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Santa Fe National Forest Plan Draft Assessment Report

Volume I. Ecological Resources

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Forest Plan Assessment Report

Santa Fe National Forest

Volume I. Ecological Report

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Assessment Introduction

Purpose

The 2012 Planning Rule (36 CFR 219) provides the process and structure to create local land and resource management plans for national forests across the nation. The rule establishes a three-phase process for plan revisions: (1) assessment; (2) plan development or revision; and (3) monitoring.

The 2012 Planning Rule is intended to create plans that guide integrated resource management in the plan area or lands administered by the Santa Fe National Forest within the context of the broader landscape. It takes an integrated and holistic approach that recognizes the interdependence of ecological processes with social, cultural and economic systems. The approach uses *best available science* and local knowledge to inform decisions along the way. Collaboration with stakeholders, including New Mexico's many cultural groups with deep and long-standing ties to the landscape, and transparency of process are key ways the 2012 Planning Rule guides creation of forest plans for the future. The revised Santa Fe National Forest *Land and Resource Management Plan* (also known as the *Forest Plan*) will consider a wide range of multiple uses on lands managed by the National Forest System (NFS), where jobs are generated and economic opportunities are created.

This document represents the assessment phase of the process and is designed to rapidly evaluate readily available existing information about relevant ecological, economic, and social conditions, trends, and sustainability and their relationship to the current *Land and Resource Management Plan* (1986 *Forest Plan*), within the context of the broader landscape. The assessment uses information that is currently available in a form useful for the planning process, without further data collection, modification, or validation.

Structure of the Assessment Report

Throughout this document, the Santa Fe National Forest is referred to as Santa Fe NF or the Forest, and the Santa Fe National Forest *Land and Resource Management Plan* is referred to as the Santa Fe Forest Plan.

This introduction to the Santa Fe NF Assessment Reports includes the Setting, Distinctive Features, and Background of the Plan Area to describe the physical and climate characteristics and setting of the forest assessment area, and its place within the greater landscape. The Ecosystem Services Framework section describes how Volumes I and II are interrelated and dependent on one another to provide sustainable ecosystem services and multiple uses. An explanation of Best Available Scientific Information follows. Public Participation describes the variety of ways the Santa Fe NF has interacted with the public, land grants and tribes during the early stages of the Forest Plan revision process. The actual assessment reports are provided in two separate volumes, the Ecological Report and the Socio-Economic Report.

Volume I. Ecological Integrity and Sustainability examines the conditions, trends, and risks to integrity and sustainability for the six ecologically–based resource areas laid out in the 2012 Planning Rule (36 CFR 219.6 (b)). In the chapter, an ecological assessment of each resource area, vegetation, soils, water, air, carbon, and federally recognized species and other species of conservation concern, is provided to understand current conditions and trends and to identify key characteristics at risk for a loss of ecological sustainability. The ecological assessment finishes with a summary of the risks to ecological integrity and discusses potential needs for change in Forest management guidance. Characteristics showing a potential or likelihood for risk, due to ongoing conditions and trends, demonstrate an ecological need for change.

Volume II. Social and Economic Resources, assesses conditions, trends, and risks to sustainability for the nine social- and economic-based topic areas listed in the 2012 Planning Rule. Here will be found an assessment of plan area contributions (goods and services) which provide social, economic, and cultural benefits to people and communities. The social and economic assessment considers the current condition of the goods and/or services, stressors affecting demand or availability, and relationships to off-forest social, cultural, and economic conditions. This portion of the assessment finishes with issues of concern or risks likely of diminishing the sustainability of the goods and/or services, and discusses potential areas for needed changes in Forest management direction.

Volumes I and II describe the nature, extent, and role of existing functions and benefits along with possible future trends within the plan area and in the broader landscape. The two volumes represent a rapid assessment of existing information about relevant ecological, economic, and social conditions, trends, and sustainability. Ecological integrity and sustainability and the ability to contribute to social, cultural and economic conditions are intricately connected and interdependent. This concept is discussed below in the section on Ecosystem Services framework. At the end of each section, representing the different key resource or topic areas, a summary of the key findings related to sustainability for those services and benefits is provided.

Ecosystem Services

Within the assessment reports, conditions and trends of key assessment topics listed in 36 CFR 219.6(b) and the likely sustainability of these socio-cultural, economic, and ecological systems or benefits (36 CFR 219.5(a)(1)) are identified and evaluated. The framework for this discussion follows the Millenium Ecosystem Assessment (MEA 2005), an international protocol developed to better account for the complex natural biological and physical processes that underlie human habitation and aspirations on this planet. This framework groups these ‘Ecosystem Services’ processes and the benefits humans derive from them into the following four categories:

1. Supporting Services—such as nutrient and water cycling, biodiversity, pollination, soil formation
2. Provisioning Services—such as food, fresh water, wood and fiber, forage, energy/fuel
3. Regulating Services—equilibrating key systems such as climate, water flow (flood management), disease (moderating outbreaks), water quality (natural filtration), air quality
4. Cultural Services—education opportunities, recreation, spiritual connection, social cohesion

While Boyd and Banzhaf (2007) argue for a standardized approach to the concept of Ecosystem Services that would focus strictly on direct human benefits as a suitable proxy for measuring the more complex systems described in these categories, such standardization has not yet occurred, so readers are provided brief information about these services in both the ecological and socio-economic volumes. In the Santa Fe NF assessment documents, high integrity ecosystems are considered the most resilient in the face of continuing known stressor trends such as population increase and global climate changes. Whether a particular system can be expected to function sustainably, or a benefit can continue to be provided, provides the basis for ‘risk’ discussions. If specific ecological resource area systems have integrity, they would be expected to offer their full range of both Regulating and Supporting Services, keeping their functions sustainable and contributing directly and indirectly to human benefits. Provisioning and Cultural Services largely derive from those functions, are dependent on them, and can be considered direct human benefits. Of course, any effort at categorization will be susceptible to the obvious overlaps in the concept of Ecosystem Services itself; for example, while air quality can be thought of as a functional service offered by the oxygen-emitting plant life found on National Forest lands, a person

breathing that air is partaking of a direct benefit *provisioned* by that function. In these combined Santa Fe NF reports, the Supporting and Regulating Services will be considered as functional activities underlying the needs of all life, including human, and Provisioning and Cultural Services will be considered specific benefits, which typically derive from those underlying functions.

Volume I will provide, at the end of each key resource topic area, a brief summary of the Supporting and Regulating Ecosystem Services discussed, with specific reference to any indications of risk or potential risk to the continued sustainable function of those activities. Volume II will similarly provide brief summaries of the Provisioning and Cultural Ecosystem Services that directly benefit human communities, and will highlight any indicators of potential risk to continuation of those benefits.

To assist readers in finding the information of most interest to them, some examples of this separation can help clarify the intent. National forests and grasslands are named for their vegetation, the most visible portion of the many integrated resources that form the ecosystems and provide the services being assessed in these reports. For Volume I, the discussion begins with vegetation's many indirect services that support and regulate these ecosystems. Direct cultural and provisioning services in the form of wood products, livestock grazing and similar resources, will be discussed in Volume II. Water, the life-blood of the land and even more crucial in the arid southwest than elsewhere, will be addressed in Volume I in terms of functioning watersheds and forms of water, whereas Volume II will contain more information about the ways water is being used in human communities. The new Planning Rule guidance focuses the ecological assessment in Volume I on wildlife and plants known or thought to be of conservation concern, so Volume I considers evidence regarding the effectiveness of current management at mitigating risks to this particular range of plants and animals. Volume II will review current status of and potential concerns regarding fish, wildlife and non-timber plants known to be of direct interest or benefit to human communities. Other resource areas appear in only one volume and should be readily located by following the Table of Contents.

Where management direction, e.g. the current Forest Plan or other legally-required protection, is sufficiently providing for system sustainability, changes may not be needed. Where potential risks are indicated in these assessment reports, however, all stakeholders are encouraged to consider what kinds of management direction may move resource and system trends in a more sustainable direction. Phase 2 of the Forest Plan Revision process will begin with workshops to discuss such potential changes.

This assessment report provides current information on planning topics (36 CFR 219.19) and is not a decision-making document. It serves to provide a basis for Phase 2 of Plan revision, which will start with these 'Need for Change' statements, comparing existing management direction to the observable trends to determine where more clarity might lead to stronger social, ecological and economic sustainability. Only at the end of Phase Two is a decision signed, formalizing direction for the future. Opportunities for feedback and input will continue to be offered as Plan revision goes forward.

Best Available Scientific Information (BASI)

In developing this assessment, Forest Service experts provide information supported by the best available scientific information (BASI) relevant to the Santa Fe NF plan area and management to inform the evaluation of conditions, trends and risks to sustainability for the topics of the assessment addressed in volumes one and two. This includes conditions and trends or the sustainability of social, economic, or ecological systems found on the Forest. Accuracy and reliability of relevant information was determined by comparing the scientific certainty and quality of the information, and using the most scientifically certain information available. Although the BASI is commonly available in the form of peer-reviewed literature, other forms of the BASI may include gray literature, expert opinion, federal agency inventory and monitoring data, and specialist observations, as long as the responsible official has a reasonable basis for relying on that scientific information as the best available. Gray literature is scientific or technical information not available through usual bibliographic sources, typically created by government agencies, universities, corporations, research centers, associations and societies, and professional organizations.The six factors that were considered when identifying the BASI include:

1. The science uses well-developed scientific methods that are clearly described.
2. Logical conclusions and reasonable inferences were drawn.
3. The information has been appropriately peer reviewed.
4. A quantitative analysis was performed using appropriate statistical or quantitative methods.
5. The information is placed in proper context including spatial and temporal scales.
6. References are appropriately cited.

In the context of the BASI, “available” means that the information is currently available in a form useful for the planning process without further data collection, modification, or validation. Analysis or interpretation of the BASI may be needed to place it in the appropriate context for planning but because limited time is allotted to complete the Assessment, BASI must be readily available and exhaustive searches for this information are limited by time. Public and stakeholder feedback regarding the accuracy, reliability, and relevance of scientific information can help ensure the use and documentation of the BASI. The BASI is cited throughout the assessment document along with lists of references found at the end of each chapter and the origin of data analyzed in the assessment. References included in this assessment reflect the most relevant documents, given the scope and scale of the assessment and determined to be the BASI.

Some uncertainty exists especially in situations relevant to global climate change and has been appropriately documented in the assessment. Similarly, throughout the assessment when assumptions are made, they are stated as such. The scientific knowledge base is dynamic and ever expanding and significant findings may be updated in the final assessment to reflect evolving scientific information. While the BASI informs the planning process, plan components, and other plan content, it does not dictate what the decisions must be. First, there may be competing scientific perspectives and uncertainty in the available science. In addition, decisions may consider other relevant factors such as budget, legal authorities, traditional ecological knowledge, Agency policies, public input, and the experience of land managers.

Public Participation

Public notice of the beginning of the Assessment was provided on March 6, 2014. Listening Sessions with community stakeholders, Tribes, relevant government organizations and internally with Forest employees took place beginning in January and February, with follow-up workshops in March. Summaries from the sessions and workshops have been available on-line and by request. Self-convening groups such as county commissioners, planners, acequias, land grants and tribes received presentations by request. Informational kiosks at special events such as county fairs have been an ongoing way to share materials summarizing the plan revision process. On social media, Forest Plan Revision can be found as a webpage as well as a Twitter account and on the Santa Fe National Forest Facebook page.

Public input on how users and visitors value the forest and what changes they have witnessed over time was collected at fourteen community meetings between April and July of 2014 and through Uses and Trends forms available online, at District Offices, or by mail to the revision mailing list and grazing permittees. Below is a summary of what we heard from members of the public during those meetings.

Ecosystems

Participants valued the importance of sustainability for a wide range of recreational and traditional uses. One emphasized the dynamism of the ecosystem, always changing and always giving back.

Negative changes witnessed include an imbalance between increasing population stress and decreasing forest management, more insect infestations and invasive species, and extreme events such as uncharacteristic fire, drought and floods. Overall, participants felt the system has weakened and has less ability to recover (resiliency) from these extreme events.

Air, Soil and Water Resources and Quality

Participants expressed high value for fresh air and clear water, noting stressors such as stream bank erosion, hard ground without topsoil, human-induced erosion, and observing June is now 'the smoky month.' The listening sessions indicated a strong recognition for the importance of healthy watershed and associated wilderness for critical community water supplies and aquifer recharge. Participants also emphasized the importance of being able to maintain and repair acequias.

Negative trends witnessed include less water all around—intermittent streams and springs going dry, poor aquifer recharge, less snow—coupled with increasing population pressure. The ongoing impacts of extreme fires on soil and watershed function were mentioned frequently.

Human Effects

Population growth was repeatedly cited as an ecosystem stressor, but potential positives can also be seen in area communities, for example a new appreciation for good forest management practices that can protect watersheds and mitigate fire danger. People seem more willing to educate each other, coordinate across old boundaries and compromise for the greater good, as noted by participants in both Los Alamos and Jemez Springs.

Fire and Fire Management

While people recognized fire as a useful ecosystem function, because of drought and other changes, extreme fires are also experienced as system stressors, with associated negative impacts, including flash-flooding, which a Cuba resident noted can translate to anxiety in communities. Fire management is seen to have changed as well, with increased emphasis on thinning and prescribed burning.

Climate Change

Participants, particularly from Santa Fe and Las Vegas, noted this as a system driver, allowing for more insects and less precipitation that create potential for large fires. Impacts to water and fish are also a concern.

Wildlife and Plant Species

Participants placed high value on the diversity of plants and animals present on the Forest, and the beauty and interest they add to living here. One (from Mora) noted that frogs and salamanders have disappeared.

Across the communities where the listening sessions took place, some differences in wildlife population trends have been seen: in Jemez Springs, for example, deer populations appear down, whereas in Abiquiu that population appears to have increased. On the other hand, elk population increases have been seen as problematic in a number of communities surrounding the Forest. Both trapping and poaching seem to be rising as well.

Economics

Participants in our meetings shared the value of the Santa Fe NF in providing for livelihoods and driving local economies. Tourism was a key theme in Santa Fe and Los Alamos, and is important for many other communities as well. Recreating in the Forest brings in tourism dollars. The Santa Fe NF can also be seen as part of the City of Santa Fe's efforts to turn around the tourism and business demographic, with more of a shift toward younger visitors. Tourism provides funding and jobs. The Forest is also a vital source of livelihood for ranchers and farmers—providing space for grazing and water for irrigation, for instance. Participants see logging as far less central to local economies as it was before, as timber sales and jobs in logging are down. Another change observed is that tourism dollars are increasingly stressed due to fires. Droughts have impacted irrigated pastures.

Social, Cultural

The long and rich history of the area provides for a multitude of social and cultural factors in and around the Santa Fe NF. See Traditional Uses.

On a broader and more historical level, several participants remarked on the "blending of culture, language, and communities" over time.

In Las Vegas, participants discussed the importance of sustainability of the forest over time, preservation for the use and enjoyment of future generations.

Traditional Uses

Many individuals and families depend on the Santa Fe NF: for sustenance as well as for cultural, social, and historic needs and ties. People view the Forest as their community. The community is not next to the Forest: the forest is a *part* of it.

Some individuals spoke about how they rely on the Santa Fe NF for wood—for fuel to heat their homes and for landscaping. Their communities gather herbs from the Forest. Their water, and the quality of their water, depends on the Forest too. Acequias provide communities with water, and the maintenance and repair of acequias is vital for these communities. People frequently highlighted livestock grazing and the ability to run cattle as critical values of the forest. Along these lines, access is important, access to get to a

sick animal and avoid loss of livestock, for instance. Livelihoods and local communities depend on the Santa Fe NF and its resources.

Family traditions and values are dependent on the forest for some participants, too. In Mora, one participant gave an account of her first job cutting Christmas trees with her father. This experience was a lesson in economics and resource stewardship along the way. These experiences influence the rest of a person's life: their values, world view, even career choice. Acequias not only provide water in acequia cultures, but also provide the basis of local governance structure. Many of these families have deep historical ties, and come from families that have lived in the area for generations, from being from a cattle-raising family that has been in the area since 1938 to a family with a three-generation logging business. The Forest is also important for traditional communities' recreation.

Participants from families or communities that use the Forest for traditional uses expressed concerns about changes they have seen. The sustainability of these communities and their way of life overall came into question. People are leaving rural communities for the cities.

One attendee in Pecos expressed the perspective that "regulations overseeing some traditional use seem to be more strict." Another attendee in Abiquiu is concerned that the "agency is removing native people off the forest." Several participants have observed a decline in native people's ability to access resources, such as restrictions on gathering firewood. Subsistence users used to be the main users of the forest. Concerns were expressed about reductions in grazing permits over time, and also the allotment system not always being fair and supporting the community. It is difficult to repair and maintain acequias – they have to cut through a lot of red tape to get into the forest. Wilderness has negatively impacted acequia management. One participant also observed that climate change and the over-harvesting of herbs has impacted heirs on his land grant.

As discussed in the Social, Cultural, and Economic Concerns section, some participants have perceived an increased conflict around traditional uses. Many participants are concerned about the perceived negative impacts of grazing on streams, forest health, and safety on trails and that there is "lots of destruction due to ranch leases on forest land." Concerns were also expressed about fence disrepair. Other participants have observed that there are too many elk, and they are taking over the grazing. One participant talked about wealthy individuals from outside the community buying property and having less tolerance of a stray cow—yet they are often unwilling to fence their property. A participant in Albuquerque told the story about how four elders in his community died after the Las Conchas Fire because they internalized responsibility. According to the participant, traditional historic communities have an environmental ethic and are stewards of the land.

Input from Technical Meeting on Traditional Uses

Tribal, ranching, and land owner participants expressed appreciation about being involved in forest planning. All participants are concerned about continuing their traditional uses of forest lands and they want the Santa Fe NF to consider their needs along with those off the Forest. They want to be involved and have input in the planning process.

Assessment Report Outreach

Public meetings to share this assessment report will begin with a Symposium, or technical session, on October 22 , 2015, in Santa Fe, and continue with ten local Need-for-Change meetings starting directly after and ending in mid-November.

Ecological Assessment Introduction

The mission of the Forest Service is to sustain the health, diversity, and productivity of the Nation's forests and grasslands to meet the needs of present and future generations. In this Volume ecosystem integrity of terrestrial, riparian, and aquatic ecosystems of the Santa Fe NF[1] will be evaluated to identify potential risk for loss of ecological integrity. Ecological or ecosystem integrity is the quality or condition of an ecosystem and its ability to withstand and recover from natural environmental perturbations. Thus, ecosystem integrity can be described as the condition where composition, structure, and disturbance processes are within the natural range of variation, where the ecological processes are sustained and biodiversity maintained into the future. This assures that the ecosystem is able to recover and renew itself when exposed to future stresses or changes including that of global climate change.

The ecosystems described in the following chapters are not truly discrete, but are closely interrelated. Ecological characteristics (e.g., composition, structure, function, connectivity, and species composition and diversity) for each ecosystem will analyze the current condition relative to reference conditions (i.e., the natural range of variation) to determine ecological integrity or loss thereof. Additionally ecosystem drivers and stressors will be considered to model trends and imply a range of changes that are reasonably foreseeable in the future. The results of these analyses will describe the contribution that the plan area makes to ecological, social, and economic sustainability based on management under the current Land and Resource Management Plan for the Santa Fe NF and identify potential information gaps. Conditions and trends for all ecosystems are integrated at the end of this volume to determine the overall ecological integrity of the plan area in support of identifying any need for change to protect the sustainability of ecological resources, due to ongoing conditions and trends. The assessment also points to priority geographies on the Forest where the role of natural disturbance processes in maintaining ecosystem diversity, and the compatibility of land management activities and land-use allocations, should be evaluated to maximize options for attaining ecological sustainability goals.

Understanding the regional context of the biological and ecological resources managed by the Santa Fe NF both the distribution and condition of those resources – is a necessary pre-requisite to the identification of management strategies that would enable the Santa Fe NF to attain ecosystem diversity and ecological sustainability goals. Moreover, multiple land managers share management responsibility for some of the same resources across northern New Mexico; analyses conducted at multiple scales is necessary to understand ecosystem structure and functions, as well as species diversity and also provide as a starting point for identifying areas where collaborative restoration would be feasible and an effective means of addressing land health issues that span jurisdictional boundaries. Additionally, this assessment will identify information gaps and any uncertainty with the data. The information contained in this assessment will be used to inform agency officials, whether current direction needs adjustment to protect ecological resources and the species and ecosystem services rely on them.

[1] Santa Fe National Forest may also be referenced as Santa NF or the Forest throughout the document.

Chapter 1. Vegetation

The Santa Fe NF comprises a broad range of ecological components, including a large diversity of vegetation systems, ranging along elevational gradients from prairie grasslands to alpine/tundra. Many species depend on these systems, especially aquatic and riparian systems, which are some of the most threatened ecosystems, especially in the arid Southwest. While these important ecological systems and species are distributed across many landowners, the Santa Fe NF like many National Forest System lands contain relatively large proportions of certain systems and species. Identifying these systems and species may be useful in planning efforts that focus on ensuring ecological sustainability across the contextual landscape.

This chapter analyzes the status and distribution of ecosystems that occur within the plan area of the Santa Fe NF (table 1). Ecological Response Units (ERUs) are coarse-scale groupings of ecosystem types that share similar geography, vegetation, and historic ecosystem disturbances such as fire, drought, and native herbivory. Eleven upland vegetation and six riparian vegetation (three riparian groups), ERUs (described below) of the Santa Fe NF and their ecological characteristics are described and analyzed. This chapter will also identify the role the Forest plays in the context of the larger landscape and the contribution to sustainability of these systems. The condition of vegetative structure, composition, and processes for individual ERUs is quantified, at multiple scales, by comparing current condition, along with modeled future trend, with our best understanding of reference condition, often reflected in the historical or natural ranges of variation (NRV), which we assume to represent the best understanding of a properly functioning ecosystem (Landres et al. 1999). This helps identify the threats and risks that have caused departures from historical and desired conditions that may hinder ecological sustainability and the sustainable use of these natural resources and ultimately ecological elements that need to be addressed. These findings also provide a context for understanding the role USFS plays in managing regional-scale resources and how proposed management strategies will affect the balance of those resources both on Santa Fe NF lands and the contextual landscape as a whole.

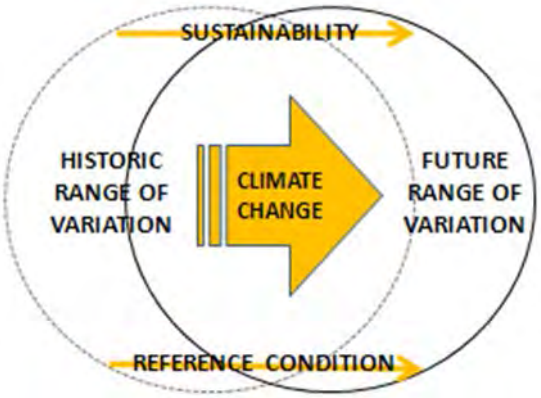
Table 1. Analyzed ecological response units (ERUs) of the Santa Fe NF

ERU	ERU Acres	% of Santa Fe NF	ERU	ERU Acres	% of Santa Fe NF	ERU	ERU Acres	% of Santa Fe NF
Mixed Conifer - Frequent Fire (MCD)	429,967	25.58%	Colorado Plateau / Great Basin Grassland (CPGB)	41,639	2.48%	RMAP Narrowleaf Cottonwood/Shrub (CWG)	15,010	0.89%
Ponderosa Pine Forest (PPF)	403,915	24.03%	Mixed Conifer w/ Aspen (MCW)	40,174	2.39%	RMAP Rio Grande Cottonwood/Shrub (CWG)	7,493	0.45%
Spruce-Fir Forest (SFF)	250,481	14.90%	Sagebrush Shrubland (SAGE)	37,457	2.23%	RMAP Willow - Thinleaf Alder (MCWG)	6,957	0.41%
PJ Woodland (PJW)	231,508	13.77%	PJ Sagebrush (PJS)	30,449	1.81%	RMAP Ponderosa Pine/Willow (MCWG)	665	0.04%
Juniper Grass (JUG)	97,470	5.80%	Montane/Subalpine Grassland (MSG)	17,707	1.05%	RMAP Upper Montane Conifer/Willow (MCWG)	495	0.03%
PJ Grass (PJG)	43,356	2.58%	RMAP Herbaceous (HERB)	15,373	0.91%			

Reference Conditions (Natural Range of Variation – NRV)

In order to quantify the condition of vegetative structure, composition, and cover for individual ERUs, we will need to compare current condition with reference condition, our best understanding of ecological sustainability. But first, we need to define reference conditions (natural range of variation) and their significance.

Reference conditions are the environmental conditions that infer ecological sustainability. When available, reference conditions are represented by the characteristic range of variation (not the total range of variation), prior to European settlement and under the current climatic period. For many ecosystems, the range of variation also reflects human-caused disturbance and effects prior to settlement. It may also be necessary to refine reference conditions according to contemporary factors (e.g., invasive species) or projected conditions (e.g., climate change). Reference conditions are most useful as an inference of sustainability when they have been quantified by amount, condition, spatial distribution, and temporal variation. Moreover, since the form and function of ERUs are shaped by these processes, HRV characterizations can assist land managers in evaluating how and where appropriate disturbance regimes (i.e., prescribed fire, thinning) may be integrated into management actions.



Reference conditions can vary within a vegetation type due to spatial variability in soils, elevation, or aspect, and are not always the same as desired conditions as site-specific factors can influence managerial objectives (e.g., wildland-urban interface).

Departure

Departure is a measure of deviation of current conditions from reference conditions. This departure from reference condition is equivalent to loss of ecological integrity. To determine a loss of integrity, current departure and departure trend (potential future departure) are considered, when applicable. Departure for each of the key ecosystem characteristics (described below) have been quantified and generalized into three different general categories: low (0 to 33 percent), moderate (34 to 66 percent) and high (67 percent+) relative to "natural" conditions using the following equation, unless otherwise noted:

Departure = (1 - (smaller value (reference or current condition)/larger value (reference or current condition)) * 100

Terrestrial Ecosystems

The geographic location, climate and elevational gradient found on the Santa Fe National Forest allows for several important ecological and biological features relative to other national forests in Southwestern Region (Region 3) of the U.S. Forest Service and other major landowners in Arizona and New Mexico. For example, the Santa Fe NF manages more high elevation ERUs (spruce-fir forests, mixed conifer forests, montane grasslands, ponderosa pine forests, and sub-alpine grasslands) than other major landowners in the Southwest with elevation ranges from 5,300 feet to 13,103 feet at the summit of Truchas Peak located in the Pecos Wilderness.The Santa Fe NF contains the largest proportion of mixed conifer forests (32 percent) across the Region. The Forest also manages large proportions of spruce-fir forests, montane grasslands, and aspen forest and woodlands relative to that found throughout the Southwest. Many unique plant and animal species can be found in these systems. Furthermore, these exceptional areas of ecological and biological distinction allows for significant opportunities for conserving vegetation systems, and plant and animal biodiversity.

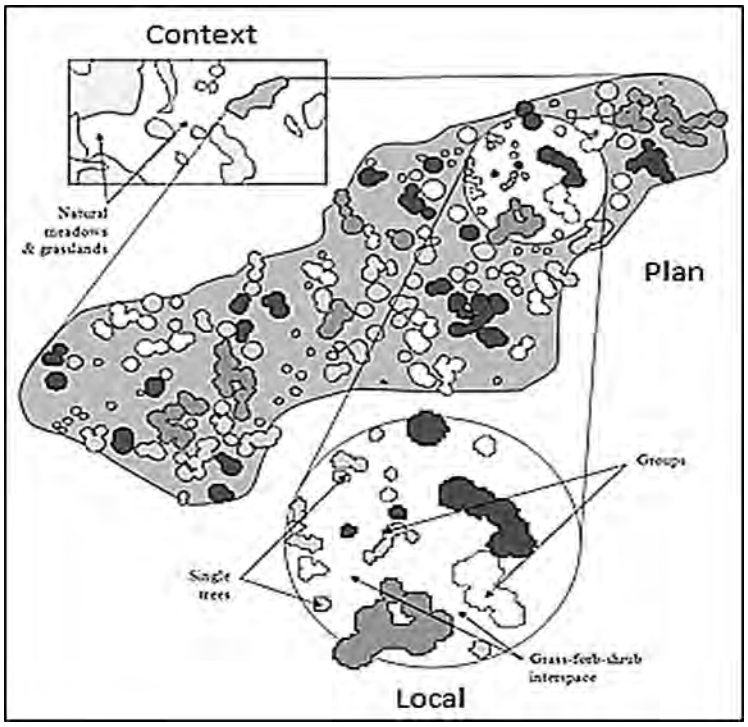
It is obvious that it is important to maintain the sustainability of these systems and the species that depend on these terrestrial ecosystems. The terrestrial ecosystem section describes the overall character of the terrestrial vegetation on the forest, the current conditions of each, and expected trends for vegetation into the future. Reference (i.e., historical or NRV) conditions are discussed to provide a comparison to existing conditions and is used as a tool in this assessment for evaluating the current ecological integrity of ecosystems and their key characteristics. This comparison is of value in providing a frame of reference for evaluating current patterns and processes. The range of ecological processes that shaped historic conditions within these ERUs, and the ability of current management actions to support ecosystem and species diversity will be considered. By understanding the context in which these ERUs exist, this information can be used to identify processes and conditions that support sustainability, formulate strategic goals, and evaluate the need to change management to meet the goal of ecological sustainability across the region.

Spatial Scales of Analysis for Terrestrial Ecological Systems

Different spatial scales provide resolution across both the greater landscape and localized conditions, helping assess whether ecological sustainability of each ecological community are being met. Knowledge of the extent to which there is ecological integrity both within the plan area and at scales broader than the plan area is important to identify opportunities or limitations for lands in the plan area to contribute to the integrity of the broader ecological systems, as well as the impacts of the broader landscape on the sustainability of resources within the plan area. In some instances, a unique role of the plan area may become apparent at this scale.

Fine scales allow us to detect small yet meaningful features of the landscape while broad scales identify important patterns over the larger spatial extent. Different ecological patterns emerge at different scales of analysis since landscapes are nested within continuously larger landscapes. For example, canopy cover can look very different at three spatial scales (figure 1). At the local (fine) scale the presence of only a few single trees and some pockets or groups of trees indicates an “open” or sparse, canopy cover. However, as we scale up to the plan scale, canopy cover looks a little denser, especially right around the extent of the local scale. Finally, at the context scale, the pattern of small patches of trees amid large natural meadows and grasslands is finally visible. These scales are especially important when we consider the diversity of organisms that inhabit these ecosystems. From a wildlife perspective, different species depend on habitat or resource patches of various sizes. Effective habitat for the Jemez Mountain salamander might be

limited to a single log or a stand of trees. In comparison, the Mexican spotted owl requires habitat which can extend from a few stands to potentially an entire ecoregion.



Adapted from USDA RMRS-GTR-310.

Figure 1. Depiction of different vegetation patterns at three spatial scales (local, plan, and context)

In this section, terrestrial systems are analyzed at three spatial scales: the context, plan (Santa Fe NF boundary), and local. The context scale to provide a "big picture" of overall sustainability across the larger area. Descriptions at the plan and local scales provide additional detail necessary for identifying areas of concern and potentially driving the ecological need for change in current management and/or implementation of future projects and activities.

Context Scale

The context scale is the largest scale analyzed. This scale shows how forest condition compares to the same vegetation types in context of the greater landscape, including lands beyond the forest boundary. The vegetative context scale (figure 2) is composed of clusters of Ecological Subsections (McNab et al. 2005), which intersect the Santa Fe National Forest boundary. Additional subsections were added to ensure the context landscape contains roughly five times (5:1 ratio) as much area off forest for all of the 11 analyzed terrestrial ERUs as is represented within the Plan unit scale (figure 3). This ratio provides a good regional context of conditions for vegetation. With the Forest having such a large proportion of Mixed Conifer – Frequent Fire (429,967 acres) and Ponderosa Pine Forest (403,915 acres) acres these two ERUs were the primary drivers of the context extent, specifically the long narrow finger that extends north through the state of Colorado (figure 1). This proportional relationship between the plan and context scales helps identify patterns in the broader surrounding landscape that may have as much, if not more, of an effect on the vegetative characteristics under consideration. The majority of the Santa Fe NF and lands within Colorado that compose the context scale overlaps with the Southern Rocky Mountains Temperate Steppe – Open Woodland – Coniferous Forest – Alpine Meadow Province (M331) (figure 2) from Bailey's ecoregions (1983). Ecological units provide an alternative spatial framework for assessing and

managing forest resources because they characterize areas of similar vegetation, climate, soils, hydrologic processes, disturbance regimes, topography, geology, and other processes such as nutrient cycling and plant community succession (Cleland et al. 1997). Each ecological unit is, therefore, similar with regard to natural processes and probable responses to management activities (Bailey 1983). When data are available and applicable, vegetative characteristics are analyzed at the context scale.

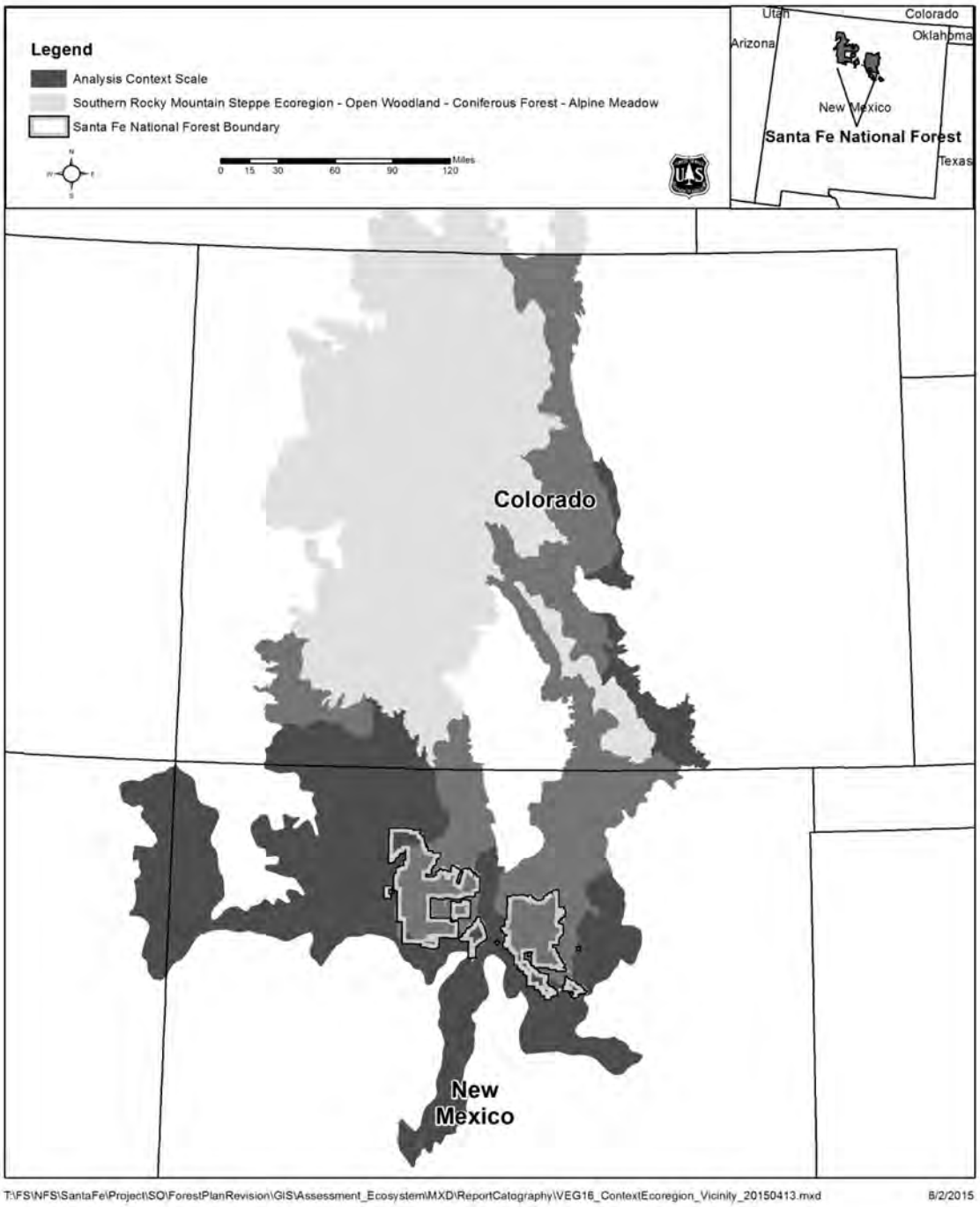


Figure 2. Context scale extent for the Santa Fe NF vegetative characteristics

The context scale is composed of Ecological Subsections (McNab 2005) and extends through Colorado to accommodate a 5:1 ratio representing acres of vegetation type off and on the forest. This ratio provides a good regional context for vegetation.

Context Niche

The spatial niche analysis relates the Santa Fe NF to its surroundings. Spatial niche is dependent on the relative distribution of an ERU, as well as the relative distribution of departure within that ERU. The contribution of the Santa Fe NF to the ecological integrity of an ERU in the context of the surrounding landscape is dependent first on the percent of the forest occupied by the ERU. The Santa Fe NF's contribution to integrity also depends on the percent of the context landscape occupied by the ERU and the relative representation of the ERU on-forest to off-forest (proportional representation).

The forest's contribution to the context for each ERU is shown in Table 2. The Santa Fe NF makes up 7.4 percent of the context landscape by area. When an ERU is more common at the plan scale than would be expected based on area (greater than 7.5% of the total ERU in the context landscape), the plan area has a disproportionate influence on sustainability of the system or greater proportional representation. ERUs that are rare at the context scale will be influenced more by conditions at the plan scale than ERUs that are more abundant, for which plan scale conditions may be overwhelmed by off-forest conditions.

$$\text{Proportional Representation} = \frac{(\%\ \text{of Santa Fe NF} - \%\ \text{of Context Landscape})}{(\%\ \text{of Santa Fe NF} + \%\ \text{of Context Landscape})}$$

A value of 1 means the percent of the forest covered by an ERU is the same as the percent of the context landscape covered by that ERU. Positive values indicate the proportion of the forest is greater than the proportion of the context (the ERU is more common on forest). Negative values indicate the opposite (the ERU is less common on forest).

Table 2. Terrestrial Ecosystem Context Niche

Shaded proportional representative cells identify high potential for the Forest to contribute to the sustainability of these ecosystems.

ERU	Plan Scale Acres	% of Santa Fe NF	Context Scale Acres	% of Context Landscape	Plan contribution to Context	Proportional Representation	Plan Seral State Departure	Context Seral State Departure
MSG	17,707	1.1	451,289	2	3.9	-0.29	Mod	High
PPF	403,915	24	3,514,152	15.8	11.5	0.21	High	High
MCD	429,967	25.6	2,263,903	10.2	19.0	0.43	High	High
JUG	97,470	5.8	1,799,893	8.1	5.4	-0.17	Mod	Mod
PJG	43,356	2.6	927,286	4.2	4.7	-0.24	Mod	Low
CPGB	41,639	2.5	2,289,984	10.3	1.8	-0.61	High	Mod
SAGE	37,457	2.2	1,923,640	8.7	2.0	-0.60	Mod	Mod
PJS	30,449	1.8	1,406,736	6.3	2.2	-0.56	Mod	Low
PJO	231,508	13.8	1,332,919	6	17.4	0.39	Low	Low
MCW	40,174	2.4	2,319,204	10.4	1.7	-0.63	Mod	Mod
SFF	250,481	14.9	1,491,541	6.7	16.8	0.38	Mod	Mod

Opportunity for the Forest to influence the context landscape is captured in table 2. The proportional representation identifies the relative spatial significance of ecosystems found on the Forest to the greater landscape. Ecosystems such as PPF, MCD, PJO, and SFF all have high proportional representation meaning the sustainability of these systems at the context scale is more sensitive to conditions at the plan

scale, and the Santa Fe NF has a significant role in restoring or maintining integrity of these systems. On the other hand CPGB, PJS and MCW are less common at the plan scale and the Forest has less opportunity to influence context scale conditions.

Highly departed ERUs are of greater concern because existing ecological integrity is already low. These may also act as an indication of priority for restoration. The relative departure between the two scales also assist in identifying potential refuge especially if conditions are significantly different between the two scales. For example MSG is less common at the plan scale but also less departed and may act as a reservoir, especially for species dependent on this ecosystem. CPGB and PJS are disproportionally represented and more common at the greater landscape but departure conditions at the plan scale are worse than at the context scale. Although the contribution to these systems is not significant there is moderate opportunity for the Santa Fe NF to influence their condition and the forest should have some role in their restoration and maintenance. Obviously PPF and MCD are highly departed at both scales and with the Forest representing a reasonable portion of these acres, there is significant opportunity for the Forest to contribute to the ecological integrity of these ERUs.

Plan Scale

The plan scale of analysis is the Santa Fe NF lands within the administrative boundary and showcases current condition and trends as an average of conditions across the Forest (figure 3).

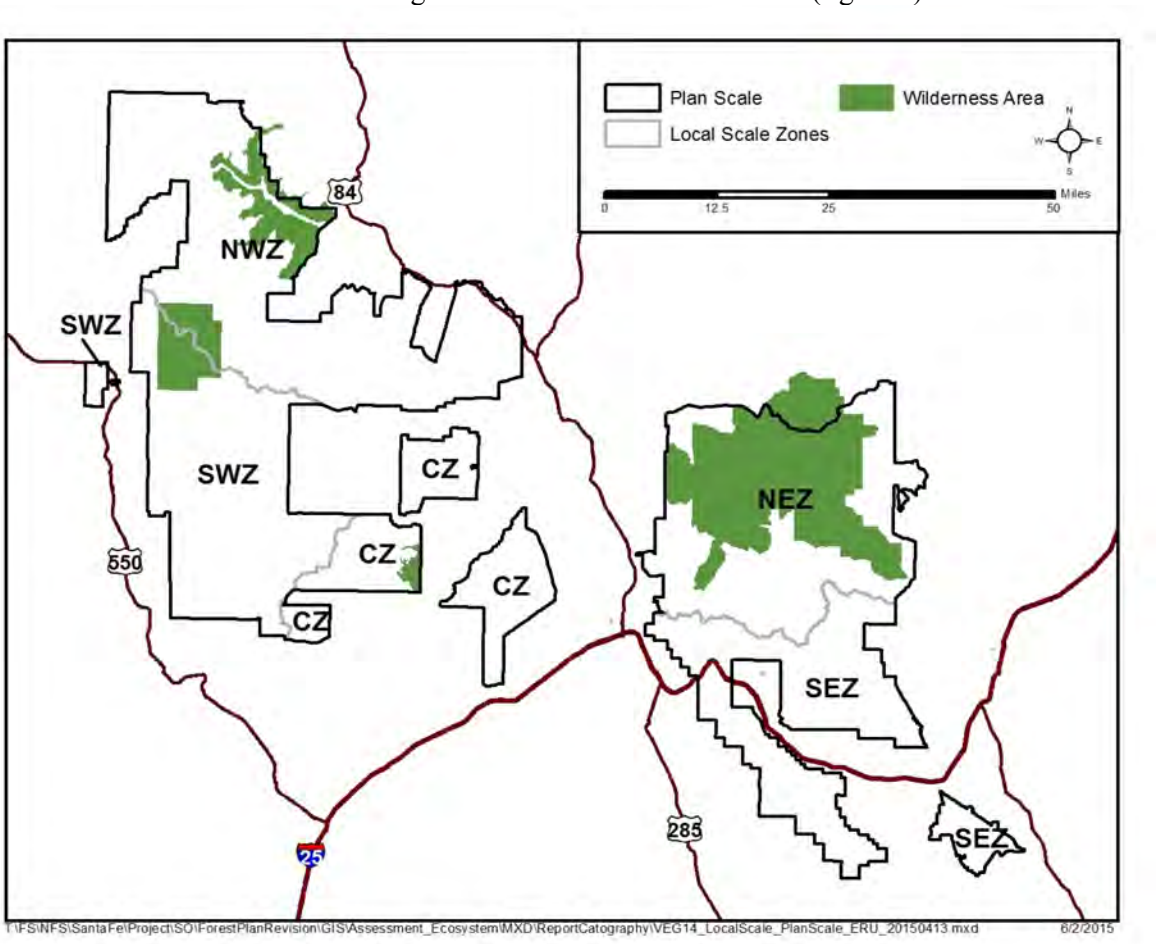


Figure 3. Map of Santa Fe NF plan (outlined in black) and local scales (outlined in grey) for terrestrial ecosystems

Forest wilderness areas are also included on the map since historically they've had a lower level of active management.

Local Scale

Local scale is valuable for describing departure patterns within the plan scale for a given characteristic and identifying where particular issues may warrant specific attention and drive forest plan components. This scale is not as likely to drive ecological need for change, but may drive development of plan components. The local scale of analysis breaks the plan scale into five local zones, delineated primarily along Hydrologic Unit Codes at the sub-basin (HUC-8) scale and sub-watershed boundaries (HUC-12). Hydrological boundaries were used as local zone boundaries because they allow for analysis across resources (hydrology, soils, etc.) including the integration of overall ecosystem risk. The groupings of hydrological units to create each of the local zones were identified based on the level or type of management, past disturbances such as wildfire, distribution of vegetation types and extent of use. The minimum zone size was identified so that each ERU (where possible) was represented by a minimal area ten times the characteristic (historical/reference) patch size for that ERU. The five local zones that make up the Santa Fe NF (figure 3) include the North-West Zone (NWZ) 29 percent, South-West Zone (SWZ) 20 percent, Central Zone (CZ) 11 percent, North-East Zone (NEZ) 15 percent, and South-East Zone (SEZ) 20 percent of the plan scale.

Key Ecosystem Characteristics for Terrestrial Vegetation

Ecosystem characteristics are specific components of ecological conditions that sustain ecological integrity. A key ecosystem characteristic describes the composition, structure, and/or function of an ecosystem that is most dominant. Key ecosystem characteristics are identified and evaluated for each ecosystem, but not all possible characteristics of ecosystems are identified. Only those characteristics needed to provide ecological conditions necessary to maintain or restore the ecological integrity of terrestrial, aquatic, and riparian ecosystems in the plan area are considered in the assessment (36 CFR 219.8). Ecosystem characteristics were selected based on information was readily available, characteristic is relevant to key issues and sensitive to drivers and stressors, and characteristics represent elements needed to assess other resource areas (e.g., at-risk species and habitat).

The key ecosystem characteristics for upland vegetation (ERUs) include:

- Vegetation Structure/Seral State Proportion
- Snag density
- Patch size
- Similarity to site potential
- Vegetative ground cover
- Coarse woody debris
- Fire frequency
- Fire severity
- Fire regime condition class
- Insect and disease

Not all key ecosystem characteristics apply to all ERUs. Coarse woody debris (CWD) and snag density are not relevant or applicable to grassland and shrubland systems.

Seral State Proportion or vegetation structure is the percent of an ERU in each seral state (sere) or stage of secondary successional development (ecological process of progressive change in a plant community after a stand-intitiating disturbance) (Hall et al. 1995). Each ERU can manifest in a range of potential overstory vegetative conditions, each representing a unique phase in the overall ecology of the system (Weisz et al. 2009). By grouping these phases into seral state classes with unique vegetation

characteristics (overstory composition and structure), models can be developed that define transitions among phases. These "state-and-transition" models can be built and adapted so that the dynamics of the system reflect NRV, and the resulting distribution among state classes represents the ERU reference condition (Weisz et al. 2009).

Data and Analysis Process

The assignment of current state class proportions uses regional satellite imagery based classifications of vegetation size class, canopy cover, dominance type, and storiedness at a 1:100,000 scale, with extensive photo interpretation and field data collection (Midscale Vegetation Mapping Project) (Mellin et al. 2008). Existing vegetation is assigned to an ERU and then to the appropriate state class within that ERU according to state class descriptions and model developed by the USFS Southwestern Regional Office, LANDFIRE, The Nature Conservancy, and the Integrated Landscape Assessment Project (Wahlberg 2014). Reference conditions are based on best available scientific information. ERU summary tables are footnoted with specific reference condition sources.

Departure from the reference distribution is quantified by comparing it to the actual current distribution and to future predicted distributions. The closer composition, structure, and process are to their historic conditions, it is assumed the system is maintaining ecological integrity, and will be more resilient to stress. For each state class, the similarity to reference is equal to the proportion in common that exists either on the current landscape or on the projected future landscape. The similarity value is equal to the lesser value between the current or projected proportion and the reference proportion. The sum of similarity values for an ERU is 100 percent or less, and 100 percent minus the similarity value equals the departure of the ERU (see figure 3). Departure is broken into thirds for descriptive purposes (0-33 percent = low departure, 34-66 percent = moderate departure, 67-100 percent = high departure), but is best addressed as varying continuously from low to high.

Projections of future state class proportions are produced using the Vegetation Dynamics Development Tool (VDDT) (ESSA 2006) and models developed by LANDFIRE, The Nature Conservancy, and the Integrated Landscape Assessment Project and refined by the regional office with input from forest specialists. These VDDT state and transition models both define seral states for each ERU and allow comparison among management scenarios. Model results are not precise predictions, but indicate relative trends and are sensitive to changes in management or disturbance. For this analysis, future trend assumes the continuation of current levels of management indefinitely. Most state transition destinations and probabilities are derived from Forest Vegetation Simulator (FVS) modeling (Dixon 2002). Burn severity information is compiled from Monitoring Trends in burn severity records (Wildland Fire Leadership Council 2014). Other inputs include Forest management activity (thinning, prescribed fire, etc.) data from the Forest Service Activity Tracking System (FACTS), insect and disease surveys from Aerial Detection Surveys (ADS), and wildfire data for the past 30 years from Monitoring Trends in Burn Severity (MTBS). ERUs that comprise less than 1 percent of the total Forest acreage (Plan scale), including riparian, have either too little acreage or inadequately map stand structure and therefore, are not appropriate for VDDT modeling and trend is not calculated and instead are addressed qualitatively.

By comparing regional Midscale and LANDFIRE current vegetation information to reference seral state proportions, departure is calculated for the context, plan, and local scales. The Santa Fe NF only affects management at the plan scale and only collects management information on the forest; so VDDT models can only be reliably parameterized at the plan scale. Therefore, future trend is modeled only at the plan scale, though trends at the context or local scale may be discussed where information suggests they differ. The trend analysis relies mostly on VDDT modeling results, while trend for other characteristics is addressed only when a probable trajectory can be inferred. Seral state proportion trend is presented in the summary table for each ERU (results

table 3). Actual future modeled departure values are captured in the ERU Overstory Structure and Composition tables.

Results

Table 3. Percentage of current vegetative structure (seral state) departure for each ERU at the three different analysis scales (local, plan, and context) and future departure at the plan scale.

ERU	Local NWZ	Local SWZ	Local CZ	Local NEZ	Local SEZ	Plan	Context	Future (100-yr Modeled)
Colorado Plateau / Great Basin	85		95		95	93	48	NA
Juniper Grass	45	49	41		53	45	41	46
Mixed Conifer - Frequent Fire	76	77	68	76	80	74	78	64
Mixed Conifer w/ Aspen	53	53	55	47		47	38	36
Montane / Subalpine Grassland	51	74		62		60	71	78
PJ Grass	56	59	38		45	45	33	41
PJ Sagebrush	43		47			46	32	28
PJ Woodland	29	40	51	22	26	28	22	19
Ponderosa Pine Forest	94	97	96	100	100	97	85	89
Sagebrush Shrubland	39					41	38	83
Spruce-Fir Forest	54	59	58	55	67	54	51	60

*Hatching indicates the ERU does not represent at least 5% of the local zone and therefore considered not sufficiently represented to analyze.

Table Legend:

Limited Acres	Low Departure	Moderate Departure	High Departure

It is evident from looking at table 2 that three ERU's (CPGB, MCD, and PPF) have highly departed seral state structures (93%, 74%, and 97% respectively) at the plan scale and across all local zones. CPGB at the context scale is only moderately departed (48%) indicating that this ERU is in better condition than the average condition of these sites found on the Forest. The majority of this departure is a result of a transition from high seral grasses transitioning into a low seral shrub and tree invaded state. The extensive settlement and use of these grasslands, especially considering the historical grazing impacts (overgrazing, soil compaction, and introduction of non-native species) and fragmentation (trails and roads) of the grassland continuity (limit fire as a disturbance process) have aided the colonization of shrubs and trees that would have typically been kept in check by wildfire.

Unlike CPGB lands, Montane Subalpine Grasslands on the Forest seral state proportions are in better condition than they are at the context scale. Similar to the departure in CPGB seen on the Forest, the enchroacment of shrubs and trees has resulted from the degragation of this ERU at the context scale. However, if the scale of restoration projects in MSG lands on the Santa Fe NF do not increase in scale in the future, 100-year VDDT models indicate that these lands will also be highly departed. At the current rate (15-yr. average), only 15 of the 17,707 acres (0.08%) on the Forest are treated annually.

The only ERU found on the Santa Fe NF that is not moderately or highly departed at the plan scale is PJW. This is primarily because the typical lengthy interval between fire occurences in this ERU has not

been altered as largely as many of the other ERUs, which have frequent fire regimes (<30 years, table 6) or have been historically degraded by targeting large diameter trees leading to an increased number of what are now medium (10-19.9" dbh) trees.

Snag Density is defined as the number of stems per acre by diameter classes (i.e., > 8 inches, > 18 inches) at the plan scale. Snags are standing dead or partially dead trees (snag-topped), often missing many or all limbs. Snags (standing dead trees) serve an important ecological function as they provide key habitat for many species, such as Mexican Spotted Owls (MSO) and other cavity nesters and are important for forest ecosystem function. Snags (standing dead trees) provide important habitat for forest wildlife (e.g., cavity nesters), as well as a source of coarse woody debris important in forest succession when they fall, providing cover and foraging sites for terrestrial small mammals (Payer and Harrison, 2002; Bull et al 1997). The creation and maintenance of appropriate biological legacies is a critical element of forest management strategies that attempt to conserve biodiversity (Lindenmayer and Franklin, 2006).

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Unfortunately, historic forest inventories in this area (Woolsey 1911) typically did not include data on snags, and little is known about natural snag densities in southwestern forests. But because of their importance to wildlife, some land management agencies such as the U.S. Forest Service have standards for snag retention. Current standards in the Southwestern Region (Arizona and New Mexico) are based on recommendations by Reynolds and others (1992) specific to the northern goshawk. These recommendations call for retention of 4.9 and 7.4 snags/ha in ponderosa pine and mixed-conifer forests, respectively, with minimum diameter at breast height (dbh) of 46 centimeters and minimum height of 9 meters. Reynolds and others (1992) stated these size requirements should "meet the minimum requirements for the majority of northern goshawk prey species."

Data and Analysis Process

Data on existing densities and composition of snag populations are scarce for many areas of the Santa Fe NF. PPF and MCD are the only two ERUs with sufficient stand exam (inventories) data necessary for analyses of any significance, as these are the two ERUs typically targeted for restoration treatment and constitute the majority of stand exams. As a result Forest Inventory and Analysis (FIA) data was used as a surrogate for the deficiencies in snag data. FIA conducts the nation's continuous forest census, collecting, analyzing, and reporting information on the status and trends of America's forests (FIA, http://www.fia.fs.fed.us). Snag data collected at the regional level was synthesized by ERU and sere or seral state to develop snag density coefficents. An analysis worksheet was then developed to calculate snag densities based upon local, plan and context reference and current seral state proportions.

Results

Table 4. Snag density (snags per acre) by size class and ERU at the three different analysis scales (local, plan, and context)

ERU*	Size Class (dbh)	Reference	Local NWZ	Local SWZ	Local CZ	Local NEZ	Local SEZ	Plan	Context
Juniper Grass	≥ 8"	3.0	3.4	3.0	3.1		5.0	3.3	3.9
	≥ 18"	1.0	0.5	0.7	0.6		0.7	0.6	0.8
PJ Sagebrush	≥ 8"	6.0	5.1		3.1			3.6	7.7
	≥ 18"	1.0	0.8		0.6			0.7	1.4
PJ Woodland	≥ 8"	2.0	8.2	7.4	6.7	9.0	8.8	8.2	8.8
	≥ 18"	1.0	1.7	1.9	1.8	1.4	1.4	1.6	1.8
PJ Grass	≥ 8"	5.0	2.8	2.7	6.5		6.0	4.6	6.7
	≥ 18"	1.0	0.6	0.5	0.9		0.7	0.7	1.1
Ponderosa Pine Forest	≥ 8"	1.1	8.0	7.6	7.6	8.3	8.4	7.9	7.5
	≥ 18"	0.8	0.9	0.8	0.9	0.8	0.8	0.8	0.9
Mixed Conifer - Frequent	≥ 8"	9.0	24.4	25.2	23.6	23.7	24.2	24.2	24.1
Fire	≥ 18"	4.0	3.5	3.4	4.1	3.4	3.3	3.5	3.5
Mixed Conifer w/ Aspen	≥ 8"	14.0	22.1	22.2	23.1	21.6		22.1	22.2
	≥ 18"	4.0	4.9	5.0	5.0	5.9		5.2	5.5
Spruce-Fir Forest	≥ 8"	25.0	15.1	15.6	10.5	10.2	16.3	11.8	6.8
	≥ 18"	9.0	6.7	7.0	4.2	4.6	6.9	5.2	3.2

*Analysis is limited to forested and woodland types as overstory tree structure is not present in grassland ecological types. Hatching indicates the ERU does not represent at least 5% of the local zone and therefore considered not sufficiently represented to analyze.

Table Legend:

Limited Acres	Low Departure	Moderate Departure	High Departure

Snag (standing dead trees) populations on the Santa Fe National Forest are dominated by small snags, with relatively fewer snags in the larger size class (table 4). This is similar to other Forests in the Southwest as Ganey (1999) found that although snags appeared to be relatively abundant in two northern Arizona national forests, snag densities were dominated by small snags even in unlogged forests. These small snags are not as valuable to wildlife because large snags are used more by wildlife than small snags (Bull et al. 1997). But despite the current relative abundance of smaller diameter snags, snag densities for the majority of the ERU types for both the small and large diameter snag classes are in low departure or exceed reference densities. Because historical fire regimes in southwestern ponderosa pine forests and mixed conifer – frequent fire systems were characterized by relatively frequent, low-intensity, stand-maintaining fires (Moir et al., 1997). These low-intensity fires generally did not cause much mortality of large trees (Woolsey 1911; Moir et al., 1997), but may have resulted in loss of snags, which are susceptible to damage or loss even in low-intensity fires (Horton and Mannan 1988) which may explain why we see a drastic difference in smaller diameter snags between current and reference conditions. As identified in the *coarse woody debris* section (page 25) the recent dieback of pinon pine is also likely responsible for the excessive density of small diameter snags in the PJ Woodland type, that have yet to fall.

Patches are contiguous areas of vegetation types in which the vegetation composition and structural state are relatively homogeneous and differ from its surroundings. Patches can be composed of randomly arranged trees or multiple tree groups, and they can be even-aged or uneven-aged. Patches typically range

in size from 10 to 1,000 acres depending on the ERU and site-specific attributes (e.g., aspect) and play a significant role in wildfire behavior.

Vegetation pattern, including patch size and distribution, reflects the cumulative and interactive effects of disturbance regimes (e.g., insects, disease, fire, wind), biophysical environments (e.g., topography, soils, climate), and successional processes (Baker, 1989). Vegetative landscapes are primarily shaped by wildland fire and vegetation succession, and conversely, these patterns will invariably influence future fire patterns, regeneration and colonization processes, and plant development (Keane et al. 1998). For example, natural large dense patches of trees (like Spruce Fir Forests) may indicate a low frequency and high severity fire regime (table 4). Patch size is also an important element of wildlife habitat. Each wildlife species has its own patch size preference, and these preferences vary by species. For these reasons, and also for reasons of wildfire behavior, current landscape distribution of patches should resemble the distribution under reference conditions the conditions to which wildlife species adapted so as to best accommodate the varying preferences of all wildlife species and simultaneously mimic historic fire behavior. The ability for species to move throughout a landscape is also important for ecological integrity. Species that are wide-ranging are able to maintain genetic diversity and sustainability in the face of changes to their population or environment. Connected landscapes allow other species to migrate in the face of climate change or other pressures.

Data and Analysis Process

Patch size is calculated based on the average patch size in acres for each seral state by ERU that intersect the plan area. Patch size is only presented at the plan scale.

Results

Table 5. Patch size analysis results for the Santa Fe NF plan scale

ERU	System Type	Reference Condition (acres)	Current Condition (acres)	Departure
Colorado Plateau / Great Basin Grassland	Grassland	295 – 513	233	Low (21%)
Montane / Subalpine Grassland	Grassland	94 – 122	53	Moderate (44%)
Sagebrush Shrubland	Shurbland	152 – 407	152	Low (0%)
PJ Woodland	Woodland	50 -400	29	Moderate (41%)
PJ Sagebrush	Woodland	50 – 200	16	High (69%)
PJ Grass	Woodland	0.07 – 1	15	High (93%)
Juniper Grass	Woodland	0.07 – 1	16	High (97%)
Spruce-Fir Forest	Forest	200 – 1,000	1,017	Low (2%)
Mixed Conifer w/ Aspen	Forest	100 – 400	57	Moderate (43%)
Mixed Conifer - Frequent Fire	Forest	0.02 – 50	247	High (80%)
Ponderosa Pine Forest	Forest	0.02 – 1	72	High (99%)

When viewing table 4 two occurences become evident, the first is that woodland and forest types are at greater departure than grassland and shrubland systems. The second is that woodland and forest ERUs with longer fire frequency periods (fire return intervals, table 8) are less departed than those with more

frequent fire cycles. Both PJW and SFF are the least departed of ERUs that share a similar system type and both have a fire return interval that can span multiple centuries in between fire occurences. These ERUs historically also had the largest patch sizes, characteristic of high severity fire. It is apparent that the cessation of wildfire in what were historically frequent fire systems has allowed for these landscapes to infill with trees creating large homogenous patches much greater than what existed historically. These large contiguous patches lend themselves to be at greater risk of larger and more severe wildfire as displayed in Figure 8 an Figure 9, as the proportion of high severity fire has increased in these ecosystems. Similar occurences have been documented at the context scale as Schoennagel and others (2004) have documented that historical timber harvest and suppression of wildfire are largely responsible for the closing of canopies resulting in increased fire severities in Rocky Mountain forests.

The effects of fire cessation along with a reduction in herbaceous cover (table 6) are also responsible for decreases in patch sizes of shrublands and grasslands, although not significant in CPGB and SAGE. Historically the frequent fire cycle of grasslands and shrublands fueled by herbaceous material would encourage surface fire through these ERUs, killing seedlings and saplings, keeping tree encroachment at bay. The removal of this disturbance has allowed for the expansion of neighboring ERUs into these sites reducing available forage available to browsers such as deer, elk, and cattle as well as habitat for wildlife that use the grasses for shelfter, cover or food source.

Similarity to site potential or ecological status is the current or existing vegetative plant community composition's degree of similarity to natural community as described in the Terrestrial Ecosystem Survey of the Santa Fe National Forest (USDA 1993). The similarity analysis results in an index value that considers all plant species collectively (as opposed to evaluating every species or every plant life form). Potential natural community is not necessarily a management goal in itself for an ecosystem or landscape, but defines the climax in the process of succession. The potential natural community along with the earliest successional stage determines the range of conditions that should prevail in a healthy ecosystem. Daubenmire transects were collected for most TES map units, and were used to develop PNC. The actual transect data was summarized by TEU and compared to PNC. The similarity from the most common TEUs in each ERU was area weighted and averaged.

Data and Analysis Process

Data used to conduct the similarity to site potential analysis was collected during the most recent terrestrial ecological unit (TEU) inventory effort and the resulting data is described in the Terrestrial Ecosystem Survey (TES) for the Santa Fe NF (1993). Daubenmire transects were collected for most TES map units, and were used to develop the Potential Natrual Community (PNC). The actual transect data was summarized by TEU and compared to PNC. The similarity from the most common and extensive TEUs in each ERU was area weighted and averaged.

Results

Table 6. Similarity to site potential (%) for the Santa Fe NF

ERU	Local NWZ	Local SWZ	Local CZ	Local NEZ	Local SEZ	Plan
Colorado Plateau / Great Basin Grassland	59				60	60
Juniper Grass	51	69	51		53	56
Mixed Conifer - Frequent Fire	61	62	64	73	70	67
Mixed Conifer w/ Aspen	68	64	70	71		67

ERU	Local NWZ	Local SWZ	Local CZ	Local NEZ	Local SEZ	Plan
Montane / Subalpine Grassland	42	54		35		41
PJ Grass	74	67	64		74	72
PJ Sagebrush	47		55			54
PJ Woodland	60	66	69	67	63	64
Ponderosa Pine Forest	63	59	69	67	62	63
Sagebrush Shrubland	60					60
Spruce-Fir Forest	60	65	59	70	67	68

*Hatching indicates the ERU does not represent at least 5% of the local zone and therefore considered not sufficiently represented to analyze.

Table Legend:

Limited Acres	Low Departure	Moderate Departure	High Departure

Ground cover is the combined cover percent of basal vegetation, bare soil, litter, and rock fragment at the plan and local scales, with an emphasis on bare soil and vegetation basal area. Ground cover is identified as a key ecosystem characteristic as continuous herbaceous and woody ground cover provide soil stability, reduce overland water flow, fostering infiltration increasing in plant-available water (Davenport et al. 1998; Wilcox et al. 2003), and improves moisture retention. A reduction in ground cover can lead to reduced productivity, changes in runoff timing and quantity, minimize surface fire activity (potentially leading to altered fire return intervals/fire frequency), and increased erosion and sedimentation.

Ground cover is an important characteristic of an ecosystem as continuous herbaceous and woody ground cover can provide soil stability, reduce overland water flow, fostering infiltration increasing in plant-available water (Davenport et al. 1998; Wilcox et al. 2003), and improves moisture retention. A reduction in ground cover can lead to reduced productivity, changes in runoff timing and quantity, minimize surface fire activity (potentially leading to altered fire return intervals/fire frequency, page 27), and increased erosion and sedimentation. Such reductions in vegetation cover also can trigger increases in erosion rates as isolated bare soil patches become connected, creating networks at broader spatial scales that promote accelerated water runoff and associated erosion and sedimentation (Davenport et al. 1998; Wilcox et al. 2003). The increased net losses of water and soil feedback to reduce the productivity and vigor of vegetation cover, potentially leading to desertification (Schlesinger et al. 1990). Once initiated, altered pattern-process relationships of accelerated erosion may persist for decades (Wilcox et al. 2003), and once desertified through loss of vegetation and soils, semiarid ecosystems may be slow to recover (Peters et al. 2006).

Similarly, rapid and extensive changes in watershed hydrology often occur when high-severity fires amplify runoff and erosion by reducing vegetation and ground cover across broad areas (Shakesby and Doerr 2006). The hydrologic effects of such fire induced surface cover changes are demonstrated by the approximately 100-fold increases in peak runoff observed for 1 to 3 years after large stand-replacing fires in the Jemez Mountains on the Santa Fe NF (Johansen et al. 2001; Veenhuis 2002).

One of the earliest changes to the Southwest landscape was the reduction of grass cover as a result of the introduction of large numbers of domestic livestock. Grazing reduced native plant cover and facilitated the colonization of invasives, altering ingspecies composition, and reduced vegetation cover through herbivory and soil compaction increasing soil temperature and decreasing soil moisture. Although

invasives can decline within a few years after grazing is reduced, recovery is incomplete according to Dick-Peddie (1993).

Data and Analysis Process

Both current and "natural" vegetative ground cover, are estimated at the plan scale by Terrestrial Ecological Unit Inventory (TEUI) as part of the Santa Fe NF's Terrestrial Ecosystem Survey (USDA 1993), the most comprehensive and current vegetative ground cover dataset available. Total percent vegetative cover includes basal area for all plant species, as well as percent cover of litter. The sum of the four separates that comprise surface cover can be greater than 100 percent, since litter often covers rock fragments in forested environments (USDA 1993). The change in percent vegetative ground cover was calculated for each Terrestrial Ecological Unit (TEU), and then area weighted to determine the average departure within each ERU. TEUs are mapped units of land within which ecological structure, function, capabilities, responses, and management opportunities and limitations can be predicted (Cleland et al. 1997). The same calculation was done for each local zone using only the area of each TEU in that zone. No departure estimate is made at the context scale, and stressors and drivers are very likely different in some ERUs due to additional anthropogenic impacts in populated areas.

The current and "natural" average percent cover is reported in the summary table for each ERU. These are area weighted averages of the percent cover for all TEUs in an ERU. The current estimate reflects decreases in vegetative cover (basal area (BA)) resulting from road construction or other development, concentrated recreation, management related ground disturbance, or legacy impacts from logging, excessive grazing, etc.

Results

Table 7. Percentage of ground cover (rock fragment, bare soil, litter, and vegetation basal area) for ERUs at plan scale

ERU	Rock Fragment Natural	Rock Fragment Current	Bare Soil Natural	Bare Soil Current	Litter Natural	Litter Current	Veg. BA Natural	Veg. BA Current
Colorado Plateau /Great Basin Grassland	8.18	8.10	31.06	48.59	40.99	22.86	25.95	15.62
Juniper Grass	52.15	52.15	26.28	28.70	19.25	13.48	13.19	8.09
Montane/Subalpine Grassland	14.62	26.24	2.78	9.91	59.70	60.94	35.09	9.82
Mixed Conifer - Frequent Fire	33.01	29.46	5.38	7.15	78.30	68.90	8.00	7.51
Mixed Conifer w/ Aspen	23.69	23.01	2.46	5.44	85.37	74.43	8.70	8.26
PJ Grass	31.94	32.11	26.92	43.58	34.48	14.65	21.82	32.11
PJ Sagebrush	32.35	32.60	23.64	40.53	33.07	13.49	20.99	13.38
PJ Woodland	33.94	33.94	23.50	32.89	38.93	26.55	20.15	12.28
Ponderosa Pine Forest	31.68	30.83	12.87	13.32	63.68	56.65	13.57	9.69
Sagebrush Shrubland	0.61	0.61	11.08	68.55	65.21	22.74	11.18	8.11
Spruce-Fir Forest	32.58	31.05	3.00	4.72	80.54	69.95	7.51	31.05

*Hatching indicates the ERU does not represent at least 5% of the local zone and therefore considered not sufficiently represented to analyze.

Table Legend:

Limited Acres	Low Departure	Moderate Departure	High Departure

It is evident that the proportion of bare soil and vegetative cover (table 7) has changed rather significantly as most of the ERUs are moderately departed and a few highly departed from "natural" conditions. The amount of bare soil for all ERUs has increased but mainly the grass- and woodland-ERUs have the most departure. Mixed conifer with aspen is the only forested type that has experienced moderate or high departure. Conversely, vegetative basal area has decreased across the majority of the ERUs. This is especially significant in the grassland types as vegetative ground cover is the dominant strata and an overstory structure is absent. Spruce-fir is the only ERU to increase in vegetative ground cover, but the departure classification is high. Aside from spruce-fir, the other forested ERUs show low departure from "natural," although ponderosa pine is nearing the moderate departure threshold at 30 percent departure.

Coarse woody debris (CWD) is defined as dead woody material three inches and greater in diameter and is typically measured in tons per acre. Coarse woody debris (downed woody material) serves as an important ecological function. It provides wildlife habitat for cavity nesting birds, small and large mammals, amphibians, and insect populations. In the arid Southwest, the natural accumulation of pine needles and woody fuels is exacerbated by the very slow decomposition rates but eventually the material is recycled contributing to the formation of soil organic matter. Coarse woody debris also helps to reduce soil erosion by shielding the soil surface from raindrop impact and interrupting rill and sheet erosion.

Snags and coarse woody debris (CWD) are important elements of the structure and function of mixed forested systems in the western United States. Snags and CWD provide habitat for cavity nesting birds, small and large mammals, and insect populations (Bull et al. 1997; Bate et al. 1999; Lehmkuhl et al. 2003; Chapter 3. Identifying and Assessing At-Risk Species in the Plan Area). On steep slopes, CWD can assist in the stabilization of forest soils, particularly after extensive removal of organic matter by wildfire or management activities (Brown et al. 2003). CWD is also a nutrient sink that with time will decompose and replenish the soil with nutrients necessary for vegetative production.

The amount of forest floor fuel (CWD) has a pronounced effect on fire hazard, moisture relations, forage production, and the general health of coniferous forests. In the Southwest, the natural accumulation of pine needles and woody fuels is exacerbated by the very slow decomposition rates characteristic of the dry, southwestern climate (Harrington and Sackett 1992). This in in combination with the cessation of fire can lead to high fuel hazards increasing the probability of crowning, torching, and spot fires in forests because of the high amount of heat generated during combustion (Brown et al. 2003; Stephens 2004). This can make suppression activities, such as fire line construction, much more difficult (Brown et al. 2003). In addition, CWD can increase the amount and duration of smoldering combustion, in turn increasing emitted particulate matter and potentially contributing to reduced air quality and visibility in local and regional airsheds (Reinhardt et al. 1997). Prolonged glowing, smoldering times of CWD can also increase the severity of soil heating (Reinhardt et al. 1997) leading to negative impacts to microorganisms and soil structure and potential hydrophobicity or sterilization (Neary et al. 2005).

Data and Analysis Process

Similar to data on snag densities, CWD information is scarce for many areas of the Santa Fe NF. As a result Forest Inventory and Analysis (FIA) data was used as a surrogate for the lack of CWD data. FIA conducts the nation's continuous forest census, collecting, analyzing, and reporting information on the status and trends of America's forests (FIA, http://www.fia.fs.fed.us). CWD data collected at the regional level was synthesized by ERU and sere or seral state to develop CWD coefficents. An analysis worksheet was then developed to calculate CWD densities based upon local, plan and context reference and current seral state proportions.

Results

Table 8. Coarse woody debris (tons per acre) for ERUs at the three different analysis scales (local, plan, and context).

ERU	Reference	Local* NWZ	Local* SWZ	Local* CZ	Local* NEZ	Local* SEZ	Plan	Context
Juniper Grass	3.0	14.3	12	11.2		17.0	13.7	12.8
PJ Sagebrush	3.0	10.2		8.3			8.8	13.2
PJ Woodland	4.1	17.4	15.6	12.8	20.5	19.5	17.4	18.6
PJ Grass	3.5	8.3	8.2	16.9		15.2	12.3	17.0
Ponderosa Pine Forest	9.0	41.8	42.2	38.3	43.8	45.4	42.3	41.3
Mixed Conifer - Frequent Fire	15.2	69.7	70.6	55.5	71.3	72.7	69.3	69.8
Mixed Conifer w/ Aspen	28.7	79.3	80.7	60.2	5.9		79.1	82.1
Spruce-Fir Forest	46.9	88.0	91.2	67.4	61.0	92.3	69.9	43.0

*Hatching indicates the ERU does not represent at least 5 percent of the local zone and is, therefore, considered not sufficiently represented to analyze.

Table Legend:

Limited Acres	Low Departure	Moderate Departure	High Departure

As with most of the vegetative characteristics, the limiting of wildfire (e.g., suppression, grazing, etc.) has considerably altered the current coarse woody debris loadings and have led to a 3-4 fold increase in surface fuel loading for the majority of the frequent fire ERU types. These frequent recurring disturbances would limit the accumulation of forest floor woody material, thereby reducing future fire intensity and resulting effects. Only Spruce-Fir Forest and Mixed Conifer w/ Aspen ecological types are low and moderately departed, respectively. These ERUs have a much longer fire return interval (table 9) and therefore historically would accumulate considerably more CWD between wildfire occurrences relative to frequent fire systems. PJ Woodland also has a long fire return interval (table 9) and wouldn't be expected to be highly departed since the disruption of the natural fire cycle (suppression) by humans has likely only affected one-to-two fire intervals. But environmental stress due to long-term drought predisposed Pinon Pine (Allen 2007), a major vegetative component, ultimately leaving them weakened and susceptible to extensive outbreaks of the Ips Pine Beetle across much of the Forest (figure 4) The widespread dieback of Pinon is likely what has driven this unexpected increase in PJ Woodland coarse woody debris loading.

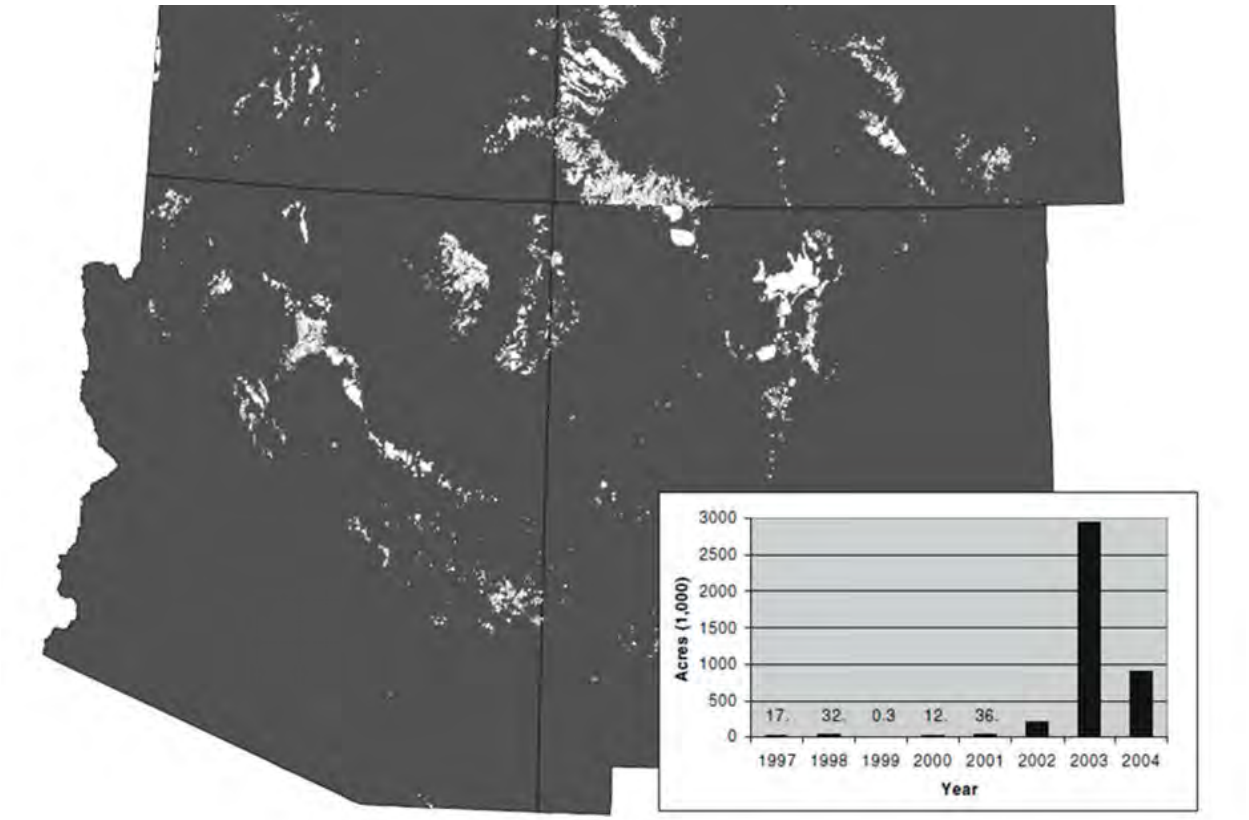


Figure 4. Extent of Pinon Pine dieback from 1997 to 2004 in the Four Corners states of Arizona, New Mexico, Colorado, and Utah is shown in white

Results shown in figure 5 are based upon annual aerial detection surveys inventoried by the U.S. Forest Service. Adapted from Allen 2007.

Fire frequency expressed as the fire return interval (FRI), is the number of fire events that occur at a specified point or within a specified area during a specified time period. In the arid Southwest fire is one of the most common and widespread disturbances. Among natural disturbances, fire is the key driver and interacts with insects and climate variation to form a disturbance complex that has major impacts. Understanding the role played by these natural forces is important for resource managers to understand the historic forces that have shaped these ecosystems.

Disturbance and succession are common elements of all terrestrial ecosystems, and the condition of ecosystems results from interplay between these two processes. In the arid Southwest, fire is one of the most common and widespread disturbances. Among natural disturbances, fire is the key driver and interacts with insects and climate variation to form a disturbance complex that has major impacts. Understanding the role played by these natural forces is important for resource managers to understand the historic forces that have shaped these ecosystems. Historic landscape character was in part due to fire patterns imposed on forest type mosaics defined by climate, soils, aspect, slope and time. Landscape vegetation patterns such as patch size (page 21), corridors, and edge are largely a product of disturbance, including fire (Agee 1993). That is, fire is not independent of the ecosystem in which it occurs as it is influenced by the amount, arrangement, and structure of variable fuel complexes and its vegetation effects are dependent on the vegetative adaptations to fire. Some species have evolved specific adaptations (e.g.,

thick bark, sprouting, fire stimulated flowering, etc.) in the presence of particular types of fire (Whelan 1995) and are critical to the overall health of these systems.

Wildfires are beneficial to fire adapted ecosystem health as they recycle nutrients, making them available to germinating and resprouting plants (Neary et al. 2005). Fire also removes litter and opens the canopy, allowing more sunlight to reach the forest floor. The increased light creates higher temperatures at the forest floor, which may stimulate seed germination (Whigham 2004). The reduction of litter also exposes bare mineral soil which provides an area for seeds to germinate. Many plants in fire-prone systems are adapted to take advantage of this short-term release of nutrients; as a result, germination and growth after fire is faster and lusher than at other times (Neary et al. 2005) (figure 5).

Figure 5. Small grove of aspen roughly 4 to 6 feet in height with other herbaceous vegetation in the foreground just one year after the Pacheco Fire

Fire only plays a beneficial role in riparian systems, like upland systems, when it is within its historical range of frequency and severity. When high-severity fire sweeps through an adjacent landscape that is adapted to low-intensity surface fire (e.g., Mixed Conifer – Frequent Fire), the effects on riparian areas can be dramatic. Horizontal continuous fuels can aid the movement of fire from adjacent uplands into the riparian areas leading to loss of riparian vegetation can lead to higher water temperatures, increased erosion, and sedimentation that negatively affect aquatic insect and amphibian larvae in streams for several years after high-severity fire (Neary et al. 2005). In some cases, it may take decades for the stream and associated riparian corridor to recover. Higher soil moistures, cooler temperatures, and greater productivity typically characterize riparian areas. In general, this means that under wetter conditions, fire intensities should be lower in riparian areas and result in patchy, mosaic-type burns.

The frequency of fires, is the number of fire events that occur within a specified area during a specified time period. The mean fire interval represents an average of this fire frequency and is spatially explicit (Romme 1980; Agee 1993).

According to Allen (2002) the Jemez Mountains of the Santa Fe NF exemplifies one of the most humanized portions of the prehistoric Southwest. At the time of European settlement in 1598 A.D., the northern Rio Grande valley region was estimated to have a population of about 100,000 people in 100 communities primarily in pinyon-juniper and lower ponderosa pine vegetative types. It is believed that populations of this magnitude and extent could substantially modify the environment. These changes likely included the use of agriculture and alteration of natural hydrological process (irrigation), the removal of vegetation in settlements and high use areas, the collection of fuelwood for warmth and cooking, and potentially the use of fire to enhance the productivity of resources such as herbs and pinyon pine seeds (Allen 2002) and possibly as a hunting strategy (Cooper 1960). However in the Southwest, it is believed that human-set fires and vegetative impacts likely only enhanced prehistoric frequencies in localized areas (Fish 1996, Allen 2002). This notion is further supported by the detailed temporal and spatial records of past fire activity contained in dendrochronological (tree ring) reconstructions of fire history from scarred samples (Allen 2002; Swetnam et al. 1999).

The written record and synthesis of fire occurrence information into databases is a relatively novel idea, and typically incomplete. Traditionally, alternative methods of identifying fire frequencies have been

developed to aid in understanding the long-term interactions between fire and climate. As we go back in time, fire history can reliably be determined for portions of the landscape where some sort of fire indicators are recorded, either on the trees themselves (dendrochronology-based fire scar analysis), in stand structure (age distribution of stands where fire can be assumed to be the dominant disturbance factor), in charcoal deposits in soils, lakes, or bog sediments (sediment charcoal analysis), or can be inferred from vegetation changes over long time periods (pollen records from packrat middens). While each of these methods has its limitations, approaches using dendrochronology and sediment charcoal and pollen data can provide excellent insights into trends in vegetation, fire and fire/climate interactions over hundreds to thousands of years, and provide perspectives on variability, drivers of fire regimes, and fire/climate/vegetation interactions (Gavin et al. 2007; Allen et al. 2008). This extensive record of fire frequency helps us identify the natural fire regime including frequency for many ecological types. Reference fire return intervals specific to the Santa Fe NF, when available, or southwestern United States are synthesized in table 9. Fire regime reference period is considered to be prior to European-American settlement (Fulé et al. 2007; Swetnam et al. 1999) as extensive land-use patterns changed with the introduction of grazing, fire suppression, and fragmentation (Swetnam & Baisan 1996; Covington and Moore 1994).

Table 9. Literature synthesis of historic fire return intervals and regimes of the major ERU types of the Santa Fe NF

Note: Scientific literature specific to the Santa Fe NF was preferable over similar literature from other research areas. If no literature specific to the Forest was available, literature available at the next scale up was used (e.g., region) and so forth.

ERU	Fire Regime Group	Fire Return Interval (yrs.)	Source
Juniper Grass	I	8	Margolis 2014
		20–30	Hauser 2007
PJ Grass	I	8	Margolis 2014
		15–30	Allen 1989
			Baisan and Swetnam 1995
			Grissino-Mayer and Swetnam 1995
		11–36	Poulos et al. 2009
Ponderosa Pine Forest	I	4–8	Swetnam and Dietrich 1985
		9–12	O'Connor et al. 2014
		2–17	Baisan and Swetnam 1990, 1996
		10–30	Muldvain et al. 2003
Mixed Conifer - Frequent Fire	I	9–11	O'Connor et al. 2014
		3–21	Heinlein et al 2005
		5	Grissino-Mayer and Swetnam 1995
		10	Baisan and Swetnam 1990
Colorado Plateau / Great Basin Grassland	II	10–30	Wright and Bailey 1982
Montane / Subalpine Grassland	II	2–22	Dick-Peddie 1993
			White 2002
PJ Sagebrush	III	50–100+	Gruell et al. 1994
Mixed Conifer w/ Aspen	III, IV	100–200	Romme et al. 2009
		50–500	O'Connor et al. 2014
Sagebrush Shrubland	IV	12–70	Miller and Tausch 2001
			Gottfried et al. 1995
			Wright and Bailey 1982
PJ Woodland	V (III)	30–60	Muldvain et all. 2003
		200–300	Gottfried et al. 1995
		400	Floyd et al. 2000
			Floyd et al. 2004
Spruce-Fir Forest	V	200+	DNR 2011
		300	Romme et al. 2009
		300–400	Grissino-Mayer and Swetnam 1995

Data and Analysis Process

Reference data for evaluating fire history vary in temporal and spatial resolution for describing different aspects of fire regimes. Each type of data has strengths and weaknesses for describing fire frequency, variability, season, severity, extent and location. Much of the information on fire frequency comes from paleoecological data, such as charcoal in lake and soil sediments (e.g., Clark 1988, 1990; Millspaugh and Whitlock 1995) and scars on the boles of trees caused by fires, or other dendroecological data such as stand ages. Basal scars on the boles of trees that result from non-lethal fires are an excellent source of information on past fires. Series of fire scars on a single tree or sets of trees can be precisely cross-dated using tree ring analysis to reconstruct long time series of historical fires and are the primary source used to identify historical fire frequency on the Santa Fe NF.

Results

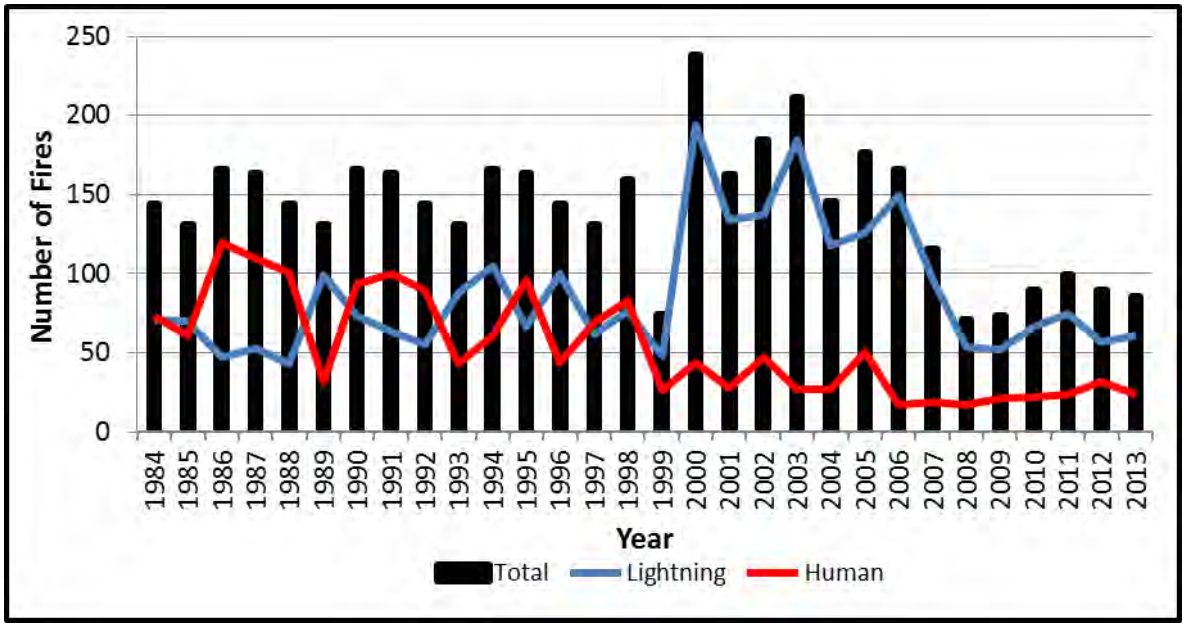


Figure 6. Wildfire occurrences on the Santa Fe National Forest from 1984 through 2013

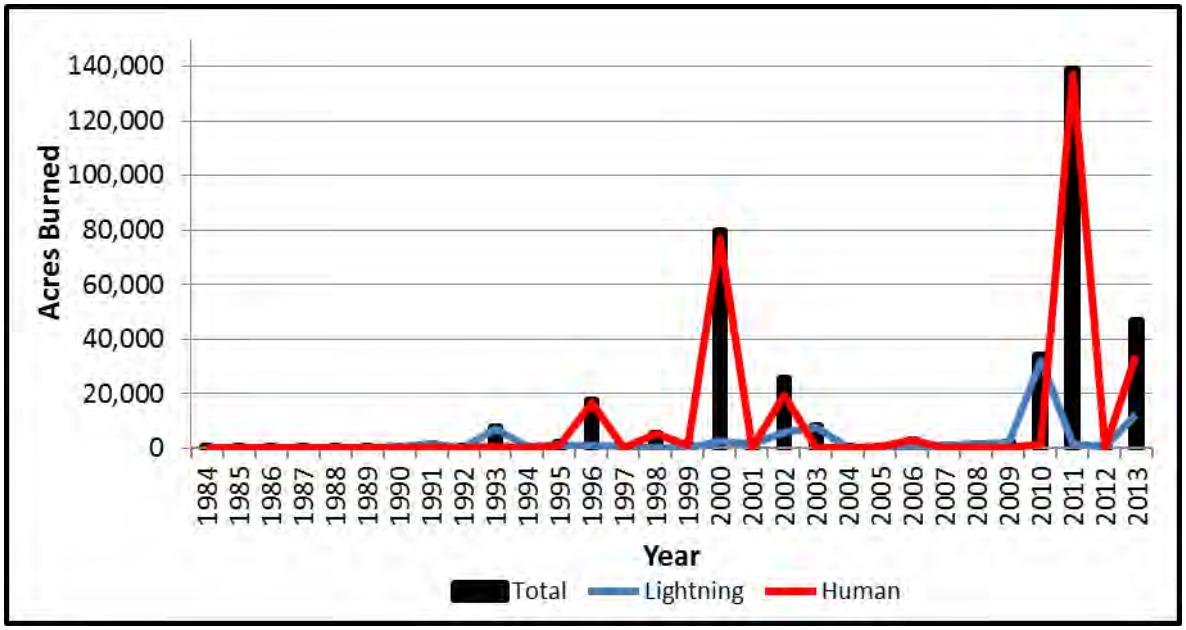


Figure 7. Santa Fe National Forest wildfire acres burned from 1984 through 2013

Between 1984 and 2013 the Santa Fe NF recorded 4,223 wildfires that burned 385,005 acres within the administrative fire boundary (figure 6). Prior to the circa 2000, wildfires on the Santa Fe National Forest were split nearly evenly between human and lightning caused, but since then the majority of fires occurring on the forest have been lightning caused (figure 7). However, some of the most destructive fires were human caused (e.g., Cerro Grande, Las Conchas).

Despite the number of fires generally decreasing over the past 15 years, the number of acres has increased significantly due to a handful of fires that burned large portions of the landscape. Which is common throughout the western United States, in which, a relatively small percentage of the fires are responsible for the majority of the area burned. For example, 1 percent of all wildfires in the western United States are responsible for 98 percent of the area burned (Strauss et al. 1989).

Table 10. Fire return interval in years for ERUs at the three different analysis scales (local, plan, and context)

ERU	Historic FRI	Local* NWZ	Local* SWZ	Local* CZ	Local* NEZ	Local* SEZ	Plan	Context
Montane / Subalpine Grassland	2–22	388	370		308		261	261
Ponderosa Pine Forest	4–30	422	692	319	94		203	203
Mixed Conifer - Frequent	5–21	322	565	207	154	> 1,000	152	152
Juniper Grass	8–30	3,037	> 1,000	3,602			831	831
PJ Grass	8–36	> 1,000		2,125			1,04	1,041
Colorado Plateau / Great	10–30	446		3,920			2,32	2,322
Sagebrush Shrubland	12–70	2,788		6,414			3,00	3,003
PJ Sagebrush	50–100			2,265			>1,0	> 1,000
PJ Woodland	30–400	2,376	> 1,000	3,141	285		1,56	1,569
Mixed Conifer w/ Aspen	50–500	283	778	497	381		238	238
Spruce-Fir Forest	200–400	215	> 1,000	748	217	> 1,000	222	222

*Blank cells at the local scale indicate no fires recorded in MTBS database (1984-2012) and are assumed to be high departure due to the lack of fire. Hatching indicates the ERU does not represent at least 5 percent of the local zone and is, therefore, considered not sufficiently represented to analyze.

Table Legend:

Limited Acres	Low Departure	Moderate Departure	High Departure

Fire severity is broadly defined as the degree of ecosystem change induced by fire (Ryan and Noste 1985). Fire severity has been described by the degree of tree mortality (Agee 1993), degree to which fires consume organic biomass on and within the soil (Neary et al. 2005), change in color of ash and soil (Ryan and Noste 1985), or a combination of these fire effects. Three broad categories of fire severity have been identified based on the physical characters of fire and the fire adaptations of vegetation, low, moderate (mixed), and high (Agee 1993). For mapping fire regimes, severity is typically defined based upon degree of mortality in overstory vegetation even where the dominant overstory is shrubs (in shrublands) or grasses (in grasslands).

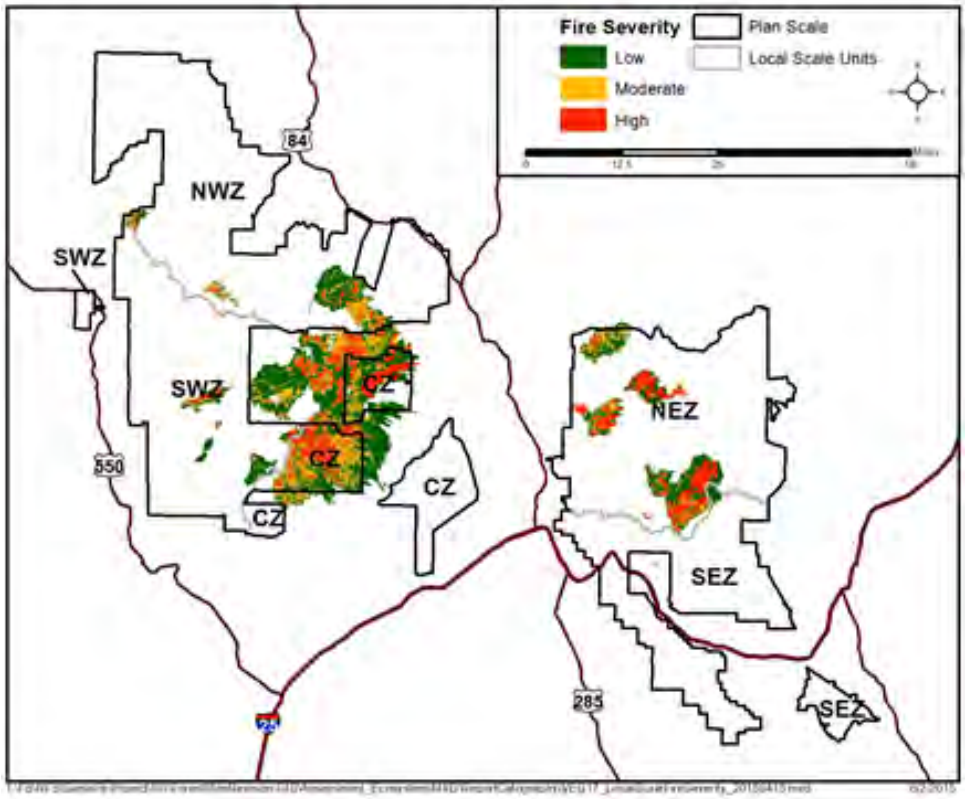


Figure 8. Fire severity for large wildfires on the Santa Fe NF for years 1984 to 2013

High-severity fires remove overstory vegetation and ground cover that dramatically affects watersheds and water resources by altering the important processes of evapotranspiration, interception, surface flow, and subsurface flow (Swanson 1981). The size of high-severity fire patches is important in determining the probability of fire-induced flooding or debris flows (Wohl and Pearthree 1991;Cannon and Reneau 2000). Recent, large stand-replacing fires in the southwestern United States have produced runoff and erosion events as much as two orders of magnitude greater than pre-fire conditions (Veenhuis 2002).

Data and Analysis Process

Current fire severity information was obtained from Monitoring Trends in Burn Severity (MTBS) data. The MTBS project uses satellite data to map all large fires[2], from 1984 to the present, including fire severity (differenced Normalized Burn Ratio - dNBR) within the fire perimeters using moderate resolution (30 x 30 m) satellite data obtained before and after each incident. This provides nationally consistent data on fire perimeters and severity for all recent large fires in the United States (Eidenshink et al. 2007). Although this dataset is limited to large wildfires, the dataset is believed to be comprehensive enough for the analysis since a relatively small percentage of the fires are responsible for the majority of the area burned. Strauss and other (1989) state that 1 percent of all wildfires in the western United States are responsible for 98 percent of the area burned. All MTBS data at the context scale for large wildfires for years 1984 to 2012 were included in the analysis. Burned Area Reflectance Classification (BARC) severity data was not used to supplement MTBS data, although the Forest did have this data available for the Diego and Pino Fires, since the data was not available for fires at the context scale that occurred in 2013 and 2014.

[2] Fires 500 acres in the eastern United States and 1,000 acres in the western United States are considered large fires (mtbs.gov).

Results

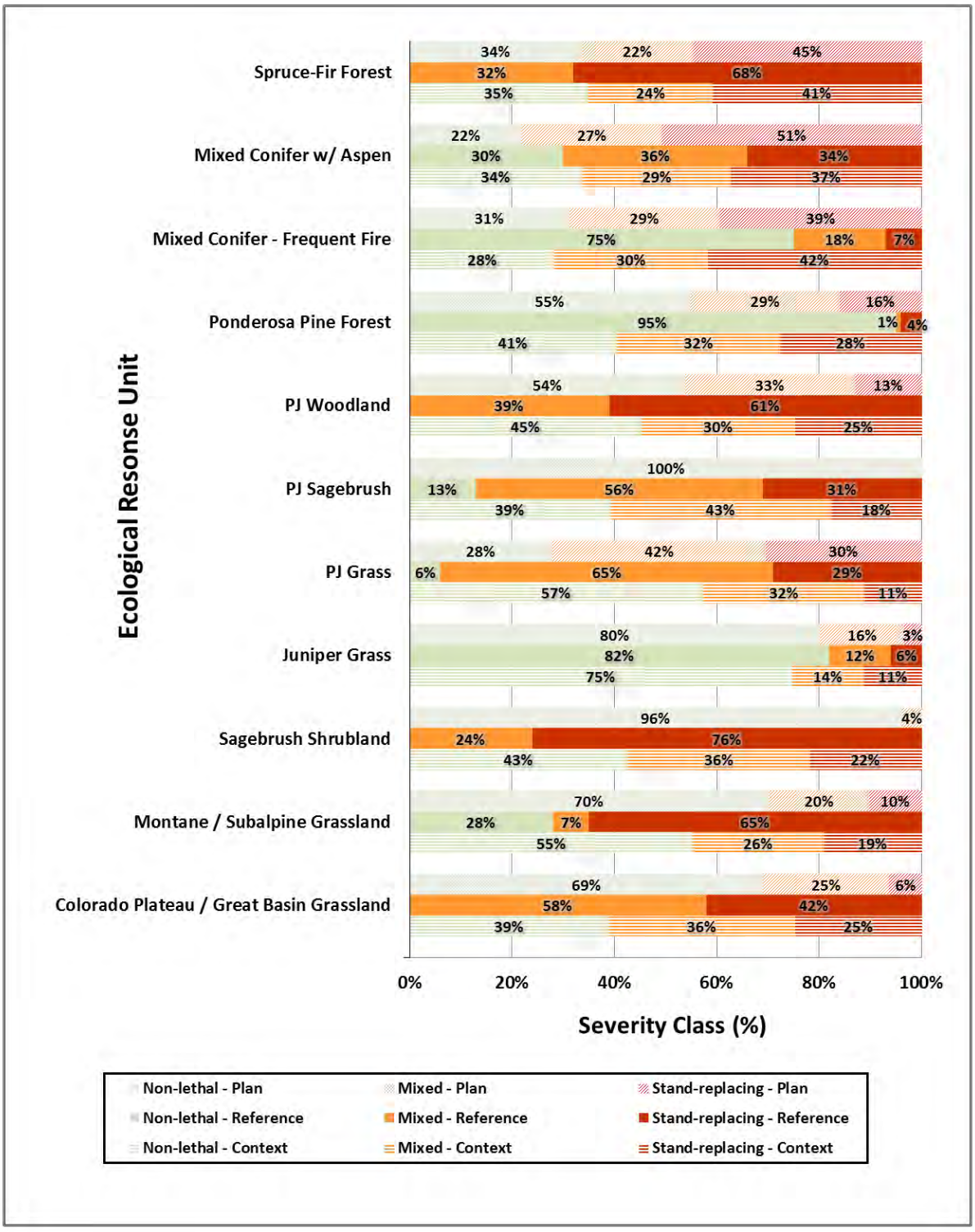


Figure 9. Resulting severity class proportions for all ERUs based on wildfires at the context and plan scales for years 1984 to 2013 in comparison with reference severity proportions. Reference severity proportions from LANDFIRE (2012).

Fire Regime Condition Class (FRCC) is an index of ecological departure from reference conditions. The FRCC departure metric can be derived by evaluating the change in composition of succession classes, fire frequency, and fire severity (Barrett et al. 2006).

The two main components of an ecosystem FRCC assessments measure include, fire regime (fire frequency and severity) and associated vegetation. Managers can use the departure and condition class data to document possible changes to key ecosystem components (Schmidt et al. 2002) including vegetation characteristics (species composition, structural stage, stand age, canopy closure, and mosaic pattern); fuel composition; fire frequency, severity, and pattern; and other associated disturbances, such as insect and disease mortality, grazing, and drought. Common causes of departure include advanced succession, effective fire suppression, timber harvesting, livestock grazing, and introduced and established exotic species (Schmidt et al. 2002; Stambaugh et al. 2008; Keane et al. 2009). Three classes corresponding to low, moderate, and high departure have been defined (Hardy et al. 2001; Schmidt et al. 2002) (table 11). Common causes of departure include fire suppression, timber harvesting, livestock grazing, introduction and establishment of exotic plants, as well as introduced insects and disease (Schmidt et al. 2002).

Table 11. Fire Regime Condition Class Descriptions as defined by Schmidt et al. (2002)

Fire Regime Condition Class	Class Description
FRCC1	Less than 33 percent departure* from the central tendency of the historical range of variation (HRV). Fire regimes are within the historical range and the risk of losing key ecosystem components is low. Vegetation attributes (species composition and structure) are intact and functioning within their historical range.
FRCC2	33 to 66 percent departure. Fire regimes have been moderately altered from their historical range. The risk of losing key ecosystem components is moderate. Fire frequencies have departed from historical frequencies by one or more return intervals (either increased or decreased). This may result in moderate changes to one or more of the following: fire size, intensity, severity, and landscape patterns. Vegetation attributes have been moderately altered from their historical range.
FRCC3	Greater than 66 percent departure. Fire regimes have been significantly altered from their historical range. The risk of losing key ecosystem components is high. Fire frequencies have departed from historical frequencies by multiple return intervals. This may result in dramatic changes to one or more of the following: fire size, intensity, severity, and landscape patterns. Vegetation attributes have been significantly altered from their historical range.

Fire Regime

A natural fire regime is a general classification of the role fire would play across a landscape in the absence of modern human intervention, but including the influence of aboriginal burning (Agee 1993, Brown 1995). In general, a fire regime characterizes the spatial and temporal patterns and ecosystem impacts of fire on the landscape (Morgan et al. 2001; Bowman et al. 2009). Fire frequency (figure 9) and severity (figure 10) are most often used to classify and map fire regimes (Heinselman 1981; Hardy et al. 1999). However, fire regimes are also described by magnitude (severity and intensity), predictability, size, seasonality, and spatial patterns (Heinselman 1981; Agee 1993). Fire frequency, expressed as the fire return interval, is the number of fire events at a point or specified area within a specified period of time. In the Southwest, the biggest fire years followed wet years (Allen et al. 1998). Fire severity is broadly defined as the degree of ecosystem change induced by fire (Ryan and Noste 1985; Albini 1976). When

mapping fire regimes, severity is typically defined based upon degree of mortality in overstory vegetation even where the dominant overstory is shrubs (in shrublands) or grasses (in grasslands).

The two most important factors influencing fire regimes are vegetation type and climate. Fire histories provide evidence of past relationships between fire and climate (Swetnam and Betancourt 1999). That evidence makes it clear that changing climate will profoundly affect the frequency and severity of fires in many regions and ecosystems in response to factors such as reduced snowpack, earlier snowmelt and more severe or prolonged droughts (Westerling et al. 2006; Flannigan et al. 2009). Understanding the historic and potential fire regimes of different types of vegetation and the factors (fuels, topography, weather, humans, and biota) that can alter these fire regimes is important for understanding and predicting potential interactions between fire and climate. Not only does climate directly affect the frequency, size and severity of fires, it also affects fire regimes through its influence on vegetation vigor, structure, and composition as changing climate will alter the growth and vigor of existing vegetation, with resulting changes in fuel structure and dead fuel loads.

As mentioned previously, fire is a fundamental disturbance process in ecology and has been a powerful agent of change in terrestrial ecosystems for millions of years. Understanding the role of fire on a landscape is critical for managing fire and forests for biodiversity, ecosystem function, and resilience to changes in climate. Information about past fire regimes can be a helpful reference to guide and inform land managers about current and future fire regime characteristics, patterns, and forest structure characteristics that are useful for strategically planning fire and natural resource management, assessing risk and ecological conditions (Morgan et al. 2001), illustrating change in disturbance regimes through time, identifying knowledge gaps, and learning how climate, topography, vegetation, and land use influence fire regimes. To better understand the role fire can play in forests today, researchers and managers have found it useful to reconstruct attributes of historical fire regimes before the onset of fire exclusion. Fire exclusion in the southwestern United States often occurred in the late 1800s, when activities such as grazing of domestic animals, logging, and fire suppression began on a widespread scale.

Table 12. Fire regime groups used in the current LANDFIRE database adapted from FRCC Guidebook, Version 3.0 (Anon 2010)

Note: These groups have been modified from earlier versions (Hardy et al. 2001, Schmidt et al. 2002).

Fire Regime Group	Frequency	Severity	Severity Description
I	0– 5 years	Low / mixed	Generally low-severity fires replacing less than 25% of the dominant overstory vegetation; can include mixed-severity fires that replace up to 75% of the overstory
II	0–35 years	Replacement	High-severity fires replacing greater than 75% of the dominant overstory vegetation
III	35–200 years	Mixed / low	Generally mixed-severity; can also include low-severity fires
IV	35–200 years	Replacement	High-severity fires
V	200+ years	Replacement / Any severity	Generally replacement-severity; can include any severity type in this frequency range

FRCC

FRCC is a standardized interagency tool for assessing a current landscape's departure from historical (natural) conditions (Hann et al. 2003). Historical or reference period is defined as the time period when ecosystems along with their natural disturbance regimes were still intact and functioning in sustainable landscapes before Euro-American settlement activities. Current condition departure assessments are based

on fire frequency and intensity, current species composition, structural stage, age and canopy closure, and fuel accumulations compared to conditions under the historic disturbance regimes.

Data and Analysis Process

FRCC is derived by comparing current conditions to an estimated central tendency of the historical range of variation that existed before significant EuroAmerican settlement. Departure of current conditions from this historical baseline can serve as a useful proxy for potential uncharacteristic fire effects and can be used to address risks to the sustainability of fire-adapted ecosystems. In applying the condition class concept defined by Schmidt and others (2002), we assume that historical fire regimes represent conditions under which fire-adapted ecosystems have evolved and have been maintained over time (Hardy and others 1998). Thus, if we observe that fire intervals, fire severity, vegetation structure, and/or vegetation composition have changed from historical conditions, we would also expect fire size, fire intensity, and burn patterns to be subsequently altered. If these basic fire characteristics have changed, then it is also likely that ecosystem components adapted to these historical fire regimes have been affected as well.

For data and analysis process used to determine current conditions please refer to the Fire Frequency and Fire Severity sections of the key ecosystem charactersitics.

Results

Table 13. Current fire regime condition classes (FRCC) identifying each local zone's current landscape departure from historical (natural) conditions for the major upland ERUs on the Santa Fe NF.
Proportions for each ERU within each of the FRCCs are also provided at the plan scale. Hatching indicates the ERU does not represent at least 5 percent of the local zone and is, therefore, considered not sufficiently represented to analyze.

ERU	Local (FRCC) NWZ	Local (FRCC) SWZ	Local (FRCC) CZ	Local (FRCC) NEZ	Local (FRCC) SEZ	Plan (FRCC Proportion) I	Plan (FRCC Proportion) II	Plan (FRCC Proportion) III
Colorado Plateau / Great Basin Grassland	III		III		III	0%	0%	100%
Juniper Grass	II	III	II		II	0%	76%	24%
Mixed Conifer - Frequent Fire	III	III	III	III	III	0%	0%	100%
Mixed Conifer w/ Aspen	II	II		II		0%	100%	0%
Montane / Subalpine Grassland	III	III		III		0%	0%	100%
PJ Grass	II	II	II		II	0%	100%	0%
PJ Sagebrush	II		III			0%	24%	76%
PJ Woodland	II	II	II	II	I	36%	64%	0%
Ponderosa Pine Forest	III	III	III	III	III	0%	0%	100%
Sagebrush Shrubland	III					0%	0%	100%
Spruce-Fir Forest	II	III	II	II	II	0%	90%	10%

As previously mentioned, fire frequency for all ERUs is highly departed on the Santa Fe NF except for MCW and SFF, both of which have very long fire free periods between disturbance events. Seral state departures are also high for ERUs that historically would have experienced frequent fire disturbances. We are also seeing a 4-5 fold in the proportion of high severity acres relative to reference in the frequent fire forested system. So when all of these factors are taken into consideration it's not surprising that

grasslands and frequent fire forests fall into FRCC III. Only PJO has a proportion of acres that fall into fire regime condition class I at the plan scale. Other woodland systems including JUG and PJG are moderately at risk of losing key ecosystem components. The lack of fire necessary to maintain vegetation attributes has put these lands at greater risk of uncharacteristic wildfire in the future.

Terrestrial Ecosystem Stressors

Stressors are influences that may directly or indirectly degrade or impair ecosystem composition, structure, or ecological process in a manner that may impair ecological integrity, such as invasive species, disruption of a natural disturbance regime, or climate change (36 CFR 219.9(c)). Many drivers may become stressors when they occur at uncharacteristic levels. These have been addressed throughout the ERU condition descriptions when appropriate.

Insect and disease is the severity and frequency of outbreaks of damage agents. Insects and diseases are important components of forest ecosystems and greatly influence forest structure and species composition over time. They are characteristic to some degree and at some frequency in all ERUs, not only as disturbance agents, but as significant contributors to ecosystem condition and function.

Insects and diseases are integral components of forest and woodland ecosystems. There are numerous positive impacts of insects and diseases on the forest ecosystem including creating small openings, increasing biodiversity, enhancing nutrient cycling, creating wildlife habitat, and many other ecologically significant benefits. Under severe disease infection levels or episodic outbreaks of insects, however, their effects are more evident, sometimes negative, and cause greater forest change. With the exception of exotic agents such as white pine blister rust, the primary forest insects and diseases in the region and on the Santa Fe NF are native organisms that have long been part of the ecosystem and have evolved with their plant hosts. White pine blister rust is established on the Santa Fe NF and expansion of the disease is expected over the next few decades. An introduced biological control agent to limit the expansion of tamarisk, the tamarisk leaf beetle has arrived in the region and has begun defoliating stands of this invasive plant. The lasting effect of this interaction is yet to be determined.

Human activities have dramatically affected and changed forest and woodland ecosystems directly and indirectly. In response to these altered environments, the extent and activity of insects and diseases change. In turn, the way we perceive the effects of insects and diseases on the landscape has also changed. Today's pine and mixed conifer forests are at greater densities and therefore more susceptible to bark beetle outbreaks and more vulnerable to the spread of dwarf mistletoes. While mistletoe distribution has likely remained relatively static, harvest activities have probably decreased the abundance of large infected trees in many areas. Although, in some cases, past harvesting activities that left mistletoe infected seed trees likely increased infestation levels in many regenerating stands, as the effects of insects and diseases are often closely interconnected. While one agent may be identified as a mortality agent, multiple factors often contributed to the tree's death. For example, trees most susceptible to attack by bark beetles often are stressed by pre-existing conditions, including overcrowding, dwarf mistletoe infection, root disease, and drought periods. Past harvesting preferences that reduced the pine component of mixed conifer stands have shifted forest composition to greater dominance by shade tolerant species favored by western spruce budworm, Douglas-fir tussock moth, and root disease. Outbreaks of western spruce budworm, in particular, are probably more extensive in the mixed conifer simply because there is a greater abundance of host trees.

The 2012 National Insect and Disease Risk Map (NIDRM) is a strategic project to assess the potential risk of tree mortality from insects and diseases across the U.S. over a 15-year time period. These insect and disease risk models evaluate the potential loss of basal area based upon current forest conditions.

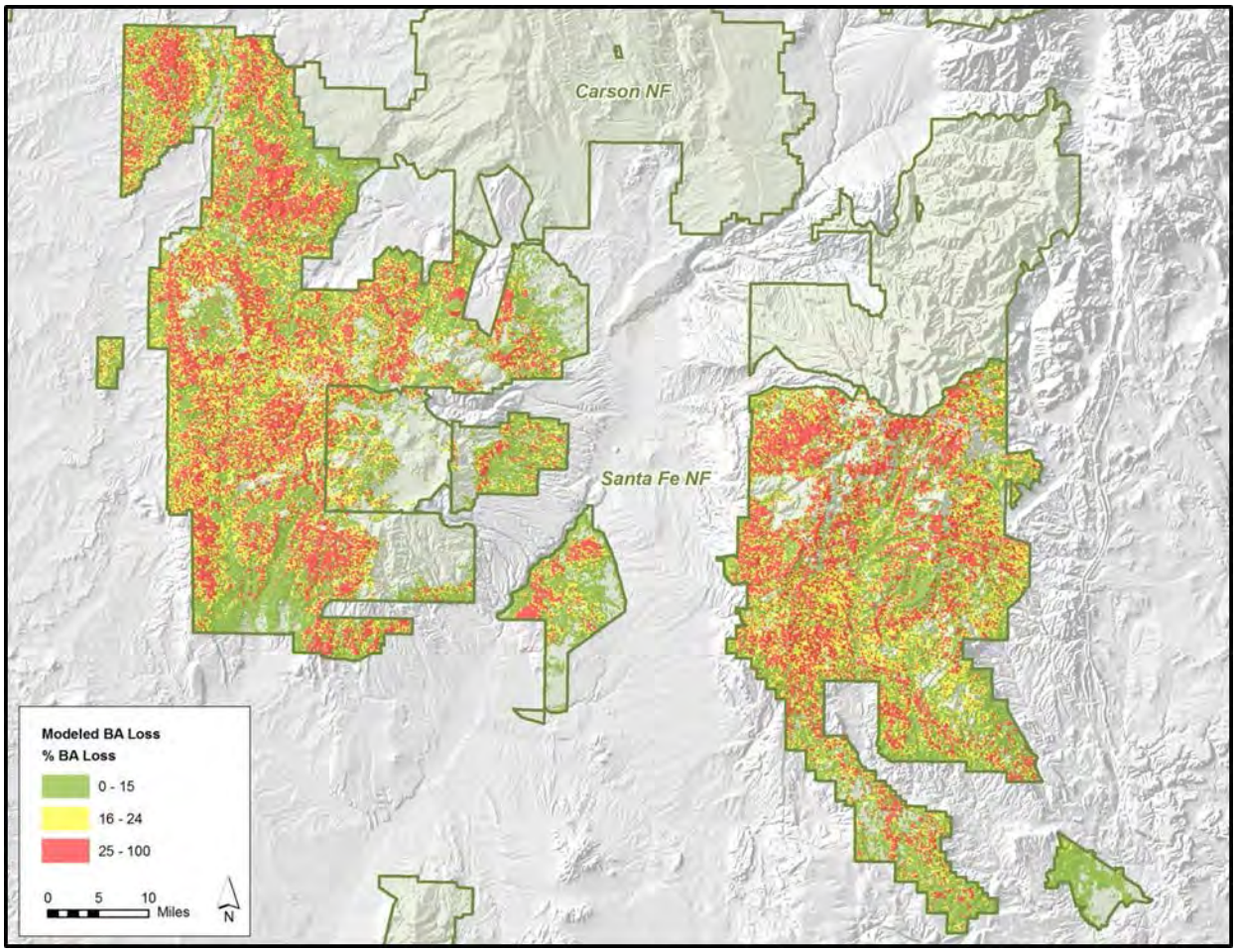


Figure 10. Modeled percent basal area at risk from insect and disease activity on the Santa Fe NF

Table 14. Percent of host basal area modeled to be at high risk by agent on the Santa Fe NF

Risk Agent	Percent Mortality
Spruce beetle	35.1%
Douglas-fir beetle	25.0%
Engraver beetles (*Ips* spp.)	20.2%
Aspen / cottonwood decline	18.1%
Fir engraver beetle	12.2%
Root diseases	9.3%
Western balsam bark beetle	7.4%
Western pine beetle	6.0%
Western spruce budworm	2.2%
White pine blister rust	1.2%
Mountain pine beetle	0.5%
Dwarf mistletoes	0.2%
Douglas-fir tussock moth	0.1%

Overall, the available historical record shows no clear changes in insect or disease outbreak patterns on the Santa Fe NF. These records, however, are more recent and often concentrate on insect activity, particularly large events. Based on these records, the widespread bark beetle outbreaks in the lower elevation forest types, particularly pinyon-juniper and ponderosa pine, in the Southwest are primarily drought induced. While altered stand conditions have exacerbated the consequences of these events and led to greater mortality, they have not been the reason these large outbreaks started. Smaller bark beetle events initiated by management, dense stands, or other site disturbances are not always well documented. Thus evaluation of these records reveals more about the role of climate variability in triggering insect activity than changes in insect and disease activity resulting from altered forest and woodland structure. Outbreaks of bark beetles in mixed conifer are related to both drought, especially fir engraver beetle, and disturbance. Spruce beetle outbreaks in contrast are more related to disturbances, such as windthrow, that occur in stands composed of dense, large diameter trees.

As has occurred throughout the evolution of ecosystems, changes in climate patterns will affect southwestern forests and woodlands. Climate change is already modifying ecosystems (Walther et al. 2002) and it is expected to substantially change forest insect and disease dynamics (Dale et al. 2001, Bale et al. 2002, Williams and Liebhold 2002, Logan et al. 2003, Ryan et al. 2008). The rising temperatures and reduced snowpack conditions observed in the western U.S. (Knowles et al. 2006) are already putting additional stress upon southwestern forests with high tree densities. If the most widely accepted climatic models are correct, warmer temperatures, less snowpack, more variable precipitation, and increased potential for extreme events (State of New Mexico 2005, Knowles et al. 2006, Seager et al. 2007) would in general create greater stresses. These stresses will add to the probability of increased bark beetle activity and could exacerbate the effects of root and other diseases. Stress in general predisposes trees to various insects and diseases, but not all agents will respond in a similar way. Mistletoes are dependent upon their hosts for growth, so weaker, stressed trees could actually result in reduced spread and intensification; however, mistletoe effects may become more damaging since mortality among infected trees will likely increase. Some defoliators, such as western spruce budworm, often have outbreaks during periods of increased moisture, so outbreaks might be less severe under a drier, warmer climate. The direction of changes in insect and disease activity will not be uniform

On the Santa Fe NF, approximately 450,000 acres are modeled as being "at risk" of losing ≥ 25 percent of the basal area over the next 15 years. The threshold is set at 25 percent basal area loss as this is considered to represent *"an uncommon, rather extraordinarily high amount of mortality"* (Krist et al. 2014).

Invasive Plant Species

Invasive species are not native to the ecosystem being described. For all ecosystems, the refence condition is that invasive species are rarely present, or are present at levels that do not negatively influence ecosystem function. Invasive plants compete with desirable plants, poisoning animals, hosting insect and disease agents, and altering various ecosystem attributes, such as fire regimes (Dick-Peddie 1993).

Invasive continue to invade rangelands, forests, and riaparian ecosystems. Control of infestations can be challengeing with the rapid exapansion and continued introduction through a number of means. The rapid expansion of exotic weed populations is a great deterent to restoring native plant communities and re-establishing conditions within the historic range of variability. If exotic plants are not kept in check, long-term devastating effects to forest ecosystems can occur. The ecological effects include replacement of native species and reduction in ground cover which leads to loss of biodiversity, forage, habitat, and soil productivity.

The identification of infestation sites on the Forest is sporadic and typically a result of employees coincidentally traveling through these locations as the monitoring of invasives is not systematic and thorough. It is very likely that additional sites exist and have not been discovered yet and the data captured below is not inclusive of all invasive plants that exist on the Forest. Occurences identified below are from the Forest's geographical information systems (GIS) invasives database for calendar years 2000 – 2014.

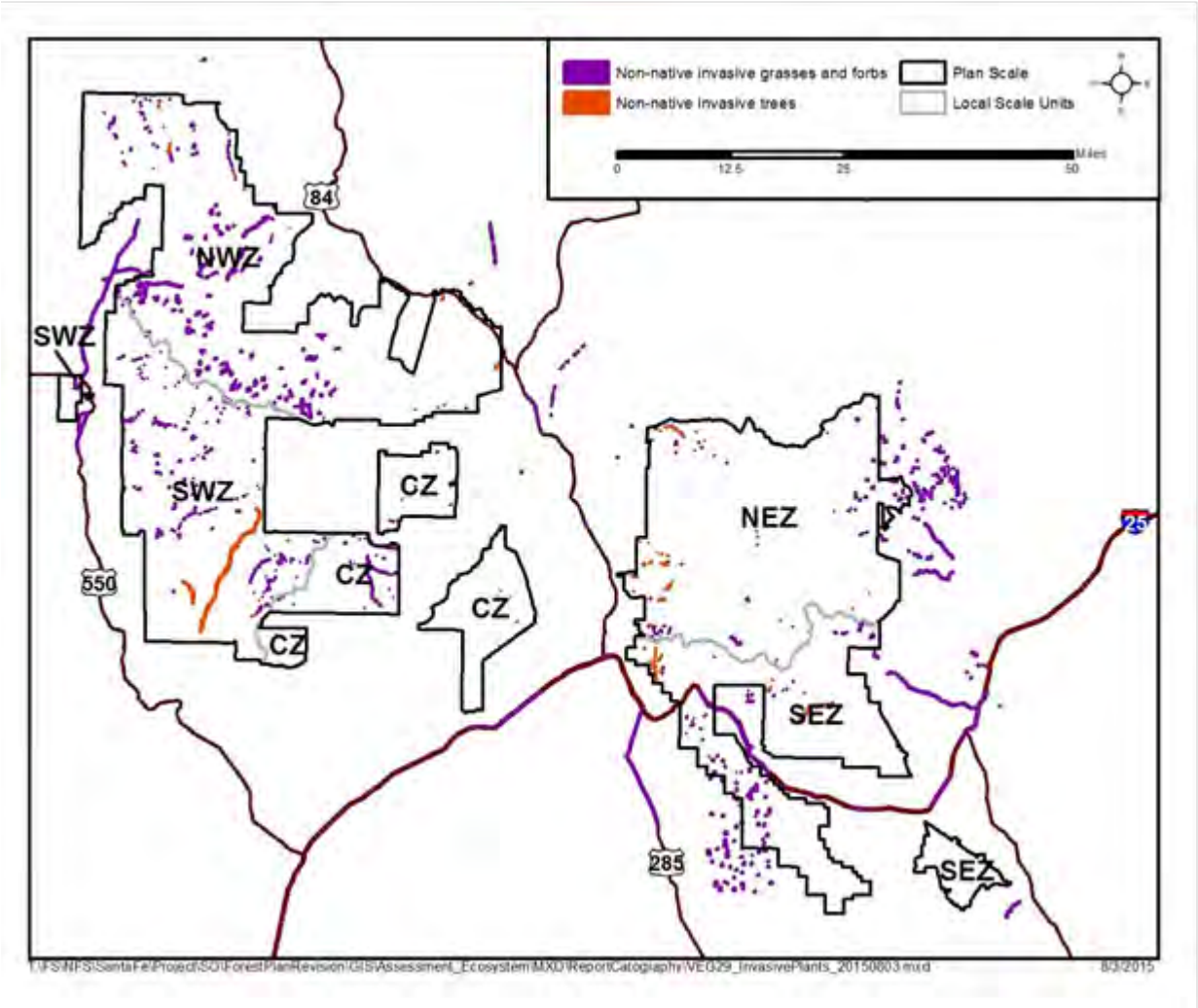


Figure 11. Invasive plants on the Santa Fe National Forest

Table 15. Inventoried invasive plants on the Santa Fe National Forest

Common Name	Scientific Name	Acres
Bull thistle	*Cirsium vulgare*	3,223
Canada thistle	*Cirsium arvense*	5,466
Cheatgrass	*Bromus tectorum*	75
Common mullein	*Verbascum thapsus*	21

Common Name	Scientific Name	Acres
Dalmation toadflax	*Linaria dalmatica*	21
Diffuse knapweed	*Centaurea diffusa*	114
Hardheads	*Acroptilon repens*	87
Nodding plumeless thistle	*Carduus nutans*	3,153
Poison hemlock	*Conium maculatum*	22
Russian olive	*Elaeagnus angustifolia*	1,760
Scotch thistle	*Onopordum acanthium*	481
Tamarisk (saltcedar)	*Tamarix ramosissima*	1,939
Siberian elm	*Ulmus pumila*	2,401
Totals		18,763

The distribution of non-native and invasive plants are displayed in Figure 11. The largest concentration occurs on the west side of the Forest, with the NWZ and SWZ accounting for over 8,000 acres each. The CZ is the least infested local zone with roughly 375 acres of documented invasives primarily residing in the PPF type. PPF, MCD and Rio Grande Cottonwood/Shrub ecosystems contain the greatest distribution of invasives of all ERUs found on the Forest. Rio Grande Cottonwood/Shrub also has the greatest annual proportion of invasion by invasives with nearly 3% of the ecosystem newly infested annually (based on 15-yr. average).

Generally thistle is the most abundant invasive found on the Forest with 65% of invasive plants found on the Forest being a form of thistle. Canada thistle being the most extensive exists in nearly every ERU found on the Forest.

Terrestrial Ecological Response Units (ERUs)

In the Southwest, the Forest Service uses a system of ecosystem types or a coarse stratification of biophysical themes called "Ecological Response Units" (ERUs) (Wahlberg et al. 2014), to facilitate landscape analysis and strategic planning. ERUs represent the climax vegetation type that would dominate a site under natural disturbance regimes and biological processes. These terrestrial ecological systems are defined by multiple components including site potential or climate, soil, geomorphology, and geology; plant associations or native species, structure and associated successional stages and ecological processes or disturbance regimes (TNC 2006).

Ecological Response Units are useful for landscape assessment. Understanding the response of these ecological groupings to the presence or absence of disturbance processes over time enables land managers to better characterize components of ecosystem diversity. In the context of land management planning, the Historical Range of Variability (HRV) specific to each ERU can provide a baseline for managers to identify desired future conditions and the management actions needed to move toward need for change by comparing current conditions with the range of natural conditions.

ERUs were formerly referred to as Potential Natural Vegetation Types (PNVTs) and are similar to other conceptual frameworks of ecosystem types such as NatureServe's Ecological Systems (Comer et al. 2003) and the biophysical settings (BpS) identified by LANDFIRE - 2010 (Rollins 2009). These products were avoided, when possible (plan and local analyses), in the analysis as they do not adequately describe some vegetation communities, and are split at too fine a detail for landscape scale analysis. The ERU framework bridges these gaps (Wahlberg et al. 2014) and better describes southwestern systems. Since ERU data are limited to the Forest Service Southwestern Region (New Mexico and Arizona), biophysical setting (BpS) data from LANDFIRE (2010) was used to supplement the ERU dataset for the portions of the context scale that extend north into the state of Colorado. Similar to ERUs, the biophysical settings layer represents the natural plant communities that may have existed on the landscape during a reference period and likely do not reflect current vegetative conditions and species (existing vegetation) on the landscape, but are based on both the current biophysical environment and an approximation of the historical disturbance regime (LANDFIRE 2014).

The Santa Fe NF is primarily comprised of 16 terrestrial (upland) and 6 riparian ERUs. But only the 11 terrestrial ERUs that account for at least 1 percent of the plan scale are modeled to estimate future conditions. Modeled ERUs represent 96.6 percent of the Santa Fe NF landscape. However, the current condition and departure from reference conditions of key ecosystem characteristics that make up 99.3 percent of the total Forest landscape have been analyzed.

Table 16. Terrestrial ecological response units (ERUs) presented for all three analysis scales (local, plan and context)

Proportions at the local scale include both percent of the total local scale acres and proportion of the total plan scale ERU acreage. Similarly the proportions at the plan scale include both percent of the total plan scale acres and proportion of the total context scale ERU acreage. Ecological response units that make up greater than 1 percent (above dark horizontal line) of the Plan (Forest) scale were analyzed in depth (values have been rounded to the nearest whole number). Italicized local scale ecological units are excluded from local scale analyses due to minor percentages.

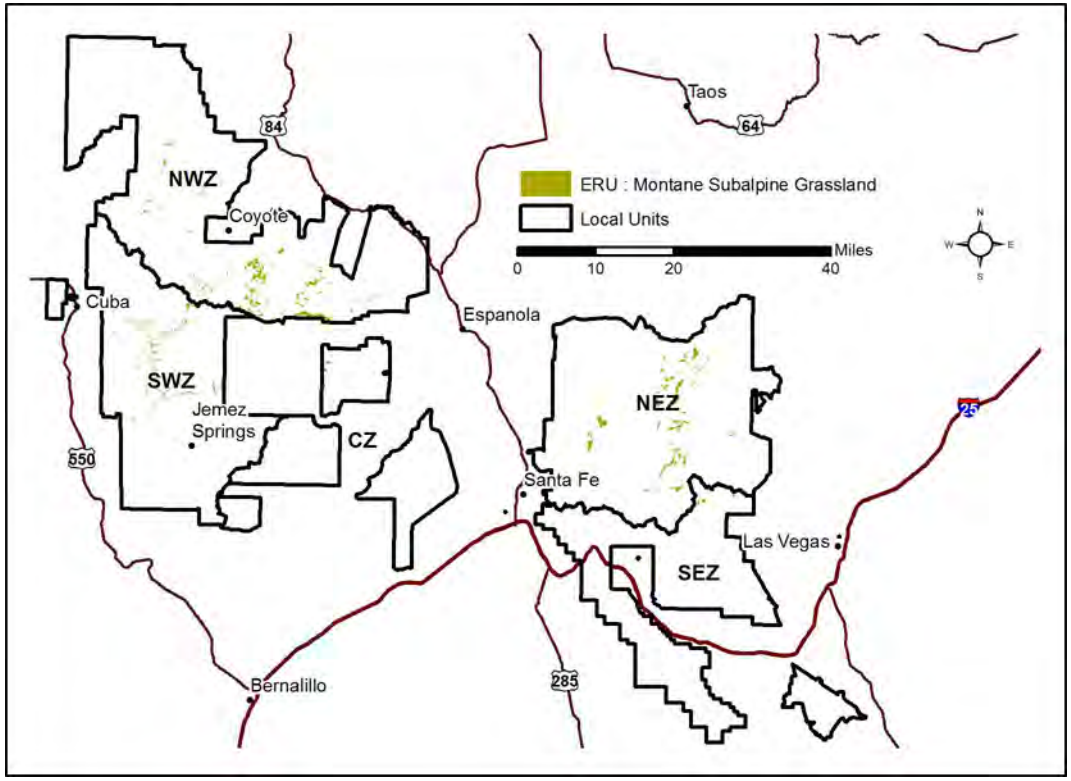
Upland Ecological Response Units (ERUs)	Spatial Scales of Analysis													
	Local										Plan			Context
	NWZ		SWZ		CZ		NEZ		SEZ					
	% of Local Scale	% of Plan ERU Acres	% of Local Scale	% of Plan ERU Acres	% of Local Scale	% of Plan ERU Acres	% of Local Scale	% of Plan ERU Acres	% of Local Scale	% of Plan ERU Acres	**ERU Acres**	% of Plan Scale	% of Context	**ERU Acres**
Mixed Conifer - Frequent Fire - (MCD)	17.4%	19.8%	34.6%	26.4%	24.6%	10.2%	35.2%	33.5%	15.7%	10.0%	**429,967**	25.58%	18.99%	**2,263,903**
Ponderosa Pine Forest - (PPF)	30.4%	36.9%	30.4%	24.7%	24.2%	10.7%	9.8%	10.0%	26.3%	17.8%	**403,915**	24.03%	11.49%	**3,514,152**
Spruce-Fir Forest - (SFF)	8.5%	16.7%	7.6%	9.9%	2.2%	1.6%	41.4%	67.8%	3.7%	4.1%	**250,481**	14.90%	16.79%	**1,491,541**
PJ Woodland - (PJW)	14.0%	29.7%	7.7%	10.9%	21.3%	16.4%	3.9%	6.9%	30.6%	36.2%	**231,508**	13.77%	17.37%	**1,332,919**
Juniper Grass - (JUG)	10.3%	51.8%	7.0%	23.6%	7.8%	14.2%	0.1%	0.3%	3.6%	10.2%	**97,470**	5.80%	5.42%	**1,799,893**
PJ Grass - (PJG)	2.3%	25.5%	2.5%	19.0%	2.0%	8.1%	0.0%	0.0%	7.5%	47.3%	**43,356**	2.58%	4.68%	**927,286**
Colorado Plateau /Great Basin Grassland - (CPGB)	1.2%	14.6%	0.0%	0.2%	2.7%	11.7%	0.1%	1.0%	11.0%	72.5%	**41,639**	2.48%	1.82%	**2,289,984**
Mixed Conifer w/ Aspen - (MCW)	2.8%	34.5%	4.5%	37.1%	1.1%	4.7%	2.1%	21.0%	0.4%	2.7%	**40,174**	2.39%	1.73%	**2,319,204**
Sagebrush Shrubland - (SAGE)	7.1%	92.6%	0.8%	7.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**37,457**	2.23%	1.95%	**1,923,640**
PJ Sagebrush - (PJS)	1.5%	23.9%	0.0%	0.1%	13.0%	75.9%	0.0%	0.0%	0.0%	0.0%	**30,449**	1.81%	2.16%	**1,406,736**
Montane/Subalpine Grassland - (MSG)	1.5%	42.1%	1.0%	17.3%	0.3%	2.6%	1.6%	36.2%	0.1%	1.8%	**17,707**	1.05%	3.92%	**451,289**
Alpine Tundra - (ALP)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%	100.0%	0.0%	0.0%	**5,015**	0.30%	7.64%	**65,679**
Bristlecone Pine - (BP)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.7%	100.0%	0.0%	0.0%	**2,784**	0.17%	0.79%	**350,757**
Gambel Oak Shrubland - (GAMB)	0.3%	99.9%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**1,716**	0.10%	0.56%	**303,881**
Mixed-Grass Prarie - (MGP)	0.2%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**1,147**	0.07%	0.54%	**210,708**
Shortgrass Prarie - (SGP)	0.0%	5.2%	0.0%	0.3%	0.0%	32.4%	0.0%	0.0%	0.0%	62.7%	**91**	0.01%	0.01%	**1,572,889**
Spatial Scale Total Acres	**478,363**		**315,424**		**176,628**		**393,379**		**271,082**		**1,634,876**			**22,224,461**

Grassland and Shrubland Systems

Montane/Subalpine Grassland (MSG)

Forest Extent: 17,707 acres | Proportion of Santa Fe NF: 1 percent | Context Extent: 451,289 acres

ERU Description



Also referred to as montane grasslands, this system occurs at elevations ranging from 8,000 to 11,000 feet as small to large openings within Spruce-Fir, Mixed Conifer, and Ponderosa Pine Forests and often harbors several plant associations with varying dominant grasses and herbaceous species. Montane subalpine grasslands are a mix of grass communities including bunchgrasses, perennial and annual forbs, sod-grasses, and sedges. These meadows typically have higher herbaceous species richness than adjacent forest and are typically dominated by Arizona fescue, mountain muhly, screwleaf muhly, oatgrasses, blue gramma, and Thurber's fescue, depending on soil texture, soil moisture, elevation, site exposure (e.g., ridges), and disturbance (Brown 1994). Trees may occur along the periphery of the meadows, and some shrubs may also be present. These meadows are seasonally wet, which is closely tied to snowmelt. They typically do not experience flooding events.

The Montane Subalpine Grassland (MSG) ERU occurs on 17,707 acres (1.05 percent) of the Santa Fe NF making it the least represented upland ERU on the Forest that will be analyzed.

Reference Conditions

Humans have manipulated grassland vegetation for thousands of years through the use of fire, livestock grazing, and other means. With limited documentation on historic composition and structure, it can be difficult at times to separate our influence from that of nature in the formation and maintenance of grassland ecosystems, thus little is known about the original vegetation. MSG relict sites are rare and generally small, and the effects of livestock grazing were both widespread and intensive. It is estimated that there were around 3 million sheep in New Mexico by the mid-1800s with the majority of the Spanish population located from the Rio Grande eastward onto the plains around present-day Las Vegas, across the Sandia and Manzano Mountains, and westward from the Rio Grande Valley. Additionally, past conditions and disturbance are not recorded by grasses the way they are by long-lived trees.

We do, however, know that historic composition, structure, and function of montane subalpine grasslands were driven by the natural disturbance regime of fire, herbivory, and extreme weather. Historically, tree and shrub canopy cover were each less than 10 percent. Moist sites likely burned only infrequently during drought years when plants and litter dried. Mesic-dry sites likely burned more often and fire frequency was probably correlated with that of the surrounding forest vegetation and to the dryness of the stand (Vankat 2013; Romme et al. 2009). Therefore, fires were less frequent in stands within Spruce-Fir Forest and moist-mesic Mixed Conifer Forest, forests that burned less frequently, and more frequent in stands within dry Mixed Conifer Forest and Ponderosa Pine Forest (Dick-Peddie 1993; Romme et al. 2009). Fires are thought to have occurred as frequently as every 2 to 22 years (Dick–Peddie 1993; White 2002), limiting the establishment and encroachment of tree species.

Based on the patch size analysis developed specifically for this assessment and is the average of all patches of an ERU that intersect the plan area historical MSG patch sizes, ranged from 94 to 122 acres in size but have been estimated by Vankat (2013) in the range of small openings less than 2.5 acres to large expanses of more than 2,500 acres. With its patchy distribution, Subalpine-Montane Grassland is the least represented upland ERU (of those analyzed) and occupies only a small percentage (roughly 1 percent) of the plan landscape. It is only found in three of the five local zones in abundance necessary for analysis with the majority found in the North-East and North-West Zones.

Current Conditions

A handful of anthropogenic disturbances are responsible for shaping current MSG conditions including fire management, modern climate change, invasive species, recreation, and land use, but the most important is legacy grazing (e.g., elk, livestock, etc.). Historic ungulate grazing has increased invasive species, as invasives can be spread by attaching to animal coats and relocation after digestion. Additionally, grazing can reduce native plant cover and facilitate colonization by invasives, alter species composition, and reduce vegetation cover ultimately through herbivory and soil compaction increasing soil temperature and decreasing soil moisture. Although invasives can decline within a few years after grazing is reduced, recovery is incomplete (Dick-Peddie 1993). The ground cover percent analysis for MSG shows that there has been a substantial reduction (41 percent departure) in the amount of vegetation basal area and a significant increase in the amount of bare soil (understory structure and composition, above). These changes can primarily be assumed to primarily be the result of ungulate grazing intensified by long-term drought but are also the product of human disturbance including road construction, and concentrated recreation. The site potential analysis also supports the significant alteration in species composition with a moderate departure of 59 percent meaning more non-natives, such as Kentucky bluegrass, and invasive species are occupying the sites and less natural potential vegetation is represented. This departure is significantly greater relative to all other ERUs being analyzed.

The seral state departure analysis for MSG further captures this vegetative transition. Montane-subalpine grasslands are generally grouped into four vegetative states as identified above. State "D," tree and shrub invaded state is found on contemporary landscapes only and is thought to have historically existed only in rare and localized occurrences but is now the dominant state represented (60 percent at plan scale) on the landscape. Conditions at the context scale are in even worse shape as seral state departure is high at 71 percent. Tree and shrub encroachment has resulted in a reduction in the current average patch size of 53 acres, moderately reduced from reference. This trend has been documented off the forest also. Montane subalpine grassland is more fragmented with less connectivity and total acreage is less than it would have been historically (Fletcher and Robbie 2004).

The fire return interval at the plan scale is significantly shorter at the plan scale than it is at the context scale (261 years and over 850 years, respectively) for montane-subalpine grasslands. Despite the fire return interval for this ERU is not as departed as it is for many of the other vegetation types on the Forest, fires in MSG are much less frequent on the Santa Fe NF than what occurred historically.

Future/Trend

Based on the current disturbance regime, modeled conditions into the future indicate that limited fire occurrence in this ERU will continue leading to degraded conditions in MSG. Mid- and high-seral states that are already currently 50 percent departed from reference will transition to tree and shrub invaded states with continued encroachment. The lack of disturbance also limits the amount of MSG sites that are reinitiated back to an early, low-seral state, similar to what exists currently. The overall seral state proportion for MSG, like other frequent-fire systems continues to remain in a highly-departed condition based on 100-year VDDT modeling.

Fortunately the projected climate change vulnerability assessment (please see Climate Change chapter, pg. 285, for additional information) for the Santa Fe NF predicts that the majority (91 percent) of the MSG ERU is in the low vulnerability category. The remaining 8 percent is in moderate vulnerability category. More than any other ERU, MSG encompasses a wide elevational range, which may be helpful in reducing the effects of climate change, as a large climatic shift would have to occur to degrade conditions (e.g., moisture availability, etc.) for that wide envelope. However, some concern exists in the uncertainty of the models, as the majority of uncertainty for MSG (67 percent) is in the moderate category; meaning future climate projections have a moderate amount of disagreement.

Limited MSG in the Central and South-East Zones as a result of restricted water availability is an indication of what could occur with continued increases in temperature and less water availability as a result of climate change. Reduced grassland productivity, including MSG sites, and lower ground cover in favor of woody-species will likely continue to result.

MSG Overstory Structure and Composition, Seral State Proportion (percentage)

State	Description	Proportion (%)								
		Reference Condition[1]	Current Condition							Future Condition
			Local Scale[4]					Plan Scale	Context Scale	Plan Scale
			NWZ	SWZ	CZ	NEZ	SEZ			
A	Low-seral - recently burned; sparsely vegetated; grass cover < 10%	20	1	2		1		1	0	2
B, C	Mid-& high-seral - all grass and forb types; shrub & tree cover < 10%, grass cover >10%	80	48	24		37		39	46	20
D[2]	Tree and/or shrub invaded	0	51	74		62		60	54	78
	% Departure	0	51	74		62		60	71	78

Average Patch Size (acres - Plan Scale)	Reference: 94 - 122	Current: 53	% Departure[3]: 44

MSG Understory Structure and Composition

Vegetation Characteristic			*Similarity to Site Potential* (%)	*Ground Cover* (%)		*CWD* (tons/ac.)
				Bare Soil	Veg. BA	
Reference Condition			100	4.1	52.2	NA
Current Condition	Local Scale[4]	NWZ	42	15.7	32.0	NA
		SWZ	54	20.6	29.6	NA
		CZ				
		NEZ	35	8.9	29.0	NA
		SEZ				
	Plan Scale		41	13.7	30.5	NA
	Context Scale		NA	NA	NA	NA
	% Departure[3]		59	70	41	NA

MSG Disturbance Regime

Vegetation Characteristic			*FRI* (yrs.)	*Severity* (%)			*FRCC* (%)		
				Low	Mod.	High	I	II	III
Reference Condition			2 - 22	22	10	68	100	0	0
Current Condition	Local Scale[4]	NWZ	388	60	30	10			X
		SWZ	370	51	29	20			X
		CZ							
		NEZ	308	74	16	11			X
		SEZ							
	Plan Scale		261	70	20	10	0	0	100
	Context Scale		852	55	26	19	NA	NA	NA
	% Departure[3]		92	17			71		

[1] Based on LANDFIRE (2010).

[2] Contemporary landscapes only, historically rare/localized

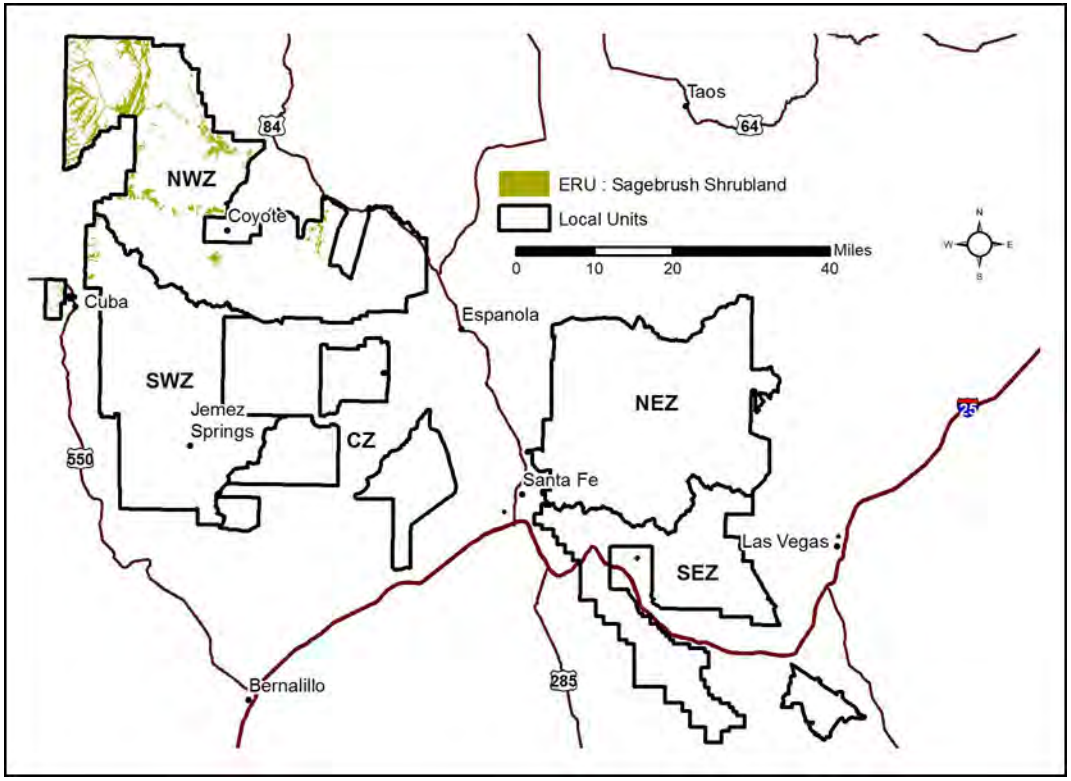
[3] Departure at the plan scale.

[4] Hatching indicates the ERU does not represent at least 5 percent of the local zone and is, therefore, considered not sufficiently represented to analyze.

Sagebrush Shrubland (SAGE)

Forest Extent: 37,457 acres | Proportion of Santa Fe NF: 2 percent | Context Extent: 1,923,640 acres

ERU Description



This ERU is dominated by big sagebrush and primarily occurs adjacent to Great Basin grassland and pinyon juniper (PJ) woodland ERUs. While big sagebrush is the dominant species, other shrubs and grasses and forbs are present. Historically, tree canopy cover exceeded 10 percent, with the exception of early, post-fire plant communities. Sagebrush shrubland sites are usually found on deep well-drained valley bottom soils between 4,800 and 5,800 feet with precipitation ranging between 10 to 18 inches per year.

Only occupying a little over two percent of the total plan scale, sagebrush shrubland is not widespread across the Forest and primarily only found in the North-West Zone where 92.6 percent of this vegetation type occurs on the Forest. The remainder is found in the northwestern most portion of the SWZ, representing less than one percent of the total local zone acreage.

Reference Conditions

Historical sagebrush shrublands were composed of native bunchgrasses combined with forbs to form an understory with discontinuous patches between shrubs. Historical fire regimes were dominated by stand-replacement mixed surface and crown fires at variable return intervals from 12 years on moister sites to 70 (Miller and Tausch 2001; Gottfried et al. 1995; Wright and Bailey 1982) to 200+ years on drier sites (Baker 2006, Welch and Criddle 2003, Whisenant 1990). Sagebrush shrubs and many of the other shrub types found in this ERU do not resprout and have limited seedling recruitment, and thus they gradually reestablish after fires, with full recovery of the shrub component taking from 15 to 60 years. Discontinuous fuel distribution often left unburned patches of sagebrush (Miller and Eddleman 2001), which were important parent seed sources for regeneration. Late successional stands were dominant in SAGE with 30 percent in a closed state and another (55 percent) in an open cover shrub state. Vegetative cover is relatively low in comparison to woodland and grassland types found on the Forest. Reference patch sizes ranged from 152 to 407 acres in size.

Current Condition

The loss and degradation of sagebrush ecosystems is significant and well-documented in western North America (Saab et al. 1995, Knick and Rotenberry 2002). Threats to sagebrush ecosystems are myriad and widespread, including urban and suburban development, agricultural conversions, livestock grazing and treatments to improve range conditions for livestock, invasion of non-native vegetation and altered fire regimes, and encroachment by successional vegetation types. The biggest alteration to contemporary landscapes is the significant encroachment of trees into the sagebrush shrubland type. Tree establishment is likely the result of a combination of causes. Historical overgrazing has limited fine fuel continuity and altered fire regimes to thousand year intervals and is also a major source of non-native plant incursions into sagebrush habitat (Saab et al. 1995). Drought and sagebrush disease are major concerns, especially where sagebrush habitats are under the pressure of heavy domestic grazing or wild ungulate use and where sagebrush recruitment has been inadequate (Wenger et al. 2003; Winward 2004) and sagebrush vegetative basal area has been reduced by 55 percent as a result. With the reduction in vegetative cover and compaction of soils from ungulates, bare soil has significantly increased, ultimately creating a positive feedback loop between erosion and limited vegetative cover leading to further degradation of the system.

Future/Trend

With limited ecosystem improvement management in the SAGE ERU, significant trees encroachment is predicted to continue into the sagebrush shrubland type. Succession modeling indicates that in 100-years over 80 percent of the MSG landscape will exist in a tree invaded state. This may be an overestimate of future proportions but still a good indication of the direction departure is moving, from moderate currently to a worsened highly departed condition. The lack of fire, along with disease related mortality of sage is captured in the significant decrease of sage shrub dominant states (45 percent currently to 15 percent, 100-year future condition) as well as the early successional grass-forb state.

SAGE is the least vulnerable ERU found on the Santa Fe NF with 96 percent in the low vulnerability to climate change category. With SAGE already limited on the Forest to one local zone and seral state conditions predicted to worsen, some encouragement exists knowing that conditions can be improved with proper management despite predicted future climate change. Water availability may be the biggest challenge as vegetative ground cover is already moderately departed, and has altered fire regimes as a result of limited fine fuel continuity.

SAGE Overstory Structure and Composition, Seral State Proportion (percentage)

State	Description	Proportion (%)								
		Reference Condition[1]	Current Condition							Future Condition
			Local Scale[3]					Plan Scale	Context Scale	Plan Scale
			NWZ	SWZ	CZ	NEZ	SEZ			
A	All grass and forb types; recently burned; sparsely vegetated	15	14					14	12	2
B	All closed cover shrub types	30	20					19	40	5
C, D	All open cover shrub types	55	27					26	21	10
E	Tree invaded; *contemporary landscapes only, historically rare/localized*	0	39					41	27	83
	% Departure	0	39					41	38	83
	Average Patch Size (acres - Plan Scale)	Reference: 152 - 407	Current: 152					% Departure[2]: 0		

SAGE Understory Structure and Composition

Vegetation Characteristic			*Similarity to Site Potential* (%)	*Ground Cover* (%)		*CWD* (tons/ac.)
				Bare Soil	Veg. BA	
Reference Condition			100	38.7	17.7	NA
Current Condition	Local Scale[3]	NWZ	60	69.6	8.1	NA
		SWZ				
		CZ				
		NEZ				
		SEZ				
	Plan Scale		60	68.4	8.0	NA
	Context Scale		NA	NA	NA	NA
	% Departure[2]		40	43	55	NA

SAGE Disturbance Regime

Vegetation Characteristic			*FRI* (yrs.)	*Severity* (%)			*FRCC* (%)		
				Low	Mod.	High	I	II	III
Reference Condition			12 - 70	0	24	76	100	0	0
Current Condition	Local Scale[3]	NWZ	>1,000	96	4	0			X
		SWZ							
		CZ							
		NEZ							
		SEZ							
	Plan Scale		>1,000	96	4	0	0	0	100
	Context Scale		>1,000	43	36	22	NA	NA	NA
	% Departure[2]		98	20			63		

[1] Based on LANDFIRE (2010).

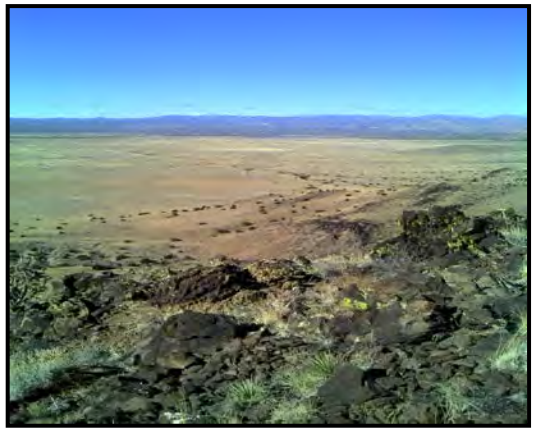
[2] Departure at the plan scale.

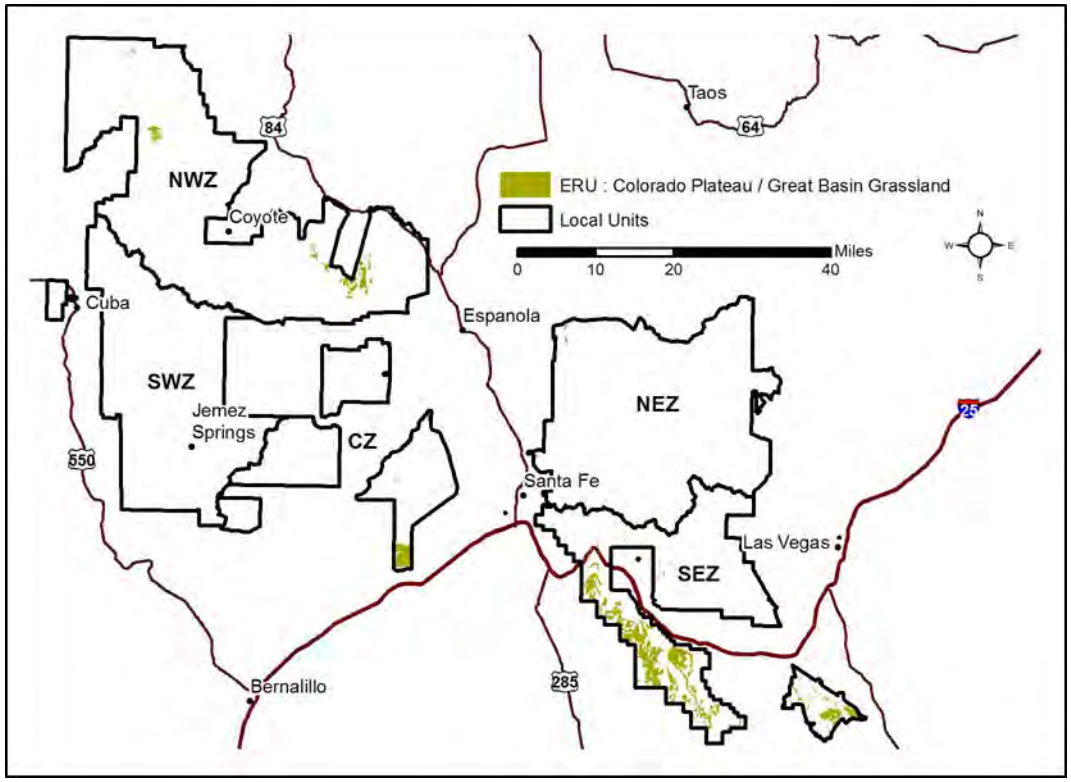
[3] Hatching indicates the ERU does not represent at least 5 percent of the local zone and is, therefore, considered not sufficiently represented to analyze.

Colorado Plateau/Great Basin Grassland (CPGB)

Forest Extent: 41,639 acres | Proportion of Santa Fe NF: 2.5 percent | Context Extent: 2,289,984 acres

ERU Description





In general, this ERU is found along elevational and temperature gradients above Semi-Desert Grasslands and below Montane-Subalpine Grasslands with vegetation coverage consisting of mostly grasses and interspersed shrubs. It occupies cooler and wetter sites than Semi-Desert Grasslands. This ERU is typically associated with Pinyon-Juniper Grass along the grassland-woodland ecotone in cool climates. Vegetation coverage consists of mostly grasses and interspersed shrubs. Grass species may include but are not limited to Indian ricegrass, threeawn, blue grama, fescue, needle and thread grass, spike fescue, muhly, James' galleta, and Sandberg bluegrass. Shrub species may include but are not limited to sagebrush, saltbush, Ephedra, snakeweed, winterfat, one-seeded juniper, Utah juniper and wax currant.

Primarily found in the South-East Zone, small proportions exist in both the NWZ and CZ. Although it only comprises 11 percent of the total local zone acres, this is the largest proportion of any grassland or shrubland type in any of the local zones.

Reference Conditions

This ERU may have had over 10 percent shrub cover historically, but less than 10 percent tree cover. Castetter (1956) believed blue grama was the climax dominant. Sideoats grama was an important component as was hairy grama. Mostly in lower spots topographically, western wheatgrass was “rather common” in association with blue grama. On sandy soils, little bluestem was a common associate often found with sand bluestem and Indian grass. In low saline areas, alkali sacaton stands were common. On the elevated plains, walking stick (cane) cholla and soapweed were uncommon due to grass competition. At the edge of sandier soils, wildfire would have restricted sand sagebrush. Fires could reduce pricklypear by either killing the plant in a hotter fire or by burning the spines, making the cactus more available to a wide range of herbivores.

Fire in the Colorado Plateau grasslands was of low intensity but adequate to keep woody shrubs from expanding. The historic average fire return interval was 10–30 years (Wright and Bailey 1982) primarily of low- and mixed-severity top-killing herbaceous species. The majority (70 percent) of CPGB seral state proportion was historically found in a high-seral, perennial grass state with <10 percent shrub cover. The remaining proportion could be found in low- to mid-seral states with the potential for shrub and tree encroachment.

Current Conditions

Grazing is the predominant use of Southwestern rangelands but improper historical grazing practices have lead to the loss of grasslands and degradation of the grasslands to the point that they are no longer suitable habitat for native species (Bock and Webb 1984, Noss and Cooperrider 1994). Uncontrolled heavy use of native arid grasslands during the 19th and early 20th century by ungulates has led to the loss of native grasses, the introduction of invasive exotic grasses and other weedy species, the destruction of cryptogamic crusts, altered grassland structure, and contribute to the conversion of grasslands to shrub-dominated desert scrub or pinyon-juniper (Bahre and Shelton 1993, Hobbs and Huenneke 1992). Most grassland systems are maintained by periodic fires that set back succession, but a history of fire suppression has allowed the widespread encroachment of shrubs and trees into such systems (Humphrey 1958, McPherson 1995) with current return intervals averaging over 1,000 years at the plan scale. The increased invasion of grasslands by exotic plants facilitated by grazing, road construction, and other forms of disturbance also contribute to altered fuel structure and fire regimes, leading to the eventual conversion of the native grassland to some other habitat type (Finch et al. 1999). Currently, 61 percent of the CPGB landscape is in a mid-seral state and 37 percent in a low-seral, reuderal invaded state. Additionally, development and rural sprawl are aiding in the degradation, and fragmentation of native grasslands. The construction of buildings, roads, fences, and other structures associated with these rural subdivisions result in a dramatic increase in habitat fragmentation (Knight et al. 1995) across many grassland types though current patch sizes are only slightly departed (21 percent) from historical averages at the plan scale. Vegetative basal area is moderately departed at the plan scale but is edging toward high departure in the NWZ and CZ.

Future/Trend

Model Not Yet Available

CPGB Overstory Structure and Composition Seral State Proportion (percentage)

State	Description	Proportion (%)							
		Reference Condition[1]	Current Condition						
			Local Scale[3]					Plan Scale	Context Scale
			NWZ	SWZ	CZ	NEZ	SEZ		
A	High seral: Perennial grasses, shrub/tree cover <10%, grass cover >30%	70	0		0		0	0	26
B	Mid-seral; perennial-mixed grasses, shrub/tree cover <10%, grass cover >10%. Includes post-fire plant communities previously high seral	5	63		51		63	61	2
C	Low-mid seral; perennial mixed grasses, shrub/tree cover ≥10%, grass cover ≥10%	25	10		0		0	2	32
D, E, F	Low-seral; ruderal/exotic grasses & forbs; shrub & tree invaded; *Contemporary landscapes only, historically rare/localized*	0	27		49		37	37	40
	% Departure	0	85		95		95	94	48
	Average Patch Size (acres - Plan Scale)	Reference: 295 - 513		Current: 233		% Departure[2]: 21			

CPGB Understory Structure and Composition

Vegetation Characteristic			*Similarity to Site Potential* (%)	*Ground Cover* (%)		*CWD* (tons/ac.)
				Bare Soil	Veg. BA	
Reference Condition			100	31.4	26.3	NA
Current Condition	Local Scale[3]	NWZ	59	47.5	12.9	NA
		SWZ				
		CZ	NA	73.4	11.3	NA
		NEZ				
		SEZ	60	44.4	17.2	NA
	Plan Scale		60	48.2	15.9	NA
	Context Scale		NA	NA	NA	NA
	% Departure[2]		40	35	40	NA

CPGB Disturbance Regime

Vegetation Characteristic			*FRI* (yrs.)	*Severity* (%)			*FRCC* (%)		
				Low	Mod.	High	I	II	III
Reference Condition			10 - 30	42	58	0	100	0	0
Current Condition	Local Scale[3]	NWZ	446	76	21	2			X
		SWZ							
		CZ	>1,000	NA	NA	NA			X
		NEZ							
		SEZ	NA	NA	NA	NA			X
	Plan Scale		>1,000	69	25	6	0	0	100
	Context Scale		>1,000	39	36	25	NA	NA	NA
	% Departure[3]		99	33			72		

[1] Based on LANDFIRE (2010) and ILAP (2012).

[2] Departure at the plan scale.

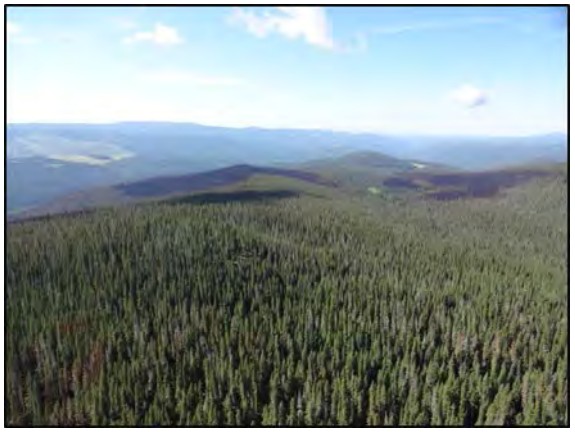
[3] Hatching indicates the ERU does not represent at least 5 percent of the local zone and is, therefore, considered not sufficiently represented to analyze.

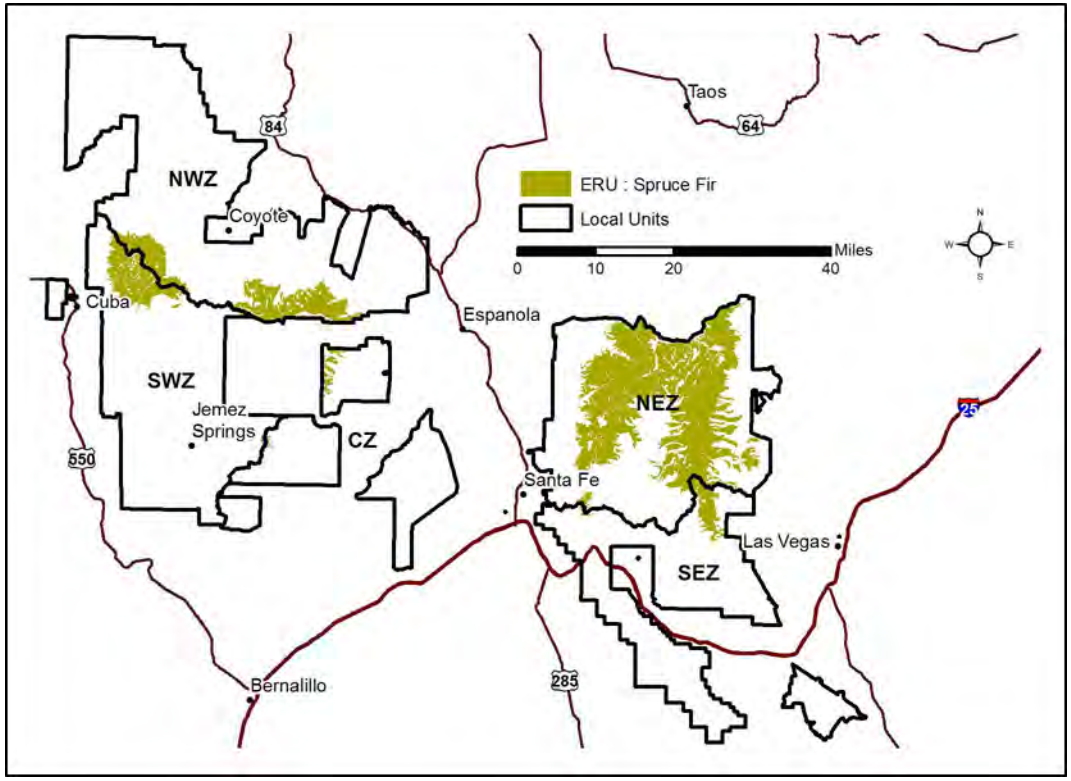
Forest and Woodland Systems

Spruce-Fir Forest (SFF)

Forest Extent: 250,481 acres | Proportion of Santa Fe NF: 14.9 percent | Context Extent: 1,491,541 acres

ERU Description





Also known as subalpine conifer forests, spruce-fir forests range in elevation from 9,000 to 11,500 feet, the highest elevation of any major forest in the southwestern United States, along a variety of gradients including gentle to very steep mountain slopes. This ERU is comprised almost entirely of Engelmann spruce and corkbark fir (subalpine fir) associations. Engelmann spruce and corkbark fir dominate the higher-elevation of this ERU, while in the lower-elevation mixed conifer species, especially Douglas-fir and quaking aspen, occur as a seral component that may be co-dominant or dominant. Montane-subalpine grasslands can also be found scattered throughout the spruce-fir forest type. Common understory species include Spruce-fir fleabane, huckleberry, and clover. Important drivers of vegetation dynamics are a diverse disturbance regime that is dominated by fire, wind, insects, climate variation, and anthropogenic disturbances that include livestock grazing, fire management, and nearby land use resulting in mosaics of stands with different structure and composition (Patten and Stromberg 1995). Spruce-Fir Forest is the 3rd most represented ERU on the Santa Fe NF and comprises 2 percent to 8 percent of each local zone except for the North-East Zone, where it accounts for 41 percent of the local zone. Despite being common on Forest, spruce-fir forest is uncommon in the Southwest (Vankat 2013) and Forest acreage accounts for roughly 17 percent of the vegetation type at the context scale.

Reference Conditions

Historical fire regime of southwestern Spruce-Fir Forest included large and small crown fires and surface fires, with their relative importance differing by elevation. Stands of Spruce-Fir closer to the upper-ecotone had infrequent, 200 to 400 years, stand-replacing fire in these higher elevations increasing in frequency with a fire return interval of 200 years from mixed-severity fire, at lower elevation sites. As a result, lower-elevation stands, particularly stands transitional with Mixed Conifer Forest, had a mixed-severity fire regime that included both surface and crown fires. Past crown fire in southwestern Spruce-Fir Forest has been inferred from the presence of small to large patches of quaking aspen of uniform age (Margolis et al. 2007, 2011; Romme et al. 2001). Margolis and others (2011) reconstructed patches of stand-replacing fire in Spruce-Fir Forest, the largest being 1,287 acres. Aspen stands sampled in Spruce-Fir Forest ranged from 74 to 2,034 acres. Crown fires forming these stands tended to have occurred synchronously and were coincident with severe droughts and regional occurrence of surface fires.

Fire, a disturbance agent in itself, also impacts other important disturbance agents such as wind and insect outbreaks in Spruce-Fir Forests. Wind impacts are variable across landscapes, depending on stand structure and composition, fire history, elevation, and topographic position. Blowdowns typically occur in winter, when branches are snow-covered and wind speeds are greatest. It has been reported that crown fire reduces the potential for wind damage by resulting in younger stands that are less susceptible (Kulakowski and Veblen 2002). Also, there is evidence that fire lessens the potential for spruce beetle outbreaks in the central Rocky Mountains as insects are the major biotic disturbance agent in southwestern Spruce-Fir Forest. Spruce beetle outbreaks are often started by large disturbances, particularly windthrow and fire events (from residual dead and down) and tend to be associated with larger diameter (>12 inches dbh) trees. As with bark beetle activity in other forest types, higher stand densities increase the risk of bark beetle activity in the spruce-fir forests.

The understory of southwestern Spruce-Fir Forest is highly variable, for north-central New Mexico and southwestern Colorado, depending on local site conditions (Romme et al. 2009). It can have greater variation in species composition than other forest types (Fisher and Fulé 2004). Typically a dense overstory and large loading of coarse woody debris limited understory vegetation to just above 7 percent cover.

Current Conditions

Anthropogenic impact in Spruce-Fir forest is limited and the key drivers of southwestern Spruce-Fir Forest appear to be livestock grazing, fire management, modern climate change, invasive species, recreation, and nearby land use. Livestock grazing has likely had a greater effect on lower-elevation Spruce-Fir Forest where the continuity of the herbaceous layer carried surface fires. As in other forest types, grazing resulted in an abrupt decrease in frequency of surface fires in these lower-elevation stands (Fulé et al. 2003). Upper-elevation Spruce-Fir Forest, which lacks the herbaceous layer and resulting surface fires, are likely impacted to a lesser degree.

Understory cover is negatively related to tree canopy cover (Fisher and Fulé 2004; Laughlin et al. 2005) and amount of coarse woody debris (Laughlin et al. 2005). Ground cover is especially high in young stands after canopy opening disturbance (Chambers and Holthausen 2000) and decreases with succession from aspen to conifer dominance. Insight into possible historical changes is provided by findings of the changes in these characteristics but is negligible as vegetative ground cover is minimally departed from reference conditions and coarse woody debris is on the threshold of low to moderate departure. There is, however, significant departure (68 percent) in similarity to site departure which may be the result of fire

exclusion leading to a decrease in the richness of annuals plant species, also hypothesized by Laughlin and others (2005).

Drought has been identified as a disturbance factor affecting Spruce-Fir Forest (Adams and Kolb 2005). Drought induces lagged tree mortality in Engelmann spruce and subalpine fir in northern Colorado, especially in trees with low growth rates (Bigler et al. 2007) which is common for Spruce Fir Forest on the Santa Fe NF as the majority (68 percent) falls into one of the medium tree seral state classes where historically the majority (44 percent) of Spruce Fir trees would have been large trees. Drought often interacts with other disturbance agents, such as wildfire, increasing the probability of landscape-scale crown fires and contributes to insect outbreaks. Drought is also a contributing factor in twenty-first century quaking aspen decline (Huang and Anderegg 2012; Ganey and Vojta 2010).

Many of the insect outbreaks on the Santa Fe NF were started either from windthrow events or from downed material created during timber or construction operations. The size of documented spruce beetle outbreaks has varied from small spot areas of 10 acres up to events affecting 75,000 acres. This largest, most notable event was from high winds during October of 1971 in the Jemez Mountains that downed spruce trees and triggered a spruce beetle outbreak from 1974 to 1977 that covered over 75,000 acres of the Cuba, Coyote, and Española Ranger Districts (Lessard 1976). With the limited available history of insect activity in the spruce-fir forests on the Santa Fe NF, there does not seem to be a change in bark beetle outbreak patterns relative to reference conditions. Bark beetle outbreaks will continue to be part of the infrequent, but often dramatic disturbance pattern of spruce-fir forests. Insect outbreaks and blowdown potentially could enhance fire hazard by producing a complex of dead fuels both vertically and horizontally.

Overall Spruce Fir Forest when considering all key ecosystem characteristics is in the best shape of all vegetation types found on the Santa Fe NF. The long fire return interval has only been moderately influenced by the cessation of fire (e.g., fire suppression) and the historical (Native American) and modern anthropogenic (limited administrative management) impacts.

Future/Trend

Limited change in seral state departure is expected in the Spruce-Fir Forest type, although a reasonable amount of state transitioning occurs. The biggest changes modeled include significant increases in the deciduous and aspen tree state (13 to 47 percent) and a transition of moderate sized trees into open stands of large trees. Most of the successional transitions in this ERU are natural or a result of natural disturbance such as insects and disease, fire, and wind as a result of limited active management. Recent large fires (e.g., Jaroso, Pacheco, etc.) on the Santa Fe NF, may be an indication of future disturbances in SFF. Recent drought and increased temperature along with fire and other types of disturbances that exacerbate insect outbreaks, are predicted to result in significant increases in the proportion of early successional aspen state.

Of the forested ERU types, SFF has the highest vulnerability to predicted climate change and only two other ERUs found on the Forest have a higher proportion of vulnerability in the high and very high categories. With a moderate amount of certainty (58 percent) and moderate vulnerability (44 percent), future active management in this ERU may be warranted with future projected climate change.

SFF Overstory Structure and Composition Seral State Proportion (percentage)

State	Description	Proportion (%)								
		Reference Condition[1]	Current Condition							Future Condition
			Local Scale[3]					Plan Scale	Context Scale	Plan Scale
			NWZ	SWZ	CZ	NEZ	SEZ			
A, K	Non-tree; recently burned; grass, forb, and shrub types	9	5	1		6		6	5	0
B	All aspen and deciduous tree mix types	13	14	23		11		13	14	47
C, G, P, L	Seedling/sapling and small trees, all cover classes	20	10	7		10		9	16	16
D, M, H, Q	Medium trees (10-19.9" d.b.h.), all cover classes	14	66	62		69		68	62	9
E, N, F,O	Large trees (≥20"), closed canopy	44	4	7		3		4	3	2
I, R, J, S	Large trees, open canopy; *contemporary landscapes only, historically rare/localized*	0	1	0		0		0	0	26
	% Departure	0	54	59		55		54	51	60
Snags (per acre)	>8"	25.0	15.1	15.6		10.2		11.8	6.8	
	>18"	9.0	6.7	7.0		4.6		5.2	3.2	
	% Departure	0	33	30		54		0	69	
Average Patch Size (acres - Plan Scale)		Reference: 200 – 1,000			Current: 1,017			% Departure[2]: 2		

SFF Understory Structure and Composition

Vegetation Characteristic			*Similarity to Site Potential* (%)	*Ground Cover* (%)		*CWD* (tons/ac.)
				Bare Soil	Veg. BA	
Reference Condition			100	1.8	7.1	46.9
Current Condition	Local Scale[3]	NWZ	60	1.4	7.6	88.0
		SWZ	65	3.5	10.7	91.2
		CZ				
		NEZ	70	2.6	5.6	61.0
		SEZ				
	Plan Scale		68	2.5	6.4	69.9
	Context Scale		NA	NA	NA	43.0
	% Departure[2]		32	29	9	33

SFF Disturbance Regime

Vegetation Characteristic			*FRI* (yrs.)	*Severity* (%)			*FRCC* (%)		
				Low	Mod.	High	I	II	III
Reference Condition			200 - 400	0	32	68	100	0	0
Current Condition	Local Scale[3]	NWZ	215	33	31	36		X	
		SWZ	>1,000	44	35	21			X
		CZ							
		NEZ	217	35	17	48		X	
		SEZ							
	Plan Scale		222	34	22	45	0	90	10
	Context Scale		748	35	24	41	NA	NA	NA
	% Departure[2]		0	33			52		

[1] Based on TNC (2006) in conjunction with Weibull age-class distribution model.

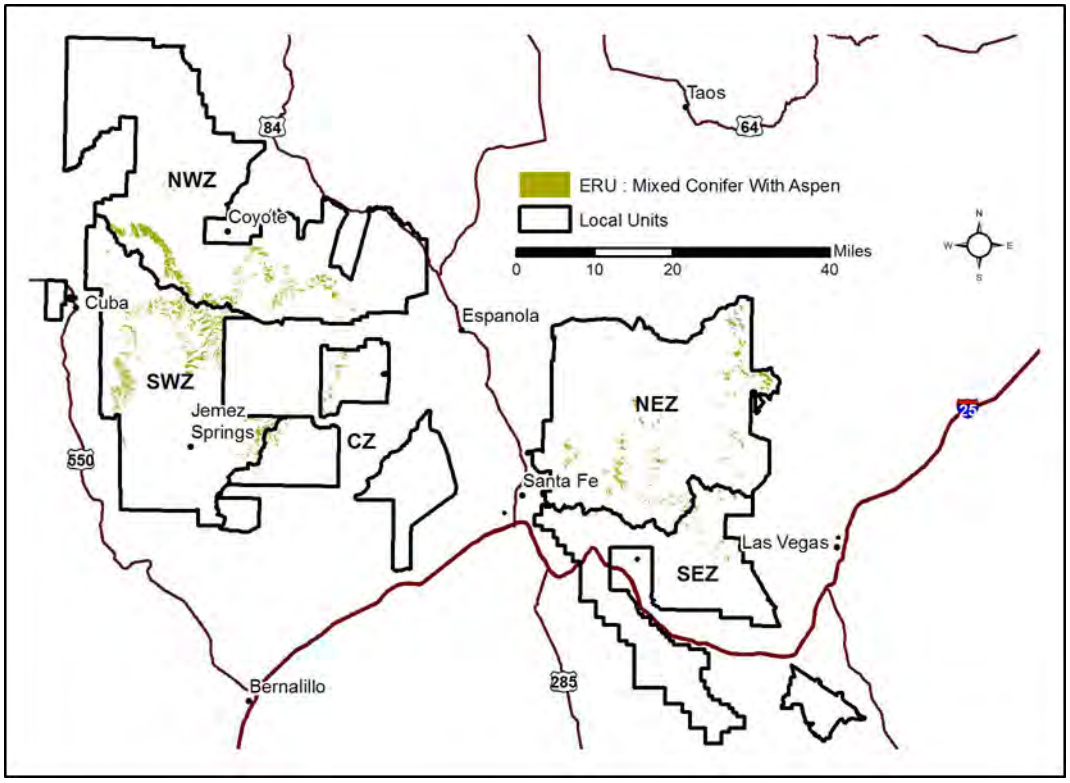
[2] Departure at the plan scale.

[3] Hatching indicates the ERU does not represent at least 5 percent of the local zone and is, therefore, considered not sufficiently represented to analyze.

Mixed Conifer with Aspen (MCW) - "Wet – Mixed Conifer"

Forest Extent: 40,174 acres | Proportion of Santa Fe NF: 2.4 percent | Context Extent: 2,319,204 acres

ERU Description



This ERU spans a variety of dominant and co-dominant species in mesic environments in the Rocky Mountain and Madrean Provinces. In the Rocky Mountains, mixed conifer forests may be found at elevations between 5,000 and 10,000 feet, situated between ponderosa pine forests below and spruce-fir forests above. Wet mixed conifer stands typically occur on north and east aspects, lower slopes, and forested valley bottoms and are more common at high elevations. Stands generally have dense structure and dominant and co-dominant vegetation varies in elevation and moisture availability, and by seral stage of the forest patches. Ponderosa pine occurs incidentally or is absent, while Douglas-fir, Southwestern white pine, white fir, and Colorado blue spruce occur as dominant and or co-dominant conifer species. Limber pine may be present in subdominant proportions. Understory vegetation is comprised of a wide variety of shrubs, graminoids, and forbs depending on soil type, aspect, elevation, disturbance history, and other factors.

The distinguishing feature of MCW from dry-mixed conifer (MCD) is a less frequent fire regime, characterized by mixed to high severity, as well as the presence of quaking aspen in a post disturbance seral state. MCW is not as extensive across the Santa Fe NF as MCD and only accounts for 2.4 percent (40,174 acres) of the landscape. It accounts for the least number of acres of all the forested types found on the Forest.

Reference Conditions

Historically, the fire regime for MCW was characterized as mixed-severity, with frequent, widespread, relatively low severity surface fires and infrequent, patchy, high-severity crown fires (Allen 1989; Allen et al. 1995; Touchan et al. 1996). Although the crown fire component of the historical mixed-severity fire regime is not as well understood as the surface-fire component (Margolis et al. 2011), there is clear evidence of infrequent, patchy crown fires. The evidence includes fire-originated stands of even-aged aspen, even-aged conifers, and Subalpine-Montane Grassland meadows. Crown fire occurrence was affected by fuel conditions, including steep slopes with vertical continuity of tree crowns (Jenkins et al. 2011). Crown fire patches were highly variable in size. Some fire-originated stands of aspen and grasslands in the Jemez Mountains are very large, extending across relatively homogeneous slopes (Allen 1984, 1989; Touchan et al. 1996). A study of aspen stands originated by historical crown fires in Mixed Conifer Forest of north-central New Mexico and south-central Colorado included patches ranging from 163 to 2,899 acres (Margolis et al. 2007), although typically they ranged from 100 to 400 acres in size.

Crown fires appear to have occurred during severe droughts that followed multi-decadal wet periods during which fuels accumulated (Margolis et al. 2007; Iniguez et al. 2009). Fire occurred at intervals of 50 to 500 years (Romme et al. 2009; O'Connor et al. 2014), as both stand replacing and mixed severity events. Fire intensities were related to variables such as stand structure and composition, fuels, elevation, topography, weather-climate, and fire history. Longer individual and mean fire-free periods were the result of more mesic conditions in MCW, where fuel moisture is usually higher as a result of greater precipitation, cooler temperatures and greater snowpack (Grissino-Mayer et al. 2004). When MCW fuels were dry, historical surface fires were generally more widespread relative to dry Mixed Conifer and Ponderosa Pine Forests (Fulé et al. 2003; Grissino-Mayer et al. 2004), presumably because of greater fuel loadings and fuel continuity. Fire years in Mixed Conifer were significantly drier than in Ponderosa Pine Forest in a watershed study in the Sangre de Cristo Mountains (Margolis and Balmat 2009).

Stand-replacing fire played an important role in aspen regeneration (Wahlberg et al. 2014), as aspen occurred as an early seral state following disturbance and resulted in approximately 100 to 400 acres patches (Table 5; Margolis and Balmat 2009) which comprised about 21 percent of the historical landscape. Stand structure, similar to Spruce Fir Forest was comprised mainly of large diameter trees with interlocking crowns (closed canopy). The reference condition for coarse woody debris is significantly lower than in SFF, but still high at 28.7 tons per acre. Standing snags were common (14 per acre ≥8 inches and 4 per acre ≥18 inches). Reference vegetative ground cover was high at 94 percent (vegetation BA and Litter).

Western spruce budworm likely had as large an impact on forest structure as fire (Romme 2009; Floyd et al. 2009) especially since spruce budworm favors Douglas-fir and white fir, which are common in mixed conifer stands (USDA FS 2014). Repeated defoliation over successive years can reduce the growth and vigor of trees and potentially predispose them to other agents (USDA FS 2014). Forests most susceptible to outbreaks are old, dense, closed-canopied, and multi-layered, have Douglas-fir and white fir as canopy dominants, have shade-tolerant species in the understory, and are stressed by drought, high density, dwarf mistletoe, root disease, or marginal site conditions (Moir 1993; Lynch and Swetnam 1992).

Current Conditions

The fire regime for MCW is one of only two ERUs that has not been significantly altered, the other being Spruce Fir Forest. Heavy grazing during the 19th century likely had less of an impact in MCW than in lower elevation ERUs (Romme 2009; Floyd et al. 2009) since fire coincides with drought and extreme fire weather more so than fine fuel accumulation (Margolis et al. 2007). Landscape wildfires such as the Los Conchas (156,593 ac.), Cerro Grande (47,650 ac.), and Viveash (28,348 ac.), among others, have burned a fair proportion of MCW acres and maintained the current fire return interval similar to what existed historically. Likewise at the context scale, fire occurrence has only slightly been altered by human impacts. Although crown fire is not unusual for this vegetation type, when a wildfire does occur, the origination of wildfire in this vegetation type is uncommon. On the Santa Fe NF there has been an increase in the number of uncharacteristic crown fires originating in frequent fire vegetation types found at the lower elevations, building momentum and running up into the Mixed Conifer with Aspen and Spruce Fire Forest types. Although not significant, there has been a 17 percent increase in the proportion of high severity acres in MCW on the Santa Fe NF. This has led to a slight overrepresentation in the extent of aspen occurrence as stands typically establish following a crown fire (Jones and DeByle 1985; Margolis et al. 2007). These stands likely persisted as a seral state more so in the past than they do today (Romme 2009; Floyd et al. 2009) and historically supported a more dense grass understory, which carried mixed severity fires at shorter intervals, repressing conifer establishment and stimulating aspen sprouting (DeByle and Winokur 1985). The reduction in understory vegetation may potentially lead to increased ungulates and domestic livestock browsing on aspen seedlings. At the context scale aspen mortality has been widespread, thought to be related to drought, slight reduction in fire frequency, and chronic defoliation by western tent caterpillar and large aspen tortrix over the last decade.

Future/Trend

MCW modeling predicts an overrepresentation in medium sized tree closed canopy state (33 percent). An improvement is predicted in the large tree closed canopy state with a 25 percent increase in representation as a portion of the medium sized trees on the Forest that currently represent 60 percent of the MCW type, mature. Overall seral state departure at the plan scale is expected to improve from 50 percent to 36 percent and will be comparable to the current departure of MCW found at the context scale (37 percent).

The vulnerability of Mixed Conifer with Aspen to climate change at the plan scale is primarily moderate, with (97 percent) in this category. Uncertainty however, is high with 52 percent and 48 percent, in the moderate and high categories, respectively. MCW serves somewhat as the ecotone between frequent fire systems and moist forests creating uncertainty in projected climate change as this vegetation band on the Forest is somewhat narrow depending on site conditions and can vary significantly in elevation. Despite the uncertainty that exists amongst the models, with moderate vulnerability, MCW will likely become more susceptible to higher severity fires (already observed), increases in insect activity and increases in root disease following long-term drought cycles.

MCW Overstory Structure and Composition Seral State Proportion (percentage)

State	Description	Proportion (%)								
		Reference Condition[1]	Current Condition							Future Condition
			Local Scale[3]					Plan Scale	Context Scale	Plan Scale
			NWZ	SWZ	CZ	NEZ	SEZ			
A, K	Non-tree; recently burned; grass, forb, and shrub types	7	7	4		1		6	4	1
B, T	All aspen, deciduous tree mix, and evergreen-deciduous mix tree types	21	30	27		15		25	21	6
C, G, P, L	Seedling/sapling and small trees, all cover classes	18	5	7		27		11	17	24
D,M,H,Q	Medium trees (10-19.9" d.b.h.), all cover classes	14	58	62		53		58	56	41
E, N, F,O	Large trees (≥20"), closed canopy	40	0	0		4		0	2	25
I, R, J, S	Large trees, open canopy; *contemporary landscapes only, historically rare/localized*	0	0	0		0		0	0	4
	% Departure	0	53	53		47		50	37	36
Snags (per acre)	>8"	14.0	22.1	22.2		21.6		22.1	22.2	
	>18"	4.0	4.9	5.0		5.9		5.2	5.5	
	% Departure	0	0	0		0		0	0	
Average Patch Size (acres - Plan Scale)		Reference: 100 - 400			Current: 57			% Departure[2]: 43		

MCW Understory Structure and Composition

Vegetation Characteristic			*Similarity to Site Potential* (%)	*Ground Cover* (%)		*CWD* (tons/ac.)
				Bare Soil	Veg. BA	
Reference Condition			100	2.3	8.6	28.7
Current Condition	Local Scale[3]	NWZ	68	5.1	8.9	79.3
		SWZ	64	5.0	7.5	80.7
		CZ				
		NEZ	71	5.0	9.0	80.0
		SEZ				
	Plan Scale		67	5.1	8.3	79.1
	Context Scale		NA	NA	NA	82.1
	% Departure[3]		33	55	4	64

MCW Disturbance Regime

Vegetation Characteristic			*FRI* (yrs.)	*Severity* (%)			*FRCC* (%)		
				Low	Mod.	High	I	II	III
Reference Condition			50 - 500	30	36	34	100	0	0
Current Condition	Local Scale[3]	NWZ	283	31	30	39		X	
		SWZ	778	7	18	74		X	
		CZ							
		NEZ	24	28	24	49		X	
		SEZ							
	Plan Scale		238	22	27	51	0	100	0
	Context Scale		497	34	29	37	NA	NA	NA
	% Departure[3]		13	17			51		

[1] Based on TNC (2006) in conjunction with Weibull age-class distribution model.

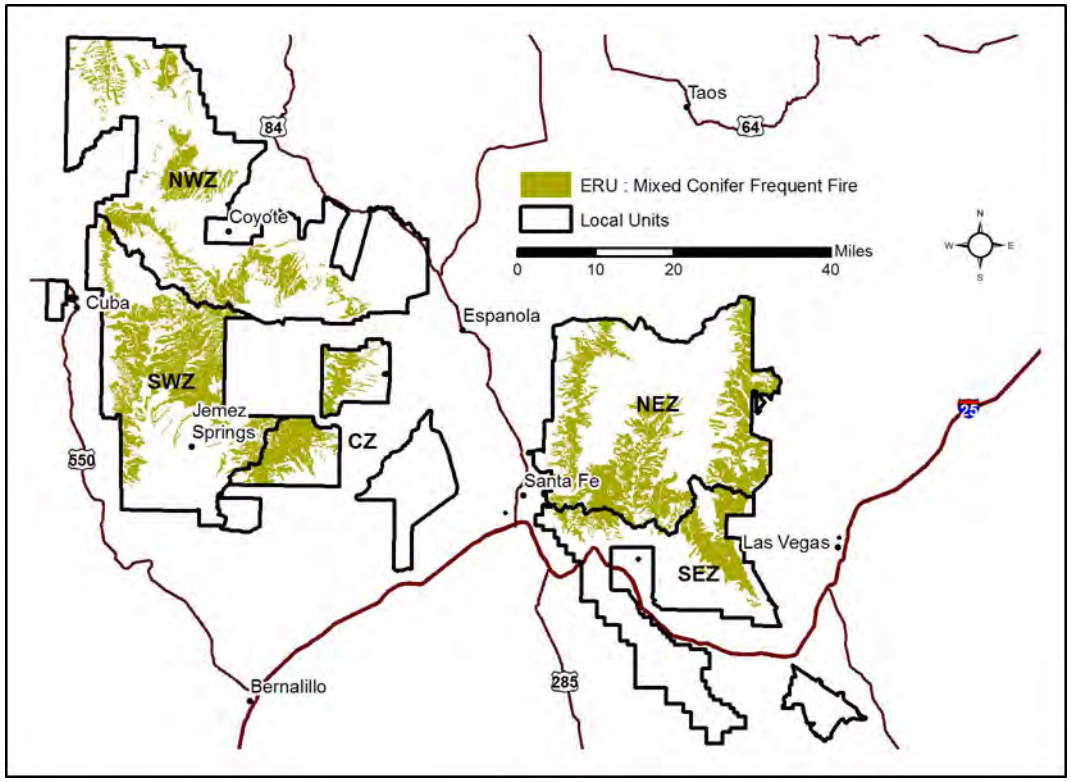
[2] Departure at the plan scale.

[3] Hatching indicates the ERU does not represent at least 5 percent of the local zone and is, therefore, considered not sufficiently represented to analyze.

Mixed Conifer – Frequent Fire (MCD) - "Dry – Mixed Conifer"

Forest Extent: 429,967 acres | Proportion of Santa Fe NF: 25.6 percent | Context Extent: 2,263,903 acres

ERU Description



This ERU spans a variety of semi-mesic environments in the Rocky Mountain and Madrean Provinces. In the southern Rocky Mountains, mixed conifer forests may be found at elevations between 5,000 and 10,000 feet, situated between ponderosa pine, pinyon-oak, or pinyon-juniper woodlands below and spruce-fir forests above. This ERU typically occupies the warmer and drier sites of the mixed conifer life zone including south and west aspects, ridgetops, and mid-slopes and are more common at low elevations. Typically these types were historically dominated by ponderosa pine in an open forest structure (<30 percent tree cover), with minor occurrence of aspen, Douglas-fir, and Southwestern white pine. Aspen in this ERU occurs within dissimilar inclusions and not as a seral stage forest type as with the Mixed Conifer with Aspen ERU. More shade-tolerant conifers, such as Douglas fir, white fir, and blue spruce tend to increase in cover in late succession, and would not typically achieve dominance under the characteristic fire regime. These species could achieve dominance in localized settings where aspect, soils, and other factors limited the spread of surface fire.

Frequent Fire Mixed Conifer or dry mixed conifer is the most extensive and prevalent ecological vegetation type found on the Forest accounting for 429,967 acres or 25.6 percent of the lands administrated by the Santa Fe NF. MCD is one of the top three represented ERUs in all local zones in terms of acreage. It is also one of the two vegetation types that drove the vast context scale delineation, the other being Ponderosa Pine Forest, both of which are historically frequent fire systems.

Reference Conditions

Fires generally burned as surface fires across these landscapes, especially at lower elevations and in relatively dry, open areas such as ridgetops and south and west aspects. In dry years, fires occasionally crowned in areas of concentrated fuels and those with vertically continuous fuels, such as at higher elevations and in mesic, dense sites on north and east aspects. The limiting factor for surface fire was generally moisture, not fuel (Allen et al. 1995; Swetnam and Baisan 1996; Touchan et al. 1996; Fulé et al. 2009; Margolis and Balmat 2009) and is typically the distinction between dry (MCD) and wet (MCW) mixed conifer. Historical crown fires in Frequent Fire Mixed Conifer Forests, were rare (e.g., Romme et al. 2009b) and can usually be identified by post-fire cohorts of early-successional trees, such as even-aged stands of quaking aspen, usually no larger than 158 acres in size (Fulé et al 2009). Typical MCD stands were open with the majority of trees (60 percent) in the medium diameter size class (10 to 19.9 inches) and only five percent of this vegetation type in a late seral, closed canopy with large diameter trees (>20 inches) state. MCD patches ranged from 0.2 to 50 acres (Moore et al. 2004). As in MCW, vegetative ground cover approached 100 percent (USDA FS 1987b), but more frequent fire left less coarse woody debris and fewer small snags (Weisz et al. 2011).

The more common historical mean fire intervals of high frequency surface fires are similar to that of Ponderosa Pine Forest and likely resulted from the spread of fires from low to higher elevation and the of proximity of the two forest types (Allen et al. 1995). Frequent surface fires every 5 to 21 years from low-severity surface fire and infrequent mixed-severity fire (Baisan and Swetnam 1990; Touchan et al. 1995; Heinlein et al. 2005) that kept forest structure open, thinning cohorts of tree seedlings and saplings but increasing growth of survivors, with fuel loads relatively constant spatially and temporally (Touchan et al. 1996; Morgan et al. 2001; Margolis and Balmat 2009) and encouraging understory herb cover. The frequent return of fire in these systems would limit the accumulation of coarse woody debris to levels around 15 tons per acre. Different lengths of fire-free intervals affected tree regeneration. Low severity, frequent fires favor ponderosa pine and Douglas-fir species, as they develop fire resistant bark at a relatively young age and have other adaptations (e.g., self-pruning) to this type of fire regime.

Current Conditions

It is widely accepted that fire exclusion and past management activities including selective logging ("high-grade"), fragmentation (e.g., construction of roads) and intensive grazing in frequent fire mixed conifer forests have contributed to higher stand densities and altered species composition from mature, large ponderosa pine and Douglas-fir trees shifting toward more shade-tolerant, less fire-resistant species (Moore et al. 2004; Romme et al. 2009) such as white fir and Douglas-fir (Reynolds et al. 2013). White fir is particularly vulnerable to fire, thus the interruption of natural fire cycles has favored it as a component of mixed conifer stands. Disturbance was more frequent prior to fire exclusion with fire return intervals outside of the Central Zone greatly departed from reference conditions resulting in increased stand densities and species homogeneity (Reynolds et al. 2013). Over 70 percent of the MCD landscape on the Santa Fe NF is currently in the large tree, closed canopy state in which only 5 percent occurred historically; likely due in some part to fire suppression, mainly in this ecological type and adjacent, dry forest and woodland types that were a major historic ignition source (Romme et al. 2009; Floyd et al. 2009).

The occurrence of aspen has also become less common in MCD across the forest (reduced by 50 percent) and has significantly decreased in three of the five local zones (NWZ, SWZ, and CZ). However, it is likely only a matter of time that the extended fire exclusion resulting in a 50 percent increase in the accumulation of smaller, more densely packed trees and the four- to five-fold in coarse woody material will lead to increased amounts of large uncharacteristic wildfire and resulting early successional grass/forb/shrub and aspen states, as those resulting from the 2011 Las Conchas Fire. This is exhibited in

the shift in resulting burn severities of fires on the Forest over the past two decades. Nearly 40 percent of the MCD landscape now results in high severity and another 30 percent at moderate or mixed-severity where historically these two severity categories only accounted for roughly 25 percent of all acres burned in this type.

Both fire exclusion, resulting in current large homogenous stands, and past management activities, such as large early successional patches as a result of uncharacteristic high severity fire, have led to drastic increases in patch size averaging nearly 250 acres at the plan scale. Large increases in the number of smaller diameter (<8 inches dbh) snags is also likely a result of these conditions as the number of snags, amount of coarse woody debris, amount of ground cover and fire severity are all very interrelated. These changes have probably increased the potential for bark beetle activity above what would have been expected in pre-settlement conditions and contribute to greater tree mortality when outbreaks do develop. However, the limited length of records for bark beetle activity in the mixed conifer forests of the Santa Fe NF exhibits no major changes in outbreak frequency or duration. Current stand structure also encourages the expansion of dwarf mistletoe, resulting in direct mortality and slower growth of trees that do survive, along with other changes that together make forests more susceptible to damaging fire (Evans et al. 2011).

Future/Trend

Despite a categorical improvement from high to moderate departure, only a slight improvement occurs in MCD, with departure reducing from 74 percent currently to 64 percent after 100-years based on VDDT modeling. MCD is the second highest ERU actively treated (e.g., fuels treatment, prescribed fire, logging, etc.) to restore resiliency and properly functioning ecological processes over the past 15-years which is the driver behind the slight improvement. This however, may be an indication that the scale of current treatment may not be sufficient with roughly only two-percent of this ERU being treated annually (15-yr. average of 8,000 acres, FACTS). This is especially of concern for a system that frequently burned at an interval of 5 to 21 years, and recent destructive effects of uncharacteristic wildfire that serve as an example of the potential results if seral state structure is not improved.

The biggest improvement in structure is reflected in the large tree, closed canopy state where the proportion is expected to be reduced by half from 72 percent to 36 percent, but still overrepresented relative to reference conditions (5 percent). A portion of these acres move into an early-successional grass-forb state and making the modeled proportion of representative of what occurred historically (20 percent). This transition however, doesn't capture the potential severity effects. The Central Zone currently shows an overestimation of early grass-forb acres, but many of those acres resulted in high-severity effects and shrub dominated landscapes with limited seed- and shelter-trees to help in the regeneration of future conifers.

Of the forested ERUs, MCD has the lowest projected climate change vulnerability with 38 percent in low and 59 percent in the moderate vulnerability category. Outside of MSG (91 percent in low) this is the largest proportion found in the low category of all ERUs modeled for the Santa Fe NF. Vulnerability is especially low in the two western zones with 55 percent of the North-West Zone and 50 percent of the South-West Zone in low vulnerability. Low to moderate vulnerability projections are encouraging granted current fire severity is already departed and additional drought will likely only exacerbate current fire and insect effects.

MCD Overstory Structure and Composition Seral State Proportion (percentage)

State	Description	Proportion (%)								
		Reference Condition[1]	Current Condition							Future Condition
			Local Scale[4]					Plan Scale	Context Scale	Plan Scale
			NWZ	SWZ	CZ	NEZ	SEZ			
A, N, B, F	Non-tree; recently burned; grass, forb, and shrub types	20	9	9	33	6	2	10	8	24
C	All aspen, deciduous tree mix, and evergreen-deciduous mix tree types	10	3	3	2	8	8	5	4	1
G	Seedling/sapling and small trees, all cover classes	5	10	7	3	15	17	11	13	9
J, K	Medium trees (10-19.9" d.b.h.), all cover classes	60	3	1	2	0	0	1	2	17
H, L, I, M	Large trees (≥20"), closed canopy	5	74	78	54	71	73	72	71	36
D, E[2]	Large trees, open canopy; *contemporary landscapes only*	0	2	1	6	0	0	1	2	12
	% Departure	0	76	77	68	77	80	74	78	46
Snags (per acre)	>8"	9.0	24.0	25.0	24.0	24.0	24.0	24.0	24.0	
	>18"	4.0	3.5	3.4	4.1	3.4	3.3	3.5	3.5	
	% Departure	0	6	8	0	8	9	6	6	
Average Patch Size (acres - Plan Scale)		Reference: 0.02 - 50			Current: 247			% Departure[3]: 80		

MCD Understory Structure and Composition

Vegetation Characteristic			*Similarity to Site Potential* (%)	*Ground Cover* (%)		*CWD* (tons/ac.)
				Bare Soil	Veg. BA	
Reference Condition			100	5.1	7.2	15.2
Current Condition	Local Scale[4]	NWZ	61	7.3	7.3	69.7
		SWZ	62	7.2	7.8	70.6
		CZ	64	10.6	6.2	55.5
		NEZ	73	6.6	6.1	71.3
		SEZ	70	5.7	6.7	72.7
	Plan Scale		67	7.2	6.8	69.3
	Context Scale		NA	NA	NA	69.8
	% Departure[3]		33	29	5	78

MCD Disturbance Regime

Vegetation Characteristic			*FRI* (yrs.)	*Severity* (%)			*FRCC* (%)		
				Low	Mod.	High	I	II	III
Reference Condition			5 - 21	75	18	7	100	0	0
Current Condition	Local Scale[4]	NWZ	322	39	31	30			X
		SWZ	565	26	23	50			X
		CZ	31	26	30	44			X
		NEZ	154	39	29	32			X
		SEZ	>1,000	78	22	0			X
	Plan Scale		152	31	29	39	0	0	100
	Context Scale		207	28	30	42	NA	NA	NA
	% Departure[3]		86	44			83		

[1] Based on LANDFIRE (2010).

[2] Contemporary landscapes only, historically rare/localized.

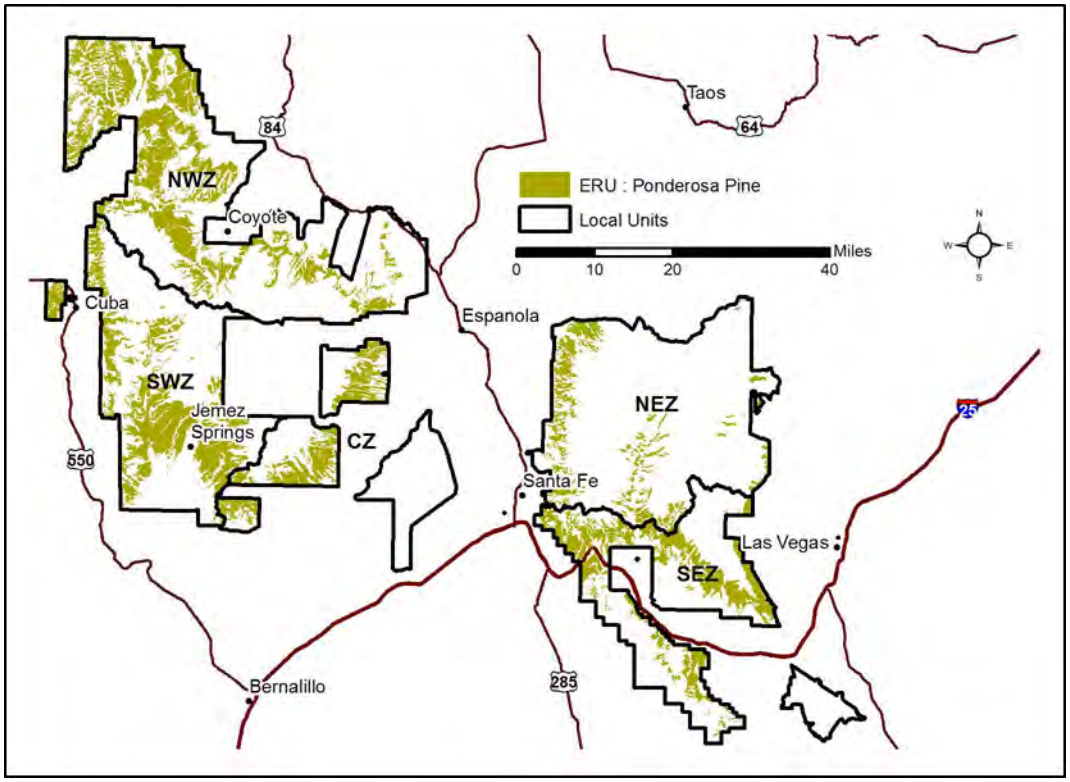
[3] Departure at the plan scale.

[4] Hatching indicates the ERU does not represent at least 5 percent of the local zone and is, therefore, considered not sufficiently represented to analyze.

Ponderosa Pine Forest (PPF)

Forest Extent: 403,915 acres | Proportion of Santa Fe NF: 24 percent | Context Extent: 3,514,152 acres

ERU Description



The ponderosa pine forest ecosystem is widespread in the Southwest occurring at elevations ranging from 6,000-7,500 feet on igneous, metamorphic, and sedimentary parent soils with good aeration and drainage, and across elevation and moisture gradients. This ERU comprises the "ponderosa pine bunchgrass" (PPG) and "ponderosa pine/Evergreen oak" (PPE) subclasses. The dominant species in this system is ponderosa pine. Other trees, such as Gambel oak, pinyon pine, one-seed juniper, and Rocky Mountain juniper may be present. There is typically a shrubby understory mixed with grasses and forbs, although this type sometimes occurs as savannah with extensive grasslands interspersed between widely spaced clumps or individual trees. This system is adapted to drought during the growing season and has evolved several mechanisms to tolerate frequent, low-intensity surface fires. A historical fire regime of frequent, low-severity surface fires is widely documented, but there is growing evidence of limited scale areas of historical mixed-severity and high severity fires, especially for steep slopes in areas of heterogeneous topography (Williams and Baker 2012; Swetnam et al. 2001; Iniguez et al. 2009).

Ponderosa pine forest is the second most prevalent vegetation type found on the Santa Fe NF, which along with the other forested frequent fire type, dry mixed conifer, account for roughly 50 percent of the Forest. It is dispersed fairly evenly across the Forest spatially, where it accounts for 25 percent to 30 percent of the vegetation found in each local zone with the exception of the North-East Zone.

Reference Conditions

Historical structure of southwestern ponderosa pine forest is characterized by multi-storied, open canopy stands of medium to large trees with a well-developed, often grass dominated understory (Covington and Sackett 1986). Overstory cover ranged from roughly 17 to 22 percent (White 1985; Covington and Sackett 1986; Covington et al. 1997). Climate had and still has a significant influence both directly and indirectly in shaping ponderosa pine landscapes. Site moisture availability directly effects tree recruitment. Indirectly, climate drives succession through influences on disturbances such as fire and insects. Successional patterns are also influenced by site elevation, proximity to seed sources, and pre-fire stand composition (Savage and Mast 2005), especially where sprouting species were present. Findings show broad pulses of recruitment separated by periods of less regeneration (Mast & Veblen 1999) where persistence of open grassy patches contrasts with canopy gap dynamics in which gaps would continuously form and close in different locations over decadal time spans.

Moreover, the open structure of historical stands of multi-storied medium to large trees resulted in a generally warm, dry microenvironment on the forest floor that kept fuel moisture very low, facilitating the ignition and spread of surface fires (Harrington & Sackett 1992). The historic average fire return interval was 4–30 years from low-severity fire (Swetnam and Dietrich 1985; O'Connor et al. 2014; Baisan and Swetnam 1990). Ponderosa pine is well-adapted to fire with deep roots, fire resistant bark, self-pruned lower branches, branches and cones distant from the ground, open arrangement of branches and needles unfavorable to spread of fire, needles with high moisture content, thick bud scales, and longevity of seed production (Covington 2003). These enable trees to survive and regenerate in the presence of frequent surface fires. Frequent fires reflect the typical dry climate of the Southwest in that the annual inputs of organic matter (CWD, litter, and duff) accumulate because of slow decomposition rates, and these fuels are often sufficiently dry to carry fire. Historical CWD loadings averaged 9.0 tons per acre.

Years with abundant surface fire are correlated with drought, especially when preceded by 1 to 3 years of high precipitation during which herbaceous fine fuels increased (Swetnam and Baisan 1996; Touchan et al. 1996; Allen 2007; Allen et al. 2008; Margolis and Balmat 2009) and represented roughly13 percent of ground cover. However, regeneration pulses also can be associated with fire and drought, which can be associated with overstory mortality and release of resources. Tree groups can vary greatly in size, but in the Southwest are generally 0.02 to 1.07 acres, with some as large as 2 acres (White 1985; Kaufmann et al. 2007).

Bark beetles are important disturbance agents in Ponderosa Pine Forest. Bark beetles affect stand structure and possibly were important historically in maintaining low tree densities, especially following surface fire and drought (Allen 1989). Bark beetles also have affected vegetation distribution, as they caused mortality of ponderosa pine in the Jemez Mountains that moved the ecotone between Ponderosa Pine Forest and Pinyon-Juniper vegetation upslope (Allen and Breshears 1998). Bark beetles typically attack scattered, small clusters of trees, but larger outbreaks also occur. Extensive outbreaks have been reported on the Santa Fe NF. Another biotic disturbance agent is ponderosa pine dwarf mistletoe, a parasite plant that infects approximately one-third of the area of Ponderosa Pine Forest in Arizona and New Mexico (Andrews and Daniels 1960).

Current Conditions

Fire management throughout most of the twentieth century focused on preventing and suppressing fires. This continued the exclusion of surface fires that was initiated by livestock grazing. Just as southwestern Ponderosa Pine Forest was profoundly shaped by fire (Romme et al. 2009), it has also profoundly been altered by the exclusion of fire, currently averaging over 200 years between cycles. Without frequent fires, southwestern Ponderosa Pine Forest increased in tree density, fuel loadings, and horizontal and vertical fuel continuities across landscapes, which has led to increased frequency and size of crown fires (Fulé et al. 2004; Romme et al. 2009). Currently, 45 percent of PPF landscapes that burn are resulting in high or moderate severity relative to only 5 percent historically. Shifts in climate could be related to this change in fire behavior, but increased fuel (e.g.,

stand density and CWD) and canopy cover (e.g., less patchiness, increased horizontal continuity) are the principal causes, based on observations of lower fire severity in sites less changed by fire exclusion (Stephens and Fulé 2005). Other factors such as livestock grazing, wildlife population dynamics, tree cutting, and climate fluctuations likely also intensified the problem as we have seen a 37 percent departure/reduction in vegetative ground cover on the Santa Fe NF that once carried frequent low-severity fire through Ponderosa Pine Forest stands. Fire management practices began to shift focus in the late 20th century to include the use of naturally ignited wildfires and prescribed fires to achieve resource management objectives. This has successfully changed fire behavior in these areas by reducing fuel loads and fuel continuity both vertically (ladder fuels) and horizontally (ability for fire to move from tree crown to crown). However, the area affected by prescribed fires has been small (approximately 3,000 acres/year over the last 15 years, FACTS[3]) and tree densities, fuel loadings, and fuel continuity continue to result in landscape-scale crown fires in many areas.

Stand densities increased during the twentieth century because of the exclusion of surface fires. Specifically, late nineteenth century livestock grazing initiated fire exclusion, which was continued by fire management through most of the twentieth century.

When density changes are examined by diameter class, it is clear that diameter distributions have changed, with increases in smaller classes (23 percent increase) (Covington et al. 1997; Fulé et al. 1997, 2002) and in some cases decreases in larger classes. The overall increases in density (60 percent in closed states) and greater homogenization of diameter classes among stands have decreased structural diversity of stands and landscapes (Allen et al. 2002). With the increased density of small trees, tree growth rates decline in all diameter classes, with increased shade and root competition and decreased moisture and nutrients because of thicker litter (Harrington and Sackett 1990). It appears that reduced vigor is especially damaging to older, larger trees. Elevated mortality rates of large have been related to older trees being more susceptible to pathogens, drought, and injury because of increased stress through increased competition (Kaufmann and Covington 2001). Impediments to recovery of sustainable Ponderosa Pine Forest include competition with sprouting species such as quaking aspen, oaks, New Mexico locust, and grasses, long distance to seed sources of ponderosa pine, and modern climate change toward higher temperatures and drier conditions (Fulé et al. 2012).

A review of exotic species in Ponderosa Pine Forest from a study in Arizona reported that cover values are typically <10 percent (McGlone and Egan 2009). However, the abundance of invasives is highly variable. For example, mean cover of exotic plants in a regional study of 10 Ponderosa Pine Forest ecosystem types in central and north-central Arizona ranged from <0.1 to 7 percent, and their relative cover was <1 to 16 percent (Abella et al. 2012). Mean exotic species richness ranged from approximately 0 to 1.7 species/m^2 (species/10.8 ft^2). This surprising result is likely accounted for by widespread anthropogenic disturbance, including livestock grazing. At the stand scale, invasives generally increase following disturbances such as fire, tree thinning for fire management, and livestock grazing (Sackett et al. 1996; McGlone and Egan 2009). Invasives are generally uncommon in areas of little disturbance (Laughlin et al. 2004) and abundant where disturbance is severe (Sackett & Haase 1996), but some studies have shown no correlation with severity. Also, invasives generally decrease with time since disturbance (Stoddard and McGlone 2008). For example, relative cover of exotics dropped from 6 percent immediately after disturbance (i.e., understory thinning and prescribed burning) to 3 percent after 6 years (Stoddard et al. 2011), but this can be negated by the introduction of other invasive species (McGlone et al. 2009).

Understory conditions changed with Euro-American influence. The changes have been linked to livestock grazing, fire exclusion, increases in tree density, and increases in litter depth (Sackett et al. 1996; Romme et al. 2009). Understory cover decreased with increased tree densities during fire exclusion. In summary, understory dynamics include increases in understory cover with high-severity disturbance, decreases during succession, and decreases as tree density increased during fire exclusion. Species composition also is dynamic, with decreases in

[3] Forest Service Activity Tracking System

abundance of grasses during succession and with fi re exclusion. Species richness increases with high-severity disturbance and decreases during succession and with fire exclusion.

In summary, stands of southwestern Ponderosa Pine Forest greatly changed with the influence of Euro-Americans because of a confluence of livestock grazing, fire management, and one or more regeneration pulses of ponderosa pine. All three factors were necessary. Without livestock grazing, some surface fires would have occurred even with fire management. Without fire management, regeneration pulses would have been thinned by fire as livestock grazing declined. Without regeneration pulses, there would have been no dramatic increase in stand densities. Changes in southwestern Ponderosa Pine Forest include increases in tree density, shifts in diameter distributions toward smaller trees, reductions in tree vigor, and shifts in species composition in higher-elevation stands. Primarily at high elevations, an increase in density of white fir in this diameter class, as well as large decreases in density and basal area of quaking aspen.

Future/Trend

Similar to MCD, seral state proportions changes will be negligible considering modeled effects are 100-years into the future. A slight improvement in seral state departure is reflected, but remains highly departed from reference conditions, improving from 97 percent currently, to 89 percent. Also like MCD, PPF improvement will occur in the medium to large tree, closed canopy state. Some of these acres move to a multi-storied, open canopy state, likely the result of active management. Despite PPF receiving the most active management of any other ERU found on the Forest, only 9,000 acres (15-year average, FACTS) or also roughly 2 percent of Ponderosa Pine Forest acres are treated annually. When considering wildfire activity, nearly 46,500 acres have burned in PPF since 1984, with the majority of those fires occurring in the last 15 years. If trends continue, this means nearly 3,000 acres will burn annually in PPF with half of those acres resulting in moderate- to high-severity. As previously mentioned, despite efforts the scale of current treatment may not be sufficient as 1 acre is being degraded as a result of wildfire for every 3 acres that are treated.

Climate change vulnerability modeling for PPF primarily results in moderate certainty (59 percent) of moderate vulnerability (62 percent). PPF in the Central Zone is projected to be at the greatest risk with 27 percent in moderate vulnerability, 37 percent in high vulnerability, and 36 percent at very high vulnerability. These projected effects along with the high large wildfire occurrence observed in this zone (Fire Severity, pg. 32) may be an indication that residual PPF in this zone may be of priority despite having the lowest proportion of closed canopy (62 percent). Closed canopy states for other zones range from 66 percent (NWZ) to 85 percent (SEZ). The PPF ERU has the highest projected seral state departure of all ERUs modeled for the Santa Fe NF.

PPF Overstory Structure and Composition Seral State Proportion (percentage)

State	Description	Proportion (%)								
		Reference Condition[1]	Current Condition							Future Condition
			Local Scale[4]					Plan Scale	Context Scale	Plan Scale
			NWZ	SWZ	CZ	NEZ	SEZ			
J, K	Multi-storied, open canopy with medium to large trees (≥10")	100	6	3	4	0	0	3	3	11
A, N[2]	Recently burned, grass, forb, and shrub types	0	3	2	8	4	2	3	3	2
B, F[2]	Seedling/sapling, all cover classes	0	8	11	6	6	2	7	8	12
C[2]	Small trees (5-9.9"), open canopy	0	3	2	3	12	10	5	5	2
D, E[2]	Medium to large trees (≥10"), open canopy	0	14	12	18	1	1	11	12	10
G[2]	Small trees (5-9.9"), closed canopy	0	5	14	13	10	18	11	15	16
H, L, I, M[2]	Medium to large trees (≥10"), closed canopy	0	61	56	48	67	67	60	54	47
	% Departure	0	94	97	96	99	99	97	85	89
Snags (per acre)	>8"	1.1	8.0	7.6	7.6	8.3	8.4	7.9	7.5	
	>18"	0.8	0.9	0.8	0.9	0.8	0.8	0.8	0.9	
	% Departure	0	0	0	0	0	0	0	0	
Average Patch Size (acres - Plan Scale)		Reference: 0.02 – 1			Current: 72			% Departure[3]: 99		

PPF Understory Structure and Composition

Vegetation Characteristic			*Similarity to Site Potential* (%)	*Ground Cover* (%)		*CWD* (tons/ac.)
				Bare Soil	Veg. BA	
Reference Condition			100	12.8	13.4	9.0
Current Condition	Local Scale[4]	NWZ	63	15.0	8.7	41.8
		SWZ	66	11.3	7.4	42.2
		CZ	69	11.1	8.6	38.3
		NEZ	67	9.5	9.5	43.8
		SEZ	62	16.4	8.9	45.4
	Plan Scale		63	13.4	8.5	42.3
	Context Scale		NA	NA	NA	41.3
	% Departure[3]		37	5	37	79

PPF Disturbance Regime

Vegetation Characteristic			*FRI* (yrs.)	*Severity* (%)			*FRCC* (%)		
				Low	Mod.	High	I	II	III
Reference Condition			4 - 30	95	1	4	100	0	0
Current Condition	Local Scale[4]	NWZ	422	57	32	11			X
		SWZ	692	56	25	20			X
		CZ	40	54	29	17			X
		NEZ	94	55	29	16			X
		SEZ	NA	NA	NA	NA			X
	Plan Scale		203	55	29	16	0	0	100
	Context Scale		319	41	32	28	NA	NA	NA
	% Departure[3]		85	40			82		

[1] Based on LANDFIRE (2010).

[2] Contemporary landscapes only, historically rare/localized

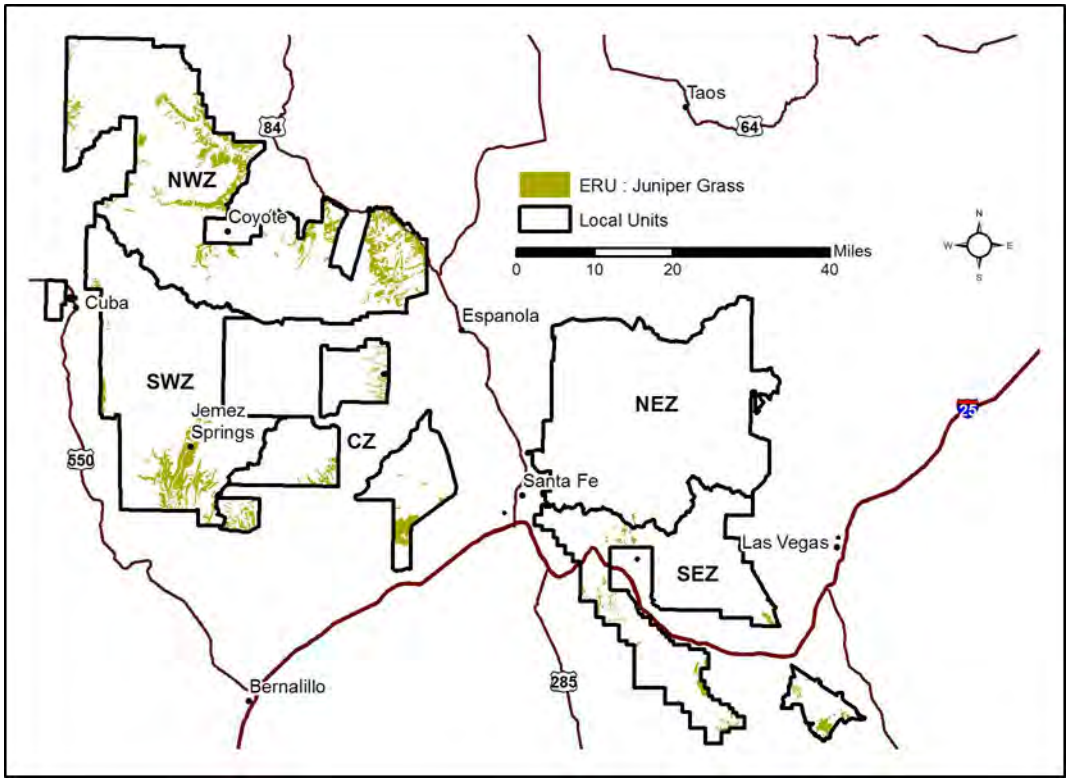
[3] Departure at the plan scale.

[4] Hatching indicates the ERU does not represent at least 5 percent of the local zone and is, therefore, considered not sufficiently represented to analyze.

Juniper Grass (JUG)

Forest Extent: 97,470 acres | Proportion of Santa Fe NF: 5.8 percent | Context Extent: 1,799,893 acres

ERU Description



Juniper Grass is typically on warmer and drier settings beyond the environmental limits of pinyon pine, and just below and often intergrading with the pinyon-juniper zone. A dense herbaceous matrix of native grasses and forbs characterize this type. Typical disturbances (fire, insects, and disease) are of low severity and high frequency with a historic average fire return interval of 0 to 35 years from low–moderate severity fire. These disturbance patterns create and maintain the uneven- aged, open-canopy nature of this type. Typically, native understory grasses are perennial species, while forbs consist of both annuals and perennials. Shrubs are characteristically absent or scattered. This type is typically found on sites with well-developed, loamy soil characteristics, generally at the drier edge of the woodland climatic zone. Generally these types are most extensive in geographic areas dominated by warm (summer) season or bi-modal precipitation regimes. Overall these sites are less productive for tree growth than the PJ Woodland Type.

Roughly 90 percent of all Juniper Grass acres are located in the Central and two western local zones with the NWZ accounting for half of the acres found on the Santa Fe NF. Despite accounting for nearly one hundred-thousand acres forestwide, it represents less than half the acres present of the next most abundant ecological type, PJ Woodland.

Reference Conditions

The Juniper Grass ecosystem is generally uneven-aged and very open in appearance. Trees occur as individuals or in smaller groups with the majority (60 percent) of medium to large in size. Like many of the other woodland types a fair proportion (35 percent) of small trees is also represented on JUG landscapes. Snags are not prevalent but exist, roughly four per acre with the majority being smaller in diameter. The dense herbaceous matrix of native grasses and forbs along with the frequent disturbance limit the average patch size from 0.07 to 1.0 acres. The herbaceous understory encourages frequent low-severity wildfire to occur every 8 to 30 years depending on site conditions. Limited overstory tree cover and woody plants limit the amount of coarse woody debris to 3.0 tons per acre. Despite the presence of a well-developed herbaceous layer, over a quarter of the soil surface is exposed and the amount of ground litter is significantly less relative to all other ERUs.

Current Conditions

The greatly diminished role of recurrent fire in these ecosystems is thought to be responsible for ecologically adverse shifts in the composition, structure and diversity of the JUG type, leading specifically to the rise of ruderal species and invasion by less fire-tolerant species. Due to the effects of long-term fire suppression in this type, in many locations the current condition is severely departed from historic conditions. Typically these changes include in-filling of the canopy gaps, increased density of tree groups; and reduced composition, density and vigor of the herbaceous understory plants. Many of these sites currently are closed-canopy woodlands, with insufficient understory vegetation to carry surface fire.

Future/Trend

Overall seral state departure for JUG doesn't change much but a fair amount of transitioning between seral states does occur. The small tree states experience the biggest reduction, with the open states (B, C, and E) changing from the current overrepresentation of 66 percent down to 2 percent in the future and the closed small tree state (F) decreasing from 33 percent currently down to just 3 percent of the JUG landscape. The majority of these acres move, by means of natural succession, into later successional medium and large open and closed state classes. These acres do not move proportionally (64 percent reduction of small tree-open canopy to an increase of 64 percent into medium to large tree, open canopy) likely as a result of limited fire occurrence in this ERU. Like many of the other woodland types, JUG has a fire return interval greater than 800 years.

Of the woodland ERUs found on the Forest, climate change vulnerability for JUG is relatively low with 29 percent low, and 54 percent in the moderate vulnerability category. The North-West Zone, where the majority (52 percent) of JUG is found on the Forest is relatively low in comparison to the other three zones where JUG is found, with 47 percent at low and 41 percent at projected moderate vulnerability. Seral state departure in this zone is moderate at 45 percent, similar to the ERU forestwide indicating there is opportunity to improve conditions.

JUG - Overstory Structure and Composition Seral State Proportion (percentage)

State	Description	Proportion (%)								
		Reference Condition[1]	Current Condition							Future Condition
			Local Scale[3]					Plan Scale	Context Scale	Plan Scale
			NWZ	SWZ	CZ	NEZ	SEZ			
A	Recently burned, grass, forb, and shrub types	5	7	7	35		18	0	28	5
B, C, E	All seedling/sapling; small trees (5-9.9"), open canopy	25	58	70	29		17	66	11	2
D	Medium to large trees (≥10"), open canopy	50	11	5	9		6	1	30	34
F	Small trees (5-9.9"), closed canopy	10	4	6	10		13	33	9	3
G	Medium to large trees (≥10"), closed canopy	10	20	12	17		46	0	22	56
	% Departure	0	45	49	41		53	45	41	46
Snags (per acre)	>8"	3.0	3.4	3.0	3.1		5.0	3.3	3.9	
	>18"	1.0	0.5	0.7	0.6		0.7	0.6	0.8	
	% Departure	0	25	15	20		15	20	10	
Average Patch Size (acres - Plan Scale)		Reference: 0.07 - 1	Current: 16				% Departure[2]: 97			

JUG - Understory Structure and Composition

Vegetation Characteristic			*Similarity to Site Potential* (%)	*Ground Cover* (%)		*CWD* (tons/ac.)
				Bare Soil	Veg. BA	
Reference Condition			100	26.7	12.7	3.0
Current Condition	Local Scale[3]	NWZ	51	33.5	5.8	14.3
		SWZ	69	20.9	5.7	12.0
		CZ	51	33.4	11.5	11.2
		NEZ				
		SEZ	53	26.1	14.1	17.0
	Plan Scale		56	29.7	7.5	13.7
	Context Scale		NA	NA	NA	12.8
	% Departure[3]		44	10	41	78

JUG - Disturbance Regime

Vegetation Characteristic			*FRI* (yrs.)	*Severity* (%)			*FRCC* (%)		
				Low	Mod.	High	I	II	III
Reference Condition			8 - 30	82	12	6	100	0	0
Current Condition	Local Scale[3]	NWZ	>1,000	71	26	3		X	
		SWZ	>1,000	100	0	0			X
		CZ	139	82	15	4		X	
		NEZ							
		SEZ	NA	NA	NA	NA		X	
	Plan Scale		831	80	16	3	0	76	24
	Context Scale		3,602	75	14	11	NA	NA	NA
	% Departure[3]		96	5			61		

[1] Based on LANDFIRE (2010) and modifications to reflect fire regime I. The LANDFIRE model description was written to include mixed-severity fire, fire events assumed to have been uncommon in the Juniper Grass or PJ Grass ERUs. Reference condition values were subsequently modified for ecological sustainability analysis work to reflect a high frequency, low severity fire regime where grass-forb-shrub (post replacement) plant communities would have been uncommon at watershed scales.

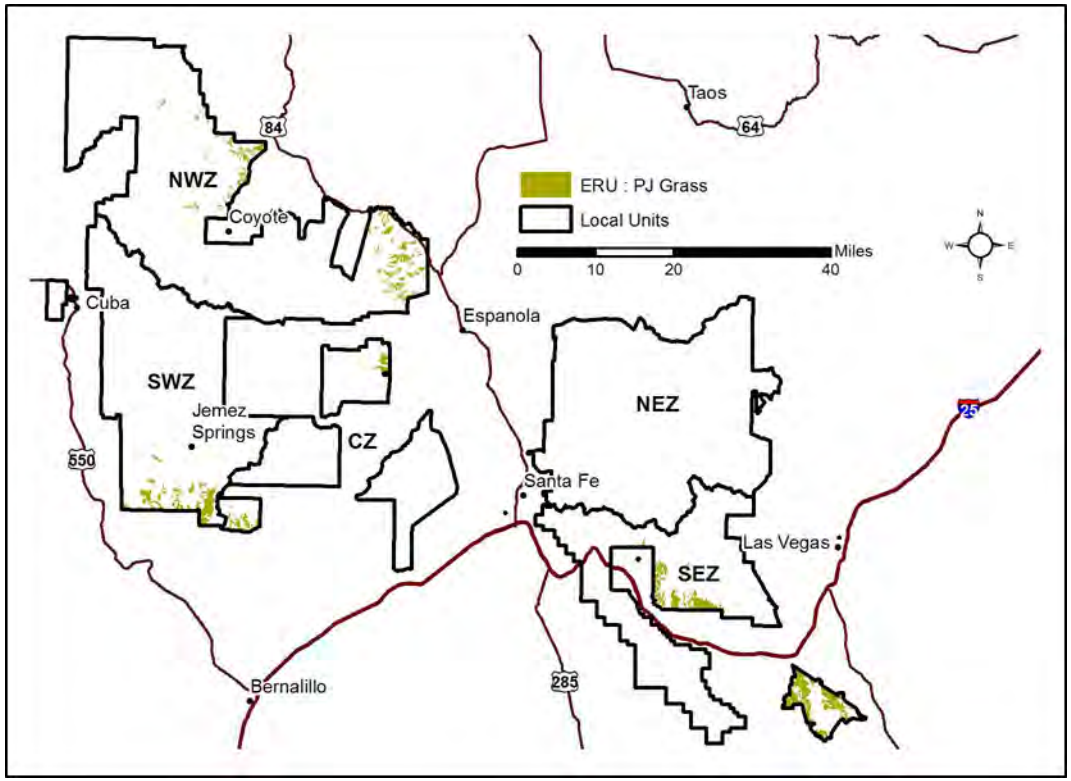
[2] Departure at the plan scale.

[3] Hatching indicates the ERU does not represent at least 5 percent of the local zone and is, therefore, considered not sufficiently represented to analyze.

PJ Grass (PJG)

Forest Extent: 43,356 acres | Proportion of Santa Fe NF: 2.8 percent | Context Extent: 927,286 acres

ERU Description



PJ Grass occurs in what were historically more open woodlands with grassy understories. Tree species include two-needle pinon, one-seed juniper, Utah juniper, and occasional alligator juniper. Native understories were made up of perennial grasses, with both annual and perennial forbs, and shrubs that were absent or scattered. Native understories are made up of predominantly cool season perennial grasses including muttongrass , squirreltail, and western wheatgrass with both annual and perennial forbs, while shrubs are absent or scarce (<1 percent cover)(Miller et al. 1995). The PJ Grass type is typically found on sites with well-developed, loamy soil characteristics, including gentle upland and transitional valley locations, where soil conditions favor grasses (or other grass-like plants) but can support at least some tree cover. Some savannas apparently have sparse tree cover because of climatic limitations on woody plant growth

PJ Grass is found in small proportions across all local zones except the North-East Zone. The South-East Zone comprises nearly half of all PJG acres found on the Forest.

Reference Conditions

Information on the historic condition of this type is sparse. The pinyon-juniper grassland type historically occured across the Southwest, with trees that would have occurred as individuals or in smaller clumps and range from young to old (uneven-aged) open woodlands with grassy understories (Ffolliott and Gottfried 2002). Scattered shrubs and a dense herbaceous understory of native perennial grasses and annual and perennial forbs characterize this type. Site productivity suggests that the development of a grass and fine fuels layer (22 percent ground cover) would have supported frequent fire, open forest dynamics (Gottfried 2003). Typical disturbances (fire, insects, and disease) were of low severity and high frequency, creating and maintaining an uneven-aged open canopy. The historic fire return interval was 8 to 36 years (Margolis 2014; Basin and Swetnam 1995; Grissino-Mayer and Swetnam 1995; Allen 1989) from low to moderate severity fire. Reference patch sizes were 1 acre and less limited amounts of CWD (3.5 tons/acre).

Current Conditions

Modern fire suppression (current FRI >1,000 years) and grazing would have since favored closed canopy structures susceptible to drought-insect induced mortality. Due to the effects of long-term fire suppression in this type, in many locations the current condition is severely departed from historic conditions. Medium to large tree, open canopies have been replaced with typical in-filling of the canopy gaps, increased density of small tree groups; and reduced composition, density and vigor. However, herbaceous understory plants for PJG has the lowest departure for similarity to site potential of all ERUs analyzed on the Santa Fe NF. Although, many of these sites have sufficient understory vegetation to carry surface fire a moderate increase in the amount of bare soil may impede some of the fuel continuity and many contemporary understories in the Region often include invasive grasses such as cheatgrass and a dominance of warm season species such as blue gramma and have uncharacteristically high shrub cover.

Future/Trend

As in JUG, modeling predicts limited changes in seral state departure for PJG. Overall departure will improve by 8 percent with proportions increasing in both (open and closed canopy) the medium to large tree states (D and G). Unlike JUG, however, there is limited change in the small tree-closed canopy state and the majority of the acres that move into the larger diameter tree states come from the small tree-open canopy states. Like many of the neighboring grasslands, without fire, continued infilling and tree expansion by juniper occurs.

Climate change vulnerability for PJG is high with the majority of acres falling into the high (22 percent) and very high (50 percent) categories. Only the Central Zone (7 percent) has less than 47 percent in the very high vulnerability category, unlike the other local zones. But unlike JUG, the Central Zone only accounts for 8 percent of the total ERU acres found on the Forest. The majority of PJG acres (47 percent) are found in the South-East Zone where 35 percent of acres are in moderate and 54 percent of PJG is in very high vulnerability. Limited water availability in this ERU indicates that there is potential with future climate change to transition to JUG, as pinon pine is not as drought tolerable as juniper. Additionally the threat of Ips Beetle outbreaks, similar to those seen in the early 2000s could contribute with this transition.

PJG Overstory Structure and Composition Seral State Proportion (percentage)

State	Description	Proportion (%)								
		Reference Condition[1]	Current Condition							Future Condition
			Local Scale[3]					Plan Scale	Context Scale	Plan Scale
			NWZ	SWZ	CZ	NEZ	SEZ			
A	Recently burned, grass, forb, and shrub types	5	18	13	14		17	16	16	1
B, C, E	All seedling/sapling; small trees (5-9.9”), open canopy	25	68	75	22		34	50	12	10
D	Medium to large trees (≥10”), open canopy	50	5	3	15		5	5	30	28
F	Small trees (5-9.9”), closed canopy	10	3	4	21		14	10	13	14
G	Medium to large trees (≥10”), closed canopy	10	6	5	28		30	19	29	47
	% Departure	0	56	59	39		45	49	33	41
Snags (per acre)	>8”	5.0	2.8	2.7	6.5		6.0	4.6	6.7	
	>18”	1.0	0.6	0.5	0.9		0.7	0.7	1.1	
	% Departure	0	42	48	5		23	21	0	
Average Patch Size (acres - Plan Scale)		Reference: 0.07 - 1			Current: 15			% Departure[2]: 93		

PJG Understory Structure and Composition

Vegetation Characteristic			*Similarity to Site Potential* (%)	*Ground Cover* (%)		*CWD* (tons/ac.)
				Bare Soil	Veg. BA	
Reference Condition			100	27.2	22.1	3.5
Current Condition	Local Scale[3]	NWZ	74	52.5	16.1	8.3
		SWZ	67	36.4	7.5	8.2
		CZ	64	36.4	9.7	16.9
		NEZ				
		SEZ	74	44.6	15.5	15.2
	Plan Scale		72	44.4	13.7	12.3
	Context Scale		NA	NA	NA	17.0
	% Departure[2]		28	39	38	71

PJG Disturbance Regime

Vegetation Characteristic			*FRI* (yrs.)	*Severity* (%)			*FRCC* (%)		
				Low	Mod.	High	I	II	III
Reference Condition			8 - 36	6	65	29	100	0	0
Current Condition	Local Scale[3]	NWZ	>1,000	NA	NA	NA		X	
		SWZ	NA	NA	NA	NA		X	
		CZ	85	28	42	30		X	
		NEZ							
		SEZ	NA	NA	NA	NA		X	
	Plan Scale		>1,000	28	42	30	0	100	0
	Context Scale		>1,000	57	32	11	NA	NA	NA
	% Departure[2]		97	23			49		

[1] Based on LANDFIRE (2010) and modifications to reflect fire regime I. The LANDFIRE model description was written to include mixed-severity fire, fire events assumed to have been uncommon in the Juniper Grass or PJ Grass ERUs. Reference condition values were subsequently modified for ecological sustainability analysis work to reflect a high frequency, low severity fire regime where grass-forb-shrub (post replacement) plant communities would have been uncommon at watershed scales.

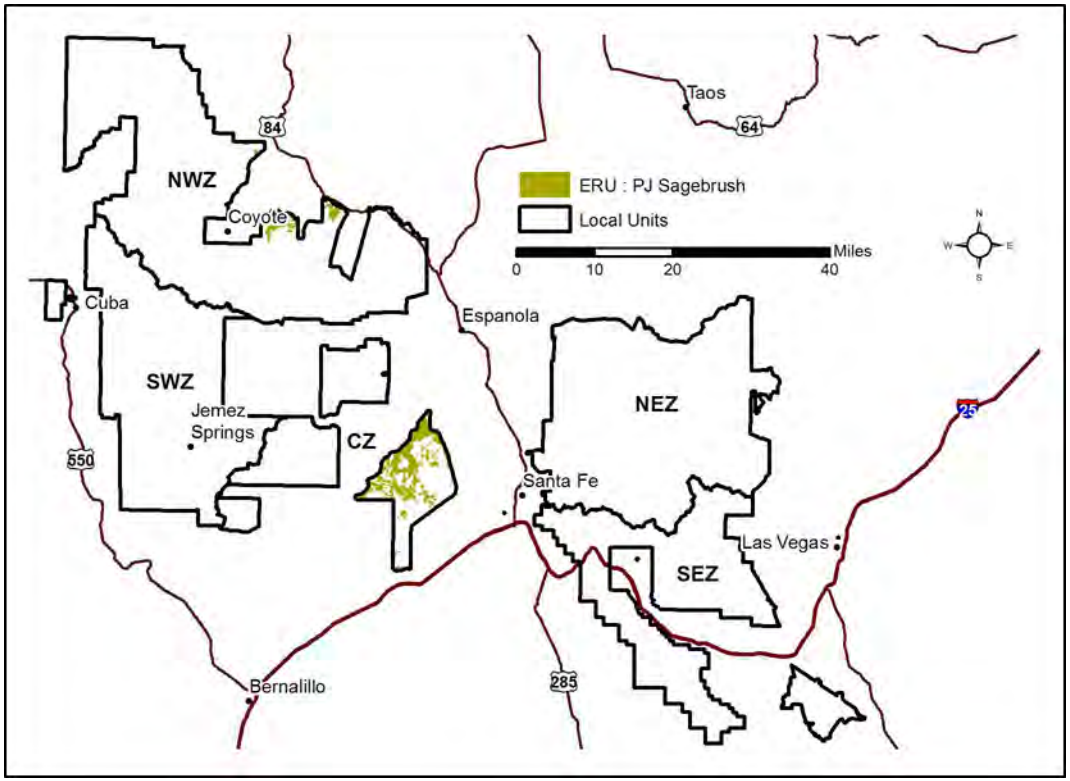
[2] Departure at the plan scale.

[3] Hatching indicates the ERU does not represent at least 5 percent of the local zone and is, therefore, considered not sufficiently represented to analyze.

PJ Sagebrush (PJS)

Forest Extent: 30,449 acres | Proportion of Santa Fe NF: 1.8 percent | Context Extent: 1,406,736 acres

ERU Description



The PJ Sagebrush ERU is concentrated in geographic areas dominated by cold (winter) season precipitation regimes and the frigid soils. These systems have a distinct physiognomy of open woodland canopies interspersed by Colorado Plateau and Great Basin shrub species. Trees occur as individuals or in smaller clumps, and range from young to old. Tree clumps are often even-aged. The understory is dominated by moderate to high density shrubs, and the development of the herb layer is limited and concentrated in canopy openings. The tree and shrub species composition varies throughout the Region; pinyon is occasionally absent, but one or more juniper species are always present. Generally the sparse native understory grass development includes perennial species, while forbs consist of both annuals and perennials. Shrubs are characteristically well distributed, and usually achieve high canopy closure during mature successional phases or where livestock grazing has favored their development over herb species.

Found only at a greater extent than Colorado Plateau/Great Basin Grasslands, PJ Sagebrush are the second least represented ERU found on the Santa Fe NF.

Reference Conditions

PJS was historically made up of nearly even proportions, medium to large closed canopy trees, medium to large open canopy trees, and early seral grass/shrub/young tree states (Romme et al. 2009b; LANDFIRE 2010). Compared to PJO, this additional diversity resulted in smaller patches (1 to 10s of acres). The sagebrush understory provides more continuous fuel to carry fire than is available in PJO; therefore, fire was likely more common and exerted a greater influence on stand structure. Low intensity fires were still very unusual. Most fires removed the shrub layer and killed some to all trees (Romme et al. 2009b, Allen et al. 2009). Fire return intervals were fairly long (50 to 100 years) (Gruell 1994; LANDFIRE 2010), but more frequent than in PJO (Allen et al. 2009).

Climate and insect and disease likely had similar effects as they did in the woodlands, though possibly to a lesser degree. Pulses of drought or insect and disease outbreaks would result in episodic tree mortality (Romme et al. 2009b, Allen et al. 2009). Snag densities are estimated to have been around 7 total snags per acre with the majority of them being of smaller diameter (≤18 inches). Drought and piñon pine *Ips* beetle outbreaks occurred in 2002 to 2004 and in the 1950s, but have also been well documented during a severe drought in the 1500s (USDA FS 2014). There is a high probability that individual piñon pine trees will experience "killing" drought during their lifespan (Romme et al. 2009b, Allen et al. 2009). Altogether, piñon pine populations are often affected by disturbance and rarely reach equilibrium (USDA FS 2014).

Current Conditions

Both snag density (35 percent), and seral state distribution (46 percent) are moderately departed, due to the overrepresentation of open canopy, small trees (57 percent), and grass-forb-shrub (21 percent) and underrepresentation of small tree closed canopy (5 percent) and mid-seral and late-seral-open tree states (4 percent). That is, there is an increase in open, non-treed states and in dense tree stands. The early seral open state on the Santa Fe NF has increased three fold. The observed infill is consistent with a documented trend across the western U.S. (Romme et al. 2009b, Allen et al. 2009). The causal drivers of infill in piñon-juniper systems are not fully understood, and human impacts are difficult to quantify. However, since fire plays a bigger role in maintaining seral state proportions in PJS as compared to PJO, it is likely fire exclusion and grazing have had a greater impact on departure in PJS. Recent fire history is similar to that of PJO, with most of the infrequent fire resulting from human causes and burning with uncharacteristically low severity (39 percent low currently compared to only 13 percent).

Vegetative basal area and litter have been moderately reduced and are now bare soil potentially a result of historic overgrazing, drought, tree harvest, or a combination of these factors. The combined effects of grazing and increased tree canopy have resulted in decreased grass cover. PJS is the most departed ERU in terms of vegetative ground cover, and it is over 35 percent departed in both the local zones (NWZ and CZ) where it occurs. The historic patch size has been greatly reduced from the 50 to 200 acre averages down to 16 acres.

Futrure/Trend

Like PJG, continued infilling and tree expansion occurs in PJS but overall seral state departure improves fairly significantly from moderate (46 percent) to low (28 percent) departure. Currently 63 percent of PJS is in small tree states (B, C, E, and F) but is predicted to only be 19 percent after 100 years according to VDDT modeling. The current 17 percent of PJS in medium to large diameter trees, increases to 67 percent, with primarily natural succession driving this system.

Forest-wide PJS is the most vulnerable ERU found on the Forest with 68 percent in the very high vulnerability category with 85 percent certainty (the highest of all ERUs). PJS is not very widely

disbursed on the Forest and is limited to just the North-West and Central Zones. PJS in the Central Zone is especially vulnerable with 83 percent in the very high and 17 percent in the high vulnerability categories. Three quarters of PJS found on the Forest exists in this zone indicating there is considerable threat to 22,000 acres of PJS found in this zone and the 30,000 acres forestwide.

PJS Overstory Structure and Composition Seral State Proportion (percentage)

State	Description	Proportion (%)								
		Reference Condition[1]	Current Condition							Future Condition
			Local Scale[3]					Plan Scale	Context Scale	Plan Scale
			NWZ	SWZ	CZ	NEZ	SEZ			
A	Recently burned, grass, forb, and shrub types	10	13		23			21	20	14
B, C, E	All seedling/sapling; small trees (5-9.9"), open canopy	25	53		58			57	13	9
D	Medium to large trees (≥10"), open canopy	35	11		2			4	28	33
F	Small trees (5-9.9"), closed canopy	20	0		6			5	6	10
G	Medium to large trees (≥10"), closed canopy	10	23		11			13	32	34
	% Departure	0	44		47			46	32	28
Snags (per acre)	>8"	6.0	5.1		3.1			3.6	7.7	
	>18"	1.0	0.8		0.6			0.7	1.4	
	% Departure	0	18		44			35	0	
Average Patch Size (acres - Plan Scale)		Reference: 50 - 200			Current: 16			% Departure[2]: 69		

PJS Understory Structure and Composition

Vegetation Characteristic			*Similarity to Site Potential* (%)	*Ground Cover* (%)		*CWD* (tons/ac.)
				Bare Soil	Veg. BA	
Reference Condition			100	23.7	21.0	3.0
Current Condition	Local Scale[3]	NWZ	47	17.5	12.8	10.2
		SWZ				
		CZ	55	48.2	13.6	8.3
		NEZ				
		SEZ				
	Plan Scale		54	40.8	13.4	8.8
	Context Scale		NA	NA	NA	13.2
	% Departure[2]		46	42	36	66

PJS Disturbance Regime

Vegetation Characteristic			*FRI* (yrs.)	*Severity* (%)			*FRCC* (%)		
				Low	Mod.	High	I	II	III
Reference Condition			50 - 100	13	56	31	100	0	0
Current Condition	Local Scale[3]	NWZ	NA	NA	NA	NA		X	
		SWZ							
		CZ	>1,000	NA	NA	NA			X
		NEZ							
		SEZ							
	Plan Scale		>1,000	NA	NA	NA	0	24	76
	Context Scale		>1,000	39	43	18	NA	NA	NA
	% Departure[2]		100	26			63		

[1] Based on LANDFIRE (2010) and Huffman et al. (2006).

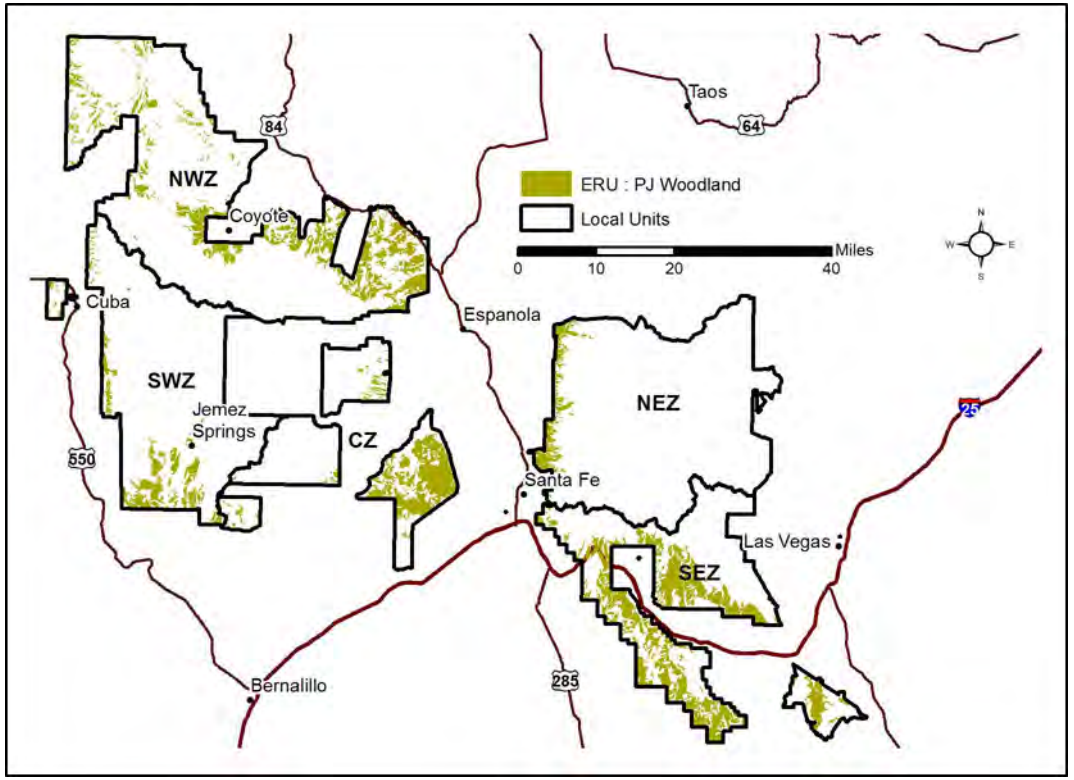
[2] Departure at the plan scale.

[3] Hatching indicates the ERU does not represent at least 5 percent of the local zone and is, therefore, considered not sufficiently represented to analyze.

PJ Woodland (PJO)

Forest Extent: 231,508 acres | Proportion of Santa Fe NF: 13.8 percent | Context Extent: 1,332,919 acres

ERU Description



PJ woodlands are a broad grouping of different plant associations with trees occurring as individuals or in smaller groups and range from young to old, but more typically as large, even-aged structured patches. PJO characteristically has a moderate to dense tree canopy and a sparse understory of perennial grasses, annual and perennial forbs, and shrubs. Woodland development occurs in distinctive phases, ranging from open grass-forb, to mid-aged open canopy, to mature closed canopy. Some types on broken or rocky terrain exhibit little to no natural fire, and insects and disease may be the only disturbance agents. Mostly found on lower slopes of mountains and in upland rolling hills at approximately 4,500 to7,500 feet in elevation. Most common pinon pine is the two-needle pinon occurring in limited areas. One-seed juniper is most common; however, there are areas with Utah juniper and Rocky Mountain juniper. In addition, annual and perennial grasses and graminoids, forbs, half-shrubs and shrubs can be found beneath the woodland overstory.

Reference Conditions

Historically, PJO was characterized by even-aged patches up to hundreds of acres. Old growth was concentrated in stands or larger areas, and very old trees (over 300 years) were present. Overall, 60 percent of trees were medium to large (>10 inches dbh). At the landscape scale, the mosaic of disturbance history and physical site potential resulted in a variety of ages and stand structures (Huffman et al. 2008). Over 75 percent of stands were dense, with closely spaced trees and a closed canopy (Dick-Peddie 1993; LANDFIRE 2010). Huffman and others (2008) reconstructed 1890 tree density and found an average of 177 trees per acre. Even though PJ Woodlands support reasonable fuel loads of both dead and live material, the fuels are very patchily distributed. Patches of heavy fuels are typically separated by comparably sized patches of rock, bare ground, or sparse cover of herbs that do not carry fire readily. Because of the lack of horizontal fuel continuity, fire spread was typically under conditions of strong winds and extremely low fuel moisture (Romme et al. 2003). Typical disturbances (fire, insects, and disease) were of high severity and occurred infrequently with a historic fire return interval of 30 to 200 years from stand-replacing fire. These disturbance patterns create and maintain the even-aged nature of this type. Widespread fire was rare, in most cases fire return intervals were on the order of centuries, up to 400 years or more (Huffman et al. 2008). The historic extent and pattern of stand replacing fires have not been well quantified since PJ Woodlands would burn completely, or not at all making crossdating of fire-scarred trees difficult (Huffman et al. 2008). Most fires likely burned single trees or small patches, but had little effect on woodland structure overall (Allen et al. 2009).

Stand structure and extent of PJO were more likely driven by climate fluctuation and insect and disease outbreaks than by fire. The resultant tree expansion and contraction along grassland and shrubland borders has likely occurred cyclically for thousands of years (Allen et al. 2009). Drought and piñon pine *Ips* beetle outbreaks occurred in 2002-2004 and in the 1950s, but have also been well documented during a severe drought in the 1500s (USDA FS 2014b). There is a high probability that individual piñon pine trees will experience “killing” drought during their lifespan (Romme et al. 2009; Allen et al. 2009). Altogether, piñon pine populations are often affected by disturbance and rarely reach equilibrium (USDA FS 2014).

Current Conditions

Drought conditions beginning in the late 1990s initiated a bark beetle outbreak from 2002 to 2004 that killed a significant portion of the piñon pine component in some woodlands of central and northern New Mexico (USDA FS 2014). Mapping of seral state distribution conducted prior to this outbreak rated PJO as slightly departed in the context landscape and plan scale. There was a slight shift toward early seral states, likely due to ground disturbances, such as chaining during the 1950s and ‘60s (Romme et al. 2009; Allen et al. 2009) and road development. Closed states were already slightly underrepresented, but have since declined further, due to bark beetle induced mortality. As a result, current departure is higher, though the magnitude has not been quantified.

Dead piñon pine trees or snags are four times what they were historically on the landscape in the small diameter (≥8 inches) class. Many of these have fallen and are now classified as coarse woody debris which has led to a four to five fold in the amount of CWD in this ERU type. This large loading in CWD is expected in vegetation types with long fire intervals, but not in this ecological type as it is site limited by nutrient and water availability. Low-elevation sites were most affected, and in some cases may have been supporting piñon pine trees that encroached upon drier juniper grassland sites during wetter periods following drought in the 1950s. However, even in areas of high mortality, observations and measurements showed varying degrees of piñon pine survival from seedlings to some mature trees. Drought may also trigger outbreaks of woodboring beetles in juniper, though mortality is less common. The resultant shift in

tree species over the last decade has been a historically common occurrence, particularly along the edges of ecotones, such as those between woodlands and grasslands (USDA FS 2014). Mistletoe has also caused gradual tree decline and increased susceptibility to beetle infestation and drought. Little direct quantitative information is available on current or historic distribution and abundance, but they are widespread and the intensity of infestations may be greater than it was in the 1800s (USDA FS 2014).

Future/Trend

Similar to other woodland ERUs, limited seral structure change occurs in PJO, based on modeling. Small diameter-open canopy states (B, C, and E) experience a 23 percent reduction in proportion while the medium to large tree, open canopy state (D) increase by 20 percent; additionally, the medium to large tree, closed canopy state (G) increases by 12 percent. Overall seral state departure is reduced by is already in the low-departure category.

Forest-wide PJO is at moderate vulnerability to climate change. The Central Zone and South-East Zones are at higher vulnerability than the other three zones, these are also the two driest (in terms of available water, Chapter 2) on the Forest. Of all the ERUs PJO is projected to have the greatest variation amongst zones when it comes to climate change vulnerability. This may be a result of the models, although certainty is fairly moderate to high at 58 percent and 35 percent respectively. But also poses an opportunity with future management as acres are fairly represented in all vulnerability categories.

PJO Overstory Structure and Composition Seral State Proportion (percentage)

State	Description	Proportion (%)								
		Reference Condition[1]	Current Condition							Future Condition
			Local Scale[3]					Plan Scale	Context Scale	Plan Scale
			NWZ	SWZ	CZ	NEZ	SEZ			
A	Recently burned, grass, forb, and shrub types	10	14	22	22	5	8	14	15	8
B, C, E	All seedling/sapling; small trees (5-9.9”), open canopy	5	29	30	44	26	25	30	13	7
D	Medium to large trees (≥10”), open canopy	10	11	13	9	2	2	7	18	27
F	Small trees (5-9.9”), closed canopy	15	3	7	13	16	21	12	16	10
G	Medium to large trees (≥10”), closed canopy	60	43	28	12	51	44	37	38	49
	% Departure	0	29	40	51	22	26	29	22	19
Snags (per acre)	>8”	2.0	8.2	7.4	6.7	9.0	8.8	8.2	8.8	
	>18”	1.0	1.7	1.9	1.8	1.4	1.4	1.6	1.8	
	% Departure	0	0	0	0	0	0	0	0	

Average Patch Size (acres - Plan Scale)	Reference: 50 - 400	Current: 29	% Departure[2]: 41

Understory Structure and Composition

Vegetation Characteristic			*Similarity to Site Potential* (%)	*Ground Cover* (%)		*CWD* (tons/ac.)
				Bare Soil	Veg. BA	
Reference Condition			100	23.0	19.8	4.1
Current Condition	Local Scale[3]	NWZ	60	34.9	10.0	17.4
		SWZ	66	18.1	10.4	15.6
		CZ	69	40.2	13.1	12.8
		NEZ	67	18.4	10.0	20.5
		SEZ	63	31.4	15.6	19.5
	Plan Scale		64	31.5	12.6	17.4
	Context Scale		NA	NA	NA	18.6
	% Departure[3]		36	27	36	76

Disturbance Regime

Vegetation Characteristic			*FRI* (yrs.)	*Severity* (%)			*FRCC* (%)		
				Low	Mod.	High	I	II	III
Reference Condition			30 - 400	0	39	61	100	0	0
Current Condition	Local Scale[3]	NWZ	>1,000	61	26	13		X	
		SWZ	>1,000	96	4	0		X	
		CZ	727	65	23	12		X	
		NEZ	285	35	49	16		X	
		SEZ	NA	NA	NA	NA	X		
	Plan Scale		>1,000	54	33	13	36	64	0
	Context Scale		>1,000	45	30	25	NA	NA	NA
	% Departure[3]		75	54			47		

[1] Based on LANDFIRE (2010) and Huffman et al. (2006).

[2] Departure at the plan scale.

[3] Hatching indicates the ERU does not represent at least 5 percent of the local zone and is, therefore, considered not sufficiently represented to analyze.

Riparian Ecosystems

A riparian area is the interface between the terrestrial and aquatic ecosystem. As ecotones, they encompass sharp gradients of environmental factors, ecological processes, and plant communities (Gregory et al. 1991). Riparian areas typically have a unique combination of flora, fauna, and soil characteristics compared to nearby deserts, grasslands, or forests. Although riparian areas occupy less than 1 percent of the context landscape (table 17), they support some of the greatest plant and animal diversity and are essential habitat for much of the native flora and fauna and migratory avian species. Riparian systems are defined by change and very responsive to disturbance. Because water availability is so variable in the Southwest, shifts in the balance between erosion, runoff, sedimentation, and vegetation resistance are discrete and episodic. It is also important to note the significance the Forest riparian areas play in the greater landscape of the contextual scale as 16.28 percent of RMAP Herbaceous, 50.25 percent of RMAP Narrowleaf Cottonwood/Shrub, 12.16 percent of RMAP Rio Grande Cottonwood/Shrub, 27.04 percent of RMAP Willow - Thinleaf Alder, 22.30 percent of RMAP Ponderosa Pine/Willow, and - 16.62 percent of RMAP Upper Montane Conifer/Willow is found on the Forest despite it only representing 6.8 percent of the context scale.

In Arizona and New Mexico, an estimated 80 percent of all vertebrate species use riparian areas for at least half their life cycles, and more than half of these are totally dependent on riparian areas (Chaney et al. 1990), even though riparian habitats occupy less than 0.5 percent of the land area. Likewise, aquatic and fish productivity are directly related to a properly functioning and healthy riparian habitat. These areas are typically, but not always, characterized by vegetation and animal communities associated with water such as willows and sedges. They experience routine inundation by water during seasonal high flows and storm events.

Riparian ERUs collectively occupy three percent of the Santa Fe National Forest landscape (for full description of individual Riparian ERUs, see Triepke et al. 2014). Because the condition of riparian ERUs is so dependent on and response to physical setting (hydrology, bank structure, etc.), status and trend of individual riparian ERUs are best assessed in a spatially explicit context.

Key Ecosystem Characteristics for Riparian Vegetation

The key ecosystem characteristics for riparian vegetation (ERUs) include:

- Similarity to site potential
- Vegetative ground cover
- Coarse woody debris
- Fire frequency
- Proper Functioning Condition

Similarity to Site Potential is the same as the metric applied to terrestrial ERUs. It evaluates vegetation composition relative to the potential natural community (PNC), as described in the Santa Fe NF Terrestrial Ecosystem Survey (1993).

Ground cover is an important characteristic that moderates overland flow and streamflow by regulating flow rate and encouraging infiltration down into the soil profile. Disruption of the surface cover and alteration of the mineral soil by wildfire can produce changes in the hydrology of a watershed well

beyond the range of historic variability (DeBano et al. 1998). Riparian vegetation can directly affect stream channel characteristics, particularly streambank habitat and stability (Abernathy and Rutherford 2001). Root systems protect stream banks through armoring (Abernathy and Rutherford 2001) and bind bank sediment, thus contributing to bank stabilization, reduction of sediment inputs to streams (DeBano et al. 1998), and development and maintenance of undercut banks. There are marked differences among riparian species and vegetation types in root characteristics and their influence on bank stability (Wynn et al. 2004). Management activities, such as logging and grazing, and natural disturbances, such as fire and debris flows, can directly affect stream bank stability through alteration of riparian vegetation.

Coarse woody debris (CWD) is important for creating habitat in streams, as well as trapping sediment. Large wood strongly influences channel form in small streams, creating pools and waterfalls and affecting channel width and depth. Many aquatic species use pools formed by large wood as habitat and in-stream wood for cover. The presence of large wood in streams affects erosion, transport, and deposition of sediment, as well as the creation and growth of gravel bars and channel and floodplain sedimentation.

Fire frequency expressed as the fire return interval or rotation period, is the number of fire events that occur at a specified point or within a specified area during a specified time period. In the arid Southwest fire is one of the most common and widespread disturbances. Fire frequency and intensity from adjacent vegetation types typically influenced riparian areas as it naturally spread into riparian areas from uplands; although sometimes in different ways and frequency than adjacent uplands. Fire is an important disturbance in western riparian systems. Lack of fire creates less patchiness, lower diversity of plants and structure, and fewer associated animals. Increased conifer and overall vegetation density and uniformity in the riparian area result in higher-intensity fires across large areas. Fire also aids in the maintenance of coarse woody debris, which create pools that provide habitat for fish and other aquatic organisms. Fires can either result in more accumulation of wood or even a complete removal of wood from the vicinity of the stream depending on preexisting forest and fire severity. The extent and intensity of wildfire also indirectly effects dissolved oxygen concentrations, stream temperature, and the distribution of freshwater fish by manipulating the amount of vegetation providing stream shading or cover. Fire also effects overland flow, when the vegetation is burned-up that typically intercepts rainfall, and encourages infiltration. High severity wildfire can consume all or nearly all of the protective vegetative cover and litter layer over extensive watershed areas, producing a significant effect on the magnitude of overland flow and streamflow from a watershed (DeBano et al. 1998). This is especially significant in the Southwestern US where monsoonal precipitation following high severity fire has increased peak flow rates hundreds of times greater than pre-fire rates (Ffolliott and Neary 2003).

Proper Functioning Conditioning is the only new key ecosystem characteristic not already discussed in the upland vegetation ERU section and is a methodology for assessing the physical functioning of riparian-wetland areas. As a result of riparian areas being patchy and narrow, the broad scale remote sensing data collection process used to collect data for neighboring upland ERU types quantitative vegetative composition and structure data is not available for riparian systems. However, PFC assessments provide a rudimentary level or starting point for assessing riparian-wetland areas. The PFC assessment provides a consistent approach for assessing the physical functioning of riparian-wetland areas through consideration of hydrology, vegetation, and soil/landform attributes. The PFC assessment synthesizes information that is foundational to determining the overall health of a riparian-wetland area. The on-the-ground condition termed PFC refers to *how well* the physical processes are functioning. PFC is a state of resiliency that will allow a riparian-wetland area to hold together during a high-flow event, sustaining that system's ability to produce values related to both physical and biological attributes. Additional information on PFC can be found in the *Riparian Area Management* guide (TR 1737-16, USDI BLM 2003).

Reference Conditions of Riparian Ecosystems

Similar to terrestrial vegetation, reference conditions will be used to determine the amount of departure and ecological risk to riparian systems. It is assumed that restoring and maintaining riparian function that support equilibrium will, in turn, promote ecological integrity. Riparian ecosystems are ecological hotspots and serve multiple functions for humans, other vegetation systems and wildlife. Continuous corridors of riparian vegetation cover hundreds of miles and served as permanent habitat and seasonal migration routes for many species of birds and mammals. Rivers and spring-fed cienegas supported specialized, endemic fish species, beavers required water and created ponds to retain it during periods of low flow, and other species like the southwestern willow flycatcher depend on the plant and animal communities of riparian wetlands. The spatial and temporal distribution of riparian ecosystems across the landscape is dependent on climate, geology, and hydrology, collectively. It is not known what combination of conditions maintained these productive sites. Frequent fires and periodic floods may have contributed to the lack of tree or shrub cover, but the inability of most trees to compete with grasses on deep soils may also have been a factor. It is likely that most of these canyons flooded periodically, especially in high precipitation years. Floods are the most important disturbance type in many riparian ecosystems. Because the effect of floods on riparian vegetation includes direct and indirect effects on a wide range of ecological attributes including vegetative abundance, distribution, structure, function, composition and site productivity. Unfortunately, historic flood regimes on the Santa Fe NF are not known and fire frequency is the only other disturbance regime with extensive data and will be used as a surrogate since the diversity of riparian areas can be attributed to the temporal variability in natural disturbances, debris flows, landslides, and wildfire (Gecy and Wilson 1990; Naiman et al. 2005).

Successional patterns of riparian plant community development are driven by responses to natural and anthropogenic disturbances, physical variables, and plant species attributes (Baker 1989; Merritt et al. 2009). There are also feedbacks between riparian plant species and the physical environment. These involve plant features that influence sediment deposition and accumulation and lead to biostabilization of streambanks and floodplains. Riparian plant characteristics include mechanical resistance and flexibility, root anchorage ability, and post-disturbance regeneration via sprouts and seedlings that influence sediment deposition and accumulation (Petitt and Naiman 2007; Corenbilt et al. 2009). Thus, the diverse composition and structure of riparian vegetation are a result of the interdependence of physical and biotic processes over time (Bennett and Simon 2004)

Wetland and riparian areas have historically been heavily impacted by anthropogenic activities throughout North America (Brinson and Malvarez 2002). Extensive land uses by Native Americans and European-Americans have likely had some impact on riparian areas on the Santa Fe NF. Wetlands and riparian ecosystems have been among the most intensely and systematically altered in North America (Dahl 1990). The wide variety of impacts, include hydrologic alterations associated with dams and water diversions (Graf 1999; Nilsson and Berggren 2000; Pringle 2000), agricultural drainage (Dahl 1990), grazing (Belsky et al. 1999; Fleischner 1994; Patten 1998), and the widespread introduction of non-native species (Crooks 2002; Mack et al. 2000; Stein and Flack 1996). Demand for water, fertile land, and forage for livestock in the arid and semi-arid West has already affected many aquatic, riparian, and wetland areas and pressures will likely increase with time, threatening the integrity and long-term viability of these vital ecosystems and the biota they support (Baron et al. 2002).

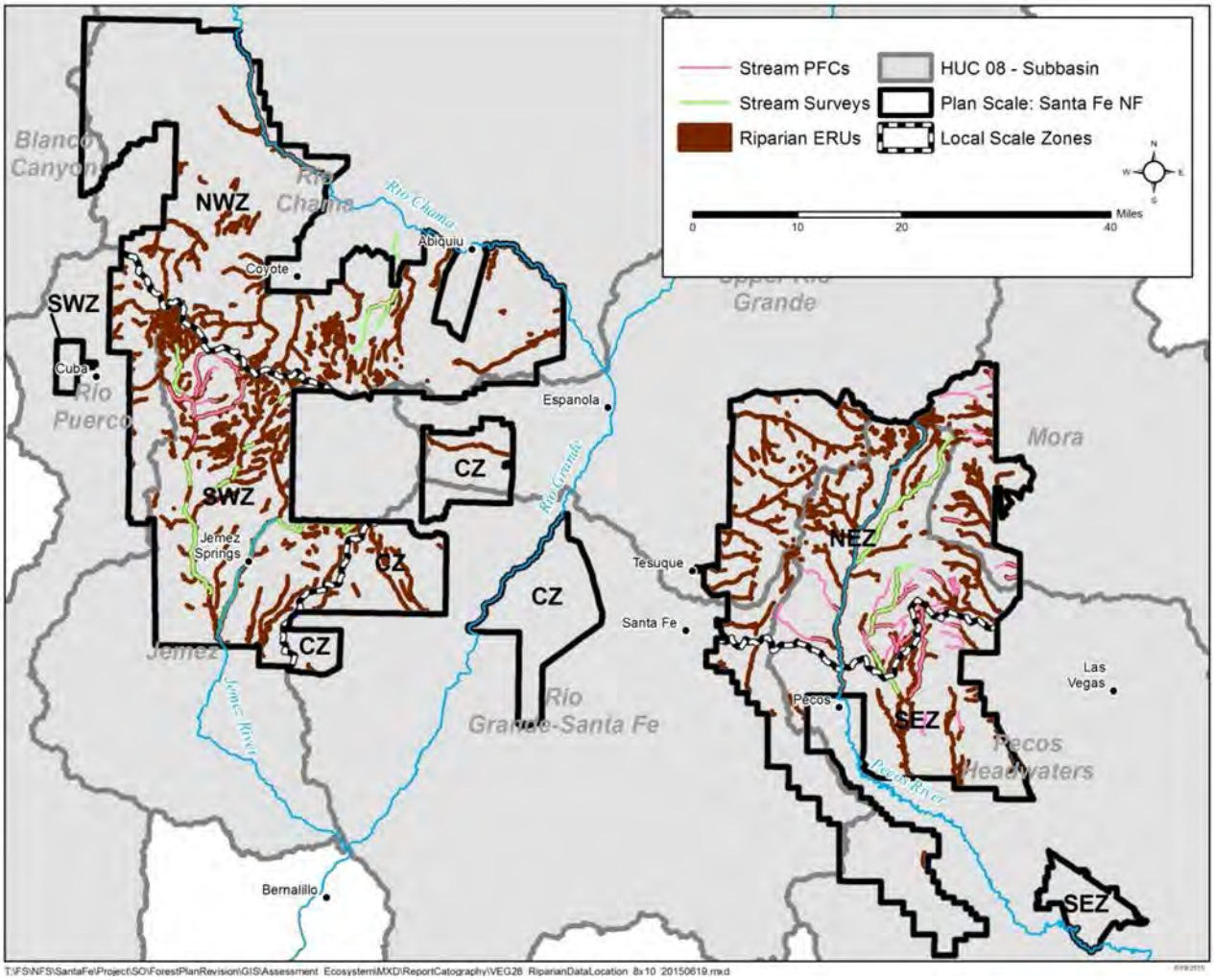


Figure 12. Map showing proper functioning condition (PFC) and stream surveys available for data analysis, relative to the location of all riparian ERUs

Table 17. Riparian Ecological Response Units (ERUs) presented for all three analysis spatial scales (local, plan and context)

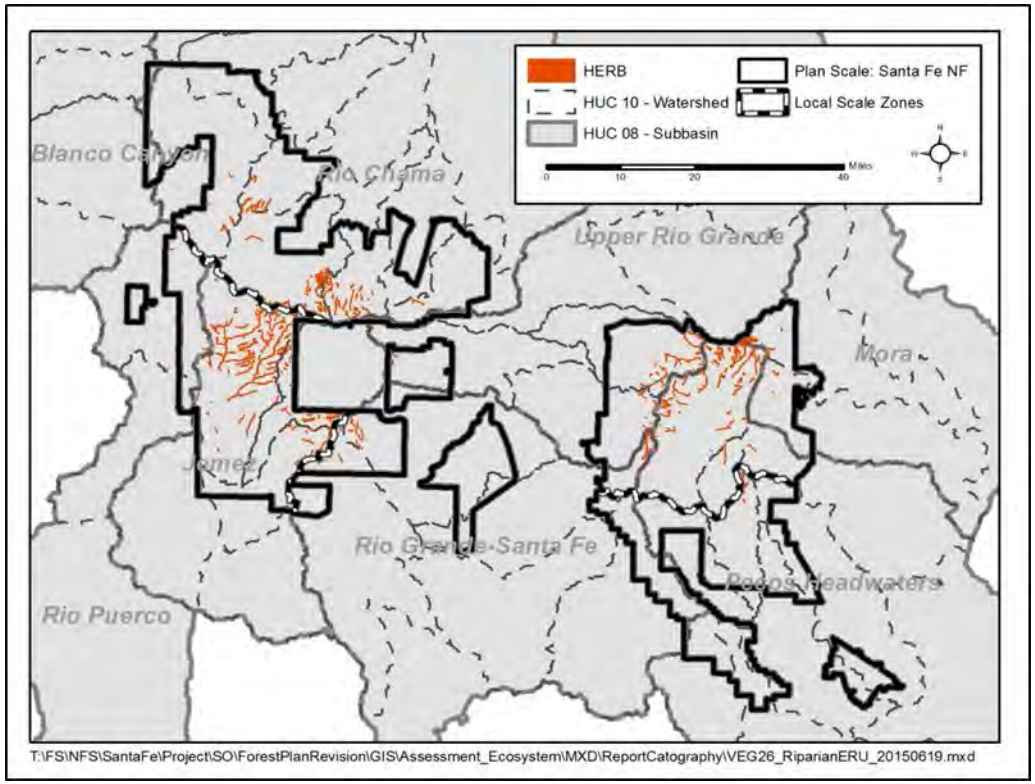
Note: Proportions at the local scale include both percent of the total local scale acres and proportion of the total plan scale ERU acreage. Similarly the proportions at the plan scale include both percent of the total plan scale acres and proportion of the total context scale ERU acreage. All riparian ERUs were analyzed in depth (values have been rounded to the nearest whole number).

Riparian Ecological Response Units (ERUs)	Local										Plan			Context
	NWZ		SWZ		CZ		NEZ		SEZ					
	% of Local Scale	% of Plan ERU Acres	% of Local Scale	% of Plan ERU Acres	% of Local Scale	% of Plan ERU Acres	% of Local Scale	% of Plan ERU Acres	% of Local Scale	% of Plan ERU Acres	**ERU Acres**	% of Plan	% of Context	**ERU Acres**
RMAP Herbaceous - (HERB)	0.8%	25.4%	1.9%	40.2%	0.2%	2.8%	1.1%	29.8%	0.1%	1.7%	**15,373**	0.91%	16.28%	**94,417**
RMAP Narrowleaf Cottonwood/Shrub - (CWG)	0.3%	9.4%	0.3%	6.8%	0.3%	4.0%	2.5%	69.1%	0.6%	10.7%	**15,010**	0.89%	50.25%	**29,871**
RMAP Rio Grande Cottonwood/Shrub - (CWG)	1.0%	63.3%	0.7%	32.0%	0.1%	3.0%	0.0%	0.1%	0.0%	1.7%	**7,493**	0.45%	12.16%	**61,641**
RMAP Willow - Thinleaf Alder - (MCWG)	0.4%	26.9%	1.0%	46.2%	0.2%	3.9%	0.2%	12.4%	0.3%	10.7%	**6,957**	0.41%	27.04%	**25,728**
RMAP Ponderosa Pine/Willow - (MCWG)	0.0%	28.8%	0.1%	30.0%	0.1%	22.1%	0.0%	8.2%	0.0%	10.9%	**665**	0.04%	22.30%	**2,982**
RMAP Upper Montane Conifer/Willow - (MCWG)	0.0%	8.5%	0.0%	0.0%	0.0%	2.7%	0.1%	78.1%	0.0%	10.6%	**495**	0.03%	16.62%	**2,978**
Spatial Scale Total Acres	**12,164**		**13,016**		**1,683**		**16,265**		**2,865**		**45,993**			**217,617**
Upland & Riparian Total Spatial Scale Acres	**490,531**		**328,457**		**178,315**		**409,644**		**273,954**		**1,680,869**			**22,442,078**

RMAP Herbaceous (HERB)

Forest Extent: 15,373 acres | Proportion of Santa Fe NF: 0.9 percent | Context Extent: 94,417 acres

ERU Description



The Herbaceous (HERB) riparian ERU is the most extensive and inclusive riparian ERU, occurring at nearly all elevations (5,500 to 12,000 feet) on the Santa Fe NF. This ERU occurs at roughly 1 percent of the local zone acreage for three of the five local zones and at limited acreage in the Central and South-East zones. It represents a total of just less than 1 percent of all lands within the plan scale (table 17). It supports a wide diversity of riparian and wetland herbaceous species that vary greatly with elevation and climate, but sedges and rushes are particularly important to system function (Neary and Medina 1995). It is most common in wide, low gradient meadows, where the water table is seasonally high with saturated soils and trees or shrubs are mostly absent (Culver and Lemly 2013).

HERB Structure, Composition, Disturbance Regime

Vegetation Characteristic		*Similarity to Site Potential (%)*	*Ground Cover* (%) Bare Soil	*Ground Cover* (%) Veg. BA	*CWD (pieces/mile)*	*FRI* (yrs.)	PFC (Rating)
Reference Condition		100	2.9	50.6	>30	Infrequent	Proper Functioning
Current Condition	Local Scale NWZ	45	11.0	36.4	40	>1,000	NA
	Local Scale SWZ	48	4.6	44.4	10	436	Functional - At Risk
	Local Scale CZ						
	Local Scale NEZ	7	8.5	21.8	29	411	Proper Functioning
	Local Scale SEZ	27	5.0	43.0	NA		Proper Functioning
	Plan Scale	27	7.3	35.7	18	871	Proper Functioning
% Departure		73	60	29	41		

Hatching indicates the ERU does not represent at least 5 percent of the local zone and is, therefore, considered not sufficiently represented to analyze. Grey indicates data is not available for the analysis.

Current Conditions

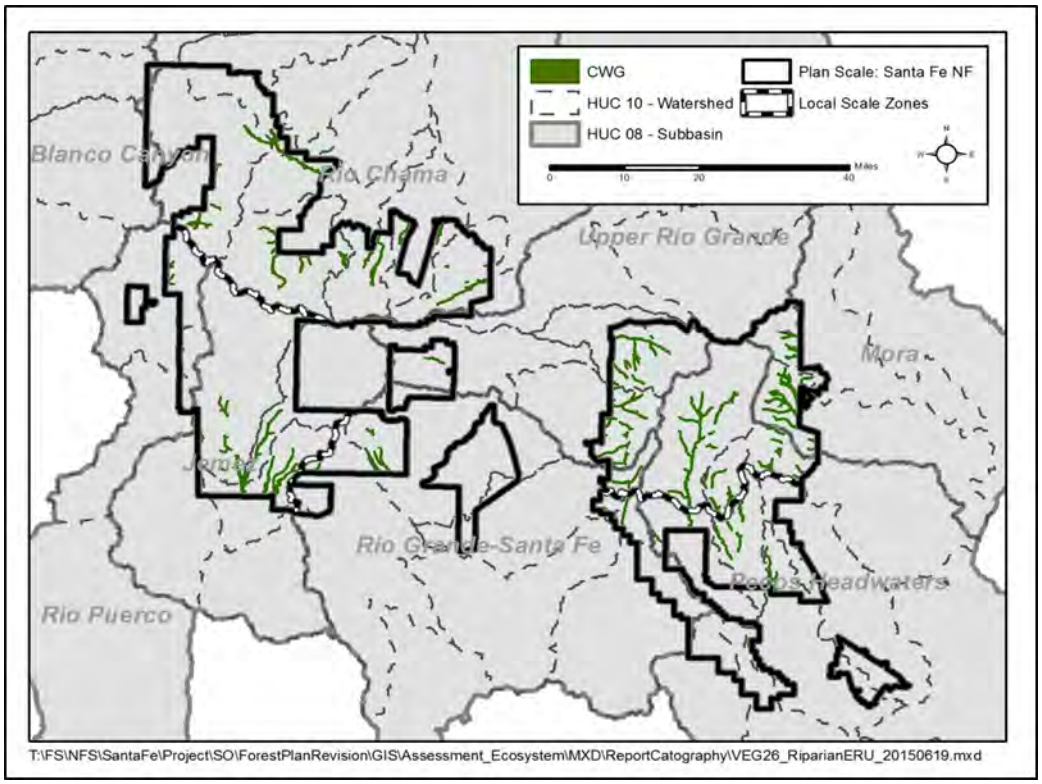
HERB is evenly distributed across the forest and local zones where it is predominantly found. It occurs in all five of the local zones. On NFS lands, instream flows are reduced and their timing is altered by human water uses (Romme2009; Floyd et al. 2009). Decreased flooding, channelization, downcutting, and lowered water tables all contribute to a reduction in available soil moisture and an increase in upland species. Road density and other anthropogenic impacts such as grazing and recreating are likely deteriorating understory composition and condition as site potential and proportion of bare soil are significantly departed at 73 and 60 percent, respectively. These alterations to the landscape have an impact on wildlife as there is a reduction in breeding and forage cover. Reduced cover and dominance by sod forming grasses negatively affects stream temperature, bank stability, and sedimentation.

HERB may be the riparian ERU most impacted by invasive species. Invasives have been identified in all of the local zones. They were originally spread mainly along roadways, but are becoming increasingly established in riparian areas, distributed by stream flows (USDA 2007). Uncharacteristic wildfire, including fire suppression activities (containment lines), are also current threats to this ecosystem as increased fire severity occurrence relative to reference is occurring in this ERU.

RMAP Cottonwood Group (CWG) – Narrowleaf Cottonwood/Shrub and Rio Grande Cottonwood/Shrub

Forest Extent: 22,503 acres Proportion of Santa Fe NF: 1.3 percent Context Extent: 91,512 acres

ERU Description



The RMAP cottonwood group is comprised of eight RMAP types but only two are found on the Santa Fe NF including 15,010 acres (0.89 percent of plan area) of Narrowleaf Cottonwood-Shrub (NCSH) and 7,493 acres (0.45 percent of plan area) of Rio Grande Cottonwood-Shrub (RGCS) riparian ERUs is found on the Santa Fe NF. Although it's presence on the landscape at the plan scale is not significant, it represents 25 percent of the ERU group at the context scale. NCSH is generally found at lower elevations, downstream from NCSP. NCSH is similar to NCSP, but lacks the spruce dominated overstory. RGCS occurs along low gradient streams with wider floodplains that provide flood terraces with infrequent flood regimes (Durkin et al. 1995). The overstory is Rio Grande cottonwood and willow species may be present.

CWG Structure, Composition, Disturbance Regime

Vegetation Characteristic		*Similarity to Site Potential (%)*	*Ground Cover* (%) Bare Soil	*Ground Cover* (%) Veg. BA	*CWD (pieces/mile)*	*FRI* (yrs.)	PFC (Rating)
Reference Condition		100	11.8	37.3	>30	Infrequent	Proper Functioning
Current Condition	Local Scale NWZ	36	36.6	17.5	23	51	
	Local Scale SWZ	60	25.2	21.1	3	200	
	Local Scale CZ	35	20.7	22.0			
	Local Scale NEZ	45	10.1	19.8	24	>1,000	Proper Functioning
	Local Scale SEZ	36	17.6	21.0	2		Proper Functioning
	Plan Scale	44	20.6	19.5	13	675	Proper Functioning
	% Departure	56	39	48	58		

Hatching indicates the ERU does not represent at least 5 percent of the local zone and is, therefore, considered not sufficiently represented to analyze. Grey indicates data is not available for the analysis.

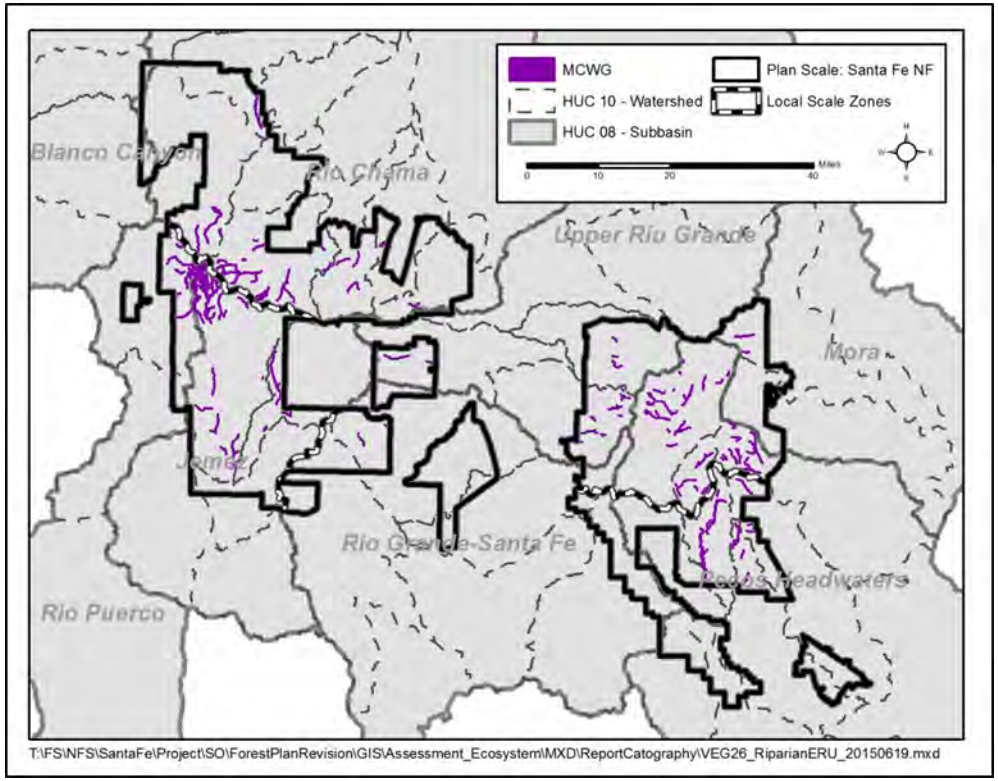
Current Conditions

NCSH's ecosystem characteristics are similar to NCSP. CWG is fairly distributed across the Forest, occurring in all but the Central local zone with the majority of the acreage found in the North-East and North-West zones. Coarse woody debris and channel organic debris are slightly less common in this ERU and half of what occurred during reference conditions or what is necessary to be considered properly functioning. Less frequent flooding has driven a shift in species composition, with a significant reduction in cottonwood cover, which is highly departed from a habitat perspective. Vegetative ground cover is moderately departed (48 percent). Sod forming grasses are nearly four times more common than bunch grasses. The mechanisms driving a large increase in willow are similar to those in NCSP. The scarcity of perennial streams on the Santa Fe NF limits available habitat for fishes in the mountain range. The Rio Grande cutthroat trout is native to high-elevation streams in the drainage of the Pecos River (Sublette et al. 1990). The Rio Grande cutthroat readily hybridizes with exotic salmonids, which have been introduced for recreational fishing. Most streams in which it occurs have been affected by overgrazing and by altered stream nutrient, sediment load, and flow regimes. As a result of human activity, riparian areas have shifted exotic shrubby species such as Russian-olive and saltcedar leading to a 56 percent departure from site potential.

RMAP Mixed Cottonwood/Willow Group (MCWG) – Thinleaf Alder, Ponderosa Pine Willow and Upper Montane Conifer/Willow

Forest Extent: 8,117 acres Proportion of Santa Fe NF: 0.48 percent Context Extent: 31,688 acres

ERU Description



The Mixed Cottonwood-Willow Group is comprised of Thinleaf Alder, Ponderosa Pine Willow and Upper Montane Conifer/Willow ERU types. This riparian group stretches along various elevational gradients from lower elevations (3,500 feet) in mountain canyons and valleys to higher mountainous elevations (10,000 feet). At lower elevations this ERU group can be found along perennial and seasonally intermittent streams. The MCWG riparian ERU frequently occurs in wet drainages associated with thinleaf Alder, willow, cottonwood, ponderosa pine and mixed conifer forests. At higher elevations, this PNVT is found along streambanks, seeps, fens, and isolated springs. At higher elevations, this ERU is shrub and herb dominated. MCWG is the least represented riparian ERU group found on the Forest. A total of 8,117 acres (0.44 percent) occur on the Santa Fe NF, with the majority being thinleaf alder.

MCWG Structure, Composition, Disturbance Regime

Vegetation Characteristic		*Similarity to Site Potential (%)*	*Ground Cover (%)* **Bare Soil**	*Ground Cover (%)* **Veg. BA**	*CWD (pieces/mile)*	*FRI* **(yrs.)**	**PFC (Rating)**
Reference Condition		100	8.3	25.0	>30	Infrequent	Proper Functioning
Current Condition	Local Scale NWZ	45	22.8	16.0	12	30	
	Local Scale SWZ	34	4.7	30.1	17		
	Local Scale CZ	55	24.3	10.2	NA	30	
	Local Scale NEZ	69	6.7	6.0	26	>1,000	
	Local Scale SEZ	61	34.4	10.8	2		
	Plan Scale	46	13.9	19.5	19	>1,000	
	% Departure	54	39	22	38		

Hatching indicates the ERU does not represent at least 5 percent of the local zone and is, therefore, considered not sufficiently represented to analyze.Grey indicates data is not available for the analysis.

Current Conditions

Anthropogenic impacts have been extensive across all riparian types Flash floods following heavy monsoon rains are common today and may cause considerable erosion damage. Though there have been climatically induced periods of arroyo cutting in the Southwest since prehistoric times (Dahms and Geils 1997), severe gullying in intermittent watercourses has become apparent following intensive human land use. This sort of erosion began with the onset of heavy grazing pressure at the end of the 19th century, which eliminated stabilizing grass cover in the seasonal watercourses. However, natural environmental changes may have contributed to the phenomenon. Livestock concentrated around water sources have caused much damage by trampling. Clearcut logging has also altered interception of precipitation, allowing more water to run off downhill. Elimination of cover on hillsides has contributed to considerable erosion following logging and heavy grazing (Reynolds 1990). Roads in canyon bottoms have also contributed considerably to erosion. Removal of beaver, overgrazing by livestock, logging, construction of roads and agriculture in riparian areas, diversion of water for irrigation, and modification of channels have altered riparian areas, sometimes irreparably (Dahms and Geils 1997).

Diversion of water for irrigation and storage and construction of flood control structures have changed the hydrologic cycles on perennial and intermittent streams. Shortly after the period of intensive logging, surface runoff increased dramatically; now, with dense regeneration and more trees than existed in the pre-settlement forest, it is likely that evapotranspiration of water by the trees has reduced the availability of surface water and may have lowered the water table (Dahms and Geils 1997). Streamflow has generally been reduced, and patterns of erosion and deposition have changed. Where flood control structures have been built, floods are less frequent but more intense when they occur, causing more severe erosion and less deposition of sediment. Sediment deposited by natural floods created seedbeds for willows and cottonwoods, which are now reduced in their regeneration. When floods cut deep channels through alluvial soils in wet meadows, the water flows through more quickly, lowering the water table and draining hydric soils.

Ecosystem Services

Supporting and regulatory ecosystem services provided by vegetation have been assessed at multiple scales in this report, including Patch, Stand, Watershed, and Ecoregional scales. Vegetation biodiversity can be considered both supporting and regulating. Vegetative biodiversity supports and reflects the biodiversity in animal life that has co-evolved with various plant forms over time. The genetic variation inherent in that biodiversity provides a regulatory service of system resilience in an ever-changing environment, including climate changes, providing adaptability of vegetative response. The current trend for biodiversity is declining, primarily driven by past fire management and the suppression of wildfires, which has limited succession and led to homogenous stands of vegetation. Similar trends have also been observed off-forest.

Water filtration and erosion control are provided by vegetative surface cover. Vegetation moderates passage of water across landscapes to mitigate floods and assists in holding soils in place so they can provide water filtration. Water filtration is necessary for plants and animals alike. Without soil, which is retained by the interlocking roots of many plants, clean water would be unattainable in the natural environment. With declining cover in grass and shrubland areas, but increasing surface cover in forested areas, similar trends are seen for these services both on- and off-forest. Uncontrolled heavy use of native arid grasslands by ungulates can lead to the loss of native grasses, the introduction of invasive exotic grasses and other weedy species, the destruction of cryptogamic crusts, altered grassland structure, and ultimately contribute to the conversion of grasslands to shrub-dominated vegetation types. However, greater overstory competition in forested lands, currently increasing tree and limb mortality, has slightly moderated this affect as a result of more coarse woody debris on the ground.

Soil formation and nutrient cycling are supported by vegetation as well, especially through plant matter decomposition. Habitat for wildlife is also an important role played by different vegetation types in various stages of existence. For example, early successional grasses and shrubs provide shelter and cover for small mammals, dead standing snags provide habitat for cavity nesting birds, and decomposing trees on the ground support insects and nematodes. This is a mutually-supportive system, clearly, as plants need the soil and soil biota to thrive, while insects, birds and wildlife may pollinate or transport seeds.

The unique ability of plants to create food from the energy of the sun through the process of photosynthesis is also the foundational support for nutrient cycling services. While climate change can add stress to vegetative systems, the increased temperatures predicted by climate models do increase photosynthetic rates in many plants.

Increased amounts of coarse woody debris are currently available on the ground surface for decomposition, but also add to the fuel hazard and potential for high severity fires. When those happen, erosion and sterilization of soil can occur, causing detrimental impacts for vegetation.

Since plants take in carbon dioxide and release oxygen as a byproduct of their respiratory process, their role in supporting breathable air supplies is also crucial. Through evapo-transpiration, plants also contribute to water cycling by pulling water up from the ground and releasing it into the air. In the Western U.S., the majority of forested lands is managed by the Forest Service and is at risk of extensive uncharacteristic wildfire, potentially leading to vegetation type conversions and reduced moisture availability in the atmosphere as a result of climate change.

Climate regulation is significant in the maintenance of many ecosystem organisms, especially those that are immobile. Many species exist at specific locations primarily as a result of the climatic conditions. Vegetation provides stream and soil shading that can mitigate increases ambient temperature. The moderation of climate is significant in the ability for some organisms to adapt, and also affects

occurrences of extreme weather (e.g., hurricanes). A declining trend both on and off-Forest in vegetation's ability to provide this service is driven by the current departures from reference conditions that result in uncharacteristic wildfire. The common result over time is thickets of smaller diameter trees, which do not store the same quantities of carbon that large trees do.

Maintaining or restoring riparian function promotes ecological integrity for many supporting services related to vegetation specific to wet areas. Continuous corridors of riparian vegetation covered hundreds of miles and served as permanent habitat and seasonal migration routes. Rivers and spring-fed *cienegas* supported specialized fish species, and other species depend on the plant and animal communities of riparian wetlands. Demand for water, fertile land, and forage for livestock in the arid and semi-arid West have driven past changes; and these pressures continue to climb (see Volume II). As a result of human activity, riparian areas have shifted to exotic shrubby species such as Russian-olive and saltcedar, leading to a 56 percent departure from site potential, indicating a potential need for changed management in order to sustain these vital services.

Chapter 2. Assessing Water Resources of the Santa Fe National Forest

This chapter describes the current condition, reference or surrogate condition and future condition of key watershed characteristics within and surrounding the Santa Fe National Forest (Santa Fe NF). The following key watershed characteristics are addressed herein: surface water (perennial streams, water bodies, seeps and springs, and water quality), ground water, and wetlands. In addition, this report explores the human impact to these resources at sub-watershed and watershed scale by observing 'watershed' condition, water rights and impaired streams. Spatial data (from the Santa Fe NF's geographic information systems, GIS) and reference data (when available) were used to compare these key watershed characteristics and watershed condition in order to establish the departure from reference (or surrogate) conditions.

Before reviewing the current, reference and future conditions of the water and water-related resources on the Santa Fe NF, a brief overview of these resources is presented. An explanation of the hydrologic unit codes and scale are described to assist the reader in understanding the terminology and extent of the analysis. An overview of the data used to describe current and reference (or surrogate) conditions is presented. A summary of the key watershed characteristics both on and off the Santa Fe NF at the watershed scale is presented to highlight the findings of the analysis. Finally for each key characteristic, the current condition, the reference (or surrogate) condition and the departure from the reference condition are presented. The section closes with a combined look at the future condition for the water resources of the Santa Fe NF.

Overview of the Santa Fe NF Water and Water-Related Resources

The Santa Fe NF is one of 155 national forests under the management of the USDA Forest Service. The Santa Fe NF lies in north-central New Mexico with portions of the forest covering six counties. The Santa Fe NF is approximately 2,627 square miles in size, and it comprises 2.2 percent of the land area of the State of New Mexico.

Groundwater, streams, lakes, ponds, playas, springs, wetlands, and riparian corridors comprise the majority of the water resources on the Santa Fe NF. Using the GIS files maintained by the Forest, most of these features were quantified. There are approximately 1,180 miles of perennial streams and 5,070 miles of intermittent and ephemeral streams. Water bodies (lakes, ponds, playa, etc.) cover nearly 1000 acres. Over 200 springs and seeps, 7,000 plus acres of wetlands and approximately 51,000 acres of riparian corridors exist on the Santa Fe NF. Please refer to chapter 1 for key riparian characteristics and analysis.

Hydrologic Unit Codes and Scale

Hydrologic unit codes (HUCs) are discussed in Water-Supply Paper 2294 (USGS 1987). As described and modified based on information in this paper, hydrologic units are arranged or nested within each other, from the largest geographic area 'region' to the smallest geographic area 'sub-watershed.' Each hydrologic unit is identified by a unique hydrologic unit code (HUC) consisting of two to twelve digits based on the six levels of classification (table 18).

Table 18. Summary of the Hydrologic Unit Codes and numbering system

Digits/HUC	Level	Hydrologic Unit	Example (HUC number, name of Hydrologic Unit)
2	1	Region	13 is the Rio Grande region.
4	2	Sub-region	1302 is the Rio Grande-Elephant Butte sub-region.
6	3	Basin	130201 is the Upper Rio Grande basin.
8	4	Sub-basin	13020102 is the Rio Chama sub-basin.
10	5	Watershed	1302010210 is the Abiquiu Reservoir watershed.
12	6	Sub-watershed	130201021003 is the Rio Puerco-Abiquiu Reservoir sub-watershed.

The Santa Fe NF lies within eight sub-basins (figure 13, table 19). They are the Rio Chama, Upper Rio Grande, Rio Grande – Santa Fe, Jemez, Rio Puerco, Mora, Pecos Headwaters, and Blanco Canyon. The majority of the Santa Fe NF is tributary to the Rio Grande. With the exception of the Mora and Blanco Canyon sub-basins, the remaining six sub-basins are tributary to the Rio Grande. In fact, approximately 95 percent of the Santa Fe NF is tributary to the Rio Grande. The Mora sub-basin and the Blanco Canyon sub-basin are tributary to the Arkansas-White-Red Region (Gulf of Mexico via the Mississippi River) and the Upper Colorado Region (Gulf of California via the Colorado River), respectively. In addition to the main stem of the Rio Grande, the Rio Chama, Jemez River and Pecos River are major tributaries arising on or flowing through the Santa Fe NF. Other tributaries originating on the Santa Fe NF are also important. For example, the Arroyo Pecos-Gallinas River sub-watershed and the Rio La Casa-Mora River sub- are important as they provide drinking water to the towns of Las Vegas and Mora, respectively.

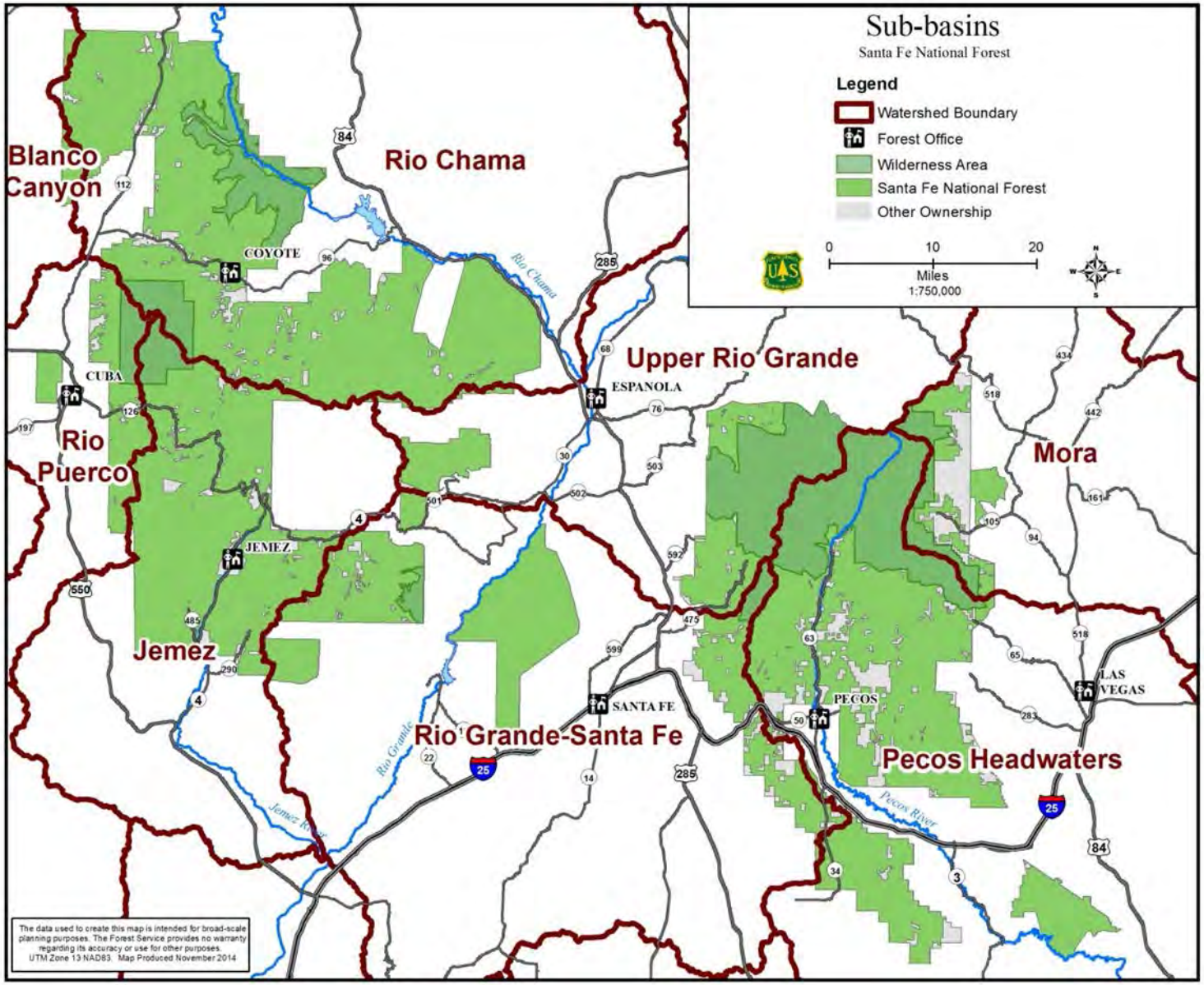


Figure 13. Sub-basins covering the Santa Fe NF

Table 19. Sub-basins (HUC8) and percent of Santa Fe NF lands contained within sub-basins

HUC8 Number	HUC8 Name	HUC8 (Square Miles)	NFS Lands within HUC8 (Square Miles)	% of NFS Lands within HUC8
11080004	Mora	1,457	115	7.9%
13020101	Upper Rio Grande	3,254	237	7.3%
13020102	Rio Chama	3,158	742	23.5%
13020201	Rio Grande-Santa Fe	1,872	335	17.9%
13020202	Jemez	1,039	416	40.0%
13020204	Rio Puerco	2,112	99	4.7%
13060001	Pecos Headwaters	3,481	665	19.1%
14080103	Blanco Canyon	1,714	17	1.0%
	Total	18,086	2,626	

For the purposes of this assessment report for Forest Plan Revision (FPR), the following HUCs are used to organize and describe the data; the sub-basin (HUC8), watershed (HUC10) and sub-watershed (HUC12) scales (table 20). The watershed will be used as the context scale. The Santa Fe NF boundary will be used as the plan and local scales.

Table 20. Comparison of Santa Fe NF to HUCs

Hydrologic Unit/Santa Fe NF	Area Covered (Acres)	% of Santa Fe NF Covered
Sub-basin	11,600,000	14.5%
Watershed/sub-watershed (Context)	5,800,000	29%
Santa Fe NF(Plan and Local)	1,680,000	100%

Thirty-seven watersheds (and the 236 sub-watersheds they contain) lie completely or partially within the Santa Fe NF boundary (figure 14). The areal extent of these watersheds was used to evaluate the water resources and water-related resources both on and off the Santa Fe NF. Data were compiled for the entire watershed and for that portion of the watershed that covers the Santa Fe NF only. Sub-watersheds were used in determining the degree of potential risk to compromised system integrity for surface water key characteristics and in the Watershed Condition Class analysis.

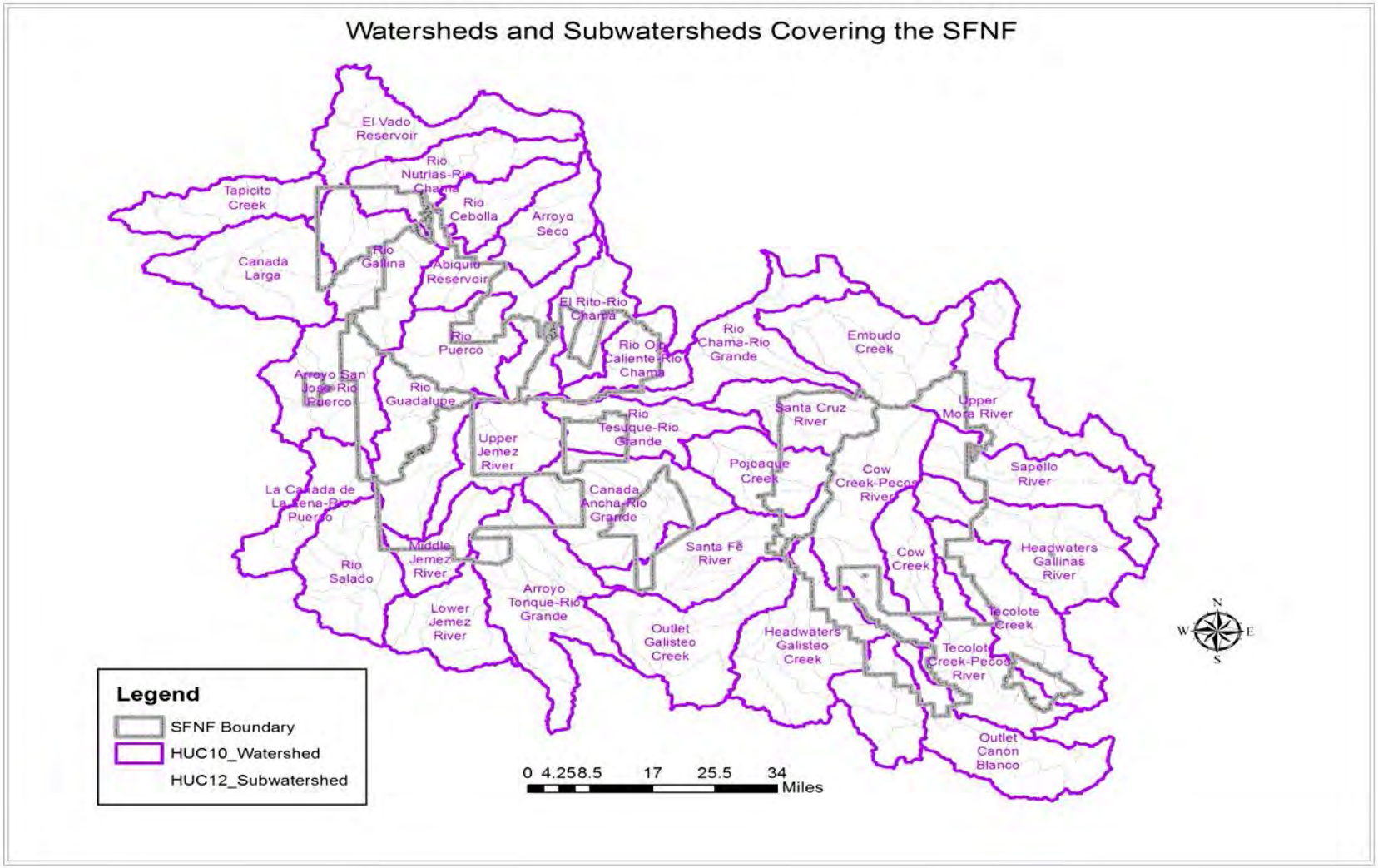


Figure 14. Watersheds and sub-watersheds covering the Santa Fe NF
This map displays the extent of the 37 watersheds and the 236 sub-watersheds and the Santa Fe NF boundary. In most cases, key characteristic data were analyzed at the watershed scale. Sub-watersheds were used in determining potential risk for surface water key characteristics and in the watershed condition class analysis. The watersheds are labeled.

Disturbances on the Santa Fe NF

The SFNF has been subject to natural and anthropogenic disturbances for centuries. Droughts, wildfires, flooding and insects/disease are some of the main natural disturbances, while past road and trail construction, grazing, developed recreation and water withdrawals are some key human-related impacts that have been occurred on the Forest since its establishment in 1915.

To help understand some of the current conditions of these disturbances at the plan/local scale, the ponderosa pine and mixed conifer frequent-fire (MCD) forests, maintenance level 2 roads (open for use by high-clearance vehicles), water-related range developments and impaired perennial stream miles are presented in table 21. At the plan scale (collectively all NFS lands within the SFNF boundary), 50% of the total acres (or approximately 834,000 acres) occur as ponderosa pine or MCD forests. As reported in Chapter 1, these forests are highly departed from their historic range of variation in large part due to the agency's ability to suppress wildfires effectively during the 20th century.

Table 21. Disturbances to water resources on the Santa Fe NF

Sub-basin Watershed	Watershed Acres	PPF & MCD[4] (Acres)	Wildfire[5] (Acres)	Approx. Net PPF & MCD (Acres)	PPF & MCD % Watershed	Roads[6] (miles)	Range Water Develop. (count)	Impaired Perennial Stream (miles)
Blanco Canyon	**10,543**	**5,239**	**0**	**5,239**	**1%**	**53**	**23**	**0**
Canada Larga	7,912	4,112	0	4,112	52%	48	21	0
Tapicito Creek	2,631	1,127	0	1,127	43%	5	2	0
Jemez	**266,076**	**174,073**	**2767**	**171,306**	**22%**	**849**	**299**	**129**
Lower Jemez River	1,083	390	0	390	36%	2	3	0
Middle Jemez River	51,736	26,717	746	25,971	50%	114	44	14
Rio Guadalupe	168,658	120,639	657	119,982	71%	654	216	79
Rio Salado	2,465	1,283	0	1,283	52%	5	2	0
Upper Jemez River	42,133	25,043	1,363	23,680	56%	74	34	37
Mora	**73,592**	**36,549**	**0**	**36,549**	**5%**	**91**	**15**	**0**
Sapello River	42,222	22,829	0	22,829	54%	31	6	0
Upper Mora River	31,370	13,720	0	13,720	44%	60	9	0
Pecos Headwaters	**425,894**	**181,190**	**6,245**	**174,945**	**23%**	**1,300**	**195**	**59**
Cow Creek	76,946	38,392	449	37,943	49%	349	10	30
Cow Creek-Pecos River	184,573	77,245	5,796	71,448	39%	292	22	24
Headwaters Canon Blanco	22,706	1,796	0	1,796	8%	176	46	0
Headwaters Gallinas River	32,980	16,862	0	16,862	51%	25	4	0
Outlet Canon Blanco	21,907	4,713	0	4,713	22%	123	30	0
Tecolote Creek	45,477	26,068	0	26,068	57%	165	57	1
Tecolote Creek-Pecos River	41,306	16,114	0	16,114	39%	171	26	4
Rio Chama	**474,945**	**227,981**	**12,361**	**215,620**	**28%**	**1,487**	**473**	**69**
Abiquiu Reservoir	106,106	47,270	2,265	45,005	42%	317	89	29
Arroyo Seco	0	0	0	0	0%	0	0	0

[4] Ponderosa Pine Forest (PPF) and Mixed Conifer – Frequent Fire (MCD), see chapter 1(Vegetation) for more information.
[5] Moderate and high soil burn severity (acres from Burned Area Reflectance Classification – (BARC) mapping) for years 2010 to 2014.
[6] Specific to Operation Maintenance Level 2 roads.

Sub-basin Watershed	Watershed Acres	PPF & MCD[4] (Acres)	Wildfire[5] (Acres)	Approx. Net PPF & MCD (Acres)	PPF & MCD % Watershed	Roads[6] (miles)	Range Water Develop. (count)	Impaired Perennial Stream (miles)
El Rito-Rio Chama	34,529	5,163	4,098	1,065	3%	60	26	3
El Vado Reservoir	201	153	0	153	76%	0	0	0
Rio Cebolla	321	218	0	218	68%	0	0	0
Rio Gallina	138,944	88,666	0	88,666	64%	470	187	12
Rio Nutrias-Rio Chama	35,402	26,916	0	26,916	76%	171	39	0
Rio Ojo Caliente-Rio Chama	56,086	8,709	4,286	4,423	8%	45	21	16
Rio Puerco	103,356	50,887	1,712	49,174	48%	423	111	9
Rio Grande-Santa Fe	**214,549**	**97,505**	**35,290**	**62,216**	**8%**	**542**	**153**	**9**
Arroyo Tonque-Rio Grande	34,582	26,705	10,589	16,116	47%	76	33	0
Canada Ancha-Rio Grande	99,366	38,510	24,701	13,809	14%	199	55	3
Headwaters Galisteo Creek	44,016	15,994	0	15,994	36%	217	49	4
Outlet Galisteo Creek	614	614	0	614	100%	6	0	0
Santa Fe River	35,971	15,682	0	15,682	44%	44	16	2
Rio Puerco	**63,499**	**39,334**	**0**	**39,334**	**5%**	**225**	**31**	**12**
Arroyo San Jose-Rio Puerco	58,027	37,184	0	37,184	64%	208	31	12
La Canada de La Lena-Rio Puerco	5,471	2,150	0	2,150	39%	17	0	0
Upper Rio Grande	**151,816**	**72,009**	**14,762**	**57,247**	**8%**	**138**	**4**	**5**
Embudo Creek	25	1	0	1	4%	0	0	0
Pojoaque Creek	46,041	21,565	6,101	15,464	34%	22	0	5
Rio Chama-Rio Grande	3,277	1,078	202	876	27%	7	1	0
Rio Tesuque-Rio Grande	32,642	21,614	4,934	16,680	51%	59	1	0
Santa Cruz River	69,832	27,751	3,524	24,227	35%	50	2	0
Watershed Totals	**1,680,914**	**833,881**	**71,425**	**762,456**	**100%**	**4,685**	**1,193**	**284**

When looking at wildfires greater than 10 acres in size on the SFNF between 1970 and 2013 (based on GIS analysis), approximately 309,000 acres have burned. Some of these fires burned the same piece of ground more than once. When not double counting those acres, nearly 264,000 acres or 16% of the SFNF has burned during this time period. Since 2010 approximately 140,000 acres have burned (45% of the 309,000 total). Of this amount, 71,000 acres (mostly ponderosa pine and MCD forests) burned that resulted in a moderate to high soil burn severity (leading to elevated rates of erosion and sedimentation). Looking to the future, a conservative estimate of 700,000 acres (adjusted for pre-2010) of ponderosa pine and MCD forests remain. These forest types cover a significant portion of 22 watersheds listed in Table 24, and these watersheds will have a greater risk of wildfire ignitions in the future.

The average fire size was 7,182 acres (or 11 square miles) between 1970 and 2013. The average fire size between 1999 and 2013 has more than doubled to 16,057 acres (or 25 square miles). As seen later in this report, both of the long-term stream gages on the SFNF experienced a steady decline in the 10-year running averages of annual stream discharge since 1999. The effect of drought on wildfires during this time period cannot be ignored.

Roads and water-related range developments also impact the watersheds on the SFNF. These are displayed in Table 21to illustrate a few examples of how the SFNF landscape has changed in providing multiple uses to the public. At the plan scale, nearly 4,700 miles of level 2 roads and 1,200 water-related range developments exist. These features impact many components of the hydrologic cycle.

In combination with other human-caused and natural disturbances, the water quality of perennial streams in many of the watersheds within the SFNF boundary have been compromised, see water quality section. As a result, approximately 24% of the perennial stream miles on the Forest have been designated by NMED as impaired.

When looking at the local scale (any watershed within the SFNF boundary), taking the Rio Guadalupe (Jemez sub-basin) as an example, approximately 71% of the watershed area is comprised of ponderosa pine and MCD forests of which nearly 750 acres have burned (which resulted in moderate to high soil burn severity). The majority of this watershed has slopes less than 30% making it quite accessible. It contains 654 miles of level 2 roads and 216 water-related range developments. Of the 155 miles of perennial streams within this watershed, 2012 NMED water quality data reports 79 of these stream miles (51%) are impaired. Some of these impairments can be directly related to the natural and human-caused disturbances.

For comparative purposes, the Headwaters Gallinas River Watershed (Pecos Headwaters sub-basin) has 51% of ponderosa pine and MCD forest cover. No significant fires have burned in this watershed since 2010. Just under 34% of this watershed has slopes less than 30% (much steeper than the Rio Guadalupe watershed) and therefore isn't as accessible. It contains 25 miles of level 2 roads and 4 water-related range developments. None of its 37 perennial stream miles are reported to be impaired based on NMED's 2012 data.

Data Used

Multiple data sources were used to evaluate the current and reference conditions of the key watershed characteristics on the Santa Fe NF (table 22). The majority of the analysis was based on these data, and the sources of these data sets are listed in the table. General and key characteristics are summarized, and how the reference condition was defined for each key characteristic is also provided.

Table 22. Watershed characteristics, data sources used, key characteristics and reference condition

General Characteristic	Source(s)	Key Characteristic(s)	Reference Condition (Defined by)
Surface Water/Streams	USGS NHD	Perennial Streams	Representativeness and Redundancy
Surface Water/Water Quality	NMED	Perennial Streams	Reference Data
Surface Water/ Waterbodies	USGS NHD	Lakes and Ponds	Representativeness and Redundancy
Surface Water/Seeps and Springs	USGS NHD	Seeps and Springs	Representativeness and Redundancy
Ground Water	NM OSE	Ground Water	Pre-European Settlement
Wetlands	USFWS NWI, UNM, NMNHP	Wetlands	Reference Data
Watershed Condition	SFNF GIS Files, Etc.	12 Indicators	Watershed Condition Rating
Water Rights	NM OSE	Water Rights	Pre-European Settlement

Note: USGS NHD = United States Geological Survey National Hydrography Dataset, NMED = New Mexico Environment Department, NM OSE = New Mexico Office State Engineer, USFWS NWI = United States Fish and Wildlife Service National Wetlands Inventory, UNM = University of New Mexico, NMNHP = New Mexico Natural Heritage Program, and SFNF GIS = Santa Fe NF Geographic Information Systems.

When a historic range of variation (HRV) is available to represent reference condition, the departure of the current condition from the HRV is used as a measure of the degree to which the integrity of that system has been altered. This measure is based on the combination of departure and trends. Reference data is available for the water quality (perennial streams) and wetlands key characteristics.

When there is no information on the HRV of a system or system characteristic, other measures are relied upon to determine the degree to which system integrity may have been or could be compromised. Two such indicators are representativeness and redundancy, and these can be used in a manner to determine the degree of potential risk to which system integrity may be compromised. As defined in the *Assessing Alternatives to the Historic Range of Variation*, representativeness evaluates whether the system under consideration contains a proportional amount of each ecosystem characteristic (e.g., perennial streams) (USDA FS 2014). Redundancy is how evenly a characteristic occurs over the landscape.

The representativeness and redundancy approach was used as a surrogate to evaluate the system integrity for perennial streams, lakes and ponds, and seeps and springs. A more detailed discussion of representativeness, redundancy and risk is presented in the discussion for these key characteristics.

Prior to the expansion of the West and to the establishment of the Santa Fe NF in 1915, the amount of surface and ground water withdrawals was a fraction of what those withdrawals are today. For the purpose of evaluating the ground water resource and water rights in and adjacent to the Santa Fe NF, this pre-1915 time period (referred to herein as 'pre-European Settlement') was used to make general statements regarding the departure of current conditions.

The Watershed Condition Classification (WCC) was used to evaluate 116 sub-watersheds on the Santa Fe NF in 2010 (USDA FS 2011). This system evaluates twelve indicators that are grouped according to four major process categories: aquatic physical, aquatic biological, terrestrial physical and terrestrial biological. The analysis of these 12 indicators results in an overall rating for each of the sub-watersheds. This rating describes if the sub-watershed exhibits a high, moderate or low geomorphic, hydrologic and biotic integrity relative to their natural potential condition.

Key Watershed Characteristics

As with many national forests, the Santa Fe NF contains many headwater streams with an overall increase in elevation over the valley floors. This higher elevation results in higher precipitation. Thus, it's not surprising that a significant portion of several key characteristics occur on the Santa Fe NF. The Santa Fe NF also offers protection from surface and ground water diversions as evidenced by the fewer number of water rights occurring on versus off the forest. A comparison of key characteristics at the context (Watershed) and plan/local (Santa Fe NF only) scales is displayed in table 23.

Table 23. Summary of key characteristics at the context and plan/local scales

Scale	Area (acres)	Perennial Streams (miles)	Ground Water Rights (count)	Lakes & Ponds (count)	Seeps & Springs (count)	Wetlands (acres)	All Water Rights (count)	Impaired Perennial Streams (miles)
Watershed (WS)	5,769,290	2,697	19,107	6,332	558	33,705	31,966	790
Santa Fe NF Only	1,680,949	1,183	2,551	704	201	7,038	3,848	284
% of WS total on Santa Fe NF	29.1%	43.9%	13.4%	11.1%	36.0%	20.9%	12.0%	35.9%

While the Santa Fe NF covers approximately 30 percent of the area at the context scale, the forest contains 44 percent of the perennial stream miles, 11 percent of the lakes and ponds, 36 percent of the seeps and springs, and nearly 21 percent of the wetland acres While all water-related resources are important, the SFNF has a proportionally higher conservation burden for sustaining perennial streams and seeps and springs.

Also at the context scale, 36 percent of the impaired perennial stream miles occur on the Santa Fe NF while the balance occur off the Forest (see Water Quality Current Conditions section of this report). Proportionally, more impaired perennial stream miles occur off the SFNF (33%). However, 24% of the perennial stream miles (284 of 1,183) on the SFNF are impaired based on NMED's 2012 water quality data. Thus the SFNF shares a considerable responsibility in improving water quality in many of these impaired reaches.

With limited water rights on NFS lands, only 12 percent of the total water rights within these 37 watersheds occur within the Santa Fe NF boundary. As seen at the context (off NFS lands) 28,000 water rights are reported in the NMSEO database. This comparison shows the importance that the SFNF plays in providing and conserving water (key ecosystem service) for the significant number of primary users off the Forest.

Key characteristics are reported at the watershed scale (table 24) and for those same watersheds within the Santa Fe NF boundary only (table 25. For any given watershed, a comparison can be made between the plan/local and context scale (table 24) to see how the characteristics vary.

Table 24. Key characteristics summarized at the context scale

Data for these characteristics are summarized by the watershed and grouped according to their sub-basin. The 37 watersheds cover nearly 5.8 million acres. Within each sub-basin, the watersheds and their corresponding percent of the sub-basin total are presented. A quick glance at any watershed will paint a picture of the water resources it contains and the reliance that humans have on these resources.

Sub-basin Watershed	**Area (acres)**	**Percentage of Watershed**	**Perennial Stream (miles)**	**Ground Water Rights (count)**	**Lakes & Ponds (count)**	**Seeps & Springs (count)**	**Wetlands (acres)**	**All Water Rights (count)**	**Impaired Perennial Stream (miles)**
Blanco Canyon	**307,534**	**5.3%**							
Canada Larga	189,991	61.8%	0.04	174	256	10	110	179	0.0
Tapicito Creek	117,543	38.2%	0.51	35	90	0	180	37	0.0
Jemez	**664,813**	**11.5%**							
Lower Jemez River	123,263	18.5%	38.90	55	49	4	2,651	55	0.0
Middle Jemez River	83,705	12.6%	47.64	356	58	20	415	638	15.4
Rio Guadalupe	171,204	25.8%	155.10	340	53	35	1,628	514	79.1
Rio Salado	158,059	23.8%	15.81	44	161	40	0	46	0.0
Upper Jemez River	128,582	19.3%	125.14	616	107	72	1,389	794	90.2
Mora	**393,076**	**6.8%**							
Sapello River	187,618	47.7%	108.88	586	353	4	15	592	27.5
Upper Mora River	205,458	52.3%	165.76	902	398	3	400	913	52.3
Pecos Headwaters	**1,112,399**	**19.3%**							
Cow Creek	81,535	7.3%	88.45	96	24	8	130	158	37.8
Cow Creek-Pecos River	222,191	20.0%	207.99	512	75	9	1,621	516	35.7
Headwaters Canon	107,250	9.6%	4.47	38	136	1	1	38	0.0
Headwaters Gallinas	200,950	18.1%	89.51	738	452	4	28	2,349	24.7
Outlet Canon Blanco	165,402	14.9%	1.16	55	223	2	39	55	0.0
Tecolote Creek	181,572	16.3%	58.32	641	336	18	373	655	28.2
Tecolote Creek-Pecos	153,501	13.8%	69.45	364	244	12	543	560	18.8
Rio Chama	**1,189,487**	**20.6%**							
Abiquiu Reservoir	168,404	14.2%	100.46	107	83	29	2,744	186	33.5
Arroyo Seco	103,524	8.7%	41.71	61	270	31	961	175	36.1
El Rito-Rio Chama	103,940	8.7%	43.63	413	38	14	892	738	12.9

Sub-basin Watershed	Area (acres)	Percentage of Watershed	Perennial Stream (miles)	Ground Water Rights (count)	Lakes & Ponds (count)	Seeps & Springs (count)	Wetlands (acres)	All Water Rights (count)	Impaired Perennial Stream (miles)
El Vado Reservoir	177,884	15.0%	83.72	130	327	26	5,678	580	30.1
Rio Cebolla	85,324	7.2%	26.90	29	274	9	199	248	0.0
Rio Gallina	179,294	15.1%	43.39	124	242	19	1,151	308	12.1
Rio Nutrias-Rio Chama	152,302	12.8%	72.02	48	358	17	1,151	156	34.6
Rio Ojo Caliente-Rio	88,598	7.4%	51.63	792	14	4	673	1,343	16.9
Rio Puerco	130,218	10.9%	102.77	137	77	26	496	306	24.3
Rio Grande-Santa Fe	**1,073,155**	**18.6%**							
Arroyo Tonque-Rio	248,840	23.2%	77.59	849	106	12	1,861	2,001	14.1
Canada Ancha-Rio	231,746	21.6%	100.96	400	54	21	2,603	496	18.3
Headwaters Galisteo	222,375	20.7%	37.85	610	241	20	35	631	25.8
Outlet Galisteo Creek	206,319	19.2%	8.19	1,827	184	11	158	1,828	17.2
Santa Fe River	163,877	15.3%	56.86	2,086	127	10	402	2,090	12.2
Rio Puerco	**276,384**	**4.8%**							
Arroyo San Jose-Rio	164,269	59.4%	87.49	252	277	12	682	396	27.8
La Canada de La Lena-	112,115	40.6%	20.82	54	159	4	343	54	0.0
Upper Rio Grande	**752,442**	**13.0%**							
Embudo Creek	205,051	27.3%	223.54	112	94	15	474	115	43.4
Pojoaque Creek	123,993	16.5%	88.37	3,036	161	4	623	4,963	8.9
Rio Chama-Rio Grande	177,912	23.6%	74.65	1317	108	9	1,879	1,913	0.0
Rio Tesuque-Rio Grande	128,714	17.1%	54.93	392	101	6	994	396	0.0
Santa Cruz River	116,773	15.5%	122.82	779	22	17	186	4,944	12.1
Grand Total	**5,769,290**	**100.0%**	**2,697.4**	**19,107**	**6,332**	**558**	**33,705**	**31,966**	**789.9**

Table 25. Key characteristics summarized for the plan/local scale (Santa Fe NF only)

Data for these characteristics within the Santa Fe NF are summarized by the watershed and grouped according to their sub-basin. A quick glance at any watershed within the Santa Fe NF will paint a picture of the water resources it contains and the reliance that humans have on these resources. For any given watershed, a comparison can be made between the plan/local and context scale (table 24) to see how the characteristics vary.

Sub-basin Watershed	Area (acres)	% of Watershed	Perennial Stream (miles)	Ground Water Rights (count)	Lakes & Ponds (count)	Seeps & Springs (count)	Wetlands (acres)	All Water Rights (count)	Impaired Perennial Stream (miles)
Blanco Canyon	**10,566**								
Canada Larga	7,929	75.0%	0.00	6	5	0	3	6	0.0
Tapicito Creek	2,638	25.0%	0.02	0	1	0	0	0	0.0
Jemez	**266,075**								
Lower Jemez River	1,083	0.4%	0.00	0	1	0	1	0	0.0
Middle Jemez River	51,736	19.4%	32.13	220	13	11	59	422	13.5
Rio Guadalupe	168,657	63.4%	154.59	340	53	35	1,627	514	78.7
Rio Salado	2,465	0.9%	0.79	0	0	1	0	0	0.0
Upper Jemez River	42,133	15.8%	50.04	570	14	24	49	743	37.1
Mora	**73,592**								
Sapello River	42,222	57.4%	43.89	115	38	1	15	115	0.0
Upper Mora River	31,370	42.6%	34.79	27	45	0	400	27	0.0
Pecos Headwaters	**425,894**								
Cow Creek	76,946	18.1%	80.00	74	23	8	97	136	29.5
Cow Creek-Pecos River	184,573	43.3%	173.91	158	47	7	1,248	161	24.0
Headwaters Canon Blanco	22,706	5.3%	4.22	4	13	0	1	4	0.0
Headwaters Gallinas River	32,980	7.7%	37.49	42	14	2	28	86	0.5
Outlet Canon Blanco	21,907	5.1%	0.00	9	27	0	6	9	0.0
Tecolote Creek	45,477	10.7%	18.13	16	24	3	46	29	1.2
Tecolote Creek-Pecos River	41,306	9.7%	25.06	9	26	2	44	10	3.8
Rio Chama	**474,961**								
Abiquiu Reservoir	106,106	22.3%	73.10	25	23	27	766	84	29.3
Arroyo Seco	0	0.0%	0.00	0	0	0	0	0	0.0

Sub-basin Watershed	Area (acres)	% of Watershed	Perennial Stream (miles)	Ground Water Rights (count)	Lakes & Ponds (count)	Seeps & Springs (count)	Wetlands (acres)	All Water Rights (count)	Impaired Perennial Stream (miles)
El Rito-Rio Chama	34,529	7.3%	14.37	127	14	3	197	153	3.2
El Vado Reservoir	201	0.0%	0.00	0	0	0	0	0	0.0
Rio Cebolla	321	0.1%	1.09	0	0	0	0	0	0.0
Rio Gallina	138,961	29.3%	40.59	83	98	19	491	264	11.8
Rio Nutrias-Rio Chama	35,402	7.5%	11.98	9	27	4	421	13	0.0
Rio Ojo Caliente-Rio Chama	56,086	11.8%	19.47	308	7	2	25	311	15.9
Rio Puerco	103,356	21.8%	76.32	56	49	26	418	201	9.0
Rio Grande-Santa Fe	**214,548**								
Arroyo Tonque-Rio Grande	34,582	16.1%	26.28	0	1	1	0	0	0.0
Canada Ancha-Rio Grande	99,365	46.3%	47.31	34	15	14	336	34	2.7
Headwaters Galisteo Creek	44,016	20.5%	0.82	36	61	1	7	37	4.5
Outlet Galisteo Creek	614	0.3%	0.00	6	0	0	0	6	0.0
Santa Fe River	35,971	16.8%	21.33	121	10	1	18	123	2.1
Rio Puerco	**63,497**								
Arroyo San Jose-Rio Puerco	58,026	91.4%	45.19	74	27	3	529	137	12.3
La Canada de La Lena-Rio Puerco	5,471	8.6%	0.00	0	0	0	0	0	0.0
Upper Rio Grande	**151,816**								
Embudo Creek	25	0.02%	0.00	0	0	0	0	0	0.0
Pojoaque Creek	46,041	30.3%	49.82	57	14	1	17	174	4.9
Rio Chama-Rio Grande	3,277	2.2%	1.13	0	0	0	0	0	0.0
Rio Tesuque-Rio Grande	32,642	21.5%	11.38	20	7	1	5	22	0.0
Santa Cruz River	69,832	46.0%	88.02	5	7	4	185	27	0.0
Grand Total	**1,680,949**	**100.0%**	**1,183.3**	**2,551**	**704**	**201**	**7038**	**3,848**	**284.1**

Surface Water (Streams, Waterbodies, Seeps and Springs, and Water Quality)

On the Santa Fe NF, surface water appears as streams, seeps and springs, and waterbodies across the 37 watersheds. Surface water is a direct result of the amount of precipitation, either as snow or rain, that falls within the watershed and that is not either intercepted by vegetation, evaporated or transpired by plants or infiltrated into the ground to replace soil moisture and recharge ground water. This excess water travels across the landscape surface filling lakes, ponds, and reservoirs and supplying water to wetlands and riparian areas and finally discharging to the stream network.

In addition to sustaining the flora and fauna of the Santa Fe NF, surface water supports many human needs. Based on the 2005 USGS Water Usage Study, the State of New Mexico diverted 1,850,300 acre-feet of surface water. Of this amount, 93.5 percent was used for irrigation, 2.8 percent for power generation, 2.3 percent for public water supply, 1.1 percent for aquaculture, 0.2 percent for livestock and 0.1 percent each used for industrial and mining purposes (USGS 2005). Based on the NM OSE's water rights database, just over 40 percent of the water rights are surface water diversions. These human impacts, erosion, and naturally occurring geochemical reactions affect the water quality of both the surface and groundwater resources.

Streams Current Condition

The stream network is important for transporting surface water and sediment (inputs) throughout the watershed. These inputs vary from year to year based on the amount of precipitation received and the existing watershed conditions (both uplands and the stream network delivery system). The distance these inputs are transported are based on the amounts supplied, the magnitude and duration of flows, and the existing channel geomorphology.

Stream types are classified by their flow characteristics into perennial, intermittent, and ephemeral. The USGS defines these stream types as:

- Perennial - Water flows year round, except in times of extreme drought.
- Intermittent - Contains water for only part of the year, but more than just after rainstorms or snowmelt.
- Ephemeral - Contains water only during or soon after rainstorms or snowmelt (USGS 2014).

The number of stream miles on the Santa Fe NF was determined from the National Hydrography Dataset (NHD) GIS layer which is maintained by the U.S. Geological Survey. This NHD layer is a "feature-based database that interconnects and uniquely identifies the stream segments or reaches that make up the nation's surface water drainage system (USGS 2013)." These data were used to calculate the miles of intermittent and ephemeral streams and perennial streams at the watershed scale and on the Santa Fe NF (table 26 and figure 15).

Table 26. Stream miles at watershed and Santa Fe NF scales

Scale	Intermittent and Ephemeral	Perennial	Total
Watershed	20,328	2,697	23,025
Santa Fe NF only	5,070	1,183	6,253

Using the USGS NHD stream layer, 23,025 total stream miles exist within the 37 watersheds. On the Santa Fe NF portion of these watersheds, 6,253 stream miles exist. Even though the Santa Fe NF only accounts for 29 percent of total area within these watersheds, 44 percent of the perennial stream miles occur within the boundary of the Santa Fe NF. Thus, activities occurring on the Santa Fe NF impact almost one-half of the perennial stream miles within these watersheds.

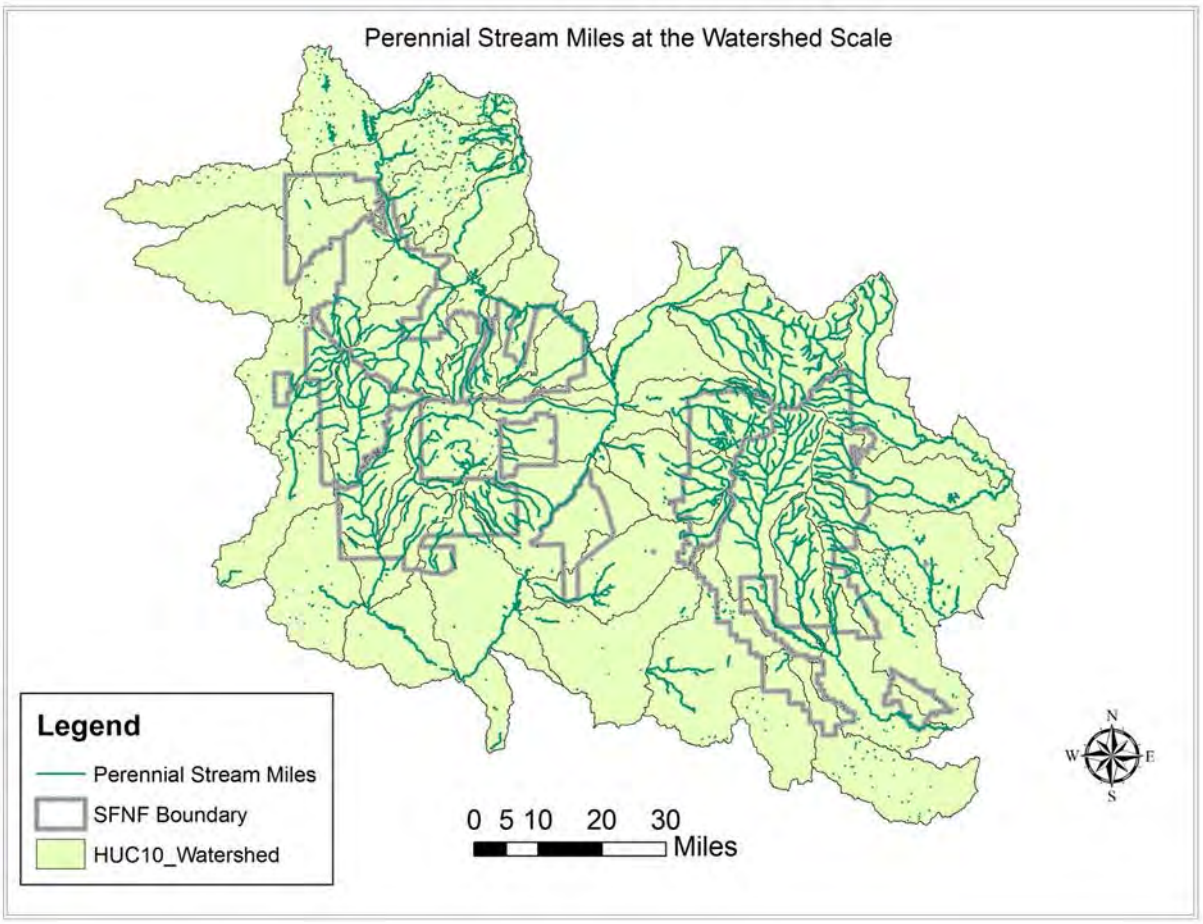


Figure 15. Occurrence of perennial stream miles on and off the Santa Fe NF
Within the Santa Fe NF, there is a higher concentration of perennial stream miles at higher (therefore wetter) elevations primarily in the Jemez and Sangre de Cristo Mountains. Several watersheds have little to no perennial stream miles.

The quantity and timing of surface water for the Santa Fe NF can best be understood by observing the streamflow records of perennial streams maintained by the U.S. Geological Survey. Two long-term stream gauges exist on the Santa Fe NF. The two gauges are:

- Pecos River near Pecos, New Mexico; station number 08378500
- Jemez River near Jemez, New Mexico; station number 08324000.

Continuous, mean annual stream flow data for the Pecos gauge (figure 16) is available from 1931 to 2014 and for the Jemez gauge (figure 17) from 1954 to 2014. These continuous reporting years will be referred to as the period of record (POR). For each gauge, the mean annual flow is displayed for each year. The flow amount is shown on the y-axis and the units are in cubic feet per second (cfs), and the years are displayed along the x-axis.

In addition, the average, mean-annual flow for the POR is displayed; this is simply the average of all the mean annual flow values. These data appear in the figures as a straight, horizontal line. By observing where each mean annual flow value falls in relation to this horizontal line, a determination can be made if the yearly value is above or below the mean-annual flow value.

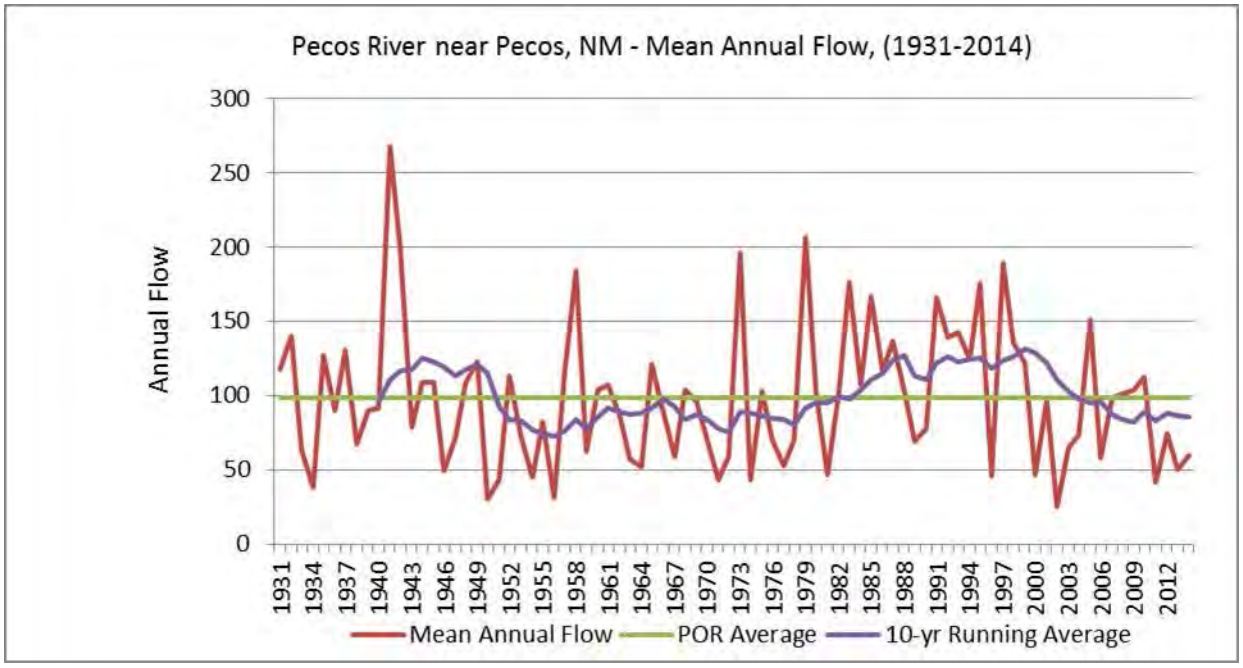


Figure 16. Pecos River near Pecos, NM – Mean Annual Flow (cfs)
The average, mean-annual flow value is 98.2 cfs. Drought periods and wet and dry cycles are also illustrated. Raw data from USGS Current Water Data website 2014; actual figure created by author.

Lastly, the 10-year running average of mean annual flow values for the POR is displayed. This running-average line in each figure allows for observing the long-term trend over the POR. When this line appears above the POR average, this time period represents a wet cycle. Conversely, when this line appears below the POR average, this time period represents a dry cycle.

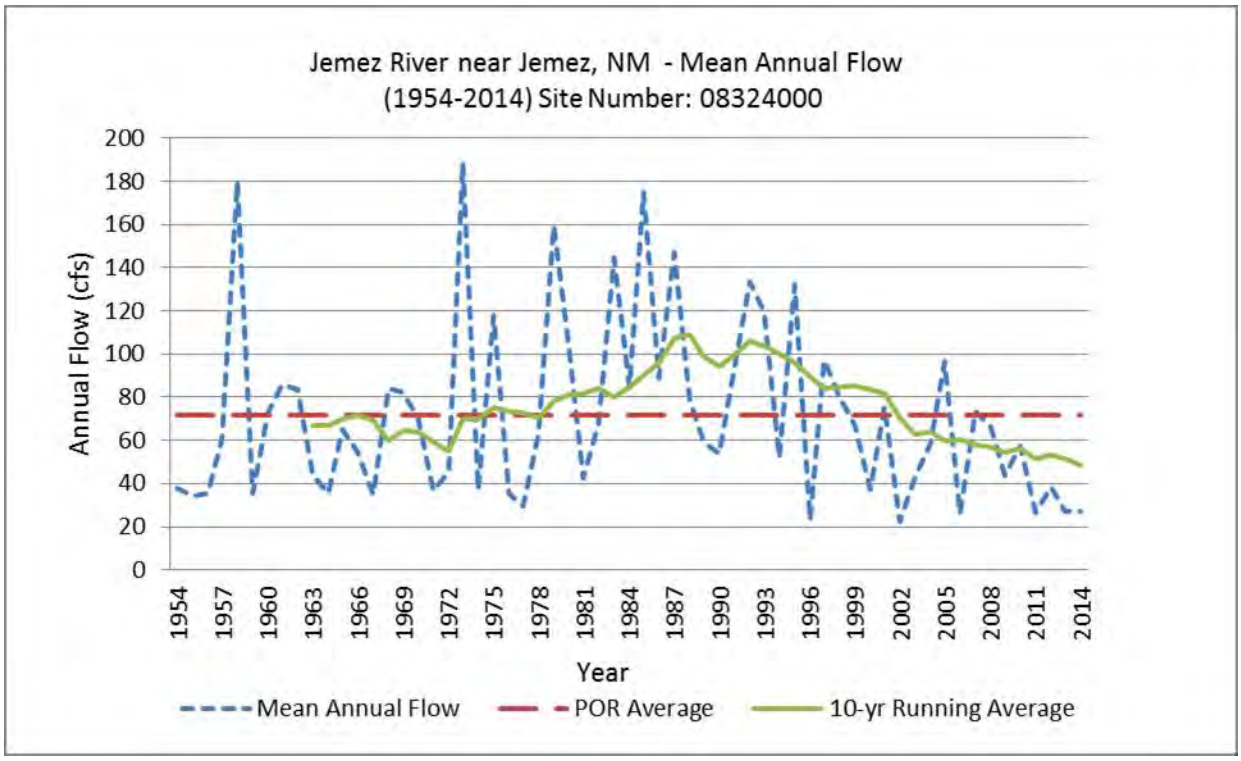


Figure 17. Jemez River near Jemez, NM – Mean Annual Flow (cfs)
The average, mean-annual flow value is 71.7 cfs. Drought periods and wet and dry cycles are also illustrated. Raw data from USGS Current Water Data website, 2014; figure created by author.

Drought periods of below-average, mean annual flow for the POR can be seen in each figure. Drought periods of three or more years have been compiled for each gauge (table 27), and similarities and variations between the two gauges can be observed.

Table 27. Drought periods for the Pecos and Jemez gauges

Pecos Gauge	Number of Years	Jemez Gauge	Number of Years
1938-1940	3	No Data	0
1953-1956	4	1954-1957	4
1962-1964	3	1963-1967	5
1969-1972	4	1970-1972	3
1976-1978	3	1976-1978	3
2000-2004	4	2002-2004	3
2011-2014	4	2008-2014	7

Reference Condition and Departure: Stream Flow

The long-term trend data for each gauge (10-year running average line in figure 16 and figure 17) was also compiled (table 28). Again some similarity between the gauges exists, yet the variation for the different geographic areas is evident. Both gauges show dry cycles (a declining trend) in excess of 10 years beginning in the early 2000s (2002 for the Jemez gauge and 2004 for the Pecos gauge).

Because stream discharge is a dynamic process, and corresponds directly to temperature and precipitation, predicting future flows is extremely difficult. Based on the POR for each gauge, wet and dry cycles can be expected into the future.

Table 28. Wet and dry cycles for the Pecos and Jemez gauges

Pecos Gauge			Jemez Gauge		
Cycle Type	**Period**	**Number of Years**	**Cycle Type**	**Period**	**Number of Years**
Wet	1941-1950	10	No data	N/A	0
Dry	1951-1981	31	Dry	1963-1974	12
Wet	1982-2003	22	Wet	1975-2001	27
Dry	2004-2014	11	Dry	2002-2014	13

Waterbodies Current Condition

Storage of water in either naturally occurring or man-made structures is a key component to the hydrologic cycle. Natural storage features such as lakes and ponds provide recreational opportunities as well as provide habitat for fish and other aquatic and plant species. Constructed storage features such as reservoirs are largely used to supply water for irrigation and/or drinking water. These features also provide for recreational opportunities and aquatic habitat, yet these are secondary benefits. Because surface water in New Mexico originates primarily in response to snowmelt and monsoonal rains, the capture of surface water is extremely important. Stored water allows for the subsequent use that would have otherwise traveled downstream.

The USGS has classified several types of storage structures in their NHD waterbodies spatial layer. These structures and their definitions follow (USGS 2014):

- Lake/pond: a standing body of water with a predominantly natural shoreline surrounded by land or a flooded river system where a dam has been built to withhold water.
- Reservoir: a constructed basin formed to contain water.
- Swamp/marsh: a non-cultivated, vegetated area that is inundated or saturated for a significant part of the year.
- Playa: The flat area at the lowest part of an un-drained desert basin, generally devoid of vegetation.

According to the USGS waterbody data, 956 acres of lakes, ponds, a playa, reservoirs, and swamps and marshes have been mapped on the Santa Fe NF. Seven hundred four lakes and ponds account for 770 acres (figure 18). There is also a 14-acre playa, 28 reservoirs averaging just under ¼-acre in size (7 acres), and 50 swamps/marshes averaging just over 3 acres (165 acres). Collectively, these 956 acres of waterbodies account for less than one-tenth of a percent of the Santa Fe NF acreage.

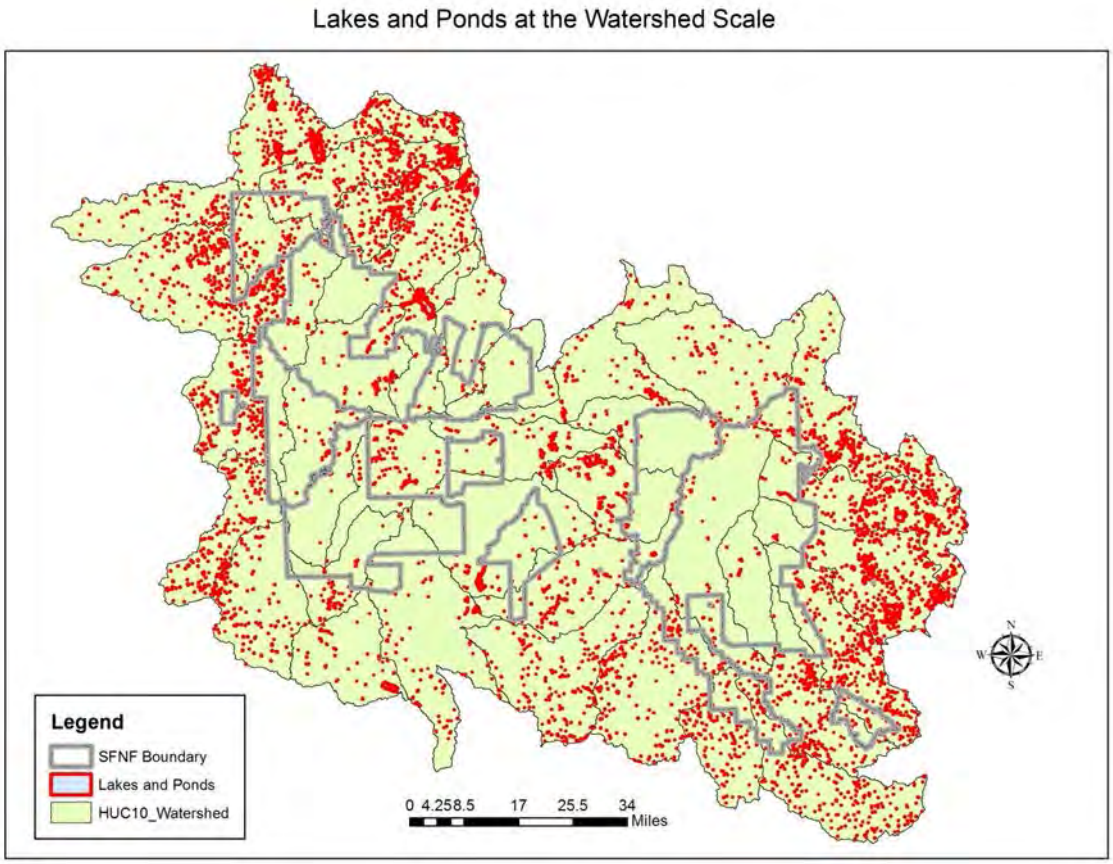


Figure 18. Occurrence of lakes and ponds on the Santa Fe NF
Storage of water is important for subsequent distribution for a variety of uses. Storage on the Santa Fe NF is limited to natural lakes and constructed ponds. Actual size of lakes is exaggerated for display purposes.

Lakes and ponds account for 95 percent of the total waterbody acreage at the watershed scale and just over 80 percent of the total waterbody acreage on the Santa Fe NF (table 29). As the predominant waterbody feature, lakes and ponds were selected as the key waterbody characteristic. Waterbody acreage of playas, reservoirs and swamps/marshes is also displayed.

Using the NHD Waterbody GIS layer, 19,300 acres of waterbodies exist at the watershed scale. Within the Santa Fe NF, nearly 1,000 acres of water bodies exist. Lakes and ponds are the dominant feature both at the watershed scale and on the Santa Fe NF. As displayed in figure 18, the vast majority of lakes and ponds occur off of the Santa Fe NF.

Table 29. Acres of waterbodieson the Santa Fe NF

Scale	Lake/Pond	Playa	Reservoir	Swamp/Marsh	Total
Watershed	18,377	195	133	633	19,338
Santa Fe NF	770	14	7	165	956

Almost 82 percent of the lakes and ponds within the Santa Fe NF are less than 1 acre in size. Nearly 16 percent of the lakes and ponds range in size from 1 acre to less than 5 acres, and less than 3 percent are greater than 5 acres in size (figure 19). In contrast, most of the 19 lakes greater than 5 acres in size are natural lakes in the Sangre de Cristo or Jemez Mountains. Two of these lakes (McClure and Nichols

Reservoirs) are used by the City of Santa Fe (Municipal Watershed) as storage vessels to supply water to the public.

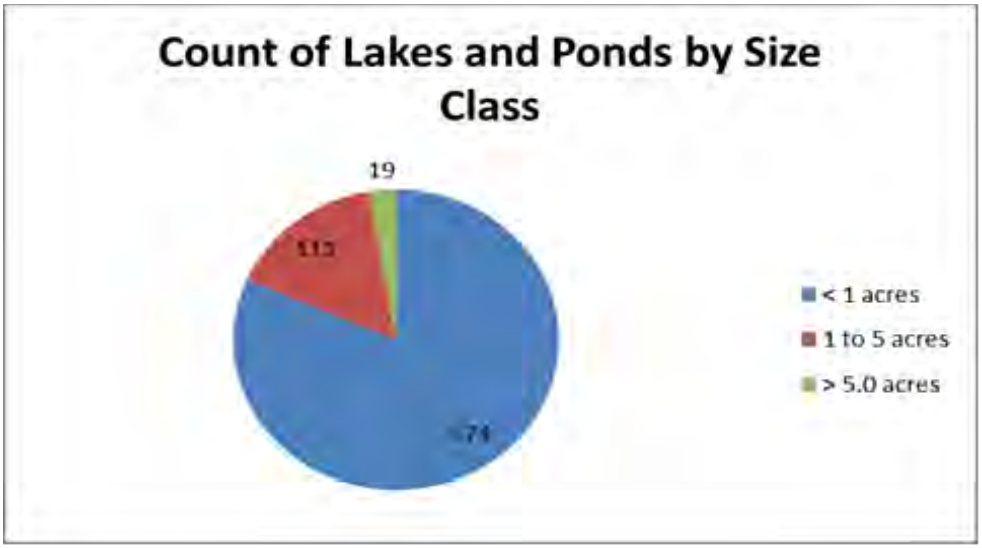


Figure 19. Count of lakes and ponds in Santa Fe NF by size class

The majority of the lakes and ponds occurring on the Santa Fe NF are less than 1 acre in size. Only 19 of the lakes and ponds are greater than 5 acres in size.

Seeps and Springs Current Condition

Seeps and springs are ground water that emanate from the ground surface. Once at the ground surface, these point sources provide surface water that can be diverted by people and applied to beneficial use or they can be left in their natural state to provide flow and support the life of the flora and fauna that are reliant upon them. Spring flow typically in one way or the other is related to the amount of precipitation that falls upon the watershed, and therefore, can be subject to seasonal variations. The water quality of springs varies depending on many factors, and they also vary by temperature (point of origin).

The USGS NHD point spatial dataset was used to quantify the number of seeps and springs at the watershed scale and on the Santa Fe NF (table 30). The USGS defines seeps and springs as a place where water issues from the ground naturally (USGS, 2014). figure 20 shows the distribution of the seeps and springs at the watershed scale. At the watershed scale, 558 springs/seeps exist. Within the Santa Fe NF, 201 springs or seeps have been mapped. The NHD point GIS layer shows a higher concentration of springs and seeps on the western portion of the Santa Fe NF (figure 20).

Table 30. Number of springs and seeps for analysis area by scale

Scale	Number of Springs and Seeps
Watershed	558
Santa Fe NF	201

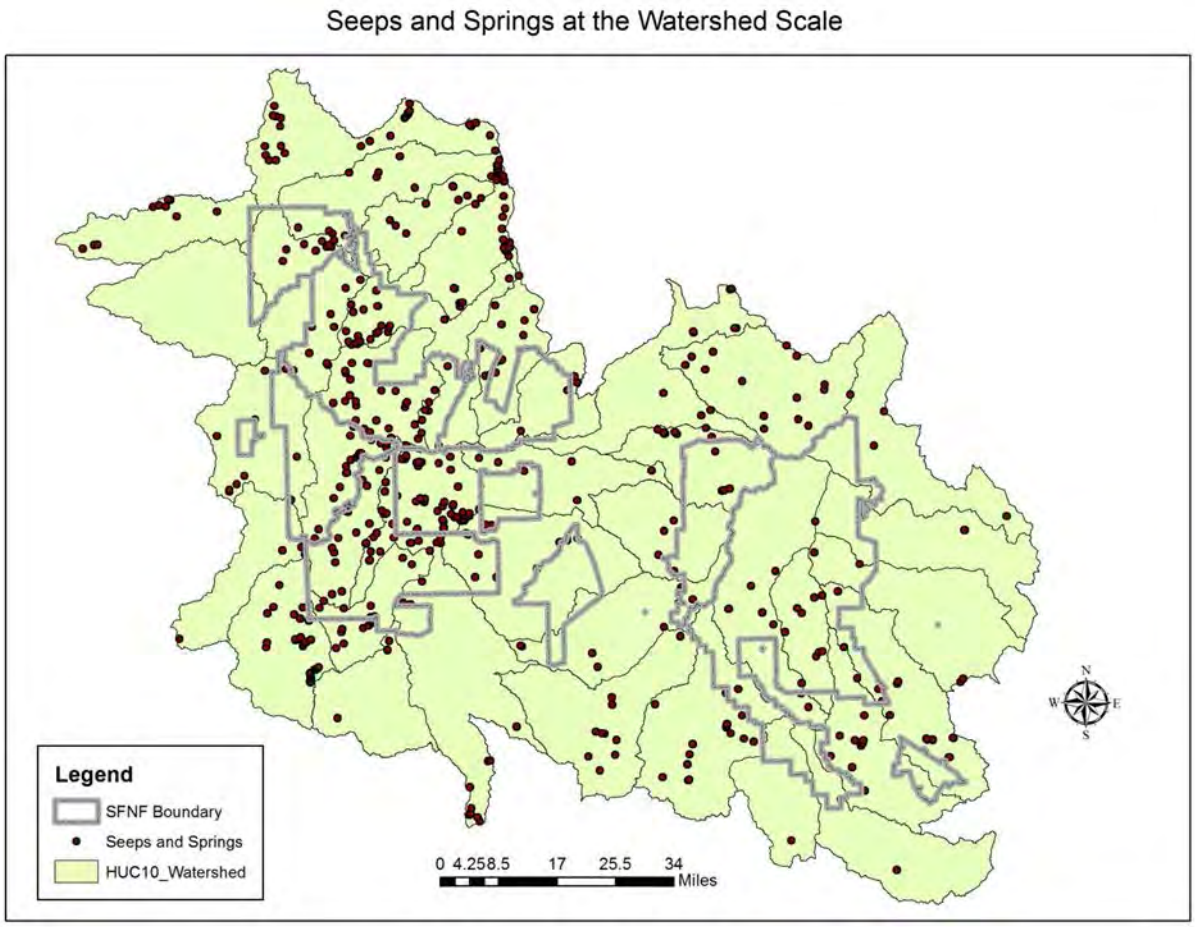


Figure 20. Occurrence of springs and seeps within Santa Fe NF boundary at the watershed scale

Springs are also used for ceremonial and recreational purposes on the Santa Fe NF. Certain springs hold sacred values to indigenous people, and hot springs are used by the public for soaking and relaxation and for spiritual healing.

Reference Condition for Perennial Streams, Lakes and Ponds, and Seeps and Springs

As defined in the *Assessing Alternatives to the Historic Range of Variation*, representativeness evaluates whether the system under consideration contains a proportional amount of each ecosystem characteristic (e.g., perennial streams) (USDA FS 2014). The representativeness of perennial streams can be described by evaluating the perennial stream component of drainage density. As defined in Dunne and Leopold's (1978) *Water in Environmental Planning*, drainage density is the length of all channels in the drainage basin divided by the basin area. Representativeness was calculated by comparing the perennial stream density of each watershed (HUC10) (miles of perennial stream divided by the area of watershed containing those perennial stream miles) covering a portion of the Santa Fe NF to the stream density calculated for that entire watershed. The resulting comparison of these stream densities is a stream density ratio.

A stream density ratio of one means the stream density of perennial streams on the Santa Fe NF is the same as the stream density of perennial streams for the entire watershed, and therefore the occurrence

both on and off the Santa Fe NF within the watershed is similar. The following representative designations were assigned for each watershed based on the stream density ratio:

- Stream density ratio equal to zero: “Not” represented.
- Stream density ratio <0.75: “Under” represented.
- Stream density ratio 0.75 to 1.25: “Proportionally” represented.
- Stream density ration >1.25: “Over” represented.

Representativeness for lakes and ponds and seeps and springs were evaluated in the same manner, yet the density was based on the count of these characteristics per unit area. The same representative designation values were assigned to the lakes and ponds and seeps and springs density ratios as were assigned to the stream density ratios.

Redundancy is how evenly a characteristic occurrences over the landscape. For each watershed, the occurrence and distribution of perennial stream miles was observed both on and off the Santa Fe NF for each sub-watershed within the watershed. Redundancy for each watershed was assigned in part by using the following ratings:

- Low redundancy: perennial stream miles do not occur in every sub-watershed within the watershed.
- Moderate redundancy: perennial stream miles occur in every sub-watershed within the watershed, but they are not evenly distributed between the sub-watersheds or are concentrated more in some sub-watersheds while rare or not present in others.
- High redundancy: perennial stream miles occur in every sub-watershed within the watershed, and they are close to evenly distributed between the sub-watersheds.

In addition, each sub-watershed was visually inspected within the watershed to see if the assigned redundancy made sense. Redundancy values assigned for each watershed, along with representativeness and risk values are reported in table 31.

This exact process was repeated for both lakes and ponds and seeps and springs.

Once representativeness and redundancy were calculated for each watershed for each of these characteristics, the potential risk to determine the degree to which system integrity maybe compromised, was assigned as low, moderate, or high. If a characteristic had a proportional density value then it was determined to be representative (yes), otherwise it was determined to be either under or over-represented (no). If a characteristic had a moderate or high redundancy, then it was determined to be redundant (yes), otherwise the characteristic was determined to have a low redundancy (no). The potential risk to compromised system integrity was determined to be low, moderate or high based on the assigned representativeness and redundancy values. A matrix was used for assigning this potential risk for the following key characteristics: perennial stream miles, lakes and ponds, and seeps and springs (figure 21). Potential risk to the compromised system integrity for these characteristics is displayed in figure 22, figure 23, and figure 24.

		Representativeness	
		Yes	No
Redundancy	Yes	Low Risk	Moderate Risk
	No	Moderate Risk	High Risk

Figure 21. Potential risk matrix
This matrix was used for assigning the potential risk to system integrity for the following key characteristics: perennial stream miles, lakes and ponds, and seeps and springs.

In general, the potential risk to compromised system integrity within the Santa Fe NF was low to moderate for perennial streams in most watersheds (figure 22). For lakes and ponds, the potential risk to compromised system integrity within the Santa Fe NF was moderate for most watersheds (figure 23). The potential risk to compromised system integrity of seeps and springs within the Santa Fe NF was high for most of the watersheds (figure 24).

Table 31. Representativeness, redundancy, and risk by watershed

*Abbreviations: Rep = representativeness, Red = redundancy, Prop = proportional, Mod = Moderate.

Watershed Count	Sub-basins/ Watershed	Perennial Streams Rep*	Perennial Streams Red*	Perennial Streams Risk	Lakes & Ponds Rep	Lakes & Ponds Red	Lakes & Ponds Risk	Seeps & Springs Rep	Seeps & Springs Red	Seeps & Springs Risk
	Blanco Canyon									
1	Canada Larga	Not	Not	None	Under	Mod*	Mod	Not	Not	None
2	Tapicito Creek	Not	Low	None	Under	Mod	Mod	Not	Low	None
	Jemez									
3	Lower Jemez River	Not	Low	None	Over	Mod	Mod	Not	Low	None
4	Middle Jemez River	Prop*	Mod	Low	Under	Low	High	Prop	Mod	Low
5	Rio Guadalupe	Prop	Mod	Low	Prop	Low	Mod	Prop	Low	Mod
6	Rio Salado	Over	Low	High	Not	Mod	None	Over	Low	High
7	Upper Jemez River	Prop	Mod	Low	Under	Mod	Mod	Prop	Mod	Low
	Mora									
8	Sapello River	Over	Low	High	Under	Mod	Mod	Prop	Low	Mod
9	Upper Mora River	Over	High	Mod	Under	Mod	Mod	Not	Low	None
	Pecos Headwaters									
10	Cow Creek	Prop	Mod	Low	Prop	Low	Mod	Prop	Mod	Low
11	Cow Creek-Pecos River	Prop	Mod	Low	Prop	Low	Mod	Prop	Low	Mod
12	Headwaters Canon Blanco	Over	Low	High	Under	Mod	Mod	Not	Low	None
13	Headwaters Gallinas River	Over	Low	High	Under	Low	High	Over	Low	High
14	Outlet Canon Blanco	Not	Low	None	Prop	Mod	Low	Not	Low	None
15	Tecolote Creek	Prop	Low	Mod	Under	Mod	Mod	Under	Low	High
16	Tecolote Creek-Pecos River	Over	Low	High	Under	Mod	Mod	Under	Low	High
	Rio Chama									
17	Abiquiu Reservoir	Prop	Mod	Low	Under	Mod	Mod	Over	Low	High
18	Arroyo Seco	Not	Low	None	Not	Mod	None	Not	Low	None

Watershed Count	Sub-basins/ Watershed	Perennial Streams Rep*	Perennial Streams Red*	Perennial Streams Risk	Lakes & Ponds Rep	Lakes & Ponds Red	Lakes & Ponds Risk	Seeps & Springs Rep	Seeps & Springs Red	Seeps & Springs Risk
19	El Rito-Rio Chama	Prop	Mod	Low	Prop	Low	Mod	Under	Low	High
20	El Vado Reservoir	Not	Mod	None	Not	Mod	None	Not	Low	None
21	Rio Cebolla	Over	Mod	Mod	Not	Mod	None	Not	Mod	None
22	Rio Gallina	Prop	Mod	Low	Under	Mod	Mod	Over	Low	High
23	Rio Nutrias-Rio Chama	Under	Mod	Mod	Under	Mod	Mod	Prop	Low	Mod
24	Rio Ojo Caliente-Rio Chama	Under	Mod	Mod	Prop	Mod	Low	Prop	Low	Mod
25	Rio Puerco	Prop	High	Low	Prop	Mod	Low	Over	Mod	Mod
	Rio Grande-Santa Fe									
26	Arroyo Tonque-Rio Grande	Over	Low	High	Under	Low	High	Under	Low	High
27	Canada Ancha-Rio Grande	Prop	Low	Mod	Under	Mod	Mod	Over	Low	High
28	Headwaters Galisteo Creek	Under	Low	High	Over	Mod	Mod	Under	Low	High
29	Outlet Galisteo Creek	Not	Low	None	Not	Mod	None	Not	Low	None
30	Santa Fe River	Over	Mod	Mod	Under	High	Mod	Under	Low	High
	Rio Puerco									
31	Arroyo San Jose-Rio Puerco	Over	Mod	Mod	Under	Mod	Mod	Under	Low	High
32	La Canada de La Lena-Rio Puerco	Not	Mod	None	Not	Mod	None	Not	Low	None
	Upper Rio Grande									
33	Embudo Creek	Not	Mod	None	Not	Low	None	Not	Low	None
34	Pojoaque Creek	Over	Mod	Mod	Under	Mod	Mod	Under	Low	High
35	Rio Chama-Rio Grande	Under	Mod	Mod	Not	Mod	None	Not	Low	None
36	Rio Tesuque-Rio Grande	Under	Mod	Mod	Under	Mod	Mod	Under	Low	High
37	Santa Cruz River	Prop	Mod	Low	Under	Mod	Mod	Under	Low	High

When looking at the potential risk of compromised system integrity of perennial streams across the 37 watersheds, 10 were assigned a low risk, 11 a moderate risk, and 7 a high risk. Nine watersheds had no risk as perennial streams were not present. The potential risk was typically low to moderate for those portions of the watersheds within the Santa Fe NF boundary. Recall that 44 percent of the total perennial stream miles occur within the Forest
boundary.

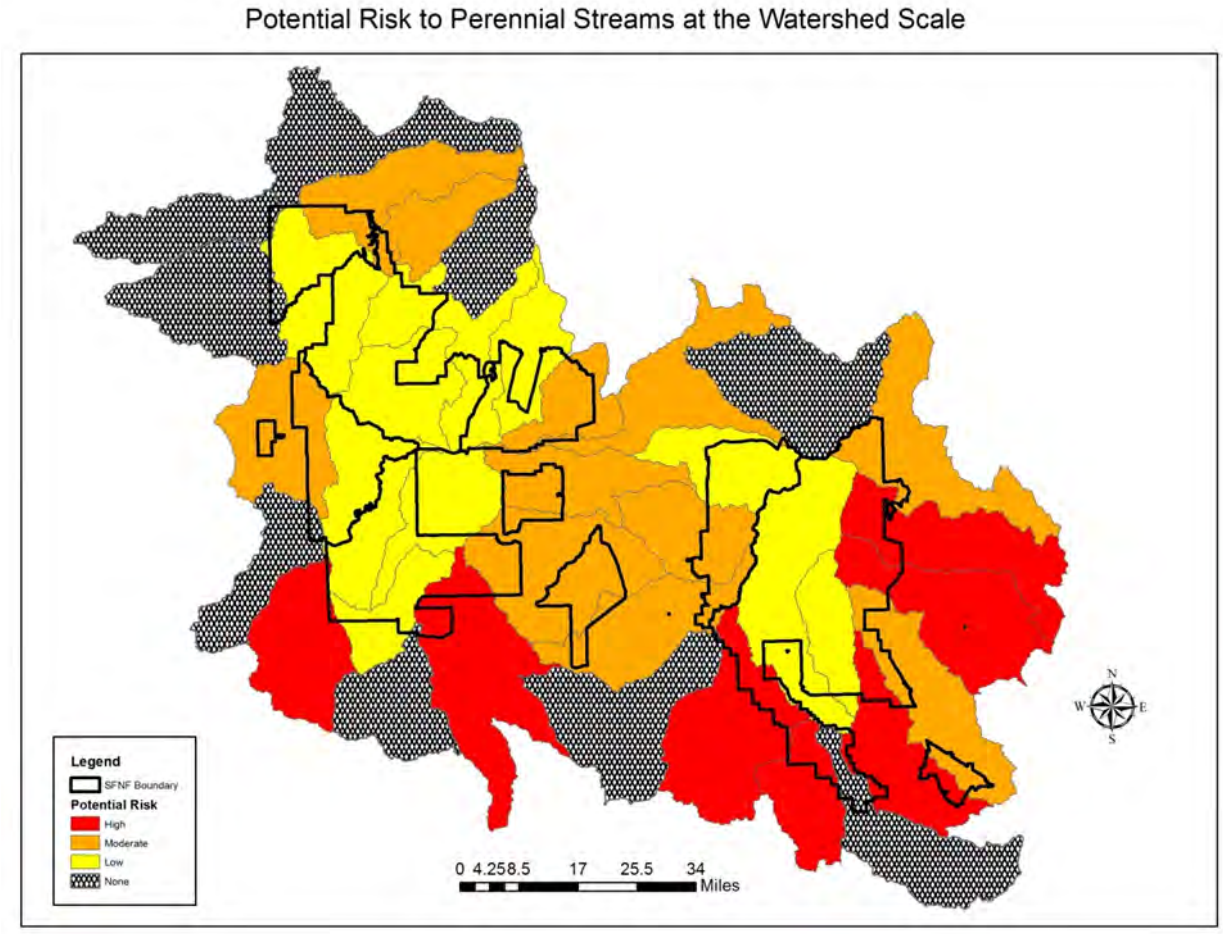


Figure 22. Potential risk of compromised system integrity for perennial stream miles by watershed

To gain a better understanding of the range of conservation burdens shared by the SFNF, three watersheds within the Jemez sub-basin were evaluated. They are: Rio Salado, Upper Jemez River and Rio Guadalupe.

As shown in table 13, the representativeness, redundancy and risk for the Rio Salado watershed is over-represented, low redundancy, and high risk, respectively. Within this watershed, less than one mile of perennial stream (out of 15.8 miles) occurs on the SFNF. When comparing the stream density ratios for this watershed (both on and off the Forest), a value of 3.2 was calculated (thus over-represented). Only 6 of the 8 sub-watersheds within the Rio Salado watershed contain perennial stream miles, and therefore this watershed was assigned a low redundancy rating. An over-represented stream density ratio and a low redundancy rating of perennial stream miles within the sub-watersheds of the Rio Salado results in a high potential risk of compromised system integrity to the 0.8 mile segment of perennial stream on the SFNF. Even though there is a high risk to this segment, the Forest has less of an overall conservation burden for the perennial streams in the Rio Salado watershed since 15 perennial stream miles occur off the SFNF.

The representativeness, redundancy and risk for the Upper Jemez River watershed is proportional, moderated redundancy, and low risk, respectively (see table 13). Fifty perennial stream miles (out of 125 miles) occurs on the SFNF. When comparing the stream density ratios for this watershed (both on and off the Forest), a value of 1.22 was calculated (thus proportional). All five of the sub-watersheds within the Upper Jemez River watershed contain perennial stream miles (not evenly distributed however), and therefore this watershed was assigned a moderate redundancy rating. A proportional stream density ratio and a moderate redundancy rating of perennial stream miles within the sub-watersheds of the Upper Jemez River watershed results in a low potential risk of compromised system integrity to the 50 miles of perennial streams on the SFNF. It is likely that all the various stream types occur both on and off the Forest, and therefore the SFNF shares in the conservation burden (approximately 40%) for sustaining these perennial stream miles.

In the last example, the representativeness, redundancy and risk for the Rio Guadalupe watershed is proportional, moderated redundancy, and low risk, respectively (see table 13). Yet nearly all of the perennial stream miles (154.6 out of 155.1 miles) occur on the SFNF. When comparing the stream density ratios for this watershed (both on and off the Forest), a value of 1.01 was calculated (thus proportional). All seven of the sub-watersheds within the Rio Guadalupe watershed contain perennial stream miles (not evenly distributed however), and therefore this watershed was assigned a moderate redundancy rating. A proportional stream density ratio and a moderate redundancy rating of perennial stream miles within the sub-watersheds of the Rio Guadalupe watershed results in a low potential risk of compromised system integrity to the 155 miles of perennial streams on the SFNF. Even though there is a low potential risk, the SFNF basically shares the entire conservation burden for sustaining the perennial stream miles within the Rio Guadalupe watershed.

The conservation burden for each remaining watershed for perennial streams can be assessed in a similar manner. Likewise, this same thought process would apply to waterbodies and seeps and springs both on and off the SFNF.

When looking at the potential risk of compromised system integrity of lakes and ponds across the 37 watersheds, 3 were assigned a low risk, 23 a moderate risk, and 3 a high risk. Eight watersheds had no risk as lakes and ponds were not present. The potential risk was typically moderate for those portions of the watersheds within the Santa Fe NF boundary. Recall that only 11 percent of the total number of lakes and ponds occur within the Forest
boundary.

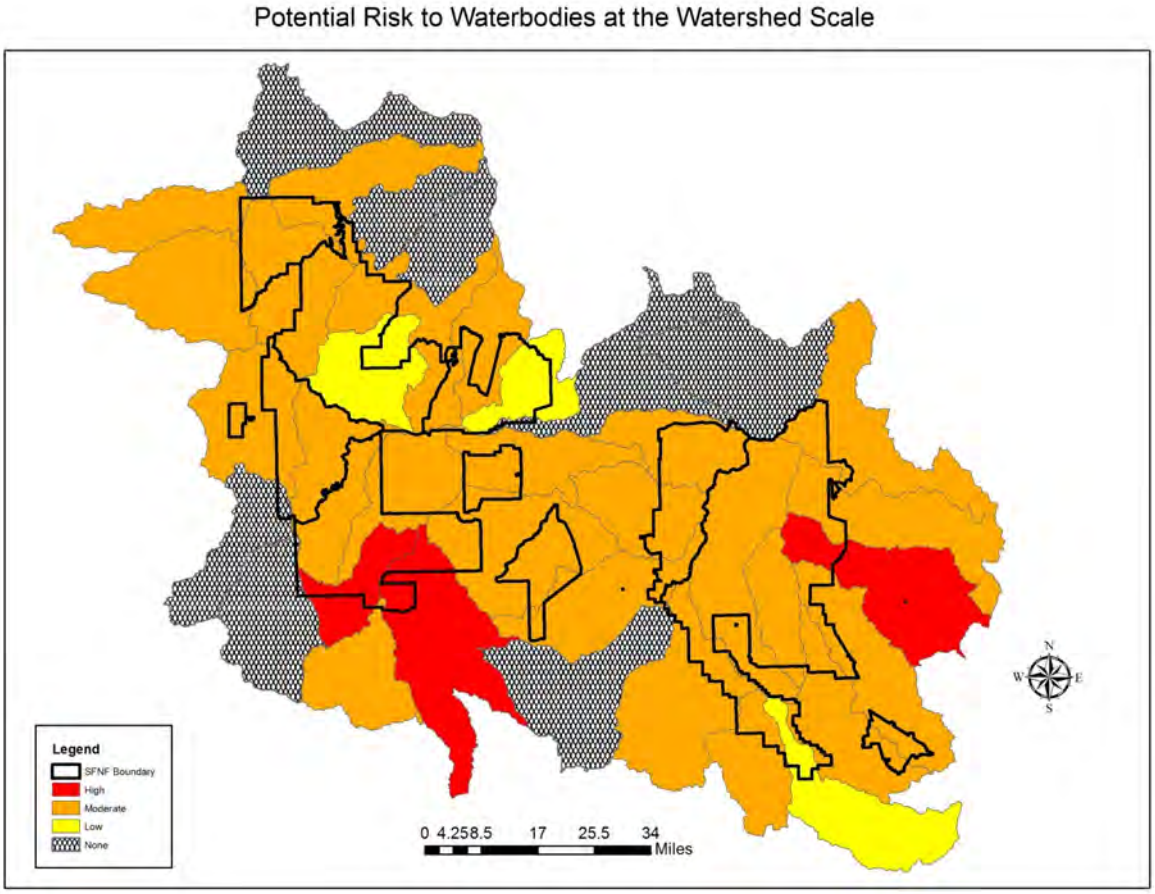


Figure 23. Potential risk of compromised system integrity to lakes and ponds by watershed

When looking at the potential risk of compromised system integrity of seeps and springs across the 37 watersheds, 3 were assigned a low risk, 6 a moderate risk and 15 a high risk. Thirteen watersheds had no risk as seeps and springs were not present. The potential risk was typically moderate to high for those portions of the watersheds within the Santa Fe NF boundary. Recall that 558 seeps and springs occur across the 37 watersheds, and 36 percent of these occur within the Forest boundary.

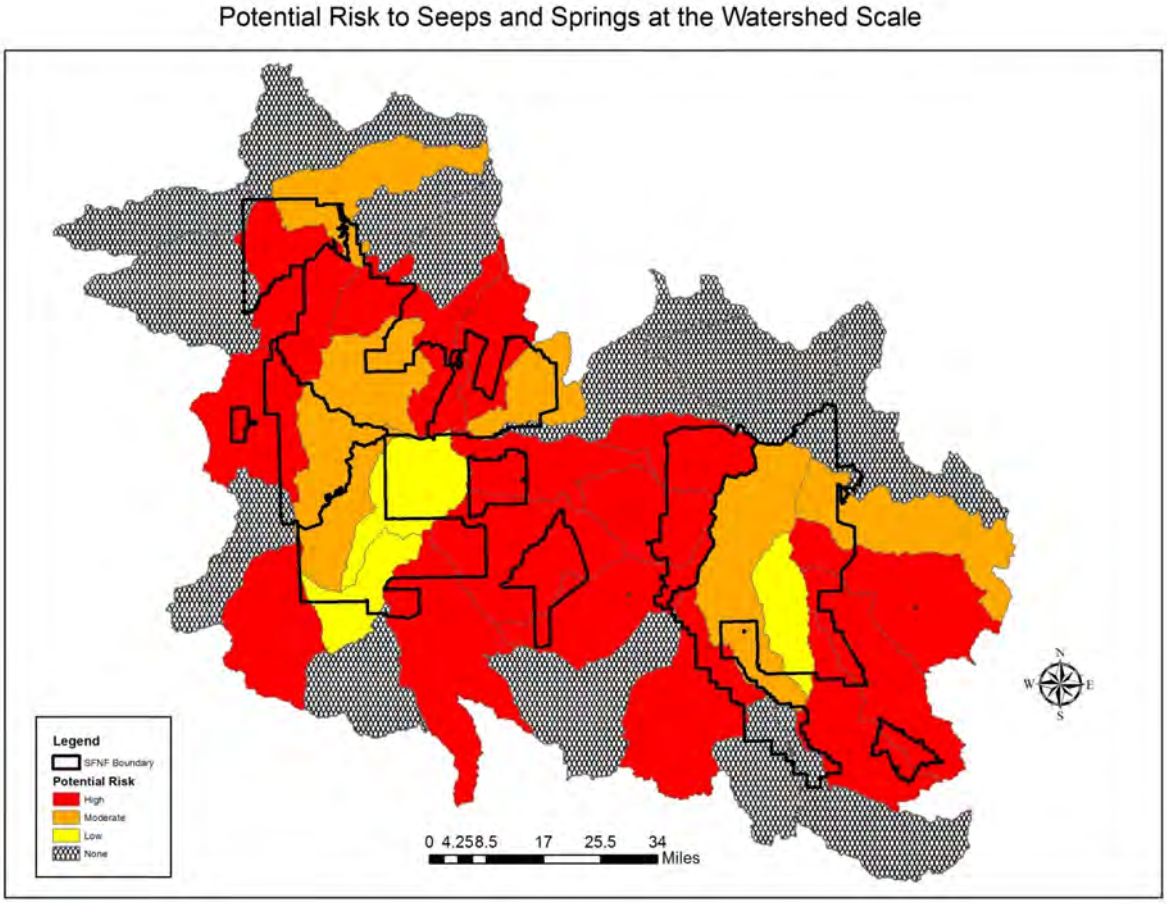


Figure 24. Potential risk of compromised system integrity to seeps and springs by watershed

Water Quality Current Conditions: Perennial Streams

The impaired perennial streams within the analysis area were identified using NMED's 2012 impaired waters GIS layer. Impaired waters are those perennial streams where a total maximum daily load (TMDL) has already been established, scheduled or underway, or being studied. Perennial streams were evaluated at the watershed scale and for those stream segments within the watershed covering the Santa Fe NF only (figure 25 and table 32).

Within the Santa Fe NF, 46 percent of the impaired waters are within the Jemez Sub-basin, 21 percent are in the Pecos Headwaters Sub-basin, 24 percent are in the Rio Chama sub-basin, the remaining 9 percent are spread across perennial streams in the Rio Grande – Santa Fe, Rio Puerco and Upper Rio Grande sub-basins. TMDLs have been established for the constituents listed and remain in effect for at least one perennial stream segment on the Santa Fe NF within the watershed.

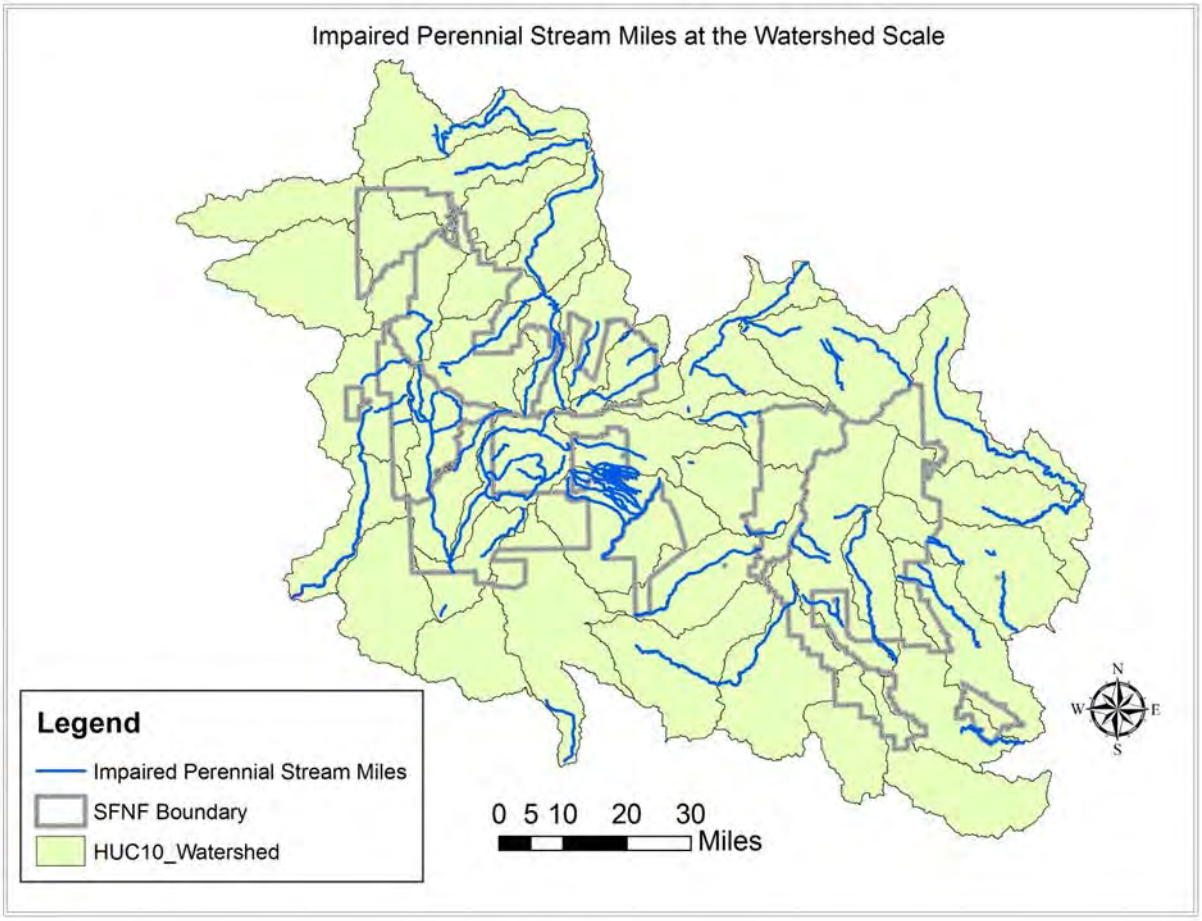


Figure 25. Impaired perennial stream miles at the watershed scale

Table 32. Summary of impaired perennial streams (miles)

Sub-basin Watershed	Watershed (Miles)	Santa Fe NF Only (Miles)	TMDLs *	Probable Sources
Jemez	**184.74**	**129.39**		
Middle Jemez River	15.39	13.54	As, B	NS, SU
Rio Guadalupe	79.11	78.73	Al, As, B, PN, SBD, Temp, TOC, Tur	Range, Rec, Rd, Rip, Etc.
Upper Jemez River	90.23	37.12	Al, As, B, PN, SBD, Temp, Tur	Range, Rec, Rd/Frd, Rip, Etc.
Mora	**79.77**	**0.00**		
Sapello River	27.45	0.00	None	NA
Upper Mora River	52.32	0.00	None	NA
Pecos Headwaters	145.28	58.98		
Cow Creek	37.80	29.53	Temp, Tur	Fire, Range, Rip
Cow Creek-Pecos River	35.73	24.00	Cd, Zn	SU
Headwaters Gallinas River	24.68	0.46	Al (dis), Temp	Range, Rip
Tecolote Creek	28.23	1.24	Not specified, further research needed	SU
Tecolote Creek-Pecos River	18.85	3.75	Not specified, further research needed	SU
Rio Chama	**200.36**	**69.15**		
Abiquiu Reservoir	33.50	29.32	Al, FC, Temp, Tur	Orv, OTS, Range, Rip, SH, SM
Arroyo Seco	36.12	0.00	None	NA
El Rito-Rio Chama	12.85	3.19	DO	OTS, Range
El Vado Reservoir	30.08	0.00	None	NA
Rio Gallina	12.08	11.82	E.Coli	SU
Rio Nutrias-Rio Chama	34.57	0.00	None	NA
Rio Ojo Caliente-Rio Chama	16.88	15.86	PCBs	SU (LANL ?)
Rio Puerco	24.28	8.97	Tur	Frd, Range, Rip, SM
Rio Grande-Santa Fe	**87.55**	**9.37**		
Arroyo Tonque-Rio Grande	14.06	0.00	None	NA
Canada Ancha-Rio Grande	18.28	2.74	Not specified, tied to LANL	WD, LF, Pdev
Headwaters Galisteo Creek	25.77	4.48	Not specified, further research needed	Range, Rip, SM
Outlet Galisteo Creek	17.22	0.00	None	NA
Santa Fe River	12.22	2.15	Nutr, SBD	Mun, OTS, Range
Rio Puerco	**27.77**	**12.34**		
Arroyo San Jose-Rio Puerco	27.77	12.34	Al, Tur	SU
Upper Rio Grande	**64.38**	**4.90**		
Embudo Creek	43.38	0.00	None	NA
Pojoaque Creek	8.89	4.90	Al	NS

Sub-basin Watershed	Watershed (Miles)	Santa Fe NF Only (Miles)	TMDLs *	Probable Sources
Rio Chama-Rio Grande	0.02	0.00	None	NA
Santa Cruz River	12.09	0.00	None	NA
Grand Total	**789.86**	**284.13**		

* Notes: Al = aluminum, As = arsenic, B = boron, Cd = cadmium, DO = dissolved oxygen, E. Coli = Escherichia coli, FC = fecal coliform, Nutr = nutrients, PCBs = polychlorinated biphenyls, PN = plant nutrients, SBD = sedimentation/siltation, Temp = temperature, TOC = total organic carbon, Tur = Turbidity, Zn = zinc.

** Probable Sources of Impairment Notes: Dev = Site clearance (land development or redevelopment), Div = Flow alterations from water diversions, Fire = Watershed runoff following forest fire, Frd = Forest roads, Imp = Upstream impoundments, LANL = Los Alamos National Lab, LF = Landfills, Mun = Municipal point source discharges, NA = Not applicable, NS = Natural sources, Orv = Off-road vehicles, OTS = On-site Treatment Systems, Pdev = Post-development erosion and sediment, Range = Rangeland grazing, Rd = Highway/road/bridge runoff, Rec = Other recreational pollution sources, Rip = Loss of riparian habitat, SH = Silviculture harvesting, SU = Sources Unknown, and WD = Inappropriate waste disposal.

TMDLs signify that the water chemistry of the waterbody is beyond a threshold that is safe for humans and/or the aquatic system as a whole. According to NMED data, 36 percent (284 of 790 miles) of the perennial stream miles within the 37 watersheds (context scale) are impaired. Within the Santa Fe NF (plan/local scale), 24 percent of the perennial stream miles are impaired based on NMED's data set.

Reference Condition and Departure: Water Quality of Perennial Streams

Any perennial stream segment that has constituents (refer to table 32 for a partial list) above naturally occurring levels is considered as departed from reference conditions. Based on NMED's 2012 impaired data, most of the perennial stream segments have been listed due to anthropogenic influences, yet some of the aluminum TMDLs are naturally occurring. Where the TMDL listing is human caused, an opportunity exists for improving the water quality to that perennial stream segment.

Ground Water

Ground Water Current Condition

Groundwater is a key component of the hydrologic cycle, and it discharges water to lakes, streams, seeps and springs, and wetlands on the Santa Fe NF (figure 26). Groundwater can be hydraulically connected to surface water, and where it is withdrawn at a rate greater than recharge can lead to a reduction of river flows, lower lake levels, and reduce or eliminate groundwater discharge to wetlands and springs. It also can influence the sustainability of drinking-water supplies and maintenance of critical ground water-dependent ecosystems.

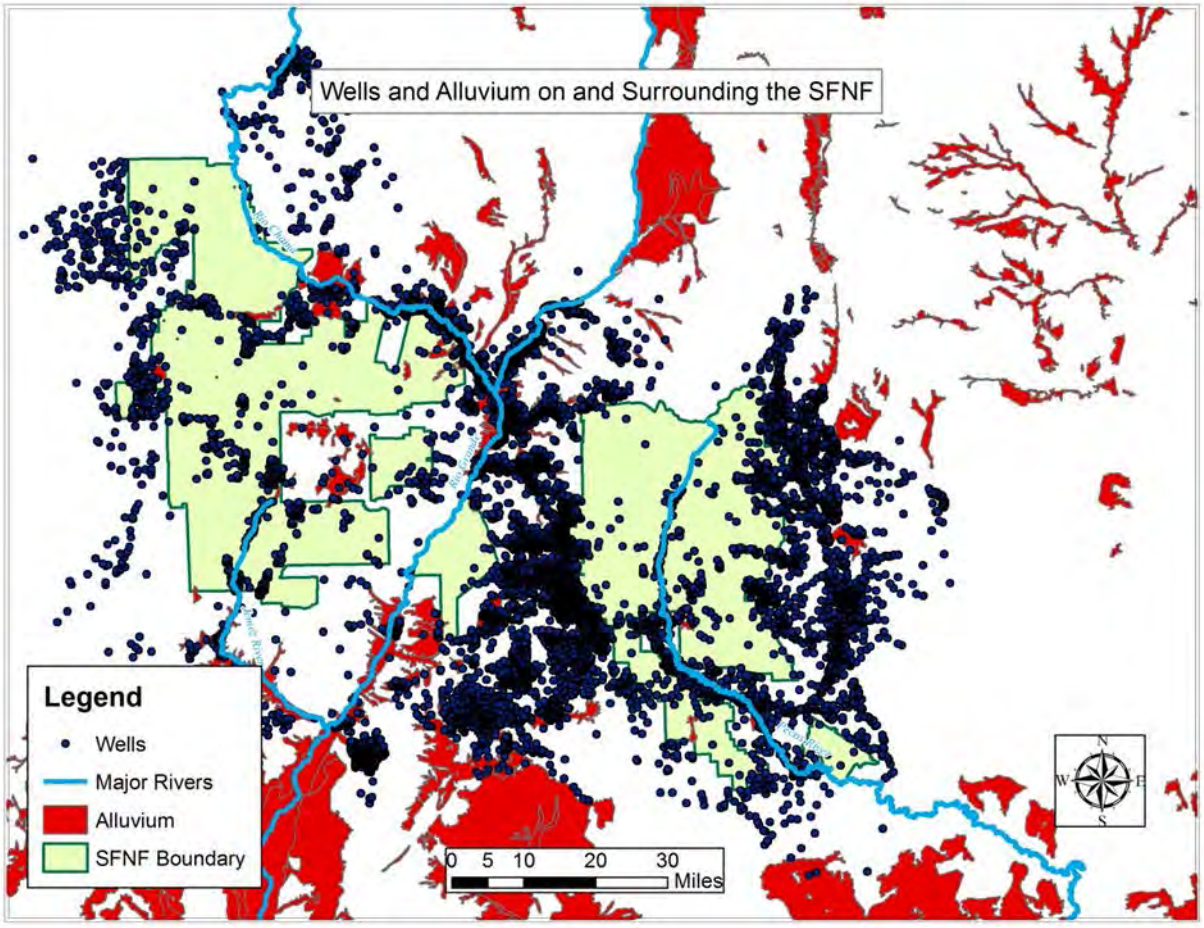


Figure 26. Wells, alluvium, and aquifers surrounding the Santa Fe NF
Raw data for alluvium and wells are from geologic map GIS coverage and NM SEO database, respectively. Figure created by author.

Alluvium (identified in red in figure 26) is a general term for all detrital deposits resulting from the operations of modern rivers, thus including the sediments laid down in river beds, flood plains, lakes and so on. These deposits often store significant amounts of groundwater. Notice the high concentration of wells (black dots) along the river corridors and in the alluvial deposits.

Recharge occurs in areas of higher precipitation, along geological faults and fractures, and in alluvial channels and floodplains. Stream diversions can reduce instream flows and aquifer recharge. In natural stream systems with a steady baseflow, long-term recharge is assumed to be in balance with spring and stream discharge from the aquifer. Even though quantitative distribution of recharge is not well known, the NM Bureau of Geology and Minerals and NM Tech are conducting a study that will look at identifying recharge areas for the State of New Mexico (NM WRRI 2014).

Areas of highest precipitation generally occur on National Forest System lands and contribute substantial recharge to aquifers both on and off the forest. Maintenance of watershed and stream conditions conducive to recharge is important in order to maintain the overall quantity and quality of groundwater.

Reference Condition and Departure: Groundwater

A high proportion of the water used on the Santa Fe NF and surrounding areas originates from groundwater. As an example, the La Cueva community and its residents (within the Santa Fe NF boundary) are reliant on groundwater (figure 27). Based on the 2005 USGS water usage study, just over 50 percent of the total water withdrawals in New Mexico were from groundwater. Groundwater is the primary source for domestic and municipal use throughout the state. Of the 80 percent of the population served by public water supplies, 87 percent of the total withdrawal is from groundwater (279,000 acre-feet/year (AF/yr). Of the 20 percent of the population whose water supply is self-supplied, 100 percent of the withdrawal is from groundwater (35,900 AF/year). Groundwater also supplies 94 percent of the livestock withdrawals (53,400 AF/yr), and 45 percent of the irrigation withdrawals (1,420,000 AF/yr) state-wide (USGS 2015).

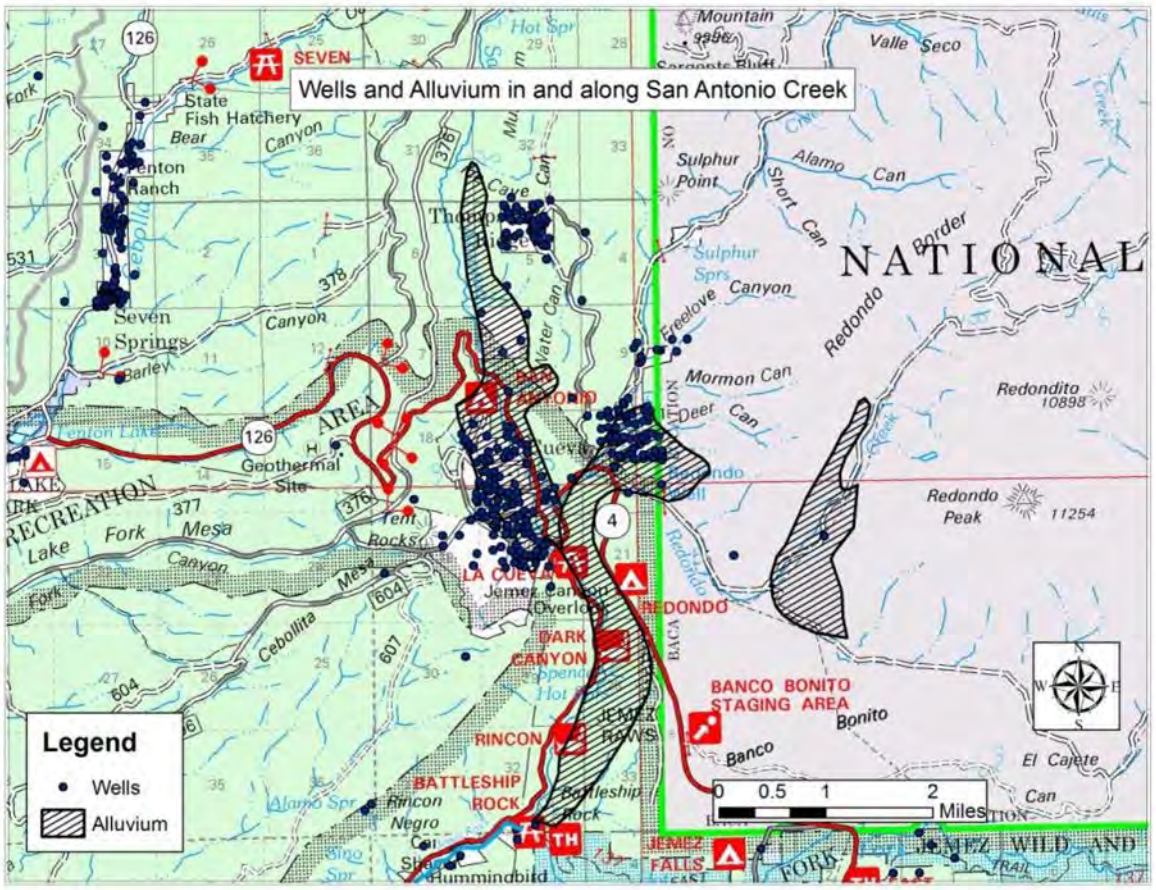


Figure 27. Wells and alluvium in and along San Antonio Creek

The alluvium along San Antonio Creek stores an ample amount of groundwater. Notice the large number of wells that exists and withdraw water from the alluvium to support the La Cueva community and its residents. Raw data for alluvium and wells are from geologic map GIS coverage and NM SEO database, respectively. Figure created by author.

Water use outside and adjacent to the Santa Fe NF is also increasing rapidly. This means that more ground water is being removed than is being recharged, also called “mining ground water” (figure 28). This results in restrictions on water supplies for new subdivisions or major commercial or agricultural uses. With the uncertainty surrounding surface water as a reliable component of the overall supply, cities are becoming even more reliant on groundwater. This additional demand will further deplete ground water.

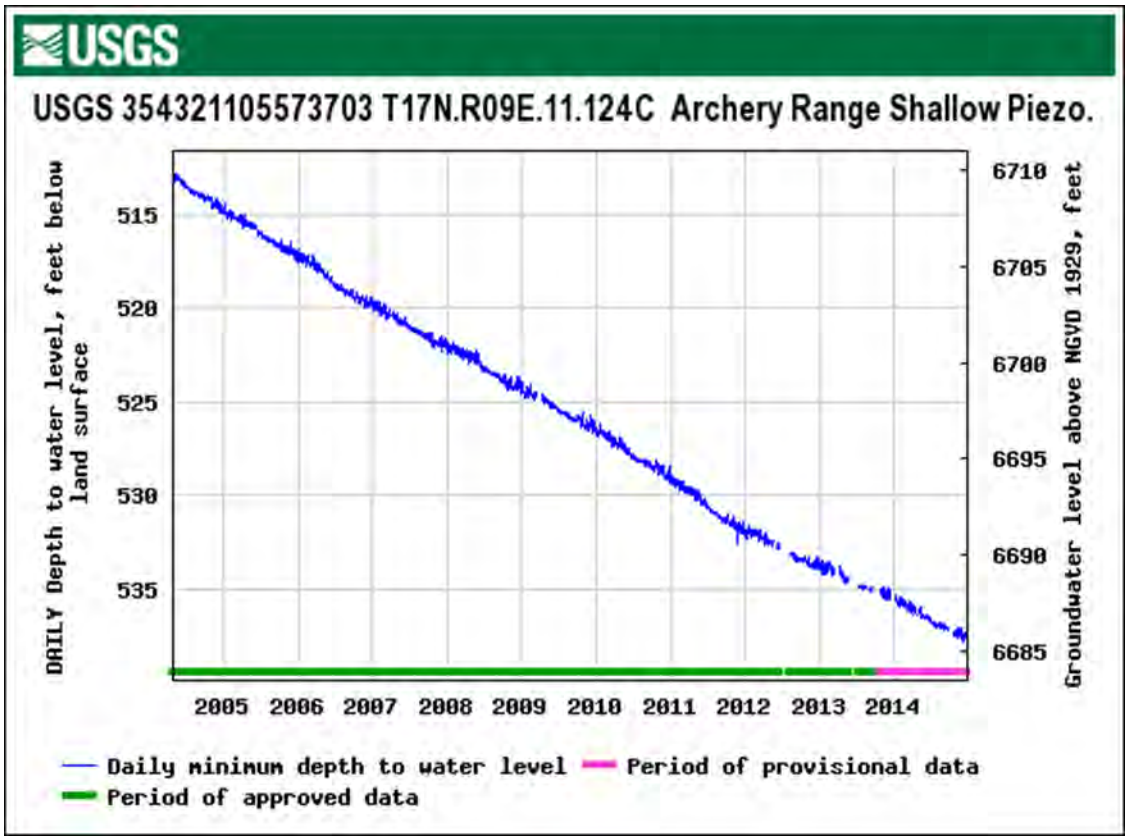


Figure 28. Water table decline in a well near Santa Fe, NM
The USGS maintains a well monitoring system with periodic measurements to evaluate changes in groundwater levels. The wells monitored are outside of the Santa Fe NF boundary in the developed urban and agricultural areas. Even though this well is off the Santa Fe NF, it demonstrates the overall decline in the water table (in this particular formation) between 2005 and 2014.

Wetlands

Wetlands Current Condition

Vegetation next to water bodies plays a major role in sustaining the long-term integrity of aquatic systems. Values provided include shade, bank stability, fish cover, woody debris input, storage and release of sediment, surface-ground water interactions, and habitat for terrestrial and aquatic plants and animals. In Arizona and New Mexico, 80 percent of all vertebrate species use riparian and wetland areas for at least half their life cycles; more than half of these are totally dependent on riparian/wetland areas (USFWS 2009). Aquatic and fish productivity are directly related to a properly functioning and healthy riparian/wetland habitat (WDFW 1995).

Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water (Cowardin et al. 1979) Wetlands are characterized by having one or more of the following three attributes: (1) at least periodically, the land supports hydrophytes, or plants that grow only in or on water; (2) the substrate is predominantly un-drained hydric soil, which are soils that are permanently or seasonally saturated by water, or (3) the substrate is non-soil and is saturated with water or covered by shallow water at some time during the growing season of each year (Cowardin et al. 1979). There are five major wetland systems: marine, estuarine, riverine, lacustrine, and palustrine.

Only riverine, lacustrine and palustrine occur on the Santa Fe NF. The riverine system includes all wetlands and deepwater habitats contained within a channel. A channel is "an open conduit either naturally or artificially created which periodically or continuously contains moving water, or which forms a connecting link between two bodies of standing water." The lacustrine system includes wetlands and deepwater habitats with all of the following characteristics: (1) situated in a topographic depression or a damned river channel, (2) lacking trees, shrubs, persistent emergents, emergent mosses or lichens with greater than 30 percent areal coverage, and (3) total area exceeds 20 acres. The palustrine system includes all non-tidal wetlands dominated by trees, shrubs, persistent emergent, emergent mosses or lichens, and all such wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 0.5 percent.

Out of the 33,700 acres of wetlands that exist within the 37 watersheds, 7,000 acres occur within the Santa Fe NF (figure 29). The National Wetlands Inventory (NWI) separates and maps these wetlands into five categories. Each category, NWI's definition (USFWS 2015) where provided and the corresponding wetland system (in parentheses) follows:

- Freshwater emergent wetlands: a herbaceous marsh, fen, swale or wet meadow (palustrine system)
- Freshwater forested/shrub wetlands: a forested swamp, wetland shrub bog or wetland (palustrine system)
- Freshwater ponds: (palustrine system)
- Lakes: a lake or reservoir basin (lacustrine system)
- Riverine: a river or stream channel (riverine system)

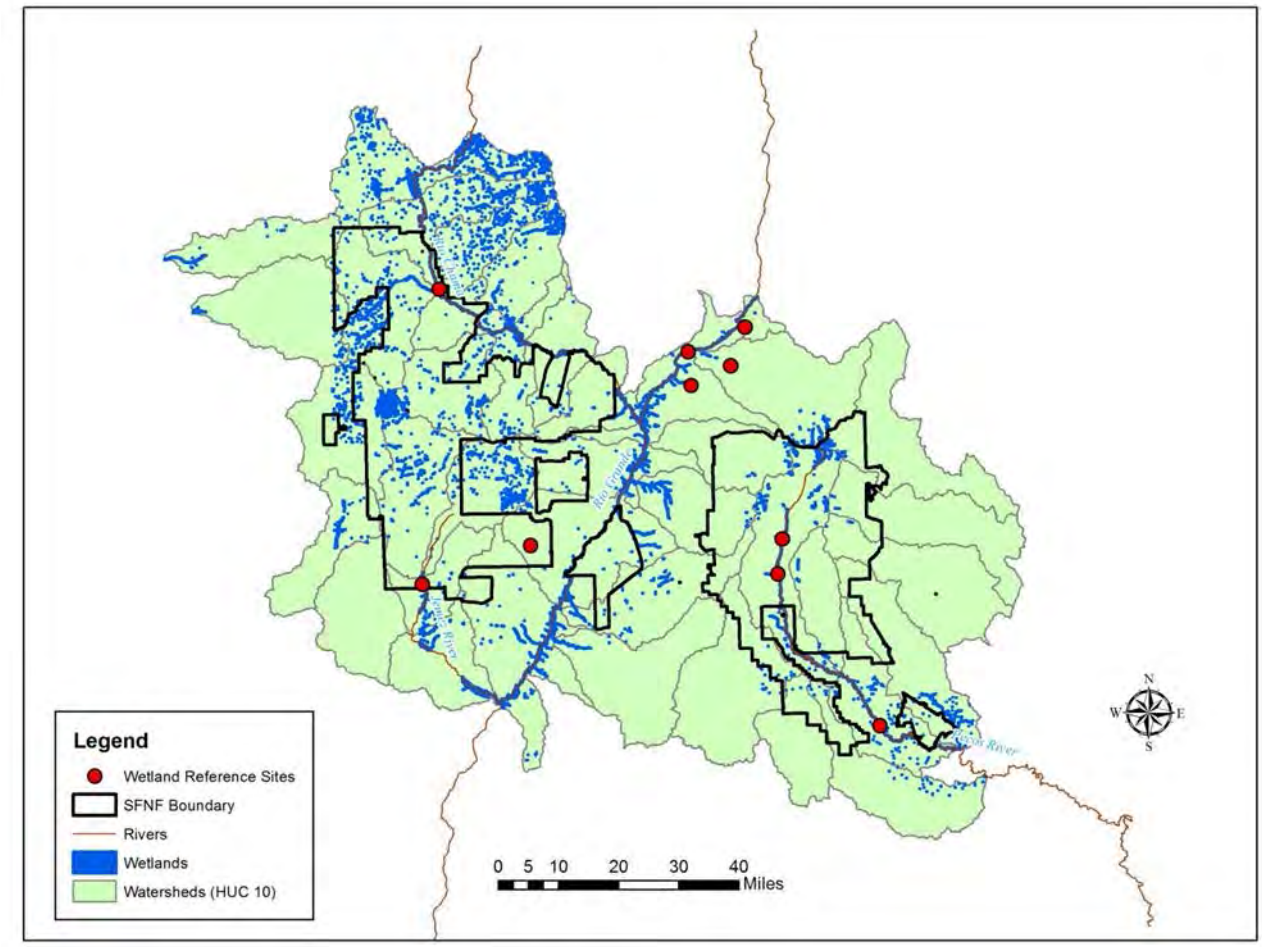


Figure 29. Occurrence of wetlands

Within the 37 watersheds, 33,705 acres of wetlands have been mapped (NWI spatial data). Of this total, 7,000 acres of wetlands exist within the Santa Fe NF. Ten reference sites are also displayed in figure 29; five of these are located on the Santa Fe NF and the other five are located off the forest. Wetlands can be seen along the rivers, around lakes and in the uplands.

At the watershed scale, slightly less than half of the wetlands fall into the palustrine system (freshwater emergent, freshwater forested/shrub or freshwater pond) (table 33). Within the Santa Fe NF, 78 percent of the wetlands are palustrine, 20 percent are riverine and the remainder are lacustrine (lakes) or other. There is a higher occurrence of lacustrine wetland systems off the Santa Fe NF as more lakes and ponds occur off of NFS lands. Riverine wetland systems account for 26 percent of the total wetlands at the watershed scale.

Table 33. Acres of wetlands at the watershed scale

Palustrine wetland systems account for a higher percentage of the wetlands on the Santa Fe NF than at the watershed scale. Lacustrine systems are more prevalent off the Santa Fe NF. Riverine wetland systems account for 26 percent and 20 percent of the total wetland acreage at the watershed and forest scales, respectively.

Scale	Freshwater Emergent Wetland	Freshwater Forested/Shrub Wetland	Freshwater Pond	Lake	Other	Riverine	Total
Watershed	9,590	5,142	1,250	8,698	355	8,670	33,705
Santa Fe NF (Plan)	4,446	775	273	86	51	1,407	7,038

Reference Condition and Departure: Wetlands

Thirty-eight wetland reference sites in New Mexico were established from a study conducted by the University of New Mexico (UNM) and the New Mexico Natural Heritage Program (NMNHP) in the early to mid-1990s, and the results were published in the Handbook of Wetland Communities of New Mexico (USEPA 1998). Ten of these reference sites are within the watersheds covering a portion of the Santa Fe NF (table 34 and figure 29); these ten sites were surveyed between 1992 and 1996. The remaining 28 reference sites are located around the state.

The ratings that were assigned to these wetlands reflect the best estimate of quality, the degree of human impact, and the wetlands potential for recovery. Ratings were based on condition factors, landscape factors and size. An explanation of the ratings (quality) used in the UNM and NMNHP study is repeated herein:

- "A" Excellent (>3.5). A diverse mosaic of natural vegetation community occurrences that are nearly undisturbed by humans, or have recovered from early human disturbance. Highest quality and condition with respect to species diversity and community structure, with ecological processes that are fully functional. Stand sizes are relatively large and are well-buffered; long-term viability is expected.

- "B" Good (2.75 to 3.5). A diverse mosaic of natural vegetation community occurrences that are still recovering from early human disturbance or have been subjected to current or recent light disturbance. Vegetation expression and ecosystem processes may have been slightly modified. In particular, some exotic species encroachment and/or reversible, small modifications to the hydrological regime may have occurred. The stand may recover to A-grade with minimum management intervention. Stand sizes are moderate and the buffer areas are adequate; long-term viability is likely, given no further environmental degradation occurs.

- "C" Fair (1.75 to 2.75). A vegetation community occurrence in the early stages of recovery or that has been significantly altered by moderate disturbance resulting in a mixed mosaic of natural vegetation communities and tracts converted to human use (agriculture, structures, roads, etc.). Vegetation expression and ecosystem processes have been significantly modified and may be declining. In particular, exotic encroachment may be significant, and/or permanent small-scale modifications to the hydrological regime may have occurred. Stand recovery to at least B-grade is still possible with proper management intervention. Size of the stand may be relatively small and/or the buffer significantly compromised; long-term viability is questionable unless declines are stopped and actively reversed.

- "D" Poor (<1.75). Highly fragmented landscapes and/or vegetation community occurrences that are severely disturbed. Species composition and structure have been greatly altered, and natural recovery is not expected. Exotics probably dominate and/or large, irreversible modifications to the hydrological regime may have occurred. Restoration and sustainability are unlikely without intensive management and/or major landscape level manipulations.

Table 34. Wetland reference sites

Name	Reach	On Forest	Quality	Survey Date
Canon	Middle Jemez	Yes	B	7/28/1994
Cochiti Canyon	Cochiti Canyon	Yes	A-	8/12/1996
Macho Canyon	Upper Pecos	Yes	B	7/21/1993
Middle Chama	Middle Chama	Yes	B-	8/11/1994
Terrero	Upper Pecos	Yes	B+	8/6/1992
Agua Caliente	Agua Caliente	No	A-	8/28/1992
Embudo	Rio Grande Gorge	No	B+	6/28/1994
Embudo Canyon	Embudo Canyon	No	A-	6/25/1994
Rio Truchas	Rio Truchas	No	B-	8/21/1992
Sena	Glorieta Mesa	No	C+	7/28/1993

All 10 of the reference sites have some level of departure from the highest rating (A+ or 4.0) (table 34). Seven of the ten sites were rated with a B+ or lower rating, and based on this study's definitions would be likened to a low to moderate departure from the best conditions. In general however, long-term viability of these sites is likely "given no further environmental degradation occurs." Three of these sites were given an A- rating suggesting a low departure from a diverse mosaic of the natural vegetation community that are nearly undisturbed by humans, or have recovered from early human disturbance.

Comparing the quality of the reference sites on and off the forest is quite similar. While each site is unique and many factors are evaluated to determine the overall ranking, if a corresponding numeric value were given to each quality rating for the five sites on and off the forest, the average overall quality for both sets of five reference sites would be a "B" (good rating). It should also be noted that these sites were surveyed between 1992 and 1996. Because these reference sites, like all of the landscape are subject to natural and human disturbances, a periodic re-assessment is necessary. For example, the Las Conchas Fire of 2011 burned much of the land above the Cochiti Canyon site, so this reference site would need to be re-evaluated.

Watershed Condition

Watershed Current Conditions

In 2007, the National Watershed Condition Team was formed and tasked with the development of a nationally consistent, science-based approach to classify the condition of all the NFS watersheds and to develop performance-based outcome measures for watershed restoration. The team evaluated alternative approaches for classifying watersheds and developed the watershed condition classification (WCC) system (USDA FS 2011).

The WCC system offers a systematic, flexible means of classifying watersheds based on a core set of national watershed condition indicators (USDA FS 2011). The 12 indicators are grouped according to four major process categories: aquatic physical, aquatic biological, terrestrial physical and terrestrial biological (figure 30).

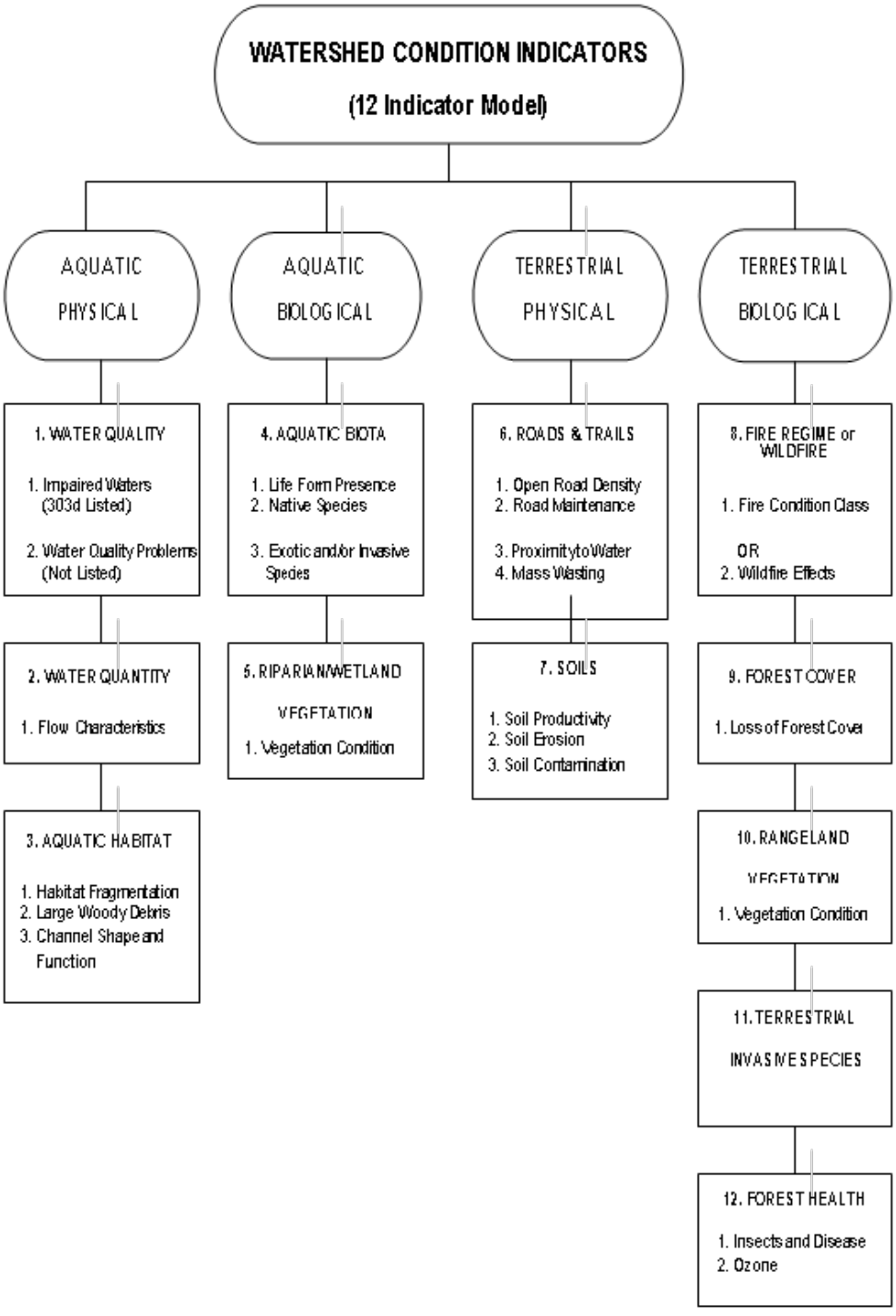


Figure 30. Core national watershed condition indicators

The Santa Fe NF assembled an interdisciplinary team (IDT) in 2010, and evaluated 116 sub-watersheds according to the procedures identified in the Forest Service WCC Technical Guide (USDA FS 2011). With the exception of the *Forest Cover* indicator (not evaluated) under the terrestrial biological process category, each of the remaining 11 indicators was assigned condition ratings of: "Good: Functioning Properly," "Fair: Functioning-at-risk," or "Poor: Impaired." A condition rating of **one** is synonymous with ***Good***, a condition rating of **two** is synonymous with ***Fair***, and a condition rating of **three** is synonymous with ***Poor.***

These numerical values were used to develop an average numerical rating for each indicator. Through the process described in the Forest Service WCC Technical Guide, a numerical rating was developed for each process category, and then each process category numerical value was weighted and added for each of the four process categories to arrive at a watershed condition score for each of the 116 sub-watersheds. Weighting for the four process categories are as follows: 30 percent each for aquatic physical, aquatic biological and terrestrial physical and 10 percent for the terrestrial biological category.

Based on the watershed condition score, a watershed condition class and condition were assigned to each of the 116 sub-watersheds on the Santa Fe NF (table 35 and figure 31). Fifteen sub-watersheds were determined to be functioning properly, 100 sub-watersheds were determined to be functioning-at-risk and one sub-watershed was determined to have impaired function (Outlet San Antonio Creek, figure 31). A watershed restoration action plan was developed for the Outlet San Antonio Creek watershed in 2011.

Out of the 138 sub-watersheds that intersect a significant portion of the Santa Fe NF boundary, 116 sub-watersheds were evaluated to determine their condition using the Forest Service WCC Technical Guide. Sub-watersheds with the majority of the area lying outside of the Santa Fe NF boundary were not evaluated; the exact metric used to exclude these sub-watersheds is unknown. Of those evaluated, 86 percent of the sub-watersheds are in a condition class of 2, "Functioning-at-Risk."

Table 35. Watershed condition summary for 116 sub-watersheds

Class	Condition	Score Range	Count	Percent
1	Functioning Properly	1.0 - 1.66	15	12.90%
2	Functioning at Risk	1.67 - 2.32	100	86.20%
3	Impaired Function	> 2.32	1	0.90%
		Total	116	100.00%

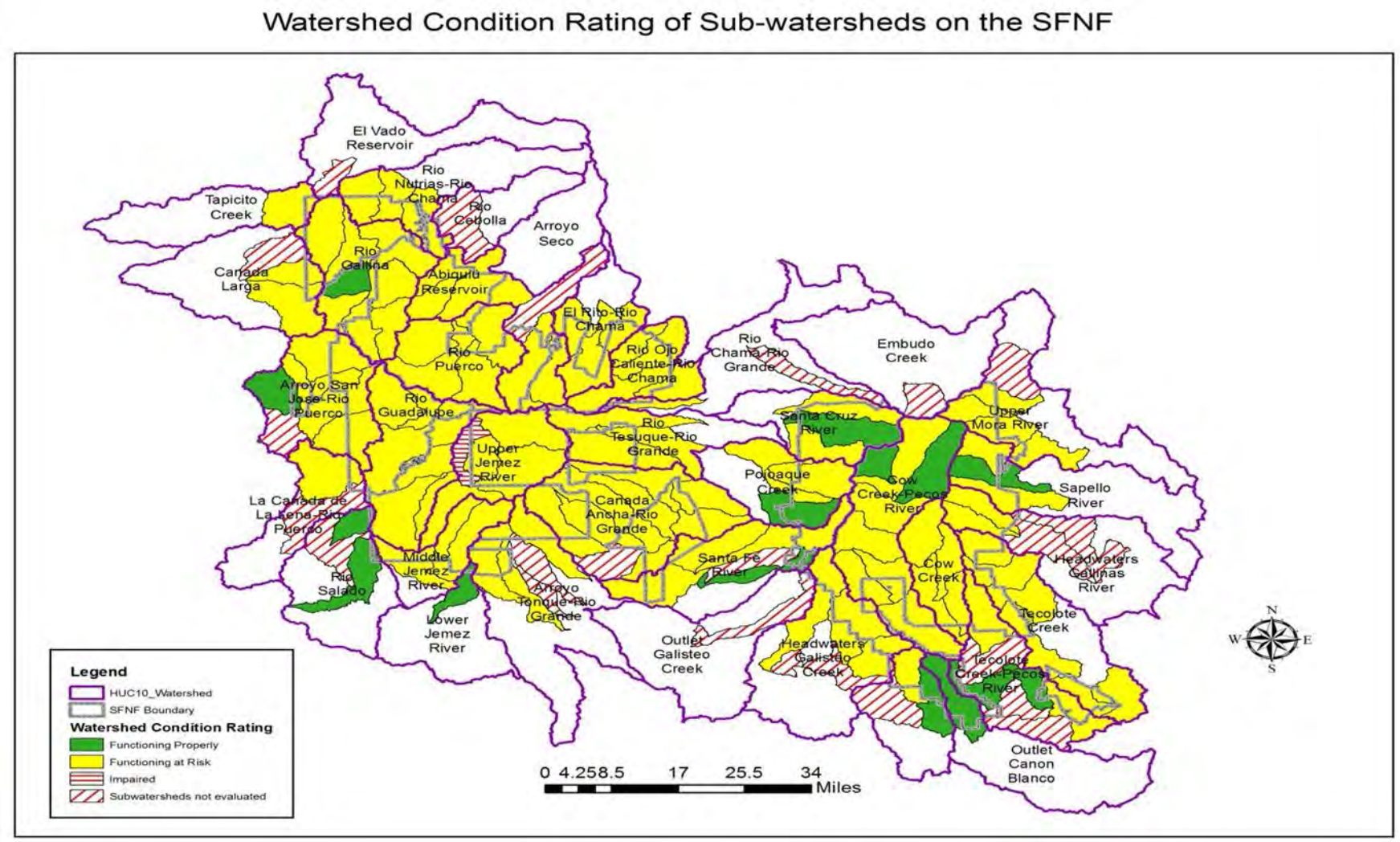


Figure 31. Watershed condition of sub-watersheds on the Santa Fe NF

Using the Forest Service WCC Technical Guide, 15 sub-watersheds were determined to be functioning properly, 100 sub-watersheds were determined to be functioning-at-risk and one sub-watershed was determined to have impaired function (Outlet San Antonio Creek). Twenty-two sub-watersheds were not evaluated due to the small amount of the sub-watershed that actually fell inside the Santa Fe NF boundary; these are represented by the sloped, parallel lines. As the graphic indicates, the majority of the Santa Fe NF was classified. The extent of the sub-watersheds and watersheds is also shown.

For the Santa Fe NF, the four indicators that had the largest impact (in order of importance) on the overall watershed scores were: (1) soils, (2) roads and trails, (3) riparian/wetland vegetation, and (4) water quantity. Average indicator values for the 116 sub-watersheds range from 0 to 2.4 (table 36).

The following indicators had the largest impact on the overall watershed score: water quantity, riparian/wetland vegetation, roads and trails, and soils. While the average fire regime/wildfire indicator had an average score of 2.4 for the 116 sub-watersheds, it only carries a 2 percent weight of the overall watershed score. The range of indicator values is also displayed.

Table 36. Range and average indicator values for the 116 sub-watersheds on the Santa Fe NF

Indicator	Min	Max	Average	Weight
Water Quality	1	3	1.5	10%
Water Quantity	1	3	1.8	10%
Aquatic Habitat	1	3	1.6	10%
Aquatic Biota	1	2.3	1.5	15%
Riparian/Wetland Vegetation	1	3	2.1	15%
Roads and Trails	1.7	3	2.2	15%
Soils	1.7	2.7	2.4	15%
Fire Regime or Wildfire	2	3	2.4	2%
Forest Cover	0	0	0.0	2%
Rangeland Vegetation	1	3	1.3	2%
Terrestrial Invasive Species	1	3	1.2	2%
Forest Health	1	1	1.0	2%

Reference Condition and Departure: Watershed Condition

For these 116 sub-watersheds, the overall watershed condition score characterizes the class and condition as of 2010 (year of IDT analysis); this also represents the current watershed condition for the 116 sub-watersheds. As previously stated, the Forest Service Manual (FSM) uses three classes to describe watershed condition. The FSM defines these classes as follows:

- Class 1 watersheds exhibit high geomorphic, hydrologic, and biotic integrity relative to their natural potential condition.
- Class 2 watersheds exhibit moderate geomorphic, hydrologic, and biotic integrity relative to their natural potential condition.
- Class 3 watersheds exhibit low geomorphic, hydrologic, and biotic integrity relative to their natural potential condition.

One can assume that the geomorphic, hydrologic and biotic integrity for these 116 sub-watersheds was largely intact (reference condition) prior to the expansion of the West and prior to receiving the intensive use that many of these sub-watersheds have seen since the establishment of the Santa Fe NF in 1915. This assumed historical condition can be used to compare the Watershed Condition Framework ratings against, and shows that the vast majority of these sub-watersheds have seen a decline in their overall watershed condition. The departure can be easily explained. As one example, the Santa Fe NF has constructed almost 6,000 miles of road to manage and provide access to the 1.68 million acres; recall that the road and trails indicator had a significant effect on the overall watershed condition score. These road miles have altered the geomorphic, hydrologic, and biotic integrity in every sub-watershed where they exist by effectively increasing the stream drainage density, and by increasing peak discharge, erosion and sediment delivery to the stream network.

Water Rights and Uses

Water Rights and Uses Current Condition

In order to legally use water in the State of New Mexico, a person must possess a decreed water right, license, permit, or at a minimum have made a declaration. A decreed water right is obtained through an adjudication process. Licenses, permits and declarations are obtained through the New Mexico Office of the State Engineer (NMOSE). In addition, the New Mexico Constitution recognizes and confirms all existing appropriations of water for useful or beneficial purposes prior to 1907. A decreed water right offers the best protection in the use of water, yet it does not guarantee the physical ability to divert. The allocation of water is based on the "first in time, first in right" principle, the doctrine of prior appropriation. Thus, people with senior water rights are entitled to divert prior to junior water right holders (filed on their right later in time) when limited quantities of water exist.

Adjudications determine who owns what water rights and in what amount. They are required by statute. The purpose of adjudications is to obtain a judicial determination and definition of water rights within each stream system or underground basin so that the State Engineer may effectively perform water rights administration and meet New Mexico's interstate stream obligations.

About 20 percent of the state has been adjudicated, and more than 50 percent of the state has adjudications in progress (NMOSE 2015). Twelve adjudications are currently pending in New Mexico courts, involving water rights within the Rio Grande, Pecos River, Upper Colorado River, and Lower Colorado River drainages. On the Santa Fe NF, the Cow Creek (tributary to the Pecos River) adjudication recently was initiated, and the USDA Forest Service has submitted approximately one dozen claims to the Hydrographic Survey Bureau staff for inclusion in this survey.

Using the water rights database maintained by the NMOSE, nearly 36,000 rights occur at the sub-basin scale, nearly 32,000 of those rights exist at the watershed/sub-watershed scale, and approximately 3,850 of those water rights exist within the Santa Fe NF (figure 32). The density of diversion points per square mile across the 37 watersheds covering at least a portion of the Santa Fe NF was calculated to be 3.5; or 2.3 times greater than the density of diversion points occurring within the Santa Fe NF boundary (table 37). The lower density of diversion points on the forest offers protection for many aquatic communities and habitats and also preserves favorable conditions of flow.

The highest density (of diversion points) occurs at the watershed/sub-watershed scale, particularly within these watersheds outside of the Santa Fe NF boundary. Significant concentrations of diversion points occur along river corridors, roads and communities.

Table 37. Number of water rights at the various scales

Scale	Number of Water Rights	Area (mi^2)	Density (no./mi^2)
Sub-basin	35,804	18,086	2.0
Watershed/Sub-watershed	31,966	9,018	3.5
Santa Fe NF (Plan)	3,848	2,518	1.5

The occurrence/density of diversion points and uses is significantly higher on non-public land. Thus, two of the many benefits of public lands are the conservation of water and the protection of many aquatic-dependent ecosystems.

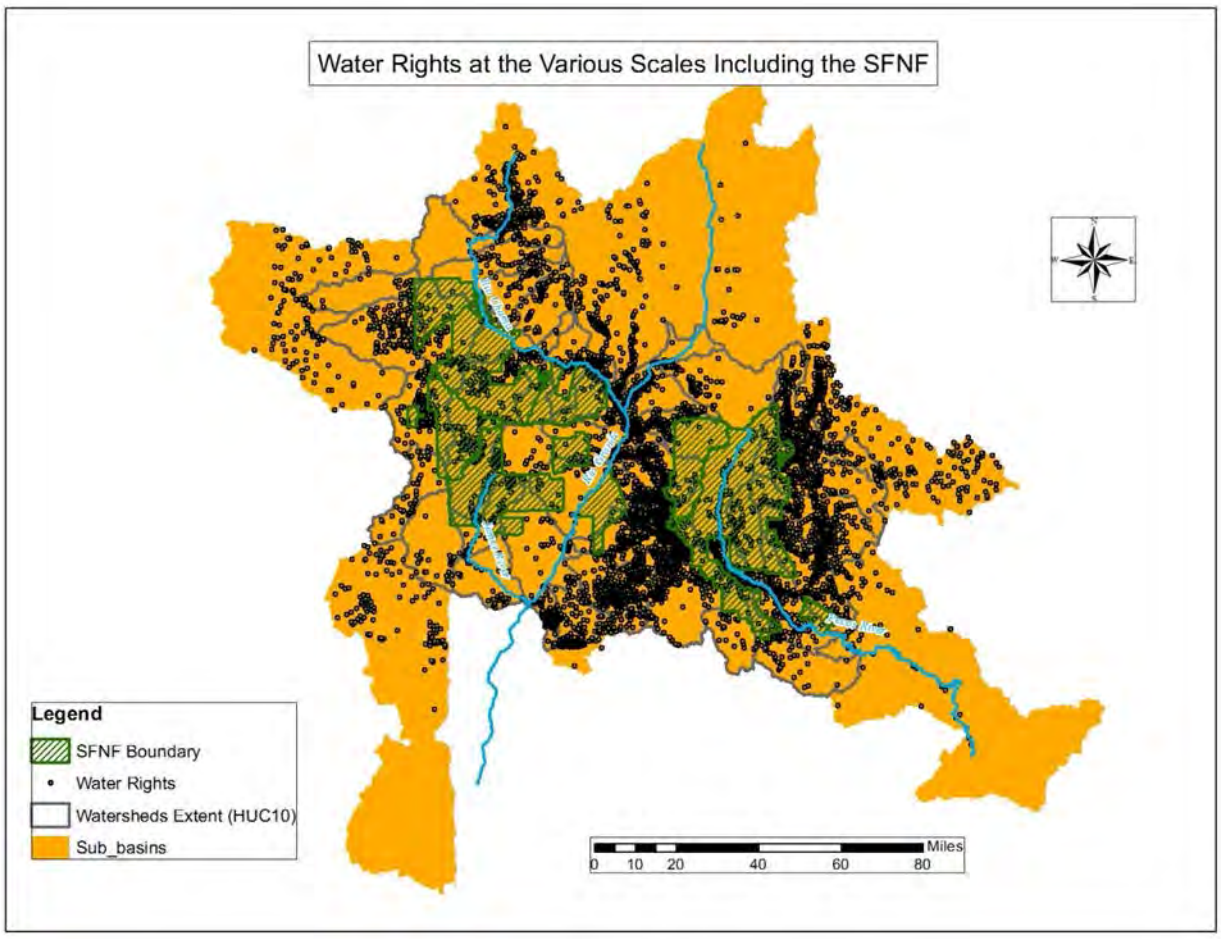


Figure 32. Points of diversion on and adjacent to the Santa Fe NF

The occurrence/density of water rights and uses is significantly higher on non-public land. Thus, two of the many benefits of public lands are the conservation of water and the protection of many aquatic-dependent ecosystems.

Reference Condition and Departure: Water Rights and Uses

Of the nearly 3,850 diversion points within the Santa Fe NF boundary, approximately 68 percent occur on private lands within the forest boundary; the balance (1,247) occurs on National Forest System (NFS) lands. The occurrences of these diversions are primarily along major stream and road corridors and in and around communities (on private inholdings) (figure 33 and figure 34). There are 900 known owners for the 1,247 diversion points mapped on Santa Fe NF lands (NMOSE database). The Santa Fe NF is one of these 900 owners and, the forest has claim to 91 water rights. Thus, 899 owners hold claim to the remaining 1,043 diversion points on Santa Fe NF lands, and no known ownership is designated for 113 of these diversion points on Santa Fe NF lands (NMOSE database).

These water rights are being primarily used for commercial, domestic, irrigation, municipal and stock uses, which account for 65.1 percent of the overall uses at the plan scale. At the watershed/sub-watershed scale, these same uses account for 75.3 percent of the overall uses.

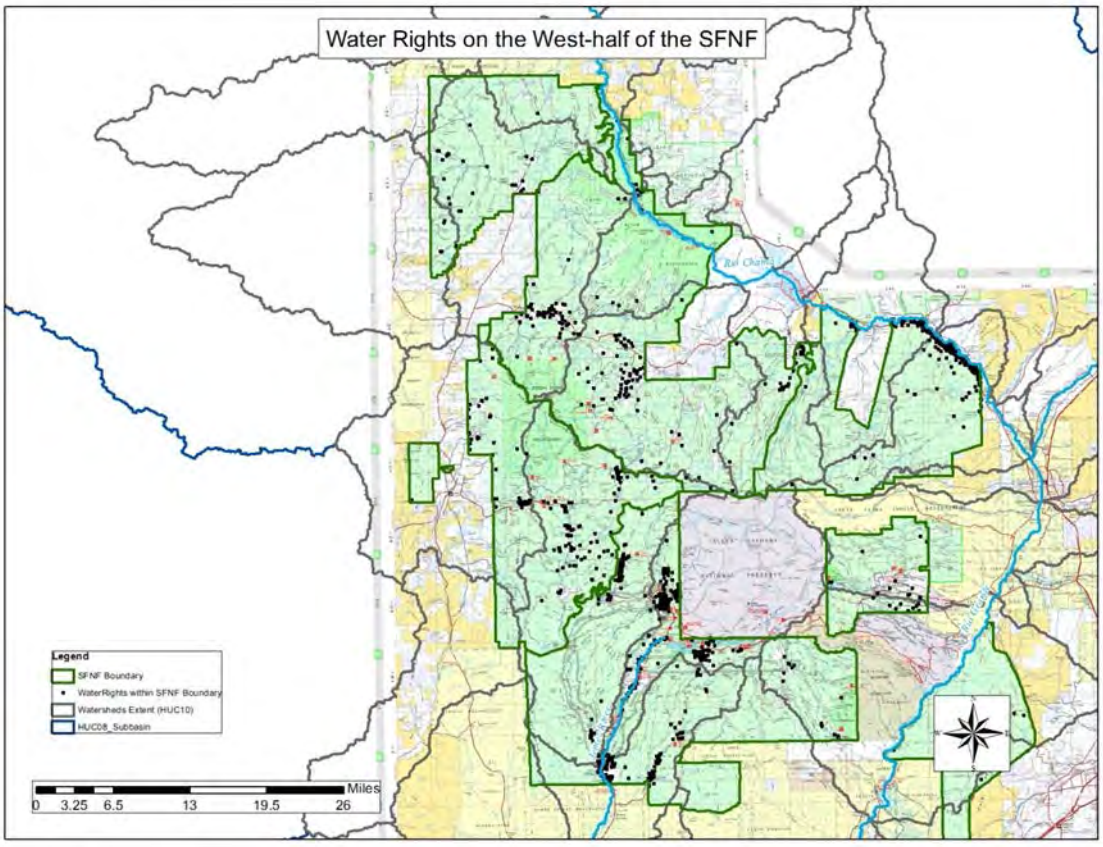


Figure 33. Points of diversion on the western half of the Santa Fe NF

Significant clusters of diversion points can be seen along streams and roads and around communities.

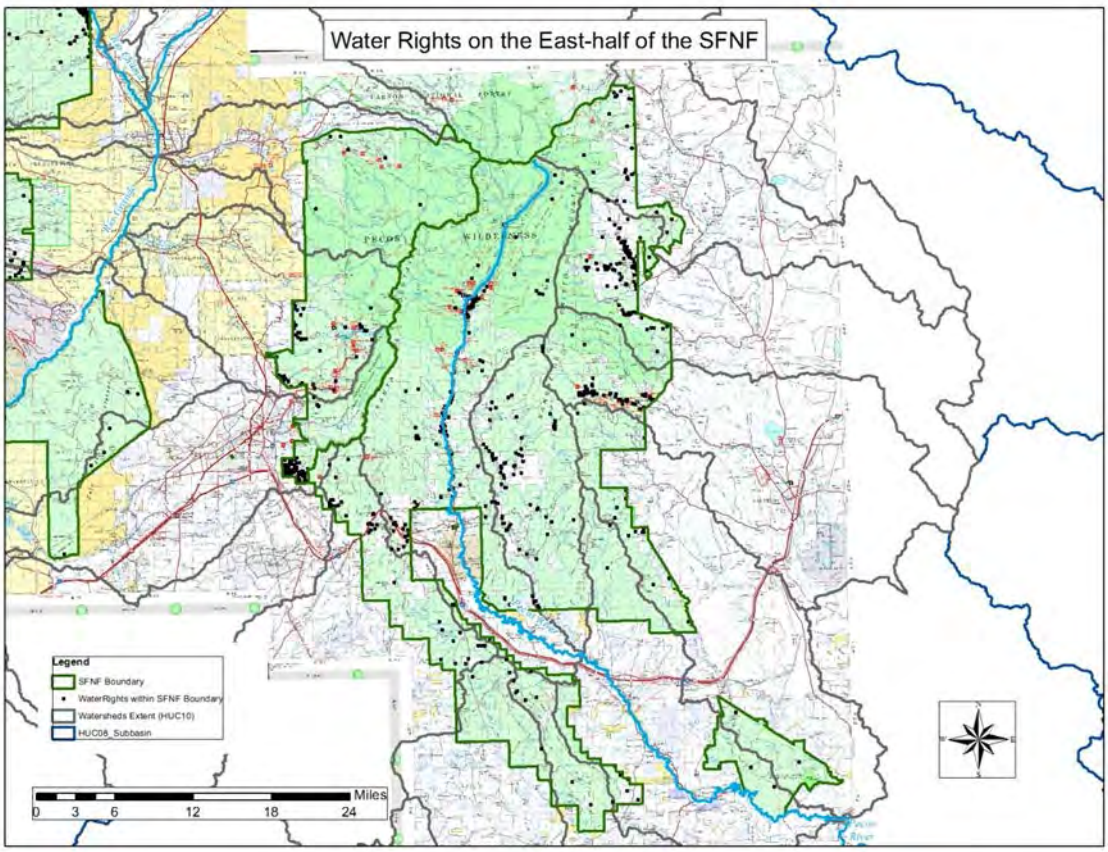


Figure 34. Points of diversion on the eastern half of the Santa Fe NF
Significant clusters of diversion points can be seen along streams and roads and around communities.

Agriculture along the Rio Grande has occurred for many centuries, so it comes as no surprise that many acequias (ditches) have been around before the Santa Fe NF was established. "Acequias, or community ditches, are recognized under New Mexico law as political subdivisions of the state. Many of the state's acequia associations have been in existence since the Spanish colonization period of the 17th and 18th centuries. Historically, they have been a principal local government unit responsible for the distribution and use of surface water (NMOSE 2015)." According to the NMOSE database, approximately 100 miles of acequias exist within the boundary of the Santa Fe NF. Approximately, 20 percent of these ditch miles occur on NFS lands with the balance occurring on private land.

According to the Santa Fe NF Water Rights and Uses (WRU) database, the forest has a record of 1,442 water uses. At this time, a spatial layer (that can be viewed in ArcGis) for these uses does not exist. The actual number of these uses that have been decreed in adjudications is also unknown. In fact, the adjudication field is null for all the uses contained in the WRU database. Out of the total number of uses, 26.3 percent (350) are used for domestic, 58.3 percent are used for stock water, and the balance is either used for irrigation or wildlife (table 38). Nearly 6 percent do not have a specified type of use. Per this database, 841 stock water uses exist across 79 range allotments. The database also shows that 237 (or 16.4 percent) of these uses have been issued a state file number by the (NMOSE).

Recall that 1,247 of the 3,850 water rights in the NMOSE water rights database occur on NFS lands within the Santa Fe NF. The Santa Fe NF WRU database identifies 1,442 uses; these two datasets need to be cross-walked to sort which of these uses have been decreed, licensed, permitted, or simply declared.

Table 38. Number of water uses by type

Type of Use	Count	% of Total
Undefined	84	5.8%
B (Domestic per WUTS)	216	15.0%
Domestic	134	9.3%
Irrigation	23	1.6%
Stock water	841	58.3%
Wildlife including Fish	144	10.0%
Total	1,442	100.0%

Prior to the expansion of the West and prior to establishment of the Santa Fe NF in 1915 (reference condition) water rights and uses were very limited in their numbers and occurrence across the landscape. Acequias, however, as previously mentioned have been around since the 17th century. Thus, since the start of the 19th century, the number of water rights has exploded with the construction of roads, the increase in population, and the growth of the established and new communities surrounding the Santa Fe NF. This increase in the number of water rights represents a significant departure from the reference condition.

Climate Change

The future conditions of the water resources and water-dependent ecosystems on the Santa Fe NF are intricately linked to Earth's climate, the existing conditions of our forests, and the demands placed on them by adjacent communities and the public. Based on decades of climate research, the Earth's climate warmed rapidly during the 20th century leading to significant changes in the hydrologic cycle. These changes are expected to intensify in the future and have large impacts on forests and the watershed services they provide (USDA FS 2010).

Research during the last decades of the 20th century show that the Earth's climate is currently warming and precipitation is increasing. Additional effects of a changing climate include: decreases in snow and extent and changes in the frequency and intensity of extreme events (heat waves, drought and heavy rainfall). In the West, inter-annual variability in precipitation has resulted in wetter wet years and drier dry years (Hamlet and Lettenmaier 2007, Luce and Holdern 2009, Pagano and Garen 2005). According to this research, the Southwest will likely become drier.

Winds have also been affected by the changing climate. An upward trend in extreme surface winds between 25° and 40° North latitudes have been observed (Graham and Diaz 2001). Latitudes covering the Santa Fe NF extend from approximately 35°15′ in the south to 36°30′ in the north. An increase in wind typically results in higher evaporation rates from free-water surfaces and higher transpiration rates in plants. Winds also play a significant role in the rates of wildfire spread.

According to *Water, Climate Change and Forests*, portions of the southwestern United States experienced increases in the April 1 snow-water equivalent during the second half of the 20th century. From these observations, little to no change was observed at the highest elevations (often above 8,000 feet). The largest changes were observed at low and mid-elevations. According to Barnett et al. (2008), lower elevations are receiving more precipitation as rain and less as snow, and late spring snow cover has decreased. Knowles et al. (2006) predict changes from snow to rain at the lowest extent of current snow lines. This research shows that the amount and timing of recent snowmelt are expected into the future.

Spring runoff is occurring earlier in snow-dominated watersheds throughout much of the West (USDA FS 2010). As the data suggest, the largest changes in snowmelt runoff timing are occurring at low to mid-elevation sites, whereas the high-elevation sites showed little change (Regonda et al. 2005). Because of this, earlier spring flows may yield lower late-season flows (Cayan 1996).

Changes in total annual flows have also been observed, and these changes are expected into the foreseeable future. Annual runoff in the Southwest is expected to decrease by as much as 20 percent (USDA FS 2010). For the Pecos River gauge site, this would result in a flow reduction per unit area from 0.52 cubic feet per second (cfs) per square mile to 0.42 cfs per square mile; for the Jemez River gauge site, this would result in a flow reduction per unit area from 0.15 cfs per square mile to 0.12 cfs per square mile. Due to reduced annual runoff and shifts in timing, seasonally flowing streams are expected to show decreases in flow duration. These decreased flows will likely shrink habitats of all aquatic species and also result in the contraction of wetlands (USDA FS 2010). These flow alterations could also impact individuals with surface (and groundwater) water rights.

On account of the shifting patterns of precipitation and runoff, timing and rates of groundwater recharge will shift accordingly. These changes in recharge will affect the baseflow component of stream discharge. According to *Water, Climate Change, and Forests*, groundwater withdrawals may increase in some areas due to these changes (losses and increased variability) in surface water supplies. In New Mexico most if not all of the surface water is dedicated to existing uses and there is little to no "new" water available to meet future demand (NMOSE 2015). Combine this fact, along with an increase in population and the effects of climate change, greater demands will be placed on groundwater in the future.

Climate change will also affect ecological disturbances. Specifically, alterations in the frequency, extent, and magnitude of floods, forest mortality, and fire are expected, each with serious implications for people and ecosystems (USDA FS 2010). According to *Water, Climate Change and Forests*, fires are burning hotter and covering larger areas. The Santa Fe NF has seen several large fires over the last decade with significant impacts to the watersheds, to the users of the forests and to downstream communities. The Santa Fe NF will not be immune to large wildfires in the future.

With the continued threat of wildfires and the effects of climate change, water quality of the streams, seeps and springs and waterbodies on the Santa Fe NF will present challenges into the future. Temperature and sedimentation from increased erosion alone will impact municipal and drinking water supplies and aquatic habitats both on and off the Forest.

Key Findings

The SFNF has been subject to natural and anthropogenic disturbances for centuries. Droughts, wildfires, flooding and insects/disease are some of the main natural disturbances, while past road and trail construction, grazing, developed recreation and water withdrawals are some key human-related impacts that have been occurred on the Forest since its establishment in 1915.

At the plan scale (collectively all NFS lands within the SFNF boundary), fifty percent of the total acres (or approximately 834,000) occur as ponderosa pine or mixed conifer frequent-fire (MCD) forests. These forests are highly departed from their historic range of variation in large part due to the agency's ability to suppress wildfires effectively during the 20th century.

When looking at wildfires greater than 10 acres in size on the SFNF between 1970 and 2013, approximately 309,000 acres have burned. Some of these fires burned the same piece of ground more than once. When not double counting those acres, nearly 264,000 acres or 16% of the SFNF has burned during this time period. Since 2010 approximately 140,000 acres have burned (45% of the 309,000 total). Of this amount, 71,000 acres (mostly ponderosa pine and MCD forests) burned that resulted in a moderate to high soil burn severity leading to elevated rates of erosion and sedimentation. Looking to the future, a conservative estimate of 700,000 acres (adjusted for pre-2010) of ponderosa pine and MCD forests remain. These forest types cover a significant portion of 22 watersheds on the SFNF, and these watersheds will have a greater risk of wildfire ignitions in the future.

Between 1970 and 2013, the average fire size was 7,182 acres (or 11 square miles). The average fire size between 1999 and 2013 has more than doubled to 16,057 acres (or 25 square miles). Both of the long-term stream gages on the SFNF experienced a steady decline in the 10-year running averages of annual stream discharge since 1999. The effect of drought on wildfires during this time period cannot be ignored, and drought undoubtedly will continue over the period while the new forest plan is in effect.

Roads and water-related range developments are a few examples of human-caused impacts on the SFNF. At the plan scale, nearly 4,700 miles of level 2 roads and 1,200 water-related range developments exist. These roads effectively increase the stream network, and they directly impact the delivery of water and sediment to the stream networks on and off the Forest. Likewise, the water-related range developments and grazing will continue to impact the rangelands and water resources into the future.

In combination with other human-caused and natural disturbances, the water quality of perennial streams in many of the watersheds within the SFNF boundary has been compromised. As a result, approximately 24% of the perennial stream miles on the Forest have been designated by NMED as impaired. Some of these impairments can be directly related to the natural and human-caused disturbances.

From the USGS Circular 1344, the Estimated Use of Water in the United States in 2005 (USGS 2009), the following facts were compiled for New Mexico:

- 3.73 million acre-feet (AF) of total water withdrawals; 84.5% was for irrigation, 8.6% was for public water supply and the remaining 7% was for domestic, livestock, aquaculture, industrial, mining and thermoelectric power.
- 321,000 AF of water withdrawals for public water supply. Eighty-seven percent supplied by groundwater, and the balance supplied by surface water.
- 57,000 AF of water withdrawals for livestock. Ninety-four percent supplied by groundwater, and the balance supplied by surface water.

According to the New Mexico Office of the State Engineer's (NMOSE) database, over 60,000 water rights point locations were identified in the six counties covering the SFNF. Within the Forest boundary, nearly 3,850 points of diversion exist. These rights are primarily used for livestock and domestic purposes (i.e. private inholdings, campgrounds and other administrative sites). Based on information compiled from the census.gov website, population in the six-county region encompassing the Forest has increased 14.5% from approximately 315,000 people in 2000 to approximately 368,000 people in 2010. According to the NMOSE website, New Mexico's surface water supplies are limited and highly variable. Most, if not all, of the surface water in New Mexico is dedicated to existing water uses and there is little to no "new" water available to meet future demands. In fact, in most areas of the state, for a new use of water to begin an existing use must be retired, meaning that the existing use must permanently end. This

increase in population and lack of surface water will place a greater demand on ground-water resources both on and off the Forest. There likely will be an increased interest to develop water-related projects on the SFNF.

As stated in the Water, Climate Change, and Forests (General Technical Report, USDA, 2010), "the long-term provision of watershed services is not guaranteed. The amount and quality of these services depend on the condition of the forest – when watershed conditions are stressed or degraded, critical services can be threatened or compromised. Based on the Watershed Condition Classification (2010) of sub-watersheds on the SFNF, 87% of them were classified as functioning-at-risk or impaired.

Climate change has directly affected and will continue to affect the global hydrologic cycle and thus the quality, quantity, and timing of streamflow from the SFNF. It has also initiated indirect effects on water resources, such as increased extent and severity of wildfire and forest mortality. According to Water, Climate Change, and Forests, the projections for the West in the 21st century are for continued warming and increased precipitation. Temperature is expected to increase 3 to 4 degrees Fahrenheit by 2030s and by 8 to 11 degrees Fahrenheit by 2090s. Precipitation is expected to increase in the winter, yet drier and lower latitude areas are predicted to become drier. This too will have to be factored into future management decisions on the SFNF.

Aquatic Biota

The current condition of aquatic biota is assessed at two scales: plan and local. The plan scale includes perennial streams in HUC 10 watersheds that intersect the Santa Fe NF. The local scale analyzes all perennial streams in HUC 12 sub-watersheds that are only within the Santa Fe NF boundary (figure 35).

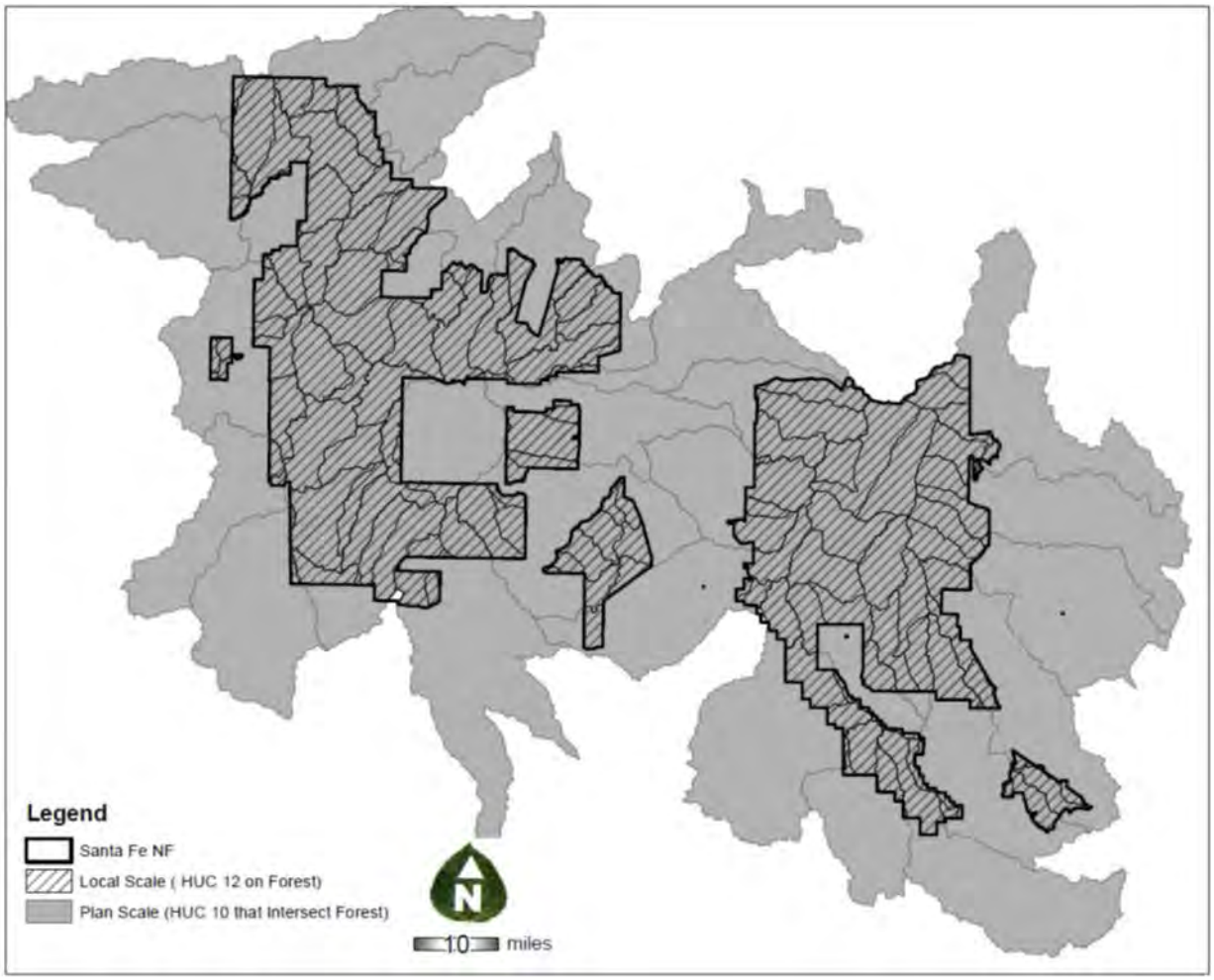


Figure 35. Plan (HUC 10 watershed) and local (HUC 12 sub-watershed) scales for aquatic biota assessment on the Santa Fe NF

Current Condition

Fish Species

Prior to Euro-American settlement, only native aquatic species (such as fish and aquatic macroinvertebrates) were present in these watersheds, their populations were more widespread, interconnected, and the aquatic habitat had all necessary components needed to persist. This pre-Euro-American status of aquatic biota is used as the reference condition. Though, it is likely that aquatic habitat conditions have changed over time, it is assumed the total current perennial stream miles should only be inhabited by native aquatic species; therefore, the current quantity of stream miles is used as reference.

Historic land uses and introduction of nonnative species that occurred within the last hundred years or more have resulted in significant negative impacts to aquatic communities and their watersheds. As a result, native fish populations have been reduced from a large interconnected population to isolated populations within altered and degraded habitats (Alves et al. 2008). Because of the altered habitat and small, isolated populations, all native fish species have lost much of their population redundancy within and outside the Santa Fe NF. These are indicators of watershed health.

Table 39 shows the current distribution of the native fish species found within the plan and local scales associated with the Santa Fe NF. Native fish species that historically occurred within the watershed, but are now extirpated is represented by the letter "R" for reference. While native fish species that occurred historically and are still occurring in the watershed is represented by "C" (Current). Blank cell indicates native fish species were not historically present within the watershed.

Table 39. Reference (R) and current (C) occurrences of native fish species at the plan (HUC 10 watershed) and local (HUC 12 sub-watershed) scales
Note: Blank cells indicate native fish species were not historically present within watershed.

Watershed (HUC 10 gray shade) Sub-watershed (HUC 12 white)	**American Eel**	**Bluntnose Shiner**	**Bluegill**	**Central Stonroller**	**Creek Chub**	**Fathead Minnow**	**Flathead Chub**	**Longnose Dace**	**Red Shiner**	**Rio Grande Chub**	**Rio Grande Cutthroat Trout**	**Rio Grande Silvery Minnow**	**Rio Grande Sucker**	**River Carpsucker**	**Southern Redbelly Dace**	**Western Mosquitofish**	**White Sucker**	**Current/Historic Numbers**	**Number of Non-Native Fish**	**Percent Departure of Current From Historic**	**Risk Ranking[7]**
Sapello River				**C**	**C**	**C**	**C**	**C**		**C**					**C**		**C**	**8/8**	**4**	**0**	**L**
Rito San Jose				C	C			C							C		C	5/5	3	0	L
HWs[8] Manuelitas Creek				C	C			C							C		C	5/5	3	0	L
Manuelitas Creek-Sapello River				C	C			C							C		C	5/5	3	0	L
Upper Mora River				**C**	**C**	**C**	**C**	**C**		**C**	**C**				**C**		**C**	**9/9**	**6**	**0**	**L**
Vigil Creek- Mora River					C	C	C	C			R						C	5/6	5	17	L
Rio La Casa				C	C			C									C	4/4	3	0	L
Rio La Casa- Mora River				C	C	C	C	C							C		C	7/7	3	0	L
Santiago Creek				C	C			C									C	4/4	2	0	L
Rito Cebolla				C	C	C	C	C		C							C	7/7	3	0	L
Santa Cruz	**R**									**R**	**C**		**R**					**1/4**	**6**	**75**	**H**
Rio Frijoles	R									R	C		R					1/4	3	75	H
Rio Medio	R									R	C		R					1/4	3	75	H
Rio Quemado	R												R					0/2	3	100	H

[7] 0 to 33 percent departure = Low (L) risk ranking; 34 to 66 percent = Moderate (M) risk ranking; 67 to 100 percent = High (H) risk ranking
[8] HWs = Headwaters

Watershed (HUC 10 gray shade) / Sub-watershed (HUC 12 white)	American Eel	Bluntnose Shiner	Bluegill	Central Stonroller	Creek Chub	Fathead Minnow	Flathead Chub	Longnose Dace	Red Shiner	Rio Grande Chub	Rio Grande Cutthroat Trout	Rio Grande Silvery Minnow	Rio Grande Sucker	River Carpsucker	Southern Redbelly Dace	Western Mosquitofish	White Sucker	Current/Historic Numbers	Number of Non-Native Fish	Percent Departure of Current From Historic	Risk Ranking[7]
Rio Chama-Rio Grande	**R**					**C**	**C**	**C**	**C**	**R**	**C**		**R**	**C**				**6/9**	**10**	**33**	**L**
Rio Truchas	R							C		R	R		R					1/5	4	80	H
Pojoaque Creek	**R**												**R**					**0/2**	**4**	**100**	**H**
Rio Nambe	R												R					0/2	4	100	H
HWs Rio Tesuque	R												R					0/2	4	100	H
Rio Tesuque- Pojoaque Creek	R												R					0/2	4	100	H
Rio Tesuque- Rio Grande	**R**		**R**			**C**	**C**	**C**				**R**	**R**	**C**		**C**		**5/9**	**7**	**44**	**M**
Santa Clara Creek	R												R					0/2	4	100	H
Los Alamos Canyon	R												R					0/2	4	100	H
Los Alamos Canyon- Rio Grande	R		R			C	C	C				R	R	C		C		5/9	4	44	M
Rio Cebolla						**C**	**C**	**C**		**R**	**R**		**R**					**3/6**	**3**	**50**	**M**
Outlet Rio Cebolla								C		R	R		R					1/4	3	75	H
Rio Gallina						**C**		**C**			**C**		**R**					**3/4**	**2**	**25**	**L**
Rio Capulin											R							0/1	2	100	H
Upper Rio Gallina											C							1/1	2	0	L
HWs Canoncito de las Lleguas												R						0/1	2	100	H
Lower Rio Gallina						C		C										0/1	2	100	H
Rio Nutrias-Rio Chama						**C**	**C**	**C**		**C**	**R**		**R**					**4/6**	**4**	**33**	**L**
HWs Arroyo del Puerto Chiquito								C		C			R					2/3	3	33	L

Watershed (HUC 10 gray shade) Sub-watershed (HUC 12 white)	**American Eel**	**Bluntnose Shiner**	**Bluegill**	**Central Stonroller**	**Creek Chub**	**Fathead Minnow**	**Flathead Chub**	**Longnose Dace**	**Red Shiner**	**Rio Grande Chub**	**Rio Grande Cutthroat Trout**	**Rio Grande Silvery Minnow**	**Rio Grande Sucker**	**River Carpsucker**	**Southern Redbelly Dace**	**Western Mosquitofish**	**White Sucker**	**Current/Historic Numbers**	**Number of Non-Native Fish**	**Percent Departure of Current From Historic**	**Risk Ranking[7]**
Outlet Arroyo del Puerto Chiquito								C		C			R					2/3	3	33	L
Huckbay Canyon- Rio Chama								C		C			R					2/3	3	33	L
Rio Puerco											**C**		**R**					**1/2**	**3**	**50**	**M**
Poleo Creek													R					0/1	3	100	H
Coyote Creek													R					0/1	3	100	H
HWs Rio Puerco											C							1/1	3	0	L
Outlet Rio Puerco													R					0/1	3	100	H
Abiquiu Reservoir						**C**	**C**	**C**		**R**	**C**		**C**	**C**				**5/7**	**12**	**29**	**L**
Ojitos Canyon													R					0/1	5	100	H
Ojito Canyon- Abiquiu Reservior													R					0/1	9	100	H
Rio Puerco- Abiquiu Reservior												R	R					0/2	9	100	H
Polvadera Creek										R	R		R					0/3	5	100	H
Canones Creek											C		R					1/2	5	50	M
Canones Creek- Abiquiu Reservior											C	R	R					1/3	7	67	H
El Rito-Rio Chama		**R**				**C**	**C**	**C**		**R**	**R**		**R**					**4/8**	**6**	**57**	**M**
Abiquiu Creek								C					R					1/2	4	50	M
Arroyo del Cobre- Rio Chama						C	C	C		R	R		R					3/6	4	50	M

Watershed (HUC 10 gray shade) Sub-watershed (HUC 12 white)	American Eel	Bluntnose Shiner	Bluegill	Central Stonroller	Creek Chub	Fathead Minnow	Flathead Chub	Longnose Dace	Red Shiner	Rio Grande Chub	Rio Grande Cutthroat Trout	Rio Grande Silvery Minnow	Rio Grande Sucker	River Carpsucker	Southern Redbelly Dace	Western Mosquitofish	White Sucker	Current/Historic Numbers	Number of Non-Native Fish	Percent Departure of Current From Historic	Risk Ranking[7]
Rio Ojo Caliente- Rio Chama							**C**	**C**			**R**	**R**	**R**					**2/5**	**4**	**60**	**M**
Canada de Tio Alfonso- Rio Chama							C	C				R	R					2/4	3	50	M
Rio del Oso											R		R					0/2	3	100	H
Rio del Oso- Rio Chama							C	C				R	R					2/4	3	50	M
Rio Ojo Caliente- Rio Chama							C	C				R	R					2/4	3	50	M
Santa Fe River	**R**												**R**					**0/2**	**2**	**100**	**H**
Arroyo Calabases	R												R					0/2	2	100	H
HWs Santa Fe River	R												R					0/2	2	100	H
Arroyo de Los Chamisos	R												R					0/2	2	100	H
Arroyo Hondo	R												R					0/2	2	100	H
Outlet Santa Fe River	R												R					0/2	2	100	H
Canada Ancha- Rio Grande	**R**					**C**	**C**	**C**	**C**		**C**	**R**	**R**	**C**		**C**		**7/10**	**9**	**30**	**L**
Hws Canada Ancha	R												R					0/2	4	100	H
Canada Ancha- Rio Grande	R					C	C	C	C			R	R	C		C		6/9	4	33	L
Water Canyon- Rio Grande	R					C	C	C	C			R	R	C		C		6/9	5	33	L
Alamo Canyon- Rio Grande	R					C	C	C	C			R	R	C		C		6/9	5	33	L
Rio Chiquito	R										C		R			C		2/4	4	50	M
Capulin Canyon- Rio Grande	R					R	R	C*	R		C	R	R			R		2/9	7	77	H
Canada de Cochita- Rio Grande	R					R	R	C	R		C	R	R			R		2/9	7	77	H

Watershed (HUC 10 gray shade) Sub-watershed (HUC 12 white)	**American Eel**	**Bluntnose Shiner**	**Bluegill**	**Central Stonroller**	**Creek Chub**	**Fathead Minnow**	**Flathead Chub**	**Longnose Dace**	**Red Shiner**	**Rio Grande Chub**	**Rio Grande Cutthroat Trout**	**Rio Grande Silvery Minnow**	**Rio Grande Sucker**	**River Carpsucker**	**Southern Redbelly Dace**	**Western Mosquitofish**	**White Sucker**	**Current/Historic Numbers**	**Number of Non-Native Fish**	**Percent Departure of Current From Historic**	**Risk Ranking[7]**
HWs Galisteo Creek	**R**												**R**					**0/2**	**2**	**100**	**H**
Arroyo Salado	R												R					0/2	2	100	H
San Cristobal Arroyo	R												R					0/2	2	100	H
San Cristobal Arroyo- Galisteo Creek	R												R					0/2	2	100	H
Arroyo Tonque- Rio Grande	**R**												**R**	**C**				**1/3**	**2**	**67**	**H**
Peralta Canyon	R												R					0/2	2	100	H
HWs Borrego Canon	R												R	C				1/3	2	67	H
Outlet Borrego Canyon	R												R					0/2	2	100	H
Rio Guadalupe								**C**		**C**	**C**		**C**					**2/2**	**1**	**0**	**L**
Rito Penas Negras											C		R					1/2	1	50	M
HWs Rio de Las Vacas											C		C					2/2	1	0	L
HWs Rio Cebolla											C		R					1/2	1	50	M
Outlet Rio Cebolla										C			R					1/2	2	50	M
Outlet Rio de Las Vacas								C		C	C		C					4/4	2	0	L
Virgin Canyon								C		C			C					3/3	0	0	L
Rio Guadalupe								C		C	C		C					4/4	2	0	L
Upper Jemez River						**C**	**R**	**C**		**C**			**C**					**4/5**	**4**	**20**	**L**
HWs San Antonio Creek						C		C		C			R					3/4	3	25	L
Sulphur Creek													R					0/1	3	100	H

Watershed (HUC 10 gray shade) Sub-watershed (HUC 12 white)	**American Eel**	**Bluntnose Shiner**	**Bluegill**	**Central Stonroller**	**Creek Chub**	**Fathead Minnow**	**Flathead Chub**	**Longnose Dace**	**Red Shiner**	**Rio Grande Chub**	**Rio Grande Cutthroat Trout**	**Rio Grande Silvery Minnow**	**Rio Grande Sucker**	**River Carpsucker**	**Southern Redbelly Dace**	**Western Mosquitofish**	**White Sucker**	**Current/Historic Numbers**	**Number of Non-Native Fish**	**Percent Departure of Current From Historic**	**Risk Ranking[7]**
East Fork Jemez								C		C			C					3/3	4	0	L
Outlet San Antonio Creek						C		C		C			C					4/4	3	0	L
Church Canyon- Jemez River						C	R	C		C			C					4/5	3	20	L
Rio Salado										**R**								**0/1**	**2**	**100**	**H**
Middle Rio Salado										R								0/1	2	100	H
Middle Jemez River						**C**	**C**	**C**		**C**	**C**		**C**					**6/6**	**2**	**0**	**L**
Canon de La Canada								C										1/1	2	0	L
Vallecita Creek								C										1/1	2	0	L
Vallecita Creek- Jemez River						C	R	C										2/3	3	33	L
Arroyo San Jose- Rio Puerco						**C**	**R**	**C**		**R**	**C**		**R**					**3/6**	**3**	**50**	**M**
HWs Arroyo San Jose								C			C		R					2/3	3	33	L
Outlet Arroyo San Jose						C	R	C		R	R		R					2/6	3	67	H
San Pablo Canyon								C			R		R					1/3	3	67	H
Arroyo San Jose- Rio Puerco						C	R	C		R	C		R					3/6	3	50	M
Cow Creek	**R**																	**0/1**	**4**	**100**	**H**
HWs Cow Creek	R																	0/1	4	100	H
Bull Creek	R																	0/1	3	100	H
Apache Creek	R																	0/1	3	100	H
Outlet Cow Creek	R																	0/1	3	100	H

Watershed (HUC 10 gray shade) Sub-watershed (HUC 12 white)	**American Eel**	**Bluntnose Shiner**	**Bluegill**	**Central Stonroller**	**Creek Chub**	**Fathead Minnow**	**Flathead Chub**	**Longnose Dace**	**Red Shiner**	**Rio Grande Chub**	**Rio Grande Cutthroat Trout**	**Rio Grande Silvery Minnow**	**Rio Grande Sucker**	**River Carpsucker**	**Southern Redbelly Dace**	**Western Mosquitofish**	**White Sucker**	**Current/Historic Numbers**	**Number of Non-Native Fish**	**Percent Departure of Current From Historic**	**Risk Ranking[7]**
Cow Creek- Pecos	**R**							**C**		**R**								**1/3**	**4**	**67**	**H**
Panchuela Creek	R																	0/1	3	100	H
Rio Mora	R																	0/1	3	100	H
Rio Mora- Pecos River	R																	0/1	3	100	H
Indian Creek- Pecos River	R							C										1/2	4	50	M
Dry Gulch- Pecos River	R							C										1/2	3	50	M
Glorieta Creek	R																	0/1	3	100	H
Glorieta Creek- Pecos River	R							C		R								1/3	3	67	H
Tortolita Canyon- Pecos River	R							C		R								1/3	3	67	H
Tecolote Creek	**R**				**C**			**C**										**2/3**	**2**	**33**	**L**
Cabo Lucero Creek- Tecolote Creek	R				C			C										2/3	2	33	L
Canon Mesteno- Tecolote Creek	R				C			C										2/3	2	33	L
Ojito Frios Creek- Tecolote Creek	R				C			C										2/3	2	33	L
Tres Hermanos Creek	R				C													1/2	2	50	M
Arroyo Leguino	R				C													1/2	2	50	M
Tecolote Creek- Pecos River	**R**					**C**		**C**		**R**								**2/4**	**3**	**50**	**M**
El Rito	R																	0/1	3	100	H

Watershed (HUC 10 gray shade) Sub-watershed (HUC 12 white)	**American Eel**	**Bluntnose Shiner**	**Bluegill**	**Central Stonroller**	**Creek Chub**	**Fathead Minnow**	**Flathead Chub**	**Longnose Dace**	**Red Shiner**	**Rio Grande Chub**	**Rio Grande Cutthroat Trout**	**Rio Grande Silvery Minnow**	**Rio Grande Sucker**	**River Carpsucker**	**Southern Redbelly Dace**	**Western Mosquitofish**	**White Sucker**	**Current/Historic Numbers**	**Number of Non-Native Fish**	**Percent Departure of Current From Historic**	**Risk Ranking[7]**
Manzanarez Canyon- Pecos River	R									R								0/2	3	100	H
Arroyo del Vegoso- Pecos River	R									R								0/2	3	100	H
El Canon de Pena- Pecos River	R							C		R								1/3	3	67	H
El Fileto Canon- Pecos River	R					C		C										2/3	3	33	L
HWs Canon Blanco	**R**					**C**		**C**										**2/3**	**3**	**33**	**L**
Barbero Canyon	R					C		C										2/3	3	33	L
HWs Gallinas River	**R**				**C**													**1/2**	**3**	**50**	**M**
Porvenir Canyon	R				C													1/2	3	50	M
Porvenir Canyon-Gallinas Creek	R				C													1/2	3	50	M
Arroyo Pecos	R				C													1/2	50	3	M
Arroyo Pecos-Gallinas River	R				C													1/2	50	3	M
Current/historic numbers of HUC 10 watershed with fish occurrences	0/14	0/1	0/1	2/2	4/4	15/15	10/13	19/19	2/2	5/14	10/13	3/3	3/19	6/6	2/2	2/2	2/2				
Percent departure of current from reference	100	100	100	0	0	0	23	0	0	64	23	100	84	0	0	0	0				

Historically, 17 native fish occurred within the plan scale (Sublette et al. 1990). Currently, 13 (76 percent) of these native species still occur, while four (24 percent) are now considered extirpated (table 39). Another four (30 percent) species still occurring at the plan scale have declined in their distributions. At the local scale, 16 native fish species historically occurred within the sub-watersheds of the Santa Fe NF (Alves et al. 2008; Clamusso and Rinne 2009; NMDGF 2013; Sublette et al. 1990), but three (18 percent) are considered extirpated (table 39). Additionally, seven (54 percent) native species still occurring at the local scale have declined in distribution, while the remaining six species are maintaining or showing slight increases in distribution (BISON-M 2014; NMDGF 2013; Propst 1999; Sublette et al. 1990).

Habitat for native species is diminished or eliminated because of unfavorable changes in riparian and upland ERUs (see Riparian Ecosystems) which has affected native fish diversity and distribution. Most riparian ERUs adjacent to waters currently exhibit altered structure, species composition, and canopy cover. In adjacent frequent fire ERUs, shifts in the fire regimes have increased catastrophic impacts associated with wildfire. Altered fire regimes have increased the susceptibility of uplands to large scale stand replacing fires or fire related catastrophic changes to the stability of the watershed, and have increased the potential for uncharacteristic fire effects in adjacent riparian ERUs. Uncharacteristic fire raises the possibility of increased sedimentation, higher water temperatures, and shifts in flood severity or frequency, essentially destabilizing the watershed as in the Las Conchas Fire.

The impacts from user-created roads, hiking trails, camping, and ungulate grazing have increased in the uplands and near streams. Increased forage removal associated with ungulate, camping, and hiking use removes protective vegetation cover from underlying soils and results in increased sedimentation, altered peak run-off flows, and greater habitat fragmentation. Existing user-created (motor vehicle) routes on the landscape, in combination with ungulate grazing, has degraded overall water quality and negatively impacted soil and vegetation conditions in floodplains and uplands. Although localized impacts can look dramatic and have lasting impacts in the immediate area, their overall impacts are small at a forestwide scale.

Hybridization, depredation, and competition from non-native fish have likely contributed to diversity and distribution declines in native fish species, as well. There are 19 non-native species that currently inhabit the streams on the plan and local scales. Moreover, there are some fish that are native to certain watersheds, such as white sucker *(Catostomus commersonii)* and fathead minnow *(Pimephales promelas)*, that have been introduced into watersheds they historically did not occupy. Non-native fish species were introduced into these watersheds for sport fishing or by accident through bait bucket transport (see Volume 2 discussing the economic and social values of sport fishing on the Santa Fe NF). Most New Mexico State Fish Hatcheries have been converted to raising triploid (sterile) trout to be stocked in waters where interbreeding with native fish is not desired (NMDGF 2009). The New Mexico Department of Game and Fish (NMDGF) coordinates fish stocking with the Santa Fe NF to reduce effects to other species where conflicts are known.

Non-native fish currently inhabit approximately 2,174 miles (95 percent) of the 2,279 miles of perennial streams intersecting the Santa Fe NF (table 40) at the plan scale. Although native fish may still inhabit these streams, their population and condition are likely in a diminished state (Alves et al. 2008) (table 39 and table 40). For example, 62 percent of Rio Grande cutthroat trout (*Oncorhynchus clarki virginalis*) populations are introgressed with rainbow trout (*Oncorhynchus mykiss*) (Alves et al. 2008). Currently, 105 (5 percent) perennial stream miles support only native fish in the plan area (HUC 10 watershed). These native-only streams are generally found in headwaters, where genetically pure populations of Rio Grande cutthroat trout are isolated by a physical barrier (man-made or natural (figure 36) (RGCTWG 2013)). Currently, 61 percent of the Rio Grande cutthroat trout range occurs on public lands (FS,BLM, State) (RGCTWG 2013). The Santa Fe NF has 1,183 perennial stream miles, of which only 89 (8 percent)

miles contain only native fish. The remaining 1,094 (92 percent) stream miles on the Santa Fe NF have a combination of native and non-native fish present. Native fish populations will likely continue to diminish in the presence of non-natives. However, native population protected by barriers have a higher likelihood of persistence. Due to the popularity of nonnative sport fish it is unlikely the Santa Fe NF would ever have a fishery that is comprised of 100 percent native fishes.

Table 40. Current native fish only stream miles and non-native/native fish stream miles at the plan and local scales

Watershed (HUC 10 gray shade) Sub-watershed (HUC 12 white)	Perennial Stream Miles	Current Native Fish Only Stream Miles	Current Native/ Non-native Fish Stream Miles	% Departure of Current Native Only from Stream Miles	Risk Ranking[9]
Sapello River	**109**	**0**	**109**	**100%**	**High**
Rito San Jose	15	0	15	100%	High
HWs[10] Manuelitas Creek	30	0	30	100%	High
Manuelitas Creek-Sapello River	24	0	24	100%	High
Upper Mora River	**166**	**15**	**151**	**91%**	**High**
Vigil Creek- Mora River	15	0	15	100%	High
Rio La Casa	23	0	23	100%	High
Rio La Casa- Mora River	28	0	28	100%	High
Santiago Creek	21	8	13	62%	High
Rito Cebolla	11	0	11	100%	High
Santa Cruz	**123**	**9**	**114**	**93%**	**High**
Rio Frijoles	26	0	26	100%	High
Rio Medio	52	3	49	94%	High
Rio Quemado	34	6	28	82%	High
Rio Chama-Rio Grande	**75**	**10**	**65**	**87%**	**High**
Rio Truchas	13	1	12	92%	High
Pojoaque Creek	**88**	**0**	**88**	**100%**	**High**
Rio Nambe	38	0	38	100%	High
HWs Rio Tesuque	18	0	18	100%	High
Rio Tesuque- Pojoaque Creek	11	0	11	100%	High
Rio Tesuque- Rio Grande	**55**	**0**	**55**	**100%**	**High**
Santa Clara Creek	23	0	23	100%	High
Los Alamos Canyon	12	0	12	100%	High
Los Alamos Canyon- Rio Grande	12	0	12	100%	High
Rio Cebolla	**27**	**0**	**27**	**100%**	**High**
Outlet Rio Cebolla	1	0	1	100%	High

[9] 0 to 33 percent departure = Low (L) risk ranking; 34 to 66 percent = Moderate (M) risk ranking; 67 to 100 percent = High (H) risk ranking
[10] HWs = Headwaters

Watershed (HUC 10 gray shade) Sub-watershed (HUC 12 white)	**Perennial Stream Miles**	**Current Native Fish Only Stream Miles**	**Current Native/ Non-native Fish Stream Miles**	**% Departure of Current Native Only from Stream Miles**	**Risk Ranking[9]**
Rio Gallina	**43**	**0**	**43**	**100%**	**High**
Rio Capulin	18	0	18	100%	High
Upper Rio Gallina	18	0	18	100%	High
HWs Canoncito de las Lleguas	2	0	2	100%	High
Lower Rio Gallina	5	0	5	100%	High
Rio Nutrias-Rio Chama	**72**	**0**	**72**	**100%**	**High**
HWs Arroyo del Puerto Chiquito	1	0	1	100%	High
Outlet Arroyo del Puerto Chiquito	1	0	1	100%	High
Huckbay Canyon- Rio Chama	17	0	17	100%	High
Rio Puerco	**103**	**0**	**103**	**100%**	**High**
Poleo Creek	21	0	21	100%	High
Coyote Creek	28	0	28	100%	High
HWs Rio Puerco	34	0	34	100%	High
Outlet Rio Puerco	19	0	19	100%	High
Abiquiu Reservoir	**101**	**22**	**79**	**78%**	**High**
Ojitos Canyon	1	0	1	100%	High
Ojito Canyon- Abiquiu Reservior	12	0	12	100%	High
Rio Puerco- Abiquiu Reservior	14	0	14	100%	High
Polvadera Creek	24	8	16	67%	High
Canones Creek	38	14	24	63%	Moderate
Canones Creek- Abiquiu Reservior	12	0	12	100%	High
El Rito-Rio Chama	**44**	**0**	**44**	**100%**	**High**
Abiquiu Creek	17	0	17	100%	High
Arroyo del Cobre- Rio Chama	1	0	1	100%	High
Rio Ojo Caliente- Rio Chama	**52**	**8**	**44**	**85%**	**High**
Canada de Tio Alfonso- Rio Chama	5	0	5	100%	High
Rio del Oso	19	8	11	58%	Moderate
Rio del Oso- Rio Chama	11	0	11	100%	High
Rio Ojo Caliente- Rio Chama	16	0	16	100%	High
Santa Fe River	**57**	**0**	**57**	**100%**	**High**
Arroyo Calabases	1	0	1	100%	High
HWs Santa Fe River	22	0	22	100%	High
Arroyo de Los Chamisos	1	0	1	100%	High
Arroyo Hondo	1	0	1	100%	High
Outlet Santa Fe River	23	0	23	100%	High

Watershed (HUC 10 gray shade) Sub-watershed (HUC 12 white)	**Perennial Stream Miles**	**Current Native Fish Only Stream Miles**	**Current Native/ Non-native Fish Stream Miles**	**% Departure of Current Native Only from Stream Miles**	**Risk Ranking[9]**
Canada Ancha- Rio Grande	**101**	**3**	**98**	**97%**	**High**
Hws Canada Ancha	1	0	1	100%	High
Canada Ancha- Rio Grande	11	0	11	100%	High
Water Canyon- Rio Grande	4	0	4	100%	High
Alamo Canyon- Rio Grande	28	0	28	100%	High
Rio Chiquito	33	1	32	97%	High
Capulin Canyon- Rio Grande	20	2	18	90%	High
Canada de Cochita- Rio Grande	4	0	4	100%	High
HWs Galisteo Creek	**28**	**0**	**28**	**100%**	**High**
Arroyo Salado	3	0	3	100%	High
San Cristobal Arroyo	9	0	9	100%	High
San Cristobal Arroyo- Galisteo Creek	6	0	6	100%	High
Arroyo Tonque- Rio Grande	**78**	**0**	**78**	**100%**	**High**
Peralta Canyon	17	0	17	100%	High
HWs Borrego Canon	16	0	16	100%	High
Outlet Borrego Canyon	3	0	3	100%	High
Rio Guadalupe	**155**	**3**	**152**	**98%**	**High**
Rito Penas Negras	15	0	15	100%	High
HWs Rio de Las Vacas	40	3	37	93%	High
HWs Rio Cebolla	29	0	29	100%	High
Outlet Rio Cebolla	26	0	26	100%	High
Outlet Rio de Las Vacas	25	0	25	100%	High
Virgin Canyon	9	0	9	100%	High
Rio Guadalupe	37	0	37	100%	High
Upper Jemez River	**125**	**0**	**125**	**100%**	**High**
HWs San Antonio Creek	26	0	26	100%	High
Sulphur Creek	16	0	16	100%	High
East Fork Jemez	45	0	45	100%	High
Outlet San Antonio Creek	14	0	14	100%	High
Church Canyon- Jemez River	24	0	24	100%	High
Rio Salado	**16**	**0**	**16**	**100%**	**High**
Middle Rio Salado	8	0	8	100%	High
Middle Jemez River	48	0	48	100%	High
Canon de La Canada	4	0	4	100%	High
Vallecita Creek	27	0	27	100%	High
Vallecita Creek- Jemez River	10	0	10	100%	High

Watershed (HUC 10 gray shade) Sub-watershed (HUC 12 white)	**Perennial Stream Miles**	**Current Native Fish Only Stream Miles**	**Current Native/ Non-native Fish Stream Miles**	**% Departure of Current Native Only from Stream Miles**	**Risk Ranking[9]**
Arroyo San Jose- Rio Puerco	**88**	**12**	**76**	**86%**	**High**
HWs Arroyo San Jose	12	3	9	75%	High
Outlet Arroyo San Jose	15	0	15	100%	High
San Pablo Canyon	18	0	18	100%	High
Arroyo San Jose- Rio Puerco	42	9	33	79%	High
Cow Creek	**89**	**0**	**89**	**100%**	**High**
HWs Cow Creek	36	0	36	100%	High
Bull Creek	21	0	21	100%	High
Apache Creek	6	0	6	100%	High
Outlet Cow Creek	24	0	24	100%	High
Cow Creek- Pecos	**208**	**0**	**208**	**100%**	**High**
Panchuela Creek	22	0	22	100%	High
Rio Mora	45	0	45	100%	High
Rio Mora- Pecos River	57	0	57	100%	High
Indian Creek- Pecos River	28	0	28	100%	High
Dry Gulch- Pecos River	19	0	19	100%	High
Glorieta Creek	5	0	5	100%	High
Glorieta Creek- Pecos River	10	0	10	100%	High
Tortolita Canyon- Pecos River	23	0	23	100%	High
Tecolote Creek	**58**	**0**	**58**	**100%**	**High**
Cabo Lucero Creek- Tecolote Creek	21	0	21	100%	High
Canon Mesteno- Tecolote Creek	15	0	15	100%	High
Ojito Frios Creek- Tecolote Creek	14	0	14	100%	High
Tres Hermanos Creek	1	0	1	100%	High
Arroyo Leguino	1	0	1	100%	High
Tecolote Creek- Pecos River	**69**	**0**	**69**	**100%**	**High**
El Rito	28	0	28	100%	High
Manzanarez Canyon- Pecos River	8	0	8	100%	High
Arroyo del Vegoso- Pecos River	4	0	4	100%	High
El Canon de Pena- Pecos River	12	0	12	100%	High
El Fileto Canon- Pecos River	17	0	17	100%	High
HWs Canon Blanco	**4**	**0**	**4**	**100%**	**High**
Barbero Canyon	4	0	4	100%	High
HWs Gallinas River	**90**	**0**	**90**	**100%**	**High**
Porvenir Canyon	23	0	23	100%	High
Porvenir Canyon- Gallinas Creek	19	0	19	100%	High

Watershed (HUC 10 gray shade) Sub-watershed (HUC 12 white)	**Perennial Stream Miles**	**Current Native Fish Only Stream Miles**	**Current Native/ Non-native Fish Stream Miles**	**% Departure of Current Native Only from Stream Miles**	**Risk Ranking[9]**
Arroyo Pecos	9	0	9	100%	High
Arroyo Pecos- Gallinas River	17	0	17	100%	High
Watersheds intersecting the Santa Fe NF	**2,279**	**105**	**2,174**	**95%**	**High**
Sub-watersheds on the Santa Fe NF	1,183	89	1094	92%	High

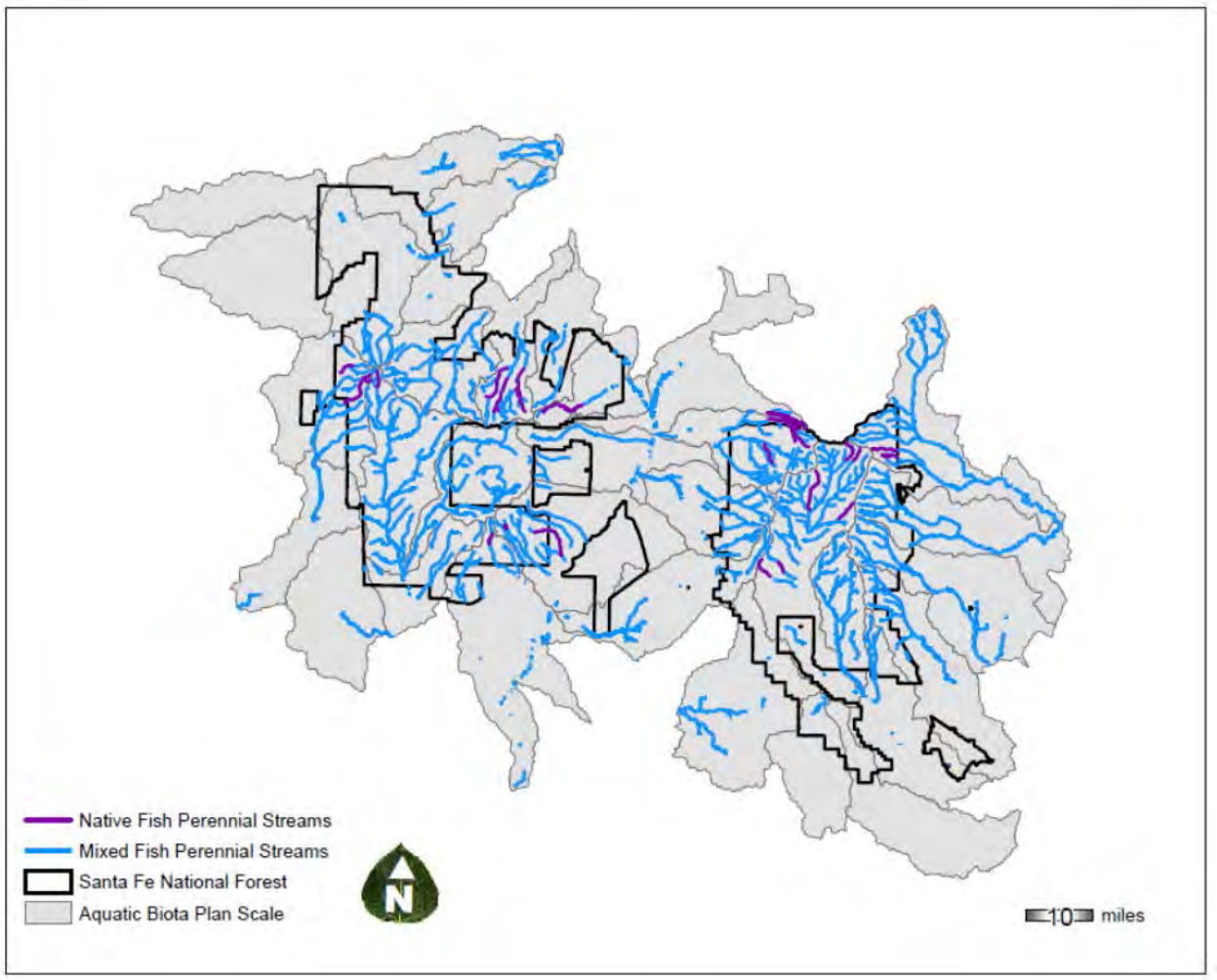


Figure 36. Native fish and mixed fish perennial streams and native fish perennial streams within plan scale

Macroinvertebrates

Aquatic macroinvertebrates are used as biological indicators of stream health, because they are found in all but the harshest or severely polluted streams. Within a stream, the composition of this diverse group of taxa is directly related to the water quality characteristics. For example, some families of invertebrates are found in high abundance in streams that are cold with cobble substrate that have high dissolved oxygen, while others do quite well in slow, muddy rivers. Furthermore, in cases of very poor water quality, only

the most tolerant invertebrate species will persist. Generally, decreased water quality (e.g., increased fine sediment) reduces intolerant species diversity and abundance (Kaller and Hartman 2004; Reynoldson et al. 1997).

There are many popular invertebrate based indices for determining water quality conditions within streams and lakes. For example, the "EPT" test evaluates the abundance and diversity of taxa within the Ephemeroptera, Plecoptera, and Trichoptera families, because they are very sensitive to poor water quality. Furthermore, some indices group invertebrates into functional feeding groups (i.e., shredders, scrapers, collectors) and make inference to water quality conditions based on their abundance and diversity. While these indices work well when comparing samples from one location over time, they don't perform well when comparing non-similar areas. For example, a small headwater stream with very good water quality may have fewer EPT taxa than a larger stream. The EPT would indicate the larger being in better condition, when, in fact, it may not be. To account for this, this assessment uses a multi-metric approach, called the Hilsenhoff Biotic Index (HBI), which corrects for abundance bias in determining the current condition of water quality in streams on the Santa Fe NF. The HBI categorizes species on their ability to tolerate organic pollution using a scale from 0 (most sensitive to pollution) to 10 (most tolerant to pollution). Though the HBI was designed specifically for organic pollution, it often works well with other environmental stressors (Griffith et al. 2005). Samples collected on the Santa Fe NF (95 sample sites), as well as data from New Mexico Environment Department (NMED) (37 Sample sites), are used for this analysis. Samples were collected with a variety of techniques from targeted riffles at 132 sites, between 1980 and 2010. Stream water quality was determined from the assigned HBI values for each stream and placed into one of following water quality categories; excellent (HBI 0-3.5), very good (HBI 3.51-4.5), good (HBI 4.51-5.5), fair (5.51-7.0), and poor (HBI > 7.0) (Hilsenhoff 1987).

Current condition of macroinvertebrates is only analyzed at one scale (Santa Fe NF), due to limited sample size. Currently, most stream sample sites on the Santa Fe NF have either excellent or very good water quality (76 percent and 67 percent, respectively), while the rest are considered good or fair with 2 sites considered poor (figure 37). Many streams on the Santa Fe NF have impaired segments, due to temperature, sedimentation, toxins, etc., according to the NMED §303d water quality list (NM WQCC 2012), and many of the sampled macroinvertebrate sites were taken in these impaired stream segments. The discrepancies between the HBI and §303d list could be that the levels considered impaired by the NMED may not impact aquatic macroinvertebrates to the point of altering the community structure within the stream, which would leave the HBI value unchanged. These impairments are more thoroughly discussed in the Water Quality section of this document. Based on the HBI analysis and the NMED §303d water quality list, the current aquatic macroinvertebrate community is somewhat departed from reference condition, likely due to low stream flow, increase sedimentation, and the presence of toxins in some areas.

The HBI analysis was further broken down into local zones (figure 37) within the Santa Fe NF. The local scale analysis determined water quality groups based on HBI values for the following local zones: Central, Northwest, Northeast, Southwest, and Southeast. The majority of sample sites within zones are very good and excellent, a few being considered good and fair, and only two sites were considered poor (table 41). However, proportionally, Northeast and Northwest have the most excellent and very good water quality ratings within its zone (table 41), followed by Southwest, Southeast, and Central, respectively (table 41). Habitat improvements may be needed within all local zones to increase the number of excellent water quality streams; however, the Santa Fe NF generally has very good water quality as indicated by the aquatic macroinvertebrate community.

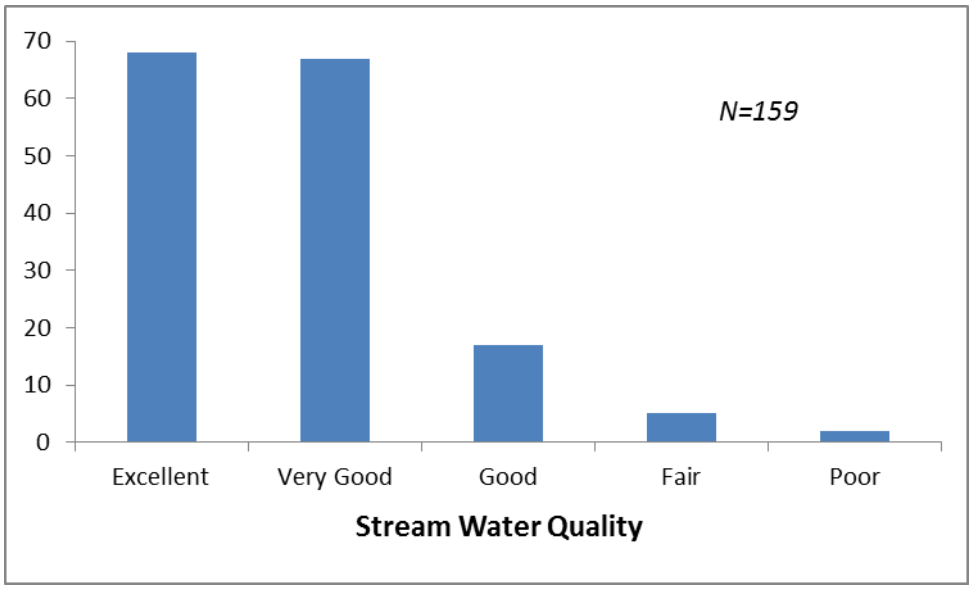


Figure 37. Water quality based on HBI ratings and enumerated macroinvertebrate sample sites for the Santa Fe NF

Table 41. Water quality categories for local zones within the Santa Fe NF based on HBI ratings

Local Zone	*N*[5]*	Excellent (%)	Very Good (%)	Good (%)	Fair (%)	Poor (%)
Central	7	1 (14)	5 (72)	0 (0)	0 (0)	1 (14)
Northeast	62	34 (55)	26 (42)	1 (2)	1(2)	0 (0)
Northwest	40	15 (38)	15 (38)	6 (15)	3 (8)	1(3)
Southeast	10	6 (60)	4 (40)	0 (0)	0 (0)	0 (0)
Southwest	40	12 (30)	17 (43)	10 (25)	1 (3)	0 (0)

Invasive Species and Disease

Four perennial streams within the local scale are known to have Didiymo (*Didymoshenia geminate*), an aquatic invasive species. Invasive species are defined as "an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health" (USDA FS 2014). Didiymo (also known as rock snot) is an invasive alga that forms thick brown mats on stream bottoms. These mats alter stream conditions and can negatively affect macroinvertebrates on the stream bottom, which are a food source for larger aquatic species (NY DEC 2014). Whirling disease is the only known fish disease or parasite currently occurring in three streams at the local scale (NMDGF 2014). Whirling disease is a parasite that infects salmonids and causes skeletal deformation and neurological damage, which, in turn, affects swimming, feeding, and makes the fish more vulnerable to predators (Montana Water Center 2002). Also found in some of streams of the Santa Fe NF is a *Batrachochytrium dendrobatidis* fungus known as Chytrid. Chytrid fungus infects amphibian species with the chytridiomycosis disease, which is linked to devastating population declines or species extinctions (Kilpatrick et al. 2009). Currently, there are no other known "invasions" besides Didiymo, chytrid, and whirling disease, but invasive species and diseases are a continuing challenge. Invasive species and diseases are added threats to native fish, along with environmental conditions, such as high water temperatures and increased sedimentation, invasive species and diseases stress native fish, making it harder to co-exist with non-native fish species.

Trend

Aquatic species and habitat are projected to continue in a stable trend and native fish will continue to persist because:

- Non-native fish species are expected to persist, but not increase for their economic importance of sport fisheries.
- Invasive aquatic species distribution and aquatic diseases are expected to persist or increase.
- Watersheds will continue to be influenced by ERUs and soils that are departed from reference conditions.
- User-created roads and ungulate grazing will continue at current levels thereby influencing water quality and riparian vegetation condition.
- Many aquatic ecosystems have the ability to trend toward reference condition given the opportunity for restoration. Implementation of native fish restoration projects continue to increase on the Santa Fe NF.

Ecosystem Services

In this volume of the Assessment, key regulating and supporting services offered by the Forest's water resources and watersheds are highlighted. Volume II focuses on the direct human benefits that can be considered cultural and provisioning services of these crucial resources.

The above chapter details, primarily at the watershed and sub-watershed scales, the flow regulation (both surface and groundwater), erosion control, water purification and water temperature control effects provided by healthy watersheds. Healthy forests provide clean waters that fill streams, lakes and ponds, recharge ground-water supplies, and supply life to the flora and fauna of the Santa Fe NF. Over 85 percent of the Santa Fe NF sub-watersheds were evaluated as functioning at risk in the 2010 WCC project. Likely drivers for that result are uplands conditions, road densities, riparian and soil conditions. Important keys in sustaining these services will be to maintain properly functioning stream systems and to improve the dimensions, patterns and profiles of those degraded streams across the Santa Fe NF. Stable stream systems with healthy riparian vegetation protect stream banks and beds, help reduce the impacts of flood flows by providing resistance, maintain streamflow and ground-water gradients, and improve water quality by reducing stream temperatures and capturing sediment, nutrients and other debris. State data also shows 36 percent of the total, impaired perennial stream miles (790 miles) within the 37 watersheds analyzed occur on the Santa Fe NF. While the trend for these underlying systems is variable across the Forest, wildfires and the resulting erosion, sedimentation and flooding on the Santa Fe NF will continue to be important drivers of water impacts for both the Forest and off-forest lands.

The primary supporting service is cycling water through its various forms and places in order to produce all its expected benefits. The hydrologic cycle continues to cycle water on a daily basis. In the West, climate change models show that temperatures are expected to rise, and more extreme wet and dry years are predicted. Healthy forests, uplands, wetlands, and riparian corridors along with healthy soils are vital to continued cycling of clean water. These systems have significant impacts to water as it moves through the many processes of the hydrologic cycle. Clearly, off-forest lands have an equally important role in sustaining the health of the hydrologic cycle, since water recognizes jurisdictional boundaries in neither its gaseous nor liquid forms. All effects occurring on the forest can also be reflected down-gradient and downstream both on and off NFS lands.

Chapter 3. Identifying and Assessing At-Risk Species in the Plan Area

This chapter of the assessment focuses on identifying those species that are federally recognized as threatened, endangered, proposed, and candidate species as well as potential "species of conservation concern" (SCC). This chapter also documents information gaps relevant to at-risk species that may be filled through inventories, plan monitoring, or research. Other species of interest on the Forest such as popular game species are addressed in Volume II, Chapter 4, Multiple Uses.

Under the National Forest Management Act (NFMA, 16 U.S.C. 1604(g)(3)(B)), the Forest Service is directed to "provide for diversity of plant and animal communities based on the suitability and capability of the specific land area in order to meet multiple-use objectives, and within the multiple-use objectives of a land management plan adopted pursuant to this section [of this Act], provide, where appropriate, to the degree practicable, for steps to be taken to preserve the diversity of tree species similar to that existing in the region controlled by the plan." To meet this objective, the 2012 Planning Rule adopts a complementary ecosystem and species-specific approach known as a coarse-filter/fine-filter approach to maintaining species diversity (36 CFR 219.9).

The premise behind the coarse-filter approach is that native species evolved and adapted within the limits established by natural landforms, vegetation, and disturbance patterns prior to extensive human alteration. Therefore, maintaining or restoring ecological conditions and functions similar to those under which native species have evolved, offers the best assurance against losses of biological diversity and maintains habitats for the vast majority of species in an area. However, for some species, this approach may not be adequate, either because the reference condition is not achievable or because of non-habitat risks to species viability.

The fine-filter approach recognizes that for many species, additional specific habitat needs or ecological conditions are required and these may not be met by the coarse-filter approach. To determine which wildlife and plant species may require this fine-filter approach, the Santa Fe NF has identified federally threatened, endangered, proposed and candidate species and developed a list of potential SCC that occur within the plan area. While this list itself will not become part of the Forest Plan, it will be used at later stages of the plan revision process to ensure that specific plan components are developed to ensure species diversity in the plan area. Maintaining species that are vulnerable to decline within the planning unit will maintain the diversity of the planning unit and will therefore comply with the National Forest Management Act diversity requirement.

Plant and animal species are frequently a function of ecosystems; specific conditions created by local soil, air, water, aspect, elevation, precipitation, etc. create areas that are favorable or unfavorable for a particular species. The most important direct drivers of biodiversity loss and ecosystem service changes are habitat change (such as land use changes, physical modification of rivers or water withdrawal from rivers), climate change, invasive species, overexploitation, and pollution (Millennium Ecosystem Assessment 2005).Therefore, this chapter builds on the reference and current conditions for the other resources assessed in this volume. It also relies very heavily on the description of vegetation types (Ecological Response Units, ERUs) on the Santa Fe NF and associated risk assessment performed. Additional information can be found in chapter 1.

The Santa Fe has five ranger districts over two mountain ranges. They are home to hundreds of animal, plant, and fungi species. The two mountain ranges are different in origin and composition. The Jemez Mountains are volcanic in origin with pumice and tuff parent materials for soil with sandy sedimentary lowlands while the Sangre de Cristo Mountains are uplift, a southern extension of the Rocky Mountains mostly granitic in origin. These differences are the basis for a few species found only on the Santa Fe or in only one mountain range. For a few species, changing land use patterns outside of the forest has reduced potential habitat availability and increased their reliance on Santa Fe managed lands. These species provide many ecosystem services that in turn benefit society as a whole. This includes ecosystem supporting services such as nutrient cycling (by plants, animals, and invertebrates), soil formation and manipulation (e.g., burrowing insects and mammals), primary production (plants), and seed dispersal (e.g., animals). Regulating services including carbon sequestration (plants), pollination (both forest plants and adjacent croplands by vertebrates and invertebrates), and erosion control and water storage (plants) are additional key ecosystem services provided. Species also provide provisioning services such as food (e.g., forage, game, and wild foods), fiber, medicine, and forest products. Finally, species provide cultural services including recreation (e.g., hunting and bird-watching), opportunities for scientific discovery and education, and cultural, intellectual, or spiritual inspiration. Because this chapter focuses on at-risk species that occur in the plan area, it follows that the ecosystem services provided by these species are decreasing and/or at risk.

Federally Recognized Species on the Santa Fe NF

The Endangered Species Act (ESA) (16 U.S.C. Sec. 1531-1544), administered by the Department of the Interior, U.S. Fish and Wildlife Service (USFWS), recognizes imperiled species and provides for their protection and recovery. There is one federally threatened species known on the Forest, the Mexican Spotted Owl, and three federally endangered species, the Jemez Mountains Salamander, the New Mexico Meadow Jumping Mouse, and the Holy Ghost Ipomopsis (Table 42; USFWS 2014). At present there are no known federal candidate or federal proposed species or federal candidate species on the forest. Two endangered species, the Southwestern Willow Flycatcher and Rio Grande Silvery Minnow are outside the forest boundary, but are within the same watershed as the forest. Neither species occurs in the plan area. A threatened species, the Western Yellow-Billed Cuckoo could potentially use limited riparian habitat on the Santa Fe NF, but is only known as a migrant species and has not been documented on the forest. Canada Lynx, threatened in NM, has not been documented to den or breed on the Santa Fe NF. An individual animal wandering south from Colorado could occasionally use the forest while exploring for territory.

Section 4 of the ESA requires the USFWS to identify and protect all lands, water, and air necessary to recover an endangered species; this is known as critical habitat. Critical habitat includes areas that have been determined to be needed for life processes for a species including space for individual and population growth and for normal behavior; cover or shelter; food, water, air, light, minerals, or other nutritional or physiological requirements; sites for breeding and rearing offspring; and habitats that are protected from disturbances or are representative of the historical geographical and ecological distributions of a species. Mexican Spotted Owl and Jemez Mountains Salamander have designated critical habitat on the Santa Fe NF. The New Mexico Meadow Jumping Mouse has proposed critical habitat on the Santa Fe NF. These USFWS designated habitats are described in more detail in Volume II, Assessing Designated Areas. Holy Ghost Ipomopsis, a flowering plant, found only in one canyon on the Santa Fe NF does not have designated critical habitat.

Section 7 of the ESA requires federal agencies to ensure that actions they authorize, fund, or carry out are not likely to destroy or adversely modify designated critical habitat. Section 7 of the ESA also requires that any Federal agency that carries out, permits, licenses, funds, or otherwise authorizes activities that may affect a listed species must consult with the USFWS to ensure that its actions are not likely to

jeopardize the continued existence of any listed species. Four species will not be carried forward because they are not established on the forest and are not becoming established on the forest (table 42).

Table 42. Federally listed threatened or endangered species that are relevant to the plan area (USDI Fish and Wildlife Service, 2014).

An asterisk (*) denotes species carried forward as federally listed species for the Santa Fe NF.

Scientific Name	Common Name	Federal Status	Critical Habitat On Santa Fe NF Designated by USFWS
Mammals			
Lynx canadensis	Canada Lynx	Threatened	No Critical Habitat. Potential occasional use. No prey base to support a population. The Forest sent this information to the FWS when they were gathering habitat information in 2006.
*Zapus hudsonius luteus**	New Mexico Meadow Jumping Mouse	Endangered	Proposed Critical Habitat. Drainages on the west side of the Forest have a very small population which was more widespread based on historic museum specimen locations.
Birds			
Coccyzus americanus occidentalis	Western Yellow-Billed Cuckoo	Threatened w of Rio Grande, Distinct Population Segment (DPS)	No Critical Habitat. No known locations of this species but slight potential to use bosque areas during migration along the Rio Grande or Jemez River.
Empidonax traillii extimus	Southwestern Willow Flycatcher	Endangered	No Critical Habitat. No known locations of this species on the forest.
*Strix occidentalis lucida**	Mexican Spotted Owl	Threatened	Yes Critical Habitat present. Several nests sites on the forest. Some sites lost due to large fires.
Fish			
Hybognathus amarus	Rio Grande Silvery Minnow	Endangered	No Critical Habitat. The are no known populations on the Forest because the species does not occur above the dam on Cochiti Reservoir that is on Cochiti Pueblo land. The minnow does not occur in the Rio Grande above Cochiti Reservoir. Northern Pike, a highly predatory fish, are in the reservoir and Rio Grande above the reservoir, making restoration of the minnow above the reservoir highly unlikely.
Amphibian			
*Plethodon neomexicanus**	Jemez Mountains Salamander	Endangered	Yes Critical Habitat present. Endemic only to the Jemez Mountains. Restricted to mesic forested habitat.
Plant			
*Ipomopsis sancti-spiritu**	Holy Ghost Ipomopsis	Endangered	No Critical Habitat. Endemic to one canyon In Sangre de Cristo Mountains.

Criteria for Identifying a Species of Conservation Concern

A species of conservation concern (SCC) is defined in the 2012 Planning Rule as "a species, other than federally recognized threatened, endangered, proposed, or candidate species, that is known to occur in the plan area and for which the regional forester has determined that the best available scientific information indicates substantial concern about the species' capability to persist over the long-term in the plan area." The guidance provided in the final directives for the 2012 planning regulations (Forest Service Handbook [FSH] 1909.12 – Land Management Planning, Chapter 10) is used to develop the SCC list for the Santa Fe NF. The criteria for identifying species of conservation concern are also the criteria for identifying potential species of conservation concern, which are (FSH 1909.12, 12.52c):[11]

All potential SCCs *must meet* the following mandatory requirements for their identification as SCC:

1. The species is native to, and known to occur in, the plan area; and,

   A species is known to occur in a plan area if, at the time of plan development, the best available scientific information indicates that a species is established or is becoming established in the plan area. A species with an individual occurrences in a plan area that are merely "accidental" or "transient," or are well outside the species' existing range at the time of plan development, is not established or becoming established in the plan area. If the range of a species is changing so that what is becoming its "normal" range includes the plan area, an individual occurrence should not be considered transient or accidental.

2. The best available scientific information indicates substantial concern about the species' capability to persist over the long term in the plan area. See FSH 1909.12, zero code section 07, guidance on best available scientific information.

   If there is insufficient scientific information available to conclude there is a substantial concern about the species capability to persist in the plan area over the long-term that species cannot be identified as a species of conservation concern.

   If the species is secure and its continued long-term persistence in the plan area is not at risk based on knowledge of its abundance, distribution, lack of threats to persistence, trends in habitat, or responses to management that species cannot be identified as a species of conservation concern.

Scales of Analysis

Three scales of analysis were used for the assessment of at-risk species: context, plan, and local. These roughly correspond with evaluating species within the state of New Mexico (context); species that occur somewhere on the Santa Fe NF (plan); and finally associating species with individual local zones described in Spatial Scales for Terrestrial Ecosystems (p. 14) (local). The local scale of analysis breaks the plan scale into five local zones, delineated along Hydrologic Unit Codes at the sub-basin (HUC-8) scale and sub-watershed boundaries (HUC-12) watershed boundaries, and differentiated by level or type of management, past disturbances such as wildfire, distribution of vegetation types and extent of use. The minimum zone size/maximum

[11] More detailed guidance for selecting SCC is presented in chapter 10 of the final directives (FSH 1909.12, 12.52).

number of zones was based on recommendations provided by the Regional Office (USDA FS 2014).

Species to Consider when Identifying Potential Species of Conservation Concern

1. ***Species native to and known to occur in the planning area.***
2. ***Species in the following categories must be considered:***
   a. Species with status ranks of G/T1 or G/T2 on the NatureServe ranking system.
   b. Species that were removed within the past 5 years from the Federal list of threatened or endangered species, and other delisted species that the regulatory agency still monitors.
3. ***Species in the following categories should be considered:***
   a. Species with status ranks of G/T3 or S1 or S2 on the NatureServe ranking system.
   b. Species listed as threatened or endangered by relevant States, federally recognized Tribes, or Alaska Native Corporations.
   c. Species identified by Federal, State, federally recognized Tribes, or Alaska Native Corporations as a high priority for conservation.
   d. Species identified as species of conservation concern in adjoining National Forest System plan areas (including plan areas across regional boundaries).
   e. Species that have been petitioned for Federal listing and for which a positive "90-day finding" has been made.
   f. Species for which the best available scientific information indicates there is local conservation concern about the species' capability to persist over the long-term in the plan area due to:

      (1) Significant threats, caused by stressors on and off the plan area, to populations or the ecological conditions they depend upon (habitat). These threats include climate change.

      (2) Declining trends in populations or habitat in the plan area.

      (3) Restricted ranges (with corresponding narrow endemics, disjunct populations, or species at the edge of their range).

      (4) Low population numbers or restricted ecological conditions (habitat) within the plan area.

NatureServe Conservation Status Ranks

NatureServe conservation status ranks are based on a scale of one to five, ranging from critically imperiled (G1) to demonstrably secure (G5). Status is assessed and documented at three distinct geographic scales -global (G), national (N), and State/province (S). The conservation status of a species or ecosystem is designated by a number from 1 to 5, preceded by a letter reflecting the appropriate geographic scale of the assessment. If 'NR' follows a letter it means it has not been reviewed. (http://www.natureserve.org/explorer/ranking.htm).

Status Rank	Status Rank Definition
1	*Species is Critically Imperiled* At very high risk of extinction or elimination due to very restricted range, very few populations or occurrences, very steep declines, very severe threats, or other factors.
2	*Species is Imperiled* At high risk of extinction or elimination due to restricted range, few populations or occurrences, steep declines, severe threats, or other factors.
3	*Species is Vulnerable* At moderate risk of extinction or elimination due to a fairly restricted range, relatively few populations or occurrences, recent and widespread declines, threats, or other factors.
4	*Species is Apparently Secure* At fairly low risk of extinction or elimination due to an extensive range and/or many populations or occurrences, but with possible cause for some concern as a result of local recent declines, threats, or other factors.
5	*Species is Secure* At very low risk or extinction or elimination due to a very extensive range, abundant populations or occurrences, and little to no concern from declines or threats.
Infraspecific taxa refer to subspecies, varieties, and other designations below the level of the species. The status of infraspecific taxa (subspecies or varieties) are indicated by a T-rank following the species' global rank. Rules for assigning T-ranks follow the same principles outlined above. For example, the global rank of a critically imperiled subspecies of an otherwise widespread and common species would be G5T1.	

Evaluating Relevant Information for At-Risk Species

A Microsoft Access database (Species Risk Assessment Database) was designed as a tool to store information on potential SCC on the Santa Fe NF. Information on each species was gathered from the BASI mainly from NatureServe but other sources such as scientific literature and species experts. Recent information was used to update the database such as changes in a species federal status or new observations in the plan area. Evaluation of relevant information collected is integral to the forest plan revision process

1. Review and screen species that meet number 1 described above, and determine which species have been documented to occur on the Santa Fe NF.

2. Determine which of the potential SCCs meet number 2 described above (species that must be considered G/T1 or G/T2 on the NatureServe ranking system; and species that were removed within the past 5 years from the Federal list of threatened or endangered species, and other delisted species that the regulatory agency still monitors).

3. Associate the remaining potential SCC species determined under number 3 above with current ecological condition and key ecosystem characteristics described within ERUs on each of the Santa Fe NF local zones.

4. Perform a risk assessment analysis on the remaining species, with their associated ERU.

Federally listed species are also tracked throughout this process, but in a separate way to potential SCC. Both the Rule and final directives mandate the use of best available scientific information (BASI) for each

of the resource parameters evaluated in this assessment. To form the list of potential SCC, BASI was used.

Review and screen species that meet number 1 described above, and determine which species have been documented on the Santa Fe NF.

According to NatureServe (NatureServe.org, 2015), there are more than 7,000 animal, plants, and fungi species found in New Mexico. A smaller number of species is entered in the Risk Assessment Database based on habitats and listed species that occur on national forest lands throughout New Mexico. The lack of many types of habitats found elsewhere in the state eliminated many species from consideration for the Santa Fe NF (for example, Chihuahuan Desert). Species records and G/T rankings were exported from the NatureServe database to meet the directives.

Determine which of the potential SCC meet number 2 described above.

Species with a numeric ranking of 1 or 2 in NatureServe have been identified by State natural heritage programs, U.S. Fish and Wildlife Service, International Union for Conservation of Nature, Canadian Wildlife Service, and others entities as facing the risk of extinction. To form the list of potential SCC following the directives BASI needs to indicate substantial concern about species' capability to persist over the long term in the plan area. Information is derived from many sources one of which is NatureServe. Other sources included are scientific literature, species studies, habitat studies, analyses of information or surveys obtained from a local area, and/or the result of expert opinion or panel consensus.

There are no species on the Santa Fe NF that were removed from the list of federally threatened or endangered species within the past 5 years. Two species, Bald Eagle and American Peregrine Falcon are still monitored for impacts of any actions on the forest.

Associate the remaining potential SCC species determined under number 3 above with current ecological condition and key ecosystem characteristics described within ERUs on each of the Santa Fe NF local zones.

To the list were added:

- Species with a status ranks of G/T3 or S1 or S2 on the NatureServe ranking system. (These species added from NatureServe and included in the Risk Assessment database)
- Species listed as threatened or endangered by relevant States, or federally recognized Tribes. (Information for the State was from New Mexico Department of Game and Fish (BISON-M, 2014) and State Forestry Division (NMEMNRD, 2013); (Species listed as threatened or endangered by adjacent Pueblos (no information received during initial discussions with them) and Tribes (Navajo Nation 2008) (no information received during initial discussions with them)).
- Species identified by Federal, State, federally recognized tribes as high priority for conservation. (No species were identified by adjacent Pueblos or from the Navajo Nation during initial discussions with them;
- Species identified as species of conservation concern in adjoining National Forest System plan areas. (A few species on the US Forest Service Southwest (Region3) Regional Forester's Sensitive Species List (USDA Forest Service, 2013) are the same as those on the adjoining Carson NF.)

- Species that are identified as recently delisted or have a positive 90-day finding in New Mexico by the USFWS (77 FR 69994); (No species within the plan area has been identified as recently delisted or have a positive 90-day finding).

- Species for which the BASI indicates there is local conservation concern about the species' capability to persist over the long-term in the plan area due to: Significant threats, caused by stressors on and off the plan area, to populations or the ecological conditions they depend upon (habitat), including climate change, declining trends in population or habitat in the plan area. Restricted ranges (narrow endemics, disjunct populations, or species at the edge of their ranges. Low populations numbers. Sources identified species of greatest conservation need by the New Mexico Comprehensive Wildlife Conservation Strategy (NMDGF, 2006) and New Mexico Rare Plant Technical Council (New Mexico Rare Plant Technical Council, 1999.

This list of approximately 1,679 species in New Mexico formed the base of the potential SCC list within the context area and was comprised of 694 vascular and non-vascular plants, 11 fungi, 332 invertebrates, and 321 vertebrates including 13 amphibians, 26 reptiles, 52 fish, 99 mammals, and 131 birds.

The next step of this process involved identifying which of these species occur on the Santa Fe NF (FSH 1909.12, 12.52c(1)). Where possible, published location information was used to filter out species that were not reported in one of the six counties (Sandoval, Los Alamos, Mora, Rio Arriba, Santa Fe, and San Miguel) encompassing the Santa Fe NF or with more precise documented locations not on the forest.

Internal databases, Natural Resources Manager (NRM) (USDA Forest Service, 2014) on-line and museum databases, including Arctos Collection Management Information System (Arctos 2014), Biota Information System of New Mexico (BISON-M 2014), Butterflies and Moths of North America 2014, Natural Heritage New Mexico (NHNM 2014), New Mexico Biodiversity Collections Consortium (NMBCC 2013), Rocky Mountain Bird Observatory (RMBO 2014), and Southwest Environmental Information Network (SEINet 2014), and unpublished breeding bird survey data (USDA Forest Service 2012) were queried for forest-specific documented locations of observations.

In addition to the databases and lists cited above, Forest Service biologists at the Santa Fe NF Supervisor's office and each of the districts and the Southwestern Regional Office consulted in the development of the potential SCC list. Subject matter experts at the U.S. Fish and Wildlife Service, New Mexico Department of Game and Fish, New Mexico Department of Forestry, Natural Heritage New Mexico, researchers and others who were able to consult internal records and databases or rely on expert knowledge to further filter the list were consulted. Subject matter experts were consulted via publications or personal communications and included staff at Natural Heritage New Mexico (NHNM) (R. McCollough and M. East); New Mexico State Forestry Division (M. Stuever); New Mexico Department of Game and Fish (F. Winslow, C. Painter, E. Goldstein, E. Rominger, M. Darr, D. Brooks, C. Hayes); New Mexico State University (J. Frey); Highland University (J. Jacobi); U.S. Fish and Wildlife Service (E. Hein, M. Christman); U.S. National Park Service (A. Chung-MacCoubrey); and the U.S. Geological Survey (C. Allen and E. Valdez).

The New Mexico Comprehensive Wildlife Conservation Strategy (CWCS) has older information and is being updated in 2015, to reflect recent knowledge and status of species. Some species in the New Mexico CWCS did not meet the NatureServe ranking criteria for SCC, thus reducing the number of species to be considered. For highly visible and high-interest species (e.g., birds) reliable collection and observation data are available.

While compiling relevant species information, there were several sources of data that appeared to fill gaps for BASI. Citizen science in conservation allows volunteers to collect and submit data to online databases

including eBird (eBird.org 2014), iNaturalist (iNaturalist 2014), and BugGuide.Net (bugguide.net 2014). These resources were used to determine presence or absence in the planning area by getting reliable location data where it was possible to verify observations.

For many other species, some information is simply not available. In many cases, it was not possible to determine if this was because surveys had been conducted but the species was not found (negative surveys), or surveys had not been conducted at all. No fungi or lichen species were carried forward because no survey information exists to verify if those identified as potentially at-risk occur on the Santa Fe NF. This is a data gap that should be addressed through future inventories, plan monitoring, or research. An example of a species not occurring on the forest is the Goat Peak Pika (Ochotona princeps nigrescens, V. Bailey 1912). It will not be considered as potential SCC because it is considered "accidental" for the Santa Fe NF due to only one recorded occurrence on the boundary with the Valles Caldera National Preserve (VCNP) (SFNF GIS 2015). All other occurrences are within VCNP under the National Park Service, Department of the Interior.

During the assessment, other data gaps were found and attributed mainly to inadequate survey data. For example, the Greene's milkweed is a conspicuous flowering plant that meets the criteria for inclusion on the list of potential SCC as described in FSH 1909.12. It has a NatureServe G3/4, T2 and S2 and it is identified on the Region 3 Regional Forester's Sensitive Species List (USFS 2013). It has only two older observations on the Santa Fe NF in the farthest southeastern part of the South East Zone. Searches by B. Sivinski (former State botanist) did not find the species (2015 pers. comm. with J.Luetzelschwab, SFNF GIS). It could be that the past 3 years of drought have affected the isolated specimens in the record. It is known to be widespread in several states in varieties of grassland habitats although uncommon in occurrence.

Of the initial 1,679 species that were evaluated from the database identified in New Mexico, 50 met one or more of the criteria for potential SCC in the directives. They are displayed in Table 43.

Codes for Rationale for Consideration:

CN = Identified as a species of greatest conservation need in the New Mexico Comprehensive Wildlife Conservation Strategy 2006.
F = Federally de-listed within last 5 years
N = NatureServe Global, Taxonomic, National, or State Ranking
RF = Southwest Regional Forester's Sensitive Species List 2013
RM = Rocky Mtn. Herbarium
RP = New Mexico Rare Plant List
S = State-listed as threatened (t) or endangered (e). (19.33.6 New Mexico Administrative Code Title 19 Chapter 33 Part 6 and 19.21.2.9)

Table 43. Possible species on the Santa Fe NF available for consideration as species of conservation concern

	Scientific Name	Common Name	Rationale for Consideration	NatureServe rank	Source of observation in or near the Plan Area	Documented on the Forest? Rationale
	Mammals					
1	*Corynorhinus townsendii pallescens*	Pale Townsend's Big- Eared Bat	RF	G3G4T3T4 N3N4 S3S4	USGS	No Recorded observations not on the Forest
2	*Cynomys gunnisoni pop. 1* *Cynomys gunnisoni*	Gunnison's Prairie Dog (montane population) (prairie population)	CN, N, RF CN	G5T2 N2 SNR G5 N5 S2	SFNF GIS	Yes Yes
3	*Euderma maculatum*	Spotted Bat	CN, RF, S(t)	G4 N3N4 S3	NHNM	Yes
4	*Lepus americana*	Snowshoe Hare	CN, N	G5 N5 S2	Wilderness ranger	Yes
5	*Marmota flaviventris*	Yellow-bellied Marmot	N	G5 N5 S2	Santa Fe NF biologist	Yes
6	*Martes caurina*	American Marten is now Pacific Marten in NatureServe based on new genetic work.	CN, N, RF, S(t)	G4G5 N4N5 S2	NRM	Yes
7	*Ochotona princeps nigrescens, V. Bailey 1912* *Syn. Ochotona princeps saxatilis, Bangs 1899*	Goat Peak Pika	RF	G5T5 N5 S1	Unknown on Santa Fe NF	No. Recorded observations not on the Forest
8	*Ochotona princeps*	American Pika	RF, N	G5 N5 S2	SFNF biologist	Yes

	Scientific Name	Common Name	Rationale for Consideration	NatureServe rank	Source of observation in or near the Plan Area	Documented on the Forest? Rationale
9	*Ovis canadensis canadensis*	Rocky Mountain Bighorn Sheep	CN, N	G4T4 N4 SNR	NMDGF	Yes
10	*Sorex cinereus*	Masked Shrew	RF, N	G5 N5 S2	NRM	Yes
11	*Sorex palustris*	Water Shrew	RF, N	G5 N5 S2	NRM	Yes
12	*Sorex preblei*	Preble's Shrew	RF, N	G4 N4 S1	NRM	No. Recorded observations not on the Forest
	Birds					
13	*Accipiter gentilis*	Northern Goshawk	CN, RF	G5 N4B,N4N S2B,S3N	Santa Fe NF biologists and GIS	Yes
14	*Aegolius funereus*	Boreal Owl	CN, N, RF, S(t)	G5 N4 S2B,S2N	E. MacKerrow	Yes
15	*Athene cunicularia hypugaea*	Western Burrowing Owl	RF	G4T4 N4 S3B,S3N	J. Luetzelschwab	Yes
16	*Aquila chrysaetos*	Golden Eagle	CN	G5 N5B,N5N S3B,S4N	SFNF GIS	Yes
17	*Cypseloides niger*	Black Swift	N	G4 N4B S2B,S2N	SFNF GIS	Yes
18	*Dendroica graciae Syn. Setaophaga graciae*	Grace's Warbler	CN	G5 N5B S3B,S4N	SFNF GIS	Yes
19	*Dendroica nigrescens Syn. Setophaga nigrescens*	Black-Throated Gray Warbler	CN	G5 N5B S3B,S4N	SFNF GIS	Yes
20	*Falco peregrinus anatum*	American Peregrine Falcon	CN, N, RF, S(t)	G4T4 N3B,N3 S2BS3N	T. Johnson	Yes
21	*Gymnorhinus cyanocephalus*	Pinyon Jay	CN	G5 N5 S3B,S3N	SFNF GIS	Yes
22	*Haliaeetus leucocephalus*	Bald Eagle	NN, RF, S(t)	G5 N5b,N5N S1B,S4N	SFNF GIS	Yes
23	*Lagopus leucurus*	White-tailed ptarmigan	RF, S(e)	G5 N5 S1B,S1N	NHNM and ebird	Yes
24	*Lanius ludovicianus*	Loggerhead Shrike	CN	G4 N4 S3B,S4N	ebird	Yes
25	*Leucosticte australis*	Black Rosy-Finch	N	G4 N4B,N4 S3N	ebird	Yes
26	*Melanerpes lewis*	Lewis's Woodpecker	CN	G4 N4B,N4N S3B,S3N	ebird	Yes
27	*Melospiza lincolnii*	Lincoln's Sparrow	N	G5 N5B,N5N S2B,S5N	ebird	Yes

	Scientific Name	Common Name	Rationale for Consideration	NatureServe rank	Source of observation in or near the Plan Area	Documented on the Forest? Rationale
28	*Pandion haliaetus*	Osprey	CN	G5 N5B,N4N S2B,S4N	USGS, BISON-M	Yes
29	*Riparia riparia*	Bank Swallow	CN, N	G5 N5B S2B,S5N	ebird	Yes
30	*Vireo vicinior*	Gray Vireo	CN,NN,RF,S(t)	G4 N4B S4B,S3N	ebird	Yes
31	*Wilsonia pusilla* *Syn Cardellina pusilla*	Wilson's Warbler	N	G5 N5B S2B,S5N	2005 (ebird)	Yes
	Reptiles and Amphibians					
32	*Lithobates pipiens*	Northern Leopard Frog	CN, N, NN, RF	G5 N5 S1	NHNM and J.Luetzelschwab	Yes
	Invertebrate					
33	*Pisidium lilljeborgi*	Lilljeborg's Peaclam	N, RF, S(t)	G5 N5 S1	BISON-M	Yes
34	*Gastrocopta ruidosensis*	Ruidoso Snaggletooth	N, RF	G1 N1 S3	RF	Yes
	Fish					
35	*Catostomus plebeius*	Rio Grande Sucker	CN, N, RF	G3G4 N3 S2	SFNF GIS	Yes
36	*Gila pandora*	Rio Grande Chub	CN, N, RF	G3 N3 S3	SFNF GIS	Yes
37	*Oncorhynchus clarkii virginalis*	Rio Grande Cutthroat Trout	RF	G4T3 N2 S2	SFNF GIS	Yes
	Plants					
38	*Abronia bigelovii*	Tufted Sand Verbena	RF, RP	G3 N3 S3	Unknown on Santa Fe NF	No. Recorded observations not on the Forest
39	*Asclepias uncialis ssp. uncialis*	Greene's Milkweed	RF	G3G4T2T3 NNR S2	2015 SFNF GIS, NHNM	Yes
40	*Astragalus micromerius*	Chaco Milkvetch	N, RF, RP	G2 N3 S2	2009 (SEINet)	Yes
41	*Calochortus gunnisonii var. perpulcher*	Gunnison's (Pecos) Mariposa Lily	RF, RM	G5T4? N4? S4?	2015 RM	Yes
42	*Cypripedium parviflorum var. pubescens*	Large Yellow Lady's-Slipper	RF	G5T5 N4,N5 S2?	2005 (SEINet)	Yes
43	*Delphinium robustum*	Robust Larkspur aka Wahatoya Larkspur	N, RF, RP	G2? N2? S?	Unknown on Santa Fe NF	No. Recorded observations not on the

	Scientific Name	Common Name	Rationale for Consideration	NatureServe rank	Source of observation in or near the Plan Area	Documented on the Forest? Rationale
						Forest
44	*Draba heilii* Al-shebaz	Heil's Alpine Whitlowgrass	N, RP, RF	GNR NNR SNR	2008 (NMRP)	Yes
45	*Erigeron subglaber*	Pecos Fleabane	RF, RM	G3 N3 S3	1996 (NHNM and 2015 RM	Yes
46	*Lilium philadelphicum*	Wood Lily	RF, S(e)	G5 N5 S3	2003 (SEINet)	Yes
47	*Mentzelia conspicua*	Chama Blazing Star	RF	G2 N2 S2	2002 (NHNM)	Yes
48	*Mentzelia springeri*	Springer's Blazing Star	RF, RM	G3 NNR SNR	2015 RM	Yes
49	*Penstemon oliganthus*	Apache Beardtongue	N	G3? N3? SNR	2009 (SEINet)	Yes
50	*Salix arizonica*	Arizona Willow	RF	G2G3 N2N3 S1	2001	Yes

Of the 50 species, ***five*** have not been reliably documented on the Santa Fe NF as shown in Table 43 and will not be carried forward bringing the number of species to 45.

Identify species that are at risk of persisting over the long term in the plan area.

The second step of the SCC analysis process determined which species can be removed from the potential SCC list because it is secure and its continued long-term persistence in the plan area is not at risk. Step 2 criteria were: (1) species has been documented to use the plan area only during the winter or as "transients" (e.g., osprey or bald eagle); (2) species inhabit areas not known to be affected by threats; (3) there is insufficient information to evaluate whether or not the species is at risk for persistence within the plan area; (4) species has a stable to upward population or habitat trend on the Santa Fe NF.

Based on knowledge of the species' abundance, distribution, lack of threats to persistence, trends in habitat, or responses to management, 16 of the remaining 45 species identified as potential SCC are secure and their continued long-term persistence in the plan area are not at risk. As such, these species are no longer considered for further analysis as potential SCCs. Table 44 shows the list the species removed and the rationale for removing them.

Table 44. Potential SCC removed from further analysis, and rationale for removal

Common Name	Rationale for Removal from Potential SCC List
Mammals	
American Pika	Inhabits rocky talus slopes that have not changes from historical reference condition and that are not affected by any threats. (BISON-M 2014).
Rocky Mountain Bighorn Sheep	The species was reintroduced to the Jemez Mountains in 2014. The herd has hundreds of acres of new habitat due to the Las Conchas Fire in 2011 and historic habitat in White Rock Canyon. Surveys by NMDGF indicate both the Pecos Wilderness and the Jemez Mountains herds are stable or increasing.
Yellow-bellied Marmot	Inhabits rocky talus slopes that have not changes from historical reference condition and that are not affected by any threats. (BISON-M 2014).
Birds	
Bald Eagle	Migrant, winter presence only. Population increasing or stable nationally. The Santa Fe NF would comply with the Bald Eagle and Golden Eagle Protection Act (16 U.S.C. 668-668d) for any activity that could possibly affect eagles including activities of outside entities applied for under a Forest Service Special Use Permit. All activities must be evaluated for possible effects to eagles which include obtaining permits from Fish and Wildlife Service. Restrictions through the permit process would alleviate any concern for their continued persistence if a potential disturbance activity cannot be avoided.
Bank Swallow	Habitat is ephemeral. Populations overall are stable. There is insufficient information to evaluate whether or not this species is at risk for persistence within the plan area (NatureServe 2015).
Black Rosy-Finch	Wintering population only in northern NM (AOU 1983) and population is deemed secure (NatureServe 2015).
Golden Eagle	Population trends for NM are holding stable (NatureServe 2015). The Santa Fe NF would comply with the Bald Eagle and Golden Eagle Protection Act (16 U.S.C. 668-668d) for any activity that could possibly affect eagles including activities of outside entities applied for under a Forest Service Special Use Permit. All activities must be evaluated for possible effects to eagles which include obtaining permits from Fish and Wildlife Service. Restrictions through the permit process would alleviate any concern for their continued persistence if a potential disturbance activity cannot be avoided.
Grace's Warbler	Population trends for NM are holding stable. Studies of response to silvicultural systems show the species is abundant in select-harvest units (Szaro and Balda 1979a, 1979b; Brawn and Balda 1988).
Gray Vireo	Population trends for NM are holding stable widespread occurrences (BISON-M 2015).
Lincoln's Sparrow	Population trends for NM are holding stable.
Loggerhead Shrike	There is insufficient information to evaluate whether or not this species is at risk for persistence within the plan area (NatureServe 2015).
Osprey	Migrant. Population trends for NM are holding stable (BISON-M 2015)

Common Name	Rationale for Removal from Potential SCC List
Plants	
Apache Beardtongue	There is insufficient information to evaluate whether or not this species is at risk for persistence within the plan area (NatureServe 2015).
Chaco Milkvetch	Not significantly threatened by the prevailing land uses within its habitat (NMRPTC 1999).
Gunnison's (Pecos) Mariposa Lily	There is insufficient information to evaluate whether or not this species is at risk for persistence within the plan area (NMRPTC 1999).
Pecos Fleabane	There is insufficient information to evaluate whether or not this species is at risk for persistence within the plan area (NMRPTC 1999).

There are 29 potential SCC that meet the criteria of not being capable of persisting in the plan area over the long term. Western burrowing owl and Gunnison's prairie dog remained as potential SCC as these species have concerns for persistence in the plan area; however, the concerns for persistence are due to actions or activities outside of agency control, authority, or capability.

In summary, Table 47 lists the potential 29 SCC that are documented to occur on the Santa Fe NF and that the best available scientific information indicates substantial concern about their capability to persist over the long term in the plan area.

Table 45. Potential SCC for the Santa Fe National Forest

Common Name	Scientific Name	NatureServe rank
Mammals		
Gunnison's Prairie Dog (montane population) (prairie population)	*Cynomys gunnisoni pop. 1* *Cynomys gunnisoni*	G5T2 N2 SNR G5 N5 S2
Spotted Bat	*Euderma maculatum*	G4 N3N4 S3
Snowshoe Hare	*Lepus americana*	G5 N5 S2
American (Pacific) Marten Listed as Pacific Marten in NatureServe based on genetic work.	*Martes caurina*	G4G5 N4N5 S2
Masked Shrew	*Sorex cinereus*	G5 N5 S2
Water Shrew	*Sorex palustris*	G5 N5 S2
Birds		
Northern Goshawk	*Accipiter gentilis*	G5 N4B,N4N S2B,S3N
Boreal Owl	*Aegolius funereus*	G5 N4 S2B,S2N

Common Name	Scientific Name	NatureServe rank
Western Burrowing Owl	*Athene cunicularia hypugaea*	G4T4 N4 S3B,S3N
Black Swift	*Cypseloides niger*	G4 N4B S2B,S2N
Black-Throated Gray Warbler	*Dendroica nigrescens* Syn. *Setophaga nigrescens*	G5 N5B S3B,S4N
American Peregrine Falcon	*Falco peregrinus anatum*	G4T4 N3B,N3 S2BS3N
Pinyon Jay	*Gymnorhinus*	G5 N5 S3B,S3N
White-tailed ptarmigan	*Lagopus leucurus*	G5 N5 S1B,S1N
Lewis's Woodpecker	*Melanerpes lewis*	G4 N4B,N4N S3B,S3N
Wilson's Warbler	*Wilsonia pusilla* Syn *Cardellina pusilla*	G5 N5B S2B,S5N
Reptiles and Amphibians		
Northern Leopard Frog	*Lithobates pipiens*	G5 N5 S1
Invertebrate		
Lilljeborg's Peaclam	*Pisidium lilljeborgi*	G5 N5 S1
Ruidoso Snaggletooth	*Gastrocopta ruidosensis*	G1 N1 S3
Fish		
Rio Grande Sucker	*Catostomus plebeius*	G3G4 N3 S2
Rio Grande Chub	*Gila pandora*	G3 N3 S3
Rio Grande Cutthroat Trout	*Oncorhynchus clarkii virginalis*	G4T3 N2 S2
Plants		
Greene's Milkweed	*Asclepias uncialis ssp. uncialis*	G3G4T2T3 NNR S2
Large Yellow Lady's-Slipper	*Cypripedium parviflorum var. pubescens*	G5T5 N4,N5 S2?
Heil's Alpine Whitlowgrass	*Draba heilii* Al-shebaz	GNR NNR SNR
Wood Lily	*Lilium philadelphicum*	G5 N5 S3
Chama Blazing Star	*Mentzelia conspicua*	G2 N2 S2
Springer's Blazing Star	*Mentzelia springeri*	G3 NNR SNR
Arizona Willow	*Salix arizonica*	G2G3 N2N3 S1

Associate and federally listed (Table 42) and potential species of conservation concern (Table 47) with current ecological conditions and key ecosystem characteristics described within ERUs on each of the Santa Fe NF local zones.

The third step associated the 29 remaining potential SCC and 4 federally listed species with Ecological Response Units (ERUs) as presented in Chapter 1, Vegetation. and key ecosystem characteristics described within ERUs on the Santa Fe NF, at the local scale. Vegetation is one of the primary factors that influences species diversity and abundance and is one of the more obvious habitat components influenced by management, land use, and natural disturbance. To make the species risk assessment relevant to other ecological risk assessments presented in this document and because vegetation is such a significant habitat component for species, vegetation types and key ecosystem characteristics were categorized following ecological response units (ERUs), as applied in the Terrestrial Ecosystems and Riparian Ecosystems sections. These ERUs are a stratification of ecosystem settings that are each similar in indicator plant species, succession patterns, and disturbance regimes that, in concept and resolution, are most useful to management. In other words, ERUs are the range of plant associations (USDA FS 1997), along with structure and process characteristics that would occur when natural disturbance regimes and biological processes prevail (Schussman and Smith 2006).

The ERU framework represents all major ecosystem types of the region and a coarse stratification of biophysical themes. The ERUs are map unit constructs, i.e., technical groupings of finer vegetation classes with similar site potential (Daubenmire 1968) and disturbance history.

For this reason, ERUs do not necessarily reflect the vegetation currently present in a particular map unit but rather reflect the unit's site potential given the natural range of variation and historical disturbance regime. ERUs are described in much more detail in the Chapter 1, Vegetation.

Federally threatened and endangered species and potential SCC were associated with dominant ERU types in Table 46 and Table 47. These associations were informed by a number of different sources including the Biota Information System of New Mexico (BISON-M 2014), the New Mexico Rare Plants website (New Mexico Rare Plants Technical Council 1999), NatureServe Data Explorer (NatureServe 2014) and personal communications with species experts and agency biologists.

In many cases, species' habitat needs were not represented solely by ERUs (e.g., raptors requiring snags for perching or nesting, or snails requiring dense leaf litter to retain moisture, etc.). In these cases, those special habitat features were recorded and assessed separately from the ERU model (Table 48). Overall, an effort was made to associate species with ERU types whenever possible because later stages of forest plan revision and development will focus on the management of ERUs. This relationship between species and ERUs is the premise of the coarse-filter approach discussed above and appropriate management of ERUs is expected to benefit not only at-risk species but also those that are common and abundant. The relationship between species and special habitat features will help to identify fine-filter plan components necessary for preserving species diversity on the Santa Fe NF. lists the potential 29 SCC that are documented to occur on the Santa Fe NF and that the best available scientific information indicates substantial concern about their capability to persist over the long term in the plan area.

Table 46. Federally listed threatened or endangered species currently documented to occur in the plan area and associated ERU.

Common Name	Alpine Tundra	Colorado Plateau / Great Basin Grassland	Juniper Grassland	Mixed-Conifer–Frequent fire	Mixed-Conifer-with Aspen	Montane/Subalpine Grassland	P-J Woodland	Ponderosa Pine	P-J Sage, P-J Grassland	Spruce-Fir	Riparian
Mammal											
New Mexico Meadow Jumping Mouse											X
Bird											
Mexican Spotted Owl				X				X			
Amphibian											
Jemez Mountains Salamander				X	X					X	
Plant											
Holy Ghost Ipomopsis				X	X						

Table 47. Region 3 Forest Service Sensitive and potential SCC currently documented to occur in the plan area and associated ERU

Common Name	Alpine Tundra	Colorado Plateau / Great Basin Grassland	Juniper Grassland	Mixed-Conifer–Frequent fire	Mixed-Conifer-with Aspen	Montane/Subalpine Grassland	P-J Woodland	Ponderosa Pine	P-J Sage, P-J Grassland	Spruce-Fir	Riparian
Mammal											
American (Pacific) Marten										X	
Gunnison's Prairie Dog (montane pop.1 and prairie population)		X	X			X			X		
Masked Shrew			X	X	X	X	X	X			X
Snowshoe Hare	X									X	
Spotted Bat		X				X		X			X

Common Name	Alpine Tundra	Colorado Plateau / Great Basin Grassland	Juniper Grassland	Mixed-Conifer–Frequent fire	Mixed-Conifer-with Aspen	Montane/Subalpine Grassland	P-J Woodland	Ponderosa Pine	P-J Sage, P-J Grassland	Spruce-Fir	Riparian
Water Shrew											X
Bird											
American Peregrine Falcon					X		X	X		X	
Black-throated Gray Warbler		X					X		X		
Black Swift											X
Boreal Owl										X	
Western Burrowing owl		X	X			X	X		X		
Lewis's Woodpecker								X			X
Northern Goshawk				X	X			X		X	
Pinyon Jay			X				X		X		
White-tailed ptarmigan	X										
Wilson's Warbler											X
Amphibian											
Northern Leopard Frog											X
Fish											
Rio Grande Chub											X
Rio Grande Cutthroat Trout											X
Rio Grande Sucker											X
Invertebrate											
Lilljeborg's peaclam											X
Ruidoso Snaggletooth			X								
Plant											
Arizona Willow											X
Chama Blazing Star		X									
Greene's Milkweed			X				X			X	
Heil's Alpine Whitlowgrass	X										
Large Yellow Lady's-Slipper					X	X				X	X
Springer's Blazing Star		X									
Wood Lily				X	X			X			

Table 48. Federally listed and potential species of conservation concern (SCC) known to currently occur in the plan area and associated special habitat features

*Denotes federally listed species, all others are potential SCC

Special Habitat Feature	Associated Species
Tree features (cavities, snags, leaves, bark, downed logs, leaf or forest litter)	• Mexican Spotted Owl* • Northern Goshawk • Jemez Mountains Salamander* • Lewis's Woodpecker
Rock Features (Canyons, cliffs, crevices, outcrops)	• American Peregrine Falcon • Mexican Spotted Owl* • Ruidoso Snaggletooth • Black Swift
Aquatic Features (Riparian areas, springs, permanent water)	• Mexican Spotted Owl* • Northern Leopard Frog • Rio Grande Sucker • Rio Grande Cutthroat Trout • Rio Grande Chub • Water shrew • New Mexico Meadow Jumping Mouse* • Large Yellow-Lady's Slipper • Wilson's Warbler
Meadows and Small Openings	• Holy Ghost Ipomopsis* • Greene's Milkweed
Soil Features	• Chama Blazing Star • Springer's Blazing Star

Grouping of Species

Species can be grouped a number of different ways that are useful for identifying broad threats to their continued existence on the Santa Fe. For efficiency during the risk assessment portion of this evaluation, species were grouped according to their associated ERUs, described above and presented in Table 47. It is acknowledged that grouping species in this manner will not accurately capture all of their specific habitat needs, and so they have also been sorted by special habitat features (Table 48).This information is summarized by taxonomic group below (Table 49). This paired well with the risk assessment process that was conducted on the ERU types and presented in the Chapter 1 Vegetation of this document.

Table 49. Federally listed and potential SCC and their associated ecological response units (ERU)

Note that species are typically associated with more than one ERU.

	Alpine Tundra	Colorado Plateau / Great Basin Grassland	Juniper Grass	Mixed Conifer-Frequent Fire	Mixed Conifer with Aspen	Montane / Subalpine Grassland	PJ Woodland	Ponderosa Pine	PJ Sagebrush, PJ Grassland	Spruce-Fir	Riparian
Mammals	1	1	2	1	1	3	1	1	1	2	3
Birds	1	0	0	3	1	0	2	3		4	6
Amphibians	0	0	0	1	1	0	0	0		1	1
Fish	0	0	0	0	0	0	0	0		0	3
Invertebrate	0	0	1	0	0	0	0	0		0	1
Plants	1	2	1	1	2	1	2	1	1	1	2
Total	**3**	**3**	**4**	**6**	**5**	**4**	**5**	**5**	**2**	**8**	**16**

Table 50. Federally listed, proposed, and potential SCC associated with each Local Zone that include all ERUs.

Note some species are associated with more than one Local Zone.

*Denotes one or more federally listed species is included.

	North-West Zone (NWZ)	South-West Zone (SWZ)	Central Zone (CZ)	North-East Zone (NEZ)	South-East Zone (SEZ)
Mammals	4*	3*	4	6	3
Birds	6*	9*	6*	8*	4*
Amphibians	2*	2*	2*	1	1
Fish	3	3	3	3	3
Invertebrate	0	0	0	1	1
Plants	4	1	1	5*	1
Total	19	18	16	25	14

The ERUs in each local zone and the current state of departure from historical reference condition are displayed in Table 51. Detailed information is presented in Chapter 1, Vegetation.

Table 51. Percentage of current vegetative structure departure for each ERU at the three different analysis scales (local, plan, and context)

ERU*	Local NWZ	Local SWZ	Local CZ	Local NEZ	Local SEZ	Plan	Context
Colorado Plateau / Great Basin Grassland	85		95		95	93	48
Juniper Grass	45	49	41		53	45	41
Mixed Conifer - Frequent Fire	76	77	68	76	80	74	78
Mixed Conifer w/ Aspen	53	53	55	47		47	38
Montane / Subalpine Grassland	51	74		62		60	71
PJ Grass	56	59	38		45	45	33
PJ Sagebrush	43		47			46	32
PJ Woodland	29	40	51	22	26	28	22
Ponderosa Pine Forest	94	97	96	100	100	97	85
Sagebrush Shrubland	39					41	38
Spruce-Fir Forest	54	59	58	55	67	54	51

*Shaded boxes represent ERUs that do not occur within that Local zone.

The coarse-filter approach considered habitat (ERUs) associated with species, and current condition and future trends modeled using the Vegetation Dynamics Development Tool (VDDT) (http://essa.com 2006). This tool was used to simulate stand structure 15, 100, and 1,000 years into the future under current management. The data presented in the Chapter 1, Vegetation of this assessment is modeled at the plan level of analysis, or Santa Fe-wide. Current departure is based on mid-scale data. Additional VDDT modeling for departure at current conditions was performed at the local zone level. This finer local zone scale of resolution was used for the species risk assessment. Some of the results of that modeling are presented in (Table 52) and the rest is available in the Forest Plan Revision Project Record.

Sometimes portions or all of a given ecosystem characteristic may be altered so that recovery is not possible even if threats are controlled or reduced (e.g., loss of topsoil from recent large fires). In some cases, the response from the reduction of the threat may be so slow that current departures will essentially be present for hundreds of years (e.g., restoring fire in spruce-fir forest when the historical fire return interval is several hundred years).

Table 52. Results of Vegetation Dynamics Development Tool (VDDT)

Modeled Ecological Response Unit (ERU) departure of current conditions from reference condition by Zone and conditions 100 years into the future forestwide. Departures from reference condition is given in percentages. N/A indicates that ERU has insufficient acres in a Zone to be modeled.

	North-West Zone (NWZ)	South-West Zone (SWZ)	Central Zone (CZ)	North-East Zone (NEZ)	South-East Zone (SEZ)	Plan Scale Modeled departure in 100-years
*Colorado Plateau Great Basin Grassland	High		High		High	Not Modeled
Juniper Grassland	Moderate	Moderate	Moderate		Moderate	Moderate
Mixed Conifer-Frequent fire	High	High	High	High	High	Moderate
Mixed Conifer with Aspen	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Montane Sub Alpine Grassland	Moderate	High		Moderate		High
PJ Grassland	Moderate	Moderate	Moderate		Moderate	Moderate
PJ Sagebrush	Low		Moderate			Low
PJ Woodland	Moderate	Moderate	Moderate	Moderate	Moderate	Low
Ponderosa Pine	High	High	High	High	High	High
Sagebrush, Shrubland	Moderate					High
Spruce-Fir	Moderate	Moderate	Moderate	Moderate	High	Moderate

Trend was not calculated for ERUs where Santa Fe NF acreages were too small to adequately model in VDDT and Shrubland types. This included the ERUs associated with at-risk species in this chapter. Nearly all of the ERUs modeled are currently departed from reference and are predicted to be departed from reference 100 years from now. An extensive discussion of that analysis is presented in Chapter 1, Vegetation and is only briefly summarized here. Fire regimes are disrupted in nearly half of the ERUs present on the Forest, typically from historical fire suppression activities. Fire suppression has led to an overall change in seral stage proportion in most of the woody ERUs modeled in VDDT (Chapter 1. Vegetation) and many stands are currently characterized by smaller diameter trees with a denser distribution whereas in reference conditions these stands were characterized by more widely spaced trees of medium or larger diameters. Many wildlife species are dependent on shrub and forbs species that once grew in the understory of various ERUs but in many cases are now crowded out by this overall shift in seral structure and density. Additionally, years of prolonged drought combined with overstocked stands increases the risk of higher-intensity, more severe fires that could further permanently change habitat.

Other features important to wildlife and plants, such as coarse woody material (e.g., downed logs) that provide shelter, food, and moisture retention and standing snags of sufficient size for roosting, nesting, or foraging are also departed from reference conditions. See the section on Snags and Coarse Woody Material in Chapter 1, Vegetation for more information. These features are more transient on the landscape. As snags fall and decay, standing live trees die becoming new snags. If the seral stage proportions of most ERUs trend towards smaller diameter trees, future trees may not be large enough to provide the habitat required by species such as Mexican Spotted Owl or Northern Goshawk.

For all modeled ERU types, current departure from reference condition and modeled departure for 100 years into the future were entered into the Risk Assessment Database. Qualitative determinations for those ERU types not modeled were made using knowledge of current condition and expert opinion. The

Risk Assessment Database calculates an overall risk rating for each ERU-Local Zone combination entered based on the parameters described below. The italicized words are the way each parameter is identified in the Risk Assessment Database. Each qualitative ranking selected is assigned a numerical value between 1 and 3 and then an overall habitat ranking value is calculated. All parameters below are evenly weighted in this calculation. A number of assumptions were made while performing the species' risk assessments using the Risk Assessment Database. They are summarized as follows:

1. The extent of habitat available to a species does not change from reference to current to future conditions. As stated above, ERU map units reflect the potential of a site and the historical disturbance regime. These are not expected to change at the time scales used. Therefore, the amount of habitat available in historical/reference conditions does not change as one moves to current or future trend. Those ERUs that make up less than 5 percent of the total area of all five Zones are considered as providing low amounts of habitat. Moderate amounts of habitat are those ERUs that range from 6 to 50 percent, and high amounts of habitat make up 51 to 100 percent of the area. There are no ERUs that make up more than 50 percent of the total plan area.

2. *Quality of habitat* represents ERU departure from reference. It is assumed that during reference conditions, all habitats were sufficient to maintain viability. Current conditions of habitats in ERUs in low departure (0 to 33 percent departure from reference condition) are considered high quality; ERUs in moderate departure (34 to 66 percent departure from reference condition) are moderate quality; and ERUs in high departure (67 to 100 percent departure from reference condition) are low quality. The future trend in quality of habitat reflects ERUs modeled for 100 years from now. While it is acknowledged that ERUs that are highly departed from reference are not necessarily low quality habitat for wildlife, for the purpose of this risk assessment, that is the assumption. The VDDT modeling for ERUs on the Santa Fe represents the most comprehensive habitat data available but where more detailed habitat information is available for SCC it was noted.

3. *Distribution* is a qualitative measure that indicates the representativeness and redundancy of ERU types across the four mountain districts. ERUs were determined to be either even (habitat dispersed broadly), restricted (habitat restricted to certain areas) or highly fragmented (habitat isolated and separated by distance or barriers). As in number 1 above, these ratings were assessed to be consistent across historical, current, and future trends.

4. *Processes* refer to ecological processes including herbivory, fire, and flooding and were evaluated using ERU departure. As in number 2 above, processes are assumed to have been functioning in historical conditions. ERUs that are 0 to 50 percent departed are considered to be functioning in both current and future conditions. ERUs that are 51 to 100 percent are considered to be disrupted. The future trend in quality of habitat reflects ERUs modeled for 100 years from now.

ERUs that were not modeled for departure in 100 years due to insufficient acres but are important to species are Riparian and Alpine.

Once the risk to habitats (ERUs and special habitat features) had been evaluated and entered into the Risk Assessment Database, historical, current, and trend of populations of potential SCCs on the Santa Fe were then evaluated. The Risk Assessment Database steps the user through a similar analysis of historical, current, and future population trends. Qualitative rankings are assigned a numerical value of 1-3 and then overall risk to the populations is calculated and all parameters are weighted equally. As with the analysis of habitats, a number of assumptions were made regarding population trends. Data informing these trends were gathered from a number of places including NatureServe (NatureServe 2012), Biological

Information System (BISON-M (2013), and North American Breeding Bird Survey Data (Sauer et al. 2012).

1. *Distribution* refers the species occurrence on the Santa Fe with respect to the overall range for that species. Detailed distribution maps for breeding birds were available from e-bird and NatureServe (2014) provided distribution maps for many non-avian species. Distribution of the species on the Santa Fe was considered by evaluating the availability and location of suitable habitat. Species were determined to be either in high isolation, moderate isolation, or high interaction.

2. *Size* refers to the overall population size across the species' range. Detailed information about populations of each species on just the Santa Fe was not available in most cases. Population sizes were categorized as small, moderate, or large.

3. *Stability* refers to a population's relative trend towards increasing, decreasing, or remaining the same. In nearly all cases, population trend information specific to the Santa Fe NF was not available; this constitutes a data gap in the analysis. For these instances, trend was inferred from regional or state information where possible. If it was not clear whether or not populations were declining or increasing, or if in the case of the Breeding Bird Survey Data the trends were not significant, it was assumed that they were stable. All species were ranked as either in decline, stable, or gaining.

4. *Diversity* refers to phenotypic, ecological, and genetic diversity. There was no information available regarding diversity for any of the species considered; however, the risk assessment calculations would not properly function without assigning a ranking. For that reason, moderate diversity was selected for most species analyzed unless more recent information was available as to the size of the local population.

Once population factors have been evaluated, the Risk Assessment Database allows for other threats to species to be accounted for, including harassment by humans, invasive species, diseases, parasitism, obstructions (e.g., collisions with wind turbines, cars, highways), or predation (Table 53). The severity of each threat is determined to be low, moderate, or high and the likelihood of that threat is also determined to be low, moderate, or high. Unlike the habitat or population factors which require assessment, these other threats do not require assessment if no data is available. Again, numerical values are assigned to both the severity and likelihood ratings. The Risk Assessment Database then calculates overall numerical risk (1-3) to each species and assigns a qualitative rank (high, moderate, low).

The RAD was used to perform a risk assessment analysis on the species remaining from SCC screening process. The RAD has been designed to assess habitat, population, and threat factors for each of the species in terms of historical, current, and future trends. These are described in detail below. Numerical values (1, 2, or 3) were assigned to each of the habitat, population, and threat factors analyzed. The RAD calculates an overall numerical ranking of risk to each species. It assesses risk for each species within each ERU type in each local zone. For example, a bird documented on four local zones and known to use 3 different ERUs would undergo 12 separate risk assessments. By and large, that degree of resolution in population or habitat factors is not available, but if it were it would allow us to tease out these subtleties.

Table 53. Additional threats to federally listed and potential species of conservation concern

*Denotes federally listed species, all others are potential SCC.

Additional Threats	Affected Species
Harassment (e.g., disrupting species during sensitive life stages, human presence, indiscriminate shooting, dogs, disturbance from mining activities, picking/digging plants, etc.)	Gunnison's Prairie Dog pop.1 and prairie pop American Peregrine Falcon Mexican Spotted Owl* Northern Goshawk Large Yellow Lady's-slipper
Invasive Species/Introduced Species Competition (e.g., bullfrogs, European starling, Tamarix, Russian olive, White Sucker, German Brown Trout, etc.)	Northern Leopard Frog Rio Grande Sucker Rio Grande Cutthroat Trout Rio Grande Chub
Diseases (e.g. chytrid fungus, sylvatic plague, whirling disease, West Nile virus)	Northern Leopard Frog Gunnison's Prairie Dog pop.1 and prairie pop Rio Grande Cutthroat Trout Pinyon Jay
Nest Parasitism (nest parasitism from Brown-Headed Cowbirds)	Black-Throated Gray Warbler
Obstruction (e.g., collisions with wind turbines, towers, or vehicles)	American Peregrine Falcon Northern Goshawk
Predation (predation from non-native invasive species, crayfish, bullfrog)	Northern Leopard Frog Rio Grande Chub Rio Grande Cutthroat Trout Rio Grande Sucker

Table 54. Potential list of species of conservation concern for the Santa Fe NF

Scientific Name	Common Name
Mammals	
Cynomys gunnisoni	Gunnison's Prairie Dog
Euderma maculata	Spotted Bat
Lepus americana	Snowshoe Hare
Martes caurina	Pacific (American) Marten
Sorex cinereus	Masked Shrew
Sorex palustris	Water Shrew
Birds	
Accipiter gentilis	Northern Goshawk
Aegolius funereus	Boreal Owl
Athene cunicularia hypugaea	Western Burrowing Owl
Cypseloides niger	Black Swift
Setophaga nigrecens	Balck-Throated Gray Warbler
Falco peregrinus anatum	American Peregrine Falcon
Gymnorhinus cyanocephalus	Pinyon Jay
Lagopus leucurus	White-tailed Ptarmigan
Melanerpes lewis	Lewis's Woodpecker

Scientific Name	Common Name
Wilsonia pusilla	Wilson's Warbler
Amphibian	
Lithobates pipiens	Northern Leopard Frog
Fish	
Onchorychus clarkia virginalis	Rio Grande Cutthroat Trout
Catostomus plebius	Rio Grande Sucker
Gila pandora	Rio Grande Chub
Invertebrate	
Gastrocopta ruidosensis	Ruidoso Snaggletooth
Pisidium lilljeborgi	Lilljeborg's peaclam
Plant	
Asclepias uncialis var. *uncialis*	Greene's Milkweed
Cypripedium parviforum var. *pubescens*	Large Yellow Lady's-Slipper
Lilium philadelpihcum	Wood Lily
Mentzelia conspicua	Chama Blazing Star
Mentzelia springeri	Springer's Blazing Star
Draba heilii	Heil's Alpine Whitlow Grass
Salix arizonica	Arizona Willow

Federally Listed Species and Species of Conservation Concern and Current Santa Fe Management Direction

All of the federally listed species and potential SCC can be affected by current Forest Plan-authorized management activities on the Santa Fe NF, especially that which pertains to timber management, watershed protection and improvement, and specific wildlife. Risk was not assessed for ERUs or other habitat factors not on Santa Fe-owned lands, and therefore, it is not possible to state with certainty the overall risk to the species at the context scale. However, for many of these species, habitat provided on the Forest represents the majority or in some cases, the only habitat available. Changing land use patterns, habitat degradation and loss, or simply the lack of suitable habitat off-Forest, place a particular emphasis on the Santa Fe to maintain these species.

Federally Listed Species

New Mexico Meadow Jumping Mouse (*Zapus hudsonius luteus*) is federally listed as endangered. The species occurs in dense mid elevation riparian long grass habitats in the western U.S. It has been documented on the Santa Fe. Proposed Critical habitat exists on the Santa Fe. The number of historic locations of the species on the forest is greater than off the forest. The major threats faced are the degradation of riparian habitat because of legacy grazing, post-wildfire flooding events, and unmanaged recreation. Off the forest agricultural uses and development of land have permanently changed historic locations.

Mexican Spotted Owl (*Strix occidentalis lucida*) is federally threatened species known on Coyote, Jemez, Española, and Pecos-Las Vegas RDs. This species is apparently non-migratory and feeds primarily

on small mammals. Young owls are known to disperse long distances. A recent record however documents the movement of a Mexican Spotted Owl banded on the Gila NF found dead on the Carson NF (RMRS 2013), which could mean it might have travelled through the Santa Fe NF. There are 80,487 hectares (198,888 acres) of designated critical habitat on the Santa Fe and this is described in more detail in Volume 2 Chapter 6, Designated Areas. The Mexican Spotted Owl requires a variety of mixed conifer habitats, proximity to riparian areas, standing large snags for roosting and nesting, or cavities in vertical canyon walls. Timber management activities negatively affected habitat before the MSO was listed as threatened in 1995. Timber harvest, prescribed burning, and other management activities are designed following the Mexican Spotted Owl Recovery Plan 2012 along with consultation with FWS. These management activities can still have disturbance affects to the Mexican spotted owl and its habitat.

Jemez Mountains Salamander (*Plethodon neomexicanus*) is a federally endangered species endemic only to the Santa Fe NF. It was listed as endangered in 2013. There are 22,974 hectares (56,770 acres) of designated critical habitat on the Santa Fe and this is described in more detail in Volume 2 Chapter 6, Designated Areas. It feeds primarily on invertebrates. Threats include habitat loss from severe wildfire or other activities that alter hydrology, and disease including chytrid fungus. Grazing is believed to be a vector for chytrid fungus when livestock carry it into the habitat from water sources where it can be present. Wildlife can also carry the fungus now but did not do so in the past as chytrid fungus was not present under reference conditions.

Holy Ghost Ipomopsis (*Ipomopsis sancti-spiritus*) is a federally endangered plant species found only on the Pecos RD. It is a genetically distinct species found nowhere else. It is endemic species found only in the Holy Ghost Canyon in the Sangre de Cristo mountain range. A Recovery Plan was written for it 13 years ago in 2002 and is being followed with the additional work of state botanists to experimentally plant seedlings to increase the population. The species has been out planted to a few other sites but success is uncertain for maintaining it.

Potential Species of Conservation Concern

Information on the species below indicates substantial concern about a species' capability to persist over the long term in the plan area, as evidenced by one or more of the following criteria:

1. Habitat is limited or rare within the plan area,
2. Current management activities are negatively impacting habitat within the plan area,
3. Available monitoring indicates a decline in population, range, or both within the plan area.

All species listed met one or more of the initial requirements for SCC (table 43) and a number of sources were consulted to determine whether the above criteria were met (see the section titled Evaluating Relevant Information for At-Risk Species above). It is important to note that meeting criteria 1 alone is not sufficient for inclusion as a potential SCC because a habitat that is rare within the plan area might always have been rare. However, when criteria 1 is considered with criteria 2, or 3, then the species warrants inclusion as a potential SCC.

Gunnison's Prairie Dog (*Cynomys gunnisoni*) is currently known on the Northwest and Central local zones but has historically been on all the local zones on the Santa Fe NF (criteria #3). Threats include recreational shooting and sylvatic plague. The state has no regulations against shooting prairie dogs. Sylvatic plague can be a limiting factor and eliminate colonies in one season preventing them from reaching a sustainable population and colonizing areas formerly occupied.

Spotted Bat *(Euderma maculata)* individuals have been recorded on the Northwest, Southwest and Southeast local zones of the Santa Fe NF. They are believed to require key ecosystem characteristics of accessible rock crevices (within all terrestrial ERUs) to roost in, which are limited or unknown on the forest (criterion #1). Recreational climbing (20% potential habitat affected) is known to impact this species (criterion #2). The potential seems low for white-nose syndrome, a lethal fungal infection found in some species of hibernating bats in the eastern and mid-western United States, as this bat is not known to hibernate in groups. This bat feeds on noctuid moths in and over the forest canopy. Large wildland fires can threaten this species and restoration of the Santa NF is needed to avoid impacts to the population, which is low to rare wherever it is found (criterion #3).

Snowshoe Hare *(Lepus americana)* is found only in the Spruce-Fir ERU in the Northeast local zone of the Santa Fe NF (criteria#1). Their numbers are low. This ERU is in moderate departure but recent large wildfires (Pacheco Fire 2011 and Jaroso Fire 2013) have reduced the Spruce-Fir ERU in the Northeast zone, where the hare is at the southern most edge of its range (criteria #3).

Pacific (American) marten (*Martes caurina*) is a cat-sized weasel family predator known only from in the Sangre de Cristo at the edge of its range. This species had extensive searches for it in the Jemez Mountains in the best habitat available but results were negative (Klingel 2014). It is a State threatened species. It is very rare and was trapped nearly to extinction in the 20th century. It lives fairly exclusively in mature spruce-fir and higher elevation mixed conifer forests (criteria #1). It feeds on mice, squirrels, bird eggs and young and some larger insects. Recent large wildfires (Pacheco Fire 2011 and Jaroso Fire 2013) have reduced the Spruce-Fir ERU in the Northeast zone, where the marten is at the southern most edge of its range (criteria #3). Some timber management practices and roads can negatively impact habitat and limit food availability or access to habitat areas (10% of potential habitat) (criteria #2).

Masked Shrew (*Sorex cinereus*) hunts insects and small mammals along banks of cold streams, in wet meadows, or under logs in cold spruce forest (Spruce-Fir Forest ERU and Herbaceous, Willow-Thin-leaf Alder, Upper Montane Conifer-Willow, and Narrow-leaf Cottonwood-Spruce riparian ERUs). Most of these ERUs' current ecological conditions on the Santa Fe NF are departed from reference, because of changes in vegetative composition and hydrology (criterion #1). The masked shrew is found on every local zone (Frey 2003). Negative impacts to the masked shrew include habitat degradation and sedimentation caused by grazing (90% potential habitat affected), fuelwood gathering (20% potential habitat affected), wildfire, recreation (2% potential habitat affected), motorized travel (8% potential habitat affected), and changes in hydrology (criterion #2).

Water shrew (*Sorex palustris*) is a unique riparian dependent shrew that hunts for insects or small minnows exclusively in clear, cold high elevation streams (criteria #1.). Sedimentation into streams from grazing, logging, and poor road management can negatively impact this species and limits its distribution within former habitat (75% of potential habitat) (criteria #2).

Northern Goshawk (*Accipiter gentilis*) is a forest habitat generalist that uses a wide variety of forest ages, structural conditions and successional stages, most of which are departed from reference condition on the Santa Fe NF because of fire suppression activities and in some cases, stand-replacing fire (50% of potential habitat) (criteria #2). Nest sites are found in all the local zones surrounded by post-fledging family areas (PFAs). They are identified and managed according to guidelines in the forest plan. Several nest sites and PFAs have been lost or abandoned because of stand-replacing fires. Annual monitoring within the plan area has documented this decline (criteria #3). Strong direction to incorporate the vegetative guidelines for developing forest structure is needed especially for the recovering burned areas for the species to persist over the long term in the plan area. Additional threats are identified in Table 55.

Boreal Owl *(Aegolius funereus)* is only found in the Spruce-Fir ERU which is in moderate departure from reference conditions in all local zones except the Southeast local zone where it is in high departure (criteria #1). This species is at the southern most extension of its range and although it has been found on surveys recent large wildfires (South Fork 2010, Pacheco Fire 2011, Las Conchas 11, Thompson Ridge 2013 and Jaroso Fire 2013) have reduced the Spruce-Fir ERU in these local zones, where the owl is at the southern most edge of its range (criteria #3).

Western Burrowing Owl (*Athene cunicularia hypugaea*) is found on the Santa Fe NF in one location in the Central zone in the Colorado Plateau Great Basin Grassland ERU. This ERU is considered in High departure (criteria #1) from reference condition thereby a greater risk to the species. The presence of the Western Burrowing Owl on the forest was only discovered in 2014. They nest and roost in recently abandoned burrows dug by mammals, including ground squirrels, prairie dogs, and badgers. These burrows may soon become unsuitable for nesting (Green and Anthony 1989) (criterion #1). For this reason, viability of the Western Burrowing Owl is inextricably linked to that of burrowing mammals, including prairie dogs. Threats to this species on the Santa Fe NF include any threats to burrowing mammals, such as Gunnison's prairie dogs, recreational shooting, dogs at large and sylvatic plague (Antolin et al. 2002; Finch 1992; USDA FS 2013a) (criteria #2).

Black Swift *(Cypseloides niger)* nests behind or near waterfalls or caves (criteria #1). It has a low reproductive rate of one nestling a year. It is known to occur at a site in the in the Southeast local zone and a site in the in the Northeast local zone. Little is known of this species so it cannot be considered secure. Threats include recreational climbing and harassment at nest sites.

Black Throated Gray Warbler (*Setophaga nigrescens*). Mapped BBS trends show mostly positive trends throughout the range, 1966-1996, with local negative trends in western Colorado, eastern Utah, northern New Mexico, southern California, northwestern Oregon, and the northern Washington Cascades (Hall et al. 1997) (criteria #3).

American Peregrine Falcon (*Falco peregrinus anatum*) is known as single pairs or very limited numbers within all the local zones where it nests in suitable cliffs and rock outcrops (criteria #1). Threats include disturbance egg shell thinning from accumulated pesticides and disturbance from recreational activities (90% of potential habitat) (criteria #2). Of the known eyries on the Santa Fe NF, about a quarter of them were monitored each year under contract with US Fish and Wildlife Service or NMDGF. Long term monitoring (Johnson and Williams III 2014) shows that declining productivity of peregrines from 2001 to 2013 in New Mexico (criteria #3).

Pinyon Jay (*Gymnorhinus cyanocephalus)* is tied to the PJ Grass, PJ Sagebrush and PJ Woodland ERUs. PJ Grassland and PJ Sagebrush are in moderate departure from reference conditions. PJ Woodland is in low to moderate departure.

White-tailed ptarmigan *(Legopus leucurus)* utilize the Alpine and Tundra ERU of the Santa NF (<1% of the forest), which is only found on the Northeast local zone (criterion #1). Threats include degradation of habitat by grazing (25% potential habitat affected), and recreation (15% potential habitat affected) (criterion #2). Monitoring on the Carson NF indicates that ptarmigan are found in the alpine and tundra habitat shared with the Santa Fe NF but in very small numbers (Wolfe et al. 2012) (criterion #3). This species was re-introduced nearly 50 years ago after extirpation. The population could at this point have low genetic diversity.

Lewis's Woodpecker *(Melanerpes lewisi)* is tied to the Ponderosa Pine ERU which is in High departure from reference condition in all local zones on the Santa Fe NF (criteria #1). Large range in western U.S. and adjacent southern Canada, but distribution can be spotty; apparently declining in abundance, and may

have declined 60 per cent or more since the 1960s. Vulnerable to loss of nesting sites (large snags) such as may result from logging, urban and agricultural development; and to degradation of riparian habitats by drought and overgrazing (criteria #3) (NatureServe2015). Large wildfires in the Jemez Mountains have negatively affected the Ponderosa Pine ERU large tree and large snag special feature needed by this species (criteria #3). Additional threats are identified in Table 55.

Wilson's Warbler (*Wilsonia pusilla)* is a riparian dependent species that utilizes mesic shrub communities (all riparian ERUs). Ammon and Gilbert (1999) stated that population increases in northern forested regions in the 1960s and1970s may have been related to increased availability of midsuccessional, deciduous scrub habitats following logging, whereas regional decreases, particularly in the west, most likely reflect extensive destruction of riparian habitats. The optimal habitat for this species consists of key ecosystem characteristics found along the edges of beaver ponds, lakes, dense riparian zones, fens, bogs, and overgrown clear-cuts (criterion #1). Most of the riparian ERUs on the forest are departed from reference, because of changes in vegetative composition and hydrology (criterion #1). Wilson's warblers are only found on the Northwest and Northeast local zones (criterion #1). Habitat degradation and sedimentation from wildfire, grazing (50% potential habitat affect), recreation (25% potential habitat affected), motorized travel (8% potential habitat affected), and changes in hydrology can negatively impact this species (criterion #2). According to Breeding Bird Surveys (2014), this species showed a declining trend of 7 percent from 2003 to 2013 in New Mexico (criterion #3).

Northern Leopard Frog (*Lithobates pipiens*) was found in all the local zones historically but is now not found in historic locations (criteria #3). This riparian species requires springs, slow streams, or other perennial water as habitat and for overwintering; during warmer months they may be found in wet meadows or other habitats near standing water and these habitats are limited on the Santa Fe (criteria #1). Current threats include degradation of these habitats caused by grazing, chytrid fungus, or siltation due to poor road management (95% of potential habitat) (criteria #2). Additional threats for special habitat features used by potential SCC and federally listed are presented in Table 55.

Lilljeborg's Peaclam (*Pisidium lilljeborgi*) is found in only one high elevation lake in the Pecos Wilderness and nowhere else on the continent *(criteria #1).* This is a State threatened species. Threats include siltation into the lake or use of chemical retardant for fire suppression that could wash into the lake (criteria #2).

Ruidoso Snaggletooth (*Gastrocopta ruidosensis*) is a snail found only in two widely separated areas in New Mexico (criteria#1). It lives in plant and leaf litter near limestone outcrops in juniper grasslands only on the east side of the Sangre de Cristo Mountains (Nekola and Coles 2010). It can be affected by prescribed burning and trampling (criteria#2). It is a rather recent discovery on the Forest and a new addition to the Regional Forester's sensitive species list of 2013.

Rio Grande Cutthroat Trout, Rio Grande Chub and Rio Grande Sucker (*Oncorhynchus clarkii virginalis) (Gila pandora) and (Catostomus plebius)* need clean, cold water to survive (criteria #1). Very few streams on the forest are free of habitat impacts whether from grazing, recreation or motorized travel, or road management (or lack of it), or non-native German Brown Trout or Rainbow Trout (criteria #1). Native fish are subject to direct predation on adults, juveniles or eggs, and interbreeding of Rio Grande Cutthroat Trout with Rainbow Trout. Sedimentation from various road sources degrades water habitat quality and negatively impacts eggs and fry (96% of potential habitat) (criteria #2). Additional threats are listed in Table 55.

Greene's Milkweed (*Asclepias uncialis ssp. uncialis)* occurs in low numbers where ever it is found (criteria #1). It has been reported from only one location in the Southeast local zone (criteria #1). Searches by experts have not found this plant in the location on the Santa Fe NF where it was originally

reported (criteria #3). Threats include trampling by livestock. The area it is reported to occur is not subject to grazing except by occasional strays.

Large Yellow Lady's –Slipper (*Cypripedium parviflorum var. pubescens)* is known from only eight locations on the forest (criteria #1). Trampling, picking or digging up plants (100% of potential habitat) (criteria #2) are recognized threats. Picking the flowers prevents seed formation. This plant is valuable to collectors and can be sold for a high price. It is known from the Pecos Wilderness and close surrounding areas which experience high recreational use. The current direction does not identify protection or public education for protection of the species (criteria #2). Additional threats are identified in Table 55.

Heil's Alpine Whitlowgrass *(Draba heilii)* is a quite recently discovered small, high alpine yellow-flowered plant (criteria #1). It is threatened by trampling of hikers, climbers, horseback riders and occasional livestock (100% of potential habitat) (criteria #2). It was found in an area near the Truchas Peaks along trails above timberline in the Pecos Wilderness. The current direction did not include this plant as it was unknown at the time. Identification and awareness of this plant is needed for trail maintenance especially when it is done by anyone unfamiliar with this plant. Until more is known about this plant and its locations it will remain at risk.

Wood Lily *(Lilium philadelphicum)* is State endangered plant associated with the Ponderosa Pine ERU which is High departure from reference condition (criteria #3). This plant was never abundant (criteria #1) and not recent reports of its occurrence on the forest are known. Threats include large wildfires such as those that have affected the Jemez Mountains in the past 20 years (Lakes, Cerro Grande, Las Conchas, Dome and others) (criteria #3). Additional threats are identified in Table 55.

Chama Blazing Star *(Mentzelia conspicua*) occurs only in the Jemez Mountains known only from Chama Canyon (NW zone) on sedimentary soils within the canyon (criteria #1). It is usually found on the key ecosystem characteristic of gray to red shales of Mancos and Chinle soil formations in the Piñon-Juniper Woodland ERU (NMRPTC 1999) (criterion #1). Threats include habitat disturbance from recreation (0.1% potential habitat affected), sagebrush mowing and road construction and maintenance (14% potential habitat affected) (criterion #2).

Springer's Blazing Star *(Mentzelia springeri*) occurs only in the Jemez Mountains on pumice deposits (criteria #1). It was formerly known only from within Bandelier National Monument. It was recently found in one location (criteria #1) on the forest alongside a major road. Trampling or road maintenance can be a threat (100% of potential habitat) (criteria #3). Pumice mines are now closed on the forest but were active for many years and undoubtedly affected habitat.

Arizona Willow (*Salix arizonica*) is found only in very high elevation areas in wet open meadows and stream banks in the Northwest (San Pedro Parks Wilderness) and Northeast (Pecos Wilderness) local zones (all Riparian ERUs) (criteria #1). This plant is preferred by grazers. Livestock impact the growth and vigor of this willow (100% of potential habitat affected) (criteria #2). Protection by small enclosures in the San Pedro Parks in the NW local zone resulted in a better condition for those plants within the past several years but these enclosures have not been maintained or monitored for a few years. Monitoring of livestock grazing does not protect this species from preferred selection by livestock and elk (criteria #2). No protection measures or monitoring has occurred on the population in the Pecos Wilderness NE local zone. The current management does not address protection measures.

Table 55. Primary threats to special habitat features and their associated species

*Denotes federally listed species; all others are potential SCC.

Habitat Feature	Primary Threats	Associated SCC and ESA listed Species
Tree features (cavities, snags, leaves, bark, downed logs, leaf or forest litter)	• Fire not only creates but can also consume tree features directly resulting in the loss of nesting, breeding, and roosting habitat. Intense smoke from fire can displace species and cause direct mortality. • Timber harvest activities may result in direct damage/loss of trees and snags. • Large-scale outbreaks of insects or disease could threaten large areas of habitat.	• Mexican Spotted Owl* • Northern Goshawk
Rock Features (Canyons, cliffs, crevices, outcrops)	• Activities including recreational rock climbing, caving, mining, construction and vandalism, can disturb or damage habitat. • Removal of surface rock causes direct mortality and damages habitat. • Alterations of the rock surfaces such as removing rock through excavation or rock climbing, can alter the habitat enough to disrupt or prevent plant establishment. • Trampling of plants in crevices causes direct mortality creating unstable rocks.	• American Peregrine Falcon • Mexican Spotted Owl*
Aquatic Features (Riparian areas, springs, permanent water)	• Groundwater depletion and streamflow diversion, roads, trails, facilities, non- native plant species and upland species encroachment, uncharacteristic fire in riparian and adjacent areas, mining, or unmanaged herbivory, leads to loss or damage of riparian characteristics.	• Mexican Spotted Owl* • Western Yellow-Billed Cuckoo* • Large Yellow-Lady's Slipper
	• Disturbance to soil in these areas due to unmanaged herbivory, dispersed camping, or construction activities can decrease plant cover. • Spring developments for livestock or wildlife use decreases water available for local ecosystems and trampling further degrades these areas. Trampling in wet areas can also spread chytrid disease. • Invasive species compete with native species for food or are predaceous on native species in aquatic features (Bullfrog).	• Northern Leopard Frog • Water Shrew • Rio Grande Cutthroat Trout • Rio Grande Sucker • New Mexico Meadow Jumping Mouse*
Meadows, Small Openings, other Grassland Features	• Unmanaged herbivory can change local conditions and invertebrate communities. • Unmanaged herbivory can stunt growth of sensitive plants and remove flower parts preventing seed production. • Encroachment by woody vegetation eliminates grasses and forbs and decreases the size and ecological function of these features.	• Arizona Willow • Large Yellow Lady's-Slipper

The final product of the RAD are species ratings tables that give a numerical overall risk value to each species for each ERU in each Zone. These have been averaged to provide a single overall risk value and qualitative ranking for each species and federally recognized species are presented in Table 56. Potential SCC are presented in Table 57. These potential SCC have been found by external entities including the

U.S. Fish and Wildlife Service, Region 3 of the U.S. Forest Service, the New Mexico Department of Game and Fish, the New Mexico Department of Forestry, the Navajo Nation, Natural Heritage New Mexico, and others to already be at-risk for extinction. It was further determined that management actions implemented or actions that failed to implemented by the Santa Fe NF further threatened these species' persistence on the Santa Fe NF. These species, in addition with federally listed species relevant to the plan area (Table 42) will be considered as the Santa Fe evaluates needs for change to the current Land and Resource Management Plan.

Table 56. Federally listed threatened and endangered species on the Santa Fe NF

Scientific Name	Common Name	Risk Assessment Value	Overall Risk
Mammal			
Zapus hudsonius luteus	NM Meadow Jumping Mouse	2.1	Moderate
Bird			
Strix occidentalis lucida	Mexican Spotted Owl	2.32	Moderate
Amphibian			
Plethodon nemexicanus	Jemez Mountains Salamander	2.40	Moderate
Plant			
Ipomopsis sancti-spiritu	Holy Ghost Ipomopsis	2.20	Moderate

The Risk Assessment Database calculates a risk value between 1 and 3. Risk values <1.50 are high, 1.51-2.50 are moderate, and >2.51 are low.

Table 57. Potential list of SCC for the Santa Fe NF

Scientific Name	Common Name	Risk Assessment Value	Overall Risk
Mammal			
Cynomys gunnisoni	Gunnison's Prairie Dog	2.25	Moderate
Euderma maculatum	Spotted Bat	2.30	Moderate
Lepus americana	Snowshoe Hare	2.31	Moderate
Martes caurina	Pacific Marten	2.31	Moderate
Sorex cinereus	Masked Shrew	2.31	Moderate
Sorex palustris	Water Shrew	2.10	Moderate
Bird			
Accipiter gentilis	Northern Goshawk	2.51	Moderate
Aegolius funereus	Boreal Owl	2.32	Moderate
Athene cunicularia hypugaea	Western Burrowing Owl	1.88	Moderate
Cypseloides niger	Black Swift	1.96	Moderate
Setophaga nigrescens	Black-Throated Gray Warbler	2.25	Moderate
Falco peregrinus anatum	American Peregrine Falcon	2.42	Moderate
Gymnorhinus cyanocephalus	Pinyon Jay	2.25	Moderate
Lagopus leucurus	White-tailed Ptarmigan	2.28	Moderate

Scientific Name	Common Name	Risk Assessment Value	Overall Risk
Melanerpes lewis	Lewis's Woodpecker	2.15	Moderate
Wilsonia pusilla	Wilson's Warbler	2.30	Moderate
Amphibian			
Lithobates pipiens	Northern Leopard Frog	1.40	High
Fish			
Gila Pandora	Rio Grande Chub	2.45	Moderate
Catostomus plebius	Rio Grande Sucker	2.46	Moderate
Oncorhychus clarki virginalis	Rio Grande Cutthroat Trout	1.99	Moderate
Invertebrate			
Gastrocopta ruidosensis	Ruidoso Snaggletooth	2.25	Moderate
Pisidium lilljeborgi	Lilljeborg's peaclam	2.48	Moderate
Plant			
Asclepias uncialis ssp. uncialis	Greene's Milkweed	2.15	Moderate
Cypripedium parviflorum var.	Large Yellow Lady's Slipper	2.27	Moderate
Draba heilii	Heil's Alpine Whitlowgrass	2.38	Moderate
Lilium philadelphicum	Wood Lily	2.23	Moderate
Mentzelia conspicua	Chama Blazing Star	2.15	Moderate
Mentzelia springeri	Springer's Blazing Star	2.10	Moderate
Salix arizonica	Arizona Willow	2.27	Moderate

These 29 potential SCC meet the requirements set forth in the final directives, FSH 1909.12 and some have been linked to current ERUs that are in moderate or high departure from reference condition, or management under the current plan that may be negatively affecting either the ERU or populations on the Santa Fe NF. Many of these species are also affected by activities outside of the plan area or beyond Forest Service control; it is important to recognize the limits to agency authority and the inherent capability of the plan area. These species and the four federally listed species will be considered as the plan revision process moves forward and considers the need for change to the existing Forest Plan. The coarse-filter/fine-filter approach used to assess species will also be carried forward through the next steps. Plan components will be developed to maintain or restore ecological conditions for ecosystem integrity and ecosystem diversity in the plan area. By working toward the goals of ecosystem integrity and ecosystem diversity with connected habitats that can absorb and recover from disturbance, it is expected that over time, management would maintain and restore ecological conditions which provide for diversity of plant and animal communities and support the abundance, distribution, and long-term persistence of native species, both those considered common and secure as well as those considered imperiled or vulnerable. In addition, species-specific plan components, the fine- filter approach, will provide for additional specific habitat needs or other ecological conditions for those species that are not met through the coarse-filter approach. The species, for which the 2012 final planning rule requires fine-filter plan components, when necessary, are federally listed threatened and endangered species, proposed and candidate species (there are no proposed or candidate species on the Santa Fe NF), and SCC.

Summary of Conditions, Trends, and Risks

The Santa Fe NF is home to hundreds of animal and plant species, some of which are found only on the Santa Fe NF, and others for which changing land-use patterns have increased their reliance on Santa Fe NF managed lands. These species provide many ecosystem services, including: (1) supporting services, such as nutrient cycling, soil formation and manipulation, primary production, and seed dispersal; (2) regulating services, including carbon sequestration, pollination, and erosion control; (3) provisioning services, such as food, fiber, medicine, and forest products; and (4) cultural services, including recreation, opportunities for scientific discovery and education, and cultural, intellectual, or spiritual inspiration. The most important drivers of change in ecosystem services are habitat change, climate change, invasive species, overexploitation, and pollution. This section focuses on at-risk species that occur on the Santa Fe NF, which indicate the ecosystem services provided by these species are decreasing and at risk.

Federally recognized and potential SCC were identified and evaluated for the Santa Fe NF. Of the 50 potential SCC, 5 have not been documented on the Santa Fe NF. Of the 45 remaining potential SCC, 16 of them were determined through BASI to be secure, or had insufficient information to conclude there is a substantial concern about the species capability to persist in the plan area over the long-term. The remaining 29 species will be carried forward into the planning process.

A total of four federally recognized species (three endangered) were determined to be within the plan area. Of the four, there is one are mammal, one bird, one amphibian and one plant. Potential SCC were determined following guidance in the final directives issued for the 2012 Planning Rule.

Wildlife and plant species identified as at-risk by a number of different entities were considered. The species that were ultimately considered to be at-risk met the following criteria: (1) met the initial requirements; (2) had been documented on the Santa Fe NF; and (3) had the potential to be both positively and negatively affected by Forest Service management activities. An overall risk assessment for each species was calculated from data identifying the status of historic, current, and future population trends and associated ERUs and data identifying direct threats to the species or to key ecosystem characteristics. A total of 29 potential SCC were determined to be at risk by low numbers or limited habitat, the current conditions of the habitat (ERU), or current Forest Service management activities or other threats, including: 1 amphibian; 10 birds; 3 fish; 2 invertebrate; 6 mammals; and 7 plants.

If management activities focus on ecosystem integrity and diversity goals by including disturbance-absorbing connected habitats, then ecological conditions would be effectively restored and maintained. These improved ecological conditions would increase the diversity of plant and animal communities and support the abundance, distribution, and long-term persistence of common and secure, imperiled, or vulnerable native species. Species-specific plan components within each ERU will be developed for those species with additional or key ecosystem characteristics or where ecological conditions are not otherwise met.

Ecosystem Services

National guidance for considering management options regarding wildlife and rare plants is intended to provide for the diversity of plant and animal communities and to support the abundance, distribution, and long-term persistence of native species, both those considered common and secure as well as those considered imperiled or vulnerable. A key supporting service this direction intends to maintain is the system resilience offered by genetic and behavioral (or niche) options available within diverse communities. While the full biotic diversity of Santa Fe NF ecosystems is not known, specifically addressing the needs of those already at risk is expected to provide assistance to many others also evolved to similar needs. Additionally, a regulating service contribution is the critical role of pollination served by many animals for a variety of plants. Retaining diversity is a way to ensure that this service continues to be provided, even without complete knowledge of the complementary associations between animals and plants.

For a number of species, habitat provided on the Forest represents the majority or in some cases, the only habitat available. Changing land use patterns, habitat degradation and loss, or simply the lack of suitable habitat off-Forest, place a particular emphasis on the Santa Fe to maintain key habitat for these species. Three of the species already federally listed as threatened or endangered inhabit riparian ecosystems. That habitat has been degraded by historic grazing practices, post-wildfire flooding events, and unmanaged recreation. Off the forest agricultural uses, especially changes in water- use and development of land have permanently changed historic locations.

Forest Plan revision requires this assessment to include a review of other species' capability to persist over the long term in the plan area, based on three criteria. The review establishes 29 total potential species of conservation concern: 6 mammals, 10 birds, 1 amphibian, 3 fish, 2 invertebrate and 7 plants. The habitats and ecosystems that support each of these are shown in Table 55, along with primary threats that could drive a lack of sustainability. As Plan revision proceeds, stakeholders will be asked to consider whether management changes could be made to better retain the ecosystem services provided by each species' particular role, and by the many roles of other species who share similar needs.

Chapter 4. Soils

Introduction

Soil is a complex and dynamic system that consists of a mineral component, organic matter, air, water, and various soil organisms resulting from interaction between parent material, climate, topography, and organisms throughout time and space. Soil provides many ecosystem services on which other life forms (including humans) depend. Many of these services are provided by the soil resource on national forest system lands that affect lands off-forest. Due to their slow rate of formation, soils are essentially a non-renewable resource.

The 2012 Planning Rule requires national forests and grasslands to consider the soil resource by identifying and evaluating current and available information important to ecological integrity and soil quality. Current condition of the soil resource is described through important characteristics of soil that make them susceptible to loss of integrity and function. This information will be used to inform agency officials on current direction and plan components for the management of the soil resource on the Santa Fe National Forest.

The diverse and productive soils of the Santa Fe NF are described, characterized, and classified in Terrestrial Ecosystem Survey (TES) of the Santa Fe National Forest (Miller et al. 1993). The information regarding the kind of soils on the Santa Fe NF is intricately linked to the climate, vegetation, geology, and landforms of the forest. This survey was completed at a 1:24,000 scale that identified 209 terrestrial ecosystems, 70 percent of which are mapped to the family level of Soil Taxonomy. The remaining mapping units are classified to the subgroup level of Soil Taxonomy, which indicate these units are highly variable and limited in site-specific interpretations that can be made (Miller et al. 1993).

The Santa Fe NF is located in the northern part of New Mexico within Santa Fe, Rio Arriba, Los Alamos, Mora, Sandoval and San Miguel Counties and is divided into an east and west half. These two halves are bisected by the Rio Grande River as well as state, federal, tribal, and private lands. The southern Sangre de Cristo Mountains are located east of the Rio Grande River and a cluster of mountain ranges including the Jemez, Nacimiento and San Pedro Mountains lie west of the Rio Grande River.

Assumptions

The first major component or ecological type of each terrestrial ecosystem (unless first component is a miscellaneous area such as rock outcrop, badlands, rubbleland, or riverwash) was used in the soil assessment analysis on the Santa Fe NF. If the first major component of a map unit is a miscellaneous area then the second major component was analyzed.

Histosols and Vertisols do not occur as the first or second major component of any map unit, but are described below to address all soil orders that occur on the Santa Fe NF.

Climate of the Santa Fe NF

The forest occurs within the central portion of the Northern Mountains climatological division of New Mexico. The climate is variable as a consequence of the uneven topography and wide range in elevation. Average annual precipitation ranges from 32 to over 88 centimeters. Approximately 50 percent of the average annual precipitation occurs during the period of 1 October to 31 March. Mean annual snowfall ranges from 70 to over 200 centimeters. Average annual air temperature ranges from 12 degrees Celsius at

the lower elevations to -2 degrees Celsius at the higher elevations. The freeze-free period ranges from approximately 165 days at the lowest elevations to less than 30 days at the highest elevations (Miller et al. 1993).

Plant communities follow an elevational-climatic gradient from low-elevation steppe grassland upward to pinyon-juniper woodland, mid-elevation montane ponderosa pine forest, upper montane mixed conifer forest, and up to high-elevation subalpine spruce fir forests including montane and subalpine grasslands, to alpine tundra at the highest elevations. On the Santa Fe NF, steppe grasslands are found at lower elevations around 5,300 feet and alpine tundra is found at the highest elevations from approximately 11,500 to just over 13,000 feet.

The Santa Fe NF is set entirely in the cold winter climatic zone characterized by deciduous oaks (Miller et al. 1993). The majority of high-sun (majority of precipitation occurs during half year period of April 1 to September 30) ecosystems of the Santa Fe NF are found on the southern boundaries of the forest heading north along the foothills of the Sangre de Cristo and Jemez Mountains and throughout the Caja Del Rio Plateau. The majority of the low-sun (October 1 to March 31) ecosystems are found throughout the Sangre de Cristo, Jemez, San Pedro, and Nacimiento Mountains.

Physiographic Provinces of the Santa Fe NF

Four physiographic provinces are identified on the Santa Fe NF as described by Fenneman in the Physiographic Divisions of the United States (1928). These include the Southern Rocky Mountains, Colorado Plateau, Basin and Range, and Great Plains provinces

figure 38 displays the Physiographic Provinces of the Santa Fe NF.

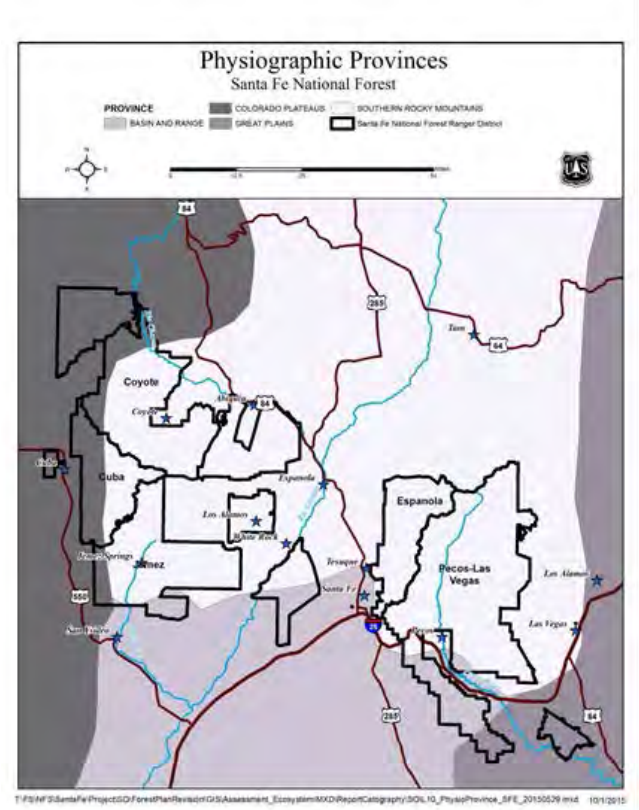


Figure 38. Physiographic provinces of the Santa Fe National Forest.

The Southern Rocky Mountains consist of mountainous terrain that includes some of the highest peaks in New Mexico. The Sangre de Cristo, Jemez, and Sierra Nacimiento mountain ranges are included in the Southern Rocky Mountains region. The main ecological response units (ERUs) in this province on forest are Mixed Conifer – Frequent Fire, Ponderosa Pine Forest, and Spruce-Fir Forest. Dominant geologies in these mountain ranges are limestone, granite, and gneiss. Five of the six soil orders that occur on the Santa Fe NF occur in this area, all but Vertisols. Alfisols and Inceptisols dominate in the Southern Rocky Mountains province of the Santa Fe NF.

The Colorado Plateau is characterized by relatively flat lying sedimentary rock that has been sculpted by water. This region covers the northwest and extreme western portions of the Santa Fe NF. The main ERUs in this province on forest are Ponderosa Pine Forest, Mixed Conifer – Frequent Fire, and Sagebrush Shrubland. Dominant geologies in this part of the forest are sandstone and limestone. Alfisols, Entisols, Inceptisols, Mollisols and Vertisols all occur in this region of the Santa Fe NF with Alfisols and Inceptisols dominating.

The Basin and Range province is for the most part a highland characterized by distinctive features of parallel mountain ranges and intervening plains. This province covers most of Glorietta Mesa and the southern half of Caja del Rio Plateau on the Santa Fe NF. The main ERUs in this province on forest are PJ Woodland, Colorado Plateau/Great Basin Grassland, and Ponderosa Pine Forest. Dominant geologies in these areas on forest include rhyolite, tuff and other Neogene volcanic rocks. Alfisols, Entisols, Inceptisols and Mollisols all occur in this region of the Santa Fe NF with Alfisols and Inceptisols dominating.

The Great Plains is an extensive region characterized by a great eastward-sloping plateau. Anton Chico and Hurtado Mesa are part of the Great Plains province. The main ERUs on forest in this province are PJ Woodland, PJ Grass, and Colorado Plateau/Great Basin Grassland. Dominant geologies in these areas consist of sandstone, siltstone, limestone and dolomite. Alfisols, Entisols, Inceptisols and Mollisols all occur in this region of the Santa Fe NF with Alfisols and Inceptisols dominating.

Soil Diversity of the Santa Fe NF

In the Southwest, the Forest Service uses a system of ecosystem types, “ecological response units” (ERUs), to facilitate landscape analysis and strategic planning. ERUs have been built from plant associations and ecosystem units that have been identified through Terrestrial Ecological Unit Inventory (Wahlberg et. al. 2013).

Currently there are 209 terrestrial ecosystem map units identified on the forest and described in the Santa Fe NF TES report. These 209 terrestrial ecosystem map units were aggregated into 20 ERUs for the Santa Fe NF. The nine upland ERUs that do not make up a significant amount of Forest land (<1 percent) were not analyzed in the soil assessment. These ERUs include Bristlecone Pine, Gambel Oak Shrubland, and Shortgrass Prairie. Within the 17 remaining ERUs (11 upland and 6 riparian), 6 of the 12 soil orders are represented: *Alfisols, Entisols, Histosols, Inceptisols, Mollisols and Vertisols*. Figure 39 displays soil orders occurring on the Santa Fe NF.

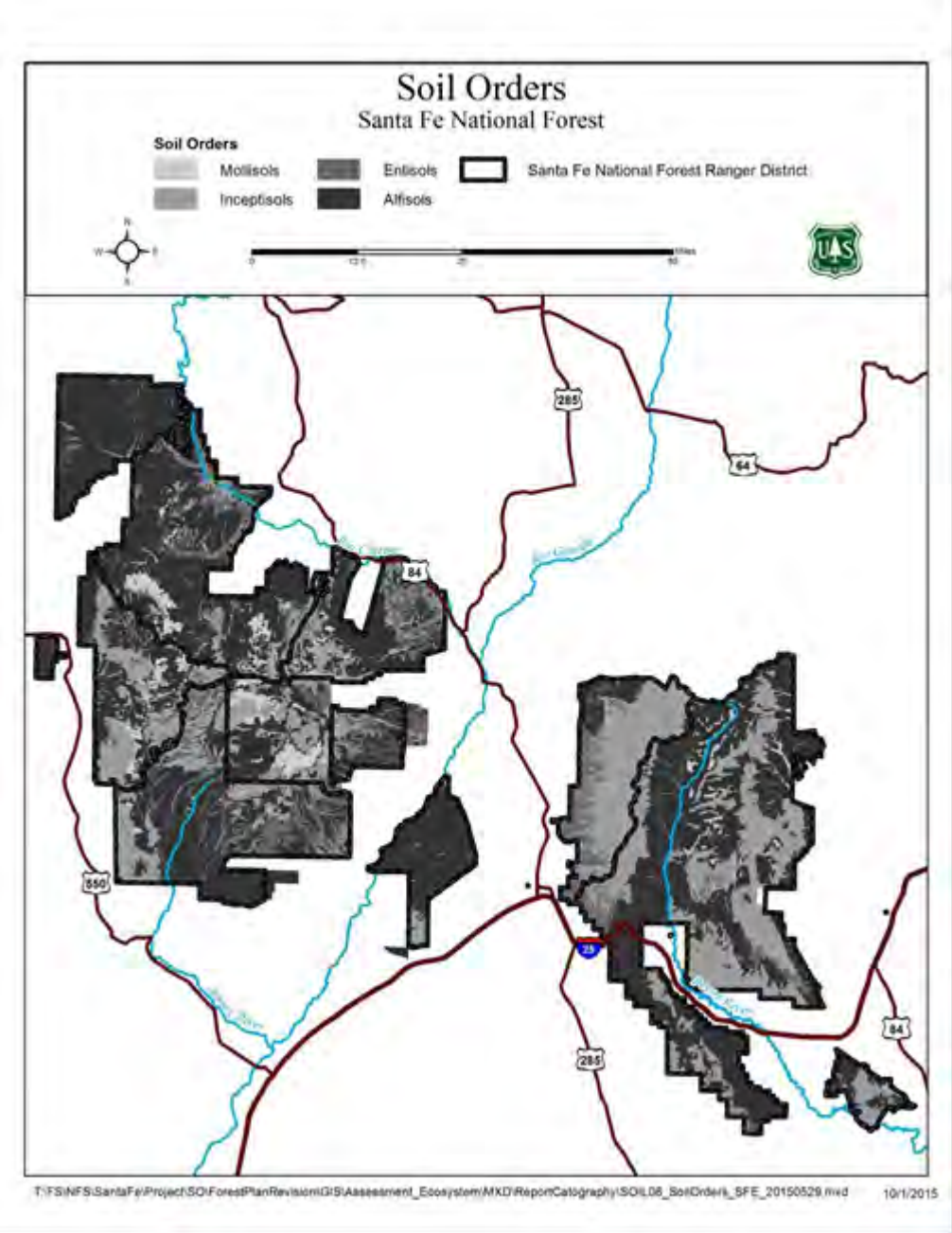


Figure 39. Soil orders of the Santa Fe NF

Alfisols are inherently fertile with soil horizon development and are normally formed under forested vegetation. These soils form in a wide range of parent materials and occur under a large range of environmental conditions (Staff 2014). In general, Alfisols are productive soils high in native fertility. Globally, Alfisols occupy about 10 percent of the total ice-free land area (Brady and Weil 2008). Alfisols dominate in the Colorado Plateau/Great Basin Grassland, Mixed Conifer w/Aspen, PJ Grass, PJ Sagebrush, PJ Woodland, Ponderosa Pine Forest, and Sagebrush Shrubland ERUs (table 58). These are the most extensive soils on the Santa Fe NF, distributed across the entirety of the forest from low to high elevations and from gentle to steep slopes.

Entisols are very young soils with little to no subsurface soil development. These soils formed in landscape positions where the soil material has not been in place long enough for soil-forming processes to create distinctive soil horizons; areas with recent deposition such as floodplains, alluvial fans, or stream terraces are examples. In general these soils exist in settings where erosion or deposition is happening at rates faster than those needed for soil formation (Staff 2014). Globally, Entisols occupy 16 percent of the total ice-free land area. Soil productivity ranges from very high for certain Entisols formed in recent alluvium (where topography is nearly level, close proximity to water, and periodic nutrient replenishment occurs from floodwater sediments) to very low for those forming in shifting sand or on steep rocky slopes (Brady and Weil 2008). These soils occur as large portions of the RMAP Ponderosa Pine/Willow and RMAP Rio Grande Cottonwood/Shrub ERUs, but also occur in the Mixed Conifer – Frequent Fire and Ponderosa Pine Forest ERUs with a relatively high amount of acres. Entisols are scattered across the Santa Fe NF mostly occurring on active steep scarp, mountain, and hill slopes although some of these soils occur on flat valley plains formed in alluvium.

Histosols have very high amounts of organic matter and less mineral soil and are located in bogs, fens, moors, peats, or mucks. These soils form in environments where inputs of organic matter exceed losses due to very slow decomposition which generally occur in cool, wet environments where precipitation exceeds evaporation. These soils contain large amounts of carbon, making them ecologically important for sequestration. Globally, Histosols occupy about 1 percent of the total ice-free land area (Staff 2014). Histosols occur in very limited extents in the Spruce-Fir Forest, RMAP Herbaceous, RMAP Upper Montane Conifer/Willow, and RMAP Willow - Thinleaf Alder ERUs on the Santa Fe NF. These soils are restricted to the higher elevations within the Sangre de Cristo Mountains along the Espanola and Pecos-Las Vegas ranger district boundary.

Inceptisols have moderate degrees of soil weathering and soil horizon development, but typically lack significant clay accumulation in the subsoil. These soils generally occur on relatively young geomorphic surfaces (landforms) that are stable enough to allow some profile development. Globally, Inceptisols occupy 17 percent of the total ice-free land area (Staff 2014). The natural productivity of Inceptisols varies widely and is dependent upon clay and organic matter content, and other plant-related factors (USDA 2015). Inceptisols occur as significant portions of the Mixed Conifer – Frequent Fire, RMAP Upper Montane Conifer/Willow, and Spruce-Fir Forest ERUs. These soils are the second most extensive on the Santa Fe NF, spread across the majority of the forest with a wide range in elevations distributed across various landforms.

Mollisols have a dark-colored surface horizon, are relatively high in content of organic matter and are highly fertile. These soils formed as a result of deep inputs of organic matter and nutrients from decaying roots and litter. Microbes, earthworms, ants and other organisms contributed to the inputs and nutrient cycling of these soils (Staff 2014). Mollisols cover a larger land area in the United States than any other soil order and globally occupy 7 percent of the total ice-free land area. Mollisols are among the world's most productive soils because of high native fertility (Brady and Weil, 2008). This soil order is probably the most economically important soil order because of its high use in agriculture. Mollisols dominate in the Montane/Subalpine Grassland, RMAP Herbaceous, and RMAP Narrowleaf Cottonwood/Shrub ERUs. These soils are distributed widely, mostly occurring on relatively flat to moderately sloping landforms on the Santa Fe NF.

Vertisols have a high content of expanding clay minerals which undergo prominent changes in volume with changes in moisture and have cracks that open and close periodically. These soils tend to be very sticky when wet and very hard and firm when dry. Most occur on gentle slopes and all require a climate where seasonal drying occurs. Globally, Vertisols occupy about 2 percent of the total ice-free land area (Staff 2014). These soils occur in the Colorado Plateau/Great Basin Grassland ERU as a small extent.

Vertisols are very limited on the Santa Fe NF and occur as a very small portion of only one map unit which is mapped around French Mesa and to the north near Puerto Chiquito.

Table 58. Percent of soil order within upland ERUs

Soil Orders	*MSG*	*SAGE*	*CPGB*	*SFF*	*MCW*	*MCD*	*PPF*	*JUG*	*PJG*	*PJS*	*PJO*
Alfisols	-	77%	83%	47%	51%	46%	79%	47%	68%	100%	60%
Entisols	-	4%	-	-	-	11%	16%	24%	-	-	10%
Histosols	-	-	-	Low	-	-	-	-	-	-	-
Inceptisols	6%	19%	17%	53%	35%	40%	4%	29%	32%	-	30%
Mollisols	94%	-	-	-	14%	3%	1%	-	-	-	-
Vertisols	-	-	Low	-	-	-	-	-	-	-	-

Upland ERU codes; MSG - Montane / Subalpine Grassland, SAGE – Sagebrush Shrubland, CPGB – Colorado Plateau / Great Basin Grassland, SFF – Spruce Fir Forest, MCW – Mixed Conifer w/ Aspen, MCD – Mixed Conifer – Frequent Fire, PPF – Ponderosa Pine Forest, JUG – Juniper Grass, PJG – Pinyon-Juniper Grass, PJS – Pinyon-Juniper Sagebrush, PJO – Pinyon-Juniper – Woodland

Table 59. Percent of soil order within riparian ERUs

Soil Orders	*190*	*230*	*350*	*260*	*280*	*290*
Alfisols	11%	5%	45%	9%	46%	16%
Entisols	Low	2%	42%	60%	8%	2%
Histosols	Low	-	-	-	Low	Low
Inceptisols	27%	3%	8%	30%	45%	23%
Mollisols	62%	90%	5%	1%	1%	59%
Vertisols	-	-	-	-	-	-

Riparian ERU codes; 190 – Herbaceous, 230 – Narrowleaf Cottonwood/Shrub, 350 – Ponderosa Pine / Willow, 260 – Rio Grande Cottonwood / Shrub, 280 – Upper Montane Conifer / Willow, 290 – Willow / Thinleaf Alder.

Across the Santa Fe NF, soils vary from ustic (dry) moisture regime and mesic (mild) temperature regime at the lower elevations in the steppe grasslands and to an udic (humid-subhumid) moisture regime and pergelic (freezing) temperature regime in the alpine tundra at the highest elevations.[12]

Soils are highly variable ranging from shallow to deep, fine (contain more than 35 percent clay) to loamy, and skeletal (contain more than 35 percent rock fragments) to non-skeletal in nature. They occur on slopes ranging from 0 to 80 percent with vertical rock outcrops present in some areas. There is less soil development on the more unstable steeper slopes. Moderately steep to flat slopes tend to have deeper more developed soils and rock fragment content can be variable. Soil texture varies by parent material kind and origin. Soils developed in parent material such as andesite and basalt tend to have more clay content because these parent materials are high in clay forming minerals. Whereas soils formed from rhyolite and tuff parent materials are lower in clay content since these parent materials have lower percentage of clay-forming minerals. Soil productivity is highly variable across the forest and is dependent on a multitude of factors including, but not limited to; soil stability, hydrologic function, nutrient cycling (these three factors define current direction on soil condition), soil biology, thermodynamics, and filtering and buffering capacities. Some of these factors can be measured more easily and more directly than others.

[12] For a complete explanation of soil temperature and moisture regimes, see *Keys to Soil Taxonomy, 12th ed.* (Soil Survey Staff 2014). Also see, *Keys to Soil Taxonomy, 3rd Printing* for classification of soils in the Santa Fe National Forest Terrestrial Ecosystem Survey report.

Soil quality can be measured directly by vegetation composition, cover, and biomass production. Potential vegetation production has been documented and described for each terrestrial ecosystem map unit across the Santa Fe NF. The unit of production potential (yield) is the air dry weight of annual plant growth up to a height of 4.5 feet during a "normal year" with the unit of measure in pounds per acre per year (Miller et al. 1993; USDA 1986). Production potential can be used for land management decisions, such as determining stocking rates for cattle.

Some soils are inherently better suited to produce larger production values. Production varies greatly within soil orders due to climate, aspect, topography, and parent material. All of the soil orders within the Santa Fe NF with the exceptions of Histosols and Vertisols occur across a variety of climatic gradients on the forest. Soils developed from parent materials high in content of soluble bases (such as basalt or limestone) will be the most productive. Soils developed from parent materials low in content of soluble bases (such as sandstone) will be the least productive.

Shallow soils are defined as soils less than 20 inches deep (Soil Survey Division Staff 1993). These soils are sensitive because they are highly susceptible to erosion, generally are weakly developed, and have relatively low organic matter, which in turn creates low nutrient levels. Soil loss or displacement in these areas can affect productivity of these sites. The majority (62 percent) of the shallow soils found on the Santa Fe NF are located in the PJ Woodland ERU. This ERU is characteristically dominated by moderate to high tree canopy density with a limited or scarce understory component. This ERU lacks sufficient organic matter inputs, thus creating a higher concern for impaired soil productivity on these sites.

Psamments are the sandy Entisols derived from eolian processes with less than 35 percent rock fragments and are sandy in all layers, generally to a depth of 100 cm or more (Soil Survey Staff 2014). These soils are low in plant nutrients, have low water-holding capacity, and rapid permeability. These soils make up a very small portion of the Santa Fe NF, but occur in a localized area in the northern foothills of the Jemez Mountains. The majority of these soils are found within the PJ Woodland ERU that has increasing crown densities and decreasing understory species which creates the potential for increased soil erosion rates and decreased organic matter inputs into the system. These soils are sensitive because they are highly susceptible to wind and water erosion, are weakly developed, and have low organic matter content.

Mass wasting is a general term for a variety of processes by which large masses of earth material are moved by gravity, either slowly or quickly from one place to another (USDA 1986). This rating provides information dealing with inherent stability. Areas with a mass wasting rating of "high" or in some cases "severe" are of special concern due to the highly unstable nature that could result in the loss of site productivity. The majority (approximately 60 percent) of soils rated as high for mass wasting are found in the Mixed Conifer – Frequent Fire ERU. Throughout the Santa Fe NF these soils are found mainly on very steep slopes (most over 50 percent) formed in sandstone, shale, or granite.

Regarding soils, wildfires are known to change soil organic matter quantity and quality; deplete soil nutrients directly by volatilization or indirectly by enhanced post-fire erosion; modify microbial populations; and induce or increase soil water repellency depending on the temperatures and residence time of fire, thus lowering water infiltration and increasing water overland flow and runoff. (Notario del Pino, 2014)

Areas of the Santa Fe NF that have experienced large wildfires such as Las Conchas, Cerro Grande, Viveash, Thompson Ridge, and others have had dramatic effects on soil condition since the Santa Fe NF TES was published. Estimated time for recovery to satisfactory conditions within the burned area depends on many factors including pre-burn conditions, burn severity, post-fire treatments, management, and weather patterns. Ground cover is expected to increase enough in high and moderate burn severity areas to bring erosion rates to a level where long-term soil productivity is no longer at risk within five years

where soils are capable (MacDonald 2013, Elliot 2000). Figure 40 displays fire history (wildfires) of the Santa Fe NF since 1993. These fires have likely contributed to changes in soil condition since the publication of the Santa Fe National Forest Terrestrial Ecosystem Survey in 1993.Ecosystem Characteristics for Assessment

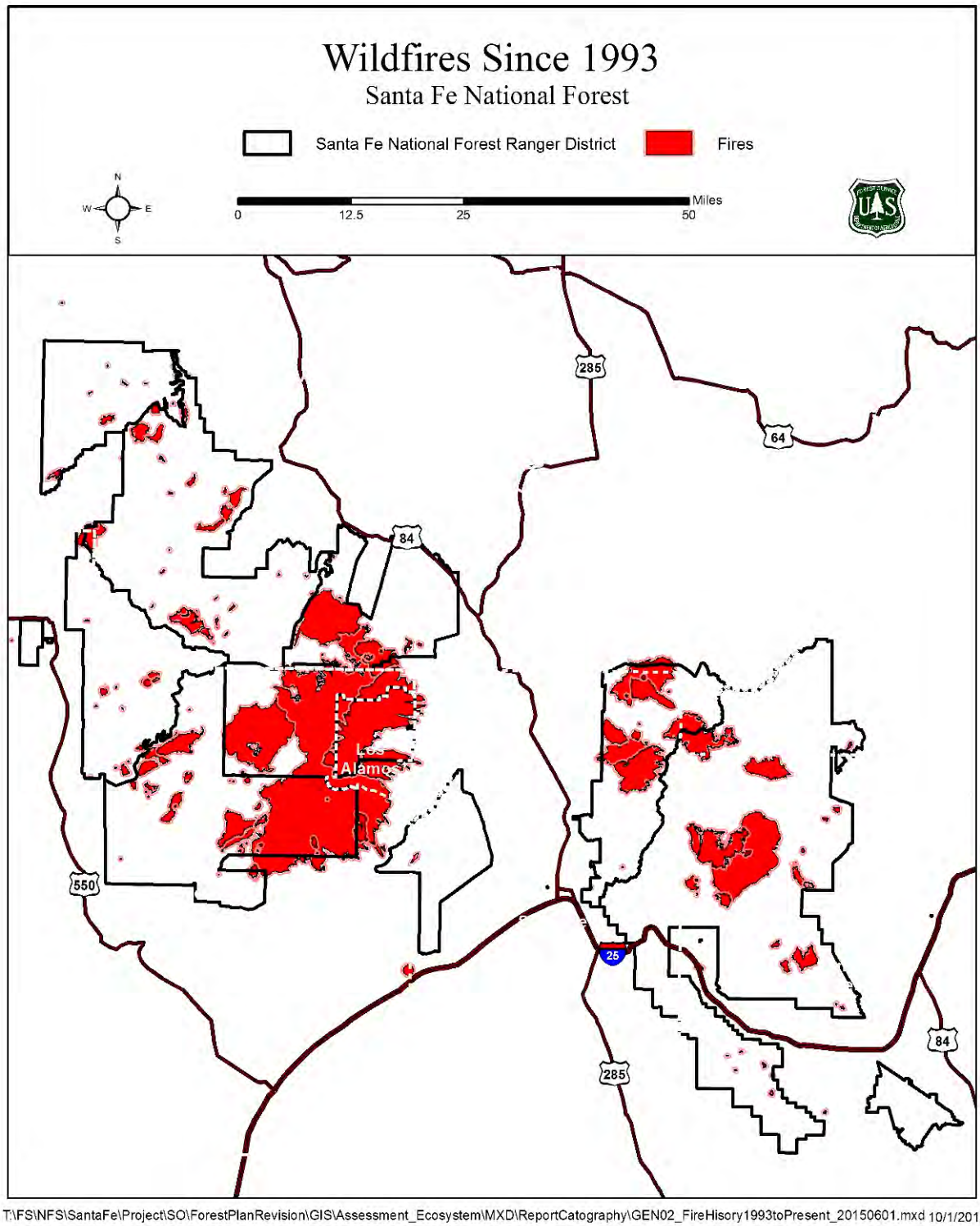


Figure 40. Wildfires on the Santa Fe NF since 1993

Ecosystem Characteristics for Assessment

The primary ecosystem characteristics—soil erosion hazard and soil condition—are directly linked to the ability of the soil to withstand disturbances from management activities and natural events while maintaining site productivity and sustainability of the soil resource, i.e., soil resilience. Soil loss rates are predicted from soil loss models and are important factors when classifying soil erosion hazard and soil condition ratings. Soil organic carbon (SOC) is an integral part of the soil resource and ultimately the ecosystem. SOC provides the main source of energy for microorganisms which are vital to the soil resource. These characteristics are used to analyze the reference and current conditions and future trends of the soil resource.

Soil Loss Rates

Annual soil loss rates are predicted from a version of the Universal Soil Loss Equation[13] (USLE). Soil loss is difficult to visually observe, unless a large amount of soil loss is taking place. For example, a soil loss rate of 0.25 in/yr (38 tons/ac/yr) is observable, but certainly an unacceptable rate for maintenance of soil productivity (Shaw et al. 1991). Acceptable soil loss rates, i.e., soil loss rates that will not impair soil productivity, are variable by soil and terrestrial ecosystem map unit type. Soil loss rates are not considered as absolute values and are useful as an index. Soil losses are predicted for the four following categories:

1. *Potential* is the rate of soil loss that would occur under conditions of complete removal of the vegetation and the litter portion of groundcover (maximum rate).
2. *Natural* is the rate of soil loss that would occur under conditions associated with a climax class (minimum rate).
3. *Current* is the rate of soil loss occurring under existing conditions of groundcover.
4. *Tolerance* is the rate of soil loss that can occur while sustaining inherent site productivity.

Reference Condition

Reference conditions generally estimate Pre-European settlement conditions (Winthers et al. 2005). The extent and magnitude of natural disturbances (e.g., fire, floods) under reference conditions was smaller than under current conditions, and the subsequent loss of vegetation cover and litter for a given site—and the likelihood of erosion—would have been smaller as well. However, it is probable that when soils were burned and farmed, accelerated erosion occurred after intense storms. There is substantial evidence that the Native American landscape of the early sixteenth century was a humanized landscape, populations were large and forest composition had been modified, grasslands had been created, wildlife disrupted, and erosion was severe in places (Denevan 1992). Soil loss, historically, would have been within natural soil loss rates in most places on the Santa Fe NF.

Current Condition

All (17 out of 17) of the ERUs analyzed on the Santa Fe NF have current soil loss rates that exceed natural soil loss rates. Most (11 out of 17) of the ERUs analyzed on the Santa Fe NF have current soil loss rates that do not exceed tolerable soil loss rates. These ERUs include Colorado Plateau / Great Basin Grassland, Mixed Conifer-Frequent Fire, Mixed Conifer w/ Aspen, Montane / Subalpine Grassland,

[13] Universal Soil Loss Equation - an empirical mathematical model used to describe soil erosion processes. USLE has been modified from its original form to predict soil loss in forestlands and rangelands (Renard K et al. 1997)

Ponderosa Pine Forest, RMAP Herbaceous, RMAP Narrowleaf Cottonwood / Shrub, RMAP Ponderosa Pine / Willow, RMAP Upper Montane Conifer / Willow, RMAP Willow - Thinleaf Alder, and Spruce-Fir Forest. These ERUs are currently sustaining inherent site productivity while the remaining 6 (as described below) ERUs have soil loss rates that are at unsustainable levels to sustain inherent site productivity.

Soil Loss Trend

Current estimates of soil loss trend were analyzed on the basis of current soil loss rates to tolerable soil loss rates. When current soil loss rates exceeded tolerable soil loss rates the ERU was considered to be trending away from reference condition. If current soil loss rates were less than tolerable soil loss rates the ERU was considered to be in stable condition.

Approximately one-third (6 out of 17) of the ERUs on the Santa Fe NF are trending away from reference soil loss conditions based on the above analysis. These ERUs include the Juniper Grass, PJ Grass, PJ Sagebrush, PJ Woodland, RMAP Rio Grande Cottonwood/Shrub, and Sagebrush Shrubland.

Soil Erosion Hazard

Soil erosion hazard is the probability of soil loss resulting from complete removal of vegetation and litter—an inherent soil property (not influenced by management). Slope, soil texture, and depth to a restricting layer greatly influence soil erosion hazard rating. The Soil Erosion Hazard rating reflects inherent site and soil characteristics which are determined from modeled soil loss rates. It is an interpretation based on the relationship between the maximum soil loss (potential) and the tolerable (threshold) soil loss of a site. Soils are given a slight, moderate, or severe erosion hazard rating.

- A rating of **slight** indicates the maximum soil loss does not exceed the threshold, and therefore, the loss of the soil production potential is of low probability.
- A **moderate** erosion hazard indicates that the loss in soil production potential from erosion is probable and significant if unchecked.
- A **severe** erosion hazard rating indicates that the loss of soil production potential from erosion is inevitable and irreversible if unchecked.

These ratings provide land managers with an index for identifying three classes of land stability. They are useful in determining where erosion control measures should be evaluated when (or before) the soil surface has been exposed by logging, grazing, prescribed burning, or other disturbances. These ratings are also useful in identifying areas that should receive minimum exposure of mineral soil. Severe ratings mean that accelerated erosion is likely to occur in most years and that erosion control measures should be evaluated. Soil erosion hazard was calculated using a version of the USLE for all major soils within the ERUs.

The range in erosion hazard classes within an ERU often reflect the various slope gradients, landforms, and associated thresholds on which they occur (

Reference Condition

Erosion hazard is an estimate of risk. Therefore, there is no reference condition or trend.

Current Condition

Approximately 51 percent of soils on the Santa Fe NF fall into the severe erosion hazard class while the majority of the rest (48 percent) fall into the moderate erosion hazard class (figure 41). Very few soils on the forest, less than 1 percent of the total area, fall into the slight erosion hazard rating. The majority of the Santa Fe NF has a high probability that accelerated erosion would occur if management disturbances that expose the soil surface neglect to incorporate erosion control measures or when natural disturbances happen.

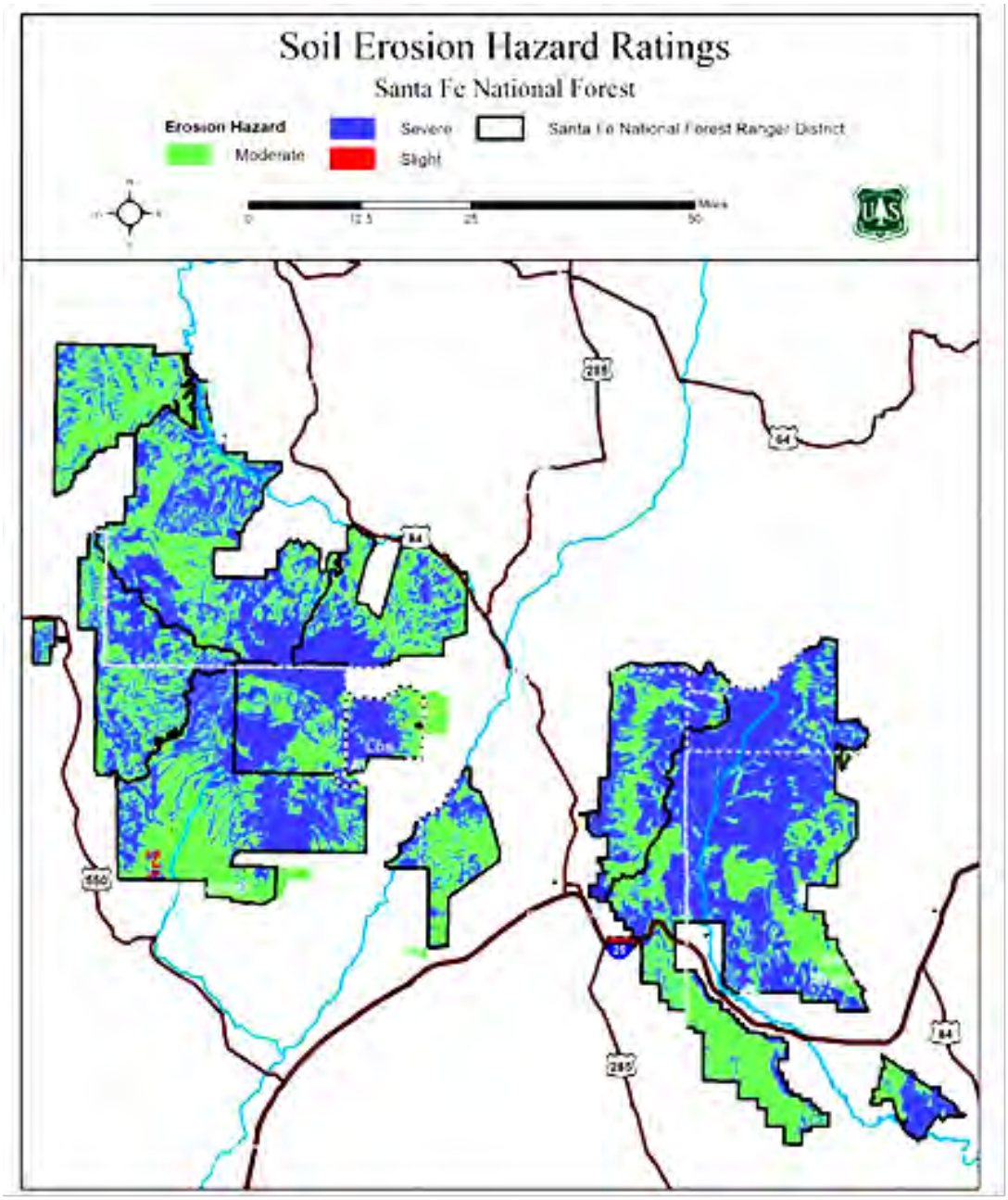


Figure 41. Soil erosion hazard ratings of the Santa Fe NF

These disturbances include natural events such as wildfires and mass movements and human-induced disturbances such as road construction and timber harvesting. Soil erosion, combined with other impacts

from forest disturbance, such as soil compaction, can reduce forest sustainability and soil productivity (Elliot et al. 1999). When accelerated erosion occurs soil productivity is decreased thus decreasing ecosystem productivity. Erosion generally decreases productivity of forests by decreasing the available soil water for forest growth and through loss of nutrients in eroded sediment (Elliot et al. 1999).

The severe erosion hazard class dominates in 4 out of the 11 upland ERUs including Mixed Conifer w/Aspen, Montane/Subalpine Grasslands, PJ Grass, and Spruce-Fir Forest. Where these systems with severe erosion hazard ratings occur within watersheds that have uncharacteristic disturbance regimes and fuel loadings, the potential risk for accelerated erosion exceeding thresholds and subsequent runoff is high. Excessive fuel loadings combined with uncharacteristic fire regimes have the potential to create large swaths of land that lack canopy cover (overstory plants) and effective ground cover. This will increase the risk of accelerated soil erosion and debris flows on the landscape.

The Moderate erosion hazard class dominates in 5 out of the 11 upland ERUs including the Colorado Plateau/Great Basin Grassland, Juniper Grass, PJ Sagebrush, PJ Woodland, and Sagebrush Shrubland ERUs. With increasing canopy densities and a decreasing understory herbaceous component in the Juniper Grass, PJ Sagebrush, and PJ Woodland ERUs the potential for accelerated erosion to occur is high if left unchecked.

The remaining upland ERUs (Mixed Conifer – Frequent Fire and Ponderosa Pine Forest) have a relatively even combination of severe and moderate erosion hazard classes.

Within the riparian ERUs the severe erosion hazard rating dominates in RMAP Ponderosa Pine/Willow and RMAP Upper Montane Conifer/Willow ERUs while the moderate erosion hazard rating dominates in RMAP Narrowleaf Cottonwood/Shrub and RMAP Rio Grande Cottonwood/Shrub. The RMAP Herbaceous and RMAP Willow – Thinleaf Alder ERUs have a fairly even distribution of severe and moderate erosion hazard ratings.

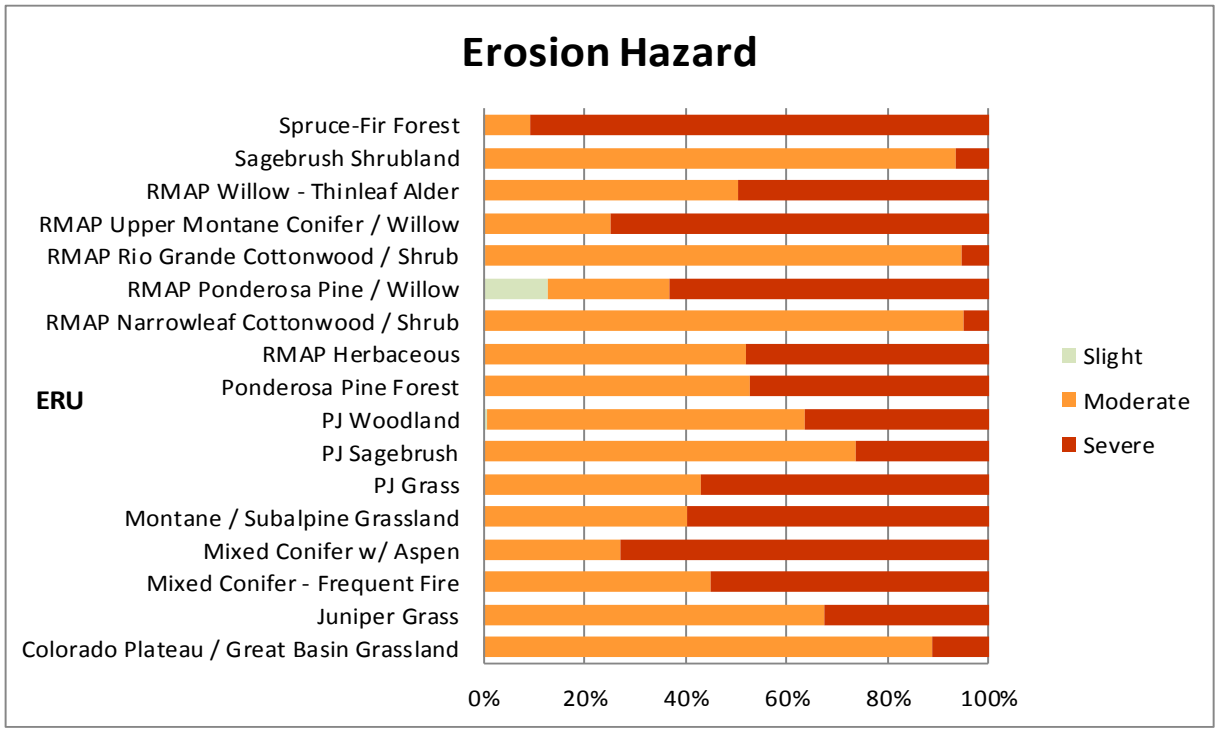


Figure 42. Erosion hazard of Santa Fe NF ERUs

Soil Condition

Soil condition is an evaluation of soil quality based on an interpretation of factors which affect vital soil functions. Soil quality is the capacity of the soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health (Doran and Parkin 1994).

Soil condition is based on three soil functions including (1) the ability of the soil to resist erosion, (2) the ability of the soil to infiltrate water, and (3) the ability of the soil to recycle nutrients. Soil condition provides an overall picture of soil health vital in sustaining ecosystems. Soil condition rates soils as they exist currently and reflects the effects of management and disturbance history—soils were generally assumed to be in satisfactory soil condition under reference conditions.

The Terrestrial Ecosystem Survey (TES) of the Santa Fe NF was used as the basis for determining current soil condition (Miller et al. 1993). The TES identifies soil condition by ecological map unit and predicted soil loss. Unlike soil erosion hazard, soil condition is influenced by management. Current soil condition in this assessment reflects conditions from 1993, when the TES was published. Since then, significant changes have occurred across the landscape from management and natural disturbances such as fire, drought, and grazing. Satisfactory soil conditions have likely decreased and unsatisfactory conditions have likely increased in areas where disturbances have occurred.

Soil Condition Categories

Ecological Response Units are assigned a soil condition category which is an indication of the status of soil functions. Soil condition categories reflect soil disturbances resulting from both planned and unplanned events. Current management activities provide opportunities to maintain or improve soil functions that are critical in sustaining soil productivity. The following is a brief description of each soil condition category:

- **Satisfactory:** Indicators signify that soil function is being sustained and soil is functioning properly and normally. The ability of soil to maintain resource values and sustain outputs is high.
- **Unsatisfactory:** Indicators signify that loss of soil function has occurred. Degradation of vital soil functions results in the inability of soil to maintain resource values, sustain outputs, and recover from impacts. Soils with an “unsatisfactory” rating are candidates for improved management practices or restoration designed to recover soil functions.
- **Unsuited:** Areas rated unsuited are those where geologic erosion rates are greater than soil formation rates (naturally erodible). Soils are inherently unstable and may occur on steep slopes. These soils are generally associated with badlands and other miscellaneous areas.

Existing management activities need to be evaluated to determine if the current management activity is contributing to the loss of soil function. In some cases, current management activities may not have caused the loss of soil function but may be preventing recovery. Management activities that slow or prevent recovery of soil function should be evaluated for best management practices.

Satisfactory soil condition (soil quality) is important in maintaining long-term soil productivity—key to sustaining ecological diversity. Unsatisfactory and impaired soil conditions have resulted in the reduced ability of the soil to grow plants and sustain productive, diverse vegetation.

Reference Condition

Very little quantitative data exist to measure historical soil condition. However, some qualitative and quantitative inferences can be made, providing insight into historical soil condition by using knowledge about present disturbances and their effect on soil stability, soil compaction, and nutrient cycling. Reference conditions generally estimate Pre-European settlement conditions (Winthers et al. 2005).

Historically (without anthropogenic disturbance), soil loss, soil compaction, and nutrient cycling would probably have been within functional limits to sustain soil function and maintain soil productivity for most soils that are not inherently unstable—the exception being during cyclic periods of drought and possibly local areas impacted through native populations and non-domestic herbivory. Natural flood disturbance would have had a limited effect on the extent of soil loss, only causing accelerated erosion adjacent to stream channels or floodplains. Natural fire disturbance would have had a limited effect on the extent of soil loss, only causing accelerated erosion in localized areas where total consumption of the litter layer and/or canopy occurred. Drought may have reduced the amount of protective vegetative ground cover resulting in accelerated erosion during prolonged rainstorms.

Most areas that are currently unsatisfactory for soil condition would probably have been historically satisfactory for soil condition.

Table 60. Estimated historic versus current soil condition percentages on Santa Fe NF

Soil Condition Class	Historic Percent	Current Percent	Difference between Historic and Current
Satisfactory	95%	77%	18%
Unsatisfactory	Low	18%	18%
Unsuited	5%	5%	0%

Current Condition

Approximately 77 percent of the Santa Fe NF is rated in satisfactory soil condition (Miller et al. 1993) (figure 43). More than half of the upland ERUs have a majority of satisfactory soil conditions (8 out of 11). These include Spruce-Fir Forest, Ponderosa Pine Forest, PJ Woodland, Montane/Subalpine Grassland, Mixed Conifer w/Aspen, Mixed Conifer – Frequent Fire, Juniper Grass, and Colorado Plateau/Great Basin Grassland ERUs. All of the riparian ERUs have a majority of satisfactory soil conditions (6 out of 6). The most productive soils (satisfactory soil condition) are within ERUs that produce high amounts of organic matter to ensure stability of the soil and support nutrient cycling. Soil organic matter generates numerous benefits for the soil resource including; improving water infiltration, soil aeration, and water holding capacity. Organic matter is an energy source for microorganisms and supplies nutrients for plant growth (Magdoff 2004). These benefits can provide maintenance of ecosystem productivity and site diversity.

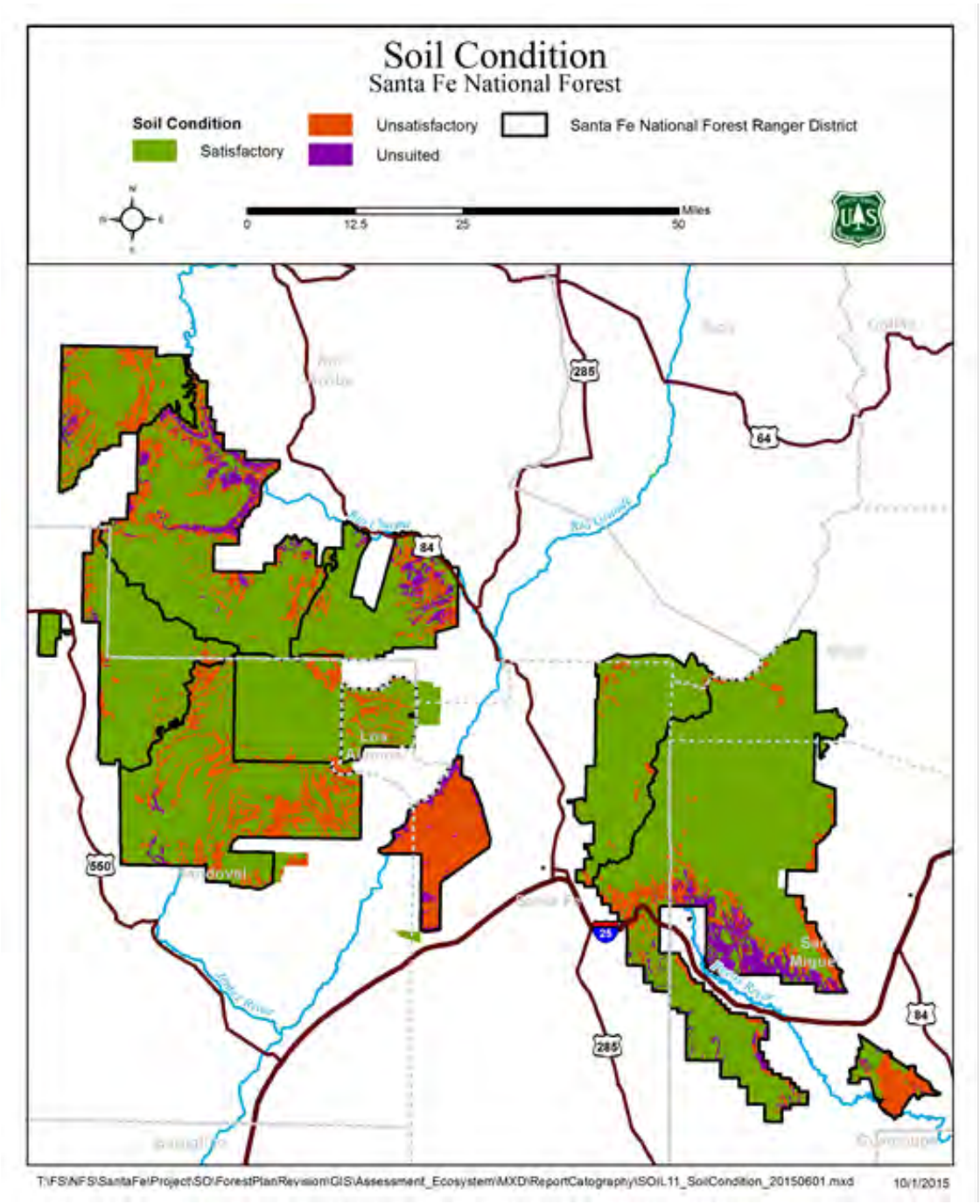


Figure 43. Soil condition classes of the Santa Fe NF

ERUs (PJ Grass, PJ Sagebrush, and Sagebrush Shrubland) that have a loss of soil productivity (unsatisfactory soil condition) through a reduction in soil function is due to a lack of effective vegetative ground cover and organic matter. This has resulted in unstable soils with reduced nutrient cycling. The pathway that nutrients are delivered back into the soil (nutrient cycling) is of high importance to a functioning system. Release of nutrients by mineralization of soil organic matter is important in the short-term nutrient cycling, but in the long run the organic matter and the nutrients it contains must be replenished or soil fertility will be depleted (Brady and Weil 2008).

A reduction in vegetative ground cover also decreases the sites ability to buffer the soil surface against rain drop impact, and excessive animal or mechanical traffic, which compact the soil surface. Left to natural processes, compacted areas are slow to re-vegetate and often undergo excessive erosion rates (Buol 1995). Compaction restricts rooting depth which reduces water and nutrient uptake (USDA 1996). Accelerated soil loss reduces the productivity of terrestrial ecosystems in a number of ways; increasing water runoff which decreases infiltration and storage of water in the soil. Organic matter and nutrients are lost as they move offsite with the soil that is eroded away (Pimentel and Kounang 1998).

Some soils are considered inherently unstable (unsuited soil condition). Inherently unstable soils are those in which their geologic formation and geomorphic properties are naturally active, and soil erosion has existed historically and will continue. Approximately 5 percent of the total area on the Santa Fe NF is rated in unsuited soil condition. Inherently unstable soils are dispersed across the landscape and occur primarily in the Juniper Grass and PJ ERUs. The Juniper Grass ERU consists of approximately 37 percent unsuited soil condition rating while the PJ Grass, PJ Sagebrush, and PJ Woodland consist of approximately 24 percent, 26 percent, and 13 percent respectively. Soil erosion hazard influences soil condition—an inherently unstable soil is more vulnerable to soil condition impairment than an inherently stable soil.

Santa Fe NF ERUs that make up approximately 78 percent of the forest (Mixed Conifer – Frequent Fire, PJ Woodland, Ponderosa Pine Forest, and Spruce-Fir Forest) are generally (at least 60 percent) in satisfactory soil condition. These ERUs contribute significant acres towards ecological sustainability and should be managed to maintain satisfactory soil conditions and improve unsatisfactory conditions. However, there are ERUs within the Forest that have high amounts of unsatisfactory soil conditions (figure 44) and risk a loss of ecosystem productivity if not improved.

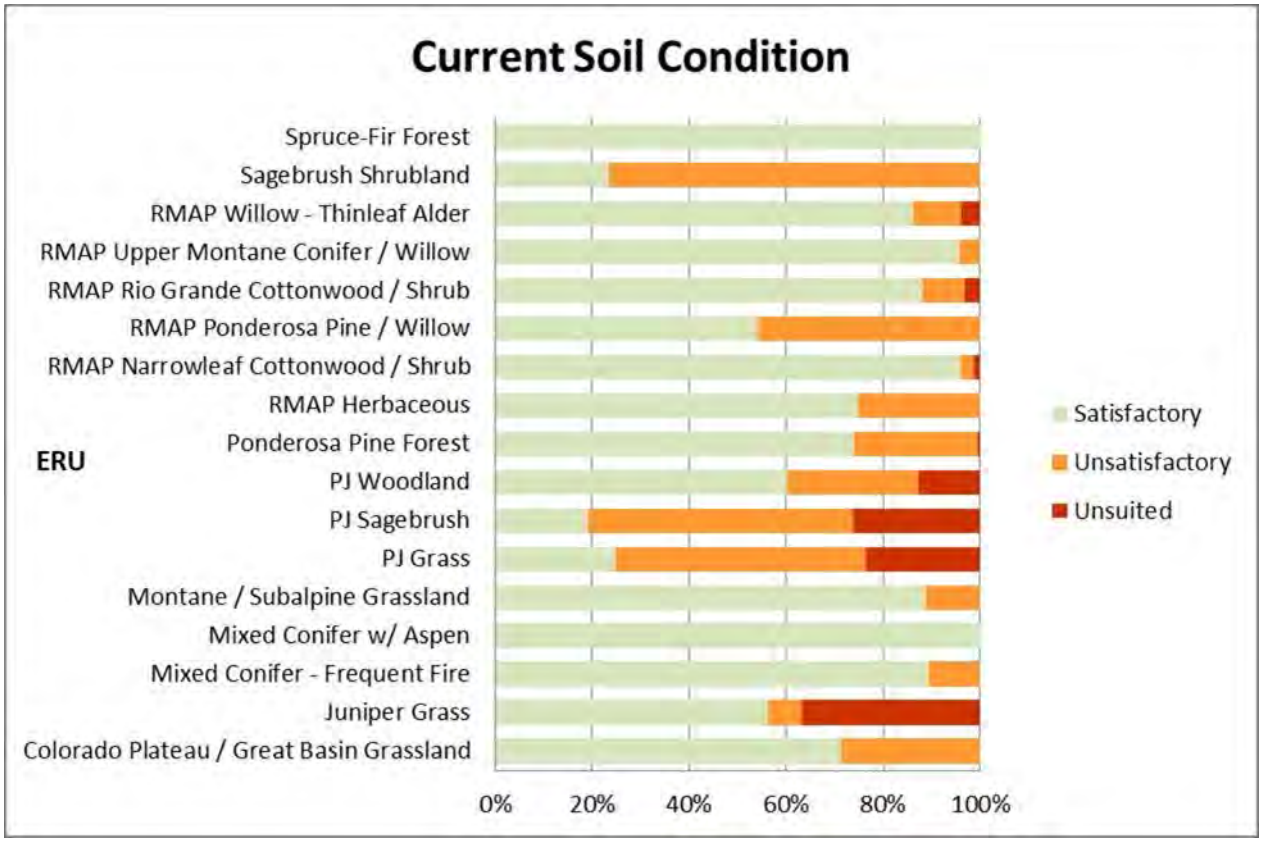


Figure 44. Current soil condition on Santa Fe NF by ERU

Soil Condition Trend

Trends of soil condition on the Santa Fe NF will be a product of a variety of factors and interactions among those factors (e.g., current and future management objectives, management practices, climate change, and natural disturbances). Current estimates of soil condition trend were analyzed using two criteria: (1) When 25 percent or more of an ERU was rated in unsatisfactory soil condition the ERU was considered to be trending away from reference condition, and (2) when 24 percent or less of an ERU was rated in unsatisfactory soil condition the ERU was considered to be in stable condition. However, stressors such as altered fire regimes, nonnative species, and drought—coupled with historical unmanaged grazing and fuelwood gathering—have produced unnaturally dense overstories and sparse vegetative ground cover. These stressors (past, current, and future) will affect soil condition trend. Soil erosion may be occurring beyond its threshold due to high amounts of bare soil and larger, more intense wildfires; and many soils may be trending toward conditions of accelerated erosion and declining site productivity. Current management practices strive to restore ecosystem health and improve soil condition.

Soil Organic Carbon

Soil organic carbon (SOC) is the energy source for soil organisms which, through their activity and interactions with mineral matter, impart the structure to soil that affects its stability and its capacity to provide water, air, and nutrients to plant roots. The amount and kind of soil organic carbon reflects and controls soil development and, ultimately, ecosystem productivity (Van Cleve and Powers 1995).

Globally, SOC contains more than three times as much carbon as either the atmosphere or terrestrial vegetation (Schmidt et al. 2011). Forest soils are the largest active terrestrial carbon pool and account for 34 percent of the global soil carbon (Buchholtz et al. 2013). Accurate quantification of SOC stocks is key to modeling atmospheric CO_2, soil productivity, and global climate. Soils represent a significant portion of the active carbon cycle, with estimates of organic C ranging from 1,500 to 2,000 C, or roughly two-thirds of the terrestrial organic C stocks (Rasmussen 2006). The Santa Fe NF contains large pools of SOC in the Mixed Conifer-Frequent Fire and Ponderosa Pine ERUs as well as the largest pool on forest in a regionally uncommon vegetation type, the Spruce-Fir Forest. Combined, these 3 ERUs make up approximately 65 percent of the forest and contribute large amounts to total SOC stock on forest.

Attempts to characterize regional soil carbon stocks include both ecosystem- and soil taxa-based approaches. The ecosystem approach involves averaging soil C data within a specific plant community or biome and multiplying the average soil C content by the estimated biome land area (Rasmussen 2006). This approach does not account for soil spatial heterogeneity and results in large variability of soil C estimations within an ecosystem or biome.

The soil taxa approach has been extensively described in the soil science literature (Rasmussen 2006) and includes segregating landscapes by soil taxa (instead of biomes) and using average taxa soil C and estimated land area to calculate soil C stocks.

The process used for the Santa Fe NF soil C stock assessment involved an ecosystem-based approach through the aggregation of terrestrial ecological units (soil/vegetation/climate) into ecological response units that represent the major potential natural vegetation communities on the Santa Fe NF.

Methods

Soil organic carbon was calculated from two sources for this assessment. Soil pedons that were selected for physical and chemical characterization during the Santa Fe NF Terrestrial Ecosystem Survey were used to establish average soil organic carbon reference values for ecological response units (ERU). The

soil pedons chosen were representative of the major kind of soil for that ERU. Other kinds of soil may also occur within ERUs however their proportion is minor relative to the representative pedon that was sampled and characterized.

The second source of soil carbon data came from the USDA-NRCS, National Soil Survey Office, Geospatial Research Unit West Virginia University. The data was compiled from the Rapid Soil Carbon Assessment project initiated by the NRCS and gridded soil survey data (gSURGGO).

Ecological Response Units were intersected with polygons from the gSURGGO data and values for soil organic carbon were calculated for 0 to 30 cm and 0 to 100 cm. These values were normalized and compared to established reference values of characterized pedons.

Bulk density was derived from both sampled pedon data and representative values from known soil textures.

The Santa Fe NF has a wide variety of soils that support many different terrestrial ecosystems. These soils have originated from igneous, sedimentary and metamorphic geologic sources and occur on a wide array of landforms. The differential weathering of soils by various climates and plant communities leads to the development of soil organic carbon.

Reference Condition

Very little quantitative data exist to measure historical SOC. Reference condition for SOC will not be analyzed.

Current Condition

Table 61. Total and average soil organic carbon for major Santa Fe NF ERUs

ERU Code	ERU Name	SOC 0-100 cm (tons/ac)	Acres	SOC 0-100 cm (tons)
CPA	Colorado Plateau / Great Basin Grassland	26	41,639	1,098,424
JUGc	Juniper Grass	23	97,470	2,286,028
MCD	Mixed Conifer - Frequent Fire	61	429,967	26,432,128
MCW	Mixed Conifer w/ Aspen	56	40,174	2,254,278
MSG	Montane / Subalpine Grassland	59	17,707	1,048,515
PJG	PJ Grass	31	43,356	1,337,085
PJS	PJ Sagebrush	23	30,449	714,141
PJOc	PJ Woodland	25	231,508	5,848,314
PPG	Ponderosa Pine Forest	59	403,915	23,822,190
190	RMAP Herbaceous	93	15,373	1,427,488
230	RMAP Narrowleaf Cottonwood / Shrub	18	15,010	264,219
350	RMAP Ponderosa Pine / Willow	17	665	11,056
260	RMAP Rio Grande Cottonwood / Shrub	12	7,493	87,275
280	RMAP Upper Montane Conifer / Willow	18	495	8,722
290	RMAP Willow - Thinleaf Alder	10	6,957	70,511
SAGE	Sagebrush Shrubland	16	37,457	593,183
SFP	Spruce-Fir Forest	119	250,481	29,895,025

The SOC values by ERU in figure 45 represents soil pedon data collected and analyzed during the Santa Fe NF Terrestrial Ecosystem Survey (Miller et al. 1993) while values of the riparian ERUs and the sagebrush shrubland ERU represent USDA-NRCS gSURRGO data provided by the NRCS Remote Sensing Laboratory at West Virginia University (Soil Survey Staff, 2013).

Considerable SOC variation exists between ERUs due to the variable numbers of soils sampled, the different kinds of soil taxa per ERUs, and the scale for which map unit composition values represent both fine and coarse scales (figure 45 and table 61).

Average soil organic carbon stock for ecological sites (pedons) on upland ERUs of the Santa Fe NF is generally greatest in the Spruce Fir Forest ERU of the sub-alpine zone at approximately 119 tons/ac and least in the Juniper Grass and PJ Sagebrush ERUs at 23 tons/ac; however the RMAP Willow – Thinleaf Alder ERU contains the least average SOC at 10 tons/ac across all ERUs (upland and riparian) on the Santa Fe NF (figure 45). The riparian system ERUs excluding RMAP Herbaceous (93 tons/ac average SOC) all have very similar and relatively low average SOC (when compared to upland ERUs) ranging from 10 tons/ac to 18 tons/ac.

The Spruce Fir Forest ERU accounts for the greatest individual contribution (31 percent) of total SOC by land area for the forest. The woodland biomes for the Santa Fe NF account for approximately 10,185,568 tons of SOC or 11 percent of the SOC stock by land area while the Colorado Plateau/Great Basin and montane grassland ERUs contribute 2,146,939 tons of SOC or 2 percent of the SOC stock by land area.

The Mixed Conifer-Frequent Fire and Ponderosa Pine Forest ERUs contribute significantly to the overall SOC stock for the Santa Fe NF. Collectivelt, they account for approximately 50,254,318 tons of SOC or 52 percent of the SOC stock by land area.

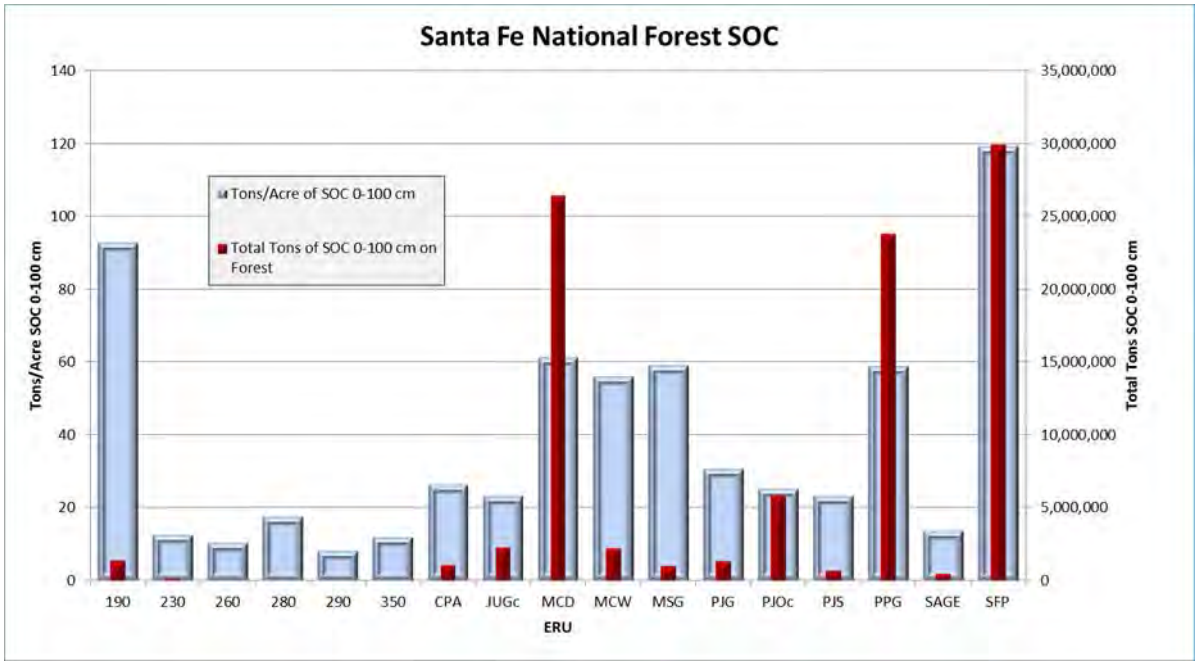


Figure 45. Total and average soil organic carbon for major Santa Fe NF ERUs

SOC Trend

The current trend of sustaining SOC is strongly influenced by vegetation growth and by activities that remove biomass; including climatic factors that influence the rates of weathering and decomposition of above- and below-ground biomass. Given the projection that biomass carbon will increase into the future, it is logical to assume that SOC will remain the same, or potentially increase, under current rates of decomposition.

The Spruce-Fir Forest (the largest pool of SOC on forest) is uncommon in the Southwest, but common on forest accounting for roughly 15 percent of the Santa Fe NF. Mixed Conifer-Frequent Fire and Ponderosa Pine Forest ERUs account for approixmately half of the vegetation types on the Santa Fe NF. These 3 ERUs store almost 5 times more SOC than all other Santa Fe ERUs combined and are significant carbon pools for future management consideration.

Current Forest Service Southwestern Region soil quality technical guidance is to maintain surface coarse woody material in woodlands and forests to ensure microbial populations for nutrient cycling (Graham et al. 1994). The exception to this would be the Grassland and Shrubland ERUs where surface biomass has decreased due to consumptive harvesting by ungulates, erosion (wind and water) and other disturbances (e.g., fire).

While most woodland and forest ERUs will maintain biomass carbon in support of SOC for the future, the continued loss or displacement (patchiness) of grassland and shrublands surface biomass could result in slower and diminished contributions to SOC stocks, and influence long-term soil productivity. Ecological response units where existing soil conditions that are rated unsatisfactory, due to the lack of surface litter, are most susceptible to continued reductions of SOC over time. Soil conditions that are rated satisfactory will continue to maintain SOC values and a loss of long-term soil productivity is unlikely.

The effects of climate change on the decomposition rates and stability of SOC are presently being debated (Davidson and Janssens 2006).

Risk Assessment

While soil erosion hazard is an inherent soil property and not influenced by management, soil condition and soil loss rates are influenced by management and are the criteria used in this risk assessment. Soil organic carbon was not analyzed in the risk assessment. Almost half (8 out of 17) of the ERUs analyzed on the Santa Fe NF are considered to be at high risk for soil condition (at least 25 percent unsatisfactory) (figure 44). Most of the lower elevation ERUs (Juniper Grass, PJ Grass, PJ Sagebrush, PJ Woodland, Sagebrush Shrubland, and RMAP Rio Grande Cottonwood/Shrub) on the Santa Fe are considered to be at high risk for soil loss (where current soil loss rates exceed tolerable soil loss rates).

In general, lower elevation ERUs (PPF and lower), with the exception of Juniper Grass and most riparian ERUs, are at risk for soil condition. Although the Ponderosa Pine Forest ERU is at 25 percent unsatisfactory soil conditions (the lower limit of high risk) the amount of total acres contributing to unsatisfactory soil conditions from this ERU is high when compared with other ERUs (due to the total amount of acres within PPF).

Effects from historical grazing and management, increasing overstories (which contribute to decreasing herbaceous cover and increasing bare soil in these ERUs), and prolonged drought are all factors affecting soil condition in these lower elevation ERUs. Higher elevation ERUs such as Spruce-Fir Forest and Mixed Conifer-Frequent Fire have low risk for soil condition due in part to wetter climatic conditions

contributing to higher amounts of coarse woody material and litter. Although these factors contribute to soil stability, soil hydrology, and nutrient cycling (satisfactory soil conditions) within these ERUs it also places them at risk for uncharateristic fire, associated accelerated erosion and decreased site productivity.

Almost one quarter (4 out of 17) of the ERUs analyzed on the Santa Fe are considered to be at high risk for both soil condition and soil loss. These ERUs include PJ Grass, PJ Sagebrush, PJ Woodland, and Sagebrush Shrubland. Ecological need for change should address the site-specific characteristics (plant basal cover, canopy cover, litter, coarse woody material, etc.) that are in need of improvement.

Stressors Associated with Soil Risk

The risk assessment considered stressors when identifying risk to soil characteristics. Below are the stressors that were considered.

1. Herbivory: Cattle grazing occur throughout lower to mid elevation ERUs. Elk and other ungulate grazing occur throughout lower to higher elevation ERUs. High levels of ungulate grazing has been observed to reduce effective vegetative ground cover and contribute to accelerated erosion, soil compaction (Shaw et al. 1991) and declined soil productivity (especially during periods of drought).

2. Forest Activities: Forest activities (management actions) that remove soil surface cover, cause compaction, or increase accelerated erosion as well as other management activities that increase bare soil would result in unsatisfactory soil conditions if best management practices are not incorporated. Activities include timber harvesting, road construction and use, recreation facility construction and use, prescribed burning, fuelwood harvesting, and grazing (see 1. Herbivory). Poorly placed roads or roads constructed with poor drainage contribute to increased erosion and unsatisfactory soil conditions.

   Some examples of impacts that have affected current soil condition include the following:

   a. Compacted soils from forest restoration treatments, grazing and recreation activities have caused or may cause reduced productivity within those localized areas.

   b. Around the turn of the 19th century, sheep and later cattle were allowed to graze heavily and unsustainably in northern New Mexico. The legacy of that overgrazing has contributed to fire exclusion, tree and shrub encroachment, shifts in species composition, and degraded soil conditions that still persist on the landscape today.

   c. Continued ungulate grazing (a combination of domestic livestock and wildlife) has combined with recent drought to significantly reduce graminoid cover and degrade soil conditions in some localized areas.

   d. Road corridors that make up the forests' road system resulted in loss of soil productivity. Roads, both administratively closed and open to motor vehicle use but under-maintained, contribute to soil erosion and reductions in vegetative groundcover. All roads contribute to habitat fragmentation and act as vectors for invasive species and human caused fires. The travel management rule has begun to address roads and motor vehicle use, but until closed roads are decommissioned (administratively or naturally) they will continue to contribute to soil erosion.

   e. Mineral extraction pits and mines resulted in permanent loss or reduction in soil productivity.

f. Footprints of administration and recreation sites have reduced soil productivity.

g. Permanent special use sites, such as communication towers and buildings eliminated soil productivity.

3. Noxious and Invasive Plants: Soils at lower eleveations (PPF ERU and lower) have reduced soil function, due to the combination of lack of effective vegetative groundcover and a shift from perennial to annual plant and shallow rooted grasses or tap-rooted woody species. Invasive plants may result in a decrease or loss of graminoid cover because of their ability to outcompete for solar energy, soil nutrients, and water. This can lead to a departure of surface organic matter. The departure of the surface organic matter can result in a departure of soil organic matter because the lack of recruitment of organics. Departure of organic matter can also result in the departure of soil loss because the loss of the protective organic matter cover and its ability to promote aggregate stability and infiltration while reducing runoff has departed from reference condition. The risk of soil loss resulting in a departure of soil productivity is associated with erosion hazard classes. All of these soil characteristics interact and result in how a soil functions which impacts soil condition. This ultimately impacts the soil productivity potential.

4. Soil Erosion Hazard: Inherent soil property not influenced by management. A soil erosion hazard rating is an estimate of risk. Where moderate and severe soil erosion hazard ratings exist, potential for accelerated soil loss is likely to occur if ground cover is removed (e.g., high severity fire.)

5. Drought: The Forest has experienced several recent years of drought (roughly since about 2000) with occasional normal levels of seasonal moisture. Reduced precipitation results in reduced vegetative growth, reduced surface organic matter and nutrient cycling and lower site productivity. Ineffective vegetative ground cover puts the soil at risk of accelerated erosion during peak storm events and subsequent erosion and loss of soil productivity. As the potential for vegetation mortality increases, there is increased risk of wild fire spread and subsequent accelerated erosion and overall watershed degradation.

6. Flooding: Flooding affects the Forests riparian ERUs as well as unmapped stream courses throughout all ERUs. Flooding may cause localized sediment production in the stream channel, stream banks and floodplains if not well protected with vegetative ground cover. Frequent flooding is a natural process and disturbance within these ERUs. Flash flooding can occur in perennial, intermittent and ephemeral streams in all ERUs, especially in large watersheds where short duration, high intensity storms occur. It is important to maintain native vegetation described in the Potential Plant Community of the TES to provide channel stability, functional riparian areas and good water quality for wildlife and aquatic species.

7. Fire Regime Condition Class and Associated Uncharacteristic High Intensity Fire: With the exclusion of wildfire throughout most ERUs during the 20th century fuel loading has increased in woodland and forest ERUs resulting in the risk of high burn severity and resulting accelerated erosion, loss of soil and vegetative productivity, and sediment transport to connected streams following wildfires in areas with moderate and high erosion hazard on the Forest. High levels of sediment can reduce fishery and aquatic habitat and those species that rely on it for their survival. Uncharacteristic wildfire has resulted in erosion rates well beyond tolerable levels.

8. Climate Change: In the Southwest, climate modelers agree there is a drying trend that will continue well into the latter part of the 21st century (IPCC 2007, Seager et al. 2007). The modelers predict increased precipitation, but believe that the overall balance between

precipitation and evaporation would still likely result in an overall decrease in available moisture. While the region is expected to dry out, it is likely to see larger, more destructive flooding. Forest ecosystems could face increased fire hazards and may be more susceptible to pests and diseases. Herbaceous cover is likely to die off in prolonged drought and leave larger areas devoid of ground cover creating an increased amount of bare soil. If storms do become more intense this coupled with a lack of ground cover will increase erosion resulting in unsatisfactory soil conditions.

Data Needs

- Soil classification has changed in some areas. One example is soils with Pergelic subgroups are now a separate soil order, Gelisols. An update to current soil taxonomy would benefit users.
- Soil condition has likely changed in some areas since the TES report was published. Large high severity fires have caused accelerated erosion to occur where tolerable soil loss rates have been greatly exceeded and has likely caused a loss in soil function. Revisit soil condition ratings for Santa Fe NF TES. Apply current direction for soil condition ratings specifically in areas of grazing, timber harvest, fire, and road construction and maintenance.
- Revisit soil loss rates for the Santa Fe NF TES. Use most current and accepted soil erosion models.
- Soil organic carbon sampling throughout ecosystems occurring on forest as identified in the TES.
- Conduct soil quality monitoring using Forest Service Southwestern Region technical guidance for assessing and monitoring soil quality.

Ecosystem Services

The report reviews information at landscape, watershed and eco-regional scales to explore the ability of area soils to continue offering a number of key regulating and supporting ecosystem services that are a required foundation to other, more direct human benefits. Key characteristics that indicate whether soils are functioning as needed include: soil loss rate, soil condition ratings, and erosion hazard ratings.

Soil condition ratings assess specific indicators such as (but not limited to) changes in surface structure and pore space, increases in bulk density, decreases in infiltration, and above- and below-ground biomass. Soil condition is an evaluation based on three primary soil functions; soil hydrology, soil stability, and nutrient cycling. Newer stressors such as altered fire regimes, nonnative species, and drought—coupled with historical unmanaged grazing and fuelwood gathering—have produced unnaturally dense overstories and sparse vegetative ground cover, leading to negative trends in some Ecological Response Units.

Two key *regulating* services provided by healthy soils are (a) water supply/release, including flood mitigation, and (b) maintenance of water quality. Satisfactory soil condition ratings indicate that water is infiltrating the soil, helping to mitigate large overland flows or floods downstream, as well as recharging groundwater. Soil condition, however, is trending away from reference condition on almost half of the Santa Fe NF, and listed as 'unsatisfactory' on 18 percent of the Forest. This trend also negatively impacts water quality as it decreases the ability of soil to filter contaminants and recycle or detoxify wastes in both surface and groundwater systems.

Other trends indicating potential risk to sustainable sediment retention services include high departures in fire regimes, and severe and moderate soil erosion hazard ratings on most of the Santa Fe NF. These factors can lead to accelerated erosion, downstream sedimentation and reduced filtering ability by the soil resources. Accelerated sedimentation and flooding have additional direct and indirect effects on local and area economics. These processes affect area reservoirs, requiring investment to clean out and maintain capacity. Accelerated erosion removes the most productive and nutrient-rich parts of the soil.

Properly functioning soil systems cycle nutrients, water and energy within forest and grassland ecosystems. Loss rates trending away from reference conditions in 6 out of 17 ERUs, coupled with the negative trends noted above, indicate negative impacts to this cycling service.

Soil's constantly changing quantity of solids, liquids, and gases create diverse habitats for various microorganisms which help cycle nutrients and energy. Soil contains invertebrates, fungi, and bacterial species that each has a special function in the ecosystem, such as food for larger organisms or acting as decomposers. They may also directly benefit humankind, as species are utilized to fix atmospheric nitrogen into plant available nitrogen, produce antibiotics (penicillin, streptomycin), provide for biological control of crop pests, and provide enzymes to bio-remediate contaminants. This micro-organism biodiversity service also contributes to genetic variation that offers adaptive resilience. Degraded soils provide less space for water necessary to plant growth and less habitat for burrowing animals (Comerford et al. 2013).

Soils support carbon sequestration, necessary for sustaining local ecosystems and species which evolved to existing climate conditions. Climate regulation is significant in the maintenance of many ecosystem organisms, especially those that are immobile. Regulation of greenhouse gases in the atmosphere is tied to this sequestration service.

Finally, high departures in current fire regimes, soil loss rates exceeding tolerable (6 of the 17 ERUs trending away), unsatisfactory soil conditions (8 of the 17 ERUs trending away), and severe erosion

hazard ratings across the forest (50 percent) would negatively affect soil's ability to offer physical support, i.e. for plants, animals, habitat and infrastructure, an often overlooked supporting service.

Soil-changing processes off-Forest, including state, county and private lands within the region, exist to a similar degree depending on current soil condition and management (past/current) of those lands.

Chapter 5. Air

Introduction

Air quality has long been recognized as an important resource on national forests. The public values the fresh air and sweeping views that national forests can provide. Poor air quality can also impact other values that the public cares aout such as forest health, water quality, and fisheries.

The 2012 Planning Rule requires national forests and grasslands to consider air quality when developing plan components. The purpose of the air quality assessment is to evaluate available information about air quality. This section assesses air quality on, and affecting, the Santa Fe National Forest. This assessment will describe the current conditions and trends regarding air quality in the plan area. This information will be used to anticipate future conditions and to determine if trends in air quality pose risks to system integrity at the forest level. Additionally, this assessment will identify information gaps regarding air quality and any uncertainty with the data. The information contained in this assessment will be used to inform agency officials, whether current direction needs adjustment to protect air resources and the systems that rely on air quality on the forest.[14]

Including in this assessment, the following components are identified, as specified by Forest Service Handbook, Chapter 10 Section 12.21 (USFS 2015):

- Airsheds relevant to the plan area
- Location and extent of known sensitive air quality areas, such as Class I areas, non-attainment areas, and air quality maintenance areas
- Emission inventories, conditions, and trends relevant to the plan area
- Federal, state, and tribal governmental agency implementation plans for regional haze, non-attainment, or maintenance areas (including assessing whether Forest Service emission estimates have been included in the appropriate agency implementation plans)
- Critical loads
- Conditions and trends of relevant airsheds assuming existing plan direction remains in place

Based on the above information, the assessment characterizes and evaluates the status of airsheds and air quality relevant to the plan area, assuming management is consistent with current plan direction.

In some cases, air quality resources on the forest are assessed differently from other resources in the ecological assessment, in that “reference conditions” are established by regulatory standards for ambient air quality that is deemed protective of human health, the environment, and visibility, which have been set by the U.S. Environmental Protection Agency (EPA) or the New Mexico Environment Department (NMED). However, for atmospheric deposition, particularly in the case of critical loads for acid deposition and nitrogen deposition, reference conditions are represented by established ecological

[14] For this assessment, the best available science was used that is relevant, accurate, and reliable. Uncertainty in the assessment has been appropriately documented where relevant. Government data that has met strict protocols for data collection was used to assess the current conditions and trends with regards to ambient air quality, visibility, emissions inventories, and deposition. The critical load information was based on multi-agency government research, analysis, and following Forest Service protocols.

thresholds, where an exceedance of these values could result in negative impacts to forest health and/or aquatic resources.

Identification of Airsheds

Airsheds are similar to watersheds, in that they are defined geographic areas that because of topography, meteorology, or climate, they are frequently affected by the same air mass. The difference with airsheds is that air masses and air pollutants move between airsheds mostly based upon larger meteorological patterns, rather than primarily by topography, as with water flowing through a watershed. As with watersheds, airsheds can be defined at multiple scales. For this assessment, airsheds were defined according to the classification used by the New Mexico Environment Department as well as looking at a larger scale including northern New Mexico and Southern Colorado.

Santa Fe NF is spread out across six counties in New Mexico and numerous airsheds. Figure 46 identifies the airsheds as classified by the New Mexico Environment Department, for the Smoke Management Program. Santa Fe NF is contained within Los Alamos, Mora, Rio Arriba, Sandoval, San Miguel, and Santa Fe counties. The Forest lies primarily within the Upper and Middle Rio Grande and Pecos airsheds but portions are also included in the Canadian airshed.

For the purpose of this assessment, the air quality and emissions will be limited to those counties in northern New Mexico and airsheds identified in figure 46, which may affect air resources on the Santa Fe NF.

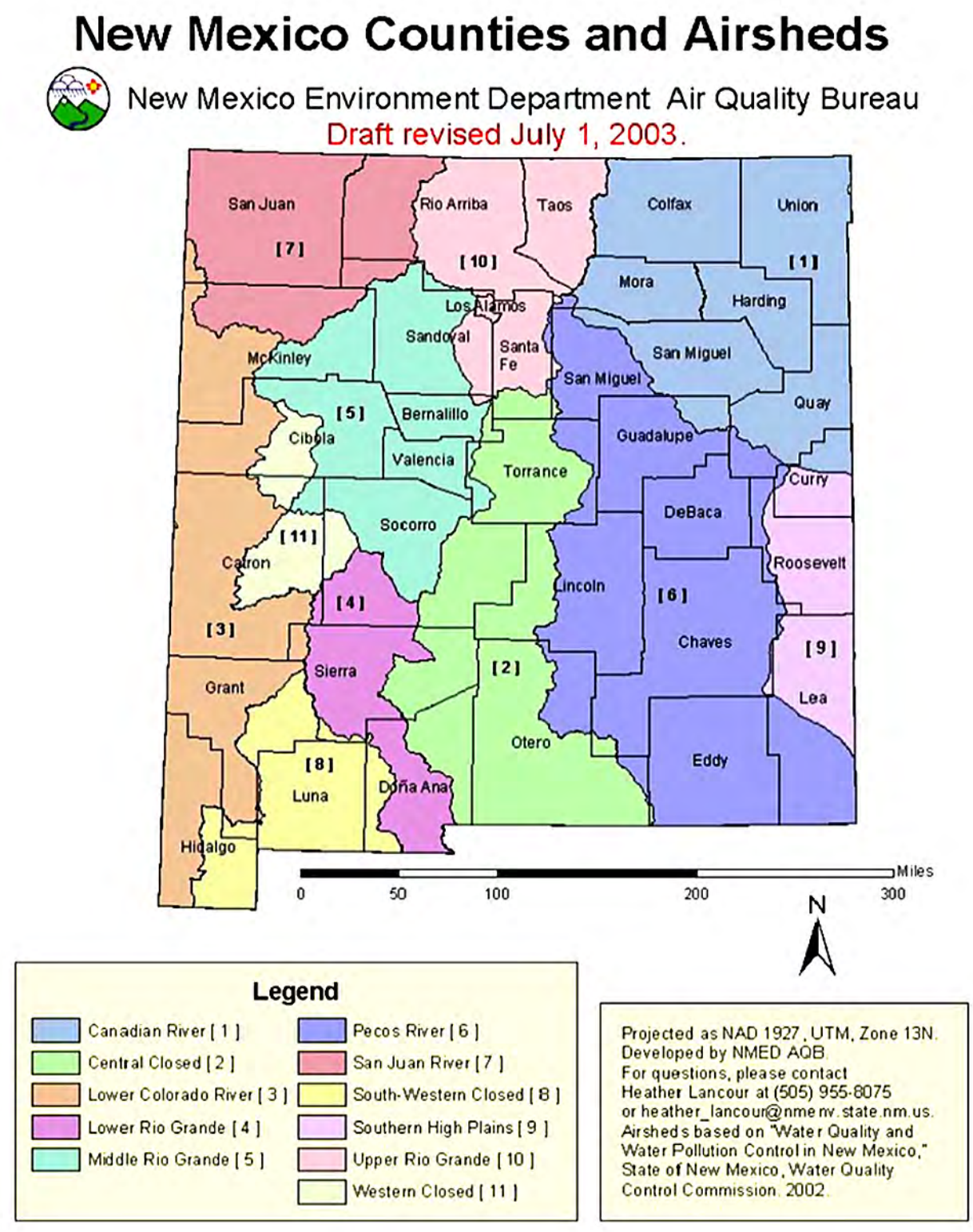


Figure 46. New Mexico counties and airsheds(NMED 2003)

Identification of sensitive air quality areas

The basic framework for controlling air pollutants in the United States is mandated by the Clean Air Act (CAA), originally adopted in 1963, and amended in 1970, 1977, and 1990. The CAA was designed to "protect and enhance" air quality. Section 160 of the CAA requires measures "to preserve, protect, and enhance the air quality in national parks, national wilderness areas, national monuments, national seashores, and other areas of special national or regional natural, recreation, scenic, or historic value."

Congress classified 158 areas as Class I areas, including national parks larger than 6,000 acres and national wilderness areas larger than 5,000 acres, in existence on August 7, 1977 (42 U.S.C. § 7472). Class I areas have been designated within the Clean Air Act as deserving the highest level of air-quality protection. These "mandatory" Class I areas may not be re-classified to a less protective classification. Santa Fe NF manages the Pecos and San Pedro Parks Wilderness Areas, both Class 1 areas. In addition, there are several nearby Class 1 areas that could be affected by projects and sources on or near the Santa Fe (figure 47). They include Wheeler Peak Wilderness managed by the Carson National Forest and Bandelier National Monument, managed by the National Park Service.

The purpose of the CAA is to protect and enhance air quality, while at the same time ensuring the protection of public health and welfare. The Act established National Ambient Air Quality Standards (NAAQS), which represent maximum air pollutant concentrations which would protect public health and welfare. The pollutants regulated by an NAAQS are called criteria air pollutants and include carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), sulfur dioxide (SO_2), lead (Pb), and particulate matter (PM_{10} and $PM_{2.5}$).

The U.S. Environmental Protection Agency (EPA) established NAAQS for specific pollutants considered harmful to public health and the environment. The Clean Air Act identifies two types of NAAQS:

1. The primary standards represent the maximum allowable atmospheric concentrations that may occur and still protect public health and welfare, and include a reasonable margin of safety to protect the more sensitive individuals in the population.

2. Secondary standards provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings.

State agencies are given primary responsibility for air quality management as it relates to public health and welfare, and are further responsible for developing their State Implementation Plans (SIPs) to identify how NAAQS compliance will be achieved. If an area in a state has air quality worse than the NAAQS, that area becomes a non-attainment area. The state is then required to develop an SIP to improve air quality in that area. Once a non-attainment area meets the standards and that area can be designated as a maintenance area.

State standards, established by the New Mexico Environmental Improvement Board (EIB) and enforced by the New Mexico Environment Department, Air Quality Bureau (NMED-AQB), are termed the New Mexico Ambient Air Quality Standards (NMAAQS). The NMAAQS must be at least as restrictive as the National Ambient Air Quality Standards (NAAQS). NMAAQS also includes standards for total suspended particulate matter (TSP), hydrogen sulfide, and total reduced sulfur for which there are no National standards. Table 62 presents the national and state ambient air quality standards.

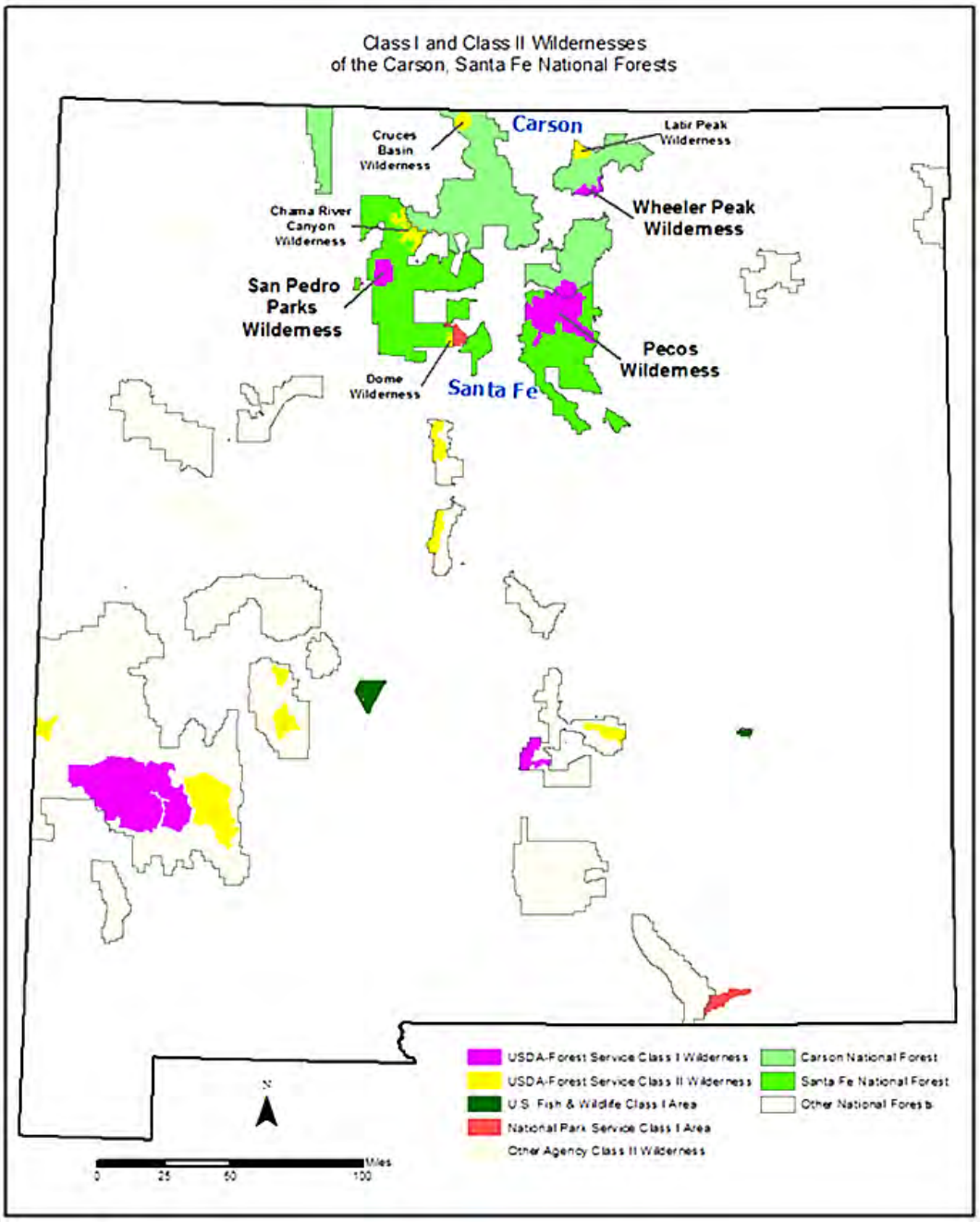


Figure 47. Class I and Sensitive Class II Areas in New Mexico

Table 62. National and New Mexico ambient air quality standards

Pollutant	Averaging Time	New Mexico Standards	National Standards[a] Primary[b,c]	National Standards[a] Secondary[b,d]
Ozone	8-hour	—	0.075 ppm	Same as primary
Carbon monoxide	8-hour	8.7 ppm	9 ppm	—
	1-hour	13.1 ppm	35 ppm	—
Nitrogen dioxide	Annual	0.05 ppm	0.053 ppm	Same as primary
	24-hour	0.10 ppm	—	—
	1-hour		0.1 ppm	—
Sulfur dioxide	Annual	0.02 ppm	—	—
	24-hour	0.10 ppm	—	—
	3-hour	—	—	0.5 ppm
	1-hour		0.75 ppm	—
Hydrogen sulfide	1-hour	0.010 ppm	—	—
Total Reduced Sulfur	½-hour	0.003 ppm	—	—
PM_{10}	24-hour	Same as Federal	150 µg/m^3	Same as primary
$PM_{2.5}$	Annual (arithmetic mean)	Same as Federal	12 µg/m^3	15 µg/m^3
	24-hour	Same as Federal	35 µg/m^3	Same as primary
Total Suspended Particulates (TSP)	Annual (geometric mean)	60 µg/m^3	—	—
	30-day Average	90 µg/m^3	—	—
	7-day	110 µg/m^3	—	—
	24-hour	150 µg/m^3	—	—
Lead	Quarterly Average	—	1.5 µg/m^3	Same as primary

Notes:

(a) Standards other than the 1-hour ozone, 24-hour PM_{10}, and those based on annual averages are not to be exceeded more than once a year.

(b) To attain the 8-hour ozone standard, the 3-year average of the fourth-highest daily maximum 8-hour average ozone concentrations measured at each monitor within an area over each year must not exceed 0.075 ppm.

(c) Concentrations are expressed in units in which they were promulgated. µg/m^3 = micrograms per cubic meter and ppm = parts per million. Units shown as µg/m3 are based upon a reference temperature of 25oC and a reference pressure of 760 mm of mercury.

(d) Primary Standards: The levels of air quality necessary, with an adequate margin of safety to protect the public health.

(e) Secondary Standards: The levels of air quality necessary to protect the public welfare from any known or anticipated adverse effects of a pollutant.

Averaging Time: the amount of time that the associated data is averaged to assess compliance with the standard.

µg/m3 = micrograms per cubic meter; ppm = parts per million

The New Mexico Environment Department – Air Quality Bureau (NMED-AQB) enforces air pollution regulations and sets guidelines to attain and maintain the national and state ambient air quality standards within the state of New Mexico, except for tribal lands and Bernalillo County which maintain separate jurisdictions.

At the present time, the plan area attains all national and New Mexico ambient air quality standards.

Federal, State, and Tribal State Implementation Plans

As stated previously, the federal Clean Air Act (CAA) provides the basic framework for controlling air pollution, but the states are primarily responsible for implementing and enforcing CAA requirements. Within this framework, there are a couple tools particularly relevant to protecting air quality related to national forests. Typically, air pollution that occurs off national forests is the primary concern for causing impacts on national forests. Pollution can result from either new or existing sources.

The primary tool for addressing air quality impacts from new sources is the Prevention of Significant Deterioration (PSD) program. The 1977 CAA amendments established the PSD program to preserve the clean air usually found in pristine areas, while allowing controlled economic growth. The PSD permitting program applies to new, major sources of air pollution or modifications to existing major sources which have the potential to emit certain amounts of air pollution regulated by the Environmental Protection Agency (EPA). The purpose of the PSD program is to prevent violations of NAAQS and to protect the environment including visibility and air quality is pristine areas such as Class 1 wilderness areas managed by the Forest Service. The PSD program can apply to non-criteria pollutants and can require analyses to assess the impacts of pollution on soils, vegetation, visibility and water resources managed by the Forest Service.

For existing sources of air pollution, the Federal Regional Haze Rule (RHR) requires states to develop programs to assure reasonable progress toward meeting the national goal of preventing any future, and remedying any existing, impairment of visibility in mandatory Class I Federal areas. The RHR addresses requirements for SIPs, plan revisions, and periodic progress reviews to address regional haze and achieve natural haze conditions in each of the Class I areas by the year 2064.

Regional Haze Rule, 40 CFR 51.308 and 40 CFR 51.309

On July 1, 1999, the Environmental Protection Agency (EPA) issued regional haze rules to comply with requirements of the Clean Air Act. Under 40 CFR 51.308, the rule requires the state of New Mexico to develop SIPs which include visibility progress goals for each of the nine Class I areas in New Mexico, as well as provisions requiring continuing consultation between the state and Federal Land Managers to address and coordinate implementation of visibility protection programs. Under 40 CFR 51.309, the rule also provides an optional approach to New Mexico and eight other western states to incorporate emission reduction strategies issued by the Grand Canyon Visibility Transport Commission (GCVTC) designed primarily to improve visibility in 16 Class I areas on the Colorado Plateau, including the San Pedro Parks Wilderness Area on the Santa Fe in New Mexico.

New Mexico Environmental Department-State Implementation Plan

On December 31, 2003, the State of New Mexico submitted a visibility SIP to meet the requirements of 40 CFR 51.309. The 2003 309 SIP and subsequent revisions to the 309 SIP, address the first phase of requirements, with an emphasis on stationary source sulfur dioxide (SO_2) emission reductions and a focus

on improving visibility on the Colorado Plateau. In the 2003 submittal, New Mexico committed to addressing the next phase of visibility requirements and additional visibility improvement in New Mexico's remaining eight Class I areas by means of an SIP meeting the requirements in 309(g). The regional haze SIP describes the Class I areas where visibility protections are in place, monitors existing visibility conditions and trends, defines the cause in terms of source emissions of visibility impairment at each Class I area, projects future trends in visibility conditions based on implementation of various emission control measures, and provides a long-term strategy to meet the stated national visibility goal of reducing all man-made visibility impairment by 2064.

Since the 2003 submittal of the 309 SIP, the EPA has revised both 40 CFR 51.308 and 309 in response to numerous judicial challenges. The latest SIP petition was filed by the New Mexico Environmental Department on June 29, 2011 (NMED 2011).The June 2011 revision was made to satisfy New Mexico's obligations under the "Good Neighbor" provision of the CAA at §110(a)(2)(D)(i). Since then, New Mexico has made revisions to update the Best Available Retrofit Technology (BART) determination and proposed reductions for the San Juan Generating Station to achieve visibility reductions relied upon by other states in setting their visibility goals (NMED 2013). This latest revision reflects and agreement between New Mexico, San Juan Generating Station and the U.S. EPA (USEPA 2013). The agreement will shut down two of the plant's coal fired units and install selective non-catalytic reduction technology on the remaining two coal fired units. The two units being shut down will be replaced by less polluting natural gas-fueled units.

Grand Canyon Visibility Transport Commission – 1996 Findings and Recommendations

In 1990, amendments to the Clean Air Act under 40 CFR 51.309 established the Grand Canyon Visibility Transport Commission to advise the EPA on strategies for protecting visual air quality on the Colorado Plateau. The GCVTC released its final report in 1996 and initiated the WRAP, a partnership of state, tribal and federal land management agencies to help coordinate implementation of the Commission's recommendations(WRAP 1996). Issues addressed by the GCVTC and WRAP are summarized below:

- Air pollution prevention
- Clean air corridors
- Stationary sources
- Areas in and near parks and wilderness areas
- Mobile sources
- Road dust
- Emissions from Mexico
- Fire

Forest Service Policy and Actions

Regional Forest Service Air Resource Management (ARM) staff act as the point of contact to receive and review permit applications filed with state and local regulatory agencies by new/modified emission sources and provide comments back to the state agency. Unless a specific issue arises, individual national forests are typically not responsible for conducting reviews of new/modified sources via the state-level air

quality applications process. The Forest Service regional office provides air quality analysis to determine if proposed actions are likely to cause, or significantly contribute to, an adverse impact to visibility or other air quality related values within the national forest system.

Additionally, the Forest Service complies with the New Mexico State Smoke Management Programs (SMP), which is described in New Mexico Section 309(g) Regional Haze SIP (NMED 2011). New Mexico's administrative code (NMED 2003)(20.2.65 NMAC-Smoke Management) stipulates that all burners must comply with requirements of the Clean Air Act and Federal Regional Haze Rule (RHR), as well as all city and county ordinances relating to smoke management and vegetative burning practices. For prescribed fires and wildfires managed for multiple objectives that exceed 10 acres, additional requirements include: registering the burn, notifying state and nearby population centers of burn date(s), visual tracking, and post-fire activity reports (NMED 2003) (20.2.65 NMAC-Smoke Management).

As indicated previously, the Forest Service typically lacks direct authority to control air emissions that impact a particular ranger district of the Santa Fe. The primary role that Air Resource Management (ARM) staff can provide the New Mexico Environmental Department (NMED) staff as they prepare Prevention of Significant Deterioration (PSD) permits or develop the Federal Regional Haze Rule (RHR), is to provide information about potential impacts that could occur on national forest land, particularly in Class I areas. Ultimately, the Forest Service can dispute the terms of a permit if analyses demonstrate that unacceptable impacts could occur on Forest Service managed Class I Areas and sensitive Class II areas.

The primary tool Federal land managers use is the critical load concept described in the next section on atmospheric deposition. Currently the Santa Fe NF has critical loads based on a national assessment developing empirical critical loads for major ecoregions across the United States. However, there are no forest-specific critical loads developed for the Santa Fe NF, and therefore, they have not been included in the New Mexico SIP.

Emissions Inventories, including current conditions and trends

This section presents current and historical data related to air quality in or near the Santa Fe NF. This data and any relevant trends in the data provide an understanding of the air quality conditions that could affect resources on the forest sensitive to air pollution. Included are a general description of baseline emissions inventories, ambient air quality measurements, visibility, and deposition measurements for sulfur, nitrogen, and mercury that define current air quality conditions of the plan area. Data are presented for the following parameters:

- Emission Inventory
- Ambient Air Quality
- Visibility
- Atmospheric Deposition (Acid Deposition and Mercury Deposition)

For emissions, the information presented in this section represents statewide totals for New Mexico. County-level emissions inventories were analyzed and can be found on the Western Regional Air Partnership (WRAP) website, using the Technical Support System tool (WRAP 2015). Emissions inventories are useful tools for understanding regional sources of pollution that could affect the forest. Emissions inventories are created by quantifying the amount of pollution that comes from point sources (power plants, factories) and area sources (emissions from automobiles in a city or oil and gas development). Emissions can also originate from natural events like a wildfire.

The Western Regional Air Partnership is a voluntary partnership of states, tribes, federal land managers and the EPA. It tracks emissions data from states, tribes, and local air agencies, as well as emissions from wildland fire, in coordination with the EPA's National Emission Inventory (NEI). In addition, WRAP supports states by analyzing this data and models what future emissions maybe based on future trends, as part of the Regional Haze Rule. The Regional Haze Rule sets a 60-year timeline for states to improve visibility within mandatory federal Class I areas from baseline (2000 to 2004) levels to natural conditions by 2064. States are required to show that reasonable progress is expected to be made toward this goal over the course of intermediary planning periods.

A summary of baseline emissions and projected emissions for 2018 for the state of New Mexico and the counties within 300 km of the Santa Fe were analyzed (WRAP 2015). The following pollutants were included in the summary: carbon monoxide, nitrogen oxides, sulfur oxides, volatile organic compounds (VOCs), coarse particulate matter (surrogate for PM_{10}), and fine particulate matter (surrogate for $PM_{2.5}$). Nitrogen oxides and VOCs were included since they are precursors to the formation of ozone, which has both effects to human health but also has been shown to impact forested systems.

Emissions information is important, as adverse air quality impacts on the Santa Fe can usually be traced to air emissions. Knowing the magnitude of emissions and recognizing trends in emissions over time is important because emissions are usually correlated to the type and severity of air quality impacts. Often, adverse air quality impacts to air quality related values can be mitigated through programs that reduce associated air emissions. However, the Forest Service typically lacks direct authority to control air emissions that impact a particular ranger district.

While emissions play an important role in determining overall air quality for a given area, air quality evaluations are also based, in part, on ambient concentrations of pollutants in the air. The EPA is primarily concerned with air pollutants that result in adverse health effects. The Forest Service also uses these ambient concentrations to determine how pollutants such as ozone (O_3), particulate matter (PM), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) impact forest resources. Because ambient air quality measurements provide quantitative information, they can also be meaningfully incorporated into air quality models. Ambient air quality data are presented in this section for a number of state, and federal monitoring stations in and around the air quality monitoring plan area.

Visibility data are presented for stations operated as part of the Interagency Monitoring of Protected Visual Environments (IMPROVE) monitoring program sponsored by the EPA and other government agencies (FED 2015). Visibility generally relates to the quality of visitors' visual experience on the forest and has been recognized as an important air quality related value in Class I wilderness areas dating back to the 1977 Clean Air Act Amendments. Generally, the presence of air pollution degrades the visual quality of a particular scene. In the Clean Air Act, a national visibility goal was established to return visibility to "natural background" conditions no later than 2064. IMPROVE monitoring data tracks the quality of visibility conditions and trends in visibility data and are specific to the wilderness areas of interest.

Deposition data are presented from the National Atmospheric Deposition Program (NADP) (NADP 2013). Deposition generally arises from the transformation in the atmosphere of air pollution to acidic chemical compounds (e.g., sulfuric acid, nitric acid), a portion of which are deposited into forested ecosystems. Excessive deposition may lead to adverse effects on ecosystems and on other resources (e.g., cultural). Acid deposition can lead to changes in the pH of stream runoff and adverse effects on aquatic species. Also, acidic depositions can accumulate in the wintertime snowpack. Research has demonstrated that when portions of the snowpack with high acid concentrations melt during spring thaw, the acids are often released as an acute pulse. The sudden influx of acid can alter the pH of high altitude lakes and streams for short periods, with dramatic consequences for respective aquatic communities.

Lastly, excessive nitrogen deposition can "over-fertilize" sensitive ecosystems, thereby promoting unnatural eruptions of native and nonnative plant species, invasions by noxious species and altering long-term patterns of nutrient cycling. National Atmospheric Deposition Program monitoring data collected in the plan area were chosen to best characterize these conditions in the wilderness areas of interest.

Where available, data on mercury deposition are also presented. Mercury is a neurotoxin which accumulates in plant and animal tissue, especially within the aquatic food chain. As birds, mammals, and humans consume fish and other aquatic organisms, the accumulated mercury is passed on to those species as well. Within human populations, mercury exposure is of particular concerns to pregnant women, as mercury can pass through the placenta to developing fetuses. Low-level mercury exposure is also linked to learning disabilities in children and interferes with the reproductive cycle in mammals that consume fish.

Emissions Inventory

Air quality effects on national forests are generally traceable back to the original source of emissions; therefore, air emissions information provides an overview of the magnitude of air pollution and is important in understanding air quality on the forest. Also, trends in precursor emissions would be expected to track with trends on the forest, e.g., visibility, acid deposition, etc. For example, improving visibility conditions in Class I areas would generally be associated with corresponding decreases in emissions for visibility precursor pollutants.

Emissions information is generally tracked for pollutants that have health-based air quality standards such as carbon monoxide (CO), nitrogen oxides (NOx), sulfur dioxide (SO_2), volatile organic compounds (VOCs), and particulate matter (PM). Volatile organic compounds emissions do not have a health-based standard, but are involved in the atmospheric chemical reactions that lead to ozone (O_3), which does. Ozone pollution is of added concern, because it can stress sensitive ecological systems. Particulate matter emissions are generally broken into two categories based on the size of the PM emissions: Fine PM (FPM) represents the particulate matter emissions sized at or below 2.5 microns in diameter. Coarse PM (CPM) represents the particulate matter emissions sized at or below 10 microns, but above 2.5 microns, in diameter. Smaller sized particles have greater health-related impacts because the smaller particles are more easily inhaled into the lungs.

Figure 48, figure 49, and figure 50 show air emissions for the state of New Mexico for the criteria air pollutants of interest: CO, NOx, SO_2, VOC, CPM, and FPM.[15] Fine particulate matter (FPM) is analogous to $PM_{2.5}$ and course PM represents the PM_{10} emissions that are not $PM_{2.5}$. Each figure also depicts the relative magnitude of emissions from various source categories, such as mobile sources (vehicle exhaust), point sources (industrial and commercial operations), fire, biogenic sources etc. These figures represent statewide emissions for the baseline period (2000 to 2004) along with projected emissions for the 2018 time frame, based on information at the end of 2005. Since that time, additional regulations have been passed which should continue to reduce emissions. All of the emissions information in these figures has been taken from the WRAP Technical Support System (WRAP 2015).

For CO, and NOx the trend shows a projected decrease in statewide emissions through 2018 for New Mexico. Most of the emissions reductions for CO and NOx emissions come from fewer mobile source

[15] Products obtained from WRAP TSS Emissions Review Tool http://vista.cira.colostate.edu/TSS/Results/HazePlanning.aspx Plan02d data represent the 5-year baseline average period. PRP18b data represent WRAP's Preliminary Reasonable Progress Inventory. Blank entries represent instances where data categories are not applicable or data are not available.

emissions and are associated with the introduction of lower emitting vehicles over time, cleaner transportation fuels, and improvements in vehicle gas mileage.

SO_2 emissions are expected to generally decrease except for area emissions in New Mexico, which are expected to increase significantly. The general improvement over time is largely from reductions in stationary source emissions, such as coal-fired power plants, which are expected, in the near term, to install emission controls defined as Best Available Retrofit Technology (BART) under the regional haze regulations. Some of the decrease in SO_2 emissions occurs from mobile sources and is associated with cleaner transportation fuels, such as the introduction of low sulfur diesel fuel.

The expected increase in oil and gas industry activity through 2018 increases emissions of NOx and SO_2, which offsets some of the emissions decreases described above, particularly in the Four Corners Area including increases in emissions in New Mexico.

The VOC emissions in New Mexico are dominated by biogenic emission sources, (i.e., trees, agricultural crops, and microbial activity in soils). Overall VOC emissions are projected to remain fairly stable through 2018, with some increases projected from oil and gas industrial activity.

Particulate emissions, both CPM and FPM, are expected to increase across New Mexico through 2018, consistent with the projected population growth in the state. Higher population translates to more vehicular traffic and the projected particulate emission increases generally occur in the “fugitive dust” and “road dust” categories.

Data analyzed using the WRAP TSS Emissions Review Tool shows similar emissions information for the pollutants of interest on a county-by-county basis(WRAP 2015). The analysis consisted of review of counties in northern New Mexico. County-by-county distribution of emissions mostly follows the distribution of population across the counties of interest.

Particulate matter (PM) and VOCs are all expected to increase or stay stable at state and county levels through 2018 in New Mexico. The primary source of PM, both coarse and fine, is from windblown dust across the land and from fugitive dust from anthropogenic sources. Higher temperatures and persistent drought could exacerbate this trend (Prospero and Lamb 2003). At the state level, VOCs are expected to increase primarily from oil and gas development in the Four Corners area. Biogenic sources of VOCs are a major source relative to the overall emissions in New Mexico and in the counties where the Santa Fe is located.

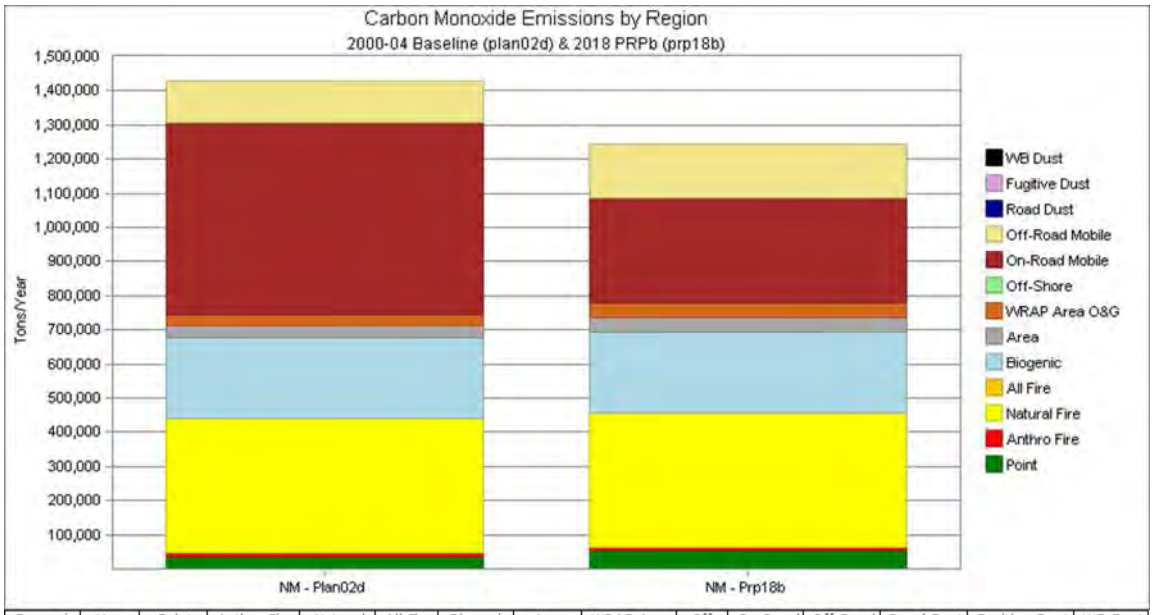
San Juan County shows significant contributions to the NOx and SO_2 emissions inventories from point source emissions. These data reflect the large coal-fired electric generating stations in that county (San Juan Generation Station and Four Corners Generating Station).

Also Rio Arriba County and San Juan County, in New Mexico show significant emissions from oil and gas development in that particular region of the state. The oil and gas industry emissions are important for SO_2, NOx and VOCs and to a lesser extent, CO emissions. In the absence of oil and gas industry sources, biogenic emissions make up most of the VOC inventory in each county. Fire was also shown as a significant contributor to the CO emissions inventory in Rio Arriba County and San Juan County.

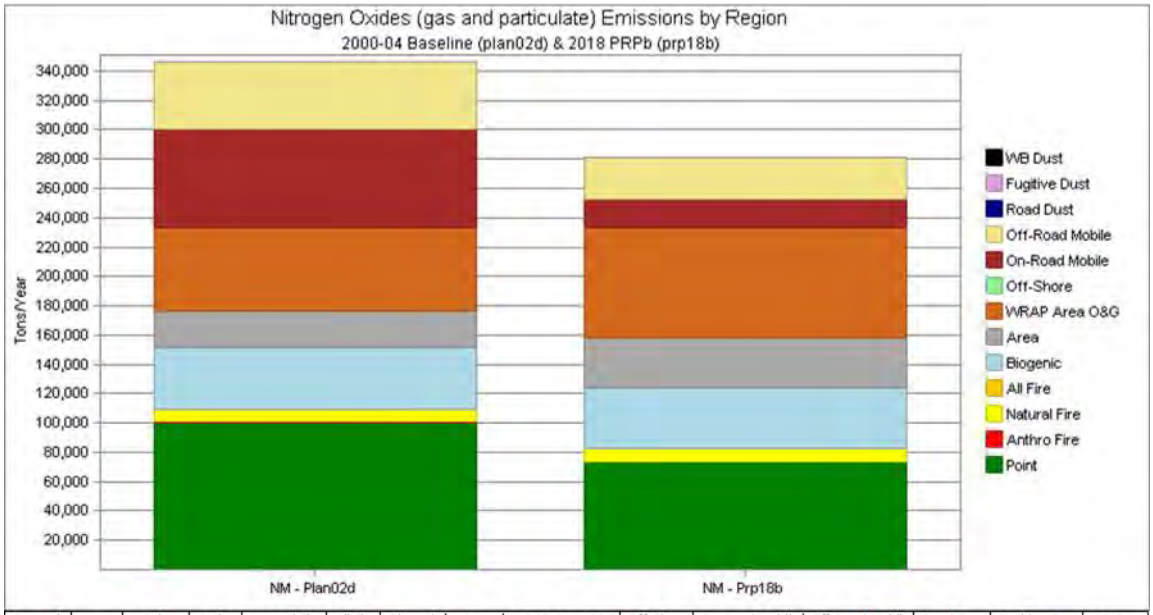
Except where the industrial emissions noted above dominate, the county-by-county distribution of emissions mostly follows the distribution of population across the counties of interest.

The county-by-county emissions trends through 2018 generally share the patterns described above for the statewide inventory trends. However, in those counties where oil and gas industry sources are significant, the downward trend of emissions noted in the state The county-by-county emissions trends through 2018

generally share the patterns described above for the statewide inventory trends. However, in those counties where oil and gas industry sources are significant, the downward trend of emissions noted in the statewide data is offset somewhat by the increased level of local oil and gas development and associated emissions.

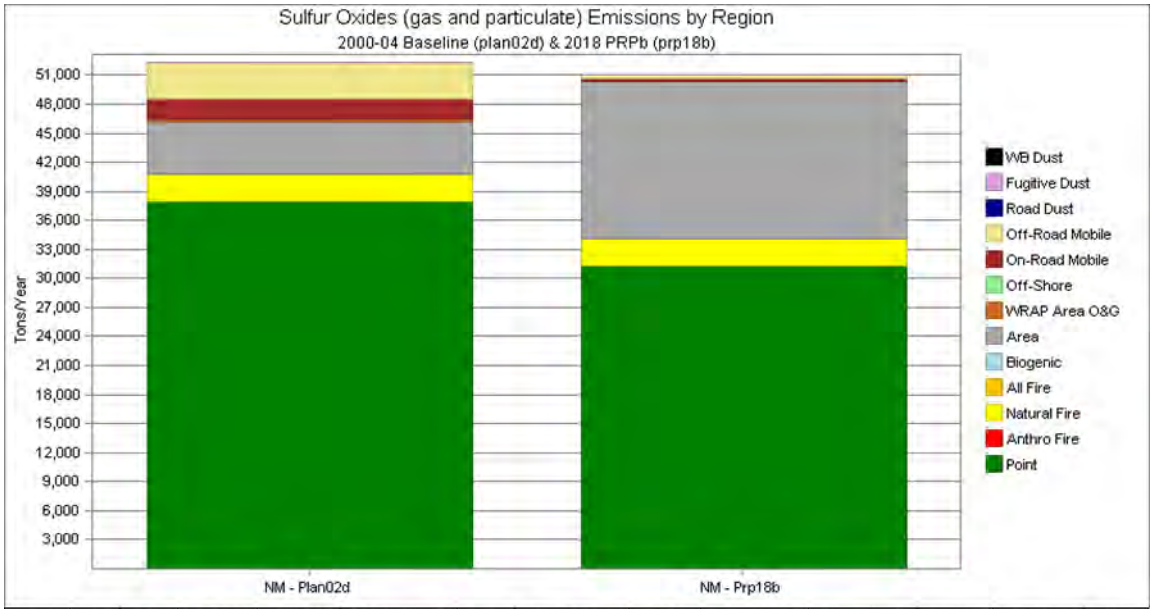


Scenario	Year	Point	Anthro Fire	Natural Fire	All Fire	Biogenic	Area	WRAP Area O&G	Off-Shore	On-Road Mobile	Off-Road Mobile	Road Dust	Fugitive Dust	WB Dust
Plan02d	2,002	36,589	9,937	393,865		238,478	34,426	31,628		561,611	124,063			
Prp18a	2,018	57,376	6,349	393,855		238,478	41,942	44,011		308,010	153,865			

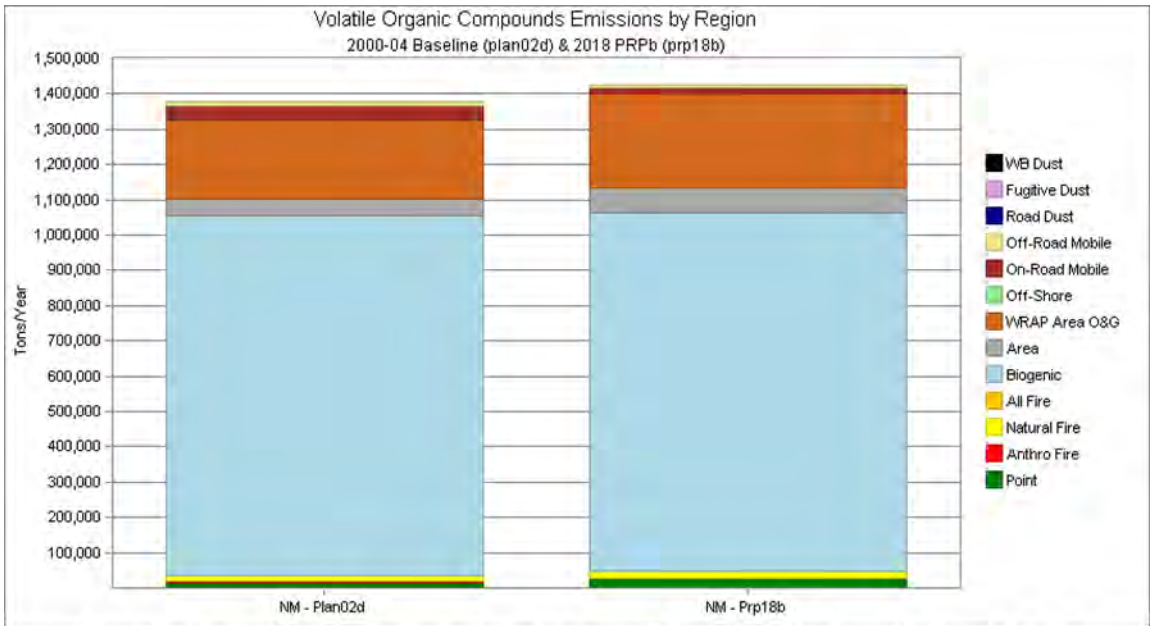


Scenario	Year	Point	Anthro Fire	Natural Fire	All Fire	Biogenic	Area	WRAP Area O&G	Off-Shore	On-Road Mobile	Off-Road Mobile	Road Dust	Fugitive Dust	WB Dust
Plan02d	2,002	100,387	394	8,570		42,139	25,130	56,210		67,835	45,311			
Prp18a	2,018	74,600	262	8,570		42,139	33,768	74,648		19,746	33,175			

Figure 48. New Mexico 2002 baseline and projected 2018 emission summaries, carbon monoxide (top) and nitrogen oxides (bottom)

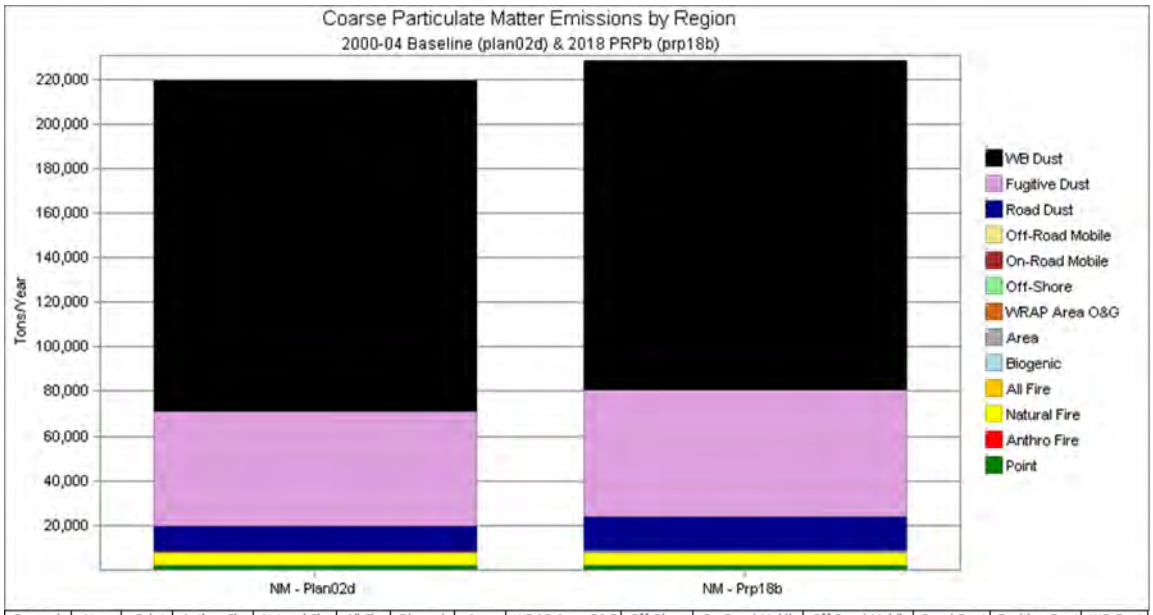


Scenario	Year	Point	Anthro Fire	Natural Fire	All Fire	Biogenic	Area	WRAP Area O&G	Off-Shore	On-Road Mobile	Off-Road Mobile	Road Dust	Fugitive Dust	WB Dust
Plan02d	2,002	37,918	94	2,729			5,433	250		2,066	3,846	4	6	
Prp18a	2,018	32,634	72	2,729			16,255	12		334	356	6	7	

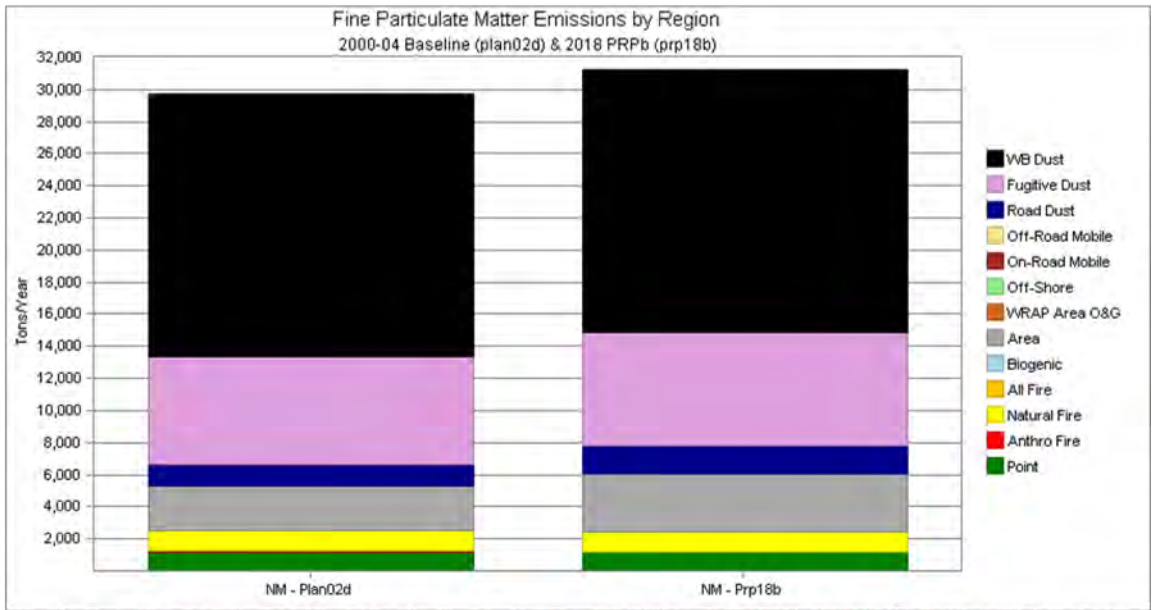


Scenario	Year	Point	Anthro Fire	Natural Fire	All Fire	Biogenic	Area	WRAP Area O&G	Off-Shore	On-Road Mobile	Off-Road Mobile	Road Dust	Fugitive Dust	WB Dust
Plan02d	2,002	17,574	608	18,846		1,016,487	49,010	224,268		38,768	13,850			
Prp18a	2,018	26,187	388	18,846		1,016,487	70,556	267,846		15,554	9,463			

Figure 49. New Mexico 2002 baseline and projected 2018 emission summaries, sulfur oxides (top) and volatile organic compounds (bottom)



Scenario	Year	Point	Anthro Fire	Natural Fire	All Fire	Biogenic	Area	WRAP Area O&G	Off-Shore	On-Road Mobile	Off-Road Mobile	Road Dust	Fugitive Dust	WB Dust
Plan02d	2,002	2,286	105	5,400			695			403		11,074	51,533	147,589
Prp18a	2,018	1,944	63	5,400			1,231			464		14,857	56,533	147,589



Scenario	Year	Point	Anthro Fire	Natural Fire	All Fire	Biogenic	Area	WRAP Area O&G	Off-Shore	On-Road Mobile	Off-Road Mobile	Road Dust	Fugitive Dust	WB Dust
Plan02d	2,002	1,180	87	1,223			2,821					1,305	6,751	16,399
Prp18a	2,018	1,144	44	1,223			3,644					1,751	7,026	16,399

Figure 50. New Mexico 2002 baseline and projected 2018 emission summaries, coarse particulate mass (top) and fine particulate mass (bottom)

Ambient Air Quality Measurements

This section summarizes the ambient air quality measurements collected between the years 2000 and 2010 at New Mexico monitoring sites in and near the Santa Fe NF. These monitoring data depict concentrations of air pollutants which have the potential to cause adverse health effects in the general population and/or adverse ecological effects. Additional discussion about the health and ecological effects of individual pollutants is provided below.

Figure 51 shows the location of the air quality monitoring sites that are relevant to the plan area. There are a variety of air monitoring stations throughout New Mexico that are operated by the state, Bernalillo County, the Navajo Nation, and by federal land management agencies that can be used to gauge ambient air quality, visibility, and deposition of pollutants. A summary of the pollutants monitored and available period of record for each site is provided in table 62. The visibility monitoring data are described in the next section.

For the Santa Fe NF, most of the nearby ambient air quality monitoring stations are located in the greater Albuquerque and Santa Fe metropolitan areas. Although air quality levels in an urban area are not likely to be totally representative of the Forest, these data do provide for a reasonable upper bound on air quality concentrations within the plan area. Lacking other data collected in more remote settings, the reported data are the best available information to characterize exiting air quality conditions for the wilderness areas of concern.

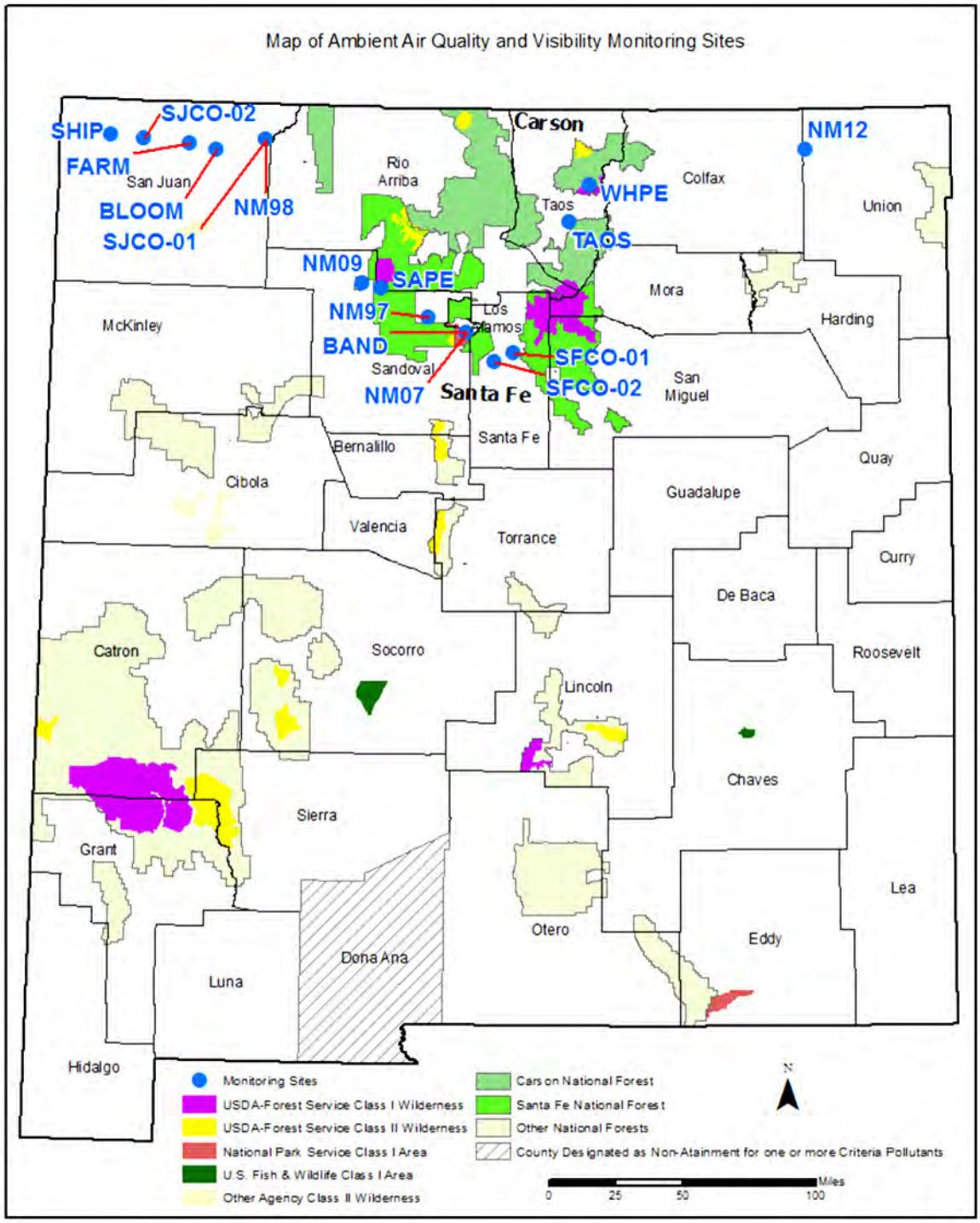


Figure 51. Map of air quality monitoring sites in the plan area

Table 63. Air quality monitoring sites for the Santa Fe NF

Monitoring Site	Site Label	Pollutants Monitored (review period)*
Bandelier	NM07	NADP/NTN (2000-2010)
Bandelier National Monument	BAND	IMPROVE Aerosol, dv (2000-2010)
Bloomfield – Highway Yard	BLOOM	O_3 (2000-2010), NO_2 (2000-2010), SO_2 (2000-2010)
Capulin Volcano	NM12	NADP/NTN (2000-2010)
Cuba	NM09	NADP/NTN (2000)
Farmington	FARM	$PM_{2.5}$ (2008-2010), PM_{10} (2008-2010)
Navajo Lake	NM98	MDN (2009-2010)
San Juan County #1	SJCO-01	O_3 (2006-2010), NO_2 (2005-2010)
San Juan County #2	SJCO-02	O_3 (2000-2010), NO_2 (2000-2010), SO_2 (2000-2010)
San Pedro Parks	SAPE	IMPROVE Aerosol, dv (2001-2010)
Santa Fe County #1	SFCO-01	$PM_{2.5}$ (2000-2010), PM_{10} (2000-2010)
Santa Fe County #2	SFCO-01	O_3 (2007-2010)
Shiprock	SHIP	O_3 (2010), NO_2 (2010), SO_2 (2010), PM_{10} (2007-2010)
Taos County	TAOS	PM_{10} (2000-2010)
Valles Caldera National Preserve	NM97	MDN (2009-2010)
Wheeler Peak	WHPE	IMPROVE Aerosol, dv (2001-2010)

*For the purposes of this assessment, only measurements collected between 2000 and forward were reviewed (dv=deciview).

Table 62 lists the current primary National Ambient Air Quality Standards (NAAQS), which represent ambient concentrations of air pollutants determined by the EPA to result in adverse health effects to the most sensitive population groups, such as: children, the elderly, and persons with breathing difficulties. The health effects of air pollution are discussed further in the subsequent sections that describe specifics of monitoring data for each pollutant.

Carbon Monoxide (CO) Concentrations

Carbon monoxide (CO) data has not been collected in the airsheds containing the Santa Fe NF. Generally, CO emissions are caused by exhaust from fuel combustion in mobile sources (cars, trucks, etc.) and as such are generally monitored only in large urban settings, like Albuquerque. CO is not expected to be an issue in areas containing or near the Santa Fe NF.

Ozone (O_3) Concentrations

Ozone (O_3) data have been collected at five sites near the Santa Fe. However, some of the monitoring has only recently commenced. The Shiprock site has O_3 data only for 2010, the Santa Fe #2 site has O_3 data starting in 2007, and the San Juan #2 site has O_3 data starting in 2006 (USEPA 2015).Ozone (O_3) is one of the major constituents of photochemical smog. It is not emitted directly into the atmosphere, but instead is formed by the reaction between nitrogen oxide (NOx) emissions and volatile organic compounds (VOCs) emissions in the presence of sunlight. The highest concentrations of O_3 typically occur in the summer months.

Excessive O_3 concentrations can have a detrimental impact on human health and the environment. Elevated O_3 levels can cause breathing problems, trigger asthma, reduce lung function, and lead to increased occurrence of lung disease. Ozone (O_3) also has potentially harmful effects on vegetation, which is usually the principal threat to forested ecosystems. It can enter plants through leaf stomata and

oxidize tissue, causing the plant to expend energy to detoxify and repair itself at the expense of added growth. Damage to plant tissue can be more pronounced where the detoxification and repair does not keep up with the O_3 exposure. The mesophyll cells under the upper epidermis of leaves are particularly sensitive to O_3. Ozone (O_3) damage can generate a visible lesion on the upper side of a leaf, termed "oxidant stipple." Other symptoms of elevated O_3 exposure may include chlorosis, premature senescence, and reduced growth. These symptoms are not unique to ozone damage and may also occur from other stresses on plant communities such as disease and/or insect damage.

Data representing the 4th highest 8-hour average O_3 concentrations for calendar years 2000 to 2010 for the Bloomfield, San Juan #1, San Juan #2, Shiprock, and Santa Fe #2 monitoring stations were analyzed (WRAP 2015). The applicable 8-hour National Ambient Air Quality Standards (NAAQS) is based on the annual fourth-highest daily maximum O_3 concentration averaged over three years. At some New Mexico monitoring sites, the annual 4th highest concentration is at or near the NAAQS level (75 ppb). However, in the last three years, the 75 ppb level has not been exceeded based on the 4th highest 8-hour average O_3 concentration. Note that given the form of the O_3 NAAQS, data analyzed does not allow for a strict comparison to the NAAQS as the data have not been averaged over three years as required for comparison to the NAAQS. However, it would appear that O_3 concentrations are below the applicable NAAQS although the margin of compliance is small. It should also be noted that the EPA has proposed lowering the standard to between 65 and 70 ppb O_3, with an expected final decision by October 1, 2015 (USEPA 2014).

Particulate Matter - $PM_{2.5}$/PM_{10}

$PM_{2.5}$ data are currently available from two monitoring sites near the forest areas of interest (Farmington and Santa Fe #1). The Farmington site has $PM_{2.5}$ data going back to 2000 while Farmington has $PM_{2.5}$ data only for 2008-10. For PM_{10}, data are available for up to four sites over the reporting period (2000 to 2010). How PM2.5 data are currently available from two monitoring sites near the forest areas of interest (Farmington and Santa Fe #1). The Farmington site has $PM_{2.5}$ data going back to 2000 while Farmington has PM2.5 data only for 2008-10. For PM_{10}, data are available for up to four sites over the reporting period (2000-2010). However, only two PM_{10} monitoring sites were active for 2006 and earlier years. The Shiprock PM_{10} site was added in 2007, and the Farmington PM_{10} site was added in 2008 (USEPA 2015).

As shown by the emissions inventory data documented in the prior section, most PM emissions in New Mexico are associated with fugitive dust and other sources of dust (e.g., wind erosion and re-entrained dust from traffic on streets and roadways). Chronic exposure to elevated $PM_{2.5}$ and PM_{10} concentrations leads to an increased risk of developing cardiovascular and respiratory diseases (including lung cancer) where the PM emissions contain toxic constituents such as heavy metals (WHO 2014).

The annual average $PM_{2.5}$ concentration was in the range of 4 to 5 micrograms per cubic meter at both of the monitoring sites, compared to the NAAQS of 12 micrograms per cubic meter. On December 14, 2012, the EPA reduced the primary $PM_{2.5}$ NAAQS from 15 micrograms per cubic meter to 12 micrograms per cubic meter (annual mean, averaged over three years). The 15 micrograms per cubic meter standard was retained as the annual mean secondary $PM_{2.5}$ NAAQS.

The 98th percentile 24-hour average $PM_{2.5}$ concentrations measured 10 micrograms per cubic meter at the Santa Fe #1 site, with a peak measurement of 15 micrograms per cubic meter in 2002. At the Farmington site, the 98th percentile 24-hour average $PM_{2.5}$ concentration was around 18 micrograms per cubic meter in 2010. The 24-hour NAAQS for $PM_{2.5}$ is 35 micrograms per cubic meter, based on the 98th percentile concentration averaged over three years.

The PM_{10} data were charted for the annual mean and the maximum 24-hour average concentration. The PM_{10} NAAQS exists only for the 24-hour average (150 micrograms per cubic meter). Except for a few readings at the Shiprock monitor in 2007 and 2008, the highest measured 24-hour average PM_{10} concentration generally ranged between 50 to 75 micrograms per cubic meter. Shiprock measured PM_{10} levels near 150 micrograms per cubic meter in 2007 and near 125 micrograms per cubic meter in 2008.

Over the period of record, the annual mean PM_{10} at the various monitoring sites averaged 10 to 20 micrograms per cubic meter, with Shiprock showing somewhat highest PM_{10} concentrations (about 25 micrograms per cubic meter). There is no obvious trend in the annual PM_{10} measurements. An applicable annual mean NAAQS no longer exists for PM_{10} concentrations, although PM_{10} is still regulated by an NAAQS for the 24-hour average as noted above.

Available PM_{10} and $PM_{2.5}$ monitoring data show that concentrations within the plan area comply with the applicable NAAQS, although the PM_{10} levels approach the NAAQS at Shiprock.

Nitrogen Dioxide (NO_2) and Sulfur Dioxide (SO_2)

Nitrogen oxides (NOx) and SO_2 emissions occur as a result of fuel combustion, either in industrial or commercial emission sources such as power generation facilities or in mobile sources (e.g., cars, trucks, busses, aircraft etc.). Sulfur dioxide (SO_2) emissions are linked to the quantity of sulfur in fuels that are combusted. These emissions may also result from smelting and refining of copper ores, due to the liberation of sulfur compounds contained in the ore body.

Nitrogen oxides (NOx) and SO_2 emissions are also linked to the formation of nitrate and sulfate aerosols, which have potential adverse effects on visibility. Also, NOx and SO_2 emissions are linked to increases in acid precipitation and acid deposition.

Nitrogen dioxide (NO_2) is the regulated form of NOx emissions. NO_2 monitoring data are currently available for four sites, although the Shiprock site only has data for 2010. NO_2 data at the San Juan #1 site are available since 2005 (USEPA 2015).

Health effects from exposure to elevated concentrations of NO_2 include inflammation of the airways for acute exposures and increases in the occurrence of bronchitis for children and other sensitive individuals chronically exposed to elevated NO_2 levels (WHO 2014).

For sites with ambient NO_2 data, the 98th percentile 1-hour NO_2 concentration was generally around 40 ppb in most years and the annual mean NO_2 concentration was generally around 10 to 20 ppb. These levels are substantially below the applicable 1-hour and annual NAAQS (100 and 53 ppb, respectively) and demonstrate that ambient NO_2 concentrations comply with the NAAQS in the area of interest. The Bloomfield monitoring site shows higher concentrations for NO_2 (annual average), while the differences between sites for the 98th percentile 1-hour average NO_2 concentrations were relatively minor.

SO_2 monitoring data are available for two sites in the area of interest from 2000 to 2010, with a third site (Shiprock) being added during 2010 (USEPA 2015). In particular, the San Juan #2 site is located near the San Juan Generating Station and as such, these SO_2 measurements are probably not broadly representative of current ambient conditions in most areas on the Santa Fe NF. Away from the local impacts of the power plant emissions, ambient SO_2 concentrations are expected to be much less however is a potential issue with regards to atmospheric deposition.

Health effects from SO_2 exposures include changes in pulmonary function and increases in respiratory symptoms along with irritation of the eyes. Inflammation of the respiratory tract may result in coughing,

mucus secretions, and aggravation of asthma and chronic bronchitis. Persons exposed to elevated SO_2 levels are also more prone to infections of the respiratory tract (WHO 2014).

The measurements at San Juan #2 have shown a significant decline in ambient SO_n levels since the Year 2000, and the 2010 levels are well below the NAAQS. Over this time period, emission reductions strategies have been implemented for SO_2 control at San Juan and the nearby Four Corners Generating Station.

The 2010 Shiprock SO_2 data show elevated concentrations for the 99th percentile 1-hour average daily maximum concentration. However, NAAQS compliance for the Shiprock SO_2 monitoring station cannot be determined because the NAAQS is based on the concentrations averaged over a 3-year period.

Visibility

Visibility has been recognized as an important value going back to the 1977 Clean Air Act (CAA) Amendments, which designated it as an important value for most wilderness areas that are designated as "Class I." Visibility refers to the conditions that allow the appreciation of the inherent beauty of landscape features. This perspective takes into account the form, contrast, detail, and color of near and distant landscapes. Air pollutants (particles and gasses) may interfere with the observer's ability to see and distinguish landscape features.

The Interagency Monitoring of Protected Visual Environments (IMPROVE) program has been monitoring visibility conditions in Class I wilderness areas in New Mexico and nationwide since the late 1980s. The following three IMPROVE monitoring sites (mapped in figure 51) are relevant to the Santa Fe:

1. Bandelier National Monument (BAND1)
2. San Pedro Parks (SAPE1)
3. Wheeler Peak (WHPE)

IMPROVE monitors concentrations of atmospheric aerosols (sulfates, nitrates, etc.) and uses these data to assess light "extinction," or the degree to which light is absorbed and/or scattered by air pollution. Visibility is normally expressed in terms of "extinction" or by using the "deciview" index, which is calculated from the measured extinction value. The "deciview" index represents a measure of change in visibility conditions which is typically perceptible to the human eye. A deciview change in the range of 0.5 to 1.0 dv is generally accepted as being the limit of human perceptibility. Figure 52 illustrates the relationships among extinction, deciviews, and visual range.

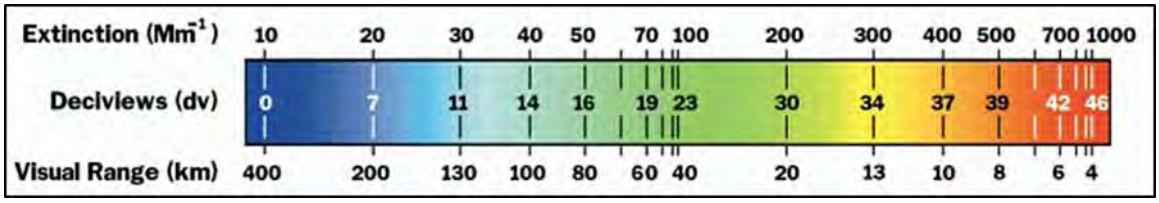


Figure 52. Relationship among extinction, deciview Index, and visual range

Measurements of annual mean visibility (as extinction) across the United States are shown in figure 53 as taken from IMPROVE (Hand, Copeland et al. 2011) These data show lower values of extinction (better overall visibility) across the western United States and high values of extinction in the eastern United

States. Western areas in and around urban centers (e.g., Phoenix, Denver, Las Vegas, etc.) also show more degraded visibility.

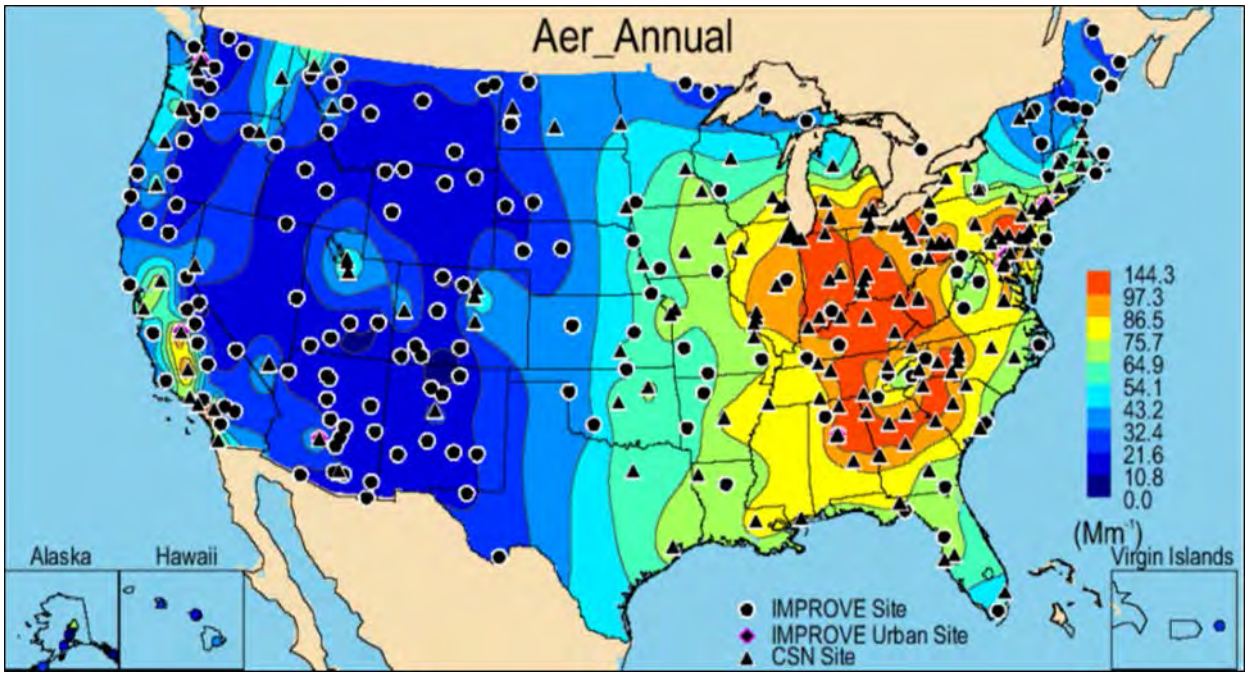


Figure 53. Reconstructed annual mean aerosol extinction from IMPROVE and other aerosol data (Hand et al. 2011)

Under the Clean Air Act (CAA), the national visibility goal is to return visibility in Class I areas to the "natural background condition" no later than 2064. To meet this goal, the CAA has instituted measures for emissions control at large stationary sources that contribute to visibility impairment.

Interagency Monitoring of Protected Visual Environments (IMPROVE) reconstructed extinction data for the Santa Fe were calculated from the IMPROVE aerosol measurements for the period 2000–2010 and are summarized in table 64 for the 20 percent worst-case days (FED 2015). The IMPROVE measurements were sorted to provide the representative visibility conditions for the "worst 20%" visibility and the "average" visibility days, which are standard techniques for reviewing and assessing IMPROVE aerosol monitoring data. The visibility condition representing the 2064 goal for achieving "natural background" is also shown in table 64. These data provide a measure of how much visibility improvement is required at each Class I area in order to achieve the 2064 National Visibility Goal.

The data in table 64 are reported using the deciview metric described earlier. Higher values of deciview represent more degraded visibility conditions. Data are shown using the "baseline period" (2000 to 2004) along with the "progress period" (2005 to 2009) corresponding to the New Mexico regional haze SIP and the 2064 National Visibility Goal (natural background).

Table 64. Summary of IMPROVE visibility monitoring data, 20% worst-case days (dv)

Wilderness	IMPROVE Monitor	2000-04 Baseline Period Average	2000-04 Baseline Period Range	2005-09 Progress Period Average	2005-09 Progress Period Range	2064 Goal Natural Background
Bandelier	BAND1	12.2	10.5–14.6	11.8	11.0–12.8	6.26
San Pedro Parks	SAPE1	10.2	9.3–11.6	9.9	8.2–10.8	5.72
Wheeler Peak	WHPE	10.4	8.4-11.4	9.1	8.6-10.1	6.08

These data show that based on the 20 percent worst days during the 2005 to 2009 "progress period," Bandelier has the most degraded visibility and San Pedro Parks and Wheeler Peak have the least degraded visibility. Also, the general trend in visibility (based on the change in the worst 20 percent days between the baseline period and progress period) has been toward moderately improving visibility conditions. Table 64 also shows that the level of visibility improvement through the 2005 to 2009 "progress period," has been relatively modest compared to the visibility improvements needed by 2064 to achieve the goal of natural background conditions.

Interagency Monitoring of Protected Visual Environments (IMPROVE) measurements at each of the nearby Class I areas of interest can be found at http://views.cira.colostate.edu/fed/ (FED 2015). Data from this site show the reconstructed extinction at each IMPROVE monitoring site for each year (2000 to 2010 where data are available for the entire period of record). This site also produces pie charts showing the percent contribution to the reconstructed extinction for the different aerosol species. The percent contribution charts represent the 2000 to 2004 "baseline" and the 2005 to 2009 "reasonable further progress" periods described above. For these particular charts, the visibility is reported using units of inverse megameters, which is a direct measure of atmospheric light extinction. Again, higher values of extinction represent more degraded visibility.

- **Bandelier National Monument** (BAND1): The reconstructed extinction for the most impaired 20 percent days showed levels generally in the 30 to 40 Mm-1 range, except during 2000, when the extinction measured around 70 Mm-1. The conditions in Year 2000 at BAND1 appear somewhat anomalous, with very high extinction budgets for organics, strongly suggesting the presence of nearby wildfires. These conditions are not apparent in any other data year. Excluding the potential bias introduced by the Year 2000 measurements, the extinction budgets at Bandelier are roughly 25 percent Rayleigh scattering, 25 to 30 percent sulfate and nitrate (indicative of industrial source emissions), 20 to 25 percent organics, and 10 to 15 percent coarse mass and soils. There has been a steady improvement in the visibility conditions represented by the 20 percent most impaired days since about 2007, which is mostly reflected by reductions in sulfate and may be a result of emissions control technology improvements at coal-fired electric generating stations.

- **San Pedro Parks and Wheeler Peak**: As mentioned above, the San Pedro Parks and Wheeler Peak have similar trends in their data. They have the least degraded visibility, and this is also evident in the extinction data. For the 20 percent most impaired days, the reconstructed extinction ranges between 25 to 35 Mm-1. Because they have the least impaired visibility, the Rayleigh contribution in the extinction budget is 30 percent, slightly larger than other IMPROVE sites. The sulfate and nitrate contribution is about 25 to 30 percent, the organics contribution is about 25 percent, and the coarse mass and soil contribution is about 15 percent. Similar to some of the other sites, the extinction data show some improvements in visibility conditions since 2007,

generally reflecting less impact from sulfate, which might be indicative of regional SO_2 emission reductions.

Atmospheric Deposition Information

Sulfur and Nitrogen Deposition

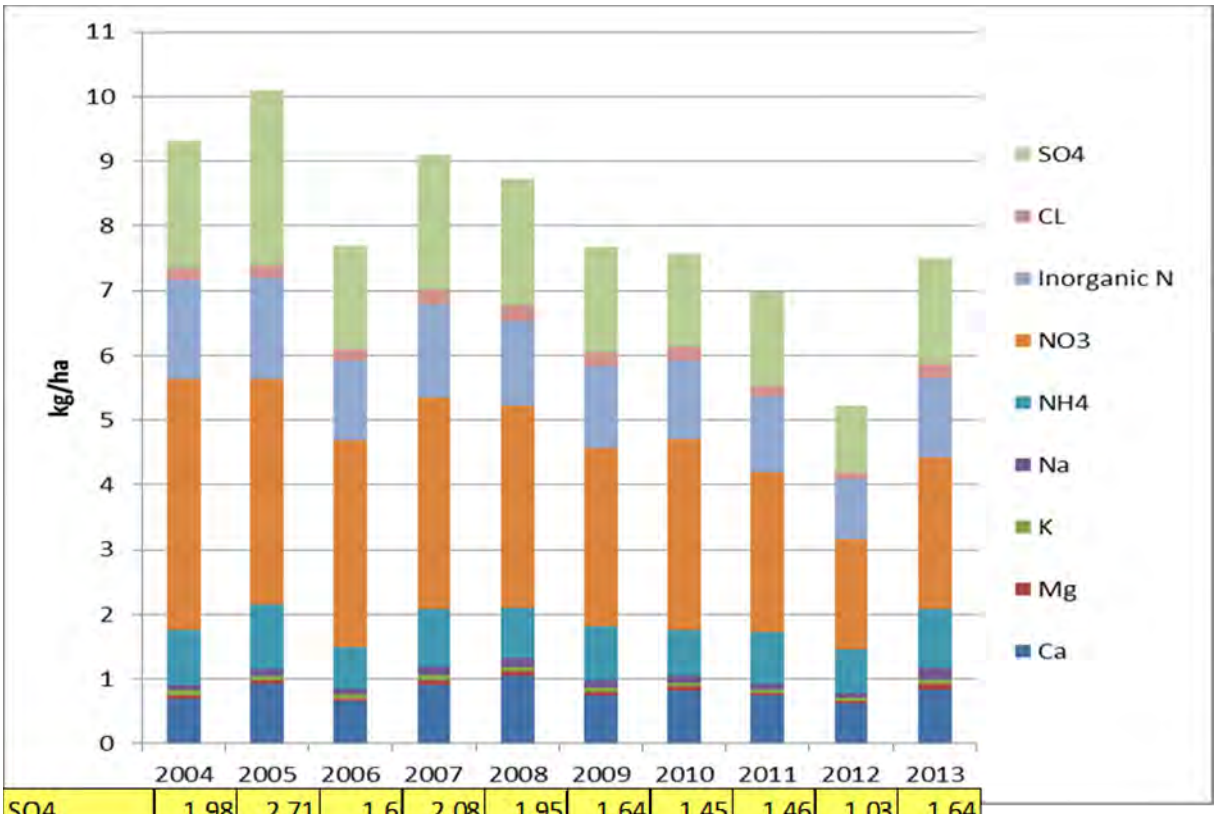
Air emissions of nitrogen oxides (NOx) and sulfur dioxide (SO_2) can lead to atmospheric transformation of these pollutants to acidic compounds (e.g., nitric acid and sulfuric acid) and the resultant deposition onto land and water surfaces in forested ecosystems. Documented effects of nitrogen and sulfur deposition include acidification of lakes, streams and soils, leaching of nutrients from soils, injury to high-elevation forests, changes in terrestrial and aquatic species composition and abundance, changes in nutrient cycling, unnatural fertilization of terrestrial ecosystems, and eutrophication of aquatic ecosystems.

Deposition impacts are generally described in terms of the "critical load," defined as "the quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment are not expected to occur based on present knowledge" (NADP 2009). In other words, the "critical load" determines the tipping point at which harmful effects attributable to deposition in a particular ecosystem start to occur. Critical loads have been established at some, but not all wilderness areas. For the New Mexico wilderness areas of interest, critical loads for nitrogen and acid deposition have been established based on a national assessment, although they lack some site-specific data for a more robust assessment (Pardo 2011, Pardo, Robin-Abbott et al. 2011). This general approach has been applied to determine critical loads for nitrogen and sulfur deposition, for some sensitive receptors on the forest.

Figure 54 shows the sulfur and nitrogen deposition measurements collected at the Bandelier National Monument station operated for the National Trends Network (NTN) over the period 2004 to 2014 (CASTNET 2015). Totals are shown for wet deposition and dry deposition for both sulfur and nitrogen, along with other chemical species. Units of measurement are kilograms per hectare (kg/ha).

Deposition has remained relatively constant over the period of record, although some year-to-year variability is noted. Generally, the observed deposition at Bandelier ranges between 5.0 to 10.0 kg/ha-yr. Nitrogen deposition makes up the bulk of the deposition and typically constitutes about 3 kg/ha-yr, while sulfur deposition is typically closer to 2 kg/ha-yr.

The Carson National Forest also supports the United States Geological Society (USGS) Snowpack Chemistry Monitoring Study, which includes two locations on the forest (USGS 2015). One site is located near the Taos Ski area and the second is near Hopewell Lake. Generally, nitrate deposition at the two sites has decreased over the last 14 years, consistent with overall emissions and the expected trend in emissions. Sulfate emissions have been more variable, with levels increasing at the Taos site and decreasing at the Hopewell site. While the expected trend is expected to decrease in sulfur emissions over time, many of the regulatory actions driving this trend have yet to take effect.



	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
SO4	1.98	2.71	1.6	2.08	1.95	1.64	1.45	1.46	1.03	1.64
CL	0.17	0.19	0.19	0.23	0.25	0.2	0.21	0.15	0.11	0.2
Inorganic N	1.53	1.56	1.22	1.44	1.3	1.27	1.21	1.17	0.91	1.24
NO3	3.88	3.49	3.2	3.26	3.12	2.76	2.94	2.48	1.72	2.34
NH4	0.84	1	0.64	0.9	0.76	0.83	0.71	0.79	0.66	0.91
Na	0.086	0.101	0.092	0.13	0.156	0.104	0.108	0.095	0.071	0.182
K	0.075	0.073	0.062	0.081	0.067	0.064	0.06	0.049	0.053	0.068
Mg	0.053	0.059	0.048	0.067	0.078	0.057	0.067	0.046	0.045	0.08
Ca	0.7	0.92	0.65	0.91	1.04	0.75	0.82	0.74	0.62	0.84

(Data obtained from http://nadp.sws.uiuc.edu/sites/siteinfo.asp?id=NM07&net=NTN)

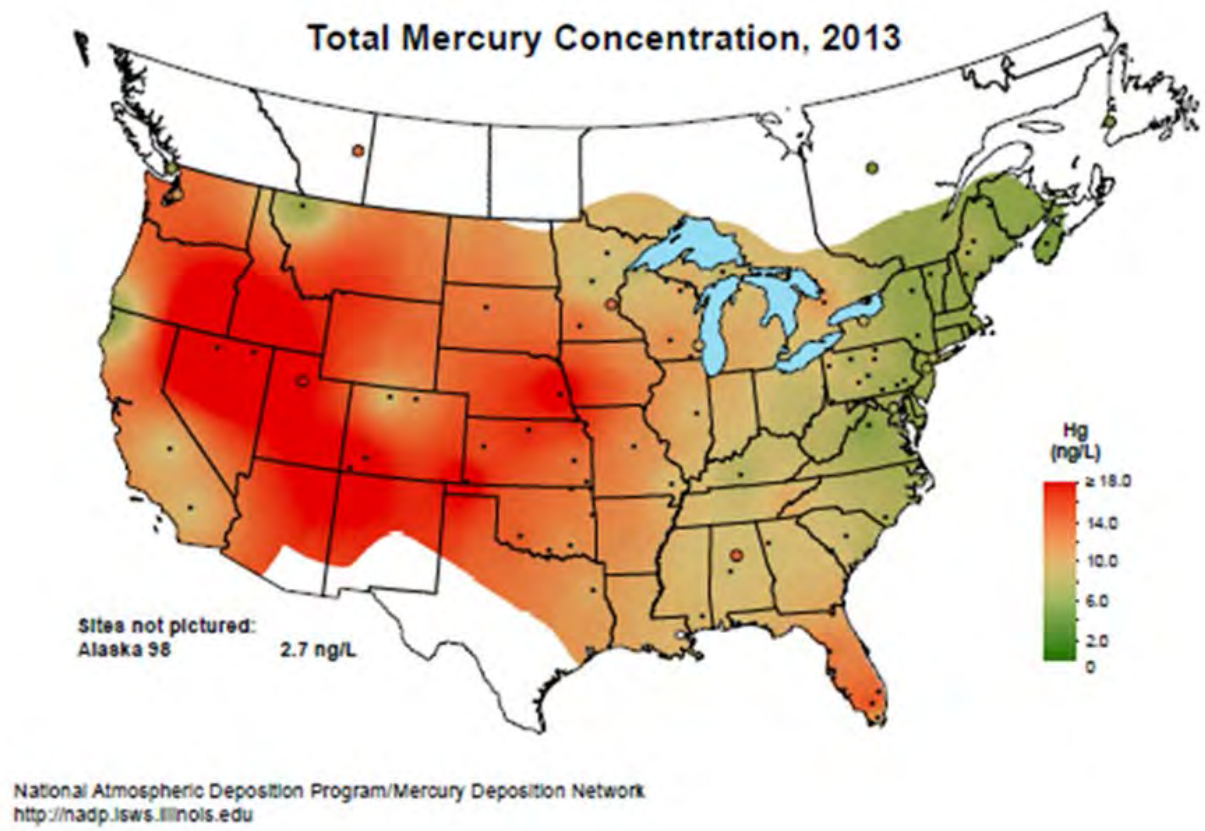
Figure 54. Chemical deposition (Bandelier Station, 2004 to 2014)

Mercury Deposition

Mercury is a persistent bioaccumulative toxin which can stay in the environment for long periods of time, cycling between air, water and soil. Mercury deposits on the earth's surface through wet or dry deposition, which can accumulate in the food chain and bodies of water. Toxic air contaminants like mercury, are emitted primarily by coal-fired utilities, and may be carried thousands of miles before entering lakes and streams as mercury deposition. Mercury can bioaccumulate and greatly biomagnify through the food chain in fish, humans, and other animals. Mercury is converted to methylmercury by sulfur reducing bacteria in aquatic sediments, and it is this form that is present in fish. Methylmercury is a potent neurotoxin, and has been shown to have detrimental health effects in human populations as well as behavioral and reproductive impacts to wildlife. Eating fish is the main way that people are exposed to methylmercury. However, each person's exposure depends on the amount of methylmercury in the fish they eat, how much they eat, and how often. Typically, larger fish that are higher up the food chain (eat lots of little fish rather than algae) will have a greater amount of methylmercury in them.

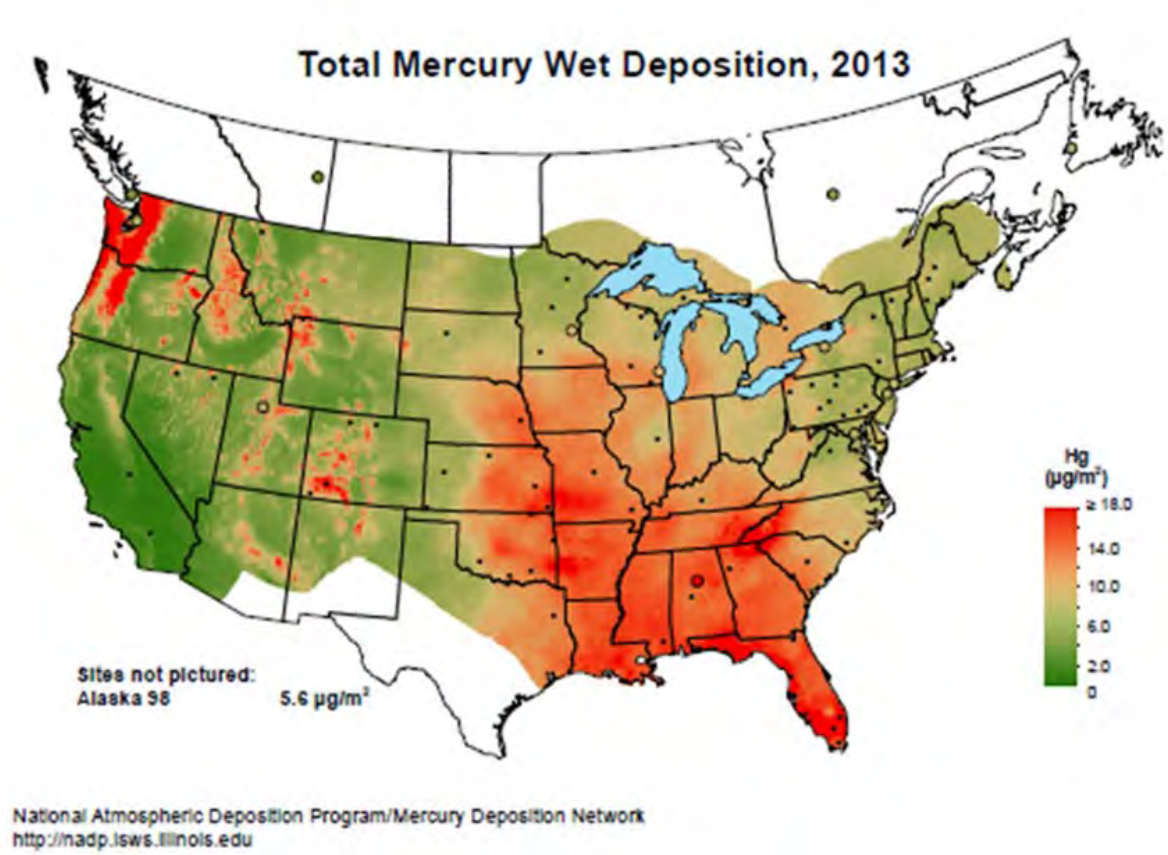
Almost every state (including New Mexico) has consumption advisories for certain lakes and streams warning of mercury-contaminated fish and shellfish. Many of the lakes on or near the Santa Fe NF have fish consumption advisories for mercury for some species of fish (NMED 2012).

The Mercury Deposition Network collects and provides a long-term record of mercury concentrations and deposition in precipitation. As a result of coal-fired utilities in the Southwest, and the limited levels of mercury pollution controls at those sites, the total concentration of mercury in the air is fairly high relative to elsewhere in the United States (figure 55) (MDN 2013)). However, due to the relatively low precipitation rates (except at higher elevations), the mercury from wet deposition is comparatively low (figure 56) (MDN 2013).



(Data obtained from: http://nadp.sws.uiuc.edu/maplib/pdf/mdn/hg_Conc_2013.pdf)

Figure 55. Total mercury concentration, 2013



(Data obtained from: http://nadp.sws.uiuc.edu/maplib/pdf/mdn/hg_dep_2013.pdf)
Figure 56. Total wet mercury deposition, 2013

Some sites also are now collecting total deposition, both wet and dry. One site is located on the Valles Caldera National Preserve, which is surrounded by the Santa Fe. While it has only been operating for two years, initial results suggest that dry deposition adds significantly to the total deposition (Sather, Mukerjee et al. 2013).

Mercury deposition measurements were collected at the MDN Valles Caldera National Preserve (Sandoval County) for 2009 and 2010, which show mercury deposition values in the range of 7,000 ng/m^2. Due to the toxicity of mercury no amount is good, but compared to the rest of the United States, these values are relatively low when compared to some sites in the East and Northeast.

The USGS also monitors for mercury at the two snowpack chemistry monitoring sites near the Taos Ski area and near Hopewell Lake. Both sites have shown an increase in mercury deposition over the last 14 years that data have been collected.

While it is difficult to assess the current effects that mercury deposition is having on the Santa Fe NF, trends in two areas suggest that overall mercury effects will decline. First, new regulatory controls at a couple regional coal fired power plants should reduce the total mercury emissions over the next several years. In addition, sulfur emissions are also expected to decline, due to new sulfur fuel standards and pollution controls at the coal-fired utilities. The link between sulfur-reducing bacteria and biotic mercury

concentrations has led researchers to establish that reductions in sulfur dioxide emissions and a resulting reduction in sulfate deposition will abate mercury concentrations in wildlife. As a result, as sulfates are reduced in aquatic systems, sulfur-reducing bacteria will reduce less sulfur, and this will lead to less inorganic mercury being methylated.

Ozone

Ground-level ozone interferes with the ability of plants to produce and store food, which makes them more susceptible to disease, insects, other pollutants, drought, and higher temperatures. Some plants have been identified as particularly sensitive to the effects of ozone and are reliable indicators of toxic levels of the pollutant on plant growth.

Ozone damages the appearance of leaves on trees and other plants. The most common visible symptom of ozone injury on broad-leaved bioindicator species is uniform interveinal leaf stippling. As a gaseous pollutant, ozone enters the stomata of plant leaves through the normal process of gas exchange, damaging the tissue. Elevated levels of ozone have not been directly measured on the Santa Fe NF, nor has an assessment of the Forest's vegetation been conducted in terms of looking for impacts from ozone. The effects of ozone on tree growth on the Santa Fe NF are not well understood.

Critical Loads

Air pollution emitted from a variety of sources is deposited from the air into ecosystems. These pollutants may cause ecological changes, such as long-term acidification of soils or surface waters, soil nutrient imbalances affecting plant growth, and loss of biodiversity. The term critical load is used to describe the threshold of air pollution deposition below which harmful effects to sensitive resources in an ecosystem begin to occur. Critical loads are based on scientific information about expected ecosystem responses to a given level of atmospheric deposition. For ecosystems that have already been damaged by air pollution, critical loads help determine how much improvement in air quality would be needed for ecosystem recovery to occur. In areas where critical loads have not been exceeded, critical loads can identify levels of air quality needed to maintain and protect ecosystems into the future.

U.S. scientists, air regulators, and natural resource managers have developed critical loads for areas across the United States through collaboration with scientists developing critical loads in Europe and Canada. Critical loads can be used to assess ecosystem health, inform the public about natural resources at risk, evaluate the effectiveness of emission reduction strategies, and guide a wide range of management decisions.

The Forest Service is incorporating critical loads into the air quality assessments performed for forest plan revision. There are no published critical loads in the southwestern United States. For this assessment, national scale critical loads were used to determine if critical loads were exceeded for nutrient nitrogen (Pardo 2011, Pardo, Robin-Abbott et al. 2011), acidity to forested ecosystems (McNulty, Cohen et al. 2007), and for acidity to surface water (Lynch, Pardo et al. 2012). In addition, mercury deposition was analyzed based on data from the mercury deposition network (MDN 2013); however, no critical loads have been developed for mercury on the forest service. Ozone deposition was not assessed, due to lack of data availability and analysis in the southwestern United States. No critical loads have been developed for ozone on the Santa Fe NF.

Nitrogen Saturation/Eutrophication

Nitrogen air pollution can have an acidifying effect on ecosystems as well as cause excess input of nitrogen in the ecosystem and nitrogen saturation. This excess nitrogen initially will accumulate in soil and subsequently be lost via leaching. While increased nitrogen may increase productivity in many terrestrial ecosystems (which are typically nitrogen limited) this is not necessarily desirable in protected ecosystems, where natural ecosystem function is desired. Excess nitrogen can lead to nutrient imbalances, changes in species composition (trees, understory species, nonvascular plants (lichens), or mycorrhizal fungi), and ultimately declines in forest health.

Based on research by Pardo and others (2011), national scale critical loads were developed for nitrogen deposition for lichen, herbaceous plants and shrubs, mycorrhizal fungi, forests, and nitrate leaching in soils. Summary results of this assessment are in table 65.

Table 65. Critical load exceedance summary for nitrogen deposition on the Santa Fe NF

	% of total	Minimum Exceedance (kg-N/ha)	Maximum Exceedance (kg-N/ha)	95% Exceedance level (kg-N/ha)
Lichens				
Exceedance	98%	0.006859144	3.294857279	2.459382343
No Exceedance	2%			
Critical Loads Not Available	0%			
Herbaceous Plants and Shrubs				
Exceedance	48%	0.003249602	2.45297718	1. 966276337
No Exceedance	52%			
Mycorrhizal Fungi				
Exceedance	12%	0.031411889	1.45297718	0.939634159
No Exceedance	88%			
Forests				
Exceedance	48%	0.003249602	2.45297718	1.966276337
No Exceedance	52%			
Nitrate Leaching				
Exceedance	45%	0.034464836	2.45297718	1.990614526
No Exceedance	55%			
Critical Loads Not Available	0%			

Lichens

Lichens, which add significantly to biodiversity of ecosystems, are some of the most sensitive species to nitrogen deposition (Pardo 2011, Pardo, Robin-Abbott et al. 2011), and are indicators of other atmospheric constituents by changes in their abundance over time, and by their chemical content as analyzed in the lab . Unlike vascular plants, lichens have no specialized tissues to mediate the entry or loss of water or gases. They rapidly hydrate and absorb gases, water and nutrients during periods of high humidity and precipitation. They dehydrate and reach an inactive state quickly, making them slow

growing and vulnerable to contaminate accumulation. As such, they are an important early indicator of impacts from air pollution.

Pardo and others (2011) used the major ecoregion types adapted from the Commission for Environmental Cooperation(CEC 1997), of which the Santa Fe is within the Northwestern Forested Mountains ecoregions. The critical loads for lichens in these two ecoregions are based on research for Northwestern Forested Mountains, with minimum levels between 2.5 and 7.1 kg-N/ha-yr (Geiser 2010, Pardo 2011, Pardo, Robin-Abbott et al. 2011). Based on these values, 98 percent of the Santa Fe NF exceeds critical loads to protect lichens, where 2 percent showed no exceedance. The minimum amount that the Santa Fe NF exceeded nitrogen deposition by was 0.0069 kg-N/ha and the maximum was by 3.29 kg-N/ha.

Herbaceous Plants and Shrubs

Herbaceous plants and shrubs comprise the majority of the vascular plants in North America (USDA and NRCS 2009). They are less sensitive to nitrogen deposition than lichens; however, they are more sensitive than trees due to rapid growth rates, shallow roots, and shorter life span (Pardo 2011, Pardo, Robin-Abbott et al. 2011). Herbaceous plants are the dominant primary producers, contributing significantly to forest litter biomass and biodiversity (Gilliam 2007). The shorter lifespan of some species can result in a rapid response to nitrogen deposition and can result to rapid shifts (1 to 10 years) in community composition sometimes resulting in an increase in invasive species compared to native species (Pardo 2011, Pardo, Robin-Abbott et al. 2011). The critical loads were based empirical data developed for the Northwestern Forested Mountains ecoregion, which noted changes in species composition and individual species responses at 4 kg-N/ha-yr (Bowman, Larson et al. 2006, Pardo 2011, Pardo, Robin-Abbott et al. 2011).

Based on the national scale empirical critical loads for nitrogen deposition for herbaceous plants and shrubs (Pardo 2011, Pardo, Robin-Abbott et al. 2011), 47 percent of the Santa Fe is potentially exceeding critical loads and 53 percent does not exceed. The areas exceeding critical loads for nitrogen deposition range from a slight exceedance of 0.003 kg-N/ha to 2.45 kg-N/ha. 95 percent of the grid cells exceed the critical loads for herbaceous plants and shrubs with values less than 1.97 kg-N/ha.

Mycorrhizal Fungi

Mycorrhizal fungi reside in the ground, between plants roots and the soil. They play an important ecological role in a symbiotic relationship with host plants by exchanging nutrients and minerals for carbon. Atmospheric deposition of nitrogen exceeding the critical load have been shown to alter community structure and composition, root colonization, and decrease species richness (Pardo 2011, Pardo, Robin-Abbott et al. 2011). However, there is high uncertainty in the data due to relatively few studies. The minimum critical loads for mycorrhizal fungi for the Northwestern Forested Mountains ecoregion, based on expert judgement, indicates responses at 5 kg-N/ha-yr (Pardo 2011, Pardo, Robin-Abbott et al. 2011).

Based on the national scale empirical critical loads for nitrogen deposition mycorrhizal fungi (Pardo 2011, Pardo, Robin-Abbott et al. 2011), 12 percent of the Santa Fe NF is potentially exceeding critical loads and 88 percent does not exceed. The areas exceeding critical loads for nitrogen deposition range from a slight exceedance of 0.03 kg-N/ha to 1.45 kg-N/ha. Ninety-five percent of the grid cells exceed the critical loads for herbaceous plants and shrubs with values less than 0.94 kg-N/ha.

Forests

Adding nitrogen to forests whose growth is typically limited by its availability may appear desirable, possibly increasing forest growth and timber production, but it can also have adverse effects such as increased soil acidification, biodiversity impacts, susceptibility to secondary stressors (freezing, drought, insects), changes in growth, and increased mortality (Pardo 2011, Pardo, Robin-Abbott et al. 2011). As atmospheric nitrogen deposition onto forests and other ecosystems increases, the enhanced availability of nitrogen can lead to chemical and biological changes collectively called "nitrogen saturation." As nitrogen deposition from air pollution accumulates in an ecosystem, a progression of effects can occur as levels of biologically available nitrogen increase.

Based on the national scale empirical critical loads for nitrogen deposition for forests (Pardo 2011, Pardo, Robin-Abbott et al. 2011), 48 percent of the Santa Fe NF is potentially exceeding critical loads and 52 percent does not exceed. The areas exceeding critical loads for nitrogen deposition range from a slight exceedance of 0.003 kg-N/ha to 2.45 kg-N/ha. For forested systems, 95 percent of the grid cells exceed the critical loads with values less than 1.97 kg-N/ha. The critical loads were based on empirical data developed for the Northwestern Forested Mountains ecoregion, which noted changes in changes in foliar chemistry, mineralization, and nitrogen leaching in soil at levels greater than 4 kg-N/ha-yr (Rueth and Baron 2002).

Nitrate Leaching

Atmospheric deposition of nitrogen can saturate some terrestrial ecosystems leading to nitrate leaching. High alpine lakes are particularly susceptible due to limited retention of nitrogen as a result of little vegetation, poorly developed soils, short hydrologic residence time and, steep topography . The critical loads for this analysis were based empirical data developed for the Northwestern Forested Mountains ecoregion, which noted increases in lake acidification for high alpine lakes in Colorado at levels greater than 4 kg-N/ha-yr (Williams and Tonnessen 2000).

Based on the national scale empirical critical loads for nitrogen deposition for nitrate leaching (Pardo 2011, Pardo, Robin-Abbott et al. 2011), 45 percent of the Santa Fe is potentially exceeding critical loads and 55 percent does not exceed minimum critical loads. The areas exceeding critical loads for nitrogen deposition range from a slight exceedance of 0.03 kg-N/ha to 2.45 kg-N/ha. For nitrate leaching, 95 percent of the grid cells exceed the critical loads with values less than 1.99 kg-N/ha.

Acid Deposition

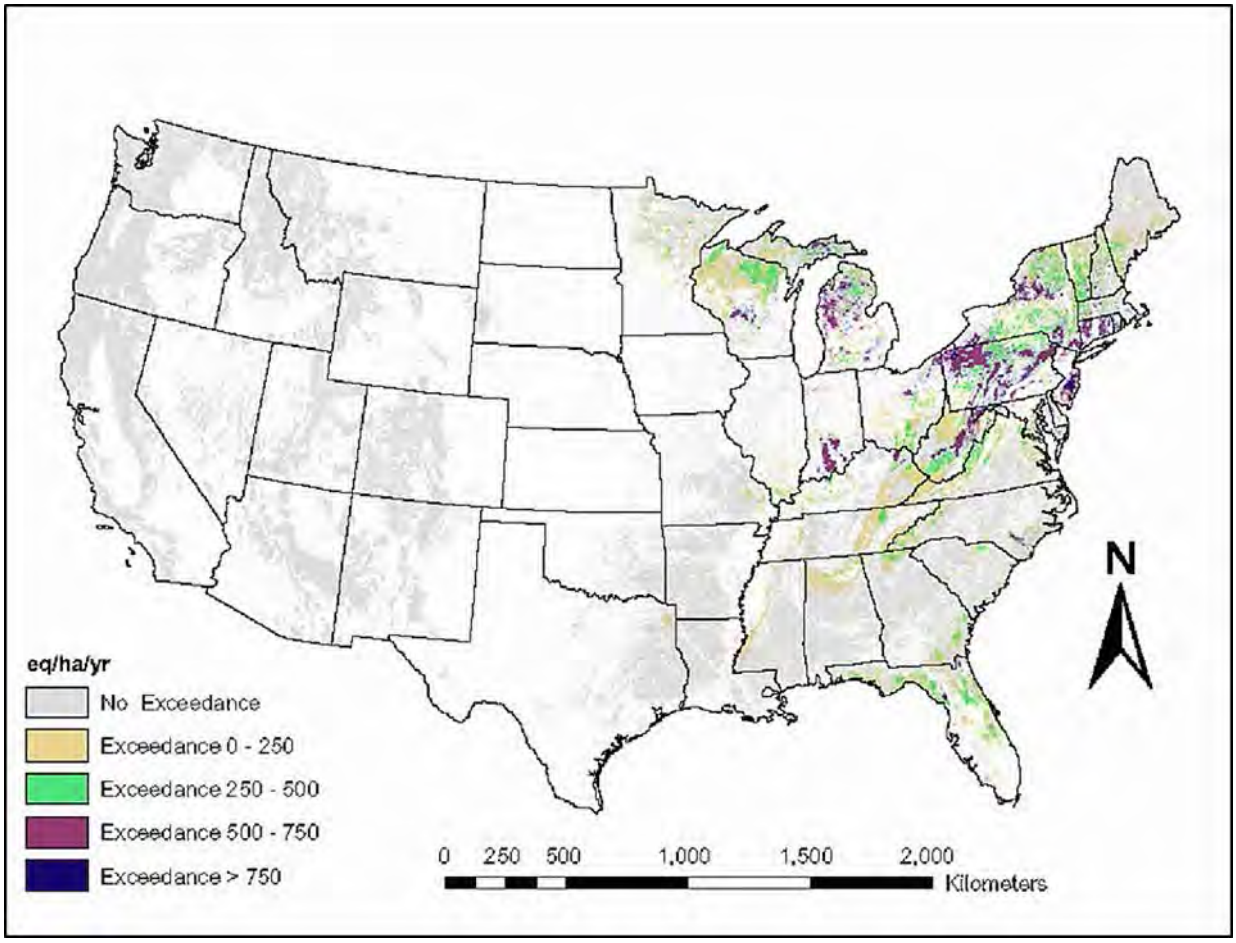
The potential for impacts from acid deposition on forests has been recognized for more than 30 years in the United States. Research has shown that deposition of nitrogen and sulfur has resulted in acidifying effects, which has had negative impacts on ecosystem health, including impacts to aquatic resources, forest sustainability, and biodiversity (McNulty, Cohen et al. 2007). Acidifying effects can lead to mortality of tree species, reduced forest productivity, reduced biological diversity, and increased stream acidity (Driscoll, Lawrence et al. 2001).

The following section presents critical acid load for soils and surface water on the Santa Fe NF. McNulty estimated critical loads and exceedances for forested soils across the United States (McNulty, Cohen et al. 2007). The surface water critical acid loads were based on research from Lynch (Lynch, Pardo et al. 2012).

Soils

Many factors contribute to an exceedance of critical acid loads in forested ecosystems. Key factors include the composition of the soil, including how weathered it is, the amount of organic matter present, and the amount of base cations (i.e., calcium, potassium, magnesium, and sodium), which all play a role in how well the soil is buffered against acid deposition (how well the soil can neutralize the acid). For example, sandy soils are typically low in base cations, which make them more vulnerable to acid deposition. Also important are the types of tree species present due to the various rates that they uptake nitrogen, and base cations, which can either counter act the effects of acid deposition or reduce soils buffering capacity. In conifer forests, as the needles break down, the soil is naturally acidified, which can also increase the system's vulnerability to acidification. Also important is the rate at which sulfur and nitrogen compounds fall to the ground through either wet or dry deposition, which is related to what sort of emissions are occurring that are adding these compounds to the airshed. Elevation also plays a role, since more precipitation tends to occur at higher elevations increasing the rate of acid deposition.

Estimates that factor all the parameters described above show that there are no exceedances of acid critical loads on the Santa Fe NF (figure 57). This is primarily a result of low amount of acid gases in the airsheds in New Mexico and the western United States.



(McNulty, Cohen et al. 2007)

Figure 57. Average annual exceedance of the critical acid load for forest soils expressed in eq/ha-yr for the coterminous United States for the years 1994 to 2000 at a 1-km^2 spatial resolution

Surface Water Impacts

Stream and lake acidification can be a result of deposition of acid gases, which can reduce the pH of surface water resulting in reduced diversity and abundance of aquatic species. As described in the previous section, many of the same factors contribute to the susceptibility of aquatic ecosystems to the effects of acid deposition. Surface water acidification begins with acid deposition in adjacent terrestrial areas (Pidwirny 2006) and the system's ability to neutralize the acid before it leaches into the surface water.

Analyzing data from a variety of sources, it appears that there are some impacts from acidification in some high elevation lakes on the Santa Fe NF, while other data suggest no acidification impacts from atmospheric deposition to other surface water. The Forest began monitoring high-elevation lakes in the Pecos Wilderness in 1989. The last two times that monitoring occurred in the Pecos Wilderness, in 1996 and 2002 to 2003, data indicated that Upper Truchas Lake and Lower Truchas Lake are probably impacted from chronic acidification (USFS 2004). This is likely a result of very small watersheds, in terms of area, with very little buffering capacity from very limited organic soil at high elevation. Alternatively, data from the national critical loads database indicates no impacts from acidification from atmospheric deposition. The four data points in the national critical loads database available for the Santa Fe NF to assess acid deposition to surface water, are located in the headwaters of the Pecos River, the mouth of the Santa Fe watershed, the Jemez River, and Nacimiento Creek below San Gregorio Reservoir. These data do not indicate that acidification of surface water on the forest is an issue. This is based on a national analysis, by Lynch, which was conducted using the Steady-State Water Chemistry model (SSWC) and a mass-balance approach to assess acid critical loads for surface water (Lynch, Pardo et al. 2012). Lastly, every two years the New Mexico Environment Department is required by the Clean Water Act to submit an assessment of the surface waters in New Mexico to the EPA. Based on the current list of impaired water in New Mexico, there are several stream segments listed as impaired waters as a result of pH on the Santa Fe (NMED 2012). However, for those segments with Total Maximum Daily Loads (TMDLs) that have been developed, none identify the pH impairment as a result of acid deposition. Rather the source is either not identified or is unclear. Possible sources that have been suggested are as a result of nutrient impairments or natural conditions related to geothermal groundwater inputs.

Uncertainty

There are many factors that contribute to the reliability and confidence of an assessment. Typically, a sufficient amount of direct measurements taken over time, provide the greatest level of confidence regarding the current state and trends of forest health as it applies to air quality impacts. In the absence of direct measurements, modeled data can be used to assess relative risk of systems to the impacts for air pollution; however, this creates a greater degree of uncertainty in the assessment. To understand the level of confidence in the modeled results, it is important to understand the assumptions in the models as well as how they perform in a given environment. In this case, how they perform assessing the potential impacts that air pollution has on various indicators, such as lichens, on the Santa Fe NF.

While there are direct measurements that have been taken over time, for ambient air quality and visibility, there are limited studies performed on the Santa Fe NF to directly measure the impacts from air pollution on forest health, such as limited lichen surveys and water chemistry surveys. The modeled results that are available, indicate that lichens and, to a lesser degree, herbaceous plants and shrubs, forests, and nitrate leaching are at risk of being impacted by nitrogen deposition. There is high amount of reliability in the critical loads, for many of the ecosystem components, accept for mycorrhizal fungi, due to the large number of studies that support them, however, other factors may affect the reliability of the assessment. Atmospheric nitrogen deposition estimates and critical loads are influenced by several other factors,

including the difficulty of quantifying dry deposition on complex mountainous terrain in arid climates with sparse data (Pardo et al. 2011), all of which are significant factors on the Santa Fe NF. At this time, there is a fair amount of uncertainty with the critical load estimates to have a high level of confidence in the assessment.

Summary of Condition, Trend, and Risk

Table 66. Summary of conditions, trends, and reliability of assessment

Air Quality Measure	Current Conditions	Trend	Reliability
NAAQS[a]			
CO	Good	Improving	High
NO_2	Good	Improving	High
SO_2	Good	Stable	High
Pb	Good	Stable	High
O_3	Good	Stable	High
$PM_{2.5}$	Good	Stable to Declining	High
PM_{10}	Good	Stable to Declining	High
Visibility[b]			
Visibility	Departed	Stable to Improving	High
	Critical Loads- Deposition[d]		
Nitrogen Eutrophication			
Lichens	High risk	Improving	Moderate
Herbaceous Plants and Shrubs	Moderate risk	Improving	Moderate
Mycorrhizal Fungi	Moderate risk	Improving	Low
Forests	Moderate risk	Improving	Moderate
Nitrate Leaching	Moderate risk	Improving	Moderate
Acid Deposition			
Soils	Good	Improving	Low
Surface Water[c]	Low risk	Stable to Improving	Moderate
Deposition (other)			
Mercury	Low risk	Improving	Moderate
Ozone	Unknown	Unknown	N/A

[a] Relative to NAAQS

[b] Relative to 2064 Regional Haze Goal

[c] Particularly for some high alpine lakes. For other surface water the data is inconclusive if atmospheric deposition is a factor.

[d] Level of risk, is based on the extent of potential impact on the forest. For example, if models indicate that 98 percent of the forest area exceeds nitrogen critical loads for lichens, that would be high risk. While approximately 50 percent of the forest area exceeds nitrogen critical loads for Mycorrhizal fungi or Forests, this is moderate risk. Break points are 0 to 33 percent- Low risk; 34 to 66 percent- Moderate risk; and 67 to 100 percent- High risk. In some cases, where there is conflicting data, the data is sparse, or has considerable uncertainty, best professional judgement was used to assign risk level.

There is some indication that current levels of nitrogen deposition have exceeded critical loads and are significant enough to have resulted in impacts to lichen diversity and community structure and to a lesser degree impacts to herbaceous plants and shrubs, forest and soil nitrate leaching. However, these results were based on modeled critical loads and have not been verified on the forest. The rate of deposition of nitrogen, which can lead to impacts affecting forest health, appear to be decreasing based on projected emissions at the state level.

Modeled results also indicate that the levels of acid gases are not at levels significant enough to result in impacts to either soils or surface water. There are no direct measurements on the forest that indicate otherwise.

There is some indication that mercury deposition at higher elevations on the forest may be significant, however, atmospheric mercury, based on regional emissions, is also expected to decrease.

Key Message

Air quality and the values dependent on air quality on the Santa Fe NF are generally in good condition or are improving as most pollutants are decreasing; however, visibility and ambient air quality conditions associated with particulate matter are expected to increase—likely a result of larger, more severe wildfires and increases in fugitive dust as the effects of climate change are realized. In addition, modeled critical loads from nitrogen deposition are being exceeded for many ecosystem components, including lichens, forests, herbaceous plants and shrubs, and nitrate leaching particularly at high elevation alpine lakes.

Ecosystem Services

This report reviews a number of key characteristics within 4 northern New Mexico airsheds to assess the ability of air to continue providing valued ecosystem services such as supporting respiration in plants and animals, carrying carbon dioxide for plant photosynthesis and nitrogen for plant nutrition, and redistributing biological and physical byproducts in a manner that contributes to, rather than detracts from, the health of biological systems, including human health. Compromised air quality stresses forest health, and all the ecosystem services provided by forests, with added acid or excess nutrients. While some plants can benefit from additional fertilization, these stresses can affect the structure and function of sensitive ecosystems, leading to disease, impaired growth, impacts to aquatic systems, changes in native species composition, and increased opportunities for invasive plants.

The primary air quality standards represent the maximum allowable atmospheric concentrations that may occur and still protect human health, including a reasonable margin of safety. Secondary standards provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings. Pollutants, emissions, deposition data and visibility data are all presented above. Monitoring data is typically limited to those indicators which are known to be detrimental to human health and the environment. Specific detrimental effects are discussed in detail under each monitored factor. Additionally, visibility is monitored, especially around wilderness areas, as an important value that allows for unhindered appreciation of landscapes and cultural sites of importance to residents and visitors in the region. Perception of higher quality ‘fresh’ air (a visual or olfactory assessment for many) is one of the ‘amenity values’ that supports population growth and an increased tax base in areas around national forests.

The primary tool federal land managers use to provide input to regulators is the critical load concept. Critical load describes the threshold of air pollution deposition below which harmful effects to sensitive resources in an ecosystem begin to occur. These measures indicate that current levels of nitrogen deposition have exceeded critical loads and are significant enough to impact lichen diversity and community structure, and to a lesser degree, to affect herbaceous plants, forests and soil nitrate leaching. Air pollution that occurs off national forests is the primary concern for causing impacts on national forests. The federal Clean Air Act (CAA) provides the basic framework for controlling air pollution, but the states are primarily responsible for implementing and enforcing CAA requirements.

Air quality and the health and welfare values dependent on air quality on the Santa Fe NF are generally in good condition and/or are expected to improve as most pollutants are decreasing under current or expected regulations. Negative visibility affects and ambient air quality conditions associated with particulate matter are expected to increase, however, likely a result of larger, more severe wildfires and increases in fugitive dust as climate change trends continue.

Chapter 6. Carbon and Climate Change

Santa Fe NF Carbon Stocks

The emission of greenhouse gases (GHGs) by human activities and natural processes contribute to the warming of the Earth's climate. Warming could have significant ecological, economic, and social impacts at regional and global scales (IPCC 2007). In 2005, U.S. forests were estimated to be sequestering nearly 220.5 million tons of carbon (Cameron et al. 2003), to suggest that forests and woodlands of the Southwest could have a significant role to play in the sequestration of carbon and climate change mitigation. The Forest Service has directed a baseline assessment of carbon stocks as part of the forest plan assessment process (36 CFR 219.6(b)(4)).

The following assessment considers the major carbon components of Southwest ecosystems including biomass, carbon emissions, and soil organic carbon. Some estimates are provided for biomass and soil carbon on the Santa Fe NF in northern New Mexico. For the moment, the carbon emissions component has been characterized by using a case study synthesis from the Apache-Sitgreaves NF. We acknowledge that the description of other carbon components, such as forest products, would provide a fuller accounting of carbon stocks and flux; for the time being, inclusion of the major components of biomass, emissions, and soil carbon will suffice for strategic purposes of Forest planning.

Biomass (vegetative carbon)

Vegetative biomass serves an integral component in forest carbon cycles. Forest vegetation, through the process of photosynthesis, converts atmospheric carbon dioxide to carbohydrates (referred to as carbon fixation). These carbohydrates (sugars) are used by plants to grow both aboveground biomass in the form of stems and leaves, and below-ground biomass in the form of roots and tubers. Conversely, through the process of decay, dead plant material slowly releases carbon into the atmosphere as it decomposes. Total carbon stored in vegetative biomass is referred to as the biomass carbon stock, and this is a value that changes through time. The primary influences on biomass carbon stock are plant growth (primary productivity) which serves to increase biomass carbon stock, decay and decomposition which slowly decreases biomass carbon stock, and disturbance in the form of fire and harvest. Wildland fire provides a major source of carbon emissions in forested settings, and is discussed in detail in the carbon emissions section of this document. Biomass harvest plays a varying role in carbon emissions, depending largely on the use of the wood products. For example, wood products utilized as saw timber in construction tends to provide long term carbon storage with slow release, while wood products used as fuelwood and burned for heat provide increased carbon emissions into the atmosphere. As ecosystems are constantly changing through natural succession and disturbance, biomass carbon stock also changes through time. This section will focus on biomass carbon stocks over time on lands of the Santa Fe National Forest (NF). For the purpose of this section, biomass carbon stock includes aboveground live biomass, standing dead biomass, downed woody debris, litter and duff, and below-ground live biomass (below-ground nonliving plant material is considered in soil organic carbon). The methods for deriving biomass values for seral states within forest and woodland ecosystems are included in Appendix 1.

Current Conditions: Biomass Carbon Quantities

The Santa Fe NF can be stratified into 11 major ecosystem types referred to as Ecological Response Units or ERUs (table 67). Each ERU contributes differently to carbon stocks and their flux based on its spatial extent, vegetation community composition and structure, and ecosystem dynamics. Generally speaking,

relative contributions to carbon stocks are lowest in grassland and shrubland ERUs, with increasing contributions by woodland and forest ERUs, respectively.

Table 67. Major ERUs on the Santa Fe NF in acres and percent

ERU	System Type	ERU Code	Acres	Percent
Montane Subalpine Grassland	Grassland	MSG	17,707	1.1%
Colorado Plateau – Great Basin Grassland	Grassland	CPGB	41,639	2.6%
Sagebrush Shrubland	Shrubland	SAGE	37,457	2.3%
Pinyon Juniper Sagebrush	Woodland	PJS	30,449	1.9%
Pinyon Juniper Grassland	Woodland	PJG	43,356	2.7%
Juniper Grassland	Woodland	JUG	97,470	6.0%
Pinyon Juniper Woodland	Woodland	PJO	231,508	14.3%
Ponderosa Pine Forest	Forest	PPF	403,915	24.9%
Mixed Conifer – Frequent Fire	Forest	MCD	429,967	26.5%
Mixed Conifer – With Aspen (w/ Elk)	Forest	MCWE	40,174	2.5%
Spruce Fir Forest (w/ Elk)	Forest	SFFE	250,481	15.4%
		Totals	1,624,123	100.0%

The figures and tables presented in this section represent carbon stock for current conditions, reference conditions, and for select ERUs, modeled future conditions under current management intensities. We will refer to each ERU by its assigned two- to three-letter code; for reference, these appear in the third column of table 67. Carbon stock values are presented below both by ERU and collectively for the Santa Fe NF. As we will demonstrate below, the current Forest carbon stock overall is about 118 percent of that present in reference (historic) conditions. A more complete picture can be drawn by looking at relative contributions from individual ERUs.

As illustrated in table 68, figure 58, and figure 59, the biomass carbon stock has decreased somewhat in one grassland system (CPGB), all woodland systems (PJS, PJG, JUG, PJO), and in the two forest systems within which wildfires were historically infrequent (MCWE and SFFE). Conversely, biomass carbon stocks have increased in the other grassland system (MSG), the only shrubland system prevalent on the Santa Fe NF (SAGE), and in the two forest types within which wildfires were historically frequent (PPF and MCD). The most dramatic differences are seen in MSG, one of the grassland systems, which has become tree and shrub encroached and now contains 123 percent biomass of reference conditions, and PPF, one of the two frequent-fire forest systems, which now holds over 40 percent more biomass than present in reference conditions. Results for MSG should be interpreted with caution, as carbon coefficients and the vegetation model for this system are both under review and revision. For the most part, carbon increases coincide with tree and shrub increase and encroachment in grasslands and shrublands, and with tree expansion in fire-adapted (frequent fire) forest ecosystems. Decreases are coincident with those systems of low to moderate fire frequency (MCWE and SFFE). Carbon increases in the fire-adapted types are presumably associated with land management patterns, including the decades-long policy of fire suppression, and limited harvest of trees in the most recent years and decades. The reduction in woodland biomass may be associated, at least in part, with chaining and other modifications that have resulted in overstory removal.

Table 68. Biomass carbon stock per ERU in reference and current conditions

Shading in orangewith line patterns indicates an *increase* in carbon stock, and shading in grey indicates a *reduction* in carbon stock. In both cases, deeper hues reflect greater departure from reference conditions.

System Type	ERU	Reference Condition (tons)	Current Condition (tons)	Departure (%)
Grassland	**MSG**	**25,622**	**57,079**	**122.8%**
	CPGB	**123,173**	**158,622**	**28.5%**
Shrubland	**SAGE**	**184,597**	**224,343**	**21.5%**
Woodland	PJS	368,605	268,348	-27.2%
	PJG	615,908	532,127	-13.6%
	JUG	1,418,465	1,330,627	-6.2%
	PJO	5,077,819	4,031,786	-20.6%
Forest	**PPF**	**12,073,018**	**17,103,934**	**41.7%**
	MCD	**25,217,432**	**29,800,962**	**18.2%**
	MCW	3,524,277	3,175,945	-9.9%
	SFF	24,000,294	21,718,522	-9.5%
	Totals	**45,104,640**	**53,507,827**	**18.6%**

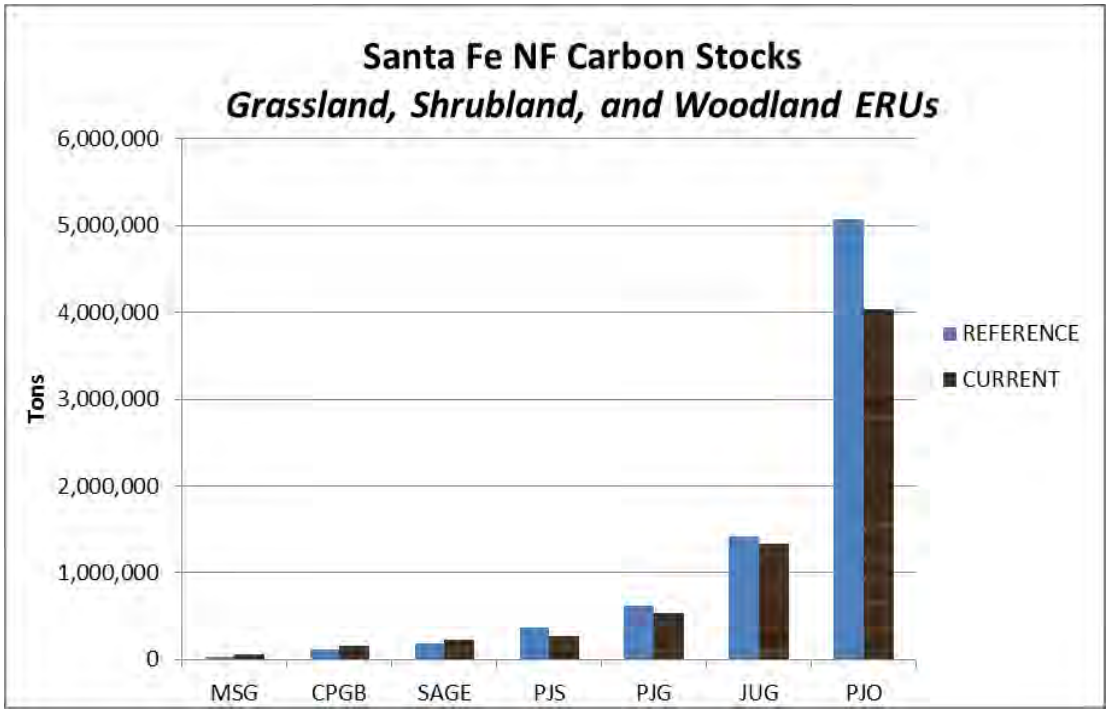


Figure 58. Biomass carbon stock by grassland, shrubland and woodland ERUs in current and reference conditions

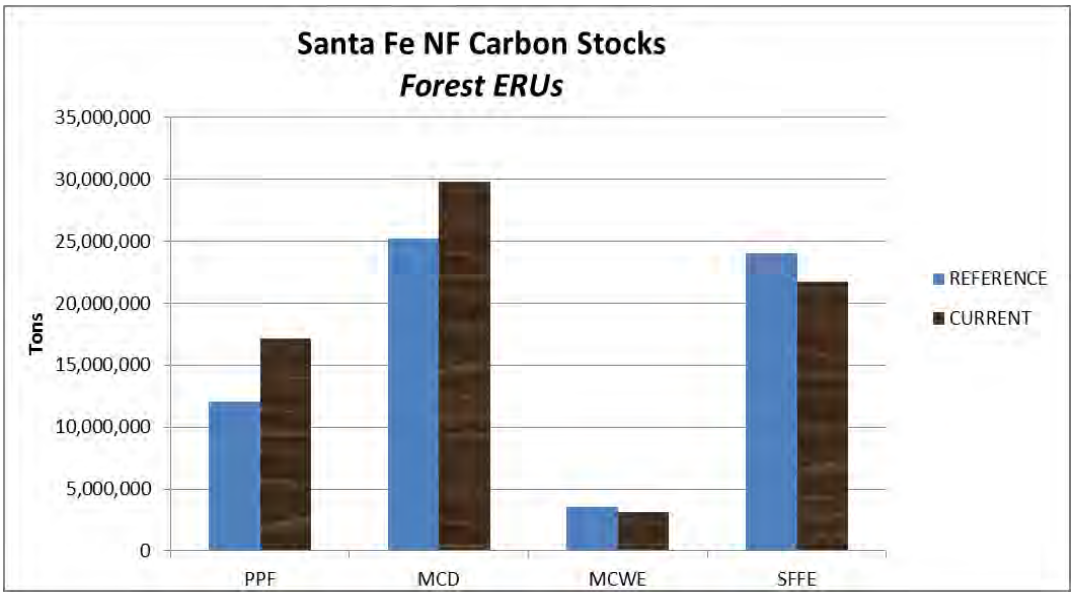


Figure 59. Biomass carbon stock by Forest ERU in current and reference conditions

Trends: Biomass Projections

Many factors will influence future carbon stocks on the Santa Fe NF, and this assessment is in no way a comprehensive accounting of all possible outcomes. Factors such as climate change, fire frequency and severity, and management budgets are all outside the control of Santa Fe Forest managers, and as such, this assessment may be useful in conveying only general patterns and trends. However, general ecosystem dynamics in southwestern systems are fairly well understood, and provide a good starting point for assessing trends in biomass carbon stocks. Vegetation conditions on the Santa Fe NF have been modeled into the future for most of its predominant ERUs using State and Transition Modeling (STM), including assumptions based on current management and disturbance patterns.[16] This allows the projection of relative biomass carbon contributions through time for key ERUs (see a full description of process and methodology in Appendix 1). Using past observations of stand development dynamics and management applications for future projections is, admittedly, inherently problematic in light of projected climate changes.

Methods

The vegetation characterization and state-and-transition modeling approaches used in other parts of the Assessment process were the foundation for our biomass carbon stock assessment as well. Please refer to the full Assessment document for details of these processes. To translate these vegetation condition characterizations (for reference conditions, current condition, and a modeled 100-year future condition) into biomass carbon stock quantities, we developed carbon coefficients for each seral state of each model to represent the tons of biomass carbon occurring per acre in that state. The total biomass carbon for a given ERU was then calculated simply by multiplying the acreage per seral state by the corresponding coefficient, and summing across all state classes in a given ERU.

[16] Modeling was conducted by the Santa Fe National Forest and Region 3 staff, August 2014 – April 2015.

Assignment of Carbon Coefficients

For each seral (or successional) state in each ERU, we have assigned carbon stock coefficients based on either information gleaned from the scientific literature and web resources (for desert, grassland, and shrubland ERUs; Boyd and Bidwell 2001, Brooks and Pyke 2001, Scott and Burgan 2005, USFS 2012) or (for woodland and forest ERUs) from FIA sample data and the carbon sub-model of FVS – Fire and Fuels Extension (Rebain, S. et al. 2015).

Because data were sparse regarding biomass carbon values for the grassland and shrubland ERUs occurring on the Santa Fe NF, where we were unable to find data specific to these systems, we made use of data from corollary state classes in other ERUs in other locations, primarily drawing upon plots sampled as part of the Natural Fuels Photo Series project (Wright et al. 2007, USFS 2012). In these efforts, we attempted to pair each seral state missing a carbon estimate with plots with similar plant community structure and climatic conditions to draw aboveground biomass carbon estimates per acre. Where we were able to find multiple plots that seemed equally appropriate matches, we averaged the aboveground carbon mass per acre from each of these to derive a single value for each seral state in each ERU.

It is worth noting that we were unable to find adequate data to address below-ground carbon in grassland and shrubland ERUs. We were also unable to locate adequate data to quantify above- or below-ground biomass carbon contributed by herbaceous understory species in woodland and forest systems, and carbon coefficients for these systems only include woody species and materials.

Calculation of Biomass Carbon Values

Carbon stock totals for each ERU were derived by multiplying the current or forecasted total acreage in each seral state by the corresponding carbon coefficient, and summing across all seral states. This process was repeated for the reference state class distribution, current state class distribution, and 100-year projected future state class distribution for each ERU.

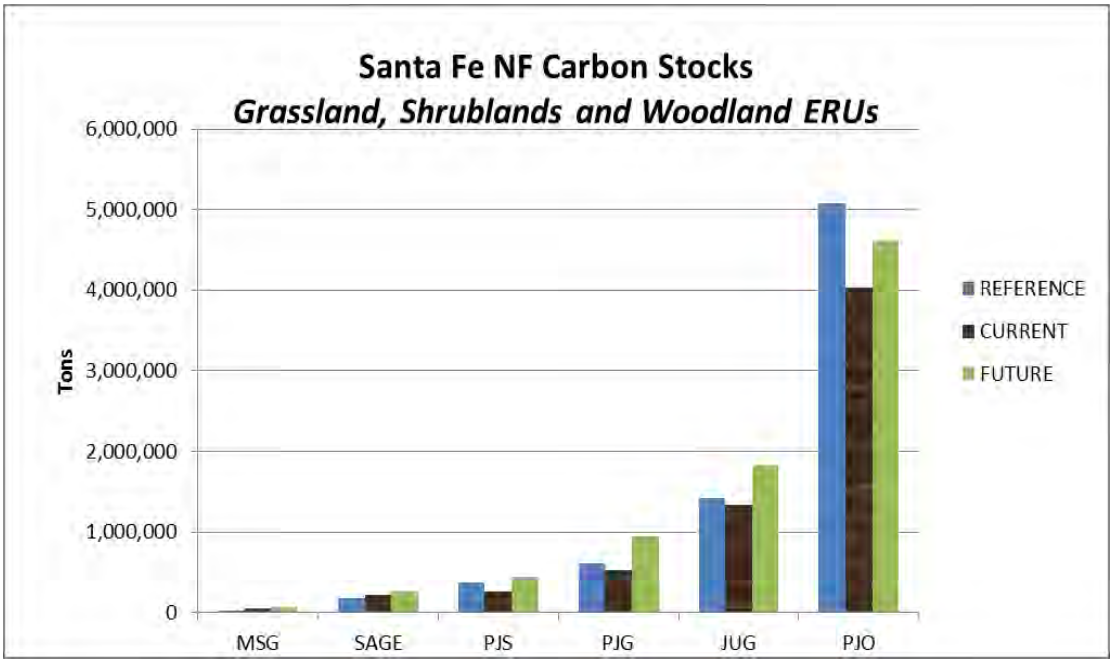


Figure 60. Trends in carbon stocks for Santa Fe NF grassland, shrubland and woodland ERUs

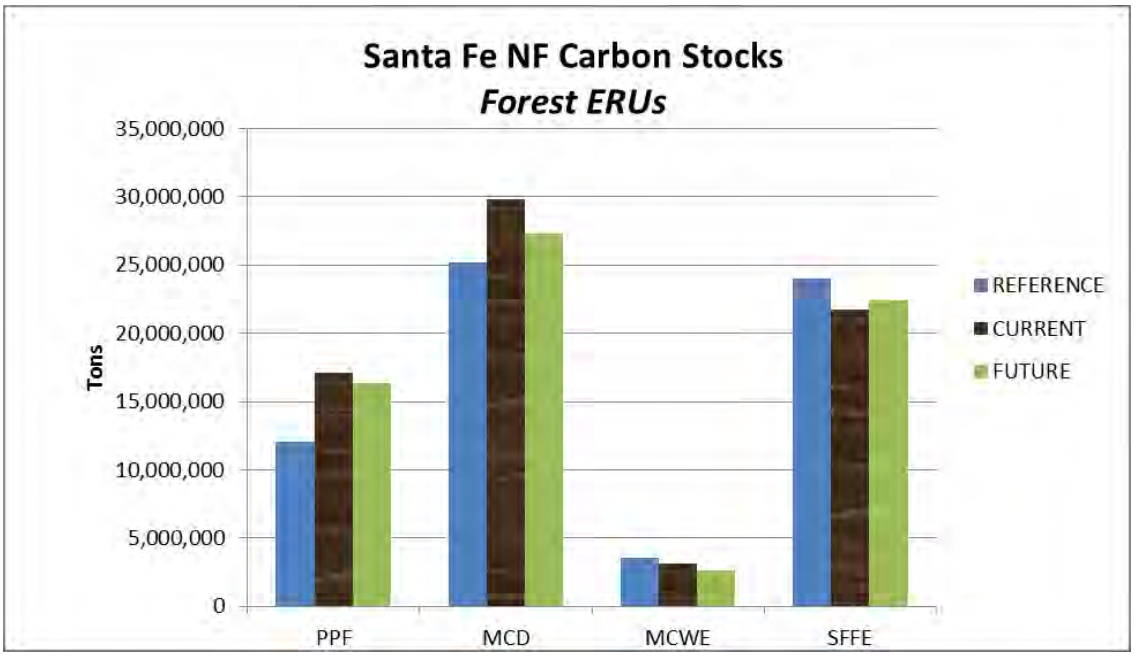


Figure 61. Trends in carbon stocks for Santa Fe NF forest ERUs

Table 69. Projected carbon stocks for major ERUs of the Santa Fe NF

ERU	Current Condition (tons)	Projected +100 years (tons)	*Projected +100 years (% change from current)*
MSG	57,079	70,476	23.5%
SAGE	224,343	262,950	17.2%
PJS	268,348	443,589	65.3%
PJG	532,127	941,636	77.0%
JUG	1,330,627	1,828,469	37.4%
PJO	4,031,786	4,620,260	14.6%
PPF	17,103,934	16,396,685	-4.1%
MCD	29,800,962	27,264,090	-8.5%
MCWE	3,175,945	2,674,948	-15.8%
SFFE	21,718,522	22,439,765	3.3%
Total	***78,243,672***	***76,942,868***	***-1.7%***

Figure 60 and figure 61 depict 100-year projections for primary Santa Fe NF ERUs against current and reference conditions. Projected change from current conditions is also in table 69. These projections assume a continuation of current management, and are not reflective of changes in management that may emerge from the Santa Fe's ongoing effort to revise its land management plan. However, these results do provide meaningful trend information with regards to biomass carbon storage in the near future. The general pattern of biomass carbon stock projections on the Santa Fe NF (assuming continuation of current management patterns) indicates a projected increase in total carbon storage above current conditions in nearly all modeled ERUs. Exceptions, which display projected reductions in vegetation biomass carbon

stocks, include PPF, MCD, and MCWE. Model improvements are necessary before too much interpretation is applied to predictions in the MSG, PPF and MCD systems, but the direction of change projected in PPF and MCD is consistent with management direction toward reference condition structure. The increases in carbon stock projections in all of the woodland ERUs are consistent with a shift to larger diameter trees and an increase in canopy closure in these systems.

Carbon Emissions – Synthesis of Study by Vegh et al. (2013)

Introduction

For the Santa Fe NF assessment, carbon emissions have been characterized below by using a case study synthesis from the Apache-Sitgreaves NFs (Vegh et al. 2013), relevant to forested ecosystems of the Southwest in terms of natural processes and common management activities. The study provides a surrogate solution for emissions assessment in lieu of emissions data and analysis specific to the Santa Fe NF.

Background

To date there has been no binding commitment by the federal government or Forest Service for the regulation of carbon dioxide (CO_2), though there has been increasing activity at state and regional levels to control carbon emissions to the atmosphere, prompting regulation, voluntary carbon exchanges, and carbon inventory and monitoring programs (Wiedinmyer and Neff 2007). The Forest Service Planning Rule directs forests to assessment baseline carbon stocks as part of the forest planning process (36 CFR 219.6(b)(4)), and though there are other carbon constituents released in wildfire and prescribed burning, CO_2 is the primary carbon compound and primary greenhouse gas associated with fire emissions (table 70).

Table 70. Proportion of constituents of wildfire emissions for both greenhouse gases (GHG) and carbon compounds (NRC 2004)

Wildfire Emissions	Proportion GHG	Proportion Carbon Constituents
Carbon Dioxide	72.14%	90.82%
Water	21.18%	
Carbon Monoxide	5.57%	7.02%
Atmospheric particulate matter <2.5µ		0.60%
Nitric Oxide	0.39%	
Methane	0.27%	0.34%
Volatile Organic Compounds	0.24%	0.31%
Organic Carbon		0.31%
Non-methane Hydrocarbon	0.20%	0.25%
Particulate Matter > 10µ		0.22%
Particulate Matter <10µ and >2.5µ		0.11%
Elemental Carbon		0.03%
Totals	100.00%	100.00%

Though emissions by fire and other forest processes (e.g., methane from the decomposition of wood) have a relatively minor impact on carbon stocks and flux, atmosphere-based emissions are strongly impacted by biosphere-atmosphere carbon fluxes at regional scales, and represent the carbon component directly involved in the positive feedback of greenhouse gas forcing on climate change. In a given year in the

Southwest, carbon emission from fire can exceed fossil fuel emissions at regional scales (Wiedinmyer and Neff 2007). In their study of fire emissions, Wiedinmyer and Neff found that on average carbon emissions were 4 to 6 percent of the total anthropogenic emissions for the United States. In a separate study, Woodbury et al. (2007) estimated that 10 percent of total anthropogenic emissions in the US are captured by forest vegetation, to suggest that forests can sequester more carbon than they emit and become an offsetting solution for anthropogenic emissions. The Intergovernmental Panel on Climate Change (IPCC) recognizes the potential for forest and woodland ecosystems, in particular, to perform climate change mitigation (IPCC 2007). In assessing carbon dynamics and emissions in the Southwest, Hurteau and others (e.g., Hurteau et al. 2008, North et al. 2009, Hurteau and North 2010) went further and proposed that large releases of carbon to the atmosphere could be minimized by reducing stand densities. Prior to the Apache-Sitgreaves NF study (presented below), it had been hypothesized, and shown through dynamical modeling and observation (Kobziar et al. 2009, Martinson and Omi 2013, Pollet and Omi 2002), that the reduction of stand densities precludes large pulses of wildfire emissions with a reduction in uncharacteristic fire, such as stand replacement fire in ponderosa pine forests. Preliminary research indicates that the sustainable management of forests, along with careful consideration of byproducts and management residues, would not only balance forest carbon stocks but could also partially mitigate global climate change through increased carbon storage.

Apache-Sitgreaves Study Overview

Recent research on carbon dynamics and emissions related to various conventional forest management activities, focused specifically on the Apache-Sitgreaves (A-S) National Forest in eastern Arizona and western New Mexico, provides surrogate information to guide national forests of the Southwest in the assessment and management of carbon (Vegh et al. 2013), which we are using here in lieu of more specific analysis of carbon emissions.

A key objective of the A-S study was to determine the long-term (100 years) difference in carbon stocks and carbon emissions between treated and untreated forest ecosystems. While the study was focused on the Ponderosa Pine Forest ERU, the results can be abstracted to other forest and woodland ecosystem types for purposes of characterizing general trends among reference condition, no-action, and treatment scenarios, in terms of (1) fire carbon emissions, (2) total (live and dead) above-ground biomass, and (3) live above-ground biomass. And while the Vegh et al. study did not consider the effects of forest restoration per se (sensu R3 desired conditions), they did evaluate the effects of reduced tree densities on carbon stocks and flux.

Analysis

In their study, Vegh et al. (2013) compare the effects of different management alternatives on overall carbon stocks and emissions. They apply three management alternatives – no action, light thinning, heavy thinning – to determine the overall management effects on carbon sequestration and emissions flux. The researchers used the Forest Vegetation Simulator (FVS) to model stand dynamics over a 100-year simulation and report outcomes for carbon stocks and emissions. For annual treatment in the analysis simulation, all suitable stands on the A-S NF were prioritized in order of the following conditions:

1. Wildland-urban interface (WUI) areas in high departure plant communities
2. WUI areas in moderate departure plant communities
3. Non-WUI areas in high departure plant communities
4. Non-WUI areas in moderate departure plant communities

5. WUI areas in low departure plant communities

6. Non-WUI areas in low departure plant communities

In all cases, "departure" is a measure of similarity between the current and reference (historic) vegetation structure, with high departure reflecting vegetation heavily altered from past structural conditions, and low departure indicating a distribution of structural states that are highly similar to those we would have expected pre-European settlement. In the FVS simulations, individual stands were further prioritized for treatment according to basal area (BA) and quadratic mean diameter (QMD), so that stands with the greatest stocking (i.e., BA) and the smallest trees (i.e., QMD) would be given highest priority for treatment.

In their modeling, the investigators assumed conventional treatment scenarios and contemporary wildfire frequencies. Stands with a preponderance of large trees over 16 inches in diameter were not included, due to some social constraints. Carbon emissions were estimated for wildfires, prescribed burning, and pile burning. In the simulations, all thinning harvests were followed by pile burning in the second year, and by broadcast burning in the tenth year. The researchers also assumed that trees would regenerate successfully after burning.

Findings and Discussion

In their results, Vegh et al. (2013) reported that carbon emissions and stocks were affected by both management alternatives and wildfire frequency. In the reporting, carbon stocks were divided into above-ground live biomass and into total carbon occurring above- and below-ground, both live and dead. The following results were generated from the 100-year model simulation:

- The no-action alternative resulted in the lowest total carbon emissions since no treatments would occur under these alternatives. The alternatives with management treatments produced approximately five times the total carbon emissions of the no-action alternative.

- Carbon emissions by wildfire were lower in the treatment alternatives than in the no-action, and wildfire emissions were lowest in the alternative with the greatest degree of thinning. Resulting wildfire emissions associated with the heavy thinning alternative were up to half the amount of emissions of the light thinning alternative, and about one third less than the no-action alternative.

- Total carbon stocks (above- and below-ground, live and dead) were lower in the treatment alternatives than in the no-action alternative, due to thinning and the removal of live tree biomass, assuming similar wildfire frequency and severity as the last three decades (1980 to 2009). The lowest carbon stocks were found in the heavy thinning alternative.

- Carbon stocks for live above-ground biomass alone were highest in the treatment alternatives, particularly in the second half of the simulation due to the accumulation of carbon in large fire-resistant trees.

We might also conclude that at landscape scales, total above-ground carbon stocks would remain somewhat higher in the treatment scenarios than in the reference condition, because of the number of untreated plant communities and because of a lower overall fire frequency compared to reference (due to fire suppression activities and loss of fine fuels in some ecological systems).

Summary and Conclusions

Biomass

Table 68 summarizes reference (historic) and current carbon conditions for ERUs of the Santa Fe NF. As one might expect, on an acre-for-acre basis the grassland ecosystems (MSG and CPGB) had the least biomass carbon concentration historically (1.4 - 3 tons/ac), while the moist forest systems had the greatest (88 tons/ac in MCWE and 96 tons/ac in SFFE). The remaining ERUs ranged from 5 to 59 tons per acre, with dry forest ERUs having the greatest concentrations, followed by woodlands, then shrubland ERUs.

The Santa Fe NF's woodland systems currently demonstrate the largest reductions from reference conditions, likely due to historic chaining activity that removed large quantities of juniper from these ecosystems. Our model predictions indicate an anticipated recovery of biomass carbon above and beyond that calculated to have occurred in reference conditions in PJS, PJG and JUG, and a trend toward reference conditions in PJO (see Figure 60) as a result of limited disturbance.

Conversely, several systems currently hold much larger biomass carbon stocks than they would have under reference conditions: MSG, CPGB, PPF and MCD. The largest increase currently occurs in MSG, at 123 percent above reference levels; because of the limited extent of this ERU on the Santa Fe, this translates to a relatively minor increase of approximately 31,000 tons across the Santa Fe NF. Projections indicate an additional 13,000 ton increase in this system after 100 years. As noted earlier, it is important to interpret these results cautiously, as both the carbon coefficients and vegetation model for this system are under review and revision. While smaller in the percentage of their discrepancy from reference conditions, the total mass of carbon increase is far greater in the dry forest ecosystems. PPF has experienced a 42 percent increase over reference conditions in biomass carbon, yielding a total increase across the Santa Fe NF of over 4M tons of carbon. Similarly, MCD has experienced an increase in biomass carbon of 18 percent above reference conditions, totaling almost 1.2M tons. In all three of these systems, as well as in CPGB, the increase in biomass is believed to have resulted from fire suppression activities resulting in tree encroachment into grasslands, and denser, more heavily vegetated conditions in the dry forest systems. Model predictions indicate a reduction in biomass carbon in PPF and MCD after 100 years (consistent with management direction), but a continued pattern of increase in biomass in MSG. Again, these three models are all under review, and their predictions should be interpreted cautiously.

Across the Santa Fe NF, the current biomass carbon mass is 18.6 percent above that present in reference conditions. Our model predictions reflect a reduction in total biomass carbon after 100 years, but even at this reduced level total biomass carbon mass is expected to exceed that present in reference conditions by 14.9 percent. Note that our estimates for forest and woodland systems include tree biomass only, and do not capture biomass contributed by understory vegetation. Further, we lack data sources to reflect below-ground biomass in the grassland and shrubland ERUs; our estimates in these ERUs thus reflect aboveground biomass only, and are also therefore likely to be underestimates of reference, current and future biomass carbon.

Carbon Emissions

Similar to implications of biomass conditions and resource management, the research synthesis on carbon emissions convey significant trade-offs among potential carbons strategies. Although the total carbon emissions were higher for the harvest alternatives in the study considered here (Vegh et al. 2013), thinning and fuels reduction did reveal lower wildfire emissions and reduced risk of uncharacteristic wildfire. The study also suggests that, in the long term, systematic thinning and burning ultimately lead to greater live above-ground sequestration. It's also important to keep in mind that the A-S is starting with uncharacteristically high levels of biomass on the heels of a century of fire suppression, and that strategies

to maximize carbon sequestration and sustain carbon stores are not necessarily compatible (Hurteau and Wiedinmyer 2010). The indirect goal of contemporary management goals is to reduce, at least in part, current carbon stocks to pre-settlement levels.

In the future, the benefits to reduced emissions and increased carbon sequestration may be more pronounced. First, because live trees continually sequester carbon and are a more stable carbon sink than dead biomass generated in particular by uncharacteristic fire, insect outbreaks, drought, and other stress, proactive management and broad-scale fuel reduction may be preferable for the long-term mitigation of atmospheric carbon. Second, there is the related issue of trees regenerating poorly or not at all following uncharacteristic fire in some forest types (Savage and Mast 2005). Others investigators (Dore et al. 2008) also show that poor regeneration after stand replacement fire in ponderosa pine can render plant communities as C sinks for many years after the fire, casting further doubt on the sustainability of a strategy that intends to maximize sequestration while indirectly promoting uncharacteristic fire and reduced ecosystem productivity (Hurteau and Wiedinmyer 2010).

The A-S study by no means represents a comprehensive analysis of the carbon emissions involved with forest management scenarios. A full accounting would include emissions involved in the harvest, transfer, and processing of any wood products, along with the sequestration and decomposition of those products and other forest residues, and the emissions involved with the associated energy consumption (Cameron et al. 2013). Cameron and others determined, on a 100-year model simulation, that even with an industrial forestry theme that the ratio of storage to emissions was 0.58. They also showed that if wood destined for paper and pulp was instead redirected to less lucrative biomass consumption that the storage ratio could increase substantially to 2.7.

Also for consideration are the effects by increased CO_2 levels on vegetation productivity and the potential for negative feedback by emissions on climate forcing. Such a feedback loop would involve carbon emitting processes, increased CO_2 levels and fertilization of the atmosphere, followed by an increase in vegetation production and increased carbon capture and sequestration (mitigation). Some research indicates that vegetation productivity does increase with elevated CO_2 levels, but productivity rates soon level off as other factors appear to compete with the growth benefits (Archer 2011, Penuelas et al. 2011).

Finally, some have forwarded the notion of *carbon carrying capacity* as a potential foundation for carbon management plans (Keith et al. 2009, 2010; Hurteau et al. 2010). Carbon carrying capacity is the maximum amount of above-ground carbon that can be sustainably stored, according to climatic conditions and the disturbance regime of a system. Carbon carrying capacity may be a useful consideration for optimizing carbon stocks according to the inherent capabilities and processes of a given ecosystem.

Soil Organic Carbon

Please see Chapter 4. Soils ***for details regarding Soil Organic Carbon for the Santa Fe NF.***

Climate Change

Although regional climates persist for centuries, they do change and vegetation responds on a similar scale (Delcourt et al. 1983). The ecosystems we see today are the products of species evolution and migration over time on a constantly shifting landscape driven by climate. Climates change at a variety of scales. Long-term, persistent trends in temperature and humidity determine the extent and location of various life zones, the elevation at which one biotic community replaces another. Short-term fluctuations in the order of years to decades determine drought cycles, fire frequencies, and pulses of tree reproduction. The Southwest is strongly influenced by oscillation in the Pacific ocean-atmosphere system. El Nino years, bring increased annual precipitation but less rain in the summer and years of La Nina bring the opposite (Batancourt et al. 1993).

Two most important factors for determining fire regimes are vegetation type (or ecosystem) and weather and climate patterns. Fire history provides evidence of past relationships between fire and climate. That evidence makes it clear that changing climate will profoundly affect the frequency and severity of fires, and vegetation ultimately, in many regions and ecosystems in response to factors such as earlier snowmelt and more severe or prolonged droughts (Westerling et al. 2006; Bowman et al. 2009; Flannigan et al. 2009; Littell et al. 2009; Morgan). Changing climate will also alter the growth and vigor of existing vegetation, with resulting changes in fuel structure and dead fuel loads. For these reasons, land managers need to assess ongoing and potential effects of climate change, and coordinate a response for ecosystems, species, and human communities.

The Nature Conservancy (TNC), the Integrated Landscape Assessment Project (ILAP), and others have developed assessments, tools, and methods for evaluating vulnerability for key ecological components. Based on the anticipated effects of climate change on site potential, the vulnerability of individual plant communities is assessed and scored as low, moderate, high, and very high, according to the degree by which their climate envelopes are exceeded under future climate projections. Climate envelopes were developed for each major ERU on the Santa Fe NF using contemporary climate data for Arizona and New Mexico. ERUs were segmented based on site potential and each segment was assigned a vulnerability score based on the projected departure in future climate from the current climate envelope of the given ERU. Departure scores are then averaged together across the plan scale, by ERU within the plan scale, and by ERU at the local scale (additional detail found in Triepke 2014).

Vulnerability reporting: This assessment categorizes climate change vulnerability based on individual plant communities and the projected difference between contemporary climate envelopes and projected climate conditions. Four categories of vulnerability are reported.

Uncertainty reporting: Future climate projections based on different General Circulation Models (GCMs) provide somewhat different values, reflecting uncertainty with a given vulnerability prediction for some ERUs in some areas. To address this concern, the Climate Change Vulnerability Assessment (CCVA) provides a measure of uncertainty, which represents the degree of disagreement between different GCMs, within a given emission scenario. Three GCMs were used to assess uncertainty (Third Generation Coupled Global Climate Model (CGCM3), Hadley Centre Coupled Model, verison 3 (HADCM3), and Geophysical Fluid Dynamics Laboratory Circulation Model (GFDLCM21)). Uncertainty is reported using a simple agreement process and categories.

Table 71. Climate change vulnerability based on the projected climate departure from the historic climate envelope for the Santa Fe NF

Vulnerability Category	Uncertainty Category Low	Uncertainty Category Mod	Uncertainty Category High	Total
Low Vulnerability	12%	12%	0%	24%
Moderate Vulnerability	2%	40%	13%	54%
High Vulnerability	6%	8%	0%	14%
Very High Vulnerability	8%	0%	0%	8%
Grand Total	**27%**	**60%**	**13%**	

Uncertainty category captures the amount of disagreement between the different global climate models.

Table 72. Climate change vulnerability and uncertainty for each major (>1% plan scale representation) ecological response unit (ERU)

ERU	Vulnerability Category	Uncertainty Category Low	Uncertainty Category Mod	Uncertainty Category High	Total
CPGB	Low Vulnerability	12%	3%	0%	15%
	Moderate Vulnerability	0%	39%	22%	61%
	High Vulnerability	1%	1%	0%	3%
	Very High Vulnerability	22%	0%	0%	22%
CPGB Total		36%	43%	22%	
JUG	Low Vulnerability	20%	9%	0%	29%
	Moderate Vulnerability	6%	42%	5%	54%
	High Vulnerability	2%	13%	0%	15%
	Very High Vulnerability	2%	0%	0%	2%
JUG Total		31%	64%	5%	
MCD	Low Vulnerability	16%	22%	0%	38%
	Moderate Vulnerability	0%	47%	12%	59%
	High Vulnerability	1%	2%	0%	3%
	Very High Vulnerability	1%	0%	0%	1%
MCD Total		17%	71%	12%	
MCW	Low Vulnerability	0%	1%	0%	1%
	Moderate Vulnerability	0%	49%	48%	97%
	High Vulnerability	0%	2%	0%	2%
	Very High Vulnerability	0%	0%	0%	0%
MCW Total		0%	52%	48%	
MSG	Low Vulnerability	32%	59%	0%	91%
	Moderate Vulnerability	0%	8%	0%	8%
	High Vulnerability	0%	0%	0%	0%
	Very High Vulnerability	0%	0%	0%	0%
MSG Total		32%	67%	0%	

ERU	Vulnerability Category	Uncertainty Category Low	Uncertainty Category Mod	Uncertainty Category High	Total
PJG	Low Vulnerability	0%	1%	0%	1%
	Moderate Vulnerability	0%	18%	9%	27%
	High Vulnerability	7%	15%	0%	22%
	Very High Vulnerability	50%	0%	0%	50%
PJG Total		57%	33%	9%	
PJO	Low Vulnerability	20%	6%	0%	26%
	Moderate Vulnerability	7%	44%	7%	57%
	High Vulnerability	3%	9%	0%	12%
	Very High Vulnerability	5%	0%	0%	5%
PJO Total		35%	58%	7%	
PJS	Low Vulnerability	2%	2%	0%	4%
	Moderate Vulnerability	0%	6%	4%	10%
	High Vulnerability	14%	3%	0%	17%
	Very High Vulnerability	68%	0%	0%	68%
PJS Total		85%	11%	4%	
PPF	Low Vulnerability	5%	8%	0%	13%
	Moderate Vulnerability	0%	41%	22%	62%
	High Vulnerability	6%	10%	0%	16%
	Very High Vulnerability	8%	0%	0%	8%
PPF Total		20%	59%	22%	
SAGE	Low Vulnerability	48%	47%	0%	96%
	Moderate Vulnerability	4%	0%	0%	4%
	High Vulnerability	0%	0%	0%	0%
	Very High Vulnerability	0%	0%	0%	0%
SAGE Total		53%	47%	0%	
SFF	Low Vulnerability	0%	7%	0%	7%
	Moderate Vulnerability	0%	38%	11%	49%
	High Vulnerability	20%	13%	0%	33%
	Very High Vulnerability	11%	0%	0%	11%
SFF Total		31%	58%	11%	

Chapter 7. Integrated Risk Analysis

Ecosystem characteristics are often related, and corroborating risk assessments can help in making determinations. Risk is a measure of the ecosystem characteristic status (i.e., departure from reference or lack thereof) in combination with trend and consideration given to any additional stressors (e.g., climate change) not already addressed in the trend analysis. The integration of risk synthesizes risk for each of the key ecosystem characteristics aggregated to one common scale, the vegetative local scale or local zones, to allow for the identification of patterns of resource risk; as more characteristics at risk in a defined landscape generally implies greater severity and concern. Additionally there is opportunity to identify characteristics or occurrences that may be impacting other ecosystem characteristics and to what extent.

Risk has been generalized into three vulnerability categories of low, moderate, and high using the matrix below (figure 62) and is summarized in table 73 for most of the key ecosystem characteristics across all resources analyzed in the assessment. Stressors are not incorporated into the matrix below, but do intensify risk and therefore are assumed to increase the level of risk by one level (e.g., moderate to high) if considered significant and influenced by that stressor in that local zone. High insect and disease and climate change ratings are considered significant stressors.

Risk Matrix				
Departure	High	Mod	High	High
	Mod	Low	Mod	High
	Low	Low	Low	Mod
		Towards	Stable	Away
		Trend (Reference Conditions)		

Figure 62. Risk Matrix based on departure and trend

Risk for each characteristic is summarized for the plan scale in the far right column and Integrated Risk across all resources within each local zone is identified at the bottom of the Integrated Risk table.

Table 73. Integrated Risk table displaying risk for key ecosystem characteristics for all resources at the plan and vegetation local scales

Resource	Ecosystem characteristic	Local - NWZ	Local - SWZ	Local - CZ	Local - NEZ	Local - SEZ	Plan
Upland Vegetation	Seral State Proportion	Moderate	High	High	High	Moderate	Moderate
	Similarity to Site Potential	Moderate	Moderate	Moderate	Low	Moderate	Moderate
	Ground Cover	Low	Low	Moderate	Low	Low	Low
	Coarse Woody Debris	High	High	High	Moderate	High	High
	Snag Density	Low	Low	Low	Low	Low	Low
	Mean Patch Size	High	High	High	Moderate	Moderate	Moderate
	Fire Frequency	High	High	Moderate	Moderate	High	High
	Fire Regime Condition Class	High	High	High	Moderate	Moderate	Moderate

Resource	Ecosystem characteristic	Local - NWZ	Local - SWZ	Local - CZ	Local - NEZ	Local - SEZ	Plan
Riparian Vegetation	Veg. Function	Moderate	Moderate	Moderate	High	Moderate	Moderate
	Ground Cover	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
	Ecological Departure	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
	Coarse Woody Debris	Low	Low	Low	Low	Low	Low
	Snag Density	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
	Fire Frequency	High	High	Low	Moderate	High	High
Soils	Soil Condition	High	Moderate	High	Low	High	High
	Soil Loss	Moderate	Low	Moderate	Low	Moderate	Moderate
	Soil Carbon	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
Water Resources	Surface Water (SW) Quantity	High	High	High	Moderate	Moderate	High
	Surface Water Quality	Moderate	High	Low	Moderate	Low	Moderate
	SW, Stream Distribution	Low	Low	Moderate	Moderate	Moderate	Moderate
	SW, Seep/Spgs Distribution	High	Moderate	High	Moderate	Moderate	High
	SW, Waterbody Distribution	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
	Water Rights, Surface Water	High	High	Low	Moderate	Low	Moderate
	Water Rights, Ground Water	Moderate	High	Low	Moderate	Moderate	Moderate
	Wetlands	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
	Watershed Condition Class	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Aquatic Biota	Native Species	Moderate	Low	High	Moderate	High	Moderate
	Invasive Species	Low	Low	Moderate	High	Low	Low
	Macroinvertebrates	Low	Low	Low	Low	Low	Low
Species	# Of At Risk Species	3	2	4	6	3	
	TES Species	3	3	2	2	1	
Air Resources	Deposition (Critical Load	Low	Moderate	Low	Moderate	Low	Low
Stessors	Climate Change	Moderate	Moderate	High	Moderate	Moderate	Moderate
	Insect and Disease	Moderate	Moderate	Low	High	Low	Moderate
Other	Erosion Hazard	High	High	High	High	High	High
	Visibility and NAAQS	Low	Low	Low	Low	Low	Low
	Integrated Risk	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate

Forestwide

Integrated Risk is generally categorized as moderate across all local zones on the Santa Fe NF. Although risk for most characteristics does vary amongst the local zones, the integration of risk for each of the zones results in a moderate rating across the Forest.

The exclusion of wildfire is probably one of the biggest alterations to Southwest landscapes including the Santa Fe NF. The removal of wildfire from ecosystem has led to the degradation, both direct and indirectly, of many of the key ecosystem characteristics. As mentioned in a previous chapter (Chapter 1, Terrestrial Vegetation), the Santa Fe NF is primarily comprised of ecological response units, or vegetation types that historically supported frequent fire (<30-year return intervals); a little over one-million acres (or 62 percent) of the forest fall into this regime. With the extensive suppression of wildfire on the landscape occurring at the turn of the 20th century, three to four disturbance cycles have been missed on the majority of the Forest.

As a result of removing wildfire from the landscape many changes have occurred including the alteration of seral state proportions, especially in ERUs that historically supported frequent fire. Fuel loadings (CWD and tree density) have increased during the 20th century in the woodland and forested ERU types also as a result of the cessation of fire. This has led to a higher risk of high burn severity and resulting accelerated erosion, increased loss of soil, and less vegetative productivity, and increased sediment transport to connected streams following uncharacteristic wildfires, such as the 2011 Las Conchas Fire. High levels of sediment also reduce fishery and aquatic habitat and those species that rely on it for their survival.

As forested and woodland types across the Forest are increasing in density and continuity, the opposite is happening in grass and shrublands. High levels of ungulate grazing has reduced effective vegetative ground cover and contributed to accelerated erosion, soil compaction and declined soil productivity. Forest activities (management actions) have also assisted in the removal of soil surface cover, compaction, and increases in erosion. Activities include timber harvesting, road construction and use, prescribed burning, fuelwood harvesting, and grazing. Poorly placed roads or roads constructed with poor drainage contribute to increased erosion and unsatisfactory soil conditions. Fire exclusion has also indirectly affected rangelands as woody species are encroaching, succession is becoming stagnant with limited acreage moving back into an early successional state, and reduced nutrient cycling occurring.

Considering current long-term drought (roughly since about 2000), reduced precipitation results in reduced vegetative growth, and reduced surface organic matter and nutrient cycling and lower site productivity. Ineffective vegetative ground cover puts the soil at risk of accelerated erosion during peak storm events and subsequent erosion and loss of soil productivity. Limited water availability and increased competition from overstocked stands increases competition and stress resulting in potential vegetation mortality. Reduced fuel moistures and predisposed vegetation is at increased risk of wildfire and insect and disease infestations and subsequent accelerated erosion and overall watershed degradation.

Results from recent climate models are not encouraging, as multiple models are in agreeance that the southwestern United States is in a drying trend that will continue well into the latter part of the 21st century (IPCC 2007; Seager et al. 2007), conditions and trend will continue to depart away from reference conditions. Although increased precipitation is predicted, temperatures are also expected to increase and the balance between precipitation and evaporation would likely result in an overall decrease in available moisture. This ultimately results in fewer precipitation events and more precipitation in a shorter period of time with larger, more destructive flooding. Herbaceous cover is likely to die off in prolonged drought and leave larger areas devoid of ground cover creating an increased amount of bare soil. If storms do become more intense this coupled with a lack of ground cover will increase erosion resulting in

unsatisfactory soil conditions. Increased temperatures also threaten surface water with increased evaporation as well as an increased demand for groundwater.

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Terminology

Biophysical setting (BpS): a grouping of ecologically similar vegetation types modeled with characteristic disturbance inputs used for FRCC assessments. In FRCC, this term is synonymous with potential natural vegetation type (PNVT) and ecological response unit (ERU).

Canopy cover is either non-tree (<10 percent tree cover), open (10 to 29.9 percent tree canopy cover), or closed (30 percent+ tree canopy cover).

Climate envelope represents the historic/characteristic climate conditions for key climate variables identified for each major ecosystem type . Envelope modeling relies on statistical correlations between existing ecosystem distribution and the selected climate variables to define ecosystem tolerance. By utilizing future climate projections for the same climate variables, vulnerability can be predicted based on the disparity between characteristic and future climate conditions. This approach is not likely a good means of predicting vulnerability at fine scales.

Coarse woody debris is dead woody material on the ground greater than three inches in diameter, including logs.

Crown fire is a fire that burns through the upper tree or shrub canopy. In most cases the understory vegetation is also burned. Depending on species, a crown fire may or may not be lethal to all dominant vegetation. An example of this would be many shrub and broadleaf tree species that sprout from roots, root crowns or stem bases after their tops are killed. A crown fire may be continuous or may occur in patches within a lower severity burn.

Dominance type refers to the primary vegetative lifeform present and can be tree, shrub, or grass.

Fire frequency is the number of times that fires occur within a defined area and time period.

Fire return interval (or fire interval) is the time between fires in a defined area, usually at the scale of a point, stand or relatively small landscape area. This is called Mean Fire Interval (MFI) in the LANDFIRE system, where it refers to the average number of years between fires in representative stands (Barrett et al. 2010).

Fire rotation (interval) or the time required to burn an area equal to a defined area of the landscape. The entire area may not burn during this period; some sites may burn several times and others not at all. This is the same as fire cycle.

Forest Service Activities Tracking System (FACTS) is an activity tracking system used by the U.S. Forest Service to document and monitor treatment activities, timber sales, contracts, and permits, NEPA decisions, and many other management activities at all levels of the agency.

Hyrdrophobicity or soil hydrophobicity is a naturally occurring phenomenon. This natural hydrophobicity usually is found at the mineral soil surface, and it is caused by the leaching of hydrophobic compounds, such as aliphatic hydrocarbons, from the litter and humus layers. During a wildfire the heat of a fire vaporizes hydrophobic compounds in the litter, humus, and soil organic matter leaving these compounds to escape into the atmosphere, or move into the soil and condense on cooler soil particles at or below the soil surface. The condensation of these compounds forms a hydrophobic coating on the soil particles which can inhibit infiltration.

Invasive species are not native to the ecosystem being described. For all ecosystems, the desired condition is that invasive species are rarely present, or are present at levels that do not negatively influence ecosystem function.

Mixed-severity fire: The severity of fires varies between nonlethal understory and lethal stand replacement fire with the variation occurring in space or time. In some vegetation types the stage of succession, the understory vegetation structure, the fuel condition and/or the weather may determine whether a low or high-severity (or surface or crown) fire occurs. In this case individual fires vary over time between low-intensity surface fires and longer-interval stand replacement fires. In others, the severity may vary spatially as a function of landscape complexity or vegetation pattern. The result may be a mosaic of young, older, and multiple-aged vegetation patches.

Patches are areas larger than tree groups in which the vegetation composition and structure are relatively homogeneous. Patches can be composed of randomly arranged trees or multiple tree groups, and they can be even-aged or uneven-aged. Patches comprise the mid-scale, typically ranging in size from 10 to 1,000 acres. Patches and stands are roughly synonymous.

Seral state ist the stage of secondary successional development (ecological process of progressive change in a plant community after a stand-intitiating disturbance).

Site potential, for a given potential vegetation type, represents the successional condition with the greatest representation of late-seral vegetation that is typical under characteristic, pre-settlement levels of fire and herbivory. The existing vegetation of such a plant community would have 100 percent similarity to site potential when computing ecological status (FSH 2090.11), and would be at *reference condition*. Site potential is relative to the potential vegetation type.

Size classes (tree) are based on tree diameter at breast height (seedling/sapling: 0 to 5 inches, small: 5 to 10 inches, medium: 10 to 20 inches, large: 20 to 30 inches, very large: 30 inches+).

Stand replacement fire, a fire that is lethal to most of the dominant above ground vegetation and substantially changes the vegetation structure. Stand replacement fires may occur in forests, woodlands and savannas, annual grasslands, and shrublands. They may be crown fires or high-severity surface fires or ground fires.

Storiedness refers to the number of tree canopy levels or layers having greater than 10 percent canopy cover, one level is "single storied," two or more levels is "multi-storied."

Structure includes both the vertical and horizontal dimensions of a plant community. The horizontal structure refers to spatial patterns of woody vegetation as well as tree or shrub size. The vertical component refers to the layers of vegetation between the floor and the top canopy of the plant community.

Surface fire are fires that burn only the lowest vegetation layer, which may be composed of grasses, herbs, low shrubs, mosses, or lichens. In forests, woodlands, or savannas surface fires are generally low to moderate severity and do not cause extensive mortality in the overstory vegetation.

Terrestrial Ecological Units (TEUs) are mapped units of land within which ecological structure, function, capabilities, responses, and management opportunities and limitations can be predicted

Uneven-aged forests are forests that are comprised of three or more distinct age classes of trees, either intimately mixed or in small groups (Helms 1998).

Woodland refers to ecosystems of the woodland life zone, immediately below the montane, that are typically tree-dominated (site potential is woodland), with the exception of post-disturbance plant communities, which also become tree-dominated later in succession. The tree component of these ecosystems is made up of a plurality of woodland species, single- or multi-stemmed trees that are relatively small in stature at maturity, and which size is measured in 'diameter at root collar' (DRC). Infrequently, forest tree species will dominate woodland plant communities.