United States Department of Agriculture

Santa Fe National Forest Plan Final Assessment Report

Volume I. Ecological Resources

Forest Service Santa Fe National Forest June 2016

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Volume I. Ecological Resources

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Abstract: The Assessment presents and evaluates existing information about relevant ecological, economic, and social conditions, trends, and risks to sustainability and their relationship to the 1987 Santa Fe National Forest plan, within the context of the broader landscape. Fifteen topics are presented in two volumes. Volume I covers vegetation, water resources including aquatic biota, at-risk species in the plan area, soils, air, and carbon. Volume II covers cultural and historic resources and uses; areas of tribal importance; social, cultural, and economic sustainability; extractive multiple uses of timber, ranger and grazing, water, and fish and wildlife; recreational settings and scenery; designated areas; infrastructure; lands status and ownership; and energy and minerals.

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List of Commonly Used Acronyms

BASI	Best Available Scientific Information
CCVA	Climate Change Vulnerability Assessment
CFR	Code of Federal Regulations
CPGB	Colorado Plateau/Great Basin Grasslands[1]
CWD	Coarse Woody Debris
CZ	Central Zone
ERU	Ecological Response Unit
FI	Fire Interval
FIA	Forest Inventory and Analysis
FRCC	Fire Regime Condition Class
HERB	Herbaceous Riparian
HRV	Historical Range of Variability
HUC	Hydrological Unit Code
ILAP	Integrated Lands Assessment Project
JUG	Juniper Grasslands[1]
MCD	Mixed Conifer – Frequent Fire[1]
MCW	Mixed Conifer w/ Aspen[1]
MSG	Montane Subalpine Grassland[1]
MTBS	Monitoring Trends in Burn Severity
NAAQ	National ambient air quality standards
NADP	National Atmospheric Deposition Program
NMAAQS	New Mexico ambient air quality standards
NMED	New Mexico Environment Department
NMED-AQB	New Mexico Environment Department, Air Quality Bureau
NSHR	Narrowleaf Cottonwood Shrub[1]
NEZ	North-East Zone
NFS	National Forest System
NRV	Natural Range of Variation
NWZ	North-West Zone
PJG	Piñon-Juniper Grassland[1]
PJO	Piñon-Juniper Woodland[1]
PJS	Piñon-Juniper Sagebrush[1]
PNC	Potential Natural Community
PNVT	Potential Natural Vegetation Types
PPF	Ponderosa Pine Forest[1]
RAD	Risk Assessment Database
RMAP	Regional Riparian Mapping Project
SAGE	Sagebrush[1]
SCC	Species of Conservation Concern
SEZ	South-East Zone
SFF	Spruce Fir Forest[1]
SWZ	South-West Zone
TES	Terrestrial Ecosystem Survey
TEU	Terrestrial Ecological Unit
TMDL	Total Maximum Daily Load
VDDT	Vegetation Dynamics Development Tool

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[1] Ecological Response Unit

Forest Plan Assessment Report

Santa Fe National Forest

Volume I. Ecological Report

Contents

Assessment Introduction 1
  Purpose 1
  Structure of the Assessment Report 1
  Setting, Distinctive Features, and Background of the Santa Fe National Forest 2
  Ecosystem Services 4
  Best Available Scientific Information 6
  Public Participation 7
    Tribal Engagement 9
Ecological Assessment Introduction 10
Chapter 1. Vegetation 11
  Reference Conditions (Natural Range of Variation – NRV) 12
    Departure 12
  Terrestrial Ecosystems 13
    Spatial Scales of Analysis for Terrestrial Ecological Systems 13
  Key Ecosystem Characteristics for Terrestrial Vegetation 18
    Seral State Proportion/Vegetation Structure 19
    Snag Density 21
    Patch Size 23
    Site Potential 24
    Ground Cover 26
    Coarse Woody Debris (CWD) 28
    Fire Frequency 30
    Fire Severity 35
    Fire Regime Condition Class 38
    Terrestrial Ecosystem Stressors 41
  Terrestrial Ecological Response Units 50
  Riparian Ecosystems 107
    Key Ecosystem Characteristics for Riparian Vegetation 109
    Reference Conditions of Riparian Ecosystems 111
  Key Findings 119
    Ecosystem Services 121
    Input Received from Public Meetings 122
    Input Received from Technical Meeting 123
Chapter 2. Assessing Water Resources of the Santa Fe National Forest 125
  Overview of the Santa Fe NF Water and Water-related Resources 125
    Hydrologic Unit Codes and Scale 125
    Data Used 128
  Key Watershed Characteristics 130
    Surface Water (Streams, Waterbodies, Seeps and Springs, and Water Quality) 136
    Ground Water 155
    Wetlands 157
    Watershed Condition 161
    Reference Condition and Departure: Watershed Condition 165

    Water Rights and Uses 166
  Drivers and Stressors on the Santa Fe NF 169
    Climate Change 173
  Key Findings 174
  Aquatic Biota 176
    Current Condition 176
    Input Received from Public Meetings 194
    Input Received from Technical Meeting 194
Chapter 3. Identifying and Assessing At-Risk Species in the Plan Area 197
  Identifying At-Risk Species 198
    Federally Recognized Species on the Santa Fe NF 198
    Grouping of Species 216
  Federally Listed Species and Species of Conservation Concern and Current Santa Fe NF Management Direction 223
    Federally Listed Species 223
    Potential Species of Conservation Concern 224
    Species Risk Analysis 232
    Summary of Conditions, Trends, and Risks 235
    Ecosystem Services 237
    Input Received from Public Meetings 237
Chapter 4. Soils 239
  Introduction 239
    Assumptions 239
    Climate of the Santa Fe NF 239
    Physiographic Provinces of the Santa Fe NF 240
    Soil Diversity of the Santa Fe NF 242
    Ecosystem Characteristics for Assessment 248
    Soil Erosion Hazard 249
    Soil Condition 252
    Soil Organic Carbon 256
    Risk Assessment 259
    Data Needs 262
    Ecosystem Services 262
    Input Received from Public Meetings 263
Chapter 5. Air 265
  Introduction 265
    Identification of Airsheds 266
    Identification of sensitive air quality areas 268
    Federal, State, and Tribal State Implementation Plans 271
    Emissions Inventories, including current conditions and trends 273
    Visibility 285
    Atmospheric Deposition Information 288
    Critical Loads 292
    Uncertainty 297
    Summary of Condition, Trend, and Risk 298
    Key Message 299
    Ecosystem Services 299
    Input Received from Public Meetings 300
Chapter 6. Carbon 301
  Santa Fe NF Carbon Stocks 301
    Biomass (vegetative carbon) 301

Input Received from Public Meetings 311
References 313
Terminology 328

List of Tables

Table 1. Analyzed ecological response units (ERUs) of the Santa Fe NF 11
Table 2. Terrestrial ecosystem context niche 16
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. 20
Table 4. Snag density (snags per acre) by size class and ERU at the three different analysis scales (local, plan, and context) 22
Table 5. Patch size analysis results for the Santa Fe NF plan scale 24
Table 6. Similarity to site potential (%) for the Santa Fe NF 25
Table 7. Percentage of ground cover (rock fragment, bare soil, litter, and vegetation basal area) for ERUs at plan scale 27
Table 8. Coarse woody debris (tons per acre) for ERUs at the three different analysis scales (local, plan, and context). 29
Table 9. Literature synthesis of historic fire return intervals and regimes of the major ERU types of the Santa Fe NF 32
Table 10. Fire return intervals in years for ERUs at the three different analysis scales (local, plan, and context) 34
Table 11. Fire regime groups used in the current LANDFIRE database adapted from FRCC Guidebook, Version 3.0 (Anon 2010) 39
Table 12. Fire Regime Condition Class Descriptions as defined by Schmidt et al. (2002) 39
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 40
Table 14. Percent of host basal area modeled to be at high risk by agent on the Santa Fe NF 43
Table 15. Inventoried acres of invasive plants on the Santa Fe National Forest 45
Table 16. Climate change vulnerability based on the projected climate departure from the historic climate envelope for the Santa Fe NF 48
Table 17. Climate change vulnerability and uncertainty for each major (>1% plan scale representation) ecological response unit (ERU) 48
Table 18. Terrestrial ecological response units (ERUs) presented for all three analysis scales (local, plan and context) 51
Table 19. Riparian Ecological Response Units (ERUs) presented for all three analysis spatial scales (local, plan and context) 108
☐ HYPERLINK \l "_Toc453754653" Table 20. Summary of the Hydrologic Unit Codes and numbering
Table 21. Sub-basins (HUC8) and percent of Santa Fe NF lands contained within sub-basins 126
Table 22. Comparison of Santa Fe NF to HUCs 128
Table 23. Watershed characteristics, data sources used, key characteristics and reference condition 128
Table 24. Summary of key characteristics at the context and plan/local scales 130
Table 25. Key characteristics summarized at the context scale 132
Table 26. Key characteristics summarized for the plan/local scale (Santa Fe NF only) 134
Table 27. Stream miles at watershed and Santa Fe NF scales 137
Table 28. Drought periods for the Pecos and Jemez gauges 139
Table 29. Wet and dry cycles for the Pecos and Jemez gauges 140
Table 30. Acres of waterbodies on the Santa Fe NF 141
Table 31. Number of springs and seeps for analysis area by scale 142
Table 32. Representativeness, redundancy, and risk by watershed 146

Table 33. Summary of impaired perennial streams (miles) 153
Table 34. Acres of wetlands at the watershed scale 160
Table 35. Wetland reference sites 161
Table 36. Watershed condition summary for 116 sub-watersheds 163
Table 37. Range and average indicator values for the 116 sub-watersheds on the Santa Fe NF 165
Table 38. Number of water rights at the various scales 166
Table 39. Number of water uses by type 169
Table 40. Disturbances to water resources on the Santa Fe NF 171
Table 41. Reference (R) and current (C) occurrences of native fish species at the plan (HUC 10 watershed) and local (HUC 12 sub-watershed) scales 178
Table 42. Current native fish only stream miles and non-native/native fish stream miles at the plan and local scales 187
Table 43. Water quality categories for local zones within the Santa Fe NF based on HBI ratings 193
Table 44. Federally listed threatened or endangered species that are relevant to the plan area (USDI Fish and Wildlife Service, 2014). 199
Table 45. Possible species on the Santa Fe NF available for consideration as species of conservation concern 204
Table 46. Potential SCC removed from further analysis, and rationale for removal 207
Table 47. Potential List of Species of Conservation Concern for the Santa Fe National Forest 211
Table 48. Federally listed threatened or endangered species currently documented to occur in the plan area and associated ERU. 213
Table 49. Region 3 Forest Service Sensitive and potential SCC currently documented to occur in the plan area and associated ERU 213
Table 50. Federally listed and potential species of conservation concern (SCC) known to currently occur in the plan area and associated special habitat features 215
Table 51. Federally listed and potential SCC and their associated ecological response units (ERU) 216
Table 52. Federally listed and potential SCC associated with each Local Zone that include all ERUs. .. 217
Table 53. Percentage of current vegetative structure departure for each ERU at the three different analysis scales (local, plan, and context) 217
Table 54. Results of Vegetation Dynamics Development Tool (VDDT) 218
Table 55. Additional threats to federally listed and potential species of conservation concern 221
Table 56. Potential list of at-risk species for the Santa Fe NF 222
Table 57. Primary threats to special habitat features and their associated species 231
Table 58. Federally listed threatened and endangered species on the Santa Fe NF 234
Table 59. Potential list of SCC for the Santa Fe NF 234
Table 60. Percent of soil order within upland ERUs 245
Table 61. Percent of soil order within riparian ERUs 245
Table 62. Estimated historic versus current soil condition percentages on Santa Fe NF 253
Table 63. Total and average soil organic carbon for major Santa Fe NF ERUs 257
Table 64. National and New Mexico ambient air quality standards 270
Table 65. Air quality monitoring sites for the Santa Fe NF 282
Table 66. Summary of IMPROVE visibility monitoring data, 20% worst-case days (dv) 286
Table 67. Critical load exceedance summary for nitrogen deposition on the Santa Fe NF 293
Table 68. Summary of conditions, trends, and reliability of assessment 298
Table 69. Major ERUs on the Santa Fe NF in acres and percent 302
f HYPERLINK \l "_Toc453754703" Table 70. Biomass carbon stock per ERU in reference and current
Table 71. Projected carbon stocks for major ERUs of the Santa Fe NF 306
Table 72. Proportion of constituents of wildfire emissions for both greenhouse gases (GHG) and carbon compounds (NRC 2004) 307

List of Figures

Figure 1. Vicinity of the Santa Fe National Forest 3
Figure 2. Depiction of different vegetation patterns at three spatial scales (local, plan, and context)........ 14
Figure 3. Context scale extent for the Santa Fe NF vegetative characteristics 15
Figure 4. Map of Santa Fe NF plan (outlined in black) and local scales (outlined in grey) for terrestrial ecosystems 17
Figure 5. Extent of Piñon Pine dieback from 1997 to 2004 in the Four Corners states of Arizona, New Mexico, Colorado, and Utah is shown in white 30
Figure 6. 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........ 31
Figure 7. Wildfire occurrences on the Santa Fe National Forest from 1984 through 2013 33
Figure 8. Santa Fe National Forest wildfire acres burned from 1984 through 2013........ 33
Figure 9. Fire severity for large wildfires on the Santa Fe NF for years 1984 through 2013 36
Figure 10. 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). 37
Figure 11. Modeled percent basal area at risk from insect and disease activity on the Santa Fe NF 42
Figure 12. Invasive plants on the Santa Fe National Forest........ 45
Figure 13. Map showing proper functioning condition (PFC) and stream surveys available for data analysis, relative to the location of all riparian ERUs........ 111
Figure 14. Sub-basins covering the Santa Fe NF 127
Figure 15. Watersheds and sub-watersheds covering the Santa Fe NF 129
Figure 16. Occurrence of perennial stream miles on and off the Santa Fe NF 137
Figure 17. Pecos River near Pecos, NM – Mean Annual Flow (cfs) 138
Figure 18. Jemez River near Jemez, NM – Mean Annual Flow (cfs)........ 139
Figure 19. Occurrence of lakes and ponds on the Santa Fe NF 141
Figure 20. Count of lakes and ponds in Santa Fe NF by size class........ 142
Figure 21. Occurrence of springs and seeps within Santa Fe NF boundary at the watershed scale 143
Figure 22. Potential risk matrix........ 145
Figure 23. Potential risk of compromised system integrity for perennial stream miles by watershed 148
Figure 24. Potential risk of compromised system integrity to lakes and ponds by watershed........ 150
Figure 25. Potential risk of compromised system integrity to seeps and springs by watershed 151
Figure 26. Impaired perennial stream miles at the watershed scale........ 152
Figure 27. Wells, alluvium, and aquifers surrounding the Santa Fe NF 155
Figure 28. Wells and alluvium in and along San Antonio Creek........ 156
Figure 29. Water table decline in a well near Santa Fe, NM 157
Figure 30. Occurrence of wetlands 159
Figure 31. Core national watershed condition indicators........ 162
Figure 32. Watershed condition of sub-watersheds on the Santa Fe NF 164
Figure 33. Points of diversion on and adjacent to the Santa Fe NF 167
Figure 34. Points of diversion on the western half of the Santa Fe NF 168
Figure 35. Points of diversion on the eastern half of the Santa Fe NF........ 168
Figure 36. Plan (HUC 10 watershed) and local (HUC 12 sub-watershed) scales for aquatic biota assessment on the Santa Fe NF 176
Figure 37. Native fish and mixed fish perennial streams and native fish perennial streams within plan scale 191
Figure 38. Number of sample sites with water quality condition inferred from the HBI rating for the Santa Fe NF........ 193
Figure 39. Physiographic provinces of the Santa Fe National Forest. 241
Figure 40. Soil orders of the Santa Fe NF........ 243

Figure 41. Wildfires on the Santa Fe NF since 1993 247
Figure 42. Soil erosion hazard ratings of the Santa Fe NF 250
Figure 43. Erosion hazard of Santa Fe NF ERUs 251
Figure 44. Soil condition classes of the Santa Fe NF 254
Figure 45. Current soil condition on Santa Fe NF by ERU 255
Figure 46. Total and average soil organic carbon for major Santa Fe NF ERUs........ 258
Figure 47. New Mexico counties and airsheds (NMED 2003) 267
Figure 48. Class I and Sensitive Class II Areas in New Mexico 269
Figure 49. New Mexico 2002 baseline and projected 2018 emission summaries, carbon monoxide (top) and nitrogen oxides (bottom) 277
Figure 50. New Mexico 2002 baseline and projected 2018 emission summaries, sulfur oxides (top) and volatile organic compounds (bottom) 278
Figure 51. New Mexico 2002 baseline and projected 2018 emission summaries, coarse particulate mass (top) and fine particulate mass (bottom) 279
Figure 52. Map of air quality monitoring sites in the plan area 281
Figure 53. Relationship among extinction, deciview Index, and visual range 285
Figure 54. Reconstructed annual mean aerosol extinction from IMPROVE and other aerosol data (Hand et al. 2011) 286
Figure 55. Chemical deposition (Bandelier Station, 2004 to 2014) 289
Figure 56. Total mercury concentration, 2013 290
Figure 57. Total wet mercury deposition, 2013 291
Figure 58. 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 296
Figure 59. Biomass carbon stock by grassland, shrubland and woodland ERUs in current and reference conditions 303
Figure 60. Biomass carbon stock by Forest ERU in current and reference conditions 304
Figure 61. Trends in carbon stocks for Santa Fe NF grassland, shrubland and woodland ERUs 305
Figure 62. Trends in carbon stocks for Santa Fe NF forest ERUs 306

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 NF, 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).

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.

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.

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.

Setting, Distinctive Features, and Background of the Santa Fe National Forest

The Santa Fe National Forest in Northern New Mexico was established in 1915 when President Woodrow Wilson signed Executive Order 2160 merging the Jemez and Pecos National Forests. Today, the Santa Fe NF administers approximately 1.6 million acres.[2] The forest is divided into two fairly distinctive sections: the west side centered on the Jemez Mountains and the east side in the Sangre de Cristo Mountains. The city of Santa Fe, the state capital of New Mexico, lies at 7,000 feet in the Rio Grande valley between these two mountain ranges.

The Santa Fe NF includes portions of seven counties – Rio Arriba, San Miguel, Sandoval, Santa Fe, Mora, Los Alamos, and a negligible amount in Taos County (figure 1). The forest shares borders with the Carson National Forest, Bandelier National Monument, Pecos National Historic Park, the Valles Caldera National Preserve, Los Alamos National Laboratories, land administered by the Bureau of Land Management, and various tribes, pueblos, and land grants. The majority (95 percent) of the forest lies within the Rio Grande Watershed. The Santa Fe NF has five ranger districts: Coyote, Cuba, and Jemez on the west side, Pecos/Las Vegas on the east side, and Española spanning both sides.

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[2] Total area within boundary is approximately 1,680,000 acres which includes 1,545,000 administered by the Santa Fe NF plus 135,000 acres administered by other owners. Data from the Automated Lands Project.

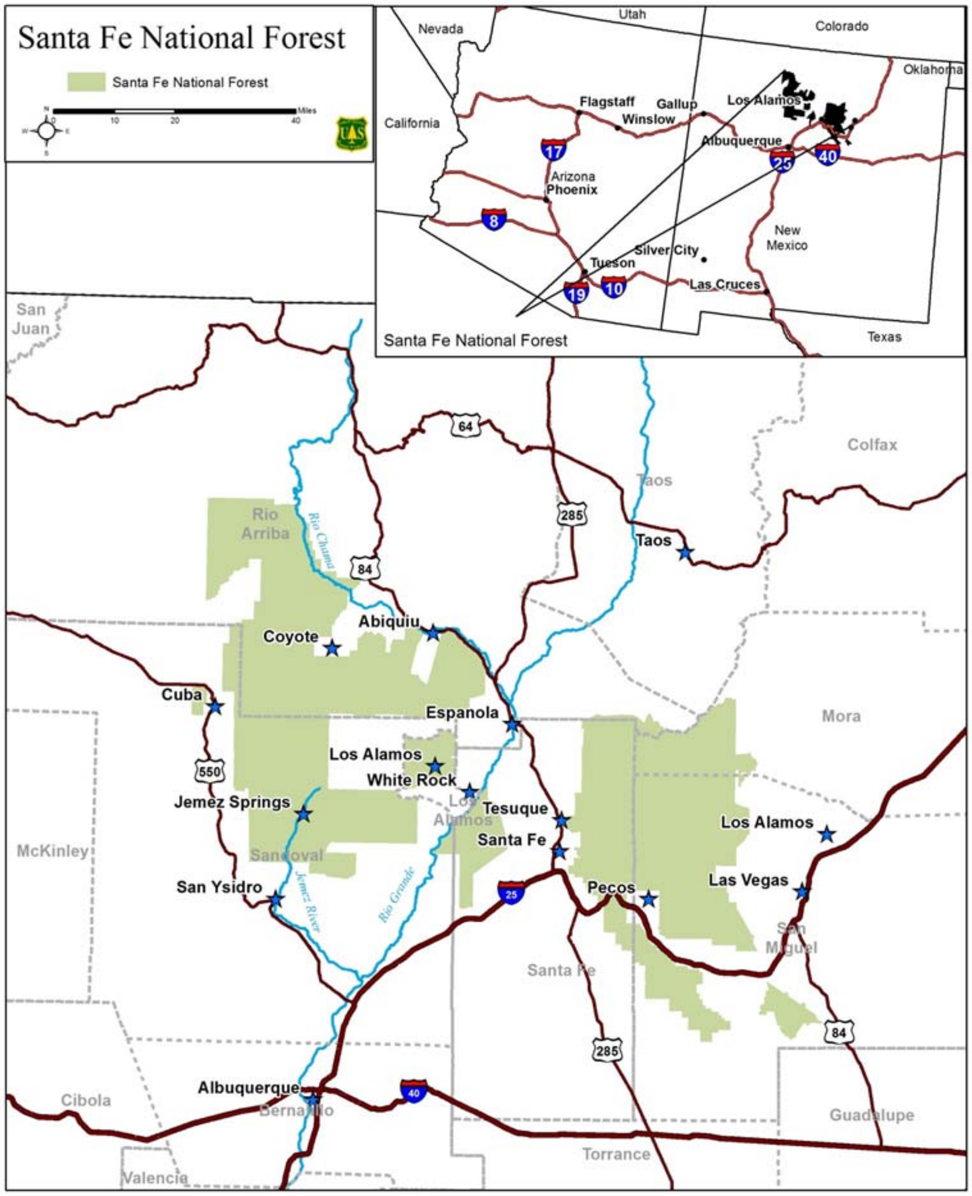

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Figure 1. Vicinity of the Santa Fe National Forest

The forest stretches across mountains, valleys and mesas of the Jemez and Sangre de Cristo mountain ranges. Elevation varies from 5,000 to 13,000 feet, with the summit of Truchas Peak (13,108 feet) within the Pecos Wilderness the highest point on the east side and Chicoma Mountain (11,561 feet) the highest on the west side. Climate across the forest is varied and related to elevational range. Mean daily air temperature for north-central New Mexico ranges from minus 35 degrees Fahrenheit to 14 degrees Fahrenheit in winter and from 30 degrees Fahrenheit to 95 degrees Fahrenheit in summer. Mean annual precipitation for the area ranges from 12 to 35 inches annually, with the highest amounts at the higher elevations. The air is clean and clear, and blue skies are typical with an average of 300 days of sunshine a year. In the higher elevations first snow usually occurs in October and then covers peaks from late

November through spring. It is not uncommon to find snow on high elevation trails into June. At lower-elevations snow is more variable, with some years receiving substantial amounts (40 inches) while other years have nothing of consequence. Spring is windy and relatively dry. June brings the beginning of monsoons, or the rainy season, which culminate in August. Lightning strikes are common during the summer months, especially on the higher peaks. Fall is marked by golden aspens on mountain sides and cottonwoods along the streams.

The Santa Fe NF is composed of a large diversity of vegetation systems ranging from prairie grasslands at lower elevations to alpine/tundra at the highest elevations. Two vegetation systems, Mixed Conifer-Frequent Fire and Ponderosa Pine Forest, together account for about 50 percent of the vegetation on the forest. In addition, the Santa Fe NF represents a considerable percentage of these vegetation types regionally. Vegetative communities throughout the forest are primarily influenced by fire, insects and disease, invasive plant species, and climate change.

The Santa Fe NF is home to a rich diversity of plants, animals and fungi including endemics, species found only on the Santa Fe NF or neighboring lands. The Jemez Mountain Salamander is unique to the Jemez Mountains, and the Holy Ghost Ipomosis is unique to a single canyon in the Sangre de Cristo Mountains. Game species, smaller animals, songbirds and wildflowers are common across the forest.

The land within and around the Santa Fe NF has a rich cultural heritage. The area has been home to Native American populations for the past 12,000 years, and Hispanics first arrived over 400 years ago. Consequently, many local residents have strong ties to traditional uses of the Santa Fe NF, including family gatherings, cattle ranching, firewood cutting, and collecting piñon and herbs. Both urban populations in nearby Albuquerque and Santa Fe and the more rural surrounding towns and communities rely heavily on the forest for recreation, subsistence and cultural tradition.

Skiing and snowboarding, river rafting and boating, hiking, mountain biking, camping, fishing and hunting are some of the diverse recreational activities that occur on the forest today. In addition, the forest has several different types of designated areas, including four congressionally designated wilderness areas (the Pecos Wilderness, San Pedro Parks Wilderness, Chama River Canyon Wilderness and the Dome Wilderness) covering 291,669 acres, three Wild and Scenic Rivers, the Jemez National Recreation Area; and two scenic and historic byways.

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 Millennium 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. Similarly, for wildlife, Volume I will focus on species known or thought to be of conservation concern. 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.

Best Available Scientific Information

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.

The Santa Fe NF provided opportunities for the public to develop a shared understanding of the BASI and how it would be used during the assessment (FSH 1909.12 Chapter 0, Section 7.11a). Prior to the initiation of the Assessment, the Santa Fe NF held workshops for Forest users, agency and government staff, and Santa Fe NF employees to engage in dialogue about shared expectations and the ability to work together through Plan Revision. This initiated the discussion on many topics, including expectations of using the BASI, especially in conjunction with local knowledge. Throughout the assessment, the Santa Fe NF provided opportunities for the public, including state and federal agencies, local government, tribes, non-profit organizations, and others; to provide input on or suggest sources of the BASI. Main venues of this included public meetings and public comment period that occurred between the spring and summer of 2014, meetings with local groups or county planning departments, or personal communication with both Forest Service and non-Forest Service experts.

Forms of the BASI used in the assessment include:

- Peer-reviewed scientific literature
- Gray literature, which 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.
- Expert opinion, which included observational data and unpublished inventories, as long as the responsible official had a reasonable basis for relying on that scientific information as the best available
- Government agency inventory and monitoring data, which included data from spatially referenced databases.
- Other scientific information from reputable sources, such as universities or national organizations.

Accuracy and reliability of relevant information (FSH 1909.12, Chapter 0, Section 7.15a.1) was determined by comparing the scientific certainty and quality of the information and using the most scientifically certain information available. All the BASI were evaluated based on the following six factors:

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

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 volume 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

Before initiating the Assessment, the Santa Fe NF sought public input on past experiences and future desires for public participation that could be used in engaging the public throughout the Forest Plan Revision process. In January and February 2014, the Santa Fe NF and Carson NF held 27 listening sessions in communities surrounding both forests. Listening sessions were attended by community stakeholders, Tribes, and relevant government organizations. The intent was to gain input and perspectives on collaborative potential – both opportunities and hindrances – and to serve as an initial step in understanding the context of local circumstances. As follow-up, two daylong workshops were held in March where both the public and Forest Service staff worked together to explore strategies for public participation during the Forest Plan Revision process. Summaries for both the listening sessions and workshops are available on-line and were distributed by email and mail on request.

Public notice of the beginning of the Assessment was provided on March 6, 2014, with notices in the *Federal Register* and *Albuquerque Journal*, the Forest's newspaper of record.

Public input was solicited early during the Assessment phase, prior to analysis occurring by forest specialists. This early input was designed so that the forest could use information received during the development of the assessment. In April and May of 2014, the Santa Fe NF held 14 public meetings in 12 communities around the forest. The purpose of these meetings was to (1) provide introductory information about forest plans and the revision process, and (2) provide an opportunity for members of the public to contribute to the assessment. One meeting was a "Technical Meeting," designed to engage participants in more in-depth discussions about the assessment, including a focus on the 2012 Planning Rule's Draft Directives. At all meetings, participants were asked two questions designed to get their input on the current conditions and trends for the 15 assessment topics.

1. What do you appreciate about the Santa Fe National Forest? (Why do you use it? Was there a time when it had a meaningful impact for you? Is there a use that you really value?)

2. Think about the things you or others appreciate about the Santa Fe National Forest? What are the things that you have seen change in the past and that you are continuing to see change.

In addition to input received at the public meetings, additional input was solicited through the "User Values and Trends" form, which was available between June and July 2014. This form was nearly identical to the worksheet used during the 14 public meetings. The form was distributed by e-mail to the mailing list, made available on the Santa Fe NF's Plan Revision webpage, available at the front desk of the Supervisor's Office in Santa Fe and all 5 ranger district offices, advertised with flyers throughout communities surrounding the forest, and a bilingual (English/Spanish) version was mailed to all the forest's grazing permittees. In total, 114 people attended one of our public meetings and we received an additional 52 User Values and Trends forms.

In April 2015, a summary of the public input received from the 14 public meetings and the User Values and Trends forms was published and made available on-line. This summary documents the diversity of values and interests of people who use the forest. Some of these values include healthy forest ecosystems and high quality air, soil, and water; abundant and diverse recreational opportunities; and traditional cultural uses such as livestock grazing or gathering wood for fuel to heat homes. Specific input received from the public was incorporated into the Assessment within relevant chapters in both Volumes I and II under the headings "Input Received from Public Meetings."

Throughout the Assessment phase, the Santa Fe NF gave presentations to 10 self-convening groups, 2 Boards of County Commissioners, 4 county planning staffs, the New Mexico Land Grant Council, and the New Mexico Acequia Commission. Informational booths were held during the 2014 legislative session, at 6 County Fairs (all Counties in 2014, Santa Fe County in 2015) and the New Mexico State Fair (2015), and at 16 community events such as health fairs, farmers' markets, and the Albuquerque International Balloon Fiesta (2014). In April and May 2015, three meetings facilitated by the Land Grant Council and hosted by individual land grants were held to discuss Plan Revision on both the Santa Fe and Carson National Forests. The Northern New Mexico Stockman's Association hosted meetings in July 2014 and November 2015, to provide and discuss their input and perspectives on both the Santa Fe NF and Carson NF's Assessments. Youth engagement occurred through presentations at Capital High School, Tierra Encantada Charter School, and a Forestry class at New Mexico Highlands University; which resulted in student participation at several of the "Need for Change" public meetings in the fall of 2015. On social media, Forest Plan Revision can be found as a webpage and also uses the Santa Fe National Forest Facebook and Twitter accounts. Through outreach efforts, the Santa Fe NF's mailing list for Plan Revision has grown to nearly 1,400 recipients. The Forest Plan Revision webpage also receives considerable more traffic, a 200 to 400 percent increase over background rates, and people spend about three times longer on the Forest Plan Revision webpage when the Forest has notified the mailing list of new information such as completed documents or announced public meetings.

The Draft Assessment was released in two volumes on October 20, 2015. On October 23, 2015, an all-day public symposium was used as a forum for specialists to present findings from the Draft Assessment. Immediately following, the Santa Fe NF held 10 public "Need for Change" meetings in communities around the forest. The focus of these meetings was to (1) present key findings from the Draft Assessment report with a focus on 12 resources that were identified through the assessment as having the greatest needs for different plan direction, and (2) get input on what aspects of the current plan "need to change" through editing preliminary need-for-change statements or formulating new ones. In total, just over 200 people attended one of our public meetings and the forest received over 500 need-for-change recommendations either directly from these public meetings or through mail or email. All recommended need-for-change statements were reviewed and used to create the final need-for-change statements. The Santa Fe NF also received 13 letters with recommendations specific to the Draft Assessment document, which were taken into account before producing the Final Assessment. A summary of the need-for-change public meetings documents the process of those meetings as well as the type of public input received.

Tribal Engagement

The Santa Fe NF has been engaging federally recognized Tribes and Pueblos throughout the Assessment Phase. Between December 2013 and January 2014, the Santa Fe NF's Tribal Liaison and the Collaboration Specialist for the Forest Plan Revision team visited 11 tribes and met with their tribal leadership and natural resource planning staff to introduce them to the Plan Revision process and Assessment Phase. In January and February 2014, four tribal-specific listening sessions were attended by ten tribes. A presentation on the importance of participating in and contributing to the forest plan revision process and Assessment specifically was made to the All Pueblo Council of Governors in March 2015. Two “Need for Change” meetings specifically for the Tribes, one in Espanola and another in Albuquerque, were held in November 2015. The Santa Fe NF has Memorandums of Understanding (MOUs) with three separate Pueblos and a regular agenda item at quarterly MOU meetings is a status on Forest Plan Revision.

Many tribal concerns align with input received from the general public. Tribes also expressed desires for continued positive relationships and expanded partnerships with the Santa Fe NF and face-to-face opportunities that go beyond formal consultation. Concerns were expressed around traditional issues such as the protection of sacred sites; the ability to access the forest for traditional uses, traditional products and places for traditional practices; and the protection and management of effects to ancestral sites. Other concerns included trespass cattle belonging to Forest Service permittees and its impacts to riparian areas on tribal lands, access to deal with fire, economic development, and issues associated with poaching and road usage. Many tribes expressed a strong desire for shared stewardship on National Forest System lands. Specific input received from the tribes was incorporated into this Assessment and can be found in Volume I1, Chapter 2: Assessing Areas of Tribal Importance under the heading “Input Received from Public Meetings.”

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[3] 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.

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[3] 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 upland (account for 1 percent of plan scale landscape) and riparian 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.

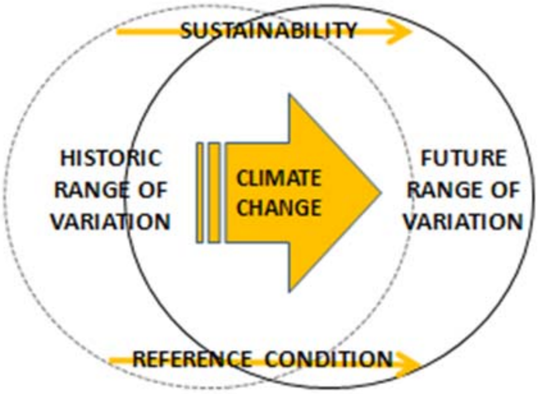
Table 1. Analyzed ecological response units (ERUs) of the Santa Fe NF

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 (PJO)	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 (Keane et al. 2009). 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. Below is the calculation used to determine departure relative to reference conditions for each of the key ecosystem characteristics (described below), unless otherwise noted, quantifying resulting departure percentages that are generalized into three different general categories:

Departure Range	Departure Category
0 to 33 percent	Low
34 to 66 percent	Moderate
Greater than 66 percent	High

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

Terrestrial Ecosystems

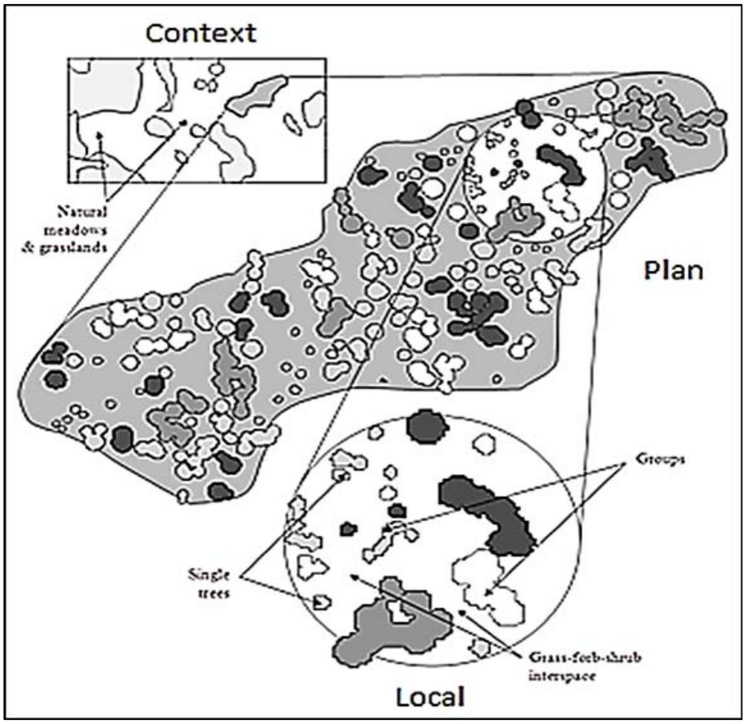
The geographic location, climate and elevational gradient found on the Santa Fe National Forest allows for several important ecological and biological features relative to other national forests in the Southwestern Region (Region 3) of the U.S. Forest Service and other major landowners in Arizona and 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 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 2). 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 2. 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 3) is composed of clusters of Ecological Subsections (McNab et al. 2007) 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 upland 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 3). 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 3) 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. 1997a). 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.

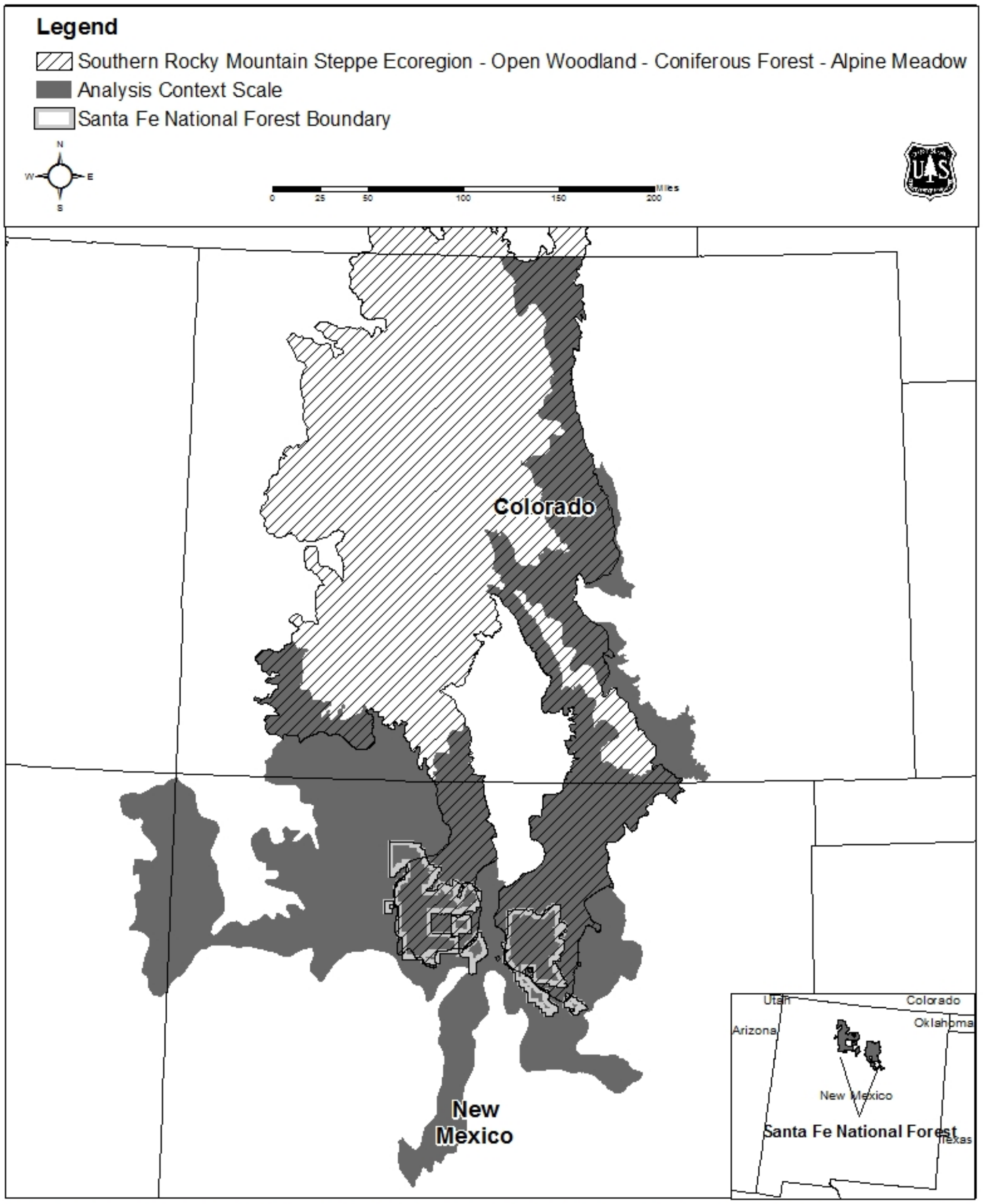


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Figure 3. Context scale extent for the Santa Fe NF vegetative characteristics

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 terrestrial 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 percent 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 Scale	Plan Scale Contribution to Context (%)	Proportional Representation	Plan Scale Seral State	Context Scale Seral State
MSG	17,707	1.1	451,289	2.0	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	6.0	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 maintaining 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 4).

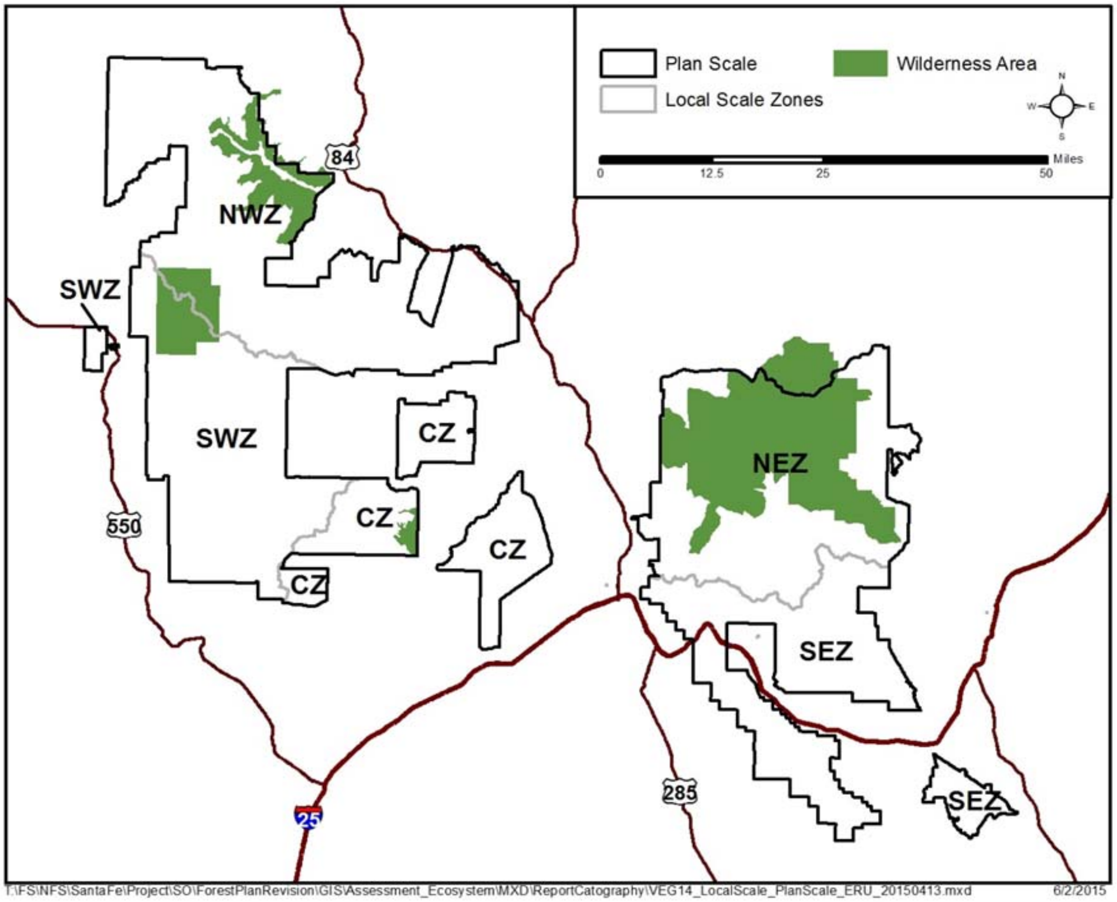

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Figure 4. Map of Santa Fe NF plan (outlined in black) and local scales (outlined in grey) for terrestrial ecosystems[4]

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[4] Local zones are based on compass quadrants, NWZ is North West Zone, NEZ is North East Zone, CZ is Central Zone, SWZ is South West Zone, and SEZ is South East Zone. Forest wilderness areas are 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 4) 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 whether information was readily available, relevant to key issues and sensitive to drivers and stressors, and represent elements needed to assess other resource areas (e.g., at-risk species and habitat).

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

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

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/Vegetation Structure

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-initiating 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. 2004). 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 (USDA FS 2011, 2014a). 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 the departure of the ERU can be calculated by subtracting 100 percent by the similarity value. 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.

The assignment of current state class proportions uses regional satellite imagery based classifications of vegetation size class, canopy cover, dominance type, and shade tolerance at a 1:100,000 scale, with extensive photo interpretation and field data collection (Midscale Vegetation Mapping Project (Mellin et al. 2004). Existing vegetation is assigned to an ERU and then to the appropriate state class within that ERU according to state class descriptions that were developed by the USFS Southwestern Regional Office, LANDFIRE, The Nature Conservancy, and the Integrated Landscape Assessment Project (ILAP).

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 ILAP; then 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, Weisz et al. 2009, Vandendriesche 2010, Weisz et al. 2010, Weisz et al. 2011). Burn severity information is compiled from Monitoring Trends in burn severity records (Finco et al. 2012). 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. The 100-year future/trend VDDT model was selected (opposed to the 10-, and 1000-) to allow for longer trend projections in later developing successional states (medium trees grow to be large trees) of some systems, specifically forests.

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 (table 3). Actual future modeled seral state proportions 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. Model)
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 percent 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 3 that three ERUs (CPGB, MCD, and PPF) have highly departed seral state structures (93 percent, 74 percent, and 97 percent respectively) at the plan scale and across all local zones. CPGB at the context scale is only moderately departed (48 percent) 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. MCD and PPF have both been influenced by the lack of wildfire which has allowed for in-fill of stands and encroachment by shade tolerant species.

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 encroachment of shrubs and trees has resulted from the degradation 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-year average), only 15 of the 17,707 acres (0.08 percent) 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 PJO. This is primarily because the typical lengthy interval between fire occurrences in this ERU has not been altered as largely as many of the other ERUs, which have frequent fire regimes (less than 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 to 19.9 inches diameter at breast height (dbh)) trees. As indicated in the local zone discussion, currently there are considerably fewer snags in SFF, especially in the small snag class (8 to 17.9 inches). Understory composition has changed some in SFF, but overall at the plan scale, similarity to site potential is in low departure.

Snag Density

Snag density is defined as the number of stems per acre by diameter classes (i.e., greater than 8 inches, greater than 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 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 (Bull et al. 1997, Payer and Harrison 2003). The creation and maintenance of appropriate biological legacies is a critical element of forest management strategies that attempt to conserve biodiversity (Lindenmayer et al. 2006).

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 per hectare in ponderosa pine and mixed-conifer forests, respectively, with minimum 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 were 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 coefficients. 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 (JUG)	**≥ 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 (PJS)	**≥ 8"**	**6.0**	**5.1**	▨	**3.1**	▨	▨	**3.6**	**7.7**
	≥ 18"	**1.0**	**0.8**		**0.6**			**0.7**	**1.4**
PJ Woodland (PJO)	**≥ 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 (PJG)	**≥ 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 (PPF)	**≥ 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 Fire (MCD)	**≥ 8"**	**9.0**	**24.4**	**25.2**	**23.6**	**23.7**	**24.2**	**24.2**	**24.1**
	≥ 18"	**4.0**	**3.5**	**3.4**	**4.1**	**3.4**	**3.3**	**3.5**	**3.5**
Mixed Conifer w/ Aspen (MCW)	**≥ 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 (SFF)	**≥ 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 percent 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 Coarse Woody Debris section recent dieback of piñon pine is also likely responsible for the excessive density of small diameter snags in the PJ Woodland type, that have yet to fall.

Patch Size

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/shrubs/or grasslands or multiple groups of, and can be even- or uneven-aged. Patches typically range in size from 1 to 1,000 acres, depending on the ERU and site-specific attributes (e.g., aspect). 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) and conversely, these patterns invariably influence future fire patterns, regeneration and colonization processes, and plant development (Keane et al. 1998). For example, natural large dense patches of trees as in Spruce Fir Forests are indicative of a low frequency and high severity fire regime (Table 11).

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 (Bender et al. 1998). 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

For grassland and shrubland systems reference conditions are based on Terrestrial Ecological Unit Inventory polygon geometry for a particular analysis area. Mean patch size is calculated with standard error to determine lower and upper patch size values from calculated average patch size in acres for each seral state for all ERUs by dissolving ERU boundaries by lifeform (i.e., shrublands and grasslands) and averaging polygons intersecting the ERU of interest. For woodland and forest ERUs, reference condition patch sizes were derived from literature/studies. The average patch size for existing vegetation was derived by averaging current patches based on Terrestrial Ecological Unit Inventory (Miller et al. 1993), Regional Riparian Mapping Project (RMAP) (Triepke et al. 2014a), and Mid-Scale Mapping (Mellin et al. 2004) data. 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 in this assessment relates only to the grassland/tree encroachment dynamic. The reference condition assumes no encroachment. 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	Shrubland	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 – Freq. Fire	Forest	0.02 – 50	247	**High (80%)**
Ponderosa Pine Forest	Forest	0.02 – 1	72	**High (99%)**

When viewing table 4, two occurrences 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 (table 10) are less departed than those with more frequent fire cycles. Both PJO 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 occurrences. 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 9 and Figure 10, as the proportion of high severity fire has increased in these ecosystems. Similar occurrences 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 7) 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 shelter, cover or food source.

Site Potential

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 (TES) of the Santa Fe National Forest (Miller et al. 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). The Potential Natural Community (PNC) 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 terrestrial ecological unit (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 Inventory effort and the resulting data is described in the TES for the Santa Fe NF (Miller et al. 1993). Daubenmire transects were collected for most TES map units, and were used to develop the Potential Natural 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	**59**	▨	▨	▨	**60**	**60**
Montane / Subalpine Grassland	**42**	**54**	▨	**35**	▨	**41**
Sagebrush Shrubland	**60**	▨	▨	▨	▨	**60**
PJ Sagebrush	**47**	▨	**55**	▨	▨	**54**
PJ Woodland	**60**	**66**	69	67	**63**	**64**
Juniper Grass	**51**	69	**51**	▨	**53**	**56**
PJ Grass	**74**	67	**64**	▨	74	72
Ponderosa Pine Forest	**63**	**59**	69	67	**62**	**63**
Mixed Conifer - Frequent Fire	**61**	**62**	**64**	73	70	67
Mixed Conifer w/ Aspen	68	**64**	70	71	▨	67
Spruce-Fir Forest	**60**	**65**	**59**	70	67	68

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

Table Legend:

▨ Limited Acres	Low Departure	Moderate Departure	High Departure

Site potential is low to moderately departed across all local zones and ERUs on the Santa Fe NF. All grassland ERUs (CPGB and MSG) are moderately departed, while woodland and forested types exhibit low to moderate departure. The NWZ has the greatest diversity in ecosystems but also displays the most departure with all but two ERUs, MCW and PJG, moderately departed. In the SWZ, the woodland types display the least amount of departure, however in the CZ, NEZ, and SEZ, it is the forested types that have greater similarity to site potential. The NEZ is in the best condition with all ERUs except MSG in low departure, likely a result of the large proportion of higher elevation ERU types and the steep terrain of the Sangre de Cristo Mountains that limit road and grazing accessibility. The big departures in MSG are a result of the transition of bunchgrass species such as Arizona fescue, Colorado fescue and Thurber's fescue to sod-forming grasses like Kentucky bluegrass and other drought-tolerant species like nodding brome and blue grama. Other significant shifts in composition across most ERUs include a shift toward woody shrub and tree species that were once primarily grass and forb species. These changes have resulted in a decrease in understory productivity as shrub and tree species shade and outcompete the once herbaceous understory.

Ground Cover

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, lessen surface fire activity (potentially leading to altered fire return intervals/fire frequency), and increase 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, table 10) 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 Southwestern landscape was the reduction of grass cover as a result of the introduction of large numbers of domestic livestock during the early 1800s (Raish and McSweeney 2008). Grazing reduced native plant cover and facilitated the colonization of invasives, altering species 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 as part of the Santa Fe NF’s TES (Miller et al. 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 (Miller et al. 1993). The change in percent vegetative ground cover was calculated for each 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. 1997b). 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**
Montane/Subalpine Grassland	14.62	**26.24**	2.78	**9.91**	59.70	60.94	35.09	**9.82**
Juniper Grass	52.15	52.15	26.28	28.70	19.25	13.48	13.19	**8.09**
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 percent 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 has changed rather significantly as most of the ERUs are moderately departed and a few highly departed from "natural" conditions (table 7). The amount of bare soil for all ERUs has increased but mainly the grass- and woodland-ERUs (CPGB, MSG, PJG, PJS, PJO, and SAGE) 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)

Coarse woody debris 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). 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 (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 coefficients. 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).

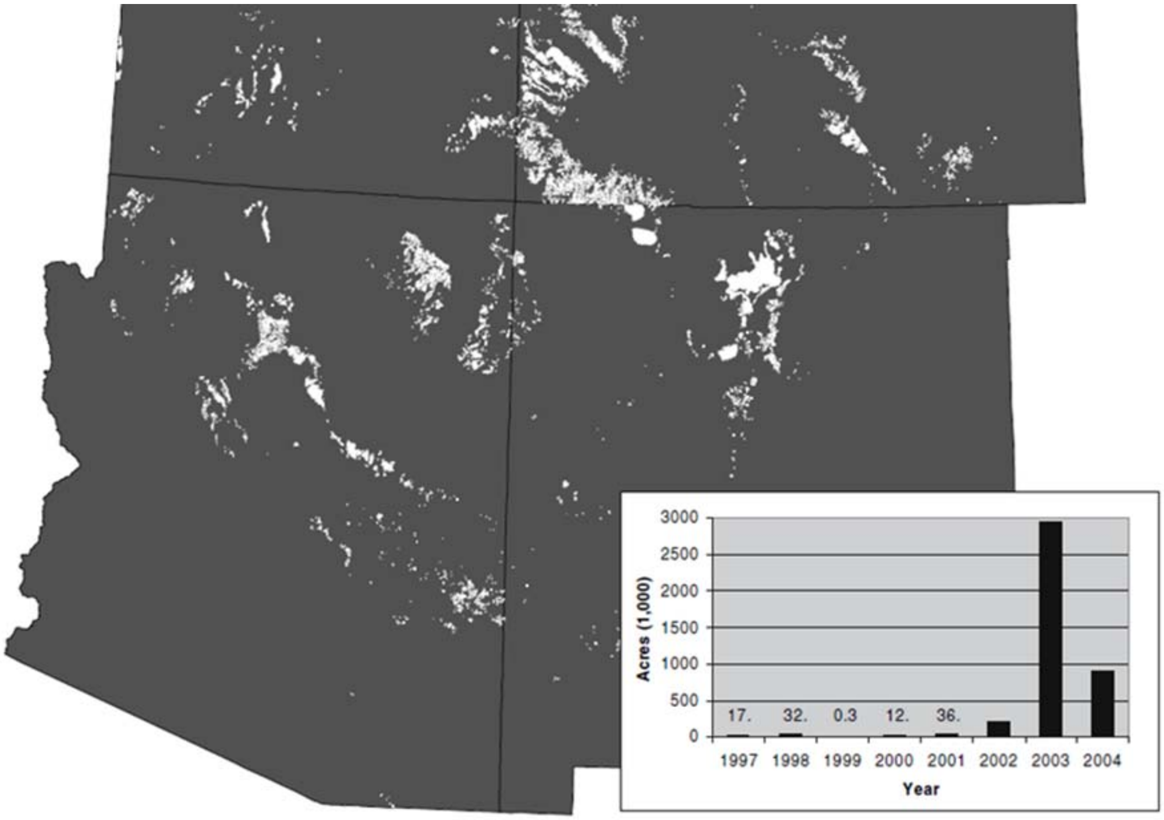
ERU	Reference	Local* NWZ	Local* SWZ	Local* CZ	Local* NEZ	Local* SEZ	Plan	Context
Juniper Grass	3.0	**14.3**	**12**	**11.2**	▨	**17.0**	**13.7**	**12.8**
PJ Sagebrush	3.0	**10.2**	▨	**8.3**	▨	▨	**8.8**	**13.2**
PJ Woodland	4.1	**17.4**	**15.6**	**12.8**	**20.5**	**19.5**	**17.4**	**18.6**
PJ Grass	3.5	**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 (suppression, transportation routes, historical grazing, etc.) has considerably altered the current coarse woody debris loadings and have led to a three- to four-fold increase in surface fuel loading for the majority of the frequent fire ERU types (table 8). 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 Piñon 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 5). The widespread dieback of Piñon is likely what has driven this unexpected increase in PJ Woodland coarse woody debris loading.



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

Figure 5. Extent of Piñon Pine dieback from 1997 to 2004 in the Four Corners states of Arizona, New Mexico, Colorado, and Utah is shown in white

Fire Frequency

Fire frequency expressed as the fire interval (FI) 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 and aside from climate, is probably the largest single impact shaping the ecology of the Southwest prior to anthropogenic influences. Among natural disturbances, fire is the key driver and interacts with insects and climate variation to form a disturbance complex that has major impacts. Disturbance and succession are common elements of all terrestrial ecosystems, and the condition of ecosystems results from interplay between these two processes. 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, 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.

Figure 6. 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

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).

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 piñon-juniper and lower ponderosa pine vegetative types. However, it is believed that human-set fires and vegetative impacts likely only enhanced prehistoric frequencies in localized areas (Allen 1996, Fish 2006). 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 (Swetnam et al. 1999, Allen 2002).

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. 2008b). 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. 1997, Swetnam et al. 1999) as extensive land-use patterns changed with the introduction of grazing, fire suppression, and fragmentation (Covington and Moore 1994b, Covington and Moore 1994a, Swetnam and Baisan 1996).

Data and Analysis Process

Reference data for evaluating fire history vary in temporal and spatial resolution for describing different aspects of fire regimes. Much of the information on fire frequency comes from paleo-ecological data, such as charcoal in lake and soil sediments (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. Current fire frequency information (1984 to 2013) was acquired from the National Interagency Fire Management Integrated Database and LANDFIRE database.

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
		8	Margolis 2014
		15-30	Allen 1989
PJ Grass	I	15–30	Baisan and Swetnam 1995
			Grissino-Mayer and Swetnam 1995
		11–36	Poulos et al. 2009
		4–8	Swetnam and Dietrich 1985
Ponderosa Pine Forest	I	9–12	O'Connor et al. 2014
		2–17	Baisan and Swetnam 1990, 1996
		10–30	Muldvain et al. 2003
		9–11	O'Connor et al. 2014
Mixed Conifer - Frequent Fire	I	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
			Miller and Tausch 2001
Sagebrush Shrubland	IV	12–70	Gottfried et al. 1995
			Wright and Bailey 1982
		30–60	Muldvain et all. 2003

ERU	Fire Regime Group	Fire Return Interval (yrs.)	Source
PJ Woodland	V (III)	200–300	Gottfried et al. 1995
		400	Floyd et al. 2000
			Floyd et al. 2004
		200+	DNR 2011
Spruce-Fir Forest	V	300	Romme et al. 2009
		300–400	Grissino-Mayer and Swetnam 1995

Results

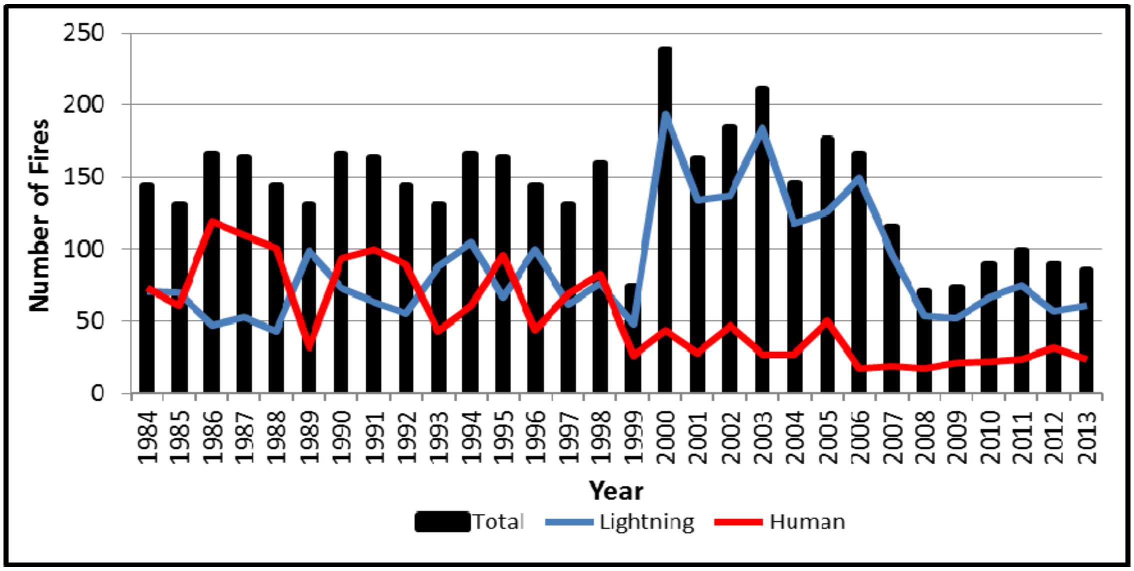


Figure 7. Wildfire occurrences on the Santa Fe National Forest from 1984 through 2013

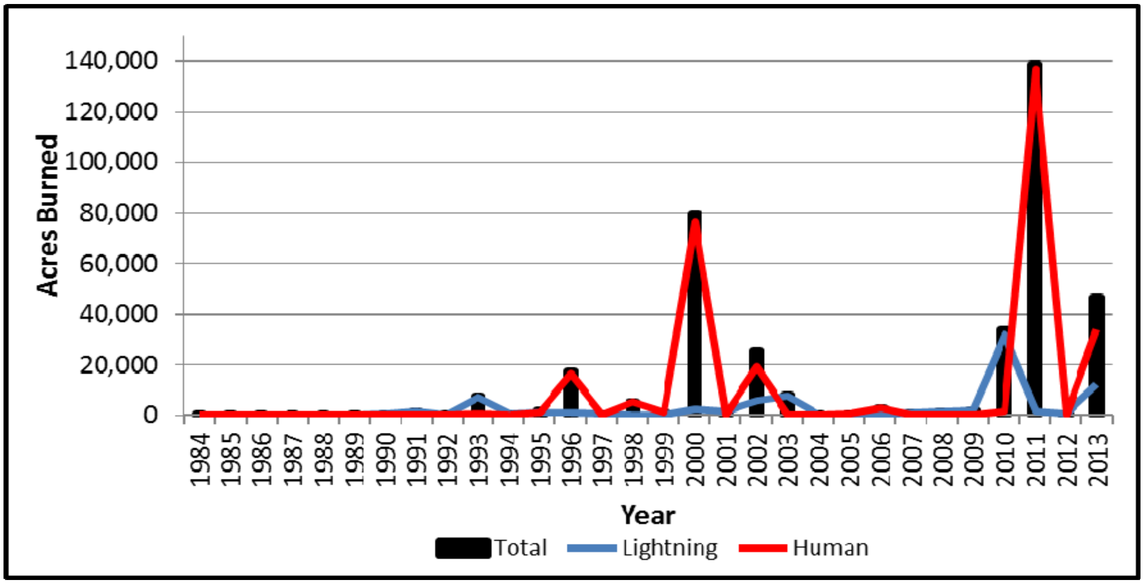


Figure 8. Santa Fe National Forest wildfire acres burned from 1984 through 2013

Between 1984 and 2013 the Santa Fe NF recorded 4,223 wildfires that burned 385,005 acres within the administrative fire boundary (figure 7 and figure 8). Prior to the circa 2000, wildfires on the Santa Fe NF 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. This 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.

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

ERU	Historic FI (yrs.)	Local* NWZ	Local* SWZ	Local* CZ	Local* NEZ	Local* SEZ	Plan	Context
Montane / Subalpine Grassland	2–22	**388**	**370**	▨	**308**	▨	**261**	**852**
Ponderosa Pine Forest	4–30	**422**	**692**	40	**94**	🟥	**203**	**319**
Mixed Conifer - Frequent	5–21	**322**	**565**	31	**154**	**> 1,000**	**152**	**207**
Juniper Grass	8–30	**>1,000**	**> 1,000**	**139**	▨	🟥	**831**	**>1,000**
PJ Grass	8–36	**> 1,000**	🟥	**85**	▨	🟥	**>1,000**	**>1,000**
Colorado Plateau / Great Basin Grassland	10–30	**446**	▨	**>1,000**	▨	🟥	**>1,000**	**>1,000**
Sagebrush Shrubland	12–70	**>1,000**	▨	▨	▨	▨	**>1,000**	**>1,000**
PJ Sagebrush	50–100	🟥	▨	**>1,000**	▨	▨	**>1,000**	**> 1,000**
PJ Woodland	30–400	**>1,000**	**> 1,000**	**727**	285	🟥	**>1,000**	**>1,000**
Mixed Conifer w/ Aspen	50–500	283	**778**	24	381	▨	238	497
Spruce-Fir Forest	200–400	215	**> 1,000**	31	217	**> 1,000**	222	**748**

*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

With ERUs in table 10 organized by fire frequency, with the most frequent fire systems at the top and ERUs with longer fire free periods at the bottom, it is apparent that the only two vegetation types not in high departure have long fire return intervals. MCW and SFF have fire free periods that can be 400 to 500 years long between disturbances. Comparing current fire intervals with reference fire frequencies, most ecosystems across the Forest have missed multiple fire disturbances. ERUs that historically burned frequently, are the most affected as a result of fire exclusion contributing to the buildup of organic material (CWD) and alteration of forest structure.

Differences in current fire intervals also exist when comparing across local zones. Of recent, generally speaking, fire has been the most frequent in the CZ and NEZ when considering all ERUs. Two frequent (PPF and MCD) and two infrequent fire ecosystems (MCW and SFF) in the central zone display fire activity within their natural range of variation. All three of the infrequent fire systems (i.e., PJO, MCW, and SFF) in the NEZ are of low departure from reference conditions. Even ecological types in this zone that are in higher departure, are still in relatively better condition than those found in other local zones aside from the CZ. The opposite is true of the SEZ, where the landscape has been almost completely absent of fire over the past 30 years. Excluding CPGB and the woodland ecosystems, fires are more frequent at the plan scale than those at the context scale.

It is widely supported and accepted that changes to current fire regimes are in large part due to human activities and have affected species composition, the amount, distribution, and proportion of living and dead biomass, and various ecosystem functions (e.g., nutrient cycling) (Dahms and Geils 1997). As a result of European and American settlement around the turn of the 20th century, livestock removed much of the grassy fuels that carried frequent, surface fires; roads and trails have also broken up the continuity of fuels (Covington and Moore 1994b); and because fire for much of the last century was seen as a threat, fire has been actively suppressed and have collectively lead to the departures presented in table 10. Many of the departures in other key ecosystems are also directly and indirectly related to this disturbance process resulting in transformation in forest conditions, structure, and composition. These changes in forest condition further contribute to changes in processes in a feedback cycle. The disruption of natural fire cycles has decreased the diversity within and across stands, permitting conifer seedling encroachment and decrease in meadows. Fire exclusion ahs also led to greater fuel accumulations (CWD) and stand densities, stand composition conversations (Seral State Proportion/Vegetation Structure), decreasing understory plant productivity (Ground Cover), and fire regime (Fire Frequency and Fire Severity) alterations.

Fire Severity

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 (i.e., shrublands) or grasses (i.e., grasslands).

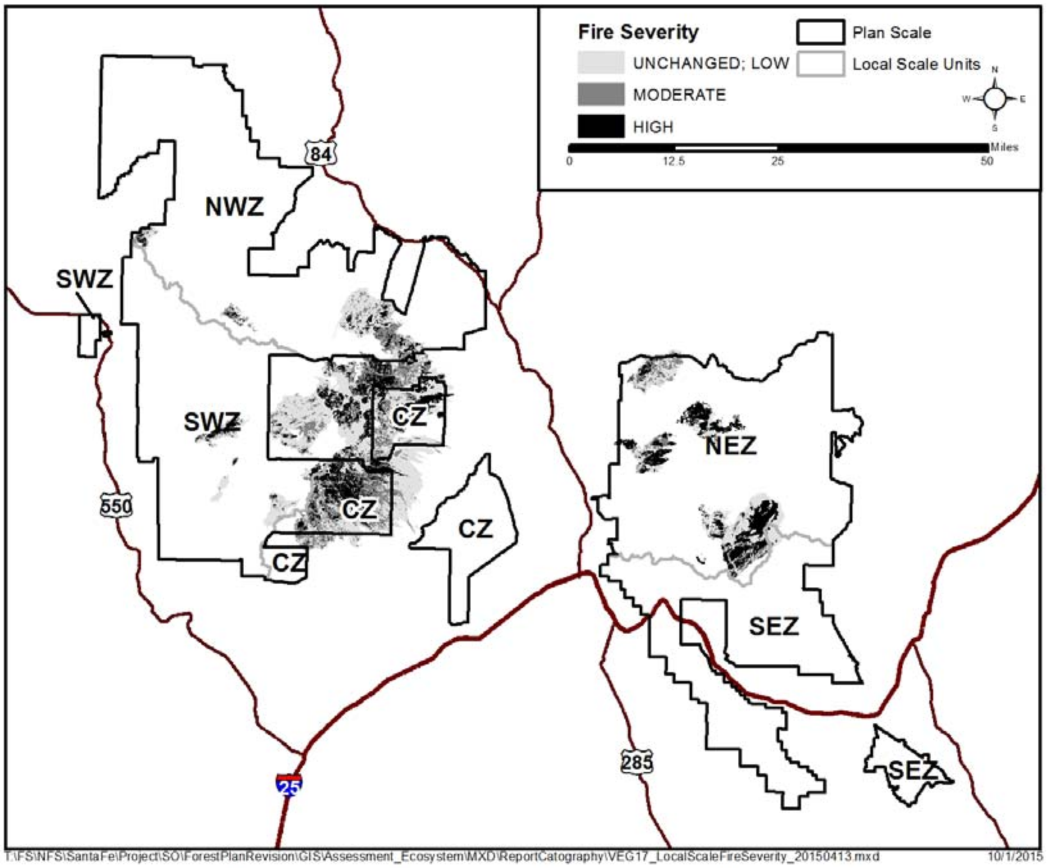


Figure 9. Fire severity for large wildfires on the Santa Fe NF for years 1984 through 2013

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[5], 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 severity data was not used to supplement MTBS data, although the Forest did have this data available for the Diego

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

and Pino Fires, since the data was not available for fires at the context scale that occurred in 2013 and 2014.

Results

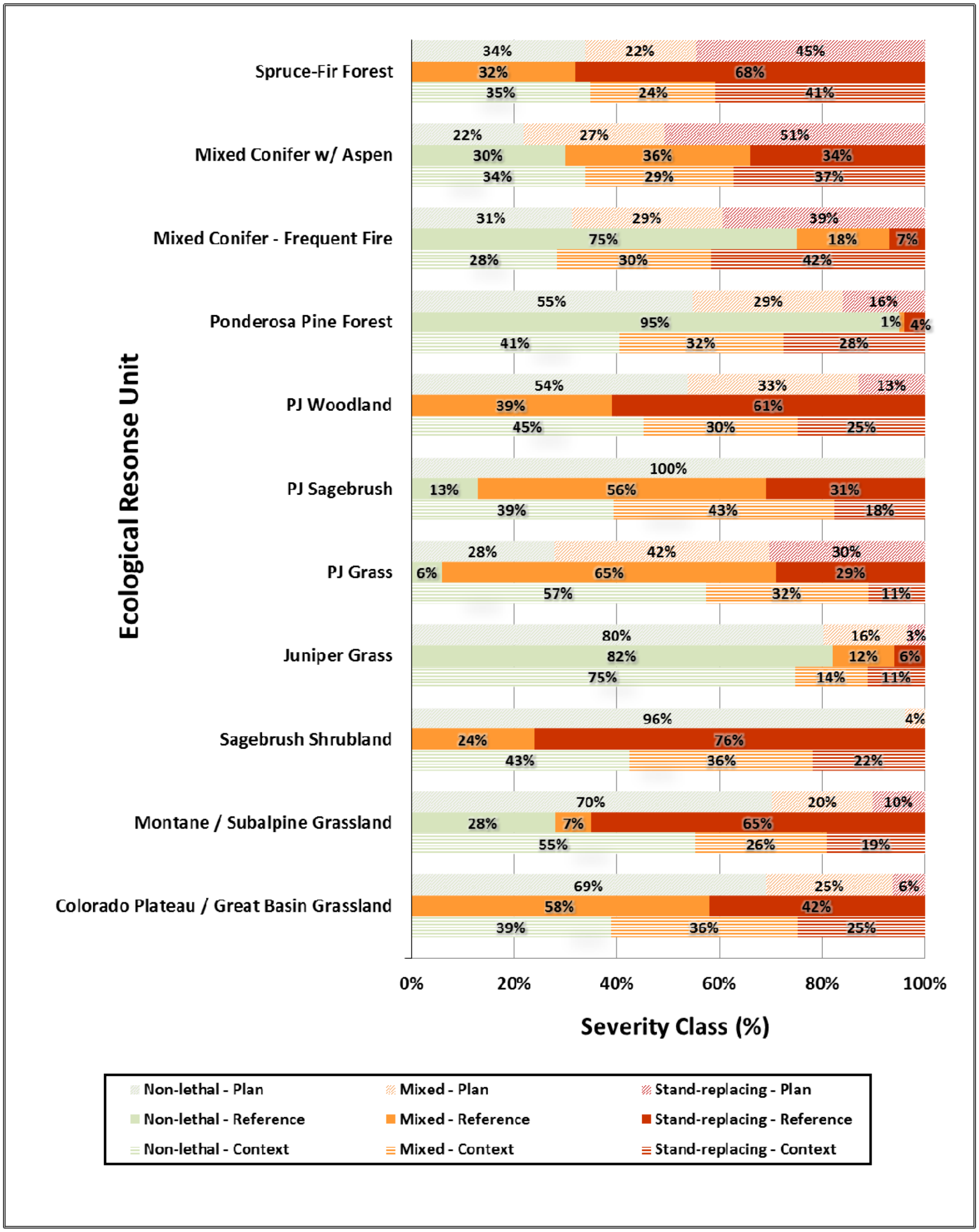

Figure 10. Severity class proportions for all ERUs based on wildfires at the context and plan scales for years 1984 to 2013 in comparison with reference severity proportions. Reference severity proportions from LANDFIRE (2012).

Current fire severities in grasslands and woodlands have decreased while forested frequent fire ecosystems have increased in resulting fire severities. Limited fire in the grassland (MSG and CPGB), shrubland (SAGE), and woodland (PJO, PJS, PJG, and JUG) systems in general is likely the cause for reductions in overstory change. The disruption of natural fire cycles have resulted in less frequent but more severe fires in the forested ERUs that historically burned frequently.

Fire Regime Condition Class

Fire Regime Condition Class (FRCC) is a standardized interagency tool for assessing a current landscape's departure from historical (natural) conditions (Hann et al. 2004). The FRCC departure metric can be derived by evaluating the change in composition of succession classes (including species composition, structural stage, age, and canopy closure), fire frequency, and fire severity (Barrett et al. 2006) compared to conditions under the historic disturbance regimes. The two main components of an ecosystem FRCC assessments measure include, fire regime (fire frequency and severity, both analyzed independently above) 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, legacy grazing, and drought. Common causes of departure include advanced succession, effective fire suppression, timber harvesting, historical livestock grazing, and introduced and established exotic species (Schmidt et al. 2002, Stambaugh et al. 2008, Keane et al. 2009).

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), expressed as the fire interval, is the number of fire events at a point or specified area within a specified period of time and severity (figure 10), is broadly defined as the degree of ecosystem change induced by fire (Albini 1976, Ryan and Noste 1985), are most often used to classify and map fire regimes (Heinselman 1981, Hardy et al. 2001). However, fire regimes are also described by magnitude (severity and intensity), predictability, size, seasonality, and spatial patterns (Heinselman 1981, Agee 1993). 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 2010). 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.

Since 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 11. 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 percent of the dominant overstory vegetation; can include mixed-severity fires that replace up to 75 percent of the overstory
II	0–35 years	Replacement	High-severity fires replacing greater than 75 percent 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

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, historical livestock grazing, introduction and establishment of exotic plants, as well as introduced insects and disease (Schmidt et al. 2002).

Table 12. 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.

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 et al. 1998, Dale et al. 2000, Bale et al. 2002, Williams and Liebhold 2002, Logan et al. 2003, Ryan et al. 2008). 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 information on data and analysis process used to determine current conditions please refer to the Fire Frequency and Fire Severity sections of the key ecosystem characteristics.

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 systems, 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 four- to five-fold increase 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 (36 CFR 219.9(c)). Stressors are influential in the direction and rate of succession. Other key ecosystem characteristics are also influenced indirectly (e.g., snag density, fire frequency, etc.) as described in ***Key Ecosystem Characteristics for Terrestrial Vegetation*** section. Examples of stressors are invasive species, disruption of a natural disturbance regime, or climate change. Many drivers may become stressors when they occur at uncharacteristic levels. These have been addressed throughout the ERU condition descriptions in the ***Terrestrial Ecological Response Units*** and are also discussed in the ***Key Ecosystem Characteristics for Terrestrial Vegetation*** section. Drivers and stressors are addressed throughout the ERU condition descriptions when appropriate.

Insect and Disease

Insect and disease is the severity and frequency of outbreaks of damaging organisms. 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, effects are more evident, sometimes negative, and cause greater forest change. 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. There are a few example of exotic agents on the forest. White pine blister rust is established 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 been introduced into 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. The spatial locations of where dwarf mistletoe is found is not known to have changed much from historic conditions, but the mistletoe continuity and severity has likely increased due to increased stand densities, and in-filling of forest interspaces. The current conditions have facilitated increased spread and continuity. In some cases, past harvesting activities have left mistletoe infected seed trees, likely increasing infestation levels in many regenerating stands. 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. Results from the model for the Santa Fe NF are displayed in figure 11 and table 14.

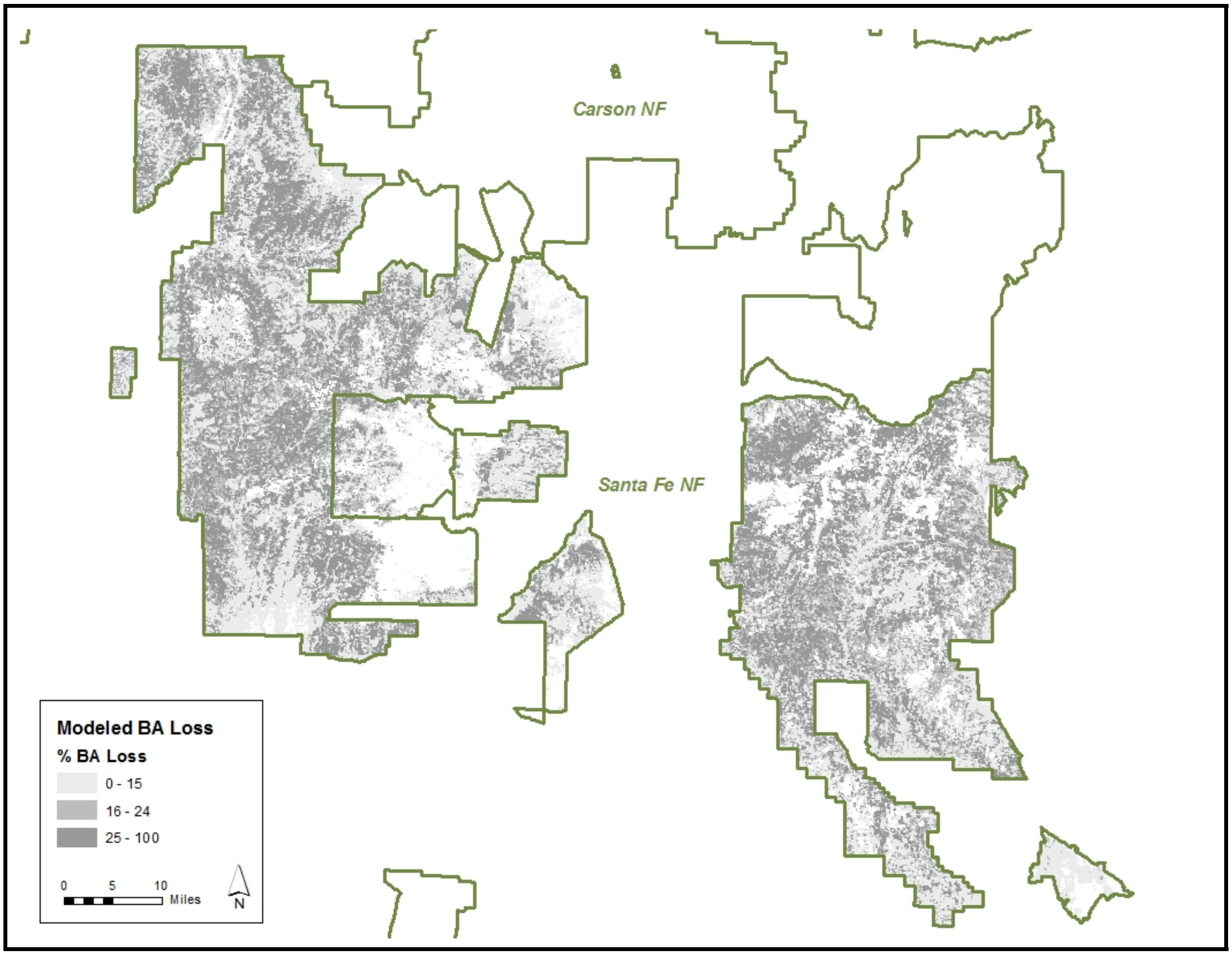

Figure 11. Modeled percent basal area at risk from insect and disease activity on the Santa Fe NF

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 piñon-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 are expected to substantially change forest insect and disease dynamics (Dale et al. 2000, Bale et al. 2002, Williams and Liebhold 2002, Logan et al. 2003, Ryan et al. 2008), and therefore, is expected to modify southwestern forests and woodlands. Recent trends of rising temperatures and reduced snowpack conditions observed in the western U.S. (Knowles et al. 2006) are 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. A 25 percent basal area loss is considered a threshold that represents *“an uncommon, rather extraordinarily high amount of mortality”* (Krist 2014).

Invasive Plant Species

Non-native and invasive plants (also known as noxious weeds), are aggressive species that displace native plant species. The National Invasive Species Council defines invasive species as, “those (species) that are not native to the ecosystem under consideration and that cause or are likely to cause economic or environmental harm or harm to human, animal, or plant health.” Whereas, Federal law, under Executive Order 13112 defines “invasive species” as: an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health. An “Alien species” with respect to a particular ecosystem is defined as, any species, including its seeds, eggs, spores, or other biological material capable of propagating that species, that is not native to that ecosystem. Invasive plant species that are particularly damaging or prolific are regulated as noxious weeds (EO 13112). Invasive species are not native to the ecosystem being described.

Invasive plants significantly alter plant composition, structure, and ecosystem functions. Invasive plants compete with desirable plants, poison animals, host insect and disease agents, and alter various ecosystem attributes by turning diverse native plant communities into monocultures (loss of biodiversity), and disrupt natural ecosystem processes such as; decreased water infiltration, increased soil erosion, decreased water quality, increased soil salinity, as well as disrupting natural fire regimes (Dick-Peddie 1993). Undesirable non-native and invasive plant species gradually out-compete native plant communities by starving native plants of space, moisture, and nutrients leading to the loss of biodiversity (Randall 1996). By reducing native plant infestations and altering natural ecosystem functions, they are also reducing the abundance and diversity of native wildlife species, and microorganisms in those ecosystems. Wildlife habitat is affected by the presence of non-native and invasive species as palatable forage is lost, and nesting and foraging cover is decreased for both aquatic and terrestrial species.

Invasives continue to invade rangelands, forests, and riparian ecosystems. Control of infestations can be challengeing with their rapid exapansion and continued introduction. The rapid expansion of exotic weed populations limits the potential to effectively restore native plant communities to conditions within the historic range of variability. If exotic plants are not kept in check, long-term devastating effects to forest ecosystems can occur. There are numerous vectors in which non-native and invasive species spread across the landscape. Natural disturbances such as wind events, rain, floods, snow runoff, and wildfire can carry seeds vast distances. Wildlife and domestic animals can carry seeds by foot, coat, or by seeds they may have ingested and discarded by feces. Human activities contribute largely to the spread of non-native and invasive species. Clothing, shoes, vehicles, and ATVs can also carry seeds great distances.

Surveys for invasive plants on the National Forest System land have been quite limited. The identification of infestation sites on the Forest is sporadic and typically a result of employees coincidentally traveling through locations for other reasons. Monitoring of invasives is not systematic and thorough on the Santa Fe NF. It is estimated there are considerably more infestations, and species that have not been inventoried and mapped. Therefore, the data captured below is not inclusive of all invasive plants that exist on the Forest. Occurrences identified below are from the Forest’s geographical information systems (GIS) invasives database for calendar years 2000 through 2014.

For all ecosystems, the reference condition is that invasive species are rarely present, or are present at levels that do not negatively influence ecosystem function.

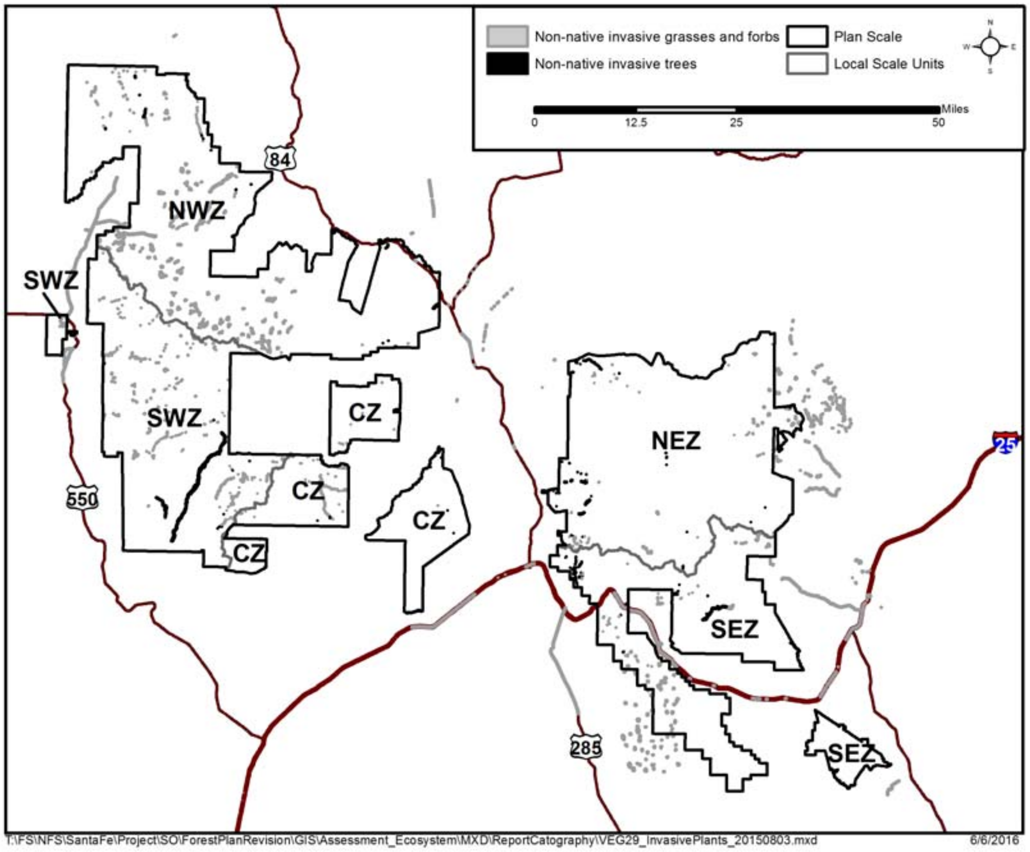

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Figure 12. Invasive plants on the Santa Fe National Forest

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

Common Name	Scientific Name	NWZ	SWZ	CZ	NEZ	SEZ	Forest
Bull thistle	*Cirsium vulgare*	106	1,864	48	521	685	3,224
Canada thistle	*Cirsium arvense*	5,178	224	58	6	0	5,466
Cheatgrass	*Bromus tectorum*	2	69	0	5	0	76
Common mullein	*Verbascum thapsus*	1	20	0	0	0	21
Dalmation toadflax	*Linaria dalmatica*	3	18	0	0	0	21
Diffuse knapweed	*Centaurea diffusa*	6	108	0	0	0	114
Hardheads	*Acroptilon repens*	36	51	0	0	0	87
Nodding plumeless thistle	*Carduus nutans*	2,474	558	106	15	1	3,154
Poison hemlock	*Conium maculatum*	0	22	0	0	0	22
Russian olive	*Elaeagnus angustifolia*	0	1,730	28	0	1	1,759
Tamarisk (saltcedar)	*Tamarix ramosissima*	161	1,733	46	0	0	1,940
Scotch thistle	*Onopordum acanthium*	10	35	82	4	350	481
Siberian elm	*Ulmus pumila*	22	1,813	6	251	309	2,401
Spotted knapweed	*Centaurea stoebe*	323	0	0	0	0	323
Totals		***8,322***	***8,245***	***374***	***802***	***1,346***	***19,089***

The distribution and documented extent of non-native and invasive plants are displayed in figure 12 and table 15. 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. Ponderosa Pine Forest, 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 percent of the ecosystem infested annually (based on 15-year average).

Generally plume thistle (Bull and Canada thistle) is the most abundant invasive found on the Forest with 46 percent of invasive plants found on the Forest being of this genera. Canada thistle being the most extensive exists in nearly every ERU found on the Forest.

Climate Change

Although regional climates persist for centuries, they do change and vegetation responds on a similar scale (Delcourt and Delcourt 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 Niño years bring increased annual precipitation, but less rain in the summer, and La Niña years bring the opposite (Betancourt 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). 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 and are reported in the Santa Fe NF Climate Change Vulnerability Assessment (CCVA) (Triepke 2015).

Summary of Tabular Reporting

Reporting at each of the three scales provides useful insights for interpretation of climate change vulnerability results for the reporting area. In the tables to follow, vulnerability and uncertainty are reported for each scale and for all ecosystems collectively. In all cases the reporting reflects an all-lands summary, regardless of ownership. For the Plan unit and local scales, reporting is also broken out by

ERU. The CCVA results for the sub-watershed scale are shown as one vulnerability category for each watershed, representing a composite scoring of vulnerability for all lands (Triepke 2015).

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 (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, version 3 (HADCM3), and Geophysical Fluid Dynamics Laboratory Circulation Model (GFDLCM21)). Uncertainty is reported using a simple agreement process and categories.

Interpretation of Results

The CCVA results infer vulnerability based on the projected climate departure from the historic climate envelope for a given ERU and location. In broad terms it may be helpful to think of future climate simply as a potential stressor of significant change (i.e., on structure, composition, and function), with the vulnerability rating on par with risk or probability of stress, either low, moderate, high, or very high. In more specific terms, vulnerability can be considered the ‘relative probability of type conversion.’ Vulnerability is a consequence of at least three factors:

1. Breadth of the envelope for a given ERU
2. Current status of a given location relative to its ERU envelope
3. Magnitude of projected climate change at that location

The thematic resolution of most ERUs is similar, and the ERU framework was modified to ensure normal distributions for key climate variables. As a result, the breadth of the climate envelopes is fairly similar among ERUs. That said, all else equal an ERU with a relatively broad envelope is inherently less vulnerable, keeping in mind that climate departure also depends on the projected climate for a given location and on how a given plant community currently falls relative to its envelope. Also, though riparian ERUs were not specifically analyzed for CCVA, some inference of the vulnerability of these systems was taken from the watershed-scale results in the final set of tables from Triepke (2015).

Finally, the current resilience and resistance of ecosystems may be interacting factors in climate change vulnerability, to be expressed in the risk assessment. Resistance is the ability of an ecosystem to endure disturbance and maintain the structure, composition, and function that are characterisitic of the system while resilience is the ability of an ecosystem, following disturbance, to regain the structure, composition, and function that are characteristic of the system on a time span consistent with its successional patterns.

The results of projected future ERU conditions and potential climate change impacts are discussed in the Future/Trend sections for individual ERUs. Though riparian ERUs were not specifically analyzed for CCVA, some inference of the vulnerability of these systems were taken from the watershed-scale results (see (Triepke 2015).

Results

Table 16. 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 17. 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%	

The vulnerability to climate change and resulting potential effects specific to each ERU are discussed in the Future/Trend sections of the Terrestrial Ecological Response Units discussions.

Terrestrial Ecological Response Units

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. 2013) 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 - 2014 (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. 2013) 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 (2014) 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[6] 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 when riparian areas are included.

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[6] ERUs found on the Forest that represent less than one percent of the plan scale landscape include Alpine Tundra (0.30 percent), Bristlecone Pine (0.17 percent), Gambel Oak (0.56 percent), Mixed-Grass Prarie (0.10 percent), and Shortgrass Prarie (0.7 percent). Excluding Alpine Tundra, these ERUs also account for less than one percent of the context scale (small proportional representation).

Table 18. 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.

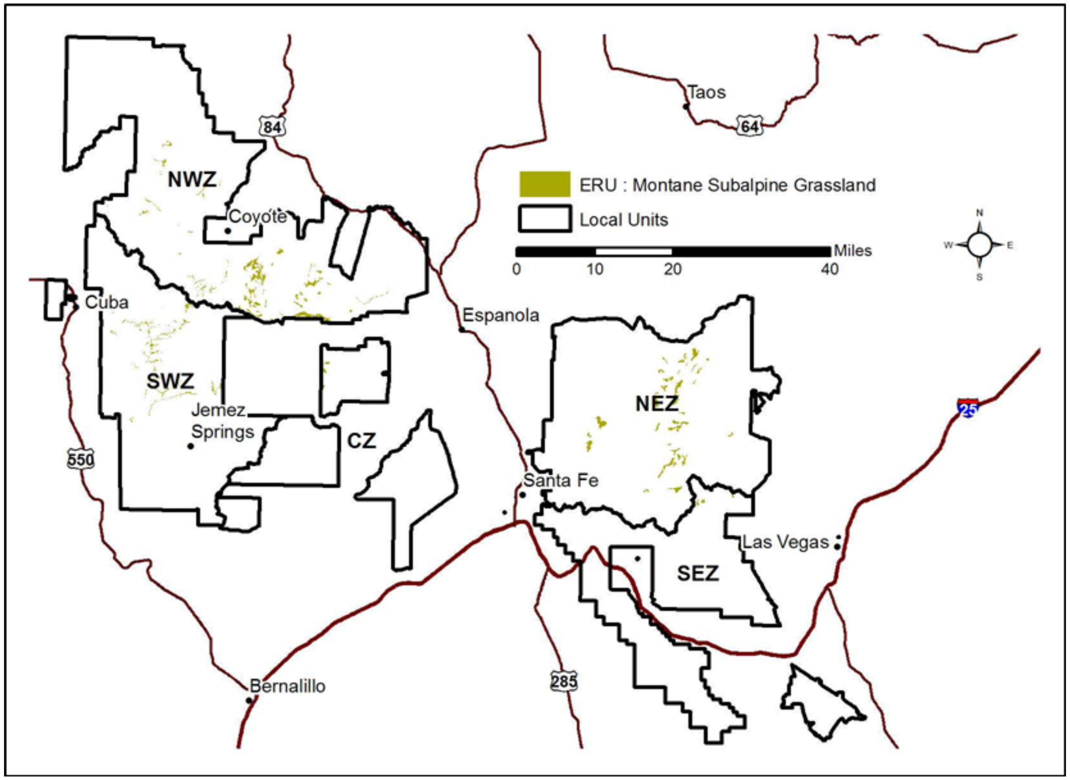
Upland Ecological Response Units (ERUs)	Spatial Scales of Analysis													
	Local										Plan			Context
	NWZ		SWZ		CZ		NEZ		SEZ					
	% of Local Scale	% of Plan ERU Acres	% of Local Scale	% of Plan ERU Acres	% of Local Scale	% of Plan ERU Acres	% of Local Scale	% of Plan ERU Acres	% of Local Scale	% 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 - (PJO)	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 Prairie - (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 Prairie - (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 1995). 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 has been analyzed.

Reference Conditions

Reference conditions for MSG, like other grassland ecological types, are difficult to identify as past conditions and disturbance are not recorded by grasses the way they are by trees. Limited documentation on historic composition and structure makes separating anthropogenic influence from that of natural succession and disturbances of grassland ecosystems challenging as MSG relict sites are rare and generally small, and the effects of historical land use 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.

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 infrequently during drought years when plants and litter were dry. Mesic-dry sites likely burned more often and fire frequency was probably correlated with that of the surrounding forest vegetation and fuel moistures (Romme et al. 2009a, Romme et al. 2009b, Vankat 2013). 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. 2009a). 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 trees and shrubs.

Based on the patch size analysis (described above) 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 (Forest patch analysis, above). 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

Local Scale

Although all zones at the local scale in which MSG is found display a significant amount of tree and shrub invasion, the SWZ is especially threatened with nearly three quarters of the zone invaded by trees and/or shrubs. The emphasis on this invaded seral state is a result of a lack of wildfire (FI) and reduced vegetative ground cover that typically aids the spread of wildfire. The SWZ is especially departed from reference vegetative ground cover and has experienced a significant increase in the amount of bare soil from 4.1 percent to 20.6 percent. Unlike forested ERUs, the lack of wildfire in this grass ecosystem hasn’t resulted in a significant departure in wildfire severity primarily because grasses are able to quickly reestablish after a fire disturbance which actually encourages new growth and system productivity. With moderate departures in seral state proportions and high departure in fire disturbance all three local zones fall into fire regime condition class 3, indicating significant departure from their natural range of variation.

Plan Scale

At the plan (forest) scale seral state proportions are 60 percent departed from reference conditions adapted from LANDFIRE reference condition models (Smith et al. 2009). As indicated in the seral state proportions section for MSG, the majority of the departure in vegetation structure is due to the transition towards the uncharacteristic shrub and tree invaded state. 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 whereas it is now the dominant state represented (60 percent at plan scale) on the landscape. The encroached state is a result of a lack of fire in combination with other influences such as drought and recreational impacts. Woody species invasion have fragmented the MSG system, reducing current average patch sizes to 53 acres, roughly half the size that existed historically and moderately departed from reference at the plan scale. The fragmentation of MSG ecosystems and reductions in total acreage has also been documented by Fletcher and Robbie (2004).

The plan scale ground cover 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, below). Primary causes of these changes include long-term drought intensified by ungulate grazing and human disturbances including road construction, fire suppression/rehabilitation and concentrated recreation. The plan scale 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 analyzed.

Fires in MSG are much less frequent on the Santa Fe NF than what occurred historically, and fire return interval (261 years) for this ERU is highly departed. Since MSG has a short fire return interval, many fire cycles have been missed in this ERU.

Context Scale

Seral state proportions at the context scale mirror The fire return interval at the context scale (852 years) is more substantially departed than at the plan scale (261 years), resulting in a high departure of seral state at the context scale (71 percent). There is also a slight shift toward higher severity proportions at the context scale.

Future/Trend

Based on the current disturbance regime, modeled future conditions indicate that limited fire occurrence in this ERU will continue leading to degraded conditions in MSG. Mid- and high-seral states that are currently 50 percent departed from reference will transition to tree and shrub invaded states with continued encroachment. The lack of disturbance also continues to limit the amount of MSG sites that are reinitiated back to an early, low-seral state. 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 (future condition) modeling.

The projected climate change vulnerability assessment (please see Climate Change section 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 the moderate vulnerability category. More than any other ERU, MSG is found across a wide elevational range, which may mitigate the effects of climate change for the ERU as a whole, as a large climatic shift would have to occur to degrade conditions (e.g., moisture availability, etc.). Some concern exists in the uncertainty of the MSG models, with the majority of uncertainty for MSG (67 percent) in the moderate category; meaning future climate projections have a moderate amount of disagreement and projected vulnerability trend may not be reliable.

In the Central and South-East Zones there is limited MSG because of restricted water availability. In a climate change scenario with continued increases in temperature and less water availability similar patterns could manifest in other areas of the forest. Reduced grassland productivity, including MSG sites, and lower ground cover in favor of woody-species will continue to result.

MSG Key Findings

MSG on the Santa Fe NF is moderately departed l (60.0 percent) due to overrepresentation in the uncharacteristic tree/shrub state, as a result of reduced fire, climate change, and decreased competitive ability from overutilization by large herbivores (Fletcher and Robbie 2004, Zier and Baker 2006, Vankat 2013). The SWZ is especially threatened with nearly three-quarters of the zone invaded by trees and/or shrubs. Enchroachment by woody species have led to the fragmentation of the MSG landscape, reducing current average patch sizes to 53 acres (44 percent departure). Drought in combination with forest activities such as timber harvesting, road construction and use, prescribed burning, and legacy grazing impacts have contributed to the removal of soil surface cover (vegetative BA). Remaining vegetation species composition has been altered significantly (59 percent) by non-natives and invasives, such as Kentucky bluegrass. Future conditions (100-year VDDT model) indicate that the MSG ecosystem will continue to be degraded by continued encroachment and limited early successional conditions as a result of limited fire and large proportions of bare soil. However the vulnerability of MSG is projected to be low based on the climate change vulnerability assessment.

MSG Overstory Structure and Composition, Seral State Proportion

State	Description	Proportion (%)								
		Reference Condition[1]	Current Condition							Future Condition 100 Yr.
			Local Scale[3]					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	Mid-seral - all grass and forb types; shrub & tree cover < 10%, grass cover >10%	35	28	12	▨	25	▨	24	28	14
C	High-seral - all grass and forb types; shrub & tree cover < 10%, grass cover >10%	45	20	12	▨	12	▨	15	18	6
D	Tree and/or shrub invaded	0	51	74	▨	62	▨	60	54	78
	% Departure	**0**	**51**	**74**	▨	**62**	▨	**60**	**71**	**78**

Departure Class
Low
Moderate
High

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			***FI*** (yrs.)	***Severity*** (%)			***FRCC*** (%)[4]		
				Low	Mod.	High	I	II	III
Reference Condition			2 - 22	65	8	28	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**			**FRCC III**		

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[1] Based on LANDFIRE (2010). [2] Departure at the plan scale.

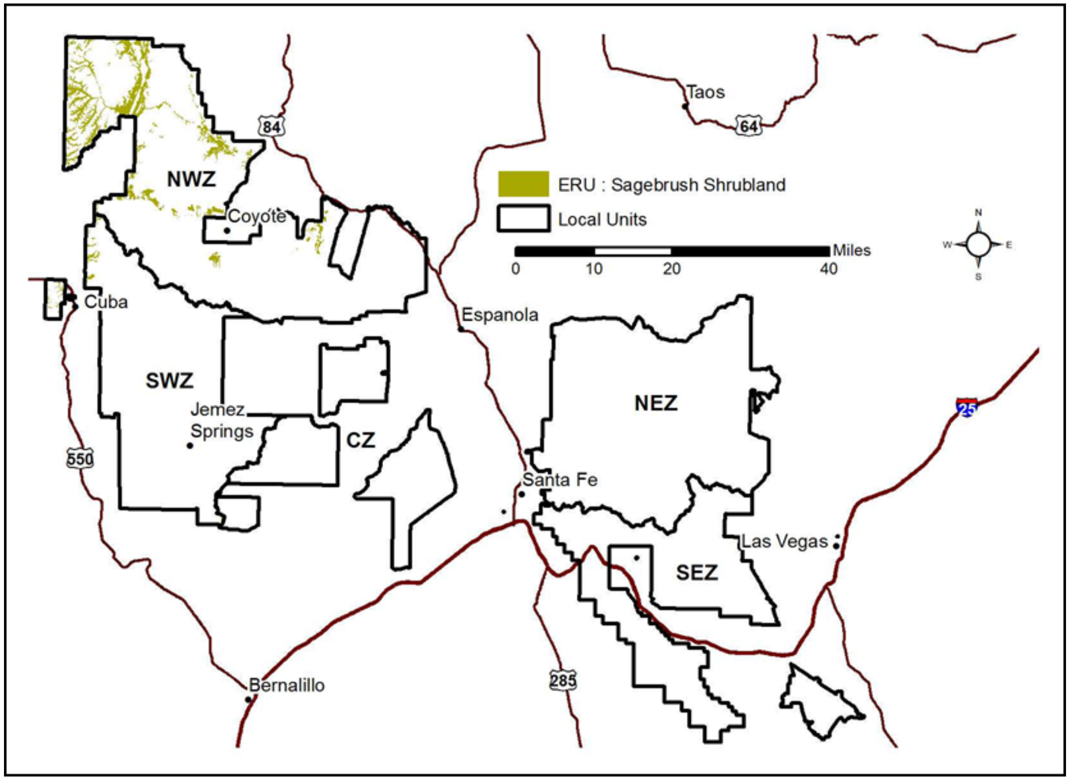
[3] Hatching indicates the ERU does not represent at least 5 percent of the local zone and is, therefore, considered not sufficiently represented to analyze.

[4] FRCC and proportions are provided at the plan scale, a "*X*" denotes dominate class at local scale.

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 piñon 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 (Wright and Bailey 1982, Miller and Tausch 2000, Gottfried 2004) to 200+ years on drier sites (Whisenant 1990, Welch and Criddle 2003, Baker 2006). 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 2000), 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

Local Scale/ Plan Scale

Not much different exists between the local scale and plan scale SAGE analyses as 93 percent of sagebrush shrublands on the Forest are found in the northwest zone. Similar to MSG, the lack of fire disturbance in sagebrush shrublands (greater than 1,000 years fire interval) have led to a significant proportion (39 percent) of the Santa Fe NF SAGE landscape has been invaded by trees and other woody shrub species. Historically on average the majority (55 percent) of SAGE was an open cover shrub landscape. Saab and others (1995) have documented that tree establishment is the result of a combination of causes including historical overgrazing which has limited fine fuel continuity and altered fire regimes and is also a major source of non-native plant incursions into sagebrush habitat. With the increased incursion of non-natives and trees, sagebrush vegetative basal area has been reduced by 55 percent as a result. The ground cover analysis indicates much of this area (70 percent) is now bare ground. Increased bare soil leads to increased chance of noxious weed infestation, decreased water infiltration down into the soil profile, increased runoff and erosion, and less vegetative production leading to decreased vegetative cover and further increased bare ground creating a negative feedback cycle.

These changes in the current seral state proportions and percent ground cover still have not led to a significant decrease in average patch size as the average 152-acre SAGE patch size found on the Forest is on the cusp of the reference range of 152 to 407 acres. Also, not effected much is the change in wildfire severity which is only 20 percent departed (low departure) from reference conditions with a decrease in the amount of moderate severity and an increase in low.

Context Scale

Tree and woody invasion at the context scale is still a threat but only 27 percent of the landscape relative to 41 percent at the plan scale is found in the tree invaded state. The majority (40 percent) of the context scale is in a late seral, closed cover state. Although tree encroachment is not as extensive at the context scale, a lack of wildfire and the removal of fine fuels (herbaceous material) has resulted in limited disturbance and closing of the shrub canopy. The increased tree and shrub density is also resulting in increased severities proportions with 58 percent of wildfires resulting in moderate and high severities.

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 it is 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 future seral state conditions are predicted to worsen, but conditions may 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 Key Findings

The loss and degradation of sagebrush ecosystems is significant and well-documented (Saab et al. 1995, Knick and Rotenberry 2002). Threats to sagebrush ecosystems are numerous and widespread, including urban and suburban development, agricultural conversions, historical 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 including historical overgrazing, development of travel routes, and drought. These occurences have 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, and can be intensified by pressure from heavy domestic grazing or wild ungulate use and where sagebrush recruitment has been inadequate (Winward 2004). As a result, sagebrush vegetative basal area has been reduced by 55 percent. With the reduction in vegetative cover and compaction of soils, 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 conditions (100-year VDDT model) indicate that the MSG ecosystem will continue to be degraded by continued encroachment (state E) and limited early successional conditions (state A) as a result of limited fire. However, like MSG, the vulnerability of SAGE to climate change is projected to be low based on the climate change vulnerability assessment.

SAGE Overstory Structure and Composition, Seral State Proportion

State	Description	Proportion (%)								
		Reference Condition[1]	Current Condition							Future Condition 100 Yr.
			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**

Departure Class
Low
Moderate
HIgh

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			***FI*** (yrs.)	***Severity*** (%)			***FRCC*** (%)[4]		
				Low	Mod.	High	I	II	III
Reference Condition			12 - 70	76	24	0	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**			**FRCC II**		

[1] Based on LANDFIRE (2010).

[2] Departure at the plan scale.

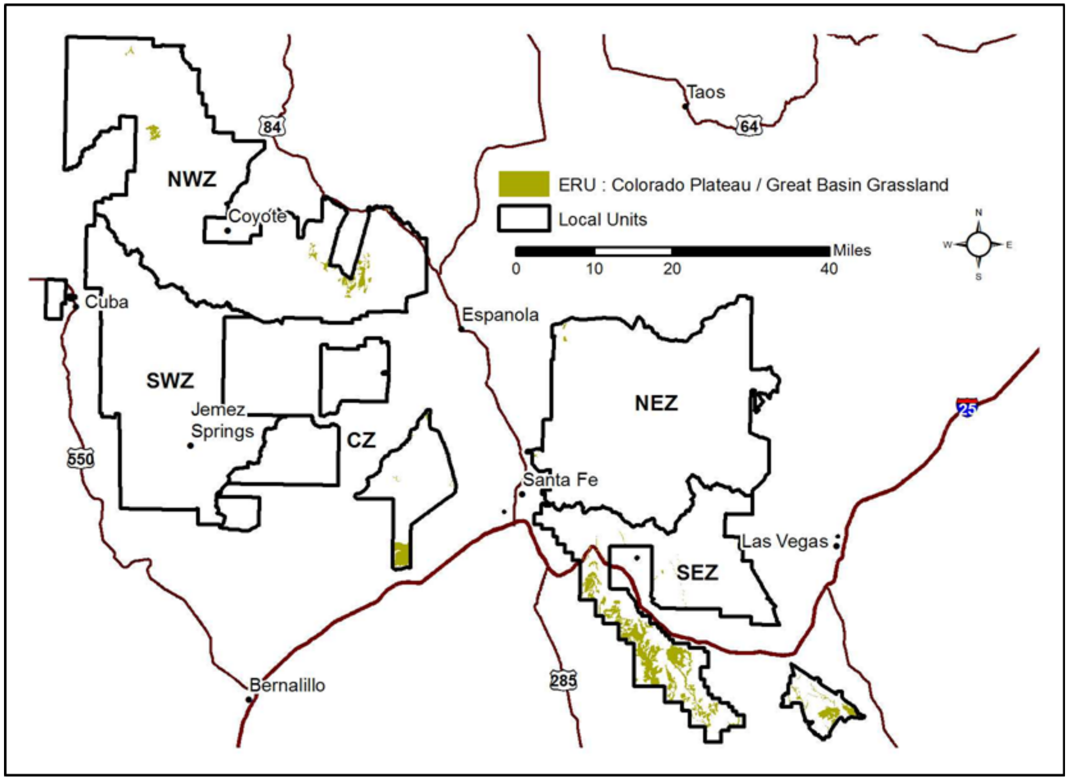
[3] Hatching indicates the ERU does not represent at least 5 percent of the local zone and is, therefore, considered not sufficiently represented to analyze.

[4] FRCC and proportions are provided at the plan scale and a "*X*" denotes dominate class at local scale.

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 late successional dominant species. Sideoats grama was an important component as was hairy grama. Mostly in lower spots topographically, western wheatgrass was 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 less than 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

Local Scale

Of all the grass ecosystems found on the SNF, the CPGB ecosystem currently exhibits the greatest amount of departure in overstory structure with 85 to 95 percent across all local zones where CPGB is found on the Forest. Although all three local zones have a fair amount of acreage in the low seral, exotic grass/forb and shrub/tree invaded seral state, the CZ has been especially been altered as nearly 50 percent of all acres in this zone are currently found in this state. This departure towards the low seral state is further captured by the similarity to site potential analysis which shows moderate departure for both the NWZ (41 percent) and SEZ (40 percent) (data unavailable for the CZ) where native species are being replaced by invasives such as bull thistle and Scotch cottonthistle. The NWZ when compared to the CZ and SEZ is in slightly better shape with a smaller proportion (27 percent) of acres in the low seral state and a bit more heterogeneity in the overstory structure with 10 percent of acres in a low to mid seral state which historically represented 25 percent of CPGB landscapes.

Vegetative cover in the SEZ is just within the moderate range of departure at 35 percent but the NWZ and CZ are marginally higher at 51 and 57 percent, respectively. The reduction in vegetative cover coincides well with the increase in the amount of bare soil relative to reference conditions for the SEZ (29 percent) and NWZ (34 percent), which are near the low to moderate departure threshold. However, the CZ has a significant increase in the amount of bare soil and is 57 percent departed from reference conditions, similar to the amount observed in vegetation cover for this zone.

Unfortunately, the natural role of fire has almost been completely removed from the CPGB ecosystem on the Santa Fe NF with only the NWZ experiencing wildfire in the previous 30 years. Still, this disturbance has been rare leaving the current fire frequency of 446 years well outside the 10- to 30-year cycles that occurred historically.

Plan Scale

Similar to what is being observed in each of the local zones, seral state proportions at the plan scale have shifted significantly toward the low/exotic/invaded and low/mid seral states. Currently, 61 percent of the CPGB landscape at the plan scale is in a mid-seral state and 37 percent in a low-seral, ruderal invaded state. These changes and the significant amount of vegetation structure departure can be attributed to a few phenomena. The shift in ground cover both from alterations in site potential towards exotics and moderate increases in the amount of bare soil have led to fire frequencies well outside the natural range of variability. The removal of this disturbance has not only led to shifts in overstory structure but has also allowed for the encroachment of woody species which typically would keep these species at bay with regular wildfire. This regular disturbance is also responsible for maintaining the patch sizes of this ecosystem but is currently only slightly departed (21 percent) from historical averages (295 to 513 acres) at the plan scale.

Context Scale

Comparing seral state departure at the plan scale with that of the context scale, it is evident that CPGB on the SNF is in significantly worse shape than on adjacent lands despite the proportion of land in the low/exotic/invaded state being rather great at the context scale. The context scale overstory structure has greater heterogeneity with 26 percent in the high-seral, 2 percent in the mid-seral and 32 percent in the low-mid seral states. Despite overstory structure at the context scale in significantly better condition, the exclusion of fire is still an issue with fire frequencies in excess of thousands of years.

Future/Trend

Model Not Yet Available

CPGB Key Findings

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 have contributed to the conversion of CPGN to shrub-dominated desert scrub or piñon-juniper (Hobbs and Huenneke 1992, Bahre and Shelton 1993). Historically CPGB systems were maintained by periodic fires that set back succession, but a history of fire suppression has allowed the widespread encroachment of shrubs and trees (Humphrey 1958, McPherson et al. 1995), with current return intervals averaging over 1,000 years at the plan scale. The increased invasion of grasslands by exotic plants facilitated by altered fire regimes, grazing, road construction, and other forms of disturbance have also contributed to altered fuel structure and fire regimes, and in some areas have lead to the conversion of the native grassland to some other habitat type (Finch et al. 1999). Additionally, development and rural sprawl are aiding in the degradation, and fragmentation of these grasslands. The construction of buildings, roads, fences, and other structures associated with these rural subdivisions result in an increase in use and impacts including the spread of non-native and invasive species (Knight et al. 1995). Future conditions (100-year VDDT model) indicate that the CPGB ecosystem will improve moderately with increases in both the high seral (state A) and low to mid seral (state C) states. The ruderal and enchroahced states (states D, E, and F) continue to persist as a result of limited restoration treatments and wildfire in this ecosystem. CPGB is moderate to highly vulnerable to projected climate change, and is especially of concern in the CZ where 92 percent falls into the very high vulnerability category.

CPGB Overstory Structure and Composition Seral State Proportion

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**

Departure Class
Low
Moderate
High

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			***FI*** (yrs.)	***Severity*** (%)			***FRCC*** (%)[4]		
				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**			**FRCC III**		

[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.

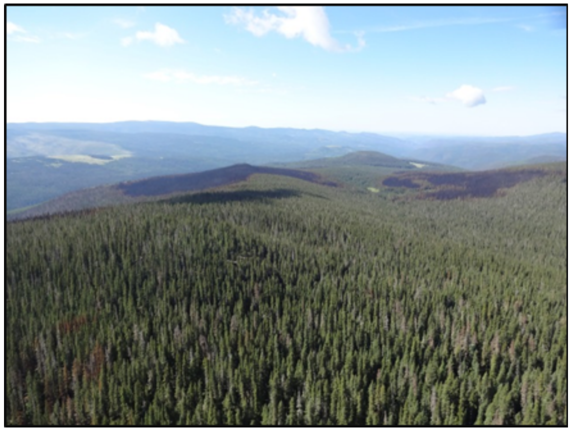
[4] FRCC and proportions are provided at the plan scale and a "*X*" denotes dominate class at local scale.

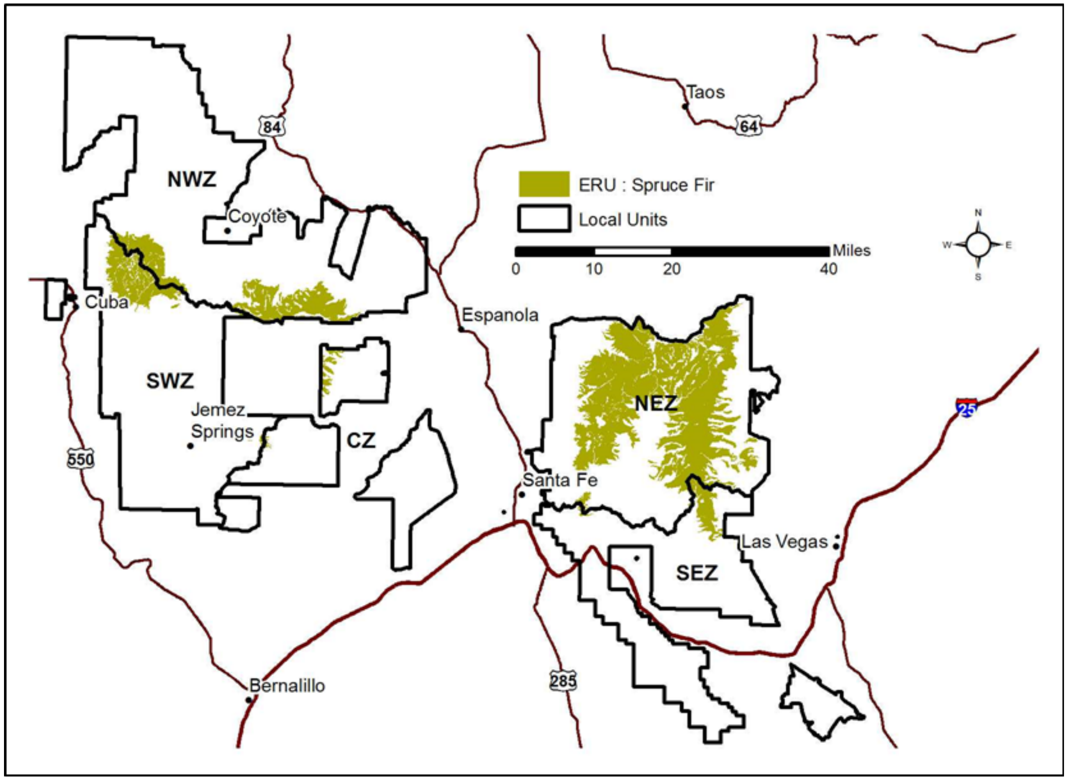
Forest and Woodland Systems

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 some livestock grazing, fire management, and nearby land use resulting in mosaics of stands with different structure and composition (Stromberg and Patten 1991). 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 year interval, 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 (Romme et al. 2001, Margolis et al. 2007, 2011). 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. 2009a). 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 in a late successional state stand.

Current Conditions

Local Scale

When comparing seral state proportions at the local scale, the three zones represented (NWZ, SWZ, and NEZ) don't have much discrepancy between them for each of the seral states, aside from the SWZ, which appears to have a significantly greater representation in the aspen/deciduous tree state (state B) than the other two zones. The SWZ currently has nearly double the proportion of aspen/deciduous state acres (23 percent) that existed historically (13 percent). Across all local zones the other significant change on the landscape in SFF is the lack in late-seral stands and significant increase in mid-seral acres.

The snag density in the NEZ is moderately departed (54 percent) compared to low departure in the NWZ and SWZ. Although all zones show a fair amount of departure in the smaller diameter snag class (8.0 to 18.0 inch dbh), the NEZ also exhibits a significant amount of departure in the large diameter snag class (greater than 18.0 inch dbh).

Understory structure and composition across all local zones is in relatively good condition, especially when compared with the condition of other ERUs found on the Santa Fe NF. Current understory composition in SFF is in reasonably fair condition with both the SWZ and NEZ exhibiting 65 to 70 percent similarity to reference site potential. The NWZ is moderately departed (40 percent) but not to distant from the low departure threshold. Similarly vegetative ground cover is also in good condition with limited departure from reference across all local zones and even displaying an increase in the SWZ for SFF. High coarse woody debris loadings are typical in SFF, but current conditions show that on average all local zones show an excessive amount of coarse woody material. These range from a 50 percent increase in the NEZ to nearly doubling in the SWZ.

Looking at the fire disturbance regimes for these zones, one can assume that a portion of these excess fuel loads is a result of the lack of fire in the SFF type, specifically in the SWZ where the current fire interval is greater than 1,000 years Although SFF typically has lengthy fire free intervals, the extended period currently between wildfires is abnormally long in the SWZ which has resulted in its FRCC III classification, high risk of losing key ecosystem components, for the nearly 25,000 SFF acres in the SWZ.

Plan Scale

At the plan scale, seral state proportions are fairly similar to historical proportions for early to mid-seral states. However, the medium (10.0 to 19.9 inch dbh) and large tree (greater than 20.0 inch) seral states exhibit a large shift in proportions relative to reference conditions from the majority (44 percent) of SFF being in the late seral, large tree states, to 68 percent of now in medium tree states. Across the Forest, the number of snags per acre has declined in SFF, especially in the smaller diameter class (8.0 to 17.9 inch dbh) where on average there are 12 snags per acre fewer. And despite the number of snags 18.0 inches in diameter and greater being more prevalent on the Forest, departure from reference conditions is still moderate (42 percent).

As stated previously, understory composition (similarity to site ponytail) is currently in good condition with 32 percent departure but is nearing the moderate departure threshold. The two biggest invaders partially leading to the departure in composition include Canada thistle and nodding plumeless thistle. Ground cover is also in relatively good condition with limited change in vegetative ground cover and a slight increase (0.7) in the percent of bare soil. Like many other ERUs, coarse woody debris loadings have also increased in the SFF. However these changes are not as pronounced given the already high levels of coarse woody material typically found in these ecosystems.

Long fire return intervals and high site productivity are two common causes for high CWD loadings. Fire frequencies on the Santa Fe NF for SFF are just passed 200-year cycles and within the historical regime. One change we do see in the fire regime is a shift in severity proportions. Historically low severity fire in SFF was limited and the majority of acres burned resulted in high severity effects but this has shifted to the majority of acres burning at low and moderate severity. These changes along with the moderate changes in seral state proportions have resulted in the majority (90 percent) of the SFF type to be classified into FRCC II, a moderate risk of losing key ecosystem characteristics.

Context Scale

Seral state proportions for SFF at the context scale are nearly identical to those found at the plan scale. There is only a slight decrease in the proportion of medium-sized trees to seedling/sapling trees at the context scale. Despite seral state proportions being similar and snag density at the plan scale being moderately departed, snag density at the context landscape is highly departed (69 percent) with only 7 snags 8.0 to 17.9 inches (dbh) and 3 snags greater than 18 inches (dbh) per acre, on average. With limited large trees on the landscape, it is apparent that there would also be limited large snags. Also, unlike the plan scale, fire has been limited in SFF at the context scale with fire intervals of 748 years, which is also a source for snag recruitment, considering the severity at which this forest type typically burns.

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 Key Findings

Anthropogenic impacts in Spruce-Fir forest are limited and the key drivers of southwestern Spruce-Fir Forest appear to be modern climate change, invasive species, recreation, and nearby land use. Historical livestock grazing likely had a slight effect on lower-elevation Spruce-Fir Forest where intermittent patches of herbaceous understory exist, but is limited by the dense overstory (Fisher and Fulé 2004, Laughlin et al. 2005) and large loadings of CWD (Laughlin et al. 2005). Upper-elevation Spruce-Fir Forest, which lacks the herbaceous layer and resulting surface fires, were likely impacted to a lesser degree. Ground cover is especially high in young stands after canopy opening disturbances (Chambers and Holthausen 2000) but changes overall are negligible as vegetative ground cover is minimally departed from reference conditions and CWD loadings are right around the low to moderate departure threshold.

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 SFF on the Santa Fe NF with the majority (68 percent) of stands in medium sized diameter seral state classes (states D, M, H, and Q) opposed to reference conditions where the majority (44 percent) would have been large trees (states E, N, F and O). Drought also predisposes trees to insect outbreaks. Although 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 10 to 75,000 acres events. The 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).

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 naturally long fire return interval of SFF has only been moderately influenced by the cessation of fire (e.g., fire suppression). Future conditions (100-year VDDT model) indicate that SFF will increase in proportions of state B, along with late successional large tree states (E,N, F, O, I, R, J and S). SFF is moderate to very highly vulnerable to projected climate change, especially in the CZ where the smallest proportion of SFF occurs on the Forest. This is important as 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 (Ganey and Vojta 2011, Huang and Anderegg 2012), although not as widespread in SFF on the Forest.

SFF Overstory Structure and Composition Seral State Proportion

State	Description	Proportion (%)								
		Reference Condition[1]	Current Condition							Future Condition 100 Yr.
			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	30
C, G, P, L	Seedling/sapling & small trees, all cover classes	20	10	7	▨	10	▨	9	16	20
D, M, H, Q	Medium trees (10-19.9" d.b.h.), all cover classes	14	66	62	▨	69	▨	68	62	18
E, N, F,O	Large trees (≥20"), closed canopy	44	4	7	▨	3	▨	4	3	13
I, R, J, S	Large trees, open canopy; *contemporary landscapes only, historically rare/localized*	0	1	0	▨	0	▨	0	0	19
	% Departure	**0**	**54**	**59**	▨	**55**	▨	**54**	**51**	**40**

Departure Class
Low
Moderate
High

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**	▨	**47**	**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			*FI* (yrs.)	*Severity* (%)			*FRCC* (%)[4]		
				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**			**FRCC II**		

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

[2] Departure at the plan scale.

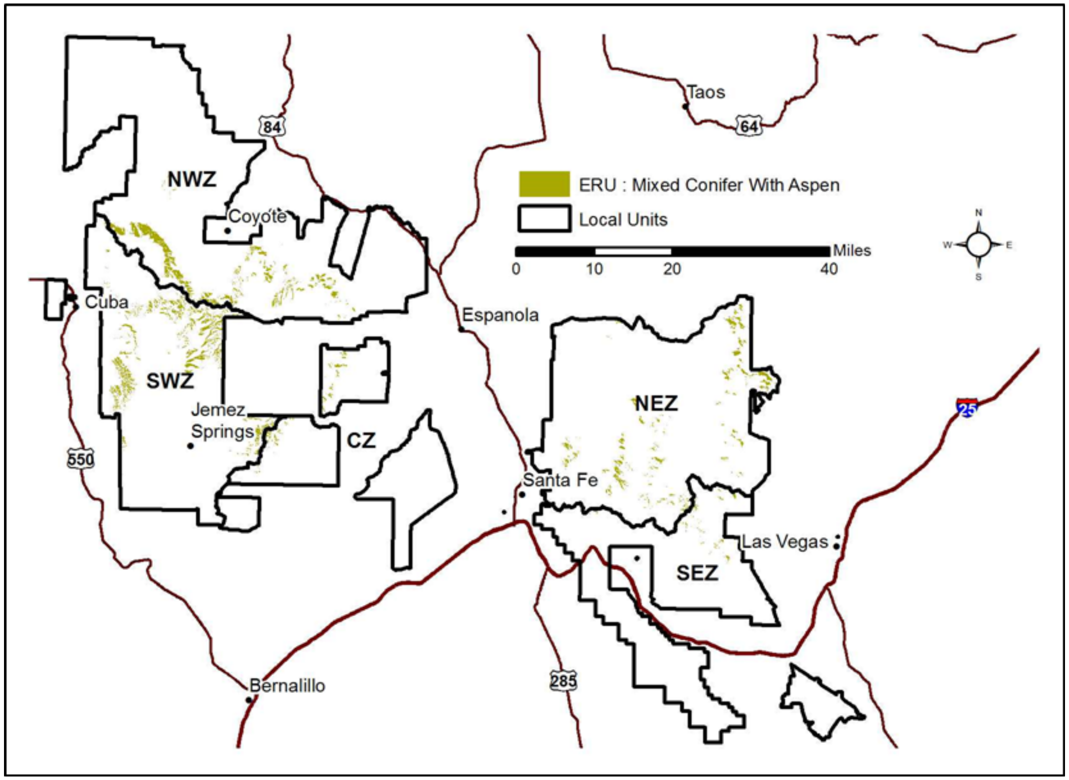
[3] Hatching indicates the ERU does not represent at least 5 percent of the local zone and is, therefore, considered not sufficiently represented to analyze.

[4] FRCC and proportions are provided at the plan scale and a "*X*" denotes dominate class at local scale.

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, Allen 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. 2009a, 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. 2013), 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 or greater and 4 per acre 18 inches or greater). 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 (Floyd et al. 2009, Romme et al. 2009b) especially since spruce budworm favors Douglas-fir and white fir, which are common in mixed conifer stands. Repeated defoliation over successive years can reduce the growth and vigor of trees and potentially predispose them to other agents (Ryerson 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 (Lynch and Swetnam 1992, Moir 1993).

Current Conditions

Local Scale

Of the forested types, MCW probably displays the greatest amount of variance in current seral state proportions across local zones. Similar to conditions in SFF, the majority of acres in MCW are in medium tree (10.0- to 19.9-inch dbh) seral states for all three local zones (NWZ, SWZ, and NEZ). The NEZ displays the greatest amount of recent higher severity disturbance as 28 percent of all acres found in this zone are in the non-tree/recently burned or seedling/sapling states compared to 12 percent in the NWZ and 11 percent in the SWZ. This shift in early successional classes in the NEZ is reinforced by the current fire frequency of 24 years and increase in resulting high severity acres (49 percent). The NEZ is currently the only zone with a decrease in the proportion of aspen and deciduous tree acres (15 percent) but can be expected to increase in the future as a result of recent wildfire disturbances. The NEZ is also the only zone that has a small proportion (4 percent) of large trees although far from the 40 percent historically. The NWZ and SWZ proportions are similar with an over representation of aspen/deciduous tree and medium tree acres relative to reference conditions.

When comparing similarity to site potential across local scales, the NEZ displays slightly less departure (29 percent) compared to 32 percent for the NWZ and 36 percent for the SWZ. Although similarity to site potential is near the low-moderate departure threshold for all three local zones, observed invasive plant populations (e.g., Canada thistle, etc.) have primarily been identified in the NWZ although populations likely exist in all local zones and are part of the cause in departure from reference species composition. Across all three local zones bare soil percentages have at least doubled but are not as pronounced on the landscape as all zones are at or just above five percent. Coarse woody debris loadings have also increased considerably to around 80 tons per acre for all three local zones.

MCW fire return intervals vary considerably across the three zones with the NEZ currently experiencing the greatest frequency of fire disturbances at every 24 years followed by the NWZ, the next most frequent cycle, with fire frequencies of 283 years. The SWZ is the only zone with a fire return interval outside of the natural range of variation for MCW found on the Forest at 778 years. The lack of fire in the SWZ is also exemplified in the resulting severities of the few fires that have occurred in this zone as the proportion of high severity acres has increased significantly with nearly three quarters resulting in high severity effects. The NWZ and NEZ are rather similar to reference conditions with the NEZ showing a small departure in moderate severities towards high.

Plan Scale

Despite there being 6 state classes for MCW the majority of acres only fall into four classes. One of the classes, not present on the Santa Fe NF, are open canopy, large tree seral states which did not exist historically and are only found on contemporary landscapes. The other being large tree, closed canopy states which accounted for the majority of this ecosystem historically, but is now very limited on the Forest. Similar to the SFF type, the majority of acres once found in these state classes are now in the medium sized tree states. However, unlike SFF, snags in MCW are more abundant on the current landscape than what existed historically for both snag size classes. Although snags on the landscape have increased and are a great benefit to wildlife, average patch size in MCW has decreased considerably to an average of 57 acres, potentially fragmenting corridors and habitat for MCW dependent species. This may impact species such as the Mexican Spotted Owl and Jemez Mtn. Salamander that may rely on larger patches for all or part of their life-cycle requirements.

Vegetative ground cover is similar to proportions found historically, but proportions in the amount of bare soil have doubled. Coarse woody debris (CWD) loadings have changed significantly and are approaching the high departure category, currently at 64 percent. This large departure in CWD occurs despite current fire return intervals in MCW at the plan scale being consistent with historical occurrences. This is partially a result of the high frequency of fire (24 year cycles) in the NEZ that decrease the average at the plan scale. The skewing of severity effects from the low and moderate categories into the high severity class is likely attributable to the increases in CWD loadings, along with prolonged drought. These changes in structure, composition, and disturbances have led to the MCW type being moderately departed or in FRCC II at the plan scale.

Context Scale

Despite seral state proportions at the context scale distributed somewhat similarly to those of the plan scale, the context scale is only 37 percent departed relative to the 50 percent observed at the plan scale. A greater representation in seedling/sapling states along with a small representation in large tree class states being part of the reason. CWD loadings at the context scale have also increased significantly and are highly departed from reference conditions, these are attributable to the long fire return intervals common in MCW, which are currently double those found at the plan scale. With MCW limited on the Forest (40,174 acres), the plan scale contributes little to the context scale as the proportional representation is the lowest (-0.63, Terrestrial Ecosystem Context Niche) of all ERUs found on the Santa Fe NF.

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 Key Findings

The fire regime for MCW is one of only two ERUs that has not been significantly altered, the other being Spruce Fir Forest. Grazing during the 19th century likely had less of an impact in MCW than in lower elevation ERUs (Floyd et al. 2009, Romme et al. 2009b). Landscape wildfires such as the Los Conchas (156,593 acres), Cerro Grande (47,650 acres), and Viveash (28,348 acres), among others, have burned a reasonable proportion of MCW on the Santa Fe NF and has maintained the fire return interval within the natural range of variability. Fire in this ERU typically coincides with drought and extreme fire weather more so than fine fuel accumulation (Margolis et al. 2007) like that of lower elevational types.

Although crown fire is not unusual for this ERU, there has been an increase in the number of uncharacteristic crown fires originating in lower elevation frequent fire vegetation types running up into the Mixed Conifer with Aspen and Spruce Fire Forest types as a result of increased stand densities and CWD loadings. Although not significant, this has led to a 17 percent increase in the proportion of high severity acres in MCW on the Santa Fe NF. This is also likely the reason for the slight overrepresentation in the proportion of aspen (states B and T), as stands typically establish following crown fires .

Future conditions (100-year VDDT model) indicate that the SFF will improve over the 100-year modeled period, primarily as a result of the transition of medium to larger diameter trees that were common under reference conditions. Despite seral state proportions improving, the proportion of aspen and deciduous mixed tree types decreases significantly. The majority of MCW is located in the SWZ and is the only local zone with a departed fire interval; this along with the underrepresentation that already exists in the NEZ (local zone with second highest proportion of MCW) are likely causes for the departure in states B and T moving into the future. The vulnerability of MCW based on the climate change vulnerability assessment is projected to be moderate.

MCW Overstory Structure and Composition Seral State Proportion

State	Description	Proportion (%)								
		Reference Condition[1]	Current Condition							Future Condition 100 Yr.
			Local Scale[3]					Plan Scale	Context Scale	
			NWZ	SWZ	CZ	NEZ	SEZ			Plan Scale
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**

Departure Class
Low
Moderate
High

Snags (per acre)		Reference	NWZ	SWZ	CZ	NEZ	SEZ	Plan Scale	Context Scale
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			*FI* (yrs.)	*Severity* (%)			*FRCC* (%)[4]		
				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**			**FRCC II**		

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

[2] Departure at the plan scale.

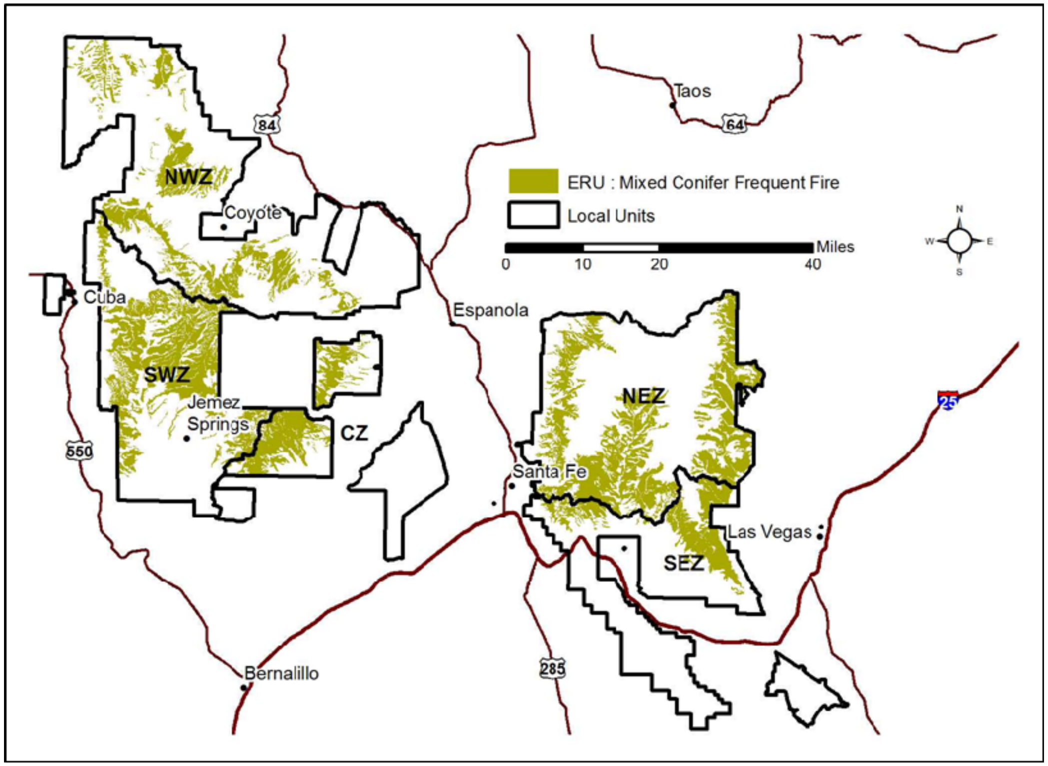
[3] Hatching indicates the ERU does not represent at least 5 percent of the local zone and is, therefore, considered not sufficiently represented to analyze.

[4] FRCC and proportions are provided at the plan scale and a "*X*" denotes dominate class at local scale.

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, piñon-oak, or piñon-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 (less than 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, Fule 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 (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 (Fule 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 (Miller et al. 1993), 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 CWD 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. Shade tolerance is also important as more open forest conditions favor regeneration and establishment of shade intolerant species.

Current Conditions

Local Scale

The mixed conifer –frequent fire ecosystem is the most abundant ERU found on the Santa Fe NF and is found in all five local zones. The CZ and SEZ display the greatest amount of variance in seral state departure from the other zones with 68 percent and 80 percent, respectively, but also only contain roughly half the number of acres (about 43,000 acres each) found in the next lowest represented zone (NWZ with 85,335 acres). The CZ has an overrepresentation in early seral states as a result of the significant amount of fire activity in the zone. The reduced representation of large tree, closed canopy states in the CZ, relative to other zones, is also a result of the abundance of recent large wildfires. The SEZ, where fire activity has been minimal is just the opposite with 73 percent of MCD acres in late seral, closed canopy states and only 2 percent in early successional, recently burned states. Little variation exists in snag density between local zones with every zone having 3 to 4 large diameter snags and 24 to 25 small diameter snags per acre. The density of large diameter snags is consistent with what was found on the landscape historically in this vegetation type but presently a greater density of smaller diameter snags exist.

Along with increases in standing dead woody material (snags), CWD has also increased considerably from 15 tons per acre historically to current levels of 56 tons per acre in the CZ, all the way up to 73 tons per acre in the SEZ. The NWZ, SWZ, and NEZ also have CWD loadings around 70 tons per acre. The lesser levels observed in the CZ are also attributable to the higher frequency of fire in this local zone. The CZ has a current fire frequency of every 31 years with the NEZ being the next most frequent at 154-year cycles. Despite being well outside the natural range of variation of every 5 to 21 years, the NEZ is not as departed as the SWZ and SEZ which have fire cycles of 565 and over 1,000 years, respectively. The lack of fire in this historically frequent fire system has led to a moderate departure in resulting fire severities. Less than 10 percent of the MCD landscape resulted in high-severity fire under reference conditions, but currently accounts for 30 to 50 percent of resulting severity acres across all local zones except the SEZ.

Plan Scale

Seral state proportions at the plan scale have shifted significantly from reference condition proportions displaying a 74 percent departure from these conditions. The biggest shift has been from mid-successional states of medium-sized trees that once accounted for 60 percent of the MCD landscape, towards late-successional closed canopy states, which now represents 72 percent of all MCD acres. This is significant considering MCD comprises 25 percent of the Santa Fe NF. Reductions in seral state proportions of early successional states including grass/recently burned lands and aspen deciduous states are also significant changes in this ecosystem. These changes have resulted in an overstory structure that is much more homogenous with a continuous canopy. These changes are also captured in the patch size analysis which captures the change in average patch sizes from less than one acre to 50 acres historically to the current average of nearly 250 acres.

MCD historically had a fire cycle of 5 to 21 years but has been altered considerably with a current fire interval of 152 years at the plan scale. The alteration in the fire regime is the biggest influence on other key ecological characteristics. The changes in seral state proportions and average patch size as discussed previously are evident as a result of the alteration in this disturbance regime. Similarly are the immense increases in the amount of CWD with loadings of 69 tons per acre on average. These key ecosystem changes have resulted in altered fire severities, notably a decrease in low severity effects and an increase in the proportion of high severity effects.

Context Scale

As departed as MCD seral state proportions are at the plan scale, context conditions are somewhat even poorer with a 78 percent departure from reference conditions. These overstory structural changes also result in an even larger shift towards higher severity effects at the context scale relative to the plan scale. Aside from these changes the condition of key ecosystem characteristics are comparable to those found at the plan scale.

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-year 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 Key Findings

It is widely accepted that fire exclusion and past management activities including selective logging ("high-grade"), fragmentation (e.g., construction of roads), fire suppression, and intensive historical 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. 2009a) 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 MCD stands. Disturbance was more frequent prior to fire exclusion with fire return intervals outside of the CZ highly departed from reference conditions. 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 and was dominated by open, uneven-aged forests, mainly in this ecological type and adjacent, dry forest and woodland types that were a major historic ignition sources (Floyd et al. 2009, Romme et al. 2009b). 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. 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).

Also as a result of fire cessation, the occurrence of aspen has 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). Aside from repressing conifer establishment and stimulating aspen sprouting (Jones et al. 1985), reductions in understory vegetation, especially during periods of prolonged drought, has lead to increased ungulates and domestic livestock browsing on aspen seedlings. Additional mortality has been observed from chronic defoliation by western tent caterpillar and large aspen tortrix over the last decade. Both fire exclusion, resulting in current large homogenous stands, and large early successional patches as a result of uncharacteristic high-severity fire from past management activities, have led to drastic increases in patch size averaging nearly 250 acres at the plan scale. This is exhibited in the shift in resulting fire severities in MCD 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.

Future conditions (100-year VDDT model) indicate that the MCD will improve considerably over the 100-year modeled period. Recent large-scale projects such as La Sotella and San Juan prescribed fires and wildfires managed to meet multiple objectives such as the Jaroso Fire are primarily responsible for the anticipated future improvement of stand conditions in MCD. The vulnerability of MCD based on the climate change vulnerability assessment is projected to be low (38 percent) to moderate (59 percent).

MCD Overstory Structure and Composition Seral State Proportion

State	Description	Proportion (%)								
		Reference Condition[1]	Current Condition							Future Condition 100 Yr.
			Local Scale					Plan Scale	Context Scale	Plan Scale
			NWZ	SWZ	CZ	NEZ	SEZ			
A, N, B, F	Non-tree; recently burned; grass, forb, & 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 & (Departure category: L-low, M-mod. or H-high)		**0**	**76**	**77**	**68**	**77**	**80**	**74**	**78**	**46**

Departure Class
Low
Moderate
High

		Reference	NWZ	SWZ	CZ	NEZ	SEZ	Plan Scale	Context Scale
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			*FI* (yrs.)	*Severity* (%)			*FRCC* (%)[4]		
				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**			**FRCC III**		

[1] Based on LANDFIRE (2010).

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

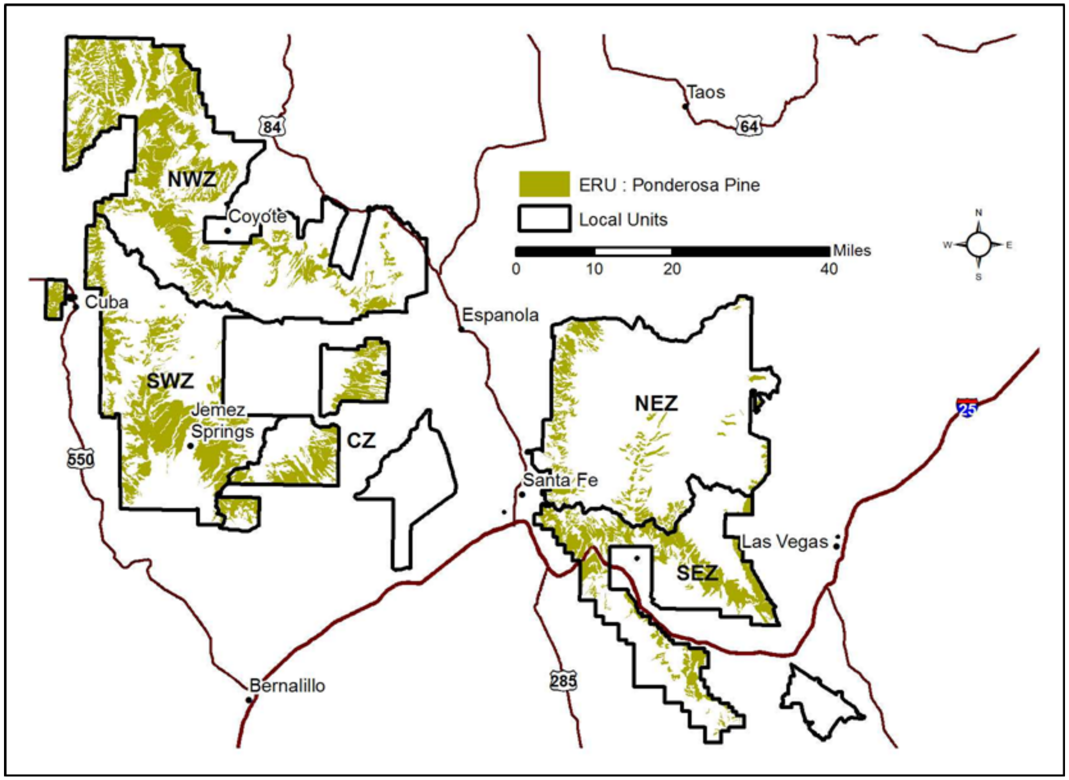
[3] Departure at the plan scale.

[4] FRCC and proportions are provided at the plan scale and a "*X*" denotes dominate class at local scale.

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, piñon 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 (Morgan et al. 2001, Iniguez et al. 2009, Williams and Baker 2012).

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 are present. Findings show broad pulses of recruitment separated by periods of less regeneration (Mast and 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 and Sackett 1992). The historic average fire return interval was 4–30 years from low-severity fire (Swetnam and Dieterich 1985, Baisan and Swetnam 1990, O'Connor et al. 2014). 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. 2008a, 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, Reynolds et al. 2013).

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

Local Scale

Similar to MCD, PPF comprises a relatively large proportion (24 percent) of the Santa Fe NF and is found in all five local zones. Also like MCD, PPF has a frequent fire cycle, which historically burned at 4- to 30-year intervals maintaining a multi-storied open canopy with mostly medium- to large-sized trees (seral states J and K). Current PPF seral state proportions have changed significantly toward single-storied, closed-canopy seral states. When considering closed-canopy states (G, H, L, I, and M) 66 percent of the NWZ, 70 percent of the SWZ, 61 percent of the CZ, 77 percent of the NEZ, and 85 percent of the SEZ are currently found in these seral states. Excluding closed canopy states, the largest proportion of acres in the NWZ (14 percent), SWZ (12 percent), and CZ (18 percent) are in open canopy, medium- to large-sized tree seral states (D and E). These states are not as abundant in the NEZ or SEZ and instead these proportions are found in the small tree, open-canopy state (C).

In all local zones, current snag density is similar to reference conditions for the large diameter snags and an excess of smaller diameter snags. These snags, as described in the key ecosystem characteristics descriptions, are beneficial for wildlife and do not pose any additional threat to the ecosystem such as the wildfire hazard from excessive CWD loadings. Similarity to site potential in PPF varies slightly amongst the local zones from 62 percent similarity in the SEZ to 69 percent in the CZ. The CZ has also had the greatest amount of fire recently and the SEZ has had so little that a fire interval could not be calculated for the zone. In addition to changes in species composition, vegetative cover has decreased across all zones. The SWZ vegetative cover proportion is roughly half (7.4 percent) of what existed under reference conditions (13.4 percent). This reduction in vegetative cover is indirectly a result of decreased wildfire.

Wildfire stimulates vegetative growth in many herbaceous species by recycling nutrients and making them available to residual plants and also by reducing woody debris on the forest floor creating an available niche for new growth. This reduction in herbaceous cover doesn’t correlates well with current levels of CWD across local zones as there is only a 2 percent variance between at most between local zones. The correlation between the cessation of wildfire and departure in CWD loadings is more pronounced. The CZ is the most similar to reference fire cycles of 4- to 30-year intervals with a current frequency of 40 years and also has the lowest CWD loadings on average of 38.3 tons per acre. Alternatively, the SEZ where wildfire has been nearly non-existent, CWD loadings are the greatest at 45.4 tons per acre on average. Although these CWD levels vary slightly across zones, conditions are highly departed in all zones and have resulted in increases in moderate and high severity proportions.

Plan Scale

At the plan scale only 3 percent of the Santa Fe NF PPF landscape is similar to reference conditions. Just over 70 percent of the landscape has moved into closed-canopy states with 60 percent representation in the medium to large tree states and 11 percent in the small-diameter tree state. Another 11 percent of PPF in the Santa Fe NF is found in the open canopy, medium to large tree states with the limited remaining proportions in early successional states. Reference patch sizes were very small in size as a result in the heterogeneous variation in structure and large interspaces. Shifts in overstory structures toward closed canopies and limited disturbance (killing of overstory trees) has resulted in a significant departure with current patches 72 acres on average in size. With limited variation between local zones, snag densities at the plan scale don’t differ much from any one local zone with roughly 1 large-diameter (18 inches and greater dbh) snag and 8 smaller-diameter (8.0 to 17.9 inches dbh) snags per acre.

Site potential is moderately departed at 37 percent, with invasives like bull thistle, nodding plumeless thistle, Canada thistle, and Siberian elm displacing native species. Vegetative ground cover, similarly, is 37 percent departed with percentages in reference conditions of 13.4 percent down currently to 8.5 percent at the plan scale. As described above in the PPF current conditions at the local scale, changes in the historic fire regime have influenced other ecosystem characteristics such as CWD and are partially responsible for the reductions in vegetative ground cover along with other influences like drought, concentrated recreation, and limited sunlight as a result of closed overstory canopies.

PPF has the most frequent fire return interval of the forested vegetative types found on the Santa Fe NF with historic fire cycles of every 4 to 30 years. This has changed considerably and are highly departed with current frequencies closer to every 200 years. The severity regime of current fires has also changed across the Forest with 45 percent of resulting severities in the moderate and high classifications. Historically only 5 percent of PPF acres burned fell into these classifications with low severity effects being the most common totaling for (95 percent). The significant alterations to the PPF landscape has resulted in the ecosystem being at high risk of losing key ecosystem components and 100 percent of PPF classified as FRCC III.

Context Scale

Seral state proportions at the context scale are nearly identical to those found at the plan scale. There is a minimal increase (4 percent) in the proportion of the PPF landscape currently in seral state G and a decrease (6 percent) in closed canopy, medium to large tree seral states relative to the plan scale. Snag densities and CWD levels are also similar to those observed at the plan scale. FI is the only characteristic that is prominently different with even longer fire free intervals of over 300 years. It is likely that the small differences in fire severities are a result of these longer fire cycles with 60 percent of resulting effects at the context scale in the moderate and high severities classes.

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) 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 Key Findings

Just as southwestern Ponderosa Pine Forest was profoundly shaped by fire (Romme et al. 2009b), it has also profoundly been altered by the exclusion of fire, currently averaging over 200 years between cycles. Fire management throughout most of the twentieth century focused on preventing and suppressing fires. The continued exclusion of surface fires was initiated by the development of communities by settlers, expansion of travel ways (trails and railroads), and historical utilization activities such as logging and livestock grazing. Without frequent fires, PPF, like MCD has increased in tree density, fuel loadings, and horizontal and vertical fuel continuities across the landscape. These alterations have led to the increased frequency and size of crown fires (Fulé et al. 2004, Romme et al. 2009b). Currently, 45 percent of PPF landscapes that burn result in moderate or high severity, relative to only 5 percent historically. Shifts in climate (e.g., drought) can 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).

When density changes are examined by diameter class, it is clear that diameter distributions have changed, with increases (23 percent) in smaller diameter classes (states B, F, C and G) (Covington et al. 1997, Fulé et al. 1997, Fulé et al. 2002). 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). Elevated mortality rates 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). These increases in overstory canopy densitites have intensified reductions in vegetative ground cover (37 percent departure) on the Santa Fe NF by shading and limiting the growth of the herbaceous understory that once carried frequent low-severity fire through PPF stands. This occurrence further degrades the disturbance process by limiting the ability of surface fires to move through the stands and reduce the density of seedling/sapling and small diameter trees (Sackett et al. 1996, Romme et al. 2009b).

Despite fire management practices shifting focus in the late 20th century to include the use of naturally ignited wildfires and prescribed fires to achieve resource management objectives, the area affected by prescribed fire has been relatively small (approximately 2,000 acres per year over the last 15 years, FACTS[7]). This is only one-third of one percent when considering all PPF and MCD acres found on the Forest; allowing tree densities, fuel loadings, and fuel continuity to result in landscape-scale crown fires in many areas.

In areas treated, alterations to the stand structure can successfully change fire behavior by reducing fuel loads and fuel continuity both vertically (ladder fuels) and horizontally (ability for fire to move from tree crown to crown). These improvements are captured by the slight improvements (89 percent departure) in the modeled future conditions (100-year VDDT model) for PPF seral state proportions. The vulnerability of PPF based on the climate change vulnerability assessment is moderate (62 percent) to high (16 percent), except in the CZ, where 36 percent falls into very high vulnerability.

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[7] Forest Service Activity Tracking System

PPF Overstory Structure and Composition Seral State Proportion

State	Description	Proportion (%)								
		Reference Condition[1]	Current Condition							Future Condition 100 Yr.
			Local Scale					Plan Scale	Context Scale	
			NWZ	SWZ	CZ	NEZ	SEZ			Plan Scale
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**	**97**	**89**

Departure Class
Low
Moderate
High

Snags (per acre)		Reference	NWZ	SWZ	CZ	NEZ	SEZ	Plan Scale	Context Scale
	>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			*FI* (yrs.)	*Severity* (%)			*FRCC* (%)[4]		
				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			
	Plan Scale		203	55	29	16	0	0	100
	Context Scale		319	40	32	28	NA	NA	NA
	% Departure[3]		**85**	**40**			**FRCC III**		

[1] Based on LANDFIRE (2010).

[2] Contemporary landscapes only, historically rare/localized

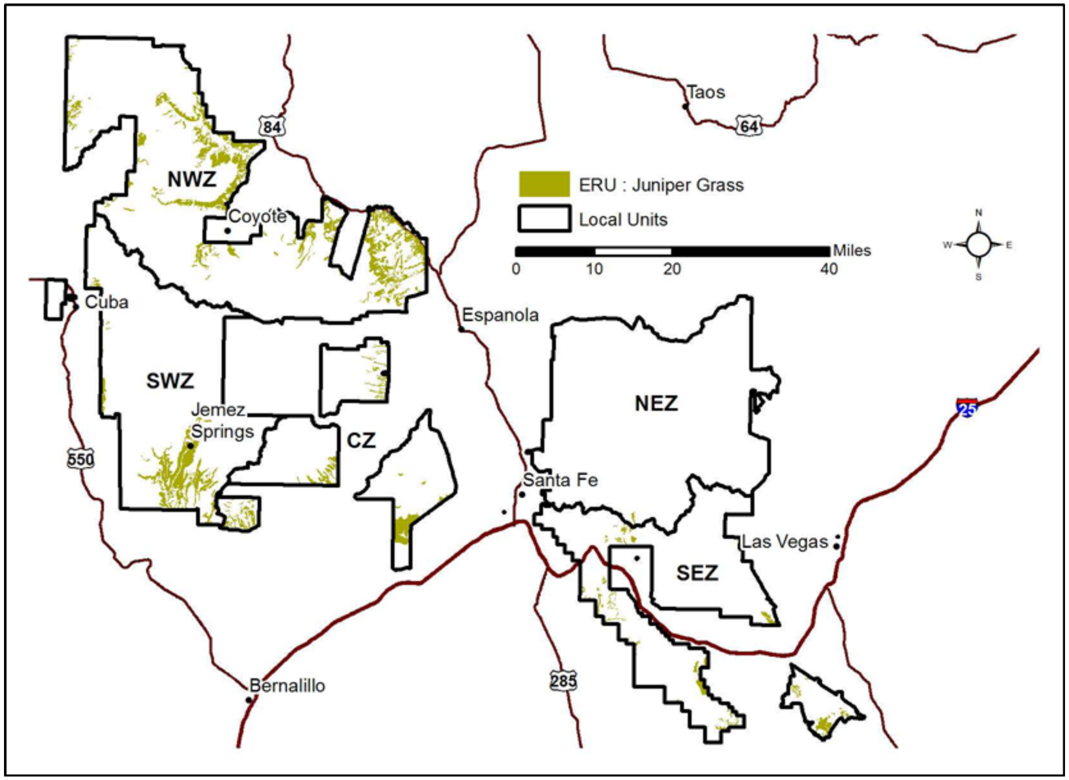
[3] Departure at the plan scale.

[4] FRCC and proportions are provided at the plan scale and a “*X*” denotes dominate class at local scale.

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 piñon pine, and just below and often intergrading with the piñon-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 acre. 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

Local Scale

JUG are found in all but the NEZ. Seral state proportions at the plan scale for JUG vary considerably between zones, although departure is moderate across all zones and range from 41 percent in the CZ to 53 percent in the SEZ. The CZ, similar to many of the other ERUs, has recently experienced the greatest amount of wildfire, with 35 percent in this recently burned, grass/shrub seral state. The other noticeable change in the CZ is the underrepresentation (9 percent) in seral state D (open canopy, medium to large trees) relative to reference conditions. The SWZ and NWZ display similar seral state proportions with overrepresentation in the seedling/sapling and open canopy small tree (5 to 9 inch dbh) states and an underrepestation in seral state D. The SEZ is also underrepresented in seral state D, but exhibits an overabundance of acres in seral state G (closed canopy, medium to large trees). Although displaying the greatest amount of departure of all local zones represented, the SEZ seral state proportion currently in G (46 percent) is similar to the amount that exists in the open canopy state (seral state D) under reference conditions (50 percent). This signifies that disturbance (overstory mortality) is limited in this zone. Despite limited disturbance snag density is the greatest in the SEZ with 5 smaller snags and just under 1 larger snag per acre. The other 3 zones (NWZ, SWZ, and CZ) are also similar to reference densities with less than 1 larger and 3 smaller snags per acre.

JUG displays a moderate amount of departure in site potential. Both the NWZ and CZ are 49 percent departed, the SEZ is 47 percent departed, and the SWZ is the least with 31 percent departure. Departures in the proportion of bare soil are similar to those of site potential with the SWZ having the least amount of bare soil, followed by the SEZ with both zones having less than reference conditions. Vegetative ground cover is good in the CZ and SEZ but is moderately departed with current cover just above 5.5 percent in both zones. Coarse woody debris loadings in JUG were historically low as a result of limited overstory and woody species but have increased considerably across all zones, similar to CWD loadings in other frequent fire ERUs.

Fire is nearly non-existent in the previous 30 years, with no fires recorded in JUG found in the SEZ and negligible amounts in both the NWZ and SWZ. The CZ is in better condition but still highly departed with fire cycles of 139 years. Because JUG is still largely found predominantly in open tree canopy states (less than 30 percent cover) and the majority of this landscape is still dominated by grass, fire severities have not been altered significantly.

Plan Scale

Seral state proportions at the plan scale display an overrepresentation in early successional states and late successional closed sere (seral state G). The medium to large tree seral state that was once dominate on the JUG landscape is greatly underrepresented with only a 9 percent representation on the current Forest landscape. The seedling/sapling and small trees with open canopy seral states (B, C, and E) dominate the current landscape accounting for over half of all acres found in this ecosystem.

Snag densities display low departure at the plan scale. However, average patch sizes have increased from less than an acre to 16 acres in size on average. Similarly, vegetative ground cover and departure in site potential are also moderately departed. Of the woodland types found on the Santa Fe NF, JUG has the most extensive documented occurrences of invasives with 1.6 percent of the 97,470 JUG acres infested with bull thistle, Russian olive, salt cedar, or Siberian elm. Yet, unlike other ERUs alterations in the species composition has not resulted in increase in the proportion of bare soil despite a moderate reduction in vegetative basal area. Decreases in vegetative ground cover can however be attributed to increases in woody biomass including CWD which has increased significantly to current levels of 13.7 tons per acre. The significance of this change is similar to proportional increases observed in MCD and PPF and too can be linked to the absence of wildland fire. Fire frequency at the plan scale is 831 years on average, and highly departed from the reference occurrence of 8 to 30 years.

Context Scale

Seral state conditions at the context scale are a slight improvement relative to those found at the plan scale but are still moderately departed from reference conditions. Unlike the plan scale over 50 percent of the context scale is comprised of moderate to large trees (seral states D and G). But like the plan scale a lack of fire with fire-free periods exceeding a thousand years has led to an overrepresentation in the late successional closed canopy, seral state (G). Snag densities are below and CWD loadings much higher than those of reference conditions at the context scale, analogous to conditions at the plan scale as a result of limited 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 Key Findings

The greatly diminished role of recurrent fire in these ecosystems is responsible for ecologically adverse shifts in the composition, structure and diversity of the JUG type. Thes changes have lead specifically to the rise of ruderal species and invasion by less fire-tolerant species as indicated in the (44 percent) departure in similarity to site potential. Due to the effects of long-term fire suppression in this type (96 percent departure in FI), in many locations the current condition is severely departed from historic conditions. A lack of fire has limited the natural thinning effect from fire, leading to the majority (52 percent) of JUG currently in the seedling/sapling and open small tree states (B, C and E). These changes also include in-filling of the canopy gaps, increased density of tree groups; and reduced composition, density and vigor of the herbaceous understory plants. Infilling and increased tree densities as a result of limited disturbance have led to homogenous and continuous stands, significantly increasing reference patch sizes from less than one a acre to over 16 currently.

Many of these sites currently are closed-canopy woodlands, with insufficient understory vegetation to carry surface fire. Understory increases in cover with disturbance and decreases during succession as tree density increases during fire exclusion. Species composition have also changed with decreases in the abundance of grasses as a result of fire exclusion. As a result future modeled conditions (100-year VDDT model) indicate that the JUG ecosystem will continue to degrade as a result of continued in-fill (56 percent in state G) and limited open canopy conditions (only 36 percent) relative to reference conditions (75 percent in states B, C, D, and E). The vulnerability of JUG is low to moderate based on the climate change vulnerability assessment, indicating that future potential of a type conversion is low to moderate.

JUG - Overstory Structure and Composition Seral State Proportion

State	Description	Proportion (%)								
		Reference Condition[1]	Current Condition							Future Condition 100 Yr.
			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	12	28	5
B, C, E	All seedling/sapling; small trees (5-9.9”), open canopy	25	58	70	29	▨	17	52	11	2
D	Medium to large trees (≥10”), open canopy	50	11	5	9	▨	6	9	30	34
F	Small trees (5-9.9”), closed canopy	10	4	6	10	▨	13	6	9	3
G	Medium to large trees (≥10”), closed canopy	10	20	12	17	▨	46	21	22	56
	% Departure	**0**	**45**	**49**	**41**	▨	**53**	**45**	**41**	**46**

Departure Class
Low
Moderate
High

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 - PlanScale)		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			***FI*** (yrs.)	***Severity*** (%)			***FRCC*** (%)[4]		
				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		>1,000	75	14	11	NA	NA	NA
	% Departure[3]		**96**	**5**			**FRCC II**		

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[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.

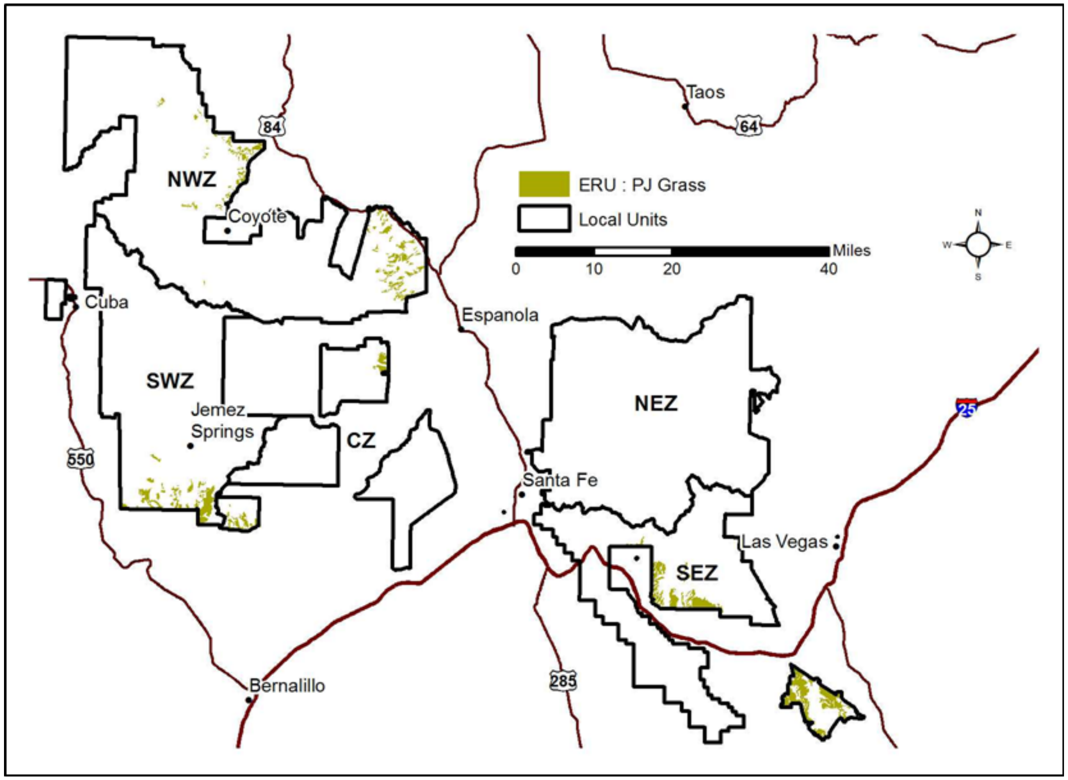
[3] Hatching indicates the ERU does not represent at least 5 percent of the local zone and is, therefore, considered not sufficiently represented to analyze.

[4] FRCC and proportions are provided at the plan scale and a “X” denotes dominate class at local scale.

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 piñon, 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 (less than 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 piñon-juniper grassland type historically occurred 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 2004). 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 (Allen 1989, Grissino-Mayer et al. 1994, Swetnam and Baisan 1996, Margolis 2014) from low to moderate severity fire. Reference patch sizes were 1 acre and less limited amounts of CWD (3.5 tons per acre).

Current Conditions

Local Scale

Medium to large trees with open canopies that historically dominated (50 percent) PJG are now the least represented sere across all local zones. The CZ while still underrepresented in this seral state has the highest proportion of acres with 15 percent and also displays the least amount of seral state departure (39 percent). Conversely the SWZ exhibits the greatest amount of departure in regards to seral state proportion and also has the least representation (3 percent) in seral state D. It is important to note however, that the CZ represents the smallest proportion of PJG, with only 8 percent of the ERU landscape forestwide in this zone. Across all local zones except the CZ, the majority of PJG is comprised of seedling/sapling and small trees with open canopies. This state is especially prevalent in the SWZ with 75 percent of the zone currently in this sere. Another 13 percent of this zone is in the grass/forb/shrub state also representative of early successional conditions. Similarly 89 percent of the NWZ currently exists in these early successional states. The CZ and SEZ display greater heterogeneity in stand structure with fair representation in all seral states.

Departures in seral state departures align well with departures in snag density, with the CZ and SEZ also displaying conditions more similar to reference. With limited medium to large trees on the landscape, it is expected that large snags would be underrepresented. Limited medium sized trees in PJG for the NWZ and SWZ have also led to moderate departures in the density of 8- to 17.9-inch snags in these two zones.

Across all ERUs found on the Santa Fe NF, similarity to site potential for JUG represents the most similarity to reference conditions. Although the CZ has the least departure (39 percent) in seral state proportion, it displays the most (36 percent departure) in regards to site potential relative to the other local zones. The NWZ and SEZ show the most similarity to site potential both with 74 percent. The SWZ and CZ not only have had the most change in understory composition but also have had the largest reduction in vegetative ground cover, although moderately departed across all local zones. Despite the changes in composition and cover, the SWZ and CZ display less departure in bare soil relative to the NWZ and SEZ. CWD loadings have significantly increased across all zones but are especially high in the CZ (16.9 tons per acre) and SEZ (15.2 tons per acre).

Decreases in herbaceous material (fine fuels) and increases in bare soil have limited the horizontal fuel continuity and therefore the ability for fire to move across the JUG landscape. This is accentuated by the current long fire intervals as a result of the absence of fire outside of the CZ. Still the CZ is moderately departed with a fire interval of 85 years, well longer than the 8- to 36-year regime that occurred historically. In spite of limited fire, all local zones result in FRCC II, or moderate departure.

Plan Scale

Similarity to site potential is high as a result of limited populations of invasives. The reductions in vegetative cover are significant along with the increases in the proportion of bare soil. Despite changes across many of the key ecosystem characteristics, specifically the lack of fire, fire severity has changed little with the majority of the JUG landscape still in open canopy states, unlike many of the other ERUs found on the Santa Fe NF. But like many of the other ERUs discussed, PJG has a overrepresentation in smaller diameter trees with 60 percent of the plan scale currently in these states (B, C, E, and F). The largest departure in seral state proportions is the underrepresentation of open large tree sites (state D), currently only 5 percent of the PJG landscape, a vast change from the 50 percent that occurred historically. The influx of smaller diameter trees have created stands of continuous tree canopies leading to increases in average patch size (93 percent departure) and horizontal fuel continuity. Increases in moderate fire severity proportions can be attributed to this change, as fire is now able to move through the crowns of the trees increasing the resulting fire effects.

Context Scale

Seral state departures at the context scale are in relatively better condition than those found at the plan scale. The biggest differce is the increased representation in medium and large trees with 59 percent of the context scale found in states D and G, relative to just 24 percent at the plan scale. Those acres are split almost evenly between the open and closed states and rather similar to the 60 percent found in reference conditions. Snag proportions and CWD loadings are slightly higher at the context scale with approximately two smaller diameter snags per acre and five tons per acre more than what exists at the plan scale.

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 piñon 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 Key Findings

Similar to the changes in JUG, the diminished role of recurrent fire in these ecosystems is primarily responsible for ecologically adverse shifts in the composition, structure and diversity of the PJG type. Departures for all PJG key ecosystem characteristics mirror those of JUG including, alterations to seral state proportions, infilling of canopy gaps and increased tree densities, increased CWD loadings and moderate departures in ground cover percentages. Due to the effects of long-term fire suppression in this type, the current condition is moderate to highly departed from historic conditions in many locations. The removal of fire from these systems (current FI greater than 1,000 years) has resulted in the fragmentation of the PJG landscape (93 percent departure) and favored closed canopy structures susceptible to drought and insect induced mortality. Medium to large tree, open canopies (currently 5 percent) have been replaced with typical in-filling of the canopy gaps, increased density of seedling/sapling and small tree groups (currently 60 percent); and reduced composition, density and vigor.

These overstory structural and composition changes have also resulted in reduced composition, density and vigor of herbaceous understory plants (38 percent departure). When compbined with moderate increases in the amount of bare soil, these changes may impede the fuel continuity in some PJG sites as there is insufficient understory vegetation to carry surface fire. This has led to many contemporary understories increasing in dominance of warm season species such as blue gramma and having uncharacteristically high shrub cover. Yet, despite reductions in vegetative ground cover, PJG has the lowest departure for similarity to site potential of all ERUs analyzed on the Santa Fe NF.

Future modeled conditions (100-year VDDT model) for PJG indicate that the seral state proportions will improve marginally with the biggest improvements a result of natural succession with the open canopy, medium to large tree state (D), increasing from 5 to 28 percent of the PJG landscape. Conversely, as a result of limited overstory management in this ERU, this natural process also results in significant increases in the closed canopy, medium to large tree state (G).

PJG has the second highest vulnerability to climate change, of ERUs found on the Santa Fe NF with 22 percent in high and 50 percent in the very high categories based on the climate change vulnerability assessment. This indicates that the future potential of a type conversion of PJG ecosystems is high to very high.

PJG Overstory Structure and Composition Seral State Proportion

State	Description	Proportion (%)								
		Reference Condition[1]	Current Condition							Future Condition 100 Yr.
			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**

Departure Class
Low
Moderate
High

		Reference Condition	NWZ	SWZ	CZ	NEZ	SEZ	Plan Scale	Context Scale
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			***FI*** (yrs.)	***Severity*** (%)			***FRCC*** (%)[4]		
				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**			**FRCC II**		

[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.

[4] FRCC and proportions are provided at the plan scale and a “*X*” denotes dominate class at local scale.

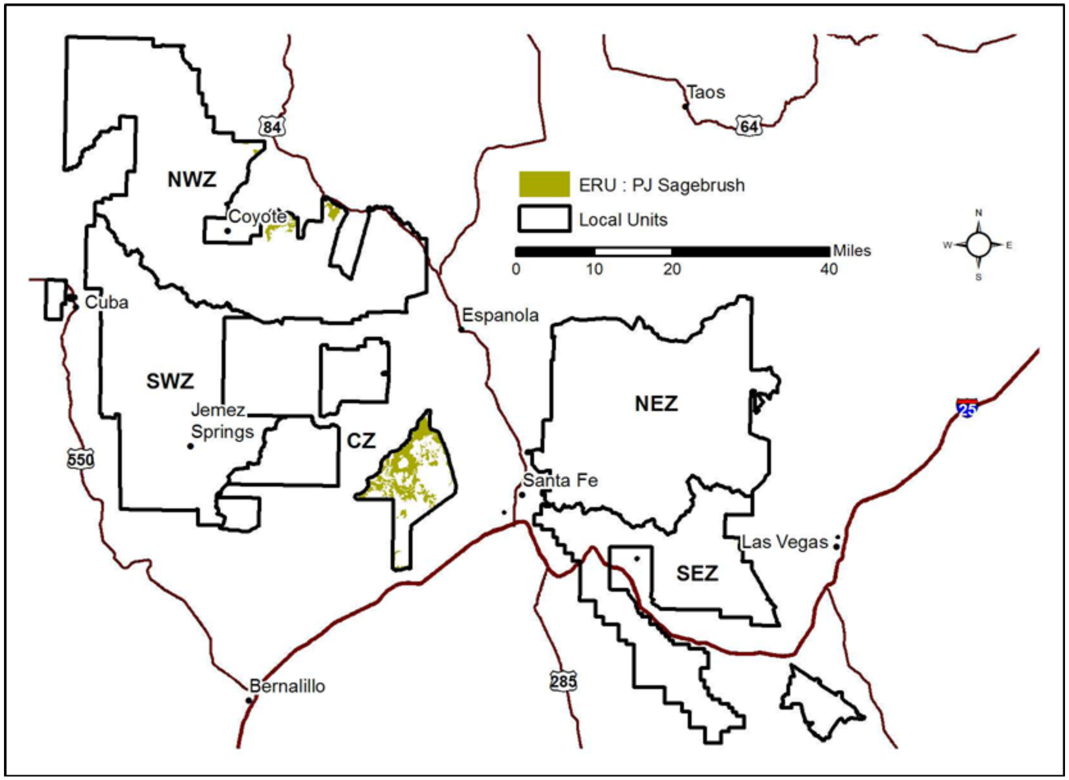
PJ Sagebrush (PJS)

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; piñon 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. 2009a, LANDFIRE 2014). 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. 2009a). Fire return intervals were fairly long (50 to 100 years) (Gruell 1999, LANDFIRE 2014), but more frequent than in PJO (Romme et al. 2009a).

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

Current Conditions

Local Scale

PJS only occurs in two local zones, with the NWZ representing nearly 25 percent and the CZ approximately 75 percent of this landscape. Seral state proportions are somewhat similar among the two zones, with the open canopy, seedling/sapling and small tree states (states B, C, and E) being the foremost states found in this vegetation type. The CZ has a larger proportion of early successional states (specifically, state A) with 10 percent more than the NWZ. Thirty-four percent of the NWZ is currently in medium to large tree states (states D and G) relative to just 13 percent in the CZ. As a result of having more larger trees, snag densities in the NWZ are also slightly higher with two small diameter (8- to 17.9-inch dbh) snags per acre more than the CZ.

The most significant difference between the two zones is seen in the ground cover proportions. Proportions of bare soil are significantly higher in the CZ (48.2 percent relative to 17.5 percent) and are very much departed from reference conditions of 23.7 percent. Vegetative ground cover is similar amid the two zones, with both moderately departed at around 13 percent cover. Just as there are slightly more snags occurring in the NWZ, CWD levels are also marginally higher at 10.2 tons per acre. CWD loadings in both zones are considerably higher than what historically occurred. Fire has been completely absent in this vegetation type during the period used to generate fire intervals and severity proportions but is an indication that there is a lack of fire disturbance as the reference interval, although not frequent, was only 50- to 100-year cycles.

Plan Scale

With PJS only occurring in two local zones, and the majority found in the CZ, conditions at the plan scale are essentially the same as those found at the CZ local scale. Similarily the open canopy, seedling/sapling and small tree states (states B, C, and E) are overrepresented while the closed canopy, small tree state (state F) is underrepresented. Unlike most other ERUs found on the Forest, snag density is underrepresented in both the small (8.0- to 17.9-inch dbh) and large (greater than 18.0-inch dbh) diameter snag classes. Ground cover has changed significantly in PJS, with moderate departues in both bare soil (increasing in proportion) and vegetative cover (decreasing in proportion). The reduction in vegetative cover and increases in soil have led to the fragmentation of this vegetation type and current average patch sizes of 16 acres. This is a significant (high) departure from the 50- to 200-acre average patches found under reference conditions. Fire has been completely absent in PJS on the Santa Fe NF.

Context Scale

Similar to PJG, seral state proportions at the context scale are in relatively better condition than those found at the plan scale. Again, the majority (60 percent) of the context landscape is in later successional medium to large tree states (states D and G). The closed canopy, medium to large tree state (state G) is overrepresented at 32 percent relative to only 10 percent historically. Contradictory to the plan scale, the context scale is underrepresented in the open canopy, seedling sapling and small tree states (states B, C, and E) with only 13 percent. Also, unlike the plan scale, snag densities are slightly higher than reference conditions. CWD loadings at the context scale are higher than those at the plan scale as expected with increases in the proportion of later successional states. Although not completely absent from the landscape, fire is rare in PJS at the context scale and highly departed from the historical regime.

Future/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 climate change 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 Key Findings

Aside from the PJO ecosystem, which has a much different fire regime (30- to 400-year intervals), current conditions for all PJ ecosystems are relatively similar in their departures from reference conditions. Despite the reference fire interval for PJS being slightly longer (50- to 100-year intervals) than PJG and JUG (approximately 8- to 35-year fire intevals), fire has been limited in these systems for so long (greater than 1,000-year fire intervals currently) that the difference is negligible and the lack of disturbance has resulted in similar deviations for many key ecosystem characterisitcs. The most notable are the departures in seral state proportions (46 percent), 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 observed infill is consistent with a documented trend across the western U.S. (Romme et al. 2009a).

The causal drivers of infill in piñon-juniper sagebrush 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 legacy grazing have had a greater impact on departure in PJS. Recent fire history is similar to that of PJO with infrequent fires, mostly a result of human causes, burning with uncharacteristically low severity (39 percent low currently compared to only 13 percent). The combined effects of the removal of fire from PJS, drought, legacy grazing impacts, development of roads/trails and increased density in tree canopies have resulted in decreased grass cover. Vegetative basal area (ground cover) has been moderately reduced (36 percent departure) and have led to increases in the proportion of bare soil. PJS is the second most departed ERU in terms of site potential, and is over 53 percent departed in the NWZ. The historic patch size has been greatly reduced from the 50- to 200-acre averages down to 16 acres.

PJS Overstory Structure and Composition Seral State Proportion

State	Description	Proportion (%)								
		Reference Condition[1]	Current Condition							Future Condition 100 Yr.
			Local Scale[3]					Plan Scale	Context Scale	
			NWZ	SWZ	CZ	NEZ	SEZ			Plan Scale
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**

Departure Class
Low
Moderate
HIgh

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			***FI*** (yrs.)	***Severity*** (%)			***FRCC*** (%)[4]		
				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**			**FRCC II**		

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

[2] Departure at the plan scale.

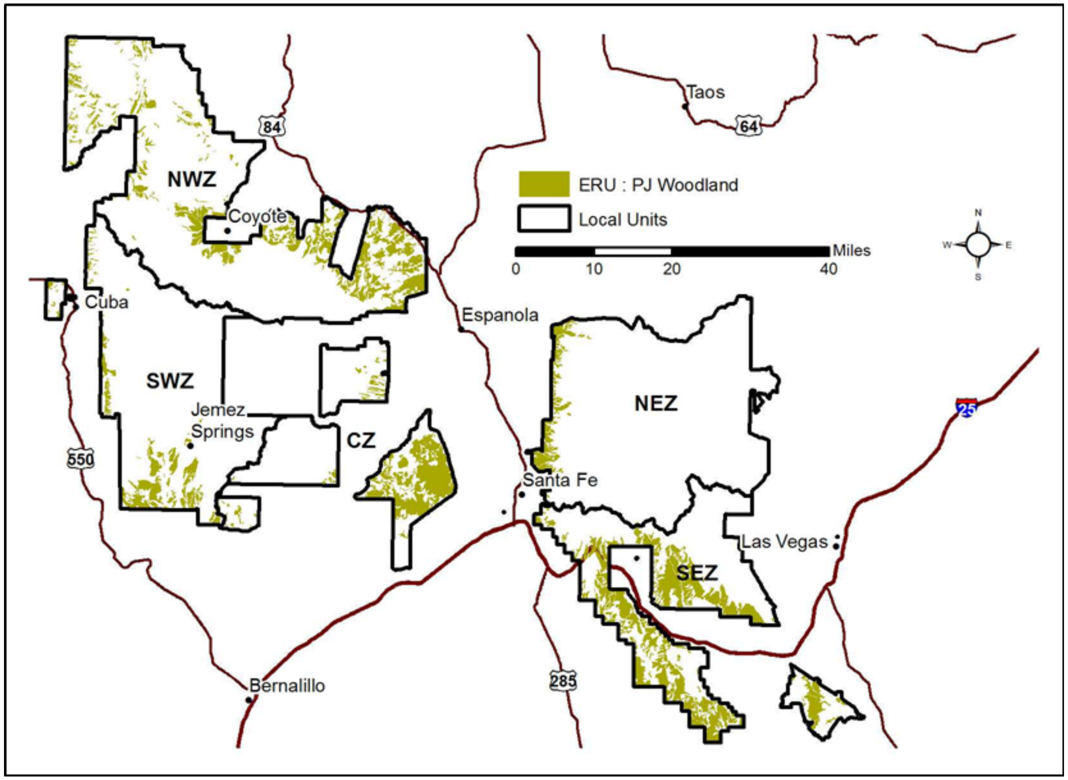
[3] Hatching indicates the ERU does not represent at least 5 percent of the local zone and is, therefore, considered not sufficiently represented to analyze.

[4] FRCC and proportions are provided at the plan scale and a “*X*” denotes dominate class at local scale.

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 to 7,500 feet in elevation. Most common piñon pine is the two-needle piñon 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 2014). 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. 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 cross-dating 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 (Romme et al. 2009a).

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 (Romme et al. 2009a). 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 (Ryerson 2014).

Current Conditions

Local Scale

Similar to MCD and PPF, PJO is the only other ERU and only woodland type found in all local zones, although proportions vary from 6.9 percent (NEZ) to 36.2 percent (SEZ). Although the NEZ represents the fewest acres of PJO, it displays the least amount of departure at 22 percent, while the CZ has the highest departure (51 percent) in regards to seral state proportions. Seral state proportions in the NWZ (29 percent), NEZ (22 percent), and SEZ (26 percent) are currently of low departure, while the SWZ (40 percent) and CZ (51 percent) are moderate. These zones with the highest departure also have the lowest proportions in the later succeissional, closed canopy state (state G). Though the open canopy, seedling/sapling and small tree states (states B, C, and E) are overrepresented in all zones, the majority (44 percent) of the CZ is currently in this state.

Snag densities across all zones and for both small (8.0 to 17.9 inch dbh) and large (greater than 18.0 inch dbh) diameter snags are relatively abundant when compared with reference densities, despite limited medium and large tree densities. As indicated in the key characteristics section, this is a result of drought and Ips bark beetle outbreaks during the early 2000s. The NEZ and SEZ have the most small diameter snags but fewer larger snags relative to the other three zones, despite having greater proportions of larger diameter trees. Proportions of the closed canopy, medium and large tree (state G) state correspond well with levels of CWD for each of the local zones. The NEZ has the highest (20.5 tons per acre) CWD levels while the CZ has the least (12.8 tons per acre), nevertheless all local zones greatly exceed conditions that existed historically (4.1 tons per acre).

Despite displaying the greatest departure in overstory conditions, understory composition (similarity to stie potential) is high in the CZ. This is in spite of also having a significant increase in the proportion of bare soil (40.2 percent). The NWZ displays the least similarity to site potential at 60 percent. Only the CZ and NEZ have high similarity to site potential, although the SWZ (66 percent) and SEZ (63 percent) are near the moderate and high similarity thresholds. Proportions of bare soil have increased considerably in three of the local including the NWZ (34.9 percent), CZ (40.2 percent), and SEZ (31.4 percent) relative to 23.0 percent in reference conditions. This is primarily a result of the reductions in vegetative basal area which decreased in all local zones, especially the NWZ, SWZ, and NEZ where percentages are half of reference proportions.

Fire intevals in PJO vary considerably across zones. The NWZ and SWZ have fire free periods that exceed 1,000 years while the CZ is moderately departed with fire intervals over 700 years. Only the NEZ, which represents the smallest proportion of acres for this ERU on the Forest, is within the natural range of variability for PJO.

Plan Scale

At the plan scale, open canopy, seedling/sapling and small tree states (states B, C, and E) are overrepresented while the medium to large trees in closed canopy state (state G) is underrepresented. All other seral states are relatively proportional to reference conditions. These proportions and departures are similar to those in JUG ecosystems on the Forest. Overall at the plan scale, PJO is in low departure; a result of it’s long and slow scuccessional pattern. As mentioned in the local scale current conditions discussion, there is currently considerably more snags and CWD as a result of drought and Ips beetle outbreak that highly impacted piñon pine on the Forest.

Understory composition has been moderately impacted (36 percent departure) by invasive species such as bull thistle, Russian olive, salt cedar, and Siberian elm. Similarity to site potential has also been influenced by drought and other disturbances that have reduced vegetative ground cover and increased the proportion of bare soil. Partial reductions in vegetative cover can be attributed to the substantial increases in CWD loadings. Despite some fire disturbance in the CZ and NEZ, the majority of PJO acres in other zones where fire has been almost completely absent have skewed the fire interval to over 1,000-year cycles. In the fires that have occurred, severities have shifted toward lower severities.

Context Scale

Seral state proportions at the context scale are comparable to those at the plan scale. The only difference really exists in the open canopy states where the context scale has a slightly higher proportion of medium to large trees (state D) (18 percent relative to 7 percent at the plan scale). The difference in these proportions is found in states B, C, and E at the plan scale. Fire frequency at the context scale, like the plan scale, is highly departed despite PJO having long fire return intervals. Severity proportions are also moderately departed at the context scale.

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 (state D) increase by 20 percent; additionally, the medium to large tree, closed canopy (state G) state increases by 12 percent. Overall seral state departure is reduced, and stays 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 among 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 Key Findings

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 (Ryerson 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 (Allen 2007, Romme et al. 2009a, Romme et al. 2009b) 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 or less) 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 wood-boring 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 (Ryerson 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 (Ryerson 2014).

PJO Overstory Structure and Composition Seral State Proportion

State	Description	Proportion (%)								
		Reference Condition[1]	Current Condition							Future Condition 100 Yr.
			Local Scale					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**

Departure Class
Low
Moderate
HIgh

		Reference Condition[1]	NWZ	SWZ	CZ	NEZ	SEZ	Plan Scale	Context Scale
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**

PJO 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**

PJO Disturbance Regime

Vegetation Characteristic			***FI*** (yrs.)	***Severity*** (%)			***FRCC*** (%)[3]		
				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**			**FRCC II**		

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

[2] Departure at the plan scale.

[3] FRCC and proportions are provided at the plan scale and a “*X*” denotes dominate class at local scale.

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 19), 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. In the Southwest, because water availability is so variable, so too are the discrete and episodic environmental changes (e.g., erosion, runoff, sedimentation, and vegetation resistance). 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 Regional Riparian Mapping Project (RMAP) (Triepke et al. 2014b) 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 only representing 6.8 percent of the context scale (table 19).

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. 2014b)) and proportions representing multiple analysis scales are presented in table 19.

Table 19. 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	**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**	**2.74%**	**0.97%**[8]	**217,617**
Upland & Riparian Total Spatial Scale Acres	**490,531**		**328,457**		**178,315**		**409,644**		**273,954**		**1,680,869**			**22,442,078**

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[8] Proportion of all riparian ERUs at the context scale.

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 (Miller et al. 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 (Abernethy and Rutherfurd 2001). Root systems protect stream banks through armoring (Abernethy and Rutherfurd 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 riparian areas, 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 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 interval (FI) 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. Despite riparian systems not being fire adapted, fire is an important disturbance in western riparian systems as the effects of fire, when within its historical range of frequency and severity in upland systems, result in beneficial effects in riparian systems.

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 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. However, continuous fuels can also aid the movement of fire from adjacent uplands into the riparian areas. When uncharacteristic 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. High severity fire resulting in the loss of riparian vegetation can lead to higher water temperatures, increased erosion, reduced oxygen concentrations and reduction in the distribution of aquatic biota through the reduction in 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 sedimentation (DeBano et al. 1998) that negatively affect aquatic organisms (Neary et al. 2005). 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). In some cases, it may take decades for the stream and associated riparian corridor to recover.

Proper Functioning Conditioning is the only key ecosystem characteristic unique to riparian areas and not in the upland vegetation ERU section. It 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 (figure 13) 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 (Prichard 2003).

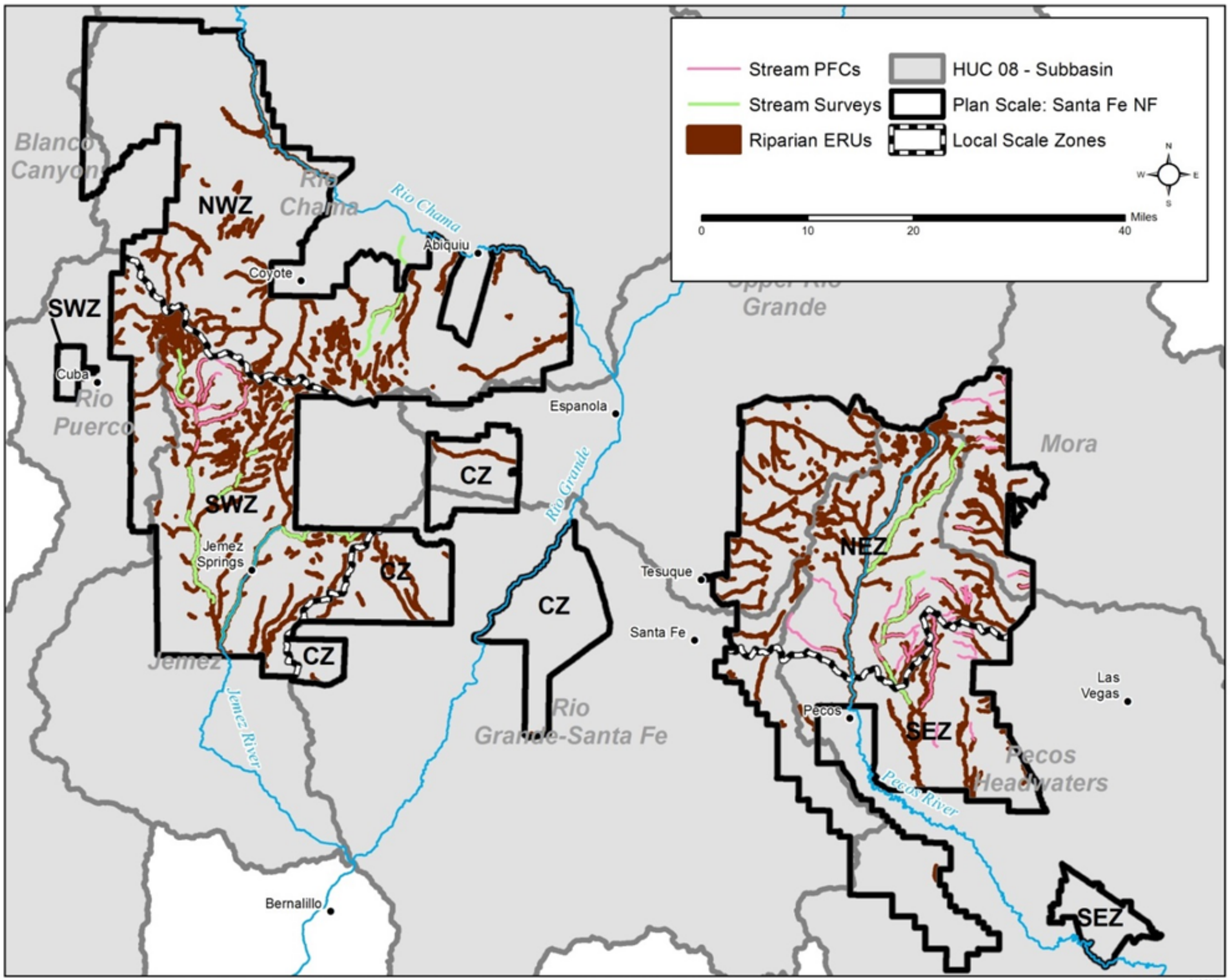

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Figure 13. Map showing proper functioning condition (PFC) and stream surveys available for data analysis, relative to the location of all riparian ERUs

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 unknown and fire frequency is the only other disturbance regime, in which the Forest has extensive data, and therefore will be used as a proxy since the diversity of riparian areas can be attributed to the temporal variability in natural disturbances including, debris flows, landslides, and wildfire (Gecy and Wilson 1990, Naiman et al. 2005).

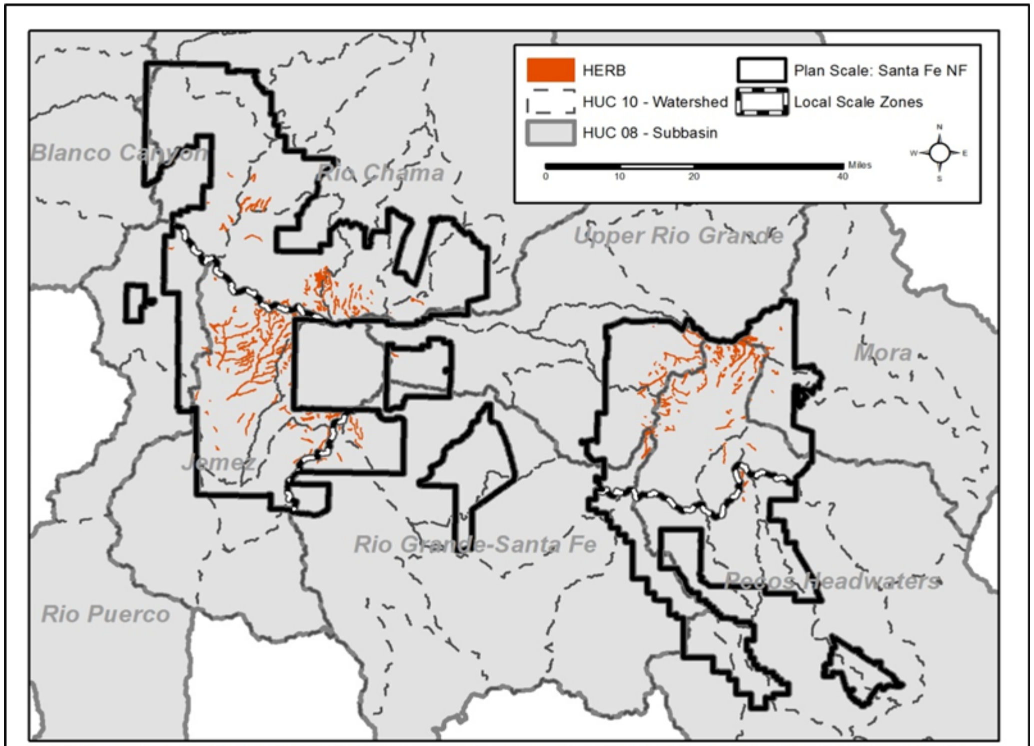
Successional patterns of riparian plant community development are driven by responses to natural and anthropogenic disturbances, physical variables, and plant species attributes (Baker 1989, Merritt et al. 2010). There are also feedbacks between riparian plant species and the physical environment. These 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 (Pettit and Naiman 2007, Corenblit 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 (Simon et al. 2004).

Wetland and riparian areas have historically been heavily impacted by anthropogenic activities throughout North America (Brinson and Malvárez 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 1993, Nilsson and Berggren 2000), agricultural drainage (Dahl 1990), grazing (Fleischner 1994, Patten 1998, Belsky et al. 1999), and the widespread introduction of non-native species (Stein and Flack 1996, Mack et al. 2000). 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).

RMAP Herbaceous (HERB)

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

ERU Description



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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 19). 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 (Lemly and Culver 2013).

HERB Structure, Composition, Disturbance Regime

Vegetation Characteristic		*Similarity to Site Potential (%)*	*Ground Cover* (%) Bare Soil	*Ground Cover* (%) Veg. BA	*CWD (pieces/mile)*	*FI* (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**	**0**	**NA**

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

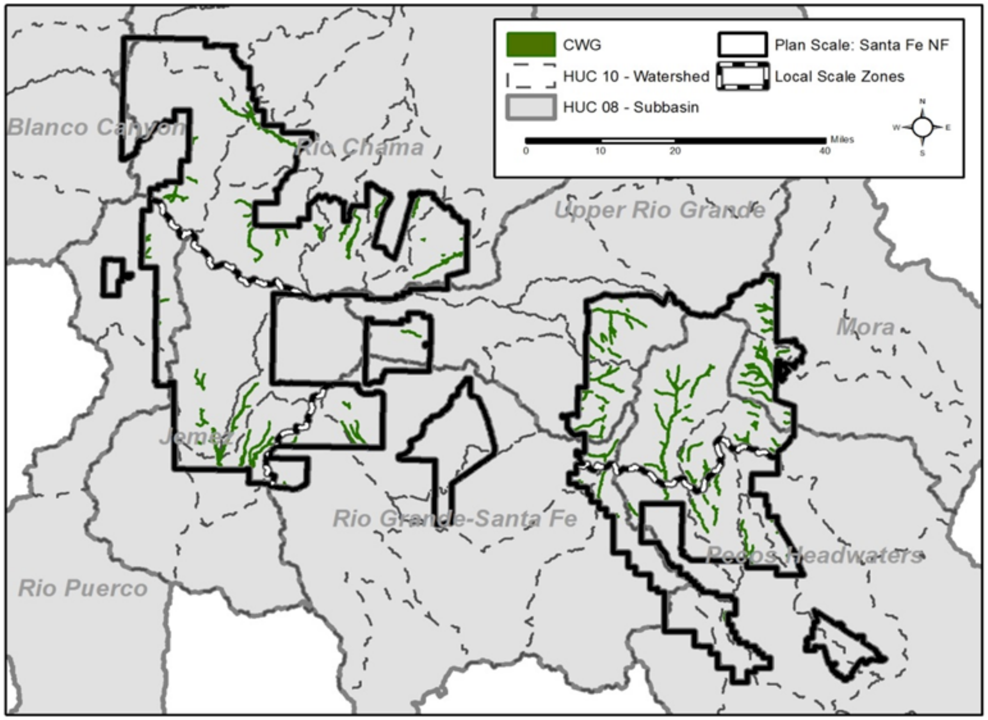
HERB is evenly distributed across the forest and local zones where it is predominantly found. It occurs in all five of the local zones. On NFS lands, instream flows are reduced and their timing is altered by human water uses (Floyd et al. 2009). Decreased flooding, channelization, downcutting, and lowered 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 historical 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 Forest Service 2013b). Uncharacteristic wildfire, including fire suppression activities (e.g., 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



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The RMAP cottonwood group is composed 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 its presence on the landscape at the plan scale is not significant, it represents 25 percent of the ERU group at the context scale, so the Santa Fe NF makes up an important part of this ERU on a larger scale. NCSH is generally found at lower elevations. NCSH 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)*	*FI (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**	**0**	**NA**

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.

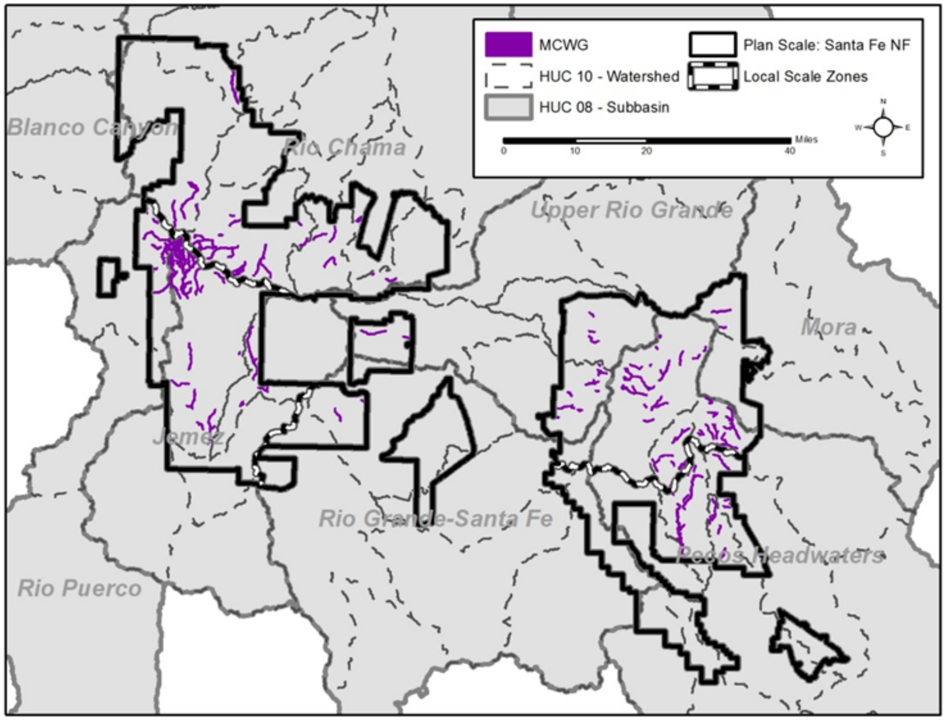
Current Conditions

CWG is found across most 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. 1990a). 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 historical 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



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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 ERU 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)***	***FI* (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**	**34**	**NA**

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. Roads in canyon bottoms have also contributed considerably to erosion. Historical operations including the 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.

Key Findings

Fire exclusion and past management activities have led to the greatest departure from historical conditions of all ecosystems found on the Santa Fe NF. Fire dependent ERUs including Ponderosa Pine, Mixed Conifer-Frequent Fire Forests, Juniper Grasslands, Pinon-Juniper Grasslands, Montane Subalpine Grasslands, and Colorado Plateau/Great Basin Grasslands, are at high risk of loss. Historical selective logging (also known as “high-grading”), removed the largest and most fire resistant trees in stands. Overgrazing during 19th and early 20th century limited fine fuels (forbs and grasses) that typically carried frequent low severity fire on the ground. Fragmentation or the construction of roads, trails, and railroad systems also impeded the spread of frequent, low-severity wildfires across the landscape. Along with early 20th century fire suppression, these changes to the landscape have contributed to higher densities of small diameter trees, increased fuel loadings, uncharacteristic wildfire, and altered species composition from mature, fire tolerant species toward shade-tolerant, less fire-resistant species.

The encroachment of shade tolerant species also increase fuel loadings and can act as ladder fuels, helping surface fire to climb into the canopy of tree crowns and resulting in increased occurrences of crown fire. The increased density of tree groups as a result of the infill of canopy gaps by tree and woody species has also reduced the density and vigor of herbaceous understory plants in forested and woodland types. Increased stand densities also contribute to increased competition amongst trees for resources (increased stress), especially during periods of extended drought. This stress makes the trees more susceptible to insect and disease outbreaks and uncharacteristic proportions of high-severity, stand replacing fire. Uncharacteristic fires can lead to further detrimental impacts including soils which repel water (hydrophobic soils), erosion, and type conversions ultimately threatening the viability of these systems.

Grassland (Montane Subalpine Grasslands and Colorado Plateau/Great Basin Grasslands) woodland (Juniper Grass, PJ Grass, PJ Sagebrush) and shrubland (Sagebrush Shrublands) ERUs have significantly less grass cover and productivity as a result of legacy (historical) grazing from livestock, wildlife grazing, roads, urban crawl, concentrated recreation and the exclusion of wildfire (encroachment of trees and woody species). The lack of cover contributes to accelerated erosion and declined soil productivity, especially during periods of drought. Erosion can have significant impacts on these ecosystems as dry, low elevation ecosystems already have shallow soils. Soil loss can lead to shifts in species composition with increases in shallow rooted grasses which are less effective in stabilizing soils. These shifts and increases in bare soil can lead to increased chance of noxious weed infestation. Reductions in grass cover also decrease the amount of water that penetrates into the soil while increasing the water that runs over the ground. This reduces the amount of water available to plants, creating a loop that thereby continues to reduce vegetative cover. The encroachment of trees and woody species as a result of decreased fire also threatens these ecosystems. Fire is significant in these systems as it removes litter, limits woody species germination and growth, and allows new lush grasses and shrubs to germinate and take advantage of the short-term release of nutrients in the ash.

Resiliency is the ability of an ecosystem to regain structure, composition, and function following disturbance, on a time span that is consistent with dynamics of the ecosystem. The prevalence of so many vegetation types on the Santa Fe NF that are highly departed from reference conditions and at high risk of uncharacteristic wildfire is an indication of systems that are not resilient. Only a small percentage (2 percent or less) of most vegetation types are treated annually on the forest, and restoration is not effective at these small scales. In addition, the current Forest Plan imposes internal management boundaries (management areas), often with different management direction, which artificially fragment the landscape within the forest boundary and make it difficult to consistently implement projects on the ground at a large scale.

Stressors compound the challenge to effectively restore ecosystem resiliency. Climate change is predicted to further increase the fire risk, but may also impact ecosystems in unpredictable ways. Invasive species are continually being introduced and can pose serious threats. Flexibility in management options is essential to maintaining the ability to accommodate both predicted and unpredicted changes as they arise.

Riparian systems have been degraded and are at risk across the Forest. Higher soil moistures, cooler temperatures, and greater productivity typically characterize riparian areas. However, human alterations to the landscape such as the diversion of waterways, the introduction of invasive plants, unauthorized use by cattle, and recreational impacts are altering these systems. The development of roads, grazing, and recreational use (including trails and dispersed recreation) are deteriorating understory vegetation, causing significant departures from reference condition in species composition and proportion of bare soil. Roads located near riparian areas can also negatively affect stream bank stability, ultimately causing erosion and sedimentation downstream.

Increased water demand (water withdrawal) and climatic changes (e.g., long-term drought) have also deteriorated these systems. Water tables are lower and there have been decreases in periodic flooding which is necessary for the regeneration of some important riparian species (e.g., cottonwood). This results in shifts in species composition and a reduction in available soil moisture. Bare soil and reduced native species allow for the introduction of invasive species brought into the area by vehicles, animals, people recreating in the area, and agricultural practices. These invasives in combination with adjacent uncharacteristically dense overstory vegetation in the uplands have led to an increased risk of fire from the uplands entering riparian areas, where fire isn't a frequent disturbance of the ecosystem. Loss of riparian vegetation leads to higher water temperatures, increased erosion and sedimentation, and an overall decrease in water quality which negatively affects aquatic biota and wildlife. The impact on wildlife is significant; an endangered species that is a riparian obligate and fifteen species of conservation concern are dependent on the riparian area for their habitat.

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 and regulation of climate through the sequestration of carbon is also crucial. Through evapotranspiration, 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 serve as permanent habitat and seasonal migration routes. Rivers and spring-fed *cienegas* support specialized fish species, and other species depend on the plant and animal communities of riparian wetlands. Water in riparian areas provide fertile land, and forage for livestock and wildlife in the arid and semi-arid.

Input Received from Public Meetings

This section summarizes input, perspectives, and feedback relevant to this assessment topic and received from the public between April and July 2014. Input was gathered from 14 public meetings and "User Value and Trends Forms" available at all Santa Fe NF office and online. Additional input was gathered from individual meetings held with the Natural Resource staff and leadership from Tribes, Pueblos and Navajo Chapter Houses. The Draft Assessment and 12 focus areas that were identified as having the greatest needs for different plan direction were released in October 2015. This was followed by a full day public symposium to present findings from the Draft Assessment and 10 public meetings and 2 tribal meetings where findings from the 12 focus areas were presented.

Ecosystems

Properly functioning forest ecosystems are, for a myriad of reasons, highly valued by participants. Some participants focused on the value of biodiversity and how it enriches our lives. Others highlighted the importance of a variety of ecological features and ecosystems. Participants in Mora emphasized the dynamism of the ecosystem, how it is always changing yet always giving back. Participants also noted the importance of healthy forests for a wide range of recreational and traditional uses.

Participants have witnessed a number of changes in forest ecosystems. They pointed to increased population as an important driver of these changes, along with the perceived impression of declining management of the forest, as well as extreme events like uncharacteristic fires and drought. These have resulted in a perceived overall degradation of resource quality. More specifically, participants notice that there are fewer meadows and "more trees in meadows" than before. One participant in Los Alamos noticed new kinds of wildflowers after fires. Overall, there appears to be more insect infestations in the forest, as well as more invasive species. The system is perceived as being weaker with "less ability to recover," or less resilient.

System drivers and stressors

Participants at the meetings discussed system drivers and stressors at length – both human and environmental drivers and stressors.

Human

On the human side of things, a growing population was commonly cited as a change that is having repercussions on a myriad of resources, from water quality to recreation to ecosystem health to the changing of landscapes.

Environmental

Key environmental drivers are fire and precipitation (or lack thereof).

Fire

Fire is seen as both a driver and a stressor. Several participants expressed that fires are important, that they need to take place to remove hazardous trees. However, participants also noted an increase in the frequency and fierceness of fires. As a result of big fires, there is also more post-fire flash flooding. Also, as a result of these fires, observers around the forest have experienced longer fire closures during the summer, which has negative effects on the local community and changes the patterns of forest use. Communities in and around the forest are also concerned about fires threatening their homes and damaging watersheds. Increased risk of fire and the fear it causes is pervasive, especially in communities that have experienced close calls.

Fire Management

The public perceives the Forest Service to be adapting in their management of fires and the public supports fire management which reduces stockpiles of fuel to prevent catastrophic fires. Jemez Springs residents talked about how people are more aware of fire risk and willing to take action to educate each other, coordinate, and communicate. In Los Alamos, participants agreed that thinning and prescribed burns are important tools for forest health. Others expressed concern about the increase in controlled burns and losing control of these burns.

A Jemez Springs participant stated that he/she sees a change in the public's attitude toward forest management – there is a new appreciation for good forest management, which includes thinning. The importance of thinning was a key topic of discussion at many of the meetings in different locations.

*Climate Chang*e

Some participants identified a changing climate as an important stressor. Some see climate change as the key driver behind fires (because it's drier) as well as bark beetle infestations. A Santa Fe participant expressed the need for the Forest Service to adapt management to a warmer climate. At least one participant also expressed the opinion that climate change is not outside historical variances in climate.

Input Received from Technical Meeting

As part of the series of public meetings, there was a Technical Meeting on April 30, 2014, which was open to all members of the public, but was more focused toward participants with technical expertise that were members of organized groups or other agencies. Participants represented a wide range of government, public, and private resources. The main difference in meeting formats was the breakout groups and discussions as the technical meetings were based on resource topics. Participants were also asked to provide specific sources that could be used in the assessment in addition to input on values and trends. Summaries and specific sources of information for each of the resource topics from this meeting follow.

Air, Smoke, Fire, and Insects

Participants discussed the change in fire return interval and suggested the plan should evaluate tradeoffs associated with use of fire and return interval, in addition to climate variability and the effects of more wildfires with increased damage.

Vegetation and Restoration

Participants expressed many concerns about vegetation and restoration including the need for statewide GIS mapping and photos and ensuring that vegetative treatments are geared toward restoration, and not timber harvesting. Participants also discussed the need for prescriptions to be uneven-aged, provide for thermal cover, and create patch dynamics instead of even-aged (which reduces fire severity, but loses ecological benefit). Other discussions focused on the effects of large wildfires and the desire to bring the forest back to a healthy state, the need for better monitoring of improvement projects and water quality on stream-side vegetation, enforcing lessee grazing rotations and duration, and determination of impacts to the New Mexican Meadow Jumping Mouse.

Thinning was the source of many concerns including availability and way of obtaining maps of forest thinning projects, interpretation of the forest-thinning maps, promoting uneven-aged stands in thinning and habitat projects, and the observation that thinning brings wildlife to town. Participants suggested public outreach including field trips and contacting trout groups to find out if they know of degraded areas. One participant in particular noted the “biodiversity of trees – conifers” (SF).

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.

As reported in Volume 2 of this Assessment, several sub-watersheds have been designated as municipal watersheds or major drinking water watersheds, and portions of these sub-watersheds lie within the Santa Fe NF boundary. Under the current Forest Plan, the Headwaters Santa Fe River sub-watershed and the Gallinas River sub-watershed have been designated as municipal watersheds for the towns of Santa Fe and Las Vegas, respectively. Thirty-seven sub-watersheds on the Santa Fe NF have been identified as major drinking water watersheds by New Mexico Environment Department (NMED); see Volume 2 for map.

Hydrologic Unit Codes and Scale

Hydrologic unit codes (HUCs) are discussed in Water-Supply Paper 2294 (Seaber et al. 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 20).

Table 20. 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 (table 21, figure 14). 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.

Table 21. 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 22). The watershed will be used as the context scale. The Santa Fe NF boundary will be used as the plan and local scales.

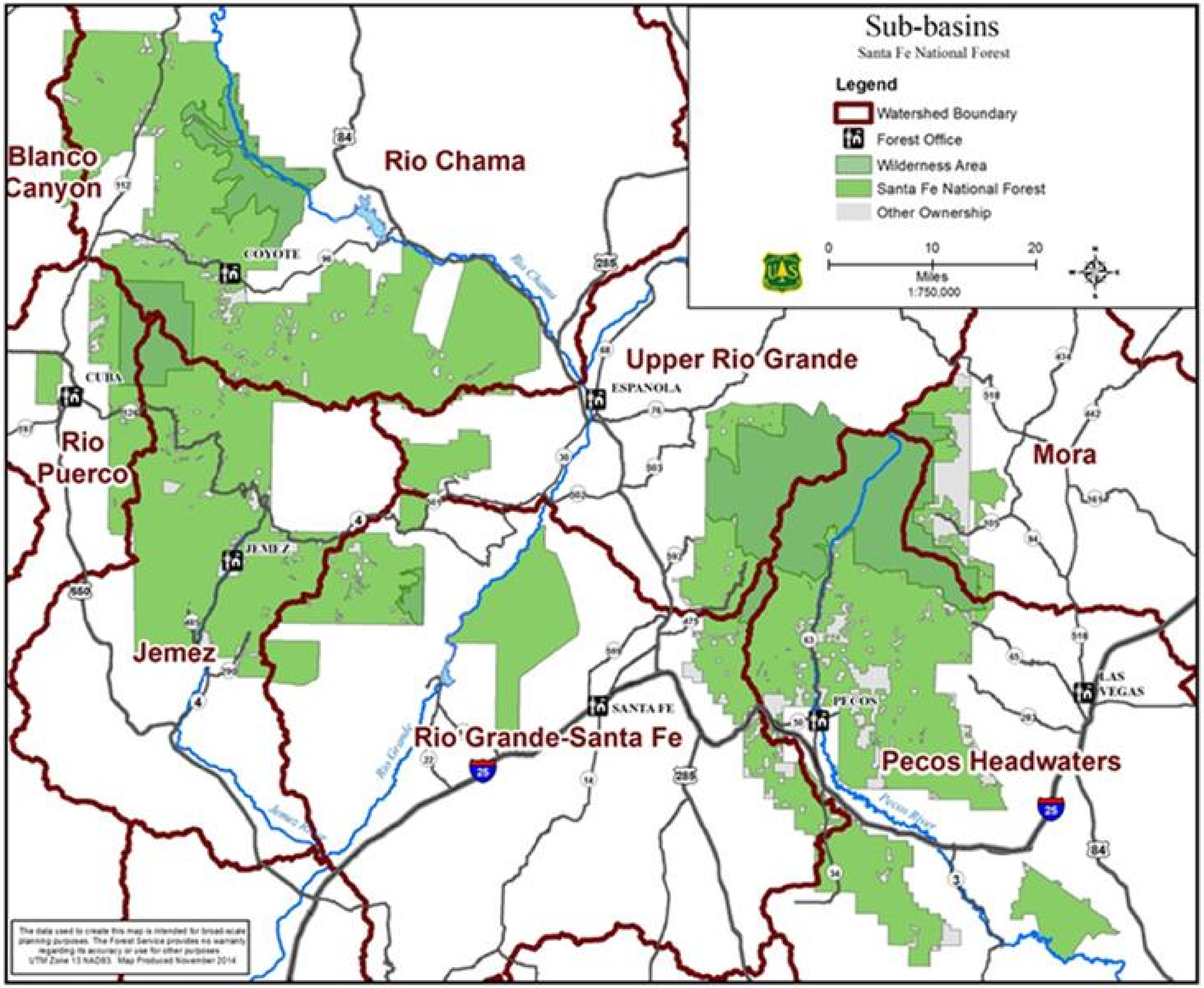


Figure 14. Sub-basins covering the Santa Fe NF

Table 22. 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 15). 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.

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 23). 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 23. 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.

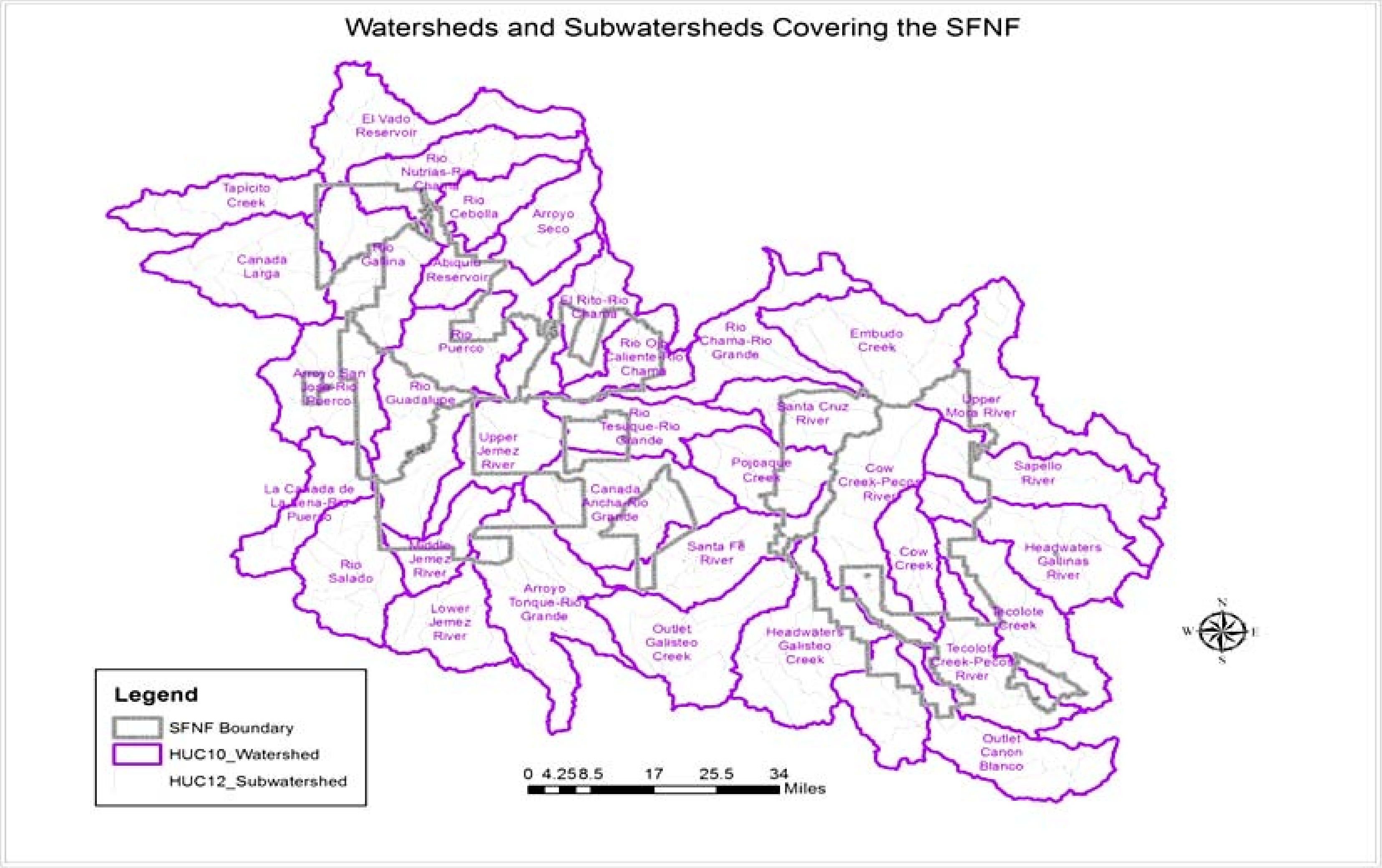


Figure 15. Watersheds and sub-watersheds covering the Santa Fe NF

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.

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 Forest Service 2013a). 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 24.

Table 24. 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 Santa Fe NF 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 Santa Fe NF (33 percent). However, 24 percent of the perennial stream miles (284 of 1,183) on the Santa Fe NF are impaired based on NMED’s 2012 water quality data. Thus the Santa Fe NF 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 Santa Fe NF 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 25) and for those same watersheds within the Santa Fe NF boundary only (table 26). For any given watershed, a comparison can be made between the plan/local and context scale (table 25) to see how the characteristics vary.

Table 25. 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 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									
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									
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									
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									
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 Blanco	107,250	9.6%	4.47	38	136	1	1	38	0.0
Headwaters Gallinas River	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 River	153,501	13.8%	69.45	364	244	12	543	560	18.8
Rio Chama									
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

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 Rito-Rio Chama	103,940	8.7%	43.63	413	38	14	892	738	12.9
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 Chama	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									
Arroyo Tonque-Rio Grande	248,840	23.2%	77.59	849	106	12	1,861	2,001	14.1
Canada Ancha-Rio Grande	231,746	21.6%	100.96	400	54	21	2,603	496	18.3
Headwaters Galisteo Creek	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									
Arroyo San Jose-Rio Puerco	164,269	59.4%	87.49	252	277	12	682	396	27.8
La Canada de La Lena-Rio Puerco	112,115	40.6%	20.82	54	159	4	343	54	0.0
Upper Rio Grande									
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 26. 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 25) 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									
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									
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									
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									
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									
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									
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									
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									
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 (Kenny et al. 2009). 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 (U.S. Geological Survey 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 (U.S. Geological Survey 2014).” 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 27 and figure 16).

Table 27. 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.

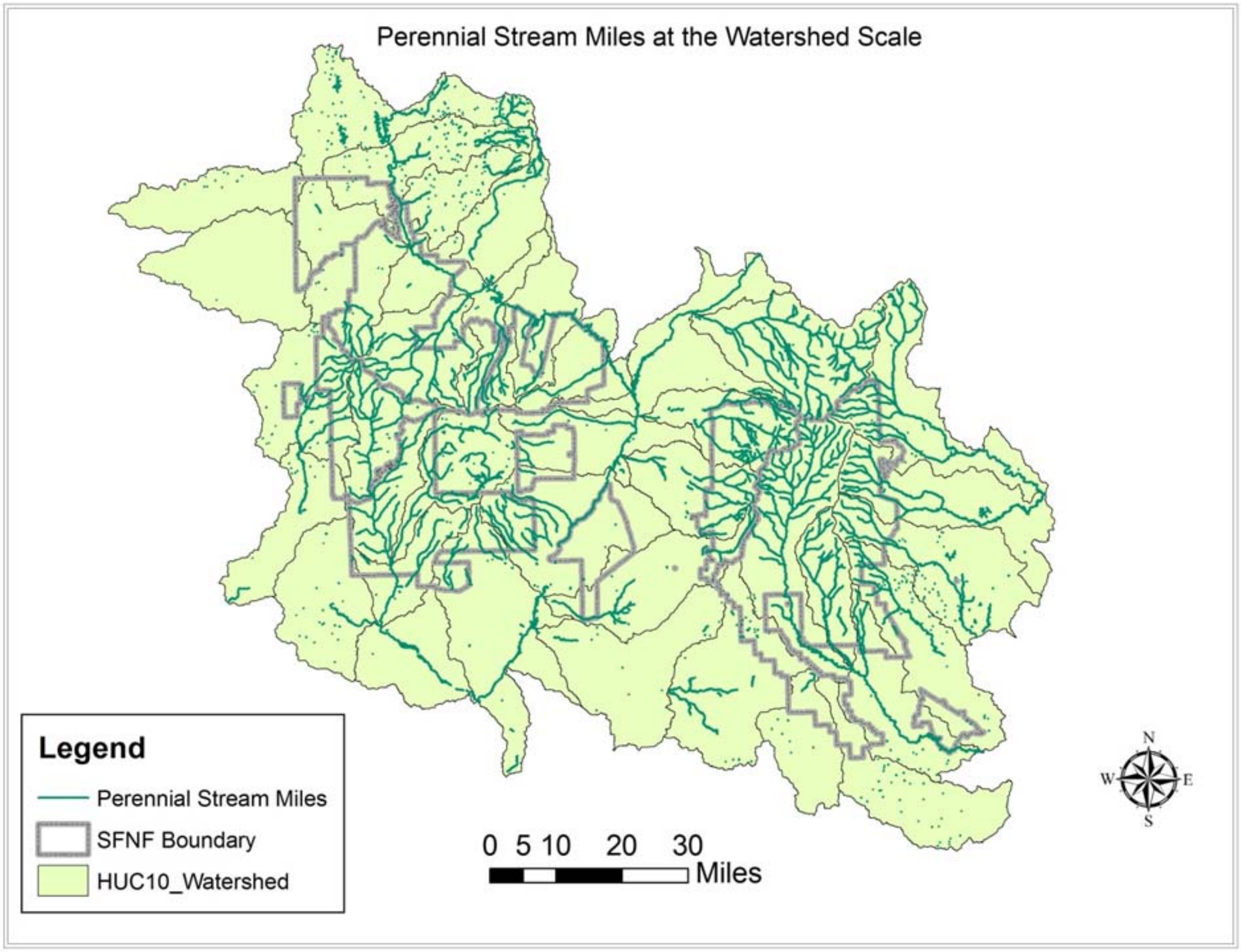


Figure 16. Occurrence of perennial stream miles on and off the Santa Fe NF
Within the Santa Fe NF, there is a higher concentration of perennial stream miles at higher (therefore wetter) elevations primarily in the Jemez and Sangre de Cristo Mountains. Several watersheds have little to no perennial stream 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 17) is available from 1931 to 2014 and for the Jemez gauge (figure 18) 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. Although each gauge is minorly affected by irrigation diversions, 75 acres (1959 determination) upstream of the Pecos gauge, and 300 acres upstream of the Jemez gauge, they do not impact the data presented here in a significant way.

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.

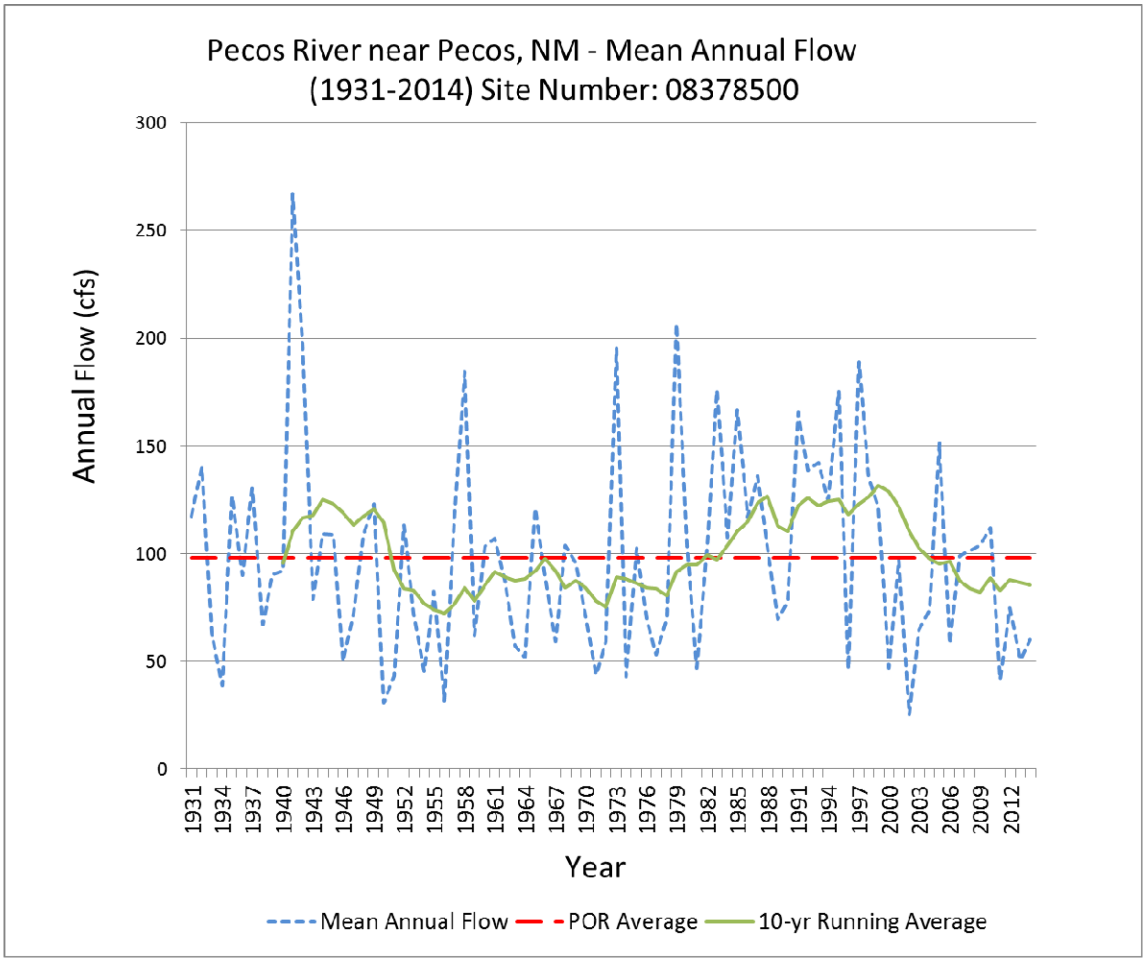


Figure 17. Pecos River near Pecos, NM – Mean Annual Flow (cfs)
The average, mean-annual flow value is 98.2 cfs. Drought periods and wet and dry cycles are also illustrated. Raw data from USGS Current Water Data website 2014.

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.

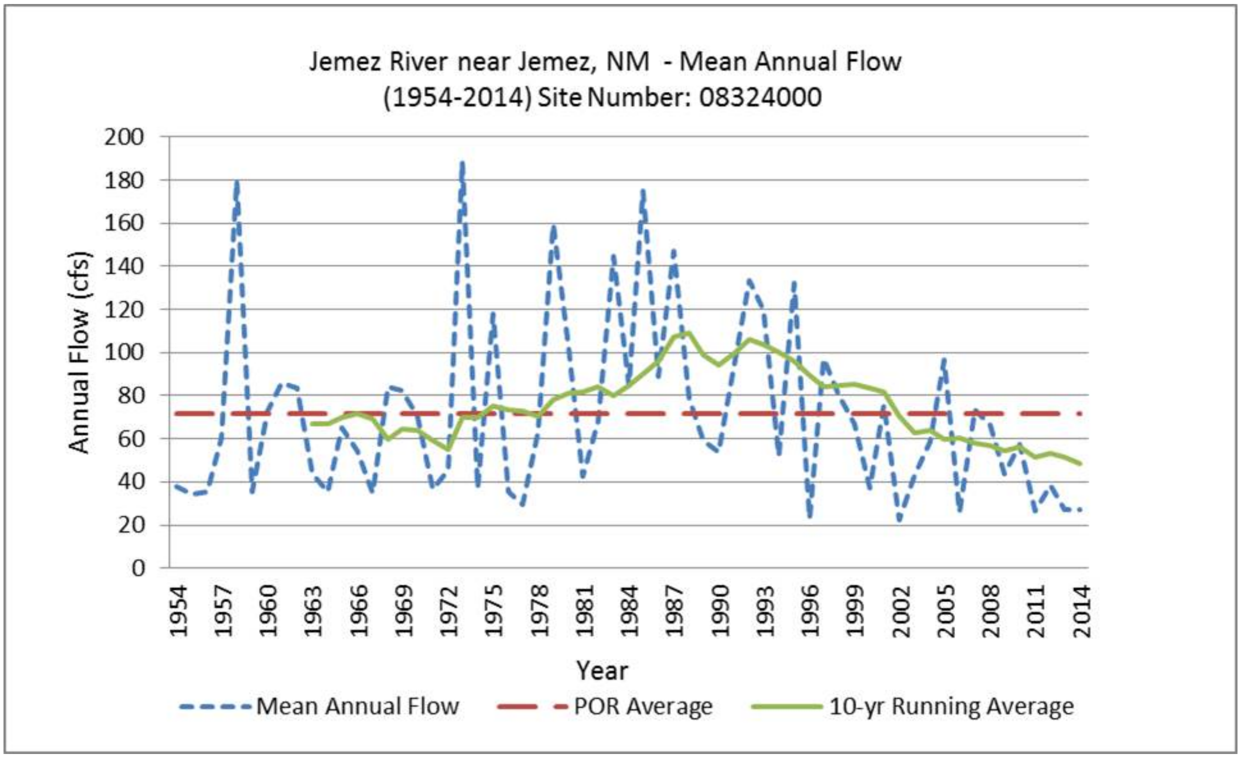


Figure 18. Jemez River near Jemez, NM – Mean Annual Flow (cfs)
The average, mean-annual flow value is 71.7 cfs. Drought periods and wet and dry cycles are also illustrated. Raw data from USGS Current Water Data website, 2014.

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 28), and similarities and variations between the two gauges can be observed.

Table 28. 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 17 and figure 18) was also compiled (table 29). 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 29. 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 (U.S. Geological Survey 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 19). 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.

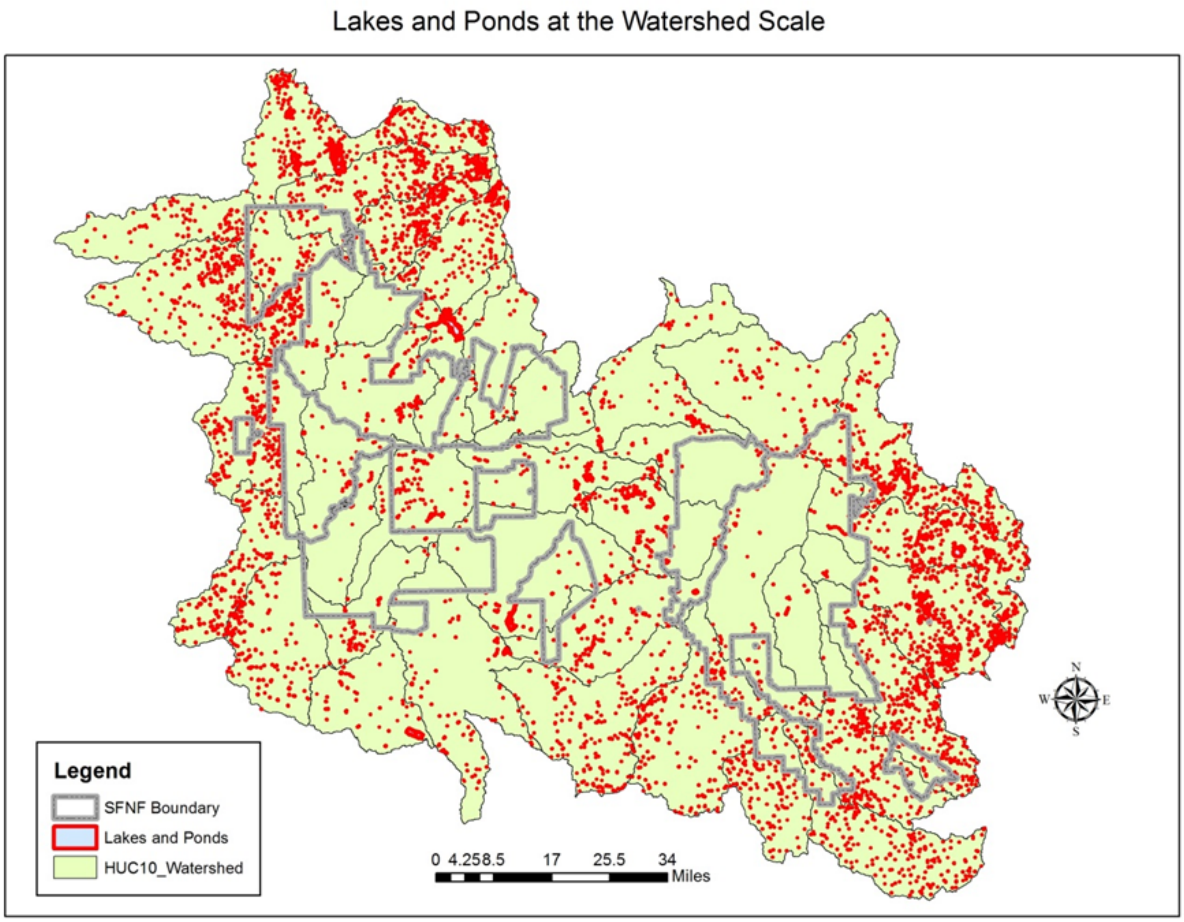


Figure 19. Occurrence of lakes and ponds on the Santa Fe NF
Storage of water is important for subsequent distribution for a variety of uses. Storage on the Santa Fe NF is limited to natural lakes and constructed ponds. Actual size of lakes is exaggerated for display purposes.

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 table 30 the vast majority of lakes and ponds occur off of the Santa Fe NF.

Table 30. Acres of waterbodies on 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 20). 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.

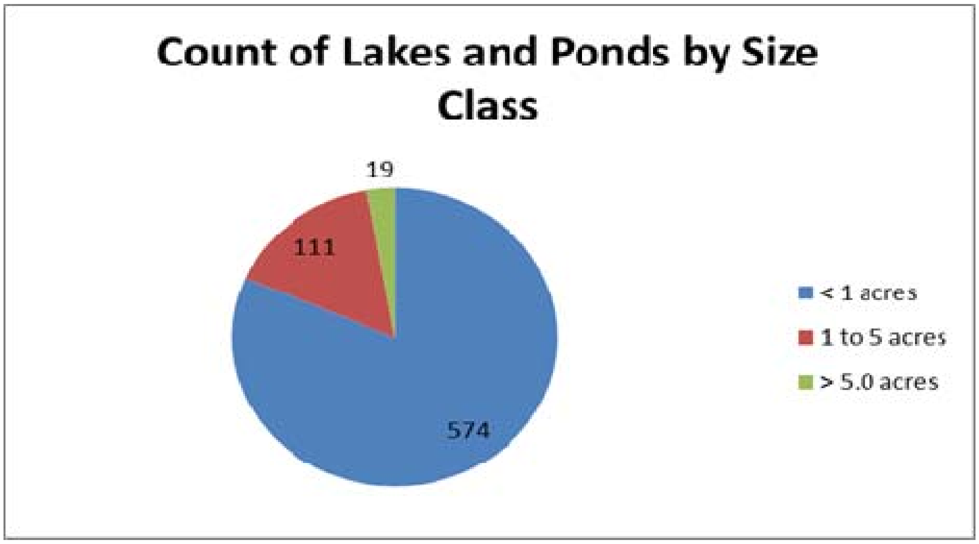


Figure 20. Count of lakes and ponds in Santa Fe NF by size class

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 31). The USGS defines seeps and springs as a place where water issues from the ground naturally (U.S. Geological Survey 2014). Figure 21 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 21).

Table 31. Number of springs and seeps for analysis area by scale

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

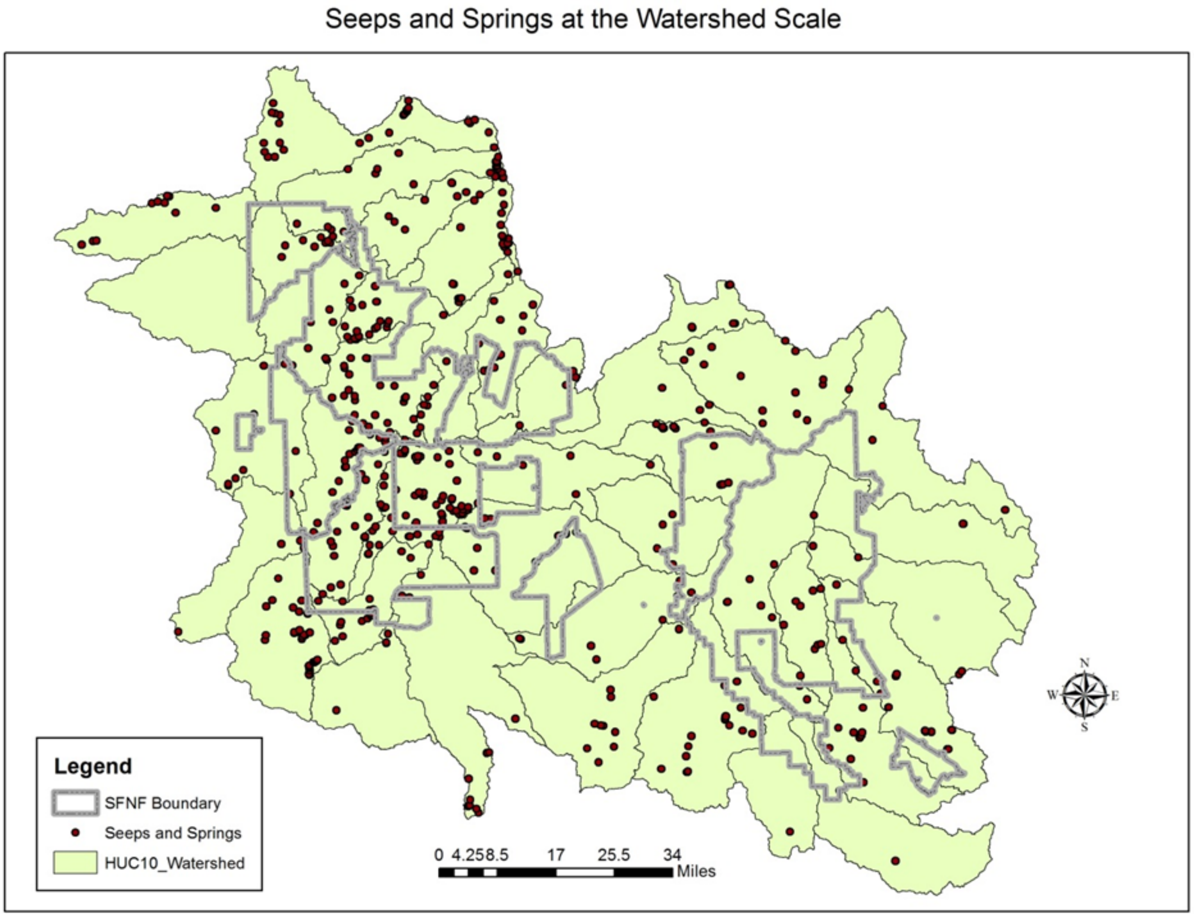


Figure 21. Occurrence of springs and seeps within Santa Fe NF boundary at the watershed scale

Many seeps and springs are likely to have been developed for the purposes of providing water to livestock. Unfortunately, data on the total number of seeps and springs and those which have been developed is not available at this time. Therefore, it is likely that more seeps and springs exist than appear mapped and that most of them, over 90 percent according to field knowledge, has been developed to provide water for livestock and wildlife.

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 Forest Service 2013a). 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 less than 0.75: “Under” represented.
- Stream density ratio 0.75 to 1.25: “Proportionally” represented.
- Stream density ratio greater than 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.

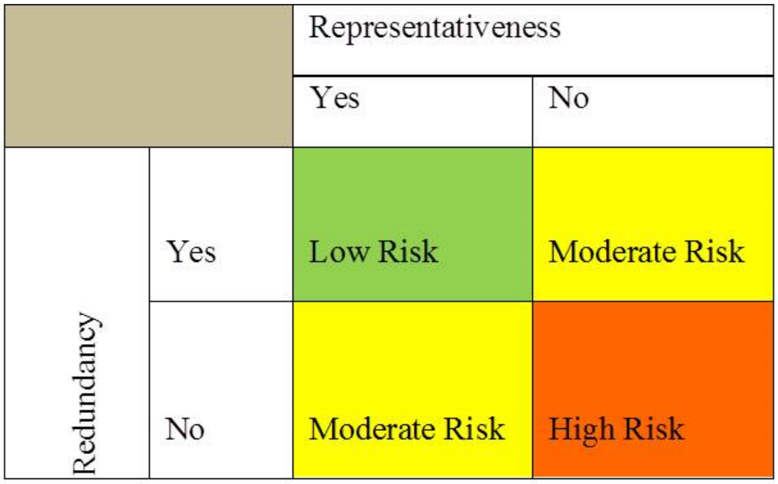
Redundancy is how evenly a characteristic occurrences over the landscape. For each watershed, the occurrence and distribution of perennial stream miles was observed both on and off the Santa Fe NF for each sub-watershed within the watershed. Redundancy for each watershed was assigned in part by using 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 32.

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 22). Potential risk to the compromised system integrity for these characteristics is displayed in figure 23, figure 24, and figure 25.



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

Figure 22. 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. For Representativeness: “Yes” indicates the data was proportionally represented; “No” indicates the data was either over- or under-represented. For Redundancy: “Yes” indicates the data had a moderate or high redundancy; “No” indicates the data had a low redundancy.

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 23). For lakes and ponds, the potential risk to compromised system integrity within the Santa Fe NF was moderate for most watersheds (figure 24). The potential risk to compromised system integrity of seeps and springs within the Santa Fe NF was high for most of the watersheds (figure 25).

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.

Table 32. Representativeness, redundancy, and risk by watershed

*Abbreviations: Rep = representativeness, Red = redundancy, Prop = proportional, Mod = Moderate. Not = not evaluated as this feature was absent in the dataset for that watershed.

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

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
	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
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

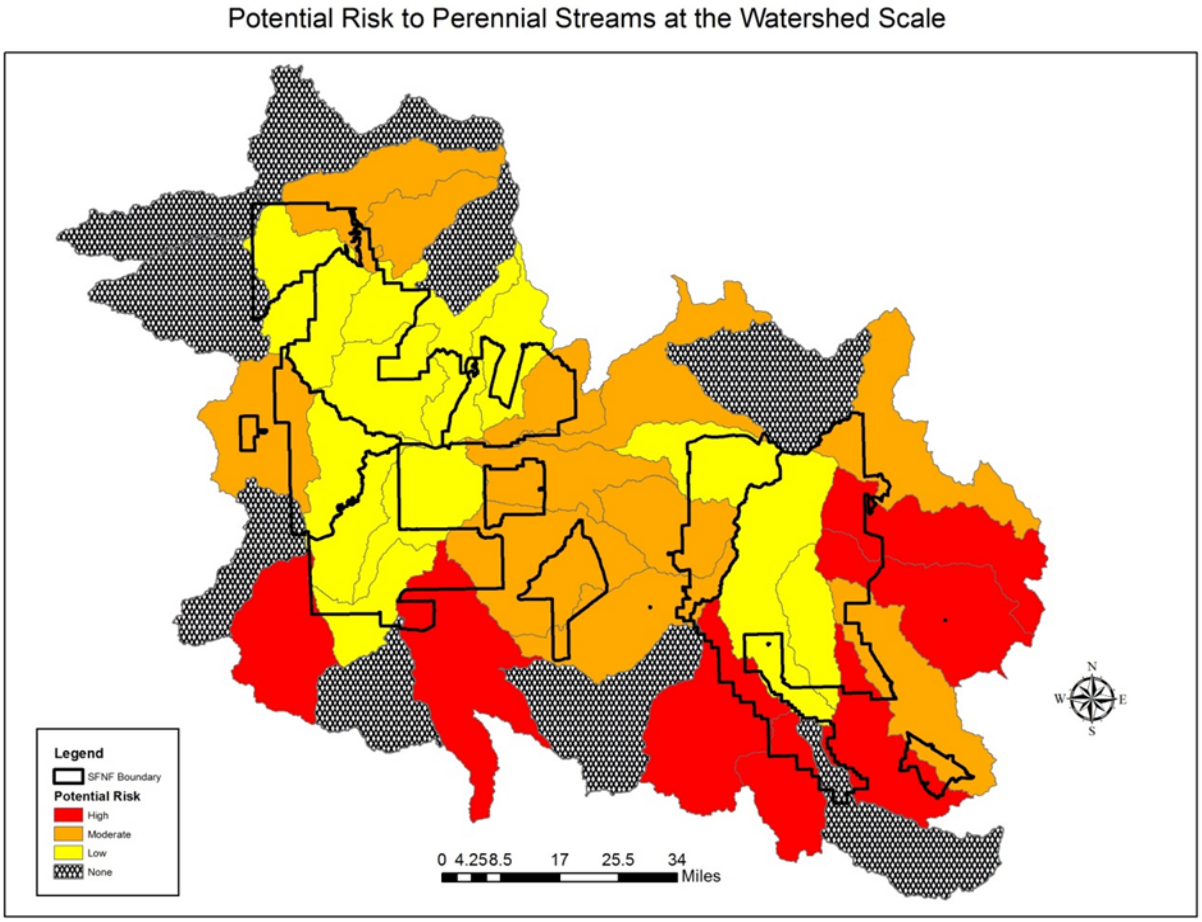


Figure 23. Potential risk of compromised system integrity for perennial stream miles by watershed

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

As shown in table 32, the representativeness, redundancy and risk for the Rio Salado watershed is over-represented, low redundancy, and high risk, respectively. Within this watershed, less than 1 mile of perennial stream (out of 15.8 miles) occurs on the Santa Fe NF. 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 Santa Fe NF. 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 Santa Fe NF. The representativeness, redundancy and risk for the Upper Jemez River watershed is proportional, moderated redundancy, and low risk, respectively (see table 32). Fifty perennial stream miles (out of 125 miles) occurs on the Santa Fe NF. 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 Santa Fe NF. It is likely that all the various stream types occur both on and off the Forest, and therefore the Santa Fe NF shares in the conservation burden (approximately 40 percent) 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 32). Yet nearly all of the perennial stream miles (154.6 out of 155.1 miles) occur on the Santa Fe NF. 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 Santa Fe NF. Even though there is a low potential risk, the Santa Fe NF 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 Santa Fe NF.

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.

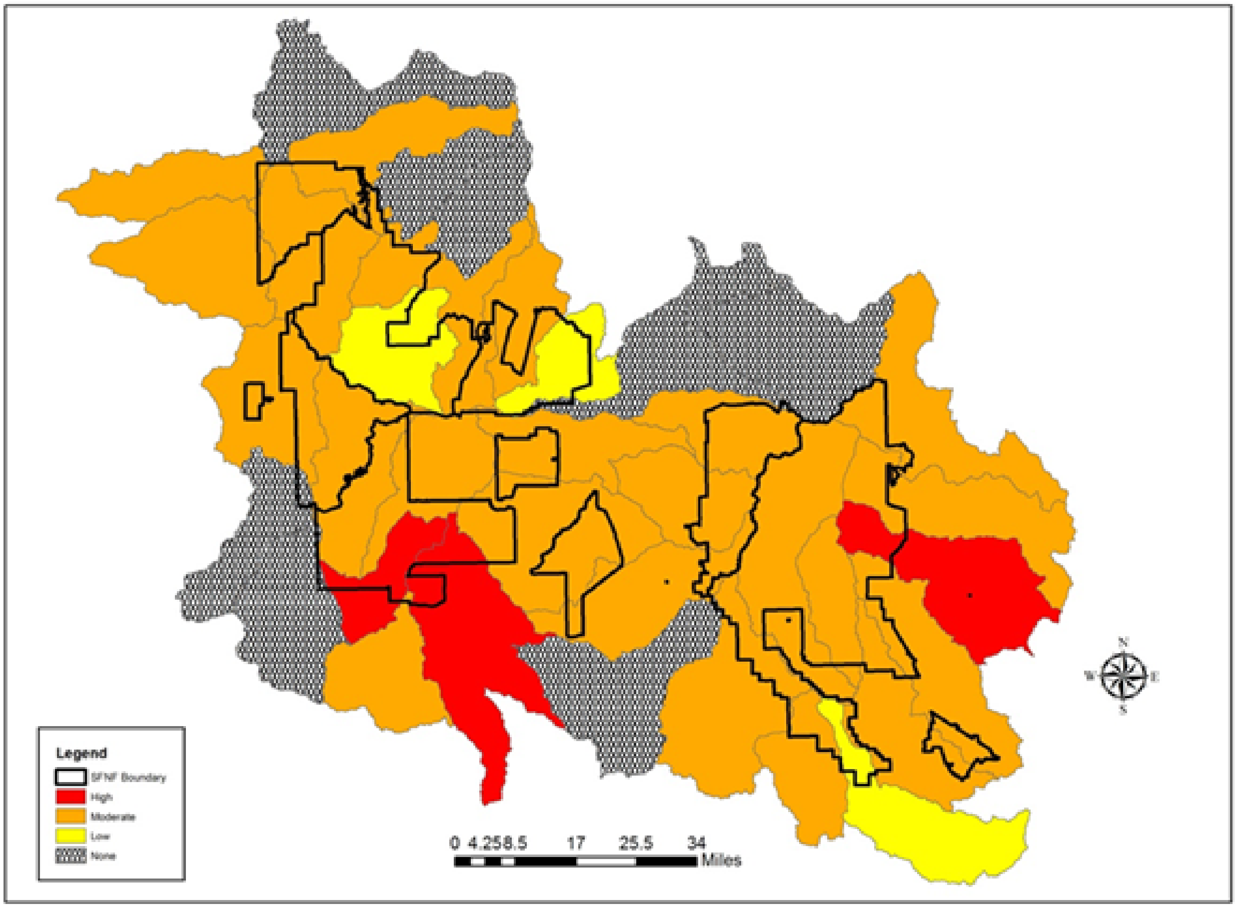

Potential Risk to Waterbodies at the Watershed Scale

Figure 24. 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.

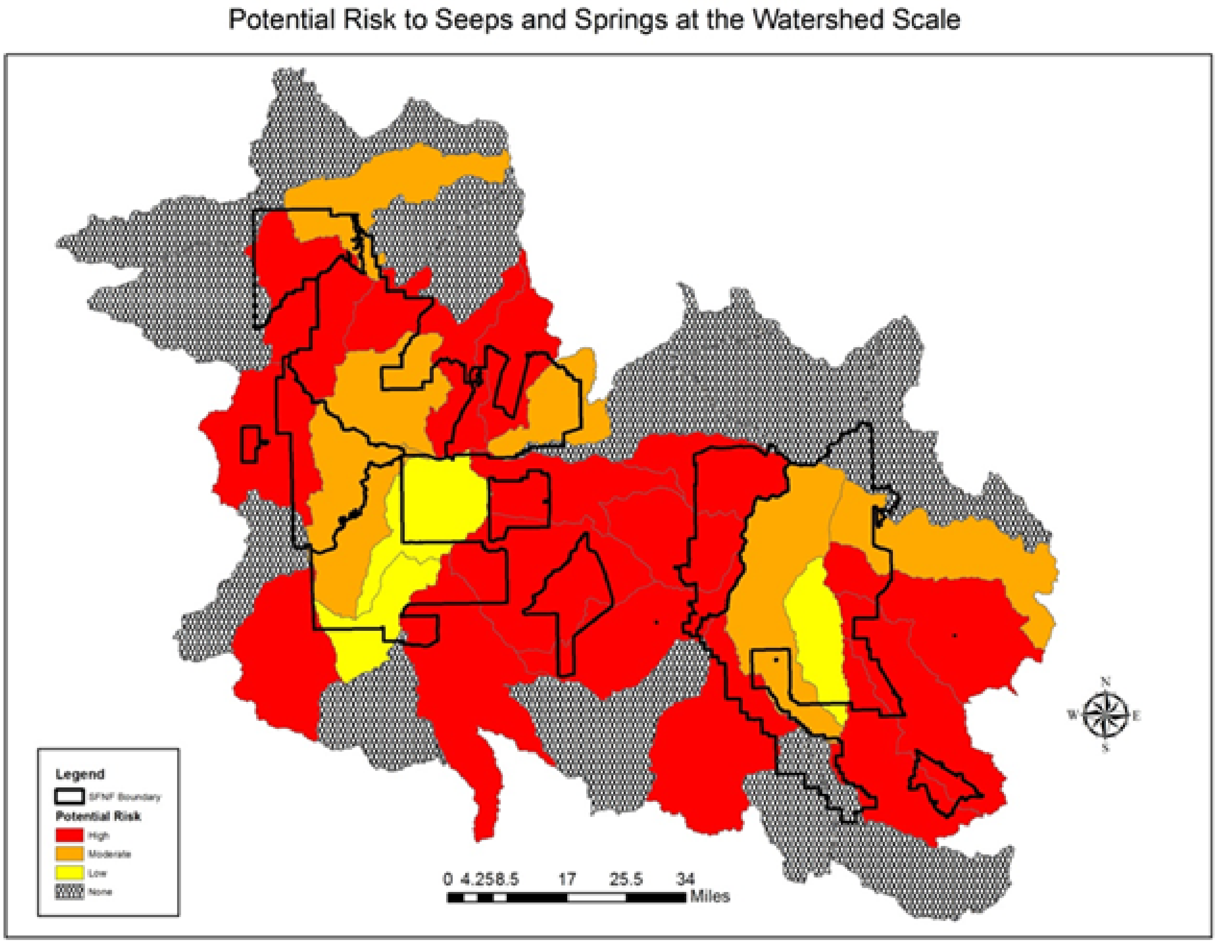


Figure 25. Potential risk of compromised system integrity to seeps and springs by watershed

Water Quality Current Conditions: Perennial Streams

The impaired perennial streams within the analysis area were identified using NMED's 2010-2012 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. 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. Perennial streams were evaluated at the context (entire watersheds) and plan (portion of watershed within Santa Fe NF boundary only) scales, and only for those watersheds containing impaired perennial streams (figure 26 and table 33).

At the context scale, 23 percent (185 of 790 miles) of the impaired waters are within the Jemez sub-basin, 18 percent (145 of 790 miles) are within the Pecos Headwaters sub-basin, 25 percent (200 of 790 miles) are within the Rio Chama sub-basin, 11 percent (88 of 790 miles) are within the Rio Grande-Santa Fe sub-basin, 10 percent (80 of 790 miles) are within the Mora sub-basin and the remaining 12 percent (92 of 790 miles) are spread across perennial streams in the Upper Rio Grande and Rio Puerco sub-basins. Within the Santa Fe NF, 46 percent (129 of 284 miles) of the impaired waters are within the Jemez sub-basin, 21 percent (59 of 284 miles) are within the Pecos Headwaters sub-basin, 24 percent (69 of 284 miles) are within the Rio Chama sub-basin, and the remaining 9 percent (27 of 284 miles) are spread across perennial streams in the Rio Grande-Santa Fe, Rio Puerco and Upper Rio Grande sub-basins.

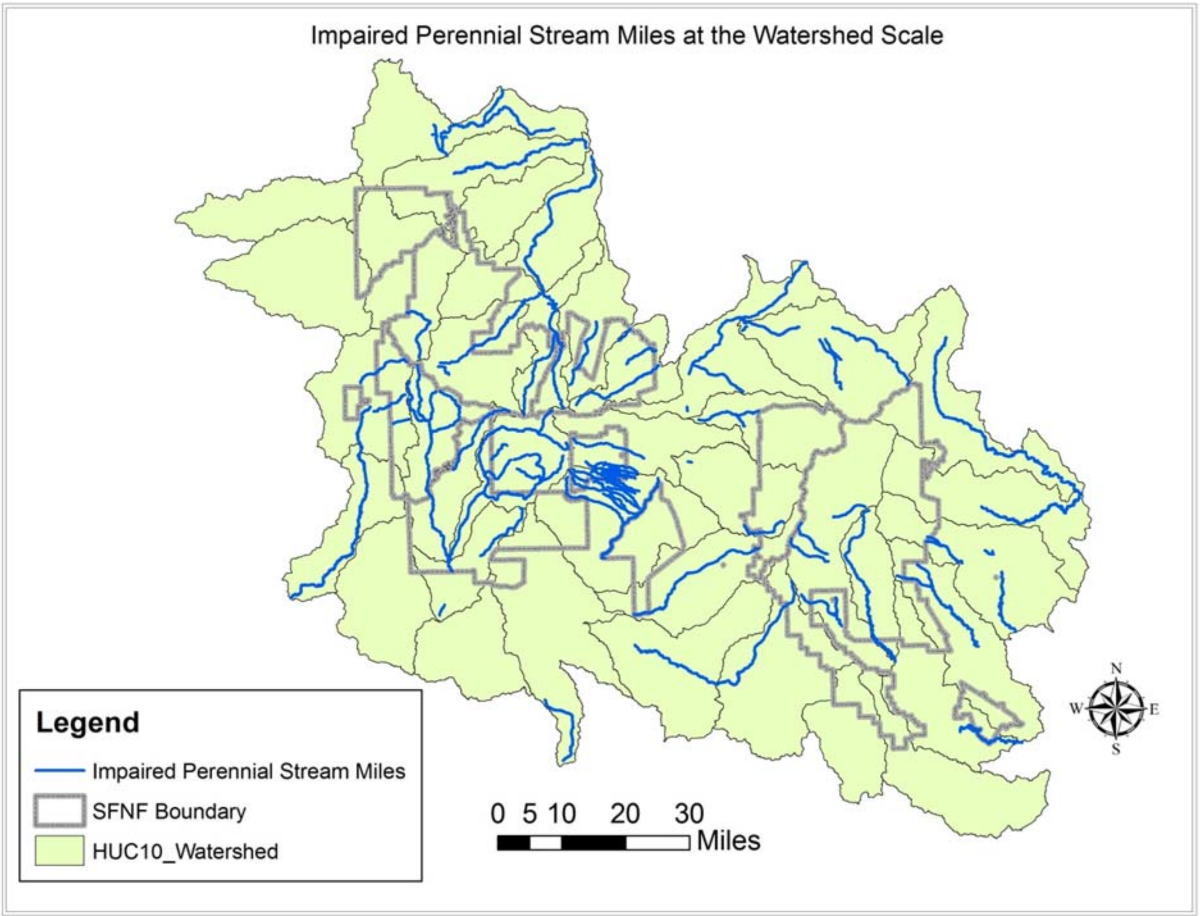


Figure 26. Impaired perennial stream miles at the watershed scale

Table 33. 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.

When comparing the percentages of impaired perennial stream miles at the context scale and plan scales, approximately 31 percent (790 of 2,534 miles) are impaired at the context scale, while 24 percent (284 of 1,166 miles) are impaired at the plan scale (within the Santa Fe NF boundary). As previously stated, on the Santa Fe NF nearly 91 percent of the impaired perennial stream miles occur within 3 sub-basins: Jemez, Pecos Headwaters, and the Rio Chama. Within the Santa Fe NF, impaired perennial stream miles exists within the Middle Jemez River, Rio Guadalupe and Upper Jemez watersheds of the Jemez sub-basin; 70 percent of the impaired perennial streams within this sub-basin occur on the Santa Fe NF. Significant impaired perennial stream miles exists on the Santa Fe NF within the Cow Creek and Cow Creek-Pecos River watersheds of the Pecos Headwaters sub-basin; nearly 41 percent of the impaired perennial stream miles within this sub-basin occur on the Santa Fe NF. Significant impaired perennial stream miles exists within the Abiquiu Reservoir, Rio Gallina, Rio Ojo Caliente-Rio Chama and Rio Puerco watersheds of the Rio Chama sub-basin; nearly 35 percent of the impaired perennial streams within this sub-basin occur on the Santa Fe NF. It should be noted that no impaired perennial stream miles were identified on the Santa Fe NF within the Mora sub-basin. See table 33 for the remaining impaired perennial streams that are present in the remaining sub-basins.

Reference Condition and Departure: Water Quality of Perennial Streams

Any perennial stream segment that has constituents (refer to table 33 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 29). 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.

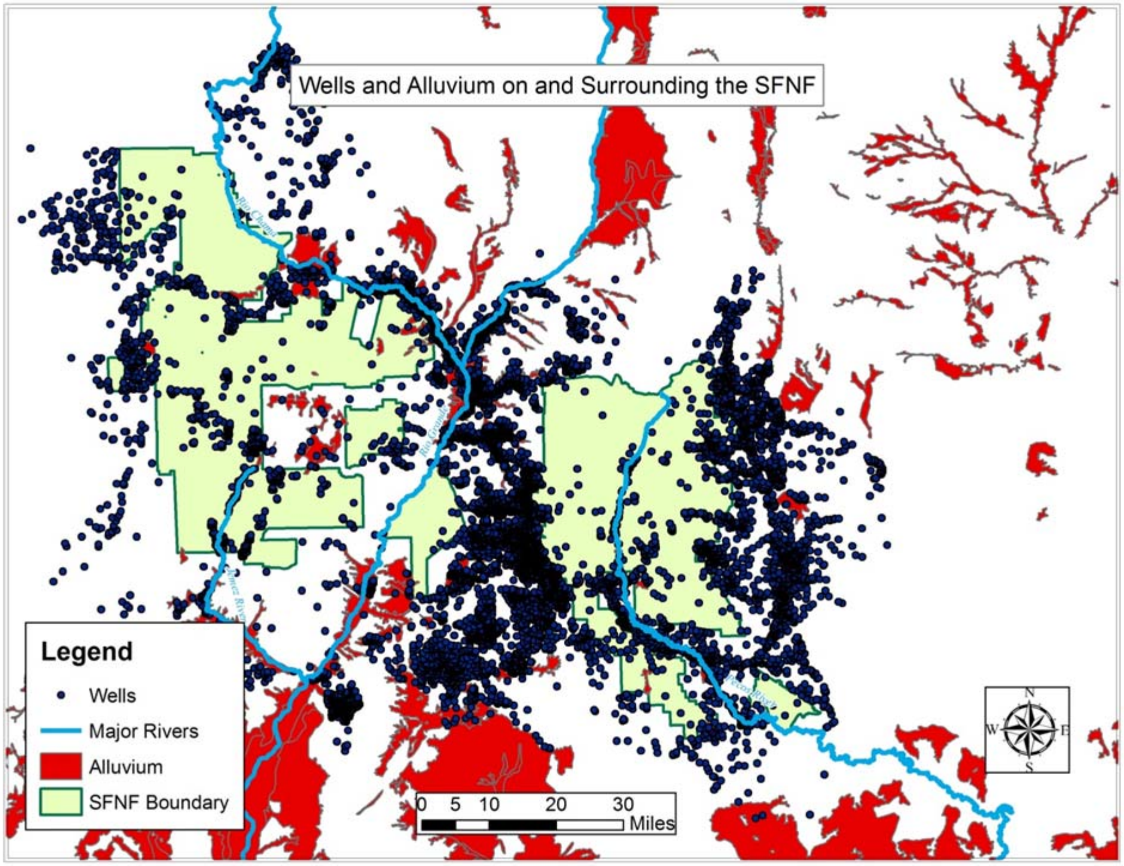


Figure 27. Wells, alluvium, and aquifers surrounding the Santa Fe NF
Raw data for alluvium and wells are from geologic map GIS coverage and NM SEO database, respectively.

Alluvium (identified in red in figure 27) 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 (New Mexico Water Resrouces Research Institute 2014).

Areas of highest precipitation generally occur on National Forest System lands because of their higher elevation, 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 28). 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 is served by public water supplies and 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).

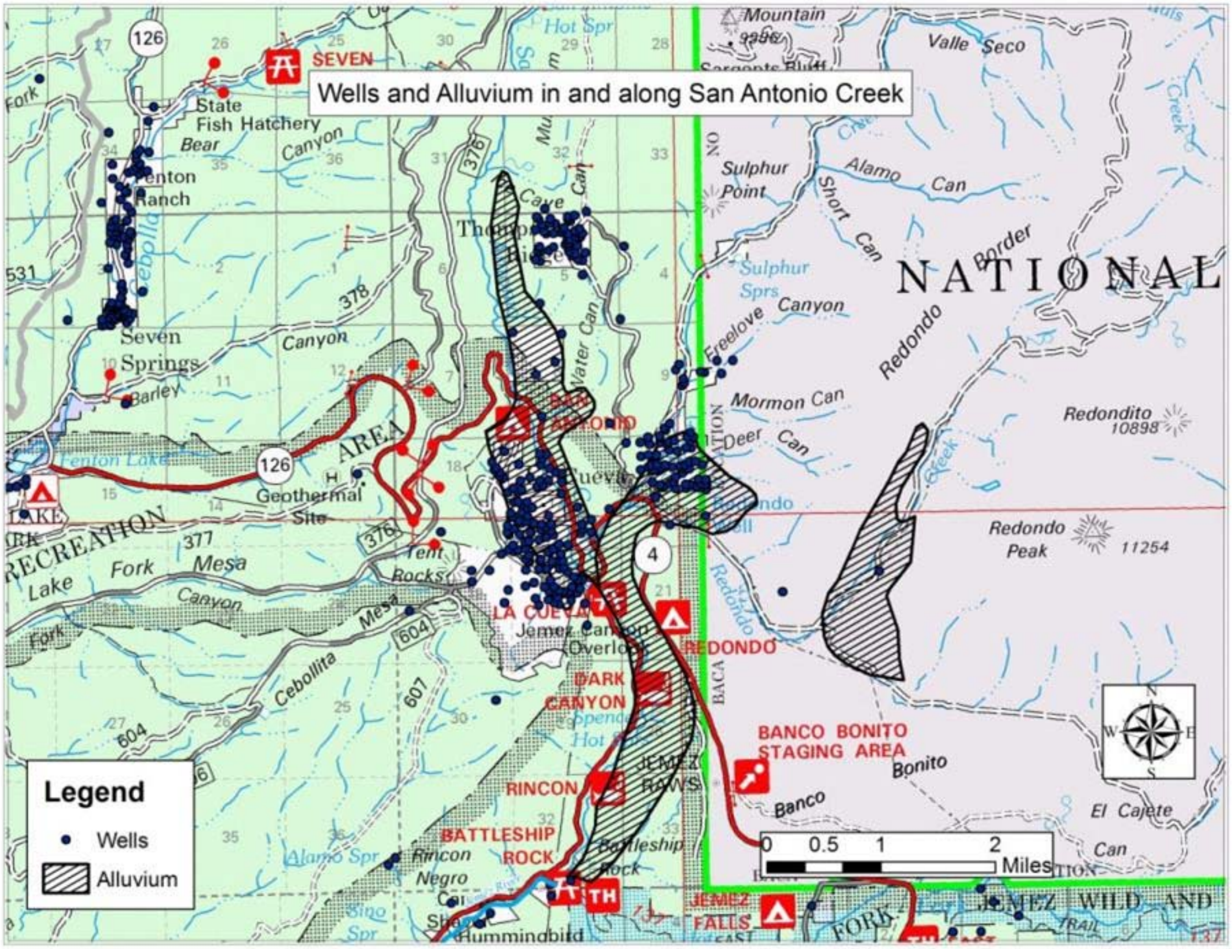


Figure 28. Wells and alluvium in and along San Antonio Creek

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.

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 29). 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.

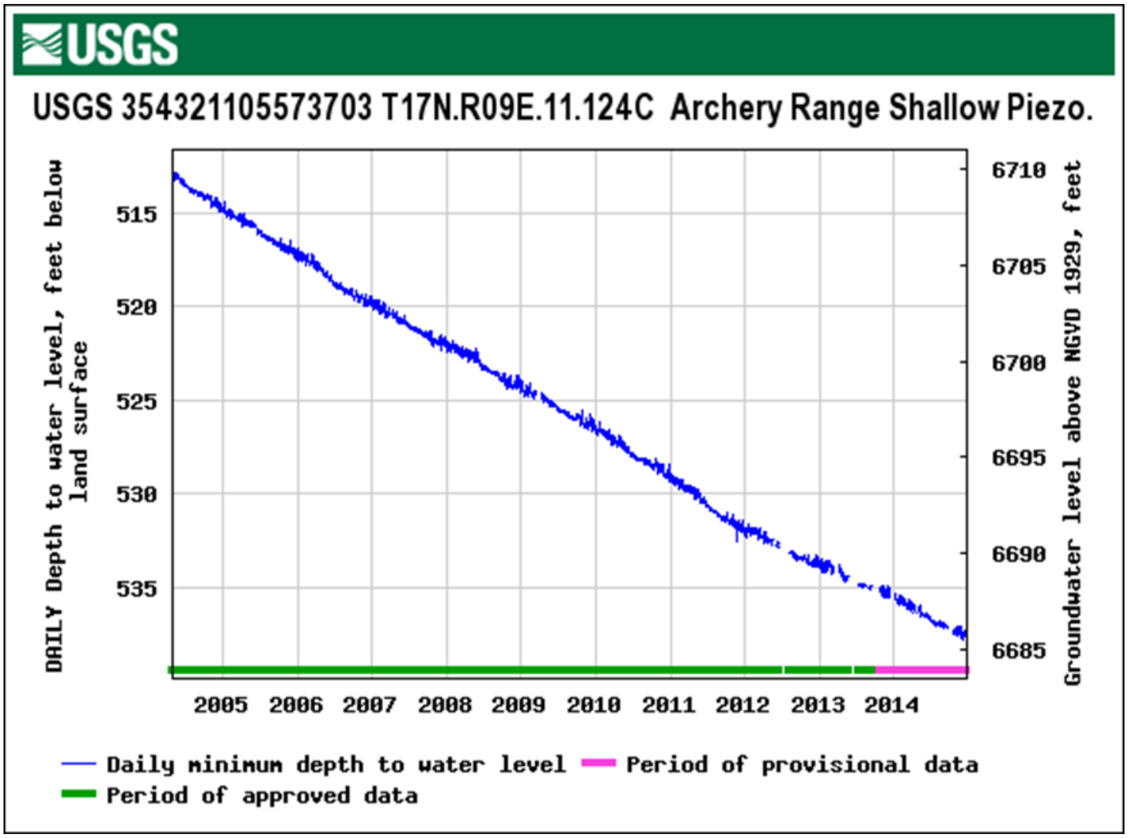


Figure 29. Water table decline in a well near Santa Fe, NM
The USGS maintains a well monitoring system with periodic measurements to evaluate changes in groundwater levels. The wells monitored are outside of the Santa Fe NF boundary in the developed urban and agricultural areas. Even though this well is off the Santa Fe NF, it demonstrates the overall decline in the water table (in this particular formation) between 2005 and 2014 (USGS, 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 (Dall et al. 2009). Aquatic and fish productivity are directly related to a properly functioning and healthy riparian/wetland habitat (Knutson and Naef 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. 1985). 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. 1985). 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 deep-water 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 deep-water 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 that overlap the Santa Fe NF, 7,000 acres occur within the Santa Fe NF boundary (figure 32). The National Wetlands Inventory (NWI) separates and maps these wetlands into five categories. Each category, NWI's definition (U.S. Fish and Wildlife Service 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)

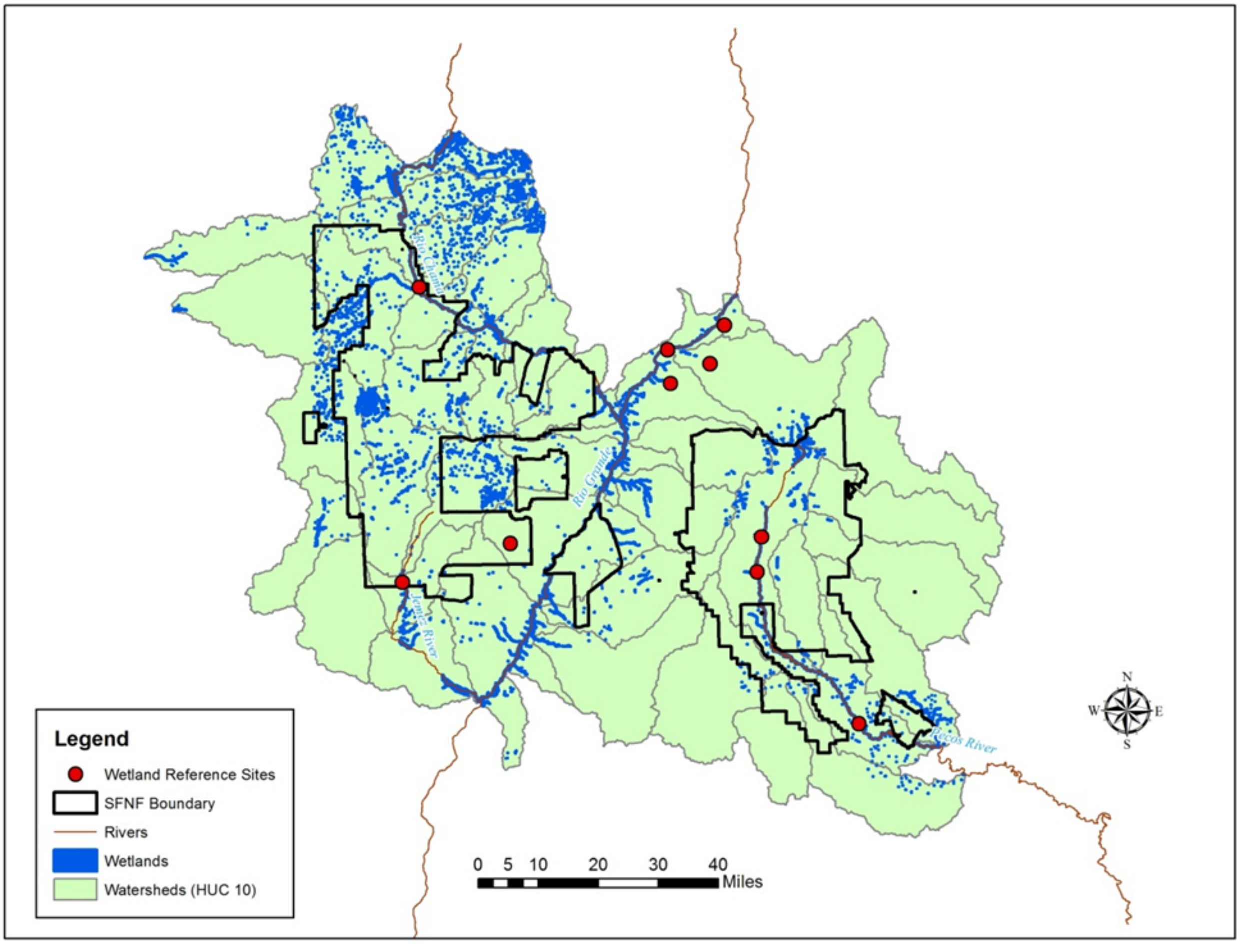


Figure 30. Occurrence of wetlands

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; 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 34). 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 34. 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 (Muldavin and Bradley 1998). Ten of these reference sites are within the watersheds covering a portion of the Santa Fe NF (table 35 and figure 30); these 10 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 (Greater than 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 (Less than 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 35. 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 35). 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 (Potyondy and Geier 2011).

The WCC system offers a systematic, flexible means of classifying watersheds based on a core set of national watershed condition indicators (Potyondy and Geier 2011). The 12 indicators are grouped according to four major process categories: aquatic physical, aquatic biological, terrestrial physical and terrestrial biological (figure 31).

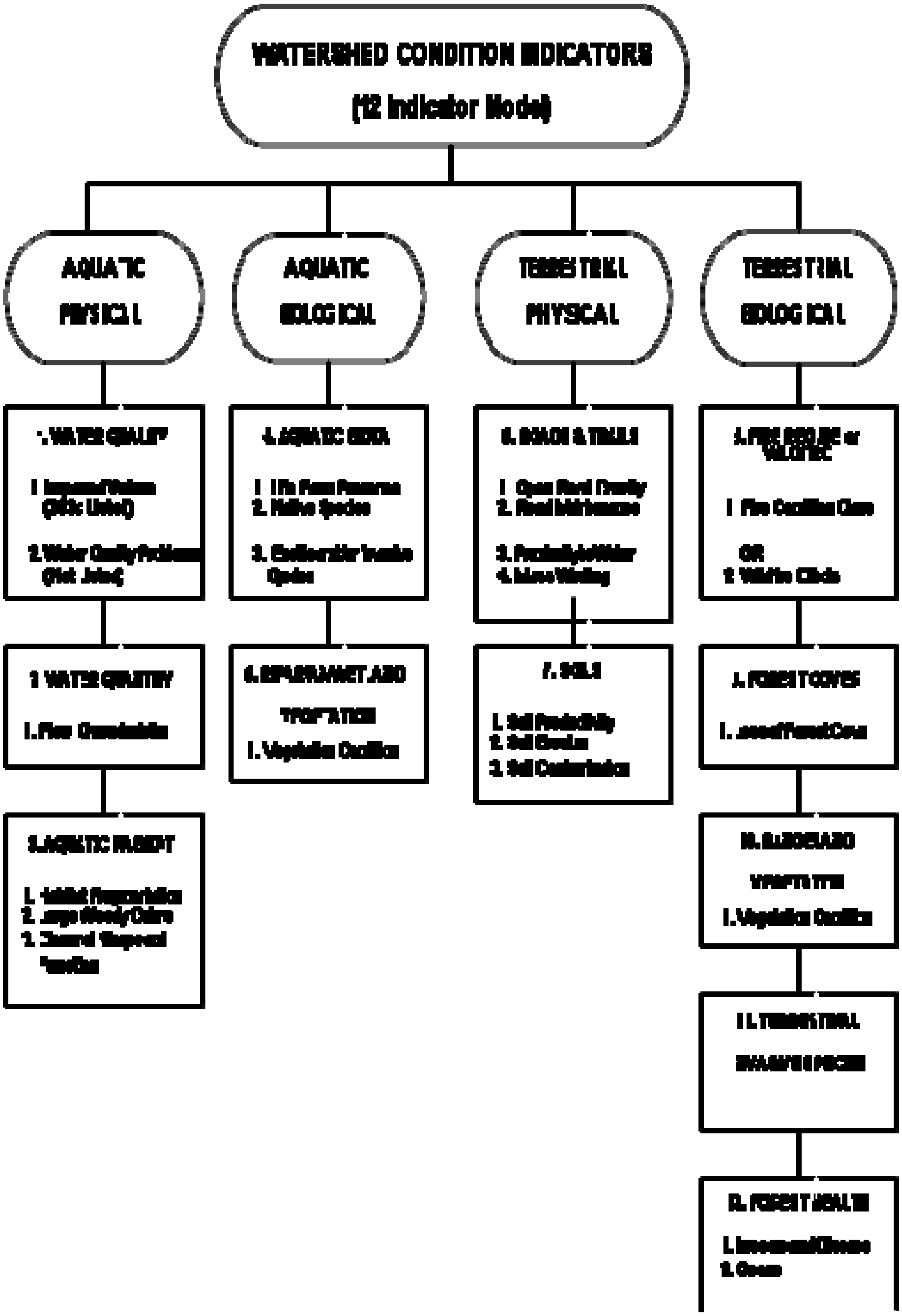


Figure 31. Core national watershed condition indicators

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 (Potyondy and Geier 2011). With the exception of the *Forest Cover* indicator under the terrestrial biological process category which was not evaluated, 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 36 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 36. 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%

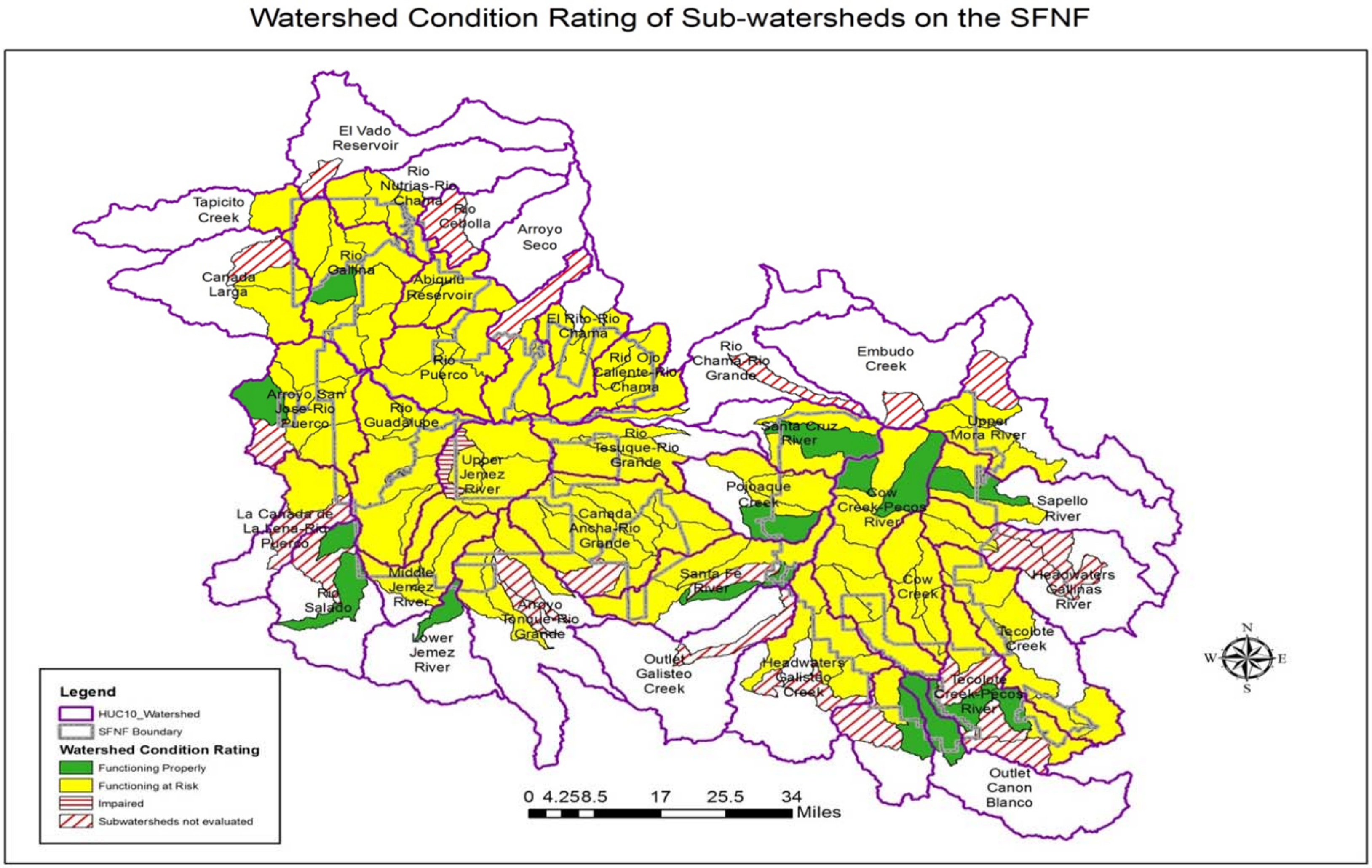


Figure 32. Watershed condition of sub-watersheds on the Santa Fe NF

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 five indicators that had the largest impact on the overall watershed scores were (in order of importance): (1) soils, (2) roads and trails, (3) riparian/wetland vegetation, (4) aquatic biota, and (5) water quantity. Average indicator values for the 116 sub-watersheds range from 0 to 2.4 (table 37). 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 37. 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 (New Mexico Office of the State Engineer 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 33). 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 38). 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 38. 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.

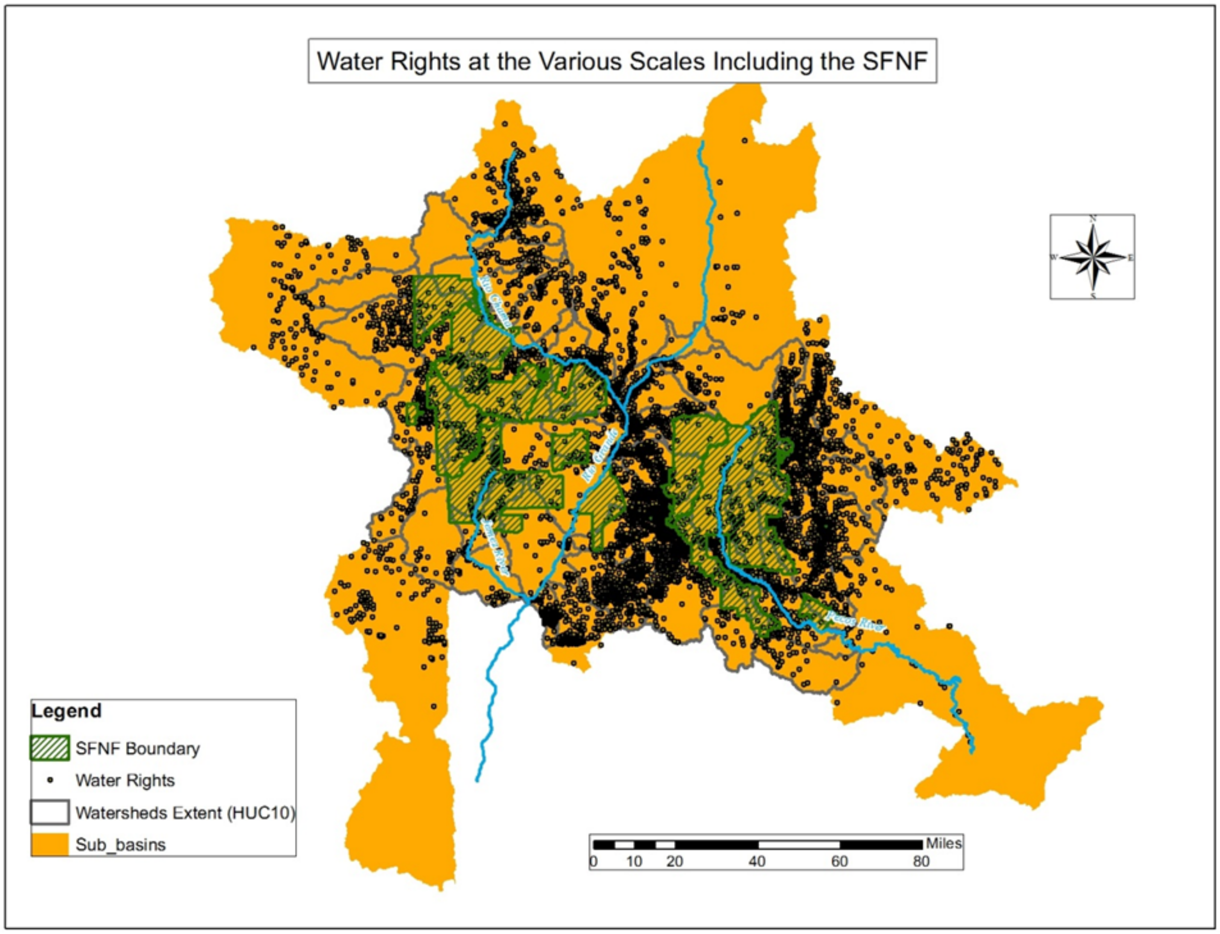


Figure 33. Points of diversion on and adjacent to the Santa Fe NF

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 34 and figure 35). 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.

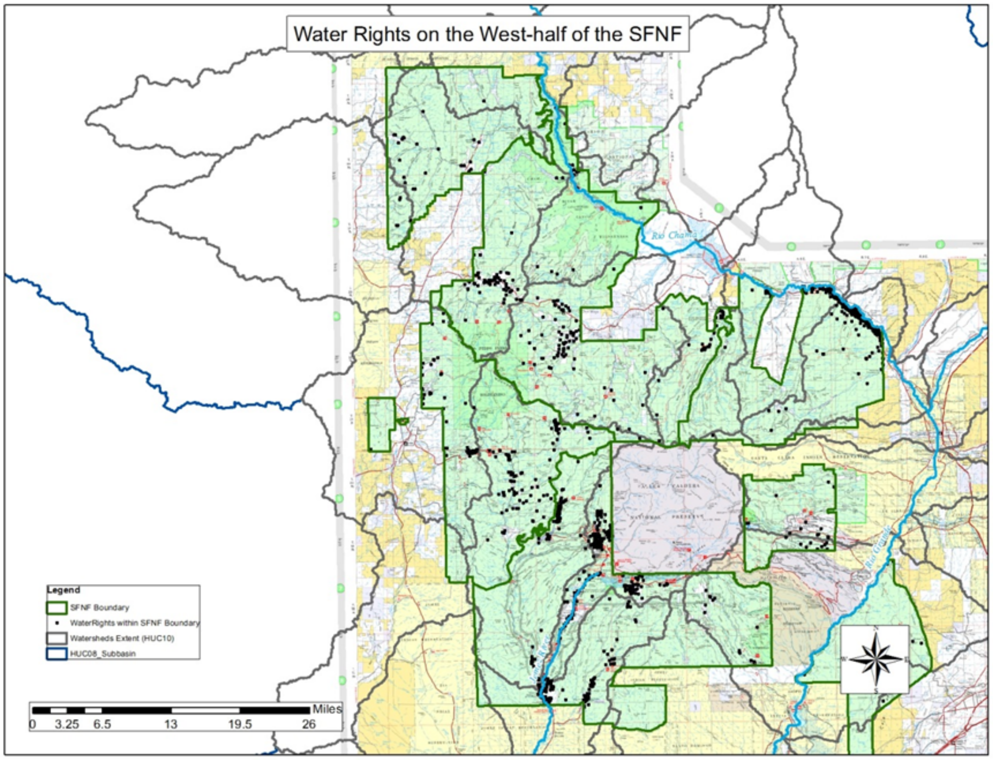


Figure 34. Points of diversion on the western half of the Santa Fe NF
Significant clusters of diversion points can be seen along streams and roads and around communities.

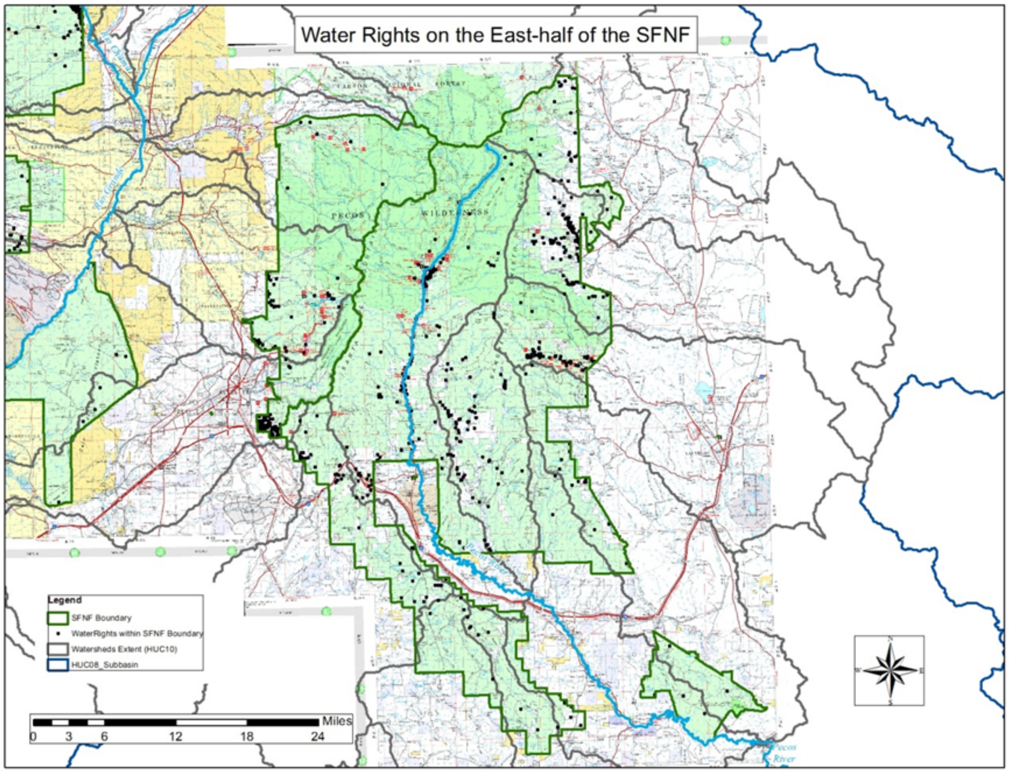


Figure 35. Points of diversion on the eastern half of the Santa Fe NF
Significant clusters of diversion points can be seen along streams and roads and around communities.

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 (New Mexico Office of the State Engineer 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, 24.3 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 39). 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 39. 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.

Drivers and Stressors on the Santa Fe NF

The Santa Fe NF 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 occurring on the Forest prior to and since its establishment in 1915. For additional information on the historic use of the Santa Fe NF and its surrounding environs, please refer to Chapter 1

Assessing Cultural and Historic Resources, and Chapter 4, *Range and Grazing* in Volume 2, Socioeconomic Resources of the Forest Plan Assessment.

To help understand some of the current conditions of these disturbances at the plan/local scale, the ponderosa pine (PPF) 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 40. At the plan scale (collectively all NFS lands within the Santa Fe NF boundary), 50 percent of the total acres (or approximately 834,000 acres) occur as PPF 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.

When looking at wildfires greater than 10 acres in size on the Santa Fe NF 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 percent of the Santa Fe NF has burned during this time period. Since 2010 more than half of that amount, approximately 140,000 acres, have burned (45 percent of the 309,000 total). Of this amount, 71,000 acres (mostly PPF 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 PPF and MCD forests remain untouched by wildfire in the last 40 years. These forest types cover a significant portion of 22 watersheds listed in Table 40, 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 earlier in this report, both of the long-term stream gages on the Santa Fe NF experienced a steady decline in the 10-year running averages of annual stream discharge since 1999. The effect of drought on wildfires frequency and size during this time period cannot be ignored.

Roads and water-related range developments also impact the watersheds on the Santa Fe NF. These are displayed in Table 40 to illustrate a few examples of how the Santa Fe NF 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 Santa Fe NF boundary have been compromised, see water quality section. As a result, approximately 24 percent of the perennial stream miles on the Forest have been designated by NMED as impaired.

The Rio Guadalupe (Jemez sub-basin) can be used as an example of the watershed situation at the local scale (any watershed within the Santa Fe NF boundary). Approximately 71 percent of the watershed area is comprised of PPF 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 percent 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 percent) are impaired. Some of these impairments can be directly related to the natural and human-caused disturbances.

Table 40. Disturbances to water resources on the Santa Fe NF

Sub-basin Watershed	Watershed Acres	PPF & MCD[9] (Acres)	Wildfire[10] (Acres)	Approx. Net PPF & MCD (Acres)	PPF & MCD % Watershed	Roads[11] (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

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

Sub-basin Watershed	Watershed Acres	PPF & MCD[9] (Acres)	Wildfire[10] (Acres)	Approx. Net PPF & MCD (Acres)	PPF & MCD % Watershed	Roads[11] (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**

For comparative purposes, the Headwaters Gallinas River Watershed (Pecos Headwaters sub-basin) has 51 percent of PPF and MCD forest cover. No significant fires have burned in this watershed since 2010. Just under 34 perceent of this watershed has slopes less than 30 percent, making it much steeper than the Rio Guadalupe watershed, and therefore, less accessible. This inaccessibility translates into fewer human developments; the watershed contains 25 miles of level 2 roads and 4 water-related range developments and none of its 37 perennial stream miles are reported to be impaired based on NMED’s 2012 data.

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 (Furniss 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 (Pagano and Garen 2005, Hamlet and Lettenmaier 2007, Luce and Holden 2009). 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 (Furniss 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 (Furniss 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 (Furniss 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 (New Mexico Office of the State Engineer 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 (Furniss 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 Santa Fe NF 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 occurred on the Forest prior to and since its establishment in 1915.

At the plan scale (collectively all NFS lands within the Santa Fe NF boundary), fifty percent of the total acres (or approximately 834,000) occur as ponderosa pine or mixed conifer frequent-fire 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. These forest types cover a significant portion of 22 watersheds on the Santa Fe NF, and these watersheds will have a greater risk of wildfire ignitions in the future.

In combination with other human-caused and natural disturbances, the water quality of perennial streams in many of the watersheds within the Santa Fe NF boundary has been compromised. As a result, approximately 24 percent 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:

- ant impacts on these ecosystems as dry, lowwithdrawals; 84.5 percent was for irrigation, 8.6 percent was for public water supply and the remaining 7 percent 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 Santa Fe NF. 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 percent 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 Santa Fe NF.

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 Santa Fe NF, 87 percent 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 Santa Fe NF. 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 (in winter). 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 Santa Fe NF.

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 36).

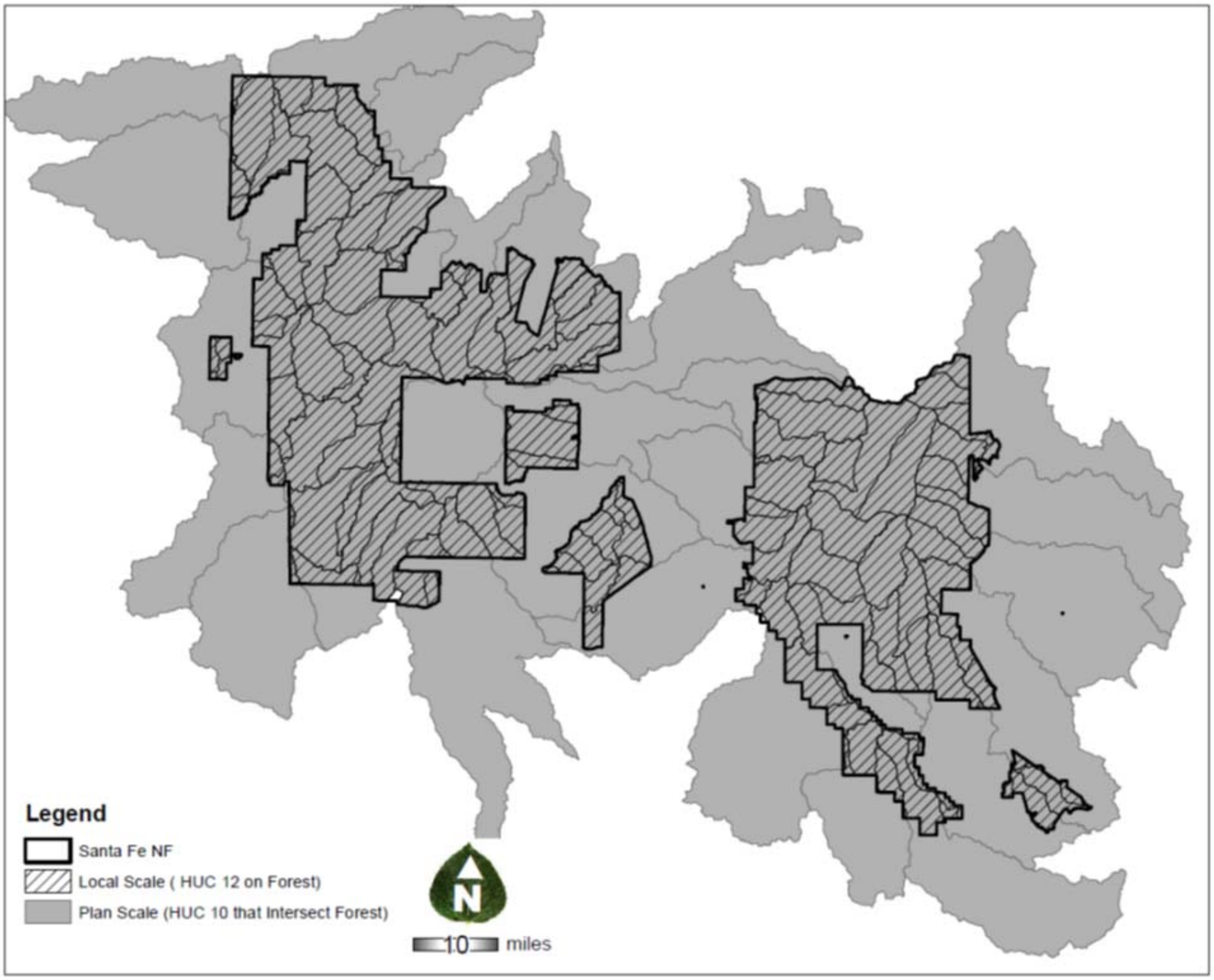

Figure 36. Plan (HUC 10 watershed) and local (HUC 12 sub-watershed) scales for aquatic biota assessment on the Santa Fe NF

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 41 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 are represented by the letter “R” for reference. While native fish species that occurred historically and are still known to occur in the watershed is represented by “C” (Current). Blank cell indicates native fish species were not historically present within the watershed.

Table 41. 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[12]**	**Percent Departure of Current From Historic**	**Risk Ranking[13]**
Sapello River				**C**	**C**	**C**	**C**	**C**		**C**	**R**				**C**		**C**	**8/9**	**4**	**11**	**L**
Rito San Jose				C	C			C			R				C		C	5/6	3	17	L
HWs[14] Manuelitas Creek				C	C			C			R				C		C	5/6	3	17	L
Manuelitas Creek-Sapello River				C	C			C			R				C		C	5/6	3	17	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			R						C	4/5	3	20	L
Rio La Casa- Mora River				C	C	C	C	C			R				C		C	7/8	3	13	L
Santiago Creek				C	C			C			C						C	5/5	2	0	L
Rito Cebolla				C	C	C	C	C		C	R						C	7/8	3	13	L
Santa Cruz	**R**									**R**	**C**		**R**					**¼**	**6**	**75**	**H**
Rio Frijoles	R									R	C		R					¼	3	75	H
Rio Medio	R									R	C		R					¼	3	75	H
Rio Quemado	R										R		R					0/3	3	100	H

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[12] Presence of non-native fish is a measure of departure as only native fish would have been present in the reference condition

[13] 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

[14] 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[12]**	**Percent Departure of Current From Historic**	**Risk Ranking[13]**
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	60	M
Pojoaque Creek	**R**										**R**		**R**					**0/3**	**4**	**100**	**H**
Rio Nambe	R										R		R					0/3	4	100	H
HWs Rio Tesuque	R										R		R					0/3	4	100	H
Rio Tesuque- Pojoaque Creek	R										R		R					0/3	4	100	H
Rio Tesuque- Rio Grande	**R**		**R**			**C**	**C**	**C**			**R**	**R**	**R**	**C**		**C**		**5/10**	**7**	**50**	**M**
Santa Clara Creek	R												R					0/2	4	100	H
Los Alamos Canyon	R										R		R					0/3	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
Lower Rio Gallina						C		C										2/2	2	0	L
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
Outlet Arroyo del Puerto								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[12]**	**Percent Departure of Current From Historic**	**Risk Ranking[13]**
Chiquito																					
Huckbay Canyon- Rio Chama								C		C			R					2/3	3	33	L
Rio Puerco											**C**		**R**					**1/2**	**3**	**50**	**M**
Poleo Creek											R		R					0/2	3	100	H
Coyote Creek											R		R					0/2	3	100	H
Outlet Rio Puerco											R		R					0/2	3	100	H
Abiquiu Reservoir						**C**	**C**	**C**		**R**	**C**		**C**	**C**				**6/7**	**12**	**14**	**L**
Ojitos Canyon											R		R					0/2	5	100	H
Ojito Canyon- Abiquiu Reservior											R		R					0/2	9	100	H
Rio Puerco- Abiquiu Reservior											R	R	R					0/3	9	100	H
Polvadera Creek										R	R		R					0/3	5	100	H
Canones Creek											C		R					½	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**					**3/7**	**6**	**50**	**M**
Abiquiu Creek								C			R		R					1/3	4	67	M
Arroyo del Cobre- Rio Chama						C	C	C		C	R		R					4/6	4	40	M
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

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[12]**	**Percent Departure of Current From Historic**	**Risk Ranking[13]**
Rio del Oso											R		R					1/2	3	50	M
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**		**R**					**0/3**	**2**	**100**	**H**
Arroyo Calabases	R												R					0/2	2	100	H
HWs Santa Fe River	R										R		R					0/3	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	R	C		C		6/10	4	40	M
Water Canyon- Rio Grande	R					C	C	C	C		R	R	R	C		C		6/10	5	40	M
Alamo Canyon- Rio Grande	R					C	C	C	C		R	R	R	C		C		6/10	5	40	M
Rio Chiquito	R										R		R			C		¼	4	75	H
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		R	R	R			R		1/9	7	89	H
HWs Galisteo Creek	**R**										**R**		**R**					**0/3**	**2**	**100**	**H**
Arroyo Salado	R										R		R					0/3	2	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[12]**	**Percent Departure of Current From Historic**	**Risk Ranking[13]**
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**		**R**	**C**				**1/4**	**2**	**75**	**H**
Peralta Canyon	R										R		R					0/3	2	100	H
HWs Borrego Canon	R										R		R	C				¼	2	75	H
Outlet Borrego Canyon	R										R		R					0/3	2	100	H
Rio Guadalupe								**C**		**C**	**C**		**C**					**4/4**	**1**	**0**	**L**
Rito Penas Negras											R		R					0/2	1	100	H
HWs Rio de Las Vacas											C		C					2/2	1	0	L
HWs Rio Cebolla										C	C		R					2/3	1	33	L
Outlet Rio Cebolla										C	R		R					1/3	2	66	H
Outlet Rio de Las Vacas								C		C	C		C					4/4	2	0	L
Virgin Canyon								C		C	R		C					¾	0	25	L
Rio Guadalupe								C		C	C		C					4/4	2	0	L
Upper Jemez River						**C**	**R**	**C**		**C**	**R**		**C**					**4/6**	**4**	**33**	**L**
HWs San Antonio Creek						C		C		R	R		C					3/5	3	40	M
Sulphur Creek											R		R					0/2	3	100	H
East Fork Jemez								C		C	R		C					3/4	4	0	L
Outlet San Antonio Creek						C		C		C	R		C					4/5	3	0	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[12]	Percent Departure of Current From Historic	Risk Ranking[13]
Church Canyon- Jemez River						C	R	C		C	R		C					4/6	3	17	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**	**R**		**C**					**5/6**	**2**	**17**	**L**
Canon de La Canada								C			R							1/2	2	50	M
Vallecita Creek								C			R							1/2	2	50	M
Vallecita Creek- Jemez River						C	R	C			R							2/4	3	50	M
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**										**R**							**0/2**	**4**	**100**	**H**
HWs Cow Creek	R										R							0/2	4	100	H
Bull Creek	R										R							0/2	3	100	H
Apache Creek	R										R							0/2	3	100	H
Outlet Cow Creek	R										R							0/2	3	100	H
Cow Creek- Pecos	**R**							**C**		**R**	**C**							**2/4**	**4**	**50**	**M**
Panchuela Creek	R										R							0/2	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[12]	Percent Departure of Current From Historic	Risk Ranking[13]
Rio Mora	R										R							0/2	3	100	H
Rio Mora- Pecos River	R										R							0/2	3	100	H
Indian Creek- Pecos River	R							C			C							2/3	4	33	L
Dry Gulch- Pecos River	R							C			R							1/3	3	67	H
Glorieta Creek	R										R							0/2	3	100	H
Glorieta Creek- Pecos River	R							C		R	R							1/4	3	75	H
Tortolita Canyon- Pecos River	R							C		R								1/3	3	67	H
Tecolote Creek	**R**				**C**			**C**			**R**							**2/4**	**2**	**50**	**M**
Cabo Lucero Creek- Tecolote Creek	R				C			C			R							2/4	2	50	L
Canon Mesteno- Tecolote Creek	R				C			C			R							2/4	2	50	L
Ojito Frios Creek- Tecolote Creek	R				C			C			R							2/4	2	50	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**	**R**							**2/5**	**3**	**60**	**M**
El Rito	R										R							0/2	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[12]**	**Percent Departure of Current From Historic**	**Risk Ranking[13]**
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**			**R**							**2/4**	**3**	**50**	**M**
Barbero Canyon	R					C		C			R							2/4	3	50	M
HWs Gallinas River	**R**				**C**						**R**							**1/3**	**3**	**67**	**H**
Porvenir Canyon	R				C						R							1/3	3	67	H
Porvenir Canyon-Gallinas Creek	R				C						R							1/3	3	67	H
Arroyo Pecos	R				C						R							1/3	3	67	H
Arroyo Pecos-Gallinas River	R				C						R							1/3	3	67	H
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	11/28	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	61	100	84	0	0	0	0				

Historically, 17 native fish occurred within the plan scale (Sublette et al. 1990b). Currently, 13 (76 percent) of these native species still occur, while 4 (24 percent) are now considered extirpated (table 41). Another 4 (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 (Sublette et al. 1990b, Alves et al. 2008, Clamusso and Rinne 2009, NMDGF 2013), but 3 (18 percent) are considered extirpated (table 41). Additionally, 7 (54 percent) native species still occurring at the local scale have declined in distribution, while the remaining 6 species are maintaining or showing slight increases in distribution (Sublette et al. 1990b, Propst 1999, NMDGF 2013, BISON-M 2014b).

Habitat for native species is diminished or eliminated because of unfavorable changes in riparian and upland ERUs (see Chapter 1. Vegetation) 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 ungulates, camping, and hiking 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.

Hybridization, depredation, and competition from non-native fish have likely contributed to diversity and distribution declines in native fish species, as well. This helps explain the apparent absence of native fish in some streams (table 42). 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 42) 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 41 and table 42). 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 37) (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.

Four species are 100% departed from current conditions, meaning that they have been completely extirpated from all streams on the Santa Fe NF where they used to be found (table 41). The bluntnose shiner, bluegill, and Rio Grande silvery minnow had limited distributions, being found in only one to three watersheds historically. However, the American eel was very widely distributed, found in 14 watersheds, and is now completely absent from the forest overall. Further, the bluntnose shiner is now considered extinct throughout its range and the Rio Grande silvery minnow is classified as endangered under the Endangered Species Act. Both species declined primarily due to habitat and flow alterations on larger rivers where they occurred historically. Amercan eel (*Anguilla ostrata*) were once widely distributed in streams of the Rio Grande and Pecos and probably the Canadian river basins, however, they have been eliminated due to mainstem dams that disrupted their extensive migrations. Eels spawn in the Sargasso Sea or other tropical areas of the Atlantic Ocean, develop from larvae into miniature adults in coastal estuaries and then female American eels migrate up to rear in rivers where they spend most of their adult life until they return to the ocean to spawn.

Table 42. 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[15]
Sapello River	**109**	**0**	**109**	**100%**	**High**
Rito San Jose	15	0	15	100%	High
HWs[16] 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%	Moderate
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

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[15] 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

[16] 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[15]**
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
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
Canada Ancha- Rio Grande	**101**	**3**	**98**	**97%**	**High**
Hws Canada Ancha	1	0	1	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[15]**
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
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

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[15]**
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
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

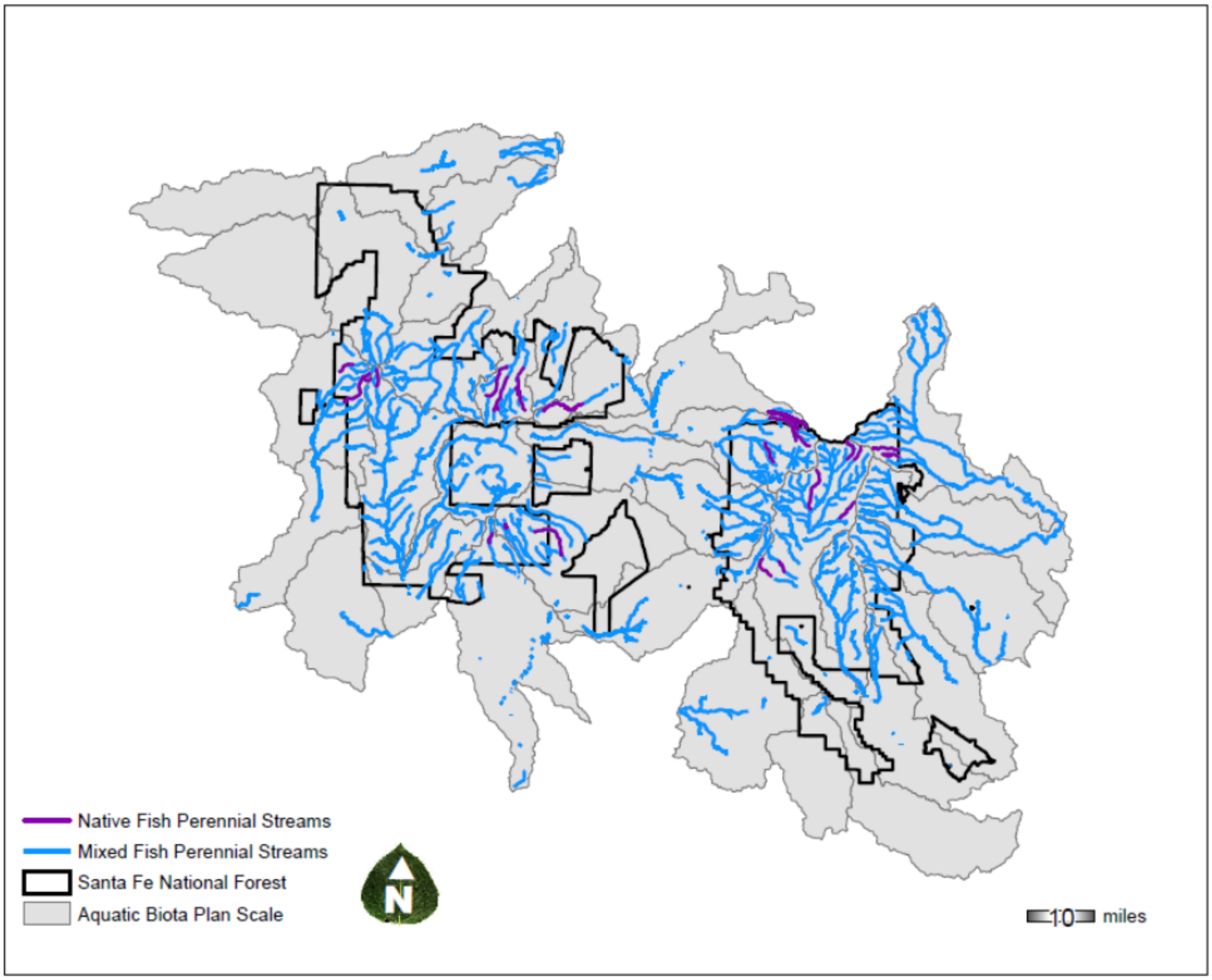

Figure 37. Native fish and mixed fish perennial streams and native fish perennial streams within plan scale

Macroinvertebrates

Aquatic macroinvertebrates are used as biological indicators of stream health, because they are found in all but those streams with the most degraded habitat conditions or with severe pollution. 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 (Reynoldson et al. 1997, Kaller and Hartman 2004).

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 collected from 1988 to 1989), as well as data from New Mexico Environment Department (NMED) (37 sample sites collected from 1981-2012), 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 to 3.5), very good (HBI 3.51 to 4.5), good (HBI 4.51 to 5.5), fair (5.51 to 7.0), and poor (HBI greater than 7.0) (Hilsenhoff 1987).

Current condition of macroinvertebrates is only analyzed at one scale (Santa Fe NF), due to limited data. 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 38). 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 Current Conditions: Perennial Streams*** 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 38) 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 43). However, proportionally, Eastern zones have the most excellent and very good water quality ratings within its zone (table 43), followed by Central, and then Western zones (table 43). Differences between the best and worst water quality ratings between the zones are not large although could be attributed to background geology and soil differences between the Eastern and Western mountain ranges. These geologic differences on the West side of the forest could make streams more susceptible to sedimentation, particularly following large wildland fires and during periods of drought. 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.

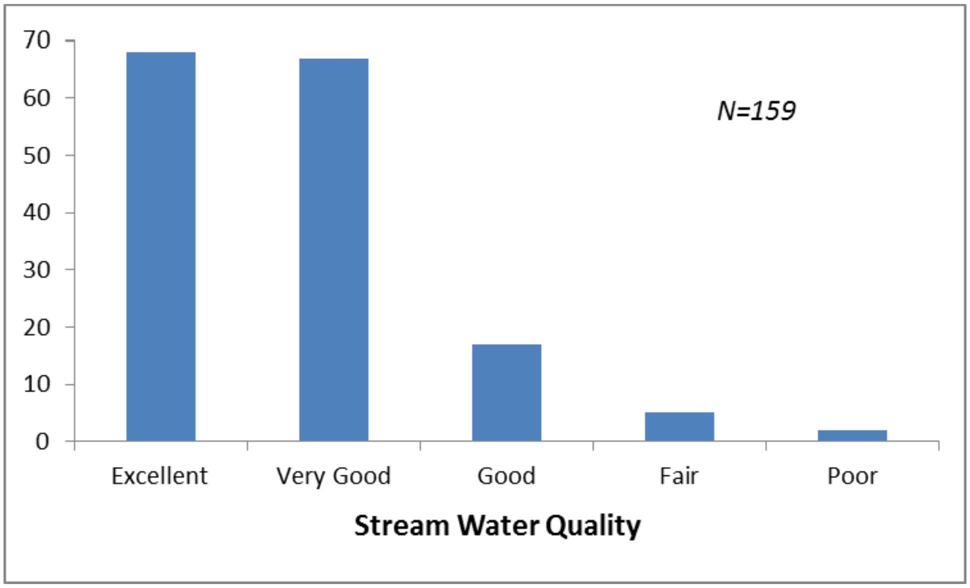

Figure 38. Number of sample sites with water quality condition inferred from the HBI rating for the Santa Fe NF

Table 43. 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

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 2014b). Didymo (*Didymoshenia geminate*), (also known as rock snot) has been found at nine sites all within the Upper Pecos watershed. Didiymo is an invasive alga that forms thick brown mats on stream bottoms and anglers are believed to be a primary vector for introduction. 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 on the forest and has been foundto occur in three streams at the local scale, Rio Cebolla, Dalton Canyon, and the Pecos River (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). Although it can be spread to new locations on fishing equipment, the most common vector for its initial introduction is through stocking of infected fish. In the year 2000, Bacterial Kidney Disease (BKD) was detected in three streams: Canones Creek in the Rio Chama drainage, and in Cow Creek and Jack’s Creek in the Pecos River Headwaters drainage. 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). Initial introductions of Chytrid fungus are generally from infected amphibians, such as those from the pet trade, with subsequent spread by any vector that transfers the fungus among aquatic sites. Currently, there are no other known "invasions" besides Didiymo, chytrid, and whirling disease, but invasive species and diseases are a continually evolving challenge, with the potential for new introductions at any time. 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 habitats are projected to continue in a stable to declining trend and native fish are likely to decrease in distribution over time due to losses of smaller, isolated populations as a result of catastrophic events such as extreme wildfires and drought:

- Non-native fish species are expected to persist, but not increase due to their importance in supporting 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.

Input Received from Public Meetings

This section summarizes input, perspectives, and feedback relevant to this assessment topic and received from the public between April and July 2014. Input was gathered from 14 public meetings and "User Value and Trends Forms" available at all Santa Fe NF office and online. Additional input was gathered from individual meetings held with the Natural Resource staff and leadership from Tribes, Pueblos and Navajo Chapter Houses. The Draft Assessment and 12 focus areas that were identified as having the greatest needs for different plan direction were released in October 2015. This was followed by a full day public symposium to present findings from the Draft Assessment and 10 public meetings and 2 tribal meetings where findings from the 12 focus areas were presented.

Air, Soil, and Water Resources and Quality

Air, soil, and water resource quality are highly valued across the forest for the benefits they provide to community health, livelihoods, and ecosystem functioning. Participants contributed observations about several changes to air, soil, and water resource quality. Overall, the forest is valued for the contributions it provides to public health.

Input Received from Technical Meeting

As part of the series of public meetings there was a Technical Meeting on April 30, 2014, which was open to all members of the public, but was more focused toward participants with technical expertise that were members of organized groups or other agencies. Participants represented a wide range of government, public, and private resources. The main difference in meeting formats was the breakout groups and discussions as the technical meetings were based on resource topics. Participants were also asked to provide specific sources that could be used in the assessment in addition to input on values and trends. Summaries and specific sources of information for each of the resource topics from this meeting follow.

Water, Watershed, and Soil

Participants expressed their concern about water quality and quantity in the forest, and its effect on the watershed and surrounding communities, recreation, and wildlife.

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 Santa Fe NF 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 (MAB 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 NF 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 NF 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 NF 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.

Identifying At-Risk Species

Guidance for identifying species at risk is provided by the Land Management Planning Handbook, Chapter 10 – The Assessments (FSH 1909.12). There are two main categories of at-risk species. They are:

1. Federally recognized threatened, endangered, proposed and candidate species
2. Potential species of conservation concern

Identification of at-risk species on the Santa Fe NF is accomplished in cooperation with numerous federal, state, and tribal agencies along with various academic and non-governmental organizations using best available scientific information standards. Although the intention of identifying species at-risk remains the same the lists are to remain separate according to the planning directive.

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 Santa Fe NF, 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 44; 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 watersheds shared by the Santa Fe NF and surrounding lands. 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 federally listed species, the Canada lynx and western yellow-billed cuckoo (threatened), and the southwestern willow flycatcher and Rio Grande silvery minnow (endangered) will not be carried forward to the final forest plan. These four species are not established, nor are they likely to become established on the forest. There has also been no critical habitat identified on Santa Fe NF for these species (table 44).

Table 44. 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 present. No known locations of this species on the Santa Fe NF. Climate change models (Lawler et al. 2009) predict decreased potential for use. No prey base to support a population on the Santa Fe NF. The Santa Fe NF 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 Santa Fe NF 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 present. No known locations of this species on the Santa Fe NF 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 present. No known locations of this species on the Santa Fe NF.
*Strix occidentalis lucida**	Mexican Spotted Owl	Threatened	Yes Critical Habitat present. Several nests sites on the Santa Fe NF. Some sites lost due to large fires.

Scientific Name	Common Name	Federal Status	Critical Habitat On Santa Fe NF Designated by USFWS
Fish			
Hybognathus amarus	Rio Grande Silvery Minnow	Endangered	No Critical Habitat present. The are no known populations on the Santa Fe NF 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 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 to the Jemez Mountains. Restricted to mesic forested habitat.
Plant			
*Ipomopsis sancti-spiritu**	Holy Ghost Ipomopsis	Endangered	No Critical Habitat present. 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):[17]

SCC Criteria:

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 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.

   4. 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.

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

> 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 (Volume 1, Chapter 1) (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 number of zones was based on recommendations provided by the Regional Office (USDA FS 2014).

Evaluating Relevant Information for At-Risk Species

A Microsoft Access database (Risk Assessment Database, also known as RAD) 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 is integral to the forest plan revision process and included the following four-step process.

1. Review and screen species that are native and found in the plan area (SCC criteria #1), and determine which species have been documented to occur on the Santa Fe NF.
2. Determine which of the potential SCCs are species where BASI indicates substantial concern about the species' capability to persist over the long term in the plan area (SCC criteria #2).
3. Associate the remaining potential SCC species 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.

NatureServe conservation status ranks were used as an initial screening tool. NatureServe is a non-profit organization that provides high-quality scientific expertise for conservation. One of their resources, NatureServe Explorer, is a database of more than 70,000 plants, animals, and habitats of the United States and Canada. This searchable database houses species information such as conservation status, distribution, ecology, life history, management, and references. The Forest Service Planning Directives (FSH 1900.12) specify using NatureServe conservation status ranks. NatureServe 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 (Na), and state/province (S). Infraspecific taxa (subspecies or other designations below the level of species) are indicated by "T rank." 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 report (G=Global, Na=National, and S =State), or infraspecific (T) where appropriate. The numbers have the following meaning: 1=Critically Imperiled, 2=Imperiled, 3=Vulnerable, 4=Apparently Secure, and 5=Secure.

Step 1: Identify species that are native to, and known to occur, in the plan area.

Of the more than 7,000 animal, plants, and fungi species found in New Mexico (NatureServe 2012), only species with habitats and known occupation on national forest lands throughout New Mexico were carried forward. Many species not carried forward are associated with habitats that exist elsewhere in the state but are not found on the Santa Fe NF (for example, Chihuahuan Desert). For those species with habitats found on the Santa Fe NF, and one or more of the following criteria, were imported into the Risk Assessment Database.

- Species with a status rank of G or T 1, 2, or G3 and S 1 or 2 on NatureServe ranking system;
- 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. (No species on the Santa Fe NF 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.)
- Species listed as threatened or endangered by relevant States, or federally recognized Tribes (Information for the State of New Mexico was derived from New Mexico Department of Game and Fish (BISON-M 2014a) and the State Forestry Division (EMNRD 2010), 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 (Species on the adjoining Carson NF, are the same as those on the US Forest Service Southwest (Region3) Regional Forester’s Sensitive Species List (USDA Forest Service 2013d));
- 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); and
- Species identified as those of the greatest conservation need by the New Mexico Comprehensive Wildlife Conservation Strategy (NMDGF 2006) and New Mexico Rare Plant Technical Council (NMRPTC 1999).

This list of approximately 1,358 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 part of step 1 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 2014a), 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 and D. Roth); 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. Forest Service (K. Kennedy); 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 2014), iNaturalist (iNaturalist 2014), and BugGuide.Net (BugGuide 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 a few recorded occurrences on the boundary with the Valles Caldera National Preserve (VCNP) (SFNF GIS 2015). All other occurrences are found within VCNP which is under the jurisdiction of 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 (USDA Forest Service 2013c). 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). Recent drought may have affected the isolated specimens resulting in failure to relocate them. It is known to be widespread in several states in varieties of grassland habitats although uncommon in occurrence.

Of the initial 1,358 species that were evaluated from the database identified in New Mexico, 52 were reported to occur on the Santa Fe NF (table 45).

Table 45. Possible species on the Santa Fe NF available for consideration as species of conservation concern

	Scientific Name	Common Name	Rationale for Consideration[18]	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 Santa Fe NF
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	NHNM	Yes
8	*Ochotona princeps*	American Pika	RF, N	G5 N5 S2	SFNF biologist	Yes
9	*Ovis 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	Yes

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[18] 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)

	Scientific Name	Common Name	Rationale for Consideration[18]	NatureServe rank	Source of observation in or near the Plan Area	Documented on the Forest? Rationale
	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	N, 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 atrata*	Black Rosy-Finch	N	G4 N4B,N4 S3N	ebird	Yes
26	*Leucosticte australis*	Brown-capped Rosy-Finch	N	G4 S1B,S3N	ebird	Yes
27	*Melanerpes lewis*	Lewis's Woodpecker	CN	G4 N4B,N4N S3B,S3N	ebird	Yes
28	*Melospiza lincolnii*	Lincoln's Sparrow	N	G5 N5B,N5N S2B,S5N	ebird	Yes
29	*Pandion haliaetus*	Osprey	CN	G5 N5B,N4N S2B,S4N	USGS, BISON-M	Yes
30	*Riparia*	Bank Swallow	CN, N	G5 N5B S2B,S5N	ebird	Yes
31	*Vireo vicinior*	Gray Vireo	CN, N, RF, S(t)	G4 N4B S4B,S3N	ebird	Yes
32	*Wilsonia pusilla* *Syn Cardellina pusilla*	Wilson's Warbler	N	G5 N5B S2B,S5N	2005 (ebird)	Yes
	Reptiles and Amphibians					
33	*Lithobates pipiens*	Northern Leopard Frog	CN, N, RF	G5 N5 S1	NHNM and J.Luetzelschwab	Yes

	Scientific Name	Common Name	Rationale for Consideration[18]	NatureServe rank	Source of observation in or near the Plan Area	Documented on the Forest? Rationale
	Invertebrate					
34	*Ashmunella ashmuni*	Jemez Woodlandsnail	N	G1 N1	Bison-M	Yes
35	*Pisidium lilljeborgi*	Lilljeborg's Peaclam	N, RF, S(t)	G5 N5 S1	BISON-M	Yes
36	*Gastrocopta ruidosensis*	Ruidoso Snaggletooth	N, RF	G1 N1 S3	RF	Yes
	Fish					
37	*Catostomus plebeius*	Rio Grande Sucker	CN, N, RF	G3G4 N3 S2	SFNF GIS	Yes
38	*Gila pandora*	Rio Grande Chub	CN, N, RF	G3 N3 S3	SFNF GIS	Yes
39	*Oncorhynchus clarkii virginalis*	Rio Grande Cutthroat Trout	RF	G4T3 N2 S2	SFNF GIS	Yes
	Plants					
40	*Abronia bigelovii*	Tufted Sand Verbena	RF, RP	G3 N3 S3	1990 NHNM	Yes
41	*Asclepias uncialis ssp. uncialis*	Greene's Milkweed	RF	G3G4T2T3 NNR S2	2015 SFNF GIS, NHNM	Yes
42	*Astragalus micromerius*	Chaco Milkvetch	N, RF, RP	G2 N3 S2	2009 (SEINet)	Yes
43	*Calochortus gunnisonii var. perpulcher*	Gunnison's (Pecos) Mariposa Lily	RF, RM, RP	G5T4? N4? S4?	2015 RM	Yes
44	*Cypripedium parviflorum var. pubescens*	Large Yellow Lady's-Slipper	RF	G5T5 N4, N5 S2?	2005 (SEINet)	Yes
45	*Delphinium robustum*	Robust Larkspur aka Wahatoya Larkspur	N, RF, RP	G2? N2? S?	Unknown on Santa Fe NF	No. Recorded observations not on the Santa Fe NF
46	*Draba heilii* Al-shebaz	Heil's Alpine Whitlowgrass	N, RF, RP	GNR NNR SNR	2008 (NMRP)	Yes
47	*Erigeron subglaber*	Pecos Fleabane	RF, RM, RP	G3 N3 S3	1996 NHNM and 2015 RM	Yes
48	*Lilium philadelphicum*	Wood Lily	RF, S(e)	G5 N5 S3	2003 (SEINet)	Yes
49	*Mentzelia conspicua*	Chama Blazing Star	RF, RP	G2 N2 S2	2002 (NHNM)	Yes
50	*Mentzelia springeri*	Springer's Blazing Star	RF, RM, RP	G3 NNR SNR	2015 RM	Yes
51	*Penstemon oliganthus*	Apache Beardtongue	N	G3? N3? SNR	2009 (SEINet)	Yes
52	*Salix arizonica*	Arizona Willow	RF, RP	G2G3 N2N3 S1	2001	Yes

Of the 52 species, ***two*** (Pale Townsend's Big- Eared Bat and Robust Larkspur) have not been reliably documented on the Santa Fe NF as shown in table 45 and will not be carried forward to Step 2, bringing the number of potential SCC candidates to 50.

Step 2: 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 populations and the ecological conditions they depend upon are not known to be affected by threats; (2) species have stable or upward trends in population or habitat; (3) species do not have restricted ranges; (4) species do not have low population numbers or restricted ecological conditions; (5) species has been documented to use the plan area only during the winter or as "transients"; or (6) there is insufficient information to evaluate whether or not the species is at risk for persistence within the plan area.

Based on knowledge of the species' abundance, distribution, lack of threats to persistence, trends in habitat, or responses to management, 18 of the remaining 50 species identified as potential SCC are secure and their continued long-term persistence in the plan area are not at risk or there is insufficient information to deem them at risk. As such, these species are no longer considered for further analysis as potential SCCs. Table 46 shows the list of species removed, rationale for removing them and the planning dirtective criteria supporting their removal.

Table 46. Potential SCC removed from further analysis, and rationale for removal

Common Name	Rationale for Removal from Potential SCC List	Planning Directive Criteria for Removal
Mammals		
American Pika	Inhabits rocky talus slopes that have not changed from historical reference condition and that are not affected by any threats. (BISON-M 2014). Populations of American pikas are found in suitable habitat throughout ecologicical range on the Santa Fe NF. Other than climate change, there are few external threats impacting their populations and/or their habitat therefore their persistence on the forest is not considered at risk.	1,2
Goat Peak Pika	Core population of *Ochotona princeps saxatilis* resides on Valles Caldera National Park (VCNP). Only confirmed observations on Santa Fe NF occurred in 1985 and 1992 along the border of VCNP. Observations on the SFNF are considered accidental or transient.	5
Prebles Shrew	There have been two documented occurrences on Santa Fe NF (1998 and 1999). According to Natureserve the shrew inhabits a wide variety of habitats including Desert, Grassland/herbaceous, Shrubland/chaparral, Woodland - Conifer, Woodland – Hardwood but much is unknown about the species. Short and long-term trends are unknown, there are no known threats, and are not intrinsically vulnerable. With only two dated observations there is insufficient information to determine whether or not the shrew is at risk for persistence on the forest.	1,3,6
Rocky Mountain Bighorn Sheep	Surveys by NMDGF indicate the Pecos Wilderness herd is stable or increasing. An additional herd was reintroduced to the Jemez Mountains in 2014. According to NMDGF the herd has hundreds of acres of new habitat due to the Las Conchas Fire in 2011 and historic habitat in White Rock Canyon. There are no known threats to the sheep or their habitat and are considered a big game (hunted) species on the forest.	1,2

Common Name	Rationale for Removal from Potential SCC List	Planning Directive Criteria for Removal
Yellow-bellied Marmot	Inhabits rocky talus slopes that have not changed from historical reference condition and that are not affected by any threats. (BISON-M 2014). Populations of yellow-bellied marmots are found in suitable habitat throughout ecologicical range on the Santa Fe NF. Other than climate change, there are few external threats impacting their populations and/or their habitat therefore their persistence on the forest is not considered at risk.	1,2
Birds		
Bald Eagle	Bald eagle populations have rebounded considerably and the species does not appear to be at risk given its NatureServe rankings (G5S1B/S4N). This species is not typically seen in or near the Santa Fe NF forest during breeding season since it is usually nests near large bodies of water. They are frequently seen along the Rio Grande during winter migration. Bald eagle populations are 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.	2,3,5
Bank Swallow	Bank swallows are dependant upon riverine systems that have steep dirt banks which are used to construct nesting burrows. The Rio Grande provides some of the only suitable areas for bank swallows and are found in abundance where this type of habitat exists. Since habitat is ephemeral, bank swallows are not expected to be full time residents within the forest. Large nesting range in North America and Eurasia; large population size; many occurences; overall trend poorly known (BBS methods not well suited to this species), but this species does not appear to warrant significant range-wide conservation concern at this time (NatureServe 2015). Although long-term and short-term trends are unknown their NatureServe ranking of G5S2B/S5N suggests the birds do not find much suitable breeding habitat on the Santa Fe NF but do so during other parts of the year.	2,5,6
Black Rosy-Finch	During migration the black rosy-finch is associated with a wide range of habitats but it prefers barren, rocky or grassy areas and cliffs among glaciers or beyond timberline. This alpine/tundra region is not departed from reference conditions. Observations of the black rosy-finch are infrequent (two eBird observations on the NEZ) and little is known about their abundance and population status on the forest. According to IUCN Red List, this species has a very large range, and hence does not approach the thresholds for vulnerable under the range size criterion (Extent of Occurrence <20,000 km2 combined with a declining or fluctuating range size, habitat extent/quality, or population size and a small number of locations or severe fragmentation). The population trend appears to be stable, and hence the species does not approach the thresholds for vulnerable under the population trend criterion (>30% decline over ten years or three generations). Due to the lack of observations and information on the forest, it is unknown whether this species is at risk.	2,5,6

Common Name	Rationale for Removal from Potential SCC List	Planning Directive Criteria for Removal
Black-throated Gray Warbler	According to the BBS there is no (significant) indication of population decline and occurences on the forest are numerous (eBird 2014). The piñon juniper habitat they occupy is in low to moderate departure and should improve over the course of the next forest plan. They are found with frequency in appropriate habitat on the forest and are not considered at-risk given their NatureServe ranking (S3B/S4N).	1,2,4
Brown-capped Rosy-Finch	Much like the black rosy-finch is associated with a wide range of habitats but it prefers barren, rocky or grassy areas and cliffs among glaciers or beyond timberline. This alpine/tundra region is not departed from reference conditions. Observations of the brown-capped rosy-finch are infrequent (three eBird observations, 1 on CZ and two on the NEZ) and little is known about their abundance and population status on the forest. According to IUCN Red List, although this species may have a small range, it is not believed to approach the thresholds for vulnerable under the range size criterion (Extent of Occurrence <20,000 km2 combined with a declining or fluctuating range size, habitat extent/quality, or population size and a small number of locations or severe fragmentation). The population trend appears to be stable, and hence the species does not approach the thresholds for vulnerable under the population trend criterion (>30% decline over ten years or three generations). Due to the lack of observations and information on the forest, it is unknown whether this species is at risk.	2,5,6
Golden Eagle	Golden eagle population trends appear stable in New Mexico and the species does not appear to be at risk given its NatureServe rankings (S3B,S4N) and wide range of habitat associations. The existence of snags is critical to Golden Eagle habitat, however, due to the eagle's varied habitat preferences, snags are not a limiting factor. 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.	2,3
Grace's Warbler	A common species found frequently in appropriate habitats throughout the Santa Fe NF. This species should benefit from pine forest management that maintains pine stands, and possibly shrub (e.g., Gambel oak) understory, with similar structure and configuration to presettlement forests. Forest management on the Santa Fe NF should continue to provide adequate protections. Studies of response to silvicultural systems show the species is abundant in select-harvest units (Szaro and Balda 1979, Brawn and Balda 1988). They are found with frequency on the forest and are not considered at-risk given their NatureServe ranking (G5S3B/S4N).	1,2,3
Gray Vireo	Population trends for NM are holding stable widespread occurrences (BISON-M 2015). Breeding bird survey results shows 5.6% increasing trend (significant) in New Mexico from 1966 to 2013. This species thrives in arid juniper woodlands on foothills and mesas, these most often associated with oaks. The piñon juniper habitat they occupy on the forest is in low to moderate departure and should improve over the course of the next forest plan. They are found with frequency off the forest where more suitable habitat exists and are not considered at-risk given their NatureServe ranking (G4S4B/S3N).	2,3

Common Name	Rationale for Removal from Potential SCC List	Planning Directive Criteria for Removal
Lincoln's Sparrow	According to the BBS there is no (significant) indication of population decline and occurences on the forest are numerous (eBird 2014). Their NatureServe ranking of G5S2B/S5N suggests the birds do not find much suitable breeding habitat on the Santa Fe NF but do so during other times of the year. They are an edge species, frequently found on the forest but prefers wetter environments. Herbaceous riparian areas are evenly distributed across the forest and local zones where it is predominantly found occurring in all five of the local zones. In a frequent fire regime, adequate habitat should be created on a regular basis. Although some of its herbaceous riparian areas are currently highly departed the species does not appear to be at-risk due to its widespread abundance and annual detections (eBird). Management practices to improve riparian areas for NMMJM should benefit this species as well.	2,3
Loggerhead Shrike	This species thrives in open grassland and is well adapted to agricultural uses of the landscape. They are found with frequency off the forest and should not be negatively impacted by current forest practices since they respond favorably to agricultural practices, often seeking fenceposts and other features in pasturelands. The piñon juniper habitat they occupy on the forest is in low to moderate departure and should improve over the course of the next forest plan. They are found with frequency off the forest where more suitable habitat exists and are not considered at-risk given their NatureServe ranking (G4S3B/S4N).	1,3
Osprey	Ospreys live amost entirely on fish and are generally found near water at lower elevations (2,800 – 5,500 ft) (Hubbard 1978). Though osprey are frequently seen over the forest, there is a lack of suitable habitat for this species on the Santa Fe NF due to its dependence on large bodies of water to meet their piscivorous dietary needs. Observations of osprey on the forest are frequent (eBird) but can be considered transient, therefore, the species does not appear to be at-risk on the forest. Population trends for NM are holding stable (BISON-M 2015).	2,3,5
Wilson’s Warbler	According to the BBS there is no (significant) indication of population decline and occurences on the forest are numerous (eBird 2014). Their NatureServe ranking of G5S2B/S5N suggests the birds do not find much suitable breeding habitat on the Santa Fe NF but do so during other times of the year. Wilson's warblers inhabit riparian areas at various elevations. Herbaceous riparian areas are evenly distributed across the forest and local zones where it is predominantly found occurring in all five of the local zones. In a frequent fire regime, adequate habitat should be created on a regular basis. Although some its herbaceous riparian areas are currently highly departed the species does not appear to be at-risk due to its widespread abundance and annual detections (eBird). Management practices to improve riparian areas for NMMJM should benefit this species as well.	2,3
Plants		
Apache Beardtongue	This is not considered a rare plant on the Santa Fe NF with numerous specimens found over a wide area (2015 pers. comm. with K. Kennedy, USFS Botanist).	2,3,4

In summary, table 47 lists the potential 32 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 47. Potential List of Species of Conservation Concern for the Santa Fe National Forest

	Common Name	Scientific Name	NatureServe rank
	Mammals		
1	Gunnison's Prairie Dog (montane population) (prairie population)	*Cynomys gunnisoni pop. 1* *Cynomys gunnisoni*	G5T2 N2 SNR G5 N5 S2
2	Spotted Bat	*Euderma maculatum*	G4 N3N4 S3
3	Snowshoe Hare	*Lepus americana*	G5 N5 S2
4	American (Pacific) Marten Listed as Pacific Marten in NatureServe based on genetic work.	*Martes caurina*	G4G5 N4N5 S2
5	Masked Shrew	*Sorex cinereus*	G5 N5 S2
6	Water Shrew	*Sorex palustris*	G5 N5 S2
	Birds		
7	Northern Goshawk	*Accipiter gentilis*	G5 N4B,N4N S2B,S3N
8	Boreal Owl	*Aegolius funereus*	G5 N4 S2B,S2N
9	Western Burrowing Owl	*Athene cunicularia hypugaea*	G4T4 N4 S3B,S3N
10	Black Swift	*Cypseloides niger*	G4 N4B S2B,S2N
11	American Peregrine Falcon	*Falco peregrinus anatum*	G4T4 N3B,N3 S2BS3N
12	Pinyon Jay	*Gymnorhinus cyanocephalus*	G5 N5 S3B,S3N
13	White-tailed ptarmigan	*Lagopus leucurus*	G5 N5 S1B,S1N
14	Lewis's Woodpecker	*Melanerpes lewis*	G4 N4B,N4N S3B,S3N
	Reptiles and Amphibians		
15	Northern Leopard Frog	*Lithobates pipiens*	G5 N5 S1
	Invertebrate		
16	Jemez Woodlandsnail	*Ashmunella ashmuni*	G1 N1
17	Lilljeborg's Peaclam	*Pisidium lilljeborgi*	G5 N5 S1
18	Ruidoso Snaggletooth	*Gastrocopta ruidosensis*	G1 N1 S3
	Fish		
19	Rio Grande Sucker	*Catostomus plebeius*	G3G4 N3 S2
20	Rio Grande Chub	*Gila pandora*	G3 N3 S3
21	Rio Grande Cutthroat Trout	*Oncorhynchus clarkii virginalis*	G4T3 N2 S2
	Plants		
22	Tufted Sand Verbena	*Abronia bigelovii*	G3 N3 S3
23	Greene's Milkweed	*Asclepias uncialis ssp. uncialis*	G3G4T2T3 NNR S2
24	Chaco Milkvetch	*Astragalus micromerius*	G2 N3 S2
25	Gunnison's (Pecos) Mariposa Lily	*Calochortus gunnisonii var. perpulcher*	G5T4? N4? S4?
26	Large Yellow Lady's-Slipper	*Cypripedium parviflorum var. pubescens*	G5T5 N4, N5 S2?

	Common Name	Scientific Name	NatureServe rank
27	Heil’s Alpine Whitlowgrass	*Draba heilii* Al-shebaz	GNR NNR SNR
28	Pecos Fleabane	*Erigeron subglaber*	G3 N3 S3
29	Wood Lily	*Lilium philadelphicum*	G5 N5 S3
30	Chama Blazing Star	*Mentzelia conspicua*	G2 N2 S2
31	Springer’s Blazing Star	*Mentzelia springeri*	G3 NNR SNR
32	Arizona Willow	*Salix arizonica*	G2G3 N2N3 S1

Step 3: Associate the federally listed and potential species of conservation concern 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 4 federally listed species (table 44) and 32 remaining potential SCC (table 46) 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 48 and table 49. 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 50). 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. There will also be attention given to riparian dependant species and their relationship with the water resources found on the forest. These precise relationships are the premise of the coarse-filter approach discussed above and appropriate management of ERUs and water resources are 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.

Table 48. 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 49. 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	

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**
Spotted Bat		X				X		X			X
Water Shrew											X
Bird											
American Peregrine Falcon					X		X	X		X	
Black Swift										X	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										
Amphibian											
Northern Leopard Frog											X
Fish											
Rio Grande Chub											X
Rio Grande Cutthroat Trout											X
Rio Grande Sucker											X
Invertebrate											
Jemez Woodlandsnail			X	X	X			X			
Lilljeborg’s peaclam											X
Ruidoso Snaggletooth			X								
Plant											
Arizona Willow											X
Chama Blazing Star		X									
Chaco Milkvetch							X		X		
Greene’s Milkweed			X				X			X	
Gunnison’s Mariposa Lily				X	X						
Heil’s Alpine Whitlowgrass	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
Large Yellow Lady's-Slipper					X	X				X	X
Pecos Fleabane										X	
Springer's Blazing Star		X									
Tufted Sand Verbena								X	X		
Wood Lily				X	X			X			

Table 50. 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* • Jemez Woodlandsnail • Ruidoso Snaggletooth • Black Swift • Chaco Milkvetch
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
Meadows and Small Openings	• Holy Ghost Ipomopsis* • Greene's Milkweed
Soil Features	• Chama Blazing Star • Springer's Blazing Star • Tufted Sand Verbena

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 NF. For efficiency during the risk assessment portion of this evaluation, species were grouped according to their associated ERUs, described above and presented in table 49. 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 50).This information is summarized by taxonomic group below (table 51). 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 51. 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	2	2	1	1	3	1	2	1	2	4
Birds	1	1	2	2	2	1	3	4	2	4	2
Amphibians	0	0	0	1	1	0	0	0	0	1	1
Fish	0	0	0	0	0	0	0	0	0	0	3
Invertebrate	0	0	2	1	1	0	0	1	0	0	1
Plants	1	2	1	3	4	1	2	2	2	3	2
Total	**3**	**5**	**7**	**8**	**9**	**5**	**6**	**9**	**5**	**10**	**13**

Table 52. Federally listed 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*	8*	5*	8*	4*
Amphibians	2*	2*	2*	1	1
Fish	3	3	3	3	3
Invertebrate	0	1	0	1	1
Plants	5	2	2	6*	1
Total	20	19	16	25	13

The ERUs in each local zone and the current state of departure from historical reference condition are displayed in table 54. Detailed information is presented in chapter 1, vegetation.

Table 53. 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.

Step 4: Perform a risk assessment analysis on federally listed and potential species of conservation concern with their associated ERUs.

The final step of the assessment process involved a risk assessment analysis of the 36 remaining species (4 federally listed, 32 potential SCC). The Risk Assessment Database was used to perform a risk analysis on the species remaining from initial 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.

The dual coarse-filter and fine-filter approach described above was used to assess risk to species on the Santa Fe NF. The coarse-filter approach considered habitat (ERUs) associated with species, and current condition and future trends modeled using the Vegetation Dynamics Development Tool (VDDT 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 NF-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 54) 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 54. 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	N/A	High	N/A	High	Not Modeled
Juniper Grassland	Moderate	Moderate	Moderate	N/A	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	N/A	Moderate	N/A	High
PJ Grassland	Moderate	Moderate	Moderate	N/A	Moderate	Moderate
PJ Sagebrush	Low	N/A	Moderate	N/A	N/A	Low
PJ Woodland	Moderate	Moderate	Moderate	Moderate	Moderate	Low
Ponderosa Pine	High	High	High	High	High	High
Sagebrush, Shrubland	Moderate	N/A	N/A	N/A	N/A	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 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 toward 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 NF 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 Colorado Plateau / Great Basin Grassland, 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 NF 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 to 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 and Link 2011).

1. *Distribution* refers the species occurrence on the Santa Fe NF 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 NF 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 NF was not available in most cases. Population sizes were categorized as small, moderate, or large.
3. *Stability* refers to a population's relative trend toward 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 55). 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 to 3) to each species and assigns a qualitative rank (high, moderate, low).

Table 55. 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 Black Swift Mexican Spotted Owl* New Mexico Meadow Jumping Mouse* Northern Goshawk Large Yellow Lady's-slipper Pecos Fleabane
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
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

Upon completion of the threat matrix for both habitat and population threats, an analysis was performed on the following 36 species (table 56) that were deemed at risk on the Santa Fe NF. The results of the analysis are provided in table 58 and table 59.

Table 56. Potential list of at-risk species for the Santa Fe NF

* Denotes federally listed species, all others are potential SCC

Scientific Name	Common Name
Mammals	
*Zapus hudsoneus luteus**	New Mexico Meadow Jumping Mouse
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	
*Strix occidentalis lucida**	Mexican Spotted Owl
Accipiter gentilis	Northern Goshawk
Aegolius funereus	Boreal Owl
Athene cunicularia hypugaea	Western Burrowing Owl
Cypseloides niger	Black Swift
Falco peregrinus anatum	American Peregrine Falcon
Gymnorhinus cyanocephalus	Pinyon Jay
Lagopus leucurus	White-tailed Ptarmigan
Melanerpes lewis	Lewis’s Woodpecker
Amphibian	
*Plethodon neomexicanus**	Jemez Mountains Salamander
Lithobates pipiens	Northern Leopard Frog
Fish	
Onchorychus clarkia virginalis	Rio Grande Cutthroat Trout
Catostomus plebius	Rio Grande Sucker
Gila pandora	Rio Grande Chub
Invertebrate	
Ashmunella ashmuni	Jemez Woodlandsnail
Gastrocopta ruidosensis	Ruidoso Snaggletooth
Pisidium lilljeborgi	Lilljeborg’s peaclam
Plant	
*Impomopsis sancti-spiritu**	Holy Ghost Ipomopsis
Abronia bigelovii	Tufted Sand Verbena
Asclepias uncialis var. *uncialis*	Greene’s Milkweed
Astagalus micromerius	Chaco Milkvetch
Calochortus gunnisonii var. perpulcher	Gunnison's Mariposa Lily
Cypripedium parviforum var. *pubescens*	Large Yellow Lady’s-Slipper
Erigeron subglaber	Pecos fleabane
Lilium philadelpihcum	Wood Lily

Scientific Name	Common Name
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 NF Management Direction

All of the federally listed species and potential SCC (table 55) 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 NF-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 Santa Fe NF 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 NF 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. Proposed Critical habitat exists on the Santa Fe NF and it has been documented on the forest. 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 caused by actions such as 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 Ranger Districts. This species is apparently non-migratory and feeds primarily on small mammals. Young owls, however, are known to disperse long distances. A recent record 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 NF 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 Mexican spotted owl 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 the USFWS. 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 NF 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 known to be 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 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 transplanted 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. All species listed met one or more of the initial requirements for SCC (table 45) and a number of sources were consulted to determine whether the species was at-risk on the Santa Fe NF. For all potential SCC candidates the ecological conditions for persistence were compared against the current and future trend of those conditions on the forest as well as other key risk factors associated with those conditions. Consideration was also given to factors not assessed by the assessment. Concerns for persistence of the following species on the Santa Fe NF are as follows:

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. It is primarily found in small numbers on the Caja del Rio Plateau and in the Chama Wild and Scenic corridor and occasionally at lower elevations on other districts. Prairie dogs typically occupy piñon-juniper habitats which are in low to moderate departure. Threats include recreational shooting (NMDGF has no regulations against shooting prairie dogs) and sylvatic plague. Due to it’s decrease range on the Santa Fe NF, 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. Due to their isolated populations and susceptibility to plague Gunnison's prairie dogs remain at-risk for persistence on the Santa Fe NF.

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. Recreational climbing (20 percent potential habitat affected) is known to impact this species due to disturbance at roost sites. 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. Though this bat is associated with multiple ERUs, their prefeered habitat is sub-alpine coniferous forests which tend to be moderately to highly departed. This bat feeds on noctuid moths in and over the forest canopy. Large wildland fires can threaten this species if uncharacteristic and catastrophic fires remove large portions of the landscape. Restoration of the Santa NF is needed to avoid impacts to the population, which is low to rare wherever it is found.

Snowshoe Hare *(Lepus americana)* is found only in the Spruce-Fir ERU in the Northeast local zone of the Santa Fe NF. Their numbers are low but this may be due to the Sangre de Cristo Mtns being at the southernmost extent of their range. 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 exists on the forest. A primary threat to the persistence of snowshoe hare is the build up of coarse woody debris in the SFF. A catastophic fire within this ERU could potentially eliminate much of the remaining habitat available for snowshoe hare. Another anthropomorphic threat may be the introduction of invasive vegetation (thistle) which is altering the composition of its native habitat. Due to its isolated range withing the Santa Fe NF an uncharacteristic fire or increased encroachment of invasive species puts snowshoe at-risk for persistence on the forest.

Pacific (American) Marten (*Martes caurina*) a cat-sized weasel family predator known only from the Sangre de Cristo Mountains, is at the edge of the species' range within the Santa Fe NF. This species had extensive searches for it in the Jemez Mountains in the best habitat available but results were negative (Long 2015) resulting in the only known population in the Spruce Fir Forests (SFF) in the NEZ. 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. Spruce-fir forests in the NEZ are moderately departed from reference condition with limited predicted change in seral state departure. Recent large wildfires (Pacheco Fire 2011 and Jaroso Fire 2013) have reduced the Spruce-Fir ERU in the Northeast zone. A primary threat to the persistence of American marten is the build up of coarse woody debris in the SFF. A catastophic fire within this ERU could potentially eliminate much of the remaining habitat available for martens. Another anthropomorphic threat may be the introduction of invasive vegetation (thistle) which is altering the composition of its native habitat. Due to its isolated range withing the Santa Fe NF an uncharacteristic fire or increased encroachment of invasive species puts American marten at-risk for persistence on the forest.

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. Negative impacts to the masked shrew include sedimentation caused by grazing (90 percent potential habitat affected), fuelwood gathering (20 percent potential habitat affected), wildfire, recreation (2 percent potential habitat affected), motorized travel (8 percent potential habitat affected), and changes in hydrology. Key characteristics of quality masked shrew habitat are currently highly departed (e.g. site potential and proportion of bare soil are departed at 73 and 60 percent, respectively), while potential to return to reference conditions remains unknown. 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. Although 9 watersheds had no risk (as perennial streams were not present), almost half of all perennial streams (where present) were deemed moderate to high hisk to system integrity. The masked shrew appears to be at-risk on the Santa Fe NF given its S2 status in NatureServe and its highly departed riparian habitats.

Water shrew (*Sorex palustris*) is a riparian dependent shrew and are similar to masked shrews in that they hunt for insects or small minnows exclusively in clear, cold high elevation streams. Most of these ERUs' current ecological conditions on the Santa Fe NF are departed from reference, because of changes in vegetative composition and hydrology. Negative impacts to the water shrew include sedimentation caused by grazing (90 percent potential habitat affected), fuelwood gathering (20 percent potential habitat affected), wildfire, recreation (2 percent potential habitat affected), motorized travel (8 percent potential habitat affected), and changes in hydrology. Key characteristics of quality water shrew habitat are currently highly departed (e.g. site potential and proportion of bare soil are departed at 73 and 60 percent, respectively), while potential to return to reference conditions remains unknown. 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. Although 9 watersheds had no risk (as perennial streams were not present), almost half of all perennial streams (where present) were deemed moderate to high hisk to system integrity. The water shrew appears to be at-risk on the Santa Fe NF given its S2 status in NatureServe and its highly departed riparian habitats.

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 percent of potential habitat). Although the departure from reference in Pondererosa pine forests has created closed canopy conditions benefifial to Northern goshawks they remain extremely vulnerable to catastrophic fire which can greatly alter/reduce optimal habitat. 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. 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.

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. Populations appear to be extremely small with only three eBird observations in the SEZ since 2012. 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. 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. A catastophic fire within this ERU could potentially eliminate much of the remaining habitat available for boreal owls. The boreal owl appears to be at-risk on the Santa Fe NF given its S2B/S2N status in NatureServe and its highly departed and potentially vulnerable spruce-fir habitat.

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 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. Prairie dog populations in PJ grasslands are a concern due to their susceptibility to sylvatic plague. These burrows may soon become unsuitable for nesting (Green and Anthony 1989). For this reason, viability of the Western Burrowing Owl is inextricably linked to that of 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, Gober et al. 2002, Dechant, Sondreal et al. 2002).

Black Swift *(Cypseloides niger)* nest behind or near waterfalls or caves. 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 Northeast local zone. Although little is known of this species, its spruce-fir habitat remains high vulnerable to predicted climate change. Primary threats include recreational climbing and harassment at nest sites. Due to its primary existent at only two geographical sites (Jemez and Nambe falls) within the Santa Fe NF the species can be seriously impacted by management or other recreational activities that occur on the forest. Since waterfall features tend to be a highly attractive to recreationists, there is increased potential for impact at nesting sites. The black swift is listed as an S2B/S2N species according to NatureServe resulting in an at-risk designation.

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. Threats include disturbance, egg shell thinning from accumulated pesticides, and disturbance from recreational activities (90 percent of potential habitat). 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 III) shows declining productivity of peregrines from 2001 to 2013 in New Mexico. Results from monitoring project show reproduction at less than one offspring per bonded pair. Given their limited numbers and stagnant reproduction, this species should be considered at-risk on the Santa Fe NF.

Pinyon Jay (*Gymnorhinus cyanocephalus)* are tied to the PJ Sagebrush and PJ Woodland ERUs. PJ Sagebrush is in moderate departure from reference conditions while PJ Woodland is in low to moderate departure. Although predicted to remain in low departure from reference conditions PJ habitats are predicted to have the greatest variation amongst zones when it comes to climate change vulnerability. Breeding Bird Survey trend data for Pinyon jays suggest declines in populations, survey results shows 4.0 percent declining trend (significant) in New Mexico from 2003-2013. Though exact cause of Pinyon jay is unknown, it may be due to their reliance on piñon trees which were significantly impacted by recent drought conditions on the forest.

White-tailed Ptarmigan *(Legopus leucurus)* utilize the Alpine and Tundra ERU of the Santa NF (less than 1 percent of the forest), which is only found on the Northeast local zone. Threats include degradation of habitat by grazing (25 percent potential habitat affected) and recreation (15 percent potential habitat affected) since the birds rely on alpine meadows with short vegetation consisting of sedges and herbaceous broad-leaved plants for nesting and brooding. 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, Larsson et al. 2014). This species was re-introduced nearly 50 years ago after extirpation and the population could at this point have low genetic diversity. Use of New Mexico's limited alpine tundra habitat by livestock plus increased human use including wilderness hiking, ski area developments, construction of snow catchment fences, and microwave relay stations, are among the threats to the state's remnant ptarmigan population. Given their limited numbers, isolated geographic range and threats to their habitat this species should be considered at-risk on the Santa Fe NF.

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. Large range in western U.S. and adjacent southern Canada, but distribution can be spotty; apparently declining in abundance, and may have declined 60 percent 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. Large wildfires in the Jemez Mountains have negatively affected the Ponderosa Pine ERU large tree and large snag special feature needed by this species. Current Ponderosa pine forest landscapes have changed significantly towards single storied, closed canopy seral states. At the plan scale only 3 percent of the Santa Fe NF PPF landscape is similar to reference conditions. Just over 70 percent of the landscape has moved into closed canopy states with 60 percent representation in the medium to large tree states and 11 percent in the small diameter tree state. With limited variation between local zones, snag densities at the plan scale don't differ much from any one local zone with roughly 1 large-diameter (18 inches and greater dbh) snag and 8 smaller-diameter (8.0- to 17.9-inch dbh) snags per acre. This species should be considered at-risk on the Santa Fe NF due to its continued population decline and its high departure from reference of their Ponderosa pine habitat.

Northern Leopard Frog (*Lithobates pipiens*) were found in all the local zones historically but are now absent in many historic locations. 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 NF. Characteristics of quality Northern leopard frog habitat are currently highly departed (e.g., site potential and proportion of bare soil are departed at 73 and 60 percent, respectively), while potential to return to reference conditions remains unknown. Threats to their aquatic habitats were moderate to high. For lakes and ponds, the potential risk to compromised system integrity within the Santa Fe NF was moderate for most watersheds, while the potential risk to compromised system integrity of seeps and springs within the Santa Fe NF was high for most of the watersheds. Ongoing threats include degradation of habitat caused by grazing, chytrid fungus, or siltation due to uncharacteristic wildlife and poor road management (95 percent of potential habitat). Northern leopard frogs should be considered at-risk due to their limited range and moderate to high risk within their habitats.

Lilljeborg's Peaclam (*Pisidium lilljeborgi*) is found in only one high elevation lake in the Pecos Wilderness and is found in no other place in New Mexico. It's highly restricted range invariably places this species vulnerable to extinction on the Santa Fe NF. The lake in which they are found has not been assessed according to its reference condition. Threats include siltation into the lake or use of chemical retardant for fire suppression that could wash into the lake. Considering the forest surrounding the lake is prone to potential catastrophic fire, this species should be considered at-risk on Santa Fe NF.

Ruidoso Snaggletooth (*Gastrocopta ruidosensis*) Ruidoso Snaggletooth (Gastrocopta ruidosensis) is a snail found only in two widely separated areas in New Mexico. It lives in plant and leaf litter near limestone outcrops in juniper grasslands (JUG) only on the east side of the Sangre de Cristo Mountains (Nekola and Coles 2010). 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. It's highly restricted range invariably places this species vulnerale to persistance on the Santa Fe NF. It can be affected by prescribed burning and trampling. It is a rather recent discovery on the Santa Fe NF and a new addition to the Regional Forester's sensitive species list of 2013.

Jemez Woodland Snail (*Ashmunella ashmuni*) is a narrow endemic occurring in only a few canyons in the SWZ of Sante Fe NF. Rated as a G1 species it is not known to be found in any other locations. They are associated with limestone outcropping in Juniper grassland, Ponderosa pine and Mixed conifer (dry) ERUs, all of which are in moderate to high departure with no significant improvement predicted. The snails are a moisture dependant species so climate change may significantly impact this species. Given the habitats of the only known populations of this species are highly departed, Jemez woodland snails should be considered at-risk on the Santa Fe NF.

Rio Grande Cutthroat Trout (*Oncorhynchus clarkii virginalis)* currently occur in approximately 10 percent of their presumed historic range. These population declines combined with losses in suitable habitat have led to considerable concern over the species' ability to persist over the long term in the plan area. Conservation populations of Rio Grande Cutthroat on the Santa Fe NF are isolated in high elevation streams above natural and manmade barriers that prevent the upstream movement of nonnative trout that hybridize with, compete with, and prey upon native cutthroat trout. On the Santa Fe NF, while there are 1183 miles of perennial streams, only 8 percent currently support native fish species in the absence of nonnative fish. Rio Grande Cutthroat Trout are further threatened by degraded stream and riparian habitat as well as water quality and quantity as a result of inadequately maintained roads and trails, water diversions, livestock grazing, and recreational use. Catastrophic fire and other extreme events such as drought and floods also threaten the persistence of small, isolated populations which, because they occur above migratory barriers, cannot be recolonized naturally.

Rio Grande Chub *(Gila pandora)* have declined in range and abundance over the last 100 years and has been extirpated from the mainstem Rio Grande River. Populations can be threatened by habitat degradation that includes habitat loss, modification, and fragmentation as well as from interactions with nonnative species. Rio Grande Chub impacts on the Santa Fe NF include degraded stream and riparian habitat as well as water quality and quantity as a result of inadequately maintained roads and trails, water diversions, livestock grazing, and recreational use. Catastrophic fire and other extreme events such as drought and floods can also impact the species. Competition and predation with nonnative species can be extensive threats to Rio Grande Chub populations through predation from brown trout and by competition for food resources with white sucker. Rio Grande Chub have been petitioned for listing under the Endangered Species Act.

Rio Grande Sucker *(Catostomus plebius)* are endemic to the Rio Grande drainage and have been extirpated from most of its historic range. Populations can be threatened by habitat degradation that includes habitat loss, modification, and fragmentation as well as from interactions with nonnative species. Rio Grande Sucker impacts on the Santa Fe NF include degraded stream and riparian habitat as well as water quality and quantity as a result of inadequately maintained roads and trails, water diversions, livestock grazing, and recreational use. Catastrophic fire and other extreme events such as drought and floods can also impact the species. Competition and predation with nonnative species can be extensive threats to Rio Grande Sucker populations through predation from brown trout and by hybridizing and competing for food resources with the white sucker. Rio Grande Sucker have been petitioned for listing under the Endangered Species Act.

Tufted Sand Verbena (*Abronia bigelovii*) also known as the Galisteo Sand Verbena have been documented in only a few locations in the Northwest zone of the Santa Fe NF. This species is generally scattered along outcroppings of gypsum or strongly gypseous soils. While this species may seem to have a relatively broad range geographically, its habitat is actually quite limited because of its spotty distribution across the landscape. Although geologic features such as gypsum and gypseous soils should remain in low departure from reference conditions, in general, these habitats are considered at risk for significant increased drying and prolonged drought from climate change increasing the stress from other threats (fire and grazing) as well.

Greene's Milkweed (*Asclepias uncialis ssp. uncialis)* occurs in low numbers where ever it is found. It has been reported from only one location in the Southeast local zone. Searches by experts have not found this plant in other location on the Santa Fe NF where it was originally reported. Threats include trampling by livestock. The area it is reported to occur is not subject to grazing except by occasional strays. Seral state departure is low in Pinyon-Juniper Woodland habitat, however, there is some departue in composition due to introduction of non-native species. Understory composition has been moderately impacted (36 percent departure) by invasive species such as bull thistle, Russian olive, salt cedar and Siberian elm. Similarity to site potential has also been influenced by drought and other disturbances that have reduced vegetative ground cover and increased the proportion of bare soil. Partial reductions in vegetative cover can be attributed to the substantial increases in CWD loadings. Given its few known populations and susceptibility to encroachment by invasive species, this plant should be considered at-risk on the Santa Fe NF.

Chaco Milkvetch (*Astragalus micromerius*) Existing populations tend to be isolated which, for plants, substantially increases the probability of genetic uniqueness within each and adaptation to the specific sites, and that is a factor in conserving diversity. Current departure from desired condition within their ERUs; PJ Woodland, PJ Sage, and PJ Grassland; may result in significantly increasing stress and decreasing vigor for these species, as these usually shallow outcrop formations will be drying more rapidly. Although projected status in PJ habitats appears to trend toward reference conditions, in general, these habitats are considered at risk for significant increased drying and prolonged drought from climate change increasing the stress from other threats (fire and grazing) as well. The Navajo nation cited increasing threats from trampling, off road vehicle use, and mining activities. While this species may seem to have a relatively broad range geographically, its habitat (these outcroppings of sandstone that are blended with Todilto gypsum or limestone) is actually quite limited because of its spotty distribution across the landscape.

Gunnison's Mariposa Lily (*Calochortus gunnisonii var. perpulcher*) is a very rare and restricted endemic, in a delicate habitat, inherently vulnerable because of its rarity: The lily occupies meadows and aspen glades in upper montane coniferous forest (MSG); 2,900 to 3,400 meters (9,500 to 11,200 feet), one of the habitats presumably very vulnerable to climate change. Mid- and high-seral states that are currently 50 percent departed from reference will transition to tree and shrub invaded states with continued encroachment. The lack of disturbance also continues to limit the amount of MSG sites that are reinitiated back to an early, low-seral state. 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. Based on the current disturbance regime, modeled future conditions indicate that limited fire occurrence in this ERU will continue leading to degraded conditions in MSG. Although the New Mexico Rare Plant site states that its response to grazing and fire is unknown the threats from grazing and fire may be a concern in the meadow and glade habitats for a species this restricted.

Large Yellow Lady's–Slipper (*Cypripedium parviflorum var. pubescens)* is known from only eight locations on the Santa Fe NF. A primary threat to the persistence of Large Yellow Lady's-Slipper is the build up of coarse woody debris in the SFF. A catastophic fire within this ERU could seriously reduce the distribution and number of specimens of this plant on the forest. Other anthropomorphic threats may be the introduction of invasive vegetation (thistle) which is altering the composition of its native habitat. Trampling, picking or digging up plants (100 percent of potential habitat) are also recognized threats while 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 isolated populations of this plant combined with its high recreational value places this species at-risk on the Santa Fe NF.

Heil's Alpine Whitlowgrass *(Draba heilii)* is a quite recently discovered small, high alpine yellow-flowered plant. Although its alpine/tundra habitat has changed little from reference condition it is threatened by trampling of hikers, climbers, horseback riders and occasional livestock (100 percent of potential habitat). It was found in an area near the Truchas Peaks along trails above timberline in the Pecos Wilderness. Identification and awareness of this plant is needed so it can be identified and impacts to it can be avoided or mitigated, in particular for trail maintenance projects. More information on the plant's locations and life history is needed but given its small isolated population it should be considered at-risk on the Santa Fe NF.

Pecos Fleabane (*Erigeron subglaber*)) is a narrow endemic, as the range is even narrower than previously thought due to a misidentification on Wheeler Peak. The largest known population on Elk Mountain also has the highest known impacts (road, radio tower, in grazing allotment with high grazing impact recorded, and recreational ORV use). It is now known to be very narrowly endemic and subject to high risk of climate change in spruce fir habitats. A primary threat to the persistence of Pecos fleabane is the build up of coarse woody debris in the SFF. A catastophic fire within this ERU could seriously reduce the distribution and number of specimens of this plant on the forest. Other anthropomorphic threats may be the introduction of invasive vegetation (thistle) which is altering the composition of its native habitat. The state botanist and Heritage program have recently reviewed its status, not yet reflected on the NM Rare Plant site, and given its imminent new ranking, falls within our guidance to maintain G1/T1 and G2/T2 ranks.

Wood Lily *(Lilium philadelphicum)* is State endangered plant associated with the Ponderosa Pine ERU which is in high departure from reference condition. At the plan scale only 3 percent of the Santa Fe NF PPF landscape is similar to reference conditions. Just over 70 percent of the landscape has moved into closed canopy states with 60 percent representation in the medium to large tree states and 11 percent in the small diameter tree state. Shifts in overstory structures towards closed canopies and limited disturbance (killing of overstory trees) has resulted in a significant departure with current patches 72 acres on average in size. 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). This plant was never abundant and no recent reports of its occurrence on the Santa Fe NF are known therefore the plant should be considered at-risk on the forest.

Chama Blazing Star *(Mentzelia conspicua*) occurs only in the Jemez Mountains known only from Chama Canyon (NW zone) on sedimentary soils within the canyon. 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). Seral state departure is low in Pinyon-Juniper Woodland habitat, however, there is some departue in composition due to introduction of non-native species. Understory composition has been moderately impacted (36 percent departure) by invasive species such as bull thistle, Russian olive, salt cedar and Siberian elm. Similarity to site potential has also been influenced by drought and other disturbances that have reduced vegetative ground cover and increased the proportion of bare soil. Partial reductions in vegetative cover can be attributed to the substantial increases in CWD loadings. Other threats include habitat disturbance from recreation, sagebrush mowing and road construction and maintenance (14 percent potential habitat affected). With its isolated populations and unique habitat characteristics this plant should be considered at risk on Santa Fe NF.

Springer's Blazing Star *(Mentzelia springeri*) occurs only in the Jemez Mountains on pumice deposits. It was formerly known only from within Bandelier National Monument. Seral state departure is low in Pinyon-Juniper Woodland habitat; however, there is some departue in composition due to introduction of non-native species. Understory composition has been moderately impacted (36 percent departure) by invasive species such as bull thistle, Russian olive, salt cedar and Siberian elm. Similarity to site potential has also been influenced by drought and other disturbances that have reduced vegetative ground cover and increased the proportion of bare soil. Partial reductions in vegetative cover can be attributed to the substantial increases in CWD loadings. It was recently found in one location on the Santa Fe NF alongside a major road. Trampling or road maintenance can be a threat (100 percent of potential habitat). Pumice mines are now closed on the forest but were active for many years and undoubtedly affected habitat making this species at risk on the Santa Fe NF.

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. A primary threat to the persistence of Arizona willow is the build up of coarse woody debris in the SFF. A catastophic fire within this ERU could seriously reduce the distribution and number of specimens of this plant on the forest. Other anthropomorphic threats may be the introduction of invasive vegetation (thistle) which is altering the composition of its native habitat. This plant is closely associated with riparion areas which are currently highly departed (e.g., site potential and proportion of bare soil are departed at 73 and 60 percent, respectively), while potential to return to reference conditions remains unknown. Livestock impact the growth and vigor of this willow (100 percent of potential habitat affected). Protection by small enclosures in the San Pedro Parks in the NW local zone resulted in a better condition for those plants 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. No protection measures or monitoring has occurred on the population in the Pecos Wilderness NE local zone placing this species at risk on the Santa Fe NF.

Table 57. 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* • Black Swift • Chaco Milkvetch • Tufted Sand Verbena
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. • 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).	• Mexican Spotted Owl* • Large Yellow-Lady's Slipper • 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 • Gunnison's Mariposa Lily

Species Risk Analysis

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 58. Potential SCC are presented in table 59. 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 44) will be considered as the Santa Fe NF evaluates needs for change to the current Land and Resource Management Plan.

Table 58. 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	2.10	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 59. 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
Falco peregrinus anatum	American Peregrine Falcon	2.42	Moderate
Gymnorhinus cyanocephalus	Pinyon Jay	2.25	Moderate
Lagopus leucurus	White-tailed Ptarmigan	2.28	Moderate
Melanerpes lewis	Lewis's Woodpecker	2.15	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			
Ashmunella ashmuni	Jemez Woodlandsnail	2.20	Moderate

Scientific Name	Common Name	Risk Assessment Value	Overall Risk
Gastrocopta ruidosensis	Ruidoso Snaggletooth	2.25	Moderate
Pisidium lilljeborgi	Lilljeborg's peaclam	2.48	Moderate
Plant			
Abronia bigelovii	Tufted Sand Verbena	2.25	Moderate
Asclepias uncialis ssp. uncialis	Greene's Milkweed	2.15	Moderate
Astagalus micromerius	Chaco Milkvetch	2.25	Moderate
Calochortus gunnisonii var.	Gunnison's Mariposa Lily	2.31	Moderate
Cypripedium parviflorum var.	Large Yellow Lady's Slipper	2.27	Moderate
Draba heilii	Heil's Alpine Whitlowgrass	2.38	Moderate
Erigeron subglaber	Pecos Fleabane	2.31	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 32 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 Santa Fe NF.

These potential SCC 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. A total of four federally recognized species (three endangered and one threatened) were determined to be within the plan area. Of the four, there is one are mammal, one bird, one amphibian and one plant. Of the 52 potential SCC, two have not been documented on the Santa Fe NF (Pale-Townsend's Big-eared bat and Robust Larkspur), and thus, do not meet the criteria for consideration as an SCC. Of the 50 remaining potential SCC, 18 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, resulting in 32 potential SCC being carried forward.

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 according to the 2012 planning rule; (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.

The initial draft assessment released in October 2015 identified 29 potential SCC candidates. During the public engagement portion of the assessment, the Forest Service was asked to re-evaluate 24 additional species that did not make the initial SCC list. The public recommended further consideration of 5 mammals, 13 birds, 1 amphibians, 1 invertebrate and 4 plants. Various reasons for inclusion on the SCC list were given and these species were reconsidered, 19 of the species did not meet the necessary criteria for inclusion on the SCC list (e.g. species was not documented on Santa Fe NF or not deemed at-risk). However, upon further examination, we confirmed that four plant species (Chaco milkvetch, Gunnison's Mariposa Lily, Pecos fleabane and Tufted Sand Verbena) and one invertebrate species (Jemez Woodlandsnail) warranted inclusion on the final SCC list.

Also during the re-valuation process new information was discovered for three bird species which resulted in their removal from the final SCC list. Wilson's warblers were originally reported to be in decline based off Breeding Bird Survey data. Further investigation revealed the data did not support this conclusion and no significant declines could be reported. EBird observations also revealed this species to be abundant on the forest with projected improvements in riparian habitat (due to planned management for New Mexico Meadow Jumping Mouse). Black-throated gray warblers were also removed from the final SCC list due to their abundance in Pinyon-Juniper habitats and its minimal current and future departure from reference condition. Lastly, it was discovered that brown-capped rosy-finches were mislabeled as black rosy-finches. These two species were separated although neither met criteria for inclusion on the final SCC list due to low departure of their preferred alpine habitat and insufficient information regarding their current population status on the forest.

At the conclusion of the assessment process, a total of 32 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; 8 birds; 3 fish; 3 invertebrates; 6 mammals; and 11 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 Santa Fe NF 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 NF 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 32 total potential species of conservation concern. The habitats and ecosystems that support each of these are shown in

Table 57, 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.

Input Received from Public Meetings

This section summarizes input, perspectives, and feedback relevant to this assessment topic and received from the public between April and July 2014. Input was gathered from 14 public meetings and "User Value and Trends Forms" available at all Santa Fe NF office and online. Additional input was gathered from individual meetings held with the Natural Resource staff and leadership from Tribes, Pueblos and Navajo Chapter Houses. The Draft Assessment and 12 focus areas that were identified as having the greatest needs for different plan direction were released in October 2015. This was followed by a full day public symposium to present findings from the Draft Assessment and 10 public meetings and 2 tribal meetings where findings from the 12 focus areas were presented.

Wildlife and Fish

Please see Volume II, Chapter 4, "Extractive Multiple Uses and Their Contributions to Local, Regional, and National Economies."

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 October 1 to March 31. Mean annual snowfall ranges from 70 to over 200 centimeters. Average annual air temperature ranges from 12 degrees Celsius at the lower elevations to minus 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 piñon-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 displayed in figure 39.

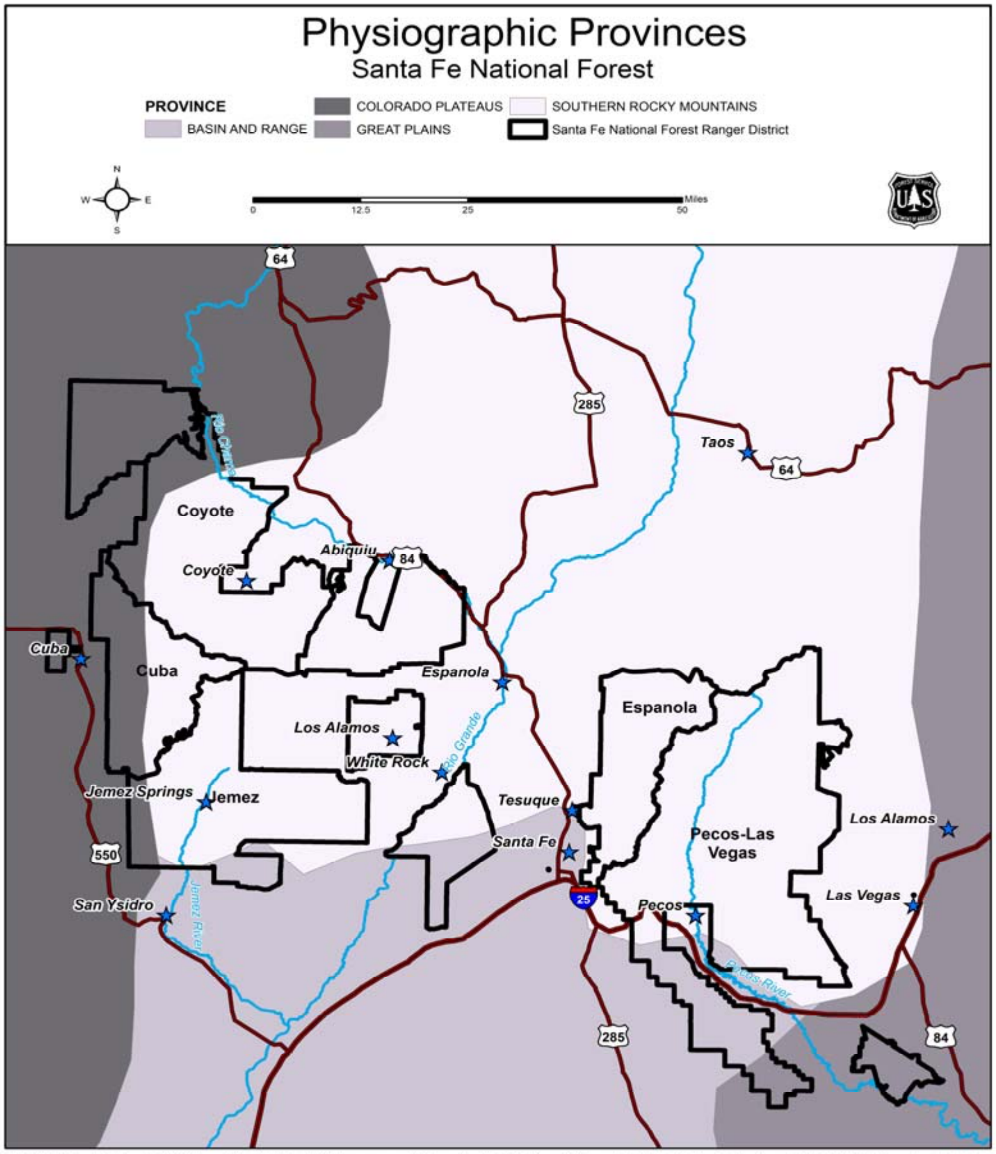

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Figure 39. Physiographic provinces of the Santa Fe National Forest.

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 northwestern 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 22 ERUs for the Santa Fe NF. The five upland ERUs that do not make up a significant amount of Forest land (less than 1 percent) were not analyzed in the soil assessment. These ERUs include Alpine Tundra, Bristlecone Pine, Gambel Oak Shrubland, Mixed-Grass Prairie 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 40 displays soil orders occurring on the Santa Fe NF.

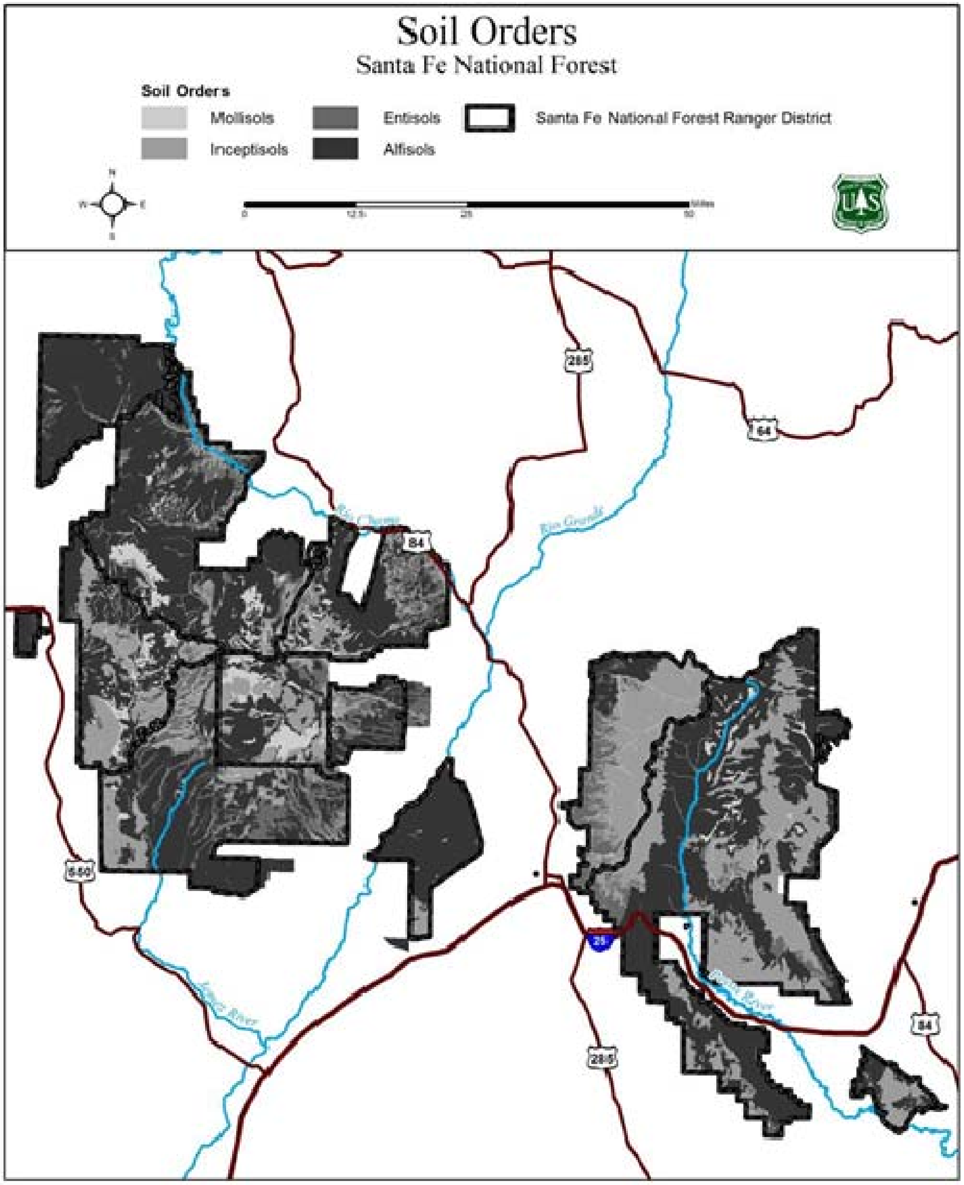

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Figure 40. Soil orders of the Santa Fe NF

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 60). 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 60. 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 61. 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.[19]

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.

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

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[19] 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.

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 41 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

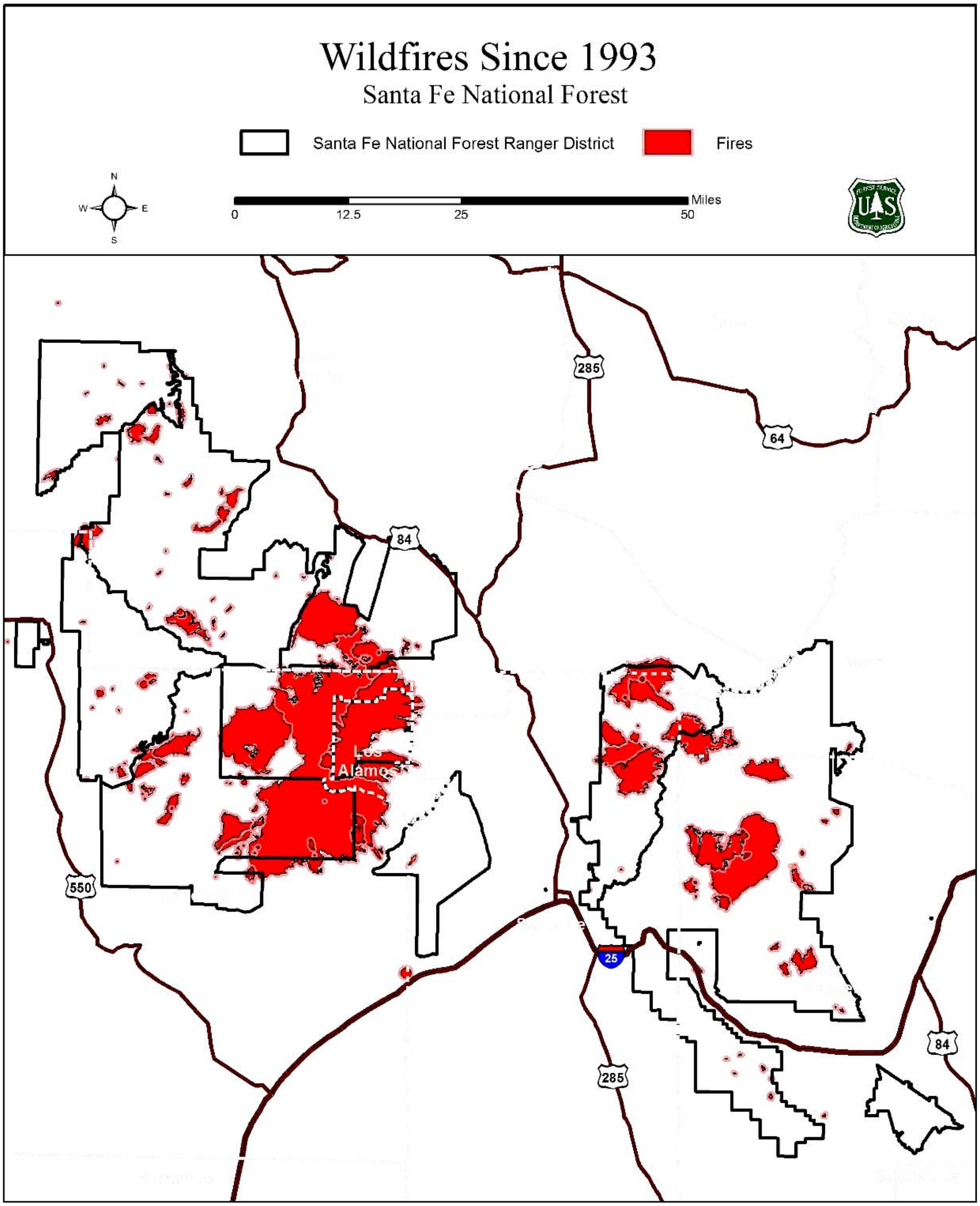

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Figure 41. Wildfires on the Santa Fe NF since 1993

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[20] (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, 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

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[20] 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)

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 42). 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.

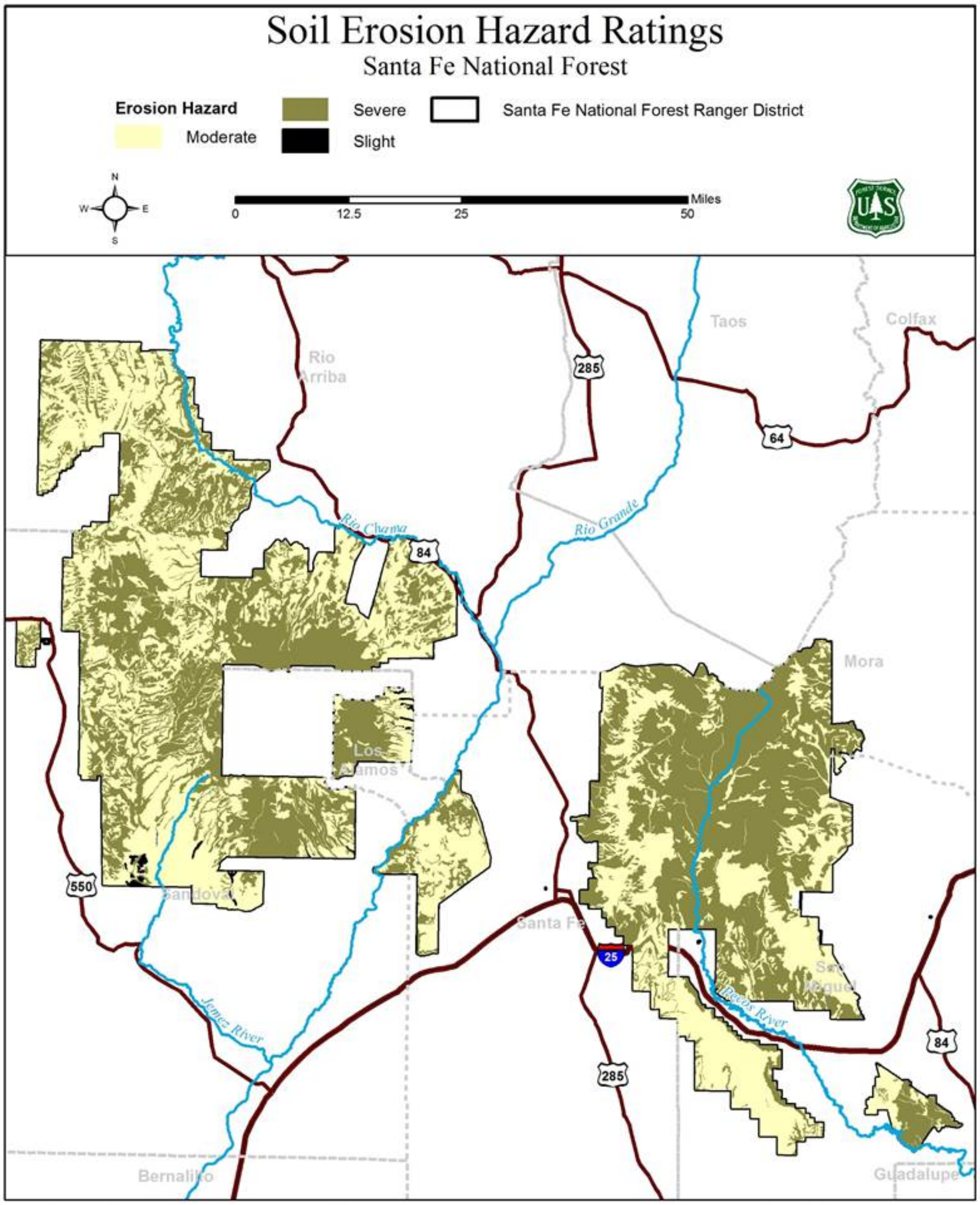

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Figure 42. Soil erosion hazard ratings of the Santa Fe NF

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.

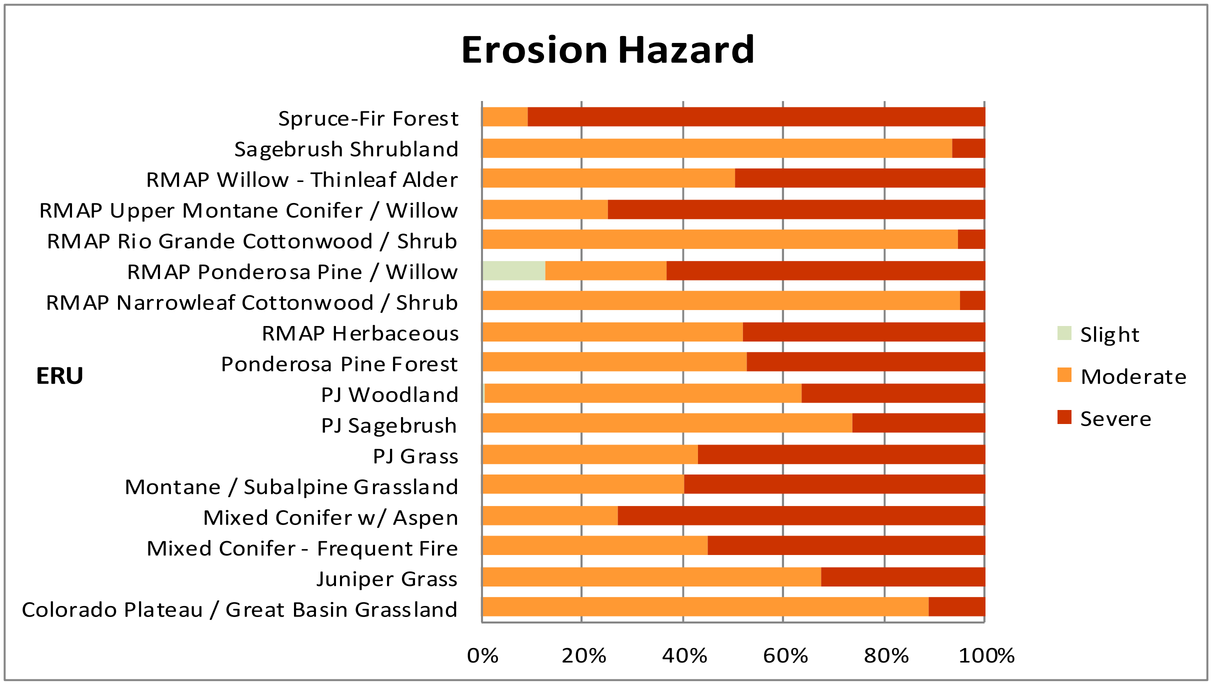

Figure 43. Erosion hazard of Santa Fe NF ERUs

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 62. 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 44). 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.

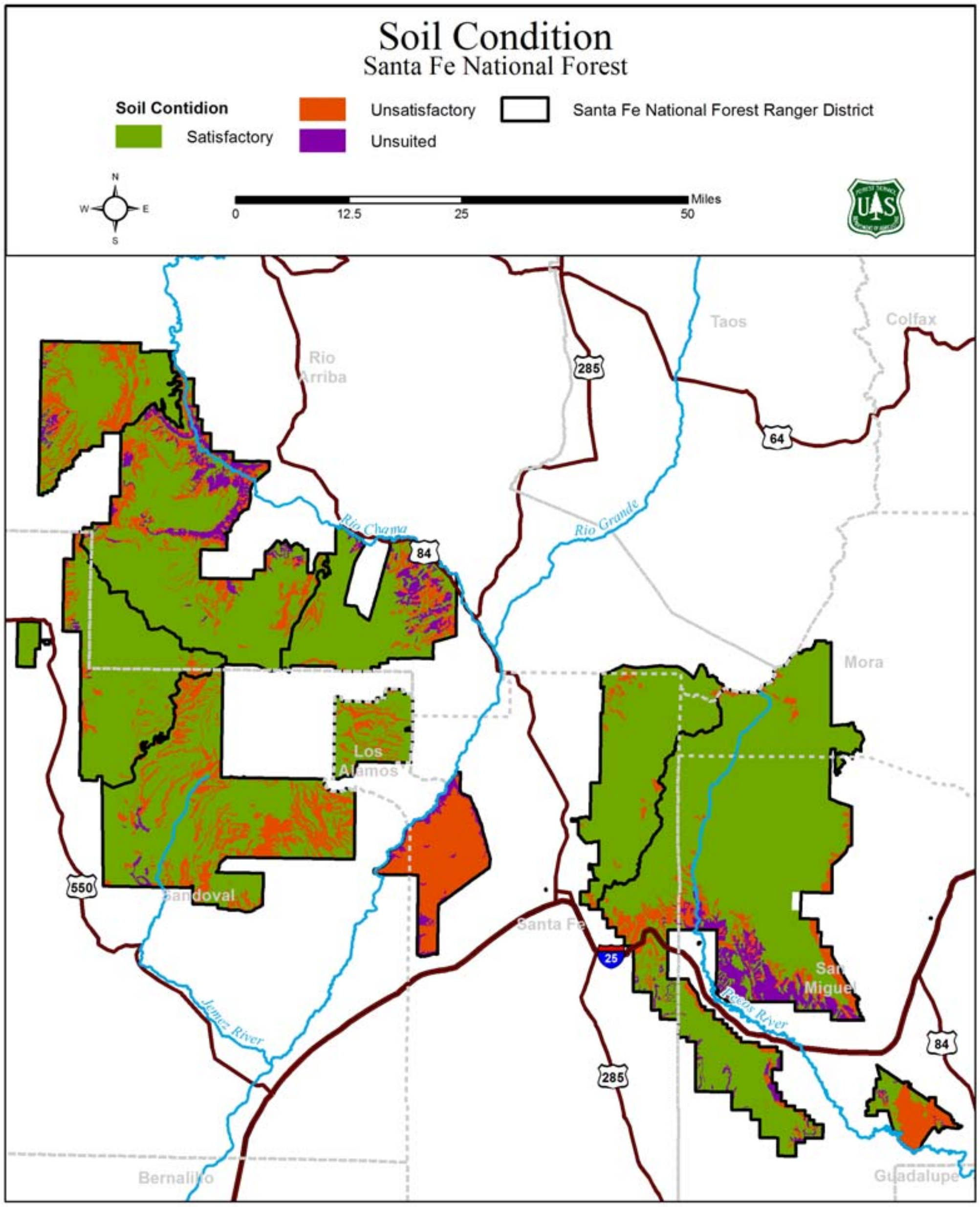

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Figure 44. Soil condition classes of the Santa Fe NF

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 45) and risk a loss of ecosystem productivity if not improved.

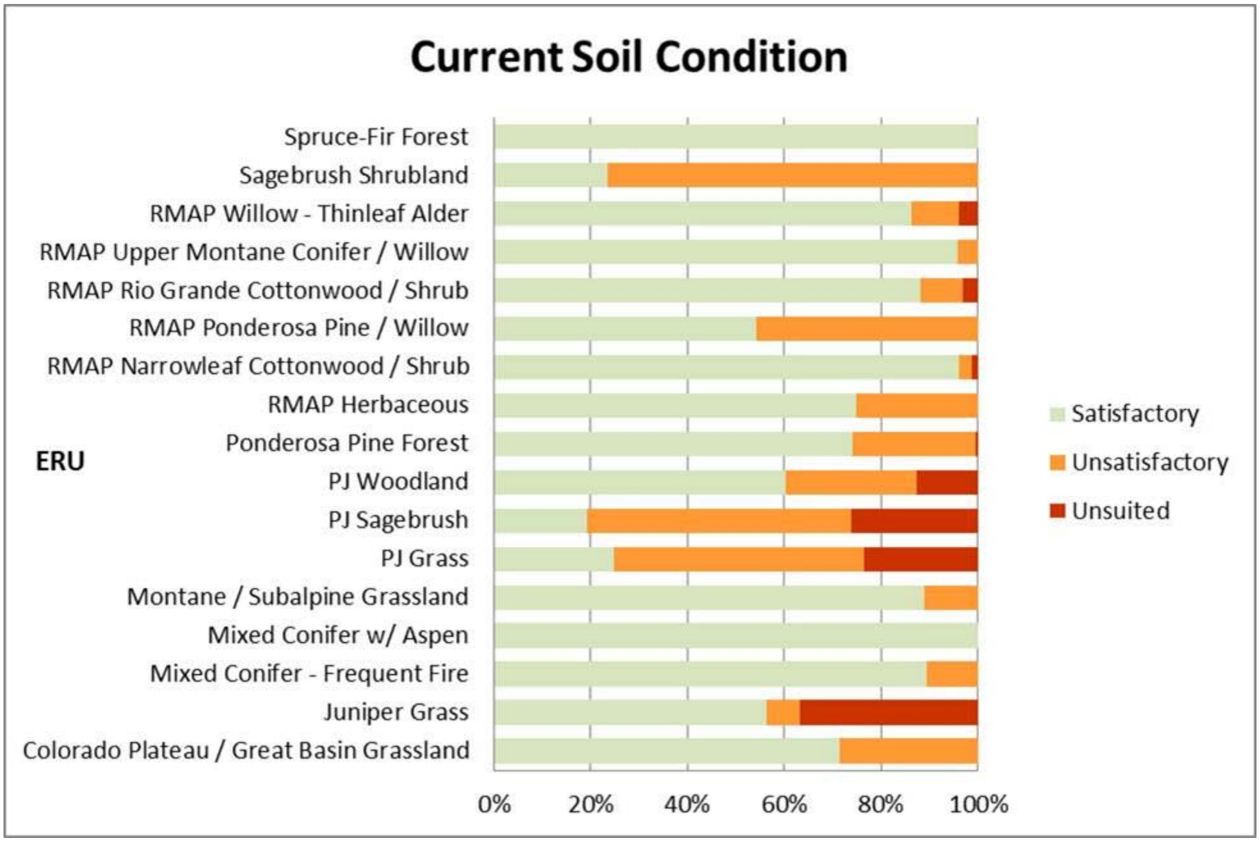

Figure 45. Current soil condition on Santa Fe NF by ERU

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 TES were used to establish average soil organic carbon reference values for ERUs. 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 and 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 centimeters and 0 to 100 centimeters. 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 63. 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 46 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 46 and table 63).

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 per acre 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 per acre across all ERUs (upland and riparian) on the Santa Fe NF (figure 46). The riparian system ERUs excluding RMAP Herbaceous (93 tons per acre average SOC) all have very similar and relatively low average SOC (when compared to upland ERUs) ranging from 10 tons per acre to 18 tons per acre.

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. Collectively, they account for approximately 50,254,318 tons of SOC or 52 percent of the SOC stock by land area.

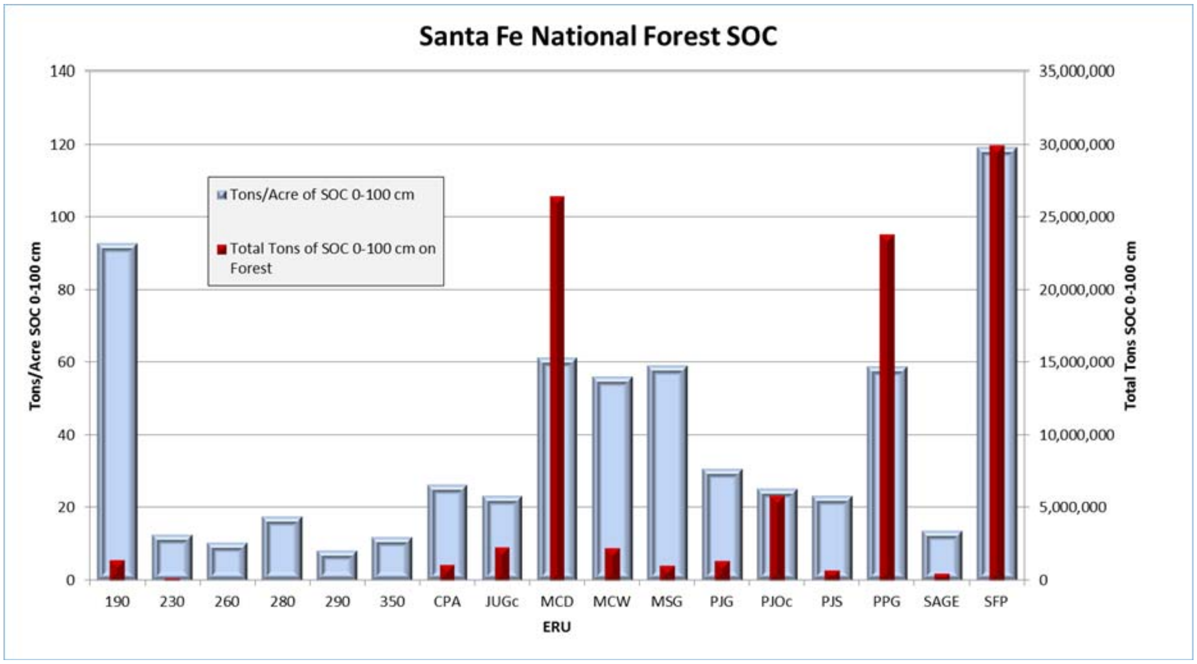

Figure 46. Total and average soil organic carbon for major Santa Fe NF ERUs

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 approximately 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 45). 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 uncharacteristic 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. <u>Herbivory</u>: 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. <u>Forest Activities</u>: 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 elevations (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.

Input Received from Public Meetings

This section summarizes input, perspectives, and feedback relevant to this assessment topic and received from the public between April and July 2014. Input was gathered from 14 public meetings and “User Value and Trends Forms” available at all Santa Fe NF office and online. Additional input was gathered from individual meetings held with the Natural Resource staff and leadership from Tribes, Pueblos and Navajo Chapter Houses. The Draft Assessment and 12 focus areas that were identified as having the greatest needs for different plan direction were released in October 2015. This was followed by a full day public symposium to present findings from the Draft Assessment and 10 public meetings and 2 tribal meetings where findings from the 12 focus areas were presented.

Air, Soil, and Water Resources and Quality

Air, soil, and water resource quality are highly valued across the forest for the benefits they provide to community health, livelihoods, and ecosystem functioning. Participants contributed observations about several changes to air, soil, and water resource quality. Overall, the forest is valued for the contributions it provides to public health.

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 about 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.[21]

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 thresholds, where an exceedance of these values could result in negative impacts to forest health and/or aquatic resources.

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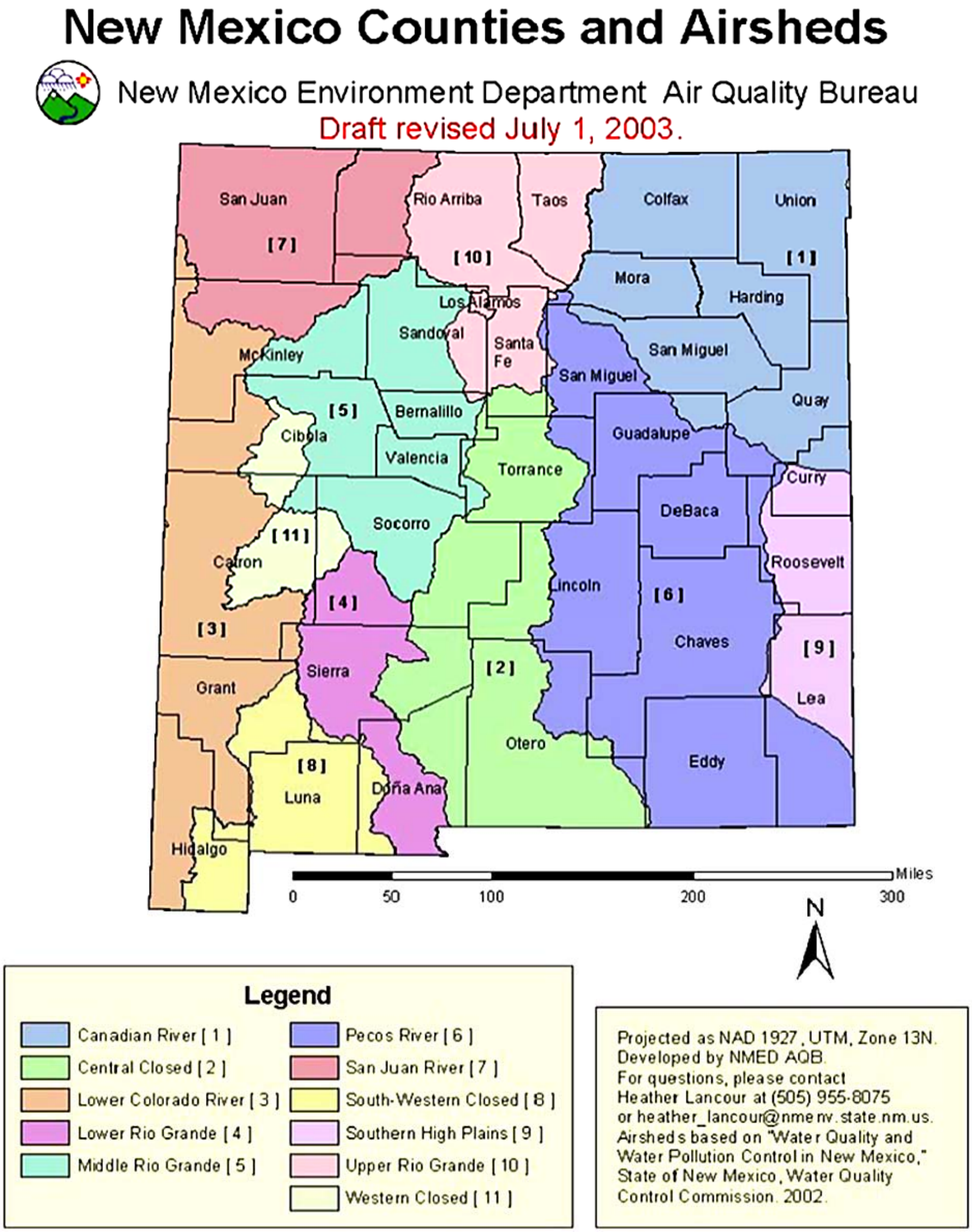
[21] For this assessment, the best available science was used that is relevant, accurate, and reliable. Uncertainty in the assessment has been appropriately documented where relevant. Government data that has met strict protocols for data collection was used to assess the current conditions and trends 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.

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 47 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 47, which may affect air resources on the Santa Fe NF.



Projected as NAD 1927, UTM, Zone 13N.
Developed by NMED AQB.
For questions, please contact
Heather Lancour at (505) 955-8075
or heather_lancour@nmenv.state.nm.us.
Airsheds based on "Water Quality and
Water Pollution Control in New Mexico,"
State of New Mexico, Water Quality
Control Commission. 2002.

Figure 47. 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 NF (figure 48). 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 64 presents the national and state ambient air quality standards.

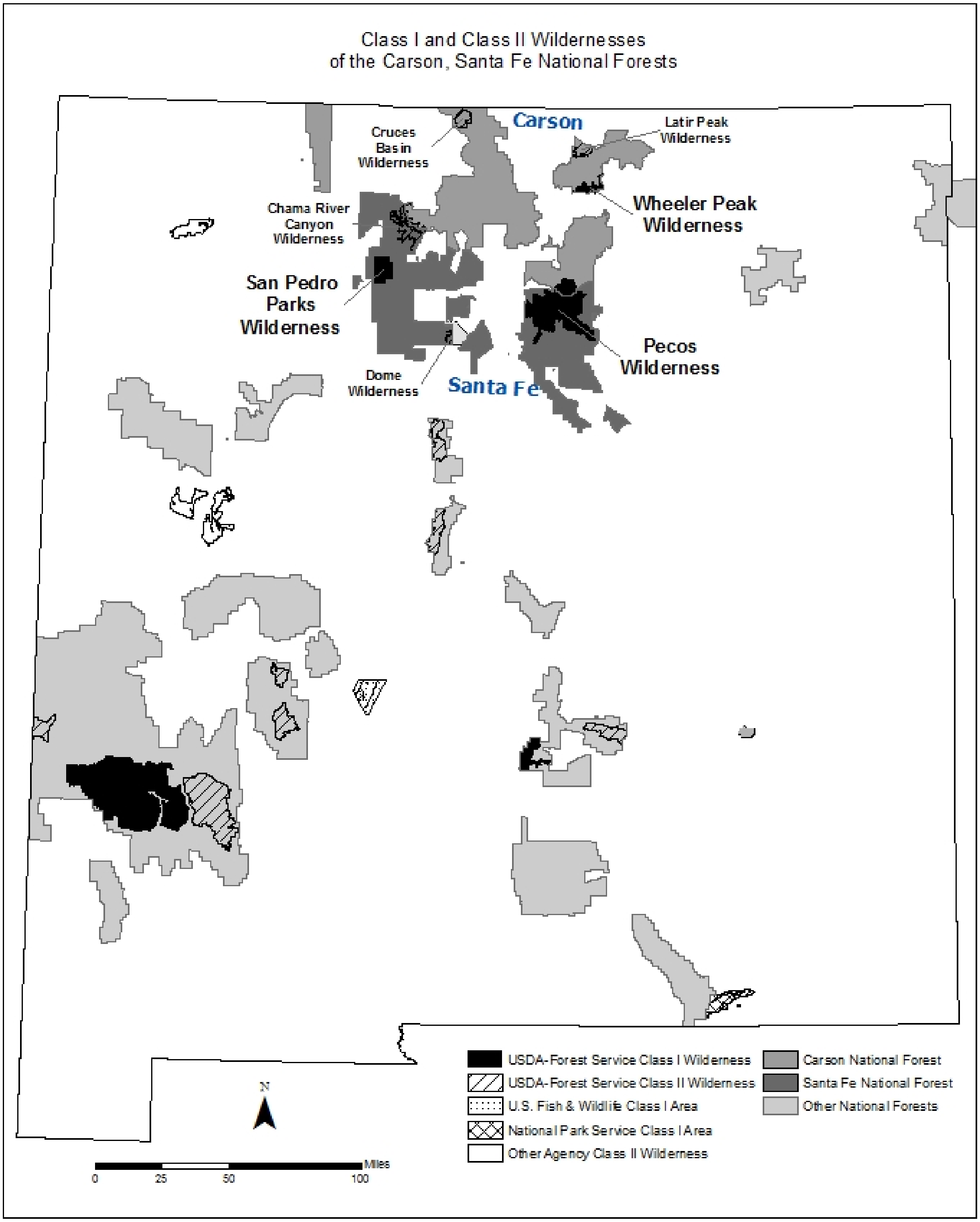


Figure 48. Class I and Sensitive Class II Areas in New Mexico

Table 64. 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 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 49, figure 50, and figure 51 show air emissions for the state of New Mexico for the criteria air pollutants of interest: CO, NOx, SO_2, VOC, CPM, and FPM.[22] 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 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

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[22] 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.

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.

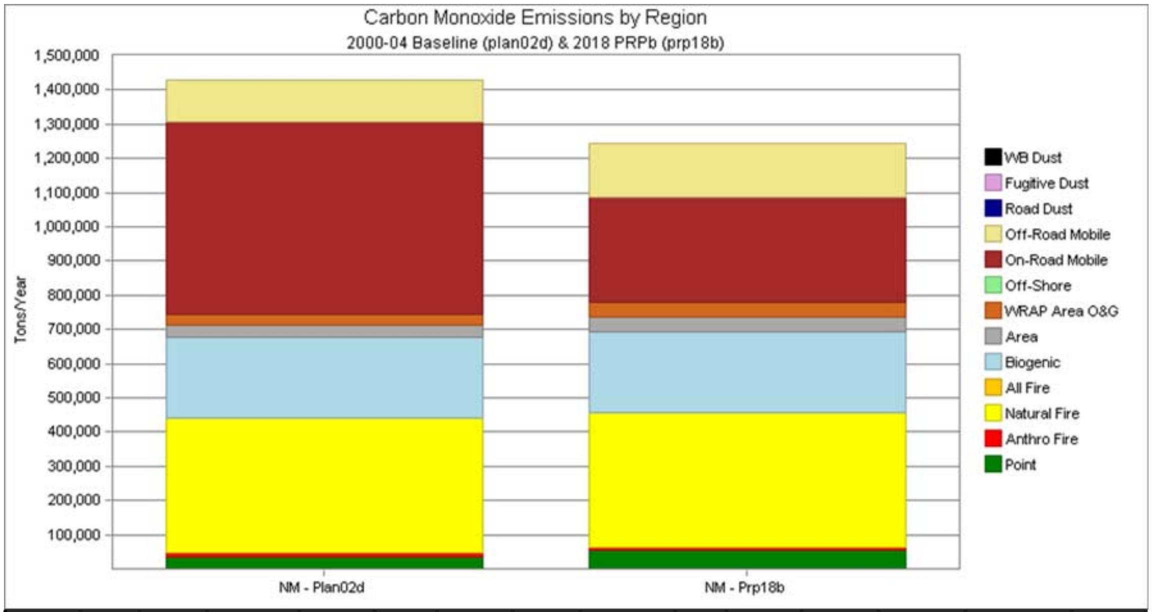
Particulate matter (PM) and VOCs are all expected to increase or stay stable at state and county levels through 2018 in New Mexico. The primary source of PM, both coarse and fine, is from windblown dust across the land and from fugitive dust from anthropogenic sources. Higher temperatures and persistent 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).

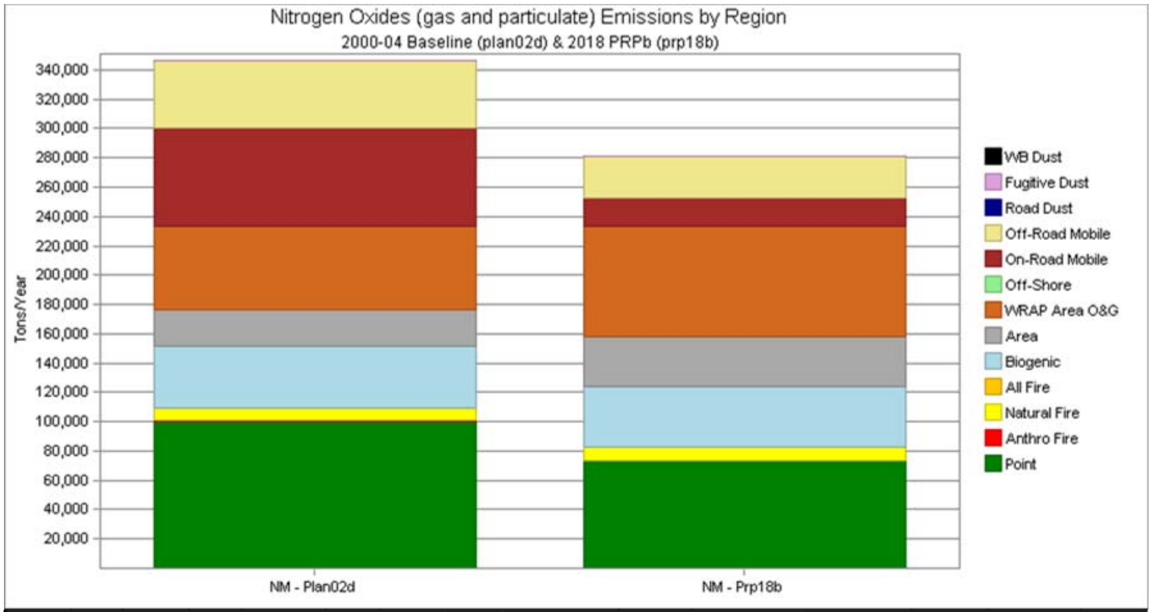
Also Rio Arriba County and San Juan County, in New Mexico show significant emissions from oil and gas development in that particular region of the state. The oil and gas industry emissions are important for SO_2, NOx and VOCs and to a lesser extent, CO emissions. In the absence of oil and gas industry 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.

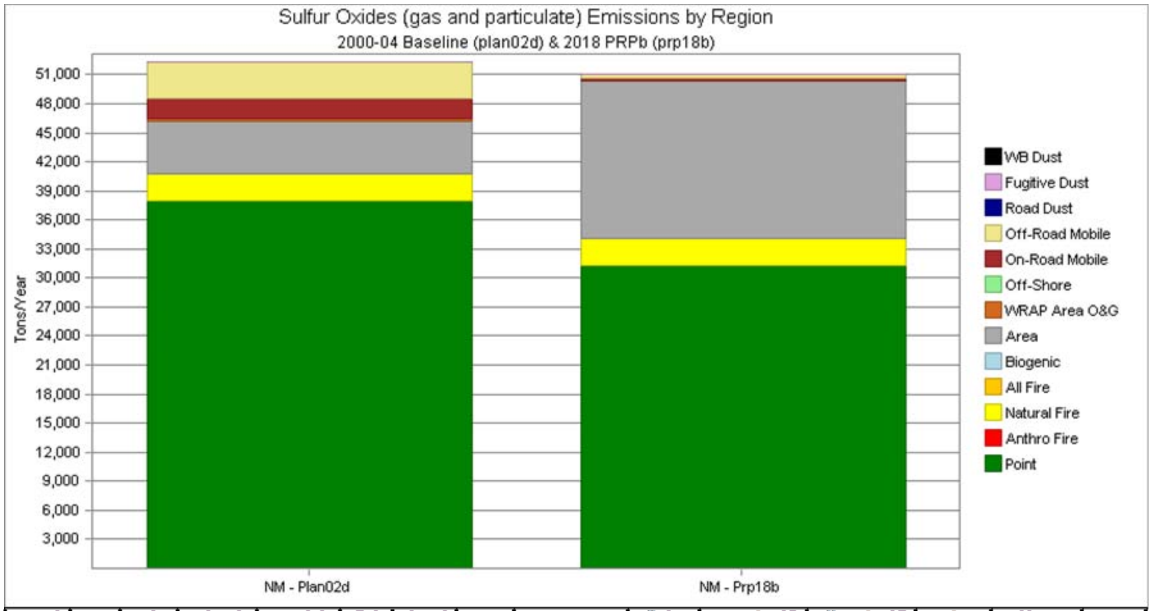


Scenario	Year	Point	Anthro Fire	Natural Fire	All Fire	Biogenic	Area	WRAP Area O&G	Off-Shore	On-Road Mobile	Off-Road Mobile	Road Dust	Fugitive Dust	WB Dust
Plan02d	2,002	36,999	9,937	393,865		238,478	34,436	31,638		561,611	124,063			
Prp18a	2,018	57,376	6,349	393,855		238,478	41,942	44,011		308,010	153,865			

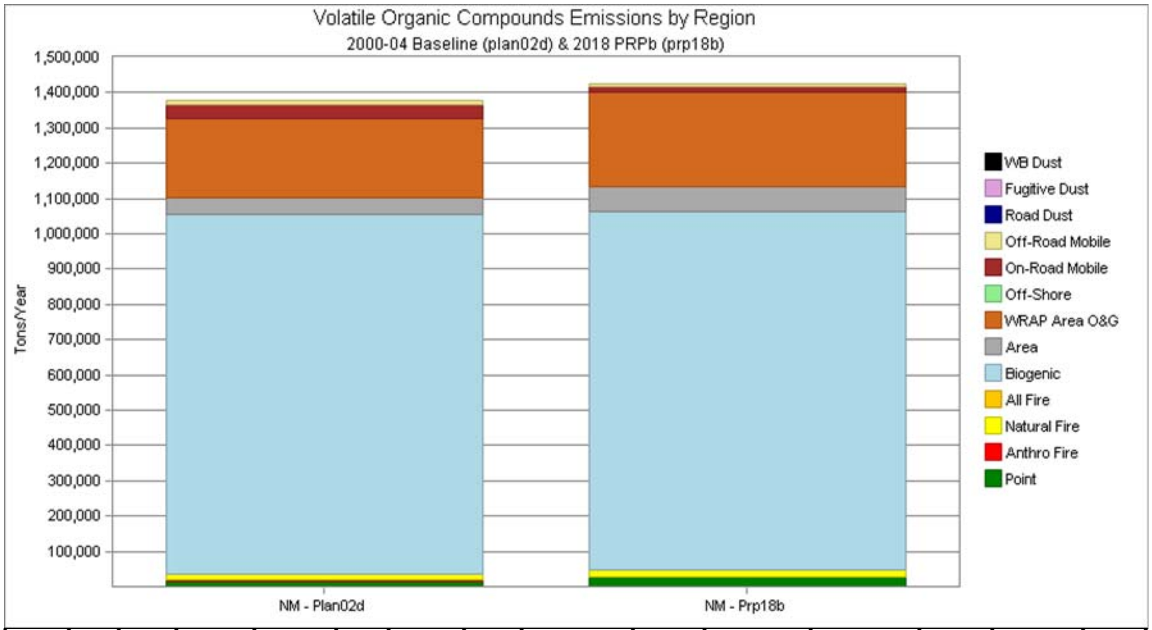


Scenario	Year	Point	Anthro Fire	Natural Fire	All Fire	Biogenic	Area	WRAP Area O&G	Off-Shore	On-Road Mobile	Off-Road Mobile	Road Dust	Fugitive Dust	WB Dust
Plan02d	2,002	100,387	394	8,870		42,139	25,130	56,210		67,635	45,311			
Prp18a	2,018	74,600	262	8,970		42,139	33,768	74,648		19,746	33,175			

Figure 49. New Mexico 2002 baseline and projected 2018 emission summaries, carbon monoxide (top) and nitrogen oxides (bottom)

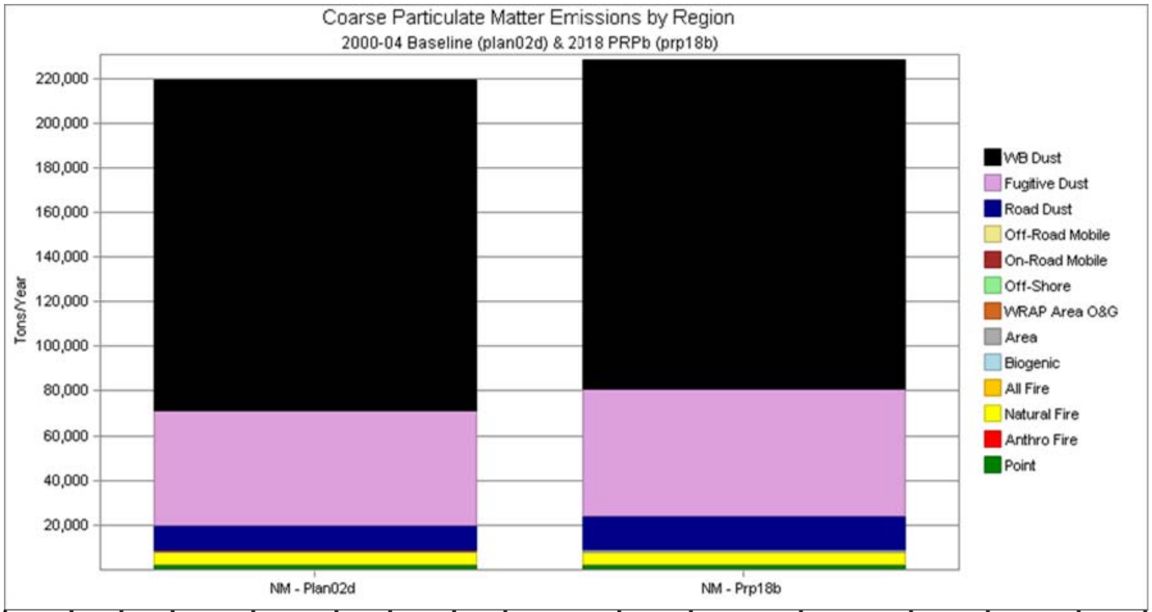


Scenario	Year	Point	Anthro Fire	Natural Fire	All Fire	Biogenic	Area	WRAP Area O&G	Off-Shore	On-Road Mobile	Off-Road Mobile	Road Dust	Fugitive Dust	WB Dust
Plan02d	2,002	37,918	94	2,729			5,433	230		2,036	3,246	4	6	
Prp18b	2,018	32,634	72	2,729			16,255	12		334	356	6	7	

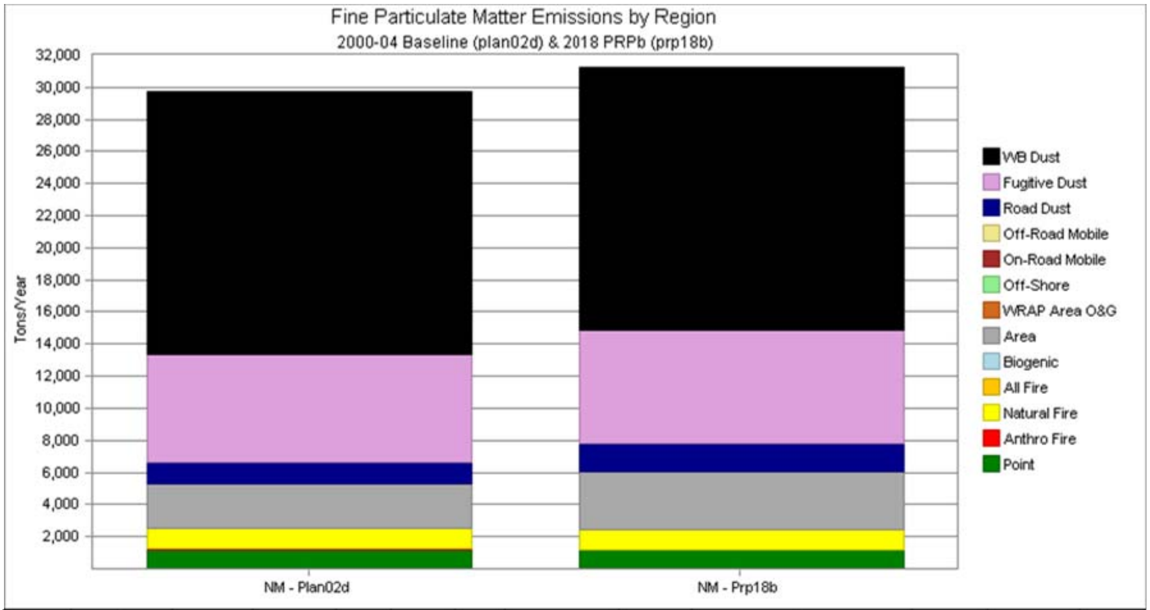


Scenario	Year	Point	Anthro Fire	Natural Fire	All Fire	Biogenic	Area	WRAP Area O&G	Off-Shore	On-Road Mobile	Off-Road Mobile	Road Dust	Fugitive Dust	WB Dust
Plan02d	2,002	17,574	608	18,846		1,016,487	46,010	224,258		38,768	13,650			
Prp18b	2,018	26,187	388	18,846		1,016,487	70,556	267,846		15,554	9,463			

Figure 50. 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			495			403		11,074	51,533	147,989
Prp18b	2,018	1,944	43	5,400			1,231			464		14,857	56,533	147,989



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			2,621					1,305	6,751	16,399
Prp18b	2,018	1,144	44	1,223			3,644					1,751	7,026	16,399

Figure 51. 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 52 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 64. 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.

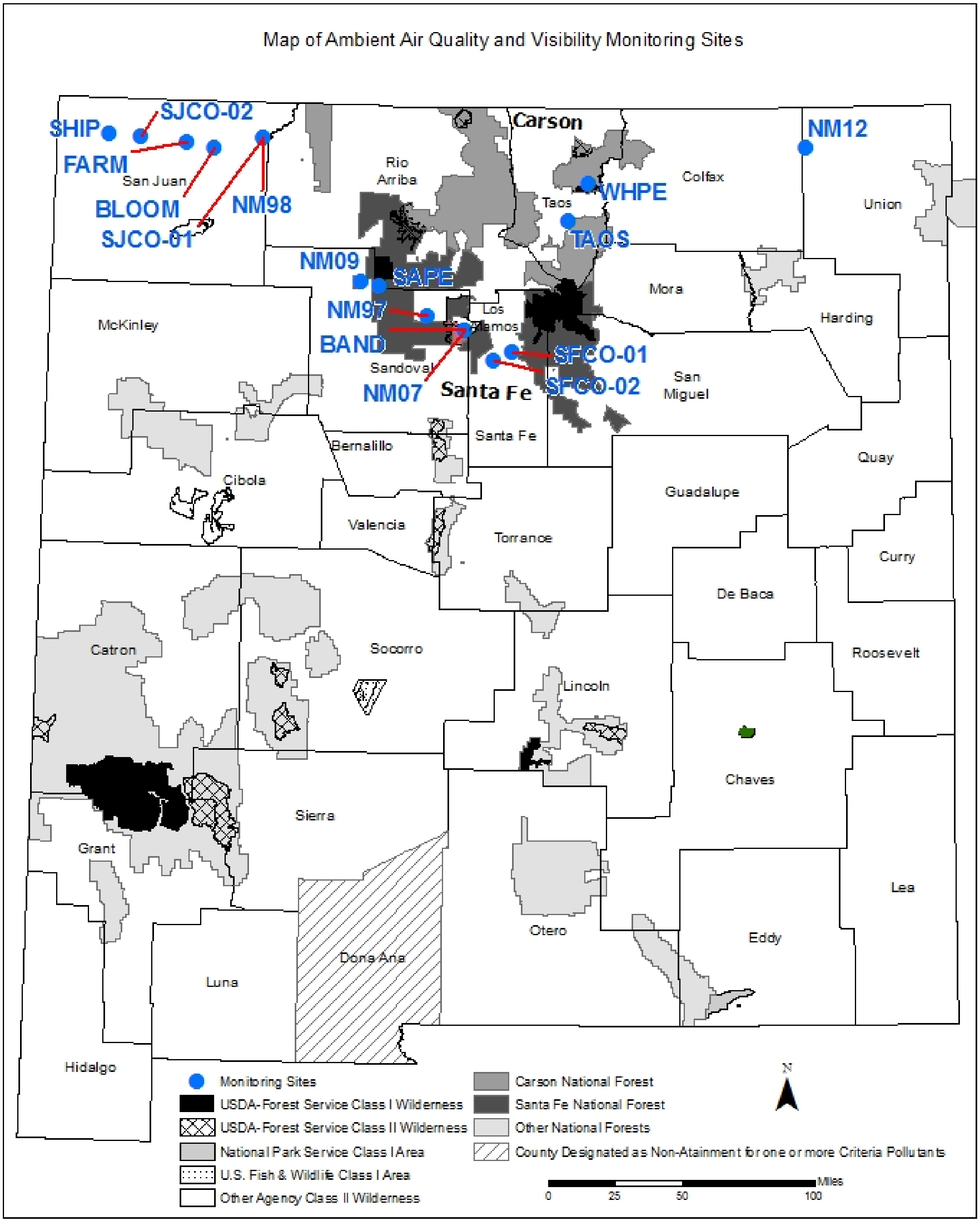


Figure 52. Map of air quality monitoring sites in the plan area

Table 65. 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 64 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 County #2 site has O_3 data starting in 2007, and the San Juan County #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 to 2010. For PM_{10}, data are available for up to four sites over the reporting period (2000 to 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, they are a potential issue with regards to atmospheric deposition.

Health effects from SO_2 exposure include changes in pulmonary function and increases in respiratory symptoms along with eye irritation. 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_2 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 52) 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 53 illustrates the relationships among extinction, deciviews, and visual range.

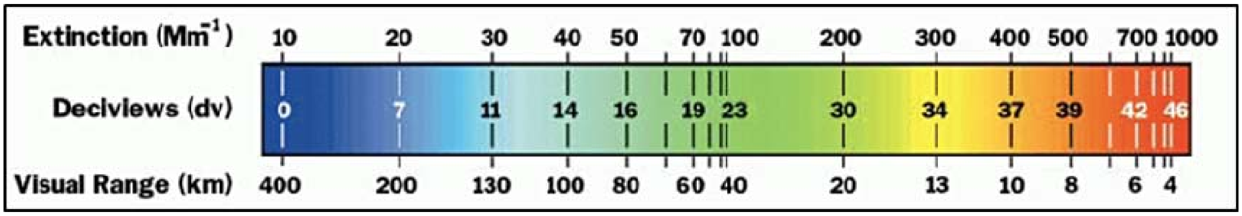


Figure 53. Relationship among extinction, deciview Index, and visual range

Measurements of annual mean visibility (as extinction) across the United States are shown in figure 54 as taken from IMPROVE (Hand 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.

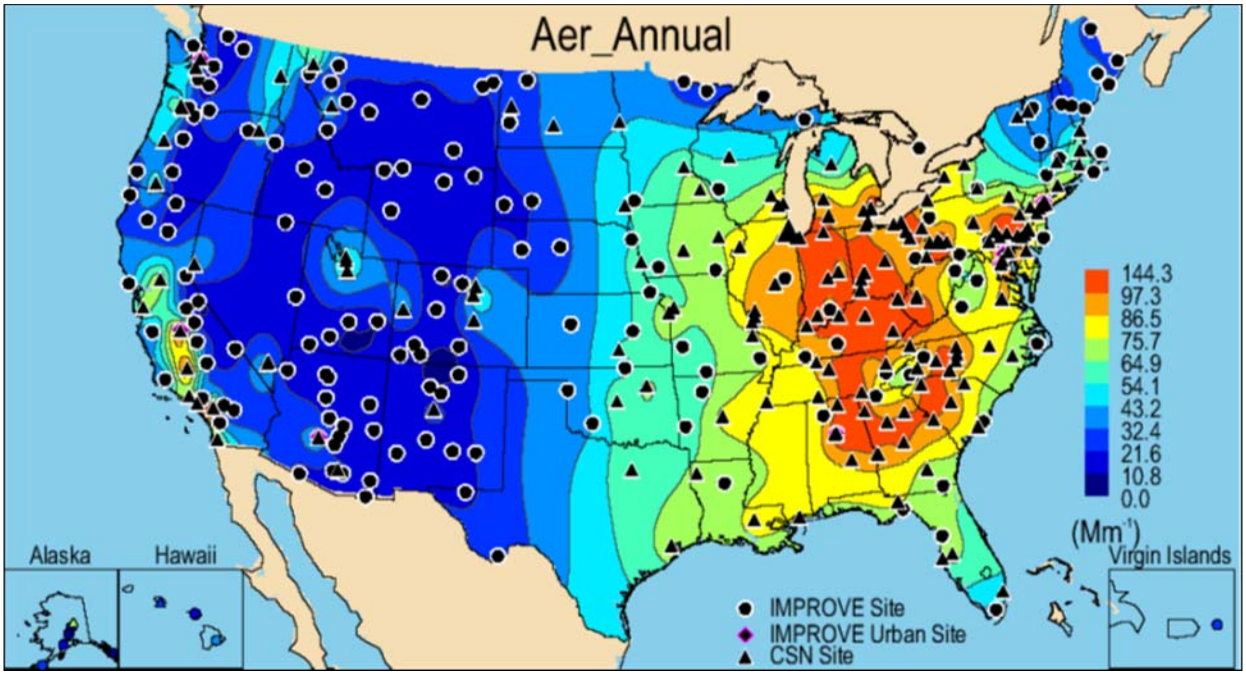


Figure 54. Reconstructed annual mean aerosol extinction from IMPROVE and other aerosol data (Hand et al. 2011)

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 66 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 66. 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 66 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 66. 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

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
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 66 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

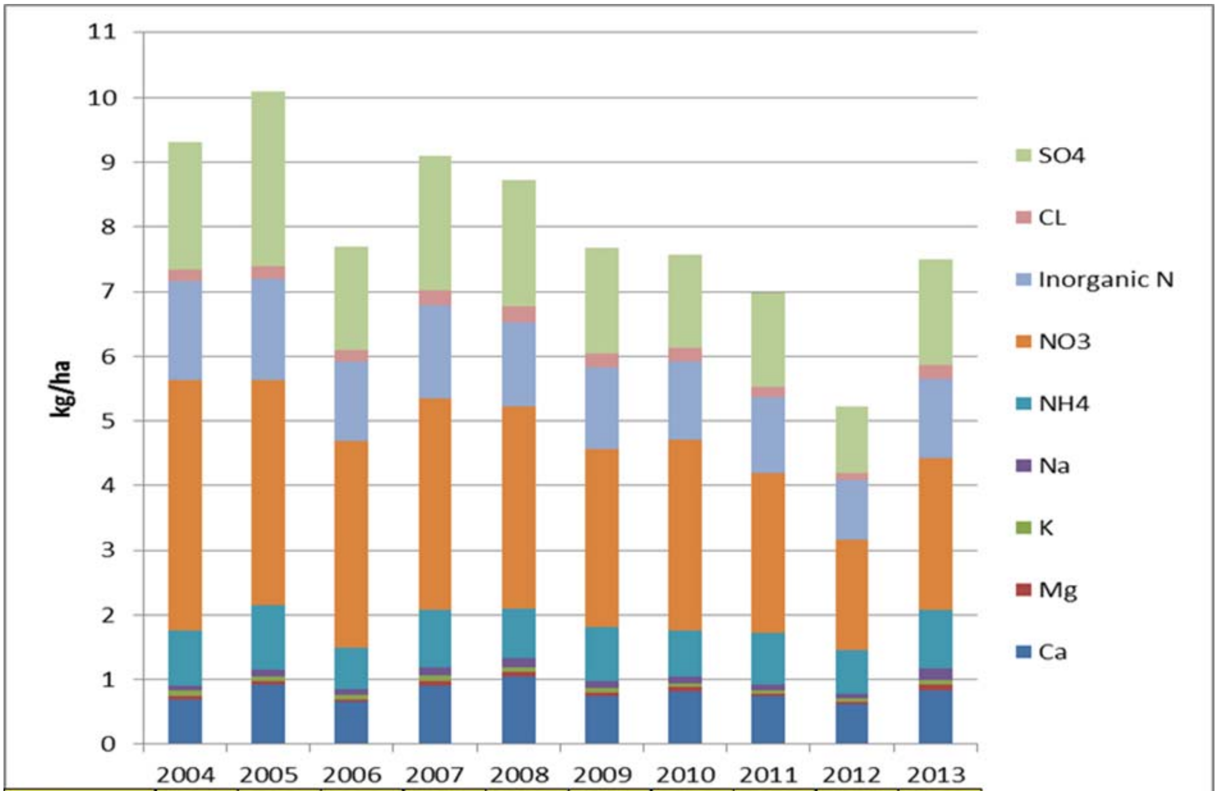
Air emissions of nitrogen oxides (NOx) and sulfur dioxide (SO_2) can lead to atmospheric transformation of these pollutants to acidic compounds (e.g., nitric acid and sulfuric acid) and the resultant deposition onto land and water surfaces in forested ecosystems. Documented effects of nitrogen and sulfur 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 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 55 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)

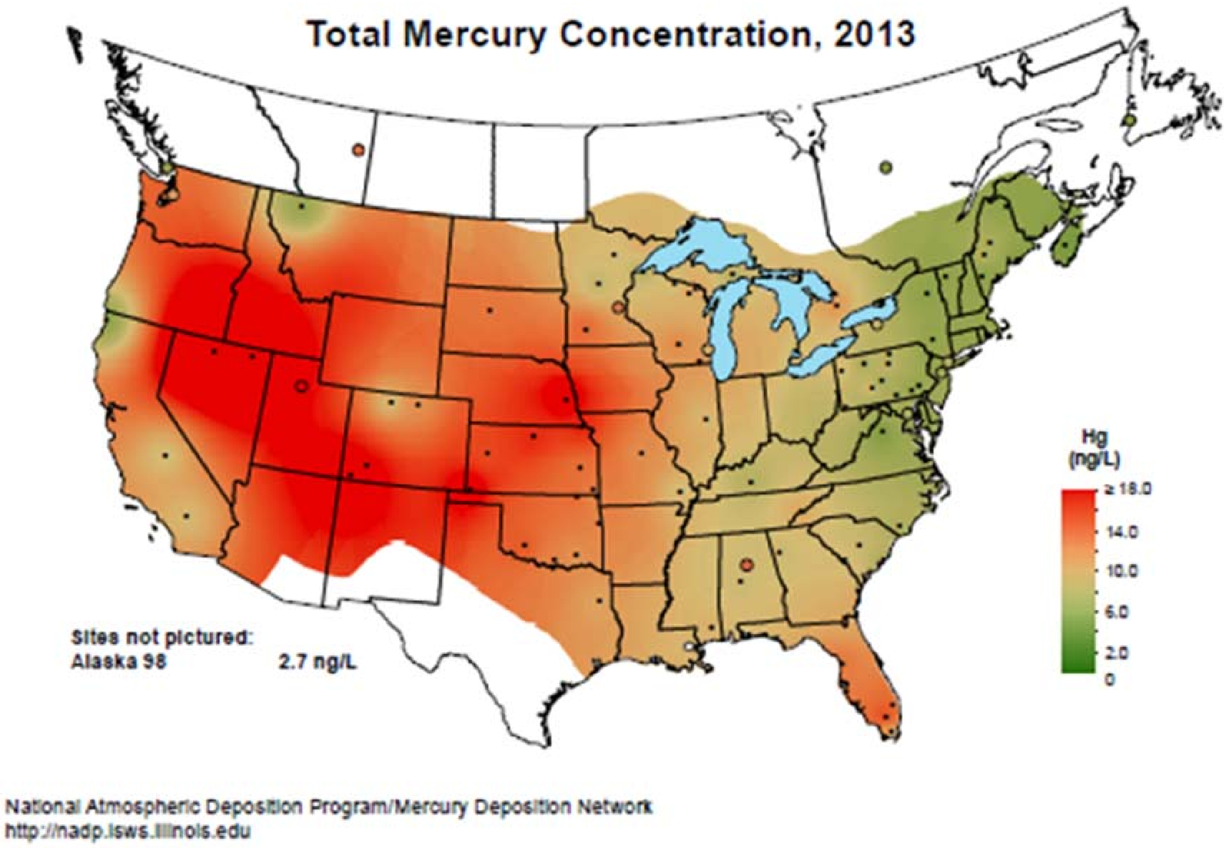
Figure 55. Chemical deposition (Bandelier Station, 2004 to 2014)

Mercury Deposition

Mercury is a persistent bioaccumulative toxin that 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.

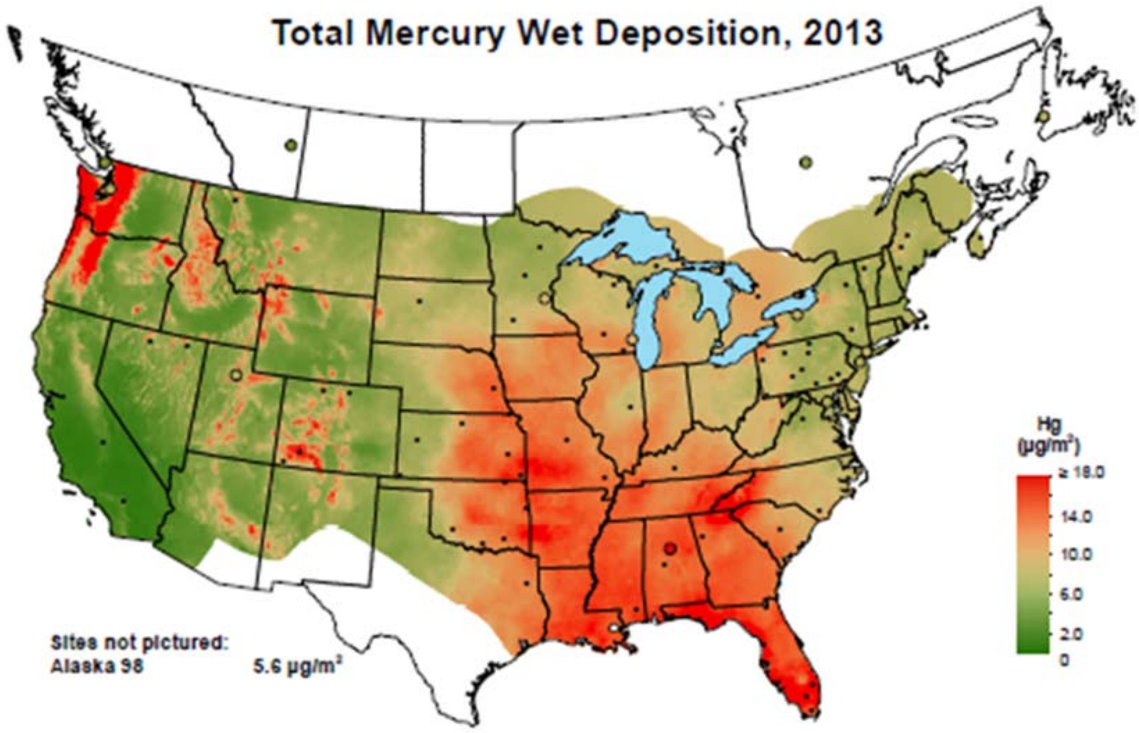
Almost every state (including New Mexico) has consumption advisories for certain lakes and streams warning of mercury-contaminated fish and shellfish. Many of the lakes on or near the Santa Fe NF have fish consumption advisories for mercury for some species of fish (NMED 2012b).

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 56) (MDN 2013)). However, due to the relatively low precipitation rates (except at higher elevations), the mercury from wet deposition is comparatively low (figure 57) (MDN 2013).



(Data obtained from: http://nadp.sws.uiuc.edu/maplib/pdf/mdn/hg_Conc_2013.pdf)

Figure 56. Total mercury concentration, 2013



National Atmospheric Deposition Program/Mercury Deposition Network
http://nadp.isws.illinois.edu

(Data obtained from: http://nadp.sws.uiuc.edu/maplib/pdf/mdn/hg_dep_2013.pdf)

Figure 57. 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 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 et al. 2011), acidity to forested ecosystems (McNulty et al. 2007), and for acidity to surface water (Lynch 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, 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 67.

Table 67. 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 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, 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 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 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 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 et al. 2006, Pardo 2011, Pardo et al. 2011).

Based on the national scale empirical critical loads for nitrogen deposition for herbaceous plants and shrubs (Pardo 2011, Pardo 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 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 et al. 2011).

Based on the national scale empirical critical loads for nitrogen deposition mycorrhizal fungi (Pardo 2011, Pardo 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 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 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 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

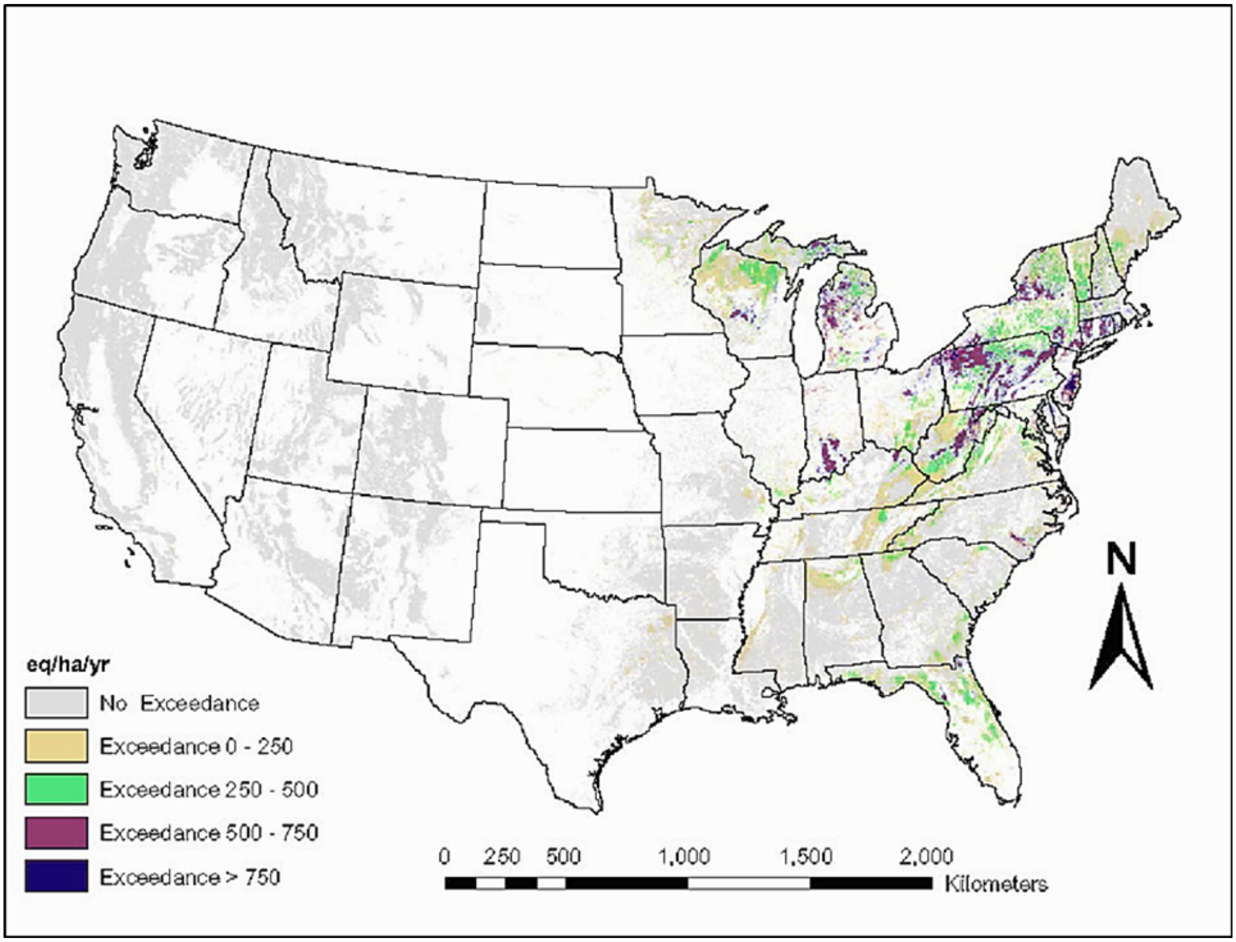
The potential for impacts from acid deposition on forests has been recognized for more than 30 years in the United States. Research has shown that deposition of nitrogen and sulfur has resulted in acidifying effects, which has had negative impacts on ecosystem health, including impacts to aquatic resources, forest sustainability, and biodiversity (McNulty et al. 2007). Acidifying effects can lead to mortality of tree species, reduced forest productivity, reduced biological diversity, and increased stream acidity (Driscoll 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 et al. 2007). The surface water critical acid loads were based on research from Lynch (Lynch 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 58). 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 58. 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 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 2012a). 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 68. 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 four 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.

Input Received from Public Meetings

This section summarizes input, perspectives, and feedback relevant to this assessment topic and received from the public between April and July 2014. Input was gathered from 14 public meetings and "User Value and Trends Forms" available at all Santa Fe NF office and online. Additional input was gathered from individual meetings held with the Natural Resource staff and leadership from Tribes, Pueblos and Navajo Chapter Houses. The Draft Assessment and 12 focus areas that were identified as having the greatest needs for different plan direction were released in October 2015. This was followed by a full day public symposium to present findings from the Draft Assessment and 10 public meetings and 2 tribal meetings where findings from the 12 focus areas were presented.

Air, Soil, and Water Resources and Quality

Air, soil, and water resource quality are highly valued across the forest for the benefits they provide to community health, livelihoods, and ecosystem functioning. Participants contributed observations about several changes to air, soil, and water resource quality. Overall, the forest is valued for the contributions it provides to public health.

Chapter 6. Carbon

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. 2013), 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).

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 69). 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 69. 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 69. 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 70, figure 59, and figure 60, 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 70. Biomass carbon stock per ERU in reference and current conditions

Shading in orange with 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%**

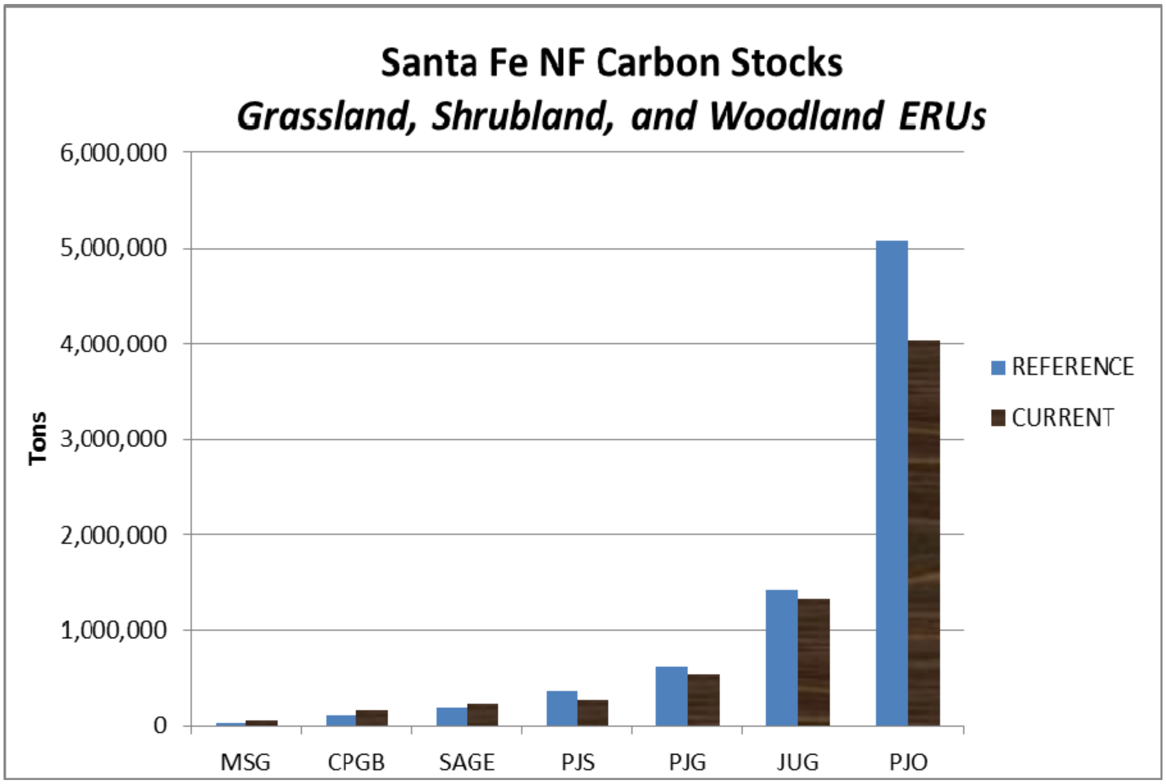


Figure 59. Biomass carbon stock by grassland, shrubland and woodland ERUs in current and reference conditions

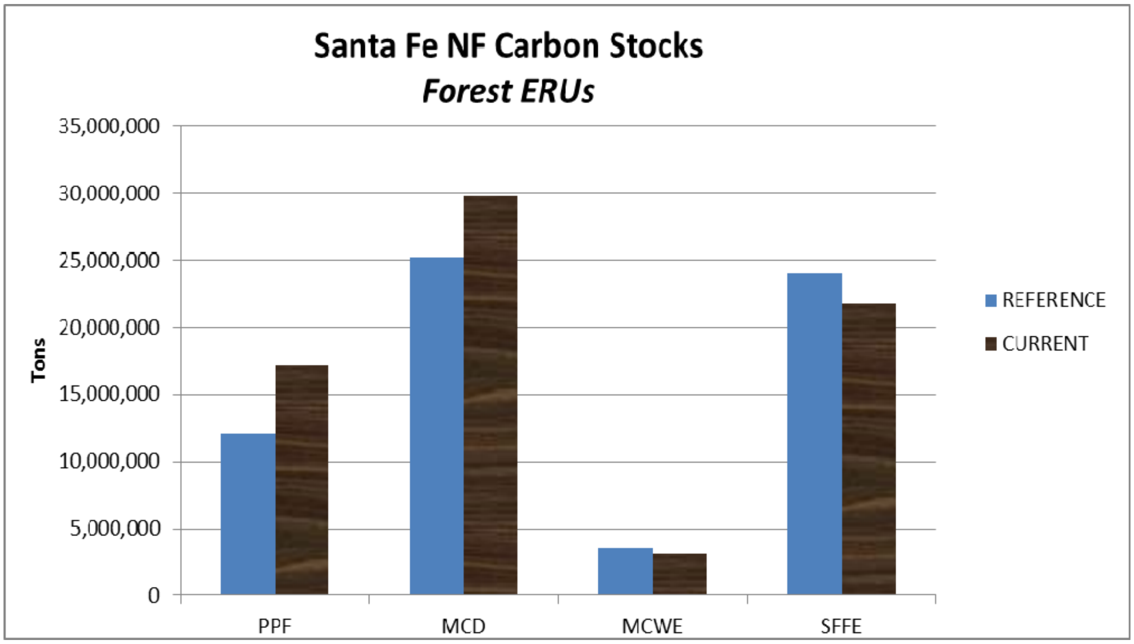


Figure 60. Biomass carbon stock by Forest ERU in current and reference conditions

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.[23] This allows the projection of relative biomass carbon contributions through time for key ERUs. 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.

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

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[23] Modeling was conducted by the Santa Fe National Forest and Region 3 staff, August 2014 – April 2015.

shrubland ERUs; (Brooks and Pyke 2000, Boyd and Bidwell 2001, Scott and Burgan 2005)) 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). 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 above-ground 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.

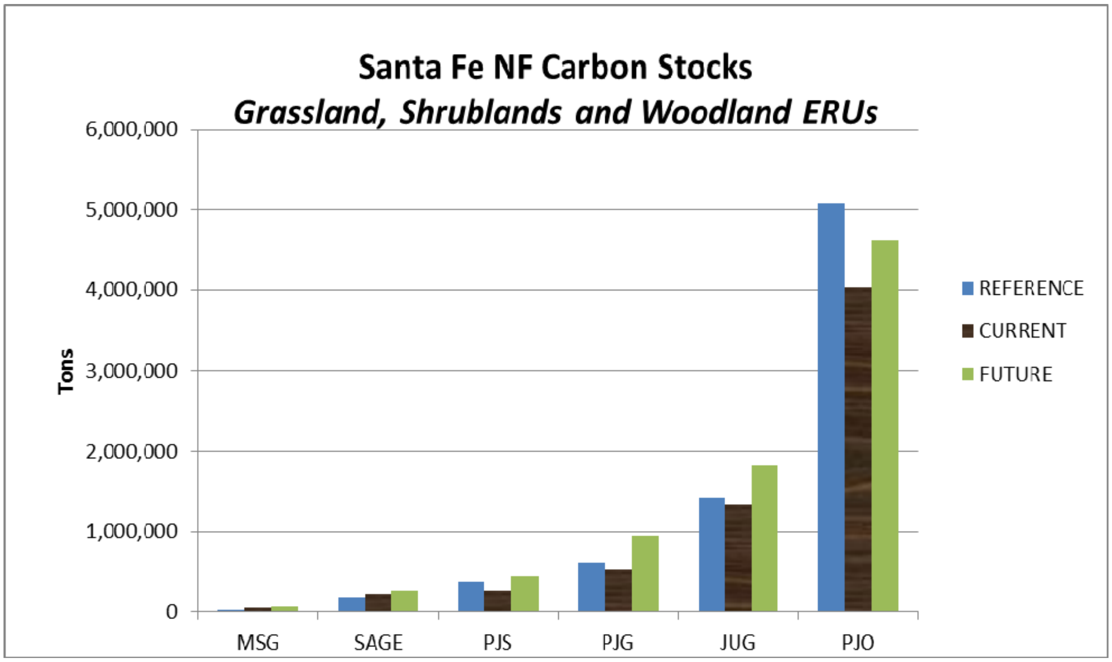

Figure 61. Trends in carbon stocks for Santa Fe NF grassland, shrubland and woodland ERUs

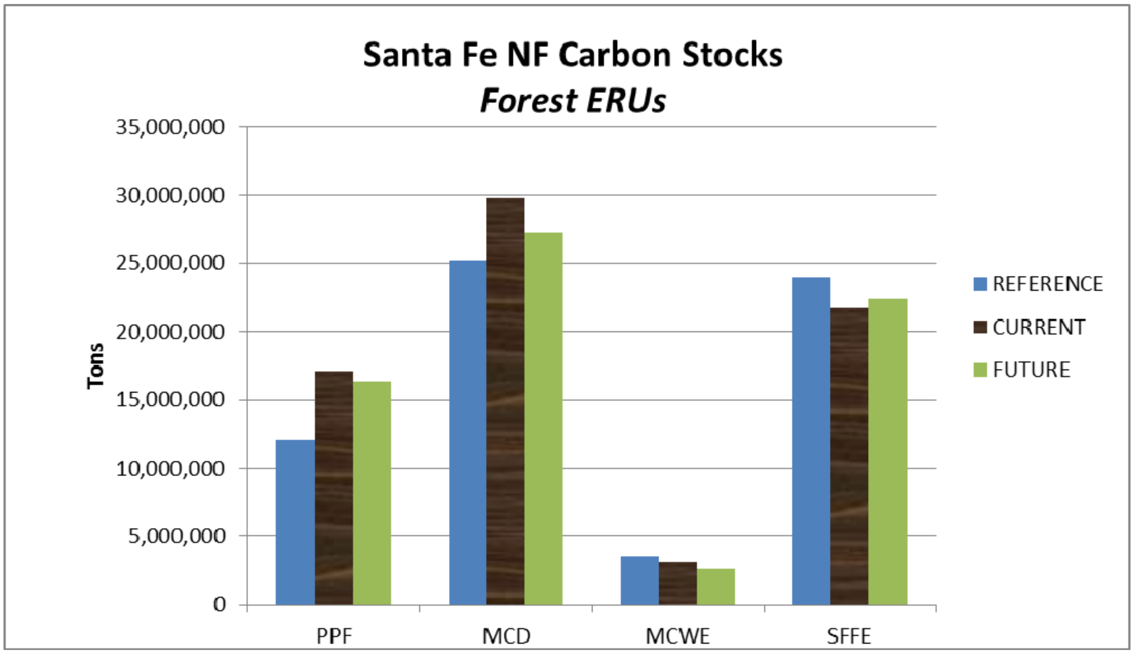

Figure 62. Trends in carbon stocks for Santa Fe NF forest ERUs

Table 71. 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 61 and figure 62 depict 100-year projections for primary Santa Fe NF ERUs against current and reference conditions. Projected change from current conditions is also in table 71. 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 assess 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 72).

Table 72. 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 United States 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, Hurteau and Wiedinmyer 2010, Hurteau et al. 2011)) 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 (Pollet and Omi 2002, Kobziar et al. 2009, Martinson and Omi 2013), 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 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 Apache-Sitgreaves 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. (2013) study did not consider the effects of forest restoration per se (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 Apache-Sitgreaves 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 70 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 to 3 tons per acre), while the moist forest systems had the greatest (88 tons per acre in MCWE and 96 tons per acre 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 61) 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 above-ground 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 carbon 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 Apache-Sitgreaves 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). Other 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 Apache-Sitgreaves 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, Peñuelas 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, Hurteau and North 2010, Keith 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.***

Input Received from Public Meetings

This section summarizes input, perspectives, and feedback relevant to this assessment topic and received from the public between April and July 2014. Input was gathered from 14 public meetings and "User Value and Trends Forms" available at all Santa Fe NF office and online. Additional input was gathered from individual meetings held with the Natural Resource staff and leadership from Tribes, Pueblos and Navajo Chapter Houses. The Draft Assessment and 12 focus areas that were identified as having the greatest needs for different plan direction were released in October 2015. This was followed by a full day public symposium to present findings from the Draft Assessment and 10 public meetings and 2 tribal meetings where findings from the 12 focus areas were presented.

One participant in Pecos highlighted the value of healthy forests in providing for better carbon management.

References

(TNC), T. N. C. 2006. Southwest Forest Assessment Project: Historical range of variation and state and transition modeling of historical and current landscape conditions for potential natural vegetation types of the southwestern U.S. Technical Report.

Abernethy, B., and I. D. Rutherfurd. 2001. The distribution and strength of riparian tree roots in relation to riverbank reinforcement. Hydrological processes **15**:63-79.

Adams, H. D., and T. E. Kolb. 2005. Tree growth response to drought and temperature in a mountain landscape in northern Arizona, USA. Journal of Biogeography **32**:1629-1640.

Agee, J. 1993. Fire ecology of Pacific Northwest forests Island Press. Washington, DC:493.

Albini, F. A. 1976. Estimating wildfire behavior and effects.

Allen, C. D. 1984. Montane grasslands in the landscape of the Jemez Mountains, New Mexico. University of Wisconsin--Madison.

Allen, C. D. 1996. Elk response to the La Mesa fire and current status in the Jemez Mountains. Pages 179-195 *in* Allen, CD (Tech. Ed.), Fire effects in southwestern forests. Proceedings of the second La Mesa Fire symposium. USDA Forest Service General Technical Report RM-GTR-286.

Allen, C. D. 2002. Lots of lightning and plenty of people: an ecological history of fire in the upland Southwest. Island Press, Washington, DC.

Allen, C. D. 2007. Interactions Across Spatial Scales among Forest Dieback, Fire, and Erosion in Northern New Mexico Landscapes. Ecosystems **10**:797-808.

Allen, C. D., R. S. Anderson, R. B. Jass, J. L. Toney, and C. H. Baisan. 2008a. HIGH-FREQUENCY HOLOCENE FIRE FROM TWO NEW MEXICO BOG SITES: PAIRED CHARCOAL AND TREE-RING RECORDS.

Allen, C. D., R. S. Anderson, R. B. Jass, J. L. Toney, and C. H. Baisan. 2008b. Paired charcoal and tree-ring records of high-frequency Holocene fire from two New Mexico bog sites. International Journal of Wildland Fire **17**:115-130.

Allen, C. D., and D. D. Breshears. 1998. Drought-induced shift of a forest–woodland ecotone: rapid landscape response to climate variation. Proceedings of the National Academy of Sciences **95**:14839-14842.

Allen, C. D., M. Savage, D. A. Falk, K. F. Suckling, T. W. Swetnam, T. Schulke, P. B. Stacey, P. Morgan, M. Hoffman, and J. T. Klingel. 2002. Ecological restoration of southwestern ponderosa pine ecosystems: a broad perspective. Ecological Applications **12**:1418-1433.

Allen, C. D., R. Touchan, and T. W. Swetnam. 1995. Landscape-scale fire history studies support fire management action at Bandelier. Park Science **15**:18-19.

Allen, G. D. 1989. Changes in the landscape of the Jemez Mountians, New Mexico. University of California Berkeley.

Alves, J. E., K. A. Patten, D. E. Brauch, and P. M. Jones. 2008. Range-wide Status of Rio Grande Cutthroat Trout (Oncorhynchus clarki virginalis): 2008., Monte Vista, CO.

Andrews, S. R., and J. P. Daniels. 1960. A survey of dwarfmistletoes in Arizona and New Mexico. Station Paper. Rocky Mountain Forest and Range Experiment Station.

Archer, D. 2011. Global warming: understanding the forecast. John Wiley & Sons.

ARCTOS. 2014. Arctos Collection Management Information System.

Bahre, C. J., and M. L. Shelton. 1993. Historic vegetation change, mesquite increases, and climate in southeastern Arizona. Journal of Biogeography:489-504.

Bailey, R. G. 1983. Ecoregions of the United States. Environmental Management **7**:365-373.

Baisan, C. H., and T. W. Swetnam. 1990. Fire history on a desert mountain range: Rincon Mountain Wilderness, Arizona, USA. Canadian Journal of Forest Research **20**:1559-1569.

Baker, W. L. 1989. A review of models of landscape change. Landscape ecology **2**:111-133.

Baker, W. L. 2006. Fire history in ponderosa pine landscapes of Grand Canyon National Park: is it reliable enough for management and restoration? International Journal of Wildland Fire **15**:433-437.

Bale, J. S., G. J. Masters, I. D. Hodkinson, C. Awmack, T. M. Bezemer, V. K. Brown, J. Butterfield, A. Buse, J. C. Coulson, and J. Farrar. 2002. Herbivory in global climate change research: direct effects of rising temperature on insect herbivores. Global Change Biology **8**:1-16.

Barnett, T. P., D. W. Pierce, H. G. Hidalgo, C. Bonfils, B. D. Santer, T. Das, G. Bala, A. W. Wood, T. Nozawa, A. A. Mirin, D. R. Cayan, and M. D. Dettinger. 2008. Human-induced changes in the hydrology of the western United States. science **319**:1080-1083.

Baron, J. S., N. L. Poff, P. L. Angermeier, C. N. Dahm, P. H. Gleick, N. G. Hairston Jr, R. B. Jackson, C. A. Johnston, B. D. Richter, and A. D. Steinman. 2002. Meeting ecological and societal needs for freshwater. Ecological Applications **12**:1247-1260.

Barrett, S. W., T. DeMeo, J. L. Jones, J. Zeiler, and L. C. Hutter. 2006. Assessing ecological departure from reference conditions with the Fire Regime Condition Class (FRCC) mapping tool.

Bate, L. J., E. O. Garton, and M. J. Wisdom. 1999. Estimating snag and large tree densities and distributions on a landscape for wildlife management.

Belsky, A. J., A. Matzke, and S. Uselman. 1999. Survey of livestock influences on stream and riparian ecosystems in the western United States. Journal of Soil and Water Conservation **54**:419-431.

Bender, D. J., T. A. Contreras, and L. Fahrig. 1998. Habitat loss and population decline: a meta-analysis of the patch size effect. Ecology **79**:517-533.

Betancourt, J. L., E. A. Pierson, K. A. Rylander, J. A. Fairchild-Parks, and J. S. Dean. 1993. Influence of history and climate on New Mexico piñon-juniper woodlands. Managing pinon-juniper ecosystems for sustainability and social needs. Gen. Tech. Rep. RM-236. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station:42-62.

Bigler, C., D. G. Gavin, C. Gunning, and T. T. Veblen. 2007. Drought induces lagged tree mortality in a subalpine forest in the Rocky Mountains. Oikos **116**:1983-1994.

BISON-M. 2014a. Biota Information System of New Mexico.

BISON-M. 2014b. Biota Information System of New Mexico. BISON-M.

Bowman, D. M., J. K. Balch, P. Artaxo, W. J. Bond, J. M. Carlson, M. A. Cochrane, C. M. D'Antonio, R. S. DeFries, J. C. Doyle, and S. P. Harrison. 2009. Fire in the Earth system. science **324**:481-484.

Bowman, W. D., J. R. Larson, K. Holland, M. Wiedermann, and J. Nieves. 2006. Nitrogen critical loads for alpine vegetations and ecosystem response: are we there yet? Ecological Applications **16**:1183-1193.

Boyd, C. S., and T. G. Bidwell. 2001. Influence of prescribed fire on lesser prairie-chicken habitat in shinnery oak communities in western Oklahoma. Wildlife Society Bulletin:938-947.

Brawn, J. D., and R. P. Balda. 1988. The influence of silvicultural activity on ponderosa pine forest bird communities in the southwestern United States.

Brinson, M. M., and A. I. Malvárez. 2002. Temperate freshwater wetlands: types, status, and threats. Environmental conservation **29**:115-133.

Brooks, M. L., and D. A. Pyke. 2000. Invasive plants and fire in the deserts of North America. Pages 1-14 *in* Proceedings of the invasive species workshop: the role of fire in the control and spread of invasive species. Fire conference.

Brown, J. K. 1995. Fire regimes and their relevance to ecosystem management.*in* Society of American Foresters. Convention (USA).

Brown, J. K., E. D. Reinhardt, and K. A. Kramer. 2003. Coarse woody debris: managing benefits and fire hazard in the recovering forest. US Department of Agriculture, Forest Service, Rocky Mountain Research Station.

BugGuide. 2014. BugGuide.net.

Bull, E. L., C. G. Parks, and T. R. Torgersen. 1997. Trees and logs important to wildlife in the interior Columbia River basin.

Cameron, R. E., C. R. Hennigar, D. A. MacLean, G. W. Adams, and T. A. Erdle. 2013. A comprehensive greenhouse gas balance for a forest company operating in northeast North America. Journal of Forestry **111**:194-205.

Cannon, S. H., and S. L. Reneau. 2000. Conditions for generation of fire-related debris flows, Capulin Canyon, New Mexico. Earth Surface Processes and Landforms **25**:1103-1121.

Castetter, E. F. 1956. The vegetation of New Mexico. University of New Mexico.

CASTNET. 2015. Clean Air Status Trends Network (CASTNET) Website. Clean Air Status Trends Network: Sulfur and Nitrogen Deposition Monitoring Data. .

Cayan, D. R. 1996. Interannual climate variability and snowpack in the western United States. Journal of Climate **9**:928-948.

CEC. 1997. Ecological regions of North America: Toward a common perspective. (Commision for Environmental Cooperation).

Chambers, C. L., and R. S. Holthausen. 2000. Montane ecosystems used as rangelands. Livestock management in the American Southwest: ecology, society, and economics. New York: Elsevier:213-281.

Chaney, E., W. Elmore, and W. S. Platts. 1990. Livestock grazing on western riparian areas.

Clamusso, B., and J. N. Rinne. 2009. Distribution of Rio Grande Cutthroat Trout and its co-occurrence with the Rio Grande Sucker and Rio Grande Chub on the Carson and Santa Fe National Forest., Flagstaff, AZ.

Clark, J. S. 1988. Particle motion and the theory of charcoal analysis: source area, transport, deposition, and sampling. Quaternary Research **30**:67-80.

Clark, J. S. 1990. Fire and climate change during the last 750 yr in northwestern Minnesota. Ecological monographs **60**:135-159.

Cleland, D. T., P. E. Avers, W. H. McNab, M. E. Jensen, R. G. Bailey, T. King, and W. E. Russell. 1997a. National hierarchical framework of ecological units. Ecosystem management applications for sustainable forest and wildlife resources:181-200.

Cleland, D. T., P. E. Avers, W. H. McNab, M. E. Jensen, R. G. Bailey, T. King, and W. E. Russell. 1997b. National hierarchical framework of ecological units. Ecosystem management applications for sustainable forest and wildlife resources. Yale University Press, New Haven, CT:181-200.

Comer, P., D. Faber-Langendoen, R. Evans, S. Gawler, C. Josse, G. Kittel, S. Menard, M. Pyne, M. Reid, K. Schulz, K. Snow, and J. Teague. 2003. Ecological Systems of the United States: A working classification of U.S. Terrestrial Systems. Nature Serve, Arlington Virginia.

Corenblit, D., J. Steiger, A. M. Gurnell, and R. J. Naiman. 2009. Plants intertwine fluvial landform dynamics with ecological succession and natural selection: a niche construction perspective for riparian systems. Global Ecology and Biogeography **18**:507-520.

Covington, W. W. 2003. Restoring ecosystem health in frequent-fire forests of the American West.

Covington, W. W., P. Z. Fule, M. M. Moore, S. C. Hart, T. E. Kolb, J. N. Mast, S. S. Sackett, and M. R. Wagner. 1997. Restoring ecosystem health in ponderosa pine forests of the Southwest. Journal of Forestry **95**:23.

Covington, W. W., and M. M. Moore. 1994a. Postsettlement changes in natural fire regimes and forest structure: ecological restoration of old-growth ponderosa pine forests. Journal of Sustainable Forestry **2**:153-181.

Covington, W. W., and M. M. Moore. 1994b. Southwestern Ponderosa Forest Structure: Changes Since Euro-American Settlement.

Covington, W. W., and S. Sackett. 1986. Effect of periodic burning on soil nitrogen concentrations in ponderosa pine. Soil Science Society of America Journal **50**:452-457.

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1985. Classification of wetlands and deepwater habitats of the United States. US Fish and Wildlife Service.

Dahl, T. E. 1990. Wetlands losses in the United States, 1780's to 1980's. Report to the Congress. National Wetlands Inventory, St. Petersburg, FL (USA).

Dahms, C. W., and B. W. Geils. 1997. An assessment of forest ecosystem health in the Southwest.

Dale, V., S. la JoyceMcNulty, R. Neilson, M. Ayres, and M. Flannigan. 2000. Forest disturbances and climate change.

Dall, D., C. Elliott, and D. Peters. 2009. A system for mapping riparian areas in the western United States. USDI Fish and Wildlife Service, National Wetlands Inventory, Lakewood, CO.

Daubenmire, R. 1968. Plant communities. A textbook of plant synecology. Plant communities. A textbook of plant synecology.

Davenport, D. W., D. D. Breshears, B. P. Wilcox, and C. D. Allen. 1998. Viewpoint: sustainability of piñon-juniper ecosystems: a unifying perspective of soil erosion thresholds. Journal of Range Management:231-240.

DeBano, L. F., D. G. Neary, and P. F. Ffolliott. 1998. Fire effects on ecosystems. John Wiley & Sons.

Delcourt, P. A., and H. R. Delcourt. 1983. Late-Quaternary vegetational dynamics and community stability reconsidered. Quaternary Research **19**:265-271.

Dick-Peddie, W. 1993. New Mexico vegetation: past, present, and future. Univ. New Mexico Press, Albuquerque.

Dixon, G. E. 2002. Essential FVS: A user's guide to the Forest Vegetation Simulator. Fort Collins, CO: USDA-Forest Service, Forest Management Service Center.

Dore, S., T. E. Kolb, M. Montes-Helu, B. Sullivan, W. Winslow, S. Hart, J. Kaye, G. W. Koch, and B. A. Hungate. 2008. Long-term impact of a stand-replacing fire on ecosystem CO2 exchange of a Ponderosa pine forest. Global Change Biology **14**:1801-1820.

Driscoll, C. T., G. B. Lawrence, A. J. Bulger, T. J. Butler, C. S. Cronan, C. Eagar, K. F. Lambert, G. E. Likens, J. L. Stoddard, and K. C. Weathers. 2001. Acid rain revisited: advances in scientific understanding since the passage of the 1970 and 1990 Clean Air Act Amendments. . Hubbard Brook Research Foundation. **1**.

Dunne, T., and L. B. Leopold. 1978. Water in environmental planning. Macmillan.

Durkin, P., E. Muldavin, M. Bradley, and S. E. Carr. 1995. A preliminary riparian/wetland vegetation community classification of the Upper and Middle Rio Grande watersheds in New Mexico. United States Department of Agriculture Forest Service:44-57.

eBird. 2014. eBird.

Eidenshink, J., B. Schwind, K. Brewer, Z. Zhu, B. Quayle, and S. Howard. 2007. A project for monitoring trends in burn severity. Fire Ecology 3 (1): 3-21. Fire Ecology Special Issue Vol **3**:4.

EMNRD. 2010. New Mexico Statewide Natural Resource Assessment & Strategy and Response Plans. Energy, Minerals, and Natural Resources Department, Forestry Division, Santa Fe, NM.

ESSA. 2006. Vegetation dynamics development tool user guide. Version 6.0.25. ESSA Technologies Ltd., Vancouver, BC, Canada.

Evans, A. M., R. G. Everett, S. L. Stephens, and J. Youlz. 2011. Comprehensive fuels treatment practices guide for mixed conifer forests: California, central and southern Rockies, and the Southwest.

FED. 2015. Federal Land Manager Environmental Database: Interagency Monitoring of Protected Visual Environment (IMPROVE) Monitoring Data.

Ffolliott, P., and D. Neary. 2003. Impacts of a historical wildfire on hydrologic processes: A case study in Arizona.*in* Proceedings of the American Water Resources Association international congress on watershed management for water supply systems.

Ffolliott, P. F., and G. J. Gottfried. 2002. Dynamics of a pinyon-juniper stand in northern Arizona: a half-century history.

Finch, D. M., J. C. Whitney, J. F. Kelly, and S. R. Loftin. 1999. Rio Grande ecosystems: linking land, water, and people: Toward a sustainable future for the Middle Rio Grande Basin.

Finco, M., B. Quayle, Y. Zhang, J. Lecker, K. A. Megown, and C. K. Brewer. 2012. Monitoring trends and burn severity (MTBS): monitoring wildfire activity for the past quarter century using Landsat data.

Fish, S. K. 2006. . Modeling human impacts to the Borderlands environment from a fire ecology perspective.

Fisher, M. A., and P. Z. Fulé. 2004. Changes in forest vegetation and arbuscular mycorrhizae along a steep elevation gradient in Arizona. Forest Ecology and Management **200**:293-311.

Fitch, E. 2013. Holocene Fire-Related Alluvial Chronology And Geomorphic Implications In The Jemez Moutains, New Mexico.

Flannigan, M. D., M. A. Krawchuk, W. J. de Groot, B. M. Wotton, and L. M. Gowman. 2009. Implications of changing climate for global wildland fire. International Journal of Wildland Fire **18**:483-507.

Fleischner, T. L. 1994. Ecological costs of livestock grazing in western North America. Conservation Biology **8**:629-644.

Fletcher, R., and W. A. Robbie. 2004. Historic and current conditions of southwestern grasslands.

Floyd, M. L., M. Clifford, N. S. Cobb, D. Hanna, R. Delph, P. Ford, and D. Turner. 2009. Relationship of stand characteristics to drought-induced mortality in three Southwestern pinon-juniper woodlands. Ecological Applications **19**:1223-1230.

Fulé, P. Z., W. W. Covington, and M. M. Moore. 1997. Determining reference conditions for ecosystem management of southwestern ponderosa pine forests. Ecological Applications **7**:895-908.

Fulé, P. Z., W. W. Covington, M. M. Moore, T. A. Heinlein, and A. E. Waltz. 2002. Natural variability in forests of the Grand Canyon, USA. Journal of Biogeography **29**:31-47.

Fulé, P. Z., J. E. Crouse, A. E. Cocke, M. M. Moore, and W. W. Covington. 2004. Changes in canopy fuels and potential fire behavior 1880–2040: Grand Canyon, Arizona. Ecological Modelling **175**:231-248.

Fulé, P. Z., J. E. Crouse, T. A. Heinlein, M. M. Moore, W. W. Covington, and G. Verkamp. 2003. Mixed-severity fire regime in a high-elevation forest of Grand Canyon, Arizona, USA. Landscape ecology **18**:465-486.

Fule, P. Z., J. E. Korb, and R. Wu. 2009. Changes in forest structure of a mixed conifer forest, southwestern Colorado, USA. Forest Ecology and Management **258**:1200-1210.

Furniss, M. J. 2010. Water, climate change, and forests: watershed stewardship for a changing climate. DIANE Publishing.

Ganey, J. L. 1999. Snag density and composition of snag populations on two National Forests in northern Arizona. Forest Ecology and Management **117**:169-178.

Ganey, J. L., and S. C. Vojta. 2011. Tree mortality in drought-stressed mixed-conifer and ponderosa pine forests, Arizona, USA. Forest Ecology and Management **261**:162-168.

Gavin, D. G., D. J. Hallett, F. S. Hu, K. P. Lertzman, S. J. Prichard, K. J. Brown, J. A. Lynch, P. Bartlein, and D. L. Peterson. 2007. Forest fire and climate change in western North America: insights from sediment charcoal records. Frontiers in Ecology and the Environment **5**:499-506.

Gecy, J. L., and M. V. Wilson. 1990. Initial establishment of riparian vegetation after disturbance by debris flows in Oregon. American Midland Naturalist:282-291.

Geiser, L. H., S.E Jovan, D.A. Glavich, and M.K. Porter. . 2010. Lichen-Based Critical Loads for Atmospheric Nitrogen Deposition in Western Oregon and Washington Forests, USA. Environmental Pollution **158**:2412-2421.

Gilliam, F. S. 2007. The Ecological Significance of the Herbaceous Layer in Temperate Forest Ecosystems. BioScience **57**:845-858.

Gottfried, G. J. 2004. Silvics and silviculture in the southwestern pinyon-juniper woodlands.

Graf, W. L. 1993. Landscapes, commodities, and ecosystems: The relationship between policy and science for American rivers. Sustaining our water resources:11-42.

Graham, N. E., and H. F. Diaz. 2001. Evidence for intensification of North Pacific winter cyclones since 1948. Bulletin of the American Meteorological Society **82**:1869-1893.

Gregory, S. V., F. J. Swanson, W. A. McKee, and K. W. Cummins. 1991. An ecosystem perspective of riparian zones. BioScience **41**:540-551.

Griffith, M. B., H. B. H., F. H. McCormick, P. R. Kaufmann, A. T. Herlihy, and A. R. Selle. 2005. Comparative application of indices of biotic integrity based on periphyton, macroinvertebrates, and fish to southern Rocky Mountain streams. Ecological Indicators **5**:117-136.

Grissino-Mayer, H. D., C. H. Baisan, and T. W. Swetnam. 1994. Fire history in the Pinaleño Mountains of southeastern Arizona: effects of human-related disturbances. United States Department Of Agriculture Forest Service General Technical Report:399-407.

Grissino-Mayer, H. D., W. H. Romme, M. Lisa Floyd, and D. D. Hanna. 2004. Climatic and human influences on fire regimes of the southern San Juan Mountains, Colorado, USA. Ecology **85**:1708-1724.

Gruell, G. E. 1999. Historical and modern roles of fire in pinyon-juniper.

Hall, F. C., L. Bryant, R. Clausnitzer, K. Geier-Hayes, R. Keane, J. Kertis, A. Shlisky, and R. Steel. 1995. Definitions and codes for seral status and structure of vegetation.

Hamlet, A. F., and D. P. Lettenmaier. 2007. Effects of 20th century warming and climate variability on flood risk in the western US. Water Resources Research **43**.

Hand, J. L., S. A. Copeland, D. E. Day, A. M. Dillner, H. Indresand, W. C. Malm, C. E. McDade, C. T. Moore, M. L. Pitchford, B. A. Schichtel, and J. G. Watson. 2011. Spatial and Seasonal Patterns and Temporal Variability of Haze and its Constituents in the United States: Report V: June 2011. .

Hann, W., A. Shlisky, D. Havlina, K. Schon, S. Barrett, T. DeMeo, K. Pohl, J. Menakis, D. Hamilton, and J. Jones. 2004. Interagency fire regime condition class guidebook. Interagency and The Nature Conservancy Fire Regime Condition Class website. USDA Forest Service, US Department of the Interior, The Nature Conservancy, and Systems for Environmental Management. Available online: www. frcc. gov.

Hardy, C. C., J. P. Menakis, D. G. Long, J. K. Brown, and D. L. Bunnell. 1998. Mapping historic fire regimes for the western United States: integrating remote sensing and biophysical data. Pages 6-9 *in* Proceedings of the 7th biennial Forest Service remote sensing applications conference.

Hardy, C. C., K. M. Schmidt, J. P. Menakis, and R. N. Sampson. 2001. Spatial data for national fire planning and fuel management. International Journal of Wildland Fire **10**:353-372.

Harrington, M. G., and S. S. Sackett. 1990. Using fire as a management tool in southwestern ponderosa pine.*in* Effects of fire management of southwestern natural resources, proceedings of the symposium. Gen. Tech. Rep. RM-191. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Harrington, M. G., and S. S. Sackett. 1992. Past and Present Fire Influences on Southwestern Ponderosa Pine Old Growth1. Page 44 *in* Old-growth forests in the Southwest and Rocky Mountain regions: proceedings of a workshop, March 9-13, 1992, Portal, Arizona. Rocky Mountain Forest and Range Experiment Station, Forest Service, US Dept. of Agriculture.

Heinlein, T. A., M. M. Moore, P. Z. Fulé, and W. W. Covington. 2005. Fire history and stand structure of two ponderosa pine-mixed conifer sites: San Francisco Peaks, Arizona, USA. International Journal of Wildland Fire **14**:307-320.

Heinselman, M. L. 1981. Fire intensity and frequency as factors in the distribution and structure of northern ecosystems [Canadian and Alaskan boreal forests, Rocky Mountain subalpine forests, Great Lakes-Acadian forests, includes history, management; Canada; USA]. USDA Forest Service General Technical Report WO.

Hilsenhoff, W. L. 1987. An improved Biotic Index of organic stream pollution. The Great Lakes Entomologist **20**:31-36.

Hobbs, R. J., and L. F. Huenneke. 1992. Disturbance, diversity, and invasion: implications for conservation. Conservation Biology **6**:324-337.

Horton, S. P., and R. W. Mannan. 1988. Effects of prescribed fire on snags and cavity-nesting birds in southeastern Arizona pine forests. Wildlife Society Bulletin (1973-2006) **16**:37-44.

Huang, C. Y., and W. R. Anderegg. 2012. Large drought-induced aboveground live biomass losses in southern rocky mountain aspen forests. Global Change Biology **18**:1016-1027.

Huffman, D. W., P. Z. Fule, K. M. Pearson, and J. E. Crouse. 2008. Fire history of pinyon-juniper woodlands at upper ecotones with ponderosa pine forests in Arizona and New Mexico. Canadian Journal of Forest Research **38**:2097-2108.

Humphrey, R. R. 1958. The desert grassland a history of vegetational change and an analysis of causes. The Botanical Review **24**:193-252.

Hurteau, M. D., G. W. Koch, and B. A. Hungate. 2008. Carbon protection and fire risk reduction: toward a full accounting of forest carbon offsets. Frontiers in Ecology and the Environment **6**:493-498.

Hurteau, M. D., and M. North. 2010. Carbon recovery rates following different wildfire risk mitigation treatments. Forest Ecology and Management **260**:930-937.

Hurteau, M. D., M. T. Stoddard, and P. Z. Fule. 2011. The carbon costs of mitigating high-severity wildfire in southwestern ponderosa pine. Global Change Biology **17**:1516-1521.

Hurteau, M. D., and C. Wiedinmyer. 2010. Response to comment on "prescribed fire as a means of reducing forest carbon emissions in the western United States". Environmental Science & Technology **44**:6521-6521.

iNaturalist. 2014. iNaturalist.org.

Iniguez, J. M., T. W. Swetnam, and C. H. Baisa. 2009. Spatially and temporally variable fire regime on Rincon Peak, Arizona, USA.

IPCC. 2007. Intergovernmental panel on climate change. IPCC Secretariat Geneva.

Jenkins, S. E., C. H. Sieg, D. E. Anderson, D. S. Kaufman, and P. A. Pearthree. 2011. Late Holocene geomorphic record of fire in ponderosa pine and mixed-conifer forests, Kendrick Mountain, northern Arizona, USA. International Journal of Wildland Fire **20**:125-141.

Johansen, M. P., T. E. Hakonson, and D. D. Breshears. 2001. Post-fire runoff and erosion from rainfall simulation: contrasting forests with shrublands and grasslands. Hydrological processes **15**:2953-2965.

Jones, J., N. DeByle, and R. Winokur. 1985. Aspen: ecology and management in the western United States. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station General Technical Report RM-119.(Fort Collins, CO).

Kaller, M. D., and K. J. Hartman. 2004. Evidence of a threshold level of fine sediments accumulation for altering benthic macroinvertebrate communities. Hydrobiologia **518**:95-104.

Kaufmann, G. A., and W. W. Covington. 2001. Effect of prescribed burning on mortality of resettlement ponderosa pines in Grand Canyon National Park.

Kaufmann, M. R., D. Binkley, P. Z. Fulé, J. Marlin, S. L. Stephens, and T. W. Swetnam. 2007. Defining old growth for fire-adapted forests of the western United States.

Keane, R. E., P. F. Hessburg, P. B. Landres, and F. J. Swanson. 2009. The use of historical range and variability (HRV) in landscape management. Forest Ecology and Management **258**:1025-1037.

Keane, R. E., K. C. Ryan, and M. A. Finney. 1998. Simulating the consequences of fire and climate regimes on a complex landscape in Glacier National Park. Montana:310-324.

Keith, H., B. Mackey, S. Berry, D. Lindenmayer, and P. Gibbons. 2010. Estimating carbon carrying capacity in natural forest ecosystems across heterogeneous landscapes: addressing sources of error. Global Change Biology **16**:2971-2989.

Keith, H., B. G. Mackey, and D. B. Lindenmayer. 2009. Re-evaluation of forest biomass carbon stocks and lessons from the world's most carbon-dense forests. Proceedings of the National Academy of Sciences **106**:11635-11640.

Kenny, J. F., N. L. Barber, S. S. Hutson, K. S. Linsey, J. K. Lovelace, and M. A. Maupin. 2009. Estimated use of water in the United States in 2005. US Geological Survey.

Knight, R. L., G. N. Wallace, and W. E. Riebsame. 1995. Ranching the view: subdivisions versus agriculture. Conservation Biology **9**:459-461.

Knowles, N., M. D. Dettinger, and D. R. Cayan. 2006. Trends in snowfall versus rainfall in the western United States. Journal of Climate **19**:4545-4559.

Knutson, K., and V. Naef. 1995. Priority habitat management recommendations: riparian. Washington Department of Fish and Wildlife, Olympia, WA.

Kobziar, L. N., J. R. McBride, and S. L. Stephens. 2009. The efficacy of fire and fuels reduction treatments in a Sierra Nevada pine plantation. International Journal of Wildland Fire **18**:791-801.

Krist, F. J. 2014. 2013-2027 National Insect and Disease Forest Risk Assessment. US Department of Agriculture, Forest Service, Forest Health Technology Enterprise Team.

Kulakowski, D., and T. T. Veblen. 2002. Influences of fire history and topography on the pattern of a severe wind blowdown in a Colorado subalpine forest. Journal of Ecology **90**:806-819.

LANDFIRE. 2014. Biophysical Settings.

Landres, P. B., P. Morgan, and F. J. Swanson. 1999. Overview of the use of natural variability concepts in managing ecological systems. Ecological Applications **9**:1179-1188.

Laughlin, D. C., J. D. Bakker, and P. Z. Fulé. 2005. Understorey plant community structure in lower montane and subalpine forests, Grand Canyon National Park, USA. Journal of Biogeography **32**:2083-2102.

Lawler, J. J., S. L. Shafer, D. White, P. Kareiva, E. P. Maurer, A. R. Blaustein, and P. J. Bartlein. 2009. Projected climate-induced faunal change in the Western Hemisphere. Ecology **90**:588-597.

Lehmkuhl, J. F., R. L. Everett, R. Schellhaas, P. Ohlson, D. Keenum, H. Riesterer, and D. Spurbeck. 2003. Cavities in snags along a wildfire chronosequence in eastern Washington. The Journal of Wildlife Management:219-228.

Lemly, J. M., and D. R. Culver. 2013. Field guide to Colorado's wetland plants: identification, ecology and conservation.

Lessard, G. D. 1976. The occurrence and control of the western spruce budworm in the Southwestern Region. Forest Insect and Disease Management **R3-75-26**:13 p.

Lindenmayer, D., J. Franklin, and J. Fischer. 2006. General management principles and a checklist of strategies to guide forest biodiversity conservation. Biological conservation **131**:433-445.

Logan, J. A., J. Regniere, and J. A. Powell. 2003. Assessing the impacts of global warming on forest pest dynamics. Frontiers in Ecology and the Environment **1**:130-137.

Luce, C. H., and Z. A. Holden. 2009. Declining annual streamflow distributions in the Pacific Northwest United States, 1948–2006. Geophysical Research Letters **36**.

Lynch, A. M., and T. Swetnam. 1992. Old-growth mixed-conifer and western spruce budworm in the southern Rocky Mountains. Old-growth forests in the Southwest and Rocky Mountain Regions. Edited by MR Kaufmann, WH Moir, and RL Bassett. USDA For. Serv. Gen. Tech. Rep. RM-GTR-213:66-80.

Lynch, J., L. H. Pardo, and C. Huber. 2012. Detailed documentation of the CLAD US critical loads of sulfur and nitrogen Access database, version 15.03.11 Created for the Critical Loads of Atmospheric Deposition (CLAD) Science Subcommittee of the National Atmospheric Deposition Program (NADP). .

MAB. 2005. Millennium ecosystem assessment. Washington, DC: New Island.

Mack, R. N., D. Simberloff, W. Mark Lonsdale, H. Evans, M. Clout, and F. A. Bazzaz. 2000. Biotic invasions: causes, epidemiology, global consequences, and control. Ecological Applications **10**:689-710.

Margolis, E. Q. 2014. Fire regime shift linked to increased forest density in a piñon–juniper savanna landscape. International Journal of Wildland Fire **23**:234-245.

Margolis, E. Q., and J. Balmat. 2009. Fire history and fire–climate relationships along a fire regime gradient in the Santa Fe Municipal Watershed, NM, USA. Forest Ecology and Management **258**:2416-2430.

Margolis, E. Q., T. W. Swetnam, and C. D. Allen. 2007. A stand-replacing fire history in upper montane forests of the southern Rocky Mountains. Canadian Journal of Forest Research **37**:2227-2241.

Margolis, E. Q., T. W. Swetnam, and C. D. Allen. 2011. Historical stand-replacing fire in upper montane forests of the Madrean Sky Islands and Mogollon Plateau, southwestern USA. Fire Ecology **7**:88-107.

Martinson, E. J., and P. N. Omi. 2013. Fuel treatments and fire severity: a meta-analysis.

Mast, J. N., and T. T. Veblen. 1999. Tree spatial patterns and stand development along the pine-grassland ecotone in the Colorado Front Range. Canadian Journal of Forest Research **29**:575-584.

McNab, W. H., D. T. Cleland, J. A. Freeouf, G. Nowacki, and C. Carpenter. 2007. Description of ecological subregions: sections of the conterminous United States.

McNulty, S. G., E. C. Cohen, J. A. M. Myers, T. J. Sullivan, and H. Li. 2007. Estimates of critical acid loads and exceedances for forest soils across the conterminous United States. . Environmental Pollution **149**:281-292.

McPherson, G. R., M. McClaran, and T. Van Devender. 1995. The role of fire in desert grasslands. The desert grassland:130-151.

MDN. 2013. Mercury Deposition Network. National Atmospheric Deposition Program. (NRSP-3). NADP Program Office, Illinois State Water Survey, 2204 Griffith Dr., Champaign, IL 61820. .

Mellin, T., W. Krausmann, and W. Robbie. 2004. The USDA Forest Service Southwestern Region mid-scale existing vegetation mapping project. Pages 1-6 *in* Remote sensing for field users: Proceedings of the 10 th Forest Service remote sensing conference. American Society of Photogrammetry and Remote Sensing.

Merritt, D. M., M. L. Scott, P. LeROY, G. T. Auble, and D. A. Lytle. 2010. Theory, methods and tools for determining environmental flows for riparian vegetation: riparian vegetation-flow response guilds. Freshwater biology **55**:206-225.

Miller, G., J. Redders, R. Stein, M. Edwards, J. Phillips, V. Andrews, S. Sebring, C. Vaandrager, and E. Benally Jr. 1993. Terrestrial ecosystems survey of the Santa Fe National Forest. USDA Forest Service, Southwestern Region.

Miller, R. F., and L. Eddleman. 2000. Spatial and temporal changes of sage grouse habitat in the sagebrush biome. Corvallis, Or.: Oregon State University, Agricultural Experiment Station.

Miller, R. F., and R. J. Tausch. 2000. The role of fire in pinyon and juniper woodlands: a descriptive analysis. Pages 15-30 *in* Proceedings of the invasive species workshop: the role of fire in the control and spread of invasive species. Fire conference.

Millspaugh, S. H., and C. Whitlock. 1995. A 750-year fire history based on lake sediment records in central Yellowstone National Park, USA. The Holocene **5**:283-292.

Moir, W. 1993. Alpine tundra and coniferous forest. Dick-Peddie WA New Mexico vegetation: past, present, and future. University of New Mexico Press, Albuquerque.

Moir, W. H., B. W. Geils, M. A. Benoit, and D. Scurlock. 1997. Ecology of southwestern ponderosa pine forests.

Montana Water Center. 2002. Learn About Whirling Disease. Montana Water Center Whirling Disease Initiative.

Moore, M. M., D. W. Huffman, P. Z. Fulé, W. W. Covington, and J. E. Crouse. 2004. Comparison of historical and contemporary forest structure and composition on permanent plots in southwestern ponderosa pine forests. Forest Science **50**:162-176.

Morgan, P., C. C. Hardy, T. W. Swetnam, M. G. Rollins, and D. G. Long. 2001. Mapping fire regimes across time and space: understanding coarse and fine-scale fire patterns. International Journal of Wildland Fire **10**:329-342.

Muldavin, E., and M. Bradley. 1998. Handbook of wetland vegetation communities of New Mexico. The Department.

NADP. 2009. National Atmospheric Deposition Program (NADP). Critical Loads, Evaluating the Effects of Airborne Pollutants on Terrestrial and Aquatic Ecosystems. .

NADP. 2013. National Atmospheric Deposition Program (NADP). National Atmospheric Deposition, National Trends Network, and Mercury Deposition Network Data. .

Naiman, R. J., J. S. Bechtold, D. C. Drake, J. J. Latterell, T. C. O'keefe, and E. V. Balian. 2005. Origins, patterns, and importance of heterogeneity in riparian systems. Pages 279-309 Ecosystem function in heterogeneous landscapes. Springer.

NatureServe, F. 2012. NatureServe Explorer: an online encyclopedia of life. NatureServe Arlington, Virginia.

Neary, D. G., and A. L. Medina. 1995. Geomorphic response of a montane riparian habitat to interactions of ungulate vegetation, and hydrology. USDA Forest Service, Rocky Mountain Forest and Research Station Gen. Tech. Rep. 272: 143-147.

Neary, D. G., K. C. Ryan, and L. F. DeBano. 2005. Wildland fire in ecosystems: effects of fire on soils and water.

New Mexico Office of the State Engineer. 2015. Office of the State Engineer.

New Mexico Water Resrouces Research Institute. 2014. Recharge Data Compilation and Recharge Area Identification for the State of New Mexico.

NHNM. 2014. Natural Heritage New Mexico.

Nilsson, C., and K. Berggren. 2000. Alterations of riparian ecosystems caused by river regulation dam operations have caused global-scale ecological changes in riparian ecosystems. How to protect river environments and human needs of rivers remains one of the most important questions of our time. BioScience **50**:783-792.

NM WQCC. 2012. Water Quality Standards for Interstate and Intrastate Streams.

NMBCC. 2013. New Mexico Biodiversity Collections Consortium.

NMDGF. 2006. New Mexico Comprehensive Wildlife Conservation Strategy.

NMDGF. 2009. Information on New Mexico's Fish Hatcheries.*in* Fisheries, editor. New Mexico Department of Game and Fish, Santa Fe, NM.

NMDGF. 2013. Stream Fish Population Surveys for New Mexico. Page Access Database. New Mexico Department of Game and Fish, Santa Fe, NM.

NMDGF. 2014. New Mexico streams whirling diesease sample data. New Mexico Department of Game and Fish, Santa Fe, NM.

NMED. 2003. Smoke Management.*in* E. Department, editor.

NMED. 2011. REVISION TO THE NEW MEXICO STATE IMPLEMENTATION PLAN FOR REGIONAL HAZE.

NMED. 2012a. 2012 – 2014 State of New Mexico Clean Water Act §303(d)/§305(b) Integrated Report.

NMED. 2012b. New Mexico Fish Consumption Advisories.

NMED. 2013. Revisions to New Mexico State Implementation Plans for Regional Haze and Clean Air Act Section 110(a)(2)(D)(ii). .

NMRPTC. 1999. New Mexico Rare Plant Technical Council - http://nmrareplants.unm.edu.

North, M., M. Hurteau, and J. Innes. 2009. Fire suppression and fuels treatment effects on mixed-conifer carbon stocks and emissions. Ecological Applications **19**:1385-1396.

NY DEC. 2014. Didymo (Rock Snot). New York State Department of Enviromental Conservation Nuisance and Invasive Species.

O'Connor, C. D., D. A. Falk, A. M. Lynch, and T. W. Swetnam. 2014. Fire severity, size, and climate associations diverge from historical precedent along an ecological gradient in the Pinaleño Mountains, Arizona, USA. Forest Ecology and Management **329**:264-278.

Pagano, T., and D. Garen. 2005. A recent increase in western US streamflow variability and persistence. Journal of Hydrometeorology **6**:173-179.

Pardo, L. 2011. Effects of Nitrogen Deposition and Empirical Nitrogen Critical Loads for Ecoregions of the United States. Ecological Applications **21**:3049-3082.

Pardo, L., M. Robin-Abbott, and C. Driscoll. 2011. Assessment of nitrogen deposition effect and empirical critical loads of nitrogen for ecoregions of the United States. . Page 291 *in* F. S. N. R. S. U.S. Department of Agriculture, editor.

Patten, D. T. 1998. Riparian ecosytems of semi-arid North America: Diversity and human impacts. Wetlands **18**:498-512.

Payer, D. C., and D. J. Harrison. 2003. Influence of forest structure on habitat use by American marten in an industrial forest. Forest Ecology and Management **179**:145-156.

Peñuelas, J., J. G. Canadell, and R. Ogaya. 2011. Increased water-use efficiency during the 20th century did not translate into enhanced tree growth. Global Ecology and Biogeography **20**:597-608.

Peters, D. P., B. T. Bestelmeyer, J. E. Herrick, E. L. Fredrickson, H. C. Monger, and K. M. Havstad. 2006. Disentangling complex landscapes: new insights into arid and semiarid system dynamics. BioScience **56**:491-501.

Pettit, N. E., and R. J. Naiman. 2007. Fire in the riparian zone: characteristics and ecological consequences. Ecosystems **10**:673-687.

Pidwirny, M. 2006. Acid Precipitation Fundamentals of Physical Geography.

Pollet, J., and P. N. Omi. 2002. Effect of thinning and prescribed burning on crown fire severity in ponderosa pine forests. International Journal of Wildland Fire **11**:1-10.

Potyondy, J. P., and T. W. Geier. 2011. Watershed condition classification technical guide. Washington, DC: US Department of Agriculture:5-6.

Prichard, D. 2003. user guide to assessing proper functioning condition and the supporting science for lentic areas.

Propst, D. L. 1999. Threatened and Endangered Fishes of New Mexico. Santa Fe, NM.

Prospero, J. M., and P. J. Lamb. 2003. African Droughts and Dust Transport to the Caribbean: Climate Change Implications. Science **302**:1024.

Raish, C., and A. M. McSweeney. 2008. Land grants and the US Forest Service. Nat. Resources J. **48**:1039.

Randall, J. M. 1996. Weed control for the preservation of biological diversity. Weed technology:370-383.

Regonda, S. K., B. Rajagopalan, M. Clark, and J. Pitlick. 2005. Seasonal cycle shifts in hydroclimatology over the western United States. Journal of Climate **18**:372-384.

Reinhardt, E., R. Keane, and J. Brown. 1997. First order fire effects model: FOFEM 4.0, users guide. Forest Service general technical report. Forest Service, Ogden, UT (United States). Intermountain Research Station.

Reynolds, R. T., R. T. Graham, and M. H. Reiser. 1992. Management recommendations for the northern goshawk in the southwestern United States.

Reynolds, R. T., A. J. S. Meador, J. A. Youtz, T. Nicolet, M. S. Matonis, P. L. Jackson, D. G. DeLorenzo, and A. D. Graves. 2013. Restoring composition and structure in Southwestern frequent-fire forests: A science-based framework for improving ecosystem resiliency.

Reynoldson, T. B., R. H. Norris, V. H. Resh, K. E. Day, and D. M. Rosenburg. 1997. The Reference Condition: A Comparison of Multimetric and Multivariate Approaches to Assess Water Quality Impairment Using Benthic Macroinvertebrates. Journal of the North American Benthological Society **16**:833-852.

RGCTWG. 2013. Rio Grande cutthroat trout distribution database. Rio Grande Cutthroat Trout Working Group, Monte Vista, CO.

RMBO. 2014. Rocky Mountain Bird Observatory.

Rollins, M. G. 2009. LANDFIRE: a nationally consistent vegetation, wildland fire, and fuel assessment. International Journal of Wildland Fire **18**:235-249.

Romme, W. H., C. D. Allen, J. D. Bailey, W. L. Baker, B. T. Bestelmeyer, P. M. Brown, K. S. Eisenhart, M. L. Floyd, D. W. Huffman, and B. F. Jacobs. 2009a. Historical and modern disturbance regimes, stand structures, and landscape dynamics in pinon–juniper vegetation of the western United States. Rangeland Ecology & Management **62**:203-222.

Romme, W. H., L. Floyd-Hanna, D. D. Hanna, and E. Bartlett. 2001. Aspen's ecological role in the West.

Romme, W. H., M. L. Floyd, D. Hanna, and E. J. Bartlett. 2009b. Historical Range of Variability and Current Landscape Condition Analysis: South Central Highlands Section, Southwestern Colorado & Northwestern New Mexicao. Colorado Forest Restoration Institute.

Rueth, H. M., and J. S. Baron. 2002. Differences in Englemann Spruce Forest Biogeochemistry East and West of the Continental Divide in Colorado, USA. Ecosystems **5**:45-57.

Ryan, K. C., and N. V. Noste. 1985. Evaluating prescribed fires.

Ryan, M., S. Archer, R. Birdsey, C. Dahm, L. Heath, J. Hicke, D. Hollinger, T. Huxman, G. Okin, and R. Oren. 2008. Land resources: Forest and arid lands [Chapter 3].

Ryerson, D. 2014. Forest Insect and Disease History of the Santa Fe National Forest.43 p.

Saab, V. A., C. E. Bock, T. D. Rich, and D. S. Dobkin. 1995. Livestock grazing effects in western North America. Ecology and management of neotropical migratory birds. Oxford University Press, New York:311-353.

Sackett, S. S., S. M. Haase, and M. G. Harrington. 1996. Lessons learned from fire use for restoring southwestern ponderosa pine ecosystems. Pages 54-61 *in* Conference on adaptive ecosystem restoration and management: Restoration of Cordilleran conifer landscapes of North America. US For. Serv. Gen. Tech. Rep. RM-GTR-278. US For. Serv., Rocky Mountain For. Range Exp. Stn., Fort Collins, CO.

Sather, M., S. Mukerjee, L. Smith, J. Mathew, C. Jackson, R. Callison, L. Scrapper, A. Hathcoat, J. Adam, D. Keese, P. Ketcher, R. Brunette, J. Karlstrom, and G. V. d. Jagt. 2013. Gaseous oxidized mercury dry deposition measurements in the Four Corners area and Eastern Oklahoma, U.S.A. . Atmospheric Pollution Research **4**.

Sauer, J. R., and W. A. Link. 2011. Analysis of the North American breeding bird survey using hierarchical models. The Auk **128**:87-98.

Savage, M., and J. N. Mast. 2005. How resilient are southwestern ponderosa pine forests after crown fires? Canadian Journal of Forest Research **35**:967-977.

Schlesinger, W. H., J. F. Reynolds, G. L. Cunningham, L. F. Huenneke, W. M. Jarrell, R. A. Virginia, and W. G. Whitford. 1990. Biological feedbacks in global desertification. Science(Washington) **247**:1043-1048.

Schmidt, K. M., J. P. Menakis, C. C. Hardy, W. J. Hann, and D. L. Bunnell. 2002. Development of coarse-scale spatial data for wildland fire and fuel management.

Schoennagel, T., T. T. Veblen, and W. H. Romme. 2004. The interaction of fire, fuels, and climate across Rocky Mountain forests. BioScience **54**:661-676.

Schussman, H., and E. Smith. 2006. Introduction to the Historic Range of Variation: in Historical Range of Variation for Potential Natural Vegetation Types of the Southwest. Prepared for the US Department of Agriculture, Forest Service, Southwestern Region by The Nature Conservancy, Tucson, AZ.

Scott, J. H., and R. E. Burgan. 2005. Standard fire behavior fuel models: a comprehensive set for use with Rothermel's surface fire spread model. The Bark Beetles, Fuels, and Fire Bibliography:66.

Seaber, P. R., F. P. Kapinos, and G. L. Knapp. 1987. Hydrologic unit maps.

Seager, R., M. Ting, I. Held, Y. Kushnir, J. Lu, G. Vecchi, H.-P. Huang, N. Harnik, A. Leetmaa, and N.-C. Lau. 2007. Model projections of an imminent transition to a more arid climate in southwestern North America. science **316**:1181-1184.

SEINet. 2014. Southwest Environmental Information Network.

Shakesby, R., and S. Doerr. 2006. Wildfire as a hydrological and geomorphological agent. Earth-Science Reviews **74**:269-307.

Simon, A., S. J. Bennett, and V. S. Neary. 2004. Riparian vegetation and fluvial geomorphology: problems and opportunities. Riparian vegetation and fluvial geomorphology:1-10.

Smith, J., K. Blankenship, D. Johnson, S. Simon, C. Ryan, R. Swaty, M. Bucher, M. Brod, and J. Patton. 2009. Adapting LANDFIRE Vegetation Dynamics Models. **24**:89.

Stambaugh, M. C., R. P. Guyette, E. R. McMurry, J. M. Marschall, and G. Willson. 2008. Six centuries of fire history at Devils Tower National Monument with comments on regionwide temperature influence. Great Plains Research:177-187.

State of New Mexico. 2005. Potential effects of climate change in New Mexico. Technical Working Group.

Stein, B., and S. Flack. 1996. America's Least Wanted: Alien Species Invasions of US. S. ecosystems. Arlington (VA): e Nature Conservancy.

Stephens, S. L. 2004. Fuel loads, snag abundance, and snag recruitment in an unmanaged Jeffrey pine–mixed conifer forest in northwestern Mexico. Forest Ecology and Management **199**:103-113.

Stephens, S. L., and P. Z. Fulé. 2005. Western pine forests with continuing frequent fire regimes: possible reference sites for management. Journal of Forestry **103**:357-362.

Strauss, D., L. Bednar, and R. Mees. 1989. Do one percent of the forest fires cause ninety-nine percent of the damage? Forest Science **35**:319-328.

Stromberg, J. C., and D. T. Patten. 1991. Dynamics of the spruce-fir forests on the Pinaleno Mountains, Graham Co., Arizona. The Southwestern Naturalist:37-48.

Sublette, E., D. Hatch, and M. Sublette. 1990a. The fishes of New Mexico. University of New Mexico Press.

Sublette, J., M. D. Hatch, and M. Sublette. 1990b. The Fishes of New Mexico. University of New Mexico Press, Albuquerque, NM.

Swanson, F. 1981. Fire and geomorphic processes [Erosion, watershed management, sedimentation]. USDA Forest Service General Technical Report WO (USA).

Swetnam, T. W., C. D. Allen, and J. L. Betancourt. 1999. Applied historical ecology: using the past to manage for the future. Ecological Applications **9**:1189-1206.

Swetnam, T. W., and C. H. Baisan. 1996. Historical fire regime patterns in the southwestern United States since AD 1700.

Swetnam, T. W., and J. L. Betancourt. 2010. Mesoscale disturbance and ecological response to decadal climatic variability in the American Southwest. Pages 329-359 Tree Rings and Natural Hazards. Springer.

Swetnam, T. W., and J. H. Dieterich. 1985. Fire history of ponderosa pine forests in the Gila Wilderness, New Mexico.*in* Proceedings—symposium and workshop on wilderness fire. Gen. Tech. Rep. INT-GTR-182, Ogden, UT: US Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station.

Szaro, R. C., and R. P. Balda. 1979. Effects of harvesting ponderosa pine on nongame bird populations. USDA Forest Service Research Paper RM (USA). no. 212.

Touchan, R., C. D. Allen, and T. W. Swetnam. 1996. Fire history and climatic patterns in ponderosa pine and mixed-conifer forests of the Jemez Mountains, northern New Mexico. UNITED STATES DEPARTMENT OF AGRICULTURE FOREST SERVICE GENERAL TECHNICAL REPORT RM:33-46.

Touchan, R., T. W. Swetnam, and H. D. Grissino-Mayer. 1995. Effects of livestock grazing on pre-settlement fire regimes in New Mexico. General technical report INT (USA).

Triepke, F. J. 2015. Climate Change Vulnerability Assessment for the Santa Fe National Forest.

Triepke, F. J., M. M. Wahlberg, D. C. Cress, and R. L. Benton. 2014a. RMAP - Regional Riparian Mapping Project. Albuquerque, NM.

Triepke, F. J., M. M. Wahlberg, D. C. Cress, and R. L. Benton. 2014b. RMAP – Regional Riparian Mapping Project.53.

U.S. Fish and Wildlife Service. 2015. Wetlands Inventory website. U.S. Department on Interior, Fish and Wildlife Service, Washington, D.C.

U.S. Geological Survey. 2014. Hydrography: National Hydrography Dataset, Watershed Boundary Dataset.

USDA, and NRCS. 2009. [U.S. Department of Agriculture, Natural Resources Conservation Service] The PLANTS database. National Plant Data Center, Baton Rouge, Louisiana, USA.

USDA Forest Service. 2013a. Forest Planning Assessments: Alternatives to Historic Reference Condition.

USDA Forest Service. 2013b. Non-Native And Invasive Plant Species Specialist Report For The Southwest Jemez Landscape Restoration Project.

USDA Forest Service. 2013c. USFS R3 Regional Forester's Sensitive Specie: Animals - 2013.*in* 2013_RFSS_Animals_List.xlsx, editor. Microsoft Excel.

USDA Forest Service. 2013d. USFS R3 Regional Forester's Sensitive Species: Plants - 2013.*in* 2013_RFSS_Plants_List.xlsx, editor. Microsoft Excel.

USDA FS. 2011. A Compendium of NFS Regional VegetationClassification Algorithms. USDA FS Forest Management Service Center, Fort Collins, CO.

USDA FS. 2014a. Climate change vulnerability assessment executive summary. USDA FS Southwestern Region, on file: Forest Service SW Regional office.

USDA FS. 2014b. Guidance for Invasive Species Management in the Southwestern Region.*in* U. F. Service, editor. USDA Forest Service, Southwestern Region, Albuquerque, NM.

USEPA. 2013. Terms of agreement regarding BART, for Regional Haze Requirements 309 SIP, between EPA, NM, & PNM.

USEPA. 2014. OVERVIEW OF EPA'S PROPOSAL TO UPDATE THE AIR QUALITY STANDARDS FOR GROUND-LEVEL OZONE.

USEPA. 2015. AirData: Interactive Map-Online ambient air quality database.*in* U. S. E. P. Agency, editor.

USFS. 2004. High Lakes Inventory: Pecos Wilderness- 2002 and 2003. Report by Sean Ferrell and Sarah Eddy, Fisheries Biologist and Biological Tech. Santa Fe National Forest. May 2004.

USFS. 2015. Forest Service Handbook (FSH) 1909.12- Land Management Planning Handbook: Chapter 10- Assessments.*in* U. S. F. S.-. USDA, editor.

USGS. 2015. Rocky Mountain Regional Snowpack Chemistry Monitoring Study Area. United States Geological Survey (USGS).

Vandendriesche, D. 2010. An empirical approach for estimating natural regeneration for the forest vegetation simulator.

Vankat, J. 2013. Vegetation dynamics on the mountains and plateaus of the American Southwest. Springer Science & Business Media.

VDDT. 2006. Vegetation Dynamics Development Tool.

Veenhuis, J. E. 2002. Effects of wildfire on the hydrology of Capulin and Rito de los Frijoles Canyons, Bandelier National Monument, New Mexico. US Department of the Interior, US Geological Survey.

Vegh, T., C.-H. Huang, and A. Finkral. 2013. Carbon credit possibilities and economic implications of fuel reduction treatments. Western Journal of Applied Forestry **28**:57-65.

Wahlberg, M. M., F. J. Triepke, W. Robbie, S. H. Stringer, D. Vandendriesche, E. Muldavin, and J. Malusa. 2013. Ecological Response Units of the Southwestern United States.*in* F. S. USDA, editor.

Weisz, R., J. Triepke, R. Truman, C. Sieg, P. Fulé, M. Hunter, C. Allen, M. Brooks, and R. Balice. 2009. Evaluating the ecological sustainability of a ponderosa pine ecosystem on the Kaibab Plateau in northern Arizona. Fire Ecology **5**:100-128.

Weisz, R., J. Triepke, D. Vandendriesche, M. Manthei, J. Youtz, J. Simon, and W. Robbie. 2010. Evaluating the ecological sustainability of a pinyon-juniper grassland ecosystem in northern Arizona.

Weisz, R., D. Vandendriesch, and M. Moeur. 2011. Calibrating natural and anthropogenic events in state and transition models with FVS. In draft proceedings of the State and Transition Modeling Conference,.

Welch, B. L., and C. Criddle. 2003. Countering misinformation concerning big sagebrush.

Westerling, A. L., H. G. Hidalgo, D. R. Cayan, and T. W. Swetnam. 2006. Warming and earlier spring increase western US forest wildfire activity. science **313**:940-943.

Whelan, R. J. 1995. The ecology of fire. Cambridge University Press.

Whigham, D. F. 2004. Ecology of woodland herbs in temperate deciduous forests. Annual Review of Ecology, Evolution, and Systematics:583-621.

Whisenant, S. G. 1990. Changing fire frequencies on Idaho's Snake River Plains: ecological and management implications. McArthur, E. Durant; Romney, Evan M.; Smith, Stanley D:5-7.

White, A. S. 1985. Presettlement regeneration patterns in a southwestern ponderosa pine stand. Ecology **66**:589-594.

White, M. R. 2002. Characterization of, and changes in the subalpine and montane grasslands, Apache-Sitgreaves National Forests, Arizona.

WHO. 2014. Ambient (outdoor) air quality and health. Fact Sheet No. 313.

Wiedinmyer, C., and J. C. Neff. 2007. Estimates of CO. Carbon Balance and Management **2**.

Wilcox, B. P., D. D. Breshears, and C. D. Allen. 2003. Ecohydrology of a resource-conserving semiarid woodland: effects of scale and disturbance. Ecological monographs **73**:223-239.

Williams, D. W., and A. M. Liebhold. 2002. Climate change and the outbreak ranges of two North American bark beetles. Agricultural and Forest Entomology **4**:87-99.

Williams, M. A., and W. L. Baker. 2012. Spatially extensive reconstructions show variable-severity fire and heterogeneous structure in historical western United States dry forests. Global Ecology and Biogeography **21**:1042-1052.

Williams, M. W., and K. A. Tonnessen. 2000. CRITICAL LOADS FOR INORGANIC NITROGEN DEPOSITION IN THE COLORADO FRONT RANGE, USA. Ecological Applications **10**:1648-1665.

Winward, A. H. 2004. Sagebrush of Colorado: taxonomy, distribution, ecology & management. Colorado Division of Wildlife, Department of Natural Resources.

Wohl, E. E., and P. P. Pearthree. 1991. Debris flows as geomorphic agents in the Huachuca Mountains of southeastern Arizona. Geomorphology **4**:273-292.

Woodbury, P. B., J. E. Smith, and L. S. Heath. 2007. Carbon sequestration in the US forest sector from 1990 to 2010. Forest Ecology and Management **241**:14-27.

Woolsey, T. S. 1911. Western yellow pine in Arizona and New Mexico. US Department of Agriculture, Forest Service.

WRAP. 1996. The Grand Canyon Visibility Transport Commission, Recommendations for Improving Western Vistas. Western Regional Air Partnership.

WRAP. 2015. Western Regional Air Partnership Technical Support System database (WRAP TSS). Emissions data resource database.

Wright, C. S., R. E. Vihnanek, R. D. Ottmar, and P. C. Eagle. 2007. DIGITAL PHOTO SERIES.

Wright, H. A., and A. W. Bailey. 1982. Fire ecology: United States and southern Canada. John Wiley & Sons.

Wynn, T. M., S. Mostaghimi, J. A. Burger, A. A. Harpold, M. B. Henderson, and L.-A. Henry. 2004. Variation in root density along stream banks. Journal of Environmental Quality **33**:2030-2039.

Zier, J., and W. L. Baker. 2006. A century of vegetation change in the San Juan Mountains, Colorado: an analysis using repeat photography. Forest Ecology and Management **228**:251-262.

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 (less than10 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 3 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 is the stage of secondary successional development (ecological process of progressive change in a plant community after a stand-initiating 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 composed 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.