



Forest Service
U.S. DEPARTMENT OF AGRICULTURE

Rocky Mountain Research Station

General Technical Report RMRS-GTR-423

May 2021

An Assessment of Forest and Woodland Restoration Priorities to Address Wildfire Risk in New Mexico

Michelle A. Day, Rachel M. Houtman, Pedro Belavenutti,
Chris Ringo, Alan A. Ager, and Steve Bassett



Day, Michelle A.; Houtman, Rachel M.; Belavenutti, Pedro; Ringo, Chris; Ager, Alan A.; Bassett, Steve. 2021. **An assessment of forest and woodland restoration priorities to address wildfire risk in New Mexico**. Gen. Tech. Rep. RMRS-GTR-423. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 70 p.
<https://doi.org/10.2737/RMRS-GTR-423>.

Abstract

The New Mexico Shared Stewardship Agreement created a framework to allow for the State of New Mexico and the USDA Forest Service to collaboratively identify mutual restoration goals to respond to the increasing suite of challenges facing the communities, landscapes, and natural and cultural resources of New Mexico. We used scenario planning to evaluate where forest management could achieve multiple shared restoration objectives, in particular, to reduce wildfire risk to water supply and quality; communities and infrastructure; and biodiversity. The results showed clusters of planning areas that were sources of substantial wildfire risk that span ownerships and forest types. Within a planning area there was a tradeoff between locating treatments to address wildfire risk to communities versus locating them in areas that will best reduce wildfire risk to water quality/supply. However, among planning areas the potential to treat two restoration priorities was often correlated, meaning that if you pick a planning area that is high risk for water quality/supply it will also be high risk to communities. The results also showed that risk was concentrated on particular ownerships within planning areas rather than spread out across multiple jurisdictions in terms of the areas identified for treatment in the modeling. Thus, planning areas are not necessarily compromised by not being cross-boundary. This report was intended as a decision support framework to prioritize planning areas, identify cross-boundary opportunities, and provide a wide array of maps and graphic outputs upon which to further develop active forest management programs.

Keywords: scenario planning, forest restoration, wildfire risk, ForSys

Cover photo

An autumn view from Mount Taylor in northwest New Mexico. Photo credit: John Formby

All Rocky Mountain Research Station publications are published by U.S. Forest Service employees and are in the public domain and available at no cost. Even though U.S. Forest Service publications are not copyrighted, they are formatted according to U.S. Department of Agriculture standards and research findings and formatting cannot be altered in reprints. Altering content or formatting, including the cover and title page, is strictly prohibited.

Authors

Michelle A. Day is a Biological Scientist in the Fire, Fuel, and Smoke Research Program, Rocky Mountain Research Station, Missoula, Montana.

Rachel M. Houtman is a Faculty Research Assistant in the Department of Forest Ecosystems & Society in the College of Forestry at Oregon State University in Corvallis, Oregon.

Pedro Belavenutti is a Research Associate in the Department of Forest Engineering, Resources, & Management in the College of Forestry at Oregon State University in Corvallis, Oregon.

Chris Ringo is a Senior Faculty Research Assistant in the Department of Crop and Soil Science in the College of Agricultural Sciences at Oregon State University in Corvallis, Oregon.

Alan A. Ager is a Research Forester in the Fire, Fuel, and Smoke Research Program, Rocky Mountain Research Station, Missoula, Montana.

Steve Bassett is Director of Spatial Planning & Management, The Nature Conservancy, Santa Fe, New Mexico.

Acknowledgments

Numerous Forest Service and State of New Mexico staff contributed data and ideas and guidance on the development of this assessment. These include (in no particular order) Ian Fox, Jack Triepke, Candace Bogart, Rick Crawford, Laura McCarthy, Ryan Heaslip, Donald Vandendriesche, Alicia San Gil, and others. Thanks to Catherine Doyle-Capitman for sharing a report summarizing results from interviews with key shared stewardship partners from the State, Forest Service, and The Nature Conservancy. Thanks also to Palaiologos Palaiologou and Ken Bunzel for spatial analysis.

Contents

Executive Summary	1
Introduction	2
Methods	4
Data	4
Analysis	17
Results and Discussion	20
Priority Areas for Addressing Wildfire Risk on Forests and Woodlands.....	20
Tradeoffs	29
Priority Planning Areas for Shared Stewardship	33
Cross-Boundary Wildfire Transmission and Risk to Communities and Infrastructure	43
Conclusions	47
References	50
Appendix A. Supplementary Maps	54
Appendix B. Additional Modeling Details	69

Executive Summary

The New Mexico Shared Stewardship Agreement created a framework to allow for the State of New Mexico and the USDA Forest Service to collaboratively identify mutual restoration goals, further common interests, and effectively respond to the increasing suite of challenges facing the communities, landscapes, and natural and cultural resources of New Mexico. We used scenario planning to evaluate where forest management could achieve multiple restoration objectives, in particular, reducing wildfire risk to: water supply and quality, communities and infrastructure, and biodiversity; and assessing tradeoffs. Tradeoffs were revealed by comparing how much risk would be reduced for each restoration objective when projects prioritized one or another of the objectives. The analysis was done for every subwatershed (12-digit hydrologic unit code, or HUC12, henceforth referred to as “watershed”) with forest and woodland cover types in the State, and watersheds were ranked according to the likelihood that restoration activities would reduce risk for all three restoration objectives combined. Overall, the results showed clusters of planning areas that are sources of substantial wildfire risk that span ownerships and forest types. Simulated treatments that target risk identified in the assessments suggested rapid, exponential outcomes in terms of reducing risk as planning areas are implemented over increasingly larger scales within the State. The results show that within a planning area there is a tradeoff between locating treatments to address wildfire risk to communities versus locating them in areas that will best reduce wildfire risk to water quality/supply. However, among planning areas, the potential to treat two restoration priorities is often correlated, meaning that if you pick a planning area that is high risk for water quality/supply it will also be high risk to communities. This simplifies the prioritization at the scale of planning areas. The results identified 500 priority watersheds for restoration across all jurisdictions with forest and woodland cover types (representing approximately 20 percent of all watersheds at risk), and of these, 250 high priority watersheds have been identified on National Forest System and adjacent lands. Such a large number of watersheds is necessary to accommodate an all-lands approach to management across a range of federal, tribal, and private lands to allow for broad engagement in management activities. In this application, scenario planning provided the opportunity to assess various resource objectives in a single model—and to examine tradeoffs between different management approaches—allowing for a more integrated approach to priority setting. It also allowed state and federal partners to see opportunities for leveraging financial, technical, and labor-based resources to achieve desired management outcomes.

Introduction

On November 14, 2019, the USDA Forest Service and the New Mexico Forestry Division signed the New Mexico Shared Stewardship Agreement, authorizing a collaborative relationship that has informally existed since 1957. The purpose of this Agreement was to create a framework for the State and Forest Service “to identify and accomplish mutual goals, further common interests, and effectively respond to the increasing suite of challenges facing the communities, landscapes, and natural and cultural resources of New Mexico” (USDA Forest Service and State of New Mexico 2019). A key priority identified in the New Mexico Shared Stewardship Agreement was for the State and Forest Service to collaboratively determine landscape-scale restoration priorities and shared goals for forest and watershed management on all lands across the State. Of special concern was the increasing size and severity of wildfires and their impacts to communities, firefighters, natural resources, and water supplies.

The New Mexico State forester and Forest Service regional planners contacted the authors of this report to initiate a collaborative assessment to analyze tradeoffs between different management priorities and to develop priority maps that consider risk of wildfire to communities, water supplies, and biodiversity. This document contains the results of the assessment of priorities and potential outcomes for shared stewardship projects in New Mexico. The analysis is based on published Forest Service, U.S. Department of Agriculture, and New Mexico State assessments and data. The broad intent of the assessment was to identify priority areas to address cross-boundary wildfire risk that threatens a wide range of values in the State. The assessment was completed using tools built by the Rocky Mountain Research Station as part of the Forest Service Scenario Investment Planning Platform (SIPP). The scenario planning system has been applied to several shared stewardship case studies as part of the shared stewardship strategy to address restoration challenges by working collaboratively to identify priorities for landscape-scale treatments. In the current application, the SIPP process evaluated where activities could achieve multiple restoration objectives, including reducing risk from wildfire and postfire impacts to water supply and water quality, communities, infrastructure, and biodiversity; and assessing tradeoffs. These were revealed by comparing how much risk would be reduced for each restoration objective (water, community, biodiversity) when projects prioritize one or another of the objectives. The analysis was done for every subwatershed (12-digit hydrologic unit code, or HUC12, henceforth referred to as “watershed”) with forest and woodland cover types in the State. Watersheds were ranked according to the likelihood that restoration activities would reduce risk for all three restoration objectives combined. These maps and associated analyses were vetted by local subject

matter experts, ensuring the results produced were accurate, ground-truthed, and could effectively help guide restoration in New Mexico over the next decade.

An important part of this project is the use of cross-boundary opportunities to address the goal of the shared stewardship initiative. Cross-boundary wildfire is an artifact of landscape fragmentation with respect to ownership and administrative fire management jurisdictional boundaries (Ager et al. 2017a). Cross-boundary conditions are an important issue in the interface between communities and large tracts of public and private wildlands (Haas et al. 2015) where natural fire regimes are often in conflict with socioeconomic values and land management goals at the parcel scale. Cross-boundary risk issues are highly relevant to fire management, including recent initiatives to expand the use of both prescribed fire and natural ignitions to reduce fuels, reduce future suppression costs, and restore low severity wildfire in fire-adapted forests (North et al. 2015, Prichard et al. 2017). We used a cross-boundary wildfire exposure assessment developed in our prior work to prioritize planning areas and contrast the results with more conventional risk assessments included in the study.

There are a number of limitations in the assessment that are being addressed with refinements to the process as part of ongoing projects. It is important to note that we simulated the potential reduction in risk from treatments within planning areas assuming that risk was largely mitigated if 30 percent of the planning areas were treated with some form of mechanical treatments. Thus, we are modeling the potential reduction in risk relative to the maximum possible in a particular planning area. It is also important to note that the timber outputs and maps in this report are preliminary until harvest prescriptions are refined to local conditions. These data were not made available to the authors in time for simulations. The information in the report will change after more detailed input data are obtained.

Methods

Data

Land Base Stratification

We built a geospatial data set for the assessment that partitioned the State of New Mexico into individual stands that were then attributed by land ownership, ecological response units, potential planning areas, and planning areas. Land ownership (fig. 1), Ecological Response Unit (ERU), and watershed boundaries were downloaded from the Forest Service Southwestern Region GIS website and the majority ERU was assigned to each stand. We used the ERU data to specifically target forested and woodland ERUs based on direction from Region 3 and New Mexico State Forestry staff. These ERUs included mixed conifer-frequent fire, ponderosa pine, and ponderosa pine-evergreen oak. The State was divided into 3,219 planning areas using 12th code hydrological units. The planning areas ranged in size from 12 to 276,432 acres (small watersheds were a result of watersheds that were bisected by state boundaries). Data on potential treatment units (henceforth “Stands”) were obtained from Region 3 staff and totaled 2,034,188 polygons. Areas with an opportunity for mechanical treatment were defined as stands that were not in protected areas (designated wilderness, designated roadless, and wilderness study areas); not in high slope areas (greater than 40 percent as derived from a one-arc-second digital surface model, as in Gesch et al. 2019); and not in areas treated or burned since 2008 (fig. 2). Burned areas were accessed from the Monitoring Trends in Burn Severity (MTBS) program (Eidenshink et al. 2007). Treated areas were accessed from the New Mexico Vegetation Treatment Database (NMFWR 2020). The landscape was further refined to allow mechanical treatments only in areas classified as forest and woodland where mechanical treatments are permitted in over half the stand and these represent areas available for treatment in the model (fig. 3). Forest and woodland stands were mapped based on ERUs.

Risk Assessments

Restoration priorities were analyzed based on predicted impacts of wildfire as described in three composite assessment layers developed for the 2020 New Mexico Forest Action Plan (NMFD 2020). These included: (1) wildfire risk to wildland communities and infrastructure, (2) wildfire risk to water quality and supply, and (3) wildfire risk to biodiversity (table 1; figs. 4, 5, 6). All restoration priorities were attributed based on the mean raster value of the stand. Relative importance of resources was not mapped for this assessment. Within the individual risk models, risk to each constituent valued resource or asset was indexed to range from 0 to 1 and then summed and re-indexed. Positive changes in resource value were not evaluated in this assessment; their omission should not be interpreted to indicate fire is always damaging to resources.

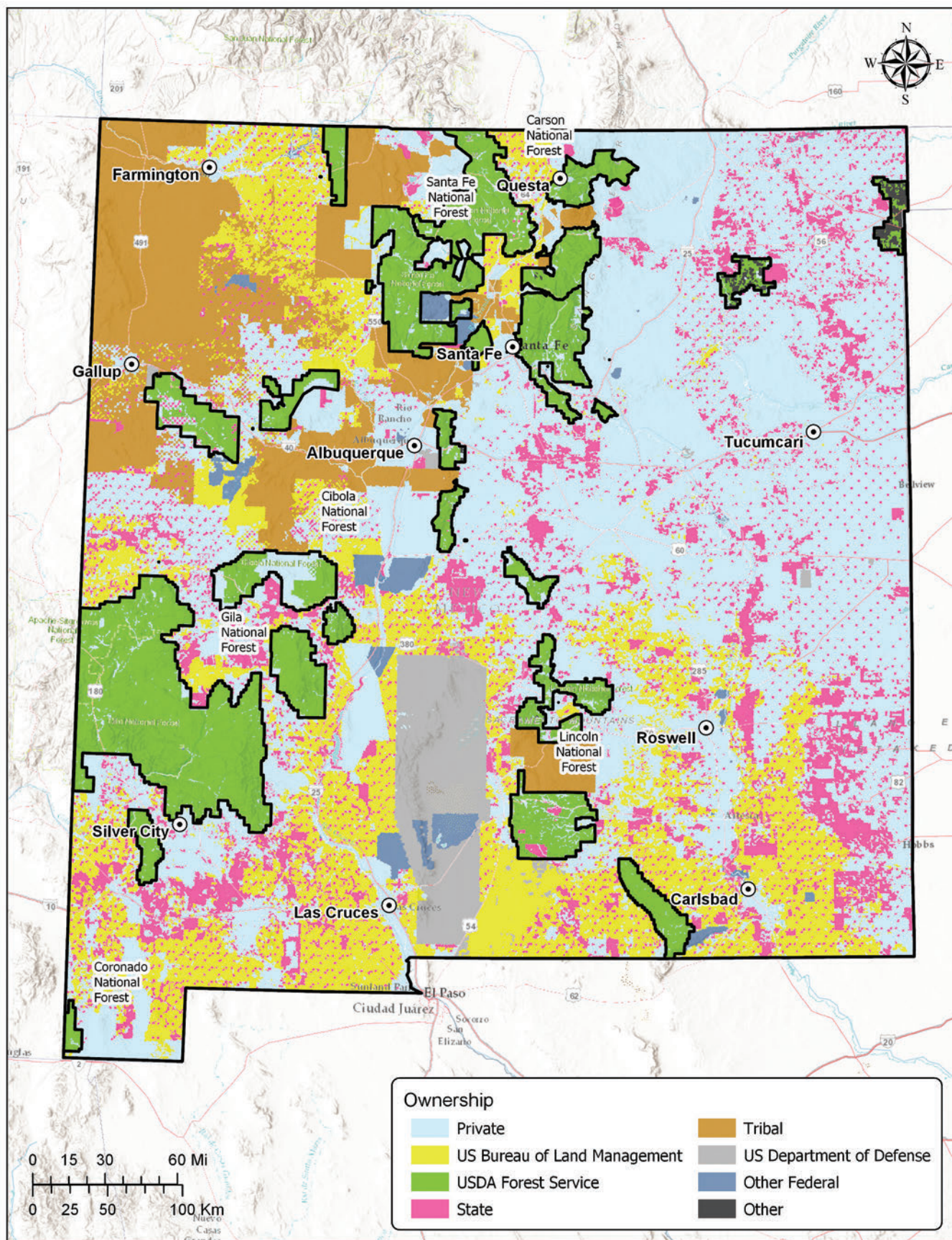


Figure 1—Land ownerships in the New Mexico shared stewardship study area. Other federal is NPS, FWS, Dept of Agriculture, BoR, DOE, or Other National Agency; State is State, State Wildlife Area, or State Park; Other = Other Govt or County.

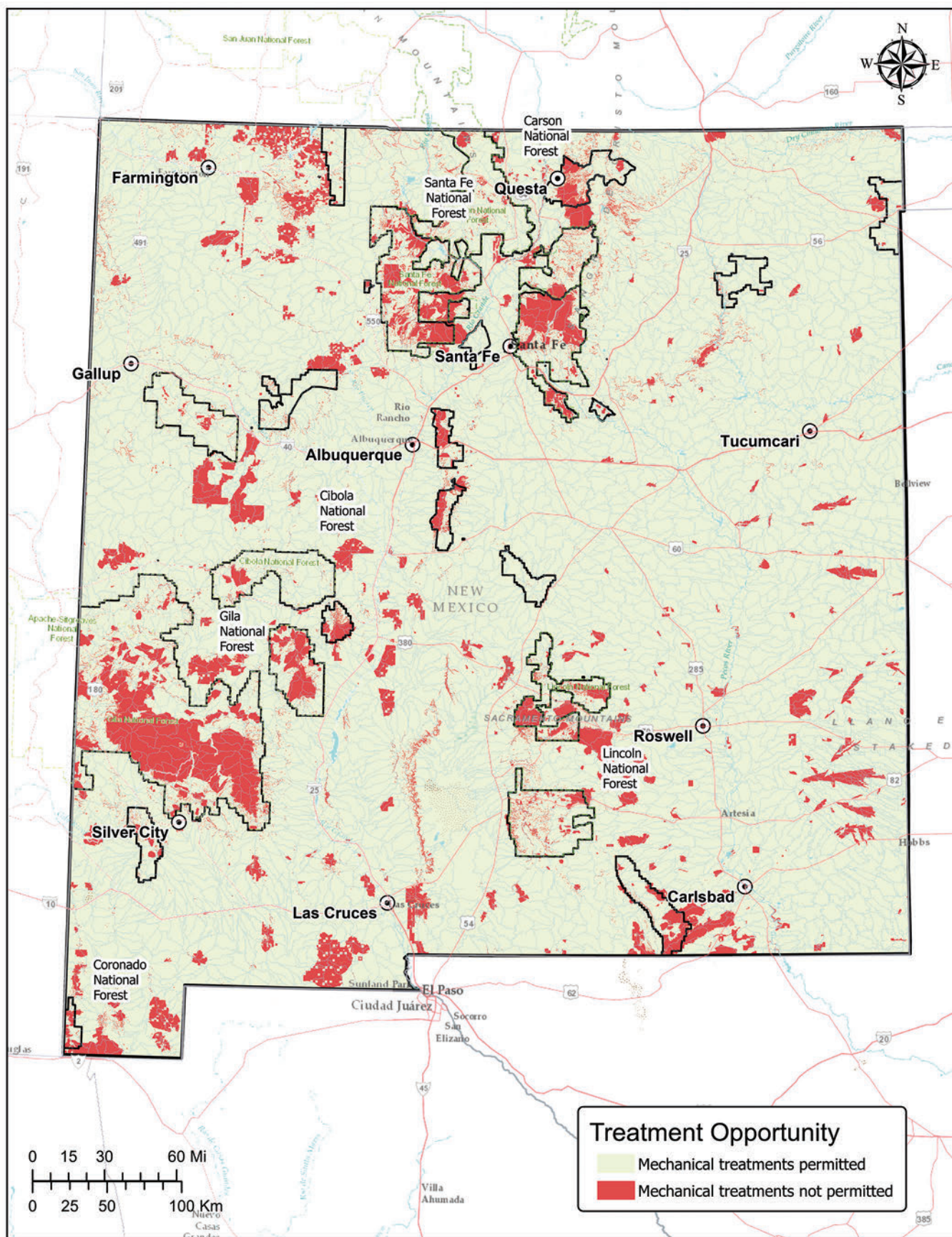


Figure 2—Areas excluded from mechanical treatments in the New Mexico study area (red areas on map). These areas include wilderness and other protected areas, steep slopes, or areas recently burned or treated.

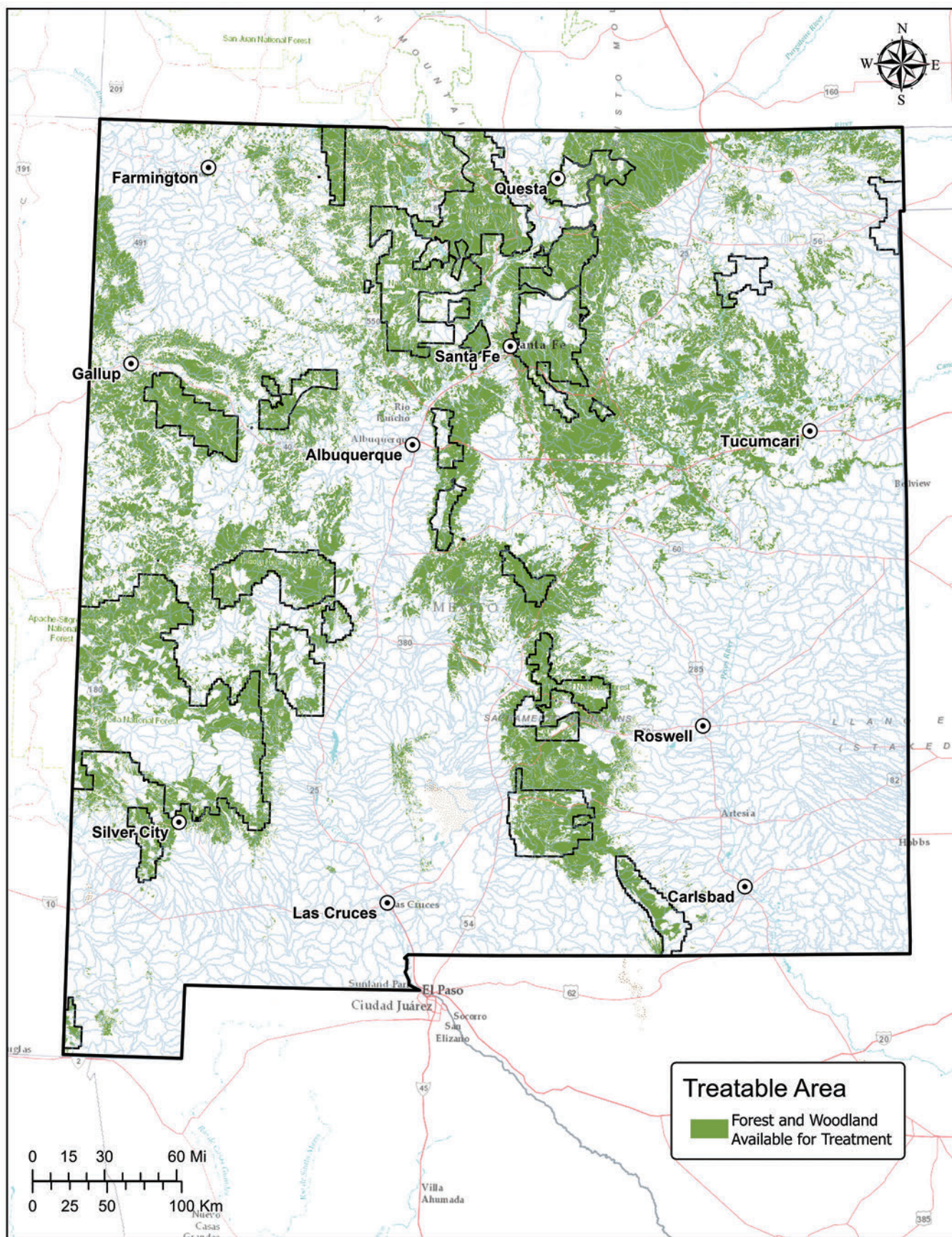


Figure 3—Areas with the opportunity for restoration treatments in the New Mexico study area in forest and woodlands. These areas are a subset of lands symbolized as white in figure 2, and represent stands available for treatment in the model.

Table 1—Composite wildfire risk metrics used as restoration priorities in scenario planning analysis and corresponding individual metrics.

Composite priority	Individual risk layer
Risk to wildland communities and infrastructure	Post-debris flow risk to major roads
	Wildfire risk to buildings
	Post-fire flood risk to buildings
Risk to water quality and supply	Post-fire erosion risk to water intakes and diversions
	Post-fire debris flow risk to water transmission
	Wildfire risk to irrigation water supply
	Wildfire risk to public water supply
Risk to biodiversity	Wildfire risk to terrestrial threatened and endangered critical habitat
	Wildfire risk to large intact blocks
	Wildfire risk to rare plants (important plant areas)
	Wildfire risk to connectivity (least cost)
	Wildfire risk to connectivity (omnidirectional)
	Wildfire risk to terrestrial species of economic and recreational importance
	Wildfire risk to NMCHAT species of concern
	Wildfire risk to riparian corridors

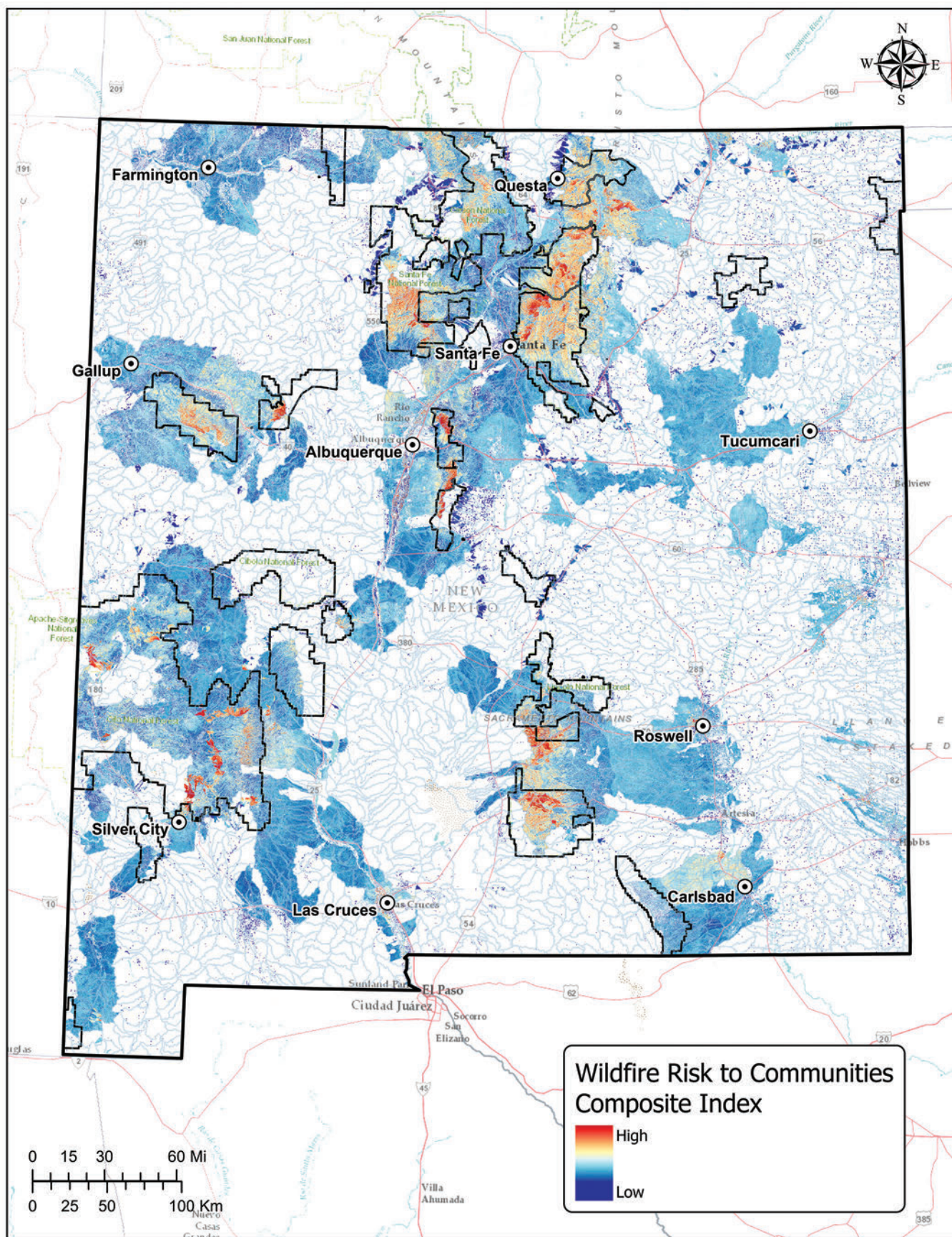


Figure 4—Wildfire risk to wildland communities and infrastructure composite index used to prioritize treatments. See table 1 for a list of individual risk metrics used in the composite. See Appendix A for maps of individual risk metrics.

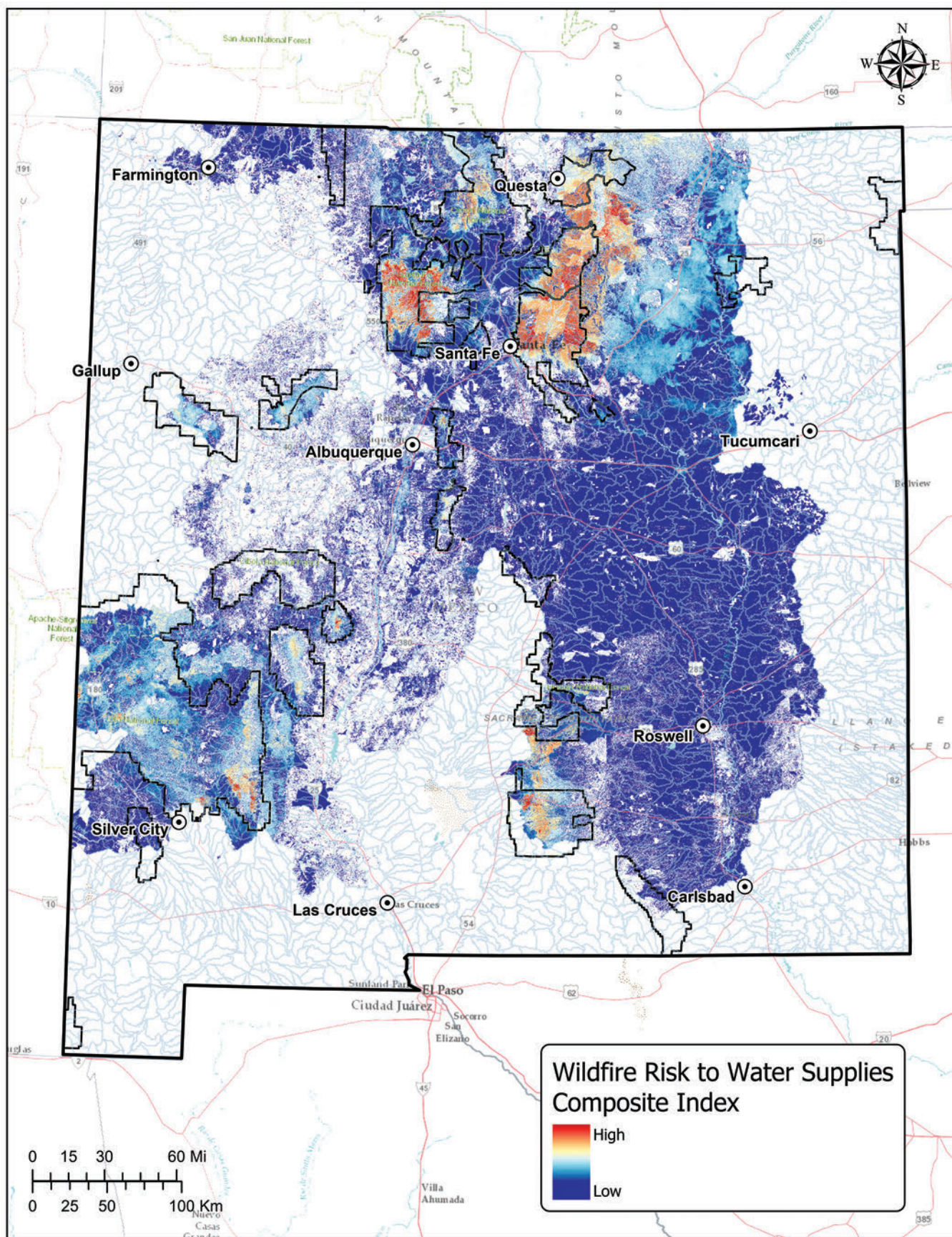


Figure 5—Wildfire risk to water quality and supply. See table 1 for a list of individual risk metrics used in the composite. See Appendix A for maps of individual risk metrics.

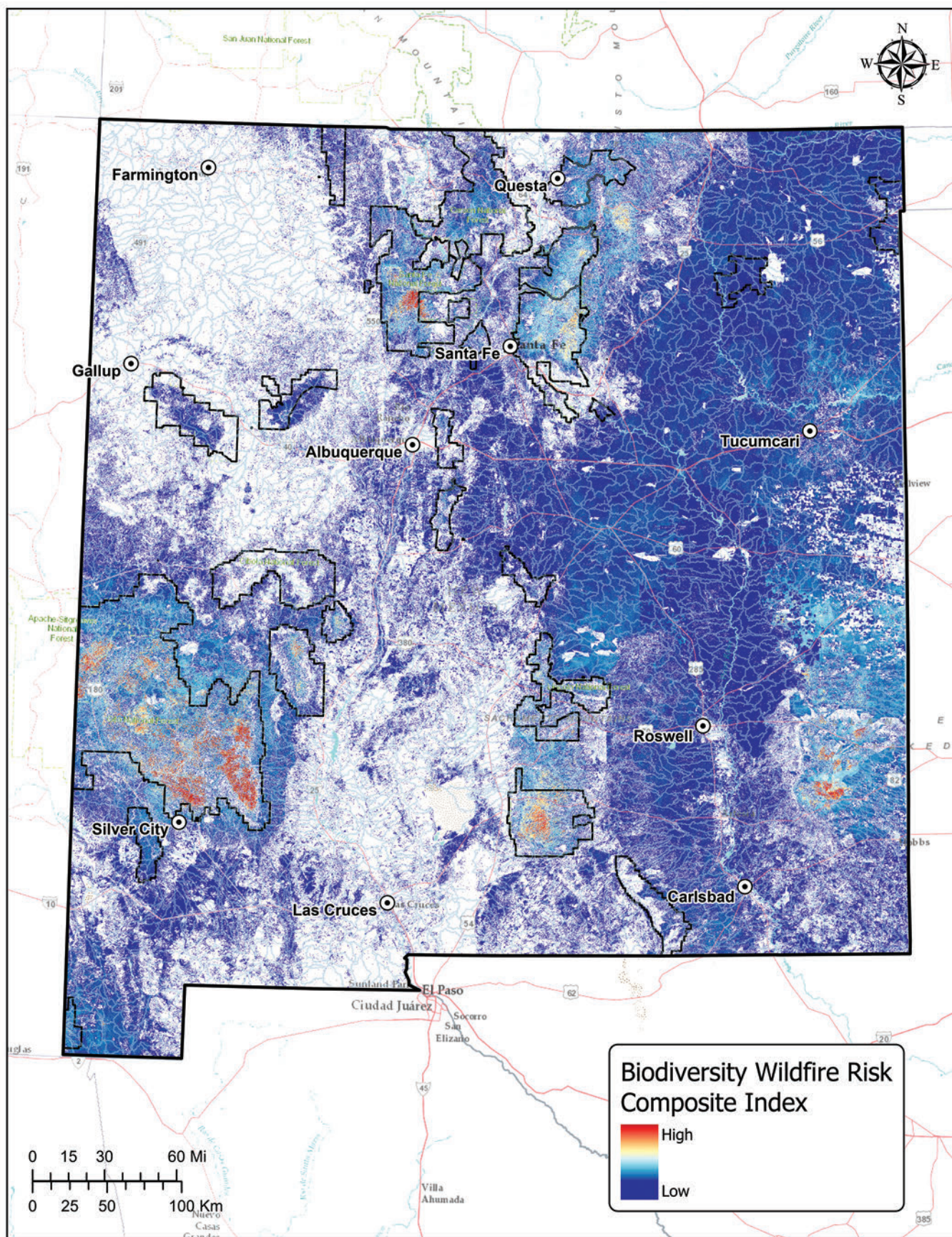


Figure 6—Wildfire risk to biodiversity. See table 1 for a list of individual risk metrics used in the composite. See Appendix A for maps of individual risk metrics.

Risk to Wildland Communities and Infrastructure

Mean risk to wildland communities and infrastructure was calculated for each stand. This risk was modeled as the indexed sum of wildfire risk to buildings, postfire flood risk to buildings, and postfire debris flow risk to major roads.

Wildfire risk to buildings was modeled using a simplified quantitative wildfire risk assessment approach, following the standard risk assessment framework (Scott et al. 2013). Building density was mapped using average building footprint cover within a 270-meter radius neighborhood around each pixel, based on a quality-screened statewide building footprint centroids dataset attributed with footprint area (Microsoft 2018). A rudimentary response function describing the susceptibility of buildings to fire was developed assuming no change in values for flame lengths less than or equal to 1.8 m and a total loss of value when exposed to flame lengths greater than 1.8 m. The annual probability of flame lengths > 1.8 m was used to map wildfire hazard (USDA Forest Service 2016). Wildfire risk to buildings was modeled as the product of the building density index and the wildfire hazard index.

Postfire flood risk to buildings was modeled assigning value to watersheds expected to produce postfire flooding that would inundate buildings in downstream floodplains, weighted by both the number of downstream buildings expected to be inundated and by the relative hazard of flood production. Flood production hazard was modeled using a differenced flash flood production index (FFPI). The FFPI was modeled under current hydrologic conditions following Zogg and Deitsch (2013). Expected postfire flood hazard was modeled using the same approach but with a conditional postfire landscape assuming burn severity is positively related to prefire vegetation density. The difference between postfire FFPI and prefire FFPI was used as the model of wildfire-induced flooding potential. Annual burn probability was used to identify the areas where stands are most likely to burn and then produce postfire flooding. Postfire flood inundation areas were mapped as areas with a prefire 500-year recurrence inundation depth greater than 0.2 m (0.5 ft) (Wing et al. 2017). Building points in the floodplain were mapped to the floodplain within each watershed and the upstream source areas were weighted by the sum of downstream buildings, limited to only the floodplains of streams that were 5th-order or lower to account for larger streams being able to carry localized postfire flood flows without reaching 500-year event levels. Upstream flood hazard was only increased in weight for a downstream watershed if there were at least 10 buildings in the flood hazard zone to reduce computer processing time.

Postfire debris flow risk to major roads was modeled based on expected burn severities, basin characteristics, and the intersection of basins with major roads. Roads in the National Highway Planning Dataset (USDOT 2019) were assumed to be major roads, relied on for access and egress during emergencies as well as critical for economic and social activity. Postfire debris flow hazard was modeled with the algorithms used by Burned Area

Emergency Response (BAER) teams following a fire (Staley et al. 2018), but instead of using burn severity data from the MTBS data to parameterize the debris flow models as the BAER teams do, a prefire model of expected burn severity was developed based on prefire canopy cover (Bassett and Lopez 2020). Annual postfire debris flow hazard was modeled by multiplying the conditional debris flow hazard (hazard if a fire burns) by annual burn probability (USDA Forest Service 2016). Because roads in New Mexico generally follow rivers in forested areas, debris flow prediction basins that intersect major roads are assumed to produce debris flow that would impact major roads. There may be road characteristics that reduce the susceptibility of the roads—such as a road far above the floodplain or with a bridge designed for postfire impacts—but this level of detail was not available for inclusion in this analysis.

Risk to Water Quality and Supply

Mean risk to water quality and supply was calculated for each stand. This risk was modeled as the indexed sum of wildfire risk to water supply for irrigation, wildfire risk to water supply for public water systems, postfire erosion risk to water intakes and diversions, and postfire debris flow risk to water transmission streams used to meet inter- and intrastate water delivery requirements.

Wildfire risk to water supply for irrigation was modeled as the expected change in value of runoff for irrigators caused by wildfire. Runoff value was modeled as the index of beneficiary-weighted annual surface runoff in beneficiaries per acre foot of runoff. Historical records of the number of irrigators dependent on each diversion were used to measure benefit where available (Saavedra 1987). Where only the number of acres irrigated was available for a diversion, an acres-per-irrigator conversion factor was used to estimate the number of irrigators. Number of irrigators per diversion was selected as the measure of beneficiaries, rather than acres irrigated, because water rights are held by irrigators, and to account for the social and cultural significance of small kitchen gardens that sustain families and communities on relatively small acreages. Historical beneficiary data were used because current data are not available. While the records are certainly out of date, geographic patterns of diversion are expected to remain the same. Total downstream beneficiaries were aggregated by intersecting source watersheds delineated for each irrigation diversion, as mapped from State of New Mexico diversion records, topographic maps, and aerial photographs. Average annual quick-flow runoff from 2000 to 2013 was used to represent the sources of water supply (Reitz et al. 2017). Total irrigators were divided by the average annual surface runoff for each stand to model the quotient of dependent downstream irrigators per acre foot of average annual runoff. This beneficiary-weighted water supply was assumed to be susceptible to wildfire through changes in watershed function caused by wildfire. The response function used to model this susceptibility was no change in value for flame lengths ≤ 1.8 m and complete value loss when > 1.8 m. Wildfire hazard was

mapped using the same data used to model wildfire risk to buildings that are described above. The resulting risk map highlights areas where wildfire impacts to water supply are likely and would affect watershed function in stands that produce runoff that is relied upon by many downstream water users.

Wildfire risk to water supply for public water systems was modeled as the expected change in value of runoff for irrigators caused by wildfire. Runoff value was modeled as the index of beneficiary-weighted annual surface runoff in beneficiaries per acre foot of runoff. Water system user data were mapped to points of diversions and their upstream source watersheds (US EPA 2019). Total downstream beneficiaries were summed for all these source watersheds to map the distribution of source dependence. Total beneficiaries for each stand were divided by the average annual surface runoff for each stand (as described above), to model the quotient of dependent public water system users per acre foot of average annual runoff. This beneficiary-weighted water supply was assumed to be susceptible to wildfire, in the same manner as the water supply for irrigation.

Postfire erosion risk to water intakes and diversions was modeled as the expected change in value of potential sources of erosion upstream from points of diversion caused by wildfire. Severe wildfire disturbance creates bare and damaged soils that are susceptible to erosion. The Kf-factor is used to model the relative susceptibility of an area to erosion. A simple model combining slope and Kf-factor was used to create a classification of erosion hazard (NRCS 1998). When multiplied by annual fire hazard, the resulting model depicts the areas where postfire erosion is most likely to occur. Water diversions and systems are most impacted by changes in watershed characteristics immediately upstream from the point of diversion, and this potential for producing impacts decreases as distance upstream increases (Weidner and Todd 2011). A course filter delineating the most critical upstream source for erosion hazard was mapped using an upstream source distance of 25 km. While sources of watershed impacts are not limited to 25 km, for this model only these close source areas are mapped as potential sources of erosion hazard. Postfire erosion risk to diversions was mapped to highlight the areas where postfire erosion is most likely to occur, and where that erosion hazard would impact the most surface water intakes and diversions.

Postfire debris flow risk to water transmission streams that are used to carry water to meet inter- and intrastate water delivery requirements was mapped using a generalized benefit/source ecosystem services value map. Water transmission streams and water delivery via those streams have been impacted by debris flows produced by recently burned tributary watersheds (NMFD 2020). Transmission streams were mapped as any stream below a federal reservoir where water is stored for delivery downstream. Impacts to streams above these reservoirs would have limited impact on water deliveries because operations would not be altered. Direct tributaries were mapped as any watershed that flows directly into a transmission stream. Postfire debris

flow hazard was mapped in the same manner as for debris flow risk to major roads described above. Risk is highest where burn probability is highest and conditional debris flow hazard is greatest.

Risk to Biodiversity

Mean risk to biodiversity was calculated for each stand. Risk to biodiversity was the indexed sum of wildfire risk to critical habitat for terrestrial threatened and endangered species, large intact blocks of habitat, state Important Plant Areas, connectivity, habitat for terrestrial species of economic and recreational importance, habitat for species of concern, and riparian corridors. These value maps were developed by The Nature Conservancy in collaboration with Natural Heritage New Mexico. Metadata describing these value maps are available in the 2020 New Mexico Forest Action Plan (NMFD 2020). Susceptibility to wildfire for the biodiversity resources was modeled with a simple response function assuming no change in values for flame lengths ≤ 1.8 m and a total loss of value when exposed to flame lengths > 1.8 m.

Potential Harvest Volume

Data on potential harvest volume (fig. 7) were generated by the authors and involved simulating harvest prescriptions with the Forest Vegetation Simulator using the imputed plot data from Riley et al. (2019) and modeling methods described in Ager et al. (2019). Timber volume was not used to prioritize any treatments but is reported as an effect of treatment in the following scenarios. Timber harvest calculations do not include insect and other mortality from 2015 to 2018. The area affected by these disturbances may be substantial. Live timber volume was derived from imputed FIA tree lists and assigned across the region using 2014 LANDFIRE landscape condition data as described in Riley et al. (2021).

Cross-Boundary Wildfire

We used a cross-boundary wildfire exposure assessment developed in our prior work (Palaologou et al. 2019) to quantify the relative magnitude of cross-boundary (incoming, outgoing) versus non-cross-boundary (i.e., self-burning) area burned based on land ownership of the simulated ignition, and the resulting fire perimeter. The layer was created using outputs from the large fire simulator, FSim. The FSim perimeters and ignitions were intersected with land ownership derived from the Protected Areas Database (USGS 2016) and thus do not fully align with the land ownership layer provided by Region 3 GIS staff. The resulting fire perimeter fragments were partitioned into self-burning (i.e., burned areas within the same land ownership as the ignition) and cross-boundary (i.e., burned areas outside of the ignition ownership). The layer was used to attribute the New Mexico stand layer with the percentage of fires that start in that land parcel, cross land parcel boundaries and burn another ownership. For example, a given stand within the national forest will be attributed with the percentage of area burned by wildfire that burned into adjacent tribal and BLM lands (and all other ownerships).

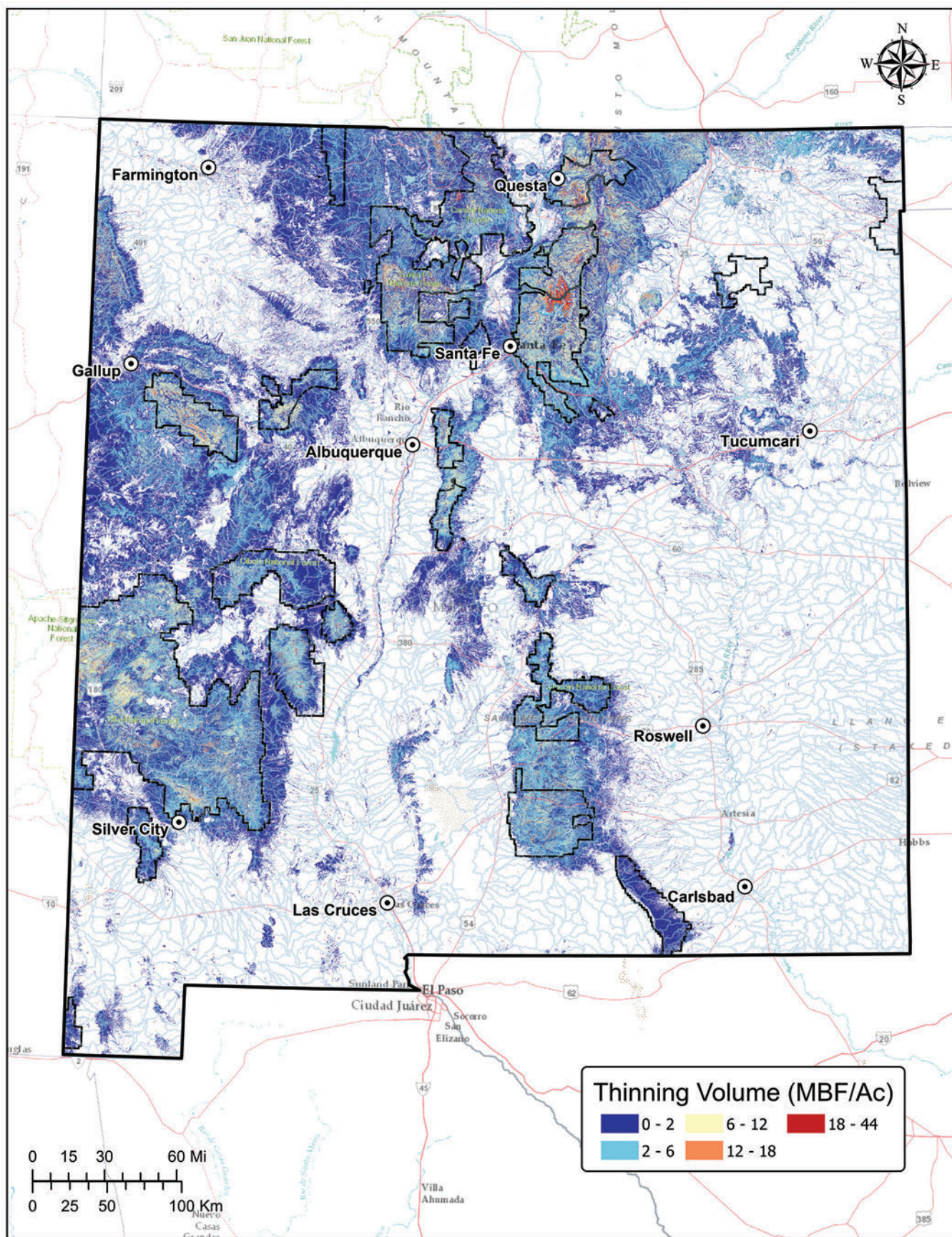


Figure 7—Merchantable live thinning volume for forests and woodlands based on Forest Inventory and Analysis (FIA) imputed tree list data (Riley et al. 2021).

Analysis

Model Description

We used the ForSys model (formerly Landscape Treatment Designer, Ager et al. 2012, Ager et al. 2013) to model hypothetical restoration scenarios and identify tradeoffs among different restoration objectives. Application of the system has been described in several publications (Ager et al. 2016, Ager et al. 2019, Ager et al. 2017b). The ForSys model can be used to generate and analyze spatial prioritization of many types of management activities, including fuel breaks, prescribed fire, aquatic restoration, and risk transmission. Scenarios are built by specifying one or more objectives (e.g., revenue), activity constraints (e.g., budget, area treated), and stand treatment thresholds (e.g., fire behavior). The outputs identify prioritized sequences of planning areas and stands to treat within them, and tradeoffs among different management objectives. ForSys solves the prioritization problem using simple optimization methods with or without adjacency constraints depending on the application. In the current application, we used existing planning areas described above within the program to identify stands to treat that maximized the objective value (e.g., restoration priorities) while meeting constraints.

Scenarios

In the current application, we simulated treating 30 percent of each planning area while prioritizing one or more of the restoration priorities described above. Treatments consisted of thinning to a specific basal area target based on the ERU. Ancillary treatments for surface fuels reduction (mastication and underburning) were assumed to be part of the treatments where conditions are appropriate. It was assumed that the risk identified in the assessment would be significantly addressed by treating 30 percent of the planning area (Finney et al. 2007). Although the reduction in risk and influences of climate vulnerability can be quantified with this system and companion tools (Ager et al. 2011), the 3-week time window for the current assessment report precluded these additional analyses. Treatments were assumed to generate merchantable timber volume as estimated from thinning simulated with the Forest Vegetation Simulator (Crookston and Dixon 2005, Dixon 2002).

We used average per-area condition of each stand in the selection algorithm to remove potential bias resulting from stand size. However, overall optimality of planning areas was based on the total objective value calculated as the area weighted quantity (e.g., total thinning volume) to account for differential contribution to the objective from stands of different sizes. Thus, stands were added to planning areas based on mean objective values for that stand, and once the treatment constraint was met, the total objective value was summed for all treated stands in the planning area. To standardize reporting of different metrics, we calculated the percentage contribution of attainment of each stand to the study area and summed these values for each planning area, thus providing a standardized metric that could be compared among different objectives.

Maps and Ranking of Planning Areas Based on Individual Risk Assessments

We identified and mapped the top 500 planning areas when prioritizing each of the three restoration priorities (i.e., communities, water resources, biodiversity) and labeled the top 25 numerically on the corresponding maps. Only areas with opportunity for restoration treatments in forests and woodlands were treated and up to 30 percent of the treatable land base within each planning area was treated.

Potential Cumulative Attainment

For each restoration priority, we measured and mapped the cumulative attainment as planning areas were treated from highest to lowest priority. Each line on the attainment graphs indicates a different restoration objective with the line with asterisk (*) symbols indicating the restoration objective prioritized in the given scenario.

Ownership and Vegetation Composition

We examined ownership and forest type composition for the highest ranked (most opportunity) planning areas based on the three different restoration priorities. We were particularly interested in identifying planning areas that had high opportunity (treatable risk) spread among many landowners within the planning area. We examined the diversity of forest types in the highest ranked planning areas to understand how much of the current risk is located in fire adapted forests where restoration treatments will need to include underburning, versus nonfire adapted forests where other types of treatments, such as tree planting, will be required to meet fire ecology and management goals.

Tradeoff Analysis

Tradeoffs among the different wildfire risk assessments were analyzed with production frontiers to understand: (1) how prioritization using the different assessments affected the spatial distribution of priority planning areas, and (2) which planning areas are optimal in terms of addressing multiple types of risk. Tradeoffs within planning areas were analyzed between selected combinations of all three restoration objectives by changing the relative weights for each objective (Eq. 2 in Ager et al. 2017b). Here, integer weights were varied in all combinations from 0 to 10 in increments of 1 in a pairwise fashion, excluding redundant weight combinations. For instance, weights of 1 and 0 for objective A and B, respectively, generated the maximum production for objective A, whereas equal weights for each objective generated a balanced production of both. Outputs were used to generate production frontiers between the different objectives. We focused on specific tradeoffs between: (1) prioritizing wildfire risk to wildland communities and infrastructure vs. wildfire risk to water quality and supply; (2) prioritizing wildfire risk to wildland communities and infrastructure vs. wildfire risk to biodiversity; and (3) prioritizing wildfire risk to water quality and supply vs. wildfire risk to biodiversity.

For each production frontier illustrated in the graphics, each line represents a separate planning area. Along a specific line, a single point on a curve represents a separate scenario for that watershed or planning area and a distinct set of stands selected for treatment. As you move along the curve, each point is a different set of selected stands emphasizing one priority objective or another or both. Shorter curves have less variability in the production of mixed objectives, while longer curves have greater variability.

Priority Planning Areas for Shared Stewardship

We also examined the top 500 watersheds in terms of opportunity to reduce risk for all three restoration objectives and identified those planning areas that had a mix of ownerships. Clusters of watersheds were identified that were listed in the top 500 for all three objectives, indicating they could be targeted to address risk reduction to communities, water, and biodiversity. The top 500 watersheds were attributed with total attainment across all three objectives by summing the total attainment when each objective was individually prioritized while treating 30 percent of each planning area/watershed.

High Priority Planning Areas for Addressing Cross-Boundary Wildfire Transmission

To strategically address cross-boundary wildfire transmission and leverage opportunities for cross-boundary planning, we used the cross-boundary wildfire transmission layer. We assessed the ownership composition of planning areas that were high priority for wildfire transmission and assessed the tradeoff between prioritizing wildfire transmission versus wildfire risk to wildland communities and infrastructure. Top planning areas that addressed both priorities were mapped.

Results and Discussion

Priority Areas for Addressing Wildfire Risk on Forests and Woodlands

It is important to note the value of scenario planning to: (1) predict treatment location and acres treated for optimal risk reduction relative to effort, and (2) show the level of incidental benefit to lower priority objectives. In terms of the potential attainment from treating areas identified as high risk for the three restoration priorities, the results showed that the bulk of the risk could be treated in less than 2 million acres (figs. 8, 9, 10). Cumulative potential attainment was nonlinear with increasing area treated, and after 2 million acres of treatments there were marginal reductions in risk with additional treated area. In general, prioritizing one type of risk among the three restoration objectives resulted in treatments that addressed the other two, although there were substantial inefficiencies in terms of the rate of attainment.

The top 500 planning areas are mapped for each of the three restoration priorities (figs. 11, 12, 13). The maps show wide distribution of planning areas that can be treated to address each of the risks.

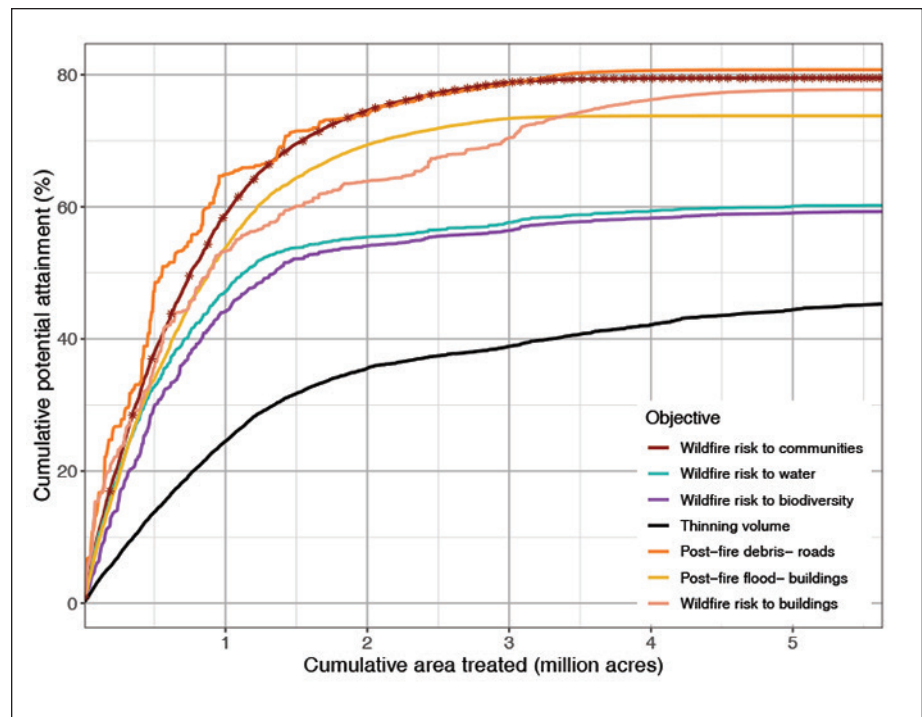


Figure 8—Potential cumulative attainment generated with increasing area treated when wildfire risk to wildland communities and infrastructure is prioritized, and treating 30 percent of the treatable planning area. Each line indicates a different restoration objective with the line with asterisk (*) symbols indicating the restoration objective prioritized in this scenario. Postfire debris flow to major roads, post-fire flood risk to buildings, and wildfire risk to buildings are all included in the wildfire risk composite priority.

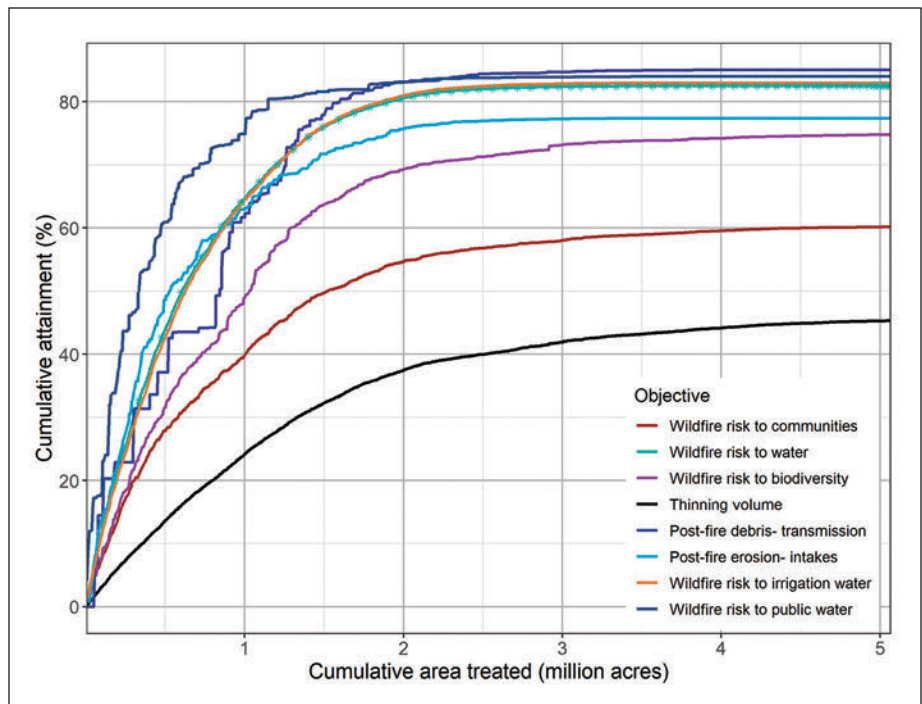


Figure 9—Potential cumulative attainment generated with increasing area treated when wildfire risk to water quality and supply is prioritized, and treating 30 percent of the treatable planning area. Each line indicates a different restoration objective with the line with asterisk (*) symbols indicating the restoration objective prioritized in this scenario. Postfire debris flow to water transmission, postfire erosion risk to water intakes, wildfire risk to irrigation water, and wildfire risk to public water are all included in the wildfire risk composite priority. Note that the composite metric and wildfire risk to irrigation water (orange line) are highly correlated as attainment is virtually identical for both.

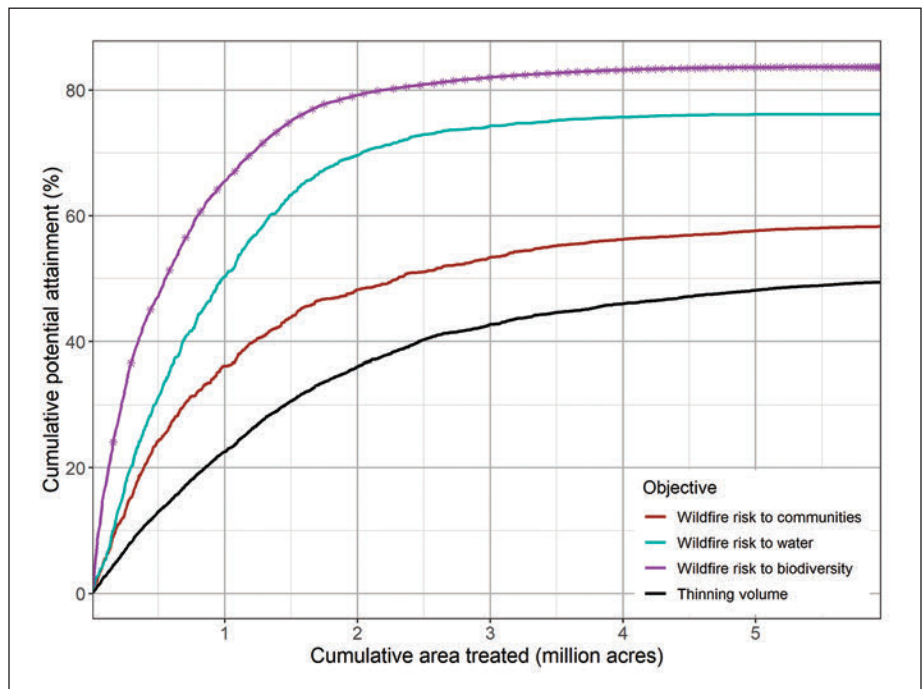


Figure 10—Potential cumulative attainment generated with increasing area treated when wildfire risk to biodiversity is prioritized, and treating 30 percent of the treatable planning area. Each line indicates a different restoration objective with the line with asterisk (*) symbols indicating the restoration objective prioritized in this scenario.

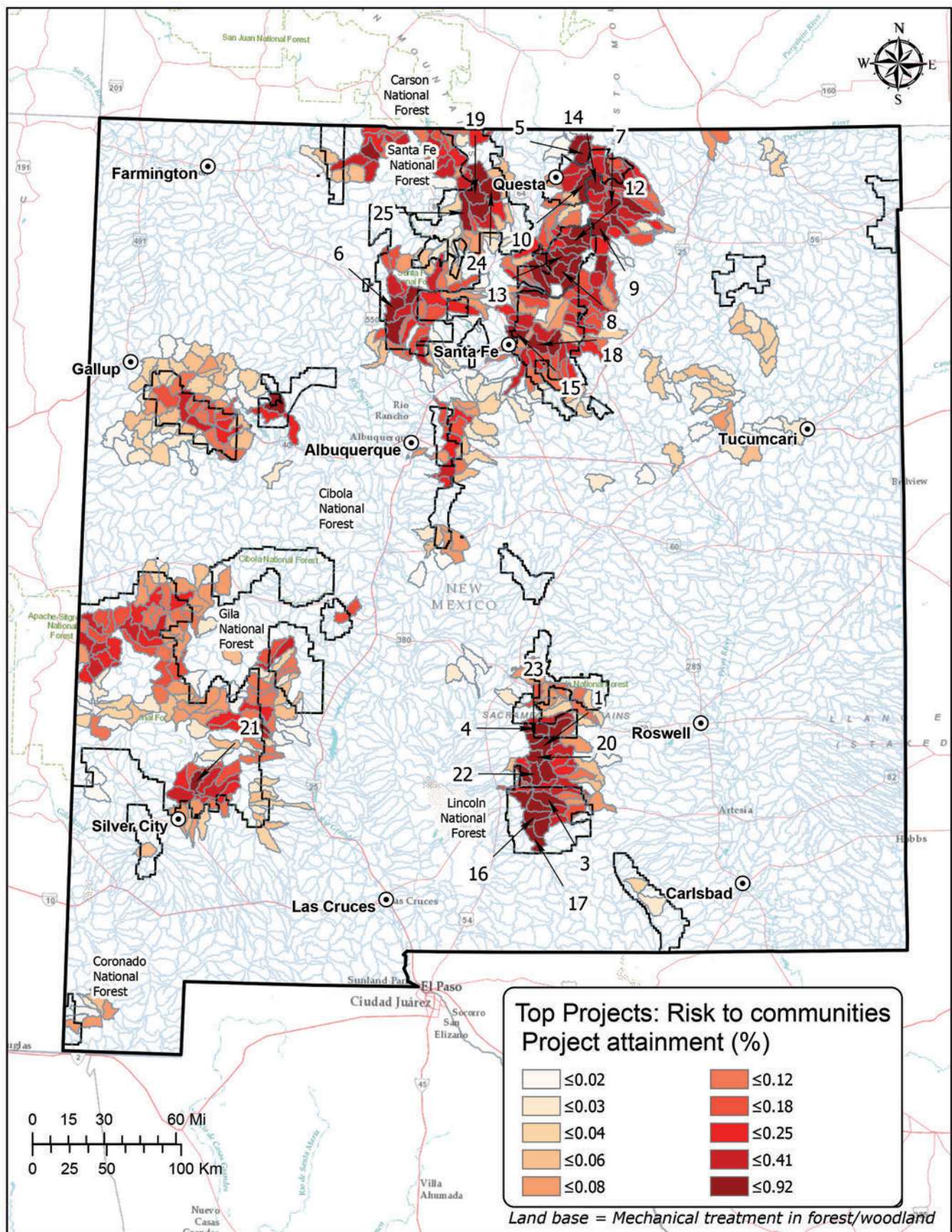


Figure 11—Top 500 planning areas when prioritizing risk to wildland communities and infrastructure. The top 500 planning areas are shown with total planning area attainment and the top 25 are labeled. Only areas with opportunity for restoration treatments in forests and woodlands were treated.

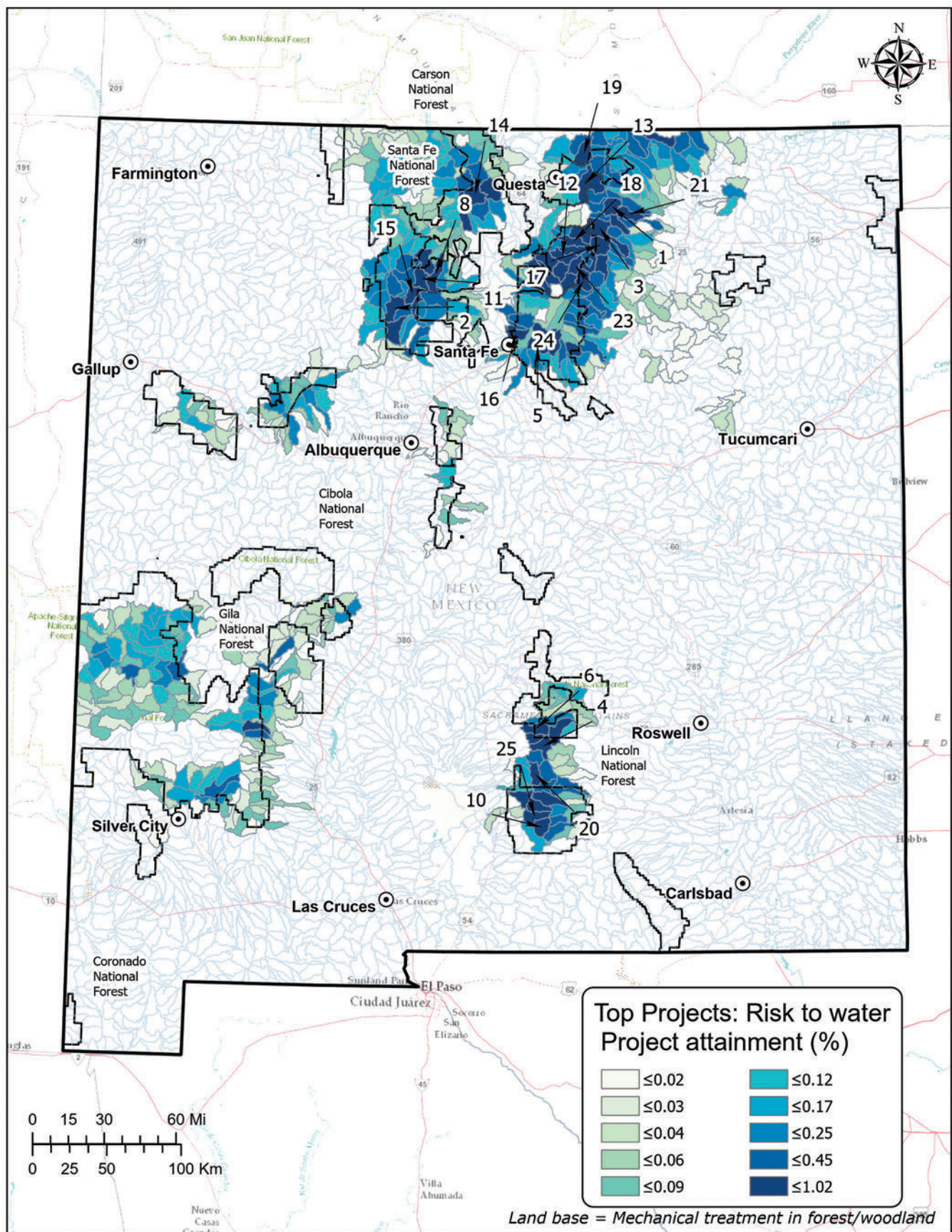


Figure 12—Top 500 planning areas when risk to water quality and supply is prioritized. The top 500 planning areas are shown with total planning area attainment and the top 25 are labeled. Only areas with opportunity for restoration treatments in forests and woodlands were treated.

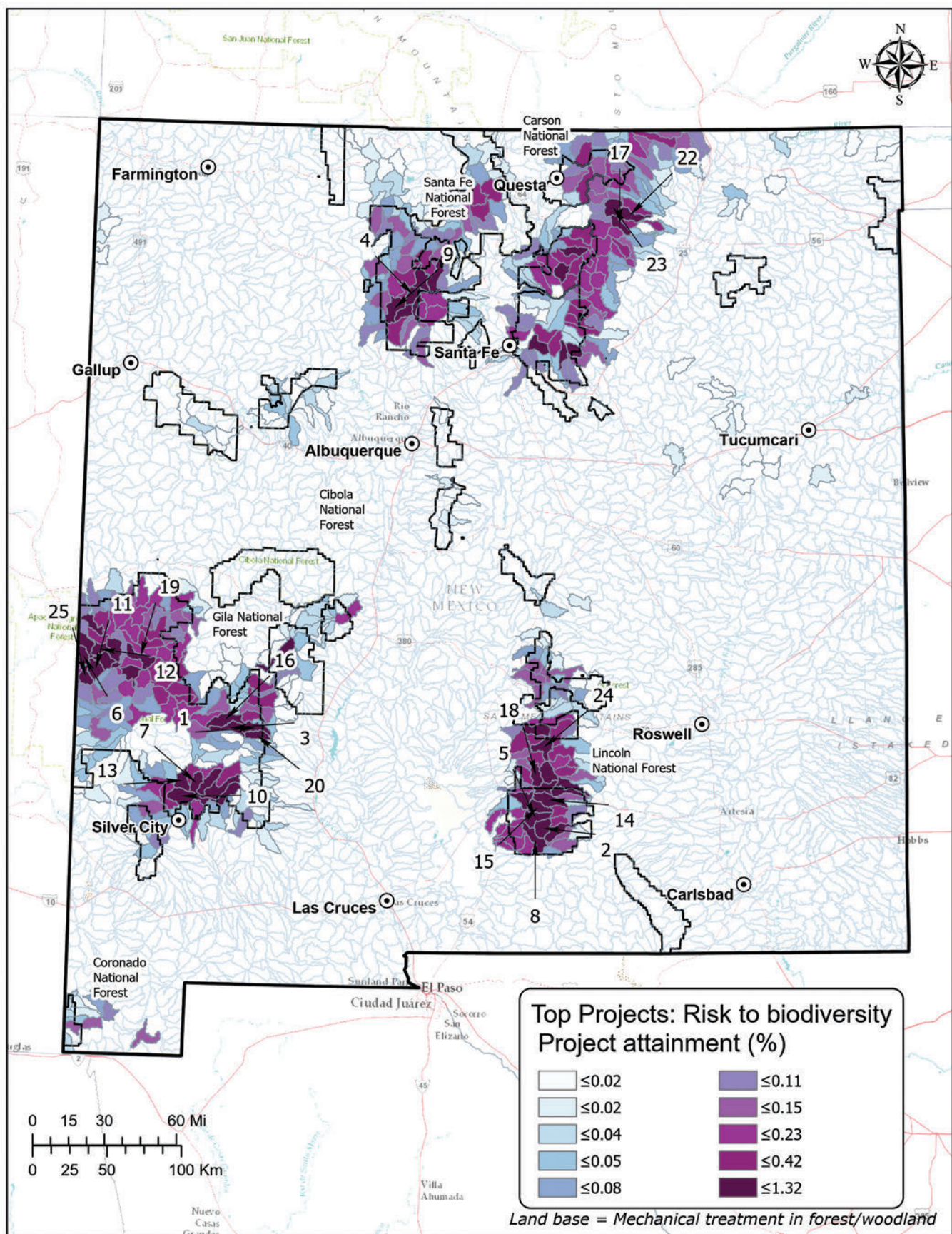


Figure 13—Top 500 planning areas when risk to biodiversity is prioritized. The top 500 planning areas are shown with total planning area attainment and the top 25 are labeled. Only areas with opportunity for restoration treatments in forests and woodlands were treated.

Vegetation composition for the top 10 planning areas identified using the three priorities (figs. 14, 15, 16) was highly variable. Planning areas could be identified that were dominated by a suite of different forest types. In general, most of the vegetation responsible for risk to biodiversity consisted of the mixed conifer, frequent fire type (fig. 16). Vegetation composition in areas mapped as high risk to water quality and supply contained substantial amounts of mixed conifer with aspen forest, although again the composition was highly variable among the top 10 planning areas. Pinyon-juniper woodlands were a significant source of risk only in the biodiversity assessment.

Ownership composition for the top 50 planning areas identified using the three risk restoration priorities showed that the majority of the risk was mapped on national forests, but several of the top planning areas also included tribal and private lands (figs. 17, 18, 19).

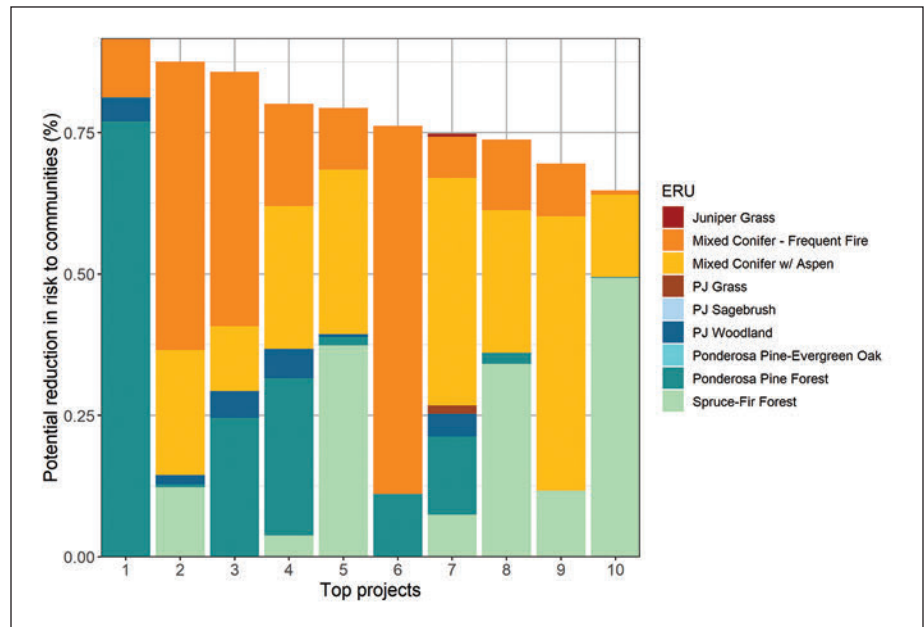


Figure 14—Vegetation composition for the top 10 planning areas when risk to wildland communities and infrastructure is prioritized. The top 10 planning areas are shown with total planning area attainment by ecological response unit (ERU). Only areas with opportunity for restoration treatments in forests and woodlands were treated.

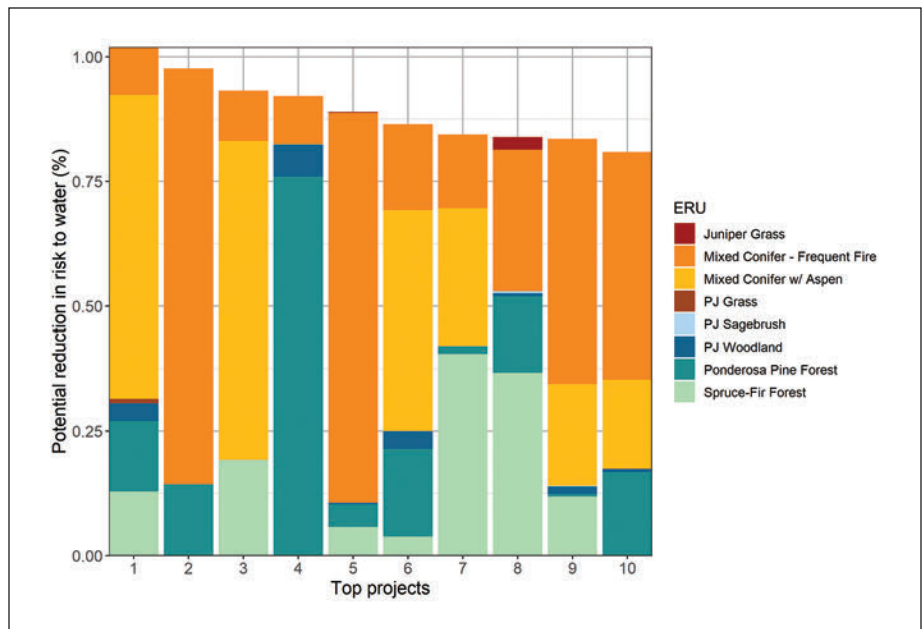


Figure 15—Vegetation composition for the top 10 planning areas when risk to water quality and supply is prioritized. The top 10 planning areas are shown with total planning area attainment by ecological response unit (ERU). Only areas with opportunity for restoration treatments in forests and woodlands were treated.

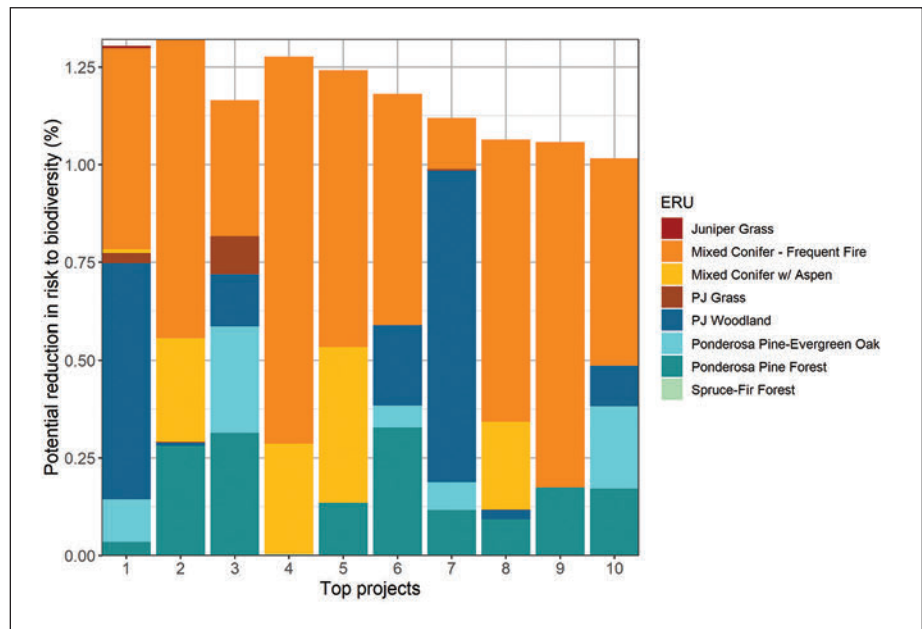


Figure 16—Vegetation composition for the top 10 planning areas when risk to biodiversity is prioritized. The top 10 planning areas are shown with total planning area attainment by ecological response unit (ERU). Only areas with opportunity for restoration treatments in forests and woodlands were treated.

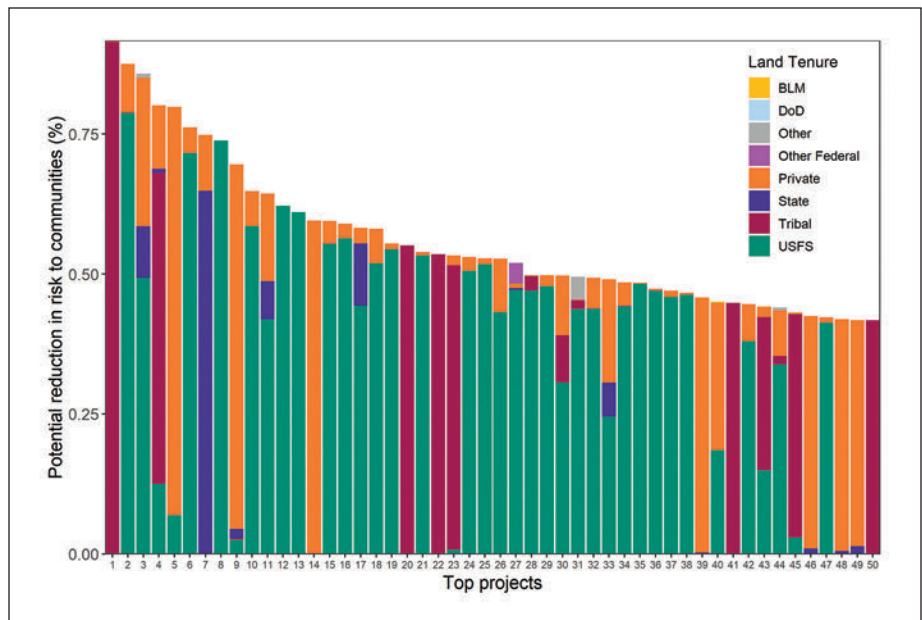


Figure 17—Ownership composition for the top 50 planning areas when risk to wildland communities and infrastructure is prioritized. The top 50 planning areas are shown with total planning area attainment by land ownership. Only areas with opportunity for restoration treatments in forests and woodlands were treated; 30 percent of the treatable land base within each planning area is treated.

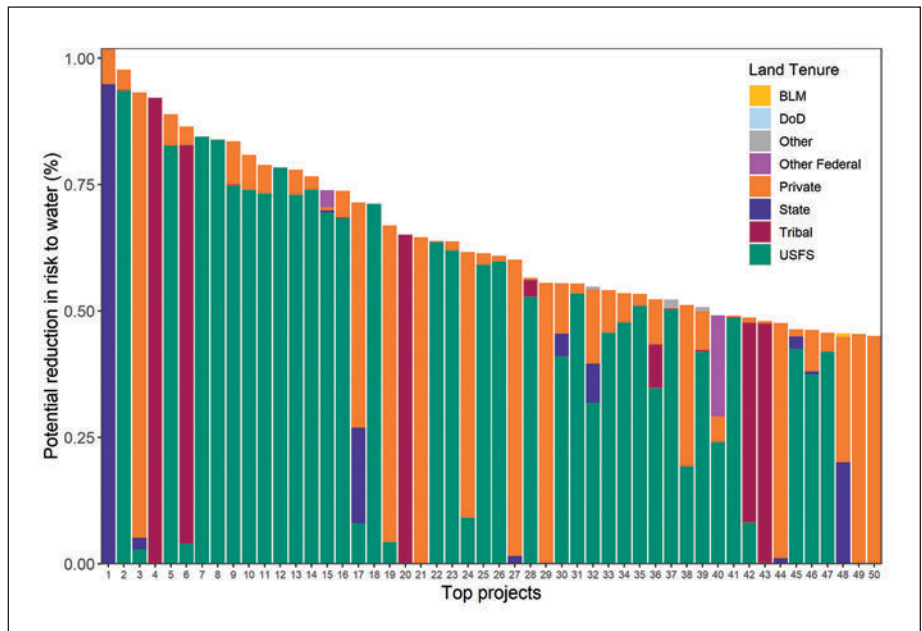


Figure 18—Ownership composition for the top 50 planning areas when risk to water quality and supply is prioritized. The top 50 planning areas are shown with total planning area attainment by land ownership. Only areas with opportunity for restoration treatments in forests and woodlands were treated.

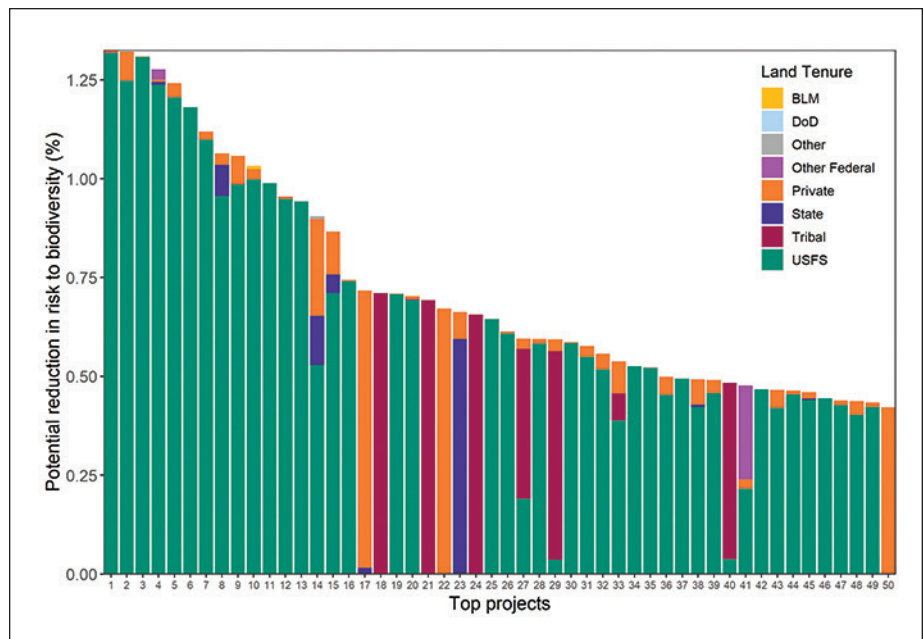


Figure 19—Ownership composition for the top 50 planning areas when risk to biodiversity is prioritized. The top 50 planning areas are shown with total planning area attainment by land ownership. Only areas with opportunity for restoration treatments in forests and woodlands were treated.

Tradeoffs

Figures 20, 21, 22, and 23 illustrate tradeoffs among the three restoration priorities and show the 25 planning areas with the highest restoration opportunity for the combination of priorities. For each production frontier graph, each line represents a separate planning area. Along a specific line, a single point on a curve represents a separate scenario for that watershed or planning area and a distinct set of stands selected for treatment. As you move along the curve, each point is a different set of stands selected to emphasize one priority metric or another, or both. Shorter curves indicate fewer opportunities for tradeoffs between priorities. Longer curves indicate a larger range of differences between stands selected while prioritizing one objective as opposed to another.

Figure 20 shows the tradeoffs between treating risk to communities versus water supplies. Planning areas in the upper right are most efficient for treating risk to both values. In general, selecting planning areas to treat risk to communities will also have an impact on risk reduction to water supplies as evidenced by the correlation between the two at the scale of planning areas. However, within planning areas there is generally a sharp tradeoff between treating risk to one versus the other value. A different pattern is apparent when comparing treating risk to biodiversity versus risk to communities.

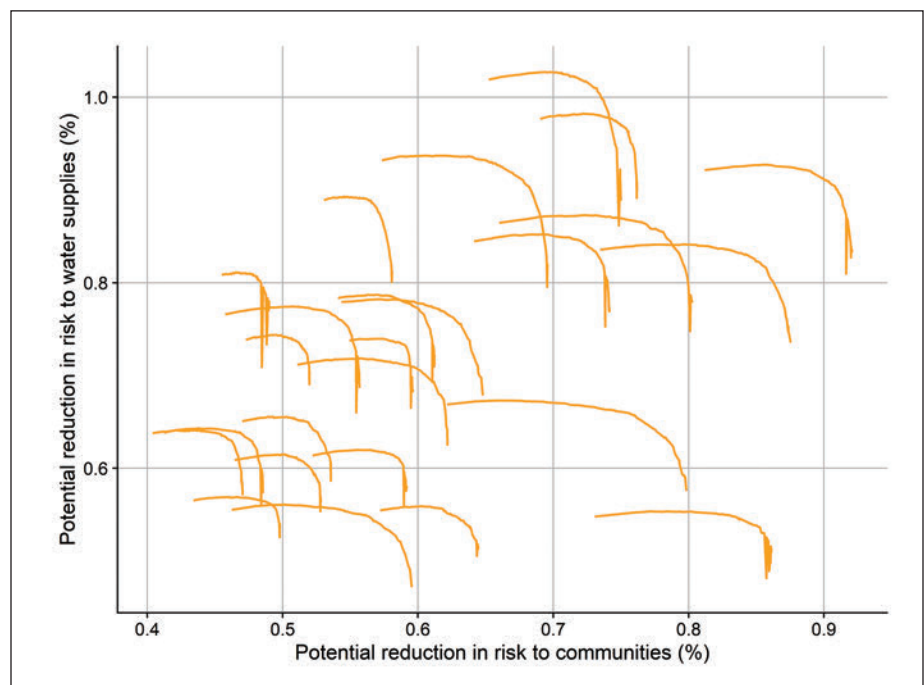


Figure 20—Tradeoff between prioritizing wildfire risk to wildland communities and infrastructure versus prioritizing wildfire risk to water quality and supply for planning areas in the New Mexico shared stewardship study area. Only areas with opportunity for restoration treatments in forests and woodlands were treated. Points along a particular line indicate a different suite of stands selected for treatment with varying emphasis on one restoration objective versus another.

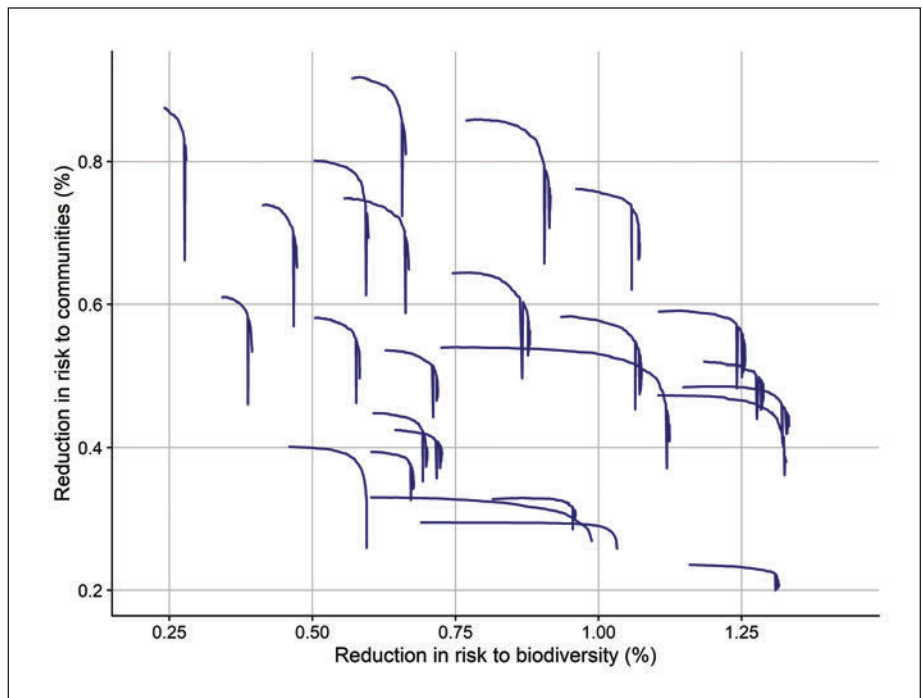


Figure 21—Tradeoff between prioritizing wildfire risk to biodiversity versus prioritizing wildfire risk to communities and infrastructure for planning areas in the New Mexico shared stewardship study area. Only areas with opportunity for restoration treatments in forests and woodlands were treated. Points along a particular line indicate a different suite of stands selected for treatment with varying emphasis on one restoration objective versus another.

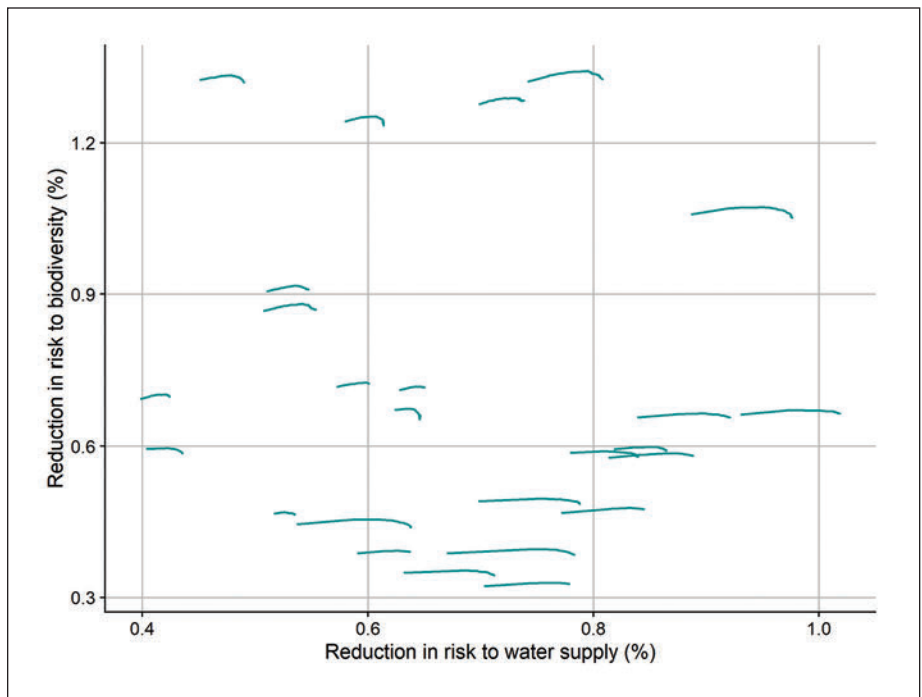


Figure 22—Tradeoff between prioritizing wildfire risk to water quality and supply versus prioritizing wildfire risk to biodiversity for planning areas in the New Mexico shared stewardship study area. Only areas with opportunity for restoration treatments in forests and woodlands were treated. Points along a particular line indicate a different suite of stands selected for treatment with varying emphasis on one restoration objective versus another.

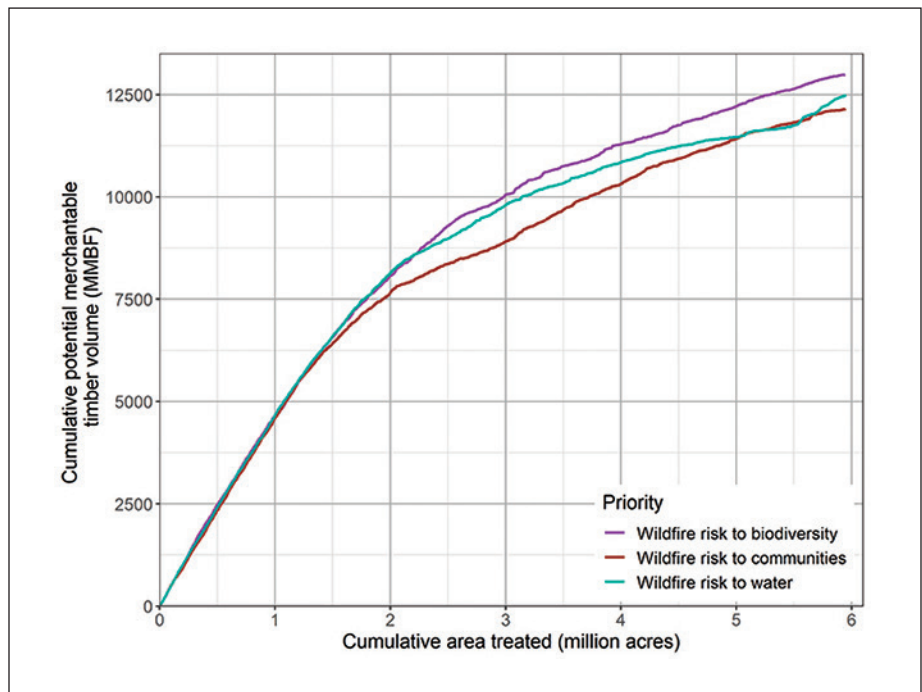


Figure 23—Tradeoff in potential merchantable timber volume when changing treatment priority in the New Mexico shared stewardship study area. Only areas with opportunity for restoration treatments in forests and woodlands were treated.

Here there is a negative correlation among planning areas, meaning that if you select planning areas to treat risk to biodiversity you will not efficiently address risk to communities. Again, within a planning area there is generally a negative relationship between treating the two values at risk. A third type of relationship is seen between prioritizing wildfire risk to water quality versus biodiversity. Here there are no tradeoffs *within* a planning area, meaning that if you prioritize treatments for one type of risk you will generally treat the other, and there is no cost to one objective to obtain more of another. There is no apparent relationship among the planning areas in terms of tradeoffs although some planning areas can be seen (upper right) that are efficient for treating both types of values at risk.

Figure 23 illustrates risk vs. harvest volume tradeoffs by showing the relative attainment in harvest volume when each of the restoration priorities is used to prioritize planning areas. Timber volume is relatively similar using different priorities to treat wildfire risk, especially for the first 1.5 million acres treated.

Figure 24 illustrates tradeoffs in terms of measuring the number of times a planning area was in the top 50 in one, two, or all three of the restoration prioritizations. Fewer than 20 of the planning areas were in the top 50 for all three measures of risk.

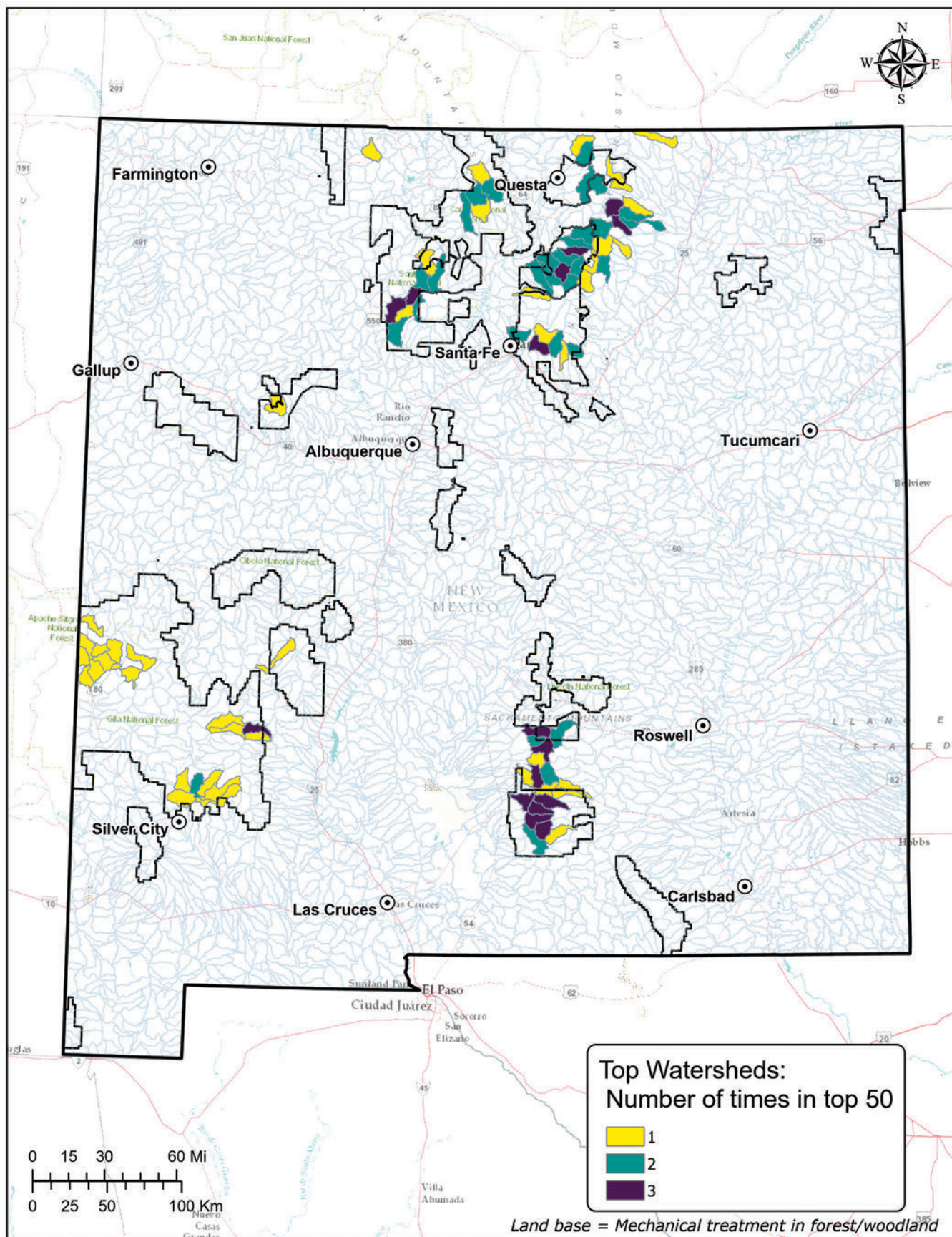


Figure 24—Number of times a particular planning area (watershed) was ranked in the top 50 for the three priority restoration objectives. For example, planning areas symbolized in dark purple were ranked in the top 50 for wildfire risk to communities, water and biodiversity.

Priority Planning Areas for Shared Stewardship

The bulk of the high priority planning areas identified in the preceding analyses were located on national forest lands. However, risk exists on the other ownerships; planning areas were used to form clusters that contain a wider array of ownerships in an attempt to organize priorities in a more inclusive assessment. Figure 25 identifies four such primary clusters of planning areas where multiple risk issues can be effectively addressed with treatments. Clusters represent groups of planning areas that were listed in the top 500 for all three restoration priorities. Total attainment for the top 500 planning areas (watersheds) was based on *individually* prioritizing communities, water, and biodiversity for regional clusters shown in figures 26–33. Note that while clusters represent watershed groups where all three restoration priorities were individually prioritized and ranked in the top 500 for attainment, there may be other watersheds with higher total attainment based on just one or two restoration priorities. Thus, there may be a cost in selecting a watershed that achieves risk reduction for three priorities, in that an adjacent watershed may be more efficient in reducing risk for one restoration goal. For example, in figure 27 the watershed just to the west of the watershed ranked #39 has higher attainment for biodiversity (fig. 13) than the watersheds in the northern part of the cluster such as #284 and #364.

The composition of the clusters in terms of ownership are shown in figures 26, 28, 30, and 32. Depending on the cluster, ownership is dominated by private land, national forests, or tribal lands.

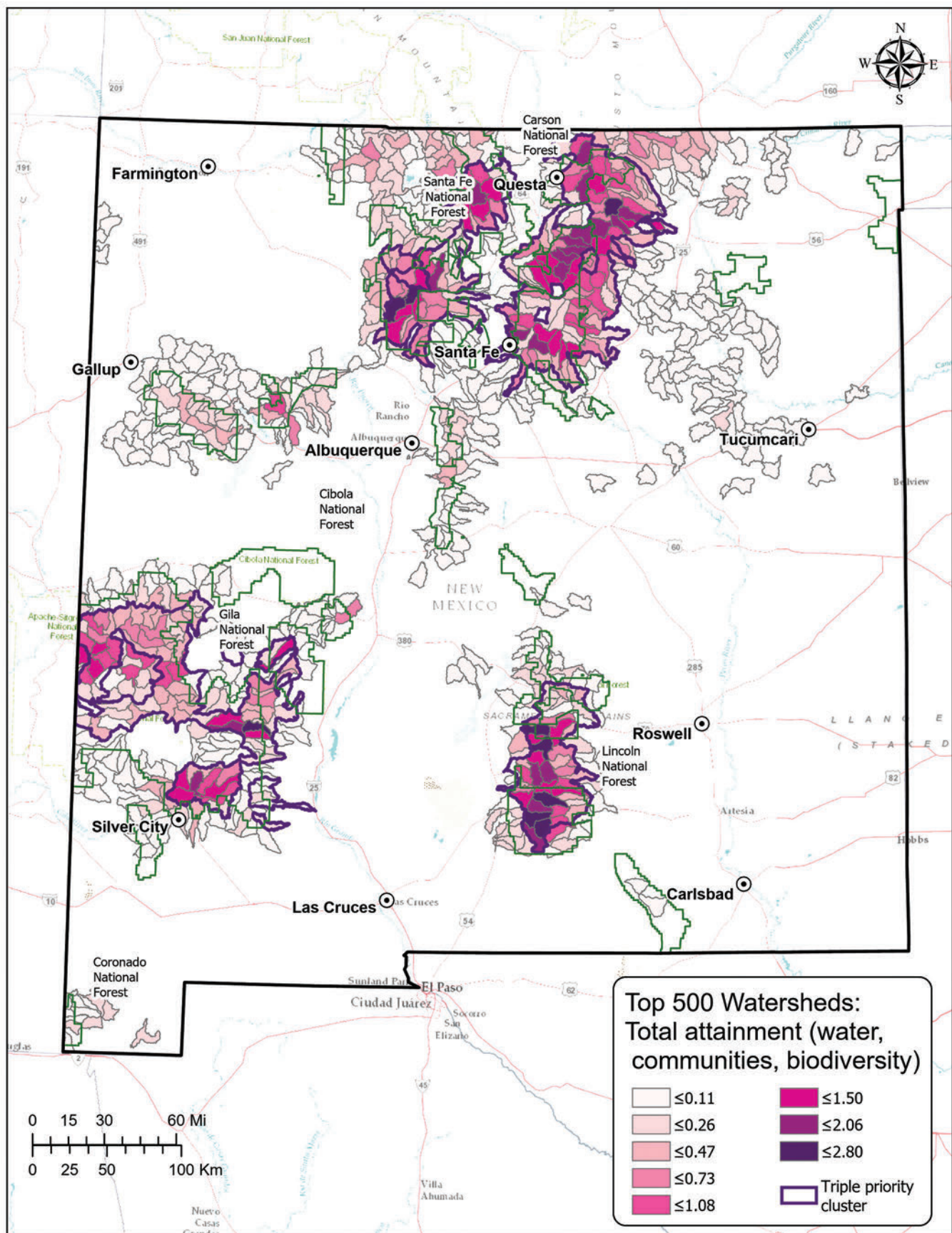


Figure 25—Total attainment for the top 500 planning areas (watersheds) based on individually prioritizing communities, water, and biodiversity. If a planning area falls outside a cluster, it was not ranked in the top 500 for all *three* priorities but may have higher attainment based on one or two restoration objectives.

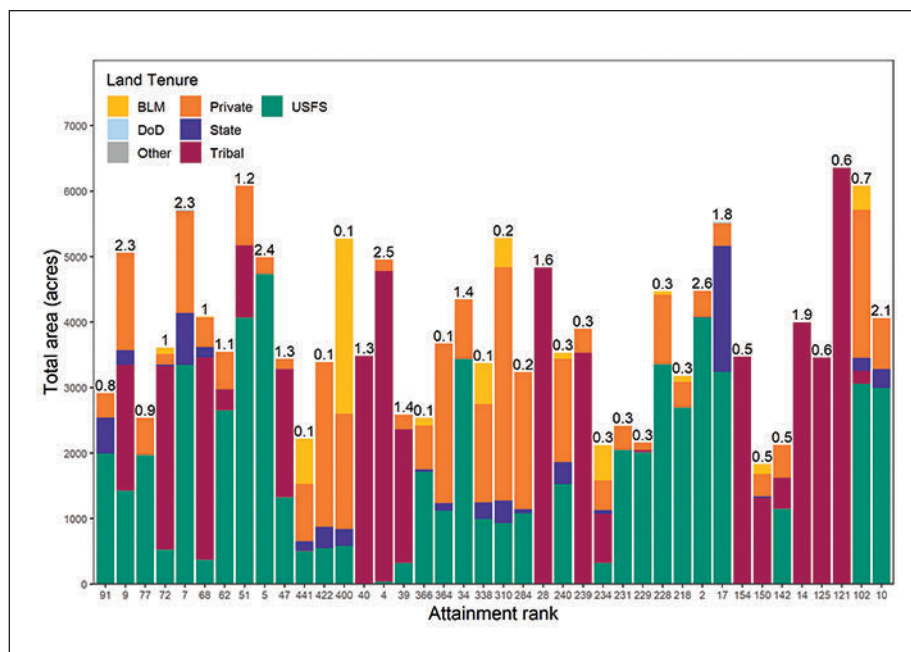


Figure 26—Southcentral cluster - Ownership composition for the planning areas identified in the top 500 for prioritizing risk to communities, water, and biodiversity in southcentral New Mexico. These planning areas are shown with total planning area attainment (numbers at top of bars) and ownership composition based on total area. Numbers on the x-axis indicate rank from 1 to 500 based on total attainment and link to planning areas on the map in figure 27. Only areas with opportunity for restoration treatments in forests and woodlands were treated.

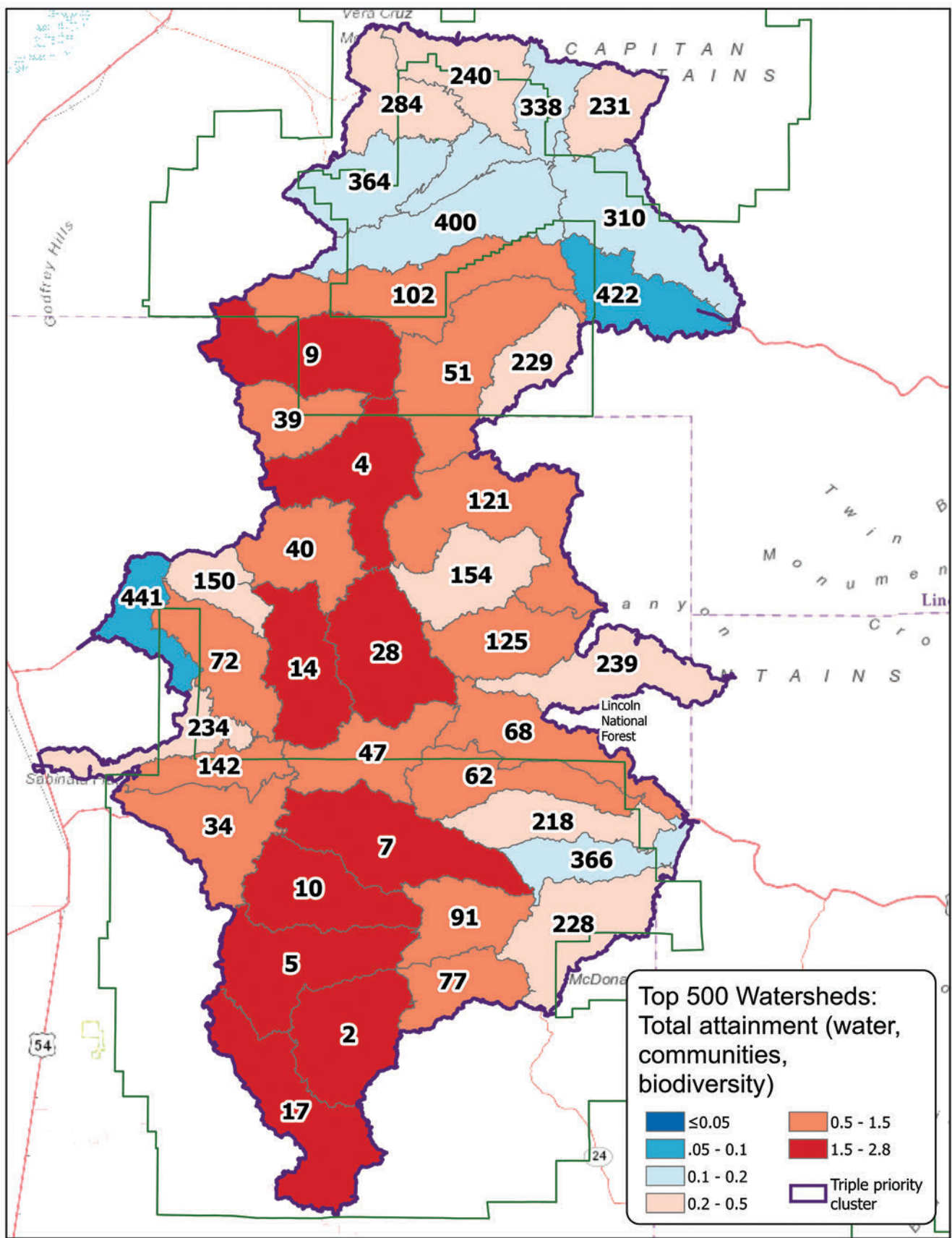


Figure 27—Southcentral cluster - Spatial distribution of total attainment for the top 500 planning areas (watersheds) based on individually prioritizing communities, water and biodiversity for the southcentral New Mexico cluster. Planning area numbers indicate ranking based on total attainment and match bars in figure 26. If a planning area is not labeled it was not ranked in the top 500 for all three priorities but may have higher attainment based on one or two restoration objectives.

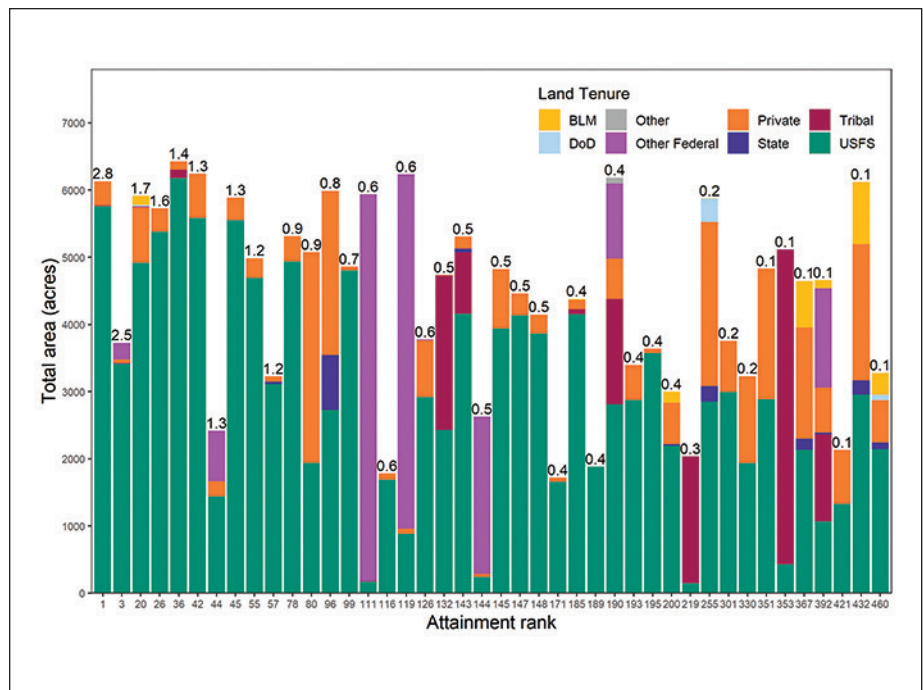


Figure 28—Northwest cluster - Ownership composition for the planning areas identified in the top 500 for prioritizing risk to communities, water and biodiversity in northwestern New Mexico. These planning areas are shown with total planning area attainment (numbers at top of bars) and ownership composition based on total area. Numbers on the x-axis indicate rank from 1 to 500 based on total attainment and link to watersheds on the map in figure 29. Only areas with opportunity for restoration treatments in forests and woodlands were treated.

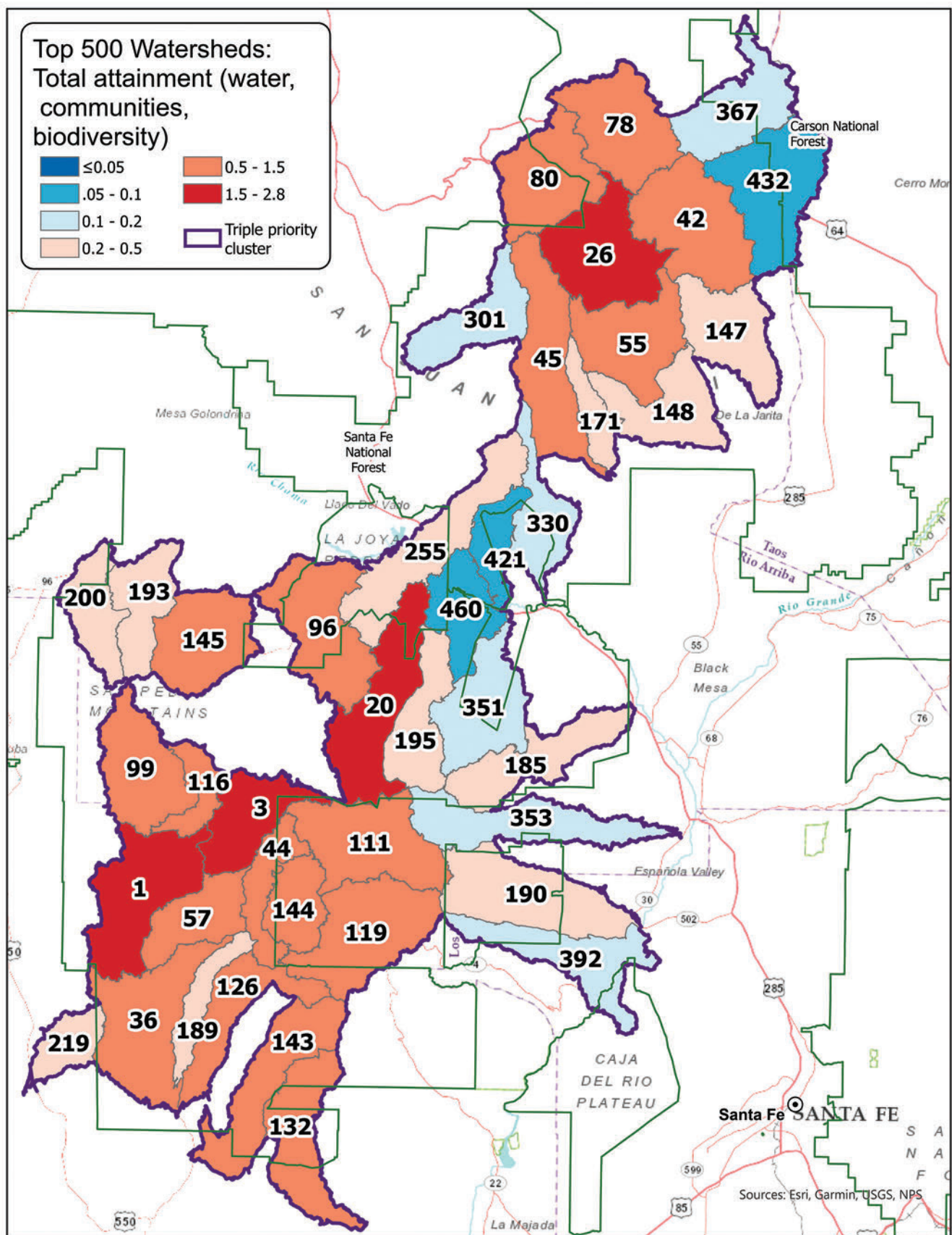


Figure 29—Northwest cluster – Spatial distribution of total attainment for the top 500 planning areas (watersheds) based on individually prioritizing communities, water, and biodiversity for the northwestern New Mexico cluster. Watershed numbers indicate ranking based on total attainment and match bars in figure 28. If a planning area is not labeled, it was not ranked in the top 500 for all three priorities but may have higher attainment based on one or two restoration objectives.

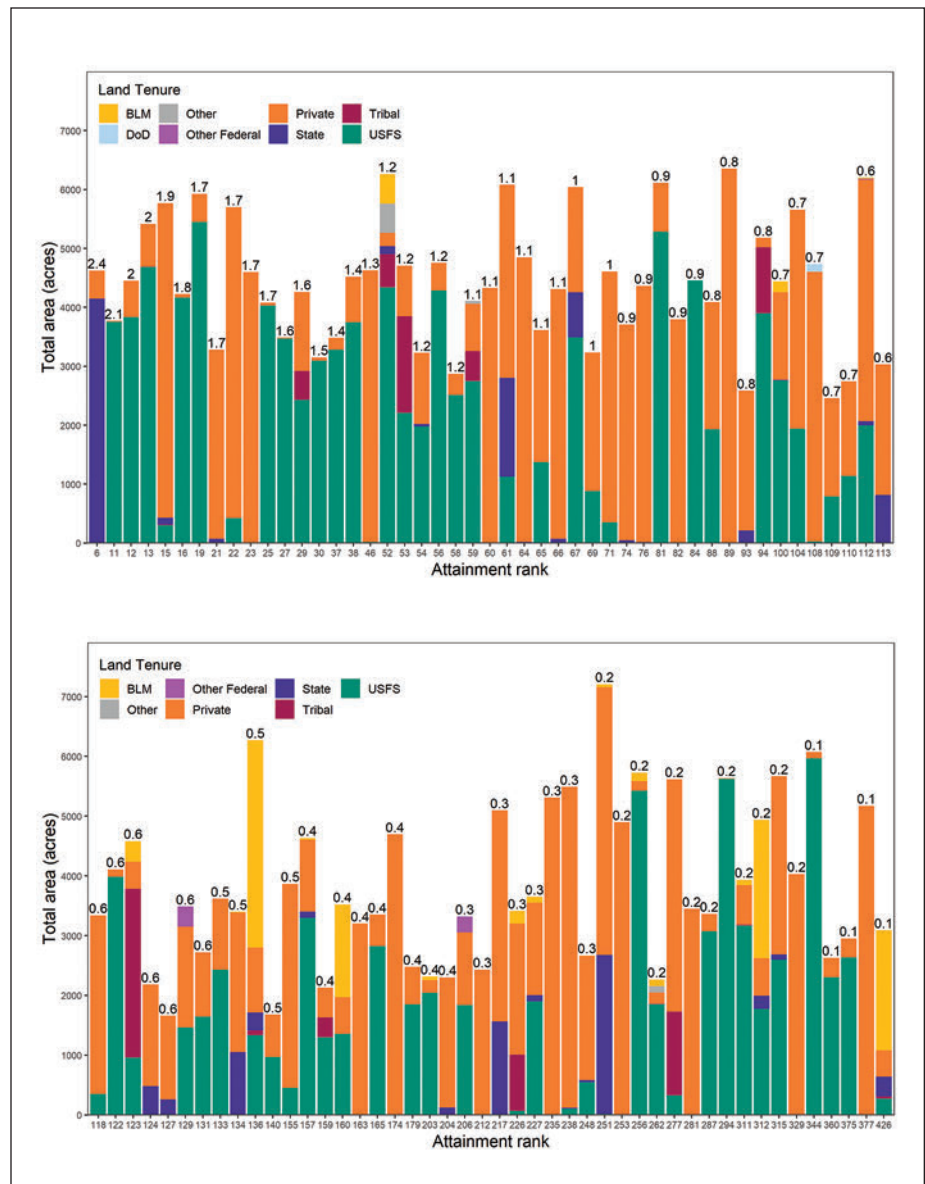


Figure 30—Northeast cluster - Ownership composition for the planning areas identified in the top 500 for prioritizing risk to communities, water, and biodiversity in northwestern New Mexico. These planning areas are shown with total planning area attainment (numbers at top of bars) and ownership composition based on total area. Numbers on the x-axis indicate rank from 1 to 500 based on total attainment and link to watersheds on map in figure 31. Only areas with opportunity for restoration treatments in forests and woodlands were treated.

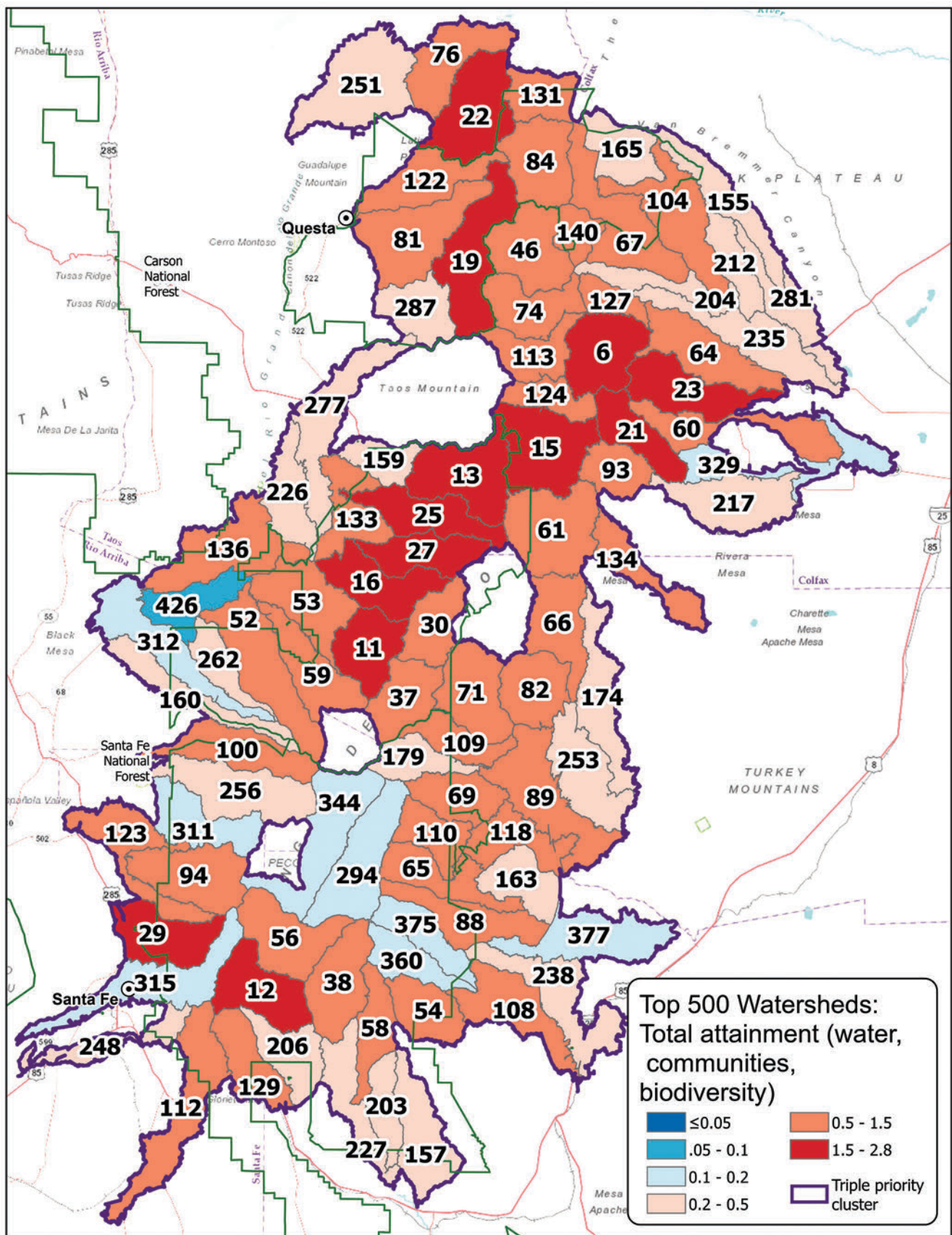


Figure 31—Northeast cluster – Spatial distribution of total attainment for the top 500 planning areas (watersheds) based on individually prioritizing communities, water, and biodiversity for the northeastern New Mexico cluster. Planning area numbers indicate ranking based on total attainment and match bars in figure 30. If a planning area is not labeled, it was not ranked in the top 500 for all three priorities but may have higher attainment based on one or two restoration objectives.

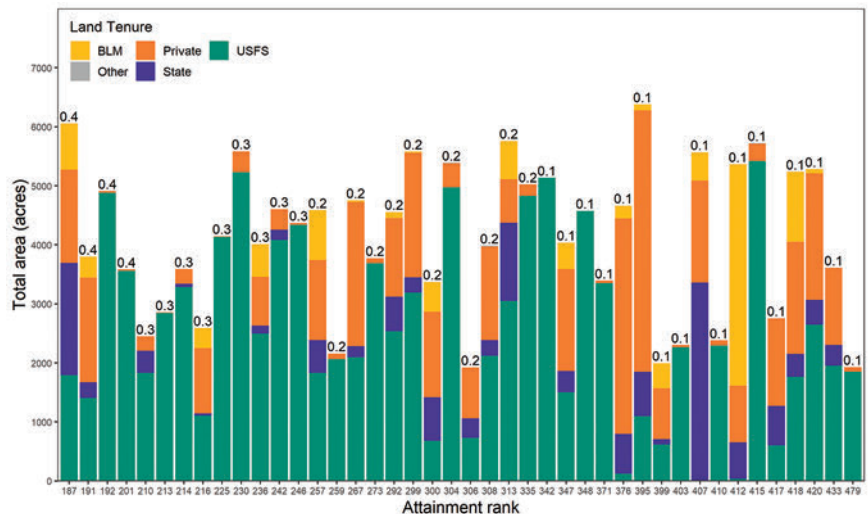
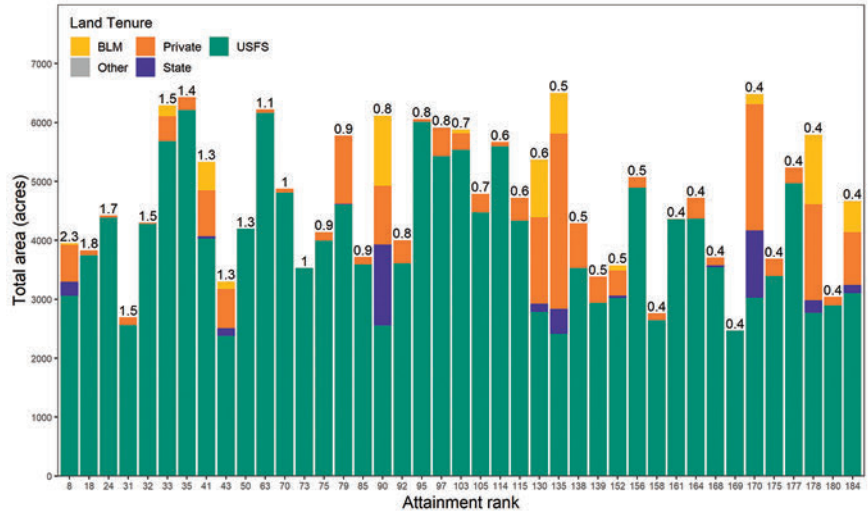


Figure 32—Southwest cluster - Ownership composition for the planning areas identified in the top 500 for prioritizing risk to communities, water, and biodiversity in southwestern New Mexico. These planning areas are shown with total planning area attainment (numbers at top of bars) and ownership composition based on total area. Numbers on the x-axis indicate rank from 1 to 500 based on total attainment and link to planning areas on map in figure 33. Only areas with opportunity for restoration treatments in forests and woodlands were treated.

Cross-Boundary Wildfire Transmission and Risk to Communities and Infrastructure

Predicted cross-boundary wildfire transmission derived from wildfire simulations is shown in figure 34. Areas of high transmission are shown in red; these are areas where if a fire ignites it is likely to affect other ownerships. Values greater than 50 percent mean that more than half of the area burned will be on an ownership other than that where the ignition started. Areas of highly fragmented ownership generally have more transmission to adjacent areas, given a fire has more opportunity to cross boundaries all things being equal.

Ownership composition for the top 50 planning areas when wildfire transmission is prioritized (fig. 35) shows that the bulk of the transmission occurs on private lands, followed by national forests. Substantial transmission also occurs on state lands for 14 of the top 50 planning areas. Tradeoffs between prioritizing wildfire transmission across land ownership versus wildfire risk to wildland communities and infrastructure is shown in figure 36. In general, locating treatments within a planning area to treat wildfire risk to communities resulted in a less effective treatment of wildfire transmission across boundaries. However, priority planning areas exist where both wildfire transmission and risk to communities can be treated (upper right, fig. 36). The top 25 planning areas identified when prioritizing both wildfire risk transmission across land tenures and risk to communities and infrastructure are shown in figure 37.

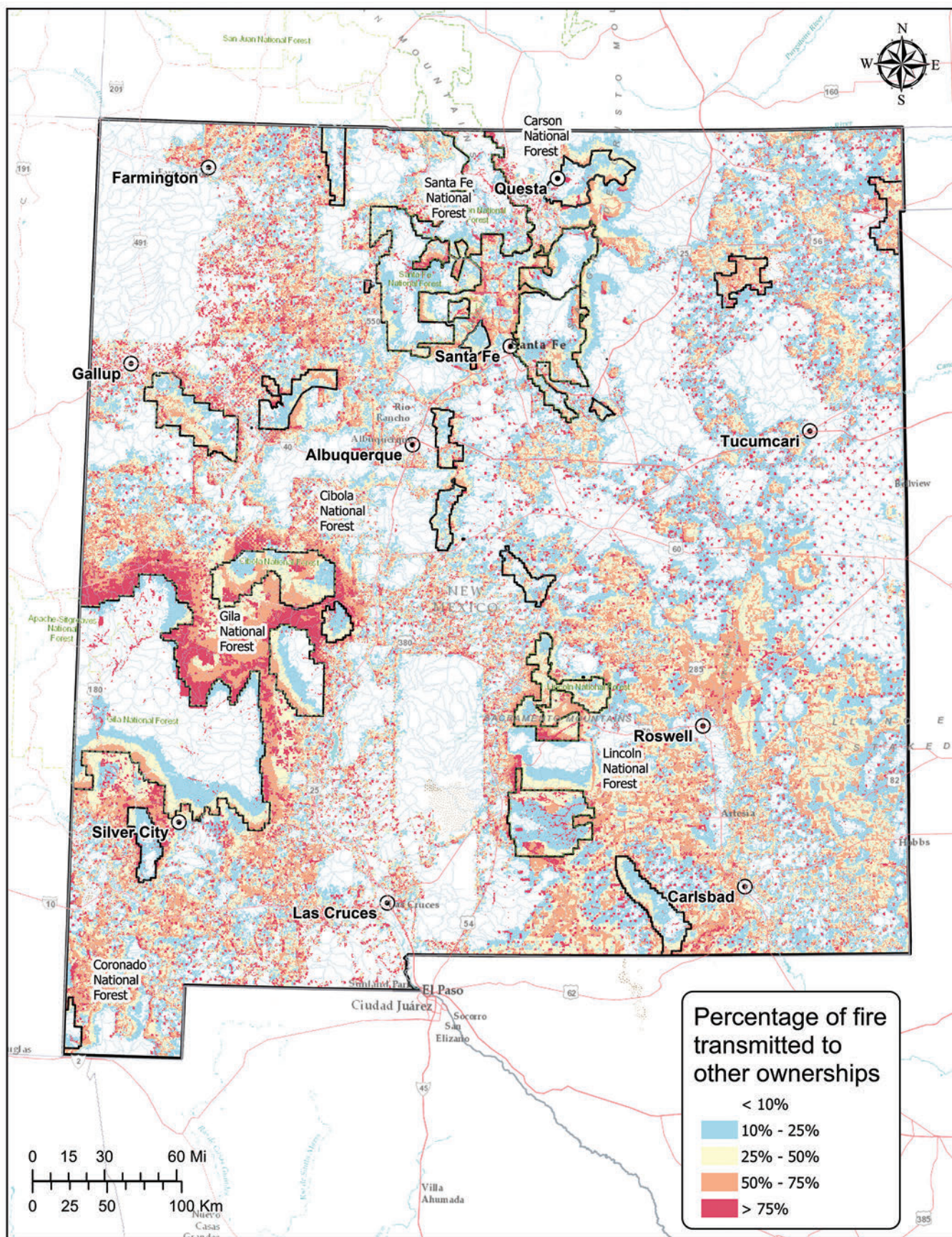


Figure 34—Wildfire transmission across land ownerships based on FSim modeling (Finney et al. 2011; Short et al. 2020) and used to prioritize treatments. See Appendix B for details on layer development.

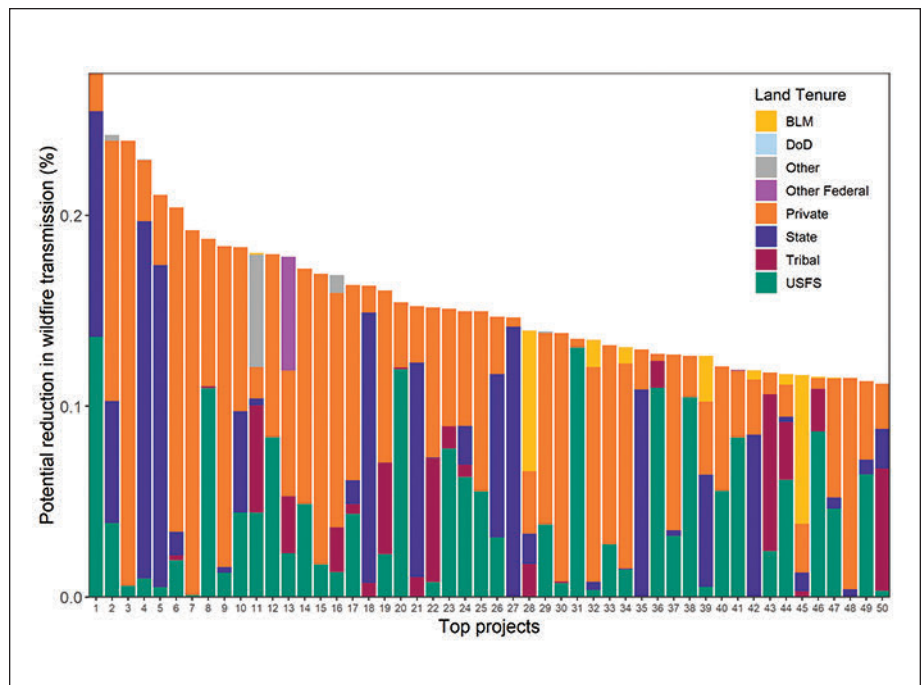


Figure 35—Ownership composition for the top 50 planning areas when wildfire transmission is prioritized. The top 50 planning areas are shown with total planning area attainment by land ownership. Only areas with opportunity for restoration treatments in forests and woodlands were treated.

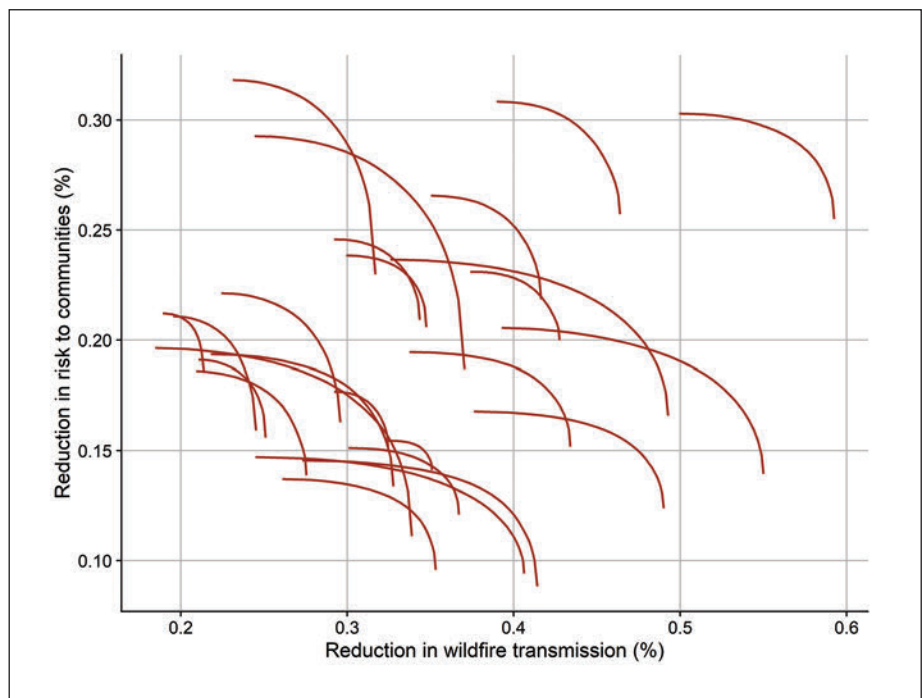


Figure 36—Tradeoffs between prioritizing wildfire transmission across land ownerships versus wildfire risk to wildland communities and infrastructure for planning areas in the New Mexico shared stewardship study area. Only areas with the opportunity for restoration treatments on forested or woodland stands were treated. Points along a particular line indicate a different suite of stands selected for treatment with varying emphasis on one restoration objective versus another.

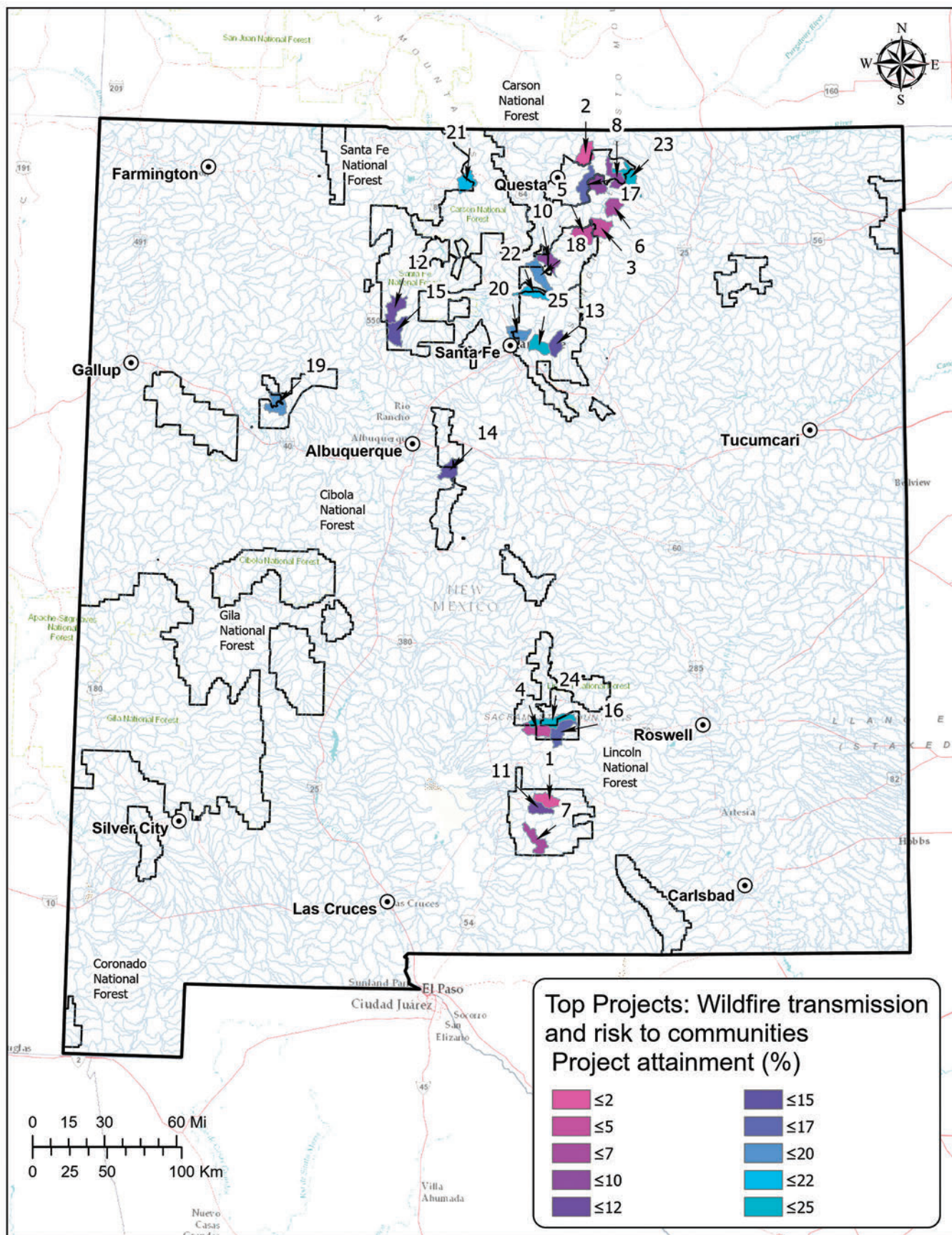


Figure 37—Top 25 planning areas when both wildfire risk transmission across land ownerships and risk to communities and infrastructure are prioritized. Planning areas match those shown in figure 36. Only areas with opportunity for restoration treatments in forests and woodlands were treated.

Conclusions

The 2020 New Mexico Forest Action Plan is the result of a highly collaborative endeavor, as are other efforts to prioritize restoration within “Shared Stewardship” landscapes. Members of the coordinating group that were part of the Forest Action Plan represented a broad diversity of natural resource agencies and other interested parties. They noted that the SIPP analytical approach allowed for a more collaborative process when determining resource priorities and identifying priority landscapes. Previously, the diverse and often competing interests of state and federal entities had made collaboration and common goal setting a challenge. However, the opportunity to assess various resource objectives in a single model—and to examine tradeoffs between different management approaches—allowed for a more integrated approach to priority setting. It also allowed state and federal partners to see opportunities for leveraging financial, technical, and labor-based resources to achieved desired management outcomes.

This report describes prioritization scenarios and associated tradeoffs based on wildfire risk assessments to biodiversity, water, and risk to communities in the State of New Mexico that are utilized in the New Mexico State Forest Action Plan. The report is intended as a decision support framework to prioritize planning areas, identify cross-boundary opportunities, and provide a wide array of maps and graphic outputs upon which to further develop active forest management programs. Limited time to prepare this assessment precluded in-depth analyses of scenarios in terms of predicting risk reduction associated with implementing treatments in the high priority planning areas, let alone addressing climate vulnerability. A number of ancillary analyses could also be conducted to bring social and economic factors into the prioritization as done in previous studies (Nielsen et al. 2019).

This report identifies 500 priority watersheds for restoration across all jurisdictions with forest and woodland cover types (representing approximately 20 percent of all watersheds at risk), and of these, 250 high priority watersheds have been identified on National Forest System and adjacent lands. Such a large number of watersheds is necessary to accommodate an all-lands approach to management across a range of federal, tribal, and private lands to allow for broad engagement in management activities.

Overall, the results showed clusters of planning areas that are sources of substantial wildfire risk and that span ownerships and forest types. Simulated treatments that target risk identified in the assessments suggested rapid, exponential outcomes in terms of reducing risk as planning areas are implemented over increasingly larger scales within the State. The cross-

boundary fire transmission analysis identified specific planning areas that could be targets for shared stewardship planning due to high levels of fire exchange among ownerships. The results show that within a planning area there is a tradeoff between locating treatments to address wildfire risk to communities versus locating them in areas that will best reduce wildfire risk to water quality/supply. However, among planning areas the potential to treat two restoration priorities is often correlated, meaning that if you pick a planning area that is high risk for water quality/supply it will also be high risk to communities. This simplifies the prioritization at the scale of planning areas. The choice of what to treat within planning areas does not have a significant effect even when treating up to 30 percent of the planning area. Prioritizing planning areas that have high wildfire risk to biodiversity did not necessarily result in treatments to address wildfire risk to communities and water sources, although planning areas were identified with opportunity to address risk identified in all three restoration prioritizations.

A cross-boundary wildfire assessment was also incorporated into the analysis to specifically identify areas of high wildfire transmission among ownerships. This assessment provides an alternative spatial framework for prioritizing planning areas that specifically address the intent in the shared stewardship initiative (USDA Forest Service 2018, 2019). As noted in the Introduction, cross-boundary wildfire is an artifact of fragmented ownership and jurisdictional boundaries. The assessment of cross-boundary risk is particularly important to map the source of wildfire risk to communities and identify where natural fire regimes conflict with socioeconomic values and land management goals at the parcel scale. Cross-boundary risk issues are highly relevant to other fire management issues, including prescribed fire and natural ignitions to reduce fuels and future suppression costs, and restoring low severity wildfire in fire adapted forests. The cross-boundary assessment led to the identification of several planning areas with high levels of fire exchange among ownerships.

Important differences were observed in terms of the land ownership identified as needing treatment to reduce risk to communities versus water and biodiversity. The biodiversity risk was almost entirely located on national forests in the top 10 planning areas, whereas 4 of the top 10 planning areas identified as high priority to treat risk to water were on private or tribal land. A similar pattern was observed for risk to communities with very different ownership patterns among the top 10 planning areas. The results imply that risk is concentrated on particular ownerships within planning areas rather than spread out across multiple jurisdictions in terms of the areas identified for treatment in our modeling. Thus, planning areas are not necessarily compromised by not being cross-boundary. Restoration projects focused on a planning area located within only one land ownership could effectively address and reduce risk. However, risk reduction activities can still benefit from cross-boundary planning that allow for adjacent planning areas to be treated together as part of a landscape project. Recent large fires in the southwest have burned at scales much larger than the planning areas

defined in this assessment. However, risk reduction activities are not totally dependent on authorizing environments created specifically for cross-boundary planning. Thus, the shared stewardship initiative in New Mexico could involve work among priority planning areas that belong to different ownerships more so than among different land ownerships within a given planning area. By contrast, the high priority planning areas are in areas of diverse forest types, meaning that a wide range of restoration treatments including thinning, underburning, and fuels mastication will be required to match fire ecology and management goals.

We showed that production frontiers were highly variable among the different restoration objectives and among and within planning areas. Thus, there are decision tradeoffs associated with selecting stands to treat, as well as selecting planning areas. Both the production frontiers and the rankings point to specific spatial priorities and opportunities to achieve restoration goals in the State of New Mexico. The tradeoffs we observed result from the juxtaposition of ecological settings with human values, especially with respect to community wildfire protection versus protecting biodiversity from wildfire impacts. In general, tradeoffs complicate the prioritization of restoration programs.

As priorities are further developed for restoration and risk reduction in the State of New Mexico, additional analyses with the existing assessments can be incorporated, such as socioeconomic and ecological factors. Ultimately, restoration program treatments need to be designed that can maintain or promote desired ecological conditions under future fire regimes that might result from an altered climate, and/or from changes in suppression policy that could allow fires to burn as a tool to reduce fuel loadings and improve fire resiliency.

References

- Ager, A.A.; Day, M.A.; Vogler, K. 2016. Production possibility frontiers and socioecological tradeoffs for restoration of fire adapted forests. *Journal of Environmental Management*. 176: 157–168.
- Ager, A.A.; Evers, C.R.; Day, M.A.; [et al.]. 2017a. Network analysis of wildfire transmission and implications for risk governance. *PLoS ONE*. 12: e0172867. doi: <http://dx.doi.org/10.1371/journal.pone.0172867>.
- Ager, A.A.; Vogler, K.C.; Day, M.A.; [et al.]. 2017b. Economic opportunities and trade-offs in collaborative forest landscape restoration. *Ecological Economics*. 136: 226–239.
- Ager, A.A.; Houtman, R.; Day, M.A.; [et al.]. 2019. Tradeoffs between U.S. national forest harvest targets and fuel management to reduce wildfire transmission to the wildland urban interface. *Forest Ecology and Management*. 434: 99–109.
- Ager, A.A.; Vaillant, N.M.; Finney, M.A. 2011. Integrating fire behavior models and geospatial analysis for wildland fire risk assessment and fuel management planning. *Journal of Combustion*. 572452: 19. doi: <http://dx.doi.org/10.1155/2011/572452>.
- Ager, A.A.; Vaillant, N.M.; McMahan, A. 2013. Restoration of fire in managed forests: A model to prioritize landscapes and analyze tradeoffs. *Ecosphere*. 4(2): 29. doi: <http://dx.doi.org/10.1890/ES13-00007.1>.
- Ager, A.A.; Vaillant, N.; Owens, D.E.; [et al.]. 2012. Overview and example application of the Landscape Treatment Designer. Gen. Tech. Rep. PNW-GTR-859. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 11 p.
- Bassett, S.; Lopez, M.K. 2020. Assessing postfire debris-flow hazard prior to wildfire to enable prefire planning and investments in risk mitigation across Colorado and New Mexico. Unpublished paper on file with: The Nature Conservancy, Santa Fe, NM. 12 p.
- Crookston, N.L.; Dixon, G.E. 2005. The forest vegetation simulator: A review of its structure, content, and applications. *Computers and Electronics in Agriculture*. 49: 60–80.
- Dixon, G.E. 2002. Essential FVS: A user's guide to the Forest Vegetation Simulator. Fort Collins, CO: USDA Forest Service, Forest Management Service Center. 226 p.
- Eidenshink, J.; Schwind, B.; Brewer, K.; [et al.]. 2007. A project for monitoring trends in burn severity. *Fire Ecology*. 3: 3–21.

- Finney, M.A.; Seli, R.C.; McHugh, C.W.; [et al.]. 2007. Simulation of long-term landscape-level fuel treatment effects on large wildfires. *International Journal of Wildland Fire*. 16: 712–727.
- Gesch, D.B.; Evans, G.A.; Oimoen, M.J.; [et al.]. 2019. The National Elevation Dataset. In: Maune, D.F.; Nayegandhi, A., eds. *Digital elevation model technologies and applications: The DEM users manual*. Third edition. Bethesda, MD: American Society for Photogrammetry and Remote Sensing: 83–110.
- Haas, J.R.; Calkin, D.E.; Thompson, M.P. 2015. Wildfire risk transmission in the Colorado Front Range, USA. *Risk Analysis*. 35: 226–240.
- Microsoft. 2018. Computer generated building footprints for the United States GitHub repository [Database]. <https://github.com/Microsoft/USBuildingFootprints>. [Accessed 1 February 2021].
- Nielsen, P.; Evers; Ager. 2019. Exposure complexity and community capacity to manage wildfire risk: A coupled biophysical and social analysis of 60 communities in the western United States. *Fire*. 2:59. <https://doi.org/10.3390/fire2040059>.
- NMFD. 2020. 2020 New Mexico forest action plan. Santa Fe, NM: New Mexico Energy, Minerals and Natural Resources Department, Forestry Division.
- NMFWRI. 2020. NM vegetation treatment mapping database [Database]. <https://www.nmfwri.org/gis-projects/nm-vegetation-treatment-mapping>. [Accessed 1 February 2021].
- North, M.P.; Stephens, S.L.; Collins, B.; [et al.]. 2015. Reform forest fire management. *Science*. 349: 1280–1281.
- NRCS. 1998. *National forestry manual: 190-V-NFM*. USDA, Natural Resources Conservation Service. 638 p.
- Palaiologou, P.; Ager, A.A.; Evers, C.R.; [et al.]. 2019. Fine-scale assessment of cross-boundary wildfire events in the western United States. *Natural Hazards and Earth System Sciences*. 19: 1755–1777. https://www.fs.fed.us/rm/pubs_journals/2019/rmrs_2019_palaiologou_p002.pdf. [Accessed 1 February 2021].
- Prichard, S.J.; Stevens-Rumann, C.S.; Hessburg, P.F. 2017. Tamm review: Shifting global fire regimes: Lessons from reburns and research needs. *Forest Ecology and Management*. 396: 217–233.
- Reitz, M.; Sanford, W.E.; Senay, G.; [et al.]. 2017. Annual estimates of recharge, quick-flow runoff, and evapotranspiration for the contiguous U.S. using empirical regression equations. *JAWRA Journal of the American Water Resources Association*. 53: 961–983.

- Riley, K.; Grenfell, I.; Finney, M.; [et al.]. 2019. Fire Lab tree list: A tree-level model of the conterminous United States landscape circa 2014 [Database]. doi: <https://doi.org/10.2737/RDS-2019-0026>.
- Riley, Karin L.; Grenfell, Isaac C.; Finney, Mark A.; Wiener, Jason M. 2021. TreeMap, a tree-level model of conterminous US forests circa 2014 produced by imputation of FIA plot data. *Scientific Data*. 8: 11.
- Saavedra, P. 1987. Surface water irrigation organization in New Mexico. Report TDDC-87-2. Santa Fe, NM. <https://www.nmacequiacommission.state.nm.us/AcequiaCommission/Acequia-Lists/Acequia-list-CoE.pdf>. [Accessed 1 February 2021].
- Scott, J.H.; Thompson, M.P.; Calkin, D.E. 2013. A wildfire risk assessment framework for land and resource management. Gen. Tech. Rep. RMRS-GTR-315. Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station. 83 p.
- Staley, D.M.; Tillery, A.C.; Kean, J.W.; [et al.]. 2018. Estimating postfire debris-flow hazards prior to wildfire using a statistical analysis of historical distributions of fire severity from remote sensing data. *International Journal of Wildland Fire*. 27: 595–608.
- USDA Forest Service [USDA FS]. 2016. Southwestern wildfire risk assessment: Detailed initial regional wildfire risk assessment results for the Cibola National Forest and Grasslands. https://edacftp.unm.edu/NMCTP/wildfirerisk/2017_06_R3WildfireRiskAssessment_Detailed_R3WildfireRiskResults.pdf. [Accessed 1 February 2021].
- USDA Forest Service [USDA FS]. 2018. Towards shared stewardship across landscapes: An outcome-based investment strategy. FS-118. Washington, DC: USDA Forest Service.
- USDA Forest Service [USDA FS]. 2019. Agreement for shared stewardship between the State of Idaho and the United States Department of Agriculture Forest Service Northern and Intermountain Regions. <https://www.fs.fed.us/sites/default/files/idaho-shared-stewardship-agreement.pdf>. [Accessed 1 February 2021].
- USDOT. 2019. National Highway Planning Network [Database]. <https://data-usdot.opendata.arcgis.com/datasets/national-highway-planning-network>. [Accessed 1 February 2021].
- U.S. EPA. 2019. Safe Drinking Water Information System (SDWIS). <https://www.epa.gov/ground-water-and-drinking-water/safe-drinking-water-information-system-sdwis-federal-reporting>. [Accessed 1 February 2021].
- USGS. 2016. Protected Areas Database of the United States (PAD-US) [Database]. <https://gapanalysis.usgs.gov/padus/data/metadata/>. [Accessed 1 February 2021].

- Weidner, E.; Todd, A. 2011. From the forest to the faucet: Drinking water and forests in the U.S. Washington, D.C.: USDA Forest Service. 34 p.
- Wing, O.E.; Bates, P.D.; Sampson, C.C.; [et al.]. 2017. Validation of a 30 m resolution flood hazard model of the conterminous United States. *Water Resources Research*. 53: 7968–7986.
- Zogg, J.; Deitsch, K. 2013. The flash flood potential index at WFO Des Moines, Iowa. NOAA National Weather Service. http://www.crh.noaa.gov/Image/dmx/hydro/FFPI/FFPI_WriteUp.pdf. [Accessed 1 February 2021].

Appendix A. Supplementary Maps

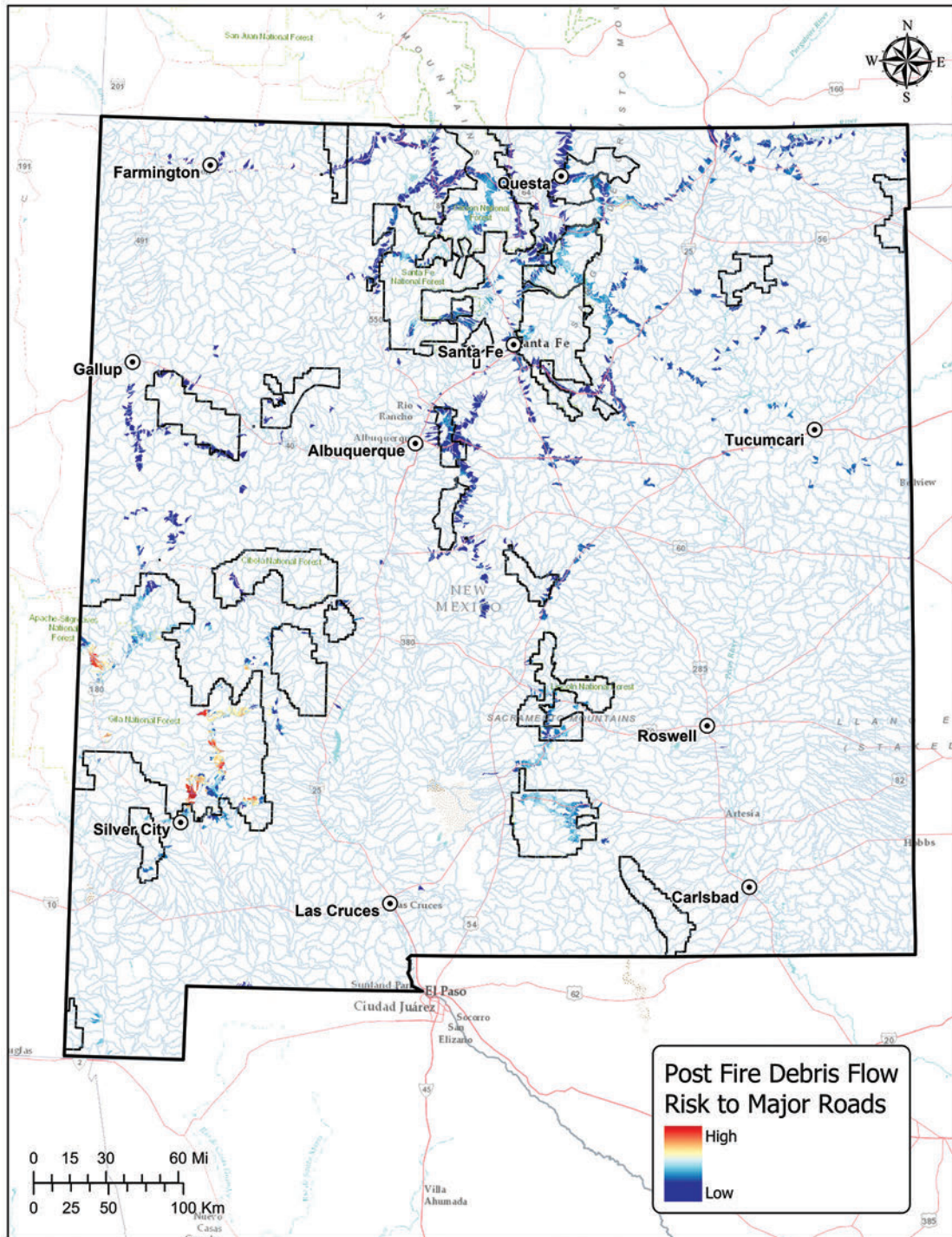


Figure A1—Postfire debris flow risk to major roads. Used in the “Wildfire risk to wildland communities and infrastructure” composite priority metric.

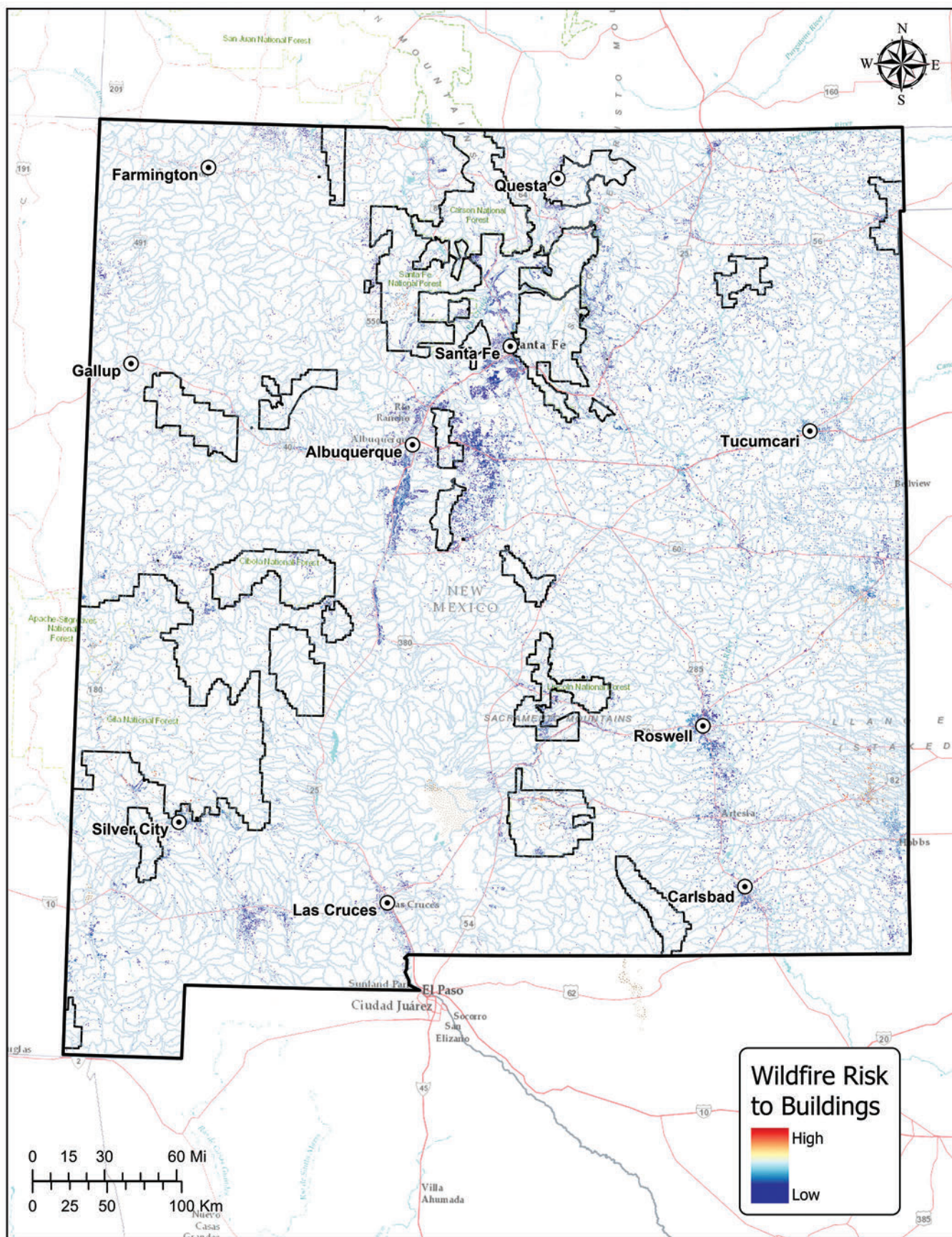


Figure A2—Wildfire risk to buildings. Used in the “Wildfire risk to wildland communities and infrastructure” composite priority metric.

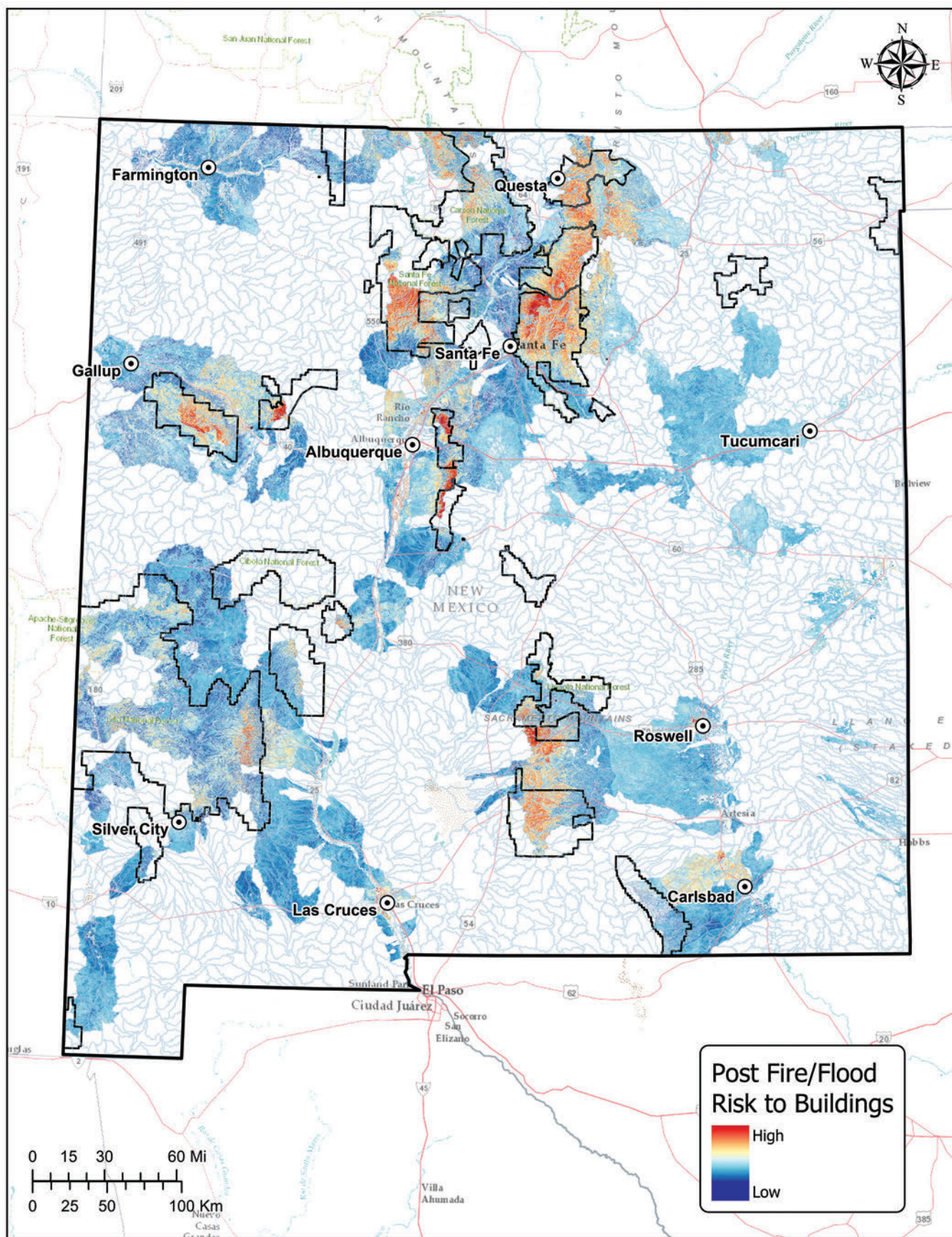


Figure A3—Postfire debris flood risk to buildings. Used in the “Wildfire risk to wildland communities and infrastructure” composite priority metric.

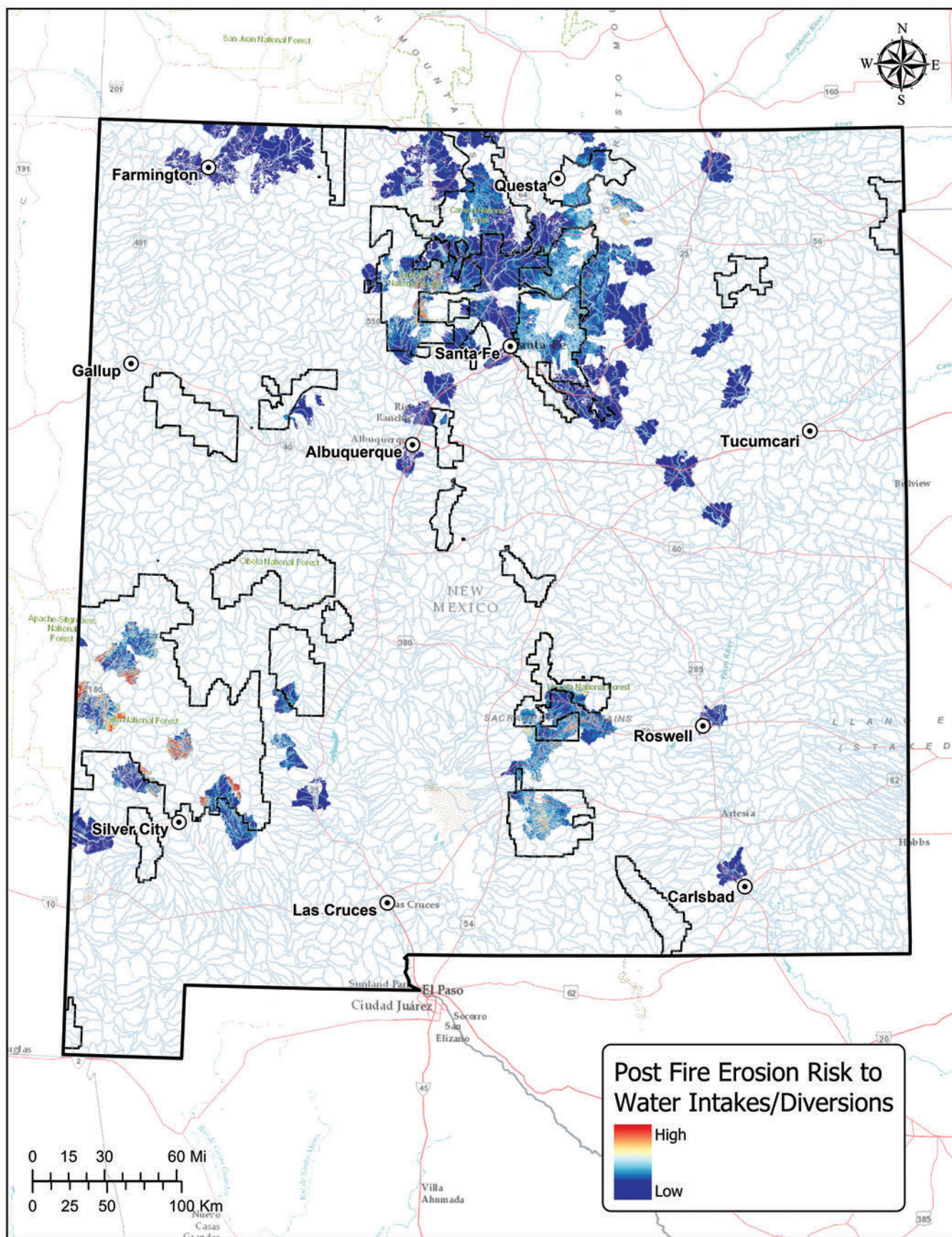


Figure A4—Postfire erosion risk to water intakes and diversions. Used in the “Wildfire risk to water quality and supply” composite priority metric.

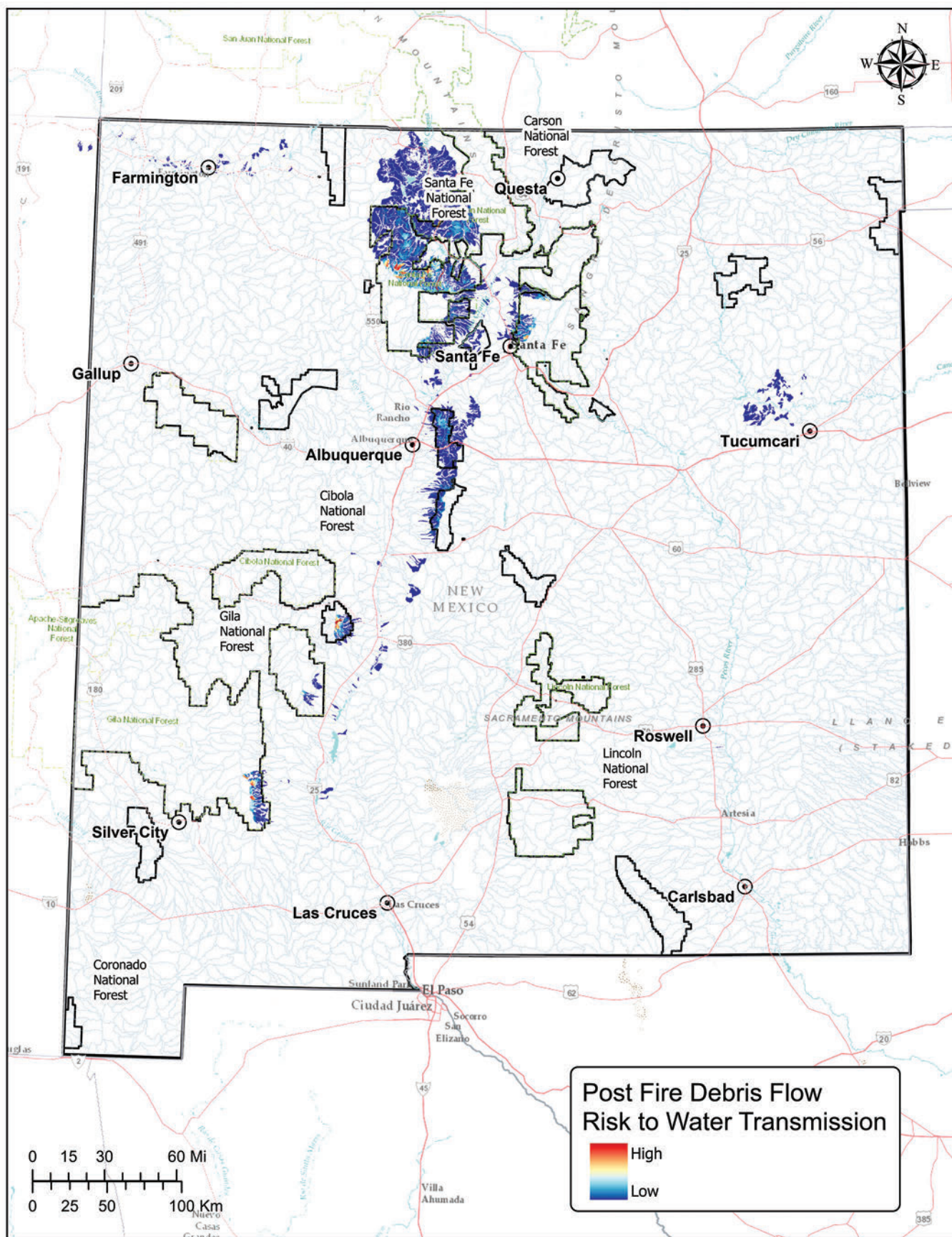


Figure A5—Postfire debris flow risk to water transmission. Used in the “Wildfire risk to water quality and supply” composite priority metric.

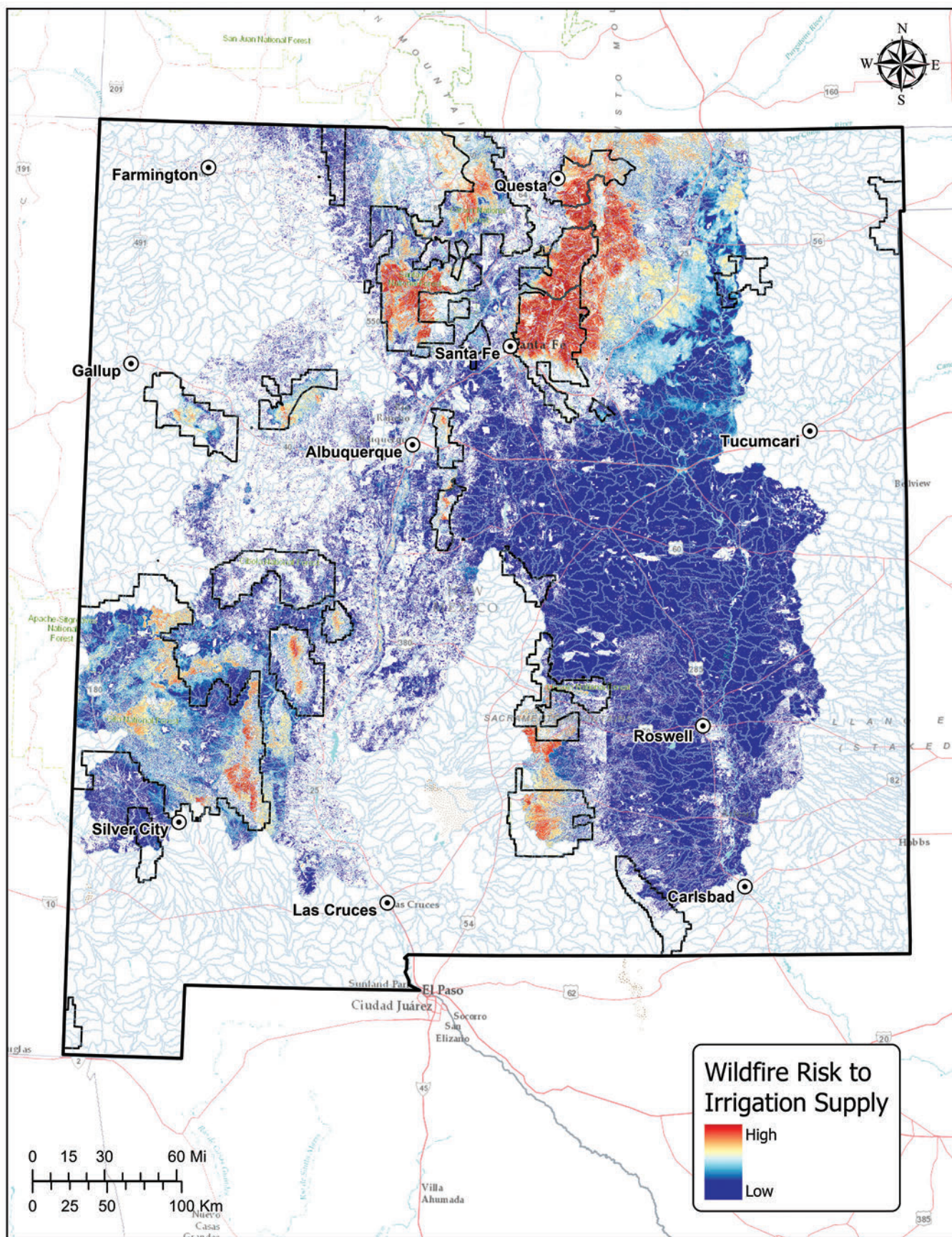


Figure A6—Wildfire risk to irrigation water supply. Used in the “Wildfire risk to water quality and supply” composite priority metric.

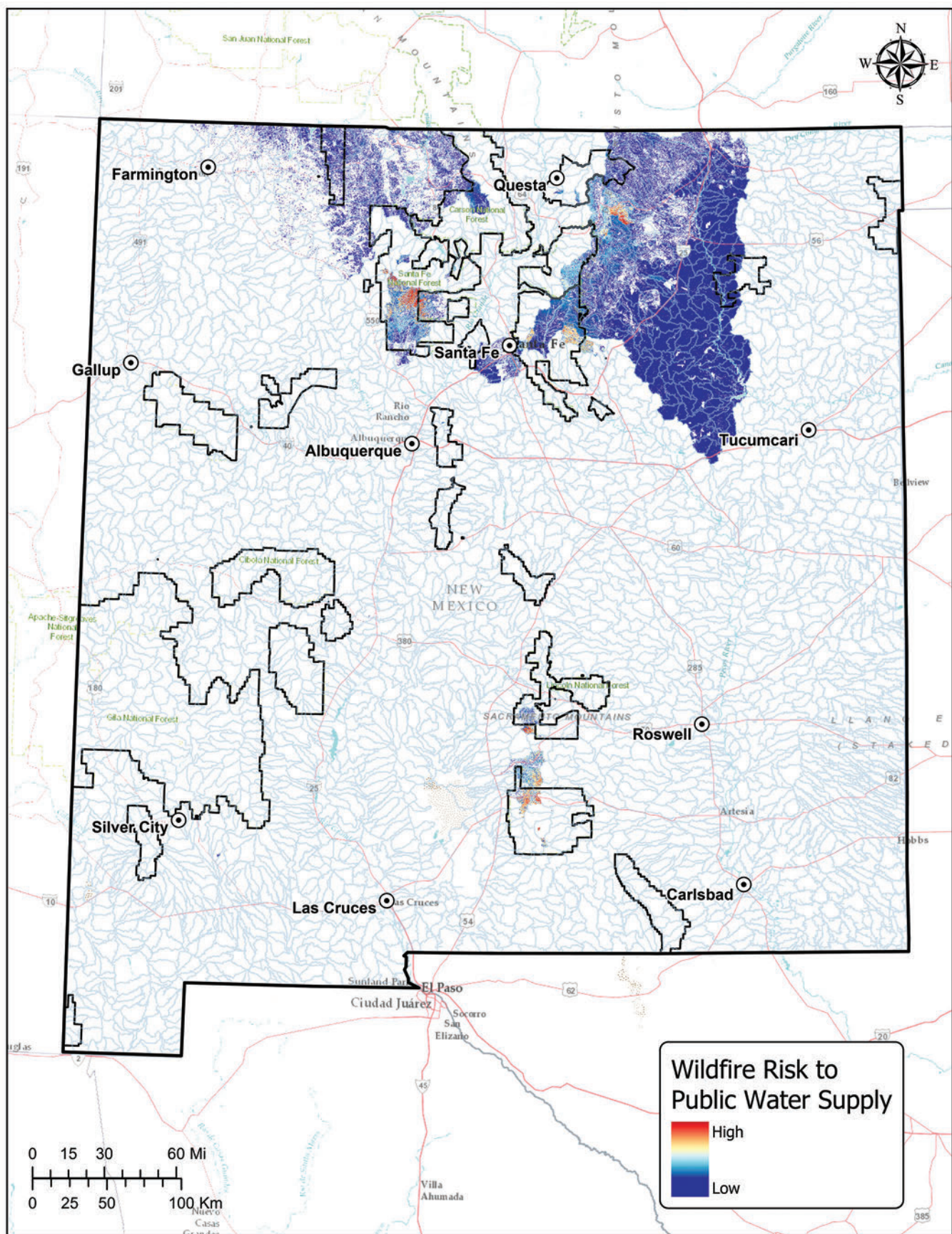


Figure A7—Wildfire risk to public water supply. Used in the “Wildfire risk to water quality and supply” composite priority metric.

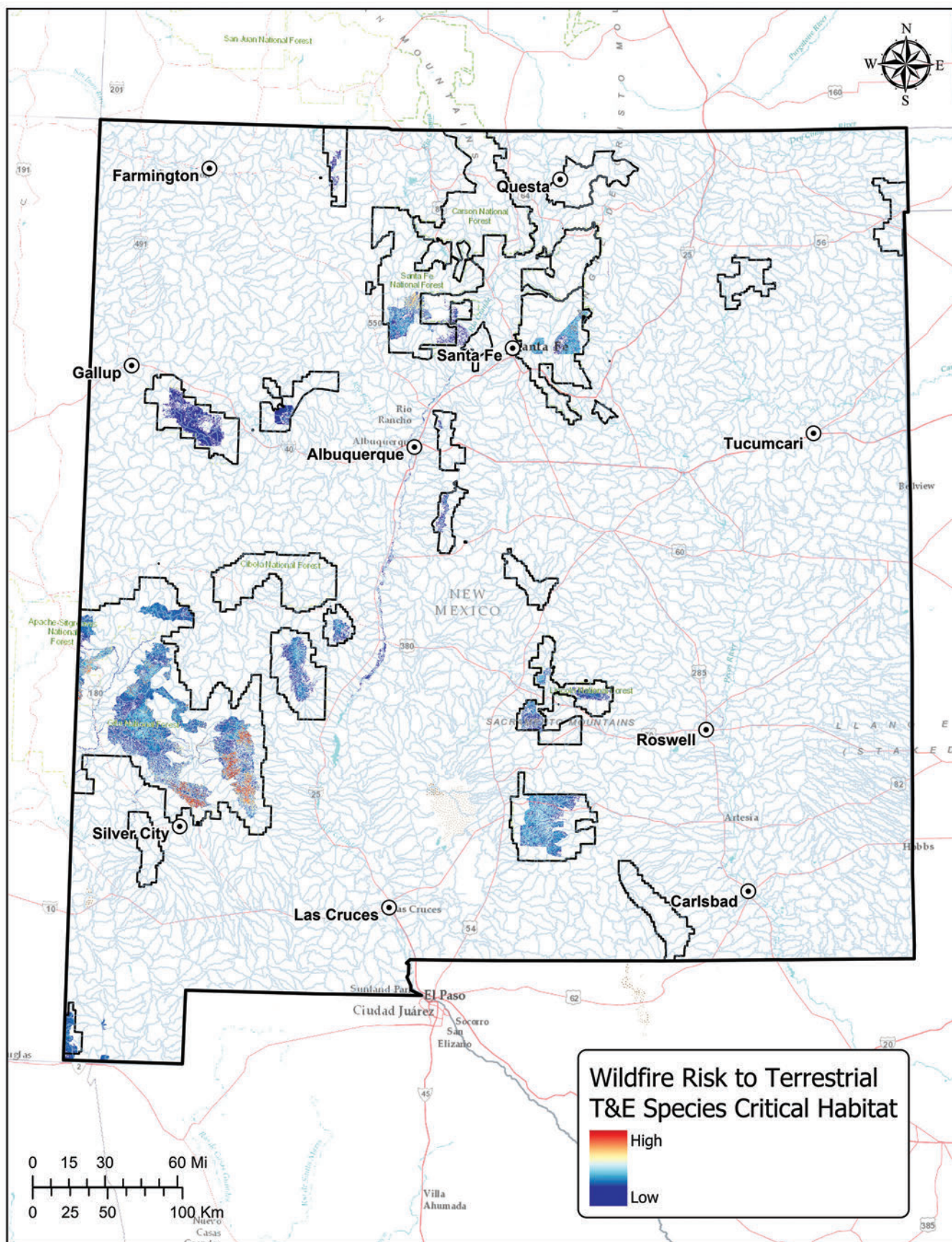


Figure A8—Wildfire risk to terrestrial threatened and endangered critical habitat. Used in the “Wildfire risk to biodiversity” composite priority metric.

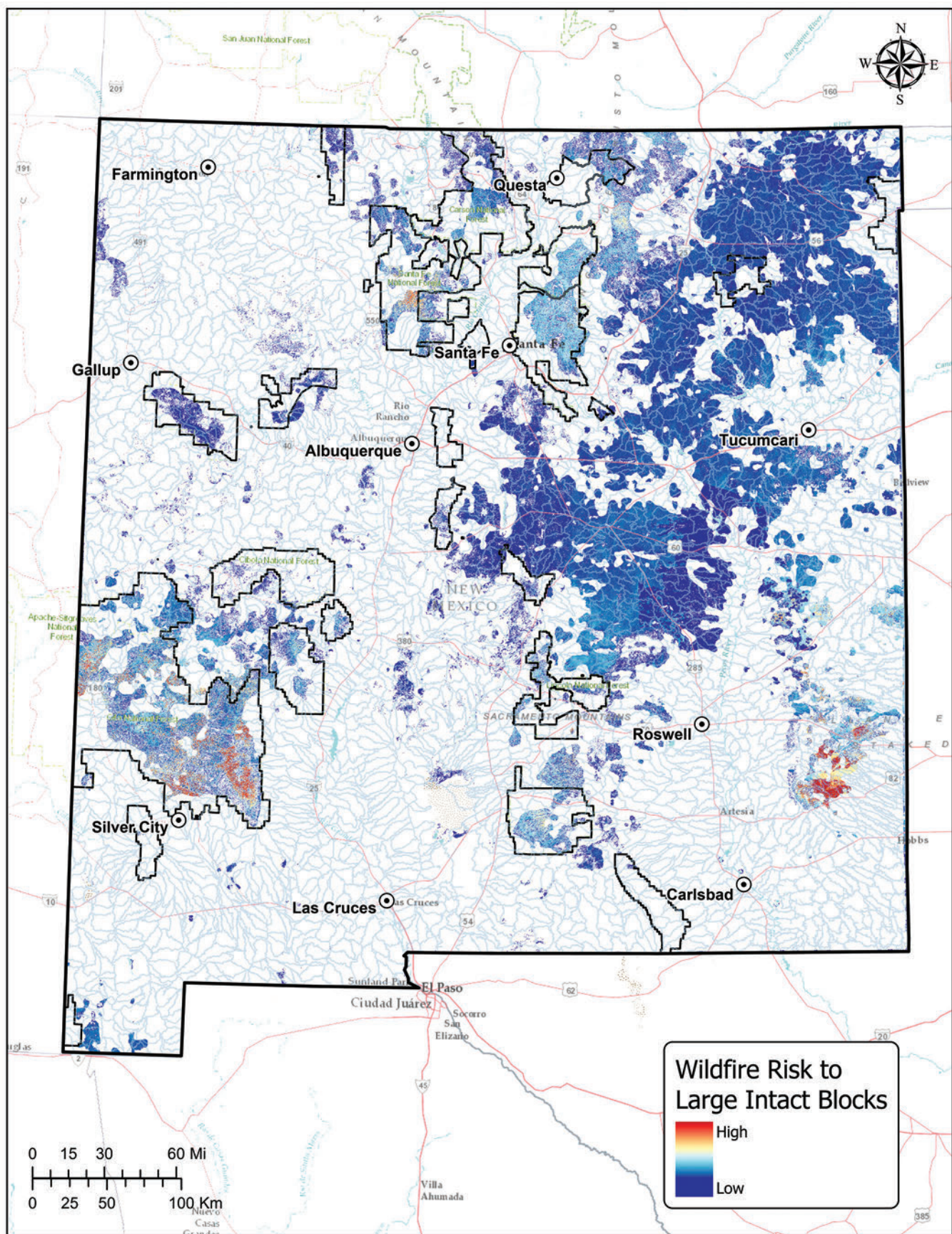


Figure A9—Wildfire risk to large intact blocks. Used in the “Wildfire risk to biodiversity” composite priority metric.

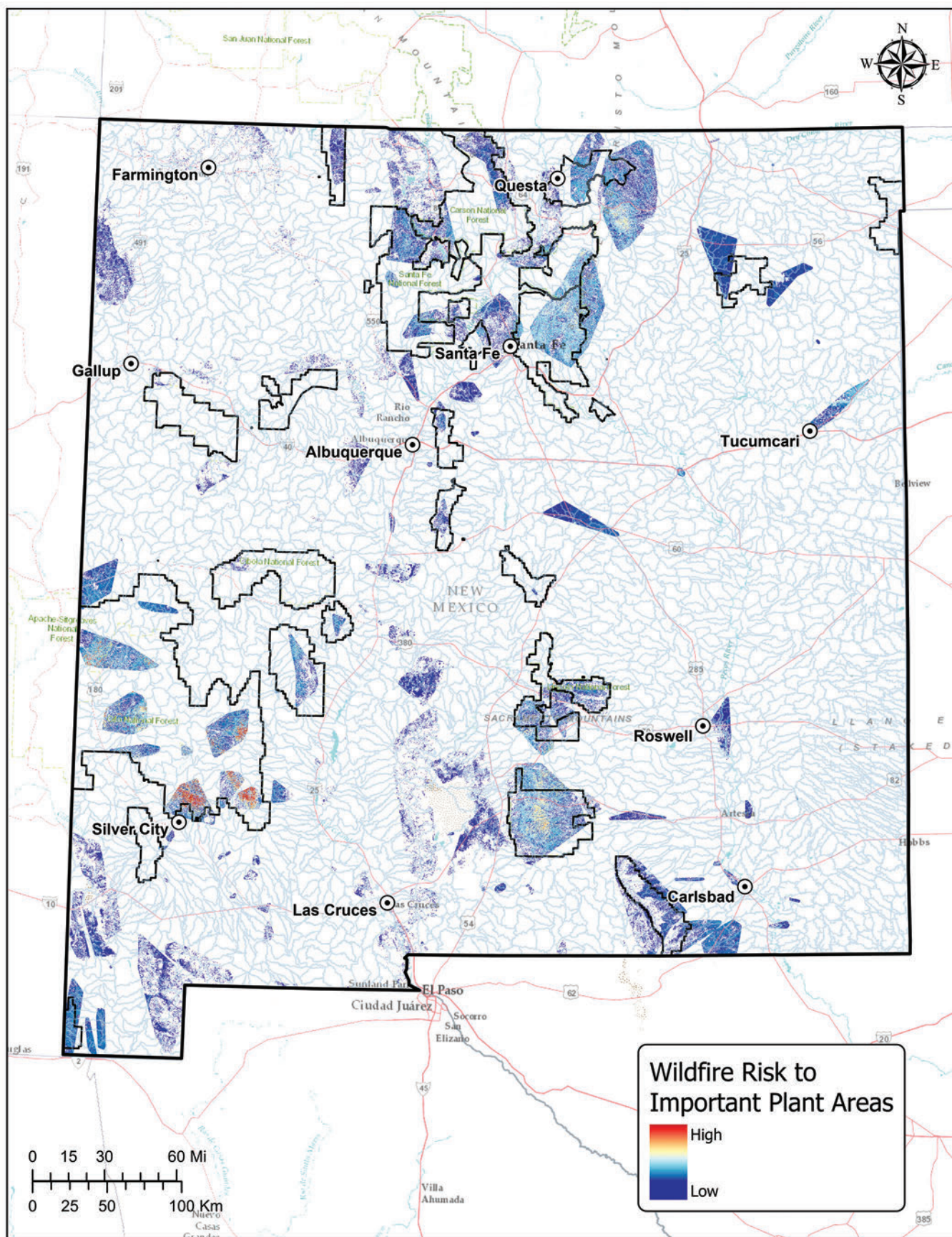


Figure A10—Wildfire risk to rare plants (important plant areas). Used in the “Wildfire risk to biodiversity” composite priority metric.

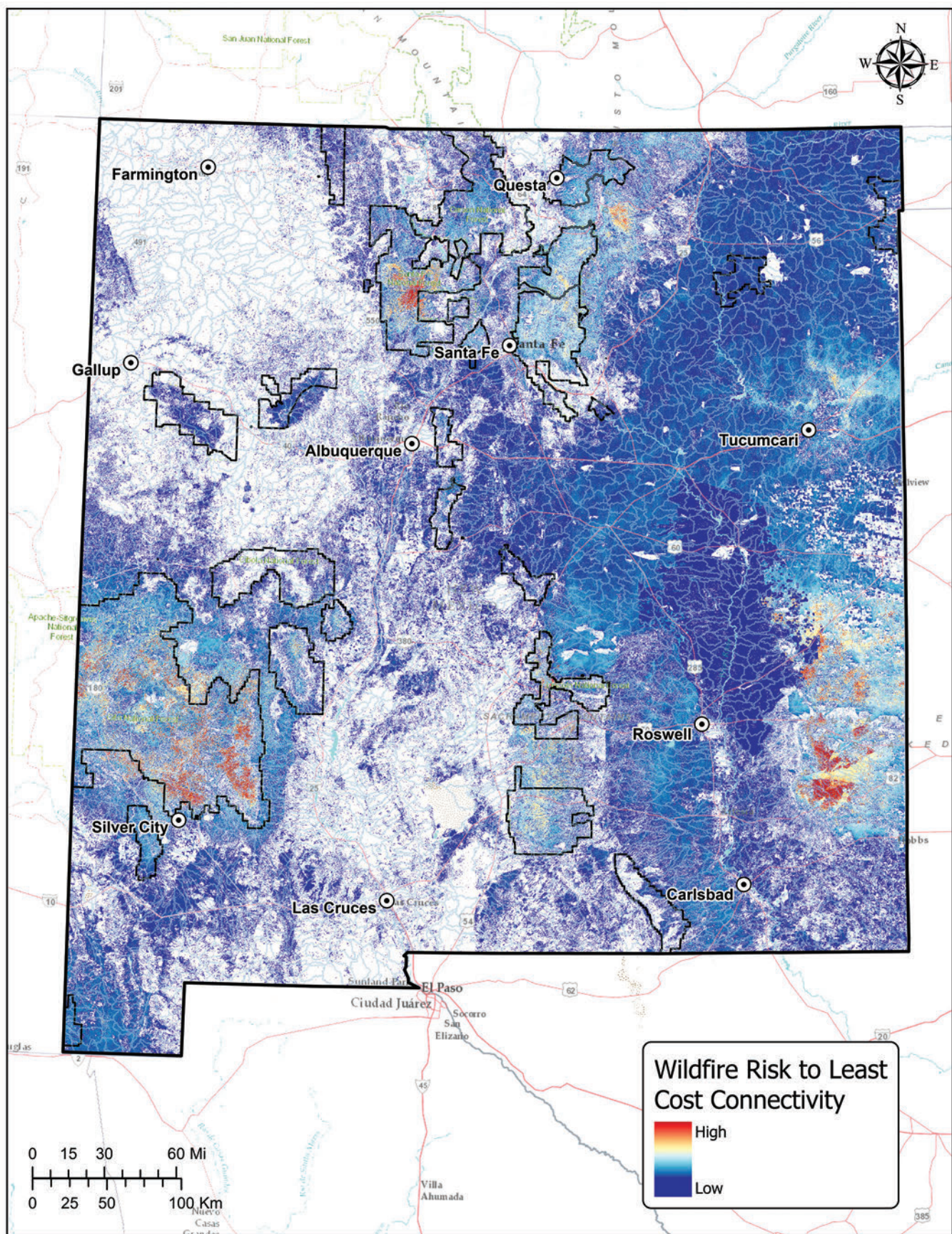


Figure A11—Wildfire risk to connectivity (least cost). Used in the “Wildfire risk to biodiversity” composite priority metric.

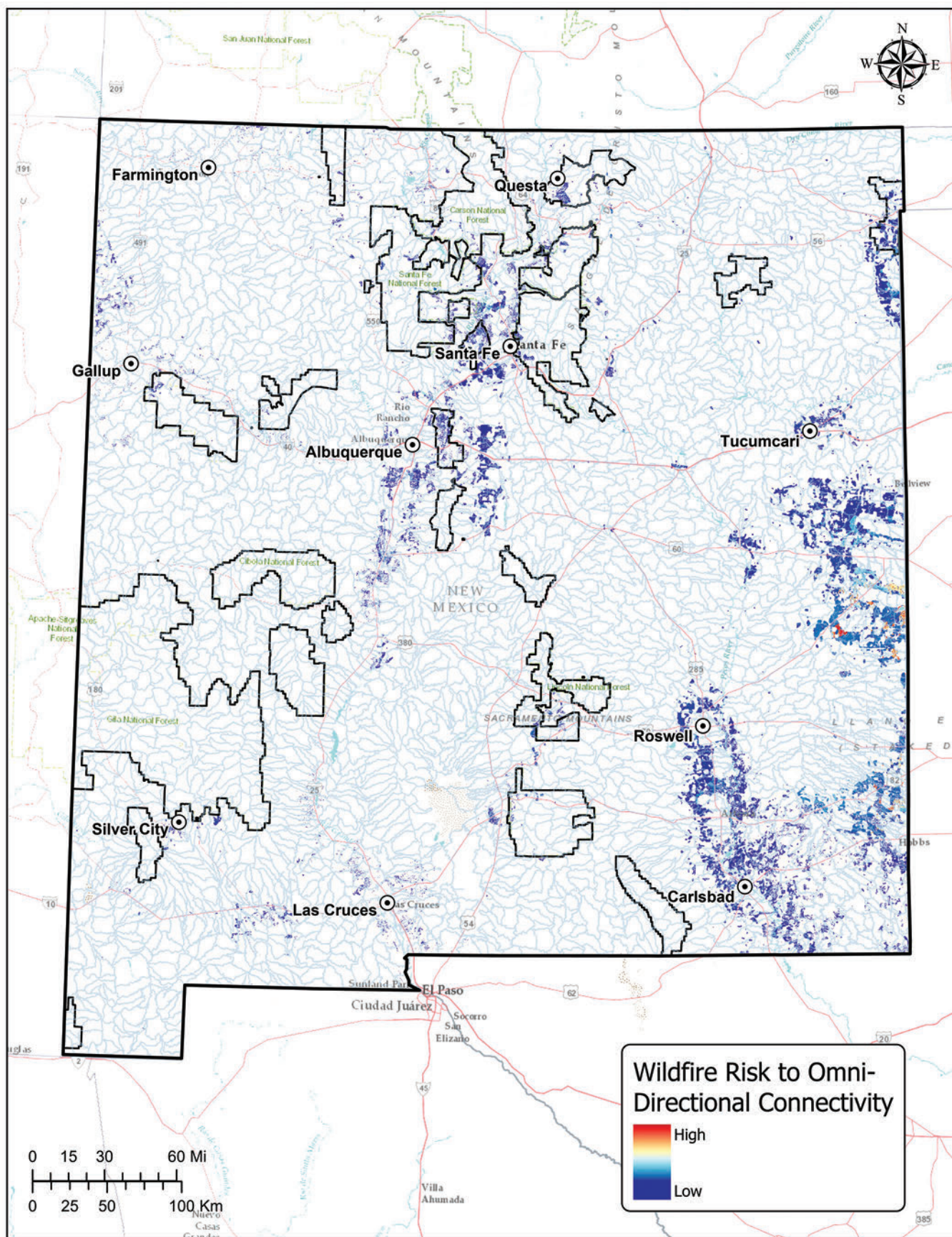


Figure A12—Wildfire risk to connectivity (omnidirectional). Used in the “Wildfire risk to biodiversity” composite priority metric.

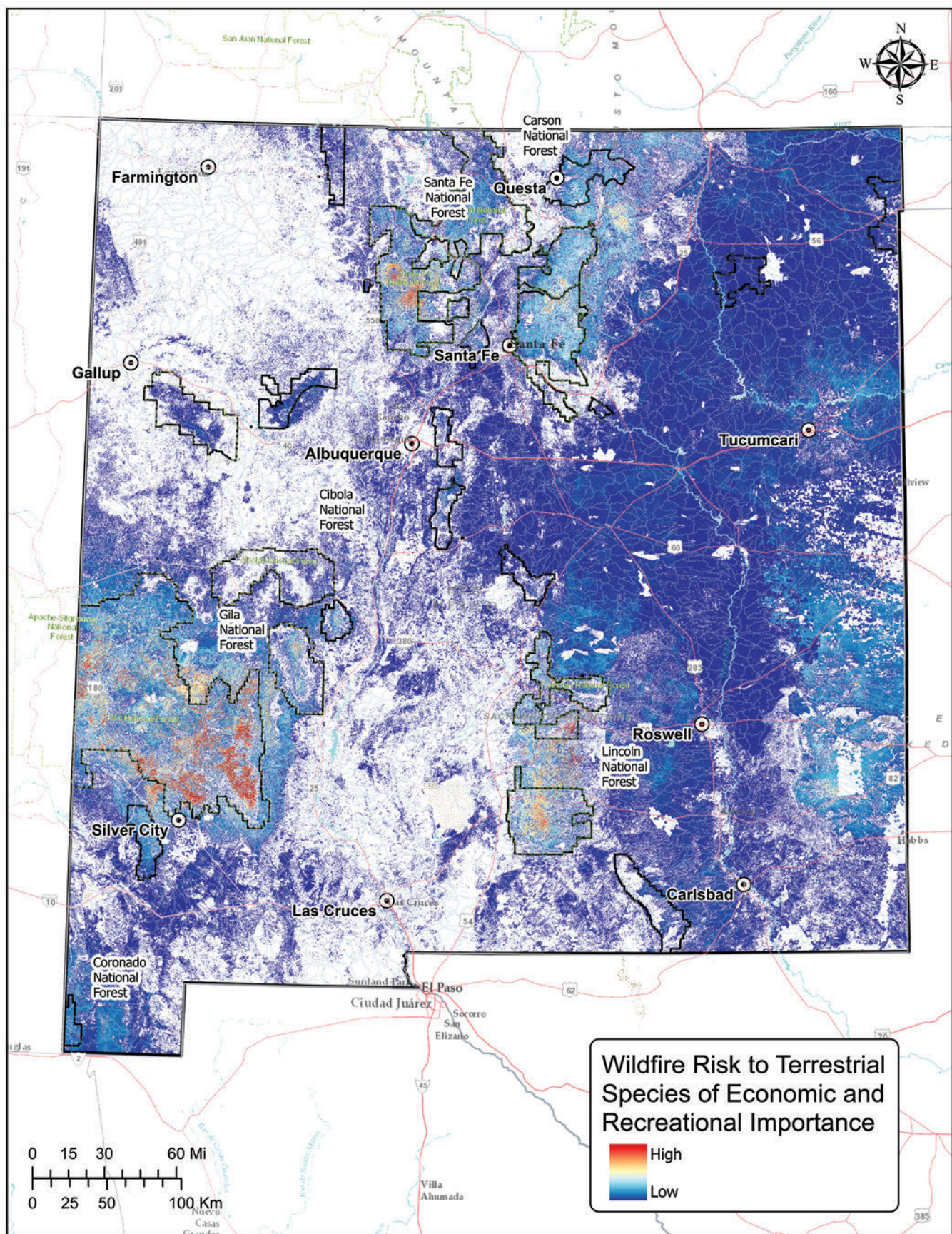


Figure A13—Wildfire risk to terrestrial species of economic and recreational importance. Used in the “Wildfire risk to biodiversity” composite priority metric.

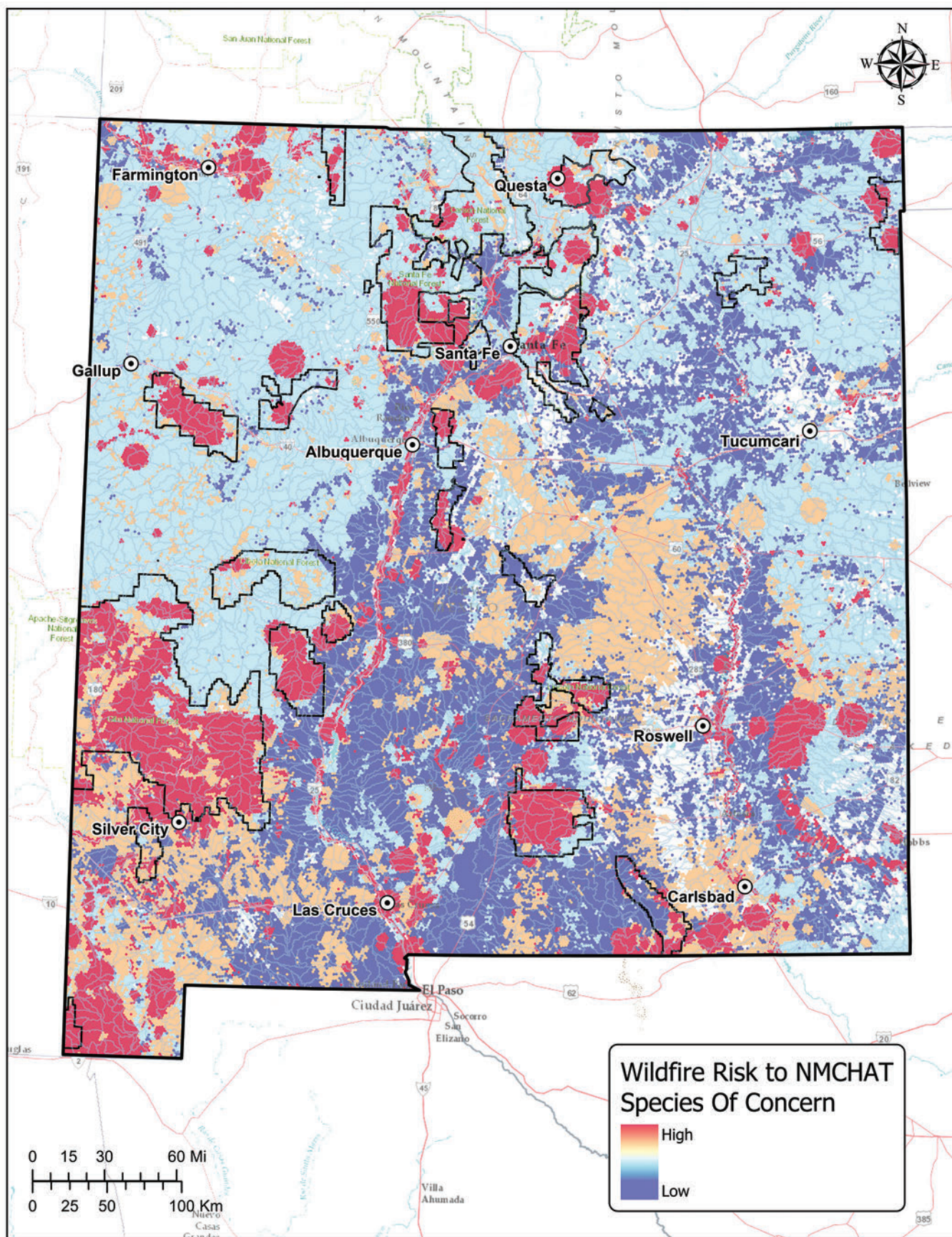


Figure A14—Wildfire risk to NMCHAT species of concern. Used in the “Wildfire risk to biodiversity” composite priority metric.

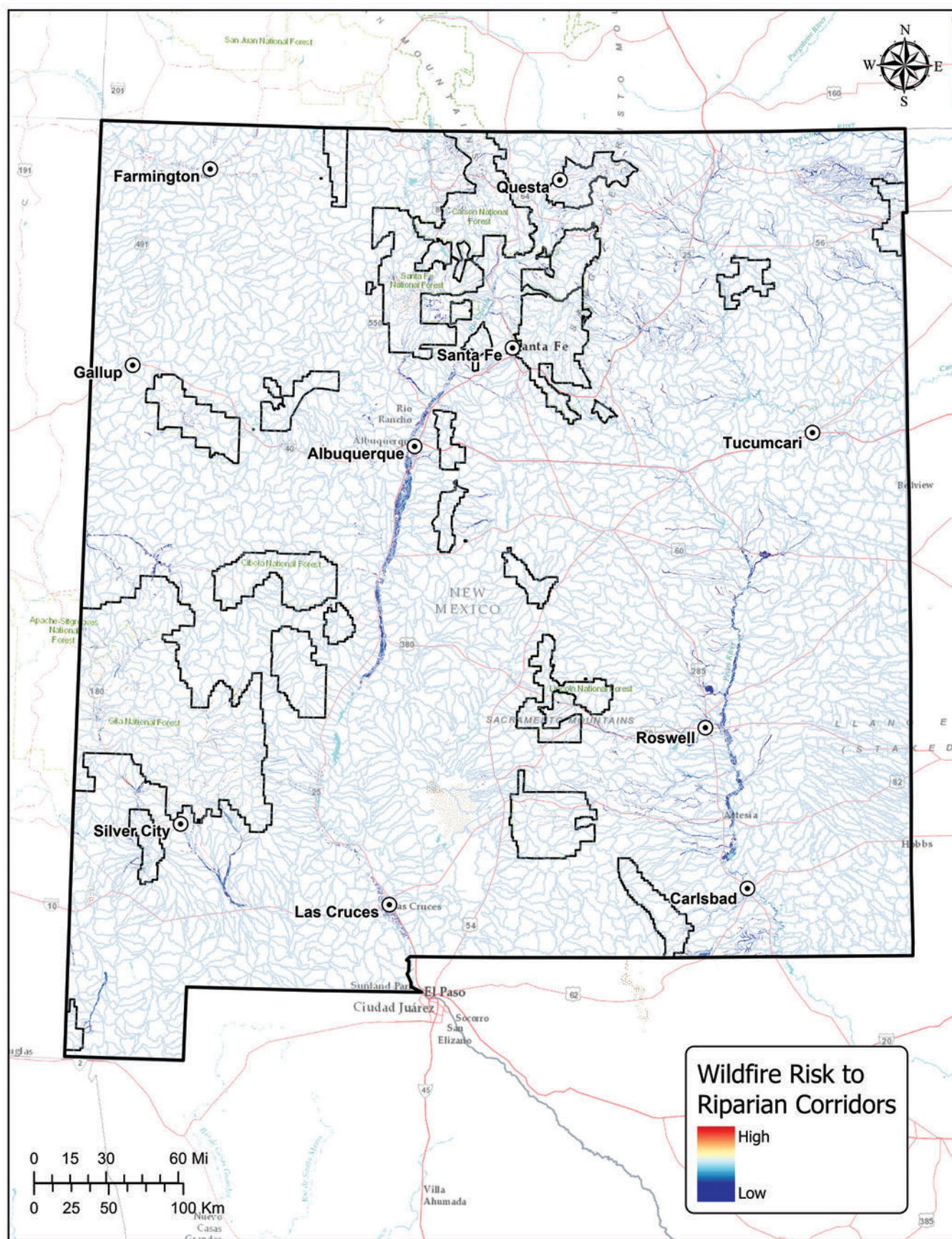


Figure A15—Wildfire risk to riparian corridors. Used in the “Wildfire risk to biodiversity” composite priority metric.

Appendix B. Additional Modeling Details

Table B1—Description of the attributes in the New Mexico stand layer used in the analysis.

Field type	Field name	Field description
Original	HUC12	Sub-watershed (planning area) code
	Name	Sub-watershed name
	WS_Percent	Percent of sub-watershed within stand
	Forest_Name	Name of majority National Forest in stand (or "Non_Forest")
	Owner	Owner
	Own_Percent	Percent of owner in stand
Stand	Cell_ID	Unique stand ID
	Area_HA	Area of stand, in hectares
	Manage_new	From original field "Precluded": Manage_new = 1 if "Precluded" = "No", 0 otherwise
Individual risk	TFRMN	PostFireDebrisFlowRisk_MajorRoads (stand mean)
	TWDMN	PostFireDebrisFlowRisk_WaterTransmission (stand mean)
	TWEMN	PostFireErosionRisk_WaterIntakesDiversions (stand mean)
	TFBMN	PostFireFloodRisk_Buildings (stand mean)
	TWBMN	WildfireRisk_Buildings (stand mean)
	TWIMN	WildfireRisk_WaterIrrigationSupply (stand mean)
	TWPMN	WildfireRisk_WaterPublicSupply (stand mean)
Timber volume	TVMBF_STND	Timber volume (stand total, in MBF)
	TVMBF_SPM	Timber volume (standardized percent of maximum)
	TVMBF_PCP	Timber volume (percent contribution to problem)
Composite risk	TCBMN	Biodiversity_WildfireRisk_Index (stand mean)
	TCBMN_STND	Biodiversity_WildfireRisk_Index (area weighted mean)
	TCBMN_SPM	Biodiversity_WildfireRisk_Index (standardized percent of maximum)
	TCBMN_PCP	Biodiversity_WildfireRisk_Index (percent contribution to the problem)
	TCCMN	WildlandCommunities_WildfireRisk_Index (stand mean)
	TCCMN_STND	WildlandCommunities_WildfireRisk_Index (area weighted mean)
	TCCMN_SPM	WildlandCommunities_WildfireRisk_Index (standardized percent of maximum)
Composite risk	TCCMN_PCP	WildlandCommunities_WildfireRisk_Index (percent contribution to the problem)
	TCWMN	WaterSupplies_WildfireRisk_Index (stand mean)
	TCWMN_STND	WaterSupplies_WildfireRisk_Index (area weighted mean)
	TCWMN_SPM	WaterSupplies_WildfireRisk_Index (standardized percent of maximum)
	TCWMN_PCP	WaterSupplies_WildfireRisk_Index (percent contribution to the problem)

(continued on next page)

Table B1 (continued)—Description of the attributes in the New Mexico stand layer used in the analysis.

Field type	Field name	Field description
Vegetation†	ERUMAJ	Majority ERU veg type
	ERUSYS	Majority ERU system (grassland, forest, woodland, etc.)
	Forest_flg	1 if majority forest system; 2 if majority woodland system; 0 otherwise (based on ERU system)
Opportunity	ODFMJ	Dry Forest Opportunity (from ERU - majority veg types PPine Forest, PPine/Evergreen Oak, Mixed Conifer - Frequent Fire)
	OMTMJ	Mechanical Treatment Opportunity
	ODMMJ	Both Dry Forest and Mechanical Opportunity
	Treat_flg	1 if Forest_flg is 1 or 2 and OMTMJ = 1; 0 otherwise
Other	OwnerCat	Ownership category, grouped from original "Owner" field**
	CCVMJ	Majority vulnerability value from Climate Change Vulnerability Assessment (LV - Low; MV - Moderate; HV - High; VHV - Very High; UNK - Unknown)

†Based on Ecological Response Unit (ERU)

**NPS/FWS/Dept of Ag/BoR/DoE/Other National Agency = Other Federal; State/State Wildlife Area/State Park = State; Other Govt/County = Other; other owners stay as in original Owner field

In accordance with Federal civil rights law and U.S. Department of Agriculture (USDA) civil rights regulations and policies, the USDA, its Agencies, offices, and employees, and institutions participating in or administering USDA programs are prohibited from discriminating based on race, color, national origin, religion, sex, gender identity (including gender expression), sexual orientation, disability, age, marital status, family/parental status, income derived from a public assistance program, political beliefs, or reprisal or retaliation for prior civil rights activity, in any program or activity conducted or funded by USDA (not all bases apply to all programs). Remedies and complaint filing deadlines vary by program or incident.

Persons with disabilities who require alternative means of communication for program information (e.g., Braille, large print, audiotape, American Sign Language, etc.) should contact the responsible Agency or USDA's TARGET Center at (202) 720-2600 (voice and TTY) or contact USDA through the Federal Relay Service at (800) 877-8339. Additionally, program information may be made available in languages other than English.

To file a program discrimination complaint, complete the USDA Program Discrimination Complaint Form, AD-3027, found online at http://www.ascr.usda.gov/complaint_filing_cust.html and at any USDA office or write a letter addressed to USDA and provide in the letter all of the information requested in the form. To request a copy of the complaint form, call (866) 632-9992. Submit your completed form or letter to USDA by: (1) mail: U.S. Department of Agriculture, Office of the Assistant Secretary for Civil Rights, 1400 Independence Avenue, SW, Washington, D.C. 20250-9410; (2) fax: (202) 690-7442; or (3) email: program.intake@usda.gov.



To learn more about RMRS publications or to search our online titles:

www.fs.fed.us/rm/publications

www.treesearch.fs.fed.us