COLORADO FOREST RESTORATION INSTITUTE
COLORADO STATE UNIVERSITY

Report on potential application of landscape-scale analyses for assistance with Forest planning

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Introduction

Ponderosa pine (*Pinus ponderosa* Douglas ex P. Lawson & C. Lawson) forests have experienced increases in forest density and fire hazard throughout much of the western US [1,2] and the Colorado Front Range [3] due to changes in land and fire management. Increasingly large and severe wildfires have impacted ponderosa pine forests with negative ecological and social consequences [4–6]. In response, the U.S.D.A. Forest Service (USFS) is seeking to increase the pace and scale of fuels reduction and forest restoration in ponderosa pine and other vulnerable dry forests [7]. Budget limitations necessitate strategic prioritization to improve the efficiency and efficacy of forest management. In ponderosa pine forests and woodlands of the Front Range, goals for fuels reduction and forest restoration treatments are to reduce tree density, canopy cover, crown bulk density, and surface fuels to mitigate the impact of future wildfires [2,8,9], while conserving large trees that contribute important wildlife habitat elements and are most likely to survive future wildfires [10,11]. However, because historical forests of the Colorado Front Range were far from uniform [3,12,13], it is challenging for forest planners to identify priority locations and treatment types that simultaneously meet stand and landscape desired conditions that shift forests towards historical density and composition and maintain important ecosystem services [10,14,15].

2012 regulations for forest planning and the USFS Shared Stewardship initiative also emphasize landscape-scale restoration and risk reduction. The 2012 planning rule describes a continuous cycle of assessment, planning, and monitoring to institutionalize adaptive management (36 CFR § 219.1). During the assessment phase, forests revising their plans are required to evaluate current ecosystem conditions and their departure from historical or desired conditions, both within the plan area and across the broader landscape [16]. Results from the assessment phase are then used to identify priority watersheds for restoration (36 CFR § 219.7), identify candidate plan components to restore or maintain ecosystem integrity (36 CFR § 219.8), and support the analysis of plan alternatives as required by the National Environmental Policy Act of 1976 (NEPA) (36 CFR § 219.1). Individual US Forests are also required to develop forest plan monitoring strategies “to inform the management of resources on the plan area, including by testing relevant assumptions, tracking relevant changes, and measuring management effectiveness and progress toward achieving or maintaining the plan’s desired conditions or objectives” (36 CFR 219.12 (a)(2)). In addition to regulatory requirements found in the planning rule, forest restoration and risk reduction is also a cornerstone of the USFS’s Shared Stewardship initiative. Shared Stewardship emphasizes: working with partners to achieve goals across jurisdictional boundaries; utilizing novel analytical and decision-support tools to prioritize investments “in the right places and at the right scale”; and realizing efficiencies for NEPA review and compliance [17].

In this report, we discuss tools and models for simulating management strategies and analyzing their implications for forest structural heterogeneity, wildfire impacts, and post-fire erosion risk mitigation. Outputs from these tools have potential applications for forest plan revision, landscape scale NEPA, treatment design, and the achievement of Shared Stewardship goals for outcome-based and collaborative restoration and risk reduction. In the following sections, we provide a brief overview of our assessment and modeling framework, followed by a description of analytical tools and outputs. We conclude with a brief discussion of potential applications, opportunities for future collaboration, and next steps.

Description and assessment of landscape-scale analyses for forest planning

Because desired conditions for Front Range ponderosa pine forests are defined at large scales, landscape-scale assessments of potential management impacts can provide valuable insight into potential treatment effects. Several existing tools have been used on federal land to prioritize the location of wildfire mitigation treatments [e.g, 18,19], and evaluate the economic benefits of landscape-scale restoration [20,21]. Together, these studies suggest that treatment placement and extent can greatly impact ecological outcomes. Here, we describe a framework which can be used to simulate forest management and evaluate the consequences of management actions for forest structural heterogeneity, wildfire risk reduction, and post-fire soil erosion. Such analyses can be used for comparing alternative scenarios for strategic planning or monitoring the landscape-scale impacts of accomplished management actions.

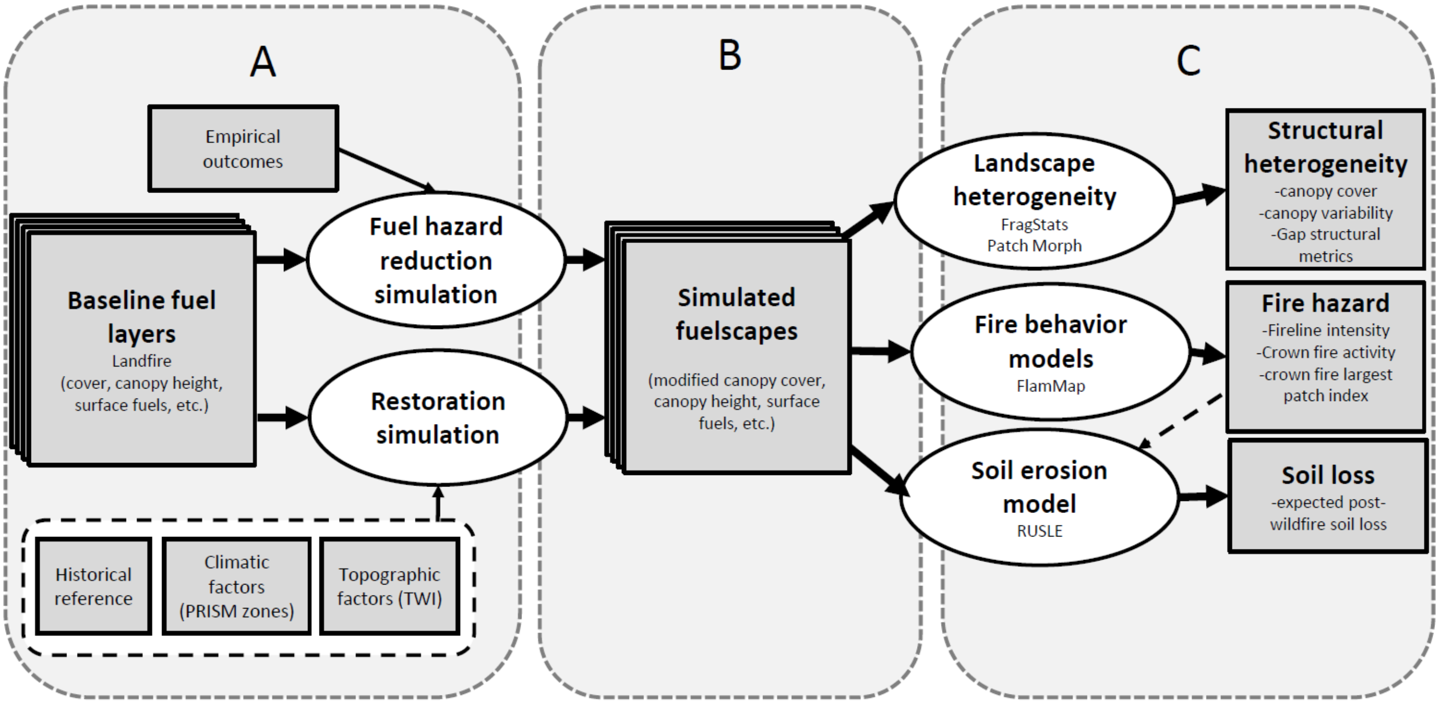

Figure 1. Example of coupled model framework for assessing tradeoffs in landscape-scale ecological outcomes among various management approaches. (A) Starting with baseline data on forest and fuel structure, management options can be simulated using empirical data on typical outcomes or expectations based on historical or desired conditions. (B) Simulated data on treatment outcomes can be used an inputs to an array of landscape assessment models. (C) Landscape-scale assessment models can provide data on treatment effects on landscape-spatial heterogeneity, fire hazard, and post-wildfire soil loss. Additional models such as those for bird diversity or smoke management can also be incorporated [e.g., 29]. Figure from Cannon et al. 2019, Rangelands in press.

Simulating management scenarios

Landfire is an important dataset for landscape-scale forest restoration and fuel management planning because it is a nationally consistent, “all lands” dataset specifically developed for modeling fire behavior (https://www.landfire.gov/). Landfire provides 30 m resolution spatial data on topography (elevation, slope, aspect) and forest and fuel structure (vegetation type, canopy cover, surface fuels, etc.) [22]. Starting with baseline information from Landfire, these data can be adjusted to simulate a variety of forest management activities—such as mechanical thinning and prescribed fire [e.g., 21] —and develop scenarios that vary in placement and extent of treatments [20]. For example, in ponderosa pine forests, mechanical thinning treatments focused on hazardous fuel reduction typically reduce canopy cover by 30% and canopy bulk density by 40%, while increasing average canopy height, canopy base height, and surface fuel loading [9,15,23–25]. Uniform thinning treatments aimed at reducing wildfire hazard are simulated with proportional adjustments to fuel attributes [20,21], but this does not capture the intentional creation of spatial heterogeneity advocated for in restoration planning [10,14]. More comprehensive simulation methods that vary thinning intensity based on local conditions and landscape context are under development [26] to operationalize restoration principles for large landscape scenario evaluation (Figure 1) . Cannon et al. [26] present a framework to simulate potential restoration outcomes across small sub-watersheds (mean size ~ 1,000 acres) that mimics restoration toward historical canopy cover and variability. Information on historical distributions for the Front Range [3,27] can be incorporated into simulations to better understand what treatment intensities and locations may be necessary to restore historical forest structure and variability [28].

Regardless of the method used to simulate treatments, output layers can then be used as inputs to a number of models to infer how an array of management practices influence forest heterogeneity, wildfire behavior, and wildfire risk (Figure 1), and can be extended to other responses such as wildlife diversity and smoke emissions [e.g., 29]. From a planning perspective, these simulations can be used to: 1) evaluate the departure of existing conditions from desired conditions as required for the assessment phase of forest plan revision, 2) compare and prioritize different landscapes for restoration [21,26], and 3) evaluate alternative large-scale management proposals for NEPA planning [20].

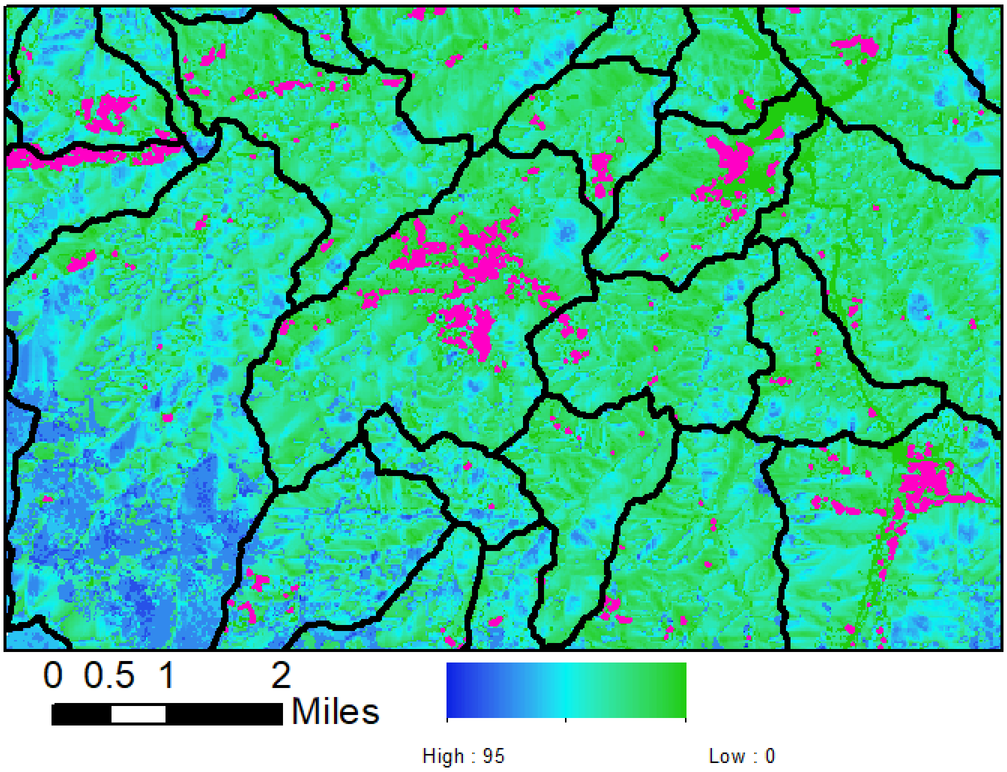

Figure 2. Example restoration treatment simulation in the Upper South Platte watershed based on historical canopy cover data, indicating a large range of canopy cover present and spatial variability in canopy cover (blue – green gradient). Gaps or meadows (shown in magenta) can be delineated using size and configuration criteria, and gap structure can be analyzed to determine how restoration treatments change components of forest heterogeneity

Modeling impacts on forest heterogeneity

Historically, ponderosa pine forests in the Colorado Front Range had a complex structure characterized by large openings, groups of trees, and individual trees [27,30,31]. Forest restoration treatments are needed to restore components of this historical structure at multiple scales [10,32], and restoration monitoring often emphasizes the extent to which these spatial outcomes are achieved [33–35]. Increased landscape heterogeneity—with elements such as large openings and juxtaposition of openings and dense canopy—is linked to a number of important ecological outcomes such as increasing fire resilience, improving wildlife habitat, and increasing understory herbaceous diversity [32,36,37]. Simulated landscapes (Figure 1B) can then be used as inputs to various tools to quantify landscape complexity (Figure 1C, upper oval). Many tools are available to compare changes in landscape complexity and heterogeneity. For example, PatchMorph [38] and Fragstats [39] can be used to quantify changes in landscape spatial pattern, and are thus useful for evaluating treatment changes in landscape heterogeneity using metrics such as diversity and contagion (Figure 1C) [39–41]. For example, simulations can be used to assess how treatment scenarios may impact landscape scale gap structure (Figure 2). These metrics can provide quantitative information about how simulated landscape-scale treatments compare to desired conditions or historical ranges. A recent study on restoration of ponderosa pine forests of the Colorado Front Range found that in general, restoration treatments increase cover and frequency of gaps, and increase complexity of tree group size distributions, yet these changes fell short of meeting historical ranges estimated from forest reconstructions in the region [3,27,33].

Modeling impacts on fire behavior

Given the driving concerns of negative ecological and social impacts of wildfire in the region [1,42,43], a core management objective in ponderosa pine forests is a reduction in uncharacteristic high intensity fire. However, higher elevation ponderosa pine and mixed conifer forests were historically shaped by mixed severity fire [13,44], and many management objectives focus on returning forests to a condition where prescribed fires can be used safely as a management tool [10]. Although stand-scale analyses can be used to assess the effectiveness of individual management actions on potential fire behavior [e.g., 9], wildfire risk is a boundary-spanning issue that benefits from a landscape scale approach [20]. Many recent advances in landscape-scale fire modeling can be used to inform treatment placement and prioritization for forest planning [18,20,21]. Fire models are increasingly user-friendly but still require a level of expertise that may not be consistently available at the Forest level. National-level fire modeling products [45] can be useful for Forest-wide risk assessment and prioritization, but they do not facilitate treatment scenario simulation and comparison. Current and simulated post-management fuel conditions can be used as inputs to fire modelling software such as FlamMap to estimate how management alternatives are expected to impact variables such as fireline intensity and crown fire activity (Figure 3). For example, Gannon et al. [21] modeled how mechanical thinning, prescribed fire, and combinations of these treatments may reduce the potential for active and passive crown fire. They found that the combined thinning and prescribed fire treatment was most effective, but prescribed fire was the most cost-effective treatment in the watersheds considered. Jones et al. [20] found that increasing the extent and altering the placement of fuel reduction treatments can greatly impact the extent to which moderate and high severity fire may occur. Because the Colorado Front Range historically experienced a mixed severity fire regime, complete elimination of crown fire may be undesirable, but model outputs such as the largest potential high severity fire patch may be useful metrics for estimating reduction in large, uncharacteristic patches of high severity fire [46,47].

Modeling impacts on post-fire soil loss

Lastly, a growing concern in many western forests is wildfire-related erosion and impacts to water supplies. Recent research has advanced new tools to better understand how management options such as mechanical thinning and/or prescribed fire can reduce wildfire impacts to watershed values [20,21,48]. Many landscape-scale factors contribute to risk of post-wildfire erosion such as wildfire likelihood and intensity, rainfall erosivity, soil erodibility, and topography, which can be leveraged to prioritize proactive fuels reduction type and placement [20,21,48]. These studies used a coupled model approach that builds on an existing wildfire risk assessment framework [18] to understand how treatment type, extent, and placement can reduce post-fire soil loss and sediment delivery to water infrastructure. Briefly, this framework combines

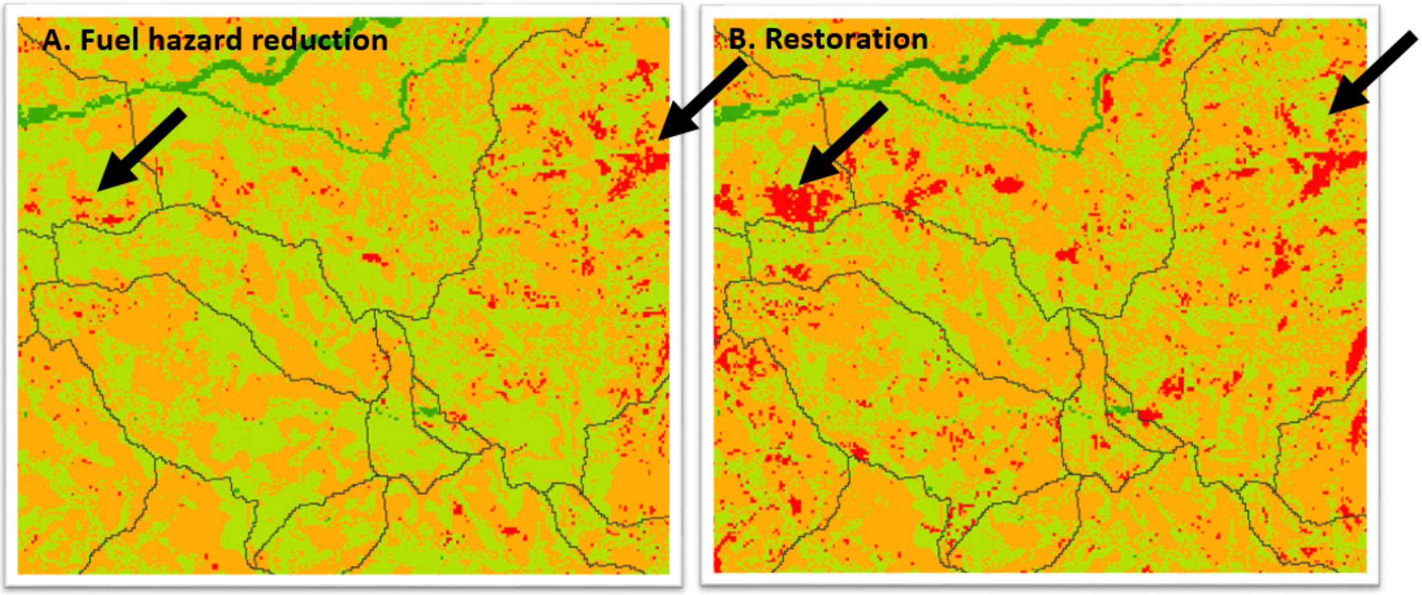

Figure 3. FlamMap fire modeling software [49] may be combined with data from simulated management practices (Figure 1B), to provide information about how a variety of management scenarios (treatment type, placement, or extent), may alter potential fire intensity and potential high severity patch sizes. Arrows represent how reductions in in the largest potential high severity patch (left arrows in A and B), may differ among treatments under consideration in some cases, but not in others (right arrows in A and B).

modeled burn probability [45] and post-fire erosion to estimate the expected hillslope erosion from each unit of the landscape (Figure 4A). Next, these estimates of hillslope erosion can be combined with empirical models of hillslope sediment delivery to quantify the potential for eroded sediment to reach streams where they may impact water quality and aquatic habitat (Figure 4B) [21]. This and similar tools can be used to better understand the distribution of wildfire risk to watershed values within USFS boundaries and across ownerships that can be addressed through partnership with other agencies. As above with forest heterogeneity and wildfire risk, this model can be used to compare a range of management scenarios via manipulation on input Landfire layers. Gannon et al. [21] compared a range of scenarios including combinations of mechanical thinning and prescribed fire to produce a prioritization plan under various budget scenarios to best reduce the potential for post-wildfire sediment impacts to water infrastructure. Landscape assessment tools can be combined with other assessments of values at risk and potential ecological impacts to inform forest planning, monitoring, and evaluation efforts, and prioritize outcome-based treatments that have the best return on investment.

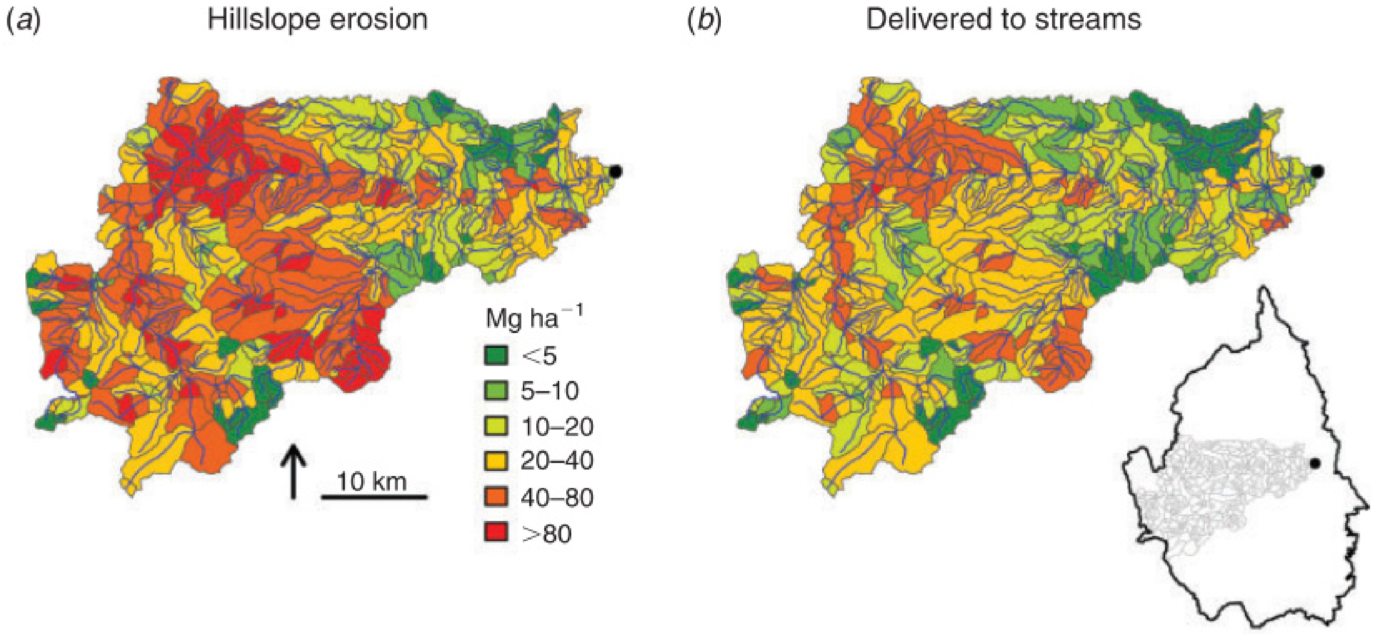

Figure 4. (A) Predicated first year mean post-fire sediment yields and (B) sediment delivery to streams in from a portion of the Cache la Poudre watershed in the Colorado Front Range. Such analyses can be used to inform extent, placement, and prioritization of management scenarios for forest planning. Figure from Gannon et al. [21].

Applications to forest planning

The analysis and tools discussed in this report provide several actionable opportunities for efficiently complying with the regulatory requirements of the 2012 planning rule and NEPA, and for achieving Shared Stewardship goals. In the context of forest plan revision under the 2012 planning rule, tools discussed in this report have potential applications for assessment, planning, and monitoring. During the assessment phase of plan revision, analyses of existing conditions, simulated conditions, and model outputs can be used to characterize existing conditions and evaluate the departure from historical conditions across the broader "all lands" planning area. Analyses of forest conditions at HUC 12 watershed scale can be used to identify priority watersheds and landscapes for restoration, and develop plan components such as quantifiable desired conditions and management objectives for different geographic areas. Simulations of different types of management interventions, and their implications for landscape heterogeneity and risk reduction, can also be used to support the analysis of different plan alternatives as required by NEPA. Using Landfire to iteratively integrate implementation monitoring data (i.e., spatial data associated with treatments) and use these data as inputs to fire behavior models likewise fulfills the planning rule's requirement to track "progress toward meeting desired conditions and objectives" by demonstrating outcome-based reductions in wildfire risk and hazard.

In addition to supporting forest planning under the 2012 planning rule, these tools also have the potential to achieve Shared Stewardship goals by supporting efficient and science-based landscape-scale NEPA planning, programmatic planning, and treatment level implementation. Simulated post-treatment conditions, and resulting ecological impacts analyzed at the landscape scale can support efficient NEPA analyses, and identify and prioritize outcome-based opportunities for collaboration with partners such as water utilities that maximize benefits and minimize treatment cost. NEPA analyses of different simulated treatment alternatives at the landscape scale also allows for flexibility in treatment implementation; the 30m resolution of Landfire products means they can be used to inform and design specific implementation strategies at the treatment scale as needed (i.e., restoration or basic fuel reduction), and foster communication about implementation strategies and their effects to stakeholders.

Conclusions, next steps, and future directions

There are additional steps highlighted by staff on the PSICC that are needed to effectively apply the tools discussed herein. To support the forest plan revision process, one important next step is to scale up Landfire simulations to encompass broader planning areas. PSICC staff indicated that products for ecosystems beyond the upper and lower montane would also be useful for planning at larger scales. PSICC staff noted additional opportunities for CFRI engagement. One important opportunity is to identify and facilitate partnerships through stakeholder outreach and engagement. Another opportunity is to expand the assessment framework (Figure 1) to include additional ecological models relevant to forest management priorities such as wildlife habitat. The creation of maps that illustrate risk reduction benefits for different treatments across boundaries may be particularly important for effective communication and outreach with stakeholders. Another important information need is for economic analyses that can be used to support long term programmatic planning. Specifically, PSICC staff highlighted the importance of understanding the costs and benefits of treatment implementation and maintenance strategies over time. Using post-treatment Common Stand Exam data to understand regeneration rates and calibrate FVS regeneration models was highlighted as an important opportunity in this regard.

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