GREATER SANTA FE FIRESHED

TRIPLE BOTTOM LINE ANALYSIS OF FUEL TREATMENTS

EARTH ECONOMICS

AUTHORS

The authors are responsible for the content of this report.

Jordan Wildish, Project Director, Earth Economics

Matt Chadsey, Principal, Non-linear Ventures

Rowan Schmidt, Program Director, Earth Economics

Kenneth Zummach, Research Analyst, Earth Economics

ACKNOWLEDGMENTS

Funding provided by the US Forest Service. We would also like to thank Earth Economics' Board of Directors for their continued guidance and support.

Earth Economics is a leader in ecological economics and has provided innovative analysis and recommendations to governments, tribes, organizations, private firms, and communities around the world. **eartheconomics.org**

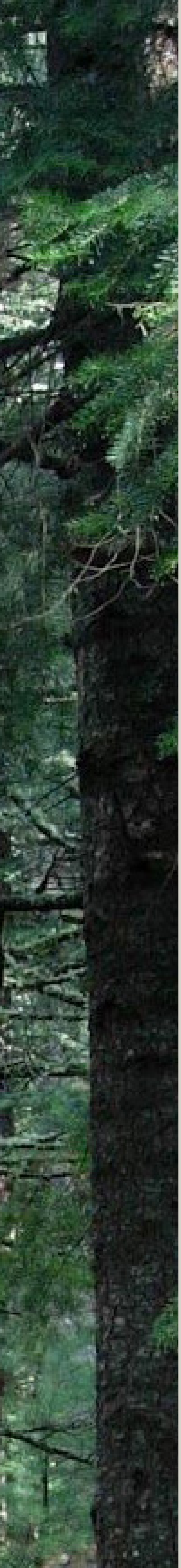


TABLE OF CONTENTS

EARTH ECONOMICS

INTRODUCTION

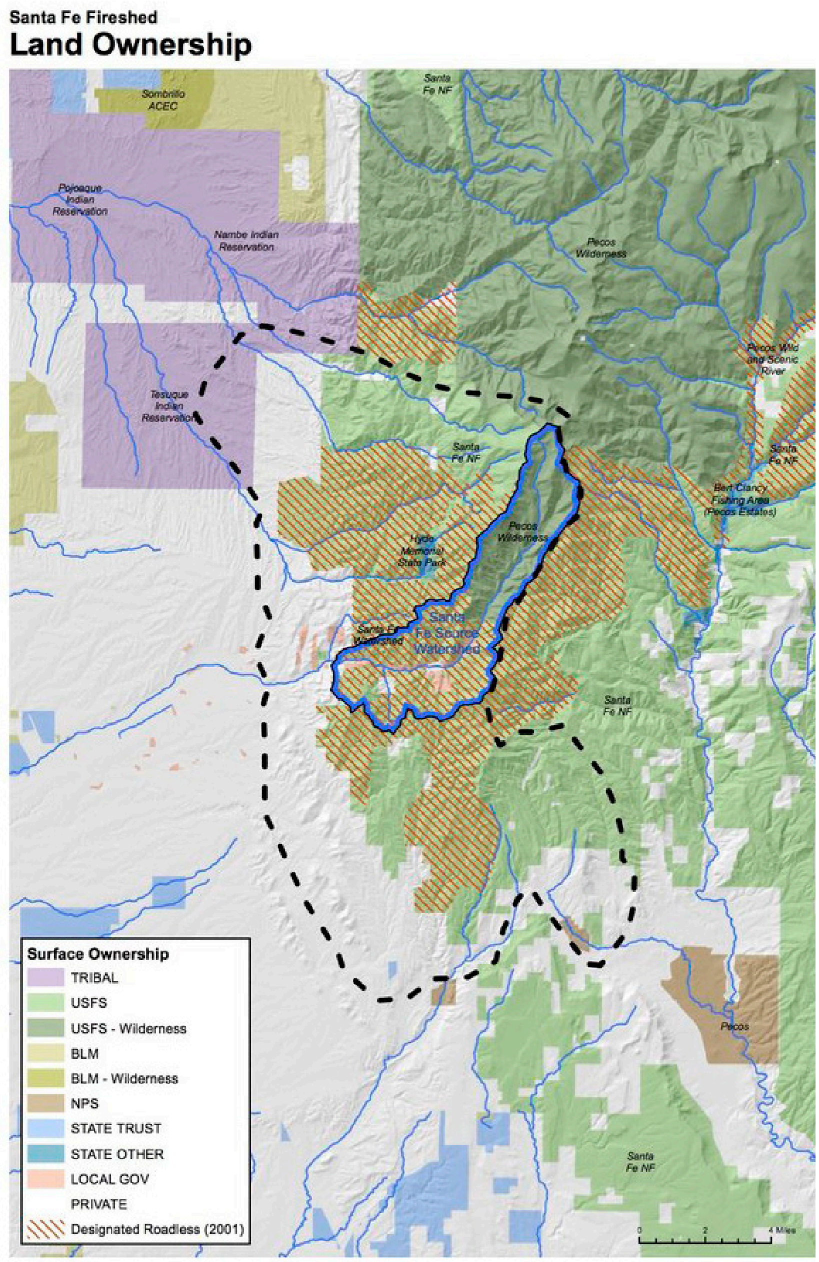
The Greater Santa Fe Fireshed ("Fireshed") is an area of forested mountains and foothills directly to the east of the City of Santa Fe, New Mexico, spanning 173 square miles directly east of the City of Santa Fe and including a portion of the Santa Fe National Forest, as well as tribal land, residential areas, and County recreation areas (Figure 1).

The Fireshed provides numerous benefits for the surrounding community. For example, the lands of the Fireshed support the recreation and tourism economy of Santa Fe; each year, hundreds of thousands of visitors use the recreational amenities within the Fireshed, including Ski Santa Fe and dozens of miles of hiking trails.

The Fireshed also contains diverse ecosystems including pinyon, juniper, and ponderosa pine forests that sequester and store carbon and provide critical habitat in an urbanizing landscape. The Santa Fe Source Watershed (contained within the Fireshed) provides nearly half of the city of Santa Fe's water.[i]

As an important community asset, protecting the Fireshed is a priority for the City of Santa Fe, Santa Fe County, the Pueblo of Tesuque, the Santa Fe National Forest, and numerous other communities and stakeholder groups in the area. The Greater Santa Fe Fireshed Coalition was established to convene these stakeholders and take collaborative action to preserve and restore this landscape.[ii]

Fire can be beneficial in the maintenance of forested lands, leading to healthy, diverse forests. Fire can also be ecologically destructive, depending on fire frequency, intensity, and the nature of vegetation subject to fire. More frequent, slower burning understory fires eliminate fuel build-up, liberate fire-activated seeds and do not burn deeply into the soil, while high intensity burns consume vegetation from tree crowns to roots, burning deep into the ground and damaging soils, which may take decades to recover.



Source: "Santa Fe Fireshed Landownership" (n.d.) The Greater Santa Fe Fireshed Coalition.

Like many forested areas in the West, the Fireshed had historically experienced relatively frequent, low-intensity fires. However, fire suppression in the 20th century has led to a buildup of fuels, and in the context of a changing climate and a growing wildland–urban interface, the Fireshed is increasingly at risk of a high-intensity wildfire.[iii]

To address this risk, the US Forest Service has proposed a combination of thinning and prescribed burning treatments within the Santa Fe National Forest to reduce the risk of severe wildfire across the landscape. The proposed treatments, detailed in the Santa Fe Mountains Landscape Resiliency Project Environmental Assessment, include treating 50,566 acres within the Fireshed, primarily in mixed conifer and ponderosa pine forests (Figure 2). The treatments include thinning, prescribed burning, and riparian restoration.

The US Forest Service engaged Earth Economics to conduct an analysis of the social, environmental, and economic benefits that the Fireshed provides for the surrounding community, and to explore the impact of the proposed fuel reduction treatment on these benefits. This study seeks to capture the costs and benefits of the proposed treatments to inform and prioritize fuel reduction decision-making.

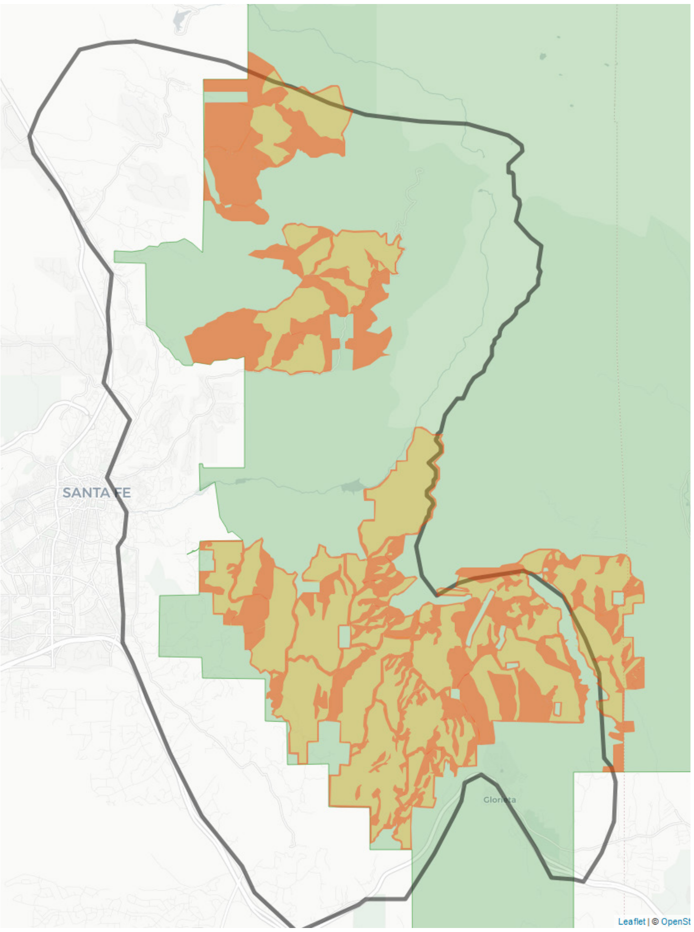


FIGURE 2 Proposed fuel treatments areas within the Santa Fe Fireshed

STUDY APPROACH

The goal of this analysis is to quantify the social, environmental, and economic impacts of the proposed fuel reduction treatments on the Fireshed. This research was conducted in three phases.

1. We spoke with stakeholder groups that interact with the Fireshed to assess the full scope of benefits provided by the lands within the Fireshed boundary and risks associated with wildfire.
2. We sought to quantify and value the social, economic, and environmental services provided by the Fireshed, informed by the benefits identified through the stakeholder interviews.
3. We quantified the impact of the proposed treatments on those baseline benefits, and conducted a benefit-cost analysis of fuel treatments.

PHASE 1: STAKEHOLDER INTERVIEWS

In order to comprehensively understand the value that the Fireshed provides for the community, Earth Economics interviewed stakeholders from 12 organizations spanning the public, private, and non-profit sectors that interact with – and benefit from – the Fireshed. Conversations with these stakeholders helped to confirm or identify key Fireshed benefits that were quantified or valued in this analysis, as well as the risks wildfires pose to these benefits.

Stakeholders were identified by our partners in the Santa Fe National Forest. We interviewed representatives from the following organizations:

THE FOREST STEWARDS GUILD

THE SANTA FE HOTEL AND LODGERS ASSOCIATION

THE SIERRA CLUB

THE NEW MEXICO AUDUBON SOCIETY

THE SANTA FE FIRE DEPARTMENT

NEW MEXICO STATE FORESTRY

THE SANTA FE WATERSHED ASSOCIATION

THE NEW MEXICO OFFICE OF OUTDOOR RECREATION

SKI SANTA FE

CITY OF SANTA FE WATER DIVISION

SANTA FE COUNTY OPEN SPACE DISTRICT

THE NATURE CONSERVANCY

PHASE 2: QUANTIFICATION OF VALUES AT RISK

Based on stakeholder responses and research, we identified a wide range of community benefits and assets supported by and located in the Fireshed that are at risk due to wildfires and the indirect post-fire effects. In order to categorize these benefits and assets, we used a modified version of the "Values-at-Risk" (VAR) framework, based upon the Fireshed risk conducted by the Nature Conservancy.[iv] The VAR framework is used internally by the Forest Service, especially by Burned Area Emergency Response (BAER) teams to assess the cost-effectiveness of post-wildfire actions by comparing the cost of those actions against the value of resources (infrastructure, timber, non-market values etc.) and risks to them.[v]

THE NATURE OF WILDFIRE RISKS IN THE FIRESHED

Wildfires have always occurred naturally and regularly in New Mexico. Although wildfires in New Mexico are a natural and vital part of the state's forest ecosystems, climate change is significantly increasing the average size and frequency of these events.[ix] Annual temperatures have increased by approximately 1.5°F in the Southwest over the past century, and are projected to increase an additional 5–9°F by the end of the 21st century.[vi] Hotter temperatures and changing precipitation patterns increase the risk of catastrophic wildfire and post-fire flooding. New Mexico is expected to experience diminished snowpack, lower stream flows, and more severe droughts over the next century, all of which exacerbate the risk of wildfire and post-fire flooding.[vii]

Patterns of new development also play a significant role in increasing the risks posed by wildfires to people and property. The wildland-urban interface (WUI) – the area where houses are in or near wildland vegetation – is growing nationwide as more homes are being constructed near undeveloped natural areas.[x] This encroachment both increases the risk of damage to structures when fires pass through those natural areas, and increases the risk of ignition due to human activity.[vii]

The Santa Fe region has experienced many recent large-scale fires that have impacted the community, and the direct impacts include harm to people and damage to infrastructure and homes. Recent examples include the Las Conchas fire in 2011,which forced the evacuation of 12,000 people, burned more than 156,593 acres, and 63 homes,[ix] and the Cerro Grande fire in 2000, which burned more than 200 homes and incurred an estimated $1 billion in damages.[x]

Indirect post-wildfire impacts can also be costly. For example, flooding and landslides that occur after wildfires pose a significant additional risk to people and property.[xi] In many documented cases throughout the West, the floods and landslides that happen after a fire can be even more costly than the initial wildfire.[xii] Even moderate rainfall may cause sediment accumulation in drinking water reservoirs and destabilize slopes.[xiii]

ESTIMATING A BASELINE FOR VALUES-AT-RISK

Earth Economics conducted a comprehensive analysis of VARs within the Fireshed, with the goal of estimating their current value and establishing a baseline for assessing the outcomes of Forest Service interventions. Some of these VARs—such as structures and roads—can be valued based on their market value or replacement cost. However, many of the benefits provided by this landscape are non-market benefits, meaning they are not traded within a market. While there are market prices for houses or road construction supplies, no such market price exists for breathing clean air, or the recreational value of a hike. The environmental and ecological economics disciplines have developed a range of methods for estimating the economic value of non-market VARs, in particular environmental benefits (often referred to as "ecosystem services"). These methods can be broadly described as "revealed preference methods" (directly or indirectly based on consumer market behavior, including replacement cost, avoided cost, travel cost, hedonic pricing), and "stated preference methods" (based on asking people their willingness-to-pay for a given good or service, including contingent valuation and choice experiments). Specific examples include:

- **Avoided Cost Method.** The economic losses that would be incurred if a natural ecosystem were removed or its function were significantly impaired. Example: wetlands and riparian buffers reduce flooding by holding and slowing runoff—removing them can lead to greater flood damages.

- **Travel Cost Method.** When people travel to visit natural areas like county parks or national forests, the willingness to incur such costs can be used to determine the nonmarket value of those amenities. Example: tourists and recreational users spend time and money to access sites of interest.

- **Contingent Valuation Method.** Estimates of value based on direct stakeholder surveys. Example: a survey that asks stakeholders about their willingness to pay to protect water quality.

While methods like these can be useful for valuing a range of non-market VARs, certain VARs (such as cultural value) are difficult to quantify or value and are often better described qualitatively.

IDENTIFY → QUANTIFY → VALUE

FIGURE 3 The general progression that was followed for assessing each VAR: Some were identified, a subset of those could be quantified, and a further subset of those quantified were valued in economic terms.

TABLE 1 Summary of the level of analysis applied to each benefit.

VALUES AT RISK	IDENTIFIED	QUANTIFIED	VALUED
CULTURAL PRACTICES	X		
EDUCATION AND JOB TRAINING	X		
HABITAT	X	X	
ROADS	X	X	X
STRUCTURES	X	X	X
DRINKING WATER	X	X	X
WATER FOR IRRIGATION	X		
AIR QUALITY	X	X	X
CARBON SEQUESTRATION	X	X	X
RECREATIONAL USE	X	X	X
ECONOMIC ACTIVITY	X	X	X

It is important to note that the absence of any economic estimate for a given VAR does not mean that the Fireshed does not produce that value; some of the VAR's clearly have economic value but are not valued in this report due to the lack of primary peer-reviewed data and methods. For example, we learned from the stakeholder interviews that the Fireshed provides opportunities for education and job training; however, we did not identify any valuation studies that estimate this value in economic terms. As shown in Table 1, appropriate valuation studies or methods were not found for habitat, cultural, irrigation water or educational-related VAR's.

VALUES-AT-RISK RESULTS

Cultural Practices

The cultural value of the land and ecosystems within the Fireshed is a critical value that was repeated by stakeholders. The Fireshed supports cultural and tribal traditions such as pinyon nut and firewood collection, and Douglas fir branch collection—practices which date back more than a thousand years in the New Mexico area.[xiv, xv] Though cultural practices supported by the Fireshed are vital to the Santa Fe community, they are not quantifiable or amenable to economic valuation and are most appropriately understood in qualitative terms. As such, they are not included in our benefit-cost analysis. A separate analysis of the impact of the proposed treatments on traditional cultural uses was conducted by the US Forest Service, in consultation with eight Pueblos.[xvi]

Education and Job Training

The forests in the Fireshed provide a valuable venue for educational fieldtrips[xvii] and job training through the Forest Stewards Youth Corps program.[xviii] The job training program engages young adults ages 16–25 in prescribed burns and other fuel reduction activities in the Fireshed. The program promotes employment skill building through interview practice and forestry training.

Habitat

The Fireshed contains multiple distinct ecosystems, including spruce–fir forest, mixed conifer forest, ponderosa pine forest, grasslands, and riparian ecosystems which provide habitat for a wide a range of species.[xix]

The full scope of biodiversity within the landscape is difficult to measure, but one example of this habitat diversity can be demonstrated from reported bird sightings. The Fireshed is an important site for birding community. There are hundreds of species of birds in the Fireshed, and birding is a common recreational activity.[xx] In 2019 alone there were more than 21,000 bird sightings reported within the Fireshed, and 205 unique bird species observed.[xxi] A list of observed species within the Fireshed that have been assessed as vulnerable by the New Mexico Avian Conservation Partners is included in Appendix A. Figure 4 provides a spatial representation of this VAR.

Habitat values are not included in our benefit-cost analysis. The intrinsic value of biodiversity and species existence is challenging to value in economic terms. One common approach to quantifying a small portion of the habitat provisioning value of ecosystems is to quantify consumer expenditures or consumer surplus of wildlife viewing activities. Recreational value is quantified separately in this analysis, as measured by recreational visitors within the Fireshed. Because many of these bird sightings likely occurred during hikes or other recreational activities, valuing these benefits separately would risk double counting.

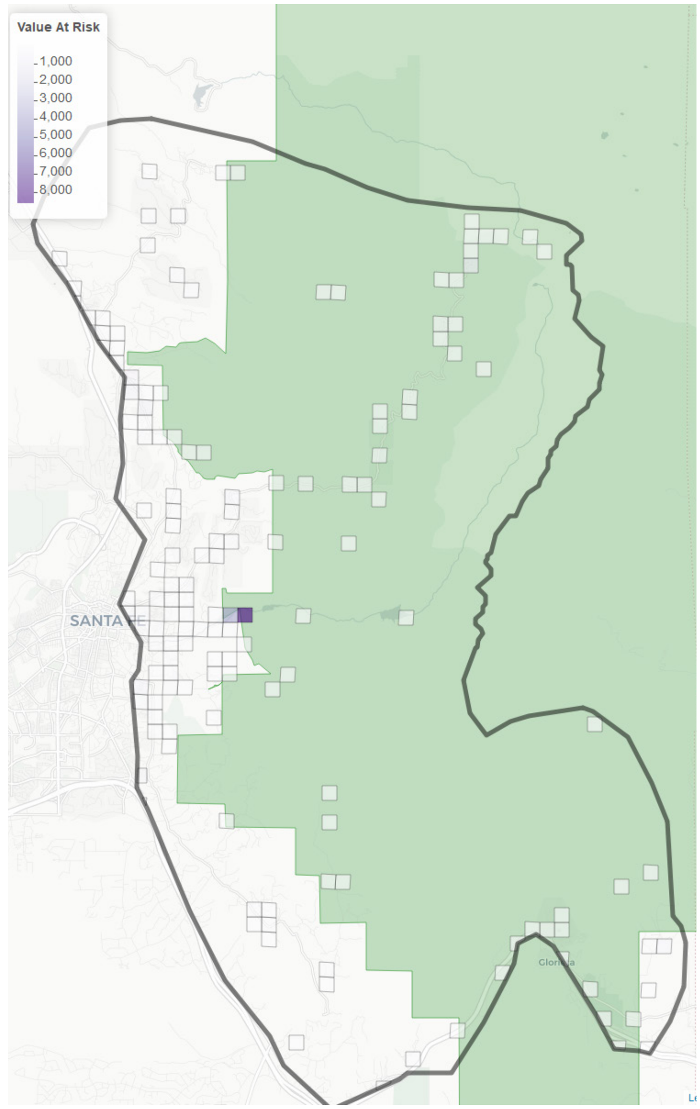


FIGURE 4 Bird Sightings in the Fireshed

Roads
There are more than 500 miles of paved and unpaved roads in the Fireshed. Roads within the Fireshed provide important access for recreational amenities and through traffic. Hyde Park Road is a critical access point for the Fireshed, serving both Ski Santa Fe and many of the area's most popular trails. Damage to the road through fire and/or associated landslides and flooding is a significant risk for the recreational use of the Fireshed. Roads were valued at the approximate cost of replacing these assets in the event of damage due to fire-related disasters. The replacement cost for paved roads is estimated at approximately $213,000 per mile. For unpaved roads the replacement cost is estimated at approximately $50,000 per mile.[xxiv] Figure 5 provides a spatial representation of this VAR.

Additional Considerations
The valuation does not include the impact of temporary road closures due to wildfire damage on the transportation network. Road closures can cause traffic congestion, loss of access to amenities, delayed emergency response times, and hinder evacuations.[xxv]

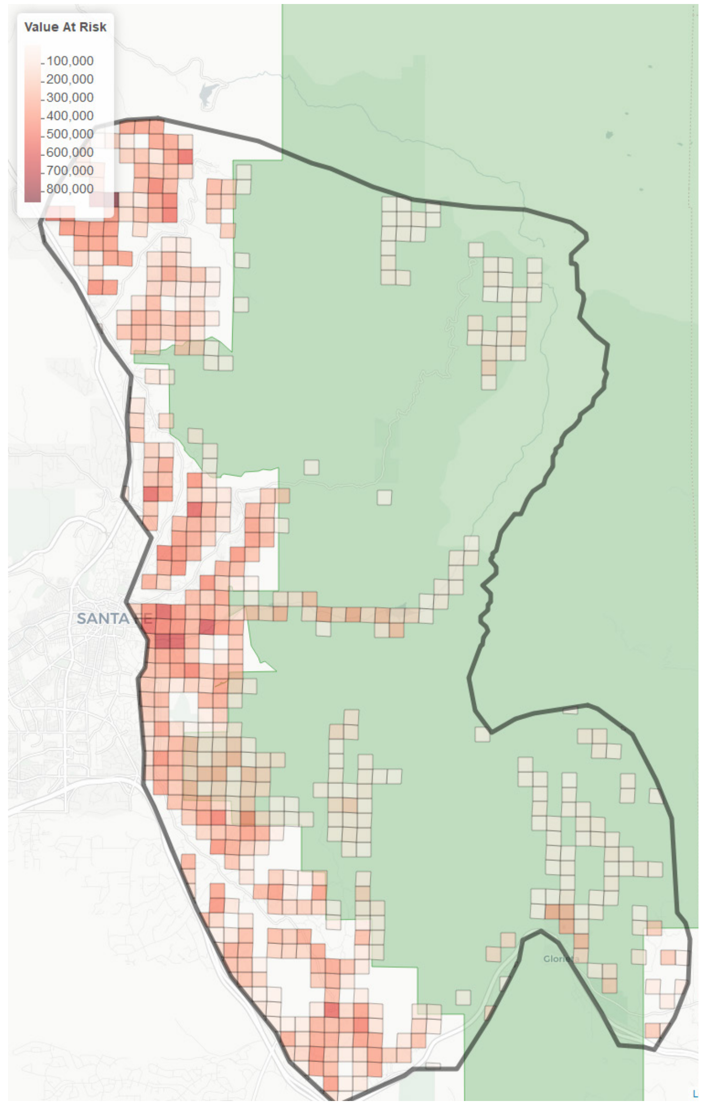


FIGURE 5 Road Values at Risk with the Fireshed

Structures

There are approximately 6,700 residential and commercial structures within the Fireshed. Reduction in wildfire risk reduces the risk of structure damage. Our analysis estimates that the value of structures within the Fireshed is approximately $5.4 billion, based on average per square foot sales values.[xxvi] Our analysis restricted the structures that would be impact by these proposed fire risk reduction treatments to those within 500 meters of the designed Wildland-Urban Interface within the Fireshed (1,600 structures with an approximate value of $1.2 billion).

Additional Considerations

Wildfire and post-fire landslides and flooding threaten residential and commercial infrastructure. A 2019 report found that nearly 24,000 homes in the City of Santa Fe are in "high" and "extremely high" fire risk areas.[xxvii] The total value of these threatened structures exceeds $7.2 billion dollars, which represents the 12th highest valued collection of properties that are threatened by high and extreme wildfire risks in the US.[xxviii] Compounding the risks posed to existing homes, the City of Santa Fe is also experiencing rapid growth that is pushing more and more development closer to the wildland border,[xxix] and the city is likely to see an increase in the number of homes within the Fireshed as its population grows.

These risks have a further financial impact on residential and commercial property owners through increased insurance premiums or loss of insurance coverage. Insurance coverage for wildfire damage has become difficult to find and maintain as insurance companies respond to the growing severity of wildfire risk. In California, the number of complaints about dropped insurance policies has tripled from 2010 to 2016.[xxx] This issue has become especially prominent in California following recent catastrophic wildfires, as many insurance companies seek to reduce their California state policy portfolios in response to this risk. Allstate reduced its home insurance policy count in the state by 50% since 2010.[xxxii] Policies are also getting more expensive. In fact, many policy holders in high risk areas have reported 2–3 fold increases in their annual premiums.[xxxii]

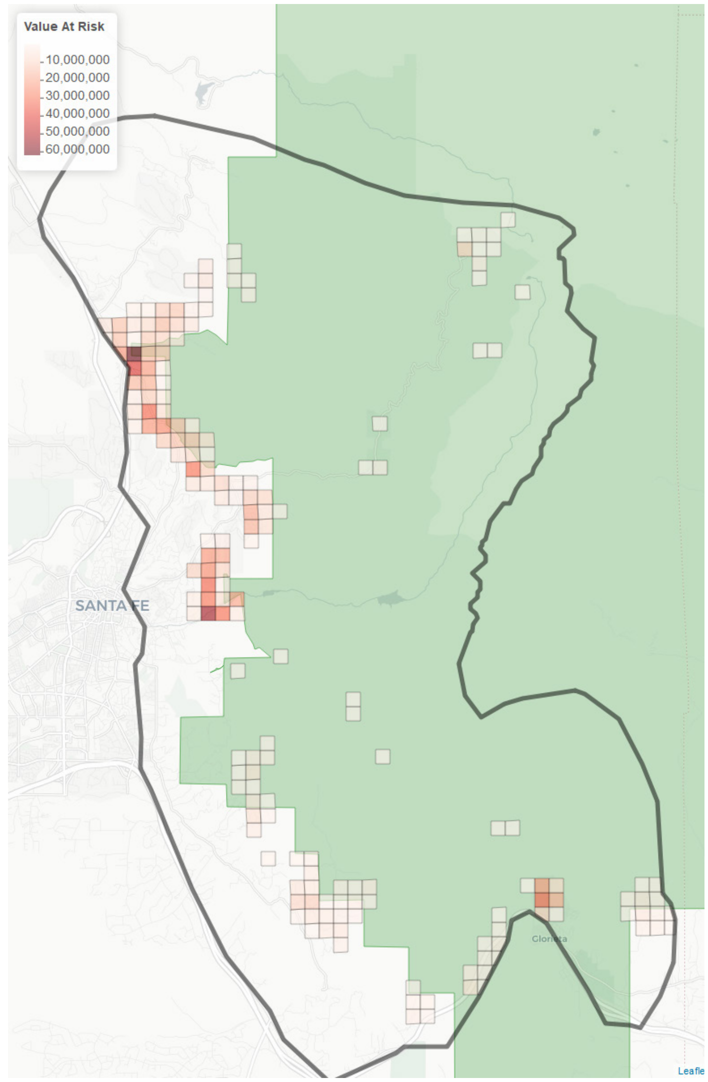


FIGURE 6 Structure Values at Risk within the Fireshed (within 500 meters of WUI)

Drinking Water
The Fireshed encompasses a large portion of the Santa Fe Municipal Watershed, which feeds the Canyon Water Treatment plant and supplies roughly 33% of the City of Santa Fe's water supply, including 30,000 households and businesses.[xxxiii] The watershed and reservoirs are at risk from sediment accumulation following a wildfire, which would require costly dredging and material removal. The sediment would include ash from the wildfire and soil and other material that may runoff into the reservoir as a result of post-fire flooding or landslides. The City of Santa Fe Water Division estimates that if a wildfire were to impact a significant portion of the watershed, the required dredging would cost between $80 million and $240 million.[xxxiv] Dredging is estimated to take more than a year to complete. However, the Water Agency has an emergency water supply plan, based on the expanded use of municipal wells and the Buckman diversion project, to sustain the City during this period.

Additional Considerations
The northern end of the Fireshed, outside of the designated Municipal Watershed, provides water for agriculture.[xxxv] This benefit is not included in our analysis, because the impact of a fire within the Fireshed on irrigation water availability is unknown.

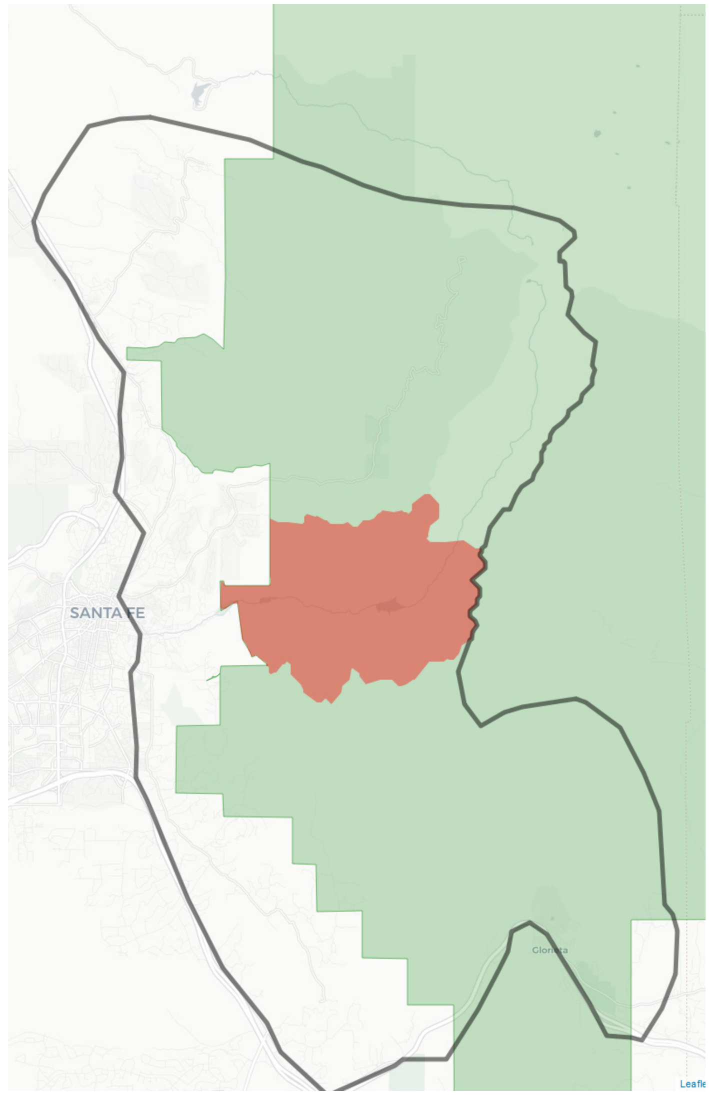


FIGURE 7 Drinking Water Values At Risk

Recreational Use

Economists typically measure the value of recreational experiences by studying visitor behavior or conducting elaborate surveys. Overall, the actual value of outdoor recreation in public lands is much greater than the amount people pay to use them as measured through their trip expenditures. The additional value that a recreational experience provides, over and above the amount that it costs, is referred to as consumer surplus.

This consumer surplus is a gain for the consumer since they pay less than the value they place on that benefit. For example, a visitor to Santa Fe may be willing to pay $100 to go hiking for one day in the Santa Fe National Forest. If the actual cost of the hiking trip is only $10, then the hiker gains a net economic benefit (consumer surplus) of $90 per day. Even though no money changes hands when this hiker obtains the consumer surplus (i.e., nobody pays the hiker $90), this concept is a useful way of understanding the true value of certain activities like outdoor recreation.

Trail Use

Annual trail and non-ski related visitation within the Fireshed is estimated at 109,452 people per year.[xxxvi]

Consumer surplus for hiking in this region is estimated at $98.13 per person, per visit ($2019).[xxxvii] This consumer surplus value is derived from the Recreation Use Values Database (RUVD), an extensive dataset of more than 3,000 recreational valuation studies. The value of recreational trail use in the Fireshed is estimated at $10,740,483 per year.

Skiing Use

Ski Santa Fe, located within the Fireshed, receives an estimated 153,850 visitors per year.[xxxviii] Consumer surplus is estimated at $95.84 ($2019) per person, per visit. The total value of skiing visitation is estimated at $14,744,984, per year.[xxxix]

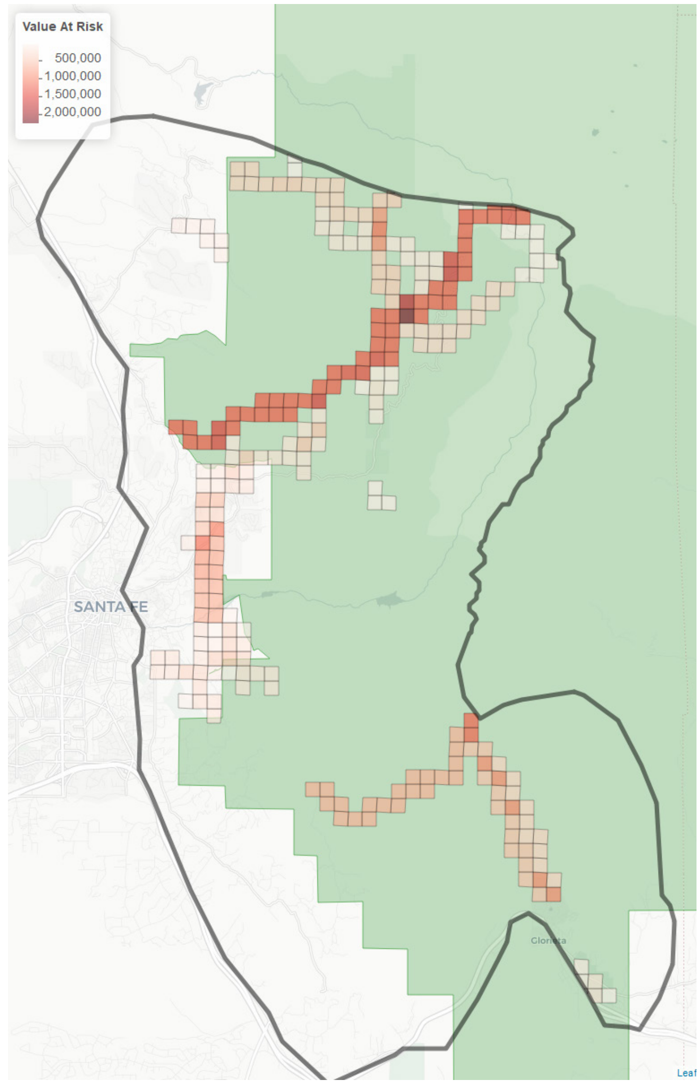


FIGURE 8 Recreational Values at Risk

Economic Activity

The Recreation Economy

Recreational activities within the Fireshed support the local economy. Visitor expenditures, which are defined as any expenditure related to recreational visitation within the Fireshed, promote economic activity. This economic activity ripples throughout the economy across a wide array of industries and generates additional income, jobs, and taxes for the region. The economic impact of recreation within the Fireshed was estimated using reported National Visitor Use Monitoring (NVUM) expenditures within the Santa Fe National Forest, on a per-visitor basis.

Recreation and tourism in the Fireshed provides a significant economic benefit for the Santa Fe community. Visitors to the national forest spend an average of $230 per trip, per party.[xl] At an estimated 263,302 visitors per year and an average party size of 1.9, the Fireshed generates $31,873,400 in economic expenditures within Santa Fe each year and supports approximately 220 local jobs.[xlii]

The Forest Restoration Economy

The proposed treatments would have a direct impact on the local economy through investment in forest restoration. This work would employ forestry crews, and support the industries that service those works. This value was estimated through an economic contribution analysis.

An economic contribution analysis demonstrates the contribution of a given industry to the surrounding economy. A contribution analysis can estimate the economic output of an industry, the number of jobs and labor income supported by an industry. This analysis measures how investment in these forest treatments would contribute to the local economy. To measure these effects, we use input-output (IO) modeling, which characterizes the financial linkages between industries within an economy.

We estimated economic contribution values for the proposed treatment based on the expenditure profiles from similar projects within the region.[xliii] Total economic contribution is broken out into direct effects and secondary effects, and secondary effects are further broken out into indirect and induced effects. Direct effects measure the economic activity of industries directly supported by consumer spending. This includes contributions from businesses such as restaurants, grocery stores, and real estate. Secondary effects are those that stem from direct effects, and they are further categorized as either indirect or induced effects. Indirect effects are the effects of the supporting industries that supply the direct industries.

Results indicate that the proposed treatments will support local job creation within the forestry industry. stemming from the direct, indirect and induced economic impacts of the proposed project. This figure is best understood as jobs created for a one-year period. In practice, because the implementation of this project would occur over multiple years, the number of permanent, long-term jobs supported by this project would be lower than 801. The proposed project would create $81 million in total economic output within the county. This job creation would occur not just within the forestry sector, but also within the local food service industry, the hospitality sector, and others.

Carbon Storage
The ecosystems within the Fireshed sequester and store carbon, and the impact of the proposed fuel treatments on this carbon storage has been thoroughly researched. A 2019 study on the impact of forest treatment regimens found that the proposed fuel treatments would increase carbon storage in the Fireshed over the long term by reducing the risk of high-severity wildfire, more than offsetting the short-term carbon storage losses due to the initial biomass removal from thinning and prescribed burning (see Figure 9). Unlike the values described above, we did not quantify the asset value of stored carbon within the Fireshed (e.g. the total value of carbon stored within the Fireshed). Instead we applied the findings of the research conducted by Krofcheck, et al (2019) within our benefit-cost analysis.

Multiplying the net ecosystem carbon balance (0.06 Tg C for the 'prioritized' treatment scenario) by the social cost of CO2 ($42/ton)[xlv], the proposed treatments would generate a carbon storage value of $10.2 million over a 50-year period.

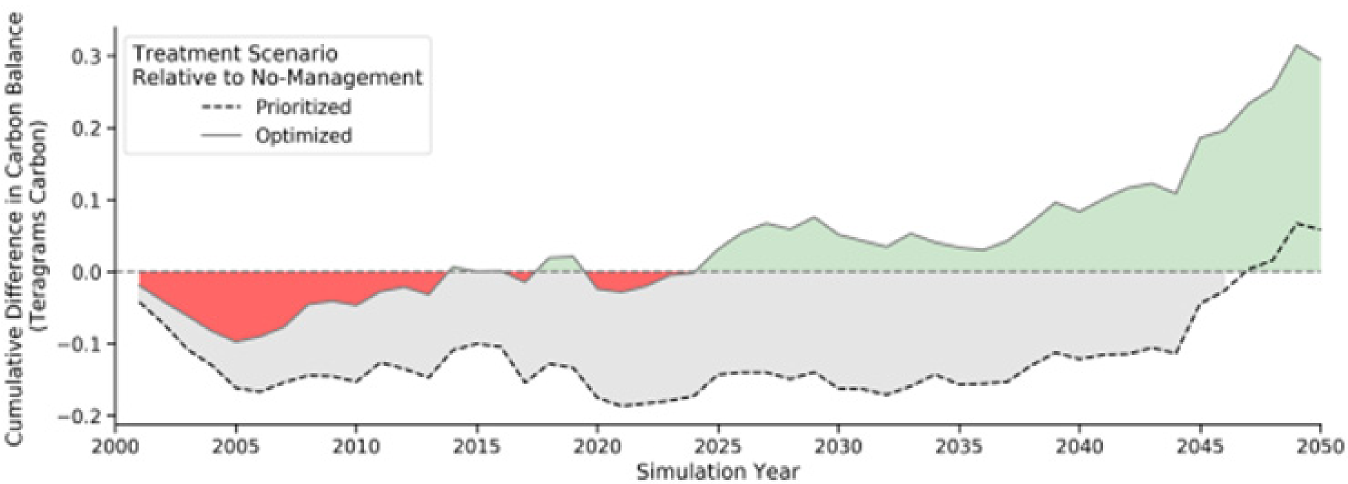


FIGURE 9 Modeled carbon storage in the fireshed across two fuel treatment scenarios

Source: "Carbon Storage Due to Proposed Treatments in the Fireshed. Source: Krofcheck, D. J., Remy, C. C., Keyser, A. L., & Hurteau, M. D. (2019). Optimizing Forest Management Stabilizes Carbon Under Projected Climate and Wildfires. Journal of Geophysical Research: Biogeosciences, 124. https://doi.org/10.1029/2019JG005206."

Air Quality
The impact of wildfire smoke on air quality in the Santa Fe area is a significant concern. The 2013 Thompson Fire was highlighted by stakeholders as a recent event that significantly impacted air quality. Fine particulate matter from wildfire smoke has a variety of impacts on human health, particularly exacerbating asthma and other respiratory conditions. Depending on wind conditions, a fire in the Santa Fe Fireshed may not directly impact the air quality within the City of Santa Fe. However, wildfire smoke can drift thousands of miles, and may impact many communities within the US.[xlvi] These health impacts result in increased hospital admissions, increased emergency department visits, and increased premature mortality.[xlvii] Health costs of wildfire smoke are challenging to measure and yield a wide range in values, based on methodological approach and wildfire behavior. Three estimates of the direct health costs associated with wildfire smoke, per acre burned, are listed in the table below. For the purposes of this analysis the average of these three values, $749 per acre burned, was used.

TABLE 2

STUDY	LOCATION	ACRES BURNED	HEALTH COST	COST PER ACRE BURNED
CASCIO, W. 2018	Pocosin Lakes, North Carolina	40,000	$48.4 Million	$1210
KOCHI, ET AL. 2012.	Southern California	750,043	$172.9 Million - $1.729 Billion	$203.5 - $2,305
JONES, B., BERRENS, R. 2017	Western United States	156,000,000	$333.51 M - $3,955.23 Million	$2.13 - $25.35
AVERAGE				$749

Avoided Fire Suppression and Restoration

Fighting fires and helping the environment to bounce back from fire disruptions is expensive. One likely outcome of the proposed treatments is a reduction in money spent on fire suppression and restoration associated with severe wildfires.

Suppression and restoration costs can vary significantly based on fire location and other factors. Fire suppression costs were estimated based on the average per-acre suppression cost for fires within the US, adjusted to 2019 dollars. Forest Service Region 3 (Arizona and New Mexico) estimates a per acre cost of fire supression of $941.[xlviii] Restoration costs are estimated at $567 per acre, based on the historical restoration costs associated with the Cerro Grande fire in the region.[xlix]

PHASE 3: QUANTIFICATION OF TREATMENT IMPACTS

Following identification of the VARs through stakeholder interviews and research, and the baseline assessment of these VARs described earlier, we sought to quantify the impact of the proposed treatments on the VARs.

ESTIMATING BASELINE FIRE PROBABILITY

The benefits and assets described in Phase 2 of this report would all be impacted in some way by wildfires and post-fire flooding and landslides. In order to quantify the benefits associated with the proposed forest treatments, in terms of reduced impacts to VARs, we first sought to quantify to current risk of fire within the Fireshed. We used LandFire's Fire Return Interval and Fire Severity data to estimate the current annual probability of low severity (less than 25% of the landscape burned), mixed severity (25%-75% of the landscape burned), and replacement severity (more than 75% of the landscape burned) fires. LandFire is a multi-organizational program developed in collaboration with the US Forest Service, the US Department of the Interior, the Rocky Mountain Research Station, the Nature Conservancy, and several other partners. LandFire provides fire regime, fuel, disturbance, vegetation, and topographic data designed to inform fire management decision-making and resource management.

All fire probability models—including the LandFire model used in this analysis—contain a degree of uncertainty. There are numerous factors that influence fire risk and severity, and only a portion of those factors are captured here. We believe that the fire probability estimates used in this analysis represent the best available annual fire probability projections for this region. Figure 10 summarized the annual burn probabilities for low, mixed, and replacement severity fires.

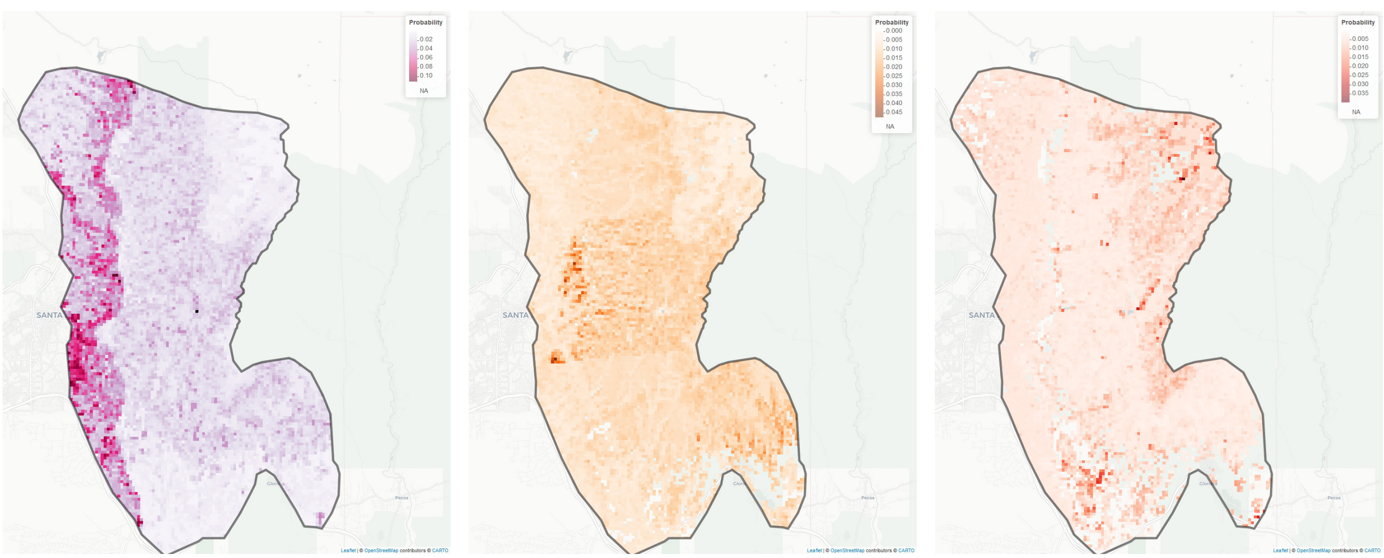


FIGURE 10 Annual probability of low (left), mixed (center) and replacement (right) severity fire within the Fireshed. Darker colors indicate higher fire probability. Fire probabilities based on LandFire modeling.

ESTIMATING THE IMPACT OF FUEL TREATMENTS ON FIRE PROBABILITY

Next, we quantified the impacts of the proposed treatment—thinning and prescribed burning of approximately 50,566 acres of forest within the Fireshed—on fire probability. In alignment with the Environmental Assessment conducted for this project,[l] we evaluated the impacts of these treatments over a 10-year period. We used two separate models to quantify the effectiveness of these treatments to account for uncertainty, so final results are presented as a low-high range.

Our analysis assumes that the proposed treatments would be successful in reducing the risk of high severity wildfires. Although the vast majority of published literature supports this assumption (see Appendix B), there are examples where certain treatments appear to worsen fire risk, or where the treatments have even resulted in the accidental ignition of a wildfire. We captured these uncertainties in treatment efficacy by using two distinct fire impact models; however, in all cases we made the assumption that the proposed treatments would successfully reduce fire risk to some degree.

Fuel Treatment – Fire Probability Model 1: IFTDSS

The Interagency Fuel Treatment Decision Support System (IFTDSS) quantifies the impact of fuel treatments on burn probability and severity, relative to weather conditions. Our IFTDSS treatment condition was based on the IFTDSS analysis of the proposed treatment scenarios on the Fireshed conducted through the course of the Environmental Assessment.[li]

The IFTDSS model provides landscape burn probabilities based on a fixed set of weather conditions. IFTDSS outputs are generated based on burn frequencies across thousands of fire simulations. In order to integrate the IFTDSS outputs (which quantify burn probabilities relative to 90th percentile fire conditions, based on temperature, moisture, and wind speeds) with total annual burn probabilities, IFTDSS outputs were adjusted based on the ratio of 90th percentile baseline burn probability to total LandFire annual burn probability. This adjustment relies on the assumption that the percentage reduction in fire risk attributed to each treatment is consistent across weather conditions.

The model shows significant, lasting reductions in the risk of replacement severity fires for light and heavy thinning treatments, whereas prescribed burn treatments lose effectiveness in year five. Although the probability of low severity fires was decreased for all treatment conditions, the most significant declines occurred in mixed and replacement fire severity. This impact is very much in line with the goals of these treatments. Table 3 summarizes the results of the IFTDSS model run.

TABLE 3 Predicted acres burned in the Fireshed over 10 Years - IFTDSS

	NO ACTION	TREATMENT	PREDICTED AVOIDED ACRES BURNED
ACRES BURNED – LOW SEVERITY	19,550	7,686	11,864
ACRES BURNED – MIXED SEVERITY	7,430	33	7,397
ACRES BURNED – REPLACEMENT SEVERITY	3,792	0	3,792
TOTAL ACRES BURNED	30,772	7,719	23,053

Fuel Treatment – Fire Probability Model 2: Literature Review
A literature review was used as a second approach used for "modeling" treatment impacts. We are referring to the literature review as a "model" in the broadest sense; while it is not a spatial model, it does provide a simple approach for quantifying treatment impacts and validating the IFTDSS results.

The results from the IFTDSS adapted model indicate that the proposed treatments would significantly reduce the frequency and severity of wildfires in the Fireshed. In order to validate these results, we conducted a review of the existing literature on the impacts of forest treatments of fire occurrence and severity (see Appendix B).

The IFTDSS model predicted a somewhat larger reduction in fire probability than the sources we identified in the literature review. However, a direct comparison between the literature and the IFTDSS adapted model is difficult because many of the literature sources lack the requisite specificity, not reporting variables like time, treatment intensity, or fire severity. In order to account for the disparate results between the IFTDSS model and the literature review, an alternative model was developed based exclusively on average treatment effectiveness as determined through the literature review.

The literature review model assumes no change in the risk of low severity fires, and a 50% reduction in mixed and severe fire risk for the proposed treatments (see Table 5).[lii] A full summary of studies reviewed can be found in Appendix B.

TABLE 4 Predicted acres burned in the fireshed over 10 Years - Literature Review model

	NO ACTION	TREATMENT	PREDICTED AVOIDED ACRES BURNED
ACRES BURNED – LOW SEVERITY	19,550	19,550	0
ACRES BURNED – MIXED SEVERITY	7,430	3,715	3,715
ACRES BURNED –REPLACEMENT SEVERITY	3,792	1,896	1,896
TOTAL ACRES BURNED	30,772	25,161	5,611

ESTIMATING THE IMPACT OF FIRES ON VALUES AT RISK

Not all the VARs within the Fireshed will be impacted by wildfire in the same way. A low intensity fire may not have a large impact on roads, for example, but may significantly damage structures. The estimated impacts to each VAR (referred to here as "value loss") at each fire severity are shown in Table 5 below. These values are derived from multiple sources, including a 2018 report conducted by the Nature Conservancy, and the municipal watershed plan.[liii]

TABLE 5 Value Loss by Fire Severity

VALUES AT RISK	LOW SEVERITY FIRE IMPACT	MIXED SEVERITY FIRE	REPLACEMENT SEVERITY FIRE
STRUCTURES	-20%	-50%	-85%
ROADS	0%	-20%	-50%
TRAILS	-10%	-20%	-50%
DEVELOPED RECREATION	-10%	-65%	-75%
CARBON STORAGE	-20%	-50%	-90%
DRINKING WATER	0%	-50%	-100%
AIR QUALITY	-25%	-50%	-100%

CALCULATED EXPECTED LOSSES, IN NO ACTION VS. TREATMENT SCENARIOS

Our analysis was conducted at the pixel scale (30 x 30 meters) over a 10-year period to estimate the impacts of proposed treatments.

For each VAR (structures, roads, etc.) in the Fireshed, current baseline values were calculated at the pixel level. Fire severity was estimated for that pixel for each of the treatments, based on the results of the IFTDSS-adapted model and literature review model (i.e. two distinct sets of results were generated). In each pixel, VAR impacts were estimated for the No Action scenario, by multiplying, the baseline VAR value by the estimated value loss associated with the fire severity after the "no action" treatment. In each pixel, VAR impacts were then estimated for the three remaining treatments: (i.e. heavy thinning and prescribed burning; light thinning and prescribed burning; prescribed burning only), by multiplying the baseline VAR value by the estimated value loss associated with the new fire severity after each treatment. The difference between value loss in the No Action treatment compared with each of the other treatments was considered the "outcome" (i.e. avoided loss) of that treatment. For example, if our LandFire model predicts that a specific area with a built structure (valued at $200,000) within the Fireshed would have a 2% chance of mixed severity fire (50% value loss) within the next ten years, the baseline structural value loss would be $2,000 ($200,000 multiplied by 2%, multiplied by 50%). If our IFTDSS and Literature Review models predict that treatment will reduce the risk of a mixed severity fire from 2% to 0.75% over the next ten years, then the expected value would following treatment is $750 ($200,000 multiplied by 0.75%, multiplied by 50%). The cost savings due to treatment is $1,250 ($2,000 minus $750) for that pixel.

Trail recreation values were calculated at the trail-scale, rather than the pixel scale, to reflect the risk of trail closure due to trail damage.

TREATMENT IMPACT RESULTS

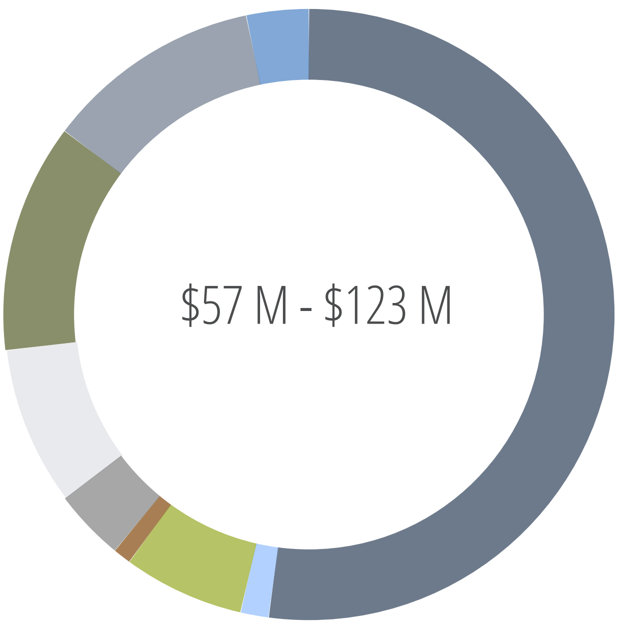
The projected costs and benefits of treatment are presented below. All values, unless otherwise noted, are presented in present value terms based on a 10-year study period (in the 2019 currency year) and a 3% discount rate. A 10-year study period was selected to align with the IFTDSS adapted model period of analysis (which projects that treatments would decline in effectiveness from years 6 through 10). A 3% discount rate is commonly used for natural infrastructure projects, to appropriately prioritize near-term impact without rendering long term benefits inconsequential. The 3% rate is used by NOAA and other agencies for ecosystem restoration projects.[liv]

Treatment Costs

The proposed treatments are estimated to cost up to $44.8 million, based on an average thinning cost of $2,000 per acre (applied to 18,077 acres) and an average prescribed burning cost of $45–$400 per acre (average $223/acre) applied to 38,804 acres, based on recent treatments completed in the area.

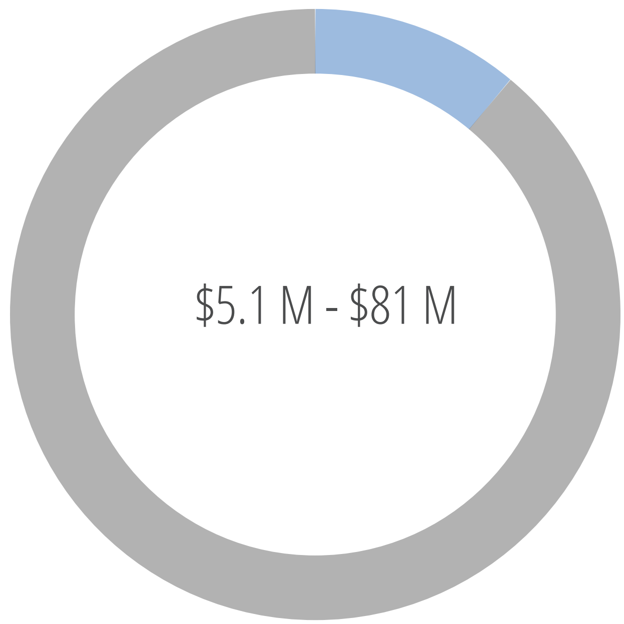
FIGURE 11 Economic, environmental, and social benefits of the proposed treatments

Treatment Benefits



- $28 million - $64 million
  Avoided damage to structures
- $0.9 million– $2 million
  Avoided road replacement costs
- $4 million – $8 million
  Avoided trail recreation value loss
- $0.4 million – $0.8 million
  Avoided skiing recreation value loss
- $3 million – $5 million
  Avoided water supply costs
- $10 million
  Carbon storage benefits
- $4 million– $15 million
  Avoided air quality costs
- $5 million- $14 million
  Avoided fire suppression costs
- $2 million - $4 million
  Avoided fire restoration costs

Economic Impacts of Treatment



- $5.1 million - $11.4 million
  Avoided economic losses of recreation
- $81 million
  Economic impacts of forest treatments

STRUCTURES

Reduction in wildfire risk within the Fireshed reduces the risk of structure damage. All three proposed treatments are projected to significantly reduce the risk of damage to structures over a 10-year period.

RECREATION

TRAILS:

The proposed treatments would reduce the risk of damage and closures to trails within the Fireshed.

SKIING:

The proposed treatments would reduce the risk of damage to Ski Santa Fe through the potential for loss of lifts and other infrastructure following a wildfire. The cost savings to these recreational assets are significantly lower than the cost savings associated with trail usage because the network of trails is far more diffuse, with more opportunities for fire to result in recreational asset closure.

ROADS

The proposed treatments are projected to avoid damage to roads within the Fireshed, due to wildfires and post-fire floods and landslides. There are approximately 500 miles of roads within the Fireshed. This valuation was based on the replacement cost of these roads, and does not capture the potential for transit disruption due to road closure. Transit disruption risks are captured in the valuation of recreational assets within the Fireshed, however our valuation likely constitutes an underestimate of the true avoided costs of road damage, as the cost of traffic disruption for non-recreational use is not included.

DRINKING WATER

The reservoirs within the Fireshed are an important source of drinking water for the City of Santa Fe. A large wildfire within the Fireshed would impair water quality and likely require reservoirs to be dredged, due to the accumulation of sediment. The estimated avoided losses are based exclusively on avoided dredging costs, and do not include the cost of alternative sourcing because the City's existing water infrastructure can accommodate a short-term disruption.

CARBON STORAGE

Carbon stocks are reduced through treatment, however a reduction in carbon losses due to wildfire is projected to generate a net reduction in carbon losses over the long term. For this analysis, we used the carbon model developed by Krofcheck, et al.[lv] This carbon model used a 50-year analysis period, rather than the 10-year study period used in this study. This decision was intentional, because using a 10-year study period would likely produce a negative value owing to the near term biomass reductions through thinning and prescribed burning. A 50-year time period is more appropriate for analysis, because it demonstrates the long-term goal of carbon storage. Krofcheck, et al. found that treatments would result in a net carbon emissions reduction of 150,000–330,000 metric tons of carbon. This reduction is valued using EPA's social cost of carbon ($42 per ton).

FIRE

SUPPRESSION:
Costs are estimated based on the reduction in acres burned attributable to treatment.

RESTORATION:
Costs are estimated based on the reduction in land that requires restoration or rehabilitation post-fire.

AIR QUALITY

Smoke from a wildfire within the Fireshed is projected to have a significant impact on the health of residents in surrounding areas. The air quality impacts are affected by a variety of factors in addition to wildfire size including severity, wind direction, and weather patterns.

ECONOMIC IMPACT

RECREATION:

Recreational use benefits Santa Fe's economy. Hikers, skiers and other recreational users spend money at local retail stores and restaurants, and out-of-the area visitors spend money on lodging and transportation. These economic contributions are dependent upon access to recreational amenities within the Fireshed, and if these recreational assets were damaged due to wildfire, expenditures would decrease. Economic Impact values are not included in the benefit-cost analysis, because economic expenditures are transferable (e.g. money not spent in Santa Fe may be spend elsewhere). It is considered best practice to omit economic impact values from a benefit-cost framework.

FORESTRY INVESTMENT:

The proposed treatments would support economic activity and job creation within the Santa Fe community. In addition to supporting the forestry industry, the investment is expected to provide economic contributions to restaurants, medical services and retail industries within Santa Fe County, and create 801 jobs within the county. In total, the proposed treatments are estimated to generate $81 million in economic output within the county, indicating that every $1 invested would generate nearly $2 in economic activity. Economic Impact values are not included in the benefit-cost analysis, because economic expenditures are transferable (e.g. money not spent in Santa Fe may be spent elsewhere).

SIMULATION ANALYSIS

The estimated impacts of treatment present wide ranges, given the differences between the two models deployed and uncertainty in the literature. These ranges reflect the inherent uncertainty in modeling wildfire and fuel treatments. To account for this uncertainty, we conducted our benefit-cost analysis using a Monte Carlo simulation. This approach uses a computational algorithm to calculate costs and benefits over thousands of simulations. Using the low and high values of each benefit, each benefit was randomly simulated along a normal distribution between the upper and lower bound. For example, the expected fire suppression cost savings due to treatment are $4.5 million–$13.7 million. The model generates a normal distribution curve with $4.5 million and $13.7 million as one standard deviation from the median expected value. Across every simulation, the fire suppression cost savings value was randomly generated along the normal distribution curve, meaning the value was most often near the median. Our analysis aggregated the results of 10,000 simulations.

With carbon storage benefits excluded (due to differing time scales) the average net present value of the project is $19.7 million and 98.8% of simulations yielded a positive net present value.

FIGURE 12 Benefit-Cost Analysis of Project (with Carbon Values Excluded)

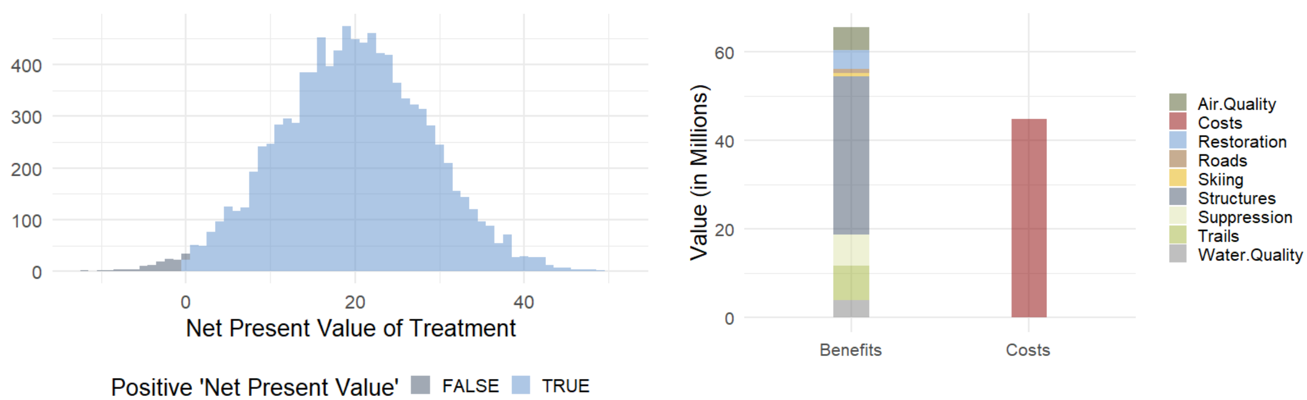
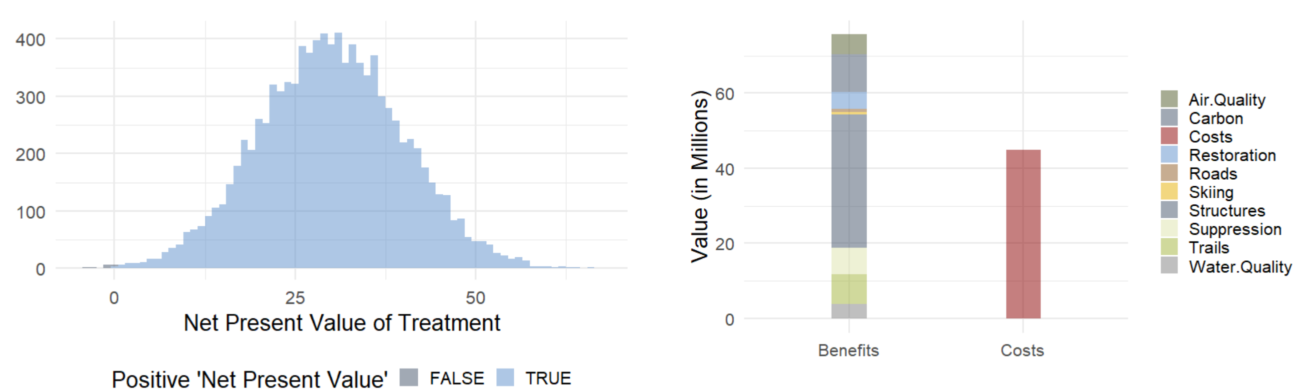


FIGURE 13 Benefit-Cost Analysis of Project (with Carbon Values Included)



In total, the project is estimated to generate between **$1.44–$1.67** in benefits for every dollar invested in treatment. The majority (74%) of these benefits directly accrue to the Santa Fe community, through avoided air quality impacts, recreational losses, structure damage and source water losses. The remaining benefits accrue to public agencies at the state and national level or to the global community (in the case of avoided carbon emissions).

TABLE 6

BENEFIT	VALUE (AVERAGE)	BENEFICIARY
AIR QUALITY	$9.1 million	Local, Regional
CARBON	$10.2 million	Global
AVOIDED RESTORATION COSTS	$3.0 million	National
AVOIDED ROAD DAMAGE	$1.2 million	Local, Regional, National
AVOIDED RECREATIONAL LOSS (SKIING)	$0.6 million	Local, Regional
AVOIDED DAMAGE TO STRUCTURES	$41.6 million	Local
AVOIDED SUPPRESSION COSTS	$9.1 million	Local, Regional, National
AVOIDED RECREATIONAL LOSS (TRAILS)	$6.1 million	Local, Regional
AVOIDED WATER QUALITY IMPACTS (DREDGING)	$3.7 million	Local

DISCUSSION

Our analysis found that the benefits generated by the proposed treatments would greatly outweigh the costs. Across both fire projection models, the treatments would provide a net benefit for the Santa Fe community. The Fireshed provides numerous benefits to the community, only a portion of which were captured by this analysis. Many key benefits have been omitted due to limits in quantification and valuation, including the cultural value of the Fireshed and the intrinsic value of biodiverse ecosystems and habitats. Although the true value of the Fireshed cannot be fully captured in monetary terms, our analysis shows that protecting this unique asset by reducing the risk of wildfire and post-fire flooding and landslides generates a positive return, despite only measuring a portion of that return. Our findings are in line with analyses of other proposed forest treatments, including a 2014 study of proposed treatments in the Mokelumne Watershed which found that proposed treatments would generate between $1.4–$2.5 in benefits to the community for every dollar invested in treatment.[lvi] This return on investment should be considered an underestimate, because it does not account for the cultural and ecosystem values that would be lost during a fire, many of which cannot be estimated using traditional economic valuation techniques, and whose value is best understood qualitatively.

This analysis was limited to the assets that lie within the Fireshed; however, other benefits from investing in fuel reduction are likely to accrue. By restoring the Fireshed to a resilient condition, the risk of fire to assets outside of the Fireshed boundary is reduced as well. The risk of fire and post-fire flooding and landslides to houses, roads, trails, and developed recreational sites near but outside of the Fireshed was not included in this analysis, but may be significant.

Downstream flooding and landslide risks were only partially captured in our risk modeling, as our approach to damage projections was limited to areas where our model projected fire damage to occur. For example if a fire burned a hillside, and a resulting flood or landslide were to damage downstream homes that were otherwise unimpacted by the fire, this damage would not be fully captured by our models. This may lead to our damage projection significantly undercounting the risk of fire-related damage. Downstream post-fire flooding is a major risk, but is very difficult to model at the probabilistic scale needed for this analysis.

Finally, our fire risk projections do not account for changes in fire risk over the next century due to climate change. The impacts of a changing climate on the Fireshed were noted by numerous stakeholders, and climate change is a major contributor to the perceived resilience challenge facing the landscape. Estimating fire probabilities is inherently uncertain, and integrating emissions scenarios and climate projections within these analyses results in very wide ranges of expected outcomes.

Despite a conservative approach to this valuation, our analysis indicates that the proposed fuel reduction treatments would improve the health and resilience of the Fireshed by reducing the risk of wildfire and post-fire flooding and landslides. Preserving this critical and unique asset is a clear priority for stakeholders within the Santa Fe community, and our research indicates that the proposed actions would be an important and cost-effective step towards a more resilient landscape.

APPENDIX

APPENDIX A SIGHTINGS OF VULNERABLE BIRD SPECIES WITHIN THE FIRESHED

The New Mexico Avian Conservation Partners assess vulnerability of avian species in the state based on distribution, notable threats, population size, population trend, and importance to the state. Species with the highest level of vulnerability are designated at “Level One” species. “Level Two” species are considered to be vulnerable, but less at risk than Level One species.[lvii]










Common Name	SCIENTIFIC NAME	SIGHTINGS REPORTED WITHIN FIRESHED	New Mexico Avian Conservation Partners Species Vulnerability
Flammulated Owl	Psiloscops flammeolus	3	1
Grace's Warbler	Setophaga graciae	42	1
Juniper Titmouse	Baeolophus ridgwayi	399	1
Lewis's Woodpecker	Melanerpes lewis	3	1
Pinyon Jay	Gymnorhinus cyanocephalus	74	1
Scaled Quail	Callipepla squamata	2	1
Virginia's Warbler	Leiothlypis virginiae	55	1
Woodhouse's Scrub-Jay	Aphelocoma woodhouseii	725	1
Band-tailed Pigeon	Patagioenas fasciata	23	2
Black-throated Gray Warbler	Setophaga nigrescens	83	2
Brewer's Sparrow	Spizella breweri	8	2
Broad-tailed Hummingbird	Selasphorus platycercus	628	2
Bushtit	Psaltriparus minimus	374	2
Cactus Wren	Campylorhynchus brunneicapillus	1	2
Canyon Towhee	Melozone fusca	203	2
Cassin's Finch	Haemorhous cassinii	231	2
Cassin's Sparrow	Peucaea cassinii	1	2
Clark's Nutcracker	Nucifraga columbiana	91	2
Evening Grosbeak	Coccothraustes vespertinus	236	2
Green-tailed Towhee	Pipilo chlorurus	34	2
Lark Bunting	Calamospiza melanocorys	2	2
Mountain Bluebird	Sialia currucoides	11	2
Mountain Chickadee	Poecile gambeli	843	2
Northern Pintail	Anas acuta	1	2
Pygmy Nuthatch	Sitta pygmaea	121	2
Rufous Hummingbird	Selasphorus rufus	185	2
Steller's Jay	Cyanocitta stelleri	365	2
Townsend's Solitaire	Myadestes townsendi	430	2
Western Bluebird	Sialia mexicana	201	2
Western Screech-Owl	Megascops kennicottii	3	2
Williamson's Sapsucker	Sphyrapicus thyroideus	77	2

APPENDIX B LITERATURE REVIEW OF TREATMENT IMPACTS

AUTHOR	STUDY TITLE	PRACTICE	KEY FINDING
M. A COCHRANE, ET AL	Estimation of wildfire size and risk changes due to fuel treatments	Mechanical Thinning + Prescribed Burning	-63.6% to 46.1% change in area burned due to simulated treatments. Treatments prevented 0.04 to 4.06 hectares from burning per hectare treated.
HANSON, C.T., ODION, D.C. 2006	Fire Severity In Mechanically Thinned Versus Unthinned Forests Of The Sierra Nevada, California	Mechanical Thinning	Contrary to expectations, thinned areas within the study site had higher mortality than unthinned areas, due to thinned areas burning at a higher intensity.
SKINNER ET AL. 2004	Effects of Thinning and Prescribed Fire on Wildlife Severity	Mechanical Thinning + Prescribed Burning	Crown fire dropped to surface fire upon entering treatment areas, and in some cases fire died out all-together upon entering treated areas.
POLLET AND OMI 2002	Effect of Thinning and Prescribed Burning on Crown Fire Severity in Ponderosa Pine Forests	Mechanical Thinning + Prescribed Burning	Crown fire severity was mitigated in stands that had some type of fuel treatment compared to stands without any treatment. At all four of the sites, the fire severity and crown scorch was significantly lower at the treated sites.
RHODES AND BAKER 2008	Fire Probability, Fuel Treatment Effectiveness and Ecological Tradeoffs in Western US Public Forests	Mechanical Thinning + Prescribed Burning	Treatments reduced the probability of high severity fire by 45%.
LYDERSEN ET AL. 2017	Evidence of fuels management and fire weather influencing fire severity in an extreme fire event	Mechanical Thinning + Prescribed Burning	Rim Fire severity was lower in areas with previous treatments. Only 1% of areas treated with thinning and prescribed burning burned at a high severity during the fire, compared to 38% of untreated areas.

AUTHOR	STUDY TITLE	PRACTICE	KEY FINDING
KALIES AND YOCUM KENT 2016	Are fuel treatments effective at achieving ecological and social objectives? A systematic review	Various	Meta-analysis of 56 studies addressing fuel treatment effectiveness in 8 states in the western US. There was general agreement that thin + burn treatments had positive effects in terms of reducing fire severity, tree mortality, and crown scorch.
MARTINSON AND OMI 2013	Fuel Treatments and Fire Severity: A Meta-Analysis	Various	Overall mean effect of fuel treatments on fire responses is large and significant, equating to a reduction in canopy volume scorch from 100% in an untreated stand to 40% in a treated stand.
SAFFORD ET AL. 2009	Effects of fuel treatments on fire severity in an area of wildland–urban interface, Angora Fire, Lake Tahoe Basin, California	Mechanical Thinning + Prescribed Burning	Fuel treatments generally performed as designed and substantially changed fire behavior and subsequent fire effects to forest vegetation.
WALTZ ET AL. 2014	Effectiveness of fuel reduction treatments: Assessing metrics of forest resiliency and wildfire severity after the Wallow Fire	Mechanical Thinning + Prescribed Burning	Fire severity, as defined by overstory mortality and basal area loss, was significantly lower in treated units; on average, trees killed per hectare in untreated units was six times the number of trees killed in treated units.
AGER ET AL. 2010	A comparison of landscape fuel treatment strategies to mitigate wildland fire risk in the urban interface and preserve old forest structure	Mechanical Thinning + Prescribed Burning	Modeled fuel reduction treatments on just 10 percent of the landscape resulted in a 70 percent reduction of large tree mortality.
MOGHADDAS AND CRAGGS 2007	A fuel treatment reduces fire severity and increases suppression efficiency in a mixed conifer forest	Mechanical Thinning + Prescribed Burning	% crown volume scorched was up to 75% immediately at the southern edge of the fuel treatment where the fire came in from, and decreased to less than 10% within 60 m of this edge.
CRAMM ET AL. 2006	Wildland Fire Effects in Silviculturally Treated vs. Untreated Stands of New Mexico and Arizona	Various; lop pile burn, lop scatter, harvest burn	All treatments had less fires severity than untreated. Measured severity on a scale of 1-4.
MARTINSON AND OMI 2003	Performance of Fuel Treatments Subjected to Wildfires	Mechanical Thinning + Prescribed Burning	Crown volume scorch averaged 38% in treated areas across the eight study sites, versus 84.5% in untreated areas.
YOCUM KENT ET AL. 2015	Interactions of fuel treatments, wildfire severity, and carbon dynamics in dry conifer forests	Mechanical Thinning + Prescribed Burning	High and moderate-severity fire was reduced from 76% in untreated areas to 57% in burn treatments and 38% in thin + burn treatments.

AUTHOR	STUDY TITLE	PRACTICE	KEY FINDING
BRIGGS ET AL. 2017	Short-term ecological consequences of collaborative restoration treatments in ponderosa pine forests of Colorado	Mechanical Thinning + Prescribed Burning	Treated areas had lower tree density and basal area, greater openness, no increase in exotic understory plants, no decrease in native understory plants, and no decrease in use by tree squirrels and ungulates.
PETRAKIS ET AL. 2018	Evaluating and monitoring forest fuel treatments using remote sensing applications in Arizona, USA	Mechanical Thinning + Prescribed Burning	Results showed harvested and thinned sites that were not treated with prescribed fire had the highest severity fire. When harvesting was followed by a prescribed burn, the sites experienced lower burn severity and reduced post-fire changes in vegetation greenness and wetness. Areas that had previously experienced resource benefit burns had the lowest burn severities and the highest post-fire greenness measurements compared to all other treatments, except for where the prescribed burn had occurred.
PRICHARD ET AL. 2010	Fuel treatments reduce the severity of wildfire effects in dry mixed conifer forest, Washington, USA	Mechanical Thinning + Prescribed Burning	Over 57% of trees survived in thin and prescribed buUQ (thin5x) units versus 19% in thin only (thin) and 14% in control units. Considering only large-diameter trees (>20 Fm diameter at breast height), 73% survived in thinRx units versus 36% and 29% in thin and control units, respectively.
SAFFORD ET AL. 2012	Fuel treatment effectiveness in California yellow pine and mixed conifer forests	Mechanical Thinning + Prescribed Burning	Increases in tree survivorship ranged from 45%-77% between treated and untreated sites; Jeffrey Pine and Ponderosa showed highest survival and Douglas Fir showed lowest. Douglas fir had largest survival difference between treated and untreated sites.
BUCKLEY, M. ET AL. 2014	Mokelumne watershed avoided cost analysis: Why Sierra fuel treatments make economic sense	Mechanical Thinning + Prescribed Burning	Treatments modeled to provide a 75% reduction in acreage burned in high intensity wildfire.
MARTINSON, ERIK J.; OMI, PHILIP N. 2013	Fuel treatments and fire severity: A meta analysis	Mechanical Thinning + Prescribed Burning	Treatments provide a 60% reduction in canopy burned. A 100% reduction observed is some cases.

AUTHOR	STUDY TITLE	PRACTICE	KEY FINDING
AGER, A., VAILLANT, N., FINNEY, M. 2009	A comparison of landscape fuel treatment strategies to mitigate wildfire fire risk in the urban interface and preserve old forest structure	Mechanical Thinning + Prescribed Burning	Treatments provide a 70% reduction in acres burned with only 10% of area acres treated.
KENT, L. L. Y., ET AL. 2015	Interactions of fuel treatments, wildfire severity, and carbon dynamics in dry conifer forests.	Mechanical Thinning + Prescribed Burning	76% reduction in High and Mixed severity fires 2 and 8 years post treatment.

UPSTREAM TECH
Powering smart conservation on a changing planet

Earth Economics & USFS Report

September 20, 2020

Overview

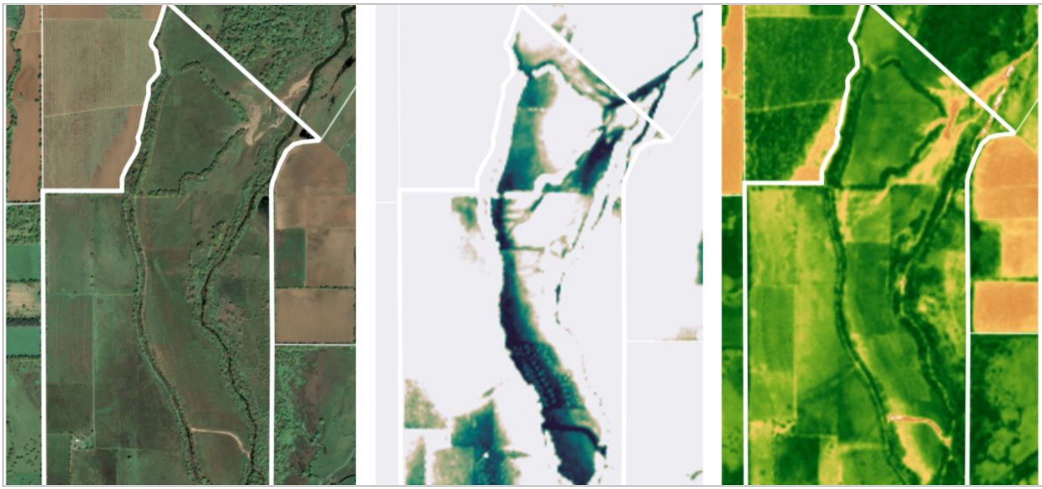
Upstream Tech builds tools to improve natural resource management and land conservation. We harness advancements in remote sensing, computer science, and machine learning to support conservation monitoring and decision-making. As part of a collaboration with Earth Economics, Upstream Tech provided mapping services to support the prioritization of possible restoration interventions within the fireshed treatment areas of the Santa Fe National Forest Program. Lens™, Upstream Tech's product for monitoring conservation lands, was used to visualize treatment areas in the Santa Fe National Forest Program. Satellite imagery and derived data was analyzed to characterize changes over time in the treatment areas and quantify vegetative response to fire or restoration interventions.

For the purposes of this project, Lens was used to visualize how surface water presence and vegetation vigor changed over recent years. These ecological metrics, in addition to high resolution satellite and aerial imagery, enabled users to characterize change over time in the predefined treatment areas to quantify vegetative response to fire and restoration interventions. This project lays the foundation for future remote monitoring methods to evaluate how landscapes have changed over recent years and how ecological variables can be tracked on an ongoing basis. Lens, which Upstream Tech utilized for the analysis described in this report, can be leveraged by stakeholders such as the USFS in the future to streamline on-the-ground monitoring and observe changes in conservation areas.

Methods

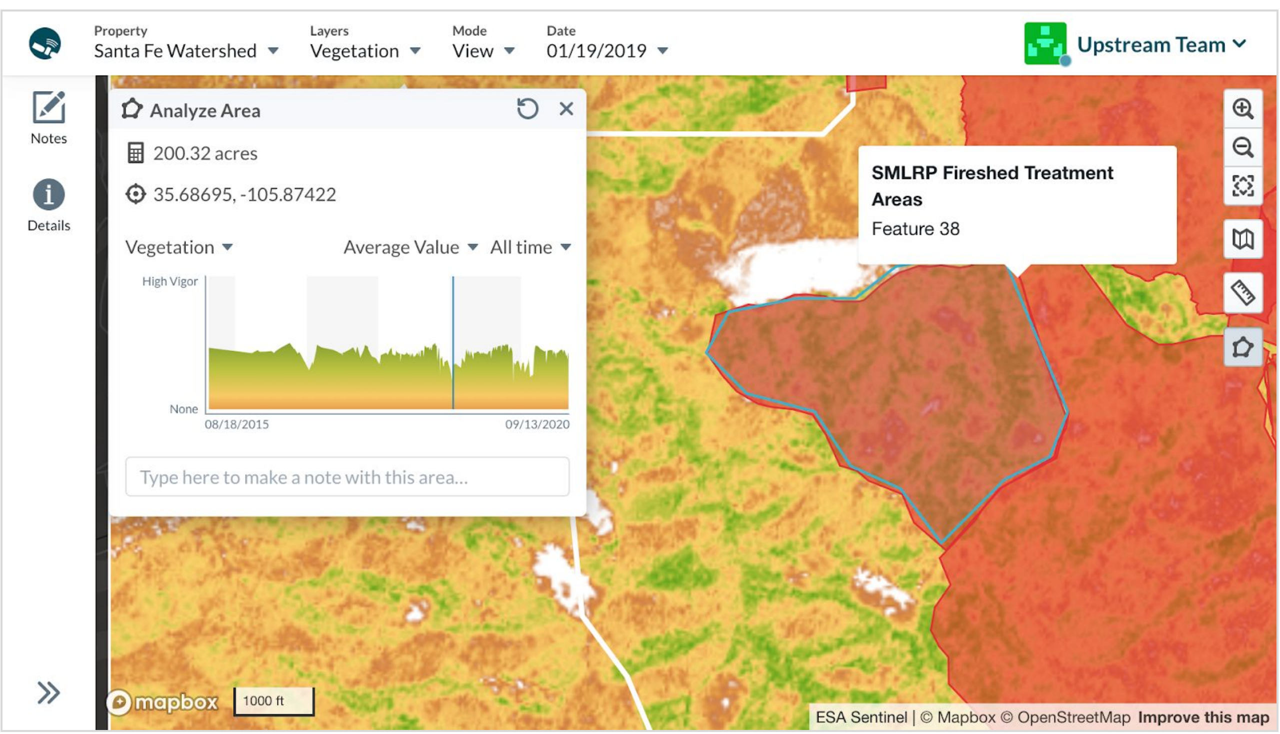
Our first step was to set up Lens with the seven areas of interest in the Santa Fe National Forest Program. Upstream Tech leverages several satellite data sources for monitoring, including from public and commercial providers. Satellite data sources vary significantly in spatial resolution as well as frequency of data capture, and the sources most useful for the purposes of this project included NASA's Landsat and the European Space Agency's (ESA) Sentinel satellite constellations. NASA's Landsat 8 satellite has a spatial resolution of 30m and a temporal frequency of 16 days. Sentinel 2, which provided the most nuanced data on vegetation changes with the most frequent updates, has a spatial resolution of 10m and a temporal frequency of 5 days.

We then analyzed satellite imagery and data on vegetation vigor and surface water to detect changes in the seven parcels evaluated for this project. The three primary types of data used in this project are shown below.



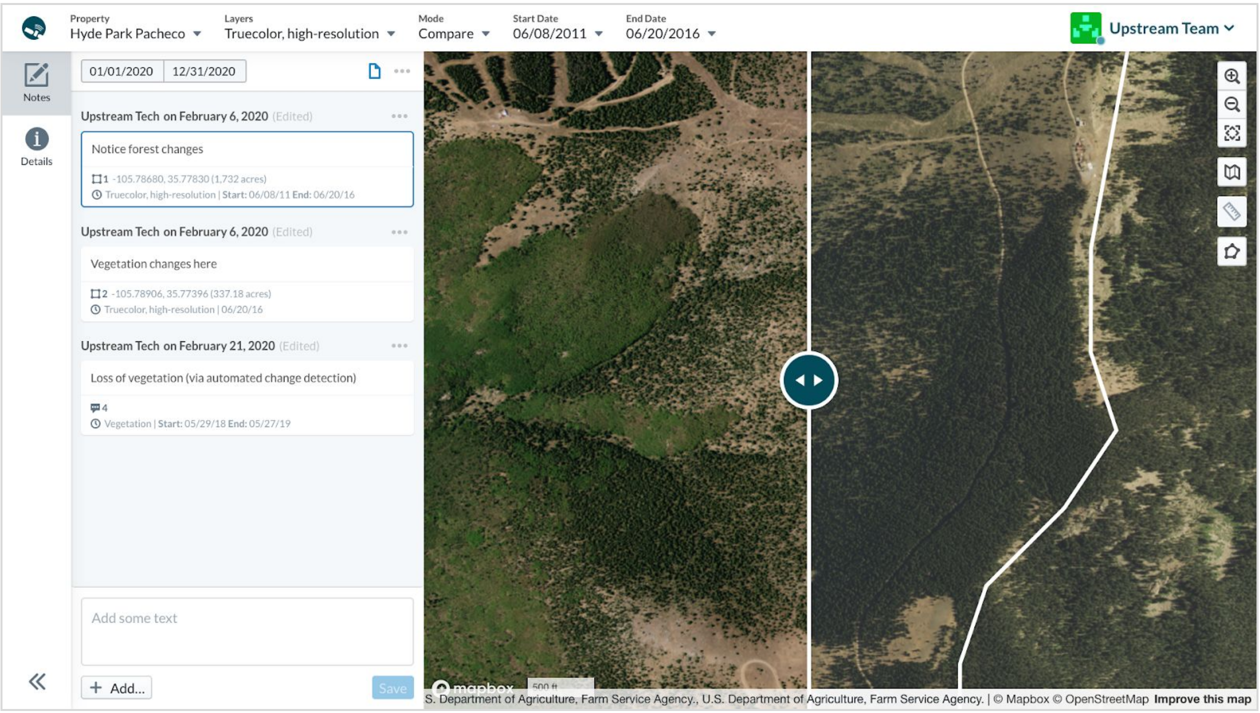
Example images of the same property comparing high-resolution true color imagery, surface water derived from the Normalized Difference Water Index, and vegetation vigor derived from the Normalized Difference Vegetation Index.

Additional provided layers, including the SMLRP Fireshed Treatment Areas, were overlaid onto the larger areas of interest to provide context and facilitate targeted analysis.



Lens screenshot showing analysis of a SMLRP FIreshed Treatment area on the Santa Fe Watershed area of interest. The graph on the left shows the pattern of vegetation vigor based on all data collected from ESA Sentinel 2 in the past 5 years.

Observations of changes were annotated as notes in Lens for future reference and documentation, as shown in the screenshot below.



Lens screenshot showing notes of observations detected on the Hyde Park Pacheco area of interest

Using the Analyze Area tool in Lens, parcels or subsets of them could also be analyzed to understand how ecological metrics, such as vegetation vigor, have changed in recent years.

All of these observations from satellite and aerial data were included in reports and documentation which was provided to Earth Economics to complement insights from stewardship staff and other stakeholders.

Conclusion & Next Steps

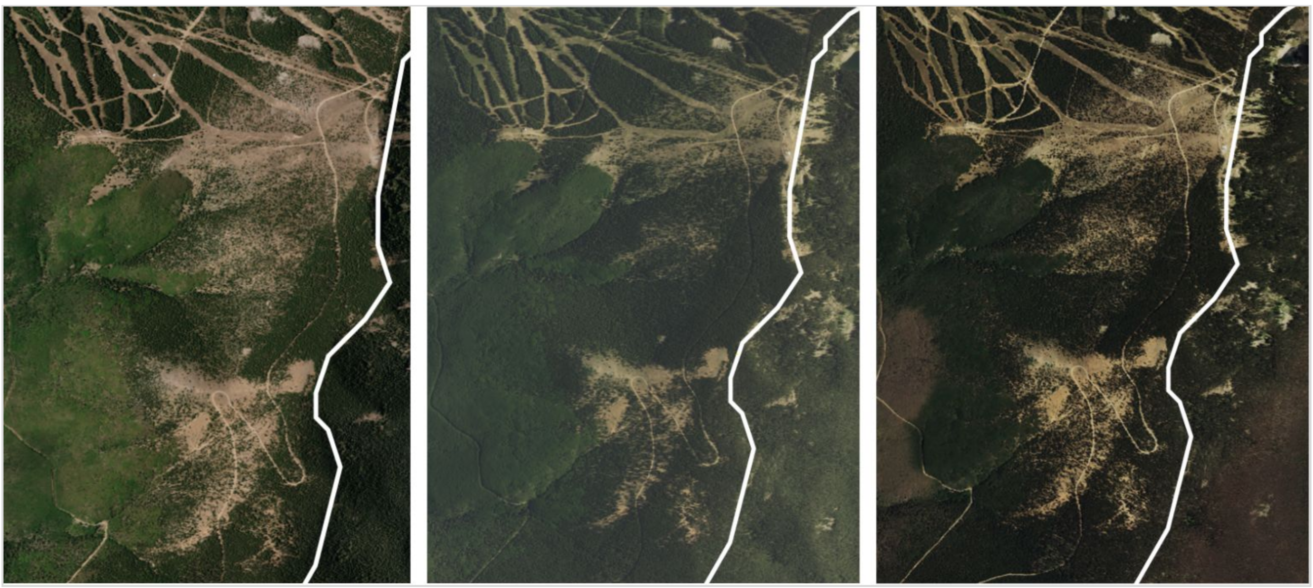
Given the importance of water availability and the risk of fires in the Santa Fe National Forest Program, the ability to consistently and efficiently gather data on how conditions are changing is necessary to inform efficient decision-making, strategic planning, and robust record-keeping. This project lays the foundation for future remote monitoring methods to evaluate how landscapes have changed over recent years and how ecological variables can be tracked on an ongoing basis. Using Lens, the geographies of interest were loaded along with fireshed treatment areas. These parcels could then be analyzed to understand how surface water presence and vegetation vigor have been altered in recent years, allowing stakeholders to rapidly assess change to understand the impact of restoration work or fires. Additionally, these metrics can enable decision-makers to prioritize areas well-suited for future treatment regimes, which complement the scenario planning and modeling work done by the Earth Economics team.

There are many potential pathways to build upon this project and leverage remotely-sensed data to impacts on-the-ground. Possible next steps could include:

- Expansion of the areas analyzed in this project using Lens to continue analyzing vegetation pre- and post-fires or restoration treatments.
- Procurement of high resolution imagery during key time periods for deeper analysis and insight. Public satellite data was used for the purposes of this project due to cost constraints. Upstream Tech has existing partnerships with commercial satellite providers and could purchase high-resolution imagery for deeper analysis of key areas and more nuanced observations.
- Quantification of fuel load, canopy cover, type and tree density with remotely sensed data
- Analysis or simulation to evaluate how changes in the fireshed, such as forest loss or degradation, impact water quality variables

Additional Observations

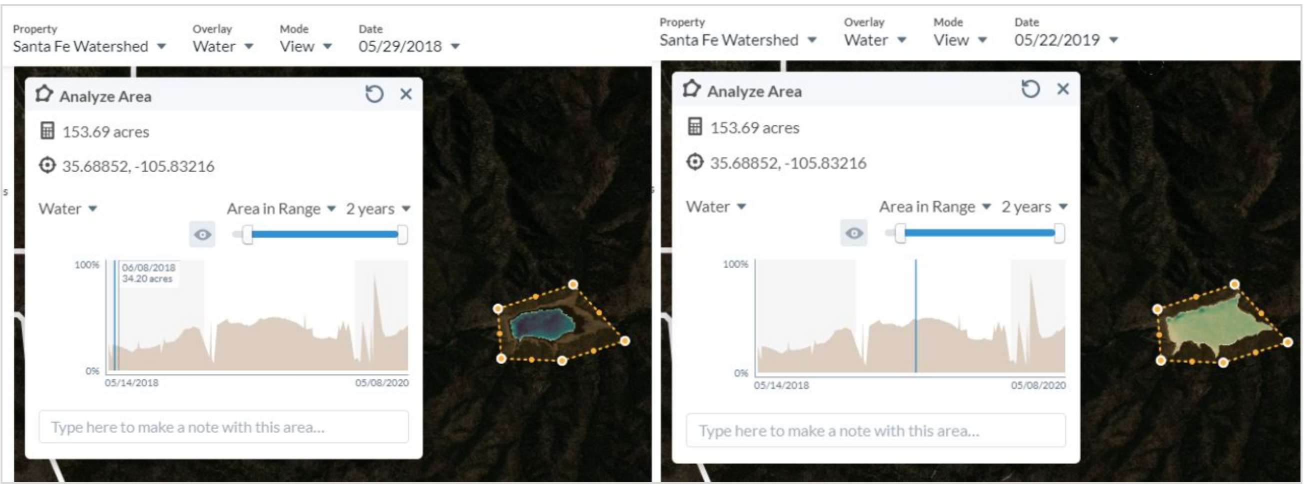
Hyde Park Pacheco



Three NAIP aerial images of the Hyde Park Pacheco area showing changes in forest cover between 2011, 2016, 2018, respectively. Based on this imagery, forest cover in 2011 was comparatively more sparse than the imagery from 2016 and 2018. Though on the far left side of the 2018 image, there is a patch of brown which may indicate degradation or tree loss.

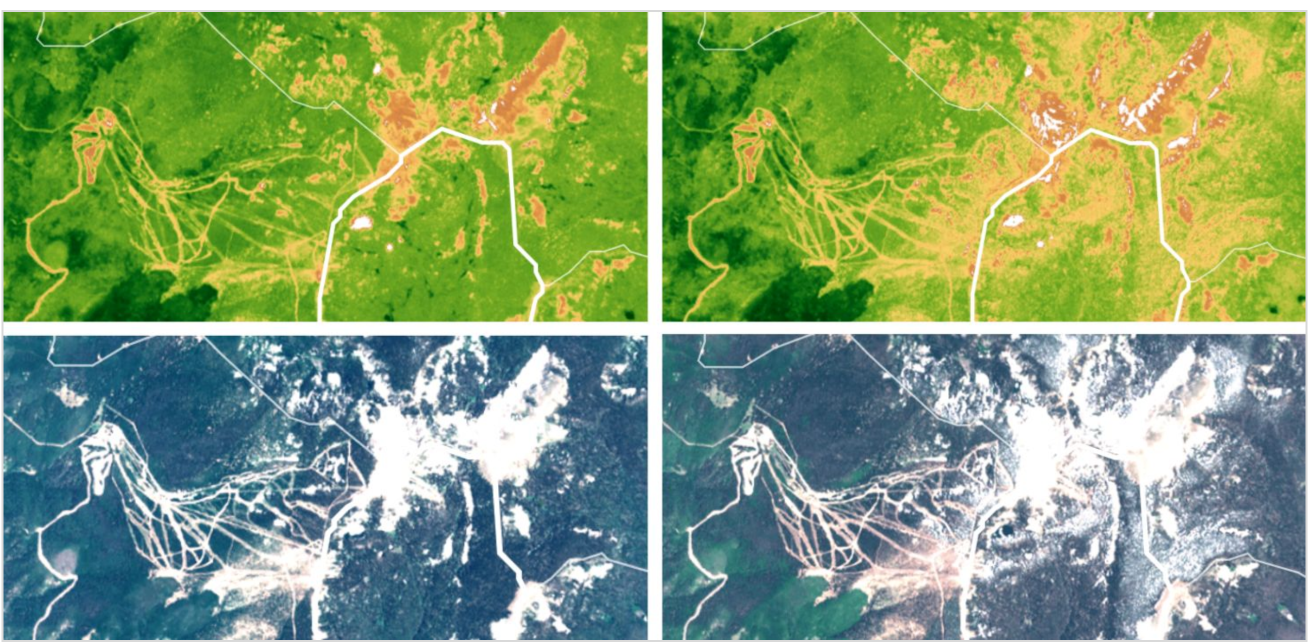
Santa Fe Watershed

Two images of the Santa Fe Watershed comparing surface water (Normalized Difference Water Index) changes, derived from ESA Sentinel 2 satellite data show a significant increase in surface water extent between May 2018 and 2019.



This same observation is shown here using the Lens Analyze Area tool, comparing one of the Santa Fe Watershed areas with water presence in May 2018 and 2019.

Pecos Wilderness



This group of images from the Pecos Wilderness area show vegetation vigor data on the top and true color imagery on the bottom. The two left images are from June 2017, and the right images are from June 2019. Visible trails, forest thinning and deforestation changes are visible.

REFERENCES

i "Where does our Drinking Water Come From" (2013) City of Santa Fe

ii "Greater Santa Fe Fireshed Resilience Strategy: Mission and Values" (n.d.) Greater Santa Fe Fireshed Coalition

iii "Fire History in the Greater Santa Fe Fireshed" (n.d.) The Greater Santa Fe Fireshed Coalition

iv Bassett, S. (2018) Greater Santa Fe Fireshed Coalition Wildfire Risk Assessment. The Nature Conservancy.

v Calkin, David E.; Hyde, Kevin D.; Robichaud, Peter R.; Jones, J. Greg; Ashmun, Louise E.; Loeffler Dan. 2007. Assessing post-fire values-at-risk with a new calculation tool. Gen. Tech. Rep. RMRS-GTR-205. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 32 p.

vi Garfin, G., S. LeRoy, D. Martin, M. Hammersley, A. Youberg, and R. Quay. 2016. Managing for Future Risks of Fire, Extreme Precipitation, and Post-fire Flooding. Report to the US Bureau of Reclamation, from the project Enhancing Water Supply Reliability. Tucson, AZ: Institute of the Environment, 33 p

vii Gutzler, D. "Climate Variability & Change in the Santa Fe Watershed" (2012) University of New Mexico

viii Radeloff, V. C., Helmers, D. P., Kramer, H. A., Mockrin, M. H., Alexandre, P. M., Bar-Massada, A., ... & Stewart, S. I. (2018). Rapid growth of the US wildland-urban interface raises wildfire risk. Proceedings of the National Academy of Sciences, 115(13), 3314-3319.

ix "People Restoring America's Forests: A Report On The Collaborative Forest Landscape Restoration Program" (2011) https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5416710.pdf

x Wyland, S. (2020) "Cerro Grand Fire Remains Burned into New Mexico's Memory 20 Years Later" Santa Fe New Mexican https://www.santafenewmexican.com/news/local_news/cerro-grande-fire-remains-burned-into-new-mexicos-memory-20-years-later/article_190f6252-896c-11ea-8ab4-e78b330ac4e3.html

xi "After Wildfire: A Guide for New Mexico Communities" (n.d.) https://ucanr.edu/sites/fire/files/288124.pdf

xii "The Economic Impact of Post Wildfire Flooding On Bill Williams Mountain" (2017) University of California https://coconino.az.gov/DocumentCenter/View/21682/The-Economic-Impact-of-Post-Wildfire-Flooding-Bill-Williams-Mountain?bidId

xiii "The True Cost of Wildfire" (n.d.) Santa Fe Fireshed Coalition. https://static1.squarespace.com/static/57b62cb1ebbd1a48387a40ef/t/5c7454f27817f77ef6beaa7f/1551127809168/postfire_impacts_highres.pdf

xiv Betancourt, J. L., Pierson, E. A., Rylander, K. A., Fairchild-Parks, J. A., & Dean, J. S. (1993). Influence of history and climate on New Mexico pinon-juniper woodlands. Managing pinyon-juniper ecosystems for sustainability and social needs, 42-62.

xv Je11'ers, R. M. (1995). Pinon pine seed production, collection, and storage. Desired Future Conditions for Piñon-juniper Ecosystems, August 8-12, 1994, Flagstaff, Arizona, (258), 191.

xvi "Tribal Consultation and Traditional Cultural Uses Report for the Santa Fe Mountains Landscape Resiliency Project" (n.d.) Santa Fe National Forest.

xvii "Greater Santa Fe Fireshed Resilience Strategy: Mission and Values" (n.d.) Greater Santa Fe Fireshed Coalition

xviii "Forest Stewards Youth Corps" (n.d.) Forest Stewards Guild

xix Bassett, S. (2018) Greater Santa Fe Fireshed Coalition Wildfire Risk Assessment. The Nature Conservancy.

xx "Mexican Spotted Owl Proposed Critical Habitat" (n.d.) https://www.fws.gov/southwest/es/MSO_Proposed_CH_NCentral_New_Mexico.html xxi eBird. (2020). eBird: An online database of bird distribution and abundance [web application]. eBird, Cornell Lab of Ornithology, Ithaca, New York. Available: http://www.ebird.org.

xxii "Mexican Spotted Owl Proposed Critical Habitat" (n.d.) https://www.fws.gov/southwest/es/MSO_Proposed_CH_NCentral_New_Mexico.html

xxiii "Special Assessment Scores" (n.d.) New Mexico Avian Conservation Partners http://avianconservationpartners-nm.org/species-assessment-scores/

xxiv Buckley, M., N. Beck, P. Bowden, M. E. Miller, B. Hill, C. Luce, W. J. Elliot, N. Enstice, K. Podolak, E. Winford, S. L. Smith, M. Bokach, M. Reichert, D. Edelson, and J. Gaither. 2014. "Mokelumne watershed avoided cost analysis: Why Sierra fuel treatments make economic sense." A report prepared for the Sierra Nevada Conservancy, The Nature Conservancy, and US Department of Agriculture, Forest Service. Sierra Nevada Conservancy. Auburn, California. Online: http://www.sierranevadaconservancy.ca.gov/mokelumne.

xxv Dalziell, E., & Nicholson, A. (2001). Risk and impact of natural hazards on a road network. Journal of transportation engineering, 127(2), 159-166.

xxvi Redfin. 2020. Redfin Property Values Database

xxvii "2019 Wildfire Risk Report" (2019) Corelogic. https://www.corelogic.com/downloadable-docs/wildfire-report_0919-01-screen.pdf

xxviii Ibid

xxix Vitu, T. (2019) "Site Ranks S.F. Among Small Cities Growing Fastest" AP News.

xxx Newberry, L. (2018) "As California Fire Disasters Worsen, insurers are pulling out and stranding homeowners" Los Angeles Times

xxxi Kasler, D., Sabalow, R., Reese, P. (2019) "'Sticker Shock' for California Wildfire Areas: Insurance Rates Doubled, Policies Dropped" The Sacramento Bee.

xxxii Ibid

xxxiii "Annual Water Report" (2015) City of Santa Fe Water Division https://savewatersantafe.com/wp-content/uploads/2016/06/2015-Annual-Water-Report.pdf

xxxiv Margolis, E., et al (2013) Santa Fe Municipal Watershed Plan 2010-2029

xxxv Bassett, S. (2018) Greater Santa Fe Fireshed Coalition Wildfire Risk Assessment. The Nature Conservancy.

xxxvi NVUM Survey Data

xxxvii Rosenberger, Randall S.; White, Eric M.; Kline, Jeffrey D.; Cvitanovich, Claire. 2017. Recreation economic values for estimating outdoor recreation economic benefits from the National Forest System. Gen. Tech. Rep. PNWGTR-957. Portland, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station. 33 p

xxxviii NVUM Survey Data

xxxix Ibid

xl Ibid

xli Ibid

xlii "Outdoor Recreation and New Mexico's Economy" (2020) Headwater Economics. https://headwaterseconomics.org/wp-content/uploads/20HE-NM-Outdoor-Rec-Report_web.pdf xliii US Forest Service (2012) Zumi Mountain Collaborative Forest Landscape Restoration Program Proposal. Retrieve from: https://www.fs.fed.us/restoration/documents/cflrp/2011Proposals/Region3/Cibola/ZuniMountainCFLRP.pdf

xliv Ibid

xlv "The Social Cost of Carbon" (2017) EPA. https://19january2017snapshot.epa.gov/climatechange/social-cost-carbon_.html

xlvi Ansmann, A., Baars, H., Chudnovsky, A., Mattis, I., Veselovskii, I., Haarig, M., ... & Wandinger, U. (2018). Extreme levels of Canadian wildfire smoke in the stratosphere over central Europe on 21–22 August 2017. Atmospheric Chemistry and Physics, 18(16), 11831-11845.

xlvii Kochi, et al. (2010) The economic cost of adverse health effects from wildfire-smoke exposure: ar review. International Journal of Wildland Fire. https://pubag.nal.usda.gov/download/46555/PDF

xlviii Gebert, K., et al. (2007) Estimating Suppression Expenditures for Individual Large Wildland Fires. https://www.fs.fed.us/restoration/documents/cflrp/R-CAT/rmrs_2007_gebert_k001.pdf

xlix Dale, L. (2010) The True Cost of Wildfire in the Western US. Western Forestry Leadership Coalition.

l Willams, S. (2020) Santa Fe Mountains Landscape Resiliency Project Environmental Assessment. United States Department of Agriculture

li Ibid

lii Yocom Kent, L. et al (2015) Interaction of fuel treatments, wildfire severity, and carbon dynamics in dry conifer forests. https://www.fs.fed.us/rm/pubs_journals/2015/rmrs_2015_kent_l001.pdf

liii Bassett, S. (2018) Greater Santa Fe Fireshed Coalition Wildfire Risk Assessment. The Nature Conservancy.

liv NOAA. Coastal Ecosystem Restoration. Available at http://coast.noaa.gov/archived/coastal/economics/discounting.htm?redirect=301ocm

lv Krofcheck, D. J., Remy, C. C., Keyser, A. L., & Hurteau, M. D. (2019). Optimizing Forest Management Stabilizes Carbon Under Projected Climate and Wildfires. Journal of Geophysical Research: Biogeosciences, 124. https://doi.org/ 10.1029/2019JG005206

lvi Buckley, M., N. Beck, P. Bowden, M. E. Miller, B. Hill, C. Luce, W. J. Elliot, N. Enstice, K. Podolak, E. Winford, S. L. Smith, M. Bokach, M. Reichert, D. Edelson, and J. Gaither. (2014). "Mokelumne watershed avoided cost analysis: Why Sierra fuel treatments make economic sense." A report prepared for the Sierra Nevada Conservancy, The Nature Conservancy, and US Department of Agriculture, Forest Service. Sierra Nevada Conservancy. Auburn, California. Online: http://www.sierranevadaconservancy.ca.gov/mokelumne.

lvii New Mexico Avian Conservation Partners (n.d.) Breeding Species Assessment Scores. Retrieved from: http://avianconservationpartners-nm.org/species-assessment-scores/

EARTH ECONOMICS