BURN TO LEARN: MAPPING, MONITORING, AND MANAGING WITH FIRE

by

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ABSTRACT

Western landowners are increasingly faced with the compounding challenges of altered fire regimes, invasive species, and limited access to practical land management tools. In semi-arid rangelands like those in Huerfano County, Colorado, fire suppression and historic overgrazing have degraded ecological resilience and increased wildfire risk. Therefore, my project addresses the need for integrated, accessible, and science-based decision-making models by developing a case study at Redwing Ranch, a 4,000-acre (1,619 hectare) working cattle ranch. My goal was twofold: (1) to build a GIS-based model for identifying where and when to apply prescribed fire, grazing, or mechanical treatments, and (2) to translate this model into usable guides and tools for land managers.

Using QGIS, LANDFIRE data, and fire behavior modeling software (FlamMap and and Interagency Fuel Treatment Decision Support System (IIFTDSS)), I combined landscape layers such as fuel models, slope, vegetation type, and infrastructure proximity to identify high-risk fire areas and appropriate treatments. Redwing Ranch was divided into management zones, each assigned one or more treatments based on ecological conditions, fire modeling outputs (e.g., flame length, rate of spread), and feasibility. Treatments included prescribed fire, shaded fuel breaks, managed grazing, mechanical thinning, and “no-treatment” zones for wildlife habitat.

Results included the successful implementation of two prescribed burns: one targeting kochia (*Bassia scoparia L.*), a fire-adapted invasive species, and another in a willow (*Salix* spp.) corridor. GIS modeling showed that prescribed fire and strategic thinning could substantially reduce predicted flame lengths and fire spread. Additionally, post-treatment monitoring using NDVI satellite imagery and field photo points helped evaluate vegetation recovery and guide adaptive management.

My project demonstrates that fire resilience can be built through integrated planning and applied skill-building. The resulting workflow and tools including burn planning checklists, monitoring protocols, and GIS guides, are intended for land stewards seeking actionable strategies. By combining geospatial modeling with real-world implementation, this work bridges research and practice and supports the development of a trained, empowered land-based workforce.

INTRODUCTION: FRAMING THE CHALLENGES

Western US landowners and land managers are facing an ongoing challenge of balancing productive agriculture with ecological resilience. The pressures of invasive species, altered fire regimes, overgrazing, and climate variability require land management solutions that are adaptive, science-driven, and practical. However, gaps between scientific research and applied, science-based solutions, can prevent land managers from effectively addressing management challenges. Beyond land management strategies, equipping land stewards with tangible skills is essential for long-term sustainability, adaptability, and resiliency. Practical, hands-on training such as chainsaw operation, prescribed fire application, intensive grazing practices, and remote sensing strategies ensures that land managers and their staff are prepared to implement the most effective management strategies. This project aims to bridge the gap between research and real-world application to help guide decision-making that integrates GIS-based landscaped assessments, prescribed fire, adaptive grazing techniques, and mechanical treatments in a comprehensive rangeland management model. Through workforce development initiatives, this project also highlights the critical role of both technical training and tangible technology in land management and ecological resilience.

At the core of this work is Redwing Ranch (RwR), a working cattle ranch in Huerfano County, Colorado, which serves as the primary case study. The ranch's commitment to regenerative land management, data-driven decision-making, and progressive management strategies makes it an ideal real-world setting for developing and testing an integrated land management model. For the last two years, I have worked full time at RwR as a ranch hand and programs

coordinator. My hands-on experience, along with my scientific background make me uniquely qualified to develop a comprehensive land management framework that is feasible, efficient, effective, and scalable.

In this project we investigated the following questions.

1. How can GIS (Geographic Information System) and remote sensing be used to develop a spatial decision-making framework for prescribed fire and land management in semi-arid rangelands?
2. In what ways can environmental conditions, site-specific factors, and grazing strategies be integrated into a prescribed fire model that helps guide a holistic management strategy for controlling invasive species such as kochia (*Bassia scoparia* (L.) A.J. Scott)?
3. How can these tools and strategies be synthesized into a user-friendly guide that supports landowners and land managers in workforce training and in the implementation of ecologically informed, risk-reducing treatments?

In addressing these questions, this project aims to provide an adaptable, step-by-step model for integrating prescribed fire, grazing, and remote sensing into land management, while also training the people needed to carry it out. Though grounded in the Redwing Ranch case study, the framework is designed to scale and support decision-making for landowners and managers across diverse fire-prone regions of the American West facing complex challenges associated with climate change and a legacy of environmental degradation.

SECTION 1: LITERATURE REVIEW – UNDERSTANDING THE PAST TO GUIDE THE FUTURE

Historical Land Management in Huerfano County: Fire

Indigenous land management, including fire practices, played a significant role in shaping the region's ecosystems. Before European settlement, Indigenous peoples in Colorado and the surrounding region actively shaped ecosystems through intentional fire use. Tribes in this area including the Ute, Arapaho, and Cheyenne applied fire strategically for hunting, land clearing, and promoting the growth of fire-adapted vegetation. These practices contributed to landscape heterogeneity, enhanced wildlife habitats, and maintained plant diversity (Sherrill & Romme, 2012; Kimmerer & Lake, 2001). Indigenous fire use was widespread and purposeful, applied seasonally to achieve specific ecological outcomes. In the grasslands and foothills of what is now Colorado, tribes used low-intensity surface fires to enhance forage for game species like bison [*Bison bison* (Linnaeus, 1758)] and elk [*Cervus canadensis* (Erxleben, 1777)] (Stewart, 2002). Native and natural fires differed from the large, uncontrolled wildfires of today, as they were typically low-intensity, frequent burns that maintained low fuel loads and improved ecological adaptability (Kimmerer & Lake, 2001; Roos et al., 2021). These traditional fire regimes played a significant role in sustaining fire-adapted ecosystems, reducing fuel loads, and limiting the frequency and extent of large-scale, high-severity burns. While some severe fire effects and ecosystem transitions have always been part of natural fire cycles, they were historically rare or confined to smaller portions of a burn. Controlled burns were a proactive tool, not reactive, used for thousands of years across the continent (Stewart, 2002; Pyne, 2016).

In both Indigenous land stewardship and natural fire regimes, frequent low-intensity fires helped shape vegetation patterns and maintain ecological balance. By burning different patches of the landscape in rotation, or through lightning-ignited fires allowed to burn under the right conditions, diverse mosaics of habitats were created that supported a broad range of wildlife and plant communities. This variation in fuel structure and moisture across burn mosaics also disrupted the continuity of fire spread, allowing fire behavior to shift depending on vegetation type, age, and density (Martin & Sapsis, 1992).

The Disruption of Indigenous and Natural Fire Regimes

With the arrival of European settlers and the subsequent implementation of fire suppression policies in the late 19th and early 20th centuries, Indigenous and natural fire regimes were largely disrupted (Williams, 2003). Fire suppression led to denser forests, higher fuel loads, and an increased frequency of stand-replacing fires (Hessburg et al., 2005). These changes have contributed to the modern fire crisis, as landscapes that once experienced frequent, low-intensity fires now suffer from infrequent but extreme wildfires.

Montane forests in Huerfano County are dominated by fire-adapted species such as ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson) and Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco), which historically thrived under frequent, low-intensity surface fires that maintained open canopies and limited shade-tolerant competitors (Kolb et al., 2007; Agee, 1993). Aspen (*Populus tremuloides* Michx.) regenerates rapidly post-fire through clonal root suckering, while juniper (*Juniperus scopulorum* Sarg.) lacks fire adaptations and was historically limited by burning. Fire suppression has shifted open woodlands into denser stands with greater ladder fuel

accumulation, increasing the risk of stand-replacing wildfires (Covington & Moore, 1994). In piñon-juniper woodlands, reduced fire and grazing pressures have led to woodland expansion into grasslands, degrading soils and understory diversity and increasing vulnerability to severe fires and invasive species like cheatgrass (*Bromus tectorum L.*) (Miller et al., 2000; Chambers et al., 2014).

Semi-arid grasslands once dominated by blue grama [*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths], needle-and-thread [*Hesperostipa comata* (Trin. & Rupr.) Barkworth], and western wheatgrass [*Pascopyrum smithii* (Rydb.) Á. Löve] evolved with fire and respond well to low-intensity burns (Wright & Bailey, 1982). Without fire, shrub encroachment by species like big sagebrush (*Artemisia tridentata.* Nutt.) and rubber rabbitbrush [*Ericameria nauseosa* (Pall. ex Pursh) G.L. Nesom & Baird] has increased, reducing habitat quality and resilience. Riparian areas that historically burned less frequently, support species like cottonwoods (*Populus deltoides* W. Bartram ex Marshall) and willows (*Salix* spp.), have also seen encroachment and increased fuel loads due to fire exclusion (Dwire & Kauffman, 2003). Mosaic burning offers a strategy for reintroducing fire in a spatially varied pattern, selectively reducing shrubs while retaining habitat structure and enhancing fire breaks (Davies et al., 2009; Strand et al., 2014). When combined with adaptive grazing, mosaic fire can restore heterogeneity, reduce invasive spread, and increase landscape resilience across shrub-grassland ecosystems.

Historical Land Use in Huerfano County: Grazing

In the early 1800s, the introduction of domesticated livestock marked a shift in land use. Settlers migrating north from the San Luis Valley brought sheep herding traditions to Huerfano County.

By the 1860s, sheep herding had expanded into the county, and by 1868, more than 35,000 sheep grazed across Huerfano and neighboring Pueblo Counties (Palmer Land Trust, n.d.; BLM Cultural Resource Series 17). Around 1870, Texas longhorn cattle were introduced to the region, initiating the expansion of cattle ranching. Throughout the late 1800s and early 1900s, both sheep and cattle were grazed extensively in the county, often on the same rangelands. This dual grazing pressure, especially on arid and riparian landscapes, led to widespread overgrazing, soil compaction, and shifts in plant communities, including the decline of native perennial grasses (Sayre, 1999; BLM CRS 17). By the mid-20th century, the number of sheep began to decline, and cattle ranching became the dominant livestock practice in Huerfano County. During this same period, federal fire suppression policies aligned with the national "Smokey Bear" era, resulting in widespread exclusion of fire from ecosystems that had evolved with frequent, low-intensity burns.

Early Ranching Practices and Their Impact on Fire Regimes in Huerfano County, CO

The establishment of large-scale cattle and sheep ranching in Huerfano County led to significant reductions in herbaceous vegetation, particularly grasses and forbs that historically carried low-intensity fires across the landscape (Belsky & Blumenthal, 1997). Overgrazing reduced fine fuels, thereby limiting the natural spread of fire and disrupting historical fire cycles (Savage & Swetnam, 1990). In addition, the expansion of haying operations removed biomass from valley bottoms and riparian zones, further reducing fuel continuity and altering plant community composition over time (Veblen & Lorenz, 1991). With fewer frequent fires, woody vegetation such as piñon pine (*Pinus edulis* Engelm) and juniper (*Juniperus* spp.) began to encroach on grasslands, increasing fuel loads and creating conditions for high-intensity fires (Romme et al.,

2009). Together, overgrazing and haying promoted more homogenized plant communities, reducing the ecological patchiness that once supported diverse fire regimes and wildlife habitats (Fuhlendorf & Engle, 2001).

Early ranching practices not only altered fire dynamics but also facilitated the spread of invasive species. In Huerfano County, one prominent example is kochia a drought-tolerant, early germinating invasive that thrives in degraded rangelands, roadsides, and former agricultural fields across semi-arid North America. Introduced from Europe in the 19th century, kochia's success is driven by its tolerance for saline and nutrient-poor soils, ability to germinate throughout the growing season following precipitation, and allelopathic root exudates that suppress native species (Friesen et al., 2009; Beckie et al., 2019; Alford et al., 2009). These traits give kochia a competitive edge in fire-suppressed, overgrazed, and ecologically degraded systems such as those that exist at several areas on Redwing Ranch.

Ecologically, kochia reduces native diversity by forming dense monocultures that alter soil chemistry, fire behavior, and habitat structure (Sebastian et al., 2017; Menalled et al., 2016). Its deep taproot extracts moisture beyond the reach of many native plants, while its canopy often leaves behind bare soil patches prone to erosion and reinvasion after senescence. Although young kochia can be grazed, it poses toxicity risks for livestock due to nitrate and oxalate accumulation during drought or late growth stages (Smith et al., 2020). Kochia management is difficult due to prolific seed production, season-long regrowth, and widespread herbicide resistance (Heap, 2021). Mechanical treatments yield only temporary suppression. Integrated strategies, such as well-timed and targeted grazing, can suppress kochia and promote native grasses when carefully managed to prevent additional soil exposure (Vollmer & Archer, 2014).

Fire as a control method remains understudied. Kochia's response varies with fire intensity: high-intensity burns may reduce seed viability, while low-intensity fires can stimulate regrowth by eliminating competition and exposing germination-friendly bare ground (Bork et al., 2012; Dix & Svejcar, 1993). As native grasses were overgrazed and fire frequencies declined, kochia and other invasive species like cheatgrass gained a competitive advantage, further disrupting fire regimes by creating flashy fuels that burn more frequently and at higher intensities (Chambers et al., 2014).

Fire suppression and continuous grazing also led to woody vegetation encroachment, contributing to soil degradation and hydrological changes. Without periodic grass fires to cycle nutrients and stabilize soils, erosion increased and watershed function declined (Neary et al., 2005). These shifts have impacted native plant communities and reduced forage availability, posing long-term challenges for sustainable ranching in the region.

The Spring Creek Fire (2018) as a Catalyst for Fire Management Strategies

The Spring Creek Fire, which ignited on June 27, 2018, in Costilla County, Colorado, and spread into Huerfano County, stands as the fifth largest wildfire in Colorado's history (Figure 1). The fire burned 108,045 ac (43,706 ha) before being fully contained on September 10, 2018 (Colorado Encyclopedia, n.d.). While its ignition was human-caused, its rapid spread and extreme fire behavior were driven by decades of fire suppression, land-use changes, and prolonged drought conditions, and likely tree stress from beetle infestation (NASA, 2020).

The Spring Creek Fire likely exhibited extensive high-severity burn patterns in forested zones due to accumulated fuels, dense understory growth, and prolonged drought stress (BAER, 2018).

In montane forests dominated by ponderosa pine and Douglas fir, decades of fire suppression allowed ladder fuels to build up, facilitating crown fires that caused widespread tree mortality and reduced seed sources for natural regeneration (Wooten et al., 2022). The fire burned intensely in many of these areas, producing fire that likely replaced trees and increased the risk of conversion to shrubland or invasive grasslands such as cheatgrass (Chambers et al., 2014).

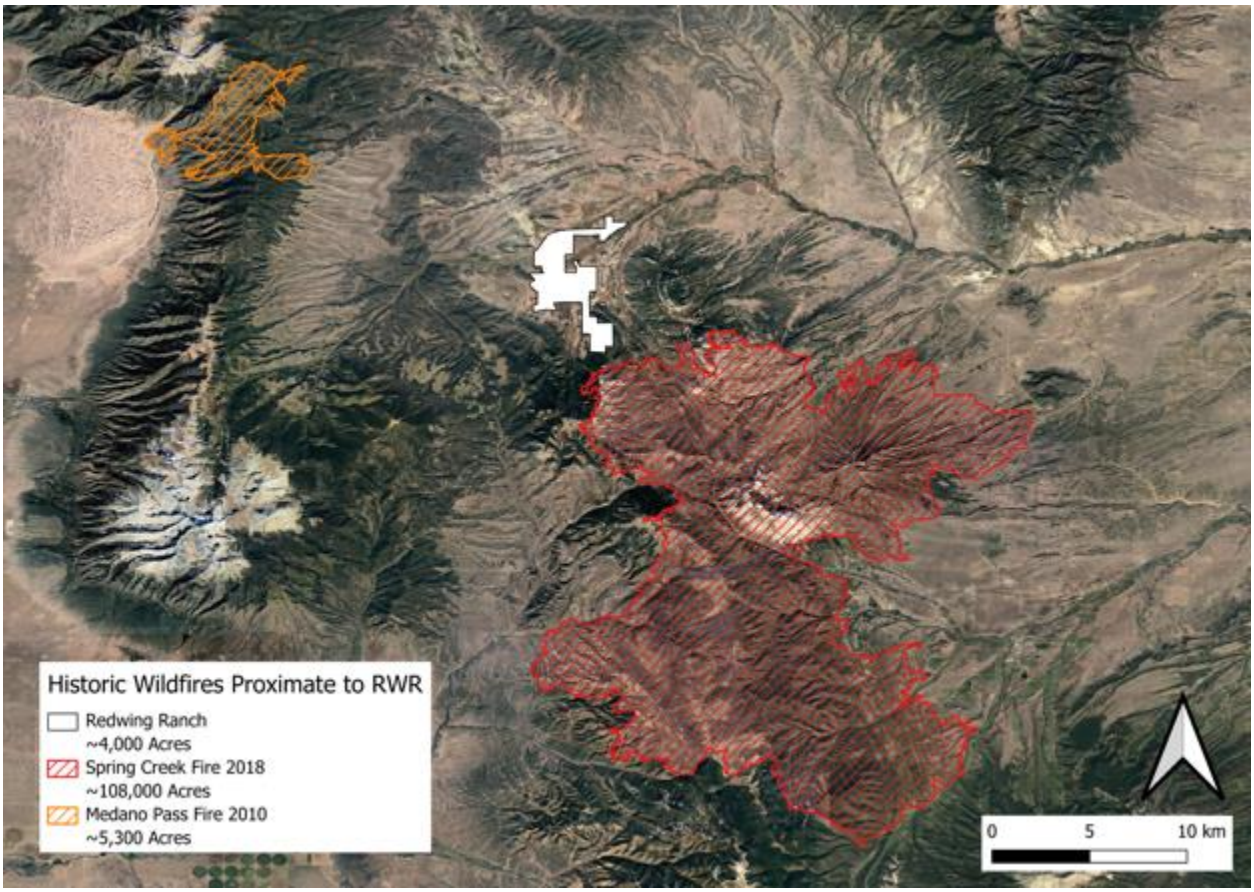


Figure 1. Recent historical wildfires proximate to Redwing Ranch in Huerfano County, CO.

In semi-arid grasslands and shrublands, historical fire return intervals ranged from five to twenty years, typically maintaining low-intensity surface fire regimes that limited woody encroachment

(Wright & Bailey, 1982). The Spring Creek Fire burned at mostly low to moderate severity in these ecosystems, aligning more closely with historical fire behavior. However, post-fire invasion by non-native annuals poses a threat to long-term recovery by increasing future fire frequency and shifting successional dynamics (Bradley et al., 2018).

Lessons for Future Fire Management

The Spring Creek Fire underscores the consequences of drought stress and fire suppression in fire-adapted landscapes. The transition from frequent, low-intensity fires to infrequent, high-severity wildfires has resulted in increased risks to both ecological integrity and human communities (Abatzoglou & Williams, 2016). As fire managers work to restore historical fire regimes, prescribed burning and strategic fuel reductions will be critical in mitigating future wildfire severity in montane forests, piñon-juniper woodlands, and grasslands (Stephens et al., 2020). Integrating Indigenous fire knowledge into modern land management strategies has become a growing focus in fire ecology. Collaborative efforts between tribal nations, researchers, and land managers are beginning to restore cultural burning practices, providing valuable insights into sustainable fire management (Lake & Long, 2014). Prescribed Burn Associations (PBA's) and other Prescribed Fire Training Exchanges (TREX) have become more actively integrated into fuel management programs. It is important that we see this traditional ecological knowledge incorporated and applied. These efforts emphasize working with, rather than against, fire to maintain ecosystem health and resilience.

In the 21st century, as catastrophic wildfires increase in frequency, and invasive non-native plant species become more widespread and problematic, a resurgence of interest in ecological fire use and sustainable grazing practices has begun to reshape land management thinking in Colorado

and beyond. Contemporary stewardship efforts are now recognizing the importance of reintroducing fire to promote ecosystem health, manage invasive species, and reduce wildfire risk. Simultaneously, landowners in Colorado began exploring different grazing techniques, integrating seasonal, strategic grazing strategies that mimic natural disturbance patterns and align with regenerative goals (Sayre, 2017; The Nature Conservancy, 2021). These modern approaches build on both traditional knowledge and emerging ecological science. This combination and intersection offer a compelling pathway toward more resilient, fire-adapted land systems, yet these practices are still underutilized due to persistent knowledge gaps around where, when, and how to apply them effectively. Barriers include limited site-specific planning tools, financial constraints, a lack of integration between fire behavior models and ecological goals, and shortage of hands-on training opportunities to support implementation. Addressing these gaps is essential for translating theory into practice and forms the basis for the Redwing Ranch case study that follows.

SECTION 2: CASE STUDY – REDWING RANCH

Integrating Fire, Grazing, and GIS for Land Management in a Water-Limited Landscape

Redwing Ranch (RwR) is a 4,000-ac (1,619-ha) working cattle ranch in Huerfano County, Colorado. The ranch's philosophy of "Grazing Forward – regenerating land, livestock, and livelihoods" incorporates managing the land utilizing cattle to rebuild and sustain soil health, promoting biodiversity, all while creating a profitable operation that supports the people working the land. Nestled at the eastern flank of the Sangre De Cristo Mountains of the Southern Rocky Mountain Range, the ranch spans elevations from 7,200 to 8,600 ft (2,195 to 2,621 m) encompassing semi-arid grasslands, montane forests, and riparian corridors. Like much of the American West, this region faces increasing pressures from drought, invasive species, and wildfire risk, requiring innovative land management approaches that balance productivity with ecological resilience.

RwR is committed to low-stress stockmanship, strategic and adaptive (managed) grazing, and ecological stewardship, using data-driven decision-making to optimize both profitability and land health. Low-stress stockmanship refers to livestock handling techniques that reduces stress and prioritizes the animal's well-being, which in turn increases the handler's safety in addition to the rancher's bottom line. Strategic and adaptive grazing refers to grazing practices that are intentionally planned and responsive to changing conditions, such as forage availability, rainfall, or ecological goals. A major component of RwR's management strategy is Adaptive Multi-Paddock (AMP) grazing, a form of planned and adaptive rotational grazing. Cattle are moved every three to five days using polywire (electric) fencing, allowing for tighter control over

grazing pressure, more uniform forage utilization, more uniform disturbance, and even improved manure distribution. This system encourages more uniform grazing utilization and adequate rest with the goal of enhancing soil health, water retention, and plant diversity (Teague et al., 2011). This grazing strategy also helps in mitigating the effects of increasing wildfire and reduced water availability which is one of the most pressing challenges in the region.

At Redwing Ranch, fire is being tested alongside AMP grazing to manage invasive kochia and shift competitive advantage back toward native species. In December 2024, I created a burn plan and we conducted a small, prescribed burn within a managed grazing zone to evaluate whether low-intensity fire could suppress kochia, improve forage conditions, and create a more favorable seedbed for desired vegetation. This project is a critical first step in a fire resilience strategy aimed at reducing invasive species and promoting native vegetation using fire and strategic grazing strategies as management tools. I am currently gathering data on post-burn regrowth and species response through field monitoring and remote sensing development. While the full outcomes of this burn are still being assessed, this effort highlighted several opportunities to improve the use of prescribed fire as a management tool through GIS-based mapping and monitoring.

To help landowners make data backed decisions, remote sensing, spatial analysis, and landscape fire modeling can provide important insights into fire risk, invasive species spread, and grazing impacts. The GIS modelling component described in this project includes mapping high-priority management zones, using fire modeling software, and integrating soil, vegetation, and wildfire history data into a land management model. By leveraging GIS, this project seeks to bridge the

gap between on-the-ground land stewardship and spatial analysis, thus equipping landowners with practical, scalable tools to improve management outcomes.

Redwing Ranch's goal of combining intensive managed grazing, prescribed fire, and GIS-based planning, can serve as a tangible case study for a holistic and adaptive land management framework. Insights gained by the management zones developed for Redwing can help inform landowners across the West by providing one approach to managing wildfire risk, invasive species, and drought conditions in rangelands. Using Redwing Ranch as a model for balancing production, conservation, and long-term wildfire and ecological resilience, we explored how these tools and techniques come together to improve management outcomes.

Soil Considerations at Redwing Ranch

The soils at Redwing Ranch reflect a complex mosaic of textures, erosion potential, and fire vulnerability that directly inform land management decisions. Dominant soils like Patent loam and Willowman gravelly sandy loam together comprise nearly half the ranch's area and are generally well-drained with slight erosion hazards, making them well-suited for prescribed fire and grazing-based treatments. In contrast, soils such as Limon clay and Bayerton-Maitland complex exhibit high potential for fire damage and moderate erosion risk, requiring more cautious approaches like mosaic burning or mechanical hand thinning to avoid soil degradation and ensure less traffic and compaction through treatment. Overall, the ranch's soils tend to range from sandy loams with low clay content, supporting good infiltration and plant recovery post-treatment, to finer-textured clays and silty clays in limited areas, which may be more prone to compaction or erosion when overly disturbed (Table 1). These patterns suggest that strategically applying treatments in zones with lower erosion and fire damage risks, while carefully managing

disturbance in vulnerable soils, can enhance wildfire resilience without compromising long-term soil health. The integration of fire behavior modeling, treatment suitability, and soil data ensures that Redwing's adaptive management approach is both ecologically grounded and site responsive.

Table 1. Soil characteristics at Redwing Ranch.

Map Unit Sym.	Map Unit Name	Acres in AOI	Percent of AOI	Fire Damage Potential	Erosion Hazard Potential	% Clay	% Sand	% Silt
4	Bayerton-Maitland complex, 25 to 50 percent slopes	14.6	0.40%	High	Moderate	25	45	30
7	Breece sandy loam, 2 to 18 percent slopes	231.2	6.20%	Low	Slight	10	75	15
8	Brownsto very gravelly loam, 3 to 15 percent slopes	68.4	1.80%	High	Slight	20	55	25
10	Castner very channery loam, 20 to 70 percent slopes	210.1	5.60%	High	Moderate	18	60	22
12	Collegiate loam, 1 to 3 percent slopes	338.9	9.00%	Low	Slight	20	50	30
13	Crooked Creek silty clay loam	69.2	1.80%	Low	Slight	35	30	35
14	Curecanti very cobbly loam, 2 to 8 percent slopes	118.6	3.20%	Low	Slight	18	60	22
28	Lakehelen-Rock outcrop complex, 15 to 80 percent slopes	6	0.20%	Low	Moderate	15	65	20
34	Limon clay, 3 to 12 percent slopes	218	5.80%	High	Moderate	40	30	30
43	Manzano loam	0.4	0.00%	Low	Slight	20	55	25
50	Neville fine sandy loam, 1 to 3 percent slopes	2.7	0.10%	Moderate	Slight	8	80	12
51	Neville fine sandy loam, 3 to 9 percent slopes	33.9	0.90%	Moderate	Slight	8	80	12
52	Noden sandy loam, 1 to 8 percent slopes	3.1	0.10%	Low	Slight	10	75	15
53	Noden sandy loam, 8 to 15 percent slopes	26.8	0.70%	Low	Moderate	12	70	18
61	Olney-Progresso sandy loams, 3 to 15 percent slopes	0.2	0.00%	High	Slight	10	75	15
64	Patent loam, 2 to 8 percent slopes	1053.8	28.00%	Moderate	Slight	25	40	35

71	Ring cobbly loam, 20 to 45 percent slopes	333.3	8.90%	Moderate	Moderate	15	60	25
72	Riverwash-Las Animas complex	1.2	0.00%	High	Not rated	5	85	10
73	Rock outcrop	323	8.60%	Not rated	Not rated	0	0	0
80	Trag loam, 3 to 12 percent slopes	51	1.40%	Low	Slight	30	40	30
84	Ustic Torriorthents-Rock outcrop complex, 5 to 40 percent slopes	3.4	0.10%	Moderate	Moderate	18	60	22
92	Willowman gravelly sandy loam, 3 to 8 percent slopes	635.9	16.90%	Moderate	Slight	15	65	20
93	Willowman gravelly sandy loam, 15 to 30 percent slopes	15	0.40%	Moderate	Moderate	15	65	20

Reintroducing Fire in a Changing Landscape as a Management Tool

At Redwing Ranch, prescribed fire is being reintroduced as part of an integrated land management strategy to reduce wildfire risk, control invasive species, and restore ecological processes that depend on periodic burning (Figure 2). Like much of the American West, this landscape evolved with fire. However, a century of fire suppression, coupled with invasive plant encroachment and legacy overgrazing, has left many rangelands degraded and increasingly vulnerable to severe wildfire. Prescribed fire offers a potential path toward rebalancing these systems, but it remains underutilized due to a lack of planning tools, operational experience, and ecological understanding.



Figure 2. Conducting the second prescribed burn in willows of an irrigation ditch at Redwing Ranch in March 2025. Photo by Luke Kraemer.

This section documents two experimental prescribed burns and reflects on the broader management implications for fire in semi-arid rangelands. These case studies also highlight critical knowledge gaps: namely, how to safely reintroduce fire, how to prioritize fire treatments, and how to scale its use in a strategic, ecologically beneficial way.

Knowledge Gaps in Fire Use and Risk Reduction

Across many private lands in the West, fire is not widely used due to limited training opportunities, unclear regulatory pathways, and uncertainty around where and how fire can be beneficial. This creates a dual problem: invasive species continue to spread in the absence of

disturbance, and wildfire risk increases due to unchecked fuel buildup near infrastructure and across large continuous fuel patches.

A key knowledge gap exists in how to integrate fire as a planned ecological treatment while also mitigating the threat of unplanned wildfire. In short, we know fire *can* help, but landowners lack accessible, site-specific tools to evaluate when and where it should be applied, and how to do so safely and efficiently. Furthermore, fire planning is rarely integrated into broader landscape-scale resilience strategies, especially in the context of private working lands. These tools are needed not only for expanding prescribed fire, but for proactively identifying wildfire risk zones and applying pre-treatment strategies accordingly. This type of planning can help reduce likelihood and severity of wildlife, particularly near homes and on roads.

Burn 1: Kochia Treatment Without Modeling Tools

Our first prescribed burn was conducted in December 2024 in an 8-ac (3.24-ha) unit in "Two Adobes," a 122-ac (49.4-ha) pasture heavily infested with kochia. The objectives were to reduce kochia biomass and seed viability, initiate nutrient cycling, and begin restoring perennial ground cover. The site exhibited high levels of bare ground and poor soil stability.

This burn was planned prior to the development of my GIS model. I relied instead on ecological field knowledge, visual fuel assessments, and prescribed fire training through TREX (Prescribed Fire Training Exchange). Despite conservative fire behavior due to high humidity and low wind speeds, the burn achieved partial kochia consumption and set the stage for follow-up treatments.

Post-burn, we broadcast seeded the unit with a triticale-rye mix and conducted bale grazing to accelerate seed incorporation and nutrient cycling (Figure 3). Cattle were introduced for 24 hours, trampling seed into the soil and supporting germination.



Figure 3. Drone image showing cattle grazing hay flakes on a post-fire seeding bed. Grey areas reflect burn footprint. Photo by Christy Wyckoff.

Burn 2: Willow Corridor Fire as Alternative to Mastication

In March 2025, Redwing Ranch carried out a second prescribed burn in a dense willow corridor along an irrigation ditch, an area previously identified for mastication due to overgrowth and poor accessibility (Figure 4). With improved planning, weather conditions, and team

coordination, this burn successfully reduced vegetation and opened access for future grazing and water management. The goal was to test the feasibility of fire as a tool in sensitive riparian areas and compare costs and impacts to mechanical treatments.

Both burns reinforced the value of fire as a targeted, low-cost, and adaptable treatment tool, especially when combined with grazing. Equally important, they underscored the limitations of field-based planning alone.



Figure 4. Me during the prescribed burning in the kochia burn unit (December 2024) and the irrigation ditch willow unit (March 2025). Photos by Christy Wyckoff.

While we were able to achieve operational success, the absence of fire behavior modeling tools limited our ability to anticipate flame lengths, rate of spread, or additional resource needs. This highlighted a second, more strategic knowledge gap: landowners and managers need spatially explicit models that integrate fuel, slope, infrastructure proximity, and vegetation type to prioritize and phase fire treatments. Equipping land managers with these tools supports both proactive prescribed fire planning and wildfire preparedness.

The Value of GIS Fire Modeling

In response to the limitations and knowledge gaps we observed when conducting prescribed burns on RwR, I developed a GIS-based fire behavior and treatment planning model using IFTDSS, LANDFIRE, FlamMap, and QGIS. QGIS is an open-source geographic information system used to compile, visualize, and analyze spatial datasets. LANDFIRE provides national-scale geospatial data on vegetation, fuels, topography, and disturbance regimes. FlamMap is a fire behavior simulation tool that models potential flame length, rate of spread, and fireline intensity under fixed weather conditions. IFTDSS (Interagency Fuel Treatment Decision Support System) is a web-based platform that integrates these fire behavior models to evaluate treatment effectiveness and landscape-level wildfire risk. This model allows users to simulate fire behavior under different weather scenarios, identify areas where fire may be beneficial or hazardous, and integrate treatments like thinning or grazing into fire risk reduction strategies.

Through improved unit design, resource staging, prescription timing, and safety planning, the fire model described here provides a powerful framework for scaling fire use across Redwing Ranch and other landowner-managed properties, regardless of size. By prioritizing areas for

treatment based on modeled fire behavior and ecological risk, it also enables a more strategic approach to wildfire mitigation at the landscape scale. This kind of integrated modeling is especially valuable for identifying treatment thresholds and aligning management strategies with site-specific goals and constraints. Whether on smaller parcels or across large, diverse landscapes, these tools help land managers make more informed, strategic, and ecologically appropriate decisions.

This project demonstrates that reintroducing fire requires both hands-on experience *and* geospatial planning tools. By bridging field-based burning with GIS-informed modeling, we are creating a replicable, scalable approach to fire that supports ecological goals, reduces wildfire risk, and builds long-term resilience into Western rangelands.

SECTION 3: GIS & REMOTE SENSING IN LAND MANAGEMENT

Developing a GIS-Based Land Management Model

The foundation of this project is a spatial decision-making framework built to enhance fire resilience and support adaptive, multi-scale land management. This model serves as both a wildfire mitigation planning tool and a method for strategically scaling prescribed fire treatments in ecologically appropriate areas. By integrating NDVI (Normalized Difference Vegetation Index, a remote sensing index used to measure vegetation vigor and biomass) analysis and vegetation health monitoring with LANDFIRE datasets (national-scale spatial data on vegetation, fuel models, and topography), remote sensing, and fire behavior modeling tools such as IFTDFSS (Interagency Fuel Treatment Decision Support System), the GIS model achieves expanded versatility while maintaining precision. These tools and combined methodologies allow users to assess wildfire risk, safety concerns associated with implementing fire, and where alternative treatments like AMP grazing or mastication may be most appropriate.

This GIS-based model combines ecological, climatic, and infrastructure data to classify land into zones for targeted treatment types. Mapped layers in the model include vegetation condition, fuel load, slope, aspect, soil type, proximity to structures, and historical fire activity. This suite of layers contributes to a thorough system that evaluates fire behavior potential and treatment compatibility. By modeling potential fire behavior and overlaying the data with site specific ecological and logistical constraints, land managers can better prioritize treatment zones and schedule interventions. The result is a scalable and replicable framework that can be used

anywhere in the semi-arid rangelands of the western U.S. where landowners are working to reduce wildfire risk while restoring ecosystem health.

This spatial framework fills a critical knowledge gap by giving landowners and managers a means of visualizing potential fire behavior under current conditions, comparing treatment strategies, and planning for defensible space and fuel continuity. Whether the objective is reducing flame lengths near infrastructure, enhancing wildlife habitat through mosaic burning, or identifying fire-adapted grazing corridors, this GIS model offers an adaptable decision-support system for a wide variety of treatment goals.

Ultimately, the integration of GIS modeling into a management framework involving prescribed fire demonstrates that land stewardship benefits from both technological precision and ecological awareness. Bridging the gap between these management components is essential to successful management outcomes in the face of multifaceted environmental challenges.

STEP 1: Essential GIS Layers & Their Role in Land Management

Data Collection & Mapping

To build my GIS model, I compiled spatial data from both public sources and on-site infrastructure layers. Key inputs included NDVI imagery (from Landsat 8 and Sentinel-2), soil type and erosion potential from the NRCS (Natural Resources Conservation Service) Web Soil Survey (SSURGO), and topographic data from USGS DEMs (United States Geological Survey Digital Elevation Models) and LANDFIRE. LANDFIRE also supplied vegetation classifications, canopy structure, and standardized fuel models for fire behavior simulations. Infrastructure

layers, and historical imagery from Google Earth, provided context on regional fire regimes. I used FlamMap and IFTDSS to integrate these datasets, model ignition scenarios, and inform spatially explicit treatment planning. While not all layers were used in the final analysis for Redwing Ranch, this compilation represents a practical and adaptable decision-support toolkit for landowners and managers working to align ecological restoration with wildfire resilience.

Fire Behavior & Fuel Conditions

Understanding fire behavior across a landscape is essential to planning safe and ecologically sound land management interventions. At Redwing Ranch, I used predictive modeling tools such as FlamMap and IFTDSS to simulate fire spread, intensity, and severity under varying fuel, topographic, and weather conditions. These simulations were informed by several key datasets, starting with LANDFIRE's fuel models (FBFM40 and FBFM240), which categorize vegetation based on fuel load and structure. The 40 and 240 model variants offer different modeling frameworks depending on regional needs, with FBFM240 providing finer resolution for shrub and grassland environments. These models are critical for estimating flame length, rate of spread, and burn intensity across different habitat types.

Canopy structure data from LANDFIRE added another layer of insight. Canopy height (CH), base height (CBH), bulk density (CBD), and canopy cover (CC) were used to assess crown fire potential, particularly in piñon-juniper systems and mixed forest stands. These metrics supported decisions to exclude prescribed fire from certain dense woodland units and prioritize mechanical thinning or shaded fuel breaks in those areas.

Fire History and Burn Severity layers help identify where fire has historically occurred and at what intensity, offering crucial insight into shifts in fire regimes or fuel accumulation (Parks et al., 2014). Sources like the Monitoring Trends in Burn Severity (MTBS) dataset, LANDFIRE, Fire Regime Condition Class (FRCC), and GEOMAC fire perimeter data provide spatial and temporal fire history. Although Redwing Ranch itself has not experienced recent wildfire, fire history from nearby large burns (ex: Spring Creek Fire) was used to assess regional fire trends and inform ignition modeling.

Weather and wind conditions were modeled using PRISM climate data, NOAA wind datasets, and RAWS station data from the Western Regional Climate Center (WRCC). Data from the Black Mountain and Great Sand Dunes National Park stations were used as they were most representative of conditions at Redwing (Figure 5). Wind patterns and fire weather data are critical to simulating fire spread direction and intensity. Prevailing wind direction, wind speed, and fire weather parameters were used in FlamMap and IFTDSS to model how fire would move under high-risk conditions. This information helped identify wind corridors and areas where shaded fuel breaks or defensible zones would be most effective. It also supported seasonal planning, helping to define burn windows where weather would support low-intensity fire (Reinhardt et al., 2001). FireFamilyPlus was used to sort the data and compile graphs and tables for variables such as relative humidity, one hour fuel moisture, wind speed and azimuth, among other important fire variables.

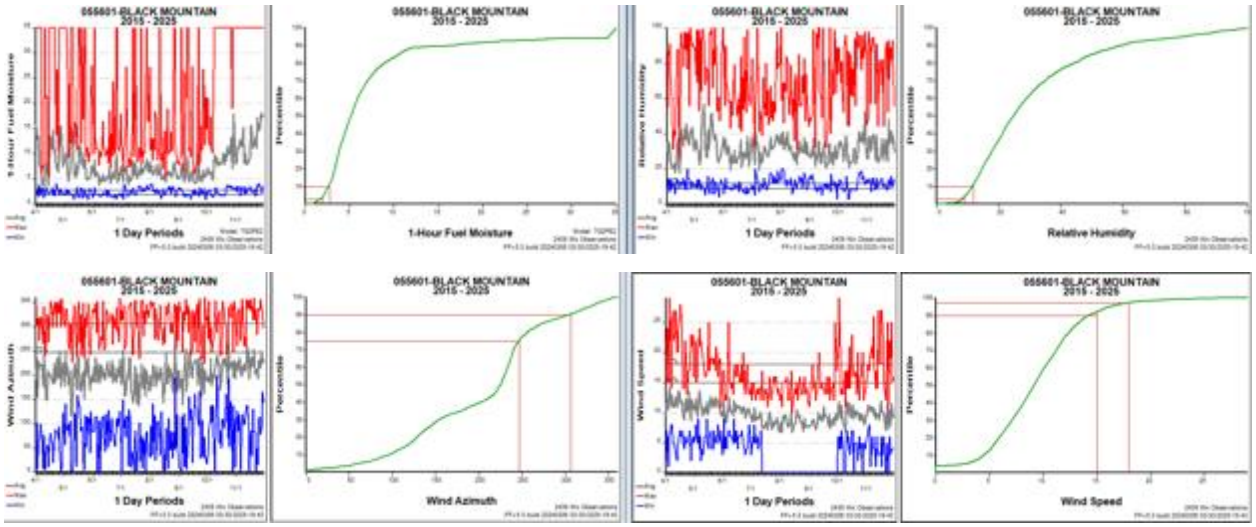


Figure 5. Example data collected from Black Mountain RAWS inputted into FireFamilyPlus.

Topographic layers, specifically elevation, slope, and aspect, are also essential inputs for fire behavior modeling. Fire tends to move faster upslope due to preheating of fuels above the flame front, while aspect determines sun exposure, moisture retention, and fuel flammability. For example, south and west-facing slopes at Redwing Ranch were identified as high-risk areas due to their dryness and potential for rapid spread. Elevation also influences vegetation type, fuel moisture, and wind exposure. Higher elevations typically retain more moisture and support different fuel beds than lower, drier areas, which can impact fire intensity and spread (Keane et al., 2001). Data for these layers came from USGS DEMs and LANDFIRE and were used throughout the treatment planning process to assess access, slope limitations for equipment, and suitability for fire or grazing (Figure 6).

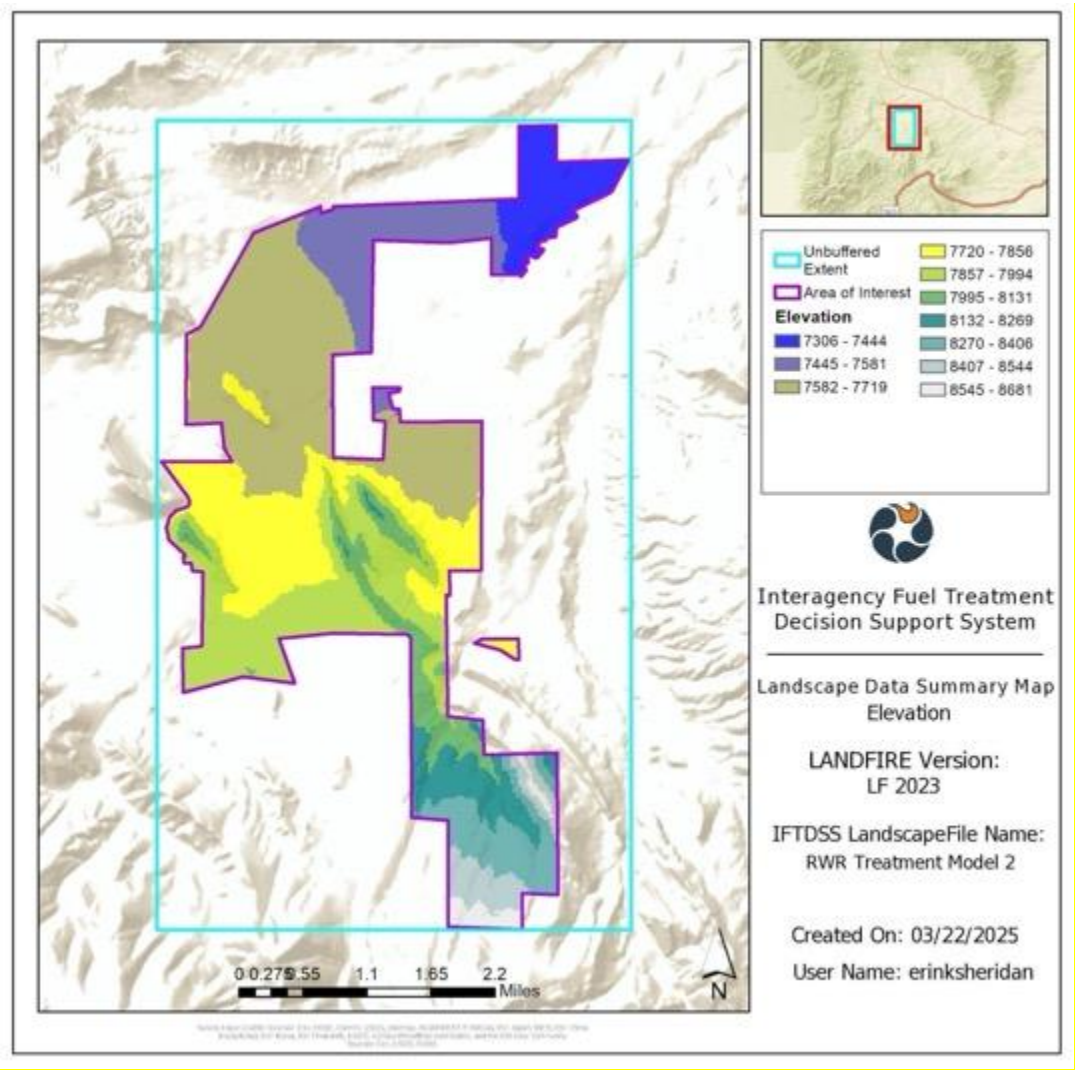


Figure 6. Interagency Fuel Treatment Decision Support System (IFTDSS) Model of Redwing Ranch landscape summary map of elevation, used in fire modeling and treatment prioritization.

Vegetation & Invasive Species Monitoring

Understanding vegetation composition, health, and change over time is essential for adaptive land management and building fire resilience. At Redwing Ranch, remote sensing and classification datasets were used to determine not only where treatments like prescribed fire or grazing should be applied, but how to monitor their effectiveness and inform future decisions.

These vegetation-based tools are critical for tracking invasive species expansion, evaluating post-treatment regrowth, and prioritizing areas for restoration.

The Normalized Difference Vegetation Index (NDVI), derived from Sentinel-2 (10-m resolution) and Landsat 8 and 9 (30-m resolution), was used to map vegetation vigor, forage productivity, and seasonal greenness trends. NDVI-based models can be used to map areas colonized by invasive species like kochia and to evaluate treatment effectiveness in different management zones over time.

LANDFIRE's Existing Vegetation Type (EVT) layer was used to classify plant communities by dominant species and canopy structure (Figure 7). EVT allowed me to distinguish fire-adapted areas, such as shrublands, from more fire-sensitive zones like piñon-juniper woodlands and riparian corridors. This layer also supports the development of Species Distribution Models (SDMs), which combine vegetation, climate, and soil data to predict where invasive species are likely to spread under varying management scenarios.

Historical imagery and time-series change detection tools, including Google Earth Engine (GEE), the Landsat archive (1984–present), and high-resolution Google Earth imagery were used to visualize long-term shifts in vegetation cover. These datasets allow land managers to track woody encroachment, post-wildfire recovery, drought impacts, and invasive spread. For example, I used historical imagery to observe changes in cottonwood canopy density and to monitor how drought affected grassland productivity across the ranch.

When layered with fire behavior and topographic data, these vegetation datasets provide a detailed ecological map of the landscape. This enables more precise prescribed fire planning by

identifying areas of fuel continuity, regrowth potential, and sensitivity. Vegetation monitoring is not simply about classification; it supports continuous assessment, guiding treatment timing, type, and intensity to maximize ecological resilience.

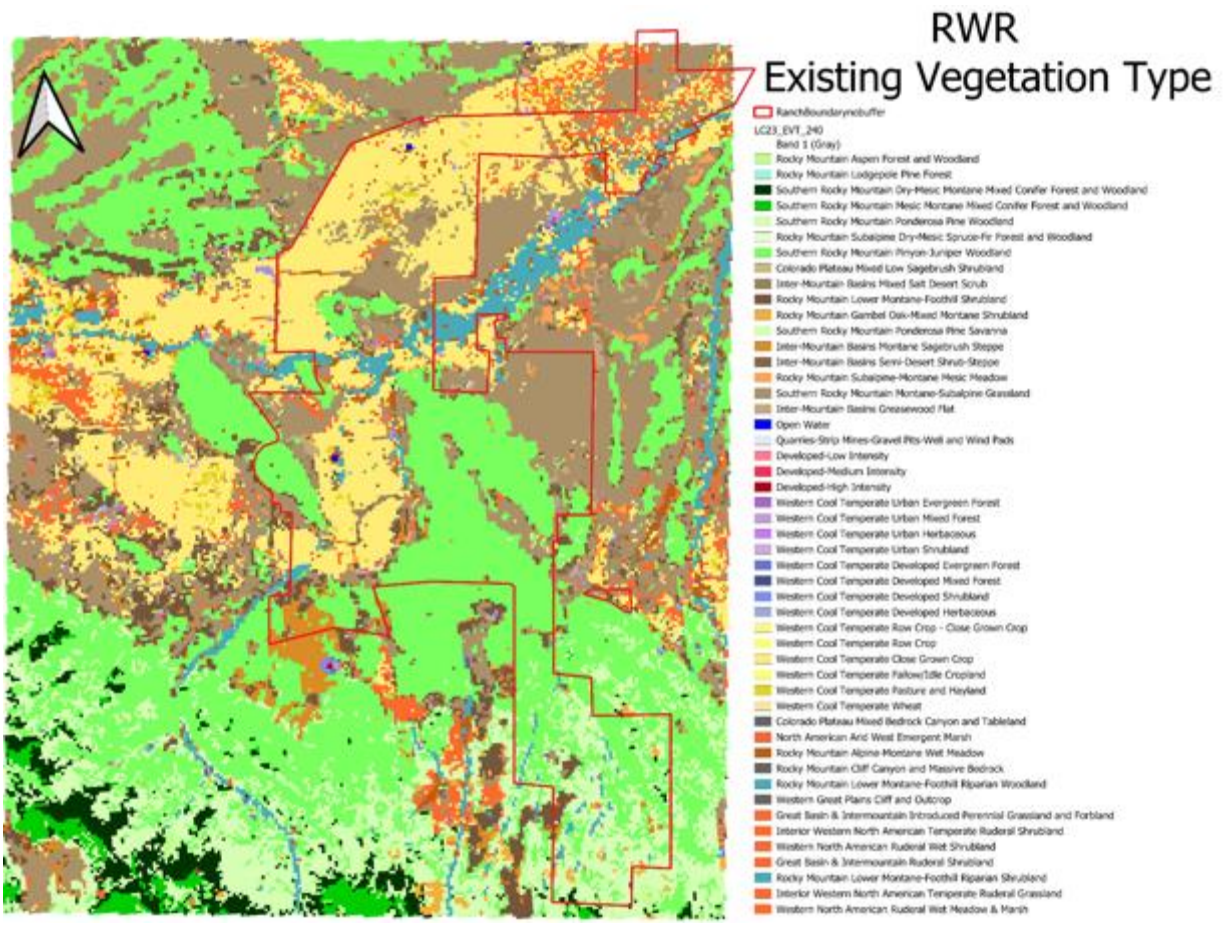


Figure 7. GIS model of Existing Vegetation Type (EVT) layer at Redwing Ranch and the surrounding landscape using LandFire data.

Grazing Infrastructure & Fuel Reduction Potential

Grazing is a foundational element of land management at Redwing Ranch, serving both ecological and fire resilience goals. While the ranch already practices Adaptive Multi-Paddock (AMP) or managed grazing across all pastures, this project explored how grazing could also be

used strategically as a fuel management tool within a broader fire mitigation framework. GIS and fire modeling tools were used to identify zones where targeted grazing could reduce biomass accumulation and improve landscape-level fire resilience.

NDVI imagery helped map vegetation vigor across the growing season, highlighting areas that remained productive later into the year and could support multiple grazing passes or late-season flash grazing. These high-vigor zones, usually sub-irrigated but not always obvious, were also recommended by Snaplands Consulting for more frequent grazing to achieve more planned forage utilization. By overlaying NDVI trends with pasture boundaries, fencing, and water infrastructure mapped via field GPS, I was able to visualize the current grazing layout and identify opportunities for expanding fuel-reduction efforts through rotational grazing practices.

Soil data from the NRCS Web Soil Survey (SSURGO) added another layer of critical information. Areas with steep slopes or compatible soils were flagged for limited grazing to avoid erosion or soil degradation. According to SSURGO data for Huerfano County, approximately 13.6% of the ranch features soils with a high potential for fire-induced damage, especially units like the Bayerton-Maitland complex and Limon clay, requiring caution during grazing and fire treatments. In contrast, more than 22% of the ranch contains stable soils such as Breece sandy loam and Collegiate loam, which are better suited for prescribed fire and repeated livestock use (Table 1).

In combination, these datasets supported a spatial strategy for integrating grazing into fire planning. NDVI and precipitation trends informed forage productivity and rotation timing, while soil characteristics guided livestock distribution with less soil degradation. Mapping pasture

infrastructure alongside these ecological variables ensured that fuel-reduction grazing could be implemented where it is most effective, without compromising long-term soil, watershed health, or operational feasibility.

Additional Suggested GIS Layers for Fire-Informed Land Management

While this framework is centered on fire-informed decision-making, the same GIS layers can support a broader range of land management goals. Landowners may prioritize erosion control, wildlife habitat connectivity, riparian health, or forage production depending on their specific objectives. For example, slope data might inform fire suppression planning in one context or help avoid overgrazing on erosion-prone terrain in another. NDVI trends can guide decisions on where to graze, where to burn, or where to rest land for habitat recovery or carbon storage. This adaptability allows managers to tailor their strategies to the ecological and operational realities of their land.

STEP 2: Fire Modeling & High Fire Risk Areas

Building on the GIS layers developed in Step 1, I used fire behavior modeling to classify Redwing Ranch into a series of priority treatment zones. These zones were based on a combination of modeled flame length, rate of spread, slope, aspect, vegetation type, and proximity to infrastructure. Each zone was assigned a recommended treatment type based on ecological suitability and logistical feasibility. To simulate worst-case wildfire conditions, I ran multiple ignition scenarios through IFTDSS using LANDFIRE 2023 inputs. These simulations were conducted under 97th percentile fire weather conditions, where fuel moisture is critically low and wind speeds (20 mph (32.2 km/h), 225°) promote rapid fire movement. By modeling

fire spread under these extremes, I was able to identify natural fire corridors, areas of high intensity, and locations where treatments like shaded fuel breaks or grazing-based fuel reduction would have the most impact.

Modeling and Classifying High-Risk Fire Areas

High-risk fire areas were defined as zones with elevated flame lengths, rapid spread potential, or close proximity to infrastructure. These included steep south-facing slopes, dense piñon-juniper stands, overgrown riparian corridors, and areas with high fuel loads adjacent to buildings or roads. Many of these zones had not burned in decades and showed signs of excessive fuel accumulation, making them vulnerable to extreme fire behavior.

To identify high-risk areas, I established key criteria: vegetation type (e.g., dense brush, piñon-juniper, and montane forest), slope and aspect (especially terrain steeper than 20° with southern exposure), proximity to infrastructure (within 100–300 feet (30.5-91.4 meters) of homes, barns, and corrals), and fire history (long intervals since last burn and visual evidence of heavy fuel loading).

I then used IFTDSS to simulate fire behavior across the ranch. These worst-case scenarios help visualize how wind, fuel moisture, and temperature can align to intensify fire behavior, providing a lens to assess the ranch's most vulnerable areas (Figure 8).

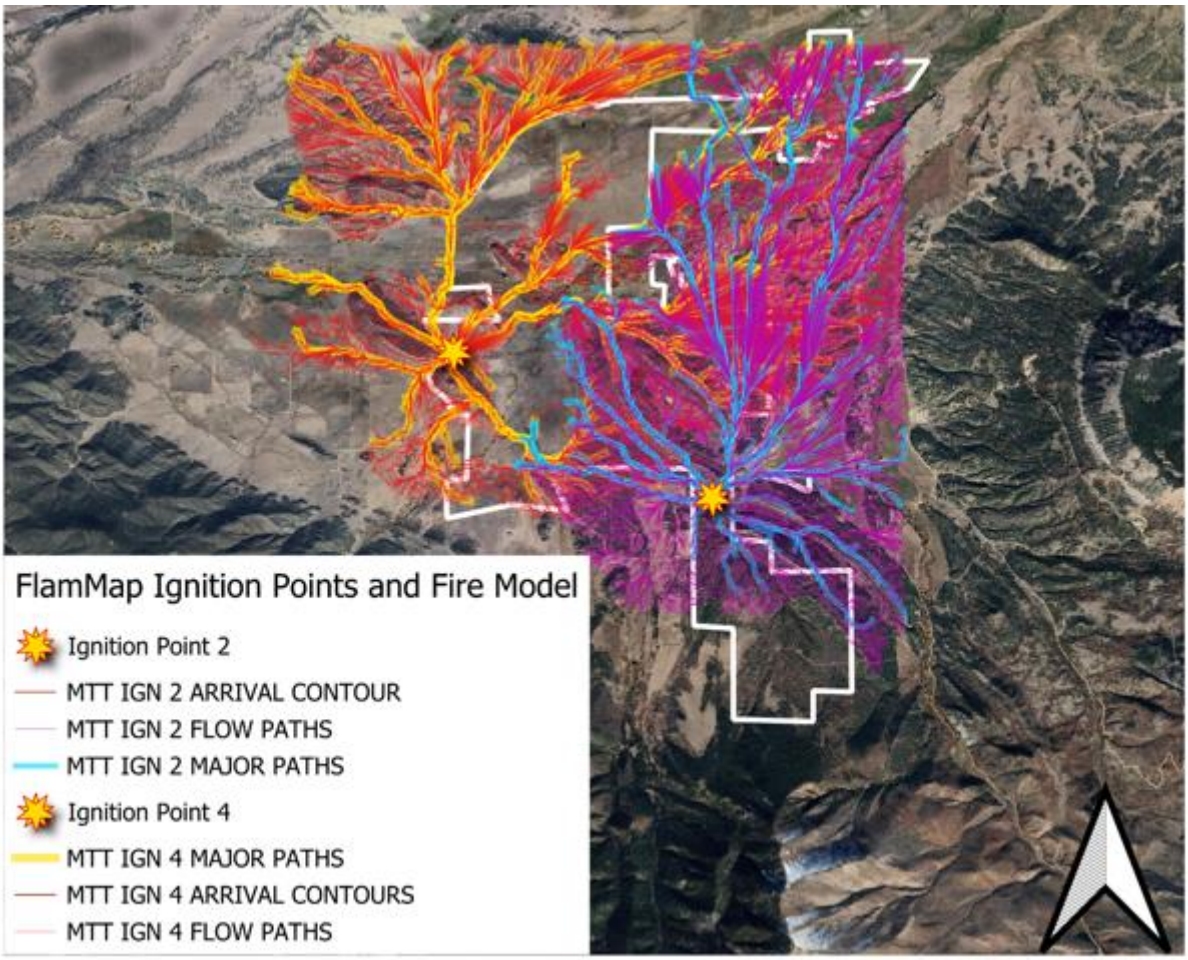


Figure 8. FlamMap ignition points and fire flow paths, modeling how fire would move through the landscape.

These model outputs were layered with slope, vegetation type, and proximity to infrastructure to define priority fire risk zones. I flagged areas that met the following criteria for elevated wildfire risk: high modeled flame lengths (>8 ft (2.44 m)), rapid rate of spread (>50 chains/hr (1006 m/hr)), south- and west-facing slopes, proximity (<300 ft (91.4 m)) to roads, fences, and key ranch infrastructure, dominance by shrubs, grasses, or ladder fuels (e.g., rabbitbrush, dense willow corridors), and pastures that had not recently been grazed or mechanically treated.

One key output was Rate of Spread, which estimates how fast fire is likely to move across the landscape. The fastest spread rates (orange and red zones) align with continuous fuel beds in low-slope, shrub-dominated areas, especially in the central regions of Redwing Ranch (Figure 9).

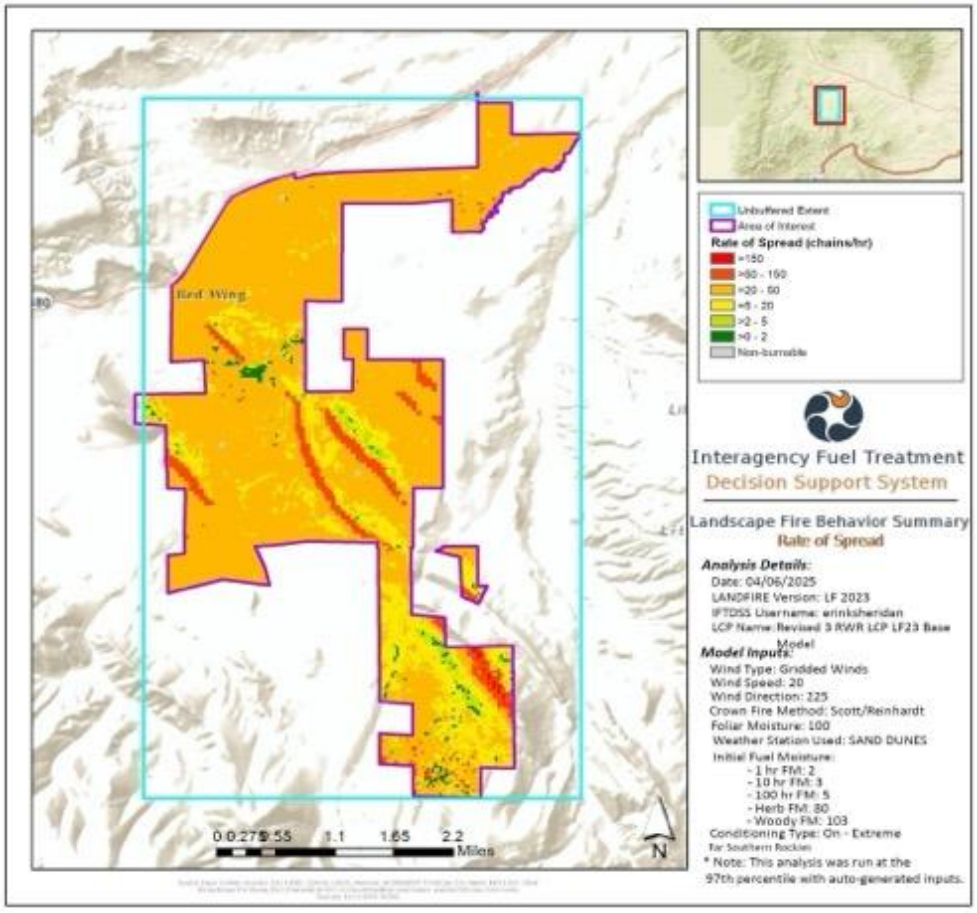


Figure 9. Interagency Fuel Treatment Decision Support System (IFTDSS) Rate of Spread model for Redwing Ranch.

Flame Length maps projected fire intensity and suppression difficulty. Fires with flames exceeding eight feet surpass hand-crew control capacity and may require mechanical or aerial support. At Redwing, several interior pastures and dense willow corridors exceeded 11 ft (3.6 m)

in flame length (Figure 10), identifying them as priority zones for pre-treatment with grazing or mastication before fire is reintroduced. At Redwing Ranch, mastication primarily refers to mowing dense willow stands, though it can also involve chipping or grinding woody vegetation to break up fuel continuity and improve access for future treatments.

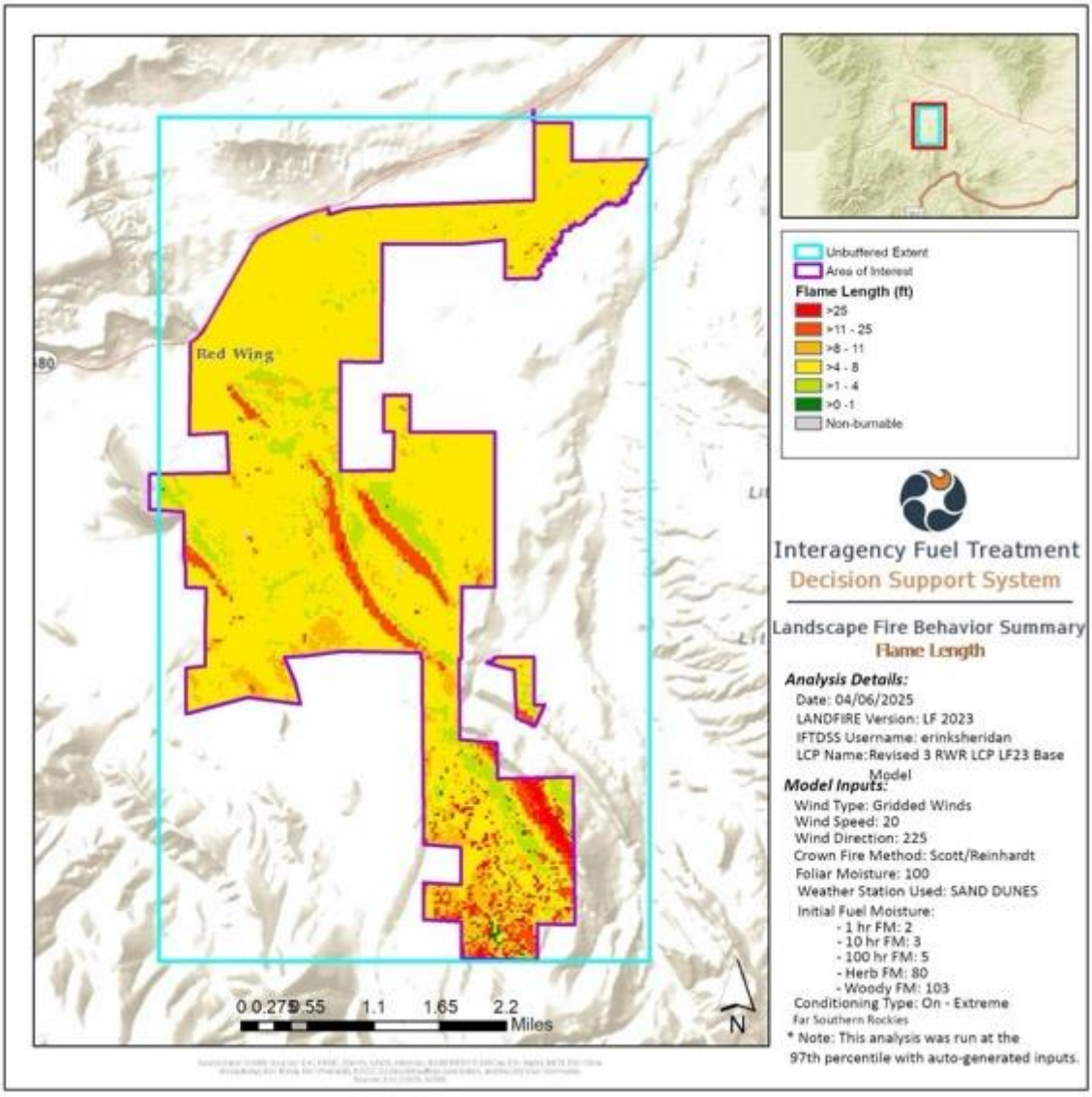


Figure 10. Flame length projection across Redwing Ranch under 97th percentile fire conditions.

Aspect determines solar exposure and drying potential. South- and west-facing slopes dry more quickly, increasing flammability and limiting regrowth potential post-treatment. Some of the rocky piñon ridges and some southern parts of Redwing Ranch are somewhat oriented toward southwest (203°–247°) and west (248°–292°) exposures, indicating faster fire spread and higher ignition risk (Figure 11).

At Redwing, landscapes facing southwest or west are uncommon. However, where these south- and west- facing slopes overlap with high flame length zones, they are deemed a higher priority for fuel reduction treatment. These areas are prime targets for buffer zones, such as goat grazing, shaded fuel breaks, or targeted mechanical thinning near structures and along likely ignition pathways. Aspect also helps inform seasonal burn timing, with shaded or north-facing areas holding moisture longer into spring or fall burn windows. Shaded fuel breaks are linear treatment zones where ladder fuels and dense understory vegetation are reduced through thinning or mastication, while retaining an overstory canopy to limit regrowth and slow fire spread.

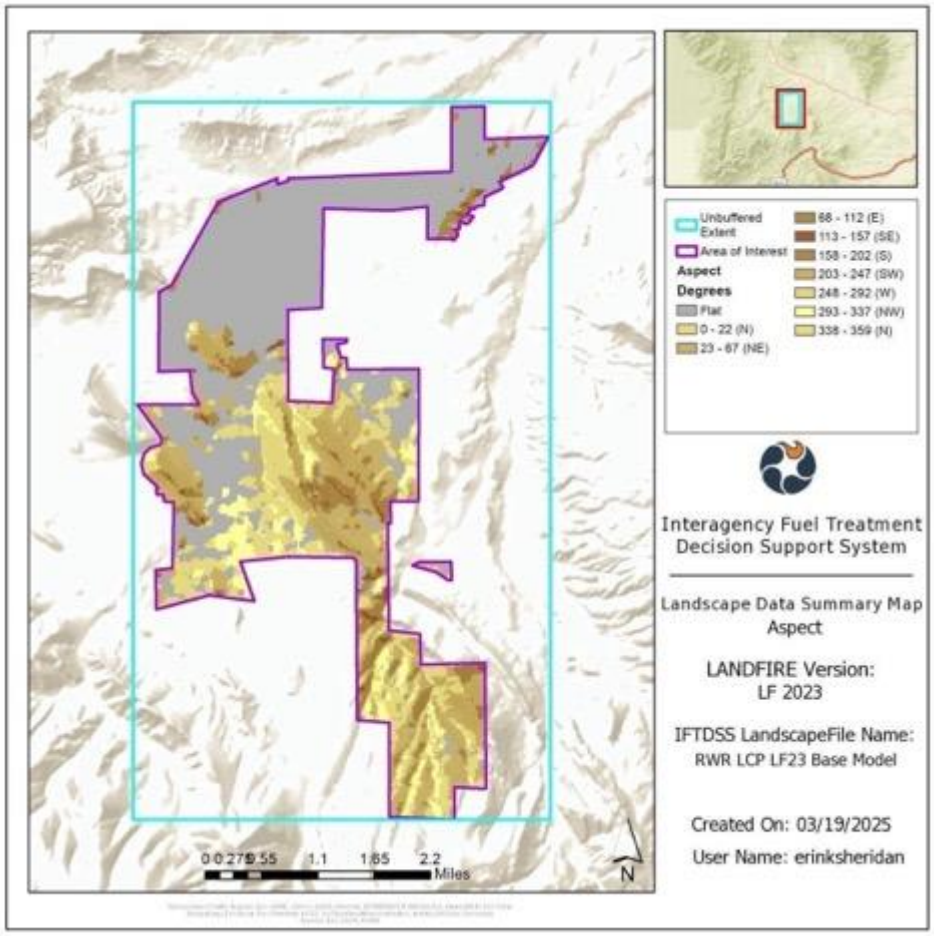


Figure 11. Aspect map of Redwing Ranch from Interagency Fuel Treatment Decision Support System (IFTDSS) landscape summary data.

Taken together, these fire behavior outputs provided a comprehensive picture of wildfire vulnerability across Redwing Ranch and helped define where management treatments should be prioritized (Figure 13). Zones with low slope, moderate flame lengths, and uniform fuel types were identified as suitable for initial prescribed burns, particularly where containment potential and operational access were high. In contrast, areas with dense vegetation, steep terrain, and long flame lengths, such as thick piñon-juniper stands or overgrown riparian areas, were flagged for mechanical thinning or phased grazing to reduce fuel loads before introducing fire.

High-risk corridors near roads and buildings were prioritized for shaded fuel breaks or targeted livestock grazing to create defensible space and slow potential fire movement. This integrated modeling framework laid the foundation for the color-coded treatment zones presented in Step 3, guiding the phased implementation of fire, grazing, and mechanical strategies based on both ecological suitability and wildfire resilience goals.

STEP 3: Applying Management Strategies

Building on the fire modeling and spatial analysis in Step 2, this phase translates data into action by assigning specific treatments to defined management zones across Redwing Ranch. Rather than approaching the landscape as a uniform unit, I developed a mosaic of treatment areas based on soil type, fire behavior modeling, vegetation type, accessibility, infrastructure vulnerability, and priority asset protection. These zones include prescribed fire units, shaded fuel breaks, targeted grazing areas, and zones reserved for other mechanical treatment or no-treatment wildlife habitat. Each treatment type was selected based on both fire mitigation potential and long-term land health objectives. This step formalizes a flexible, zone-based framework that landowners can adapt to local conditions, using fire as just one of many tools in a larger wildfire resilience strategy.

Management Tools

Effective land management in fire-prone regions, requires a decision-making process that goes beyond gut instinct or tradition. It must be grounded in ecological understanding, logistical feasibility, and financial practicality. For RwR I recognized early on that not every zone could or should be treated with fire alone. In some areas, grazing offers better control of fine fuels. Some

areas, especially steep slopes, dense piñon-juniper woodlands, and willow-dominated riparian zones are not ideal candidates for prescribed fire due to erosion concerns, crown fire risk or proximity to infrastructures. To help structure these decisions, I developed a Decision Grid referred to later in this section (Table 2).

Defensible Space & Infrastructure Protection

In zones at high risk to fire mechanical thinning or mastication was selected as the preferred treatment method (Figure 12). These are high-priority areas surrounding homes, barns, equipment sheds, and other critical infrastructure. They represent the interface between developed ranch operations and flammable wildland fuels.

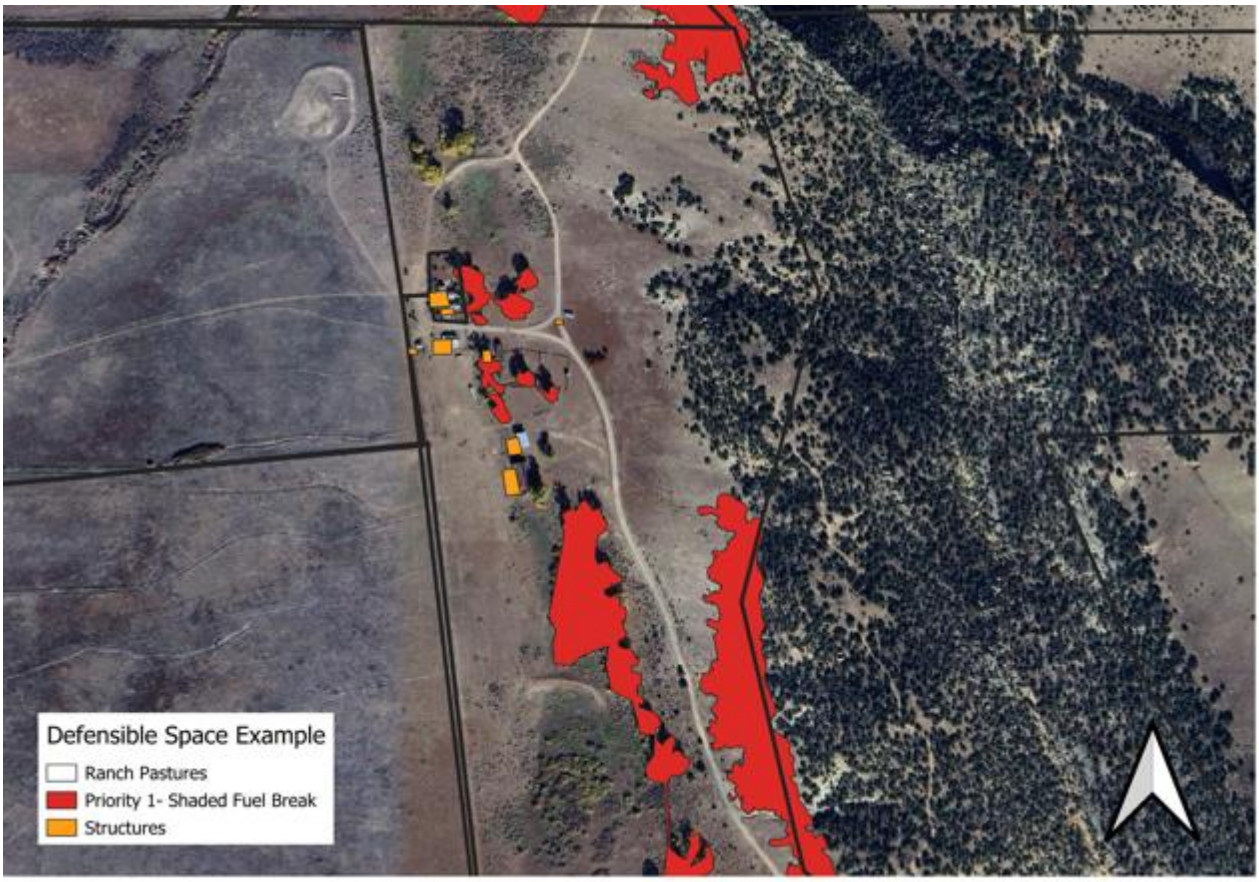


Figure 12. Defensible space and shaded fuel break example at Redwing Ranch near structures, along a main road, and in a modeled fire path.

Zone-Based Management Strategies at Redwing Ranch: Ecological Justifications

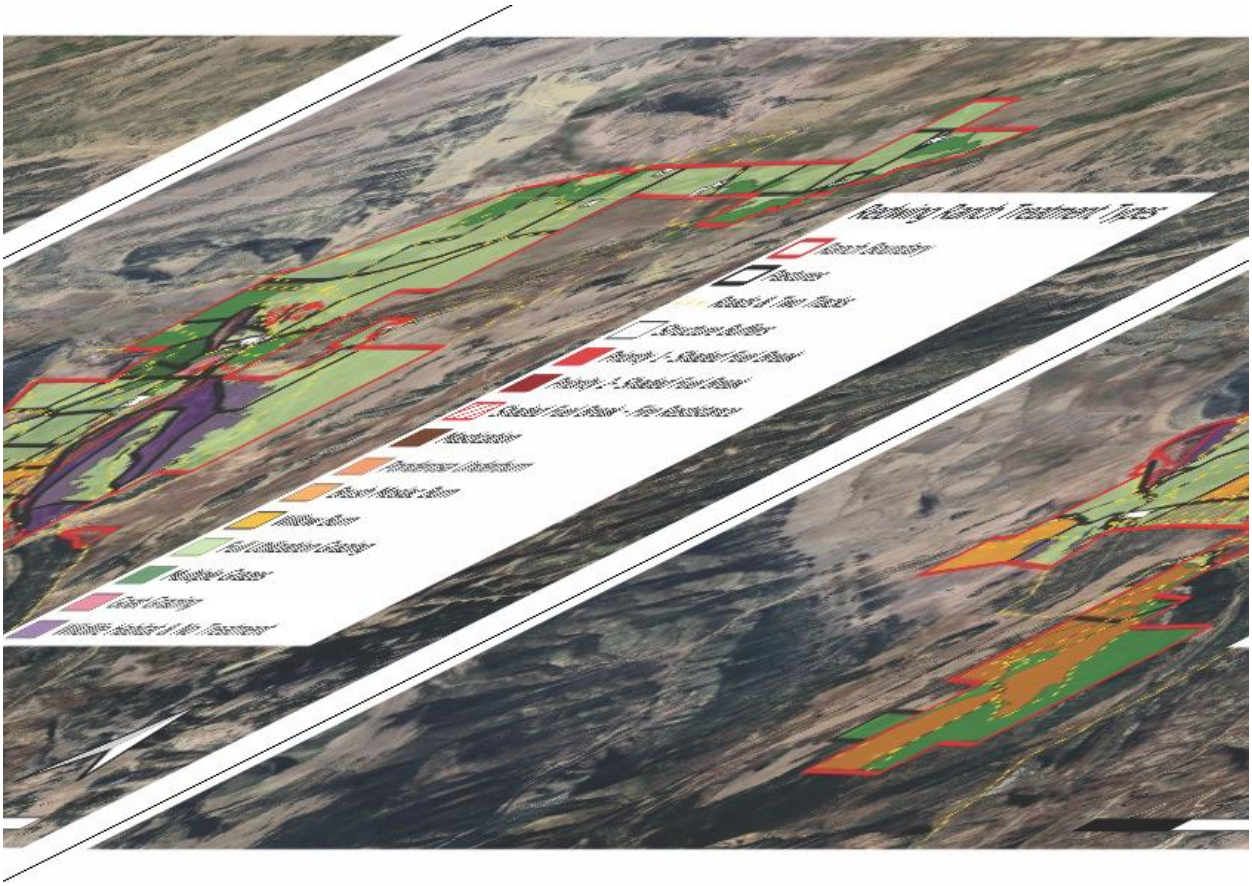


Figure 13. Redwing Ranch Treatment Types Map. Color-coded layers indicate recommended treatment strategies.

1. Rabbitbrush Dominated Pastures

Recommended Treatment: Mosaic burning + targeted grazing

Justification: Rabbitbrush is a vigorous colonizer following fire and can dominate degraded grasslands if not actively managed. In this zone, the goal is to use low-intensity prescribed burns to break up dense shrub patches and promote patchy heterogeneity that favors native grasses like blue grama and needle-and-thread, which recover well post-fire (Wright & Bailey, 1982; USDA NRCS, 2007; Launchbaugh & Owensby, 1978). Post-burn grazing is used strategically to suppress rabbitbrush regrowth and shift competition back toward herbaceous species, following

the literature-supported approach of a burn-graze mosaic (Fuhlendorf & Engle, 2004; Davies et al., 2016).

2. South-Side Ponderosa Pine Zone

Recommended Treatment: Prescribed underburn + strategic shaded fuel break

Justification: Underburning is defined by prescribed fire ignited under the forest canopy that focuses on the consumption of surface fuels (e.g. grasses, shrubs, and small trees) but not the overstory vegetation (USDA Forest Service, 2024). This area contains fire-adapted ponderosa pine stands with open canopies and some ladder fuels. First, a shaded fuel break and defensible space around burn units to create a safe burn unit for ingress and egress. Historically, these systems burned every 5–30 years under low-intensity surface fire regimes. Fire exclusion has increased buildup and shade-tolerant encroachment, elevating crown fire risk. Underburning is reintroduced here to reduce fine fuels, restore open forest structure, and promote native regeneration, aligning with the historical fire regime. (Agee, 1993; Covington & Moore, 1994). The potential damage by fire is also minimal in this treatment area (Figure 14). Additionally, in the ponderosa pine forests on the ranch's south side, low-intensity ground-level underburning mimics historical fire regimes and benefits hole nesting species such as Lewis's woodpecker (*Melanerpes lewis*) and nuthatches (*Sitta* spp.), both of which rely on older trees and somewhat open canopies (Hutto, 2008 & Colorado Parks and Wildlife, n.d.). Underburning also supports small mammal forage availability and mobility for predators for species like grey fox and porcupine, also both documented at Redwing. Research from ponderosa pine forests in the Southwest shows that small mammal biomass tends to increase following thinning and low-intensity wildfire, suggesting that these treatments create favorable conditions for small mammal communities and their predators (Converse, White, & Block, 2006).

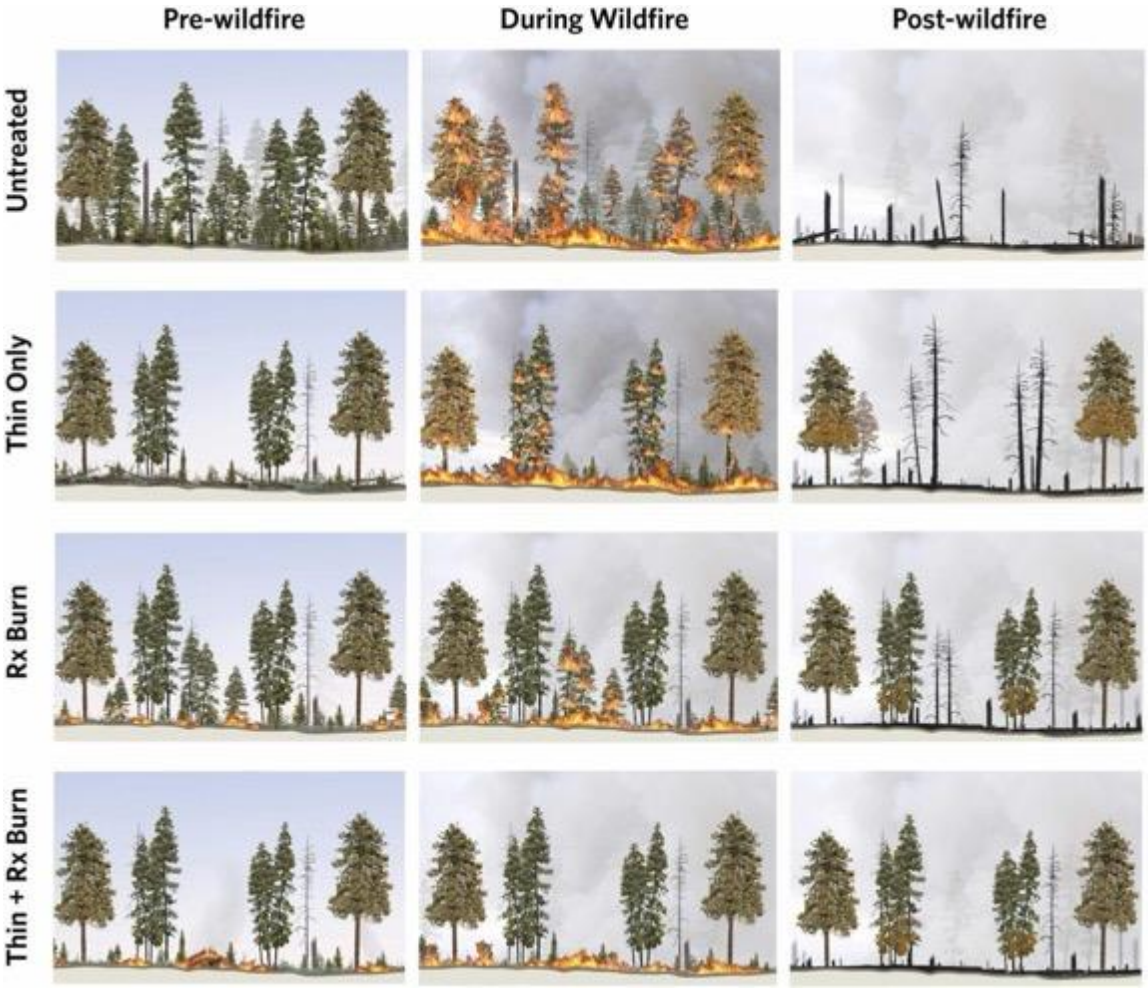


Figure 14. Fuel treatments reduce future wildfire severity (USDA Forest Service, 2024).

3. Dense Willow Riparian Corridors

Recommended Treatment: Strip burning or mastication + goat grazing

Justification: Riparian willow zones at Redwing Ranch are dense, overgrown, and sometimes too wet or unreachable for machinery. Fire has historically played a minor but ecologically significant role in maintaining species diversity in these areas. Strip burning, paired with goat grazing, is used to reduce decadent growth, open understory habitat, and create access corridors.

Willows regenerate well post-fire, especially when overstory cover is thinned to improve light availability. This treatment mimics historical disturbance and improves livestock grazing access while minimizing erosion from equipment. It is important to note that not all willows need management done to them. There are several patches of willows I highlighted as "wildlife/no treatment" other than reinvigorating with Rx (prescribed) fire. These recommended treatment areas can be seen on the zoomed in version of the "Redwing Ranch Treatment Types Map" (Figure 13).

4. Piñon-Juniper Ridge Slopes

Recommended Treatment: Mechanical thinning only

Justification: Piñon-juniper woodlands on steep terrain can be extremely vulnerable to erosion and crown fire. These species have low fire tolerance, and fire can lead to complete stand loss and post-fire invasions. In this zone, fire is excluded, and hand thinning is used to reduce ladder fuels and restore understory diversity while retaining wildlife habitat structure. Treatments are highly constrained by slope and accessibility, so ecological benefits are balanced with operational limitations.

5. Kochia Burn Trial Area

Recommended Treatment: Experimental burning + follow-up grazing

Justification: This zone is designed to evaluate fire as a management tool for kochia. Fire is applied following a summer grazing prep phase to reduce biomass and expose seedbeds. Post-fire grazing (including seeding and bale grazing) is used to add nutrients and increase competition from native species. While fire alone may not control kochia, this multi-phase approach reflects best practices.

6. Key Cottonwood/Piñon Pine Habitat

Recommended Treatment: No treatment

Justification: These zones contain valuable wildlife habitat and limited fire risk due to their location and further proximity from important structures and assets. In the fire models, these zones have potential to burn but are not a high priority. Cottonwood-dominated areas near water bodies support riparian biodiversity, while piñon-juniper woodlands offer bird habitat and structural diversity. Given the fire sensitivity of piñon-juniper and the role of cottonwoods in stabilizing riparian systems, these zones are designated as "no treatment" to preserve ecological function and minimize prolonged disturbance, other than current grazing practices. They can also serve as reference or control sites for monitoring treatment impacts elsewhere.

7. Shaded Fuel Break Corridors (Priority 1, 2, Extended)

Recommended Treatment: Thinning + Rx fire near roads

Justification: Modeled fire behavior indicates several fire flow corridors near roads and ranch infrastructure. Priority 1 shaded fuel breaks are implemented where fire modeling shows highest flame lengths and near high-value assets. Thinning ladder fuels and limbing trees four to eight feet above the ground reduces crown fire potential. Prescribed fire may be phased in later to maintain treatment zones in key areas. These fuel breaks also serve as ingress/egress buffers and suppression access lines in wildfire scenarios.

8. Goat Grazing Zones (Willow Thickets near Infrastructure)

Recommended Treatment: Browsing only

Justification: In dense willow patches near homes and barns, mechanical access is limited and prescribed fire may be too difficult to accomplish before priori treatment and or complete fuel

breaks. Goat browsing is used to reduce understory fuels and promote defensible space in more saturated and sensitive areas. Goats are effective at penetrating tight and thick brush and consuming regrowth. This approach avoids soil disturbance from equipment, aligns with regenerative grazing principles, and reduces the need for herbicide use. Once areas become more accessible, prescribed fire could be used as the second phase of management.

9. Multiple Grazing Zones (NDVI-Informed)

Recommended Treatment: AMP/ intensive grazing, 2–3x per season

Justification: NDVI analysis shows high vegetation productivity in sub-irrigated and some irrigated grassland pastures. These areas are well suited for multiple grazing passes per year under an RwR's adaptive management framework. Grazing can be timed to maintain low fine fuel height and stimulate plant regrowth while protecting soil. These zones can also serve as preparation or follow-up areas for prescribed burns and can help maintain fuel breaks over time.

10. Mosaic Brush Burn Zones (Rabbitbrush/Sagebrush Mix)

Recommended Treatment: Patchy prescribed fire + mastication

Justification: These semi-arid shrubland zones contain a native mix of rabbitbrush and sagebrush, alongside fire-adapted grasses such as blue grama and needle-and-thread). Rabbitbrush is a native early successional shrub that establishes readily after disturbance, particularly in degraded pastures. While valuable for pollinators and erosion control, dense rabbitbrush stands can suppress herbaceous growth and reduce plant diversity over time (Blaisdell et al., 1982; Chambers et al., 2014). Sagebrush is also native and a lot more fire-sensitive; it is typically killed by fire and regenerates slowly, relying on seed dispersal rather than resprouting. Because of these contrasting responses, a mosaic burn approach is applied,

using low-intensity, patchy prescribed fire to break up continuous shrub cover, reduce rabbitbrush density in selected patches, and retain unburned sagebrush islands for habitat structure and long-term shrub presence (Davies et al., 2009). This patchy disturbance regime favors a dynamic balance promoting openings for native grasses while preserving shrub cover in a spatially heterogeneous pattern. Post-burn targeted grazing is used to limit rabbitbrush regrowth in treated areas and maintain herbaceous dominance where desired (Launchbaugh et al., 2008; Boyd & Svejcar, 2009). Ongoing monitoring helps track vegetation response, ensuring that treatment does not lead to shrub monocultures or the spread of invasive species like cheatgrass (Balch et al., 2013). The ultimate goal is structural and species diversity, not shrub removal, supporting wildlife habitat, soil health, and resilient fire-adapted plant communities.

Evaluating Treatment Effectiveness with IFTDSS Modeling

To determine how various management strategies influenced wildfire risk across Redwing Ranch, I used IFTDSS to model fire behavior before and after applying treatment types in the GIS-based zone map. This model allowed me to simulate how fire would behave across the landscape under extreme fire weather conditions, comparing untreated scenarios with post-treatment landscapes.

integrating treatments such as shaded fuel breaks, prescribed fire, grazing, and mechanical mastication directly into the model, I was able to assess where and how fire behavior was most effectively reduced (Figures 15 & 16). These simulations enable a direct comparison of recommended pre- and post-treatment fire spread patterns.

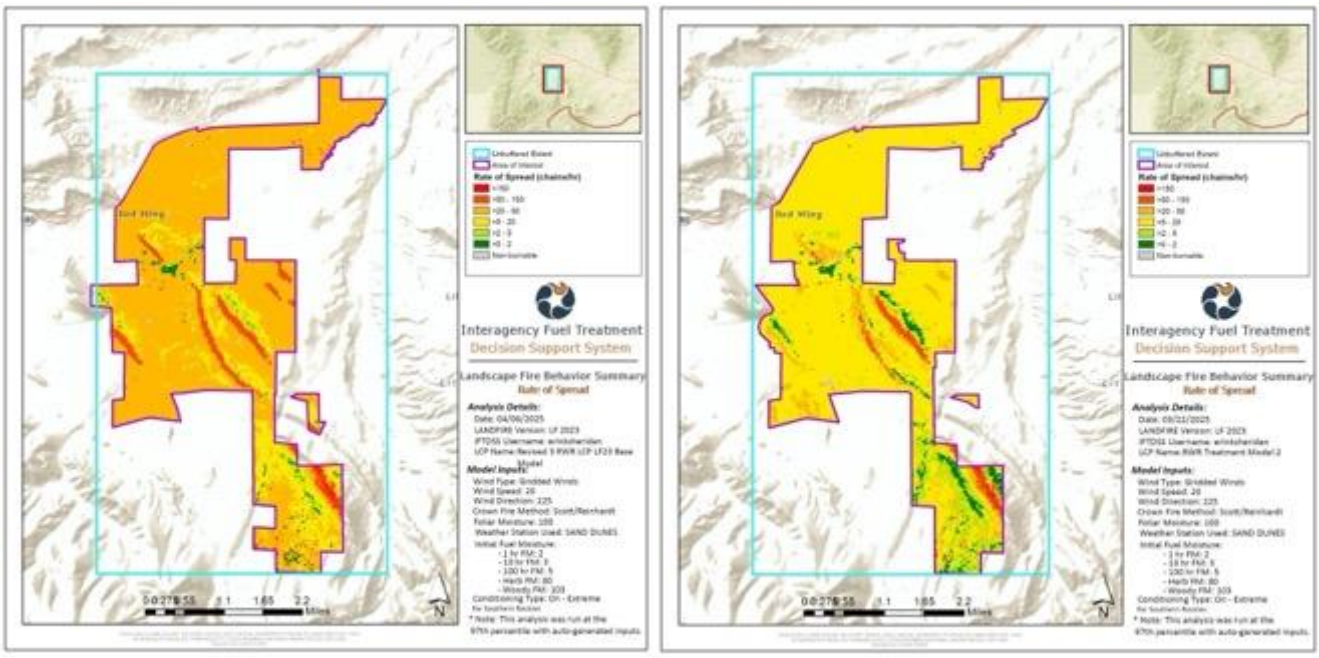


Figure 15. Interagency Fuel Treatment Decision Support System (IFTDSS) comparison of Rate of Spread in an untreated landscape vs treated landscape on Redwing Ranch.

Key areas, such as the headquarters compound and more central ridges, showed substantial reductions in rate of spread following the implementation of shaded fuel breaks and coordinated treatments. The visual contrast between untreated and treated rate of spread maps illustrates how targeted interventions can interrupt continuous fuel beds and reduce fire intensity across vulnerable zones. In some regions such as the eastern piñon-juniper ridge fire behavior remained largely unchanged, validating the decision to focus on shaded fuel break on the western side and

maintaining no-treatment habitat on this eastern side, while creating a fuel break at lower elevation levels on the west ridge.

On the other hand, zones targeted for prescribed fire, such as the rabbitbrush flats and the south pastures saw modeled reductions in both rate of spread and flame length, confirming their value as priority fire units once fire buffers were in place. This modeling validated the phased strategy applied in Step 3: implementing shaded fuel breaks and defensible space first, then expanding fire use in areas where suppression complexity was reduced. These IFTDSS outputs helped demonstrate not only where fire could carry, but where fuel treatments slowed or redirected its spread (Table 2).

Table 2. Interagency Fuel Treatment Decision Support System (IFTDSS) fire spread modeling comparison pre- and post-treatment.

IFTDSS Fire Spread Modeling Comparison Pre- and Post-Treatment					
Zone	**Dominant Vegetation**	**Primary Treatment Applied**	**Modeled Rate of Spread (Pre)**	**Modeled Rate of Spread (Post)**	**Change in Fire Behavior**
Southside Ponderosa Forest	Ponderosa Pine	Underburn + Fuel Breaks	>50 chains/hr (>1005.84 m/hr)	<20 chains/hr (402.34 m/hr)	Major reduction due to fuel break + Rx fire
Pinon-Juniper Ridge	Pinon-Juniper Woodland	Shaded Fuel Breaks + Thinning	50 chains/hr (1005.84 m/hr)	<25 chains/hr (502.92 m/hr)	Crown fire risk reduced through shaded fuel break
Rabbitbrush Flats	Rabbitbrush & Grass Mix	Mosaic Burning + Grazing	>25 chains/hr (>502.92 m/hr)	<10 chains/hr (<201.17 m/hr)	Lower flame length, slower spread in treated patches
River Yard Area	Willow & Juniper Mix	Fuel Breaks + Mastication + Grazing	20 – 50 chains/hr (402.34-1005.84m/hr)	<5 chains/hr (<100.58 m/hr)	Fire intensity decreased around key infrastructure
Riparian Willows	Dense Willows	Goats + Strip Burning	25-50 chains/hr (502.92-1005.84 m/hr)	<10 chains/hr (<201.17 m/hr)	Improved access and interrupted continuity
Kochia Trial Unit	Kochia, Weedy Annuals	Prescribed Burn + Grazing	10-20 chains/hr (201.17-402.34 m/hr)	<5 chains/hr (<100.58 m/hr)	Significant reduction: Rx fire prepped by grazing

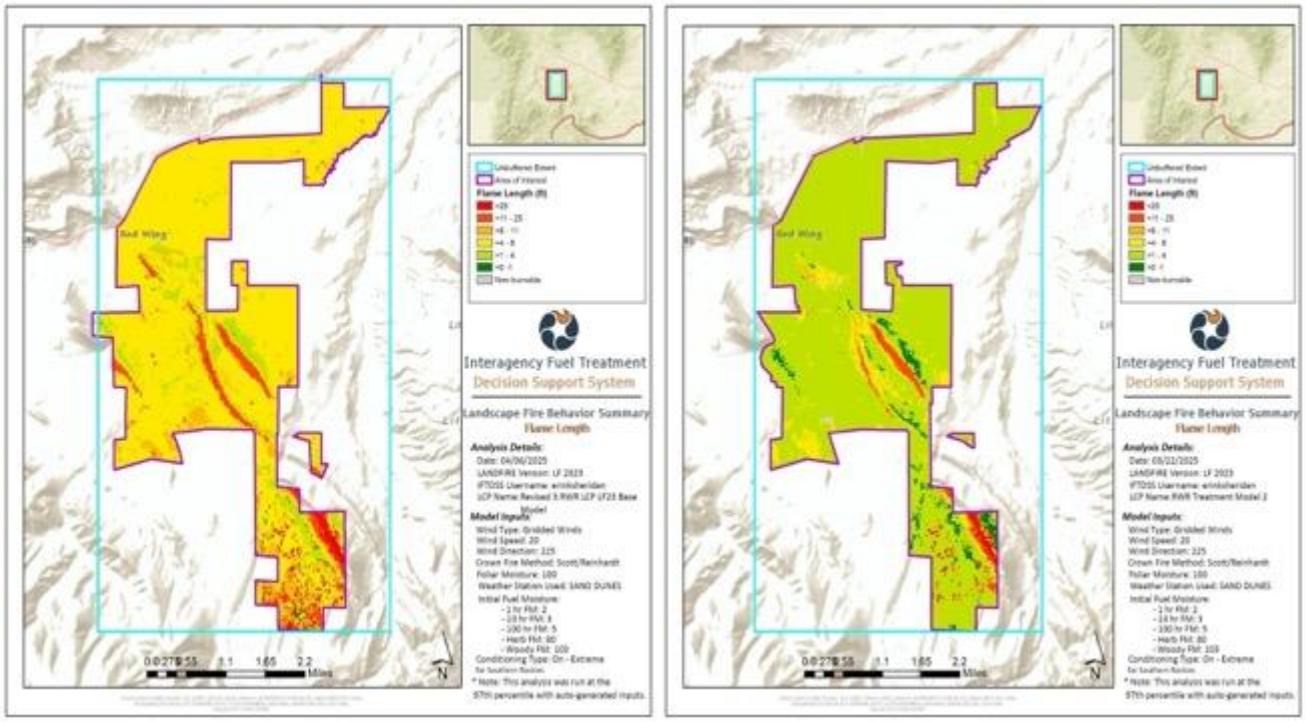


Figure 16. Interagency Fuel Treatment Decision Support System (IFTDSS) Models comparing flame length before and after modeled treatment.

Results showed that a combination of shaded fuel breaks, prescribed fire, and managed grazing significantly reduced flame lengths, rate of spread, and overall fire intensity in priority treatment zones. Shaded fuel breaks, created by thinning ladder fuels to a 4–8-ft (1.22-2.44 m) height and paired with either targeted grazing or underburning, were particularly effective along roads and infrastructure, serving as anchor lines for fire suppression and slowing fire progression. Prescribed burns in dense willow corridors reduced fine fuels in areas too wet for mechanical treatment, while post-burn goat grazing helped maintain low understory biomass. Underburning in the ponderosa pine forest restored natural fire cycles and reduced surface and ladder fuels, lowering the risk of crown fire ignition. In upland shrublands, mosaic burning of rabbitbrush and sagebrush broke up fuel continuity, resulting in a patchwork of variable-age fuels that decreased the modeled rate of spread. Managed cattle grazing in sub-irrigated pastures, especially those

grazed two to three times per year, as recommended by Snaplands Consulting, further reduced herbaceous fuel loads across the growing season. IFTDSS outputs confirmed that these combined treatments not only reduced fire behavior metrics but also strategically compartmentalized the ranch into defensible zones. The difference in modeled burned area and flow paths for a 10-hr period, demonstrates the advantages of applying treatments to the Redwing Ranch landscape (Figure 17).

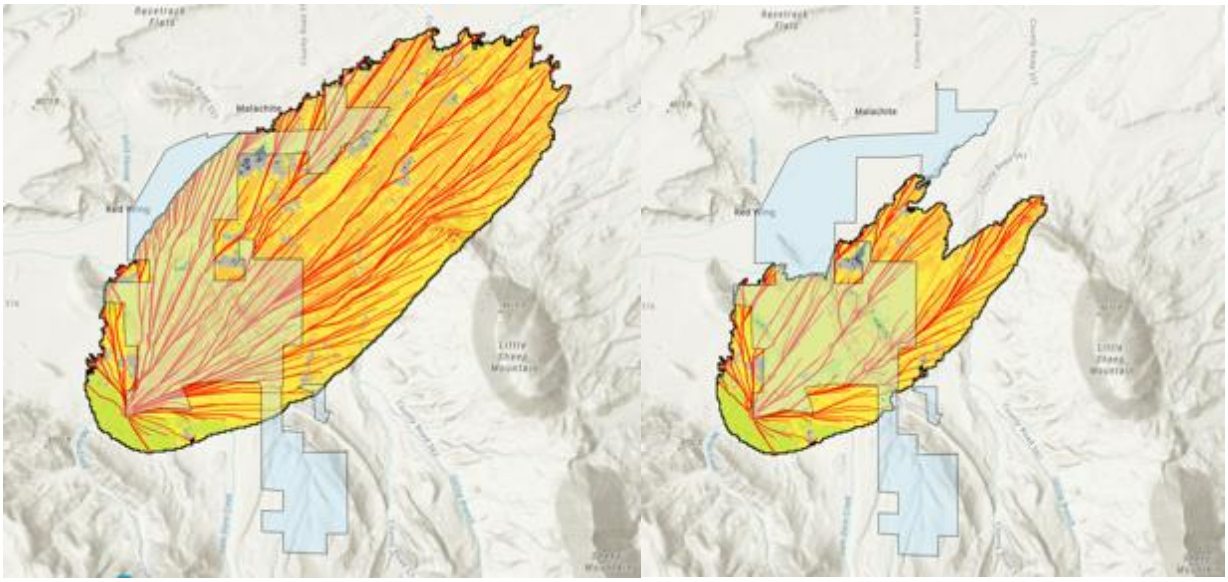


Figure 17. Interagency Fuel Treatment Decision Support System (IFTDSS) fire model showing pre- and post- recommended treatments through Redwing Ranch.

Management Zone Decision Making Matrix

By stacking ecological data, fire modeling, and infrastructure priorities, Redwing Ranch now has a clear, actionable strategy for building wildfire resilience.

To support implementation of the treatment zones and fire modeling work, we developed a decision-making matrix that helps prioritize management actions based on ecological, logistical, and financial considerations (Table 3). Each zone at Redwing Ranch was assessed using a scoring framework across eight key criteria: fire risk, flame length, rate of spread, asset value, fire adaptation potential, soil erosion potential, soil compaction risk, treatment cost, and accessibility. This matrix is adapted from the Ranching for Profit decision-making model and tailored to Redwing's unique fire ecology and infrastructure context. Each category is scored using a weighted system (1 = low priority or high resilience, 50 = high priority or low resilience), allowing land managers to systematically compare zones and determine where treatment will be most impactful. For example, a zone with high modeled flame lengths, proximity to structures, and poor accessibility may receive a higher combined score, indicating a more urgent need for mitigation, while areas with high fire adaptation potential and minimal risk may be deferred. This grid-based approach brings clarity to complex treatment decisions and ensures that limited resources are directed toward zones where fire, grazing, or mechanical treatments will provide the greatest ecological and risk-reduction benefit. It also supports transparency and repeatability in planning, making it a practical tool for future stewards of the ranch and a scalable model for landowners across the West.

Table 3. This is a fluid decision making matrix to support decision making in ranking priority treatment across Redwing Ranch.

CRITERIA DEFINED		**SCORING (+/-)**			
		1 (highly resiliency)	**3**	**5**	**50 (low resiliency)**
Fire Risk	In a modeled fire corridor	No modeled fire path	Fire path within 1.0 miles (1.6 km)	Fire path within 0.5 miles (0.8 km)	Management Zone is within modeled fire path
Flame Length	High flame length	0-4’ (0-1.2 m)	5-8’ (1.5-2.4 m)	9-12’ (2.7-3.65 m)	12’+ (12.7+ m)
Rate of Spread	High rate of travel	0-2 chains/hr (0-40.2 m/hr)	2-5 chains/hr (40.5-100.5 m/hr)	5-20 chains/hr (100.5-400.336 m/hr)	21+ chains/hr (401+ m/hr)
Asset Value	Monetary value of assets within zone	Grass, fence	Grass, fence, stock water	Grass, fence, stock water, structure	Grass, fence, stock water, structure, habitable structure, equipment
Fire Adaption Potential	Ecological adaptation potential	Needs fire for ecological resilience	Would benefit from fire	No potential for fire adaption	Damage from fire
Soil Erosion	Potential erosion of soil	Little to- no erosion potential	Minimal erosion	Erodible	High erodible
Soil Compaction	Potential compaction of soil	No compaction	Minimal compaction	Medium compaction	High compaction
Financial Cost (USD$)	Estimated treatment cost per zone	0-10	11-50	51-999	1000-1000000
Accessibility	Accessibility based on slope (equipment, truck, hand)	Accessible by all	Accessible with equipment and vehicles	Accessible by atvs	Only accessible on foot, or not at all

STEP 4: Monitoring & Adaptive Management

Tracking Vegetation Recovery and Guiding Treatment Decisions at Redwing Ranch

Monitoring is the cornerstone of adaptive land stewardship at Redwing Ranch. While Steps 1–3 focus on modeling, zoning, and applying treatments like prescribed fire, grazing, and thinning, Step 4 ensures those actions are effective and deliver the desired outcome or improve strategies over time. By systematically tracking how vegetation and soils respond to treatments, the ranch can adjust management practices based on in-field data. Monitoring is not a final step, but a recurring process that informs decision-making, prevents unintended consequences such as overgrazing or soil degradation, and builds ecological resilience across seasons and years.

This step integrates remote sensing with field-based monitoring to evaluate treatment outcomes, identify successes or failures, and guide next steps. NDVI is used to measure plant vigor and biomass at the landscape scale (Figure 18). Imagery from Sentinel-2, Landsat 8/9, and NAIP is analyzed using QGIS and Google Earth Engine to establish pre-treatment baselines and compare post-treatment vegetation response to detect regrowth of both target species like native grasses and undesirable species such as kochia or high populations of rabbitbrush. These spatial datasets help identify variability in recovery across zones, point out areas needing follow-up, and provide a repeatable method to assess effectiveness over time.

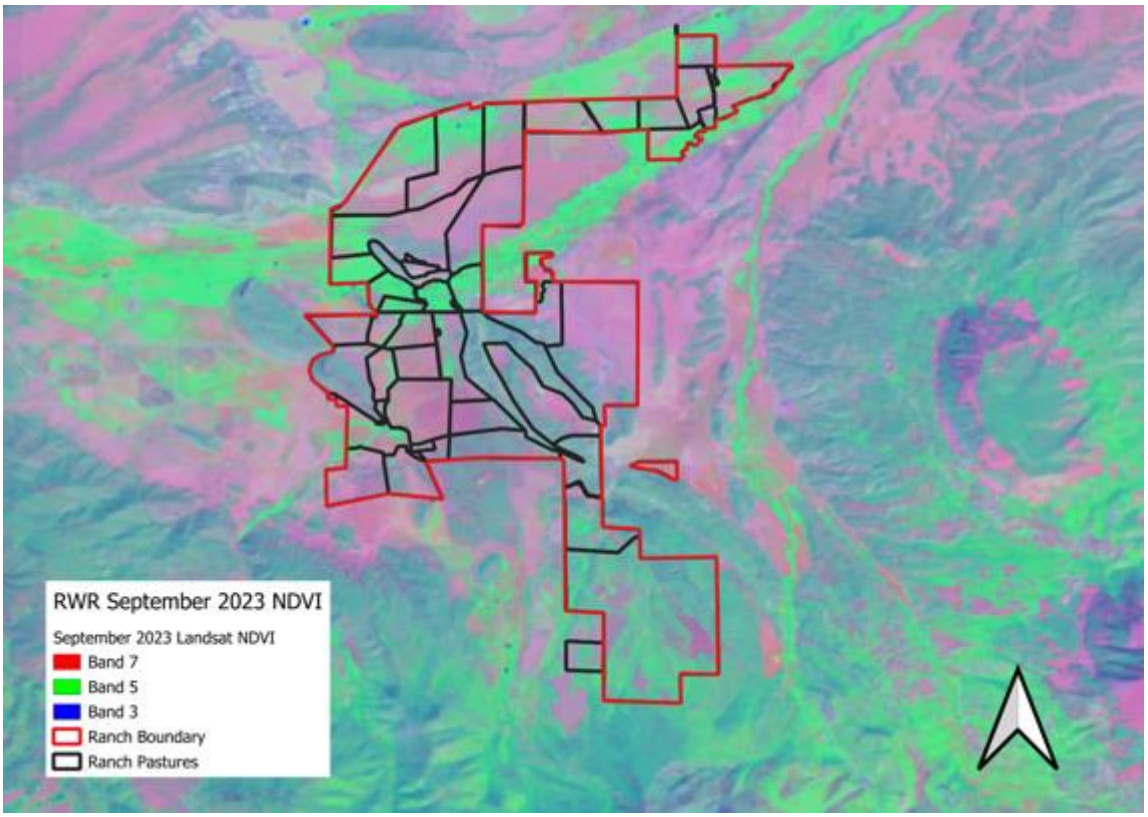


Figure 18. Normalized Difference Vegetation Index (NDVI) Imagery showing vegetation vigor in late summer (Sentinel-2, September 2023).

Ground-based monitoring complements this remote data by capturing site-level nuances. At Redwing, photo point monitoring (adapted from Dr. Christy Wyckoff's SOP) visually documents change over time, while vegetation transects are used to track species composition, ground cover, and bare soil exposure. Soil health assessments such as infiltration and compaction testing, are paired with wildlife observations across riparian areas, burn units, and key habitat zones. Both spatial and field-based monitoring occur before treatment, again at 1–3 months post-treatment, and at longer intervals of 6–12 months and 1–3 years to evaluate both short-term response and long-term ecological trends.

These monitoring results feed directly into adaptive management. For example, if NDVI shows slow post-fire recovery, grazing may be postponed and native seeding prioritized. If field data indicate invasive regrowth, targeted grazing may be introduced to suppress expansion. This real-time feedback loop supports more responsive, ecologically informed decisions.

To support this process, I developed several monitoring, management, and training tools as part of this project: a concise guide to GIS-based management zones (summarizing this full framework), a standardized field monitoring data sheet, a user-friendly monitoring guide for ranchers and land stewards, a remote sensing and NDVI workflow for kochia tracking in QGIS and GEE, a decision-making matrix for adjusting treatments, and a prescribed burn checklist. These tools are designed to be simple, repeatable, and transferable, ensuring that monitoring and adaptive management remain accessible and actionable for land stewards at Redwing and across other working landscapes in the West.

CONCLUSION: TOWARD RESILIENT, FIRE-ADAPTIVE LANDS

My project developed an integrated, adaptive land management framework using prescribed fire, spatial modeling, and ecological monitoring. Through two experimental burns at Redwing Ranch, I experienced firsthand both the potential and the limitations of field-based planning. While those treatments aimed to meet key ecological goals: reducing kochia biomass and opening dense willow corridors, they also exposed a critical need for predictive tools that support safe, strategic, and scalable fire implementation.

In response, I created a GIS-based fire behavior and treatment model using IFTDSS, FlamMap, LANDFIRE, and QGIS. This model simulates fire behavior under different weather scenarios and fuel conditions, helping land managers visualize not only where fire can be applied beneficially, but also where wildfire risk is highest. By layering vegetation, slope, and infrastructure proximity with modeled flame lengths and rates of spread, the model identifies areas that are both ecologically suited for prescribed fire and especially vulnerable to unplanned ignition. In this way, the model supports dual objectives: guiding the proactive use of prescribed fire and informing wildfire mitigation efforts through defensible space planning, shaded fuel breaks, and pre-treatment prioritization.

The outputs from this model informed the creation of zone-based treatment strategies at Redwing Ranch, integrating fire, strategic grazing, mechanical thinning, and monitoring in ways that align with both ecological function and fire resilience. By pairing modeled insights with on-the-ground data from NDVI trends and field surveys, the framework allows land managers to make data-

informed decisions that respond to seasonal variability, ecological feedback, and long-term landscape goals.

Importantly, this work underscores a broader gap in western land stewardship: fire is not underused because it lacks ecological merit, but because the tools to plan, model, and manage it effectively are often inaccessible or siloed. This project bridges that gap by combining technical modeling with practical application, offering a replicable system that can be adapted for ranches, public lands, and collaborative stewardship initiatives across the West.

In addition to modeling and monitoring, the project emphasized the importance of field-based training. Workshops like the Buckin' Babes+ Chainsaw Workshop I created at Redwing Ranch demonstrated how technical tools and hands-on experience go together with building confidence, expanding access to land management, and turning resilience planning into action.

Resilient rangelands require both ecological knowledge and the operational tools to act on it. This project offers a roadmap for integrating fire science, spatial planning, and real-world implementation - building a future where fire is once again a tool for regeneration, not just a threat to avoid.

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