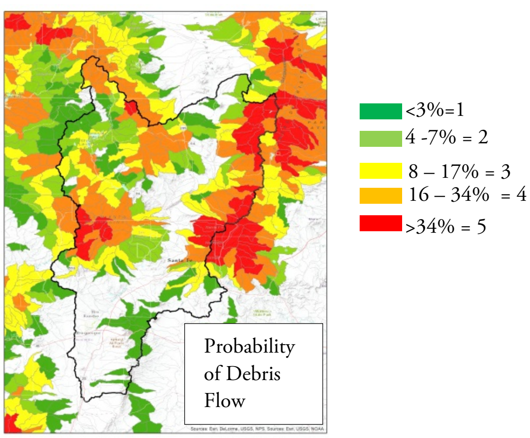
A 30-meter DEM from the NED used in basin delineation was used to calculate the percent of each basin with slopes greater than 30% and the elevation component of ruggedness or Melton ratio. A 10 meter DEM was available for the study area but was not used because of data processing limitations.

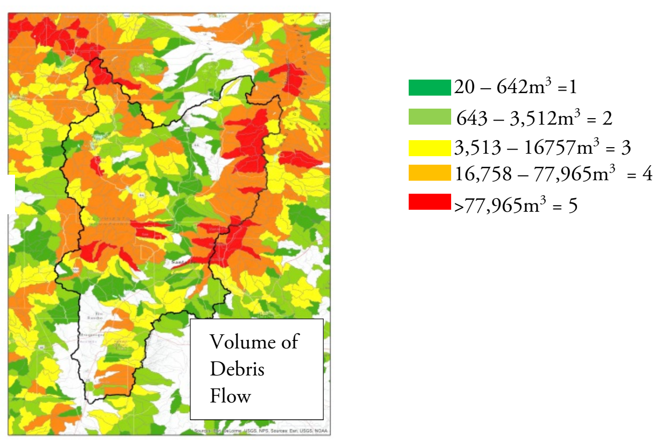
Storm intensity data for the study area was available from the Atlas 14 Precipitation Frequency Estimates produced by the National Oceanic and Atmospheric Administration (NOAA). The 2year return interval storm intensity was used with 30 minute duration.

Soils data was obtained from the STATSGO database which is maintained by the U.S.Department of Agriculture, Natural Resources Conservation Service (Schwartz and Alexander, 1995). STATSGO contains clay content and liquid limit attributes in a consistent and comparable format for the entire study area and was used in the development of the predictive model (Cannon et. al., 2009).

Modeled fire behavior was used as an analog of burn severity due to the predictive nature of this study. Area of active and passive crown fire was substituted for observed area burned at moderate and high severity values used in the BAER studies that implemented this model (**AB** became the area of the basin expected to experience active or passive crown fire (km^2)).

The average predicted probability and sum of predicted volume for each HUC 12 watershed were reclassified using a geometric mean classification as follows:





GROUNDWATER RECHARGE AREAS

Areas where groundwater recharge is occurring are important to protect and manage. This layer represents watersheds with potential to recharge aquifers and was developed using the Chaturvedi formula:

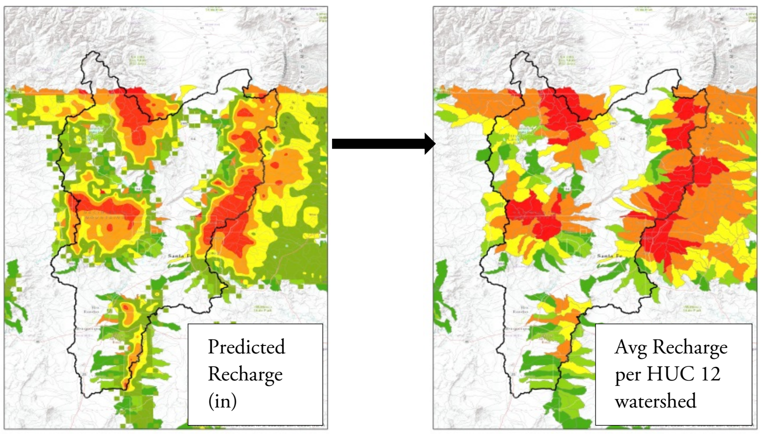
$$R = 2(P-15)^{0.4}$$

where

R = recharge due to rainfall (in)

P = annual precipitation (in)

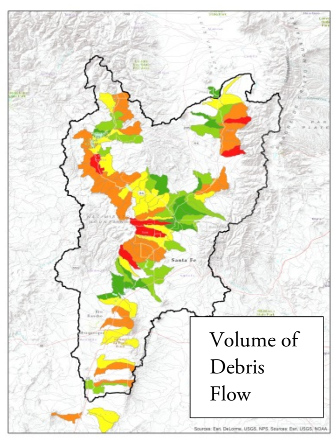
The formula relates precipitation to recharge and is more fully described in “Estimation of Natural Groundwater Recharge” edited by Simmer (1997)[x]. The precipitation data was based on the PRISM average monthly and annual precipitation data sets for the climatological period of 1951-2006. The layer was originally developed for the NM Statewide Natural Resource Assessment (http://www.emnrd.state.nm.us/SFD/statewideassessment.html.). The average predicted groundwater recharge for each HUC 12 watershed was reclassified as follows:



<0.5 in =1
0.6 – 1.4 in = 2
1.5 – 2.6 in = 3
2.7 – 4.5 in = 4
>4.5 in = 5

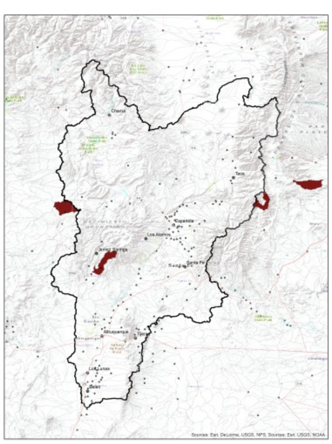
WATERSHEDS WITH DEBRIS FLOW RISK THAT CONTRIBUTE DIRECTLY TO THE RIO CHAMA AND RIO GRANDE

Watersheds contributing directly to the Rio Grande and Rio Chama are of particular concern and have a higher likelihood of affecting water supplies of major cities. To reflect this importance the sum of the predicted volume of debris flow for each watershed contributing to the Rio Chama and Rio Grande was added. This same classification used in the volume of debris flow layer above was used, and the addition of this layer essentially represents a doubling of the weight for volume of debris flow for the watersheds that contribute directly to the Rio Grande and Rio Chama in the overall water quality and supply model.



20 – 642m^3 =1
643 – 3,512m^3 = 2
3,513 – 16757m^3 = 3
16,758 – 77,965m^3 = 4
>77,965m^3 = 5

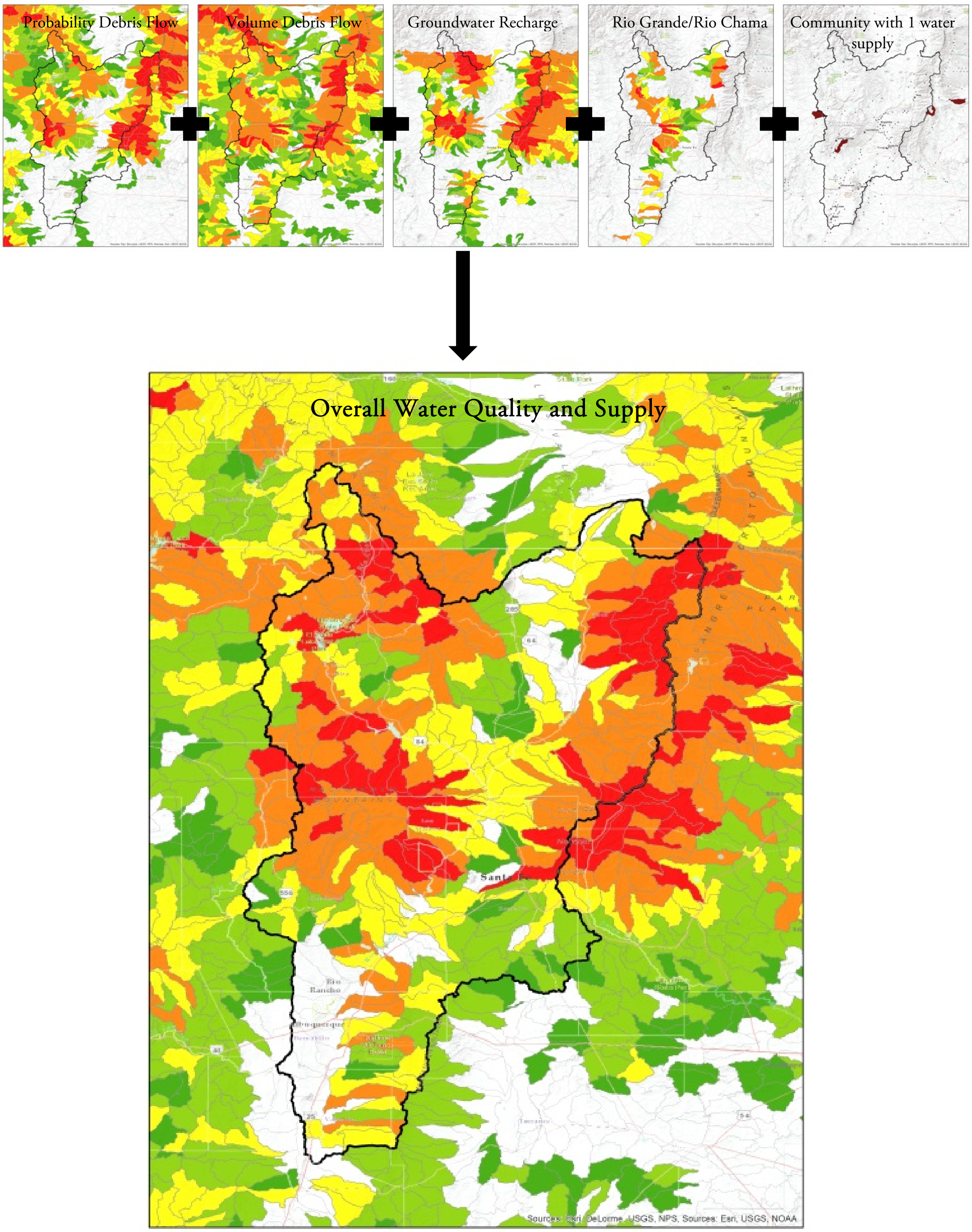
WATERSHEDS WITH DEBRIS FLOW RISK THAT CONTAIN THE ONLY SOURCE OF DRINKING WATER FOR A COMMUNITY



Four communities within the water fund boundary depend upon surface water as their only source of drinking water. Protection of these watersheds is critical to supplying sustainable, clean water for these communities. The watersheds that contribute surface water to these communities were identified given a value of 5.

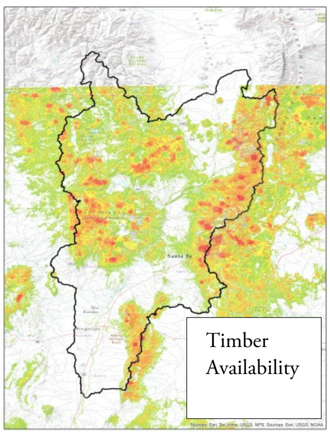
OVERALL WATER QUALITY AND SUPPLY

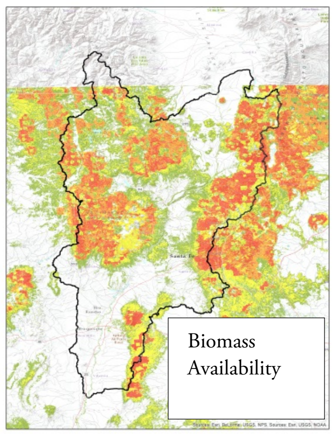
An equal weight overlay analysis was also used to create the overall water quality and supply risk model. The common scale of 1 to 5 created for each input layer was weighted equally and summed for each HUC 12 watershed. A natural breaks classification was used to identify area important for water quality and supply. The watersheds with a rank of 5 (shown in red) represent those that are important for supplying sustainable, clean water supplies to communities and have the highest potential risk of post-fire debris-flows that will impact these supplies.



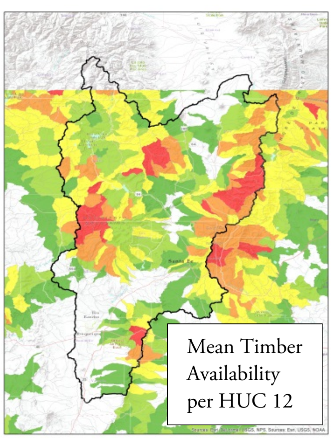
Economic Opportunity

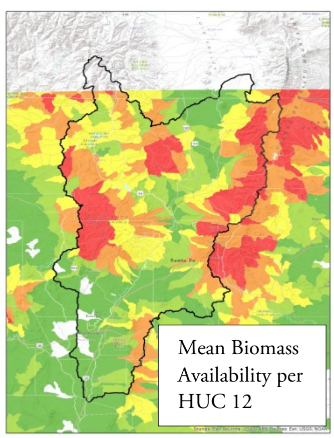
The economic opportunity data model highlights where forests and woodlands could play a major role in local or state growth in the future. The data model highlights areas where there is significant amount of available timber and biomass. The timber data layer depicts areas where sawtimber could be harvested and was created by combining basal area data with quadratic mean diameter (QMD) then excluding areas with inaccessible slopes (>30%). The QMD layer 2006 National Insect & Disease Risk map (NIDRM) and was used to identify stands with larger trees for the timber layer and smaller trees for the biomass layer. For the timber layer the QMD was >10ft.; for the biomass layer the QMD was <10ft. The biomass layer depicts where forest products besides sawtimber, that is, small diameter and underutilized material, could be harvested. It was created using the same data layers above. The basal area layer was developed by the 2013 National Insect & Disease Risk map (NIDRM) and was scaled to represent stands with more wood(see below. The total area of available timber and biomass for each HUC 12 watershed was summed and reclassified. The overall economic opportunity layer represents the equal weight overlay of the reclassified timber and biomass layers. See below

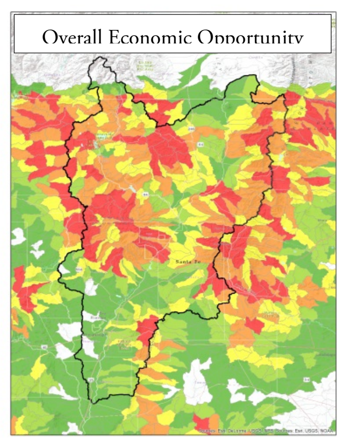




- 1 – 20 ft^2 =1
- 21 – 60 ft^2 = 2
- 61 – 80 ft^2 = 3
- 81 – 120 ft^2 = 4
- >120 ft^2 = 5

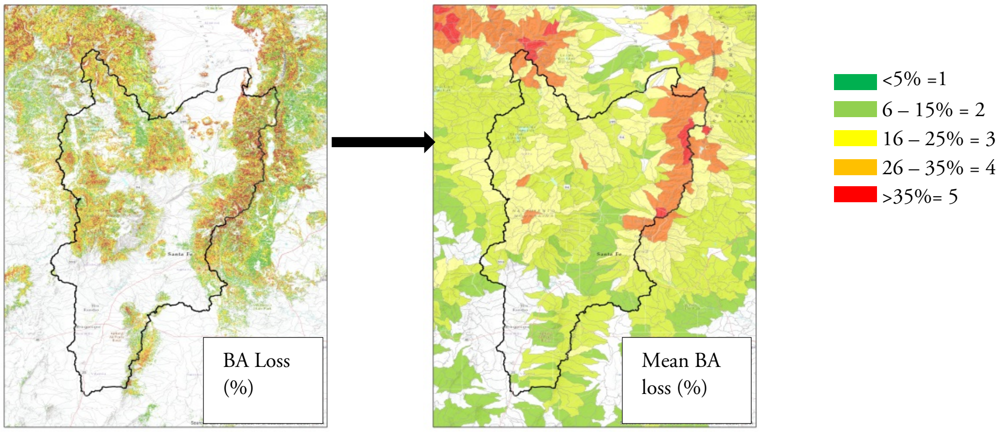






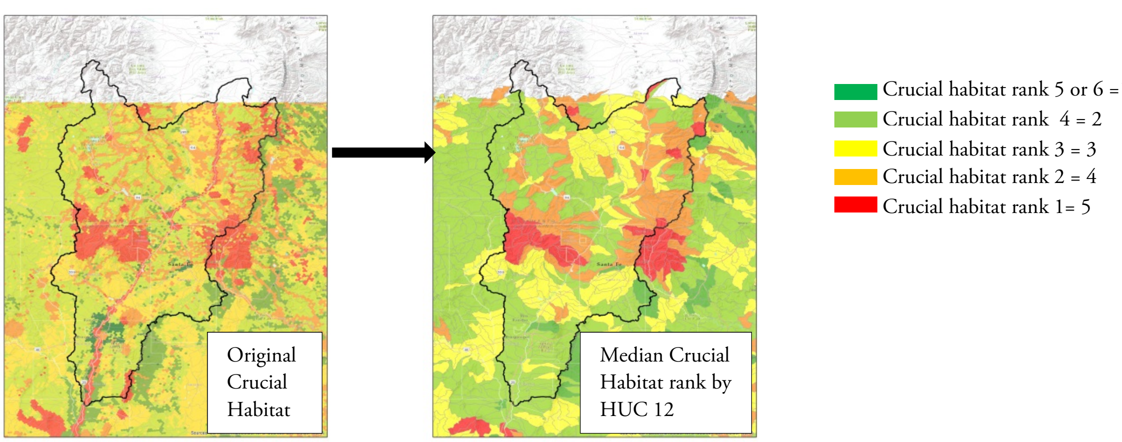
Forest Health

The forest health data model identifies areas that are predicted to be damaged from major insect and disease agents in the foreseeable future. One dataset was used as an input, 2013 National Insect & Disease Risk map (NIDRM). NIDRM data layer depicts percent basal area loss (BA loss) as a result of projected tree mortality over the next 15 years due to insect and disease agents. The mean BA loss for each HUC 12 watershed was calculated and was used to group and reclassify each watershed as follows:



Fish and Wildlife

The fish and wildlife data model identifies areas critical for conservation of biodiversity in New Mexico. The data model includes only one input layer, the crucial habitat ranking developed by Natural Heritage New Mexico and New Mexico Department of Game and Fish for the Western Governors Association WGA in 2013. For this mapping effort, crucial habitat was defined as "places that are expected to contain the resources necessary for the continued health of fish and wildlife populations or where important ecological communities are expected to provide high value for a diversity of fish and wildlife." The specific methodology and information used to develop the crucial habitat layer can be found at http://nmchat.org/data.html. The crucial habitat ranking ranges from 1 indicating crucial habitat of greatest importance to 6, indicating less important crucial habitat. The focal area ranking for the comprehensive plan ranges from 1 to 5, where 1 indicates least important and 5 indicated greatest importance. For the overall data model, the median crucial habitat rank for each HUC 12 watershed was calculated and was used to group and reclassify each watershed as follows:



Focal Area Identification

A weighted overlay analysis was used to identify areas and produce focal area maps for the Comprehensive Plan. A weighted overlay analysis is a technique for applying a common scale of values to distinct and varied inputs to create a cohesive and comparable analysis. The steps of a weighted overlay analysis include the following two steps:

1. Select an evaluation scale— Values at each end of the scale represent the extremes. The scale selected for this analysis was 1 to 5. The input data models (wildfire, water quality and supply, economic opportunity, forest health, and fish and wildlife habitat) were created using this scale, where 1 indicates least suitable or least risk and 5 indicates most suitable or greatest risk.
2. Assign weights to input data—Each data model was assigned a percentage influence, based on its importance. The total influence for all data layers must equal 100 percent. The comparison ranking and weights used for this process were based on a protocol developed by the USFS for the State and Private Forestry State Assessment Toolbox (see tables below). The greatest weight was given to wildfire risk data model since it was considered the most significant source of risk. Water quality and supply and economic opportunity are weighted moderately less and forest health and fish and wildlife are weighted very strongly less. The final focal area score was clipped to a treatable forest layer and focal areas were selected (see diagram below).

USFS State and Private Forestry Ranking Worksheet

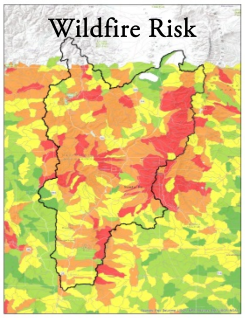
:Description	Comparison Rating
Most Important	1
Moderately Less	1/3
Strongly Less	1/5
Very Strongly Less	1/7
Extremely Less	1/9

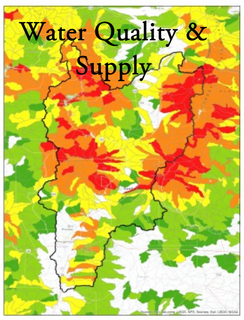
Translation of Comparison Rating to Weight

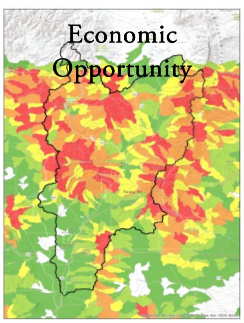
Data Model	Comparison Rating	Weight
Wildfire Risk	1	17.36%
Water Quality and Supply	1/3	52.07%
Economic Opportunity	1/3	17.36%
Forest Health	1/7	7.44%
Fish and Wildlife	1/9	5.79%

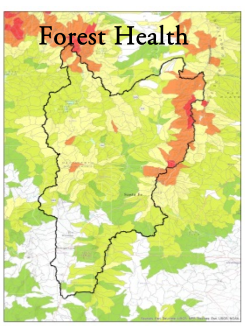
Focal Area Identification

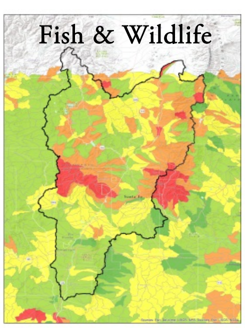
1. Key Data Models

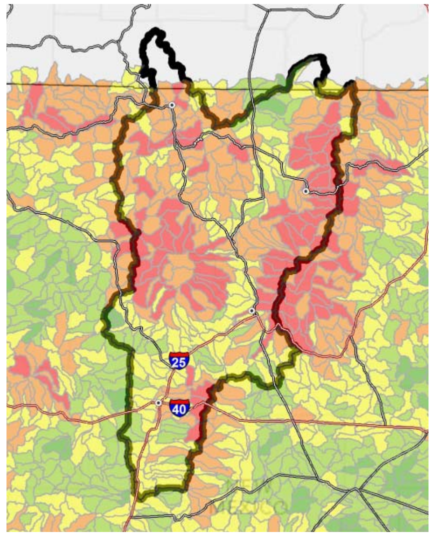






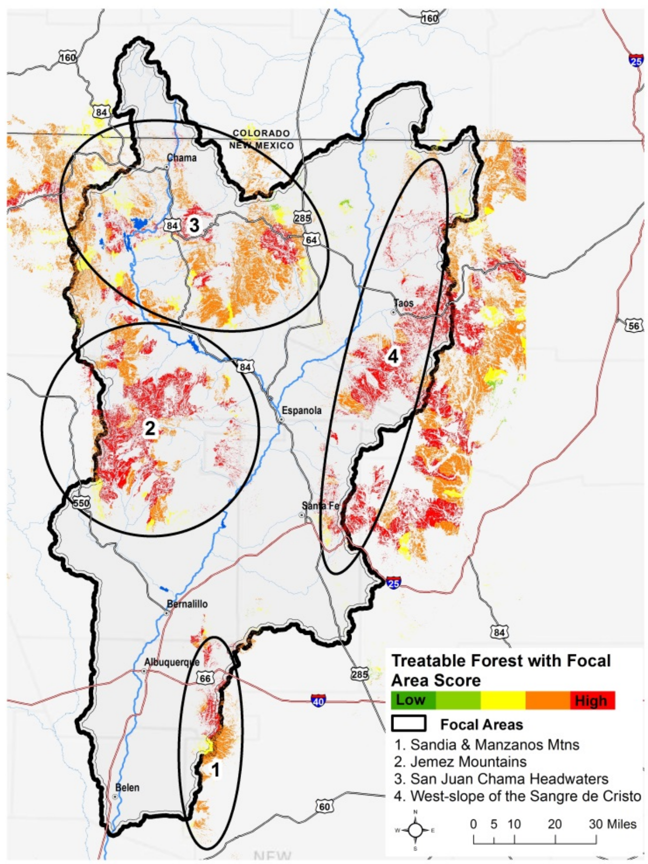






2. Summed Statewide Focal Areas by HUC 12 Watershed

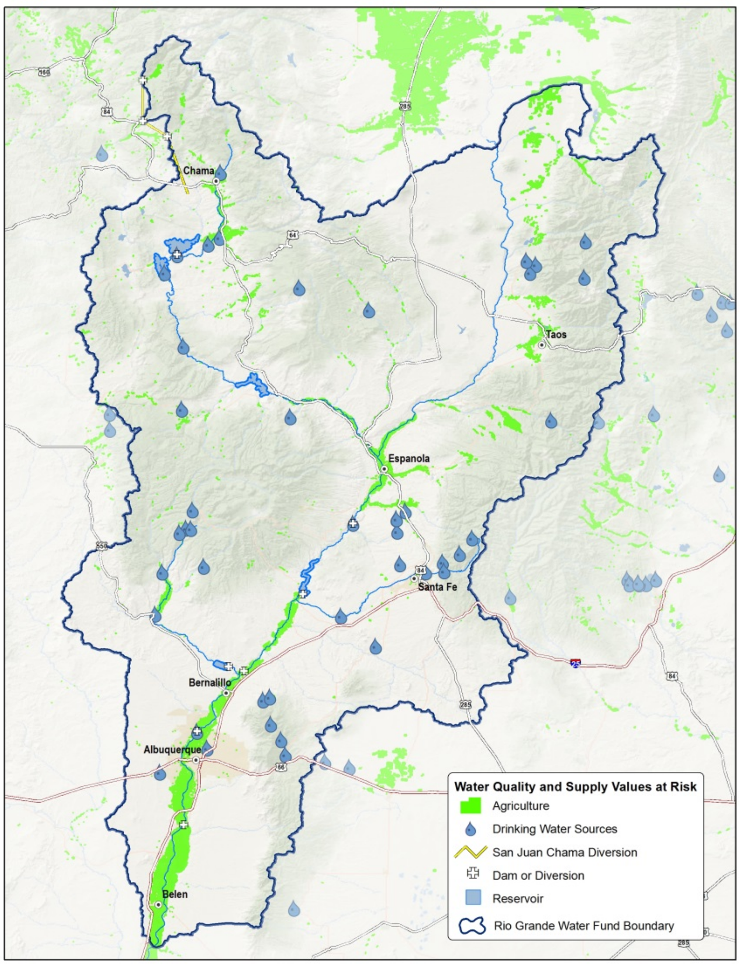
3. Summed Statewide Focal Area Score for Treatable Forest



Data Considered but Removed from the Focal Area Analysis

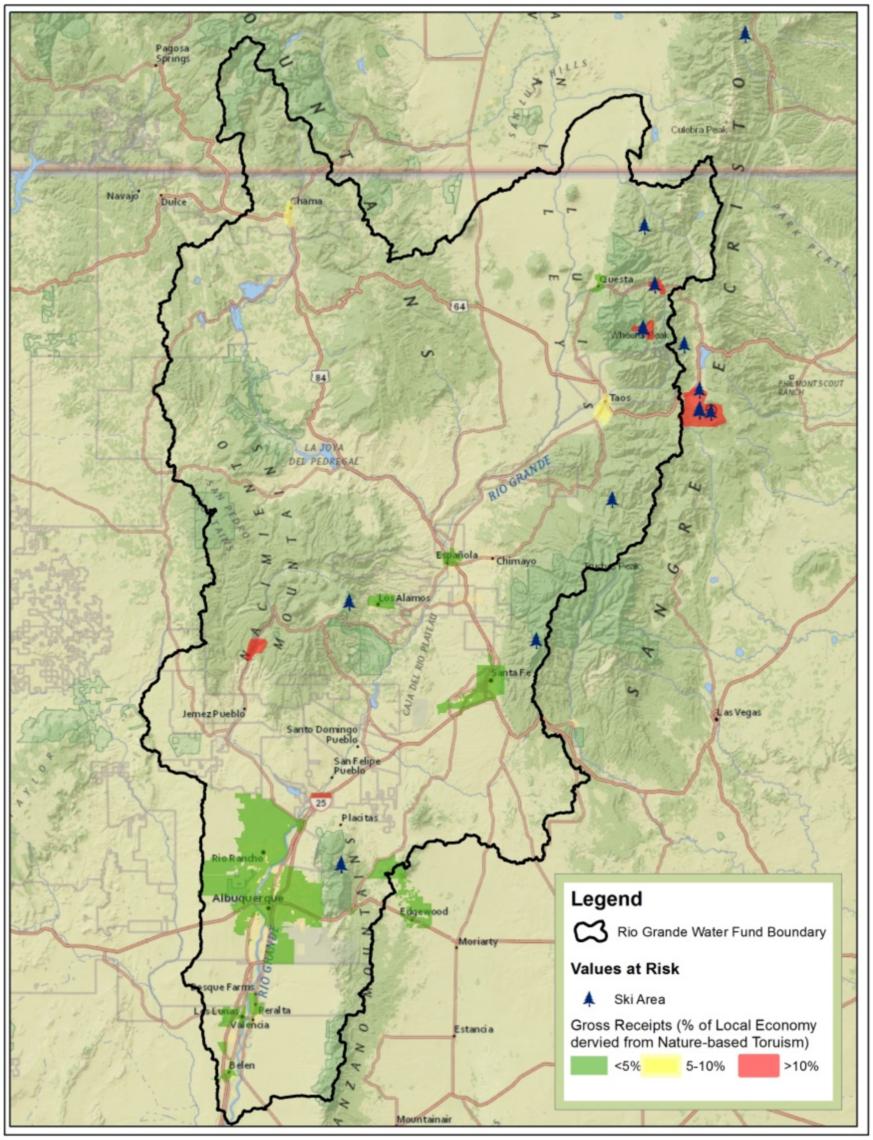
The focal area analysis identifies large landscapes with significant sources of risk from wildfire with precedence given to areas that could potentially provide other benefits such as wood supply or fish and wildlife habitat or were considered essential for protection of a critical resource such as the only source of drinking water. The emphasis, however, remains on sources of risk to the watershed. Treatment of these areas will provide additional benefits downstream. As a part of this effort, data were compiled to highlight other key values that are likely to be impacted by wildfire. The locations of these values represent critical places to be protected that are at risk; however, in many cases the locations are not in watersheds where treatment money to reduce risk of wildfire would have an impact. As a result, when included in the focal area analysis, watersheds with no treatable forest were identified as focal watersheds. For this reason, these values were ultimately removed from the focal area analysis. The data collected and identified included:

WATER QUALITY AND SUPPLY VALUES



1) Agriculture
2) Statewide drinking water sources
3) Dams, diversions, reservoirs

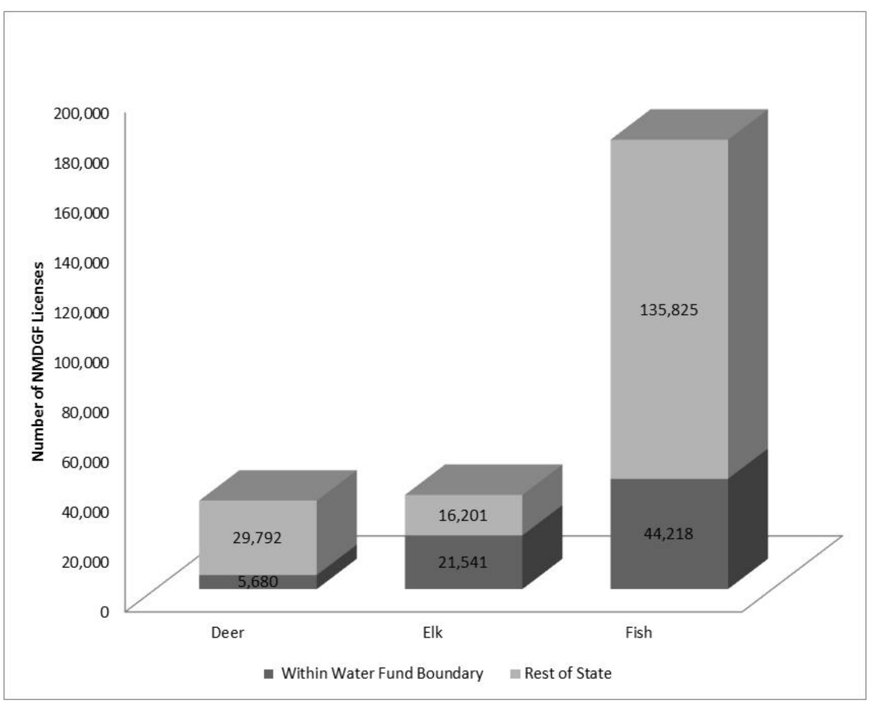
TOURISM VALUES



1) Ski Areas

2) Local economy (gross receipts from tourism as % of local economy)

3) Hunting and fishing (number of licenses)



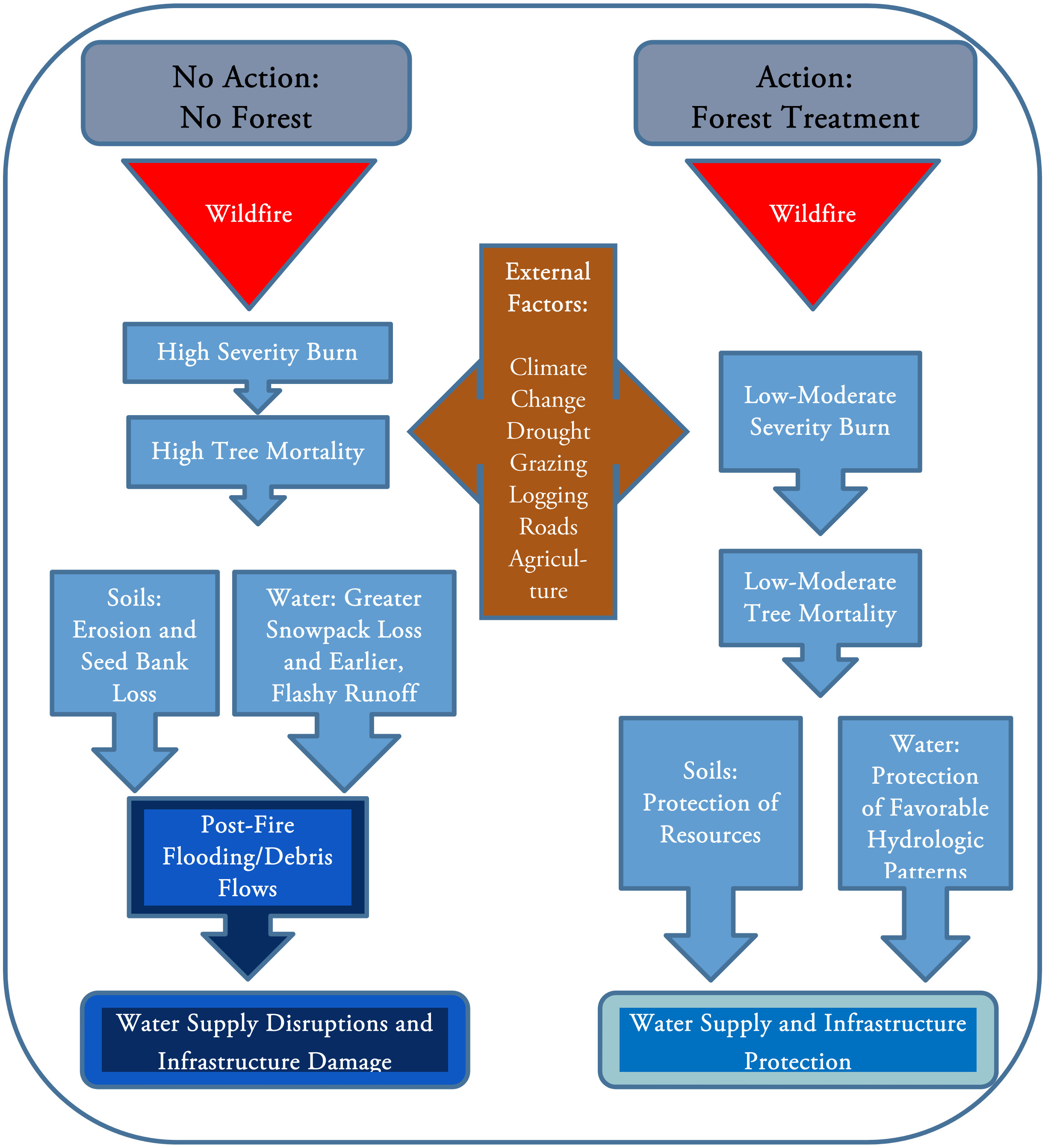
Appendix H – Monitoring Plan

Conceptual Model for the Rio Grande Water Fund

Based on the threats posed to water resources and on planned water fund activities to mitigate those threats, a conceptual model was developed to define critical monitoring information needed to ensure the Water Fund's goals are met. The conceptual model is based on the premise that forest tree density is a major factor controlling wildfire burn severity, which in turn influences post-fire effects such as tree mortality, soil erosion, seed bank loss, runoff (water yield), snowpack retention, flooding and debris flows that could impact the Rio Grande. Under the same moisture and weather conditions, the model assumes that a forest with high tree density (stems/acre) will burn more severely than a forest with lower tree density. Indeed, restored ponderosa pine forests maintain a more resilient structure that benefits from natural surface fires, which, in turn, discourage young tree survival to older age-classes and overstocking and thus reduces the consequent threat of stand-replacing wildfires[xi] (Mast, 2003). Furthermore, reducing the impact of wildfire over time in treated ponderosa pine forests, remaining trees grow thicker bark and ladder fuel limbs are shed, making the older trees more fire resistant than young trees[xii] (Habeck, 1992). Restored forests also provide more beneficial ecosystem services such as a reliable supply of high-quality water, which benefits downstream water users.

The conceptual model illustrates two distinct outcomes based on whether or not action is taken to reduce the risk of wildfire. Under the No Action scenario, a wildfire burns at high severity, resulting in subsequent loss of soil and vegetative resources, causing downstream impacts to water quality and quantity. Under the Action scenario, where forest treatments are conducted, a wildfire burns with lower severity, resulting in less loss of soil and vegetative resources, thereby limiting impacts to water quality and quantity.

As noted in the conceptual model (next page) , external factors also directly and indirectly impact water quality in the Rio Grande. Because the degree to which external factors impact water quality and quantity is difficult to determine and beyond the scope of the Water Fund, it is recommended that monitoring of water yield and water quality be limited to assessing the effects of forest treatments on these variables in a controlled setting, such as a paired basin study.


No Action:
No Forest
Action:
Forest Treatment
Wildfire
Wildfire
External Factors:
Climate Change
Drought
Grazing
Logging
Roads
Agricul-ture
High Severity Burn
High Tree Mortality
Soils: Erosion and Seed Bank Loss
Water: Greater Snowpack Loss and Earlier, Flashy Runoff
Post-Fire Flooding/Debris Flows
Water Supply Disruptions and Infrastructure Damage
Low-Moderate Severity Burn
Low-Moderate Tree Mortality
Soils: Protection of Resources
Water: Protection of Favorable Hydrologic Patterns
Water Supply and Infrastructure Protection

Appendix I – Glossary of Terms

Benefit transfer: A method of estimating economic values by transferring information available from studies already completed in one location or context to another. In the Las Conchas wildfire cost study, the benefit transfer method is used to estimate costs by transferring information from wildfire cost studies in other, comparable locations to New Mexico.

Bone dry ton: Wood or forest residue that weighs 2,000 pounds at zero percent moisture content.

Canopy closure: The percent area of tree canopy overlying the forest floor or the proportion of a forest stand covered by the crowns of live trees.

Crown fire: A fire that moves across the tops of trees or shrubs, typically killing them. As compared to a surface fire, which stays close to the ground surface and burns downed wood and herbaceous vegetation.

Dissolved oxygen: Dissolved oxygen refers to microscopic bubbles of gaseous oxygen that are mixed in water and available to aquatic organisms for respiration—a critical process for almost all organisms.

Ecosystem Services: The Millennium Ecosystem Assessment, an international synthesis of the world's ecosystems, compiled by hundreds of scientists, defines ecosystem service generally as benefits people obtain from ecosystems and divides these service into four categories: (1) supporting services such as seed and nutrient dispersal that are necessary to maintain ecosystems; (2) provisioning services that represent products people obtain from ecosystems such as food and water; (3) regulating services that represent benefits people obtain from the proper functioning of ecosystems such as water purification and carbon sequestration; and (4) cultural services that represent non-material benefits such as recreation and spiritual values.

Electrical conductivity: Electrical conductivity is a measure of water's ability to conduct electricity, and therefore a measure of the water's ionic activity and content—the higher the concentration of ionic (dissolved) constituents, the higher the conductivity. Conductivity in water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulfate and phosphate anions (ions that carry a negative charge) or sodium, magnesium, calcium, iron, and aluminum cations (ions that carry a positive charge).

Environmental impact statement: A public document produced by federal agencies that describes proposed activities on a landscape and discloses how those activities may impact the natural and social environment.

Fire-adapted forest: Forest types that evolved with, and are dependent on, periodic fire for tree regeneration, nutrient recycling and diversifying the structure and composition of the forest.

Fuel load: The total amount of combustible fuels in a defined area.

Groundwater: Water that collects or flows beneath the Earth's surface, filling the porous spaces in soil, sediment and rocks. Groundwater originates from rain, melting snow and ice and is the source of water for aquifers, springs and wells. The upper surface of groundwater is the water table.

Landscape-scale: A term commonly used to refer to action that covers a large area.

Low-value material: Woody material from forest restoration treatments that has no commercial value.

Resilience (ecological, forest or watershed): The ability of an ecosystem, forest or watershed to regain structural and functional attributes that have suffered harm from stress or disturbance.

Restoration (forest or watershed): For the water fund project "restoration" refers to ecological restoration. Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed. Forests that are overgrown because of past fire exclusion or inappropriate past management are considered damaged. Scientific understanding of historic natural conditions guides restoration actions.

Riparian area: The interface between land and a stream or river, often characterized by a green ribbon of plants.

Stewardship contract: A contracting agreement that focuses on end results rather than extracted wood or other resources. Stewardship contracts often include a number of activities that when combined will improve watershed health, such as thinning dense forests and planting riparian vegetation. These contracts can involve interested community groups as well as traditional forest businesses.

Surface water: Water found on the Earth's surface such as in a stream, river, lake, or wetland. It can be contrasted with groundwater and atmospheric water.

Turbidity: Turbidity is a measure of water clarity—how much the material suspended in water decreases the passage of light through the water. Suspended materials include soil particles (clay, silt and sand), algae, plankton, microbes and other substances. These materials are typically in the size range of 0.004 mm (clay) to 1.0 mm (sand). Turbidity can affect the color of the water.

Values at risk: Property, structures, physical improvements, natural and culture resources, community infrastructure, and economic, environmental, and social values that people care about, and that are at risk of being degraded or lost if the pace and scale of forest restoration is not increased.

Watershed: A watershed is the drainage area of a landscape where water from rain or melting snow and ice drains downhill into a body of water such as a river, lake, reservoir, pond, estuary, wetland, or aquifer. Watersheds include the streams, lakes and shallow aquifers that store and convey the water as well as the land surfaces from which water drains and the aquatic ecosystems that they support.

Watershed function: The five essential functions of watersheds are to: collect water that falls as rain or snow; store water and snow in various amounts and for different lengths of time; release water as runoff; filter and clean stored water and runoff; and provide habitat for plants and animals.

Appendix J: Endnotes

---

[i] Cannon, S.H., Gartner, J.E., Rupert, M.G., Michael, J.A., Rea, A.H., and Parrett, C. 2009. Predicting the probability and volume of post wildfire debris flows in the Intermountain Western United States: Geological Society of America Bulletin, v. 122, p. 127–144.
[ii]Finney, M.A., McHugh, C.W., Grenfell, I.C. and others. 2011. A simulation of probabilistic wildfire risk components for the continental United States. Stochastic Environmental Research and Risk Assessment; 25 (7):973-1000.
[iii] Finney, M. A. 2006. An overview of FlamMap fire modeling capabilities. In: Fuels management—how to measure success: conference proceedings. 2006 March 28-30; Portland, Oregon. Proceedings RMRS-P-41. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 213-220. (647 KB; 13 pages).
[iv] Brown, H.E. Baker Jr, M.B. Rogers, J.J. Clary, W.P.Kovner, J.L. Larson, F.R. Avery, C.C. and Campbell R.E. Opportunities for increasing water yields and other multiple use values on ponderosa pine forest lands. 1974. USDA Forest Service Research Paper RM-129
v U.S. Forest Service (USFS). 2014. Public LANDFIRE Reference Database (LFRDB). http://www.landfire.gov/
[vi] U.S. Forest Service (USFS). 2012. National Insect & Disease Risk Map. 30-meter data. Forest Health Technology Enterprise Team. Personal Communication
[vii] Oregon State University (OSU), PRISM Climate Group. 30-year climate normals, 1981–2010 http://www.prism.oregonstate.edu/, retrieved January 2014
viii Reynolds, Richard T.; Sánchez Meador, Andrew J.; Youtz, James A.; Nicolet, Tessa; Matonis, Megan S.; Jackson, Patrick L.; DeLorenzo, Donald G.; Graves, Andrew D. 2013. Restoring composition and structure in Southwestern frequent-fire forests: A science-based framework for improving ecosystem resiliency.Gen. Tech. Rep. RMRS-GTR-310. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.
ix Youtz, JA. Implementing Northern Goshawk Habitat Management in Southwestern Forests. From: Deal, R.L., tech. ed. 2008. Integrated restoration of forested ecosystems to achieve multi-resource. Gen. Tech. Rep. PNW-GTR-733. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.
[x] Simmers, I. (ed.). 1997. Recharge of phreatic aquifers in (semi-) arid areas. International Association of Hydrogeologists, 19, Balkema, Rotterdam
[xi] Mast, J.N. 2003. Tree Health and Forest Structure, Ecological Restoration of Soutwestern Ponderosa Pine Forests. Friederici, Peter (ed) Island Pres
[xii] Habeck, R. J. 1992. Pinus ponderosa var. ponderosa. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/ [2013, December 20].