Chaffee County Fuel Treatment Prioritization

December, 2019

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Purpose and Scope

The purpose of this fuel treatment prioritization is to inform a revision of the Chaffee County Community Wildfire Protection Plan (CWPP) and the Chaffee Common Grounds Initiative. The focus of the prioritization is identifying cost-effective treatment opportunities at the county scale using the results of the Chaffee County Wildfire Risk Assessment and available spatial data on treatment constraints.

Methods

The Colorado Forest Restoration Institute's Risk Assessment and Decision Support (RADS) model was used to prioritize fuel treatment type and location considering constraints on treatment feasibility and cost. RADS uses a generalized form of the linear programming optimization model described in Gannon et al. (2019) and Figure 1 to select treatment locations and types that maximize risk reduction for the available budget. Spatial treatment units are defined by the user at an appropriate scale for decision-making. Each treatment unit is attributed with the area feasible for treatment and the average risk reduction and treatment cost for each treatment type. Linear optimization is then used to identify the optimal treatment plan for the available budget (see Appendix I – Model formulation). The resulting treatment plan represents the most cost-effective means to reduce wildfire risk given the specified constraints.

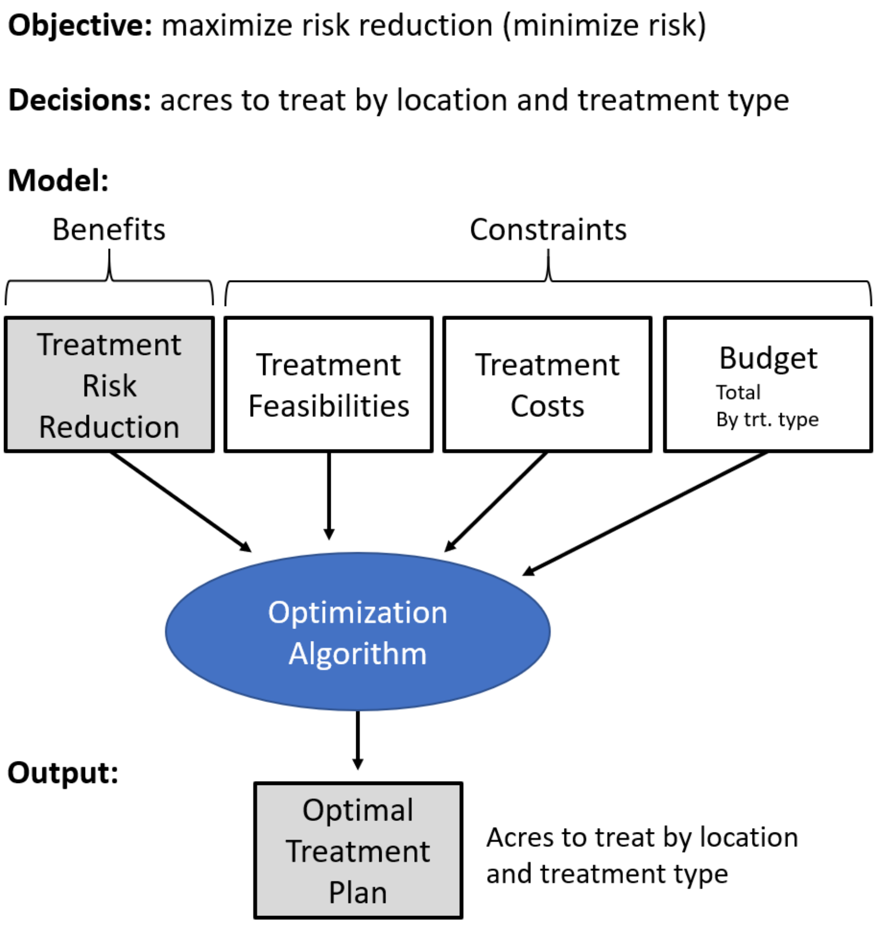


Figure 1: Conceptual diagram of the Risk Assessment and Decision Support (RADS) fuel treatment optimization model. Fuel treatment benefits and constraints are summarized for the feasible treatment area in each treatment unit. Linear optimization is then used to maximize risk reduction for the available budget. Budget is manipulated by the user to focus or expand priorities.

Treatment units

The Community Wildfire Protection Plan Working Group selected National Hydrography Dataset Plus (NHDPlus) catchments as treatment units for the prioritization (USEPA and USGS 2012). There are 830 catchments in Chaffee County. The median, mean, and maximum sizes are 510, 788, and 14,058 acres respectively.

Treatment types

This prioritization considered four treatment types: 1) thin only, 2) prescribed fire only, 3) complete (thin followed by prescribed fire), and 4) mastication.

Treatments are simulated in the baseline fuels data from LANDFIRE (2014) and CO-WRA (Technosylva 2018) by changing surface and canopy fuel attributes by the mean effect sizes for hazardous fuels reduction and forest restoration projects in the western U.S. (Stephens and Moghaddas 2005; Stephens *et al.* 2009; Fulé *et al.* 2012; Ziegler *et al.* 2017) and mastication projects in the Arkansas Valley (Coop *et al.* 2016). Treatment effects on canopy attributes are applied as proportional adjustments to the pre-treatment data (Table 1). Treatment effects on surface fuels are represented by changing the fire behavior fuel model (Scott and Burgan 2005). For this assessment, it was assumed that the thin only treatment would not alter the fire behavior fuel model, except in the case where baseline conditions are mapped as slash blowdown; prescribed fire would shift the fire behavior fuel model to the least intense model in the same category; the complete treatment of thinning followed by prescribed fire would achieve the same effects as prescribed fire; and mastication would result in a uniform slash blowdown fuel model (Heinsch *et al.* 2018) (Table 2).

Table 1: Fuel reduction treatments are simulated with proportional adjustments to baseline canopy attributes using mean effect sizes from fuels reduction and forest restoration projects in the western U.S. (Stephens and Moghaddas 2005; Stephens et al. 2009; Fulé et al. 2012; Ziegler et al. 2017) and mastication projects in the Arkansas Valley (Coop et al. 2016).

Parameter	Thin Only	Rx Fire Only	Complete	Mastication
Canopy base height	1.20	1.09	1.20	0.65
Canopy height	1.20	1.13	1.20	1.00
Canopy cover	0.70	0.95	0.75	0.15
Canopy bulk density	0.60	0.92	0.50	0.22

Table 2: The categorical fire behavior fuel model was not modified for thinning treatments except for slash blowdown models. The surface fuel reduction from prescribed fire is representing by transitioning fire behavior fuel models to the least intense fire behavior fuel model in the same category (e.g. grass shrub, timber litter from Scott and Burgan [2005]). Changes are highlighted with red text.

Category	Code	Current	Thin	Rx Fire	Complete	Mastication
Grass	GR1	101	101	101	101	201
	GR2	102	102	101	101	201
	GR3	103	103	101	101	201
	GR4	104	104	101	101	201
	GR5	105	105	101	101	201
	GR6	106	106	101	101	201
	GR7	107	107	101	101	201
	GR8	108	108	101	101	201
	GR9	109	109	101	101	201
Grass shrub	GS1	121	121	121	121	201
	GS2	122	122	121	121	201
	GS3	123	123	121	121	201
	GS4	124	124	121	121	201
Shrub	SH1	141	141	141	141	201
	SH2	142	142	141	141	201
	SH3	143	143	141	141	201
	SH4	144	144	141	141	201
	SH5	145	145	141	141	201
	SH6	146	146	141	141	201
	SH7	147	147	141	141	201
	SH8	148	148	141	141	201
	SH9	149	149	141	141	201
Timber understory	TU1	161	161	161	161	201
	TU2	162	162	161	161	201
	TU3	163	163	161	161	201
	TU4	164	164	161	161	201
	TU5	165	165	161	161	201
Timber litter	TL1	181	181	181	181	201
	TL2	182	182	181	181	201
	TL3	183	183	181	181	201
	TL4	184	184	181	181	201
	TL5	185	185	181	181	201
	TL6	186	186	181	181	201
	TL7	187	187	181	181	201
	TL8	188	188	181	181	201
	TL9	189	189	181	181	201
Slash blowdown	SB1	201	201	201	201	201
	SB2	202	201	201	201	201
	SB3	203	201	201	201	201
	SB4	204	201	201	201	201

Treatment feasibility

Hard constraints are captured in binary rasters representing whether each pixel is feasible (1) or infeasible (0) the target treatment type. Economic constraints are instead captured with variable treatment costs described in the Treatment cost section.

Feasible locations for the **thin only** treatment were defined by the following constraints:

- Must have trees to cut (LANDFIRE canopy cover ≥ 10%)
- No treatment in wilderness
- No treatment in upper tier roadless
- No treatment in special designation areas (Browns Canyon)

Given these constraints, 242,215 acres or 37.3% of Chaffee County are considered feasible for the thinning only treatment (Figure 2).

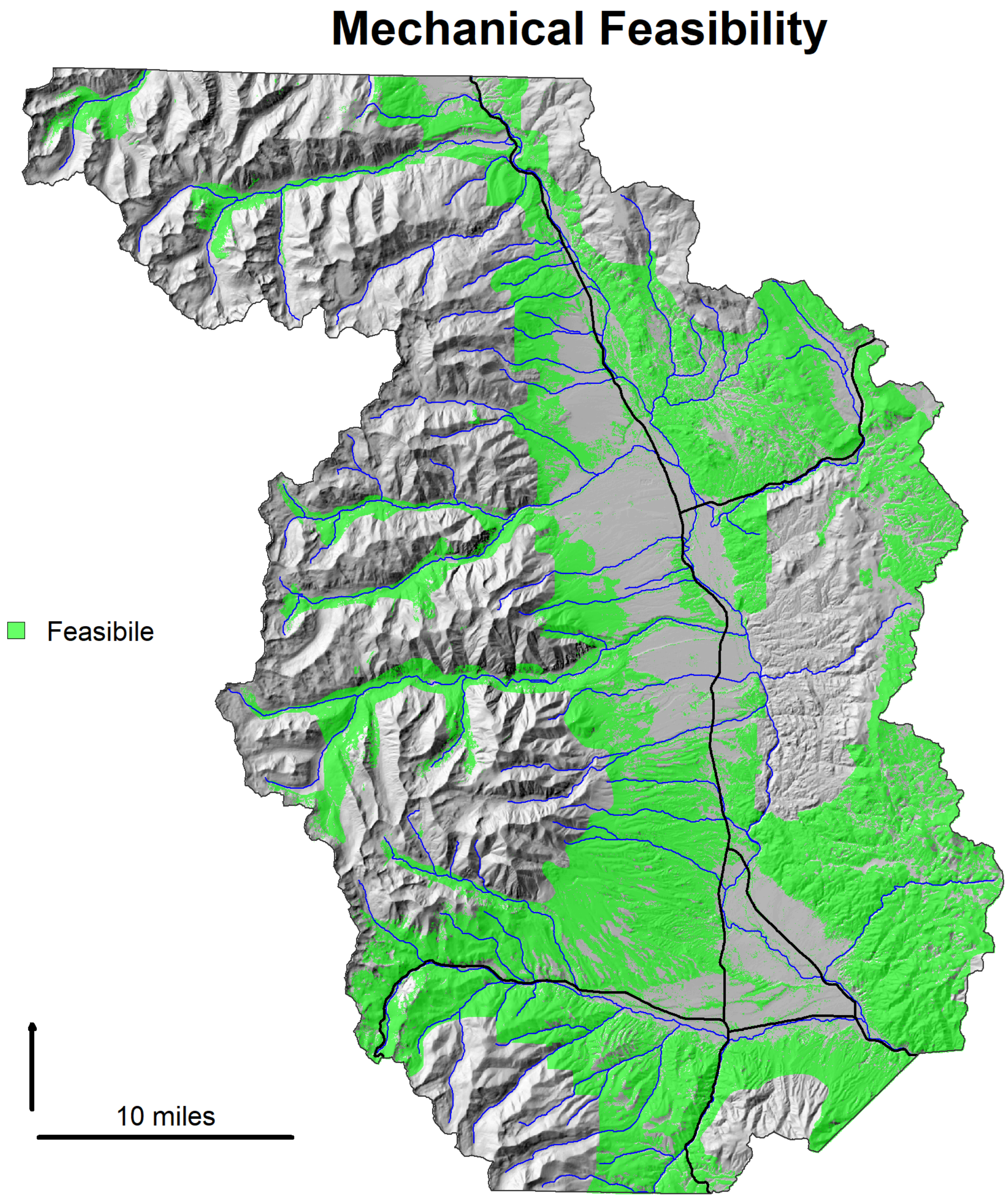


Figure 2: Feasible locations for the mechanical thinning treatment in Chaffee County.

Feasible locations for the **prescribed fire only** treatment were defined by the following constraints:

- No burning < 250 m from structures in the wildland urban interface (from Caggiano *et al.* 2016 and Microsoft 2018)
- Limited to "frequent" fire forest types that can be burned with prescribed fire as a first entry treatment - no high elevation forest types (lodgepole or spruce-fir) and no pinyon-juniper because of the need to rearrange fuels or burn under extreme weather conditions (Chris Naccarato, personal communication)

Given these constraints, 138,497 acres or 21.3% of Chaffee County are considered feasible for the prescribed fire only treatments (Figure 3).

Additionally, stakeholders expressed that prescribed fire use is constrained by the availability of personnel and to some degree smoke permitting and hunting impacts. To capture that it is unrealistic to drastically increase prescribed fire use in the short-term, an additional constraint was created to limit spending on prescribed fire to 30% of the total budget.

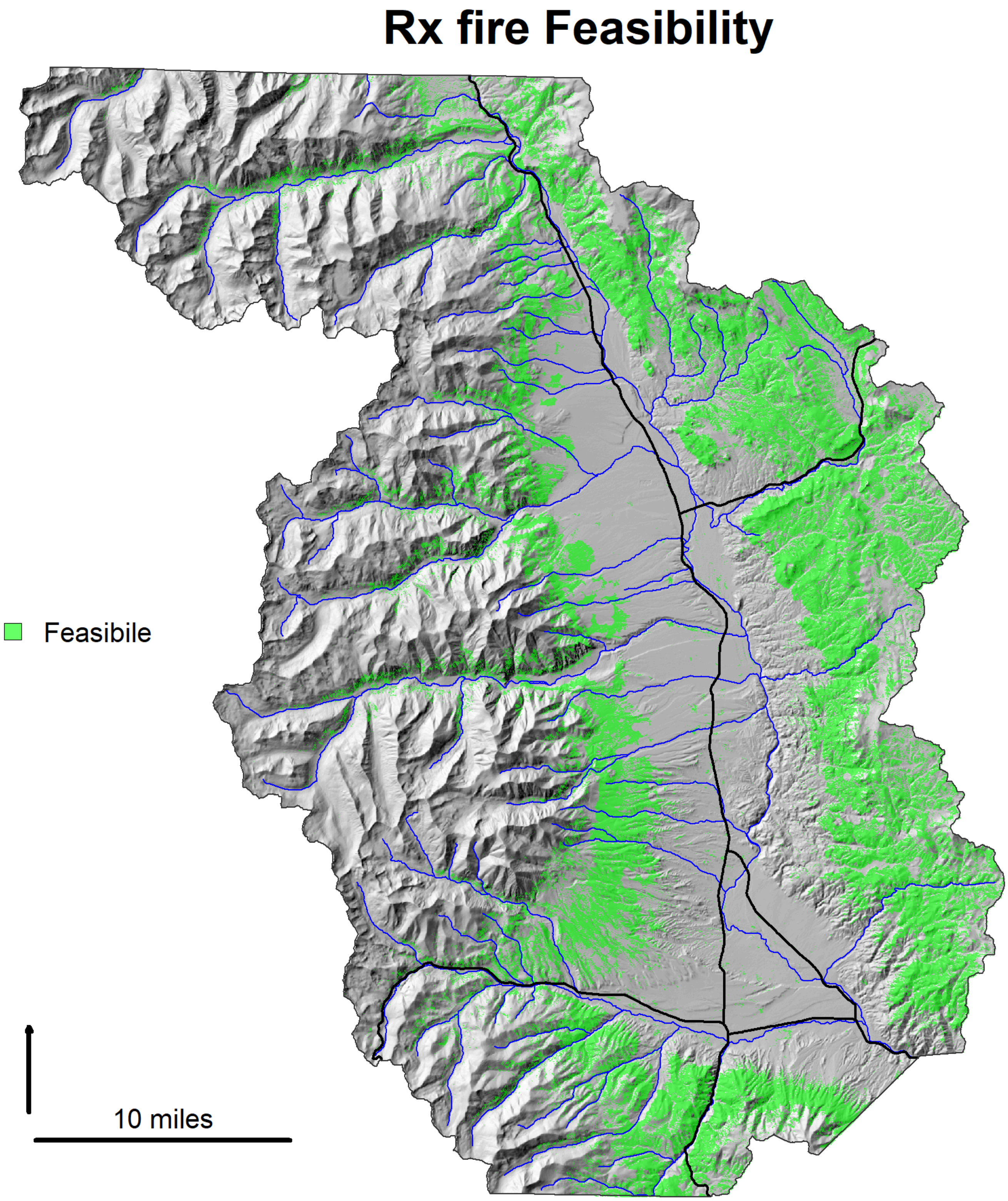


Figure 3: Feasible locations for the prescribed fire treatment in Chaffee County.

Feasible locations for the **complete** treatment were assumed to be the same as the thin only treatment:

- Must have trees to cut (LANDFIRE canopy cover ≥ 10%)
- No treatment in wilderness
- No treatment in upper tier roadless
- No treatment in special designation areas (Browns Canyon)

Given these constraints, 242,215 acres or 37.3% of Chaffee County are considered feasible for the complete treatment (Figure 4).

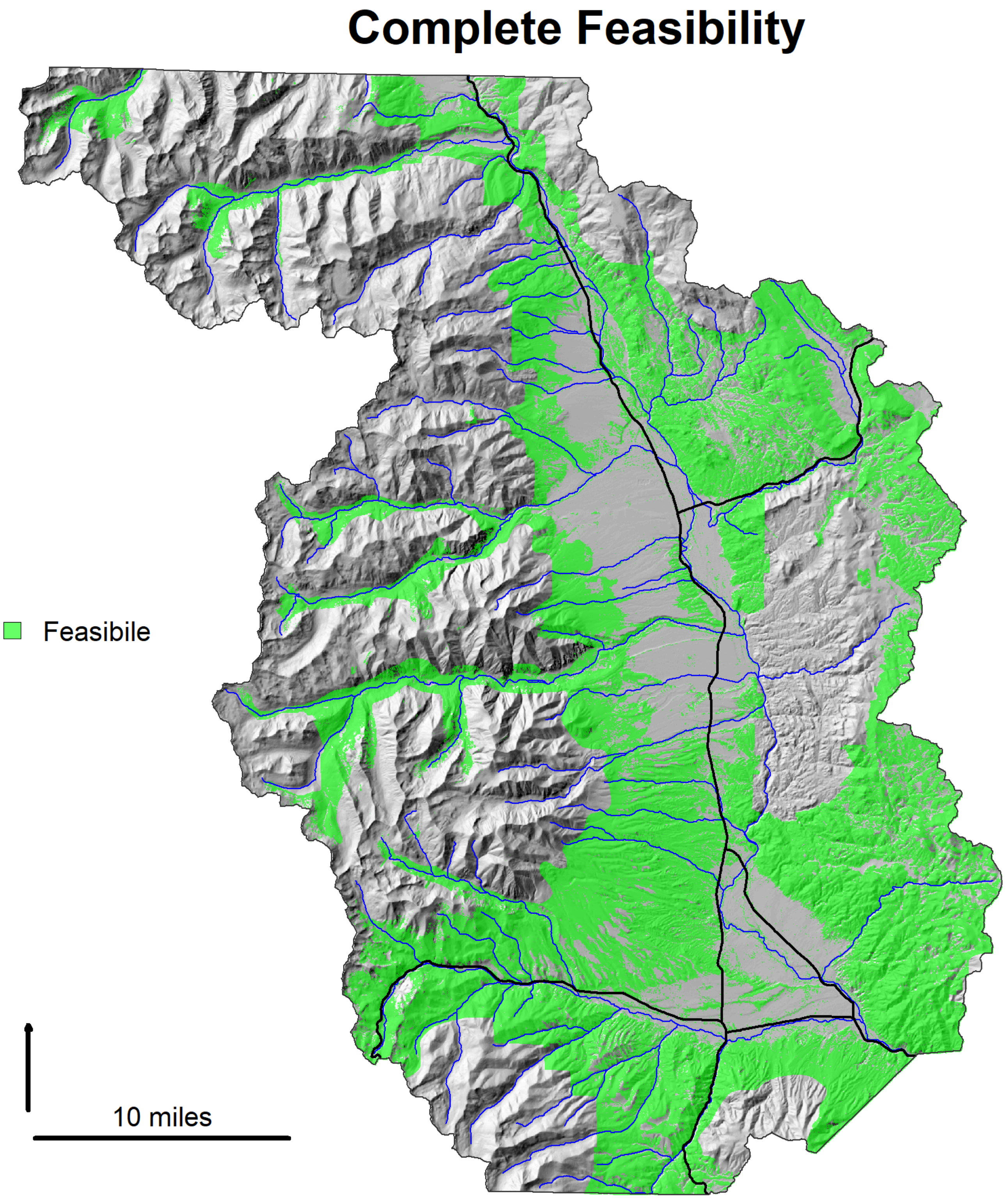


Figure 4: Feasible locations for the complete treatment in Chaffee County.

Feasible locations for the **mastication** treatment were defined by the following constraints:

- Must have trees to cut (LANDFIRE canopy cover ≥ 10%)
- Must be pinyon-juniper
- Must have slopes ≤ 40% (Jain *et al.* 2018; local feedback)
- No treatment in wilderness
- No treatment in upper tier roadless
- No treatment in special designation areas (Browns Canyon)

Given these constraints, 52,878 acres or 8.1% of Chaffee County are considered feasible for the mastication treatment (Figure 4).

Additionally, stakeholders expressed concern that widespread use of mastication in pinyon juniper could negatively impact ecological and scenic values. While mastication is often used to improve habitat for ungulates and other species that benefit from increased grass, forb, and shrub production, drastic reductions in pinyon juniper canopy cover over large portions of the landscape is expected to negatively impact species that depend on closed canopy habitats. To limit mastication treatment extent, an additional constraint was created to limit spending on mastication to 20% of the total budget.

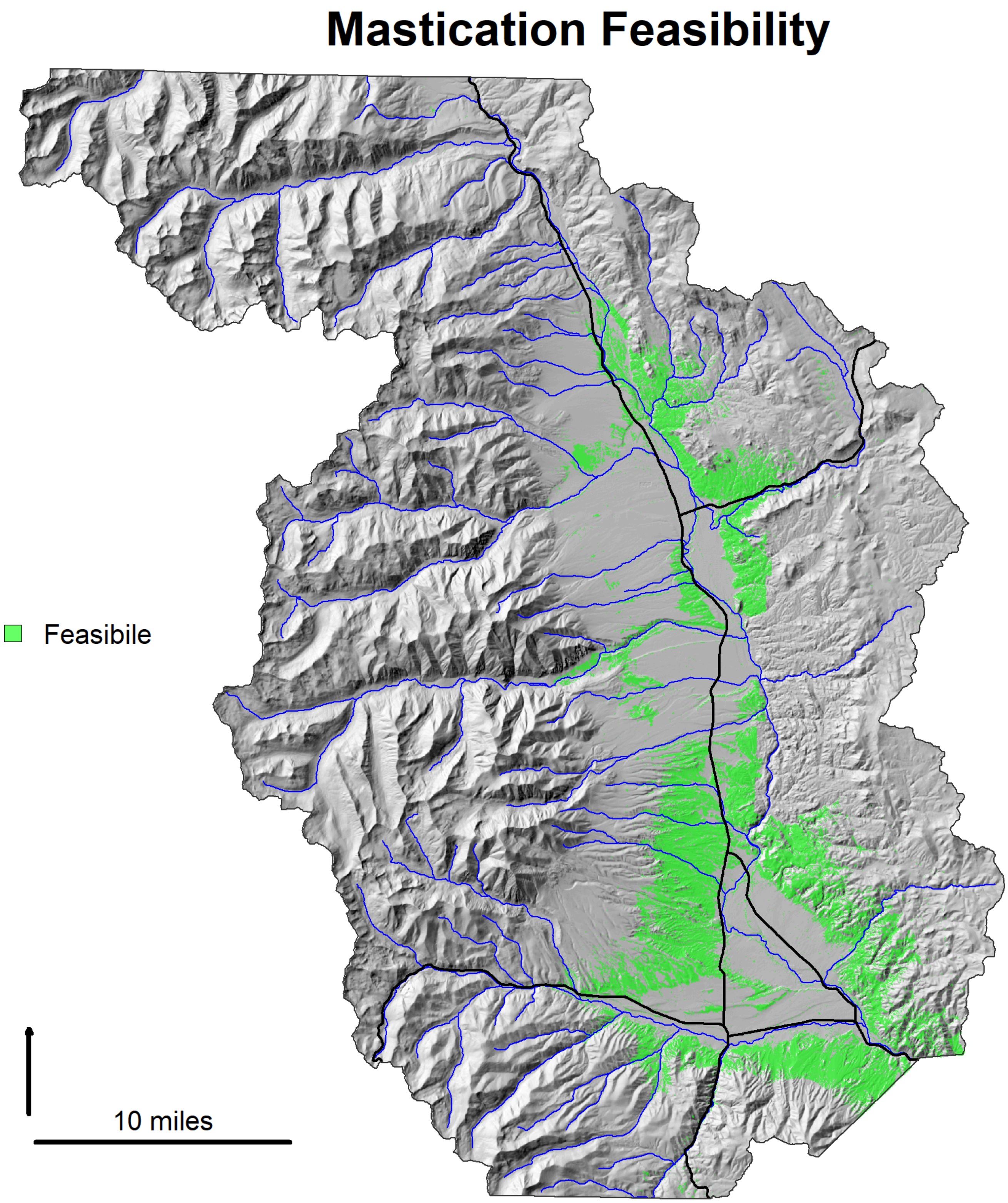


Figure 5: Feasible locations for the mastication treatment in Chaffee County.

Risk reduction

The risk reduction benefit of treatment is assessed on a per-pixel basis as the difference between current risk and simulated post-treatment risk using the Chaffee County CWPP Risk Assessment. The benefit of fuel treatment is only represented as changing fire behavior (flame lengths, crown fire activity) as modeled with FlamMap 5 (Finney *et al.* 2015), not burn probability. This approach is consistent with the primary objectives of fuel treatments (Reinhardt *et al.* 2008), but it could underestimate fuel treatment benefits where they are expected to reduce area burned (Thompson *et al.* 2013). Risk reduction estimates are mapped for each treatment type in Figure 6 through Figure 9.

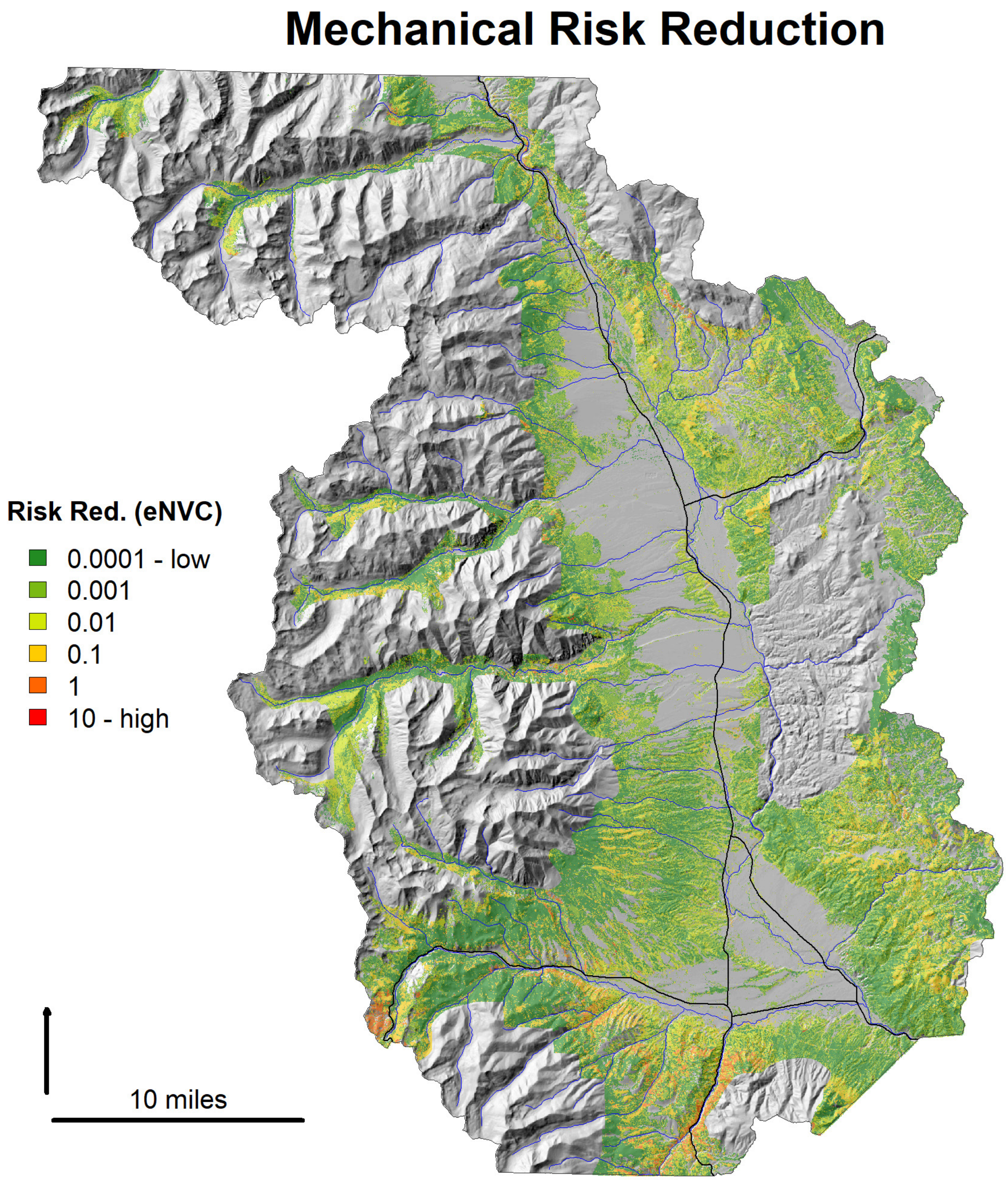


Figure 6: Estimated risk reduction for the mechanical thinning only treatment.

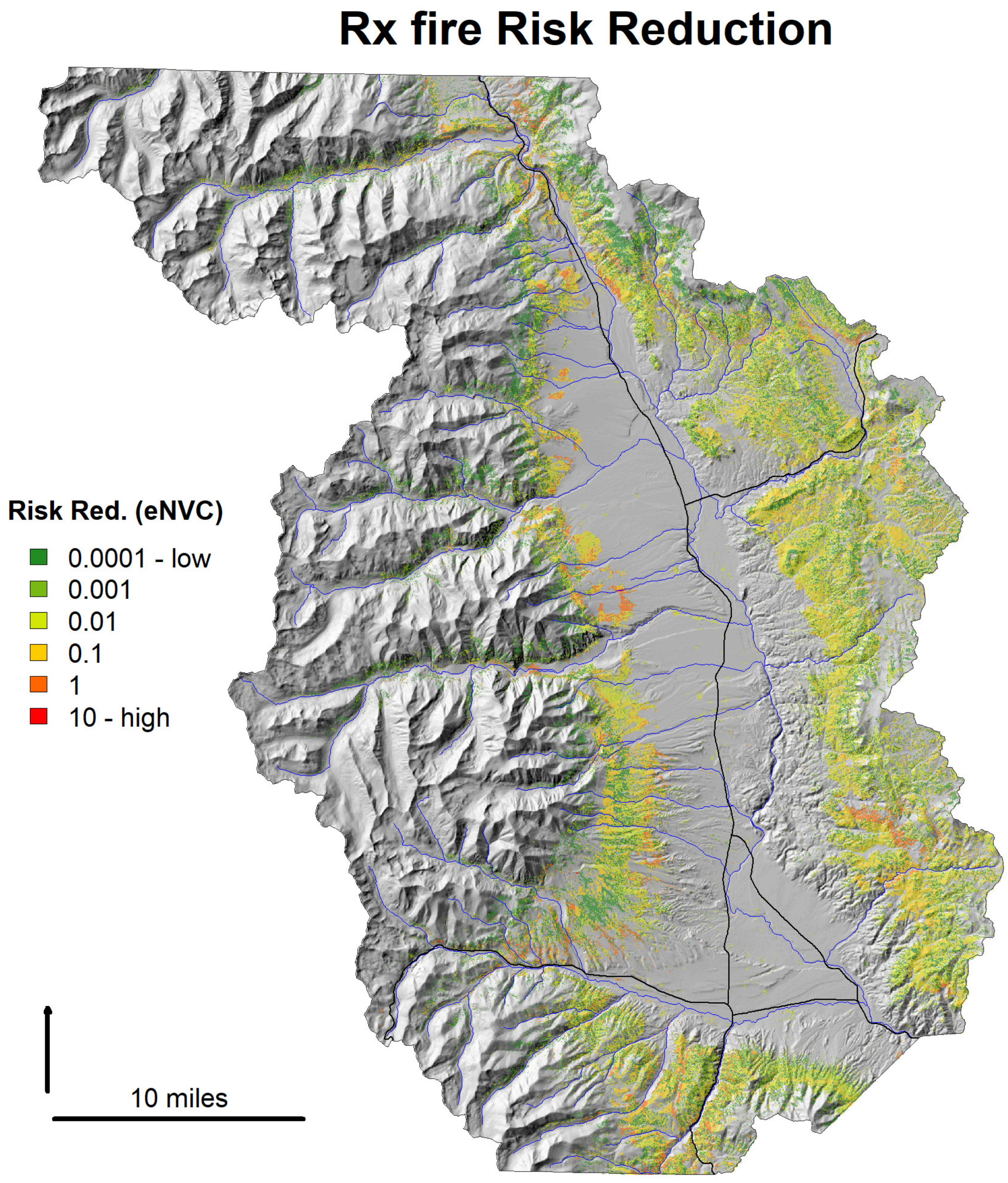


Figure 7: Estimated risk reduction for the prescribed fire only treatment.

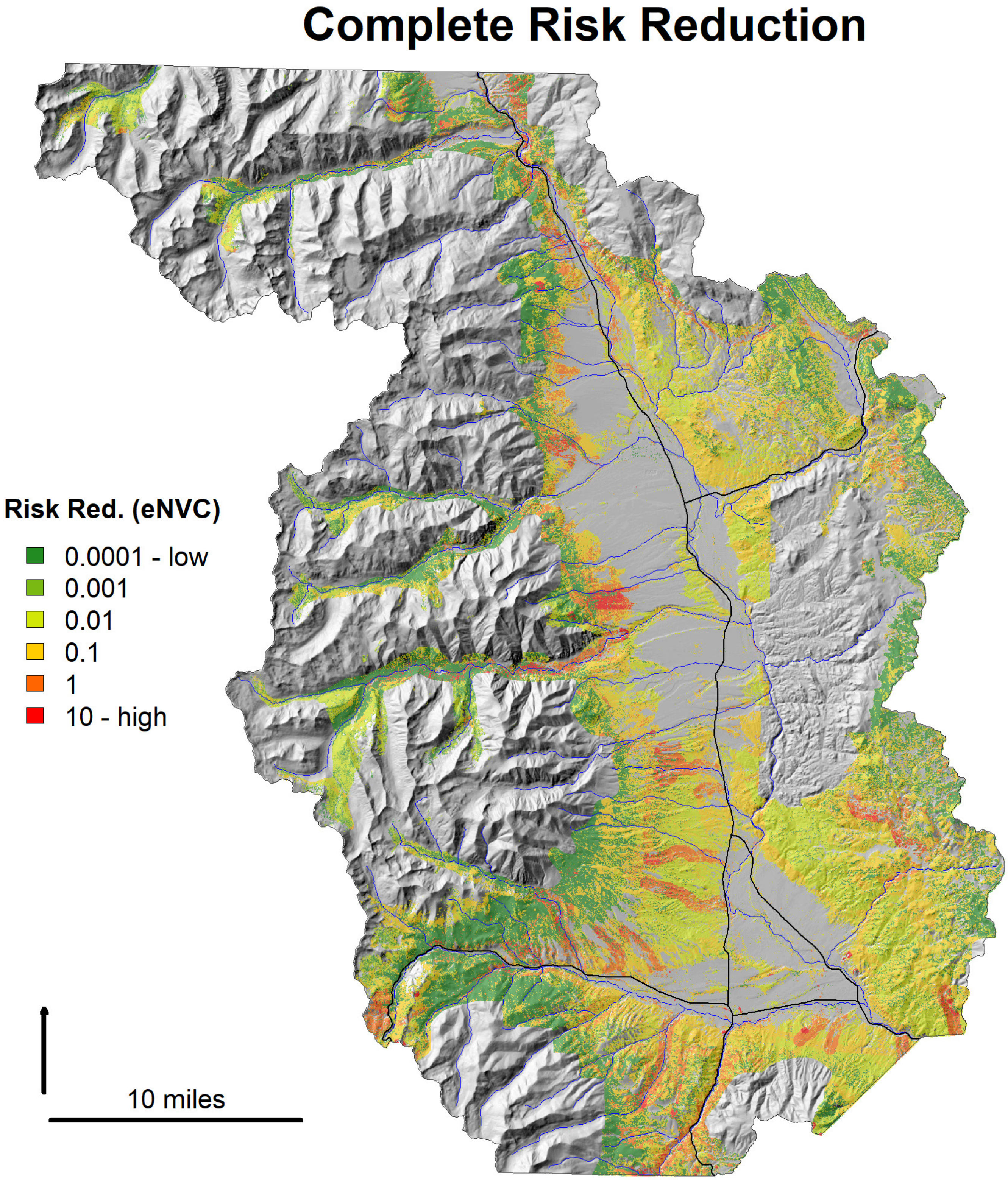


Figure 8: Estimated risk reduction for the complete treatment.

Mastication Risk Reduction

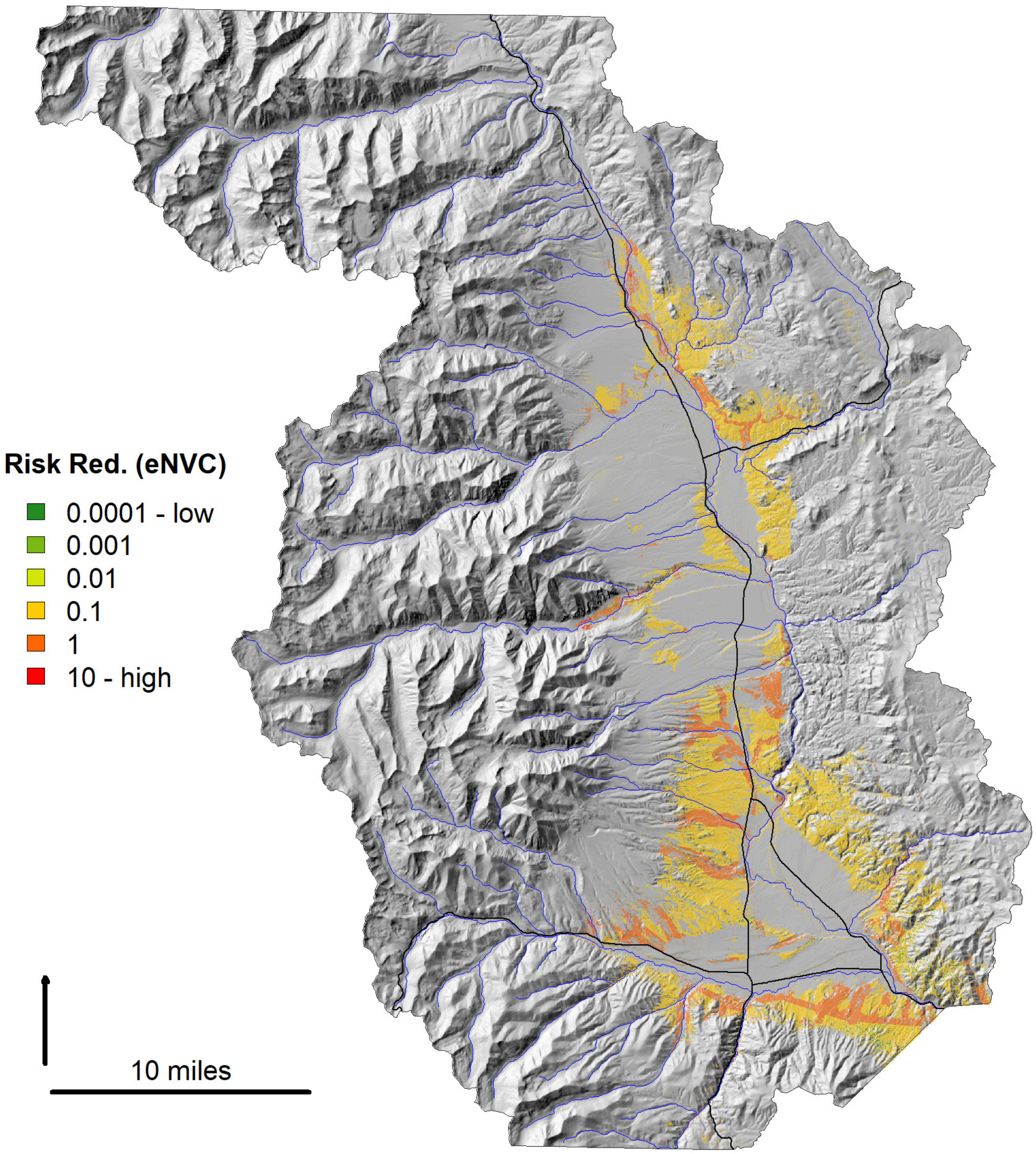


Figure 9: Estimated risk reduction for the mastication treatment.

Treatment cost

Treatment costs were based primarily on expert opinion because current treatment cost models either do not consider landscape-scale variation (Calkin and Gebert 2006) or require detailed data on stand conditions that are not available for most the landscape (Fight *et al.* 2006).

Per acre cost for the **thin only** treatment is approximated by adapting an expert model developed in northern Colorado (Gannon *et al.* 2019) for use in Chaffee County. Cost is considered a function of base treatment cost under ideal conditions ($1,800/ac) with adjustments for distance from roads (*Dcost*) and slope steepness (*Scost*) in Eqn 1.

$$Cost = 1{,}800 + Dcost + Scost$$ **Equation 1**

Cost increases with distance from roads > 800 m as specified in Eqn 2 such that the total cost of treatment increases to $10,000/ac at four miles from the nearest road.

$$Dcost(x) = \begin{cases} 0, & x < 800\ m \\ 1.46 * (x - 800), & x \geq 800\ m \end{cases}$$ **Equation 2**

Cost increases with slope > 35% as specified in Eqn 3 such that the total cost of treatment increases to $10,000/ac at 200% slope.

$$Scost(x) = \begin{cases} 0, & x < 35\ \% \\ 49.7 * (x - 35), & x \geq 35\ \% \end{cases}$$ **Equation 3**

This formulation suggests the base cost applies anywhere within 800 m of roads and less than 35% slope. Total thinning costs were limited to a maximum of $10,000/ac if the combination of road distance and slope adjustments predicted costs in excess of $10,000/ac. The thin only treatment costs are shown in Figure 10.

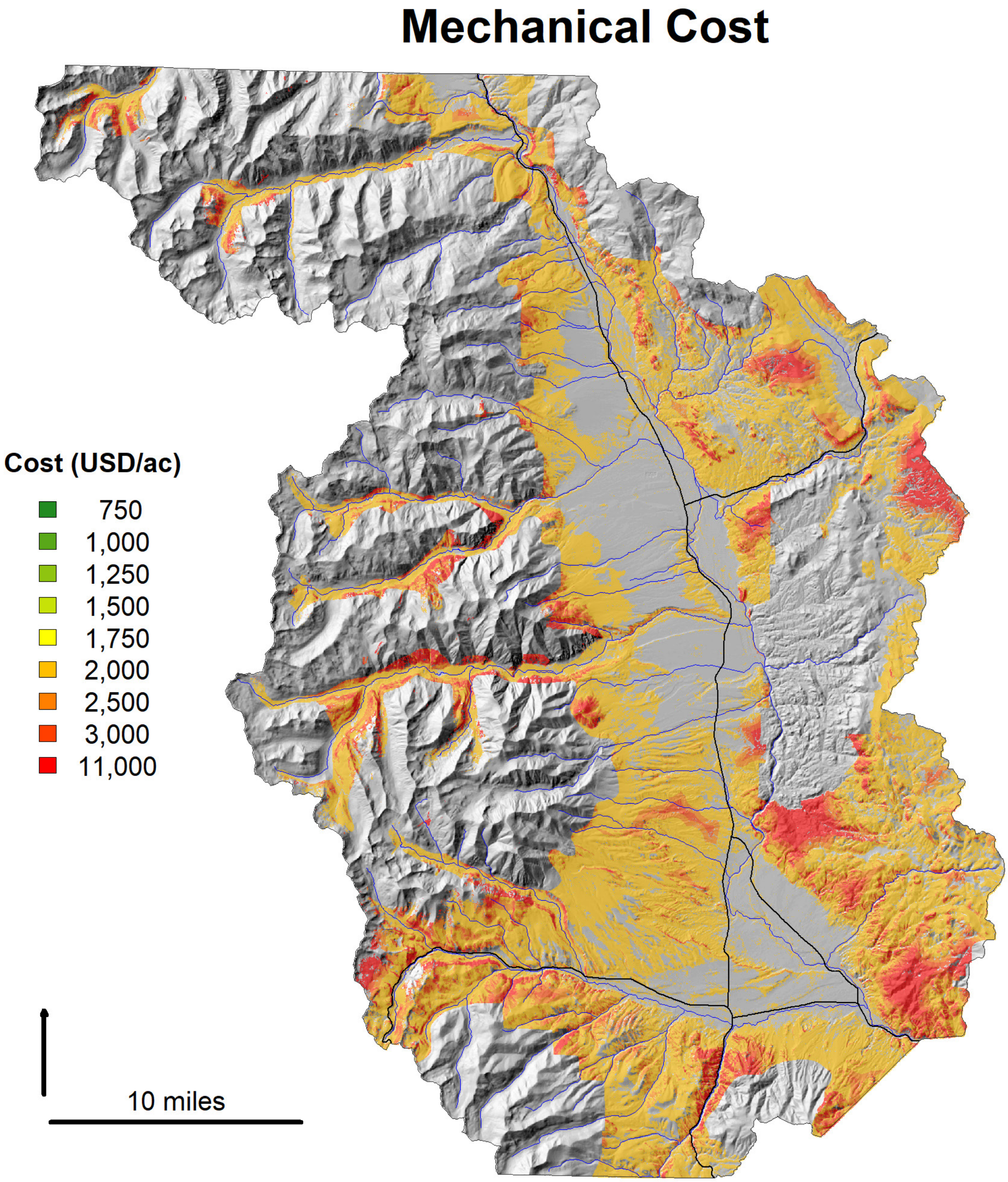


Figure 10: Mechanical thinning cost for Chaffee County estimated using distance from roads and slope steepness.

Per acre cost for the **prescribed fire only** treatment is assumed constant. While prescribed fire costs do vary widely, the causes of this variation are highly site and condition specific and therefore difficult to quantify with coarse spatial data. Prescribed fire costs are difficult to characterize in part because preparation costs are not consistently recorded. We therefore assumed a flat rate of $1,000/ac to cover both the preparation and day of costs. The prescribed fire only treatment costs are shown in Figure 11.

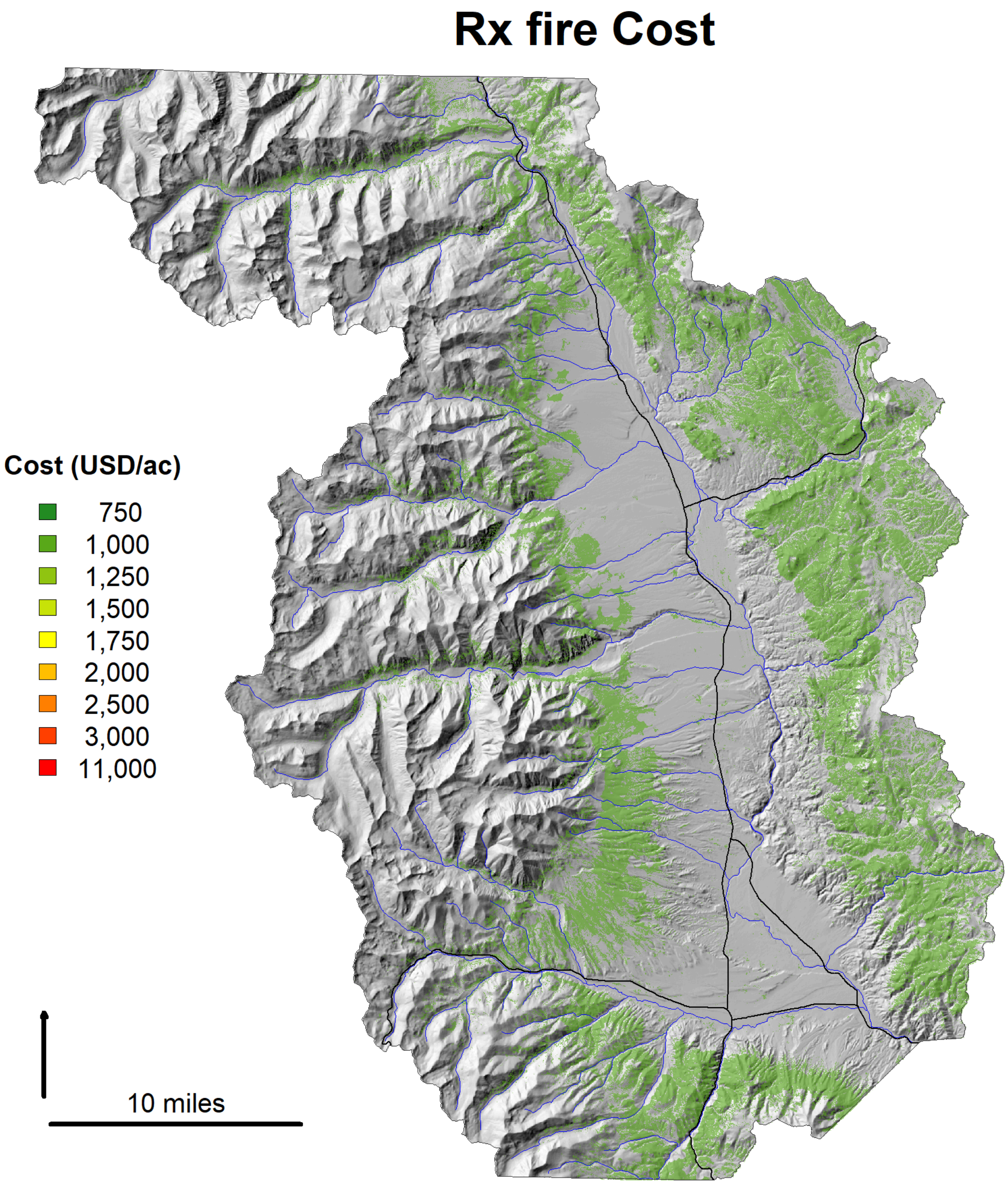


Figure 11: Prescribed fire cost for Chaffee County estimated as a constant value.

Per acre cost for the **complete** treatment is assumed to be the sum of the thinning and prescribed fire treatment costs. The Working Group discussed whether the thinning treatment would reduce the prescribed fire costs by eliminating preparation work. Fire and fuels planners said there is rarely a synergy. Previously thinned areas may require pile burns or other fuel manipulations before broadcast burning will achieve the desired effects. A similar effort is still required to prep control lines. The complete treatment costs are shown in Figure 12.

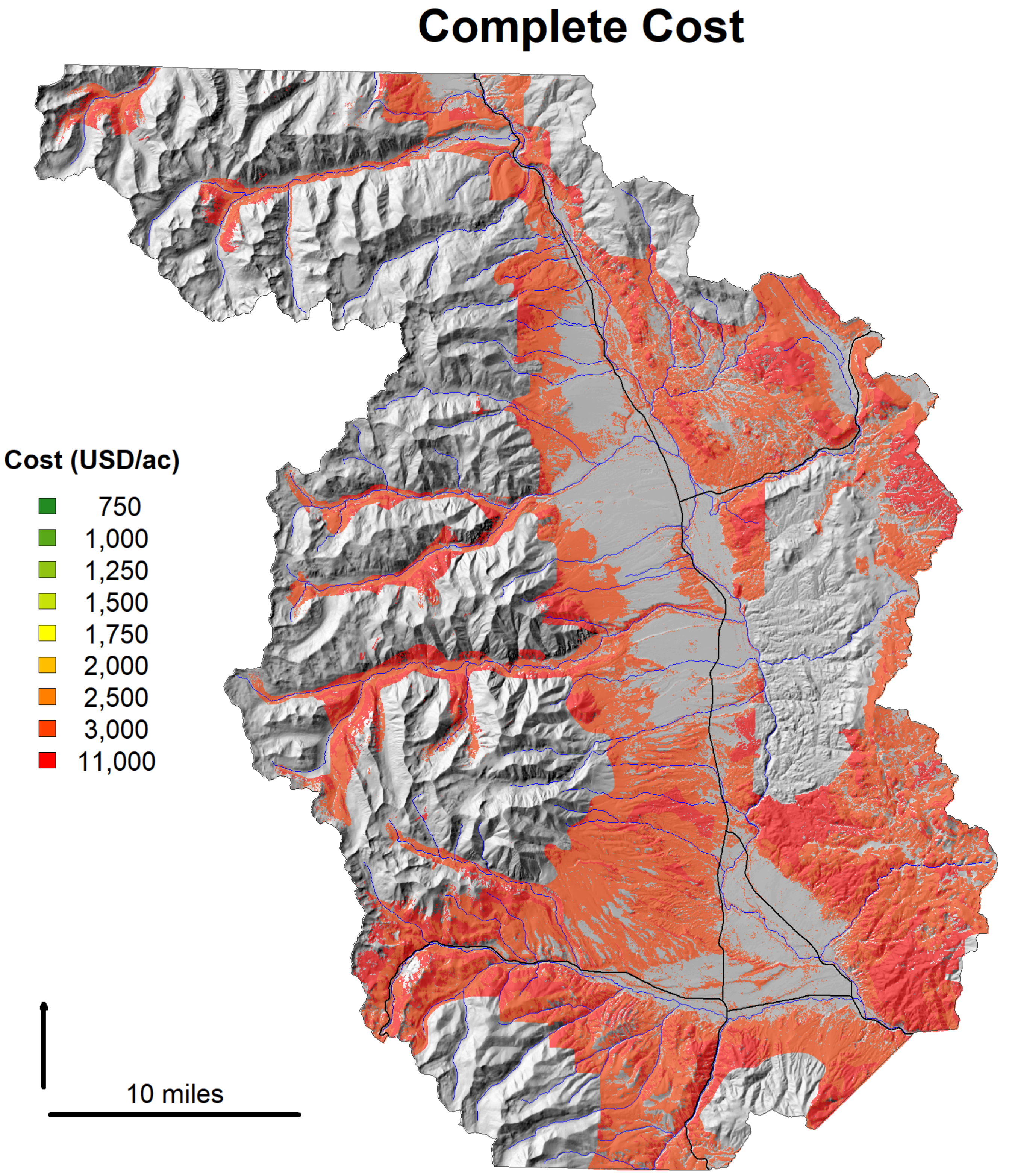


Figure 12: Complete treatment cost for Chaffee County estimated as the sum of thinning and prescribed fire costs.

Per acre cost for the **mastication** treatment is modeled similar to thinning. Cost is considered a function of base treatment cost under ideal conditions ($700/ac) with adjustments for distance from roads (*Dcost*) and slope steepness (*Scost*) in Eqn 4.

$$Cost = 700 + Dcost + Scost$$ **Equation 4**

Cost increases with distance from roads > 800 m as specified in Eqn 5 such that the total cost of treatment increases to $5,000/ac at four miles from the nearest road.

$$Dcost(x) = \begin{cases} 0, & x < 800\ m \\ 0.77 * (x - 800), & x \geq 800\ m \end{cases}$$ **Equation 5**

Cost increases with slope > 20% (Jain *et al.* 2018) as specified in Eqn 6 such that the total cost of treatment increases to $1,400/ac at 40% slope.

$$Scost(x) = \begin{cases} 0, & x < 20\ \% \\ 35 * (x - 20), & x \geq 20\ \% \end{cases}$$ **Equation 6**

This formulation suggests the base cost applies anywhere within 800 m of roads and less than 20% slope. Total mastication costs were limited to a maximum of $5,000/ac if the combination of road distance and slope adjustments predicted costs in excess of $5,000/ac. The mastication treatment costs are shown in Figure 13**.**

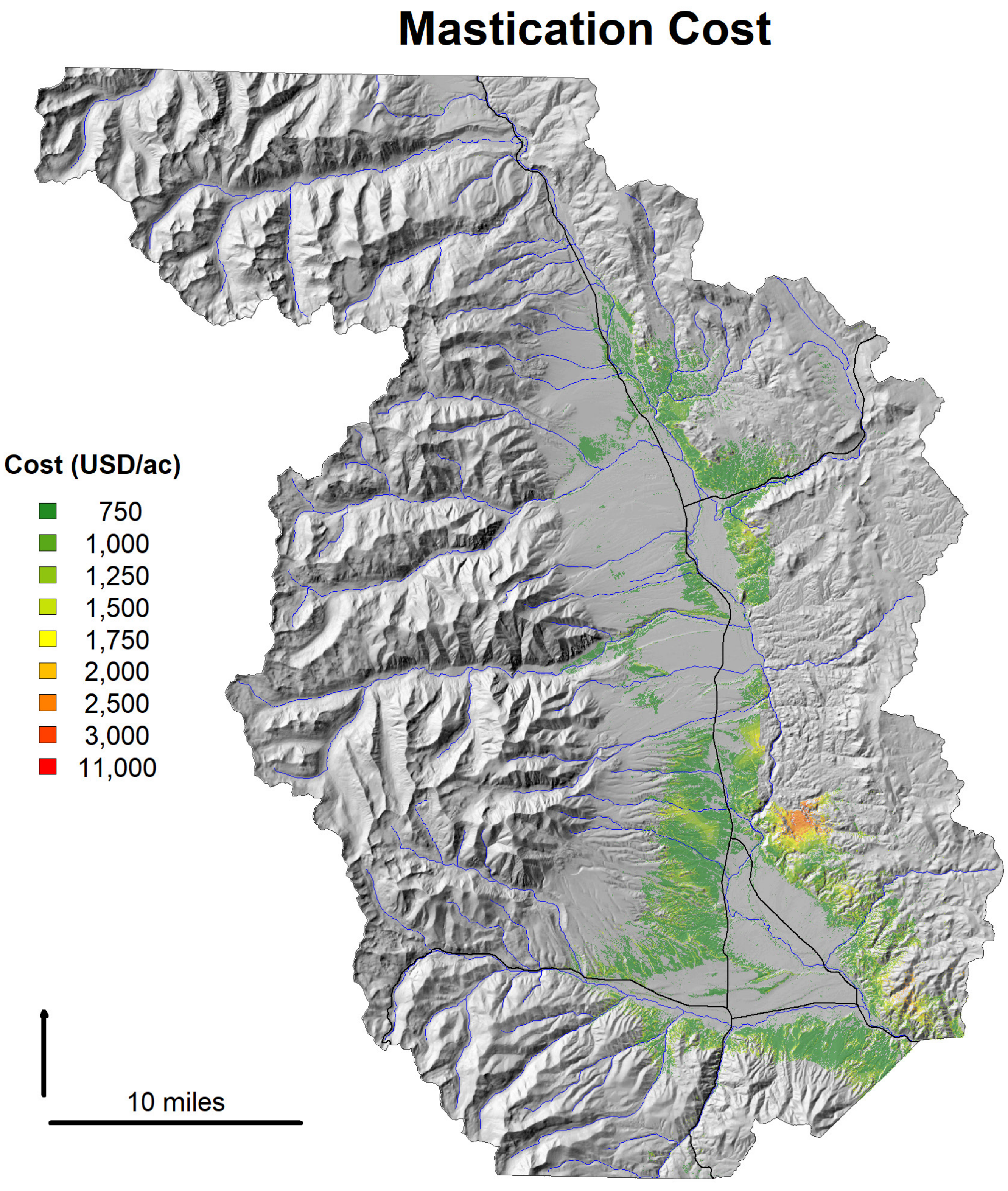


Figure 13: Mastication cost for Chaffee County estimated using distance from roads and slope steepness.

Prioritization

The RADS model is used for prioritization by identifying the optimal treatment locations and types for a wide range of budget levels – $10M, $50M, $100M, and $200M. Areas selected at a lower budget levels are more cost effective than those selected at higher budget levels.

Results

The RADS optimization model selected between 7,252 and 130,521 acres for treatment across the modeled budgets (Table 3). Budgets of $10M, $50M, $100M, and $200M correspond to selecting the top 2.5%, 12%, 22%, and 45% of treatment opportunities respectively. The draft fuel treatment priorities for Chaffee County are mapped in Figure 14.

Table 3: Budget summary of risk reduction achieved and treatment allocation.

Priority	Budget	Risk Reduction (eNVC)	Thin only (acres)	Rx fire only (acres)	Complete (acres)	Mastication (acres)	Total (acres)
Highest	$10M	1,184	174	3,000	1,484	2,593	7,252
Higher	$50M	2,848	141	13,652	8,565	12,361	34,719
High	$100M	3,873	141	22,180	18,816	24,524	65,661
Moderate	$200M	4,827	141	44,987	37,615	47,778	130,521

The model was also run across the full range of possible fuel treatment budgets (Figure 15). The top panel illustrates that although less than half the area available for treatment is selected at the $200M budget level, this treatment plan is expected to achieve most of the risk reduction that is possible with fuel treatment. The RADS model selects close to the maximum allowed use of prescribed fire and mastication (Table 3; Figure 15) because they are very cost-effective treatments (Appendix II – Cost-effectiveness results). Despite the cheaper cost of the thin only treatment, the model primarily choses the more expensive complete treatment because there is substantial benefit to managing the surface fuels. The dominant treatment type assigned to each catchment is mapped in Figure 16 for the $200M treatment plan to provide a general indication of what treatment types are most appropriate in which areas. This map is not meant to be prescriptive or to replace the need for field assessment of current conditions to identify the appropriate treatment type. The RADS model often allocates multiple treatment types within large catchments, so the map should be interpreted with caution; for example, 105 of the 258 catchments prioritized for treatment at the $200M budget level are assigned multiple treatment types. The spatial distribution of treatments is reflective of the current forest conditions and associated management practices: 1) mastication is assigned exclusively within the pinyon-juniper zone; 2) prescribed fire is targeted towards the ponderosa pine and dry mixed conifer zones; and 3) the complete treatment is assigned primarily to dense mid- to high-elevation forests.

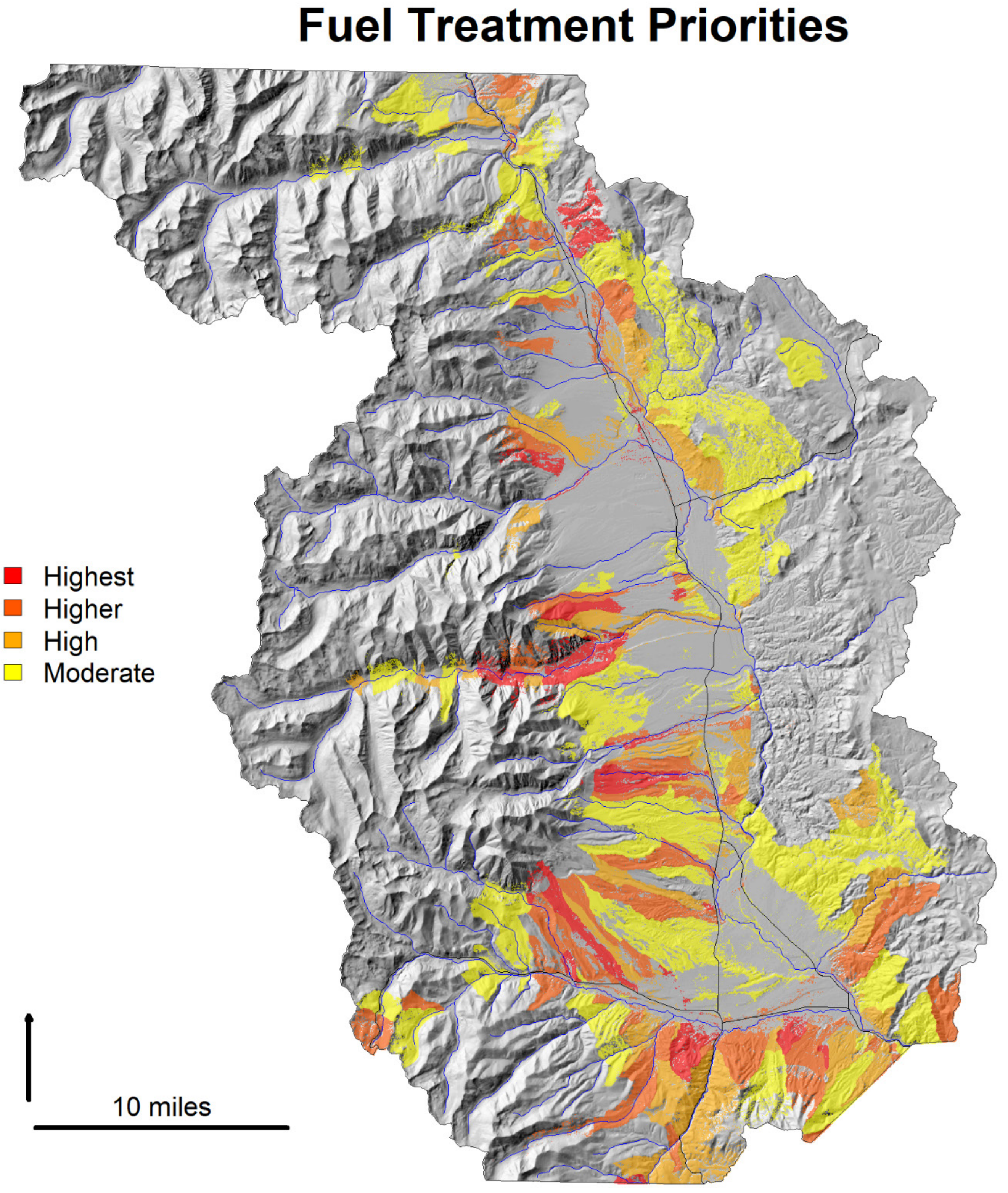
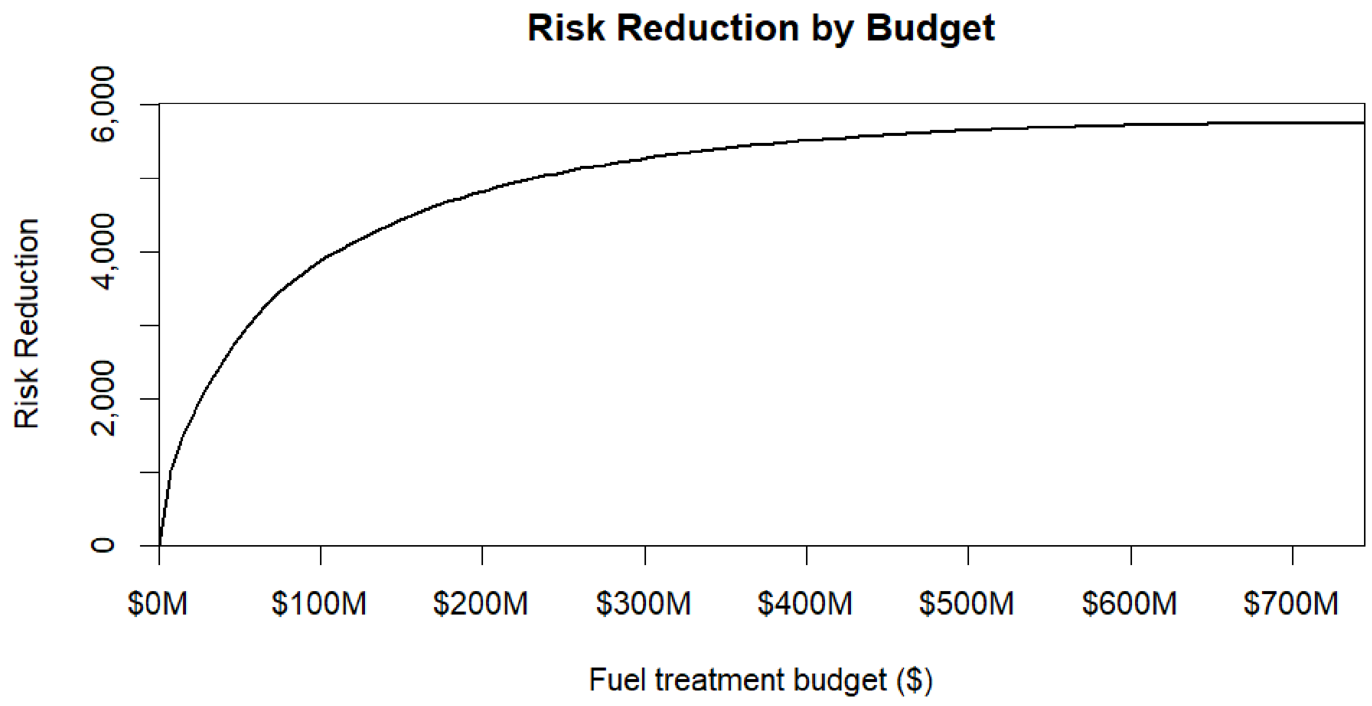


Figure 14: Fuel treatment prioritization for Chaffee County. Highest, higher, high, and moderate treatment priorities correspond to $10M, $50M, $100M, and $200M fuel treatment budgets.



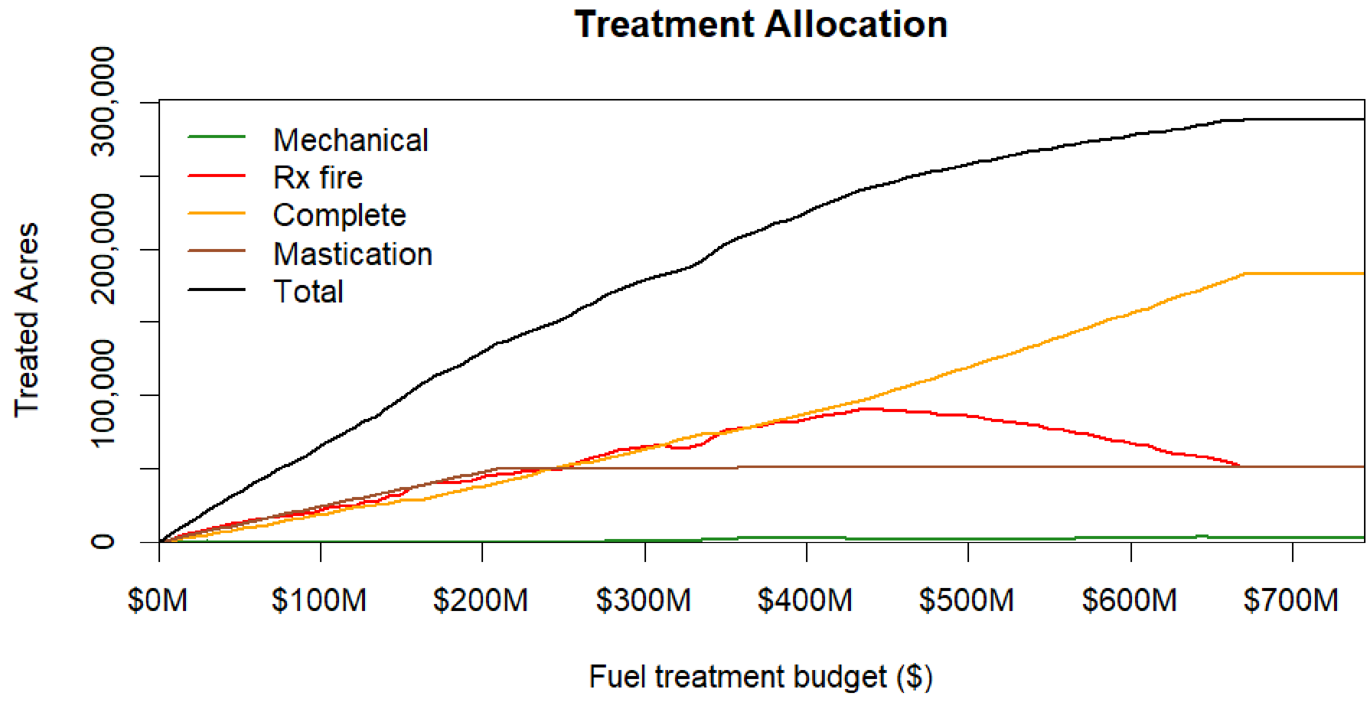


Figure 15: The avoided risk curve shows the level of risk reduction achieved across a wide range of fuel treatment budgets in the top panel. Treatment type allocations are tracked by budget level in the lower panel. Risk is unitless (or relative) measures of expected Net Value Change from the Chaffee County Wildfire Risk Assessment.

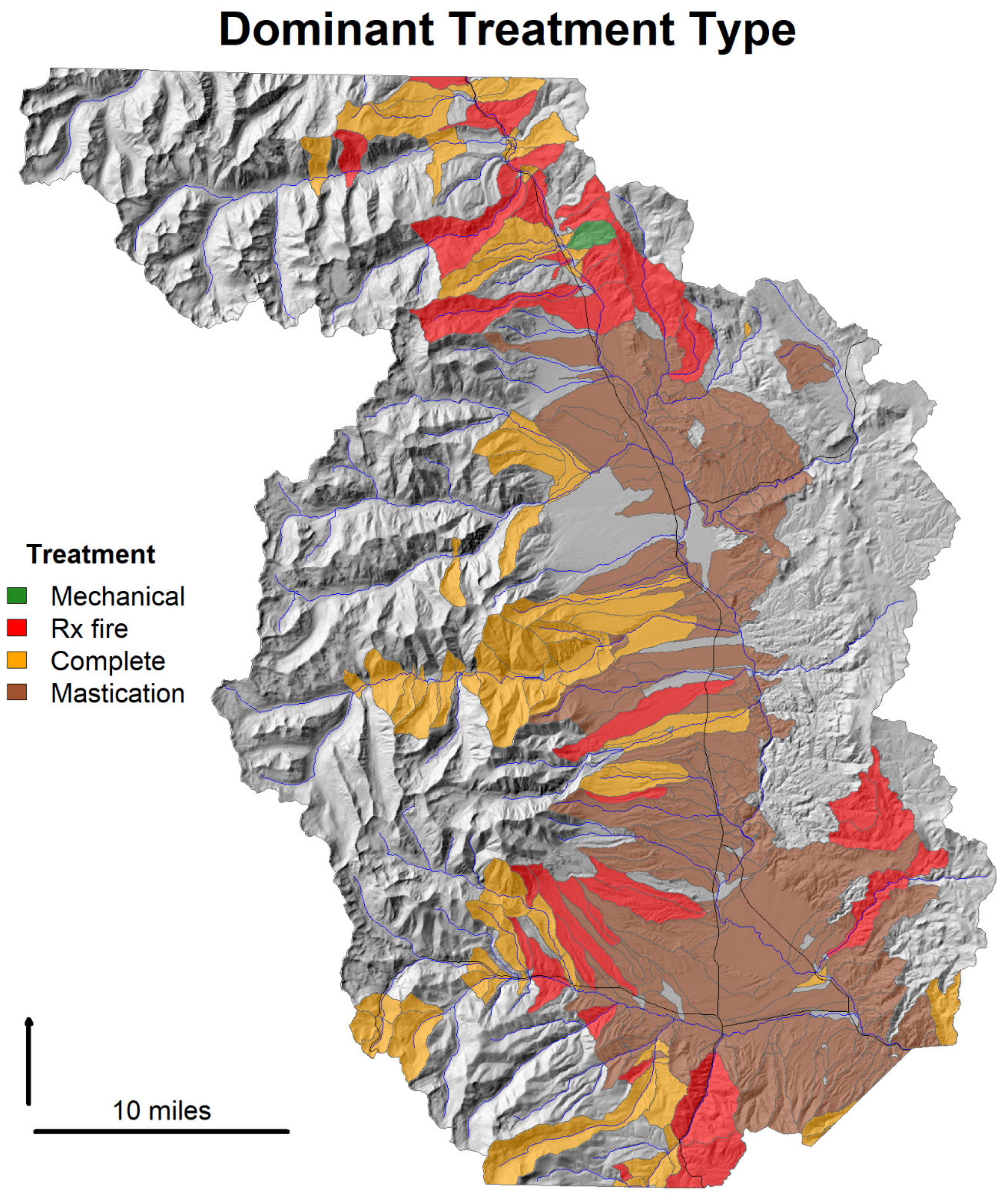


Figure 16: The RADS model can assign multiple treatment types within a catchment. This simplified map shows the dominant treatment type by acres in each catchment for the $200M treatment plan (moderate-highest priority areas). It does not imply that the mapped treatment type is applied across the entire catchment.

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Appendix I – Model formulation

Linear program formulation

Objective function:

$$\max Z = \sum_{i=1}^{N} \sum_{t=1}^{P} RR_{i,t} * x_{i,t}$$

Constraints:

$$x_{i,t} \leq F_{i,t} \qquad \forall\, i, t$$

$$\sum_{t=1}^{P} x_{i,t} \leq tF_i \qquad \forall\, i$$

$$x_{i,t} \geq 0 \qquad \forall\, i, t$$

$$\sum_{i=1}^{N} \sum_{t=1}^{P} TC_{i,t} * x_{i,t} \leq Budget * BP_t \qquad \forall\, i, t$$

$$\sum_{i=1}^{N} \sum_{t=1}^{P} TC_{i,t} * x_{i,t} \leq Budget$$

Subscript notation:

i is used to index treatment units from 1 to N
t is used to index treatment types from 1 to P

Decision variables:

$x_{i,t}$ is the area (ac) of treatment t assigned to treatment unit i

Parameters:

Z is the total risk reduction (unitless)
$RR_{i,t}$ is the risk reduction per acre of treatment t applied to treatment unit i
$F_{i,t}$ is the feasible area (ac) for treatment t in treatment unit i
tF_i is the total feasible area (ac) for any treatment in treatment unit i
$TC_{i,t}$ is the cost ($/ac) of applying treatment t in treatment unit i
Budget is the funding available for fuel treatment ($)
BP_t is the maximum budget proportion that can be allocated to treatment type t

Minimum and maximum treatment sizes (ac) are also imposed on the model by pre-processing decision units to eliminate those that fall under the minimum treatment size and by shrinking the feasible acres for those decision units that exceed the maximum treatment size.

Appendix II – Cost-effectiveness results

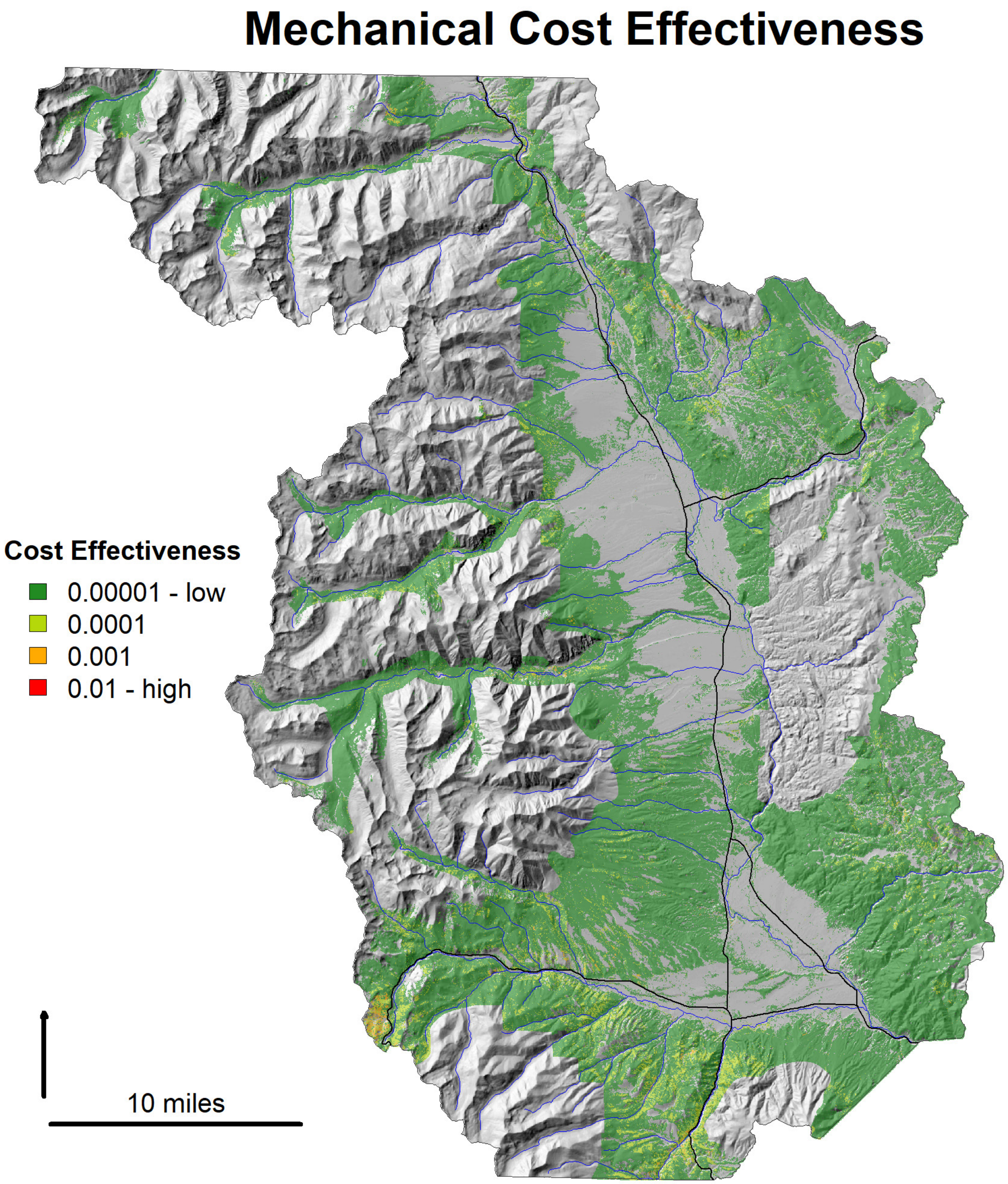

Figure 17: Cost-effectiveness (risk reduction/treatment cost) of the mechanical thinning only treatment.

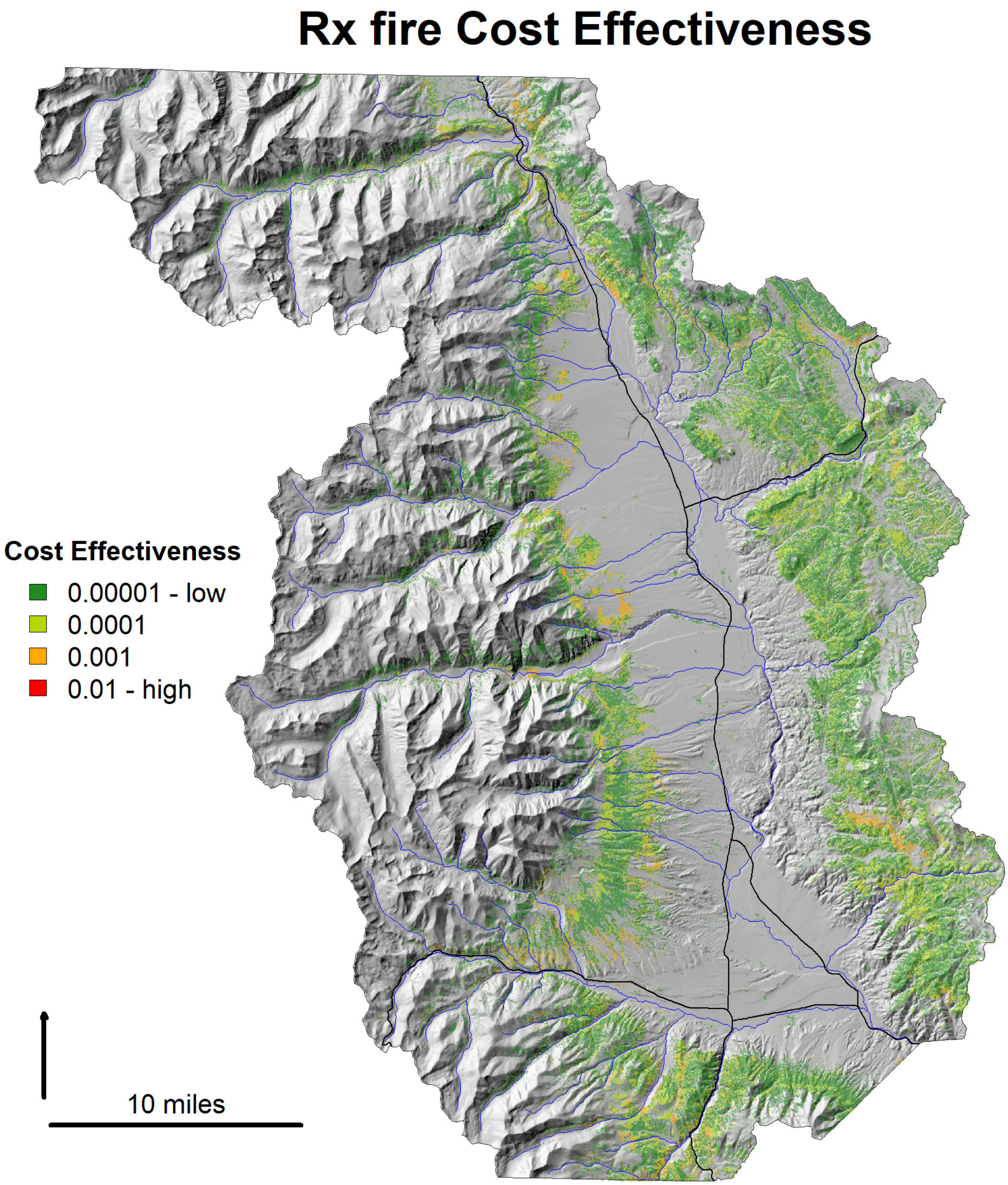

Figure 18: Cost-effectiveness (risk reduction/treatment cost) of the prescribed fire only treatment.

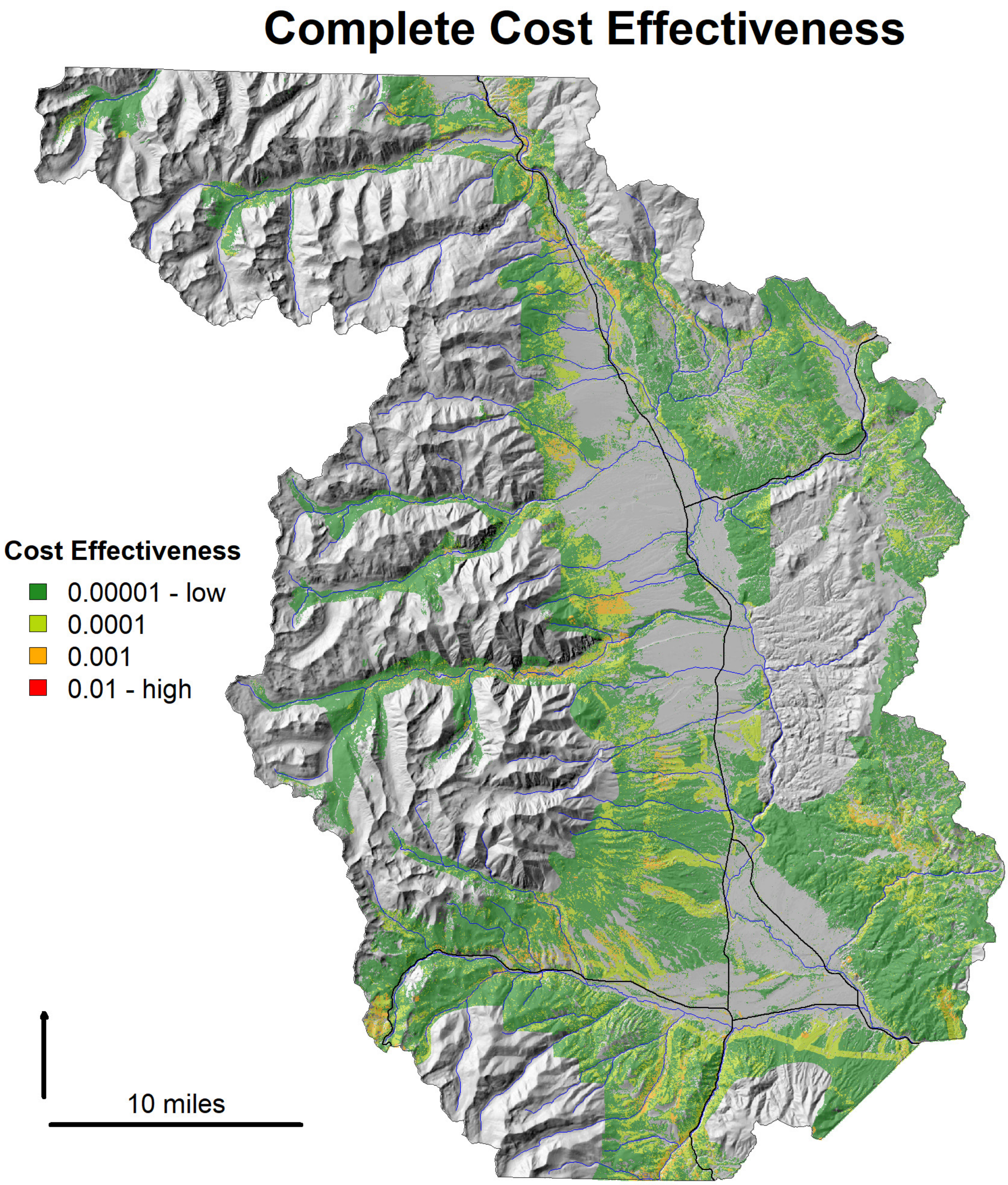

Figure 19: Cost-effectiveness (risk reduction/treatment cost) of the complete treatment.

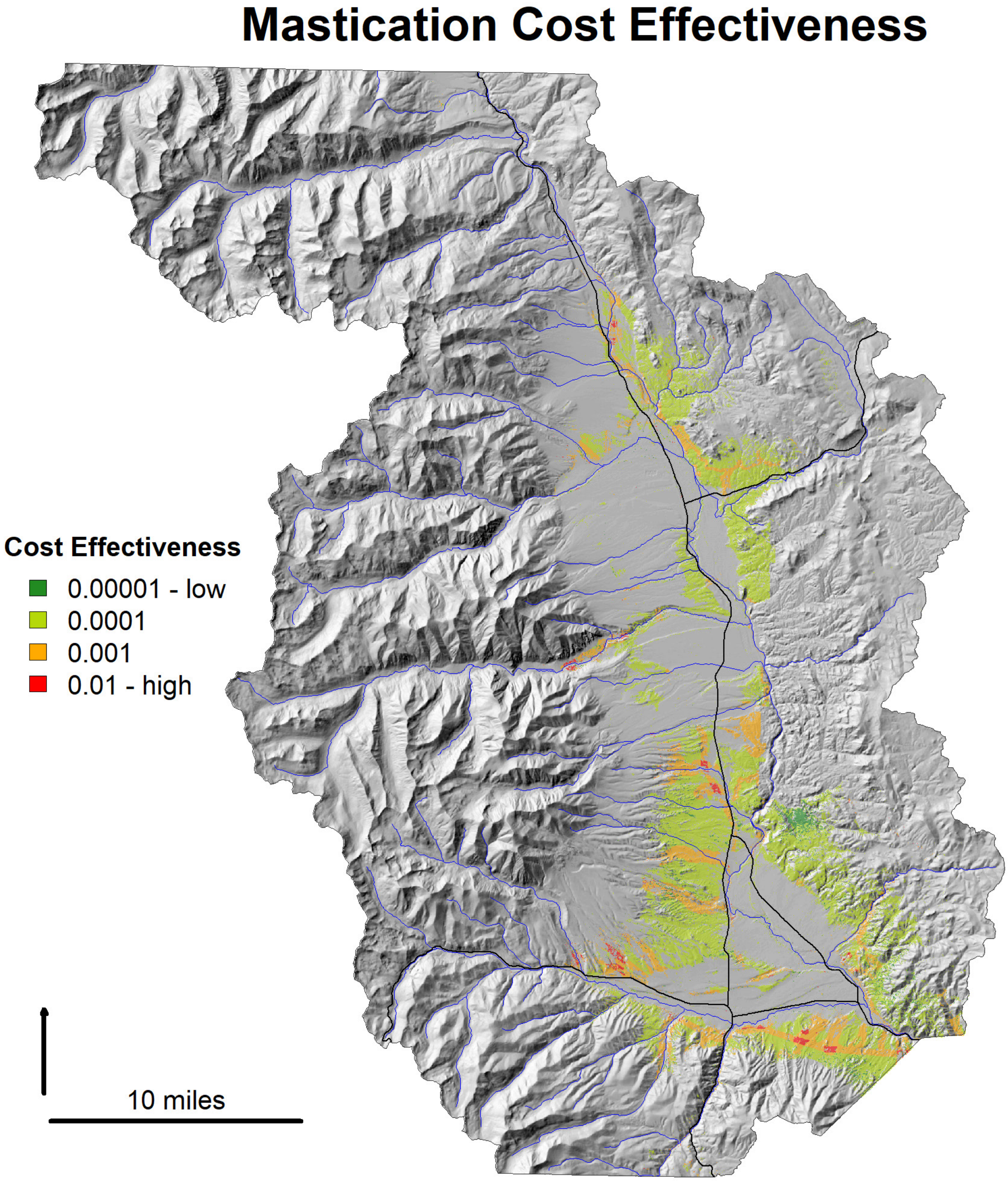

Figure 20: Cost-effectiveness (risk reduction/treatment cost) of the mastication treatment.