Middle Truckee River Watershed Forest Health Assessment

Technical Report

Prepared for Truckee River Watershed Council

foriver
TRUCKEE RIVER WATERSHED COUNCIL

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Introduction and Background

Landscape Overview

The Middle Truckee River watershed is a 313,341 acre sub-drainage of the greater Truckee River basin. The mainstem of the Truckee River in the Middle Truckee Watershed flows from the outlet of Lake Tahoe at Tahoe City, CA and the downstream outlet of the watershed is located near Verdi, NV.

The population of the watershed is ~18,000 citizens that primarily live in the communities of Truckee, Northstar, Olympic Valley, Floriston, and Verdi. These communities are largely supported by a strong local recreation economy; there are three ski areas in the watershed (Northstar, Palisades Tahoe, and Tahoe Donner), over 25 state and federal campgrounds and recreation sites, and at least 300 miles of designated motorized and non-motorized trails.

The watershed provides critical water supply via groundwater to local communities and surface water for the downstream communities of Reno, Sparks, Pyramid Lake Paiute Tribe. The MTRW also supports hydroelectric power generation, agricultural water supply, storage for drought conditions, flood control, recreation, and fish and wildlife habitat (significant ecological assemblages including Protected Activity Centers (PACs) for Northern Goshawk and California Spotted Owl, aspen stands, meadows and fens, and sensitive vegetation species). There are also significant above-ground carbon storage pools in the west side of the watershed, particularly in meadows and large, old-growth forests. The health of these ecosystems is critical for both maintaining long-term carbon storage and their ability to continue to sequester carbon from the atmosphere (Sherbune, 2021).

Figure 1. Overview map of Middle Truckee River Watershed

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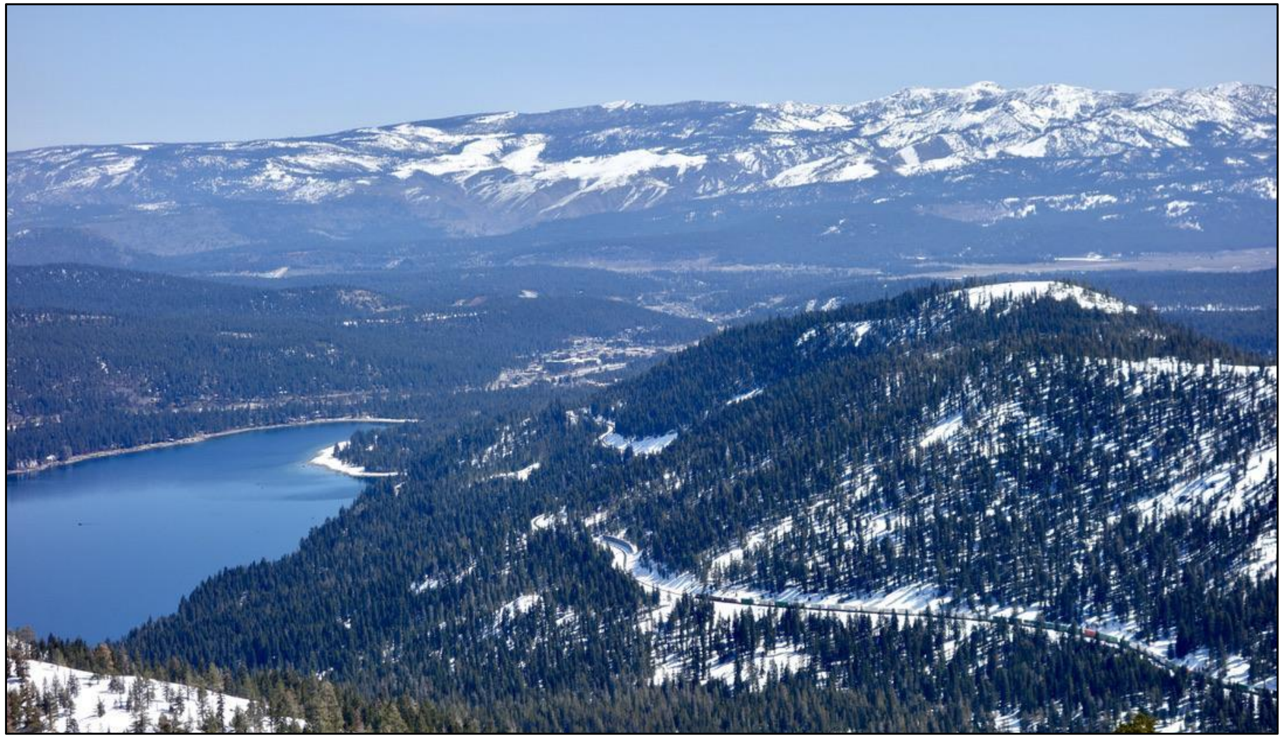
Introduction and Background

Environment

The Truckee River is an endorheic basin that begins on the east side of the crest of the Sierra Nevada and flows northeast to its terminus in Pyramid Lake. The Middle Truckee River is the segment of the mainstem of the Truckee River, beginning at the outlet of Lake Tahoe and ending in the sagebrush in Verdi, NV. There are several important tributaries for the Truckee River that are located in the Middle Truckee River watershed, including Bear Creek, Squaw Creek, Donner Creek, Martis Creek, and the Little Truckee River..

The watershed is characterized by a Mediterranean climate typical of the Sierra Nevada, with wet winters and dry summers. The hydrology of the Truckee River is snowmelt-dominated, with the majority of the precipitation falling as snow during the winter and melting during the spring and early summer, resulting in peak streamflow during this season. Because the Middle Truckee River watershed is located on the east side of the Sierra crest, it is subject to a strong orographic effect which results in a notable precipitation gradient from west to east, with the highest snowfall amounts occurring on the west side of the watershed nearest to the Sierra crest and less precipitation falling on the east side of the watershed. The highest elevation in the watershed is actually located on its eastern side at the summit of Mt. Rose (10,785 ft), and the lowest elevation is at the watershed outlet (4,780 ft). The vegetation patterns somewhat mirror the precipitation gradient, with Red fir and Sierran mixed conifer forests at the mid to upper elevations on the west side of the watershed, gradually transitioning to eastside pine and sagebrush in the eastern portion of the basin and at the lower elevations.



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Introduction and Background

Human and disturbance history

Humans have been present in the Truckee River watershed for at least the past 9,000 years during the Late Pleistocene/Early Holocene period (~12,500-8,000 years ago). Although multiple Native American Tribes likely inhabited the watershed, the Washoe people have the largest sustaining population and the longest history in the area. The Washoe people actively managed vegetation, for hunting and gathering, using fire as a management tool (Lindstrom, 2000). Understory, low intensity burning incorporated by the Washoe helped to maintain open forest structure and an open understory, preventing large-scale devastation seen in recent mega-fires.

During Euro-American settlement during the Comstock Era (1859-1880), there was significant timber harvesting in the watershed and Tahoe Basin during this time to build infrastructure for silver mining, flumes, railroads, and cities (Johnston, 1998; Wilson, 1992; Shepperd et al., 2006; Valliant and Stephens, 2009). Post-logging burning and sheep grazing (including burning for improved grazing) during this time and into the early 20th century also had a significant impact on the landscape (Shepperd et al., 2006; Valliant and Stephens, 2009).

The intensive logging efforts incorporated during the mid to late 1800's led to widespread decimation of the large fire-resistant trees that had formed the majority of forest stand composition within the watershed. The lack of heterogeneous forest stands and over 100 years of fire suppression activity has led to overstocked forests that lack resiliency and that are highly susceptible to wildfire and extended drought conditions, not only in the Truckee River basin, but across the Western U.S (Shepperd et al., 2006).

Truckee Donner Historical Society

Truckee Donner Historical Society

Introduction and Background

Disturbance today

During the last century of fire suppression, fire-adapted forests like those in the Middle Truckee River watershed have become more dense, experienced changes in species composition, and are heavily loaded with fuels (Valliant and Stephens, 2009). These forest conditions combined with climate change have increased high intensity wildfire hazard across the western US. The number of acres burned in wildfires and the size of fires has been increasing over the last 60 years; megafire occurrence (fires that burn greater than 100,000 acres) has increased significantly since 2000, with no megafires recorded prior to 1970 (Patel, 2018). Several large wildfires have occurred in the Middle Truckee River watershed in the last 60 years, including the Donner Ridge Fire (1960, ~45,000 acres) Crystal Fire (1994, ~7,000 acres) and Martis Fire (2001, ~14,500 acres). The risk of wildfire posed to communities, assets, and ecological resources has become a growing concern not only in the Middle Truckee River watershed, but across the western US.

Marilyn Newton (Reno Gazette Journal file)

Climate change and homogenous and dense forest conditions has also decreased the resilience of forests to drought-related stress and insects. The functionality of watersheds is also greatly compromised by overly dense forest conditions, which results in higher evapotranspiration, increased canopy interception and sublimation of snowfall, and decreased stream baseflow during the dry season (NSF, 2018). Conversely, watersheds that experience high severity burns or widespread tree mortality events are prone to higher rates of stream sedimentation, snowpack loss through sublimation, increased evaporation, flashier hydrographs (particularly in the short-term) and higher peak flows, and lower baseflows (Neary et al., 2011; Goeking and Tarboton, 2020). In other words, healthy forests support healthy watersheds.

Introduction and Background

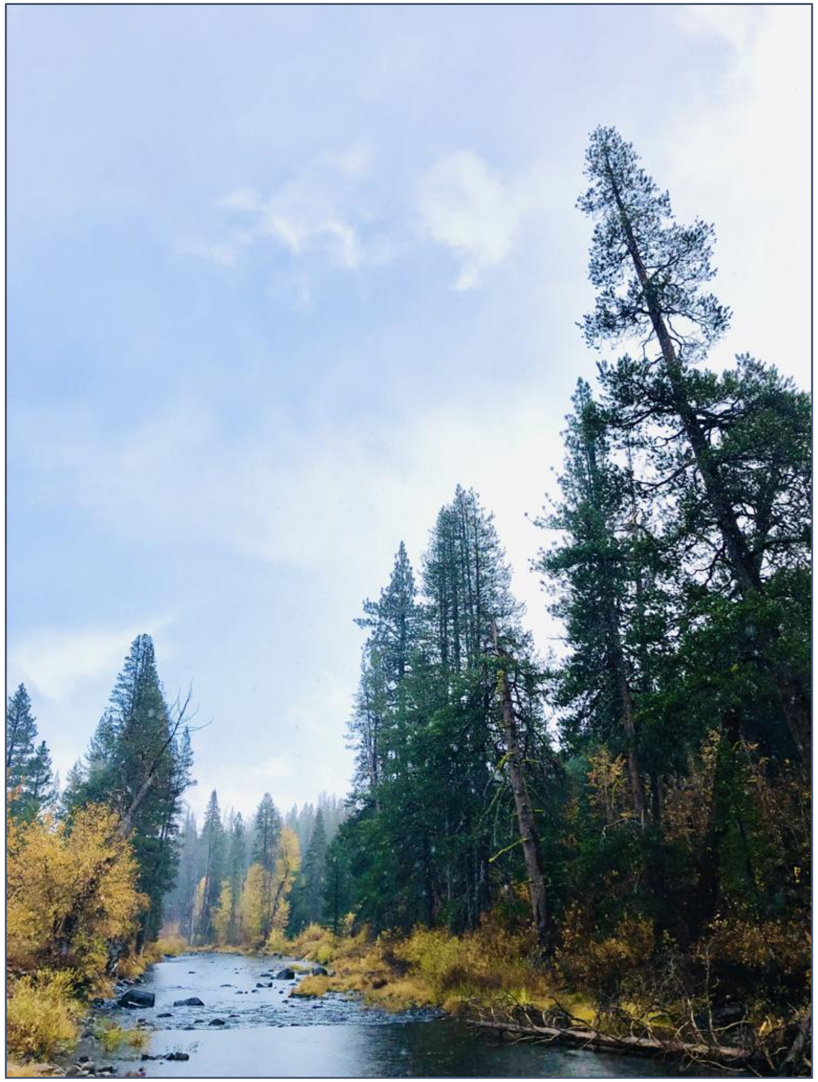
Purpose and Goals of the Forest Health Assessment

In 2019, **the Truckee River Watershed Council (TRWC) identified a need to conduct a Forest Health Assessment** to help identify areas in the Middle Truckee River watershed (MTRW) where forest health treatments could have the greatest benefit for improving watershed health and reducing risk from disturbances like wildfire. The goals of the Forest Health Assessment were:

- Define and delineate land ownership
- Identify historical, current, and desired conditions as related to forest health
- Explore management opportunities that will help to identify priority areas where forest health treatments may occur

Scope of work

The processes, calculations, and overall workflow described in this report were based upon previous applied science and planning frameworks and tools developed for wildfire risk assessments, specifically GTR-315 (Scott et al. 2013), "A wildfire risk modeling system for evaluating landscape fuel treatment strategies" (Ager et al., 2006), and the work being conducted by TCSI (Wilson and Manley, 2021). The work conducted for the MTRW Forest Health Assessment was based on the best available scientific information at the time of development, and the methodology presented here was developed specifically to meet the needs of the Truckee River Watershed Council and the many landowners who have a vested interest in forest management practices in the Middle Truckee River watershed.



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Findings Summary

The analysis conducted for the MTRW Forest Health Assessment identified **20 prioritized forest health projects** (2,500 acres each) across the landscape that were identified based on:

- Current ecosystem health conditions
- Current risk from wildfire and drought
- Impact of treatments on improving ecological function and reducing risk

39% of the landscape-scale benefits of treatment (reducing risk and improving ecological function) **can be achieved by treating 16% of the landscape.**

- The highest concentration of projects fell within the southwest and northwest areas of the MTRW due to greater exposure of strategic areas, resources, and assets to risk from both drought and wildfire, as well as the potential for treatments to both reduce that risk and improve ecosystem function.
  - The highest priority areas were identified based on the the most contiguous 2,500 acre areas that provide the greatest net benefit to strategic areas, resources and assets if restoration treatments are implemented. This benefit is realized both in terms of both risk reduction and improvements in ecological function and community protection.
- Conversely, no projects were identified in the southeast area of the MTRW due to a lower concentration and less exposure of strategic areas, resources, and assets to drought and wildfire relative to other areas within the watershed.

Based on the findings of the Assessment, TRWC will continue working with landowners and land managers to further delineate and prioritize the 20 recommended project areas in preparation for project planning and implementation. Initial planning and coordination tasks will examine current forest health projects throughout the watershed that are already in progress (planning or implementation). Additionally, close coordination with landowners will also help to determine areas where there is a need to implement forest health treatments, but where no treatments are currently planned or underway. This work is underway as of December 2021.

A full description of the data development methodology, analysis, and findings for the MTRW Forest Health Assessment is further detailed in the following sections of this report.

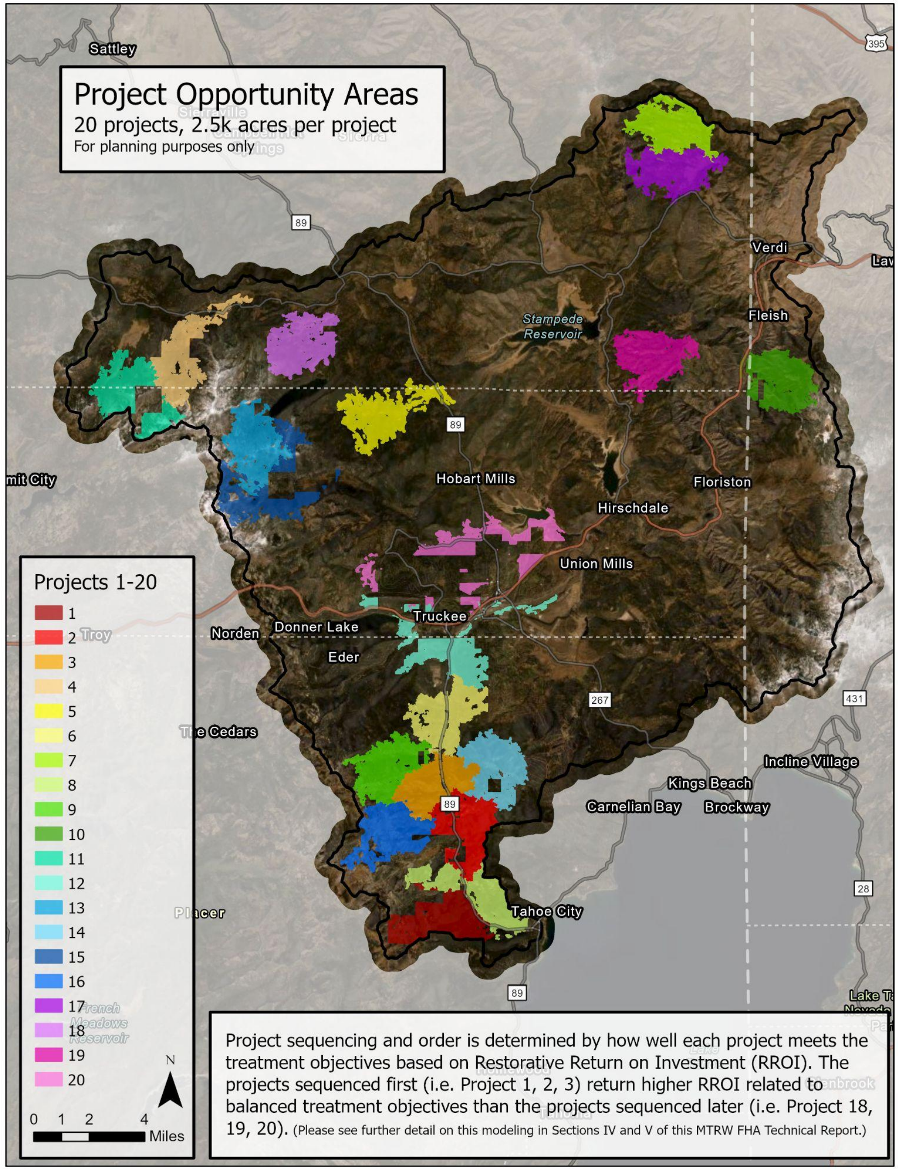

Figure 2. Findings summary: prioritized project opportunity areas identified for further planning for implementation

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Methodology Overview

The purpose of this work was to identify and prioritize areas for vegetation management treatments within the Middle Truckee River Watershed (MTRW) landscape that would most improve forest health and reduce risk from disturbances (wildfire and drought).

The primary initial phases of this work included: inventorying and appraising the resources and assets of importance within the landscape; aligning resources and assets with management objectives; developing mapped treatment units; and modeling landscape departure and disturbance hazards. All of the pieces of information derived from these initial steps were then used in a spatial-calculation framework (Restoration Abacus) to model where treatments could have the greatest impact toward improving ecological health and reducing risk. The spatial outputs of this modeling framework were used in a spatial-optimization program (ForSys) to develop sequenced projects based on parameters provided by the Truckee River Watershed Council (TRWC). An overview of this methodological framework is shown in the figure, with the following sections further detailing each step.

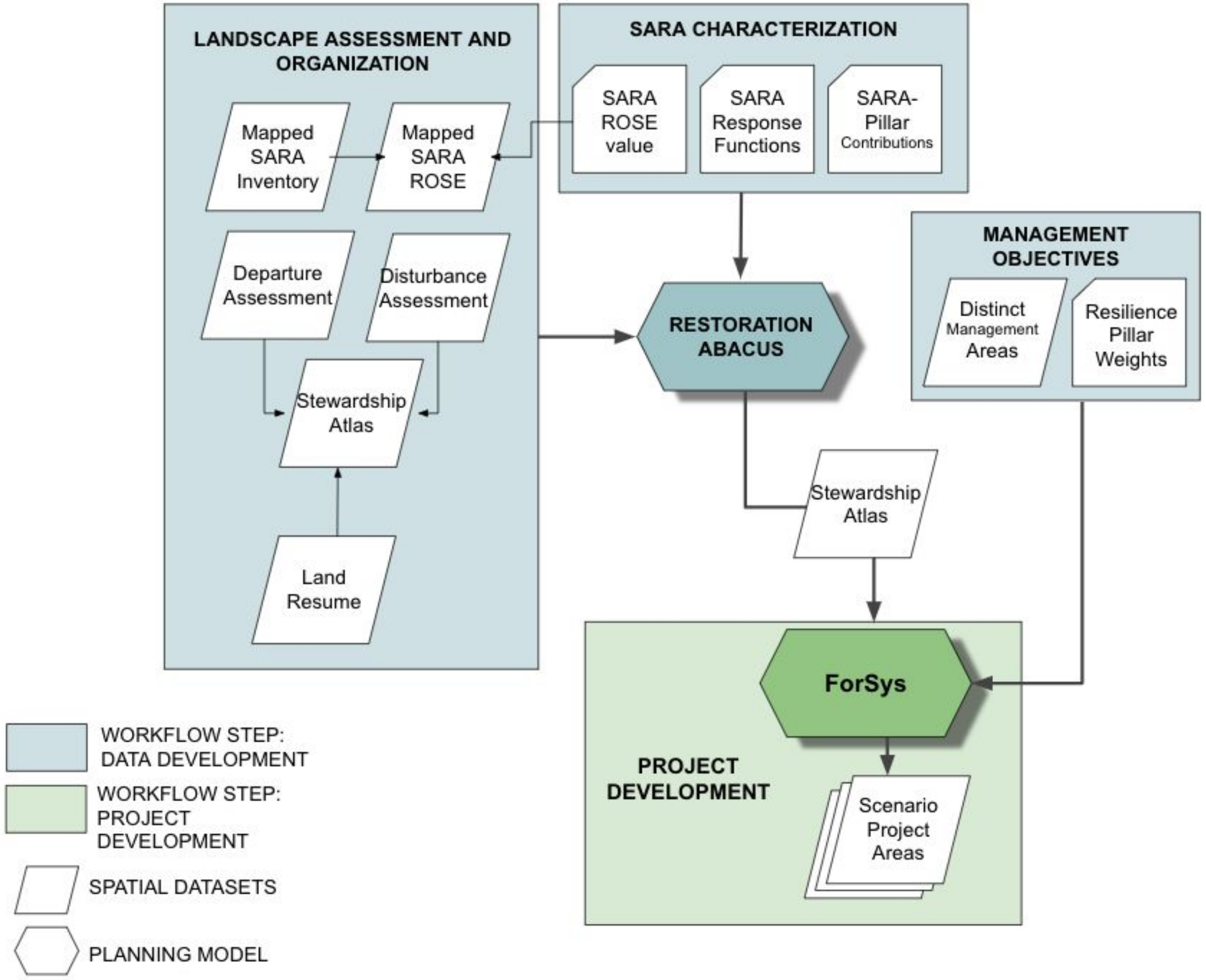

Figure 3. Methodological overview of analysis steps for the MTRW Forest Health Assessment

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Strategic Areas, Resources, and Assets (SARAs)

Overview

For this study, Strategic Areas, Resources, and Assets (SARAs) within the MTRW landscape were identified, mapped, and characterized. SARAs are features on the landscape that are anthropogenic or ecological that have been identified as having societal value, and are an important underlying driver of treatment prioritization across the landscape. SARAs were identified through a collaborative process with TRWC.

- **Strategic Areas**: Area on the landscape identified/designated/planned to serve a particular purpose. (See slide 16.)
  - Examples: strategic fireshed, strategic watershed
- **Resources**: Ecological resources with social value. (See slides 14-15)
  - Examples: nest/den sites, meadows/fens
- **Assets**: An item of property owned by a person or company. (See slides 11-13)
  - Examples: Structures, infrastructure

All SARAs must meet the following criteria:

- Have the ability to be mapped with some precision
- Can affect and be affected by "unplanned disturbances" (i.e. wildfire) and "planned disturbances (i.e. treatments, such as prescribed fire)
- Have societal value (not just personal value)

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Figure 4. Examples of a few MTRW SARAs that are visible within this photo are: the railroad, a waterbody (Donner Lake), and structures (visible in Truckee in the center of the photo).

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SARA Mapping Element Development

A total of **32 SARAs were identified on the MTRW landscape**. Each individual SARA could have multiple contributing datasets/factors. Generally, for each SARA, the following steps were taken to define its geospatial "footprint" (geoprocessing was conducted within a GIS (ESRI's ArcMap software and open-source QGIS software) or using open source python packages):

1. All relevant spatial datasets were collected and aggregated, either from existing data or, in some cases, by manually digitizing features using aerial imagery.
2. Relevant datasets were merged.
3. Duplicative SARAs were reconciled.
4. Buffers were applied as needed. A "buffer" was applied to a SARA feature in order to (1) create its footprint, particularly when the raw data source was line or point data, and/or (2) account for the area around the SARA where disturbances like fire would begin to have an impact on the SARA.

Maps of each SARA are available in the Appendix, and **on the 34N OPENNRM platform (login available upon request from TRWC).**

Figure 5. Example: Fire and Police SARA processing for a single feature

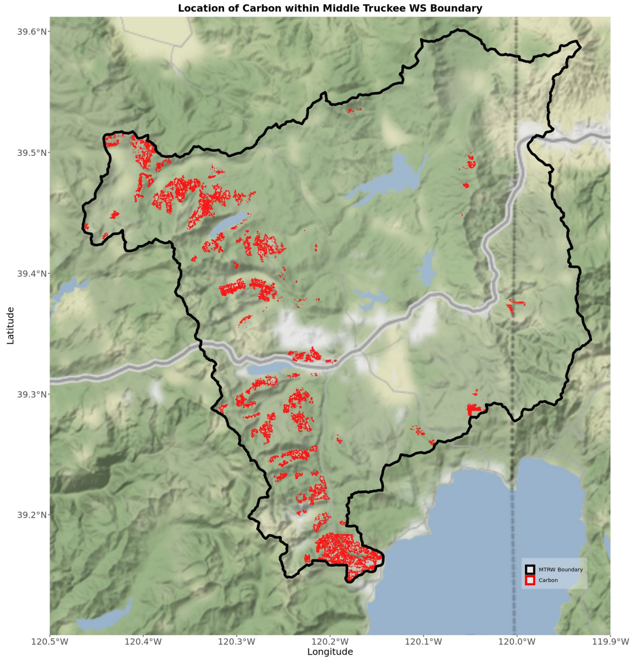

Figure 6. Example: a mapped SARA "footprint" for the MTRW landscape (High Carbon Storage Areas)

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SARAs: Assets

Table 1. Structures and Emergency Services SARAs

SARA Layer	Definition	Rationale	Data Source	Buffer
Structures				
Primary (non-transitory) Structures	Homes	Important to evaluate disturbance impacts on the health and assets of the community.	Town of Truckee, Placer County, Nevada County, 2018 Microsoft Building	100 ft
Transitory Structures	Major structures that are not primary dwellings, such as businesses, second homes, and non-emergency government buildings.	Important to evaluate disturbance impacts on the health and assets of the community.	Town of Truckee, 2018 Microsoft Building	100 ft
Other Structures	Small structures < 500 ft that have the lowest probability of occupancy before, during, and after an incident.	Important to evaluate disturbance impacts on the health and assets of the community.	Town of Truckee, 2018 Microsoft Building	100 ft
Emergency Services				
Fire and Police Structures and Compounds	Fire and police structures identify where emergency service personnel and equipment are located.	Fire and police provide direct support for multiple emergency services.	2018 Microsoft Building, Town of Truckee, USGS National Structures Dataset (Fire and Police), Cal Fire	300 ft around compound
Medical Structures and Compounds	Medical structures identify where medical services and equipment are located.	Medical facilities provide direct support and are locations where people seek treatment during emergencies.	2018 Microsoft Building, USGS National Structures Dataset (Health and Welfare)	300 ft around compound

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SARAs: Assets (continued)

Table 2. Communication Infrastructure, Power Infrastructure, and Water Resources Infrastructure SARAs

SARA Layer	Definition	Rationale	Data Source	Buffer
Communication Infrastructure				
Cell Towers and Radio Antennae	Infrastructure that is important for communication.	Asset that is important for emergency response and social well-being.	CA HVRA database	200 ft
Power Infrastructure				
Transmission Power Lines	Location of transmission lines.	Important to protect community well-being.	Homeland Infrastructure Foundation-Level Data	300 ft
Power Substations	Location of power substations.	Important to protect community well-being.	US Energy Information Administration	250 ft
Water Resources Infrastructure				
Water Delivery Infrastructure	Location of water resources delivery infrastructure (above-ground pipes, ditches, etc.).	Important to protect community well-being.	National Hydrology Dataset	150 ft
Water Resources Monitoring Stations	Hydrologic monitoring stations (streamflow, snow monitoring, weather stations, etc.).	Important because hydrologic monitoring datasets contribute to our understanding of past and current hydrologic trends, which allow us to plan for the future.	CDEC	100 ft

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SARAs: Assets (continued)

Table 3. Recreation SARAs

SARA Layer	Definition	Rationale	Data Source	Buffer
Recreation				
Trails	Motorized and non-motorized system trails.	Have recreational value which contributes to community economics.	National Forest System Trails, USFS Motorized Vehicle Use Trails,CA State Parks, Tahoe-Pyramid Trail	10 ft
Ski Areas	Skiable terrain within the ski area boundary.	Have recreational value which contributes to community economics.	Northstar, USFS, Open Street Map	n/a
Ski Lifts	Ski lift infrastructure.	Have recreational value which contributes to community economics.	Northstar, Open Street Map	100 ft
Campgrounds	Location of US Forest Service and California State Park campgrounds.	Have recreational value which contributes to community economics.	USFS Region 5 Recreational Opportunities, CA State Parks	n/a
Day Use Areas	Location of US Forest Service and California State Park day use areas (picnicking, etc.).	Have recreational value which contributes to community economics.	USFS Region 5 Recreational Opportunities, CA State Parks	n/a
Boating Sites	Location of US Forest Service and California State Park boating sites (boat ramps, etc.).	Have recreational value which contributes to community economics.	USFS Region 5 Recreational Opportunities	n/a

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SARAs: Resources

Table 4. Forest Investments and Ecological Assemblages SARAs

SARA Layer	Definition	Rationale	Data Source	Buffer
Forest Investments				
High Carbon Storage Areas	Above ground and below ground live, dead, and organic carbon pool (top 25% of TCSI carbon storage areas).	High Carbon Areas were identified to account for baseline conditions and to ascertain how vulnerable that carbon is to unplanned disturbance, avoided loss of some of that carbon if action is taken, and potential flux over time.	TCSI-TNC	n/a
Ecological Assemblages				
Large Tree Groves	Areas of trees with quadratic mean diameter greater than 30" in a minimum patch size of 1/3 acre.	In the Sierra Nevada, ecosystem functions such as carbon storage, species habitat, and historic fire dynamics of low to moderate severity fire rely on a few large trees compared to many smaller trees. Therefore, these large tree groves are important for forest resilience.	MTRW EcObject	n/a
Aspen Stands	Populus tremuloides (Quaking Aspen); the dominant overstory vegetation species in aspen stands.	In the Sierra Nevada, Aspen distribution is limited, is a biodiversity hotspot associated with high soil moisture and provide important habitat as well as recreational value.	California Fish & Game	100 ft
Nest and Den Sites	Historic nest roost and den points (2000-2020) for a number of species.	Nest and den sites are reused annually.	US Forest Service	300 ft

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SARAs: Resources (continued)

Table 5. Ecological Assemblages Cultural Resources SARAs

SARA Layer	Definition	Rationale	Data Source	Buffer
Ecological Assemblages (continued)				
Meadows and Fens	Meadows are ecosystems dominated by herbaceous vegetation reliant on shallow groundwater. A fen is a wet meadow that is saturated for most of the growing season where peat (partially decayed organic matter) is accumulating.	Meadows and fens with their seasonally moist waterlogged soils contain the most botanically diverse ecosystems in the Sierra Nevada.	UC Davis: Center for Watershed Sciences	100 ft
Sensitive Plants: Alpine/Subalpine	Location of sensitive plant assemblages and habitat.	Sensitive plant species are relatively rare on the landscape and respond poorly to disturbance.	US Forest Service	100 ft
Sensitive Plants: Forest				
Sensitive Plants: Riparian				
Tall Tree/High Canopy Cover Forest	Areas (top 20% of the landscape) with the highest quadratic mean diameter and canopy cover (>32 m height) where tall trees provide suitable habitat for the California spotted owl (North et al. 2017) .	Tall trees and high canopy cover forests are important for California Spotted Owl. Specific identification methods were informed by Keane and Gerrard (2020).	MTWR Stewardship Atlas	n/a
Cultural Resources				
Historic Resources	Historic eligible sites.	Preservation of cultural resources.	US Forest Service	100 ft

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SARAs: Strategic Areas

Table 6. Water and Strategic Fuel Areas SARAs

SARA Layer	Definition	Rationale	Data Source	Buffer
Water				
Infiltration Basins	Groundwater basins.	Areas of groundwater recharge that would likely result in negative impacts to water resources as a result of planned or unplanned disturbance.	California's Groundwater (Bulletin 118)	n/a
Waterbodies, Rivers and Perennial Streams	Location of waterbodies, rivers, and perennial streams and associated riparian areas identified in the USFS Riparian Conservation Areas.	Riparian areas are managed to maintain the function of aquatic, riparian and meadow ecosystems and habitat and ensure water quality.	US Forest Service Riparian Conservation Areas	n/a
Strategic Fuel Areas				
Critical Access Roads	Roads necessary for ingress of emergency services and egress of the public during incidents.	Important areas to maintain for public safety.	Town of Truckee, 34 North (using TIGER data)	250 ft
Railroads	Rail infrastructure.	Have economic value.	Homeland Infrastructure Foundation-Level Data	250 ft
Community Transmission Zones	Estimate of the annual number of structures exposed to wildfire based on simulated fire perimeters and community data.	Identifies high fire hazard that leads to a high risk of structures burning.	Alan Ager (US Forest Service Rocky Mountain Research Station, RMRS-GTR-392, Ager et al. 2019)	n/a
Community Fuel Reduction Zones	Wildland Urban Interface (Defense Zone).	Treatment zone necessary to protect communities in the case of a wildfire.	34 North	¼ mile

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SARA Characterization: Normalized Appraisal

Overview

A normalized appraisal process was developed to assign and map relative socio-ecological importance scores for each SARA. This process is done in order to expose SARA "value" to disturbance hazard to calculate risk and assess the impact of treatments (further described in Section IV). SARAs span a wide variety of assets and natural resources; while assets (like a home) can be appraised for their market value, there are other SARAs such as meadows or nest locations that are difficult to appraise for their "value." Therefore, conducting a normalized relative importance appraisal allows for the evaluation of all SARAs within the same relative scoring space. (Scott et al. (2013) further describes the importance of assigning relative scores to evaluate SARAs within a risk assessment framework, rather than assuming all SARAs to have the same value.) It is critical to note that these scores are not reflective of market-based absolute value, but rather are relative to one another in the context of socio-ecological importance.

For this study, **an objective framework for evaluating SARA importance scores and spatially distributing those scores across the landscape was developed by Vibrant Planet and a natural resource economist from EcoNorthwest (Buckley et al, 2021)**. During the normalized appraisal process, SARAs are evaluated based on a multi-criteria categorical ranking approach, and are assumed to be fully functional. Hence, scores developed from this process are referred to as **"relative potential socio-ecological" (ROSE) values**, and represent a maximum value per unit area (i.e. square meter).

The following steps were completed to map ROSE values for each SARA:

1. Calculate SARA base ROSE score (value per square meter)
2. If applicable, spatially-vary SARA base ROSE score according to their corresponding geographic beneficiary model
3. Generate final mapped SARA ROSE raster

***ROSE** (Relative Potential Socio-Ecological score/value):*
Maximum potential score of a SARA relative to other SARAs, based upon its uniqueness, replaceability, and ecosystem/social service(s). Assumes the SARA is fully functioning. ROSE is appraised for equivalent spatial units, and is applied to the entire SARA footprint area (i.e. buffer areas, when applicable).

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SARA Characterization: Normalized Appraisal

1. Calculate SARA base ROSE scores (value per square meter): sum of the sub-scores resulting from a categorical evaluation using the following criteria.

- **SARA regional uniqueness**
  - Within the study area or regional ecosystem, is the SARA generally rare or abundant, common?
  - Scoring: yes (1) or no (0)
- **SARA global uniqueness**
  - Globally is the SARA generally rare or abundant, common?
  - Scoring: yes (1) or no (0)
- **SARA is a discrete occurrence**
  - Does the SARA have a precise physical location and representation (discrete) or does it represent a characteristic across a region (assemblage)?
  - Scoring: yes (1) or no (0)
- **Relative duration until SARA replacement**
  - If the SARA is damaged or lost, particularly due to wildfire, does it take a relatively short or long amount of time for it to recover or be restored?
  - Scoring: low (0), medium (1), high (2)
- **Relative SARA replacement cost**
  - If the SARA is damaged or lost, particularly due to wildfire, is the financial and/or resource cost for it to recover or for it to be restored relatively high or low?
  - Scoring: low (0), medium (1), high (2)
- **SARA related to public safety**
  - Does the SARA contribute to supporting or improving public safety, particularly in the context of a wildfire?
  - Scoring: yes (1) or no (0)

Hence, the **maximum possible ROSE base score** is 8, and

the **minimum possible ROSE base score** is 1.

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SARA Characterization: Normalized Appraisal

Table 7. MTRW SARA base scores

SARA category	SARA	Total Score	*Discrete (not Assemblage)*	*Regionally Unique (not Common)*	*Globally Unique (not Common)*	*Years to Replacement (low, medium, high)*	*Replacement Cost (low, medium, high)*	*Public Safety*
Structures	Primary Residential	**5**	1	0	0	1	2	1
	Transitory	**4**	1	0	0	1	1	1
	Other	**4**	1	0	0	1	1	1
	Fire and Police	**6**	1	1	0	1	2	1
	Medical	**6**	1	1	0	1	2	1
Communications	Cell towers	**6**	1	1	0	1	2	1
	Radio antennae	**4**	1	0	0	1	1	1
Power	Transmission lines	**6**	1	1	0	1	2	1
	Substations	**6**	1	1	0	1	2	1
Water	Delivery	**6**	1	1	0	1	2	1
	Water Resources Monitoring Stations	**6**	1	1	0	1	2	1
	Infiltration	**2**	0	0	0	1	1	0
	Waterbodies/Rivers and perrenial streams (includes riparian areas)	**3**	0	0	1	1	1	0
Cultural	Historic	**7**	1	1	1	2	2	0
Recreation	Trails	**1**	1	0	0	0	0	0
	Ski Areas	**5**	1	0	1	1	2	0
	Ski lifts	**5**	1	0	1	1	2	0
	Campgrounds	**2**	1	0	0	0	0	1
	Day use areas	**1**	1	0	0	0	0	0
	Boating sites	**4**	1	0	0	1	1	1
Strategic Fuel Areas	Critical access roads	**6**	1	1	0	1	2	1
	Railroads	**5**	1	0	0	1	2	1
	Community transmission zones	**4**	1	0	0	1	1	1
	Community fuel reduction zones	**3**	1	0	0	0	1	1
Forest Investments	Carbon	**2**	0	0	0	1	1	0
Ecological Assemblages	Large tree groves	**6**	0	1	1	2	2	0
	Aspen stands	**4**	0	1	0	2	1	0
	Meadows and fens	**3**	0	0	1	1	1	0
	Sensitive plants	**5**	0	1	1	1	2	0
	Nest and den sites	**7**	1	1	1	2	2	0
	Tall Tree/High Canopy Cover	**6**	0	1	1	2	2	0

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SARA Characterization: Normalized Appraisal

2. If applicable, spatially-vary SARA base ROSE scores according to their corresponding geographic beneficiary model

For some SARAS, it was assumed that their base ROSE score should vary based on the proximity of that SARA to beneficiaries (such as human population or other dependent SARAs). For SARAs where it was determined that the base ROSE score should be varied spatially, SARAs were first segmented by a 500 x 500 m fishnet (i.e. grid), and then the base score for each 500 m^2 segment was varied according to one of the spatial models below (see table below).

Table 8. Spatial models applied for varying SARA base score

Spatial model	Beneficiary data	Boundary data	Description	Applied to:
Downstream Beneficiary	Population (census data)	USGS National Watershed Boundary Dataset HUC10s	Vary value of SARA between HUC10s based on the size or share of the dependent human population it serves. SARAs were divided based on HUC10 boundaries, and then value varied depending on the percentage of the total population within the entire project area that falls within the same HUC10.	- Waterbodies/Rivers and perrenial streams (includes riparian areas) - B118 Infiltration basins
Proximal Beneficiary	Dependent SARAs	USFS Fireshed Registry Project Areas	Vary value based on share of dependent SARAs within the same fireshed boundary. SARAs were divided based on USFS FIreshed Registry Project Area boundaries and value varied depending on the percentage of area of all dependent SARAs within the same fireshed boundary. Value within the firesheds was further varied by up to 10% using inverse distance weighting to dependent SARAs within the same fireshed boudary (i.e. areas of the SARA closer to other dependent SARAs would be of higher value than areas of the SARA further away from its dependent SARAs).	- Community Fuel Reduction Zones - Community Transmission Zones - Critical Access Roads - Communication infrastructure - Transmission Lines - Substations

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SARA Characterization: Normalized Appraisal

3. Generate final mapped SARA ROSE rasters

Lastly, final mapped SARA ROSE rasters were generated using the SARA base scores using one of three approaches. These can be categorized as rasters where the final mapped SARA ROSE raster either contained single values (non-spatially variable) or values that were variable across the landscape. Examples are shown on slide 23.

- **Spatially-variable SARA ROSE rasters:**
  - **Map SARA ROSE using SARA concentration and non spatially-variable base ROSE score:** For some SARAs, it was determined that the final SARA ROSE raster should account for the concentration of that SARA (i.e. areas of higher concentrations of that particular SARA should have greater value). SARA concentration was determined by assessing the number of overlapping features of the SARA (i.e. where there are overlaps in the buffered areas around features). A treatment conducted in an area where a SARA has multiple features located within close proximity of each other (i.e. multiple nest sites with overlapping buffers) would have a greater effect than an area where there is just a single feature of the SARA. For these SARAs, an "overlap raster" at a 5 m^2 gridcell resolution was generated and then multiplied by the SARA base ROSE score (value per m^2) and then a factor of 5 (to convert from 1 m^2 to 5 m^2) to generate the final SARA ROSE raster.
    - *Primary Residential Structures, Transitory Structures, Other Structures, Fire and Police Structures, Medical Structures, Water Resources Monitoring Stations, Ski Lifts, Sensitive Plants, Nest and Den Sites*
  - **Map SARA ROSE using SARA concentration and spatially-variable base ROSE score:** For some SARAs, it was determined that the final SARA ROSE raster should account for the concentration of that SARA *and* the spatially-varied SARA base score (accounting for its geographic beneficiary effect). First, the mean mapped SARA base score at the 500 m^2 fishnet grid-level was calculated for each SARA feature; this was done because it was possible for a single distinct SARA feature to be split by the fishnet and thus have several base ROSE scores assigned to it, and hence it was necessary to calculate a single base ROSE score for each SARA feature (i.e. cell tower footprint). Second, this SARA base ROSE score layer was converted to a 5 m^2 raster, and values were multiplied by a factor of 5 (to convert from 1 m^2 to 5 m^2). Lastly, the base ROSE score raster was multiplied by the SARA overlap raster (generated as described above) to generate the final SARA ROSE raster. For example, an area with a high concentration of communication infrastructure (i.e. cell towers) that is located near other SARAs that depend on it would have a high ROSE score.
    - *Communication Infrastructure, Substations*
  - **Map SARA ROSE using spatially-variable base ROSE score :** For some SARAs, it was determined that the final SARA ROSE raster should just account for the spatially-varied SARA base score (accounting for its geographic beneficiary effects) (i.e. no effect of concentration, or no information in the dataset about concentration of features). First, the mean mapped SARA base score at the 500 m^2 fishnet grid-level was converted to a 5 m^2 raster, and then values were multiplied by a factor of 5 (to convert from 1 m^2 to 5 m^2) to generate the final SARA ROSE raster.
    - *Transmission Lines, Waterbodies/Rivers and Perennial Streams, Infiltration (B118 Basins), Critical Access Roads, Community Transmission Zones, Community Fuel Reduction Zones*

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SARA Characterization: Normalized Appraisal

3. Generate final mapped SARA ROSE rasters (cont'd)

- **Non-spatially variable SARA ROSE rasters:**
  - **Map SARA ROSE using SARA footprint and base ROSE score:** For some SARAs, it was determined that not enough information existed to spatially vary their value across the landscape. For these SARAs, a 5 m^2 raster was generated using the SARA footprint and the base ROSE score (value per m^2) was multiplied by a factor of 5 (to convert from 1 m^2 to 5 m^2) to generate the final SARA ROSE raster.
    - *Water Delivery Infrastructure, Trails, Ski Areas, Campgrounds, Day Use Areas, Boating Sites, Railroads, Carbon, Large Tree Groves, Aspen Stands, Meadows and Fens, Tall Tree/High Canopy Cover*

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SARA Characterization: Normalized Appraisal

Examples: final mapped SARA ROSE rasters

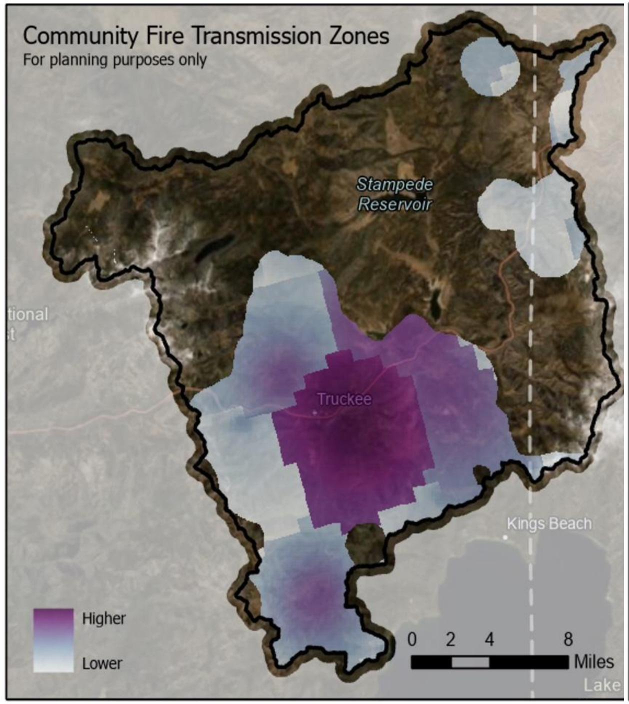

Figure 7. SARA ROSE mapped using spatially-variable base ROSE score (Proximal Beneficiary model)

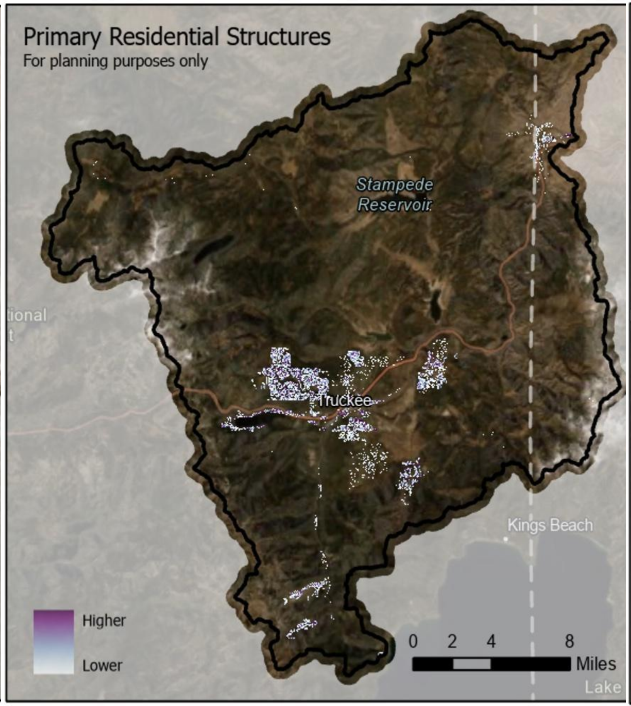

Figure 8. SARA ROSE mapped using SARA concentration and non spatially-variable base ROSE score

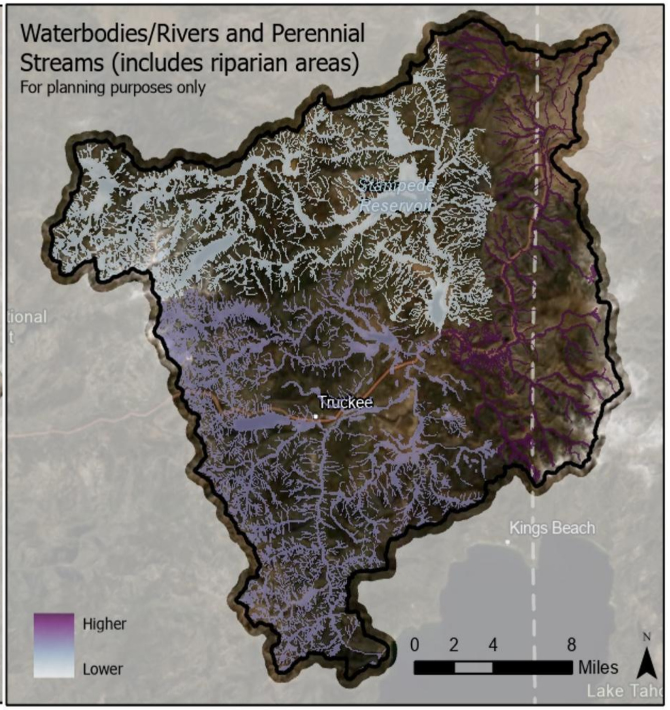

Figure 9. SARA ROSE mapped using spatially-variable base ROSE score (Downstream Beneficiary model)

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SARA Characterization: Response Functions

Overview

Categorical response functions were developed to characterize the effects of disturbances (fire, drought) and treatment types on individual SARAs. The process of creating response functions is well documented in the literature (e.g. Fairbrother and Turnley 2005, Kiker et al. 2005, Ven and Calkin 2011), and the application of response functions in wildfire risk assessments has been outlined and shown in GTR-315 (Scott et al. 2013). **Response functions are used to estimate the change in value for each SARA when exposed to a disturbance or treatment**; although response functions are simple, they are beneficial when evaluating effects on a wide variety of different landscape features (i.e. anthropogenic assets versus ecological resources) within a single model framework. Response functions are helpful for **differentiating the effects of a given disturbance type/intensity on multiple different SARAs**; for example, a house may experience some loss when exposed to moderate intensity wildfire, whereas aspen stands would actually benefit from the same intensity of wildfire.

Table 9. Response function ratings and their associated percent change in value

Response Rating	Description	NVC (% change in value)
-3	Greatest Loss	-99%
-2	Significant Loss	-66%
-1	Some Loss	-33%
0	No Loss or Benefit	0 (no change)
1	Some Benefit	33%
2	Significant Benefit	66%
3	Greatest Benefit	99%

Specifically, the response functions developed for this planning effort quantified the percent value change of a SARA if exposed to a disturbance at a given intensity or a certain treatment type. As further described in “Section II: Disturbance Modeling,” disturbance intensity class rasters were developed for both fire and drought disturbance types (six intensity classes per disturbance) (see slides 46 and 50). As further described in “Section II: Stewardship Atlas”, each Stewardship Atlas unit (i.e. treatment unit) was assigned a likely potential treatment based on landscape and vegetation characteristics. Each SARA was assigned a response rating (-3 to 3) corresponding to a given intensity class for each disturbance type (wildfire, drought) or treatment type. The response ratings are then associated with a net value change (NVC), which is a percent change in value (see table above).

It should be noted that **all response functions were developed to characterize the net effects over a 10-year period**. The following figures show the response rating of each SARA to each disturbance type and intensity. Response functions were created from a combination of expert opinion and experience by staff scientists at Vibrant Planet as well as literature review, when possible.

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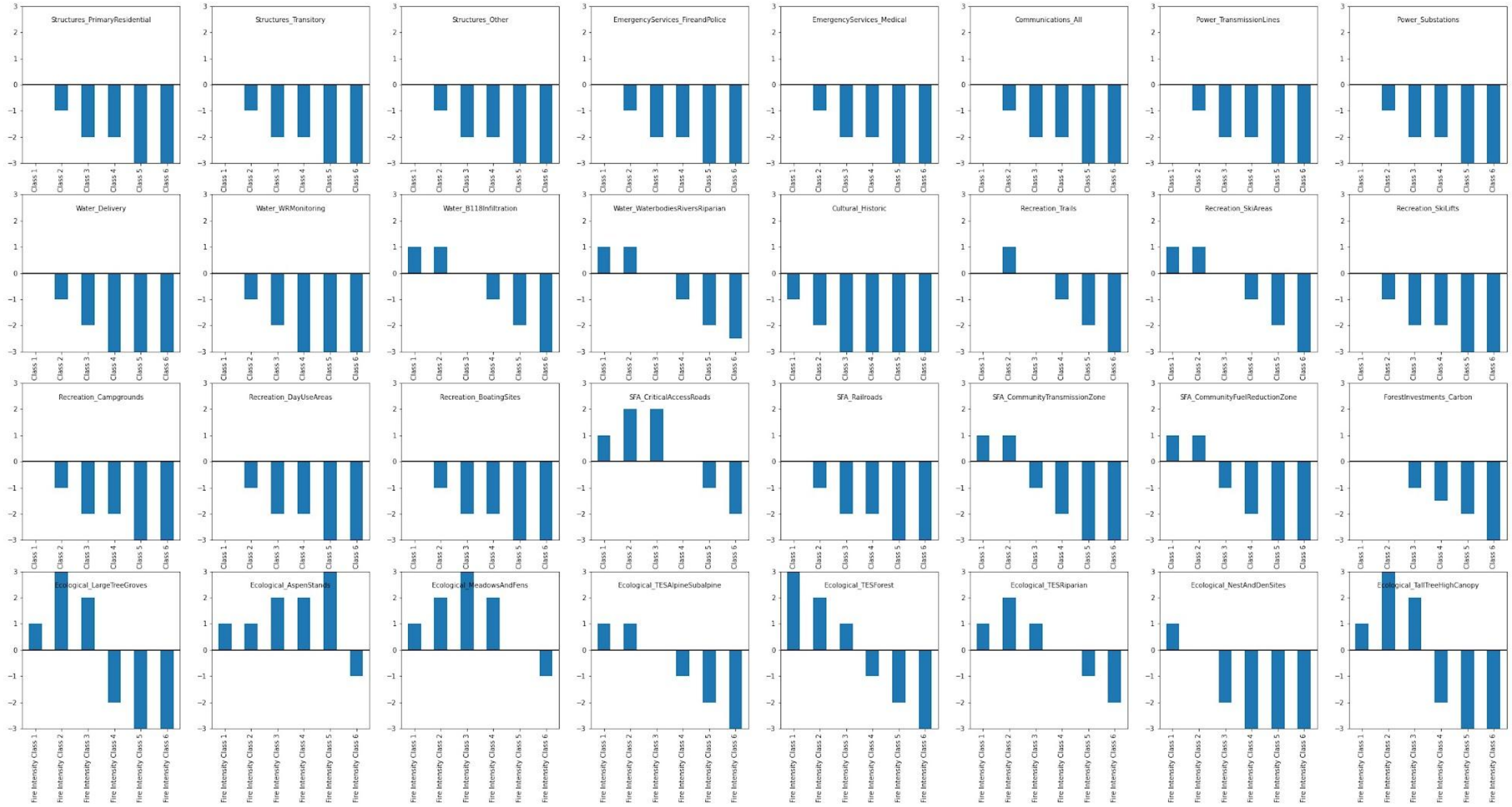
SARA Characterization: Response Functions

Figure 10. SARA Response to Disturbance Intensity: Wildfire



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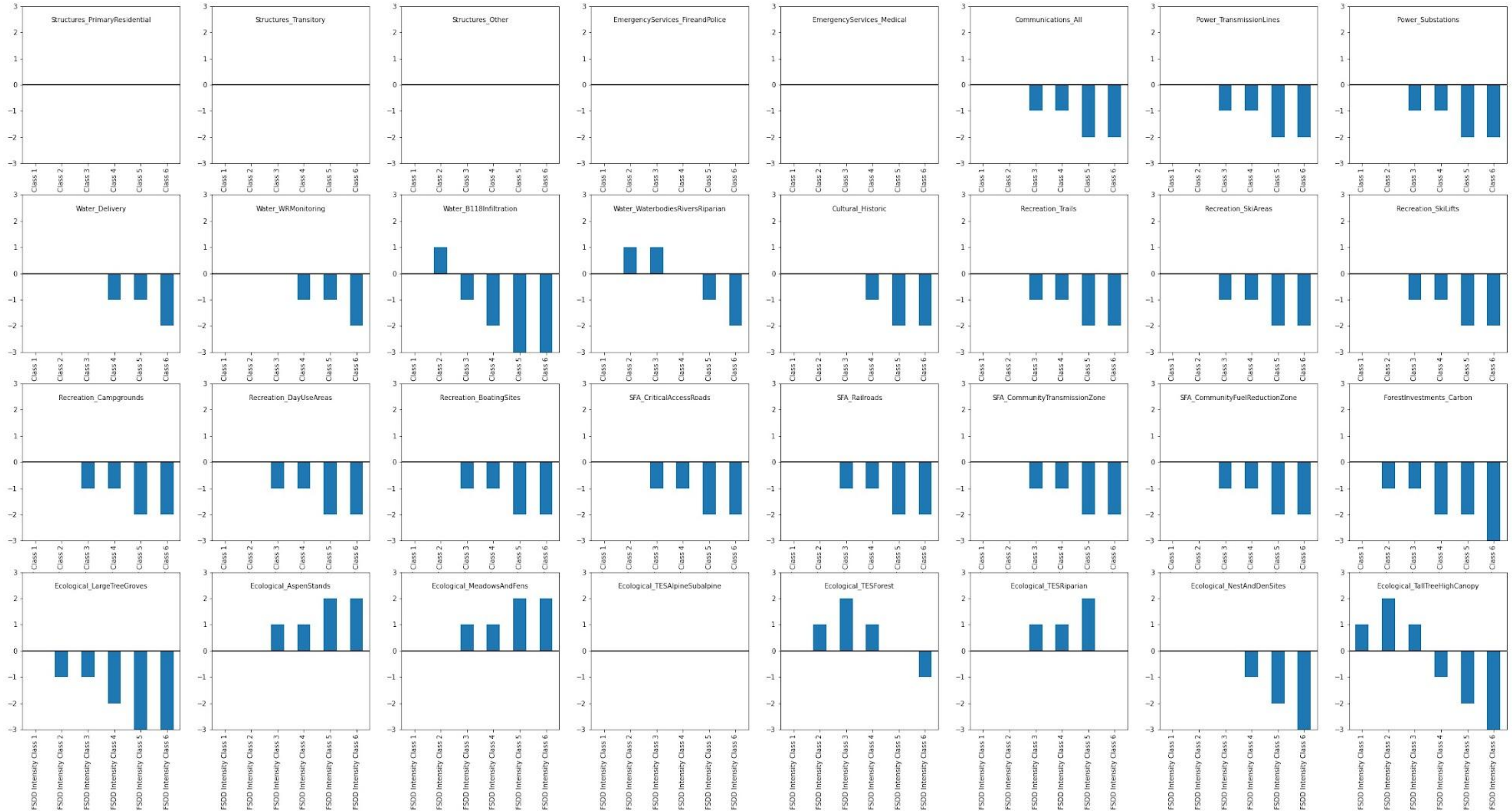
SARA Characterization: Response Functions

Figure 11. SARA Response to Disturbance Intensity: Drought (i.e. Forest Structure Dependent Disturbance, or "FSDD")



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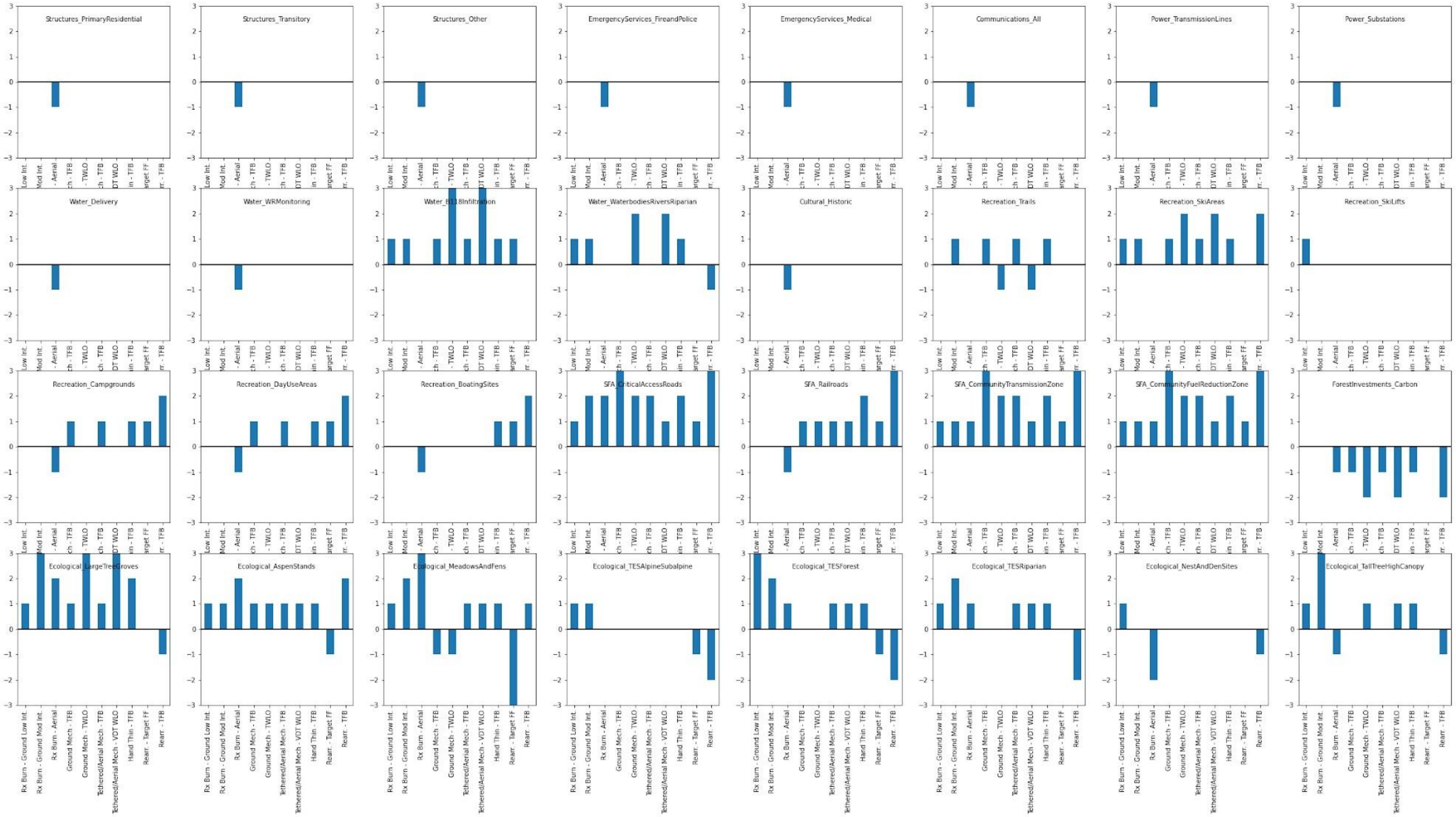
SARA Characterization: Response Functions

Figure 12. SARA Response to Treatment Type



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Resilience Pillars

Overview

Treatment priorities were organized by ten socio-ecological Resilience Pillars (herein referred to as the "10 Resilience Pillars"), which were developed as part of the Tahoe-Central Sierra Initiative (TCSI) framework for promoting socio-ecological resilience across forested landscapes in the Sierra Nevada (Manley et al., 2020; Sierra Nevada Conservancy, 2020). The 10 Resilience Pillars represent desired landscape outcomes for both social systems and ecological systems. For this study, the pillars were used to aggregate SARAs. Each SARA was grouped into the associated pillar if it contributed to resilience of desired landscape outcome for the associated pillar. This method of using the pillars to group SARAs rather than use the specific metrics as identified by Manley et al. (2020) was conducted for several reasons:

- SARAs provided flexibility to use data that managers are directly familiar with using.
- SARAs allowed managers to identify their important resources rather than rely on predefined metrics.
- While SARAs can have similarities between regions, the wildland interface resilience environment lacks a common language. The pillars are an excellent approach to bridge and package disparate values into a single framework for any landscape where disturbance affects socio-ecologic value.

Figure 13. The 10 TCSI Resilience Pillars (Sierra Nevada Conservancy, 2020)

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Resilience Pillars

Table 10. Description of the 10 Resilience Pillars

Resilience Pillar	Pillar Importance
Air Quality	Air quality is important for the health and resilience of social and ecological systems. Particulate matter, visibility, and greenhouse gases all influence air quality.
Biodiversity Conservation	Biodiversity conservation focuses on the diversity of native species and incorporates individual species, species diversity, and the health of the community. Biodiversity is essential for the persistence of individual species, suites of species, community interactions, and ecosystem functions.
Carbon Sequestration	Land management of forests, as well as other ecosystems such as meadows, are important for addressing carbon and climate policy goals. Resilient ecosystems contribute to greenhouse gas emissions reduction through carbon storage and carbon stability.
Economic Diversity	Community economic diversity is highly dependent on the creation and sustainability of long-term employment opportunities, in addition to the flexibility to adapt to changing social and ecological events. Natural resource-based economies include, but are not limited to: workforce needs and activities related to forest management, wood products, water, recreation, and disturbances (e.g. fire fighter).
Fire Adapted Communities	Fire adapted communities have an understanding and appreciation for the role of fire as a natural disturbance in ecosystems. These communities have reduced hazards associated with fire and smoke, have reduced vulnerability to fire (e.g. through defensible space), and have developed and disseminated a community response to fire (e.g. ingress and egress).
Fire Dynamics	Fire as a major disturbance agent is a key ecosystem process particularly for dry forests. Fire dynamics are influenced by the spatial and temporal variations in topography, climate, and fuel (including vegetation type). Functional outcomes can be evaluated by fire severity/intensity, fire frequency, and fire season which can identify if fire is functioning as desired (e.g. similar to historic fire regime).
Forest Resilience	When resilient forests experience disturbance (i.e. natural disturbances such as wildfire, or planned human disturbances such as thinning treatments), the structure and composition of the vegetation is within the desired range of conditions.
Social and Cultural well-being	Active cultural and social connections to resilient landscapes are facilitated by exposure to nature through recreational experiences, culturally valued resources, and engagement in land management and conservation.
Water Security	The quality, quantity, storage, and timing of hydrologic resources plays an important role and function for ecosystem health and resilience, terrestrial and aquatic biodiversity, and water resources management for anthropogenic purposes including municipal, agricultural, energy, and recreational uses.
Wetland Integrity	Structure, composition, and hydrologic function are key metrics for functioning meadow, riparian, and other wetland ecosystems. These ecosystems play an essential role in providing social-ecological benefits, such as water quality improvement, flood storage, erosion control, carbon sequestration, biodiversity, and recreational opportunities.

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SARA-Pillar Contributions

Aligning SARAs with Pillars: an objective framework

To estimate the relative association of each SARA to the pillar(s) it is related to, an objective framework was developed to estimate the SARA-pillar contributions as percentages of total value. Each SARA could contribute to as many as 10 pillars or as few as one pillar. The total SARA was distributed amongst the SARAs such that 100% of its value was redistributed to the pillars through its pillar contributions. Similar to the normalized appraisal process to calculate SARA ROSE, the SARA-pillar contributions were determined through a categorical characterization process through a series of questions and scored responses. After raw scores are assigned, they are relativized such that the total sum of pillar contributions is equal to 100%. There are several important definitions important to the use of the objective framework for estimating SARA-pillar contributions:

Strategic Areas vs Resources vs Assets

Strategic Areas: SARA is an area on the landscape identified/designated/planned to serve a particular purpose. Examples: strategic fireshed, strategic watershed

Resources: SARA is an ecological resources with social value. Examples: nest/den sites, meadows/fens

Assets: SARA is an item of property owned by a person or company. Examples: Structures, infrastructure

Discrete vs Assemblage

Discrete: SARA is an isolated unit. Other isolated individuals of the SARA are spatially interspersed and therefore are identified as separate SARA. Example: nest, individual tree, structure

Assemblage: SARA is made up of a collection of connected features. The features within the SARA are directly connected. [The SARA does not need to have a large footprint to be considered an assemblage.] Example: Large Tree Groves, Community Fire Transmissions

Anthropogenic vs Ecologic

Anthropogenic: SARA is a component of human communities; created/built by humans for human purposes. Examples: structures, any infrastructure, strategic fuel areas, plantations

Ecologic: SARA is a component of ecological communities; naturally-occurring. Examples: nest/den sites, habitat areas.

Active vs Passive

Active: SARA is directly related to (i.e. directly impacts or is directly impacted by) the pillar definition/outcomes. [One way to think about this is, can the SARA be used to actively fight fire or was the SARA developed to actively fight fire]. Example: strategic fuel areas are directly related to (i.e. actively influences) fire dynamics, and would hence be considered as “active” contributors to that pillar.

Passive: SARA is indirectly related to the pillar definition/outcomes. Example: residential structures are indirectly related to (i.e. passively influences and is passively influenced by) fire dynamics, and would hence be considered as “passive” contributors to that pillar.

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SARA-Pillar Contributions

Aligning SARAs with Pillars: an objective framework

Table 11. Resilience Pillars and questions applied for determining the SARA-pillar contribution scores

Resilience Pillar	Question for SARA characterization	Scoring
Forest Resilience	Is this SARA associated with the persistence of forest vegetation (includes structure, composition, distribution, species diversity associated with ecosystem)?	No: 0 Yes, the SARA is an anthropogenic resource (e.g. plantations): 0.5 Yes, the SARA is an ecological resource: 1
Fire Dynamics	Does this SARA contribute to how fire burns on the landscape (e.g. does the SARA influence severity, frequency, spread across the landscape)?	No: 0 Yes, this SARA is discrete, and passively influences fire dynamics: 0.25 Yes, this SARA is discrete, and actively influences fire dynamics: 0.5 Yes, this SARA is an assemblage, and passively influences fire dynamics: 0.75 Yes, this SARA is an assemblage, and actively influence fire dynamics: 1
Carbon Sequestration	Does this SARA influence carbon storage on the landscape?	No or insignificant: 0 Yes, this SARA contributes to carbon storage in harvested wood products (e.g. plantations): 0.5 Yes, this SARA contributes to longer-term carbon storage on the landscape: 1 Yes, this is a carbon specific SARA: 1.25
Wetland Integrity	Is this SARA related to wetlands, and if so, how?	No: 0 SARA is of a species that is associated with a meadow, riparian, or other wetland system: 0.5 SARA is a meadow, riparian, or other wetland ecosystem: 1
Biodiversity Conservation	Does this SARA contribute to biodiversity (e.g. individual species identified as SARA, individual ecosystems important for biodiversity)?	No: 0 Yes: 1

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SARA-Pillar Contributions

Aligning SARAs with Pillars: an objective framework (cont'd)

Table 11. Resilience Pillars and questions applied for determining the SARA-pillar contribution scores

Resilience Pillar	Question for SARA characterization	Scoring
Water Security	Does this SARA influence/ or monitor hydrologic dynamics on the landscape (e.g. does the SARA influence quality, quantity, or storage of water)?	No: 0 Yes, SARA monitors hydrologic dynamics (i.e. anthropogenic asset such as water monitoring infrastructure): 0.25 Yes, SARA influences hydrologic dynamics and is also identified as contributing to wetland integrity: 0.5 Yes, SARA is an anthropogenic asset that influences hydrologic dynamics (e.g. water infrastructure): 0.75 Yes, SARA does contribute to hydrologic dynamics and does not contribute to wetland integrity and is not an anthropogenic asset: 1
Air Quality	Does this SARA contribute to air quality or greenhouse gases (GHG)?	No: 0 Yes, this SARA actively contribute to the fire dynamics pillar (reduced fire emissions improves air quality – values 0.5 or 1): 0.5 Yes, this SARA contributes to the carbon pillar (a reduction in GHG increases air quality): 0.5 Yes, this SARA does contribute to air quality and does not contribute to fire dynamics or GHG: 1
Fire Adapted Communities	Is the SARA an anthropogenic asset?	No: 0 Yes, discrete anthropogenic asset: 0.5 Yes, anthropogenic assemblage: 1
Economic Diversity	Does the SARA contribute directly to economic diversity (e.g. jobs are created as part of the SARA – recreation, wood products, infrastructure positions)?	No: 0 Yes: 1
Social and Cultural well-being	Does this SARA provide a cultural or social connection to the landscape?	No: 0 Yes, this SARA is an ecological SARA that people are connected to: 0.5 Yes, this SARA is a cultural resource: 1 Yes, this SARA provides direct connection the landscape through recreation opportunities: 1

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SARA-Pillar Contributions

Below are examples of SARA-pillar contribution results. The full tables of results (both raw scores and final pillar contributions) can be found in the Appendix.

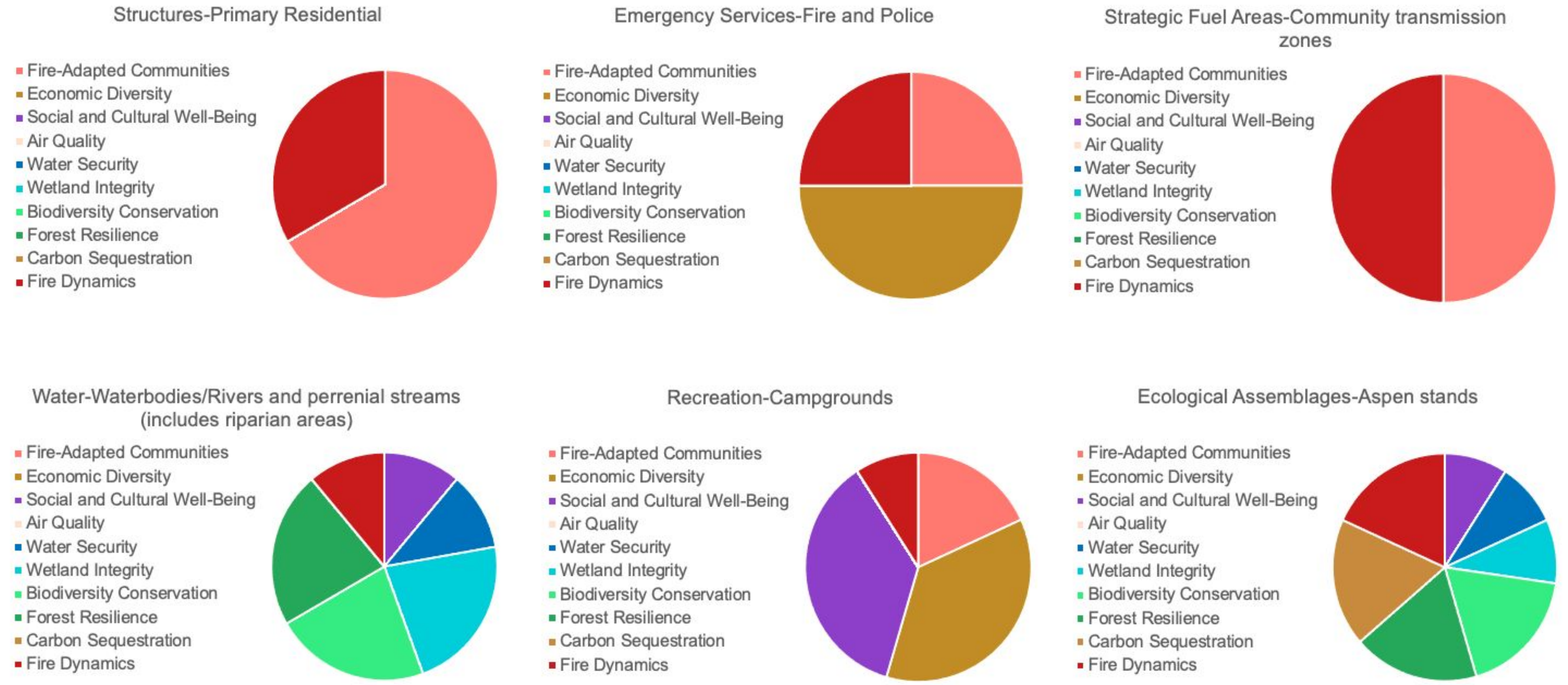

Figure 14. Examples of contributions of SARAs to each of the 10 Resilience Pillars

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Estimating landscape departure

Overview

Natural range of variability (NRV) and historical range of variability (HRV) can be used by managers to bring insights from historical ecology to resource management (Hayward et al. 2012). NRV was defined by Landres et al. (1999) as "the ecological conditions, and the spatial and temporal variation in these conditions, that are relatively unaffected by people, within a period of time and geographical area appropriate to an expressed goal." As Morgan et al. (1994) put it, "The concept of (NRV) provides a window for understanding the set of conditions and processes that sustained ecosystems prior to their recent alterations by humans."

Historical range of variation was developed to allow the explicit incorporation of human influences on ecosystems into the analysis since humans have been major ecological players for millennia. HRV was defined by Wiens et al. (2012) as "the variation of ecological characteristics and processes over scales of time and space that are appropriate for a given management application." When applying NRV/HRV concepts it requires consideration of the ecosystems of interest, the spatial and temporal scales of analysis, the ecological indicators to be assessed, whether to include human influences, whether to use only historical information or to use contemporary reference conditions (CRC) and modeling as well, and so on (Morgan et al. 1994, Landres et al. 1999, Wiens et al. 2012). For the MTRW landscape, HRV and CRC concepts were used to characterize biophysical conditions and quantify departure metrics, which were used in other steps of this analysis.

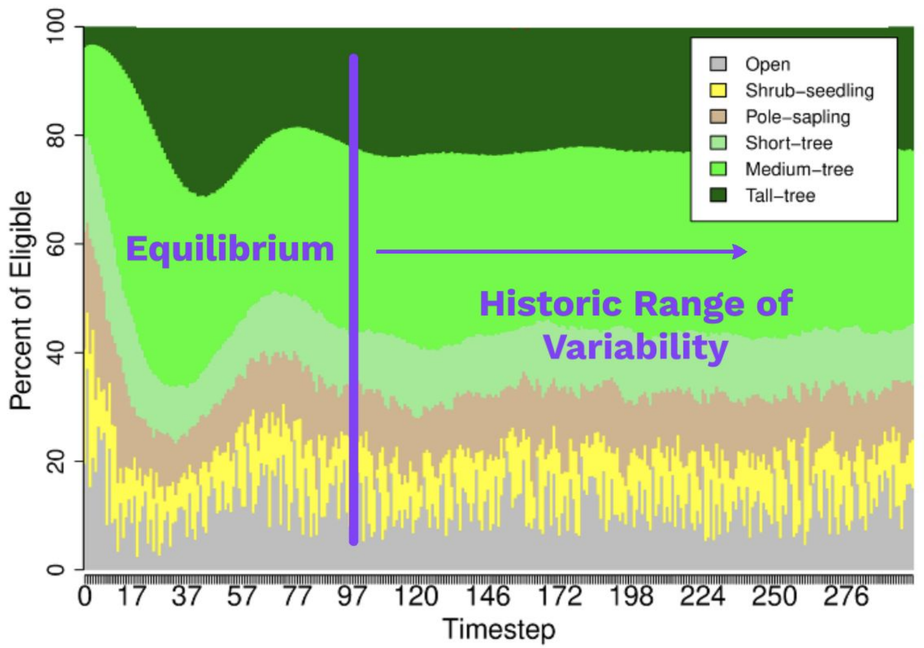

Figure 15. Example depiction of historic range of variability modeling, showing the composition of developmental stage for a single cover type on a landscape. (Figure provided by Kevin McGarigal). In this example, years 0-97 of the model are used as a "spin-up" period to allow the model to reach a stable state ("equilibrium", shown as the vertical bar); historical range of variability is assessed for the time period after the model has reached equilibrium. This allows for assessment of what the range of variability in various vegetation metrics (such as quadratic mean diameter, developmental stage, etc) may have been pre-European settlement and forest management.

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Historical Range of Variability (HRV)

HRV was quantified using output from the Landscape Disturbance-Succession Simulator (LDSim) which was developed by McGarigal based on the RMLands framework (McGarigal and Romme 2012). LDSim models disturbance and succession under historical reference period conditions (~1550-1850). Disturbance causes a modification of vegetation attributes depending on fire and succession influences the establishment, growth and senescence of vegetation over time. LDSim ensures spatial consistency with the project landscape. HRV was determined during equilibrium (500 year initial model period). The MTRW landscape was modeled using LDSim at a 5 m^2 gridcell resolution, with a 5 km modeling buffer used to minimize edge effect (McGarigal et al. 2021). Spatial gridded datasets developed as model inputs include: aspect, elevation, streams, topographic position index, mesic index, heat load index, cover, age (i.e. vegetation age), site index, tau index, vegetation state, and vegetation state age.

The disturbance and succession processes in LDSim have user defined parameters that make the application scenario-specific in relation to the underlying assumptions. Both wildfire and succession were parameterized in the model. Wildfire was parameterized using a combination of external data as well as LDSim derived data, external data included both spatial and non-spatial data. Wildfire parameters included: wildfire climate, susceptibility, initiation, spread, termination, mortality, and disturbance transitions. Succession included a climate index coefficient that was assigned at each time step to identify the probability of tree regeneration which was based on 5-year average Palmer Modified Drought Severity Index. Succession parameters included: succession climate and succession transitions. The succession transitions were modeled separately for shrublands and forests, all other cover types were non-seral and thus consisted of a single state that remained constant over time.

- For shrubland succession transition immediately following fire, shrublands transitioned into early-shrub, secondary and late succession based on a logistic function of developmental stage age and site index. Once in late-shrub the cell would remain in that stage indefinitely until a high-mortality event.
- For forests, succession was modeled with consideration of 6 "metrics" (tree establishment, quadratic mean diameter, tree growth height, tree cover, tree diameter growth, and senescence) based on the cumulative Weibull function based on breast height age and probability of mortality.

The MTRW LDSim model was calibrated to make sure that selected outcomes were consistent with data, literature, and expert opinion. Disturbance process parameters were considered independent variables and were calibrated to achieve the targeted disturbance regime while the vegetation conditions were dependent outcomes and were not calibrated. The five disturbance regime metrics that were used in calibration included: fire rotation period, fire mortality rate, fire size distribution, variability in total area burned, and relationship between total area burned and climate.

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Contemporary Reference Conditions (CRC)

CRC was quantified using data from TCSI (Wilson and Manley 2021), specifically using the contemporary range of tree density, which was then translated into an index for incorporation into departure. This data evaluated forest structure metric departure against areas that are considered contemporary reference conditions. The idea is that these areas have experienced current climate pressures and are therefore representative of what the natural range of variability is under current climate. A brief summary of the methodology used to generate CRC basal area departure can be found in the Appendix, with further detail in Wilson and Manley (2021). It should be noted that CRC departure for the TCSI landscape was not available for the entire MTRW landscape (i.e. the eastern portion of the MTRW that is outside the TCSI landscape). See slide 39 for information on how CRC basal area departure was incorporated for this landscape.

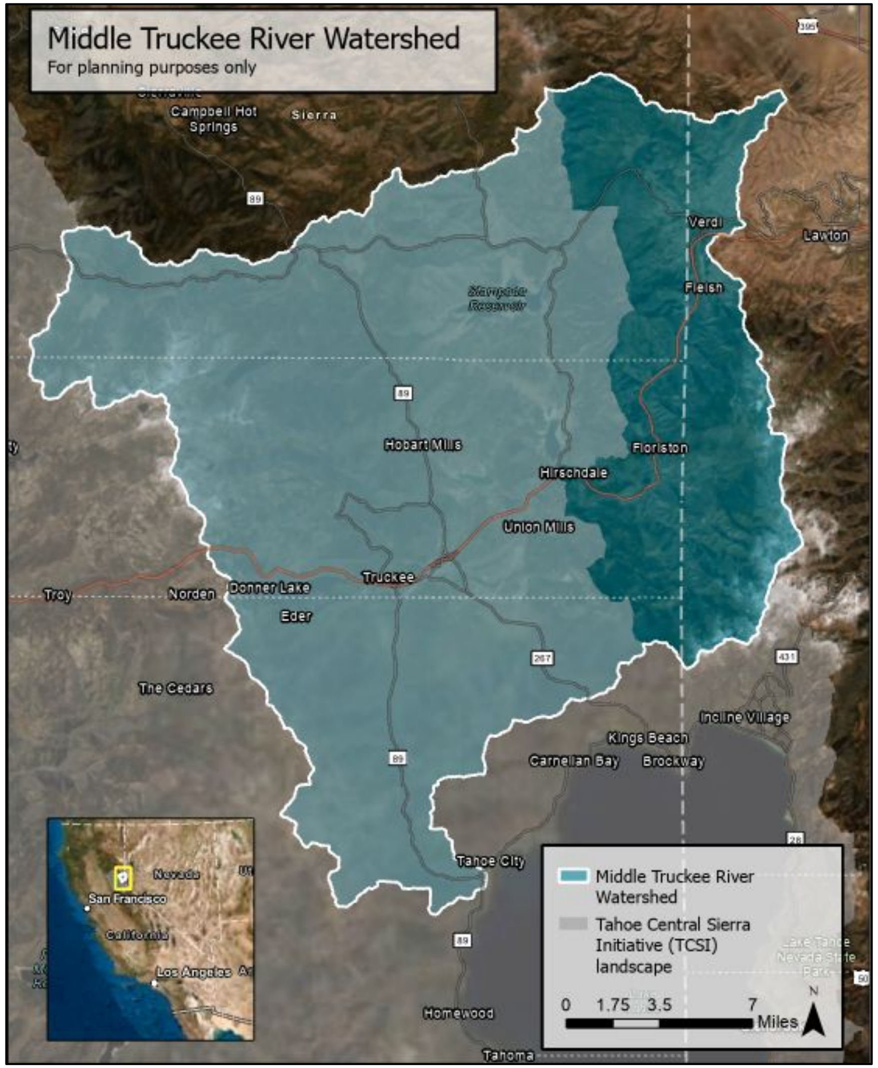

Figure 16. Overview map of Middle Truckee River Watershed, showing the overlap with the TCSI landscape.

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HRV-informed Biophysical Units

To aid in the summary of Historical Range of Variability (HRV) and current departure in landscape structure, as well as for the landscape segmentation process (further detail in "Section II: Stewardship Atlas"), the landscape was subdivided into a set of Biophysical Classes (BPCs). BPCs serve as a means of "packaging" the results in a manner that would be most relevant to management at both the "stand" and subasin levels and would best discriminate differences in the landscape metrics. A parsimonious suite of BPCs was selected, such that the suite is composed of the fewest number of BPCs that would best characterize meaningful differences in the landscape metrics. BPCs were then vectorized to create Biophysical Units (BPUs), which are areas of contiguous BPC on the landscape. After consideration of many alternative approaches, the **methodology described in the Appendix** was applied. The figure to the right shows BPC mapped on the MTRW landscape.

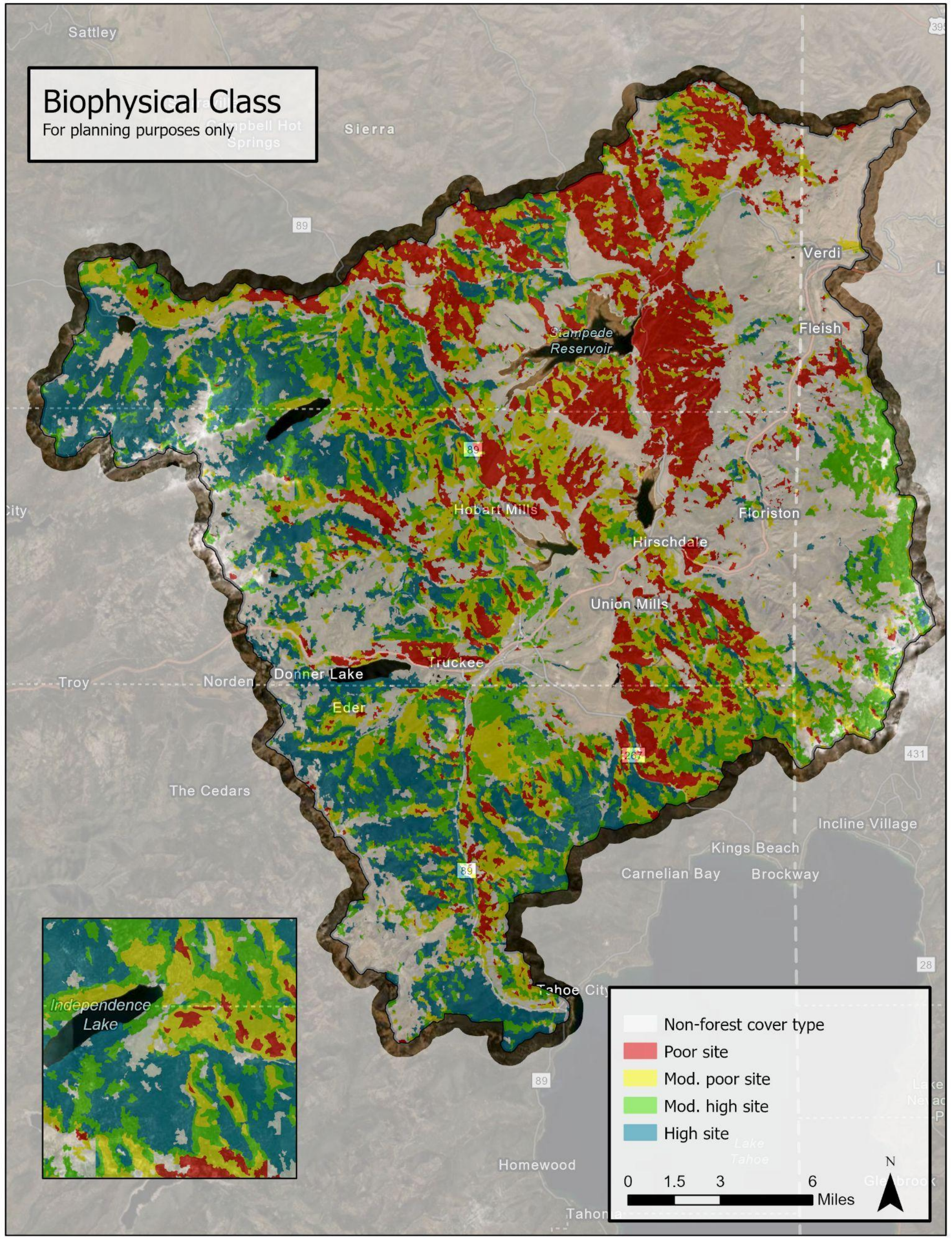

Figure 17. Mapped biophysical class for the MTRW landscape

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HRV-informed fire return interval departure

The Fire Return Interval Departure (FRID) metric quantifies the extent (in percent) to which contemporary fires (1909-present) are burning at frequencies similar to simulated HRV frequencies at a 5 meter gridcell resolution (McGarigal et al. 2021). The greater the HRV-FRID, the greater the departure from historic conditions, indicating that the landscape is burning less frequently than historic conditions.

As described further in “Section IV. Restoration Opportunity Modeling,” HRV-FRID was the departure metric used to approximate ecologically-functional conditions. The mean HRV-FRID was summarized for each Stewardship Atlas unit (the Stewardship Atlas is described further in “Section II: Stewardship Atlas”), and quantiled into six classes for the MTRW landscape, with each class representing an intensity of fire return interval departure (FRID Intensity Class; FIC). **The resulting mapped FRID Intensity Class is shown in “Section III. Existing Conditions.”**

For the purposes of assessing SARA current value and the potential impact of treatments (described further with examples in “Section IV. Restoration Opportunity Modeling”), the FIC were then related to ROSE factors (i.e. fraction of ROSE values) for application in the Restoration Abacus to estimate SARA current value.

Table 12. Quantiled HRV-FRID into six intensity classes; these classifications were related to a factor that was related to the ROSE, used to estimate SARA current value (see “Section IV. Restoration Opportunity Modeling” for further information).

FRID Intensity Class (FIC)	HRV-FRID range	ROSE factor
FRID Intensity Class 1	0-45	1
FRID Intensity Class 2	45-55	0.9
FRID Intensity Class 3	55-65	0.8
FRID Intensity Class 4	65-75	0.7
FRID Intensity Class 5	75-78	0.6
FRID Intensity Class 6	>78	0.5

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Composite forest structure departure index

A composite index representing forest structure departure from NRV was computed for the MTRW. The NRV is the spatial and temporal variation in the ecological conditions within an identified period of time and geographical area appropriate to an expressed goal/objective. For the MTRW, NRV departure was calculated using a composite of equally weighted combinations of metrics derived from the Historical Range of Variability (HRV-75%) and Contemporary Reference Conditions (CRC-25%). As noted previously, CRC departure was not available for the entire MTRW landscape (i.e. the area of the landscape falling outside the TCSI boundary). For these area, the composite departure metric was calculated using equal weights of the HRV departure metrics. Specific metrics used included:

- Tree Density (25%) calculated from basal areas departure (CRC)
- Tree Cover (25%) calculated from the coefficient of variation in tree cover (HRV)
- Tree Developmental Stage (25%) calculated from four equally weighted metrics (HRV): Percent open forest departure; Simpson's diversity of developmental stages; the coefficient of variation in open patch departure and in developmental stage patch size.
- Tree Size (25%) calculated from five equally weighted metrics (HRV): Simpson's diversity of tree size classes; percent large tree departure; coefficient of variation in quadratic mean diameter departure, large tree patch size departure, and patch size based on tree size departure.

This composite departure index was used to characterize the potential intensity of drought-related tree mortality disturbance, described further in “Section II: Disturbance Modeling.”

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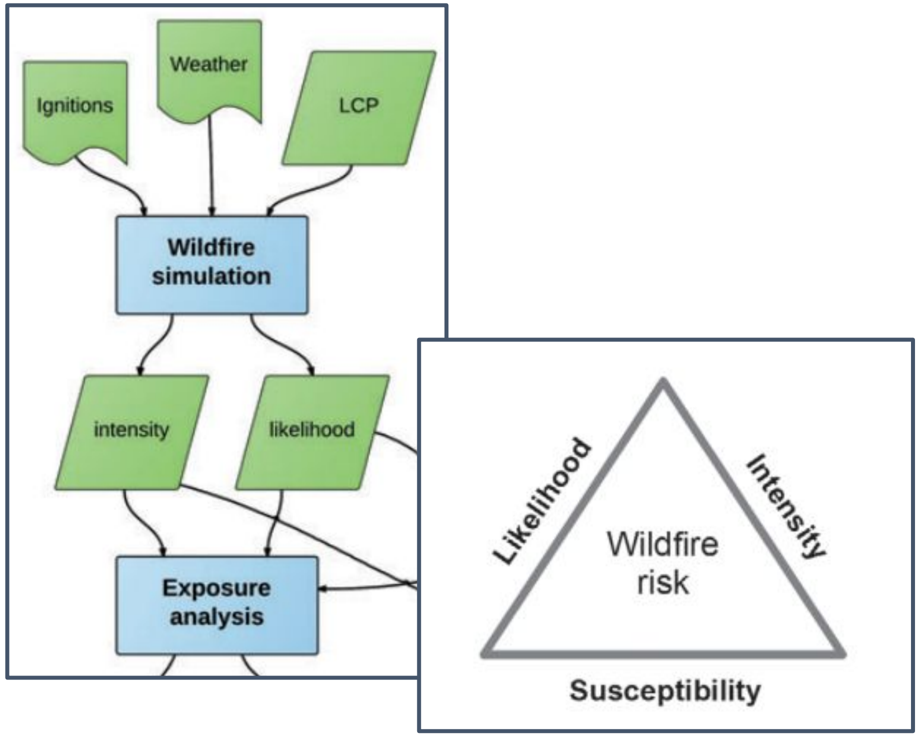
Disturbance Modeling

Overview

Disturbance information identifies where unplanned disturbances (i.e. wildfire, drought) are most likely to occur ("Disturbance probability") and how intense they're likely to be ("Current disturbance intensity"). Disturbance "hazard" is used to refer to the probabilistic intensity of disturbance (i.e. probability x intensity).

For the MTRW, both **wildfire** and **drought** hazard and their subcomponents were evaluated. These datasets were used to assess the risk posed to SARAs by disturbances, where "risk" refers to the probabilistic changes in value of SARAs when they are exposed to disturbance intensities of a given probabilities across the landscape, as defined in GTR-315 (Scott et al., 2013).



GTR-315 (Scott et al., 2013)

Figure 18. Figures from GTR-315 (Scott et al., 2013) showing how disturbance (wildfire, in this case) hazard can be characterized by intensity and probability, which can then be used to estimate risk.

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Disturbance Modeling

Wildfire Modeling: Overview

A wildfire hazard assessment involves modeling of both the probability of wildfire (burn probability) and the intensity at which wildfire is likely to burn (conditional flame length). A stochastic approach can be used to simulate a large number of fires across a given landscape to estimate these two metrics.

Input datasets for stochastic wildfire modeling include spatial data regarding:

- **Landscape:**
  - **Topography** (elevation, slope, aspect)
  - **Vegetation and fuels** (canopy cover (aerial fuels), stand height (aerial fuels), canopy bulk density (aerial fuels), canopy base height (ladder fuels), surface fuel model (surface fuels))
- **Weather conditions** (wind speed, wind direction, fuel moisture content)
- **Ignitions**

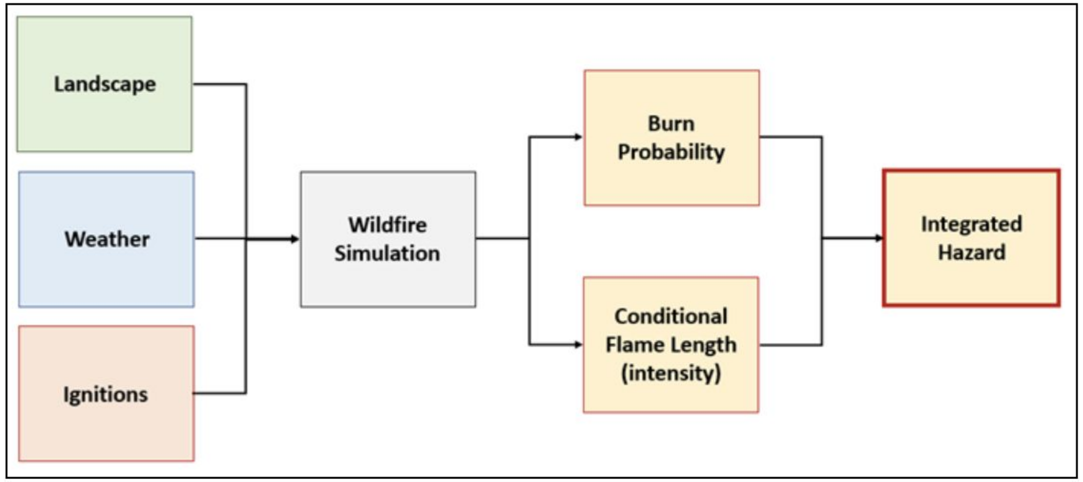

Figure 19. Depiction of the wildfire burn probability modeling framework (figure from the Interagency Fuel Treatment Decision Support System)

For this analysis, the Interagency Fuel Treatment Decision Support System (IFTDSS) was used to conduct wildfire hazard modeling. IFTDSS is a web-based application designed to make fuels treatment planning and analysis more efficient and effective. IFTDSS provides access to models and input LANDFIRE data through a simple user interface. It is available to all interested users, regardless of agency or organizational affiliation. IFTDSS is designed to address the planning needs of users with a variety of skills, backgrounds, and needs. A simple and intuitive interface provides the ability to model fire behavior across an area of interest under several weather conditions and to easily generate downloadable maps, graphs, and tables of model results. It can be used at a variety of scales from local to landscape level (US Department of Interior, 2020).

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Disturbance Modeling

Wildfire Modeling: Minimum Travel Time model

The model used for this analysis was Minimum Travel Time (MTT) through IFTDSS. The Minimum Travel Time (MTT) is a spatially-dependent model that "computes fire growth between the cell corners, holding all environmental conditions constant in time (Finney, 2006; Stratton, 2009). It can be run deterministically (single simulation) or stochastically (multiple simulations). Fire growth is computed under the same assumptions as FlamMap Basic fire behavior. When run stochastically, it also enables end-users to create all the necessary results and files from multiple ignition simulations (burn probabilities, fire perimeters, flame length probabilities, fire size list). MTT results can be used both for fuel management planning and for single event fire propagation (spread and intensity)" (Kalabokidis, et al., 2013). For MTRW, MTT was used to generate the burn probability and conditional flame length (i.e., intensity) datasets.

When run stochastically, MTT is referred to as "Landscape Burn Probability" in IFTDSS. Across all simulations, all inputs are held constant except the location of the ignition; in other words, each simulation begins with the same starting conditions, and a wildfire is simulated as starting in a different location on the landscape. A three-mile buffer area was applied around the MTRW landscape to address potential edge bias effects in the fire modeling.

Model outputs used in this analysis include:

- **Conditional flame length**: estimate of the mean flame length for all the fires that burn a given point on the landscape across all simulations. (See IFTDSS page for further description of calculations.)
- **Burn probability:** likelihood of a given location within the landscape burning across all simulations. (See IFTDSS page for further description of calculations.) Used to represent the probability of wildfire at a given location within a fire season (i.e. 1-year probability).

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Disturbance Modeling

Wildfire Modeling: Model landscape inputs

The following datasets were used and created through IFTDSS as inputs for MTT. LANDFIRE 2016 was assessed initially, and ground truthed at strategic locations. Ground truthing identified several locations with a mis-classification of some fuel inputs. Therefore, LANDFIRE 2014 was used as it better represented fuel types and conditions on the landscape. Because of the time elapsed since 2014 to the date of this analysis, it was necessary to update the surface fuel model based on where management efforts have occurred since 2014 (further information below).

- **Topography** (elevation, slope, aspect)
  - Used LANDFIRE 2014

- **Vegetation and fuels** (canopy cover (aerial fuels), stand height (aerial fuels), canopy bulk density (aerial fuels), canopy base height (ladder fuels), surface fuel model (surface fuels))
  - Used LANDFIRE 2014 and then performed updates using:
    - USFS Forest Activity Tracking System (FACTS) Timber Harvest
    - USFS FACTS Hazard Fuel Treatments
    - CALFIRE Timber Harvest Plans
  - Areas that had been affected by forest activity during the period of time since LANDFIRE 2014 (i.e any areas with a completion date after 2014) were **updated using the relationships shown in the Appendix**. Note that the most recent completion dates were during 2019.

- **Ignitions** (location)
  - Generated internally by IFTDSS; random ignition pattern. See IFTDSS page for further detail. Note: although it is understood that there may be more likely ignition locations, particularly near Interstate 80, biasing ignitions may mute impacts of large fires that could ignite randomly from lightning in less human impacted areas of the watershed.

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Disturbance Modeling

Wildfire Modeling: Model forcing inputs

The following datasets were used and created through IFTDSS as inputs for MTT.

- **Ignitions** (location)
  - Generated internally by IFTDSS; **69,418 random ignitions**. See IFTDSS page for further detail.
- **Weather conditions** (wind speed, wind direction, fuel moisture content)
  - For this analysis, we used 97th percentile historical fire weather to analyze fire behavior under extreme weather conditions. Percentiles are based on a scale of 0 to 100 and are used to sort and rank a collection of data. For wildfire, when values at the upper end of the scale occur, complex fires are expected, where initial attack may often fail. The **97th percentile weather is often termed, "the *most likely* worst-case scenario"** (US Department of Interior, 2020).
  - IFTDSS uses data from the nearest Remote Automatic Weather station (RAWS) representing 97th percentile fire weather conditions and resulting conditions was used to determine weather conditions during the stochastic simulations. The same weather conditions were used across all simulations. Weather conditions forcing data used for the MTRW simulations are shown to the right.
  - See IFTDSS page for further detail information on foliar fuel moistures.

Table 13. Description of weather station and associated data used for the MTRW wildfire modeling in IFTDSS

RAWS Station	
Name	STAMPEDE
Period of recorded observations	3/31/2006 - 10/4/2016
Location (latitude, longitude)	39.471094, 120.086975
Elevation	6,207 ft
Aspect	6 deg
97th percentile Wind	
Speed	14 mph
Direction	180 deg
97th percentile Fuel Moisture Content	
1-hour fuel moisture	2%
10-hour fuel moisture	3%
100-hour fuel moisture	6%
Live herbaceous fuel moisture	90%
Live woody fuel moisture	112%

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Disturbance Modeling

Wildfire Modeling: Model simulation parameterization

MTT is also parameterized through IFTDSS using several user-defined inputs related to spotting, crown fire simulation methods, and run time. Below are the inputs that were used to parameterize MTT for the MTRW burn probability modeling. These parameters are described in further detail on this IFDSS page.

Table 14. Description of model parameters applied for the MTRW wildfire modeling in IFTDSS

Fuel moisture conditioning	
Conditioning	On - Extreme - Northern Sierra Nevada
Conditioning Start-End	8/11/2012 13:00 - 8/17/2012 15:00
Crown fire method	
Crown fire method	Scott/Reinhardt
Foliar moisture content	100%
Wind	
Type	Gridded
Spotting	
Probability	20%
Simulation	
Duration	12 hours
Resolution	60 m

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Disturbance Modeling

Wildfire Modeling: Wildfire Intensity Class

To assess the effects of wildfire hazard (wildfire probability and intensity) on SARAs, the output conditional flame length raster was classified into six fire intensity classes (see table below) for the purposes of application with the SARA disturbance response functions. Use of the burn probability and fire intensity class datasets in this analysis is further described in "Section IV. Restoration Opportunity Modeling."

Table 15. Intensity classes associated with conditional flame lengths, with description of effects.

Fire Intensity Class	Conditional Flame Length Range	Category Effects on Natural Vegetation
Fire Intensity Class 1	<2 Feet (non-zero)	Scorch height 5-20'; typically, low severity; ground/surface fire in low fuel load and/or mild conditions. Fire burns surface fuels, small shrubs or seedlings.
Fire Intensity Class 2	2-4 Feet	Scorch height 10-40'; typically, low-to-moderate severity; ground/surface fire, moderate fuel load and/or moderate conditions. Fire burns surface fuels, shrubs and smaller trees.
Fire Intensity Class 3	4-6 Feet	Scorch height 20-60'; typically, moderate severity; ground/surface fire in moderate fuel and moderate-to-severe conditions. Fire burns surface fuels, shrubs and smaller trees, as well as individual mature trees.
Fire Intensity Class 4	6-8 Feet	Scorch height 30-80'; typically, moderate-to-high severity; some ground/surface fire transitioning to canopy fire in moderate-to-heavy fuel and moderate-to-severe conditions. Fire burns surface fuels, shrubs and smaller trees, and some smaller clumps of mature trees.
Fire Intensity Class 5	8-12 Feet	Scorch height 50-100'; typically, high severity; some ground/surface fire transitioning to canopy fire in moderate-to-heavy fuel load and moderate-to-severe conditions. Fire burns very hot, killing larger clumps of mature trees as well as consuming under-story and surface fuels.
Fire Intensity Class 6	> 12 Feet	Scorch height exceeds tree height; high severity; crown/canopy fire in heavy fuel in moderate-to-severe conditions. Fire burns very hot, killing nearly all mature trees in a wider area, as well as consuming under-story and surface fuels.

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Disturbance Modeling

Drought (i.e. Forest-Structure Density Dependent Disturbance, "FSDD"): Overview

Drought was included as a disturbance to be assessed for the MTRW landscape. Because it is not possible to model drought stochastically in the same way that wildfire can be modeled, it was necessary to develop proxies for the same model output layers as the wildfire modeling in order to assess the impact of drought on SARAs (and impact of treatment on changing drought risk to SARAs) within the same framework as wildfire as a disturbance (i.e. probability and intensity). **Here, drought refers more so to drought-related forest mortality due to insects and other agents (a forest-structure density dependent disturbance, or "FSDD")**; when trees are more water-stressed during drought conditions, they are more susceptible to insects and disease. One of the primary drivers related to whether forests will experience mortality during a drought is related to the stand structure; stands that are more homogenous and dense tend to experience higher rates of mortality than stands that are of lower densities and heterogenous in their vegetation age, structure, and species composition. Throughout this analysis and document, "drought" and "FSDD" are used interchangeably.

Drought as a disturbance was assessed for the MTRW landscape by producing an annual drought vulnerability spatial layer (as a proxy for annual probability) and by using the mapped composite forest structure departure metric (NRV, derived from HRV modeling; previously described in "Section II. Landscape Assessment Methods: Departure Modeling") as a proxy for the spatial variability in intensity at which a drought-driven forest mortality event would occur.

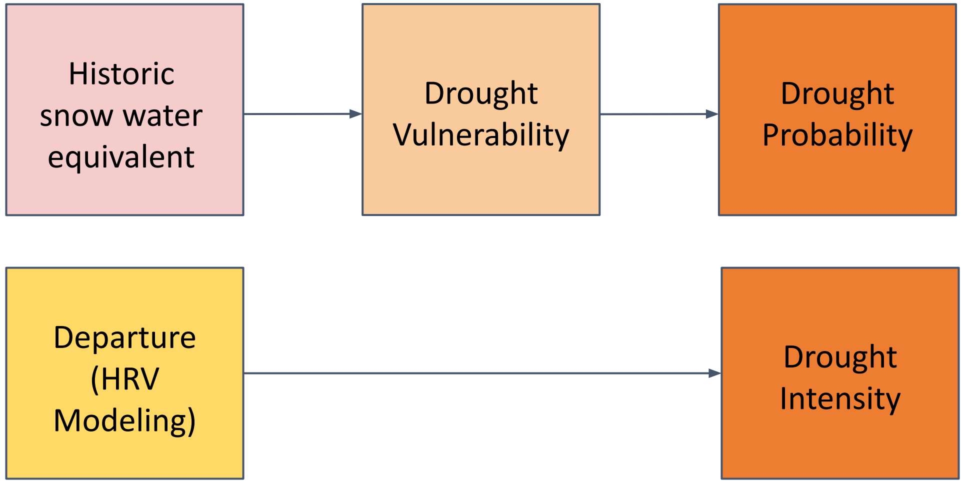

Figure 20. Overview of process used to develop drought hazard metrics (probability and intensity)

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Disturbance Modeling

Drought (i.e. Forest-Structure Density Dependent Disturbance, "FSDD"): Drought vulnerability

Because the MTRW is a snowmelt-driven watershed and ecosystem, drought vulnerability was assessed for the MTRW landscape by using snow water equivalent (SWE) as drought vulnerability indicator. SWE is a measure of the amount of water stored in the snowpack as a depth of liquid water; in other words, SWE is the depth of water in the snowpack if it were melted. Annual SWE deficit can be a good indicator of snow-drought conditions within a snowmelt dominated system that is dependent upon that snowmelt for its soil water during the growing season (NIDIS, 2021), and helps to identify areas where tree roots may not be able to draw sufficient water from the ground to meet evaporative demand and, therefore, are most susceptible to drought-stress and FSDD.More information about snow drought can be found here.

To estimate drought vulnerability, the percent difference from average historic (time period used 1981 to 2010) to the 2014 water year (Oct 2013 to Sept 2014). This year was selected because the 2012-2016 California drought was arguably the most severe of the last millennium (Griffin and Anchukaitis 2014, Mann and Gleick 2015). The drought occurred due to low precipitation combined with record high temperatures (Griffin and Anchukaitis 2014).

The output raster (4 km gridcell resolution) generated using TerraClimate (see right for further information) reflected a percent difference, with areas of greater percent difference as more vulnerable to drought conditions.

For this analysis, the Climate Engine Application was used. The Climate Engine Application enables users to quickly process and visualize satellite earth observations and gridded weather data. We specifically used TerraClimate. TerraClimate combines high-spatial resolution climatological normals from WorldClim with coarser spatial data that have greater temporal information (Abatzoglou et al. 2018). This data source provides annual averages from 1958-present, and the stability of input stations was prioritized in the development of the Climatic Research Unit gridded Time Series (CRU TS) products, and therefore errors due to spurious trends from data collection are reduced.

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Disturbance Modeling

Drought (i.e. Forest-Structure Density Dependent Disturbance, "FSDD"): Drought probability

To account for the combination of assessing risk of both wildfire and drought disturbances to SARAs, it was necessary to rescale the drought vulnerability raster to the same range as the annual burn probability raster (smaller range of value) so as to not over-influence the drought disturbance in the risk assessment modeling. Hence, a range re-scaled drought vulnerability raster was generated and applied as a proxy for annual drought probability for further use in this analysis.

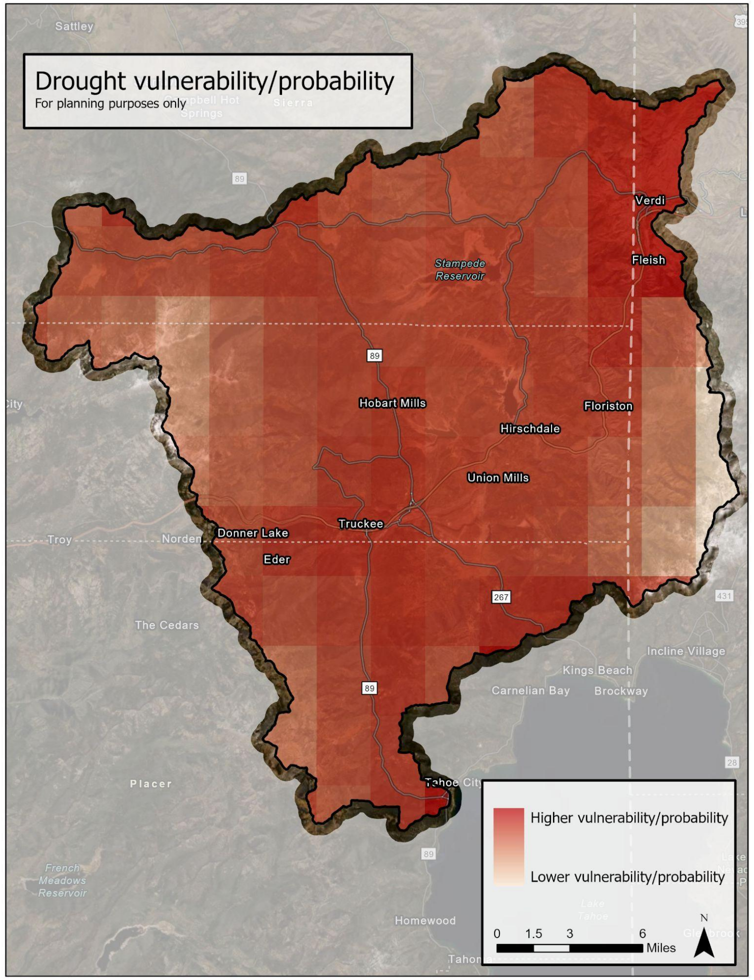

Figure 21. Drought vulnerability (used as probability) developed for the MTRW landscape

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Disturbance Modeling

Drought (i.e. Forest-Structure Density Dependent Disturbance, "FSDD"): Drought Intensity Class

The composite departure index served as a proxy for the intensity of disturbance from drought/FSDD. As described previously in "Section II. Landscape Assessment Methods: Departure Modeling," this represents the vegetation departure from NRV with regards to tree density, tree cover, developmental stage, and tree size. To assess the effects of drought hazard (drought probability and intensity) on SARAs, the composite forest structure departure metric calculated for each Stewardship Atlas unit (for more information on the Stewardship Atlas, see "Section II. Landscape Assessment Methods: Stewardship Atlas") was rasterized and quantiled into six classes (see table below) for the purposes of application with the SARA response functions. Use of the drought probability and intensity class datasets in this analysis is further described in "Section IV. Restoration Opportunity Modeling."

Table 16. Intensity classes associated with NRV Departure Range (used as a proxy for intensity of drought-mortality), with description of effects.

Drought Intensity Class	NRV Departure Range	Category Definitions
Drought Intensity Class 1	0 - 3.25	Area is well within NRV and should be the most resilient to disturbance with natural amounts of dominant tree mortality when an event does occur: < 10%
Drought Intensity Class 2	3.25 - 6	Area is slightly deviated from NRV and although it should be able to withstand most density dependant disturbances with only small amounts of dominant tree mortality when an event occurs: 10 - 25%
Drought Intensity Class 3	6 - 9.4	Area is moderately deviated from NRV and may be departed by one or more indices. A density dependant disturbance event may create moderate amounts of dominant tree mortality: 25% - 35%
Drought Intensity Class 4	9.4 - 13.5	Area is deviated from NRV and is most likely departed significantly by one indice or moderately departed by multiple indices. A density dependant disturbance event may create moderate amounts of dominant tree mortality: 35% - 45%
Drought Intensity Class 5	13.5 - 20.1	Area is considerably deviated from NRV and is mostly likely considerably departed by many indices. A density dependant disturbance may create considerable amounts of dominant tree mortality: 45% - 55%
Drought Intensity Class 6	> 20.1	Area is significantly departed from NRV and is most likely significantly departed by many indices that exposes the area to a wide range of density dependant disturbances that could lead to the loss of the majority of a single or multiple dominant tree species: 55% - 65%

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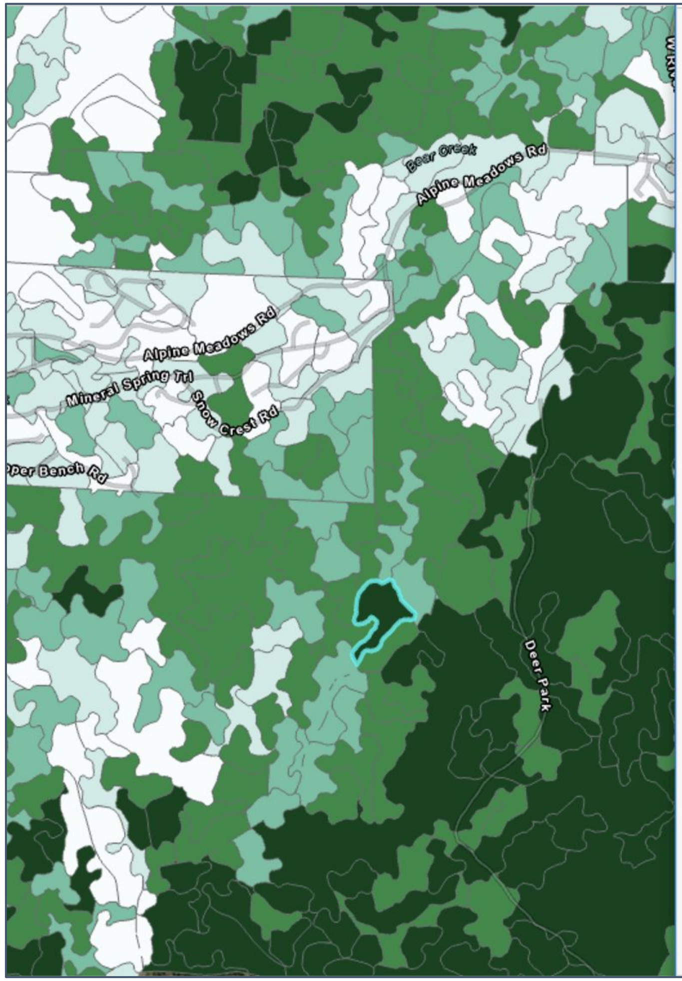
Stewardship Atlas

Overview

The Stewardship Atlas provides a comprehensive set of landscape segments that serve as an ecological-based package for summarizing landscape metrics. Additionally, it feeds the scenario construction and tradeoff analysis that were completed as a part of the project development and sequencing. The Stewardship Atlas is composed of polygons that are relatively homogenous in terms of their horizontal and vertical vegetation structure, slope, biophysical class, and ownership class. These Stewardship Atlas units can be associated with attributes such as treatment types, forest structure metrics (i.e. average canopy height, tree diameter, ladder fuels), disturbance and forest health metrics (i.e. vegetation departure, fire hazard, drought hazard, etc), and descriptive/topographic attributes (i.e. average slope, ownership) by summarizing both raster and vector information at that segment level. The Stewardship Atlas units are further populated with a likely treatment type using an objective ruleset; these mapped treatments are then used to assess the impacts of potential treatments across the landscape.



Unit_ID	780
Easting	-18021.601433
Northing	128614.617528
Ownership	USFS
Acres	7.703392
Avg_Slope	48.49839
BPU	4
Can_Cov	48.048309
CC2_8	15.824476
CC8_16	19.685184
CC16_32	27.194847
CC32None	2.073269
CH_Mean_M	12.531157
QMD	20.839777
per_NWA	0
per_water	0
per_dev	0
per_dSARA	0
per_PAC	0
per_SCFS	0
per_wdef	0
Ini_Trt	Tethered/Aerial Mechanized - Thin from below
Fol_Prep	
Fol_Trt	Rx Burn - Ground, Moderate Intensity
Ini_Trt_p	65
Fol_Prep_p	0
Fol_Trt_p	50
pSawMBF	568.7812
pTotMBF_ac	73.835167
Est_Remova	56.87812

Figure 22. Example of attributes for a selected (blue outline) Stewardship Atlas unit. Here, the Stewardship Atlas has been symbolized by QMD.

The full MTRW Stewardship Atlas Product Guide describes all attributes and calculations in detail and can be found here. Information on the segmentation process and treatment assignment logic can be found in the following sections in this document. A subset of the Stewardship Atlas and product guide can also be found on the 34N OPENNRM platform.

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Stewardship Atlas

Land Resume: Ownership class mapping

To characterize and map the major landowners within the landscape, a "Land Resume" was developed. The Land Resume is a spatial dataset of all major landowners and ownership type boundaries that are important for determining likely treatments and prescriptions that could be applied and for helping to better understand where projects cross ownership and jurisdictional boundaries. **The Land Resume is an important input layer for the Stewardship Atlas segmentation process.**

The Land Resume for the MTRW was developed to capture boundaries of owners that fell into the following classes:

- Federal
- State
- Local
- Large Private owners (with total ownership within the landscape ≥ 500 acres)

Any parcels whose owners did not fall into one of the above categories was grouped into a single category for small private ownership.

A comprehensive dataset was then developed to capture all ownership boundaries of landowners in the MTRW falling into these different categories. The table to the right shows the different landowners whose ownership boundaries were included in the MTRW landscape. The Land Resume was then used as part of the landscape segmentation process to help develop Stewardship Atlas units.

Table 17. Land Resume (ownership) types and classes

Land Resume Class Type	Ownership boundaries included in Land Resume
Federal	Army Corps of Engineers
	USFS
State	CA Dept. of Fish and Wildlife
	CA Dept. of Parks and Recreation
Local	Placer County
	Squaw Valley Mutual Water Company
	Squaw Valley Public Service District
	Tahoe Truckee Unified School District
	Town of Truckee
	Truckee Donner Public Utility District
	Truckee Donner Recreation & Park District
	Truckee Meadows Water Authority
	Truckee Sanitary District
	Truckee Tahoe Airport District
Large Private	James Teel Trust
	Martis Camp Club
	MVWP Development LLC
	Palisades Tahoe
	Sierra Pacific Industries
	Tahoe Donner Association
	The Nature Conservancy
	Trimont Land Company
	Truckee Donner Land Trust
Small Private	Small private (all remaining parcels grouped into this category)

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Stewardship Atlas

LiDAR and EcObject mapping

EcObject is a spatial dataset resulting from ecological object-based vegetation mapping from source high resolution LiDAR data. Polygons within EcObject represent landscape units that are relatively homogenous in terms of their vertical and horizontal vegetation structure, and are spatially variable in size. Ecobjects are created from a multi-resolution segmentation of LiDAR-derived tree approximate objects and a 1-m canopy height model, which were then aggregated by stand and tree-level ecologic relationships. The resulting segments were then populated with a collection of metrics relevant to management at the ecological-unit scale, such as QMD, percent canopy cover at different height strata (i.e. 2-8 m to estimate ladder fuels), and merchantantable board feet (among other attributes). **EcObject is an important input layer for the Stewardship Atlas segmentation process.** Two EcObject datasets were curated for the MTRW landscape:

1. **Tahoe National Forest (TNF) EcObject**: generated by the USFS Remote Sensing Lab from QL1 LiDAR acquired in 2014.
2. **MTRW-Nevada EcObject**: generated by 34N specifically to fill in the missing Nevada-area of the MTRW landscape not covered by TNF EcObject. This was conducted using a 2017 QL1 LiDAR acquisition centered on Reno and Carson City, Nevada. The raw point cloud was processed into canopy height, canopy cover, and tree approximate object models utilizing the FUSION LIDAR package. These products were then utilized in a custom segmentation pipeline adopted from the USFS Remote Sensing Lab to produce a final EcObject map.

The resulting two EcObject datasets were merged to create a continuous EcObject product for the MTRW landscape.

Below is the general methodology used by the USFS Remote Sensing Lab to generate EcObjects:

1. Use LiDAR point cloud data to develop a canopy height model (CHM) using the Watershed Segmentation Model.
2. The CHM is then used to identify Tree Approximate Objects (TAO). These are the first individual “units” on the landscape, and are used to approximate individual trees and their crowns.
3. The CHM in combination with the TAO is used to identify forest structure based on stand height. The result is clumped TAOs to identify similar groups of trees in single units. These units are often larger than the TAOs, but if a TAO is isolated and is greater than 10 meters tall, it becomes an EcObject without aggregation.
4. The remaining areas are then further aggregated into EcObjects based on connected areas with similar vegetation height or lack thereof (i.e. shrub fields or forest openings void of significant vegetation).

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Stewardship Atlas

Segmentation pipeline

The Stewardship Atlas is a vector based dataset and is tasked with appropriately organizing critical metrics for analysis. Therefore a rigorous object based segmentation process is deployed so those metrics are more appropriately assigned to the realities on the ground.

The general pipeline process to generate Stewardship Atlas segments, or "units," is described below.

1. After the EcObject dataset was created, individual EcObject units are then aggregated into larger units using information regarding a refined California Wildlife Habitat Relationship (CWHR) classification, operability (slope), access (distance from roads), and ladder fuel concentrations.
2. The aggregated units are then disaggregated using thematic data representing where landscape change occurred since the 2013 lidar flight and post-2019 season Forest Activity Tracking System (FACTS) dataset to update bio-physical characteristics, BPU delineation (see "Section II. Landscape Assessment Methods: Departure Modeling"), and the Land Resume (see earlier sub-section within Stewardship Atlas section).

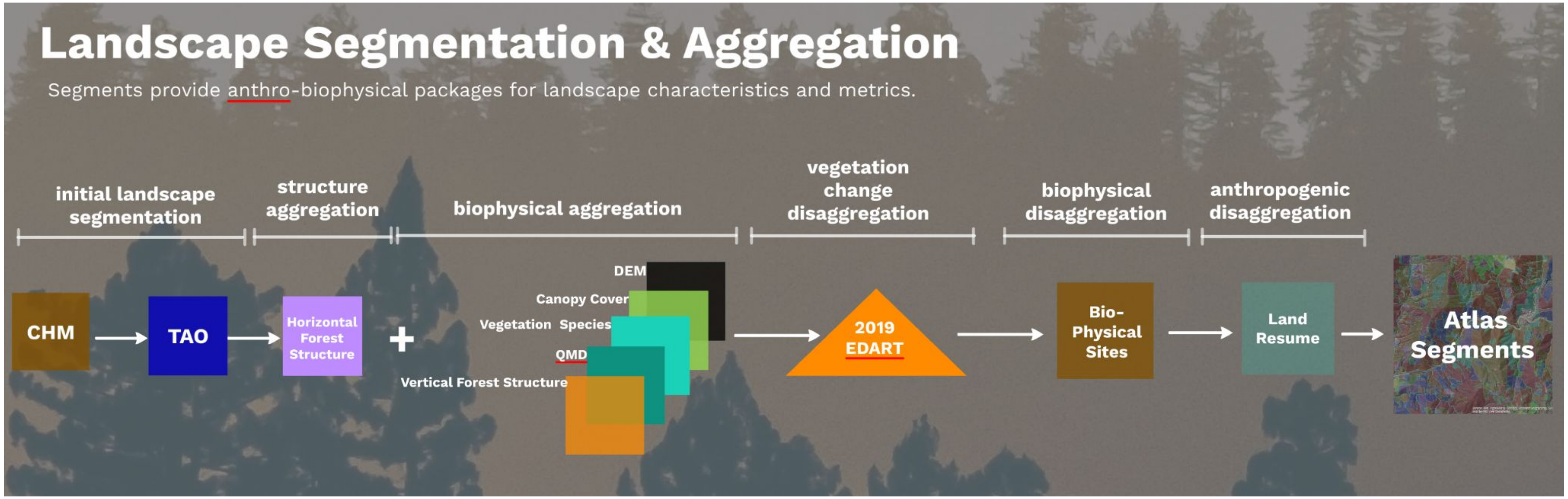

Figure 23. General workflow overview for the landscape segmentation and aggregation approach used to develop the Stewardship Atlas

Stewardship Atlas

Segmentation pipeline (cont'd)

As a final step in the initial segmentation pipeline, the resulting units were populated with the following information:

a. Forest structure metrics (i.e. average canopy height, tree diameter, ladder fuels)
b. Disturbance and forest health metrics (i.e. vegetation departure, fire hazard, drought hazard, etc)
c. Descriptive/topographic attributes (i.e. average slope, ownership, etc)

The Stewardship Atlas then provides the base landscape units across which all analysis and planning is summarized; further calculations and analysis are all summarized to the Stewardship Atlas units for meaningful packaging and planning of treatments across the landscape. The units in the Stewardship Atlas serve as a helpful starting place for field personnel and should facilitate the hand-off between planning and implementation, but are not a substitute for treatment layout.

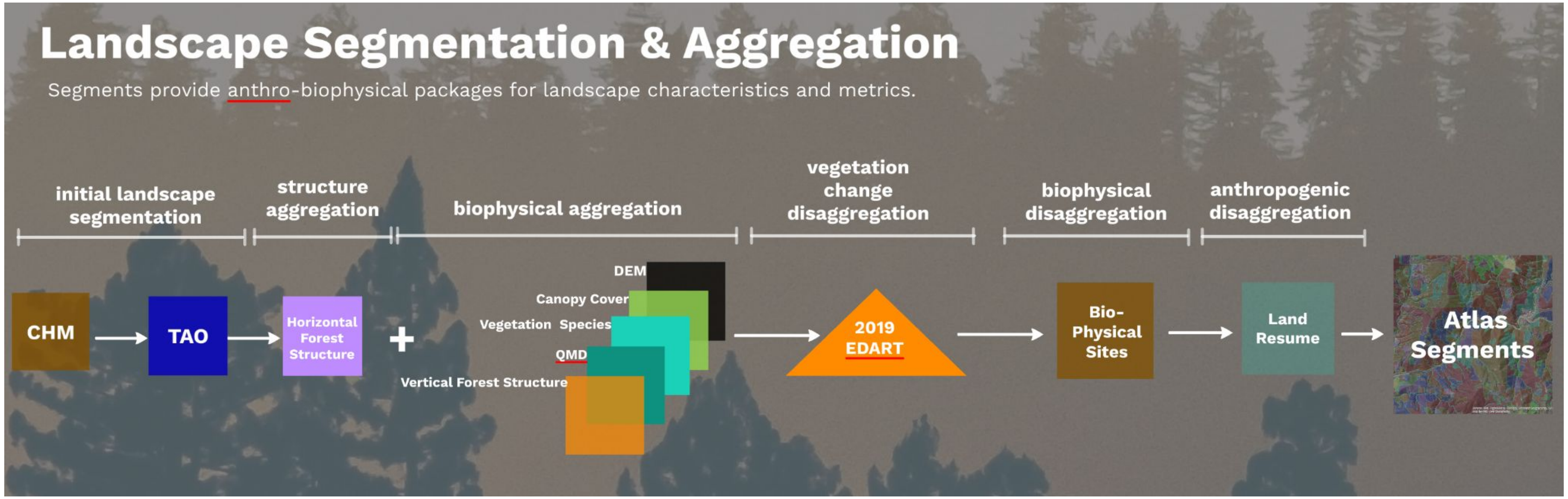

Figure 24. General workflow overview for the landscape segmentation and aggregation approach used to develop the Stewardship Atlas

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Assigning potential treatment types

After the Stewardship Atlas was developed, each segment was attributed with information regarding vegetation management treatments, including: likely treatment methods (initial and follow), treatment probabilities, cost of treatments, and product and biomass removal. It was necessary to develop potential treatments for the purpose of assessing the impact of those treatments; this information could also be used to roughly estimate potential project costs. Treatments were assigned through an automated process using a developed ruleset based upon slope, canopy cover, quadratic mean diameter (QMD). In some cases, the presence of sensitive SARAs also informed treatment selection. For example, Stewardship Atlas units that had any built asset density exceeding 10% of its area or a California Spotted Owl and Northern Goshawk Protected Activity Centers (PACs) covering more than 50% of its area, that unit was assigned to hand-thinning. This information is also detailed here in the MTRW Stewardship Atlas Product Guide and is also attached in the Appendix. Below are the potential treatments assigned to MTRW Stewardship Atlas units, along with their descriptions and the 10-year probabilities assigned to each. It was necessary to assign 10-year probability treatments for assessing the impact of treatments within the same framework as disturbances (for further information, see "Section IV. Restoration Opportunity Modeling").

Table 18. Treatments assigned to Stewardship Atlas units within the MTRW landscape for the FHA analysis

Treatment	Type	Description	10-year Probability
Ground Mechanized - Thin from below	Mechanized	Treatment is generally consistently and equally applied across an area and is focused on significantly reducing the effects of high intensity fire. Dominant woody vegetation is generally unaffected. Co-dominant woody vegetation is affected by as much as 25%, however overall canopy cover remains intact. Dominant woody vegetation is generally unaffected, while as much as 90% of subdominant woody vegetation is cut and removed. Herbaceous vegetation is disturbed by as much as 40%. Soil is disturbed by as much 25%. Most resource protection and mitigation measures can reasonably be applied without affecting prescription goals. Response functions for SARAs that can't be protected or mitigated for are qualitatively/quantitatively assessed after 10 years of growth and/or recovery.	65%
Ground Mechanized - Thin w/ large openings	Mechanized	Treatment is generally variable and is applied so as to mimic vegetation structure patterns that would exist in the area's intact disturbance regime and includes large opening creation of areas greater than 1 acre. Dominant woody vegetation is affected by as much as 35% over the treatment area but can be as high as 100% in some areas and as low as 0% in others. Co-dominant woody vegetation is affected by as much as 50%, but effects are also variably distributed. Overall canopy cover may be reduced by as much as 40%. As much as 75% of subdominant woody vegetation is cut and removed but may also be left in concentrations. Herbaceous vegetation is disturbed by as much as 40%. Soil is disturbed by as much 35%. Most resource protection and mitigation measures can reasonably be applied without affecting prescription goals. Response functions for SARAs that can't be protected or mitigated for are qualitatively/quantitatively assessed after 10 years of growth and/or recovery.	65%

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Assigning potential treatment types (cont'd)

Table 18. Treatments assigned to Stewardship Atlas units within the MTRW landscape for the FHA analysis

Treatment	Category	Description	10-year Probability
Tethered/Aerial Mechanized - Thin from below	Aerial/Tethered	Treatment is generally consistently and equally applied across an area and is focused on significantly reducing the effects of high intensity fire. Dominant woody vegetation is generally unaffected. Co-dominant woody vegetation is affected by as much as 20%, however overall canopy cover remains intact. Dominant woody vegetation is generally unaffected, while as much as 75% of subdominant woody vegetation is cut and removed. Herbaceous vegetation is disturbed by as much as 10%. Soil is disturbed by as much 5%. Most resource protection and mitigation measures can reasonably be applied without affecting prescription goals. Response functions for SARAs that can't be protected or mitigated for are qualitatively/quantitatively assessed after 10 years of growth and/or recovery.	65%
Tethered/Aerial Mechanized - Variable Density Thin w/ large openings	Aerial/Tethered	Treatment is generally variable and is applied so as to mimic vegetation structure patterns that would exist in the area's intact disturbance regime and includes large opening creation of areas greater than 1 acre. Dominant woody vegetation is affected by as much as 35% over the treatment area but can be as high as 100% in some areas and as low as 0% in others. Co-dominant woody vegetation is affected by as much as 50%, but effects are also variably distributed. Overall canopy cover may be reduced by as much as 40%. As much as 65% of subdominant woody vegetation is cut and removed but may also be left in concentrations. Herbaceous vegetation is disturbed by as much as 10%. Soil is disturbed by as much 10%. Most resource protection and mitigation measures can reasonably be applied without affecting prescription goals. Response functions for SARAs that can't be protected or mitigated for are qualitatively/quantitatively assessed after 10 years of growth and/or recovery.	65%
Rearrangement - Target fine fuel	Mechanized	Predominantly achieved by mowers. Generally, treatment is consistently and equally applied across an area and is focused on significantly reducing fine fuels and a fire's rate of spread. Woody vegetation is generally unaffected. Herbaceous vegetation is significantly affected at no less than 90%. Rearranged material is left on site. Soil is disturbed by as much 10%.	65%
Rearrangement - Thin from below	Mechanized	Predominantly achieved by mastication tracked machines. Generally, treatment is consistently and equally applied across an area and is focused on significantly reducing fine fuels, ladder fuels, and reducing canopy bulk density which decrease a fire's rate of spread, the potential for crown initiation, and the ability for sustained crown fire. Dominant woody vegetation is generally unaffected. Co-dominant woody vegetation is affected by as much as 25%. Overall canopy cover may be reduced by as much as 25% As much as 90% of subdominant woody vegetation is affected through rearrangement. Herbaceous vegetation is disturbed by as much as 35%. Rearranged material is left on site. Soil is disturbed by as much 20%.	65%

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Assigning potential treatment types (cont'd)

Table 18. Treatments assigned to Stewardship Atlas units within the MTRW landscape for the FHA analysis

Treatment	Category	Description	10-year Probability
Hand Thinning - Thin from below	Manual Thin & Pile	Treatment is generally consistently and equally applied across an area and is focused on significantly reducing the effects of high intensity fire. Dominant woody vegetation is generally unaffected. Co-dominant woody vegetation is affected by as much as 25%, however overall canopy cover remains intact. As much as 90% of subdominant woody vegetation is cut and removed. Herbaceous vegetation is disturbed by as much as 25% through foot traffic and the dragging or piling of cut woody debris. Soil disturbance is insignificant.	65%
Rx Burn - Aerial	Aerial Rx Burn	Scorch height 20-60'; typically, moderate severity; ground/surface fire in moderate fuel and moderate-to-severe conditions. Fire burns surface fuels, shrubs and smaller trees, as well as individual mature trees.	10%
Rx Burn - Ground, Low Intensity	Ground Rx Burn	Scorch height 5-20'; typically, low severity; ground/surface fire in low fuel load and/or mild conditions. Fire burns surface fuels, small shrubs or seedlings.	10%
Rx Burn - Ground, Moderate Intensity	Ground Rx Burn	Scorch height 10-40'; typically, low-to-moderate severity; ground/surface fire, moderate fuel load and/or moderate conditions. Fire burns surface fuels, shrubs and smaller trees.	10%

Mapped Potential Treatments

To the right is a map of the assigned potential treatments for each Stewardship Atlas unit across the MTRW landscape (initial and follow treatments). Again, the treatments were assigned to each Stewardship Atlas unit based on the characteristics of that unit, including slope, vegetation characteristics, presence of sensitive habitat, etc.

As described previously, these treatments are associated with a response function for each SARA to characterize how that SARA would respond to the treatment (see "Section II. Landscape Assessment Methods: SARA Inventory"). These treatments and response functions are used to determine the potential impact of treatment on SARAs *and* the potential impact of treatment on the effects of disturbances on SARAs (see "Section IV. Restoration Opportunity Modeling" for further detail).

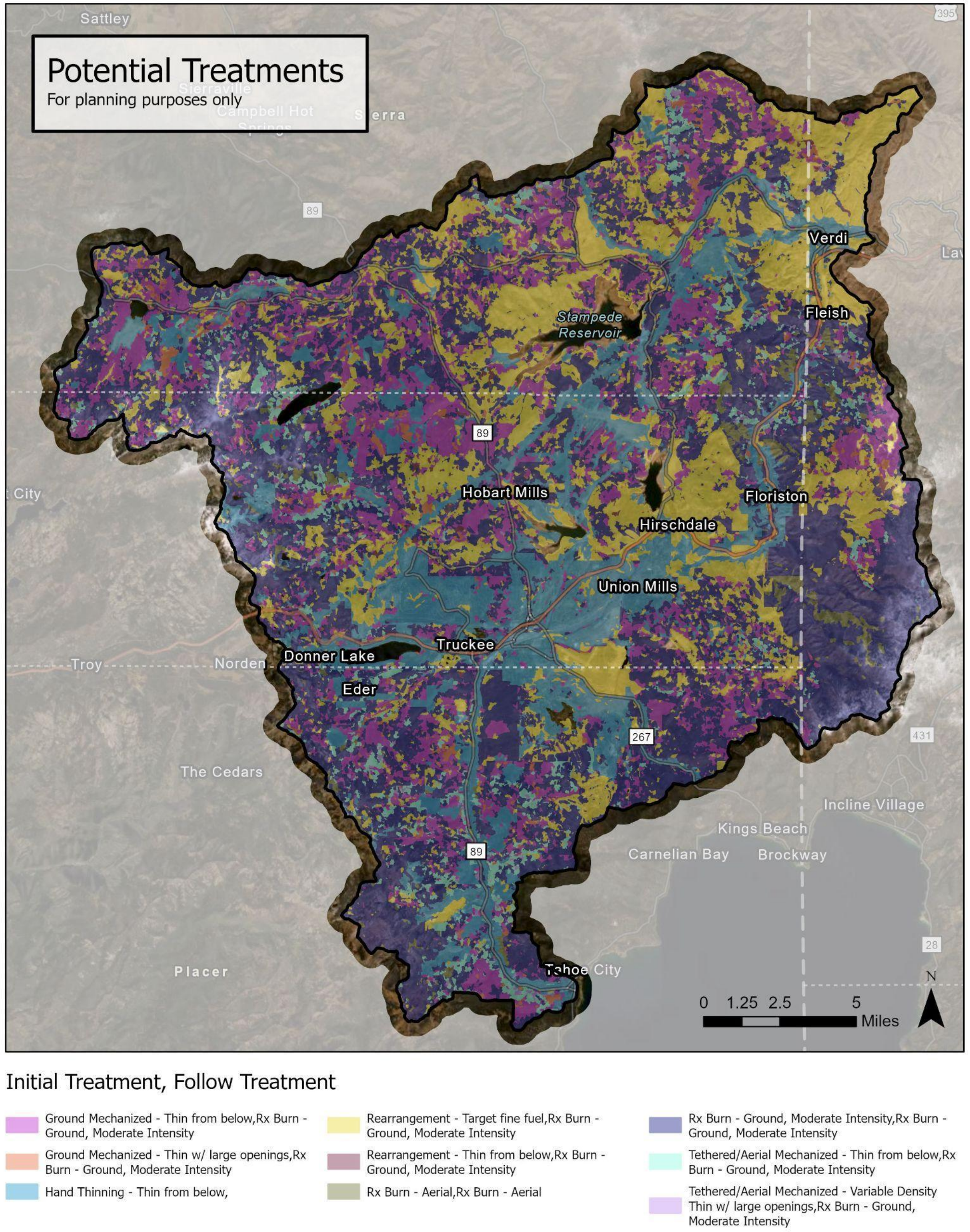

Figure 25. Assigned potential treatments for each Stewardship Atlas unit for the MTRW landscape

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Disturbance Response to Treatment Types

Treatments have the potential to decrease the intensity at which disturbances occur; for example, pre-treatment, wildfire may burn at much lower intensities post-treatment than pre-treatment, due to removal of fine fuels, increasing canopy base height, etc. Therefore, it was necessary to characterize how treatments impact the intensity of disturbances. To do this, we developed disturbance intensity reduction factors for each treatment type and disturbance type. These represent a change in disturbance intensity class, which cannot be reduced less than a disturbance intensity class of 1; in other words, if the disturbance intensity class is 2 and the treatment reduction factor is 2, the post-treatment disturbance intensity would be calculated as 1 (i.e. can only reduce intensity, but not remove the disturbance itself).

Below are the treatments and their associated disturbance reduction factors for each disturbance type (wildfire and drought).

Table 19. Treatments and disturbance reduction factors

Treatment	Wildfire Intensity Class Reduction Factor	Drought Intensity Class Reduction Factor
Ground Mechanized - Thin from below	-3	-2
Ground Mechanized - Thin w/ large openings	-3	-4
Tethered/Aerial Mechanized - Thin from below	-2	-2
Tethered/Aerial Mechanized - Variable Density Thin w/ large openings	-2	-3
Rearrangement - Target fine fuel	-1	0
Rearrangement - Thin from below	-3	-2
Hand Thinning - Thin from below	-2	-2
Rx Burn - Aerial	-2	-2
Rx Burn - Ground, Low Intensity	0	-1
Rx Burn - Ground, Moderate Intensity	-1	-1

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Distinct Management Areas

Overview

Within a given landscape, it is likely that vegetation management objectives may differ based on ownership, land use, and other factors. For example, areas in the WUI could have different treatment objectives (i.e. reducing risk from wildfire) than a National Wilderness Area (i.e. improving ecological condition).

To account for these differences, we developed Distinct Management Areas (DiMAs) for the MTRW landscape. These are to be used for planning forest health treatments, and do not relate to zoning or other types of analysis. These are simply used to **differentiate the treatment objectives** for different areas of the landscape. Here, **the 10 Resilience Pillars** (described previously in "Section II. Landscape Assessment Methods: Resilience Pillars") **are used to represent treatment objectives**.

DiMAs were assigned to each Stewardship Atlas unit based on its Ownership and corresponding Land Resume Class Type and other characteristics of that unit. It should be noted that the DiMAs were assigned hierarchically according to the order shown in the table at right; for example, if a Stewardship Atlas unit was both in a Wilderness/Research Area *and* part of California Spotted Owl Protected Activity Center (PAC), the Stewardship Atlas unit was assigned the "Wildlife" DiMA.

Development and application of the DiMA pillar weight for project scenario development is further described in "Section V. Project Scenario Development."

Both MTRW DiMAs and DiMA pillar weights were co-developed by Vibrant Planet and the TRWC.

Table 20. Distinct Management Areas identified for the MTRW landscape; used for project scenario development purposes.

Distinct Management Area (DiMA)	Description
Timberlands	Owned by Sierra Pacific Industries (SPI) (see Land Resume)
Large Private Ownership	Private landowners with cumulative ownership greater than 500 acres (non-SPI) (see Land Resume)
Wildlife	Northern Goshawk and California Spotted Owl Protected Activity Centers (PACs)
Wilderness/Research Areas	Sagehen Experimental Forest and Mt. Rose Wilderness Area
WUI Defense Public Lands	Community Fuel Reduction Zone (SARA) on owned by any Local public landowners (see Land Resume)
Recreation	Ski resort areas, boating sites, campgrounds, day use areas (SARAs)
Forest Matrix Public Lands: Local	Local public landowners (see Land Resume)
Forest Matrix Public Lands: State/Federal	State and Federal public landowners (see Land Resume)

Existing Conditions in the MTRW

Overview

After the initial landscape assessment, we were able to better map, quantify, and understand the existing conditions within the MTRW landscape related to ownership, Distinct Management Areas, SARA spatial distribution and relative landscape value, vegetation and fire return interval departure, and wildfire hazard.

All of this information (and other developed datasets previously described in "Section II. Landscape Assessment Methods") were then used to **model the impact that treatments may have on ecological health and risk from disturbances** (see "Section IV. Restoration Opportunity Modeling"); these **modeled treatment impacts were then used to develop priority treatment opportunity areas** within the MTRW landscape based on different treatment objectives (see "Section V. Project Scenario Development" and "IV. Treatment Matrix").

Truckee River Watershed Council

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Existing Conditions in the MTRW

Ownership A total of 24 landowner classes were identified within the MTRW landscape. 23 of the ownership classes correspond to a single landowner (i.e. USFS, Truckee Donner Land Trust), with just the "Small Private" ownership class representing more than one owner (i.e. all private landowners who have less than 500 cumulative acres of ownership within the MTRW). The table below shows the ownership classes listed in order of highest to lowest ownership acreage within the MTRW; the map to the right shows the spatial distribution of ownership.

Table 21. Acreage of each ownership class within the MTRW landscape

Ownership	Acres
USFS	187,585
Small Private	56,737
Truckee Donner Land Trust	12,322
Sierra Pacific Industries	11,339
Trimont Land Company	6,999
CA Dept. of Fish and Wildlife	5,508
James Teel Trust	4,669
CA Dept. of Parks and Recreation	3,579
Tahoe Donner Association	3,486
Palisades Tahoe	2,725
Truckee Tahoe Airport District	2,443
The Nature Conservancy	2,243
Army Corps of Engineers	1,700
Martis Camp Club	1,143
Truckee Sanitary District	1,090
MVWP Development LLC	1,051
Placer County	586
Truckee Meadows Water Authority	468
Truckee Donner Public Utility Dst	184
Tahoe Truckee Unified Sch Dist	68
Truckee Donner Rec & Park District	49
Town of Truckee	48
Squaw Valley Public Service District	2
Squaw Valley Mutual Water Co	0.5

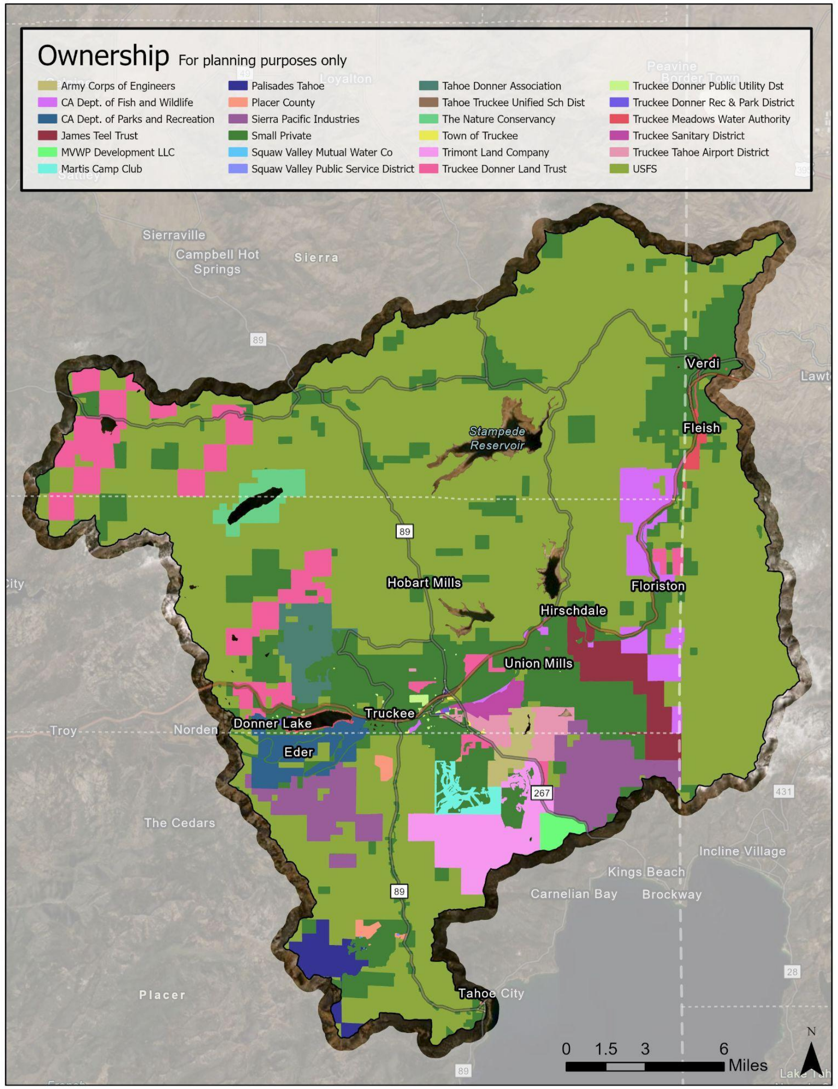

Figure 26. Mapped ownership classes (i.e. Land Resume) for the MTRW landscape

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Existing Conditions in the MTRW

Distinct Management Areas (DiMAs) A total of 8 DiMAs were identified within the MTRW landscape. Stewardship Atlas units were assigned to a single DiMA; the only areas where a DiMA was not assigned was if the ownership was Small Private. These areas were not grouped into a DiMA and were excluded from the project scenario development due to the difficulty in identifying treatment objectives and planning landscape-scale treatments that would include this myriad of ownership within this category. The table below shows the total acreage by DiMA.

Table 22. Acreage of each Distinct Management Area class within the MTRW landscape

Distinct Management Area (DiMA)	Acres
Timberlands	11,339
Large Private	29,437
Wildlife	11,864
Wilderness/Research Areas	18,417
WUI Defense Public Lands	9,054
Recreation	6,508
Forest Matrix Public Lands: Local	2,402
Forest Matrix Public Lands: State and Federal	160,645
N/A	56,356

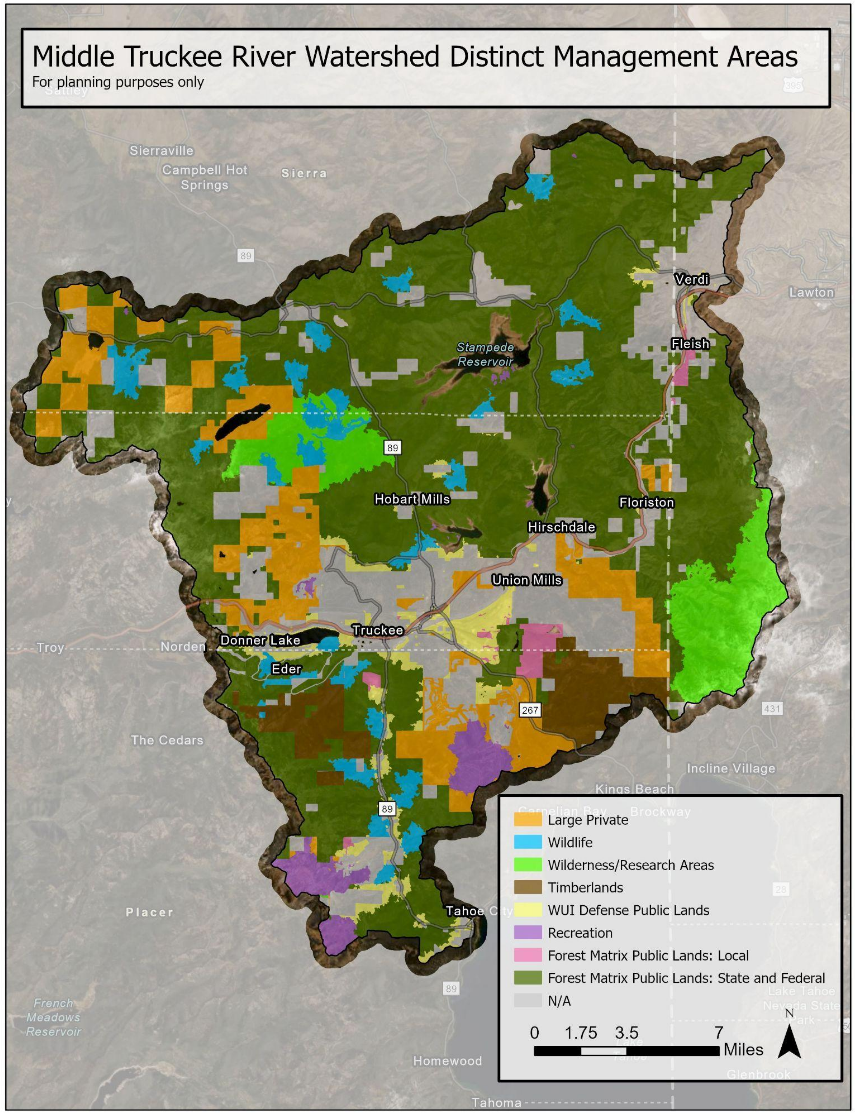

Figure 27. Mapped Distinct Management Areas for the MTRW landscape

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Existing Conditions in the MTRW

Cumulative SARA ROSE (Relative Potential Socio-Ecological value) A total of 32 SARAs were identified and characterized within the MTRW landscape. A normalized appraisal process was conducted to characterize and map the relative potential socio-ecological (ROSE) value of the SARAs (see "Section II. Landscape Assessment Methods: SARA Inventory"). The ROSE can be thought of as the maximum potential value on the landscape, assuming full ecological function (i.e. no forest departure); when mapped, it helps to identify both the concentration of SARAs and concentration of importance. The map to the right shows the cumulative SARA ROSE value per acre by Stewardship Atlas units. Stewardship Atlas units with a higher concentration of SARA ROSE per unit area are shown in deep purple. Areas with no SARA ROSE (i.e. no SARAs present) are transparent (note that waterbodies are excluded from the Stewardship Atlas since they are not locations where vegetation management treatments could occur, and appear as transparent here as well). Nearly all of the MTRW landscape has at least one SARA present.

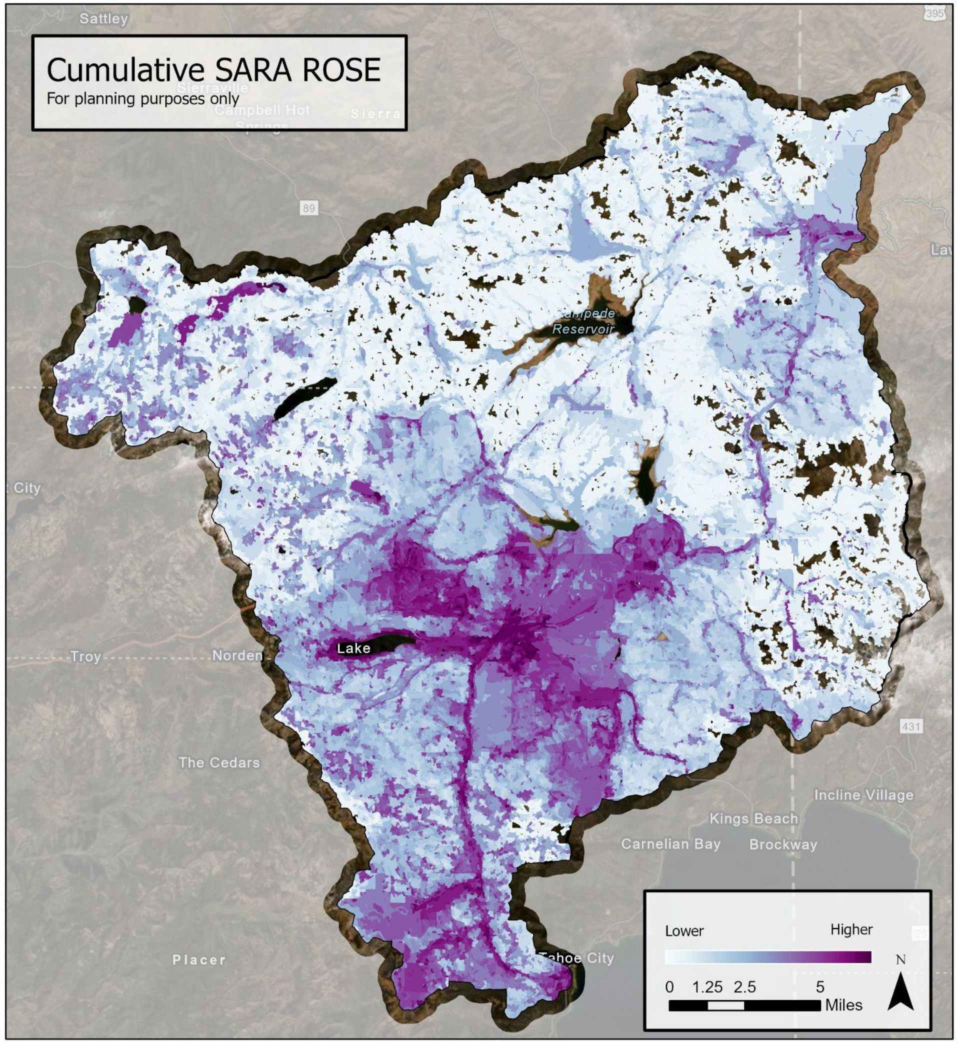

Figure 28. Cumulative SARA ROSE per acre for the MTRW landscape

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Existing Conditions in the MTRW

HRV Fire Return Interval Departure The Fire Return Interval Departure (FRID) metric quantifies the extent (in percent) to which contemporary fires (1909-present) are burning at frequencies similar to simulated HRV frequencies. HRV-FRID was summarized for each Stewardship Atlas unit and then quantiled into six classes for the MTRW landscape. Each class represents an intensity of fire return interval departure (FRID Intensity Class; FIC). The resulting mapped FRID Intensity Class by Stewardship Atlas unit is shown in the map to the right. For the purposes of assessing SARA current value and the potential impact of treatments (described further in “Section IV. Restoration Opportunity Modeling”), the FIC were then related to ROSE factors (i.e. fraction of ROSE values) for application in the Restoration Abacus to estimate SARA current value.

Table 23. Quantiled HRV-FRID into six intensity classes

FRID Intensity Class (FIC)	HRV-FRID range
FRID Intensity Class 1	0-45
FRID Intensity Class 2	45-55
FRID Intensity Class 3	55-65
FRID Intensity Class 4	65-75
FRID Intensity Class 5	75-78
FRID Intensity Class 6	>78

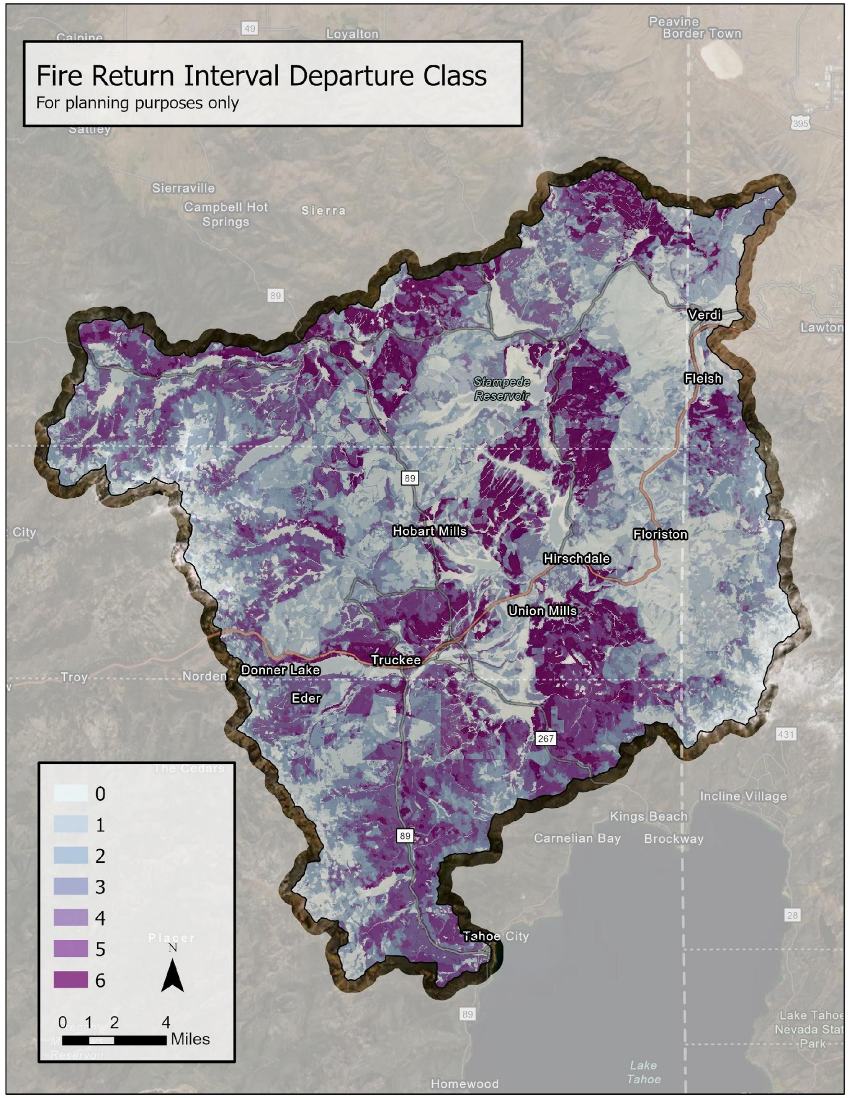

Figure 29. Cumulative SARA ROSE per acre for the MTRW landscape

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Existing Conditions in the MTRW

Forest NRV Departure A composite index representing forest structure departure from NRV was computed for the MTRW. For the MTRW, NRV departure was calculated using a composite of equally weighted combinations of metrics derived from the Historical Range of Variability (HRV-75%) and Contemporary Reference Conditions (CRC-25%) (described previously in "Section II. Landscape Assessment Methods: Departure Modeling"). As noted previously, departure was only calculated for forest cover types (excludes urban forest). NRV Departure was summarized for each Stewardship Atlas unit and then quantiled into six classes for the MTRW landscape. Each class represents an intensity of NRV Departure, and was used as a proxy for drought disturbance intensity to characterize the potential intensity of drought-related tree mortality disturbance, described previously in "Section II: Disturbance Modeling." . The resulting mapped HRV Departure intensity class by Stewardship Atlas unit is shown in the map to the right.

Table 24. Quantiled NRV Departure into six intensity classes used to represent drought intensity

HRV Composite Departure/Drought Intensity Class	NRV Departure Range
Intensity Class 1	0 - 3.25
Intensity Class 2	3.25 - 6
Intensity Class 3	6 - 9.4
Intensity Class 4	9.4 - 13.5
Intensity Class 5	13.5 - 20.1
Intensity Class 6	> 20.1

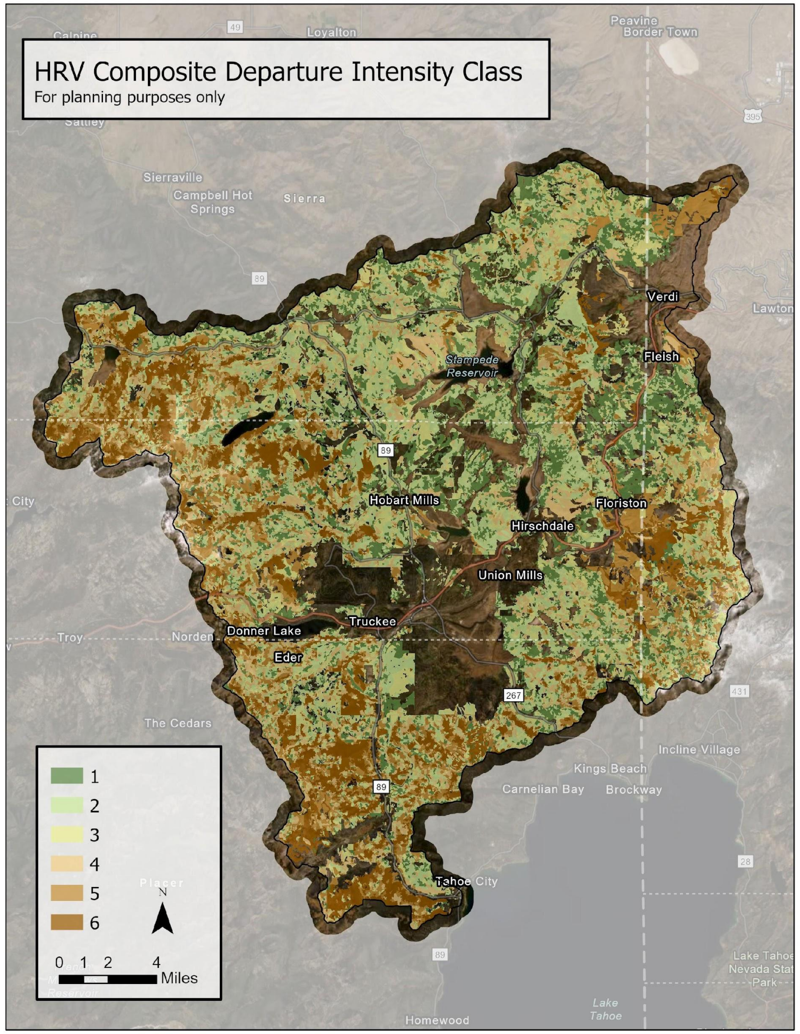

Figure 30. Departure shown quantiled as six classes; the greater the departure, the greater the intensity would be of drought-related forest mortality

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Existing Conditions in the MTRW

Wildfire Hazard Hazard is the probable intensity of a disturbance; for wildfire, it can be calculated as the product of burn probability and conditional flame length. The map to the right shows continuous wildfire hazard for the MTRW landscape (shown in raster format, not yet summarized by Stewardship Atlas units). Areas of greater hazard indicate both higher flame lengths and burn probabilities across the ensemble of stochastic wildfire model runs (described previously in "Section II. Landscape Assessment Methods: Disturbance Modeling"). Note that low hazard does not mean no hazard. SARA risk to wildfire (and drought) is assessed by exposing the SARAs to the components of wildfire hazard (probability and quantiled conditional flame length) to determine how they would respond (using the disturbance response functions described earlier in "Section II. Landscape Assessment Methods: SARA Inventory"). This process and calculations are described further in "Section IV. Restoration Opportunity Modeling."

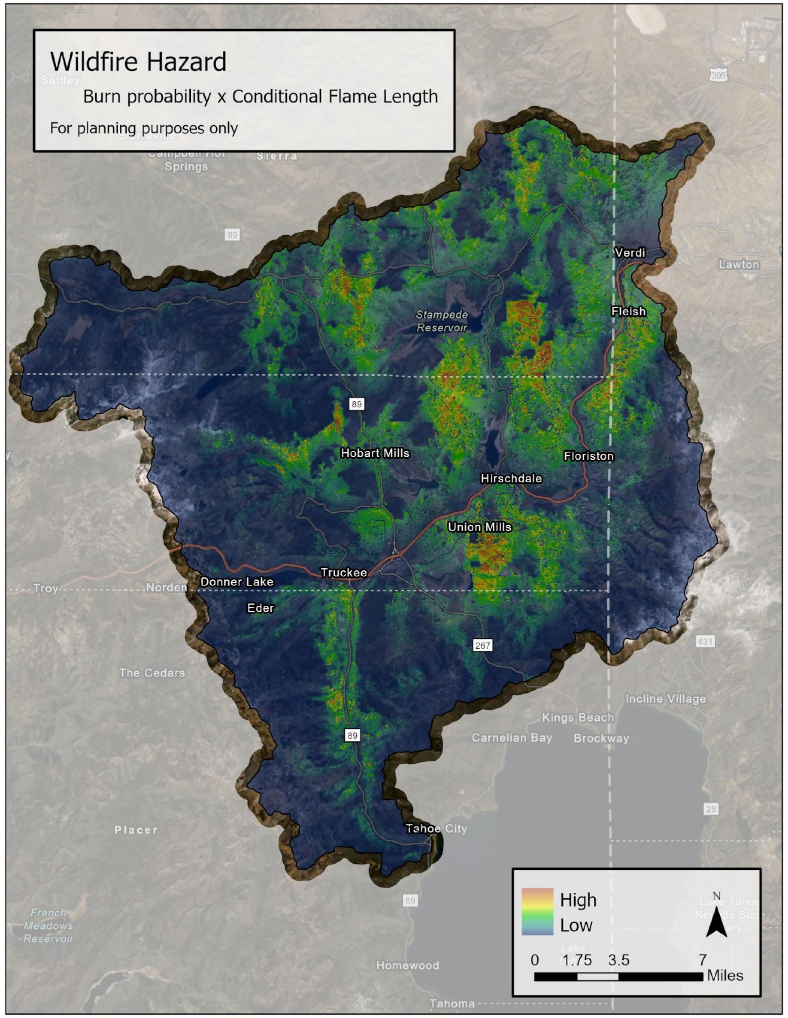

Figure 31. Wildfire hazard (i.e. likely wildfire intensity) displayed continuously for the MTRW landscape.

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Restoration Abacus

Overview

Given the existing conditions on the MTRW landscape, the next step in the analysis was to **identify areas where treatments could improve ecological health and reduce risk from disturbances.** Typically, the fundamental factor driving fuel treatment planning efforts is the need to reduce the risk associated with disturbances such as wildfire. This motivation has been well documented in publications like "A Wildfire Risk Assessment Framework for Land and Resource Management" by (Scott et al. 2013) and operationalized in tools like IFTDSS (https://iftdss.firenet.gov). These frameworks, although valuable for fuel reduction projects with a focused goal, only require the co-location of the highest hazard areas with the highest value areas. These inherent analysis limitations do not provide spatially explicit solutions to reduce risk, nor do they assess the impacts of proposed treatments, both on (1) the change in risk associated with disturbance(s) and (2) the functional value of the landscape itself, regardless of disturbance(s). Although risk should certainly be a piece of information that helps inform decision-makers about areas that are in need of treatment in order to avoid loss, assessing treatment and disturbance effects helps provide decision-makers with information about the where, when, why, and how of vegetation management plans so they can better understand the true return on an investment from performing treatments instead of just what a landscape has to lose if nothing is done.

A **risk and opportunity-based framework using econometrics to quantify planned and unplanned disturbance effects was applied to derive landscape-scale information about the Restorative Return on Investment (RROI) from performing vegetation management treatments**. This framework is referred to as the **"Restoration Abacus" (REBA)**, which is a stepwise, combination of fuzzy and probabilistic-logic workflows that guides a host of geospatial and database inputs through a series of calculations (see Appendix).

Workflow description: The REBA uses a host of geospatial and relational databases containing information about SARAs, disturbances, treatments, and departure. The REBA processes each SARA separately, and then combines the outputs into the 10 Resilience Pillars by Stewardship Atlas unit. Prior to performing the SARA calculations, the REBA approximates the post-treatment intensity of mapped disturbances (i.e. wildfire, drought). Then the following calculations are performed for each SARA:

1. Calculate the SARA current value
2. Calculate the SARA Treatment Effects (impact of treatment on SARA value, regardless of disturbance)
3. Calculate the SARA Change in Disturbance Effects (impact of treatment on SARA risk from unplanned disturbances)
4. Sum the SARA Treatment Effects and SARA Change in Disturbance Effects to determine SARA Restorative Return on Investment (RROI) .

These calculations were performed at the finest gridcell resolution of all input rasters (5 m^2) for each SARA across the MTRW landscape, resulting in SARA RROI rasters. It should be noted that the RROI values are the assumed net effects over a 10-year period (same as assumed timeframe for net effects in the developed response functions). The SARA RROI rasters are then used to calculate Pillar RROI rasters, which are then summed for each Stewardship Atlas unit, and serve as input to the spatial optimization program for project scenario development. The REBA calculations are described in great detail in the Appendix.

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Restoration Abacus

REBA input datasets

Table 25. Input datasets used for the Restoration Abacus (development described in "Section II. Landscape Assessment Methods")

Dataset category	Datasets
SARAs	• SARA relative potential socio-ecologic value (ROSE) (rasters) (5 m^2) • Response functions to disturbance intensities (lookup table) • Response functions to treatments (lookup table) • SARA-pillar contributions (lookup table)
Wildfire and drought disturbances	• Disturbance intensity classes for each disturbance type (rasters) (60 m^2 and 5 m^2 for wildfire and drought, respectively, resampled to 5 m^2 for the wildfire raster; note that drought intensity class raster developed by rasterizing the Stewardship Atlas) • 1-year disturbance probability for each disturbance type (rasters) (60 m^2 and 4 km^2 for wildfire and drought, respectively, resampled to 5 m^2)
Treatments	• Initial and follow treatments (rasters) (5 m^2; note that was developed by rasterizing the Stewardship Atlas, hence the finer resolution) • Initial and follow treatment 10-year probabilities (rasters) (5 m^2; note that was developed by rasterizing the Stewardship Atlas) • Treatment-disturbance intensity reduction factors (lookup table)
Fire return interval departure class	• FRID intensity class (rasters) (5 m^2; note that was developed by rasterizing the Stewardship Atlas)

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Restoration Abacus

REBA workflow to calculate SARA RROI

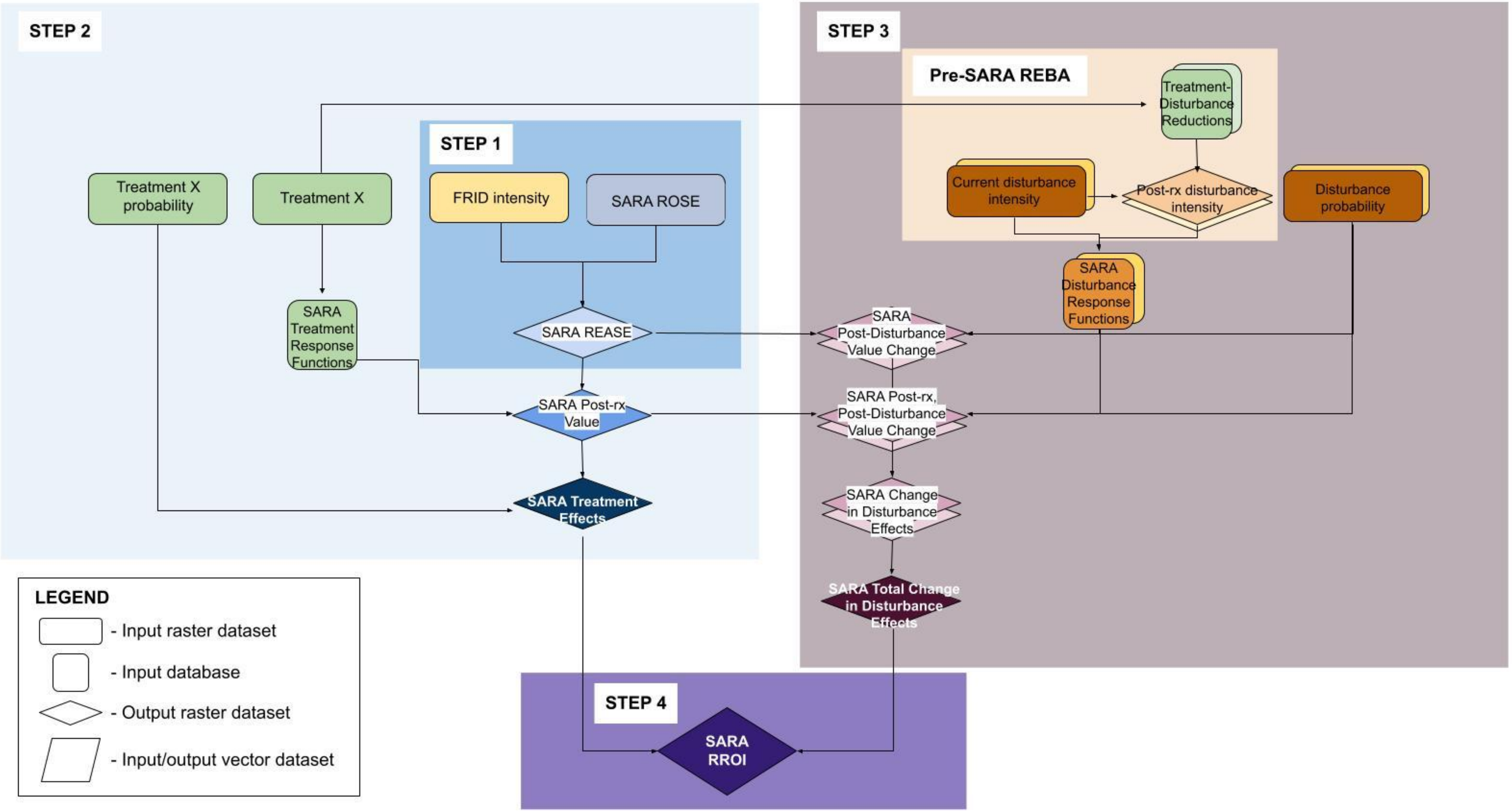

Figure 32. Workflow implemented to calculated SARA Restorative Return on Investment (RROI)

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Project Scenario Development

Overview

The final step of the analysis involved developing scenarios of sequenced project areas using a spatial optimization program (ForSys), which was parameterized using mapped pillar RROI in the Stewardship Atlas and parameters provided by the TRWC for the MTRW.

ForSys background

ForSys is a multicriteria spatial prioritization and optimization system created by Ager and the U.S. Forest Service (Ager 2012). The program input is a shapefile (here, the Stewarship Atlas) that is attributed with treatment objectives (in our case RROI for 10 Resilience Pillars) and constraints (acres and cost of treatment per polygon). Two types of scenarios are generated using ForSys: 1) a non-spatially optimized scenario and 2) a spatially optimized scenario. In both cases, a set of "weights" or scalar values are multiplied by the 10 RROI values and summed together to generate a single objective score for each Stewardship Atlas segment:

$$SPV_{x,y} = \sum_{y=1}^{n} p_{x,y} \times w_{x,y}$$

Where SPV is the Stand Priority Value, x is a given stand (i.e. a given Stewardship Atlas unit in the MTRW), y is a vector of priorities y (i.e. y = 10 pillars), p is the unweighted value (i.e. RROI), and w is a weighting factor (i.e. Table 1). Thus, for each Stewardship Atlas unit in the MTRW, a composite-MOU-weighted RROI (in ForSys, the SPV) was calculated based on the unweighted pillar RROI values and MOU pillar weights.

The non-spatially optimized scenario returns a shapefile of the entire Stewardship Atlas with each segment attributed by this weighted RROI score. For the spatially-optimized scenario, a matrix of polygon adjacency is included in order to utilize the aggregation function to build projects that are composed of a set of contiguous polygons. The ForSys program uses the aggregation logic to group individual Stewardship Atlas segments together to maximize the RROI for a project, subject to constraints in project size and/or cost. Using this method, we generated a set of scenarios of projects that are designed to maximize the RROI across the 10 Resilience Pillars, based on the pillar weights identified for the different Distinct Management Areas. Each scenario is made up of a user-defined number of projects, and each resultant project contains a set of adjacent polygons that can be treated as a single project area.

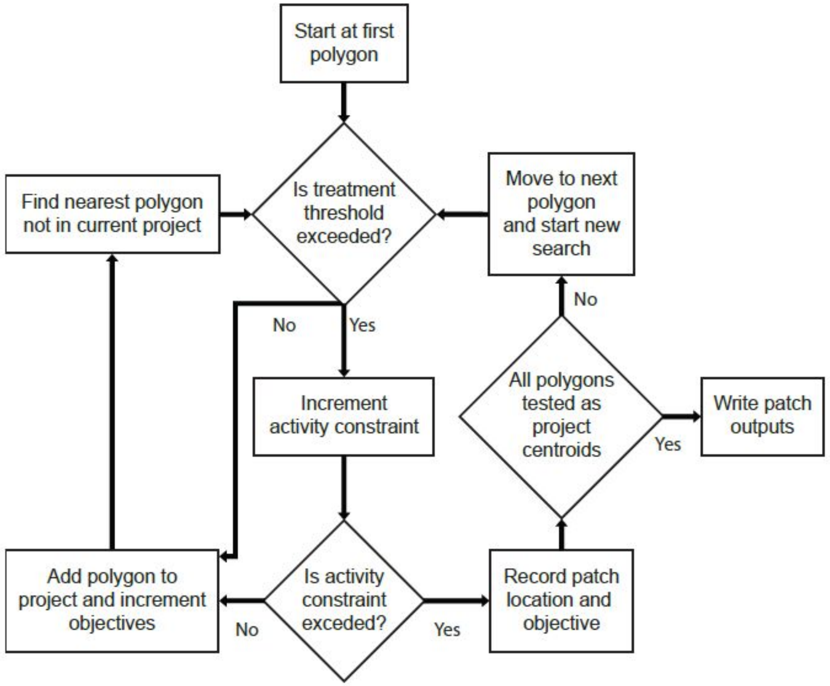

Figure 33. Flow chart of program control for the ForSys program showing the decision framework for simulations that use the aggregation option (Ager, 2012)

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Distinct Management Area Pillar Weights

For each DiMA (Distinct Management Area (described previously in "Section II. Landscape Assessment Methods: Distinct Management Areas"), each of the 10 Resilience Pillars received a different weight (on a scale of 0-5) (see table below). Higher weights indicate that objectives related to that pillar are more important; lower weights indicate that the pillar is less related to management objectives, and a weight of 0 indicates that the pillar is not important for management objectives. After initial development by DiMA, the pillar weights were are then standardized to ensure that the cumulative pillar weight is not greater in one DiMA versus another.

Table 26. Weights for each of the 10 Resilience Pillars by Distinct Management Area

	Timberlands	Large Private Ownership	Wildlife	Wilderness/ Research Areas	WUI Defense Public Lands	Recreation	Forest Matrix Public Lands: Local	Forest Matrix Public Lands: State/Federal
Forest Resilience	5	3	4	4	3	2	0	5
Fire Dynamics	3	2	3	4	5	2	2	4
Biodiversity Conservation	2	3	5	4	1	1	0	4
Wetland Integrity	2	2	5	4	1	1	0	4
Carbon Sequestration	2	1	1	2	1	1	0	2
Water Security	1	2	1	2	2	1	0	3
Air Quality	1	2	1	1	3	2	0	1
Fire-Adapted Community	2	3	1	2	5	3	5	3
Economic Diversity	4	4	1	1	4	5	5	2
Social and Cultural Well-Being	1	4	1	1	3	5	5	4

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Project Scenario Development

Unrefined orientation (non-spatially optimized)

The first step in project scenario development is to determine the objective that the optimization (i.e. ForSys) should try to maximize. Here, two types of objectives were identified: (1) a balanced-objective approach, where treatment objectives were weighted according to their Distinct Management Area ("Balance Objectives"), and (2) a simple approach to solely maximize RROI, no matter the differing treatment objectives ("Maximize RROI"). The first approach is aimed at identifying priority areas based on which areas of the landscape best meet different treatment objectives; the second approach is aimed at identifying priority areas based on which areas of the landscape have the greatest benefit, but does not balance different treatment objectives. Both are methods for calculating the total RROI per Stewardship Atlas unit (i.e. SPV); one is a weighted approach, the other is simply a summation (i.e. equal weights). These two methods are shown below.

Balance Objectives: calculate DiMA pillar-weighted RROI

The "Balance Objectives" approach calculated the total RROI per Stewardship Atlas unit as a weighted sum of pillar RROI based on the unit's DiMA and corresponding pillar weights. Because the range of RROI values for each pillar varies, it was necessary to first normalize each pillar RROI for RROI≥0 and RROI<0; the result was that all pillar RROI values where RROI ≥ 0 was within the range of 0-1. Then, per the SPV calculation shown on the previous page: for each Stewardship Atlas unit, each pillar normalized RROI value was multiplied by its unique DiMA pillar weight, and all weighted normalized pillar RROI values were summed to calculate a weighted sum of RROI for each Stewardship Atlas unit.

Maximize RROI: sum pillar RROI

The "Maximize RROI" approach calculated the total RROI per Stewardship Atlas unit as a sum of pillar RROI. Per the SPV calculation shown on the previous page: for each Stewardship Atlas unit, each Pillar RROI was multiplied by a weight of 1, and then all values were summed (i.e. simple sum of pillar RROI).

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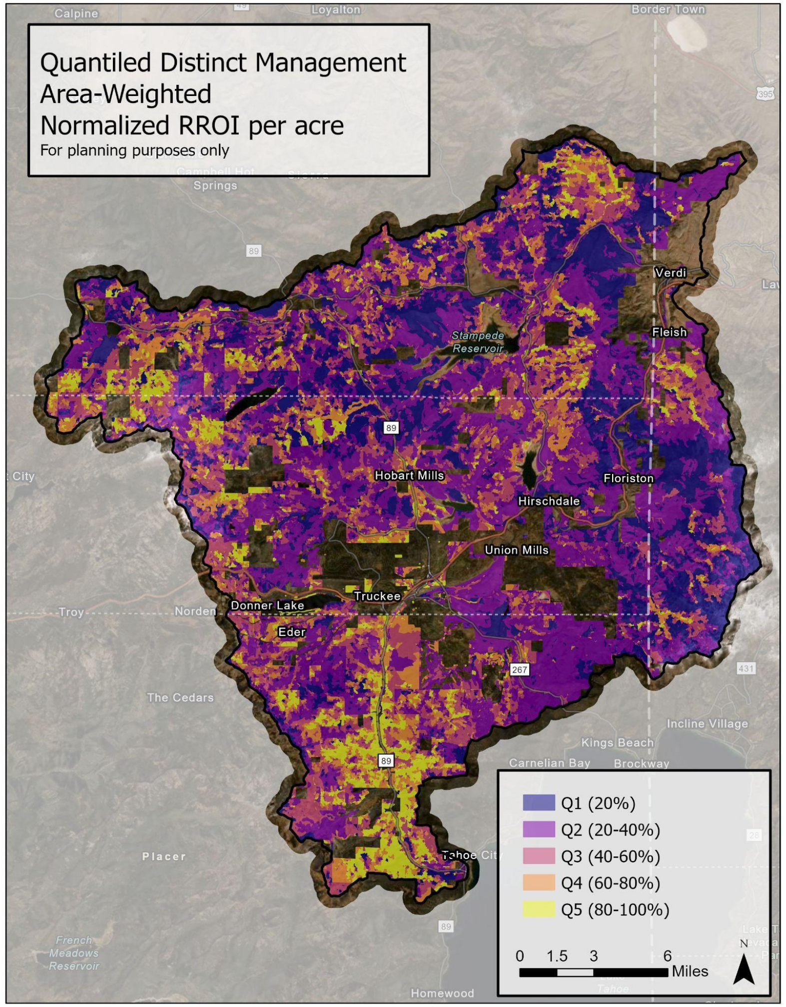
Project Scenario Development

Unrefined orientation (non-spatially optimized)

Balance Objectives



Maximize RROI

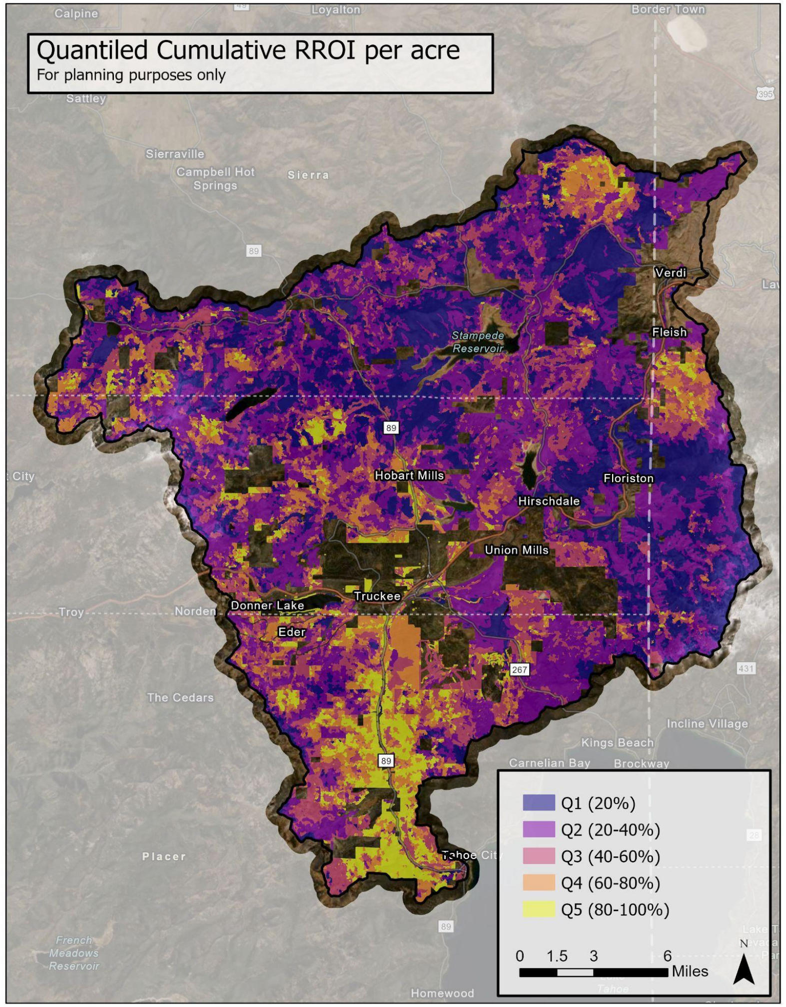


Figure 34. RROI per acre for the two scenario categories ("Balance Objectives" and "Maximize RROI"). Note: Stewardship Atlas units where no DiMA was assigned are not symbolized, as projects were not developed for these areas

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Project Scenario Development

Spatially-optimized project scenario development

Planners could simply use information from the DiMA pillar-weighted RROI ("Balance Objectives") or cumulative pillar RROI ("Maximize RROI") by Stewardship Atlas unit to determine which individual units to treat. However, on larger landscapes, it is typically more optimal to treat contiguous areas where there are high concentrations of value related to treatment objectives due to economies of scale, particularly related to costs associated with moving equipment, staff, building roads, etc. ForSys facilitates this spatially-optimized project development that builds upon the previous step of calculating a weighted RROI (i.e. SPV).

In order to generate a single scenario of spatially-grouped project areas that are optimized to maximize the DiMA pillar-weighted RROI, it was necessary to define assumptions and parameters for ForSys. Firstly, ForSys requires an adjacency matrix of the Stewardship Atlas segments (i.e. matrix providing information about which Stewardship Atlas units are adjacent to other Stewardship Atlas units); an adjacency matrix for the MTRW Stewardship Atlas was generated to facilitate the grouping of polygons into contiguous projects. Next, we designated that although projects could be developed across Stewardship Atlas units with no DiMA (i.e. small private ownership), these units could not be included in the final project areas (upon guidance from TRWC). Similarly, projects could be built across Stewardship Atlas units with negative DiMA pillar-weighted RROI, but these units could not be included in the final project area for treatment and prioritization. Lastly, for a single scenario, ForSys requires the user to define the number of projects to develop; a constraint per project for either size (acres) or budget; and an objective. **For this analysis, six scenarios were identified.**

Here, **the ForSys "objective" is to maximize the RROI based on the user's treatment goals**. If the goal is to balance objectives (i.e. which pillars are more or less important to management), then ForSys will build projects in areas that most meet those objectives based on the DiMA pillar weights. If the goal is to maximize RROI, then ForSys will build projects in areas that simply maximize the cumulative RROI, regardless of which treatment goals (i.e. pillars) may be more or less important for particular areas.

Table 27. Six scenarios identified for analysis and comparison, with differing combinations of objectives, number of projects, and target acreage per project

Scenario	Objective	Number of projects	Target acreage per project
A	Balance Objectives	10	5,000
B	Balance Objectives	20	2,500
C	Balance Objectives	50	1,000
D	Maximize RROI	10	5,000
E	Maximize RROI	20	2,500
F	Maximize RROI	50	1,000

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Project Scenario Development

Results: Scenario A Projects

Objective	Number of projects	Target acreage per project
Balance Objectives	10	5,000
36% of the RROI achieved by treating 16% of the landscape		

Please see Appendix for detailed results regarding estimated cost per project, ownership breakdown, and potential treatment type breakdown.

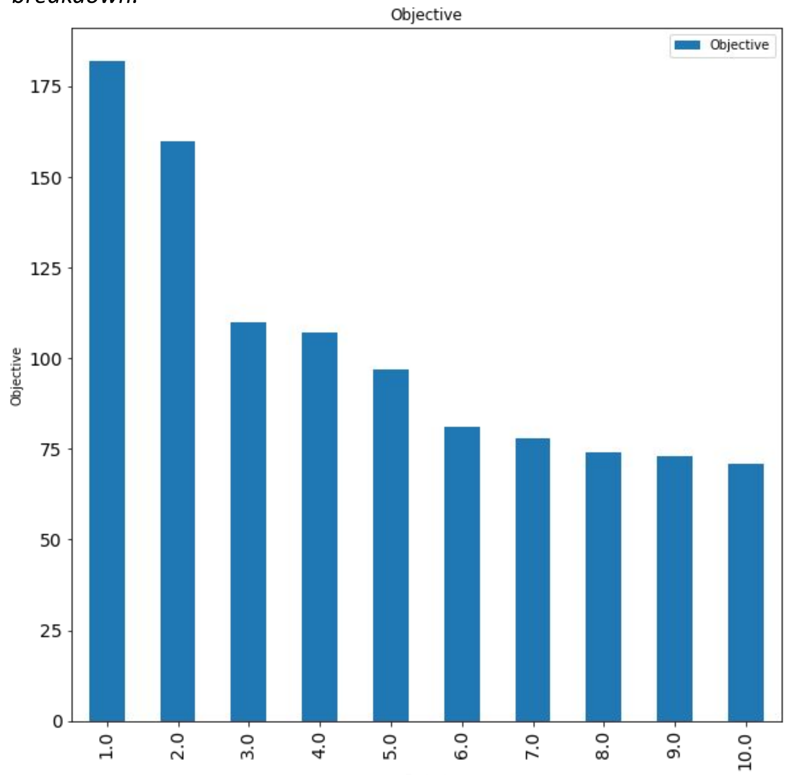

Figure 37. Scenario A DiMA-weighted RROI per project (i.e. "Objective" for the ForSys optimization program)

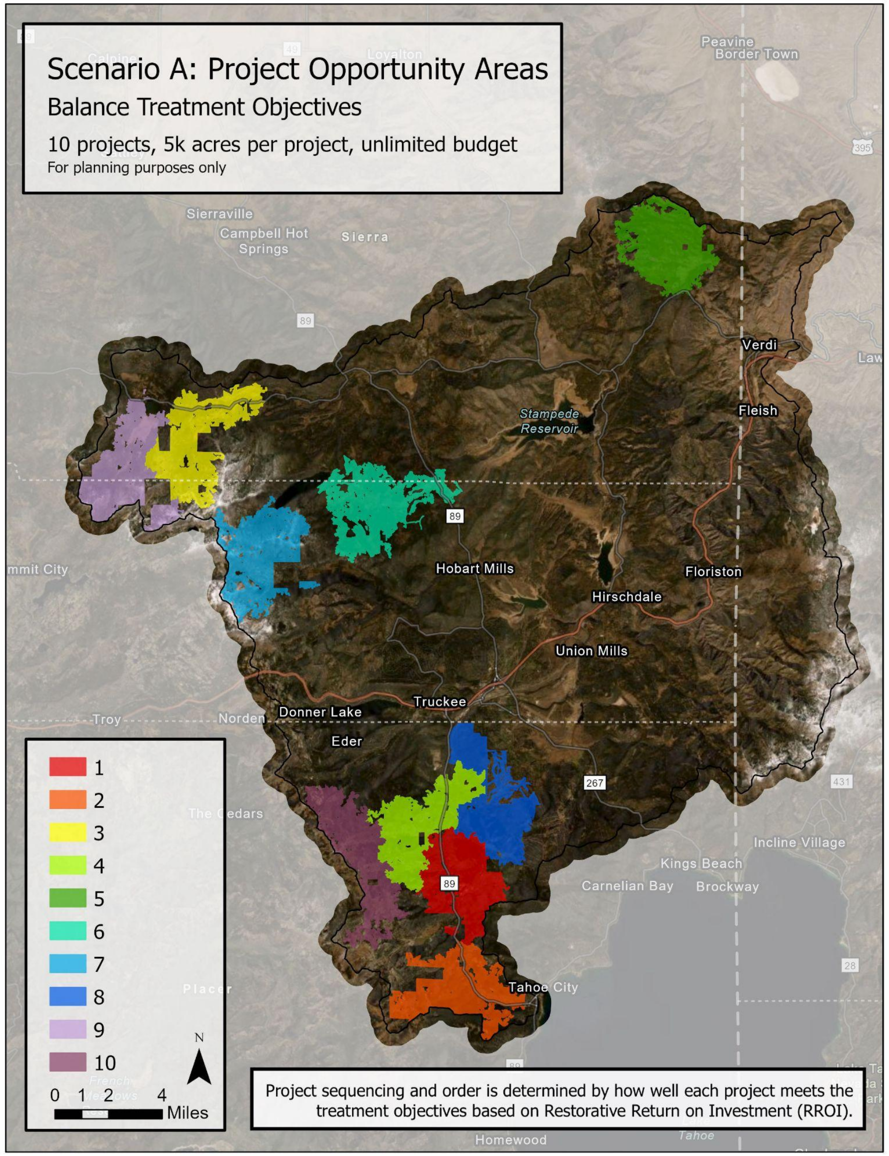

Figure 36. Scenario A projects

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Project Scenario Development

Results: Scenario B Projects

Objective	Number of projects	Target acreage per project
Balance Objectives	20	2,500
39% of the RROI achieved by treating 16% of the landscape		

Please see Appendix for detailed results regarding estimated cost per project, ownership breakdown, and potential treatment type breakdown.

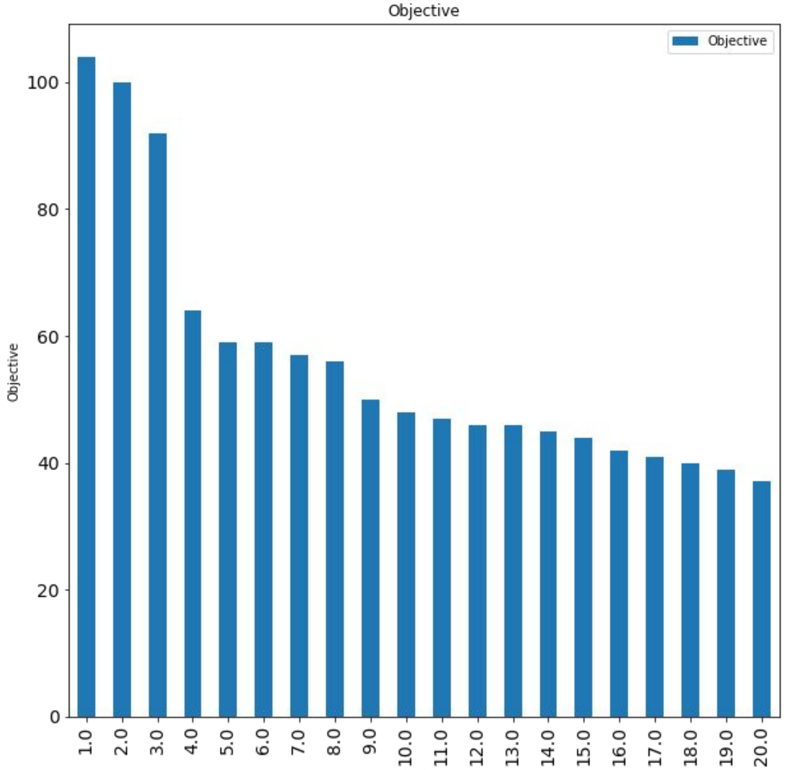

Figure 37. Scenario B DiMA-weighted RROI per project (i.e. "Objective" for the ForSys optimization program)

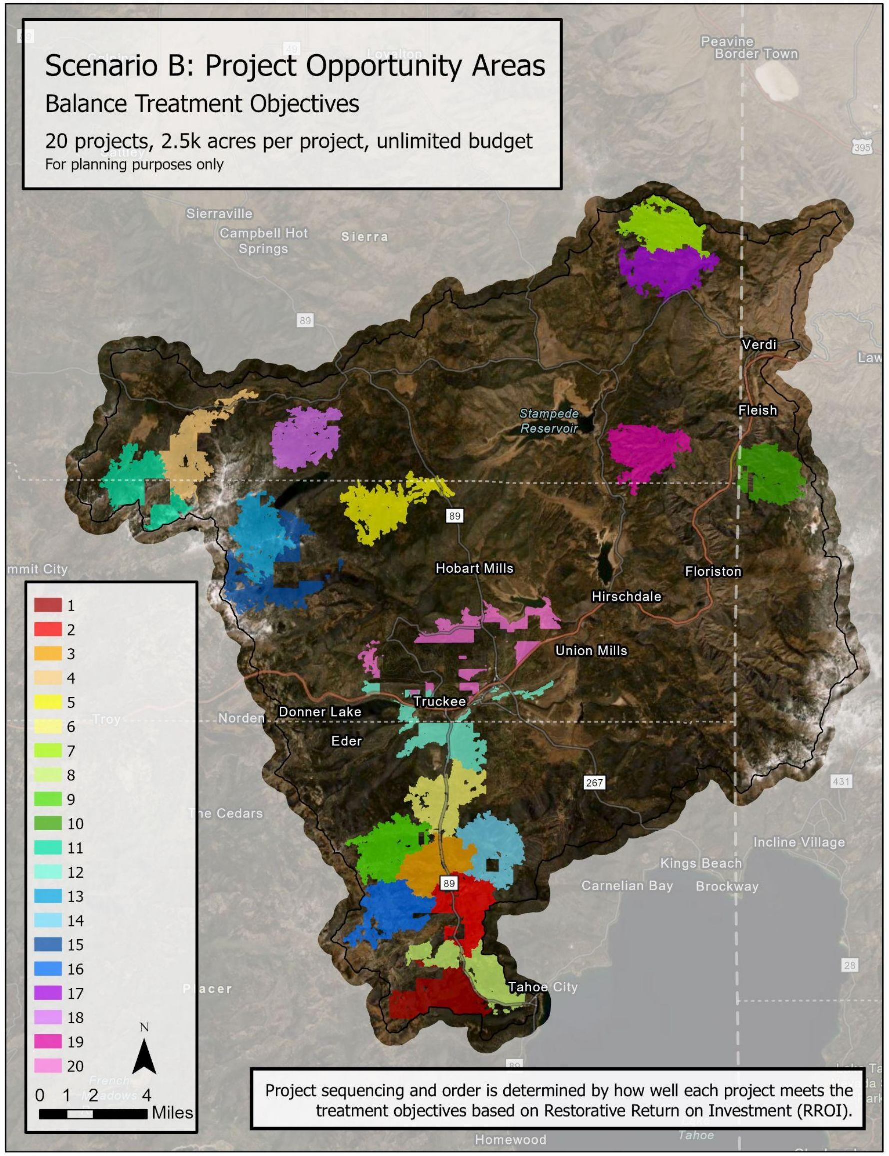

Figure 38. Scenario B projects

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Project Scenario Development

Results: Scenario C Projects

Objective	Number of projects	Target acreage per project
Balance Objectives	50	1,000
41% of the RROI achieved by treating 16% of the landscape		

Please see Appendix for detailed results regarding estimated cost per project, ownership breakdown, and potential treatment type breakdown.

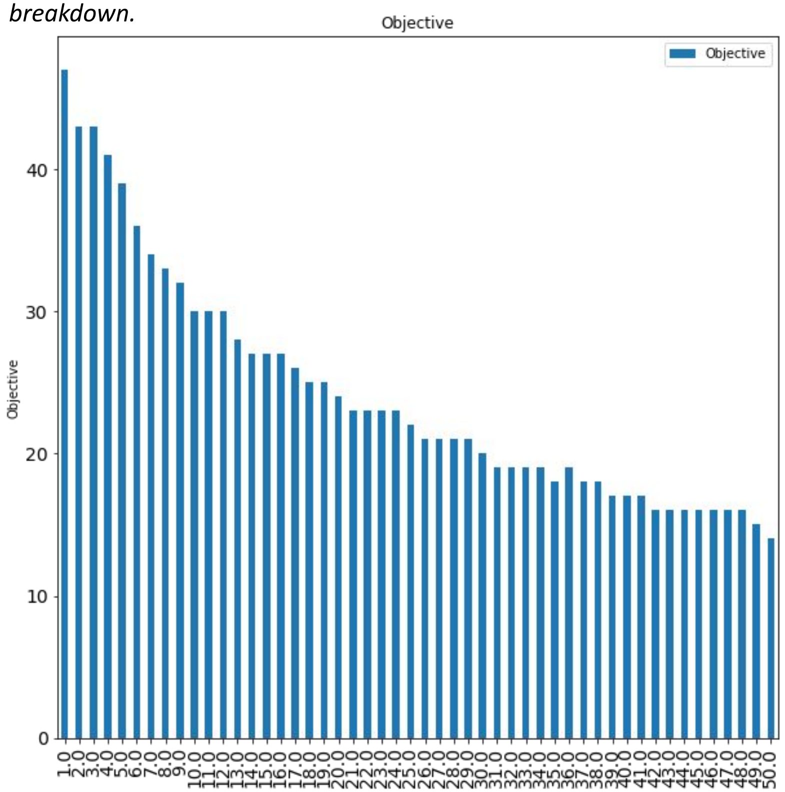

Figure 37. Scenario C DiMA-weighted RROI per project (i.e. "Objective" for the ForSys optimization program)

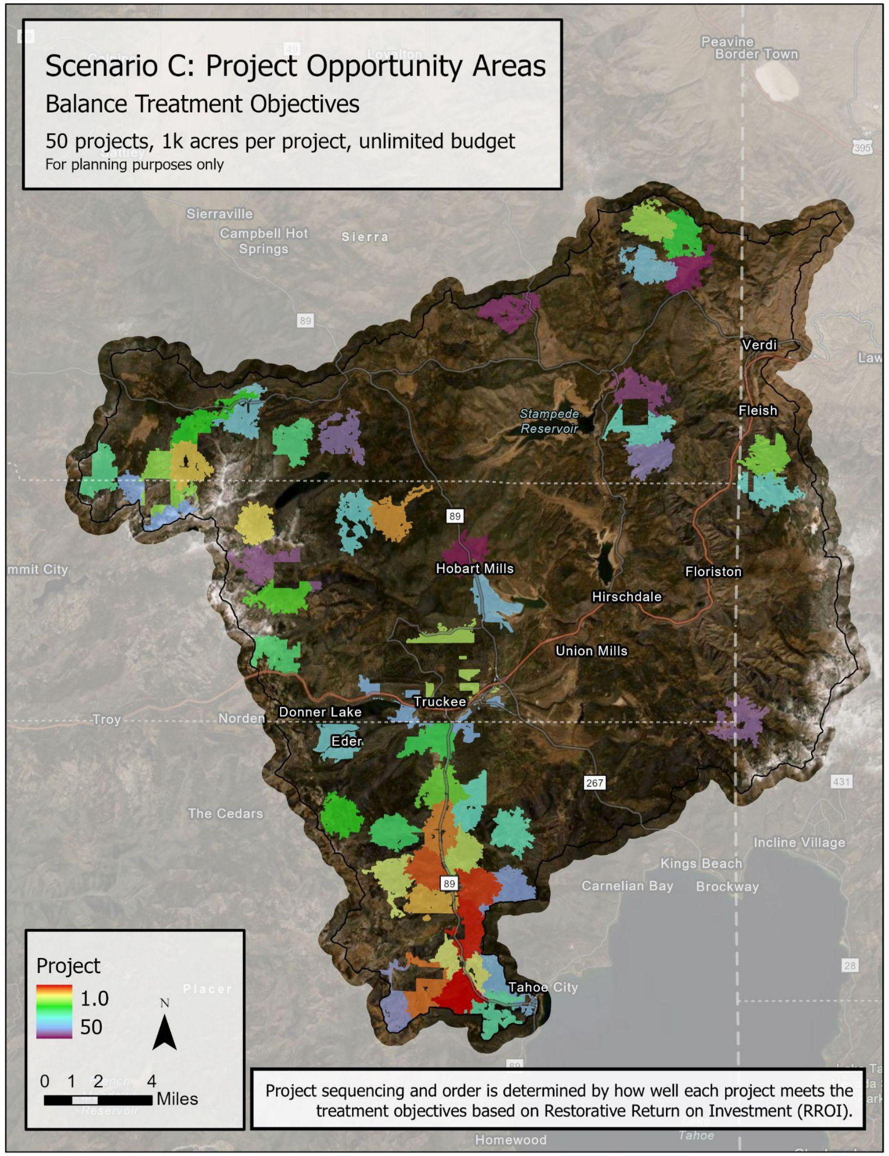

Figure 40. Scenario C projects

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Project Scenario Development

Results: Scenario D Projects

Objective	Number of projects	Target acreage per project
Maximize RROI	10	5,000
41% of the RROI achieved by treating 16% of the landscape		

Please see Appendix for detailed results regarding estimated cost per project, ownership breakdown, and potential treatment type breakdown.

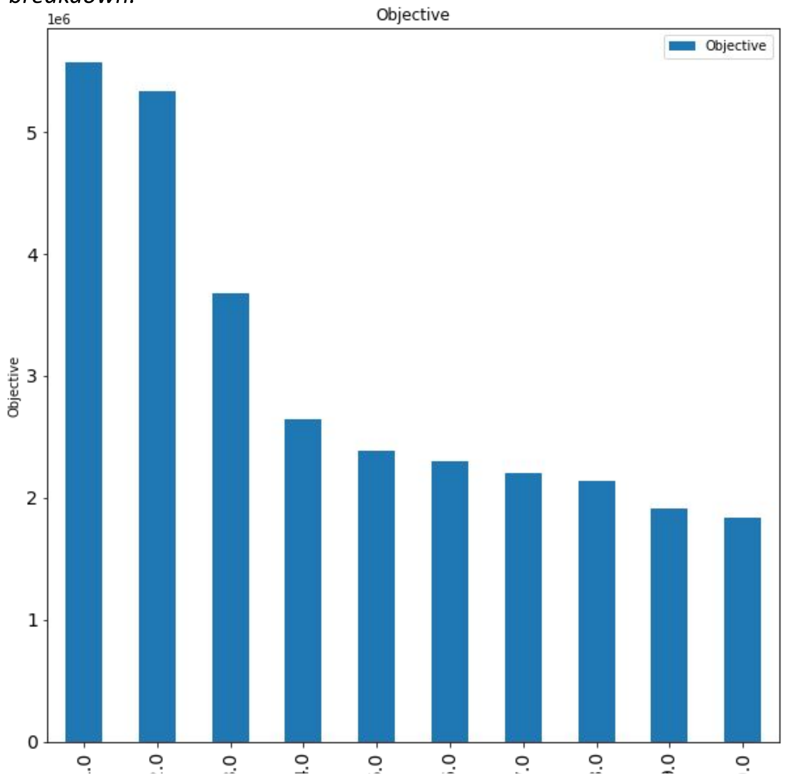

Figure 37. Scenario D cumulative non-pillar weighted RROI per project (i.e. "Objective" for the ForSys optimization program)

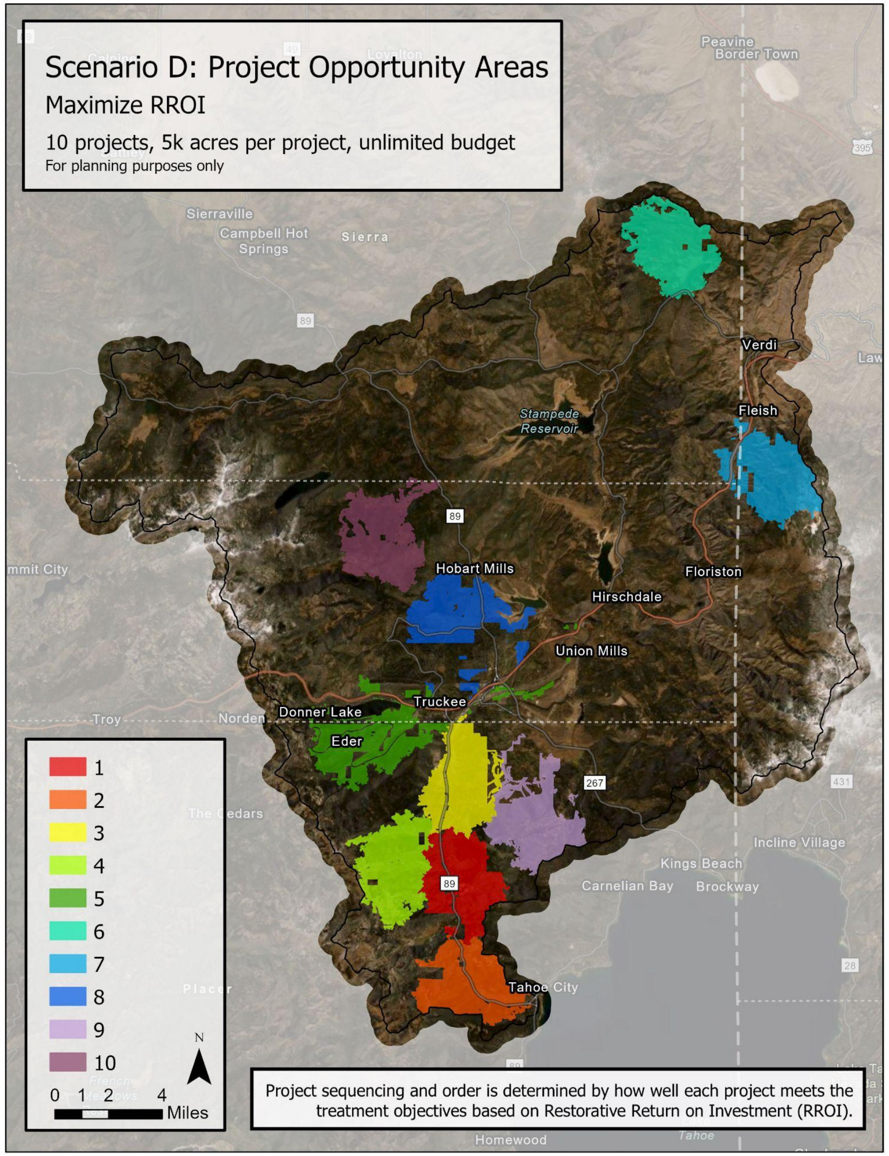

Figure 42. Scenario D projects

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Project Scenario Development

Results: Scenario E Projects

Objective	Number of projects	Target acreage per project
Maximize RROI	20	2,500
42% of the RROI achieved by treating 16% of the landscape		

Please see Appendix for detailed results regarding estimated cost per project, ownership breakdown, and potential treatment type breakdown.

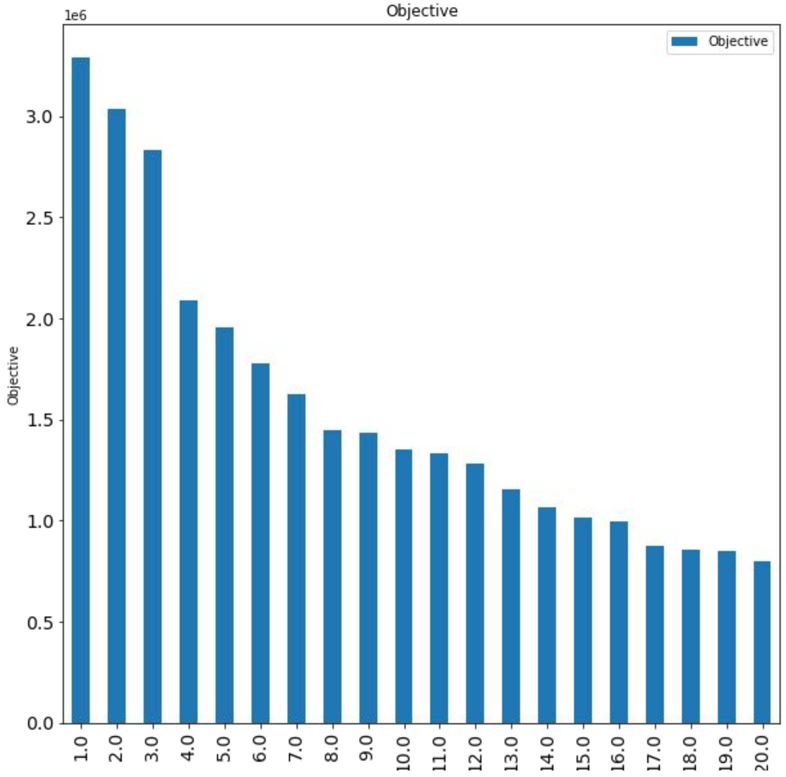

Figure 37. Scenario E cumulative non-pillar weighted RROI per project (i.e. "Objective" for the ForSys optimization program)

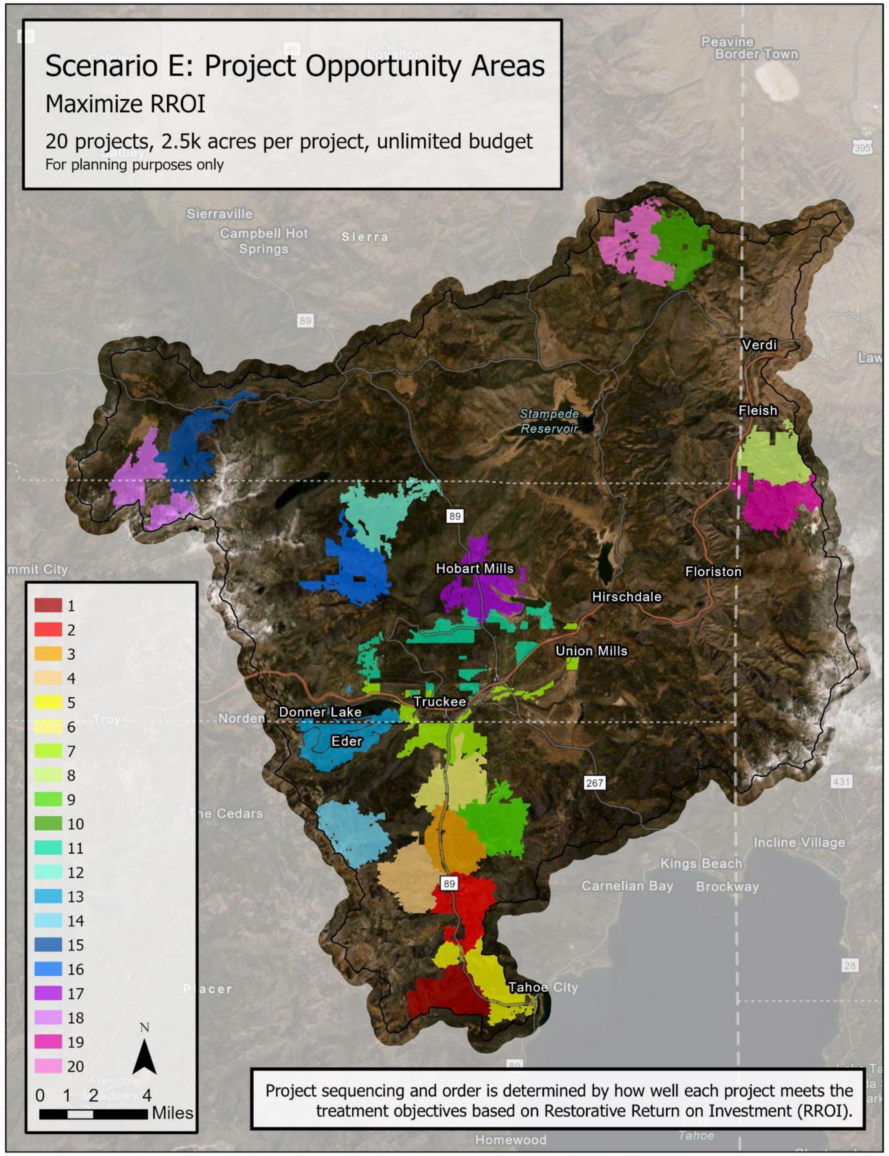

Figure 44. Scenario E projects

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Project Scenario Development

Results: Scenario F Projects

Objective	Number of projects	Target acreage per project
Maximize RROI	50	1,000
45% of the RROI achieved by treating 16% of the landscape		

Please see Appendix for detailed results regarding estimated cost per project, ownership breakdown, and potential treatment type breakdown.

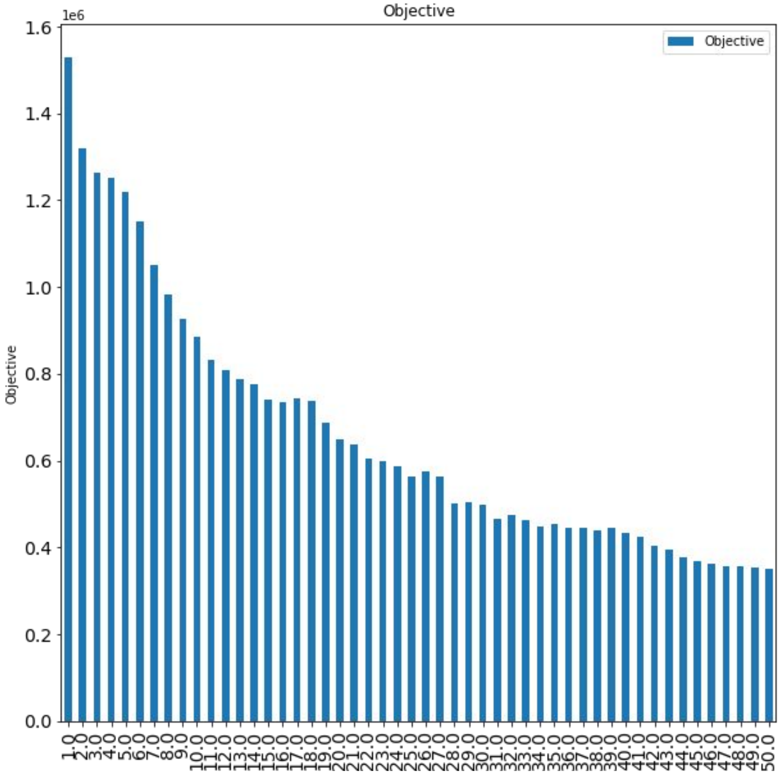

Figure 37. Scenario F cumulative non-pillar weighted RROI per project (i.e. "Objective" for the ForSys optimization program)

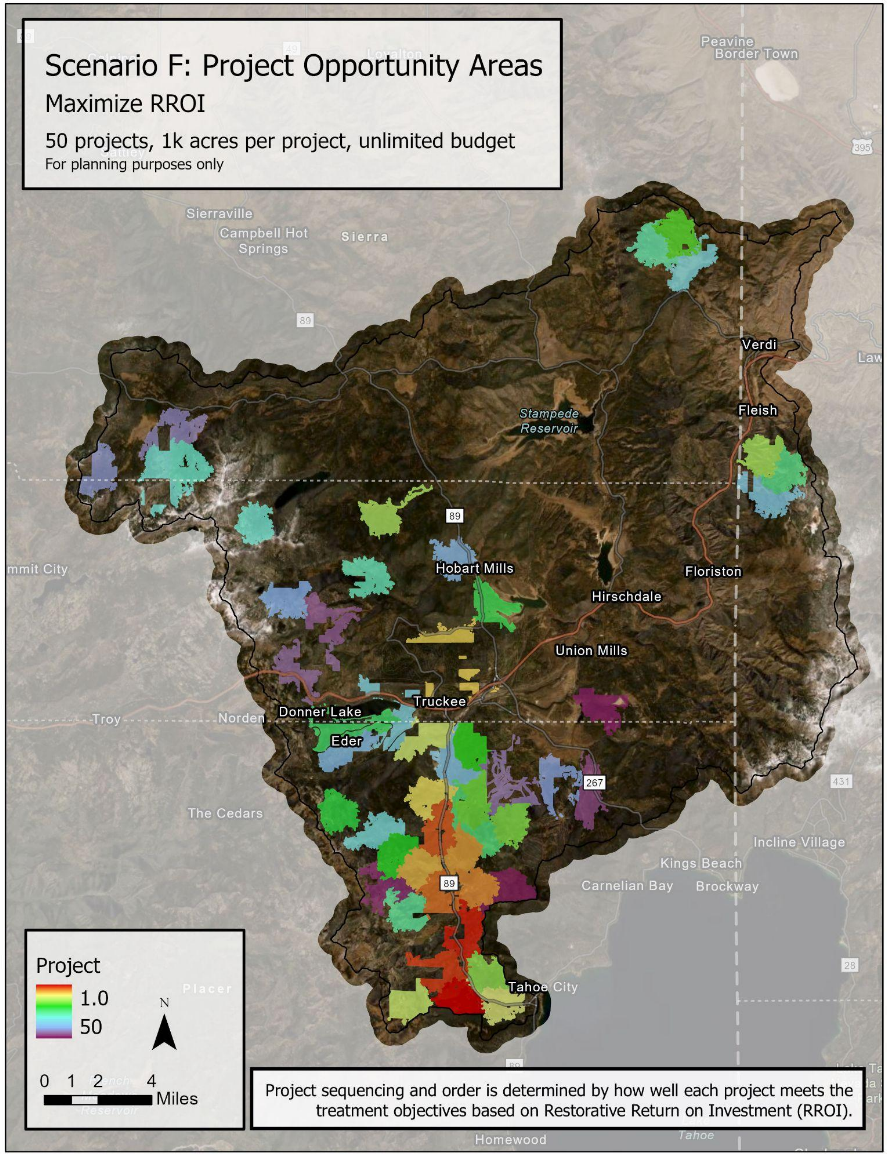

Figure 46. Scenario F projects

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Project Scenario Development

General summary

Generally, across all scenarios:

- **Areas identified with a high RROI** (whether "Balance Objectives" or "Maximize RROI") **represent areas where forest health treatments could have the greatest impact on reducing risk and improving ecological function.**
- Within each scenario, **projects were prioritized based on how well they met their objectives**; the highest priority projects best achieved the objective for each scenario (i.e. "Balance Objectives" or "Maximize RROI").
- Information regarding ownership distribution, potential treatments, and potential treatment costs have been summarized for all scenarios, and can be used to help facilitate the hand-off between planning and implementation.

There were several important differences and trends amongst the six developed scenarios:

- The total RROI achieved in Scenarios A, B, and C ("Balance Objectives") was slightly less than that of Scenarios D, E, and F ("Maximize RROI"). This makes sense in that **when treatment objectives are balanced, it will result in some tradeoffs and may result in less RROI achieved**; in other words, balancing objectives may drive treatments toward areas that don't necessarily maximize the total RROI.
- The **total RROI achieved by scenario increased as the number of projects increased and the project size decreased**; Scenarios C and F had the greatest RROI achieved for the "Balance Objectives" and "Maximize RROI" scenarios, respectively. This is due to the way that projects are developed using the adjacency function when spatially-optimized in ForSys; larger projects must aggregate adjacent polygons, which may result in some polygons being included when they have lower RROI than a different area that is non-adjacent. However, this **increase in RROI for a greater number of projects may be deemed to not be worth the cost in terms of the economies of scale with respect to treatment logistics**. Note that project costs shown in the Appendix are only approximations based on vegetation removal, and not the secondary costs of building roads and other logistical constraints that may increase cost.

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Treatment Matrix

Overview

The **TRWC selected Scenario B** as the scenario to pursue for further investigation with regards to planning and implementation.

This scenario was selected due to the following factors:

- Projects were developed using a balanced-objective approach that accounted for differences in management goals across different areas of the landscape: this approach allows benefit of treatments to be distributed amongst different priorities (i.e. both biodiversity conservation and enhancement of fire adapted communities).
- 2,500 acres is accepted as a suitable project size target for obtaining environmental compliance and moving forward with coordinated project planning considerations.
- Twenty projects allowed for high RROI to be achieved while still balancing economies of scale with regards to treatment funding and implementation.

A treatment matrix (i.e. mapped treatments by Stewardship Atlas unit) was developed for this scenario to better understand the distribution of potential treatments within each project area. For the treatment matrix, we chose to display just the initial treatment, since it is possible and likely that the follow treatment would need to be determined based on site assessments.

As stated previously, the delineated Stewardship Atlas units and assigned potential treatments serve as a helpful starting place for field personnel and should facilitate the hand-off between planning and implementation, but are not a substitute for treatment layout.

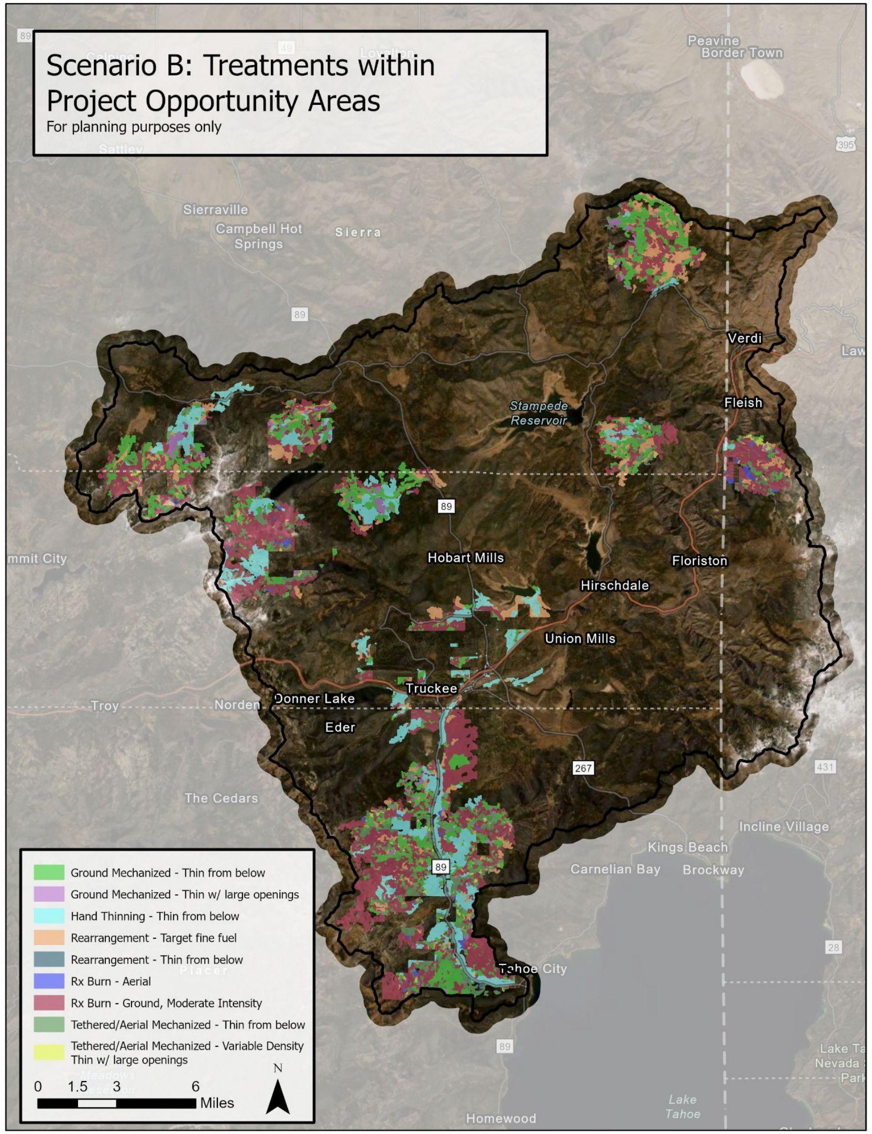

Figure 47. Scenario B treatments

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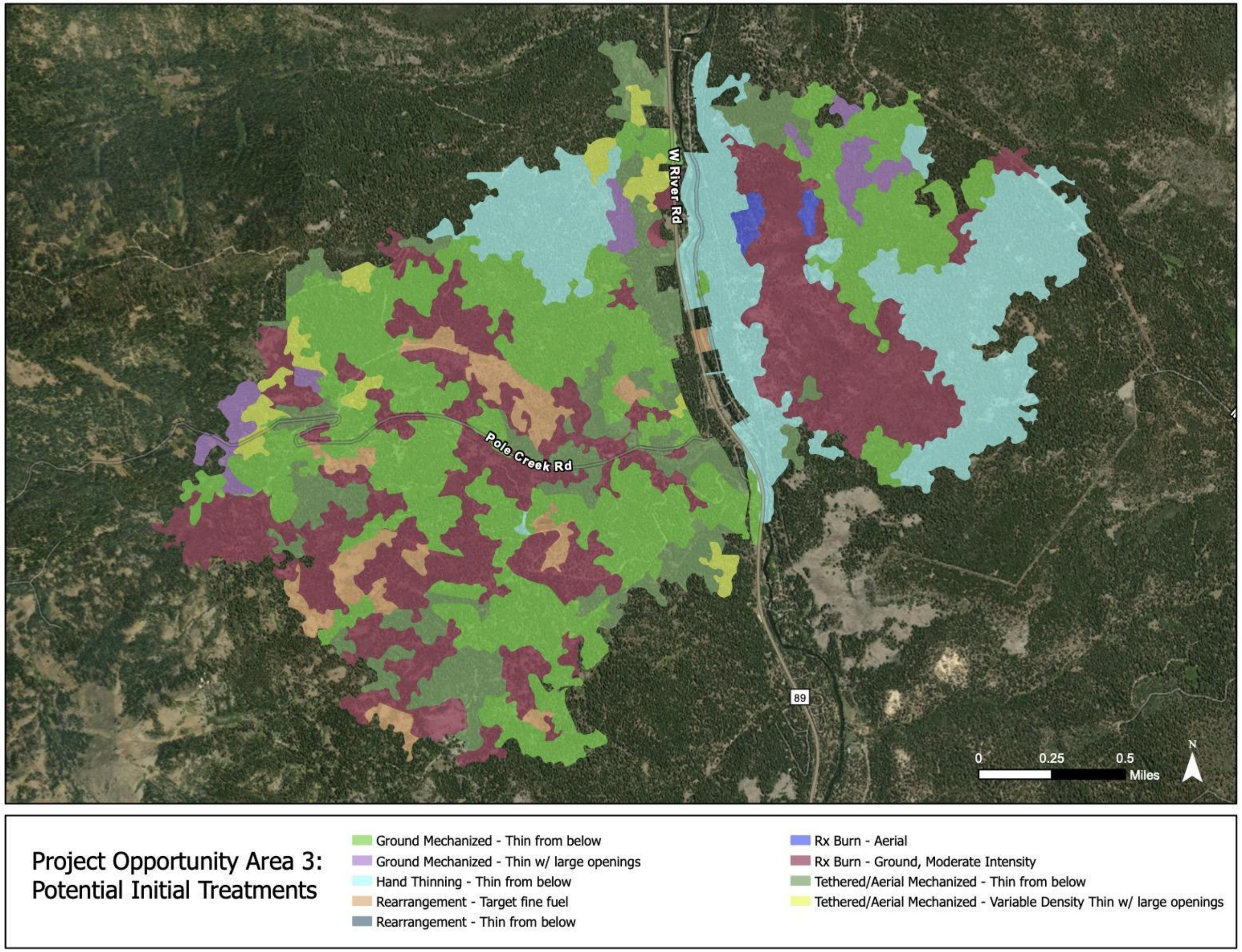
Treatment Matrix

Figure 48. Example of Treatment Matrix for single project from Scenario B (all Treatment Matrices by project are included in the Appendix)



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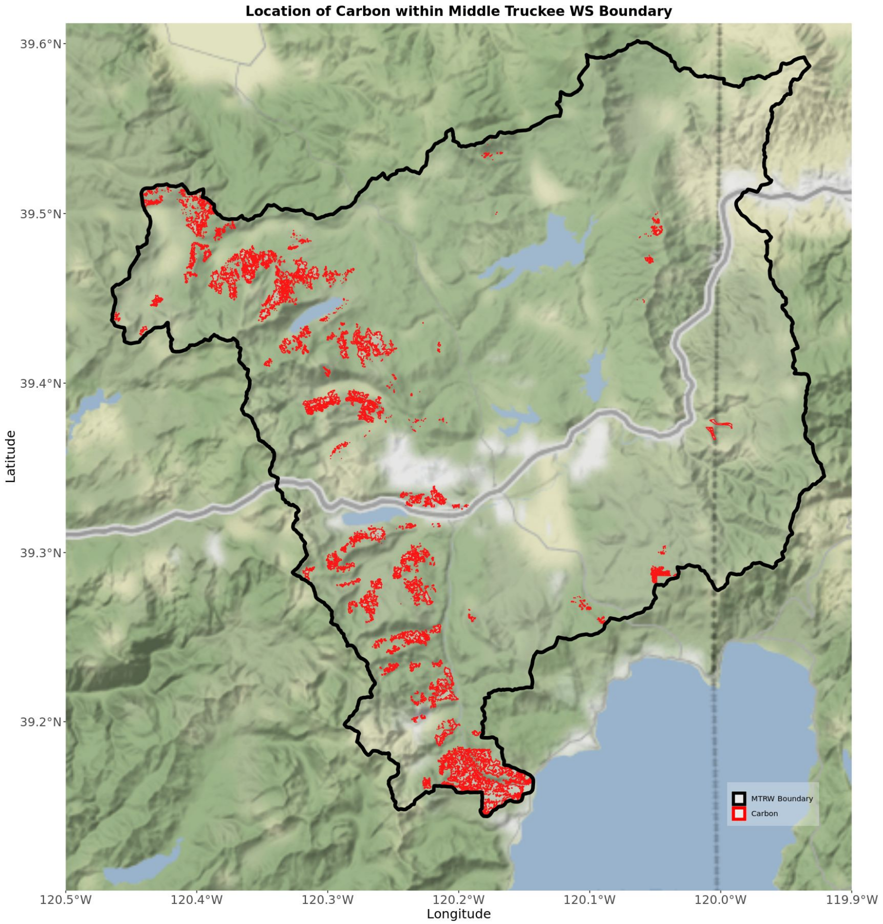
Appendix: SARA maps

A directory containing maps of SARA footprints can be found in this supplemental data folder. These data are also available on the 34N OPENNRM platform (available upon request from TRWC) as interactive webmaps.

/supplemental_data
/sara_maps
/[sara_name].png

Example for High Carbon Storage Areas:



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Appendix Table: SARA-pillar contributions questionnaire raw scoring

SARA QUESTIONNAIRE RAW SCORES										
	Fire-Adapted Communities	Economic Diversity	Social and Cultural Well-Being	Air Quality	Water Security	Wetland Integrity	Biodiversity Conservation	Forest Resilience	Carbon Sequestration	Fire Dynamics
Structures-Primary Residential	0.5	0	0	0	0	0	0	0	0	0.25
Structures-Transitory	0.5	0	0	0	0	0	0	0	0	0.25
Structures-Other	0.5	0	0	0	0	0	0	0	0	0.25
Emergency Services-Fire and Police	0.5	1	0	0	0	0	0	0	0	0.5
Emergency Services-Medical	0.5	1	0	0	0	0	0	0	0	0.25
Communications-Cell towers and radio antennae	0.5	1	0	0	0	0	0	0	0	0.25
Power-Transmission lines	0.5	1	0	0	0	0	0	0	0	0.25
Power-Substations	0.5	1	0	0	0	0	0	0	0	0.25
Water-Delivery	0.5	1	0	0	0.75	0	0	0	0	0
Water-Water Resources Monitoring Stations	0.5	1	0	0	0.25	0	0	0	0	0
Water-Infiltration	0	0	0	0	1	0	0	0	0	0
Water-Waterbodies/Rivers and perrenial streams (includes riparian areas)	0	0	0.5	0	0.5	1	1	1	0	0.5
Cultural-Historic	0.5	0	1	0	0	0	0	0	0	0.25
Recreation-Trails	0.5	1	1	0	0	0	0	0	0	0.25
Recreation-Ski Areas	0.5	1	1	0	0	0	0	0	0	0.5
Recreation-Ski lifts	0.5	1	1	0	0	0	0	0	0	0
Recreation-Campgrounds	0.5	1	1	0	0	0	0	0	0	0.25
Recreation-Day use areas	0.5	1	1	0	0	0	0	0	0	0.25
Recreation-Boating sites	0.5	1	1	0	0	0	0	0	0	0
Strategic Fuel Areas-Critical access roads	0.5	0	0	0	0	0	0	0	0	0.5
Strategic Fuel Areas-Railroads	0.5	1	0	0	0	0	0	0	0	0.5
Strategic Fuel Areas-Community transmission zones	1	0	0	0	0	0	0	0	0	1
Strategic Fuel Areas-Community fuel reduction zones	1	0	0	0	0	0	0	0	0	1
Forest Investments-Carbon	0	0	0	0.5	0	0	0	1	1.25	0.75
Ecological Assemblages-Large tree groves	0	0	0.5	0.5	1	0	1	1	1	1
Ecological Assemblages-Aspen stands	0	0	0.5	0	0.5	0.5	1	1	1	1
Ecological Assemblages-Meadows and fens	0	0	0.5	0	0.5	1	1	1	1	0.5
Ecological Assemblages-Sensitive plants - Alpine species	0	0	0.5	0	1	0	1	0	1	0.5
Ecological Assemblages-Sensitive plants - Subalpine species	0	0	0.5	0	1	0	1	1	1	0.5
Ecological Assemblages-Sensitive plants - Riparian species	0	0	0.5	0	0.5	1	1	0	1	0.5
Ecological Assemblages-Nest and den sites	0	0	0.5	0	0	0	1	0	0	0.5
Ecological Assemblages-SPOW Habitat (Tall Tree/High Canopy Cover Forest)	0	0	0.5	0	1	0	1	0	1	1

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Appendix Table: SARA-pillar contributions

SARA PILLAR CONTRIBUTIONS										
	Fire-Adapted Communities	Economic Diversity	Social and Cultural Well-Being	Air Quality	Water Security	Wetland Integrity	Biodiversity Conservation	Forest Resilience	Carbon Sequestration	Fire Dynamics
Structures-Primary Residential	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
Structures-Transitory	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
Structures-Other	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
Emergency Services-Fire and Police	0.25	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25
Emergency Services-Medical	0.29	0.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14
Communications-Cell towers and radio antennae	0.29	0.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14
Power-Transmission lines	0.29	0.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14
Power-Substations	0.29	0.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14
Water-Delivery	0.22	0.44	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00
Water-Water Resources Monitoring Stations	0.29	0.57	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00
Water-Infiltration	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
Water-Waterbodies/Rivers and perrenial streams (includes riparian areas)	0.00	0.00	0.11	0.00	0.11	0.22	0.22	0.22	0.00	0.11
Cultural-Historic	0.29	0.00	0.57	0.00	0.00	0.00	0.00	0.00	0.00	0.14
Recreation-Trails	0.18	0.36	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.09
Recreation-Ski Areas	0.17	0.33	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.17
Recreation-Ski lifts	0.20	0.40	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Recreation-Campgrounds	0.18	0.36	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.09
Recreation-Day use areas	0.18	0.36	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.09
Recreation-Boating sites	0.20	0.40	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strategic Fuel Areas-Critical access roads	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50
Strategic Fuel Areas-Railroads	0.25	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25
Strategic Fuel Areas-Community transmission zones	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50
Strategic Fuel Areas-Community fuel reduction zones	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50
Forest Investments-Carbon	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.29	0.36	0.21
Ecological Assemblages-Large tree groves	0.00	0.00	0.08	0.08	0.17	0.00	0.17	0.17	0.17	0.17
Ecological Assemblages-Aspen stands	0.00	0.00	0.09	0.00	0.09	0.09	0.18	0.18	0.18	0.18
Ecological Assemblages-Meadows and fens	0.00	0.00	0.09	0.00	0.09	0.18	0.18	0.18	0.18	0.09
Ecological Assemblages-Sensitive plants - Alpine species	0.00	0.00	0.13	0.00	0.25	0.00	0.25	0.00	0.25	0.13
Ecological Assemblages-Sensitive plants - Subalpine species	0.00	0.00	0.10	0.00	0.20	0.00	0.20	0.20	0.20	0.10
Ecological Assemblages-Sensitive plants - Riparian species	0.00	0.00	0.11	0.00	0.11	0.22	0.22	0.00	0.22	0.11
Ecological Assemblages-Nest and den sites	0.00	0.00	0.25	0.00	0.00	0.00	0.50	0.00	0.00	0.25
Ecological Assemblages-SPOW Habitat (Tall Tree/High Canopy Cover Forest)	0.00	0.00	0.11	0.00	0.22	0.00	0.22	0.00	0.22	0.22
TOTAL	7.05	6.53	3.87	0.23	2.72	0.72	2.15	1.24	1.78	5.73

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Appendix: TCSI Contemporary Reference Condition Basal Area Departure

Per Wilson and Manley (2021), the contemporary range of variability (CRV) was defined for reference sites and compared to the TCSI landscape, based on similar climate classes, where 1 equal identical distribution and 0 equal no similarity in distribution. Reference sites and climate classes were based on Jeonimo et al (2018). Reference sites were areas with no historical vegetation management, where the fire regime intact (≥2 fires in last 60 years with ≥1 fire in last 30 years) and fire severity of fires were primarily low to moderate severity (≥1 fire with moderate severity effects, <10 hectares of high severity effects). Climate classes were based on climatic water deficit, January minimum temperature, and actual evapotranspiration. The TCSI landscape was classified into four topographic positions using the LMU tool (version 2: https://www.ice.ucdavis.edu//project/landscape_management_unit_lmu_tool): ridgetops, valley bottoms, northeast slopes, and southwest slopes. Land Management Units (LMUs) larger than 500 ha were split along watershed boundaries and LMUs smaller than 4 ha were joined with neighboring LMUs. Each LMU was assigned the majority climate class (Jeronimo et al., 2019). Tree density and basal areas was then identified using Silviaterra data. Five of the fourteen climate classes did not have reference data, these sites were grouped with adjacent climate class data.

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Appendix: Methodology for mapping HRV-informed Biophysical Units

First, a proxy for cumulative tree biomass production under HRV conditions (i.e. historical, pre-settlement dynamic equilibrium conditions) was derived at a 5 meter raster cell level for all forested cells. This was computed by summing tree height (feet) values every 20 years between simulation years 500-1,500 for the MTRW. We posit that the cumulative sum of tree height (hereafter, "biomass") under HRV conditions represents an index of realized site productivity that effectively integrates the effects of all the disturbance and succession processes in LDSim, including the frequency and severity of wildfire, the rate of tree establishment and the rate of tree growth after establishment, as well as numerous other metrics. To reduce the "noise" in the data caused by pixelation, a 25x25 meter focal mean smoothing was applied to the cumulative tree biomass layer. Thus, each 5 meter cell value was replaced with the mean of the cell values within a 5x5 meter cell window centered on the focal cell.

Second, one million cells were randomly sampled to extract the values of biomass and the following nine derived biophysical variables. Each of these biophysical variables is involved either directly or indirectly (e.g., combined with other variables into a composite index, such as the site index) in one or more of the processes affecting cumulative tree biomass. An asterisk (*) indicates that the variable is climate-based.

- Precipitation*
- Water balance deficit*
- Available soil water
- Topographic wetness index*
- Heat load index
- Growing degree days*
- Topographic position index
- Aspect (linearly transformed along NE-SW axis)
- Elevation

In addition, the climate-based variables were derived from local climate data representing the period 1981-2010 as provided in the 2014 California Basin Characterization Model, which were deemed as a reasonable proxy for the climate during the historical reference period.

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Appendix: Methodology for mapping HRV-informed Biophysical Units (cont'd)

Third, a Random Forest analytical framework (Breiman 2001) was used to predict biomass from the biophysical site variables. Random Forest is a non-parametric machine learning (ML) technique that allows for non-linear and heterogeneous responses (e.g., biomass may respond differently to precipitation as elevation increases), and thus can account for complex interactions among the covariates, or multiple predicting variables. The predicted value at each cell is an index of the likely long-term realized productivity of the site under historical dynamic equilibrium conditions. In effect, this is a "site index," since Random Forest did not produce a single equation for predicting biomass that can be reported here. Rather, Random Forest built a model composed of 500 regression trees (i.e. a hierarchical, tree-like partitioning of the data based on the predictors), and calculated the final predicted value as the average predicted Biomass value across the 500 regression trees. The resulting model from Random Forest was able to explain ~70% of the variation in biomass; the remaining 30% of variation in biomass was "noise" that could not be explained by the nine predictors (at least by this technique). This was deemed reasonable performance metrics for the data available and application of the results.

Fourth, the predicted spatially-distributed biomass was classified into four equal-area classes, or Biophysical Classes (BPCs), based on quartiles of the data across the landscape, plus a zero class for all non-forest cells. Each class encompasses approximately 20% of the landscape. The four non-zero classes in the final BPC layer range from the least productive to most productive sites. Each class represents the relative biophysical site conditions supporting differing levels of tree biomass (on average, over time) under historical dynamic equilibrium conditions (as simulated). The zero, non-forest class represents areas supporting "unknown" biomass. Each BPC was distinguishable across the nine biophysical variables and cover type, although there was considerable overlap in each variable among the BPCs.

Lastly, a custom algorithm was applied to simplify the BPC raster by dissolving patches < 1 ha in size (and replacing each cell with the nearest neighbor) and trimming narrow sections or "arms" < 30 m in width. Thus, the final BPC raster was comprised of patches, or Biophysical Units (BPUs) with a minimum size of 1 ha and minimum width at its narrowest of 30 m. The BPUs were used as part of the landscape segmentation process for generating the MTRW Stewardship Atlas.

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Appendix: Methodology for updating LANDFIRE vegetation and fuels using FACTS and CALFIRE THPs

The following completed prescriptions from the CALFIRE and USFS FACTS were used to update MTRW LANDFIRE datasets according to the relationships shown below. IFTDSS was used to update these datasets using their interactive Edit Landscape tool. In order to use the tool, masks were created for each area where LANDFIRE datasets should be updated differently. Information about the Fire Behavior Fuel Model 40 (FBFM40) can be found on an IFDSS page here.

dataset	**Rx type (naming from dataset)**	**Update FBFM40 or apply IFTDSS rule**	**Raise canopy base height by:**
mtrw_CALFIRE_THPS	Alternative Prescription, Sanitation Salvage, Intermediate Treatments	TL3	
mtrw_CALFIRE_THPS	Alternative Prescription, Shelterwood Removal Step, Evenaged Management	TU1	
mtrw_CALFIRE_THPS	Group Selection, None, Unevenaged Management	Clearcut (IFTDSS rule)	
mtrw_CALFIRE_THPS	Selection, None, Unevenaged Management	TL3	1 m
mtrw_CALFIRE_THPS	Alternative Prescription, Group Selection, Unevenaged Management	Clearcut (IFTDSS rule)	
mtrw_CALFIRE_THPS	No Harvest Area, None, No Harvest Area	n/a	
mtrw_CALFIRE_THPS	Sanitation Salvage, None, Intermediate Treatments	TL3	
mtrw_CALFIRE_THPS	Conversion, None, Timberland Conversion	n/a	
MTRW_FACTS_TimberHarvest	Group selection cut	Clearcut (IFTDSS rule)	
MTRW_FACTS_TimberHarvest	Commercial Thinning	TL3	1 m
MTRW_FACTS_TimberHarvest	Shelterwood preparat	TU1	
MTRW_FACTS_HazFuelTrt	Broadcast Burn	TL1	
MTRW_FACTS_HazFuelTrt	Lop and Scatter	SB1	
MTRW_FACTS_HazFuelTrt	Thinning	TL3	1 m
MTRW_FACTS_HazFuelTrt	Chipping	SB1	
MTRW_FACTS_HazFuelTrt	Machine Pile	TL1	
MTRW_FACTS_HazFuelTrt	Jackpot Burn	TL1	
MTRW_FACTS_HazFuelTrt	Machine Pile Burn	TL1	
MTRW_FACTS_HazFuelTrt	Crushing	SB1	
MTRW_FACTS_HazFuelTrt	Biomass Removal	TL3	1 m

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Appendix: Ruleset applied for assigning treatment types

Initial Treatment	Conditions for Initial Treatment (Stewardship Atlas attributes)								Initial Treatment Economics			Follow Treatment	Condition for Follow Treatment	Follow Treatment Economics
	Avg_ Slope	**QMD**	**Can_Cov**	**CC2_8**	**per_dSARA and/or per_PAC**	**per_NWA**	**per_water**	**per_dev**	**Sawlog removal estimate**	**Cost ($/MBF or $/acre)**	**Product Benefit ($/MBF)**		**CC2_8**	**Cost ($/acre)**
Ground Mechanized - Thin from below	<= 35	>10	>40, <=60		<10 and <50	=0	<60	<95	10%	Conditional upon estimated removal. if <6 MBF/acre, $75; elif >=6 and <10 MBF/acre, -$100; else -$200	$500	Rx Burn - Ground, Moderate Intensity	<30	$700
												Ground Mechanized - Thin from below	>=30	$900
Ground Mechanized - Thin w/ large openings	<= 35	>10	>60		<10 and <50	=0	<60	<95	15%	Conditional upon estimated removal. if <6 MBF/acre, $75; elif >=6 and <10 MBF/acre, -$100; else -$200	$500	Rx Burn - Ground, Moderate Intensity	<30	$700
												Ground Mechanized - Thin from below	>=30	$900

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Appendix: Ruleset applied for assigning treatment types (cont'd)

Initial Treatment	**Conditions for Initial Treatment (Stewardship Atlas attributes)**								**Initial Treatment Economics**			**Follow Treatment**	**Condition for Follow Treatment**	**Follow Treatment Economics**
	Avg_ Slope	**QMD**	**Can_Cov**	**CC2_8**	**per_dSARA and/or per_PAC**	**per_NWA**	**per_water**	**per_dev**	**Sawlog removal estimate**	**Cost ($/MBF or $/acre)**	**Product Benefit ($/MBF)**		**CC2_8**	**Cost ($/acre)**
Tethered/Aerial Mechanized - Thin from below	>35, <=65	>10	>40, <=60		<10 and <50	=0	<60	<95	10%	Conditional upon estimated removal. if <8 MBF/acre, $350; elif >=8 and <10 MBF/acre, -$50; else -$100	$500	Rx Burn - Ground, Moderate Intensity	<30	$700
												Hand Thinning - Thin from below	>=30	$2,200
Tethered/Aerial Mechanized - Variable Density Thin w/ large openings	>35, <=65	>10	>60		<10 and <50	=0	<60	<95	15%	Conditional upon estimated removal MBF. if <8 MBF/acre, $350; elif >=8 and <10 MBF/acre, -$50; else -$100	$500	Rx Burn - Ground, Moderate Intensity	<30	$700
												Hand Thinning - Thin from below	>=30	$2,200

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Appendix: Ruleset applied for assigning treatment types (cont'd)

Initial Treatment	Conditions for Initial Treatment (Stewardship Atlas attributes)								Initial Treatment Economics			Follow Treatment	Condition for Follow Treatment	Follow Treatment Economics
	Avg_ Slope	QMD	Can_Cov	CC2_8	per_dSARA and/or per_PAC	per_NWA	per_water	per_dev	Sawlog removal estimate	Cost ($/MBF or $/acre)	Product Benefit ($/MBF)		CC2_8	Cost ($/acre)
Rearrangement - Target fine fuel	<= 35	<=10	<=40	<=30	<10 and <50	=0	<60	<95	0%	$900 per acre	0	Rx Burn - Ground, Moderate Intensity		$700
Rearrangement - Thin from below	<= 35	<=10	<=40	>30	<10 and <50	=0	<60	<95	0%	$900 per acre	0	Rx Burn - Ground, Moderate Intensity		$700
Hand Thinning - Thin from below					>=10 or >=50		<60	<95	0%	$2200 per acre	0			
Rx Burn - Aerial	>65				<10 and <50		<60	<95	0%	$500 per acre	0	Rx Burn - Aerial		$500
Rx Burn - Ground, Low Intensity	<=65				>=10 or >=50		<60	<95	0%	$700 per acre	0	Rx Burn - Ground, Low Intensity		$700
Rx Burn - Ground, Moderate Intensity	<=65				<10 and <50		<60	<95	0%	$700 per acre	0	Rx Burn - Ground, Moderate Intensity		$700

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Appendix: Restoration Abacus

General post-treatment or disturbance value calculation

An important calculation used throughout the Restoration Abacus is the calculation of post-disturbance (planned or unplanned) value. Here, “planned” disturbances refer to treatments. This calculation is used repeatedly in the REBA (with different inputs, depending on the metric to be calculated) to compute various SARA impact metrics, such as value post-treatment, value post-disturbance (no treatment), and value post-treatment and post-disturbance.

EQN 1: $$v_{SARA,t+1} = v_{SARA,t} + (ROSE_{SARA} \times NVC_{SARA,d}/100),$$

where $v_{SARA,\ t+1}$ is the post-disturbance (planned or unplanned) value, $v_{SARA,\ t}$ is the pre-disturbance (planned or unplanned) value, $ROSE_{SARA}$ is the Relative Potential Socio-Ecological value of the SARA, and $NVC_{SARA,d}$ is the SARA’s net value change response to the disturbance (planned or unplanned) represented as a percent net value change (see table at right). The post-disturbance (planned or unplanned) value $v_{SARA,\ t+1}$ is limited to values ranging from 0 to $ROSE_{SARA}$ (i.e. 0 is the minimum allowable value and $ROSE_{SARA}$ is the maximum allowable value).

This equation will be referred to in the following sections describing the steps of the REBA for calculating SARA RROI.

It should be noted that for the MTRW, the NVC was scaled by the percent canopy cover and/or ladder fuels for assessing impacts of treatments and the drought disturbance; areas with higher values would have a greater impact from drought. This was conducted to account for discrepancies in Stewardship Atlas unit delineation and cover mapping used for the HRV modeling to determine forest departure.

Response Rating	Description	NVC
-3	Greatest Loss	-99%
-2	Significant Loss	-66%
-1	Some Loss	-33%
0	No Loss or Benefit	0 (no change)
1	Some Benefit	33%
2	Significant Benefit	66%
3	Greatest Benefit	99%

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Appendix: Restoration Abacus

Pre-SARA REBA: Calculate Post-Treatment Disturbance Intensity

Firstly, post-treatment disturbance intensity rasters are created through an iterative process. Treatments influence the way future unplanned disturbance (i.e. wildfire, drought)occurs on the landscape. For example, if a fire is predicted to burn at high severity on the landscape prior to treatment, a treatment may reduce the unplanned disturbance to a moderate severity. In order to evaluate the impact of treatment, disturbance reduction responses were developed to quantify how treatments can influence future unplanned disturbance.

Each disturbance intensity raster is evaluated separately (i.e. drought and wildfire evaluated separately); first, the treatment intensity raster is converted to a treatment disturbance reduction raster using the Treatment Disturbance Reduction lookup table (shown in table below and described previously in "Section II. Landscape Assessment Methods: Treatment Types"). This reduction is then applied to the current disturbance intensity raster to generate the post-treatment disturbance intensity raster, such that:

$$I_{gridcell\ x,\ post-rx} = I_{gridcell,\ current} - t,$$

where $I_{gridcell\ x,\ post-rx}$ is the post-treatment disturbance intensity at a particular raster gridcell, Igridcell, current is the current disturbance intensity at a particular raster gridcell, and t is the treatment-disturbance reduction. For example, if Treatment X is associated with a treatment-disturbance reduction of 2 for Disturbance Y, and the current disturbance intensity raster value is 5 at a particular gridcell, the post-treatment disturbance intensity raster would be 3.

Treatment	Wildfire Intensity Class Reduction Factor	Drought Intensity Class Reduction Factor
Ground Mechanized - Thin from below	-3	-2
Ground Mechanized - Thin w/ large openings	-3	-4
Tethered/Aerial Mechanized - Thin from below	-2	-2
Tethered/Aerial Mechanized - Variable Density Thin w/ large openings	-2	-3
Rearrangement - Target fine fuel	-1	0
Rearrangement - Thin from below	-3	-2
Hand Thinning - Thin from below	-2	-2
Rx Burn - Aerial	-2	-2
Rx Burn - Ground, Low Intensity	0	-1
Rx Burn - Ground, Moderate Intensity	-1	-1

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Appendix: Restoration Abacus

1. Calculate SARA Relative Actual Socio-Ecological Value (REASE)

The SARA ROSE is not necessarily the SARA's current value. Therefore, *current* functional condition is considered in order to identify the Relative *Actual* Socio-Ecological value (REASE). For most anthropogenic SARAs, the current functional value was assumed to be equivalent to the ROSE. A primary home, for example, may have structural deficiencies that would keep its potential value from being realized, but (1) only a site-specific inspection could allow for that assessment and (2) vegetation treatments cannot change the function of a home by addressing its structural deficiencies. For these types of SARAs, the REASE was set equivalent to the ROSE. Conversely, the current value of an ecologic SARA like a mature, fire-suppressed large tree grove can be approximated by assessing departure from its ecologically-functional condition. Below is a list of all SARAs where the REASE was estimated based on ecologically-functional condition and allowed to vary from the ROSE:

- Waterbodies, rivers, and perennial streams
- B118 Infiltration Basins
- All recreation SARAs (except ski lifts)
- Critical access roads
- Community fuel reduction zones
- Community transmission zones
- High carbon areas
- Large tree groves
- Meadows and fens
- Tall tree/high canopy cover
- Aspen stands
- Nest and den sites
- Sensitive plants

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Appendix: Restoration Abacus

1. Calculate SARA Relative Actual Socio-Ecological Value (REASE) (cont'd)

As described earlier, to approximate ecologically-functional conditions, we used the HRV-derived FRID, which was quantiled into classes representing intensity of fire return interval departure, and then related to ROSE factors (i.e. fraction of ROSE values) (see table; also described in "Section II. Landscape Assessment Methods: Departure Modeling").

To calculate REASE, first, the FRID intensity class (FIC) raster is related to a ROSE factor for each gridcell. Then, the ROSE value of the SARA is adjusted to the REASE value, such that:

$$REASE_{SARA} = dr \times ROSE_{SARA},$$

where $REASE_{SARA}$ is the SARA Relative Actual Socio-Ecological value, *dr* is the ROSE factor related from the FIC, and $ROSE_{SARA}$ is the SARA Relative Potential Socio-Ecological value. For example, for a given gridcell where the FIC is 4, which is related to a ROSE factor of 0.7, an ecological SARA ROSE value of 10 would be calculated as a SARA REASE value of 7, whereas an anthropogenic SARA ROSE value of 10 would not be reduced and the SARA REASE value would also be 10.

FRID Intensity Class (FIC)	ROSE factor
FRID Intensity Class 1	1
FRID Intensity Class 2	0.9
FRID Intensity Class 3	0.8
FRID Intensity Class 4	0.7
FRID Intensity Class 5	0.6
FRID Intensity Class 6	0.5

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Appendix: Restoration Abacus

2. Calculate SARA Treatment Effects (TE)

The SARA Treatment Effects metric represents the impact of treatments on SARAs in terms of their functional value. First, the SARA post-treatment value is calculated. First, a SARA post-treatment value is calculated; then, this is used to quantify the probabilistic change in value associated with treatment (SARA Treatment Effects).

The **calculation of the SARA post-treatment value raster** uses EQN 1 described previously. First, the treatment intensity raster is converted to SARA response function ratings using the SARA Treatment Response Functions. Then, the response function ratings are converted to NVC values per the table shown earlier (i.e. -3 equates to an NVC of -99%, -2 equates to an NVC of -66%, etc). Then, EQN 1 is applied as:

$$v_{SARA,t+1} = v_{SARA,t} + (ROSE_{SARA} \times NVC_{SARA,d}/100)$$

where $v_{SARA, t+1}$ is the post-treatment SARA value, $v_{SARA, t}$ is the SARA REASE value, $ROSE_{SARA}$ is the Relative Potential Socio-Ecological value of the SARA, and $NVC_{SARA,d}$ is the SARA's response to the treatment represented as a percent net value change. For example, if the SARA REASE value is 8, the ROSE SARA value is 10, and the treatment for a particular gridcell of this given SARA is related to a response rating of 1 (NVC of 33), then $v_{SARA, t+1}$ would be 11.3; as described previously, because the maximum allowable value of each SARA is its ROSE value, $v_{SARA, t+1}$ would then be capped to a value of 10. It should be noted that for the MTRW, the NVC was scaled by the percent canopy cover/ladder fuels; areas with higher values would have a greater impact from treatment.

Then, the **SARA Treatment Effects (TE) is calculated.** The SARA Treatment Effects (TE) value is the probabilistic SARA value change associated with treatment, calculated as:

$$\Delta v_{SARA} = (v_{SARA,t+1} - v_{SARA,t}) \times p_{SARA},$$

where Δv_{SARA} is the SARA TE, $v_{SARA, t+1}$ is the post-treatment SARA value, $v_{SARA, t}$ is the SARA REASE value, and p_{SARA} is the 10-year treatment probability. For example, if the post-treatment SARA value is 10, the SARA REASE value is 8, and the treatment probability is 0.1 (i.e. 10% probability), the SARA TE value would be 0.2. A negative SARA TE value indicates that the treatment had a negative impact on the SARA, whereas a positive SARA TE value indicates that the treatment had a positive impact on the SARA.

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Appendix: Restoration Abacus

3. Calculate SARA Change in Disturbance Effects (CDE)

The effects of treatment on disturbances are evaluated to generate a value called SARA Change in Disturbance Effects. This step effectively evaluates whether the treatment results in avoided loss for a SARA, or if the treatment instead negatively impacts the beneficial impacts of the disturbance intensity at a given location. The third step of the Restoration Abacus involves several substeps, which are as follows:

3a. Calculate the probabilistic SARA post-disturbance value change (no treatment) (for each disturbance)

To calculate the SARA post-disturbance (i.e. wildfire) value change in the absence of treatment, the SARA post-disturbance values must be calculated iteratively for each disturbance and then compared to the pre-disturbance value (in this case, the SARA REASE). For each disturbance, the current disturbance intensity raster is converted to SARA response function ratings using the SARA Disturbance Response Functions. Then, the response function ratings are converted to NVC values per the table shown earlier (i.e. -3 equates to an NVC of -99%, -2 equates to an NVC of -66%, etc). Then, for each disturbance, the post-disturbance SARA value (no treatment) is calculated using EQN 1 as:

$$v_{SARA,t+1} = v_{SARA,t} + (ROSE_{SARA} \times NVC_{SARA,d}/100)$$

where $v_{SARA,\,t+1}$ is the post-disturbance SARA value, $v_{SARA,\,t}$ is the SARA REASE value, $ROSE_{SARA}$ is the Relative Potential Socio-Ecological value of the SARA, and $NVC_{SARA,d}$ is the SARA's response to the disturbance represented as a percent net value change. It should be noted that for the MTRW, the NVC was scaled by the percent canopy cover for the drought disturbance; areas with higher values would have a greater impact from drought.

For example, if the SARA REASE value is 8, the ROSE SARA value is 10, and a given disturbance is equated to an NVC of -99% for a particular gridcell for the SARA of interest, then $v_{SARA,\,t+1}$ would be -1.9; as described previously, because the minimum allowable value of each SARA is 0, $v_{SARA,\,t+1}$ would then be set to a value of 0.

After each SARA post-disturbance value is calculated, the SARA post-disturbance value change (again, in the absence of treatment) is evaluated iteratively for each disturbance, calculated as:

$$\Delta v_{SARA,\,disturbance} = (v_{SARA,disturbance,t+1} - v_{SARA,t}) \times (p_{disturbance} \times 10),$$

where $\Delta v_{SARA,disturbance}$ is the probabilistic SARA post-disturbance value change (if no treatment had occurred), $v_{SARA,disturbance,\,t+1}$ is the post-disturbance SARA value, $v_{SARA,\,t}$ is the SARA REASE, and $p_{disturbance}$ is the 1-year disturbance probability. Here, because the disturbance probabilities are annualized but the Restoration Abacus performs calculations over a 10-year basis (and treatment probabilities and response functions are characterized over a 10-year period), the disturbance probability is multiplied by 10. For example, if the post-disturbance SARA value is 0, the SARA REASE value is 8, and the disturbance probability is 0.01 (i.e. 1% probability), the SARA probabilistic post-disturbance value change would be -0.8. A negative value indicates value loss from the disturbance intensity, whereas a positive value indicates value gain from the disturbance intensity.

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Appendix: Restoration Abacus

3. Calculate SARA Change in Disturbance Effects (CDE) (cont'd)

3b. Calculate the probabilistic SARA post-treatment, post-disturbance value change (for each disturbance)

The post-treatment, post-disturbance value change is calculated similarly as the post-disturbance (no treatment) value change calculated in the previous step, except with different inputs. For each disturbance, the post-treatment disturbance intensity raster is converted to SARA response function ratings using the SARA Disturbance Response Functions. Then, the response function ratings are converted to NVC values per the table shown earlier (i.e. -3 equates to an NVC of -99%, -2 equates to an NVC of -66%, etc). Then, for each disturbance, the post-treatment, post-disturbance SARA value is calculated using EQN 1 as:

$$v_{SARA,t+1} = v_{SARA,t} + (ROSE_{SARA} \times NVC_{SARA,d}/100)$$

where $v_{SARA,\ t+1}$ is the post-treatment, post-disturbance SARA value, $v_{SARA,\ t}$ is the SARA post-treatment value (calculated in Step 2), $ROSE_{SARA}$ is the Relative Potential Socio-Ecological value of the SARA, and $NVC_{SARA,d}$ is the SARA's response to the disturbance represented as a percent net value change. Again, it should be noted that for the MTRW, the NVC was scaled by the percent canopy cover for the drought disturbance; areas with higher values would have a greater impact from drought.

For example, if the SARA post-treatment value is 10, the ROSE SARA value is 10, and a given post-treatment disturbance is equated to an NVC of -33% for a particular gridcell for the SARA of interest, then $v_{SARA,\ t+1}$ would be 6.7.

After each SARA post-treatment, post-disturbance value is calculated, the SARA post-treatment, post-disturbance value change is evaluated iteratively for each disturbance, calculated as:

$$\Delta v_{SARA,\ disturbance} = (v_{SARA,disturbance,t+1} - v_{SARA,t}) \times (p_{disturbance} \times 10),$$

where $\Delta v_{SARA,disturbance}$ is the probabilistic SARA post-treatment, post-disturbance value change, $v_{SARA,disturbance,\ t+1}$ is the post-treatment, post-disturbance SARA value, $v_{SARA,\ t}$ is the post-treatment value, and $p_{disturbance}$ is the disturbance probability. Again, because the disturbance probabilities are annualized but the Restoration Abacus is calculated over a 10-year basis (and treatment probabilities are over a 10-year period), the disturbance probability is multiplied by 10. For example, if the post-treatment, post-disturbance SARA value is 6.7, the SARA post-treatment value is 10, and the disturbance probability is 0.01 (i.e. 1% probability), the SARA post-disturbance value change would be -0.33. A negative value indicates value loss from the disturbance intensity, whereas a positive value indicates value gain from the disturbance intensity.

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Appendix: Restoration Abacus

3. Calculate SARA Change in Disturbance Effects (CDE) (cont'd)

3c. Calculate the SARA Change in Disturbance Effects (for each disturbance)

The SARA change in disturbance effects for each disturbance is calculated as the probabilistic difference between the post-disturbance SARA value change, with and without treatment. It should be noted that treatment only affects the disturbance intensity values within this framework and not the disturbance probabilities; although the probabilities are applied in steps 3a and 3b, they are constant and could instead be applied at this step.

The SARA change in disturbance effects is calculated iteratively for each disturbance, such that:

$$\Delta DE_{SARA,disturbance} = \Delta v_{SARA,\,disturbance,treatment} - \Delta v_{SARA,disturbance,\,no\ treatment}$$

where $\Delta DE_{SARA,disturbance}$ is the change in SARA disturbance effects for a particular disturbance, $\Delta v_{SARA,disturbance,treatment}$ is the SARA post-treatment, post-disturbance value change (3b), and $\Delta v_{SARA,disturbance,no\ treatment}$ is the SARA post-disturbance value change (no treatment) (3a). For example, if the SARA post-treatment, post-disturbance value change is -0.33 and the SARA post-disturbance (no treatment) value change is -0.8, the change in SARA disturbance effects would be 0.47. A positive value indicates that the treatment resulted in avoided loss from the disturbance for the SARA, whereas a negative value indicates that the treatment reduced the positive benefits of disturbance for the SARA.

3d. Calculate the SARA Change in Disturbance Effects (across all disturbance types)

Finally, the total SARA Change in Disturbance Effects (DESARA) is calculated as:

$$\Delta DE_{SARA} = \Sigma \Delta DE_{SARA,disturbance},$$

such that all of the calculated change in disturbance effects are summed for all disturbances. For example, for a given gridcell, if there are two disturbances (wildfire and drought-induced beetle mortality), and the resulting change in disturbance effects for a SARA was 0.47 and 0.11, respectively, the total SARA Change in Disturbance Effects would be 0.58.

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Appendix: Restoration Abacus

4. Calculate SARA Restorative Return on Investment (RROI)

The fourth and final step in the Restoration Abacus is to calculate the Restorative Return on Investment (RROI), such that:

$$RROI_{SARA} = TE_{SARA} + \Delta DE_{SARA},$$

where $RROI_{SARA}$ is the SARA Restorative Return on Investment, TE_{SARA} is the SARA Treatment Effects, and ΔDE_{SARA} is the total SARA Change in Disturbance Effects. For example, if TE_{SARA} is 0.2 and ΔDE_{SARA} is 0.58, the $RROI_{SARA}$ would be 0.78. A positive value indicates net benefit from treatment, whereas a negative value indicates a net negative impact of treatment. Within each Planning Atlas unit, the RROI (calculated on a per-gridcell basis) is variable due to the variable nature of several of the Restoration Abacus inputs (i.e. disturbance intensity, disturbance probability, current vegetation departure).

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Appendix: Restoration Abacus

Calculate Pillar Restorative Return on Investment for each Stewardship Atlas unit

The final step is to calculate Pillar Restorative Return on Investment for each Stewardship Atlas unit. In order to use the SARA Restorative RROI metrics for project development and planning, it is necessary to align each SARA with each pillar (i.e. objective) and then aggregate gridded raster values to Stewardship Atlas units (i.e. treatment units). Pivoting from SARA RROI to pillar RROI is done using the SARA-pillar contributions (described previously in "Section II. Landscape Assessment Methods: SARA Inventory").

After SARA RROI rasters are calculated, SARA-Pillar rasters are generated:

$$RROI_{SARA,Pillar} = RROI_{SARA} \times P_{SARA,\,Pillar}$$

where $RROI_{SARA,Pillar}$ is the proportion of the SARA's RROI that is associated with a particular pillar, $RROI_{SARA}$ is the SARA RROI, and $P_{SARA,Pillar}$ is the proportional contribution of the SARA to the given pillar. As described earlier, all $P_{SARA,Pillar}$ values associated with a given SARA must sum to 1. For example, for a given SARA whose RROI is 0.5 and whose $P_{SARA,Pillar}$ for a given pillar is 0.2, the $RROI_{SARA,Pillar}$ would be 0.1.

Finally, Pillar RROI is calculated as:

$$RROI_{Pillar} = \Sigma\, RROI_{SARA,Pillar}$$

In other words, cumulative landscape RROI is maintained, but is re-allocated to pillars from the SARAs for the purposes of developing projects based on the DiMA pillar weights (i.e. objectives).

After the final 10 Pillar RROI rasters are generated, values are summed for each Stewardship Atlas polygon (zonal statistics sum), such that each Stewardship Atlas polygon has an RROI value associated with each of the 10 Resilience Pillars.

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Appendix: Tabular project outputs for all scenarios

A directory containing all tabular scenario outputs can be found and downloaded in this supplemental data folder. This includes information regarding cost summaries, ownership, and treatment distribution.

/supplemental_data
    /scenario_summaries
        /Scenario_[A, B, …F]
            /tables
                /projects_summary_initrx.csv → *contains information regarding the initial treatment type distribution by project*
                /projects_summary_ownership.csv → *contains information regarding the ownership distribution by project*
                /projects_summary.csv → *contains summary information regarding costs, objective, etc by project*

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Appendix: Stewardship Atlas

A directory containing the full Stewardship Atlas shapefile and accompanying product guide can be found in this supplemental data folder. The product guide describes all fields included. A subset of the Stewardship Atlas is also available on the 34N OPENNRM platform (available upon request from TRWC) as an interactive webmap.

/supplemental_data
    /mtrw_stewardship_atlas
        /MTRW_STELA_20211220_FINAL_projscens.zip
        /MTRW_Stewardship_Atlas_ProductGuide.pdf

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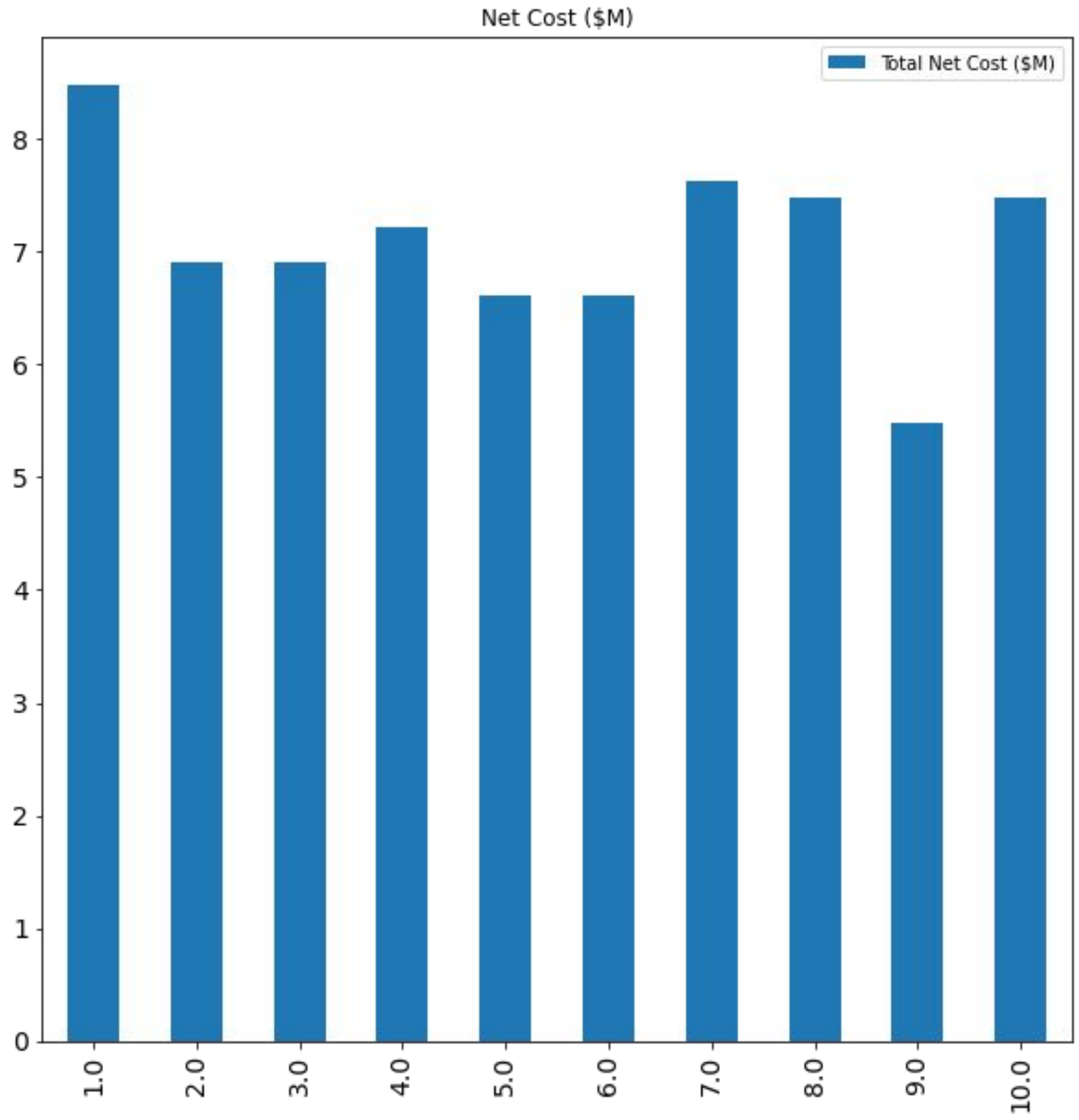
Appendix: Scenario A results (Estimated Net Cost ($M) by project)



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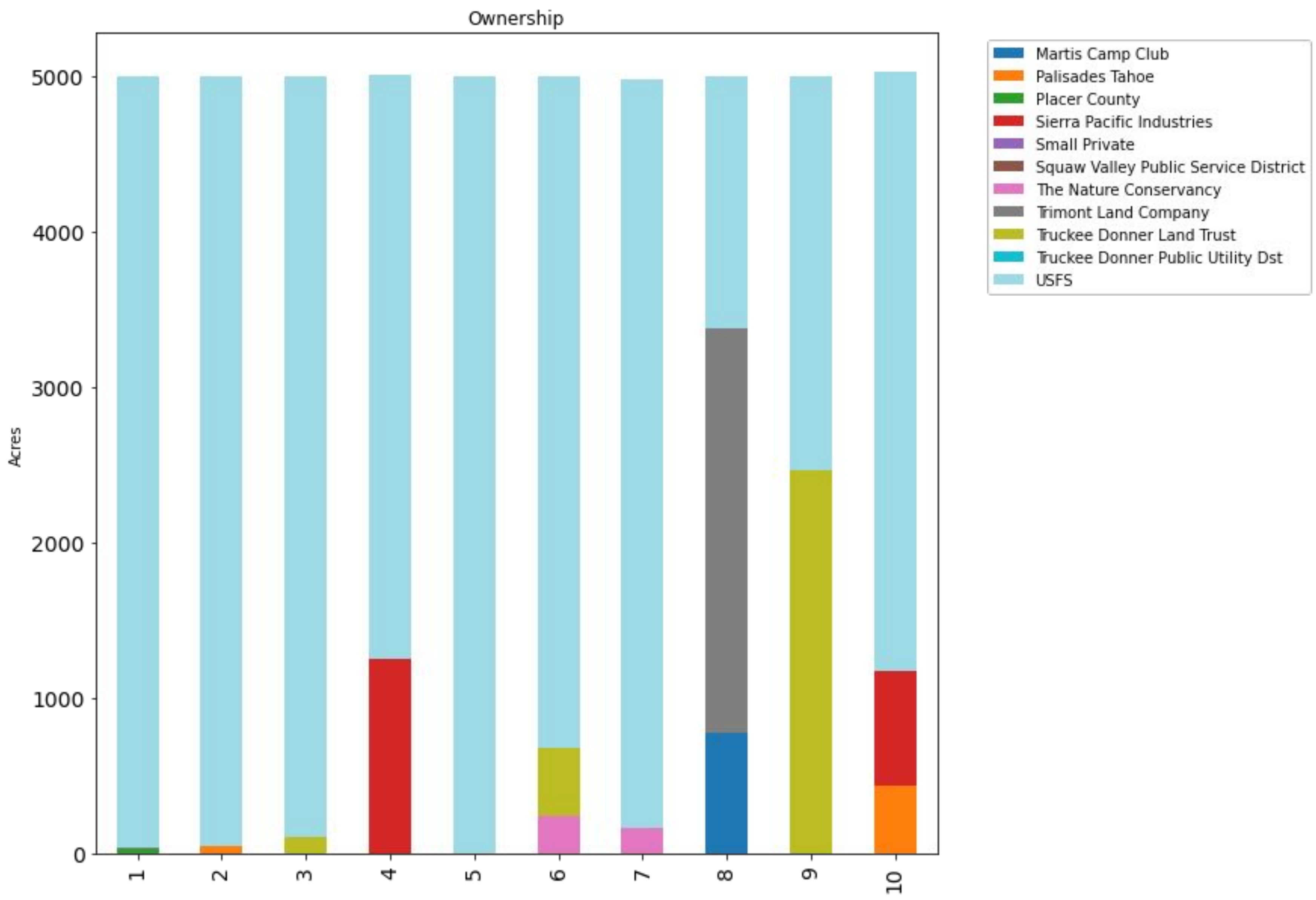
Appendix: Scenario A results (Ownership by project)



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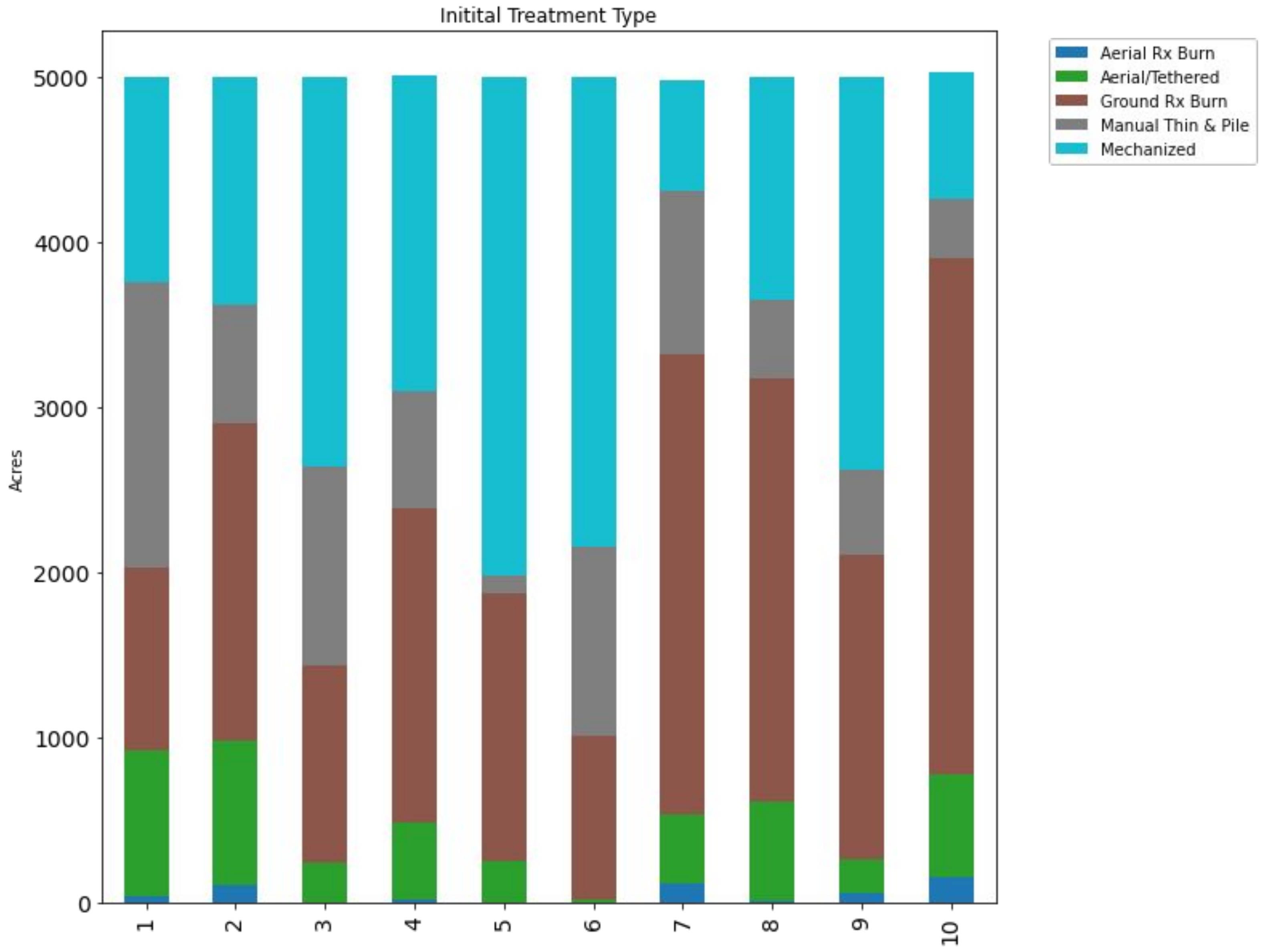
Appendix: Scenario A results (Initial Treatment Type by project)



Appendix: Scenario B results (Estimated Net Cost ($M) by project)

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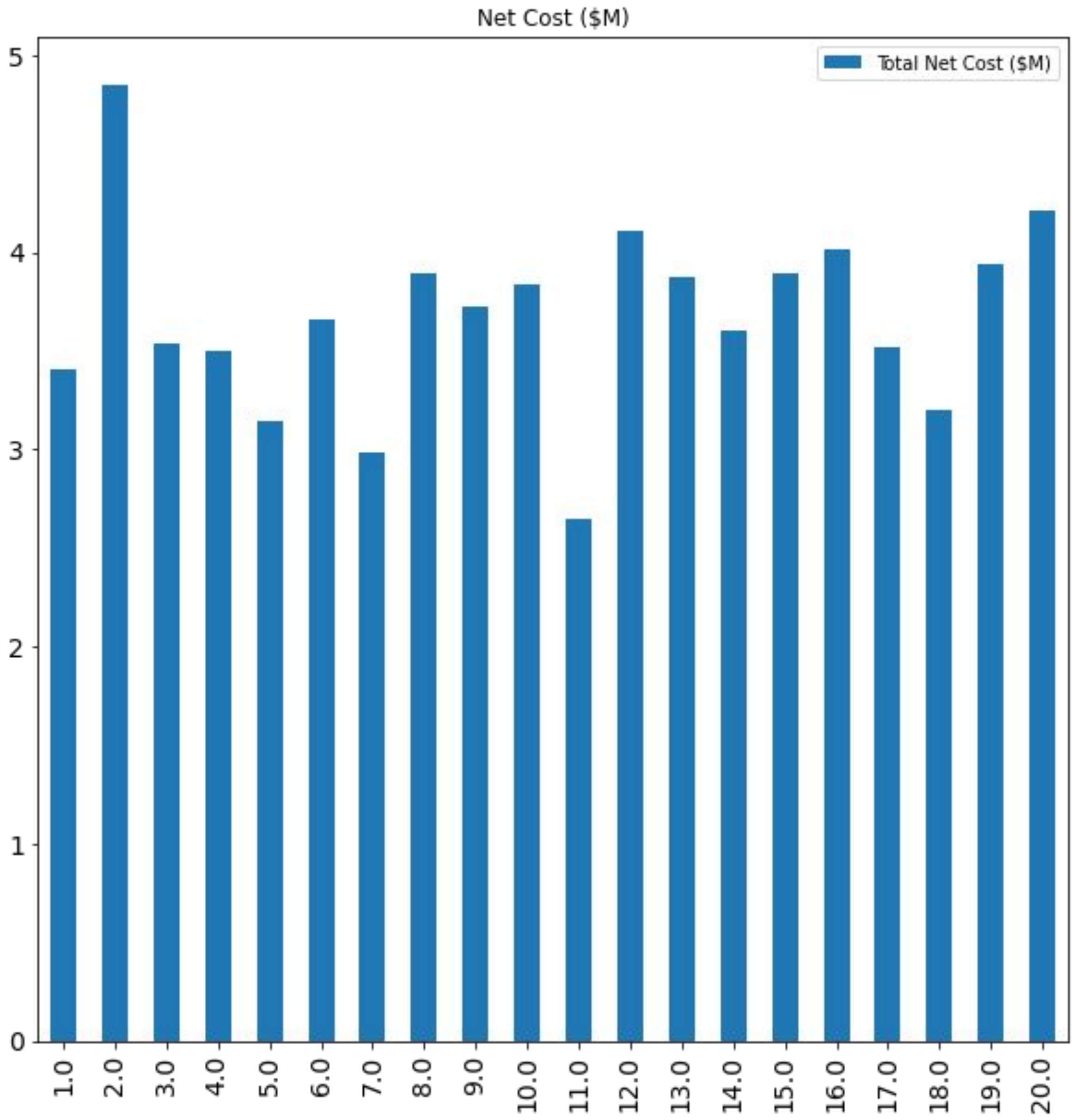
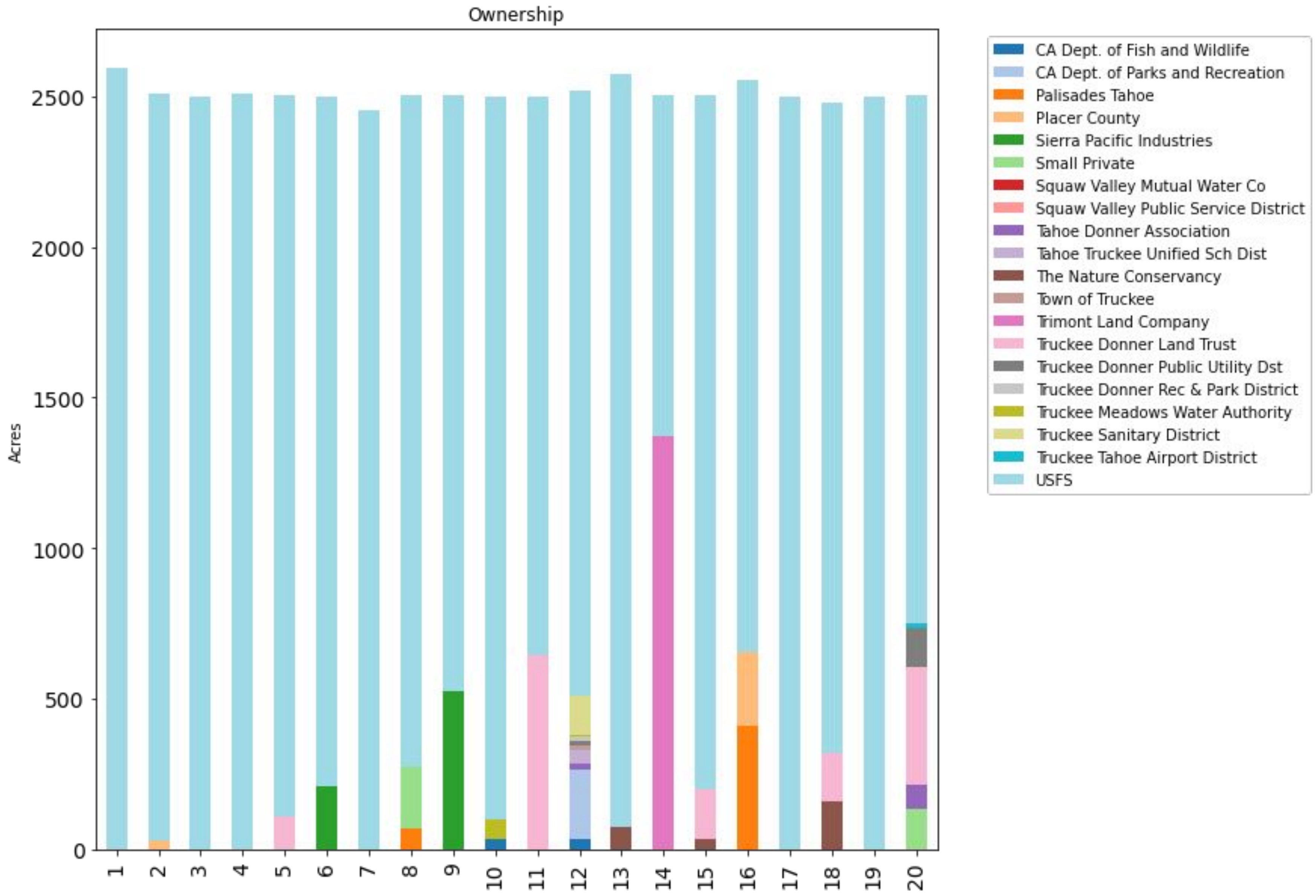


Appendix: Scenario B results (Ownership by project)



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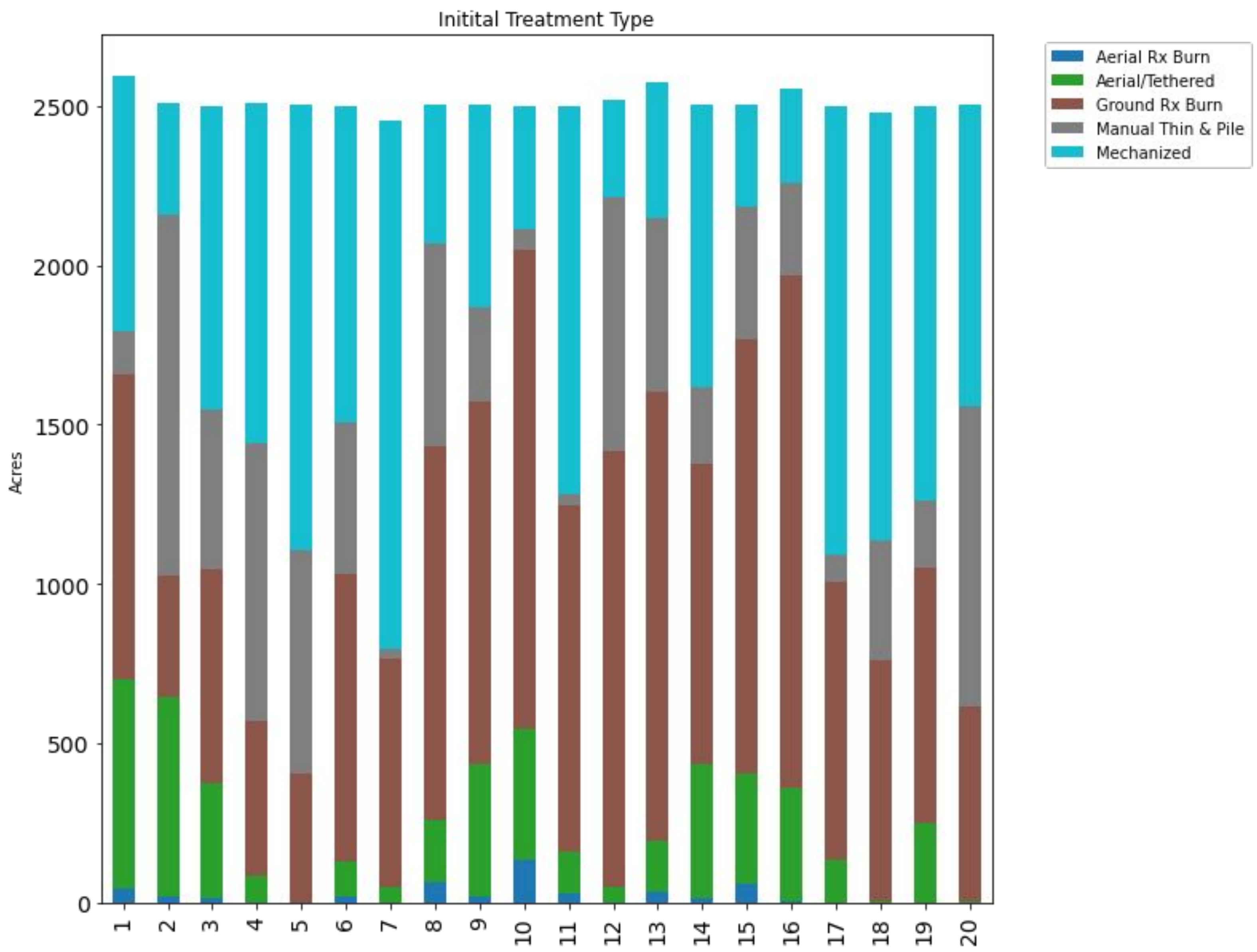
Appendix: Scenario B results (Initial Treatment Type by project)



Appendix: Scenario C results (Estimated Net Cost ($M) by project)

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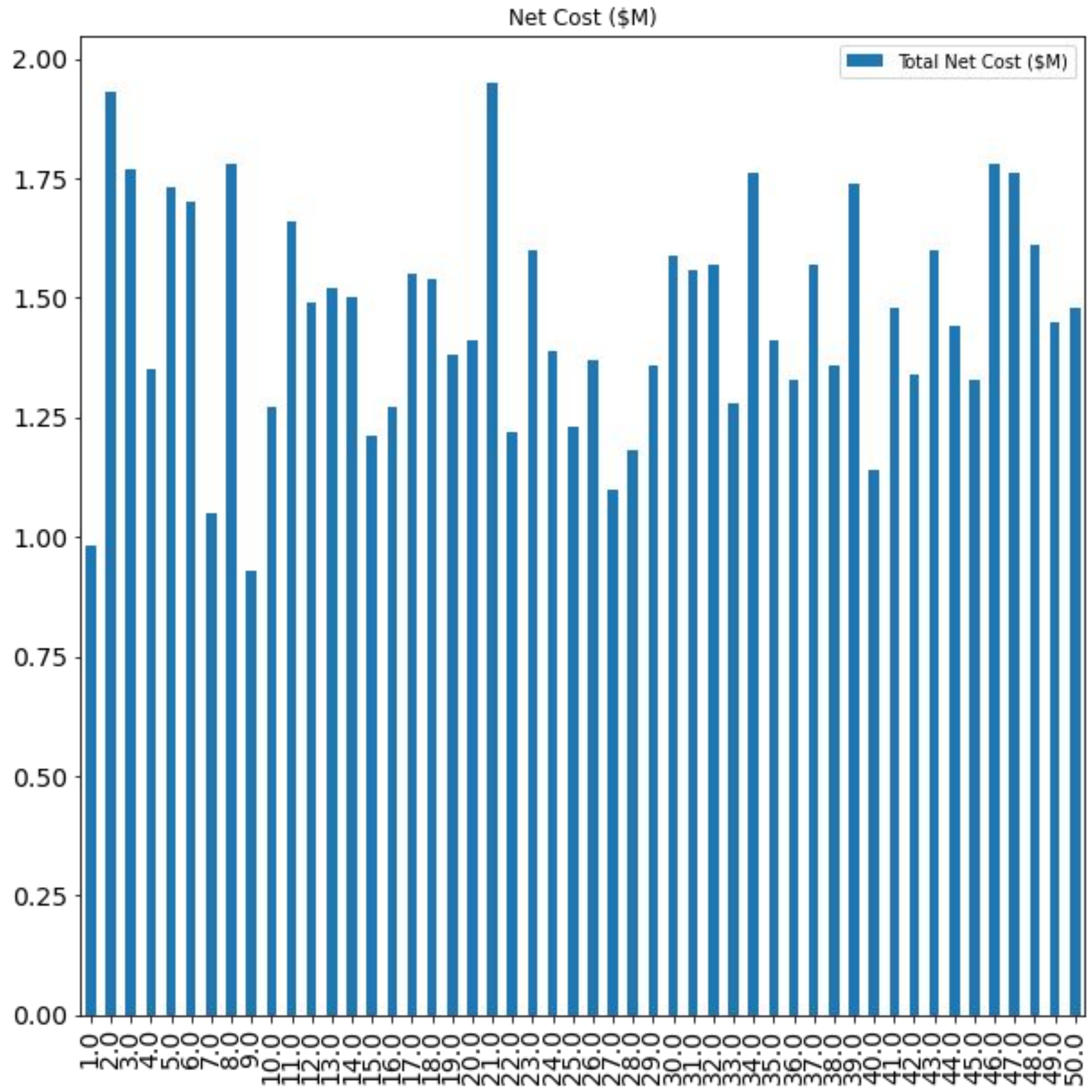
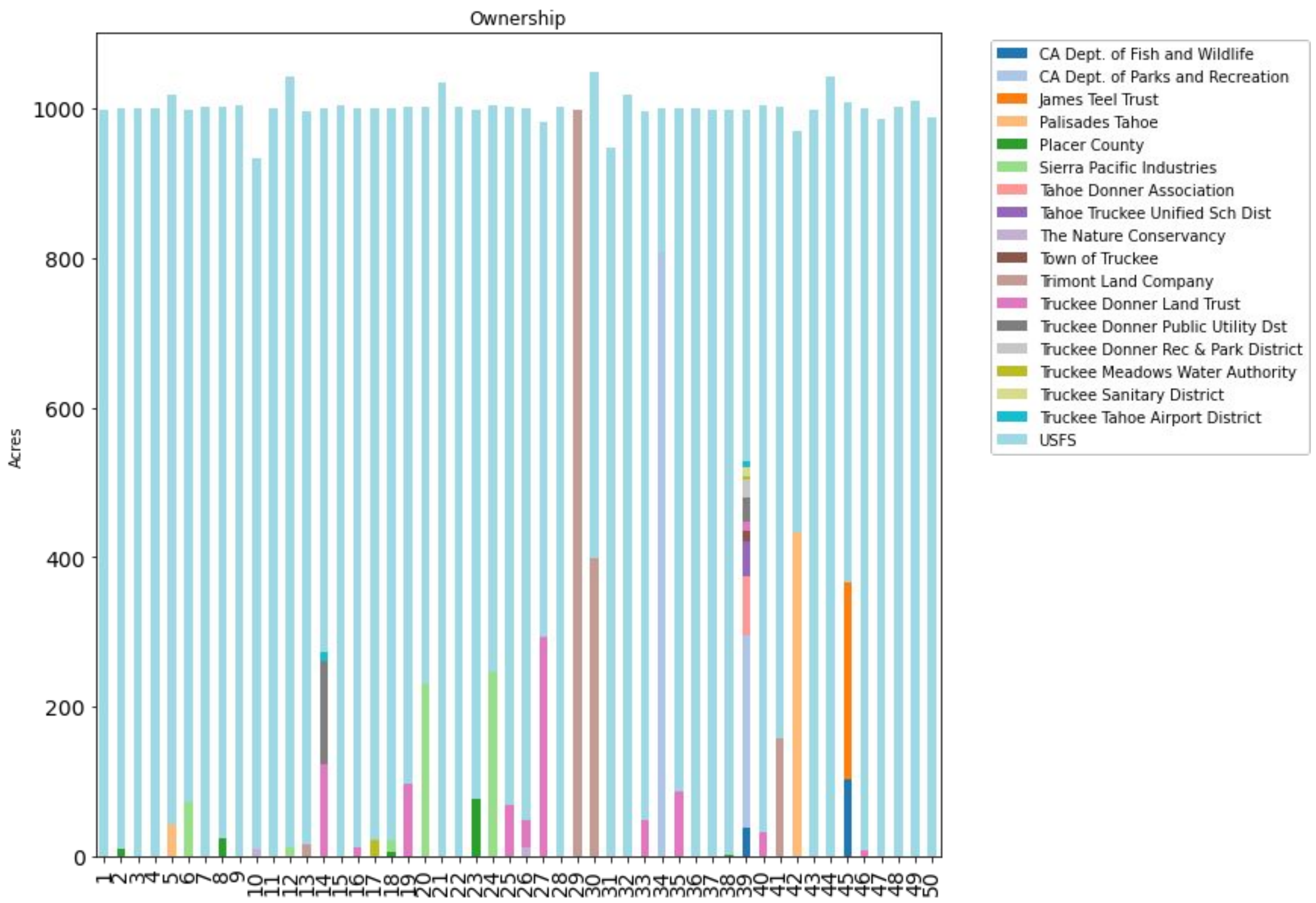


Appendix: Scenario C results (Ownership by project)



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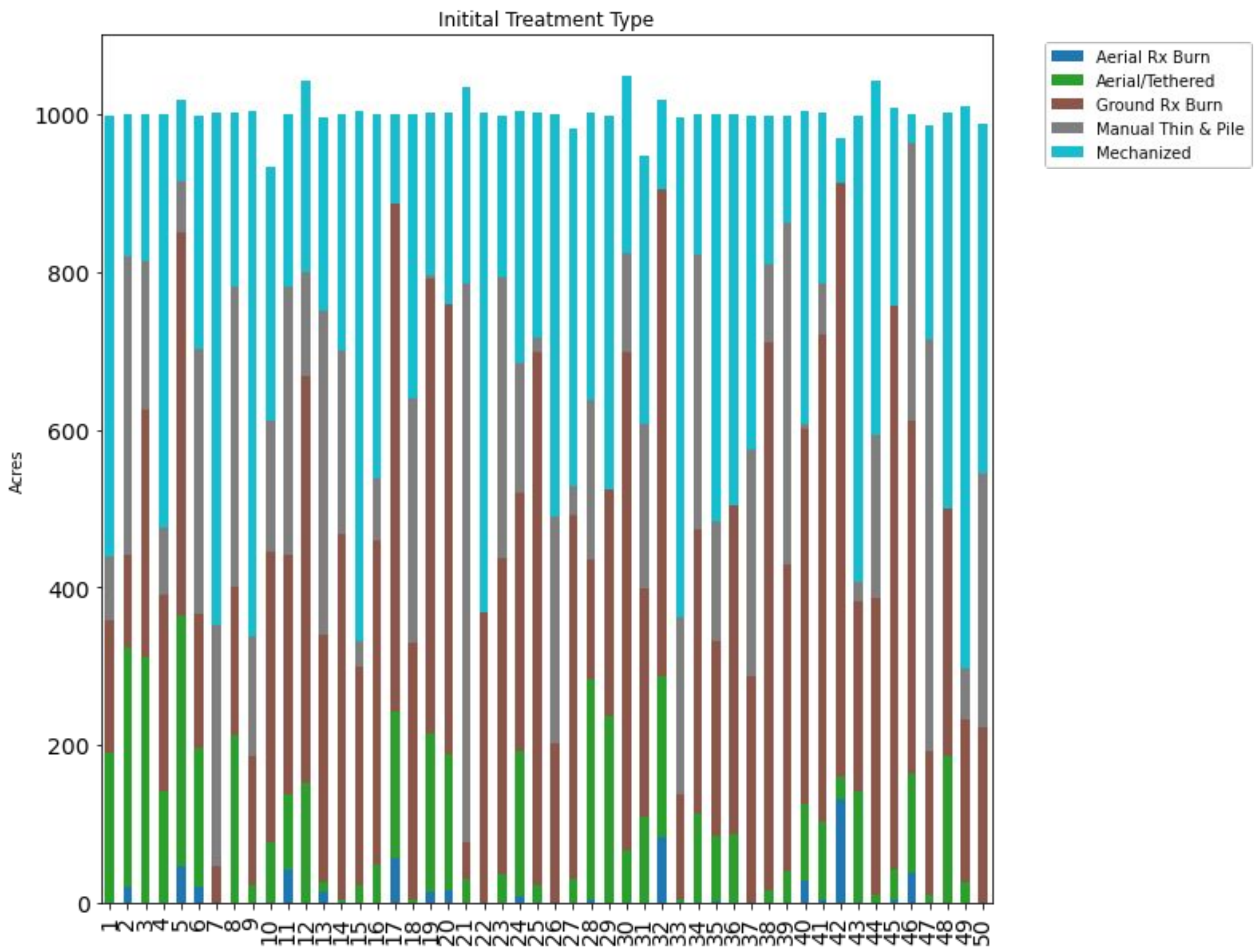
Appendix: Scenario C results (Initial Treatment Type by project)



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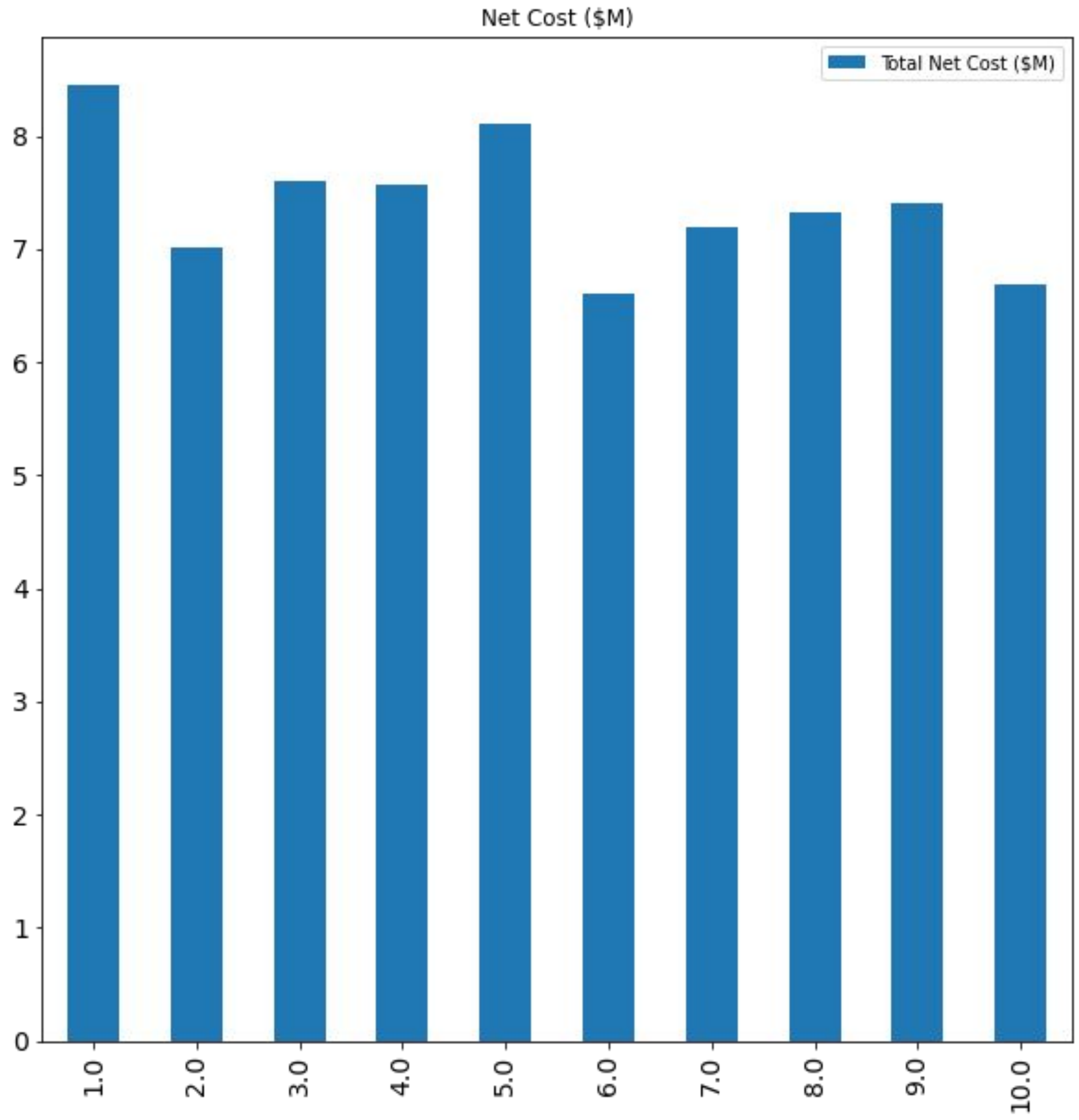
Appendix: Scenario D results (Estimated Net Cost ($M) by project)



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Appendix: Scenario D results (Ownership by project)

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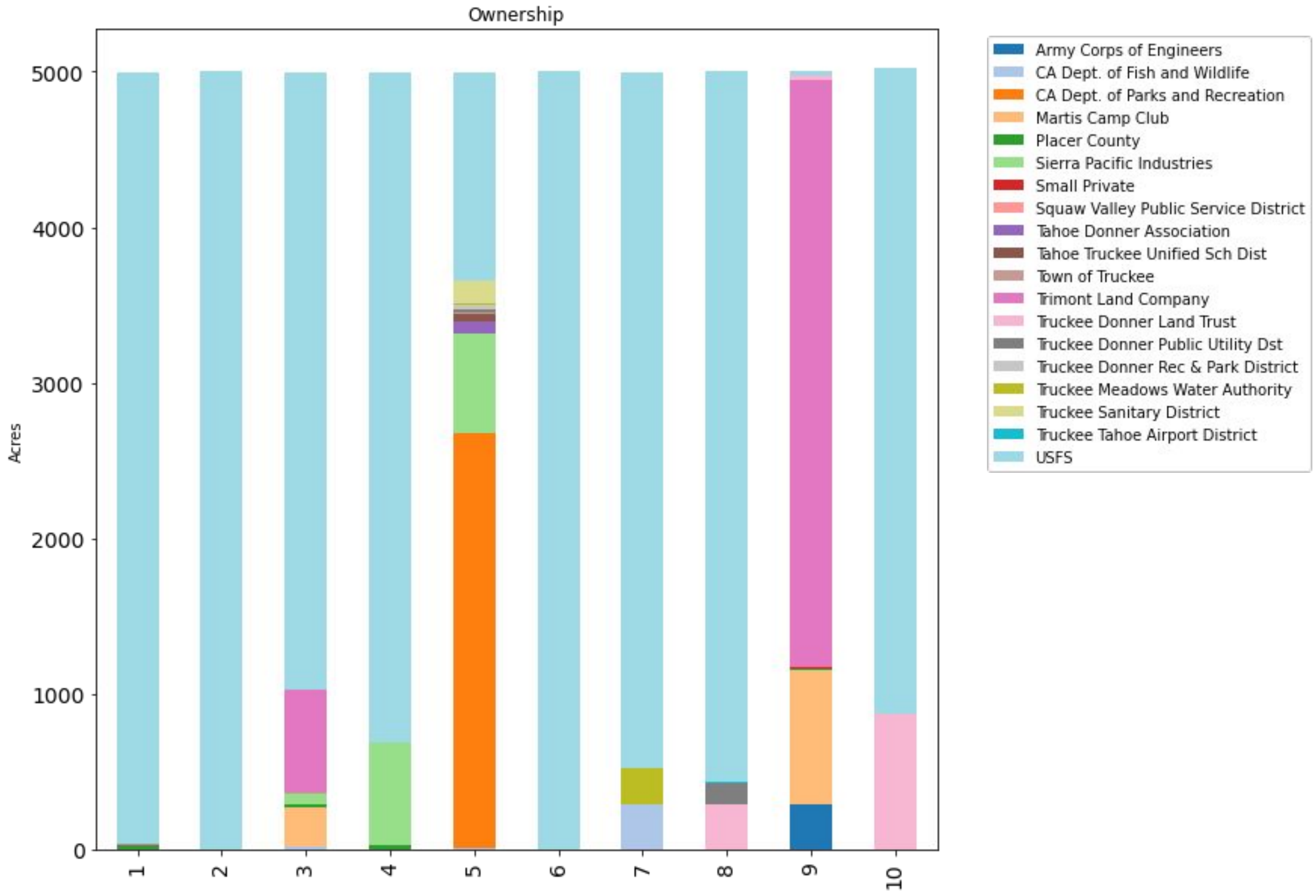
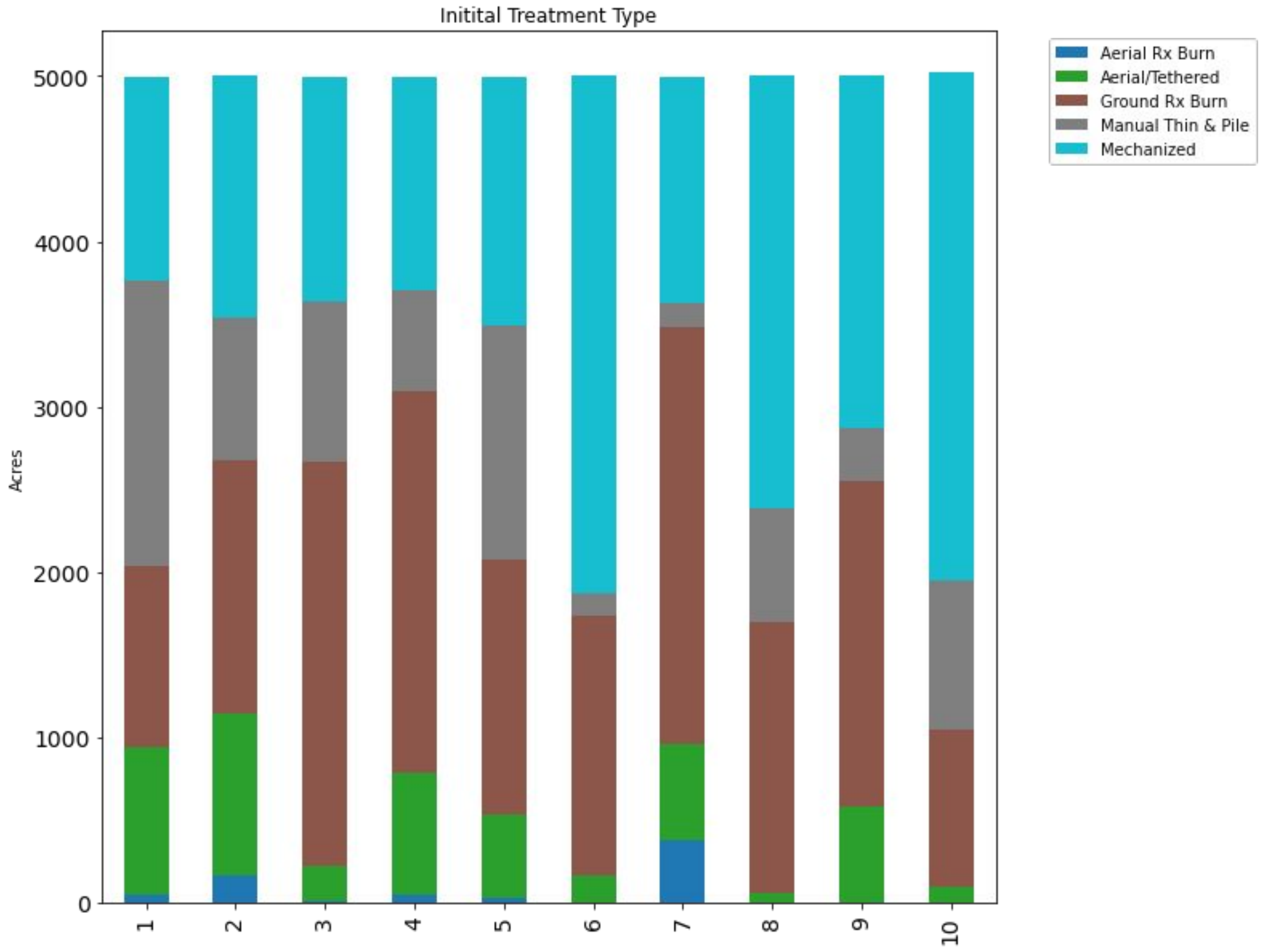


Appendix: Scenario D results (Initial Treatment Type by project)



Appendix: Scenario E results (Estimated Net Cost ($M) by project)

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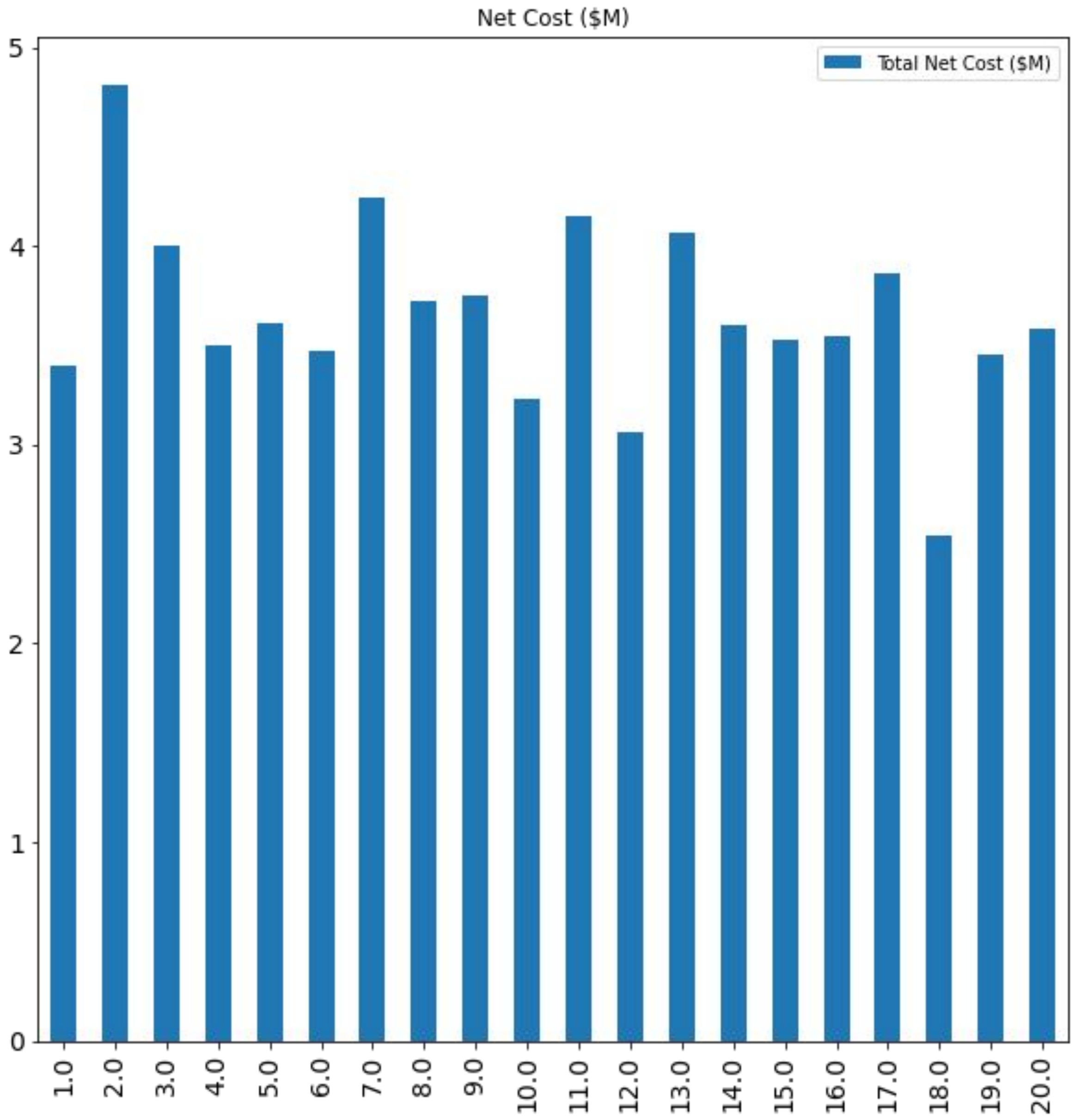
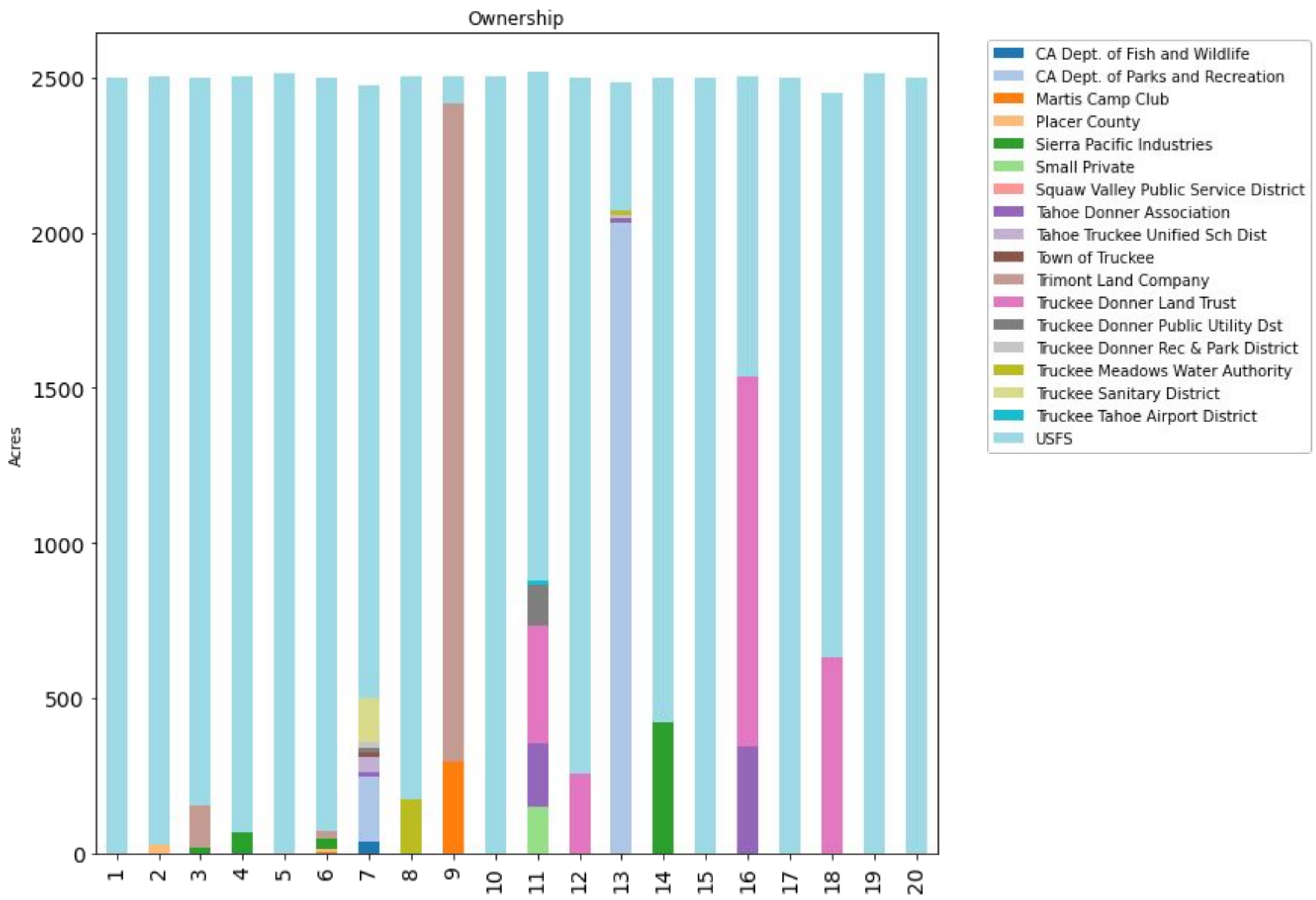


Appendix: Scenario E results (Ownership by project)



Appendix: Scenario E results (Initial Treatment Type by project)

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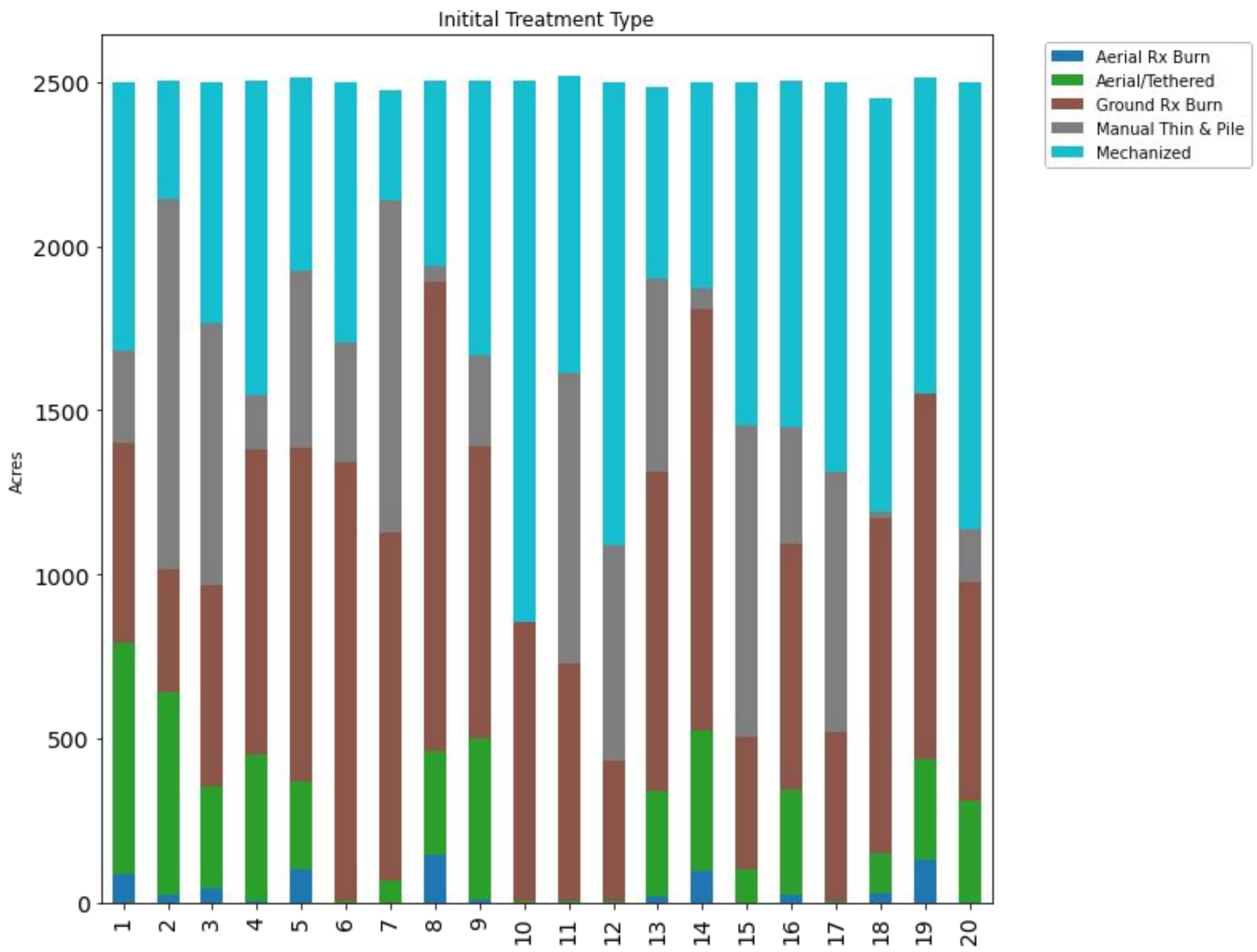

Appendix: Scenario F results (Net Cost ($M) by project)

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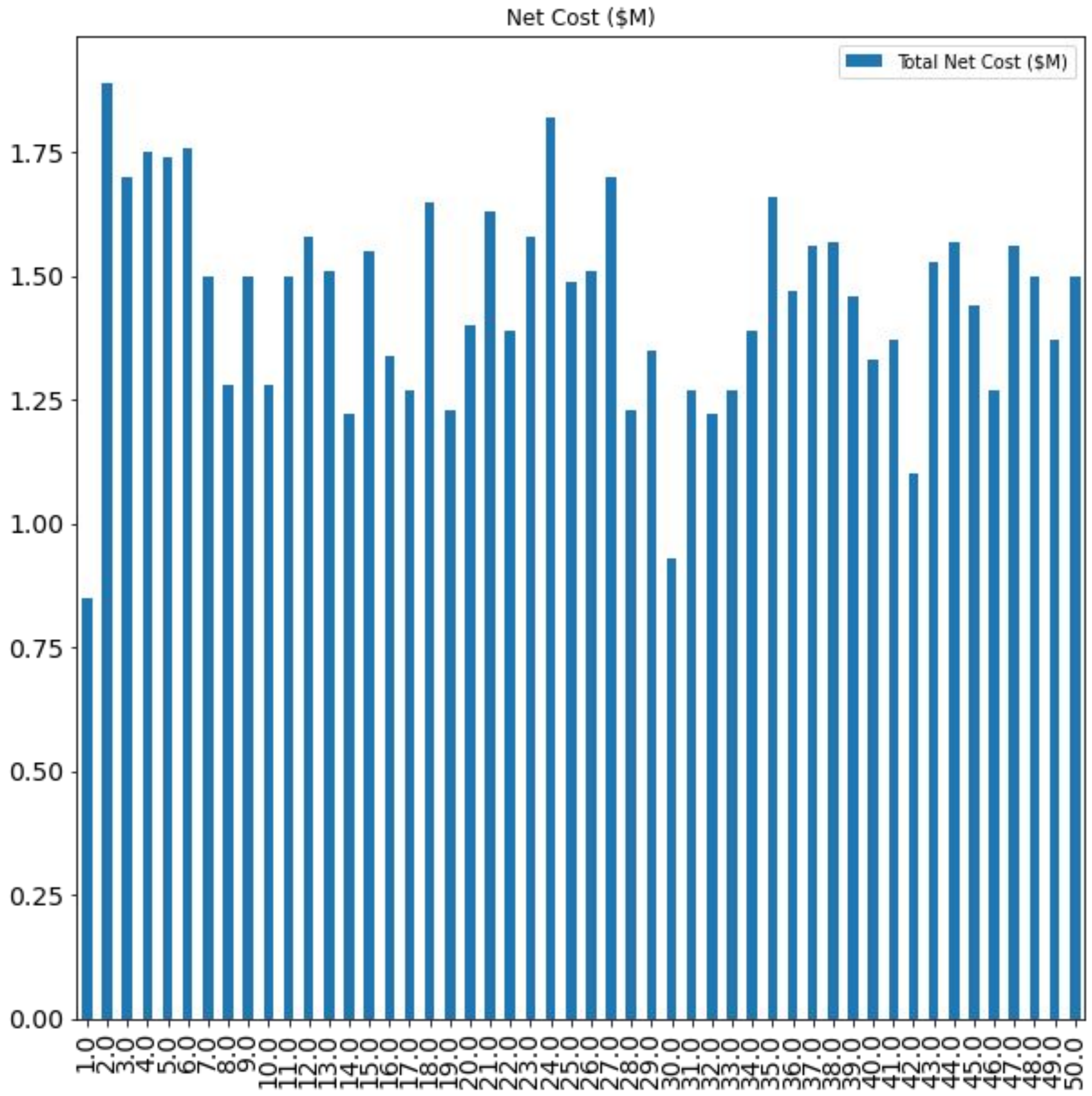
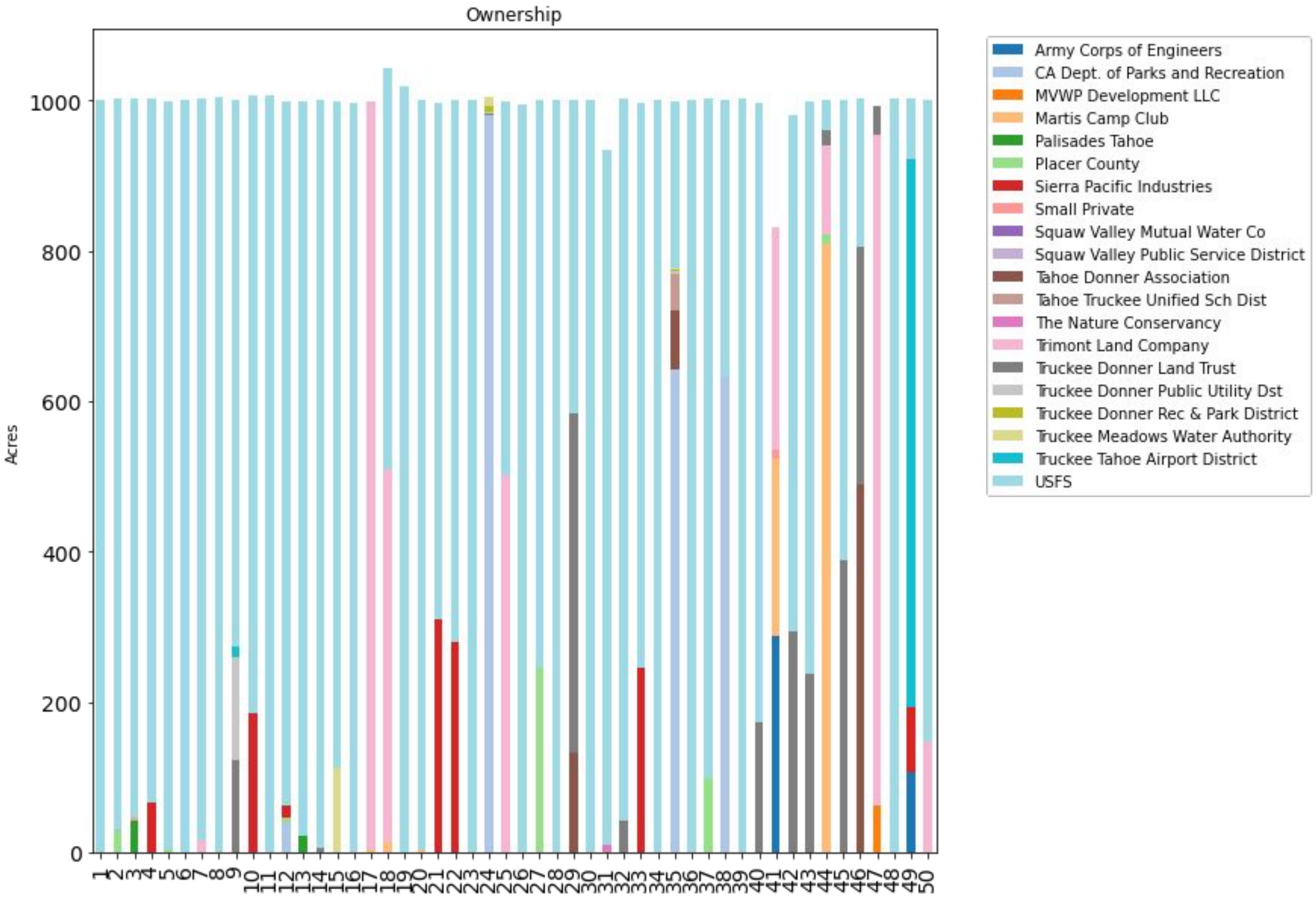
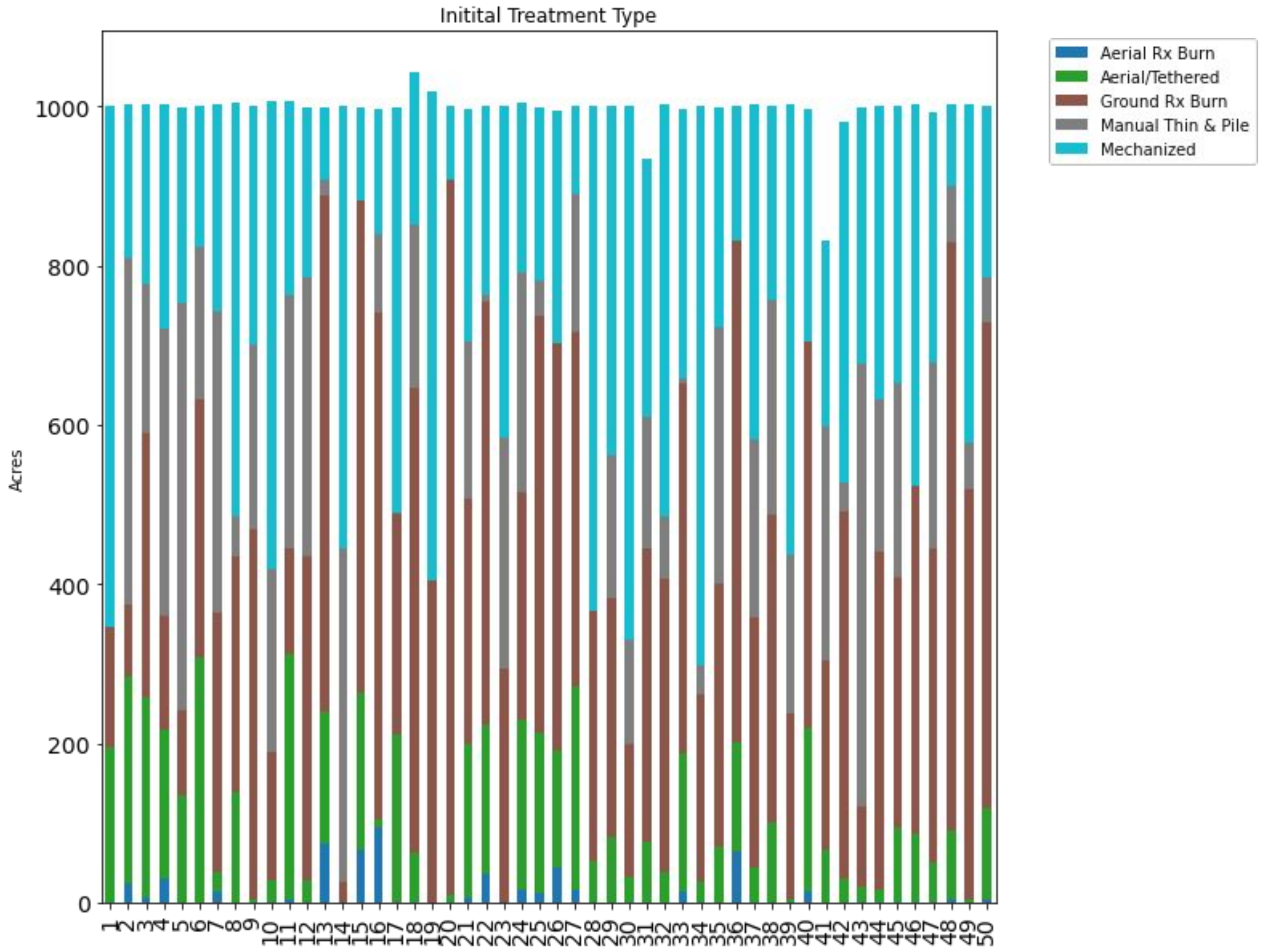


Appendix: Scenario F results (Ownership by project)



Appendix: Scenario F results (Initial Treatment Type by project)



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Appendix: Treatment Matrices by project for Scenario B

A directory containing treatment matrix maps of each Scenario B project can be found and downloaded in this [supplemental data folder]. These are georeferenced pdfs that could be used in the field in applications like Avenza. *Note: as stated previously, the delineated Stewardship Atlas units and assigned potential treatments serve as a helpful starting place for field personnel and should facilitate the hand-off between planning and implementation, but are not a substitute for treatment layout.*

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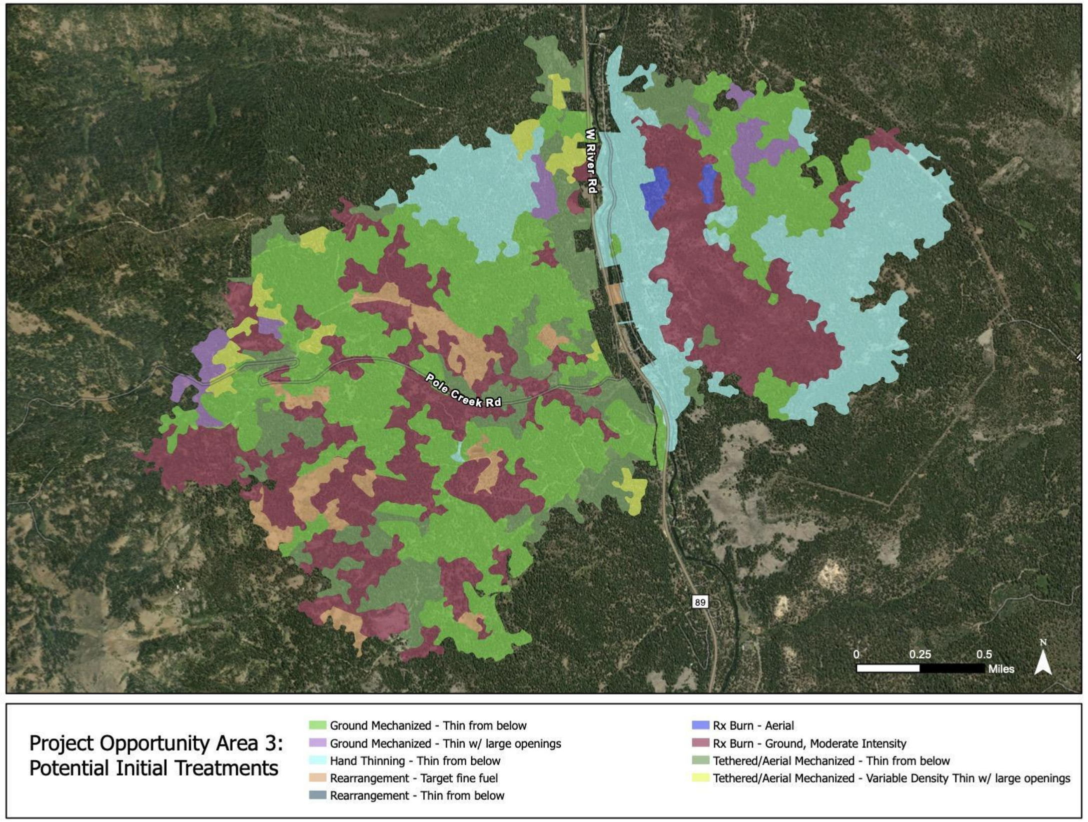
Example:



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Acknowledgement and Land Tender

Acknowledgement

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foriver
TRUCKEE RIVER WATERSHED COUNCIL

MARTIS FUND

"The Martis Fund is a collaborative project of the developers of the Martis Camp community and its members, Mountain Area Preservation (MAP), and Sierra Watch."

Land Tender

Due to the importance of facilitating and enabling collaborative planning projects like this one, Vibrant Planet built Land Tender (https://www.vibrantplanet.net/landtender), a first-of-its-kind land management and planning tool. The methodology presented here provided a unique opportunity to apply processes and calculations used in Land Tender. Land Tender is being made available through the TRWC with trial licenses for TRWC and landowner use. At the time of this report, the methodology reflected in this report is also reflected in the Land Tender product guide; however, it should be noted that datasets, processes, and calculations used in Land Tender are currently being further refined for future landscapes. Vibrant Planet can provide more specific information on changes made for Land Tender and changes anticipated to interested parties.