

**Modeling Forest Planning Trade-offs on the Colorado Front Range, using MAGIS,
an Optimization, Spatial Decision Support Tool.**

by

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Modeling Forest Planning Trade-offs on the Colorado Front Range, using MAGIS, an Optimization, Spatial Decision Support Tool.

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The fires of 2000 and 2002 catalyzed a national mandate for fuel treatment programs to facilitate wildfire mitigation, yet the issues that need to be considered when planning large landscape projects are daunting, often ending in gridlock due to planning conflicts. Hazardous fuels maps help little when planning for integrated, system-wide ecological objectives and fail to address the complex, contentious social issues inherent in the process. Budgets and manpower, limit how much area can be treated, so prioritization is a must. This thesis is a demonstration of MAGIS, a spatial decision support tool (SDST), which can integrate innumerable social, economic and wildlife issues coupled with the discipline-specific analysis of three companion SDSTs. MAGIS provides a graphical interface, modeling framework and functionality for scenario building, while its optimization and GIS components supply tabular and graphical feedback and spatially explicit scheduling—prioritized by the user's parameters. MAGIS scenarios facilitate: analysis of short and long-term effects; forest plan creation/revision; consensus building and NEPA reporting. Once built, scenario runs can provide rapid interactive information for dissemination at public meetings. Companion SDSTs used in this study are: 1) SIMPPLLE, 2) combination of fire behavior tools FARSITE, FlamMAP, MTT and TOM and 3) WEPP. SIMPPLLE, an ecology based, vegetation simulator, provides analysis and resulting risk-maps of processes such as stand-replacing fire. The fire behavior tools provide an analysis based on physical relationships of forest fuels, topography, and extreme fire conditions. From this model fire growth, intensity and spread is predicted. These tools can also determine the size and placement of treatments to efficiently inhibit fire progression. WEPP provides erosion prediction driven by stochastic weather events. This study was conducted on a 92,000-ac site in the Colorado Front Range. The site is characterized by a spectrum of difficult social, political and ecological issues, most notably, residential/forest intermix and the watershed's prominence as Denver's chief water supply. The goal of this study was to use MAGIS to integrate analysis of all these models and to identify ways to restore the site to the historical landscape, while mitigating wildfire risk. The results from this study indicate that great efficiency can be achieved in terms of reduction of risk indices given fixed projected costs.

Keywords: decision support, ecosystem restoration modeling; fuel treatment; wildfire mitigation; optimization modeling; forest planning, COPPER

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1 INTRODUCTION

1.1 Problem and objectives

Dangerously altered fire regime

Forest management practices have caused a build-up of forest fuels that threaten human communities and in many cases the ecological health of the Colorado Front Range (CFR). Year 2002 clearly demonstrated the potential for extreme wildfire on the Front as the Hayman fire burned the area of interest, eventually affecting 138,000-ac of the Pike-San Isabel (PSI) National Forest (NF), located south of Denver (Graham, 2003). This fire was no anomaly, but was one of many fires that have been augmented by the increased loads of forest fuels. It was preceded by other recent large fires in the area such as the Buffalo Creek and the High-Meadows fires, as well as the Rodeo-Chediski fire complex in Arizona.

The South Platte watershed greatly coincides with (PSI) in the study area. The Front is in a progressively problematic water shortage due to rapid growth. This high demand is exacerbated by long-term drought and the population is dependent on the South Platte watershed for 80% of their water supply (Kaufmann et al., 2001a). A public concerned for the natural beauty and health of the environment, jaded by a legacy of region-wide unsustainable harvest (in the fading past) have left Forest managers in a very difficult position when planning for multiple-use of forest resources. Yet, these resources are at risk if we, the public, fail to act to reduce the hazard of broad-scale extreme wildfire. This situation often ends in gridlock, thus no action.

Organizational limits to strategic planning

The South Platte sub-basin is in excess of one million acres and the members of the Front Range Fuel Treatment Partnership (the Partnership) can treat only a small portion of this massive landscape each decade (Figure 1). With a large and diverse area at risk from extreme fire behavior, the issues affecting placement, timing and selection of fuel treatments are enormously complex, especially when scheduled over a proper planning horizon of five decades or more. The considerations of this level of planning transcend un-aided human abilities.

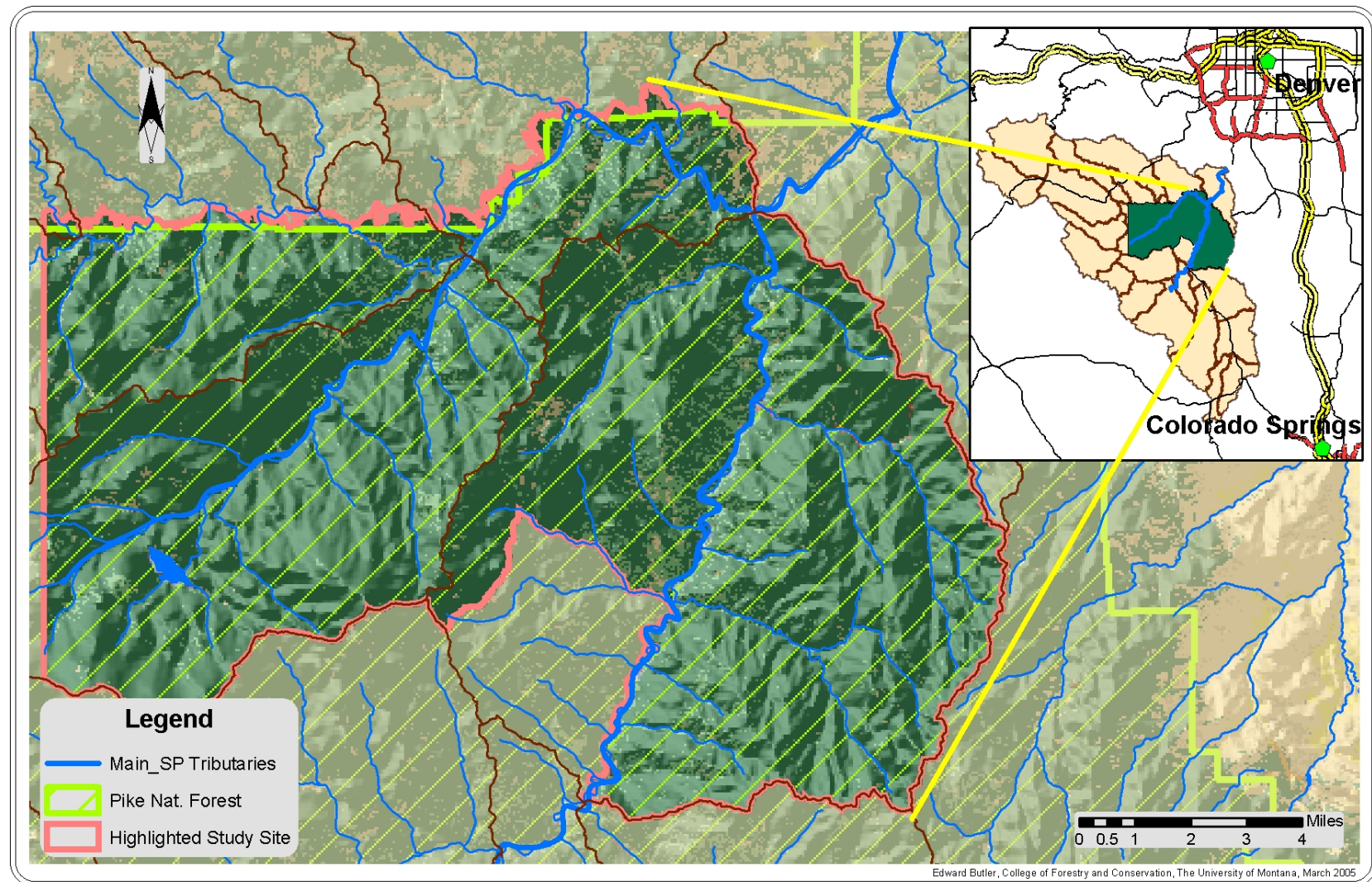


Figure 1. Map of the area of interest with topography

GIS, permits an analyst to synthesize and simulate spatial relationships, perhaps over a time span if the operator is talented in temporal modeling techniques. This gives only marginal utility.

Veteran resource managers often are known to exclaim that they know where their problem areas are i.e., GIS provides little new information—it only better illustrates what is already known.

Often, organizing and scheduling of management activities is the most difficult parts of a resource manager's job, with mapping fuels is only one of many preliminary steps. Optimization planning models can help with difficult task of choosing where and when to treat and have been proven to increase efficiency of ~50% over local, expert opinion (Jones et al., 1986). However, I note that optimization does not fit into the paradigm most readers have of efficiency.

Optimization is a relevant term where efficiency is dependent on given constraints. Conceptually the "decision space" or "area under the curve" for optimization modeling rapidly shrinks as constraints are added, thus with greatly constrained scenarios, the question of "efficiency relative to what variables," i.e. what metric, must be explicitly defined in order to discern a reasonable answer. Often an answer is not possible, because a number of variables have been fixed by the modeler's subjective choice (constraints), thus efficiency cannot be judged within that mix of variables.

The primary objective of this study is to provide a range of efficient and effective fuel-treatment solutions within the constraints provided by the PSI NF and the Front Range Fuel Treatment Partnership. Both in combination are referred to as the "client." An additional challenge addressed here is developing these solutions while producing conditions more closely resembling what Kaufmann envisions as an ecologically balanced, historical *mixed severity* fire regime (Kaufmann et al., 2001a). Assistance with this level of complexity is clearly needed, but no individual modeling tools address all of the client's issues.

Integrated solution

This optimization modeling demonstration is a component of a larger project, which is supported by a suite of three Spatial Decision Support Modeling Tools (SDST). This thesis details MAGIS' role as an integration vehicle for the project, but collectively MAGIS and these DST form a Decision support system (DSS), coined here as Comprehensive Optimized Project Planning for Ecosystem Restoration (COPPER). The intent is to provide a multi-perspective, multi-scale analysis. Further detail on each model will be provided in the “Decision Support Tools–COPPER Cohort Modeling Tools” section. As a planning model, MAGIS assumes the defacto role that binds the other models of COPPER into a cohesive decision support system.

SIMulating Patterns and Processes at Landscape scaLEs (SIMPPLLE) is a stochastic simulation tool that models change via successional vegetative "states" through defined "pathways." Interjected into the flow, it also models natural disturbance processes and forest management activities. For COPPER, SIMPPLLE provides prediction of forest vegetation changes in the presence of natural disturbance processes with and without management activities.

FlamMap is the fire behavior team's aggregation of tools based on FARSITE. The FARSITE fire area simulator (Finney, 1998) is a simulation model for predicting the spread and intensity of fires across a landscape. FARSITE and its derivatives, model fire behavior via process-based, fire spread logic and static user-defined weather and fuel conditions. FlamMap is itself a suite of tools, reporting numerous key values, such as Crown Fire Activity (CFA), Rate of Spread (ROS), Minimum Travel Time (MTT), and Treatment Optimization Model (TOM).

Goals and objectives

The goal of this research is to demonstrate the MAGIS modeling tool as an effective and efficient aid for planning treatments. These treatments are to facilitate ecological restoration of the study area to a condition, described as “healthy,” by Kaufmann et al. (2001a). Kaufmann, a research forester who has spent much of his career studying Colorado’s Front Range, states that the ponderosa pine / Douglas-fir habitat type in the historical landscape was characterized by a mixed severity fire regime and that the currently altered forest would present a diminished threat to human and natural communities if returned to that state. Hann and Strohm have also studied the area of interest and agree that the best way to make communities in the area safer is to treat across the Forest, not merely in areas of housing density (2003).

Subordinate objectives and constraints

Guiding and constraining this research, the client has a number of sub-objectives and constraints.

Subordinate objectives:

- Reducing wildfire risk* to the wildland urban interface (WUI)
- Maintaining a reduced risk* condition in the (WUI)
- Mitigating risk to species of concern
- Estimating volumes, costs and revenues of forest products

Constraints on the solutions:

- Minimizing sediment production and delivery to the stream network
- Constraining the road network to current levels
- Minimizing net costs of management activities

*This modeling study does not attempt to qualify risk beyond an assessment of nominal "risk" from companion models. Model inputs used help quantify extreme fire behavior for modeling purposes and the term is used correspondingly.

1.2 Decision support systems for planning ecosystem restoration

While modeling for natural resource management planning is not at all new, certain aspects of this effort are. A spatial dimension has evolved over the last fifteen years as the processing power of computers has grown. Also, there has been a shift from single perspective modeling tools to interdependent resource management under the collective title of “ecosystem management decision support”. Mowrer (1997) states, “decision support systems (DSS) may be interpreted so loosely as to include any system that supports a decision in any way, or so strictly that no system fully satisfies this generic definition”—so some clarification is in order.

A review of DSS tools shows Mowrer's statement is accurate. Here I distinguish that models used to analyze issues are *analysis tools*. Models that give spatial representation with static “snapshot” analysis are *analysis and visualization tools*. Models that incorporate dynamic processes spatially and over time are *dynamic simulation tools*; all simulation tools by default are enhanced analysis and visualization tools. Models which directly support planning by using management’s objectives and constraints, extrapolating and then projecting solutions into several planning periods are *planning tools*. If this planning is done with the benefit of heuristics, linear or mixed-integer programming or optimization and artificial intelligence techniques, I refer to these planning tools as *optimization planning tools*. I also believe that the above tools are not inherently systems. Webster’s New Collegiate Dictionary (7th edition) offers “a group of devices or artificial objects or an organization forming a network esp. for distributing something or serving a common purpose.” In this study, I call narrowly focused, monolithic modeling entities *Decision support tools* (DST).

Michael Rauscher (1999), a Research Forester currently with the Southern Research Station of Bent Creek and author of many publications on decision support modeling believes that a system should incorporate a broad array of analysis tools and that a *full-service* system should consider

all aspects of ecosystem management. Also, a full-service system should do so at both the tactical and strategic planning levels, complete with integrated planning tools. These distinguishing factors in no way denigrates standalone tools or systems, but rather illustrates that modeling is maturing and true *full-service* DSS are now being employed for projects of increasing complexity. The term DSS I use to describe two or more planning tools integrated (each with a different focus) to solve complex ecosystem management problems. This does not include sub-component models that augment a single focus. There is ambiguity also in the term *ecosystem management*. Rauscher refers to ecosystem management, yet makes the point that humans are an inexorable part of the Earth's ecosystems and therefore human demand on federal public land must be considered when planning for ecosystem health. "Full-service" as it refers to DSS and "ecosystem" as it refers to ecosystem planning or management are Rauscher's definitions.

Expertise supplied to MAGIS via COPPER cohort modeling tools

SIMPPLLE

SIMPPLLE, developed by Jimmie Chew starting in 1992 at the Forest Service's Intermountain Research Station, (Chew, 2004) is maintained and supported by the USDA, Forest Service, Rocky Mountain Research Station–Forestry Sciences Lab in Missoula, Montana (RMRS-4151), Ecology and Management of the Northern Rocky Mountain Forests. SIMPPLLE, an analysis and dynamic simulation DST, is used to model succession at landscape scale (via aggregated stands) to stochastically project succession or occurrence, location and frequency of natural disturbance processes on the landscape. Although successional stages of vegetation as characterized by a mix of species, size class, density and stand structure are in constant flux, it is a popular modeling paradigm to view vegetation communities as progressing in site-specific, predefined *vegetative states*. Succession is modeled either with or without management actions (Jones et al., 2003,

Chew et al., 2004). Each *pathway* follows a logical progression from one *state* to another per planning period, unless a natural or anthropogenic disturbance alters the routing in the *pathway*. Disturbances such as wildfire, disease, windthrow or fuel treatments result in a new *state* in their aftermath. This new post-disturbance *state* becomes the first of such in a new *pathway* (Jones et al., 2003). The location and frequencies of disturbance processes quantified from numerous (typically a minimum of 20) stochastic simulations provide estimates of the location and probabilities of future disturbances. This provides a risk index, as well as a basis for estimating costs and effects associated with disturbances. SIMPPLLE's logic is based on historical data or expert opinion (Jones et al., 2003, Chew et al., 2004).

Examples of SIMPPLLE's functionality—it can:

- *Simulate future vegetative changes caused by the occurrence of disturbance processes.*
- *Identify not just averages, but a range of conditions of both plant communities and processes that can be expected for specific landscapes.*
- *Track insect and disease process and how changes in vegetative patterns influence their activity*
- *Analyze treatment scenarios for their impact on processes and the attainment of desired condition*
- *Identify areas that have high priority for treatments to achieve sustainability of desired conditions*
- *Predict cumulative effects on resources as they are defined by a combination of vegetative conditions and spatial attributes.*
- *Provide a basis for identifying the probability of processes or conditions occurring.*

(Chew et al., 2004)

SIMPPLLE's fire simulations can be made with or without suppression; with or without fuel treatments; and under average or extreme weather conditions. Although SIMPPLLE is generally used to model the effects long-term disturbance processes on vegetation, it has the ability to model in time steps smaller than one year (Chew, 2004). A facet of SIMPPLLE that receives little attention, but is a rare and valuable aid when modeling spatially related issues is *spatial context*. Many vegetation and dynamic process models are spatially explicit, but only a few

consider conditions in neighboring stands during analysis (Barrett, 2001) e.g., site regeneration from neighboring seed sources.

FlamMap

FlamMap is a new suite of tools, but a derivative of the established FARSITE program, USDA, Forest Service, Rocky Mountain Research Station, Missoula, Montana–Fire Sciences Lab (RMRS-4401), Fire Behavior: Fundamentals and Systems Development. FARSITE, was first publicized by Finney in 1994, with the USDA Forest Service, Intermountain Research Station, (Finney and Andrews, 1994). FlamMap requires raster format spatial data for elevation, slope, aspect, surface fuel model, canopy cover, crown base height, crown bulk density and stand height. FlamMap and FARSITE output layers include fire perimeter modeling, rate of spread (ROS), fireline intensity, flame length, and heat per unit area. Also output are indicators of severe fire behavior, including torching, spotting, and crowning, notably through the index value of crown fire activity (CFA). FlamMap evaluations are based on ignitions at user-defined locations and fire spread typically modeled with settings representing extreme conditions for fuel moisture and wind (Finney and Andrews, 1994, Finney, 1998).

FlamMap also includes minimum travel time analysis (MTT), which is an analysis and visualization tool that models the fastest paths of fire spread across a site (Finney, 2002a).

Treatment optimization model (TOM) uses MTT and FARSITE logic to compare effectiveness of a range of spatial fire-break patterns and scales (Finney, 2002b). To derive optimal placement, numerous variations are run until calculations such as travel time are minimized. FlamMap and tools of the fire lab are tactical scale, intended for application to address the current landscape. There is no vegetation simulation function to address effectiveness of treatments over time. The

fire behavior tools are limited to fire behavior modeling only, their tools are therefore well complemented by MAGIS and SIMPPLLE.

MAGIS

Background and Support

MAGIS is a spatially explicit planning optimization DST developed in 1992 by Hans Zuuring and others with support from the Montana Department of State Lands, the University of Montana and the USDA, Forest Service, Intermountain Research Station, (Zuuring et al., 1995). Support was provided in some phases of the development by Bruce Meneghin, now with the Forest Service, IMI group (Zuuring, 2004). MAGIS is maintained by the USDA, Forest Service, Rocky Mountain Research Station–Forestry Sciences Lab in Missoula, Montana, (RMRS-4802) Economic Aspects of Forest Management on Public Lands.

Overview

From its inception MAGIS was designed to schedule user-defined management activities. Estimates of volumes and other outputs e.g., timber, sediment, acres of activity, acres of "x, y or z" species habitat affected, net revenue/costs of biomass, etc. can be tracked in detail. Objectives, constraints, value-weighting schemes and other inputs are user defined. MAGIS can accommodate a wide variety of management activities with associated costs, revenues and environmental and economic effects. MAGIS' planning and analysis capabilities are commonly applied to spatially related aspects of: reducing catastrophic wildfire through treatments to forest structure; habitat needs for target wildlife (terrestrial or aquatic); landscape scale biodiversity; recreation issues; production of typical forest commodities such as timber products and forage, along with the growing interest in utilization of treatment byproducts such as biomass chips

(Troutwine, 2005). MAGIS can also be used to plan management activities that minimize erosion, stream contributions to total maximum daily load (TMDL) and other long-term cumulative effects.

MAGIS models are defined to stand level, however stands can be aggregated for landscape scale analysis. Computer processing improvements of the last decade have facilitated MAGIS' ability to aggregate stands to increasingly larger projects, while maintaining its tactical level of detail. MAGIS can handle long-term planning horizons up to a maximum of five planning periods. Planning period length is user defined, but in this study is a decade. MAGIS, being custom defined for each new application, serves well to incorporate auxiliary tools.

Anatomy and Functions

Though MAGIS offers standalone functionality via analysis, optimization and simulation with deterministic pathway logic, functionality is expanded when it is paired with a vegetation simulator that can add stochasticity to the process modeling. For a current vegetation (CV) layer MAGIS can handle data from models like SIMPPLLE with little preparation. Any locale specific vegetation is latently provided to MAGIS if it receives *vegetative states* and *pathways* from a vegetation simulator.

MAGIS is built on a ***model specification framework***, which draws information from two sub-models.

1. *site sub-model (spatial and non-spatial data)*

- a. Current vegetation (CV) data (with necessary attributes) (required)
- b. Hydrography
- c. Topography
- d. Soil and erosion
- e. Wildlife issues
- f. Social issues
- g. Roads (required if solving for traffic or road planning)

2. *dynamic vegetation sub-model*

- Regional vegetation model (*vegetative states* + successional *pathways*) must be defined or acquired then imported.
- Post-treatment *states* must be defined. (required)

MAGIS requires only basic classifications of dominant species, size class and density for the *dynamic vegetation sub-model*. Vegetation simulators generally require much more detailed information which include as a subset, these attributes required by MAGIS. It is efficient for MAGIS' companion vegetation simulator (SIMPPLLE in this study) to begin manipulations of the current vegetation data in an ESRI coverage format (format maintained throughout this study) though shapefiles can be used.

Most of the *site sub-model* data can be readily procured or synthesized from commonly available, public domain, GIS data. The most critical GIS data layer is a high quality, properly attributed, current vegetation layer; this can be difficult to obtain with the required attributes of *species*, *size class* and *density*, but can sometimes be extrapolated from related attributes. When solving more complex issues, the auxiliary data may contribute greatly to enrichment of the *site-sub-mod*—this is readily apparent in this study, which models with over 40 additional attributes added to the CV layer. Examples might be: segregation of the site data by zones such as watershed, wildlife management units, distance from a stream or road (Troutwine, 2005). In conjunction to all this information, the model benefits from a *site risk index* of some sort—this model has several.

Model specification framework is a set of user-defined building blocks and relationships that permit planning scenarios to be specified or modeled. Among these building blocks are the client's definitions, objectives and constraints that form the working parameters for scenarios.

These building blocks are:

- *Treatment*—any group of activities (or standalone) designed to treat stands, typically to reduce hazard. MAGIS' candidate treatments are pre-qualified for eligibility by *state groups* and *zones*—term *activity* is preferred when describing independent activities.
- *Timber outputs*—any merchantable goods produced in the process of *activities*. This comes with associated revenues
- *Non-timber outputs*—non-merchantable products produced by *activities*. This includes sediment, hazard or risk indices, smoke, etc.
- *Activities*—management activities confined to a single planning period, typically a silvicultural prescription (Figure 2). This has associated costs and when used in sequence across planning periods, is the building block for *management regimes*.
- *Stand*—minimum map unit (MMU) with homogeneous mix of vegetation species, size class, density and other attributes in common
- *Treatment unit*—an aggregation of stands and the map unit area to which an activity is applied. It is incumbent on the modeler to aggregate *stands* with similar attributes in order that resolution is preserved within tolerable limits. Treatment units can be synonymous with stands, but working with units of aggregated stands allows the modeler additional control when applying treatments on-site.
- *State group*—non-spatial aggregation of treatment units based on an attribute in common (Figure 3) used to exert uniform control by non-spatial attributes.
- *Zone*—an aggregation of treatment units based on a common attribute (Figure 4) used to exert uniform control beyond the scale of treatment units.
- *Adjacency constraints*—a constraint on the final solution that considers adjacency limitations, i.e. no adjacent stands of a threatened species habitat may be concurrently harvested (this would be to provide critical nearby habitat during the treatment period).
- *Management regimes*—sequence of *activities* for all periods (Figures 2, 3, and 4) e.g., "thinning" in period x, followed by "prescribed fire" in periods y and z Conceptually, this could be any string of treatments, similar, disparate or intermixed including "no action."
- *Effects function*—candidate *objective function* i.e. a "construct" of plans to accomplish various objectives. Assembled individually, collectively they form a library of the client's concerns and de facto parameters for "what is possible" in the scenario build step to follow. *Effects functions* form parameters of a client's interests and a matrix of how they may interact across individual stands, zones, planning periods and per some quantifiable "constraining metric" such as acreage (of treatments) or tons (of sediment produced). Building the *effects functions* is the process of qualifying allowable actions and refining the objectives to quantifiable relationships across time and space (Troutwine, 2005).. All Effects functions are tabulated in every scenario.
- *Objective function*—user selected *effects function* the solver attempts to satisfy by optimization.

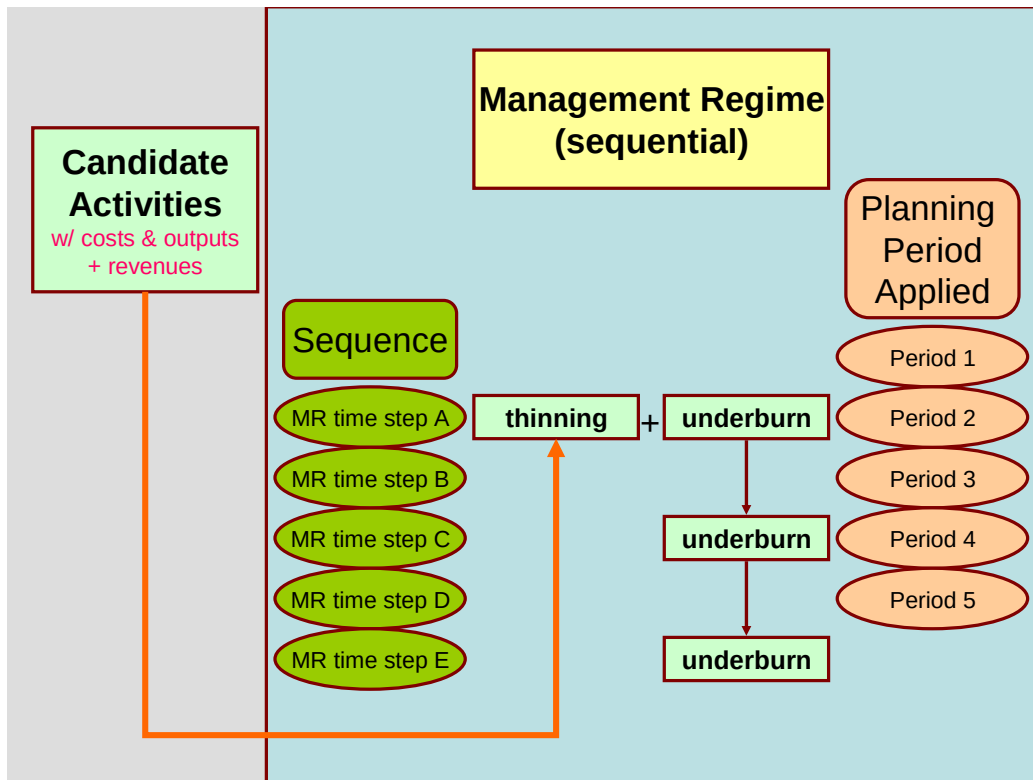


Figure 2. Illustration of interrelation between activities and management regimes

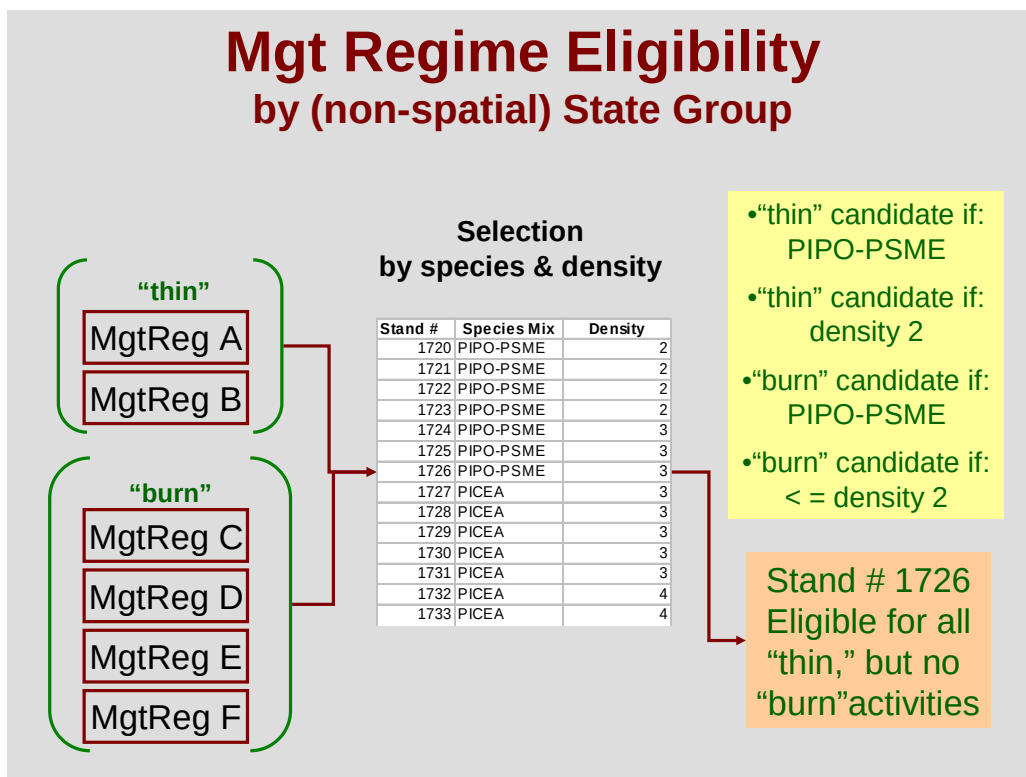


Figure 3. Illustration of interrelation between state groups and management regimes

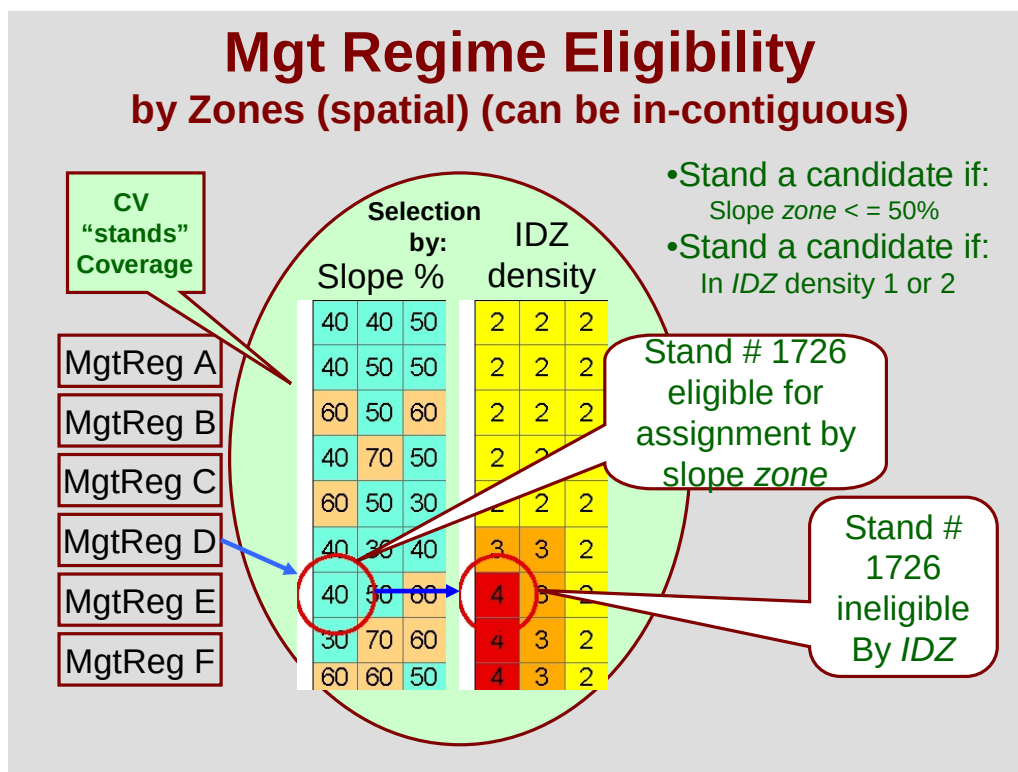


Figure 4. Illustration of interrelation between zones and *management regimes*

Solution

Once the framework and sub-models are defined, the user can import the GIS coverage (and pathway files if not already in place). There is a quality checking feature governing the import of data attributes to "legal" nomenclature and format. A "pre-matrix build" provides further error checking for the model, which precedes a *model build*. The *model build* is an automated process that constructs matrices to facilitate background functions for MAGIS.

Following the *model build* action, *model runs*, can be initiated by designing the query. This choice is defined with an objective function (from the list of assembled effects functions) and optionally with constraints by the previously mentioned "constraining metric," i.e. cost, revenue, volume, length, risk index value, acreage, outputs—by way of absolute or upper / lower bounds. The objective function can be maximized or minimized. The linear programming solver (C-

WHIZ) provides solutions to most problems, but mixed-integer programming (MIPS) is used where [yes / no] or [go / no-go] answers are required rather than numerical solutions. Both optimization packages are supplied by Ketron Management Science, Inc..

Considerations for prospective clients

Development of a MAGIS planning model has been typically performed by analysts of the RMRS, Economics group on a site-specific basis because the *model specification framework* and *site sub-model* are unique for each project and are interactively developed by the interplay of stakeholder's concerns, and modeling limitations / assumptions (see following subsection for user-based modeling). MAGIS may be adapted for any environmental, economic or social concern that can be temporally and spatially quantified using the defined building blocks. There is an economy of "common-application" with MAGIS and SIMPPLE. Once the model's framework and the *dynamic vegetation sub-model* are completed they can be used in neighboring or similar projects with relatively minor manipulation. This requires only that a new *site sub-model* be built for the each new area.

The client of this project has stipulated that there be no notable change in the site road network. So no road network analysis is conducted, but MAGIS is well suited in optimizing road traffic, maintenance, costs and outputs. Another valuable feature of MAGIS is the ability to incorporate "spatial context" such as adjacency or security areas as part of its analysis (Barrett, 2001). Few decision support models reviewed offered this feature.

Ongoing MAGIS development

Two different versions of MAGIS exist. MAGIS Express is currently limited to issues regarding timber and transportation outputs, though efforts are possible for expanded functionality. Express will soon be released with a public-domain heuristic-solver, whereas MAGIS Pro requires the use of commercial MPSIII software from Ketron Management Science, Inc. (Troutwine, 2005).

MAGIS Pro has the full functionality described and used in this study and has the greatest range of flexibility, going well beyond basic timber harvest and transportation.

MAGIS program specifications

MAGIS executes under Microsoft Windows 2000 or XP. Program execution and dialogues are controlled by a system of computer programs written in Microsoft Visual FoxPro database software development language. MAGIS integrates a commercial mathematical software package and custom GIS interface. MPSIII, the mathematical package from Ketron Management Science, Inc., consists of several modules, but only MIPIII (a mixed integer programming solver), C-WHIZ (a linear programming optimizer) and a runtime version of DATAFORM (a special database management system) are required. MAGIS' mapping interface designs are implemented via ESRI ArcGIS ArcObjects as Microsoft Visual Basic standalone ActiveX user controls or ArcMap VBA projects. The standalone ActiveX controls are embedded in and managed by Microsoft Visual FoxPro forms Launched by the MAGIS VFP framework. An ArcGIS 8.x (or 9.x) license is required to run MAGIS. FoxPro, a database management system, is not needed to execute MAGIS. However, DBF files are needed to import attribute data linked to geographic locations. (Troutwine, 2005)

WEPP

WEPP is a process-based, analysis and simulation DST that estimates erosion production and sediment delivery to a stream network. This software was developed by an interagency group of scientists including the USDA Research Service (ARS), Forest Service, Natural Resources Conservation Service, USDI's Bureau of Land Management and Geological Survey (Flanagan and Livingston, 1995).

WEPP simulates the variables that influence erosion—such as the solar radiation, coverage of vegetation canopy and the surface residue (in combination the *interception*) as well as, the soil water content for every day of a multiple-year run. WEPP's outputs are driven by a statistical distribution derived from historical weather. For each day having a precipitation event, WEPP determines if the event is rain or snow and calculates the infiltration and runoff. If runoff occurs, WEPP routes the runoff over the modeled profile, calculating erosion or deposition rates for no less than 100 points on the hillslope. It then calculates the average sediment yield to streams based on distance from the source and vegetation buffer characteristics.

Comparing the models

The models within COPPER each address some aspect of the fuel treatment planning problem, but they differ in terms of data requirements, temporal scale or what is included in the analysis. These differences suggest unique roles for these types of models. Neither SIMPPLLE nor MAGIS address fire and fuel treatments from the perspective of fire physics as with FlamMap. The analysis conducted by fire behavior models is based only on the current fuels present on a landscape. As mentioned, TOM uses MTT and FARSITE logic to compare the effectiveness of treatments for slowing fires under extreme conditions (Finney, 2002b). There is however, no extended temporal dimension to these analyses; fire behavior can only be examined as a snapshot of the current vegetation and not on projected conditions. Combining TOM with a vegetation simulation DST, such as SIMPPLLE provides a long-term view of treatment effectiveness inclusive of succession, regeneration, plus insect and disease problems, which could exacerbate the fuel buildup beyond pre-treatment levels.

For this study TOM and SIMPPLLE are used to identify at-risk areas. This is valuable information, but stops short of integrating other forest issues into a spatial treatment pattern or into cohesive plan. MAGIS develops placement and schedules that can incorporate treatment costs and revenues, budget and manpower limitations, as well as environmental limitations on air quality and water quality issues by drainage. In addition, the placement of treatments in TOM does not consider feasibility factors associated with location (such as roads or WUI) or shape, nor do they address resource effects, or management limitations such as costs. Used in conjunction, a planning DST such as MAGIS incorporates such desired capabilities.

Contemporary, similar systems and tools

Forest ERA

ForestERA is a modeling framework for decision support designed by natural resource managers for natural resource managers. ForestERA is built focused on ecosystem restoration with a strong emphasis on biodiversity, as primarily characterized by wildlife habitat and population modeling (Forest ERA Project, 2004), thus closely fitting Gordon et al.'s definition of a biodiversity DSS. ForestERA is built on ESRI's GIS platform. Forest ERA qualifies as a DSS, in that a framework of modeling tools is typically a system and technically any framework built on ESRI's GIS platform qualifies since it in itself is a system. The Forest ERA website (2004) shows that much of what ForestERA has created is *analysis facilitation –procedures and protocol*, in that the majority of tools the system employs not unique, but are based on the common tools of ArcGIS. ForestERA does not meet Rauscher's definition of a full service DSS.

An objective of ForestERA is data facilitation in data poor environments. Understanding that lack of data may end a budding modeling project, ForestERA's designers made it an early priority

to appraise potential data sources. Frequently, readily available data sources fail to supply key attributes for the modeling work, so ForestERA derives the needed attributes through regression and extrapolation methods. With the growth of remote sensing and the relatively high expense incurred from ground-based data collection, there appears to be a growing number of DSTs that are attempting to derive attributes from middle-scale aerial imagery. Data provided by LANDSAT 7 are used by ForestERA to conduct broad-scale analysis with visualization (Forest ERA Project, 2004). Accurate estimates of attributes such as stems per acre, basal area and mean diameter can only be obtained on a stand-level scale from costly data collection methods and conservative extrapolation. ForestERA uses remotely sensed images to create data that function only at mid or coarse-scale, thus making the data development phase of their work achievable for most projects. ForestERA models to a MMU of one hectare, but the developers are attempting to derive finer resolution data or data synthesis techniques (Hampton et al., 2003).

SPECTRUM

SPECTRUM is a resource allocation and scheduling, optimization and planning DST developed by the USDA, Forest Service and maintained within its Planning and Analysis Group. It is based on K.N. Johnson's FORPLAN, but with some spatial aspects in its analysis (USDA FS, 1996, Zuuring, 2004). Unlike FORPLAN, there is no network analysis (traffic routing etc.) (Meneghin, 2005). SPECTRUM helps resource managers develop and evaluate resource plans through the scenario building / trade-off evaluation in the same manner as MAGIS. SPECTRUM plans for the long-term (up to 90 planning periods of any length) with succession modeling as an imbedded function in conjunction with a deterministic disturbance process. Spectrum is flexible in its application in that its data inputs, objectives and constraints are problem specific, which is essentially the same as MAGIS. Though this type of structure is not constrained to any particular focus, such models are often used for:

- Strategic forest planning
 - Scheduling management activities
 - Fire and fuel analysis
 - Land and resource allocation
 - Forest Plan revision/amendments
 - Developing detailed objectives and treatments
 - Estimating growth and sustainable yield
 - Analyzing and predicting ecological response
 - Landscape analysis (not scale dependent)
 - Economic and social analysis and consideration
- (USDA FS, 2005a) (NCSSF, 2004)

SPECTRUM lumps spatial data into non-spatial pools where it is tracked by a user defined metric e.g. hectares, for analysis. This method reduces computational complexity and speeds computer processing, but as a trade-off results in loss of spatial resolution in the output. SPECTRUM may receive data in a spatial format and the modeler may use that information, depending on the objectives and constraints, to analyze several relationships. This can be accomplished, while maintaining some degree of spatial relationship with zonal attribution (Jones, 2004).

SPECTRUM's overview documentation (USDA FS, 1996) describes typical analysis groupings, "strata and area-based analysis units at user-defined scales" as: (1) homogeneous attributes, but in-contiguous (scattered, but sharing common features); (2) heterogeneous attributes, but contiguous (common zone with disparate features); (3) homogeneous and contiguous (common block with common features) (Meneghin, 2005). SPECTRUM uses a companion ArcView extension SpectraVision to display its spatial inputs. Following Spectrum's modeling, SpectraVision provides GIS to analyze the solutions (USDA FS, 2005a, b).

1.3 Forest analysis and treatment projects in the vicinity

The Buffalo Creek Fire of 1996 and subsequent flooding and sedimentation brought increased interest in fuel reduction projects including this modeling study. The first study providing information was the Foster Wheeler (1999) *Landscape Assessment of the Upper South Platte Watershed* (Appendix A, Figure a). In 2001, the Pike-San Isabel (PSI) NF selected for evaluation seven distinct treatment units for a combined total of 32,000-acres within the Trout-West site. The Polhemus prescribed fire was implemented that same year (Figure 5).

For guidance in the Trout-West (immediate southwest of the study site), the PSI, contracted with an enterprise team to perform detailed analyses of site-specific treatment plans. Concurrently, Hann and Strohm, (2003) Forest Service researchers, performed an evaluation based on the FRCC work of Hardy and others. Their project was to estimate what was needed (across six vegetation types) to reduce the current conditions to the marginal departure of condition class 1 (Hann and Strohm, 2003). Their suggestion for wildfire hazard mitigation was treatments in areas of high departure (from natural regime range) with maintenance in areas of low departure. Their study also promoted landscape wide application of these treatments as the best method for diminishing hazard in the WUI proper (Hann and Strohm, 2003). The enterprise team reviewed the FRCC analysis in the Fall of 2001 and affirmed that the site-specific proposal would treat sufficient acreage to reduce the FRCC departure from an average of 2 to 1, especially within the stands of the target species of ponderosa pine and Douglas-fir (Leaverton, 2003). According to Fred Patten (2005), project leader for the PSI's fuel treatments, 32,000-ac are targeted and as of this writing, roughly 7,835-ac have had mechanical treatment and 735-ac have had controlled burns.

A site prioritization, wildfire mitigation study was prepared by the PSI for internal use, compiled by Elise Bowne (2002 unpub.). I refer to this study as the "Bowne" study. It encompassed all of the PSI and was based on scientific principles and local knowledge of the Forest. It relied heavily on local expertise and subjective weighting of issues affecting treatment choice and placement.

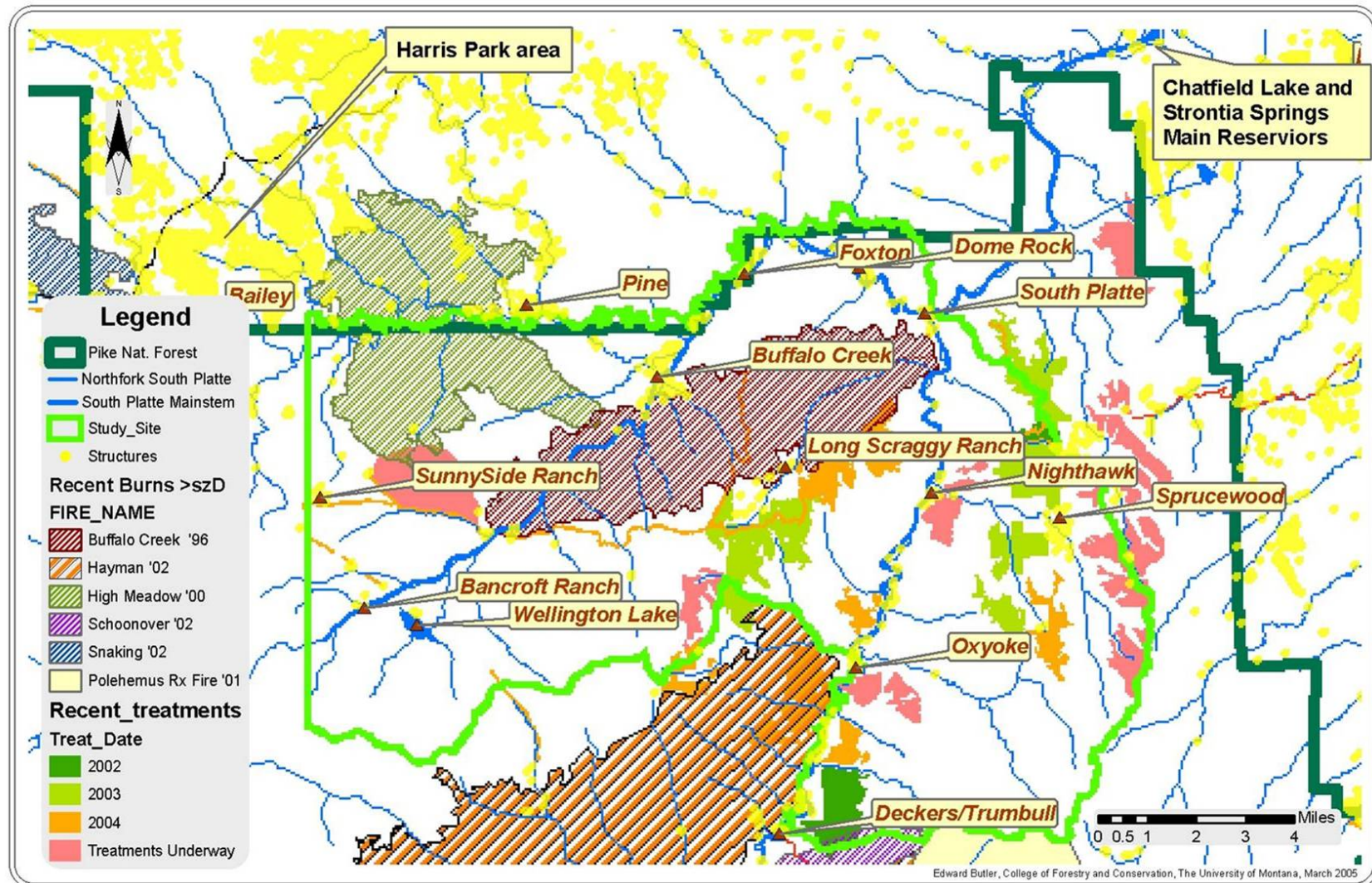


Figure 5. Map of recent fires and fuel treatments near the site

2 METHODS

2.1 Site selection driven by data availability

The Principal Investigators (PI)s of this study chose the general area of interest (approximately 100 square miles) with the intent of providing data not limited to jurisdictional bounds. They were unable to provide data to MAGIS and SIMPPLLE having the key attribute of size-class. The supporting, fire behavior team, however was able to use the data provided, which was derived from a joint "airborne visible/infrared imaging spectrometer" (AVIRIS) remote sensing project provided by Colorado State University and NASA. With the COPPER modeling teams working from different datasets, site selection within the area of interest was narrowed to the area of overlap in the data coverages.

Site selected—"central vegetation unit" format "R2veg" dataset

With help from contacts on the PSI NF, I discovered a suitable dataset. Protocol for the central vegetation unit (CVU) vegetation inventory system was developed in cooperation between the USDA, Forest Service's Region 2 and Dan Green and others of the Grand Mesa, Uncompahgre, Gunnison National Forest and the Integrated Resource Inventory Center of Delta, Colorado. This protocol as it was applied to the inventory of the PSI NF is now referred to as the "(R2veg" data. This R2veg project is an on-going vegetation inventory being compiled by Ed Biery and others of the USDA, Forest Service's Region 2 (2004). R2veg data for most of the extents of the area of interest had been recently compiled into patchwork coverage from inventories taken in the mid to late 1990's. These datasets varied somewhat in quality and coverage, thus making site selection a subjective choice of watersheds exhibiting the highest degree of several qualifications:

1. This study relies on the spatial and attribution accuracy of the R2veg dataset and other layers generated or supplied by the client. There was no primary source data created by this study and quality control standards for all CVU based data affirms 1:24,000 scale, USGS spatial

- accuracy standards. There was therefore no systematic attempt to quantify accuracy of the dataset other than simple comparison to USGS 1:24,000 scale, digital raster graphic (DRG)s "topo" coverages and digital ortho-rectified aerial images (DOQ)s.
2. Site data must exhibit completeness, i.e. very few missing or non-attributed stands.
 3. Data extents for study must be within the South Platte watershed 4th level hydrologic unit codes (HUC) (a subset of the general area of interest) in order to protect the water supply for Denver.
 4. Site should be an expanse of ~100,000-acres, dominated by stands of our target stand mix of ponderosa pine and Douglas-fir; Kaufmann felt treatments must be conducted on a large scale to be effective and wished to "push the envelope" of modeling science by working on this large area.
 5. Grouping by habitat types and other modeling functions are made easier by limiting site extents to watershed bounds. Selecting data that most completely conforms to USGS 6th level HUC was therefore desirable.
 6. The site must include a notable degree of intermix of private structures with hazardous forest fuels.

Data coverages covering small portions of a watershed were summarily removed from consideration. A similar exclusion of watersheds not draining to Denver's main reservoir eliminated a more sites. Final consideration of the remaining sites became an issue of fine points that we the modeling teams felt would benefit the modeling effort as a whole. Portions of four contiguous sixth code watersheds were selected to comprise the ~92,000-acre site named by the MAGIS team as *nfork/splatte* CV (Figure 1). Wildland urban interface / intermix, a notable proportion of recent burns and adjacency of the sub-watersheds were final considerations for selection as a site. Final consensus on the site was reached with agreement with USDA, Forest Service employees: Merrill Kaufmann, Research Forester; Ted Moore, Fire and Fuels Manager with the PSI NF; Fred Patten, Project Leader for ongoing fuel treatments; Chuck Dennis represented the State of Colorado Division of Forestry.

2.2 Site characteristics

The area of interest neighbors the large population centers of Denver; urban sprawl and rapid population growth in the wildland urban interface and forest inholdings set-up a number of difficult issues that must be analyzed then planned for. Communities not immediately proximal

to the site can be greatly affected by wildfire, since this watershed supplies the majority of the water to this semi-arid land. The site is dominated by the Pike portion of the PSI NF. Ultimately the study's current vegetation (CV) dataset was provided by the PSI and therefore encompasses lands of the PSI NF, and only incidental in-holdings and contiguous parcels of private land.

Topography

The expanse of the site is ~20-miles to the west of the juncture of the Rocky Mountain Front with the plains of eastern Colorado and is primarily the habitat type and topography representative of ponderosa pine and Douglas-fir forests in this region (Figure 1). The terrain is mountainous with an average slope of 27%, standard deviation of 16%. Nearly all of the study area falls within the montane habitat zone with the exception of mountain peaks in the federally designated Lost Creeks Wilderness (Appendix A, Figure b). Elevation within the study area ranges from just above 11,589-feet in the Lost Creek Wilderness, Freeman Peak down to 6,095-feet where the South Platte River exits the study area at the abandoned town of South Platte.

Climate

The climate of the study area is semi-arid montane with cold winters and warm summers. Weather statistics are long-term yearly averages and were derived from an aggregate of three weather stations at an average of 6-miles from the chosen site. Elevations for these stations range from 6,800-feet to 8,900-feet ASL. Precipitation, at the average elevation of 7,733-feet for the area is 16.2-inches, with approximately half this attributed to snow (Miller et al., 1973, WRCC, 2005). Seventy percent of the rainfall falls from April through September, making this a summer rain dominated hydrologic cycle (Libohova, 2004). Minimum average winter temperatures

(January) range daily between 8 and 9 degrees (F) up to 34 to 45 degrees. Summer maximum temperatures (July) range daily between 42.6 to 47 degrees to 75 to 84 degrees (WRCC, 2005).

Geology & Soils

The soils of the site are predominantly sandy loam in texture and composed of potassium feldspar, quartz, weathered biotite, muscovite and hornblende with the parent material being Precambrian granite (Foster Wheeler Environmental Corporation, 1999). Rock content in the site's soil varies from 0 to ~80%, at an average of ~20%; rock outcropping is common on the steeper slopes. The granite weathers to gruss, which is an acidic base for soil development, yielding thinly developed sandy to gravelly loams with deteriorating gravel. This substrate and the developing soils are highly erodible when subjected to direct impact of rain, overland flow, channelized hydraulic flow or other catalysts such as high intensity fire (Foster Wheeler Environmental Corporation, 1999).

Fire suppression in the last century, has retarded the frequency of fire and likely geomorphic processes that would have contributed to soil development and movement over time.

Catastrophic wildfires, borne from decades of fuel accumulation, can act as a trigger for severe erosion and mass wasting. These precarious conditions will remain until a catalyst frees the material to assume its natural repose (Foster Wheeler Environmental Corporation, 1999). Soils are analyzed in detail in the section on WEPP erosion modeling.

Hydrology and geomorphology

The entire site is limited to the central portion of the Upper South Platte Watershed 4th level HUC (Appendix A, Figure a). Denver Water, the entity responsible for the supply of water for Denver

and surrounding areas, owns numerous parcels of riparian property in direct support of its mission of protecting the water supply. Thirteen intense rain events followed the 1996 Buffalo Creek fire causing flooding, and transporting large amounts of sediment and fire debris downstream to Strontia Springs Reservoir—a major water storage facility. Denver Water spent millions of dollars cleaning debris from the reservoir and will spend millions more in dredging operations to remove the sediment that has filled the reservoir since the fire (USPWPA, 2001). Several attempts in the past to create more water storage along the South Platte River corridor were met with opposition. The community of South Platte now stands empty from the last attempt to dam the river, thus expanding water storage is problematic and protecting the existing water supply is a priority (Moore, 2005).

Riparian health

The South Platte drainage is a major recreation area in Colorado, highly regarded for its “Gold-Medal” trout fishery, its wildlife habitat, and its trails. It is home to many concerns, including several Threatened and Endangered Species (USPWPA, 2001). In a recent Record of Decision, the PSI chose to protect 49.2-miles of the South Platte River and 22.9-miles of the North Fork of the South Platte River within the Forest bounds, by promoting them for Federal, Wild and Scenic River designation. (Leaverton, 2003).

Roads

Roads miles vary in a positive relation to the density of structures within the Forest. Many of the roads are for private access to forest inholdings, but there are major Forest Service, State and County thoroughfares too (Appendix A, Figure b). State highway 126 provides access into the western half of the study site and passes through communities of Pine, Buffalo Creek and

Deckers. To the immediate east of the study site, the west facing slopes of the South Platte Sub-watershed and the community of Sprucewood, are home to many private residences and are therefore notably roaded. As a whole, the communities within the site are provided improved access via a number of arteries leading from the forest in several directions. There are areas of federally designated as Wilderness and Inventoried Roadless Areas, which influence the distribution of roads on the site. As a whole the study site's road density, at a mean of 1.37 road-miles/square-miles is notably less the watersheds to the immediate south—mean = 2.01-rm/sqmi.

Species of concern

The client named four possible species of concern in the Front Range: Preble's meadow jumping mouse (PMJM) (*Zapus hudsonius preblei*), Canadian lynx (*Lynx canadensis*), Mexican spotted owl (MSO) (*Strix occidentalis lucida*), and the Pawnee montane skipper butterfly (PMSB) (*Hesperia leonardus Montana*). These species were further researched when it was determined that their probable home ranges overlapped with the study area (Appendix A, Figure c), more information provided in Appendix C.

Forest Fuels—historic and current conditions

Pre-Euro-America forests, characteristic of the central Colorado Rocky Mountain's mixed severity fire regime are defined by Kaufmann and others (2004) as having a non-lethal surface fire component, spatially mixed with a lethal component that kills the overstory, often in a patchy mosaic. Sporadic tree recruitment following this fire regime often led to a diverse stand structure resulting in forest patterns conducive to patchy isolated crown fire, and yet widespread low intensity surface fire also (Kaufmann et al., 2004). The return interval for landscape scale fires often exceeded 40–50-years (Brown et al., 1999). While the species mix of ponderosa pine and

Douglas-fir was historically common, extensive dense stands were not the norm. Overall, the mixed burn severity patterns contributed to wide diversity across the landscape that manifested in frequent openings ~2 to ~40ac in size across 25–35% area (Table 1)(Kaufmann, 2005c); grasses and shrub were more prevalent than today with crown cover ranging from 0-30% (Colorado Forestry Advisory Board, 2005). The potential for high intensity crown fires is greater as crown density increases and the more continuous the canopy the more likely it will carry. All variables conducive to fire being equal, density of 35% and greater crown cover is favorable for carrying crown fire (Solari, 2002, Kaufmann et al., 2004).

Table 1. Kaufmann's density analysis of the general area (all species) (Kaufmann, 2005c)

The Stand Density Problem				
Canopy Cover	Description	% of Landscape		
		Historical	Current	
0-10%	Openings	30	2	
10-20%	Openings	42	6	
20-30%	Woodland	19	24	
30-40%	Woodland/Forest	6	17	<i>Active Crown Fire</i>
40-50%	Forest	2	24	
>50%	Forest	0	28	

Fire regime current conditions

The Fire Regime Current Condition (FRCC) project is an interagency, coarse-scale classification system that indicates the degree of departure from reference conditions of vegetation, fuels and disturbance regimes (Appendix D). The FRCC national map, (Current Condition Classes, Version 2000, 2001), indicates that there has been a ubiquitous departure from historic fire regimes across the study area, with the vast majority of the site (~89%) placed in condition class I-2 (Table 2). Observation shows the current condition of ponderosa pine/Douglas-fir forests of the study area (primarily in the 0-35yr return interval) has shifted from the range of natural variability by at least one interval (Appendix A, Figure d). A small minority of the site,

represented by FRCC values III-2, III-3, and IV-1, are predominantly in the upper montane zone. While the scientific community harbors questions about the efficacy of restoration treatments in these zones of longer fire regime intervals, there are communities at risk in the higher elevation of the site (Colorado Forestry Advisory Board, 2005) and therefore I am including these areas in my restoration treatment modeling. Due to the coarse resolution of FRCC and the uniformity of class I-2 on the site, there is no benefit to its use as a risk index.

Table 2. Results of an FRCC analysis showing the vast majority of the site classified as condition class 2, i.e. moderate departure from the historical natural fire regime on 89% of the site.

FR	Historical natural regime	CC	Departure from HRV	Ac in site	Pct of Site
I	0-35yr frequency, low severity	2	moderate	81,889	89%
III	35-100yr+ frequency, mixed severity	2	moderate	1,096	1%
III	35-100yr+ frequency, mixed severity	3	high	6,317	7%
V	200yr+ frequency, stand-replacing	1	low	2,546	3%

Human Demand

Euro-American settlers began to exert changes on the land in 1858 (Kaufmann, 2005a). Impacts included extensive grazing, logging, fire suppression and likely use of fire as a management tool. These changes have cumulatively altered the forest structure, species distribution and spatial patterns. Wildfire is the primary change-agent of ponderosa pine and these changes have altered natural ecosystem disturbance processes, notably that of wildfire (Foster Wheeler Environmental Corporation, 1999, Current Condition Classes, Version 2000, 2001, Grant, 2005).

Grazing and logging no longer dominate the human activities in the site. Colorado's populace and visitors value recreation, and in particular, the beauty of the landscape of the Colorado Front Range, but an already dense and rapidly increasing population (18% increase statewide between 1990-1997) is making the management of forested landscapes difficult because of these human influences and attitudes towards the land. The study area is nearly surrounded by dense

population. Populations of the site and neighboring counties are: Arapahoe 463,201; Denver 498,985; Jefferson 496,656; El Paso 480,041; Douglas 126,248; Teller 19,790; and Park 12,730, this combined population represents 54% of the state's total population (UC Boulder, 2004). A sizeable population has built within the wildland urban interface of the PSI NF and overall recreation use in the South Platte watershed was estimated at 1,650,000 visitor days in 1995 (Denver Water, 2000). In addition to the public's recreation and housing demands on the Front Range, the South Platte River must remain protected to serve this development with water. Over 80% of Denver water system's (customer base extends well beyond Denver proper) potable water is supplied by the Upper South Platte watershed (Denver Water, 2000).

Recent Fires in the Vicinity

The current site is prone to high intensity fire that is exacerbated by the frequent dry conditions of the area. Burning conditions in the spring and fall can also be exacerbated by Chinook (Foehn) winds (Solari, 2002). Three large fires in the vicinity have burned a combined total of over 160,000-acres in the last decade (Figure 5). Only the Buffalo Creek and Hi Meadow fire intersect the study site. Even though classified as a mixed severity fire regime these fires are atypical: "the size of the patches created by recent fires appears to be considerably larger than occurred historically...the occurrence of crown fires with large areas of complete tree mortality is inconsistent with ecological sustainability"(Colorado Forestry Advisory Board, 2005).

The 1996 Buffalo Creek fire burned in the north central part of study area, traveled 11-miles in 4.5 hours and led to severe post-fire erosion. Ultimately it burned 11,900-acres, twelve structures were destroyed, and many more damaged. This fire burned so severely that the majority of forested stands were entirely consumed, while producing large areas of water repellant soil. Two

months later, an intense thunderstorm rapidly dumped 2.5” of rain on the burned area, leading to severe flooding, a washout of Highway 126 and the ruin of Town of Buffalo Creek’s potable water. Total fire and flood costs were estimated at \$25 million (Denver Water, 2000). The burn was the catalyst for the deposition of approximately 600,000 cubic yards of sediment into Strontia Springs Reservoir and the deaths of two Buffalo Creek residents (Agnew et al., 1997, Kaufmann et al., 2001b)

The Hi Meadow fire of 2000 started on private land and burned 10,872-ac, half of which were in the site. Total fire costs were \$13 -\$18-million, with 58 structures destroyed (Denver Water, 2000).

The Hayman fire started near Tarryall Creek and was Colorado’s largest recorded conflagration. The 138,000-acre Hayman burned to the southern edge of the study area during a 20-day span in June of 2002, consuming in the process 600 structures, including 132 homes with an insured private value loss of \$38.7 million dollars. The expense borne by the Forest Service for this fire was \$38 million, three times the expenditures for all fires in the area for the preceding decade. Estimated financial losses attributed to degradation of the potable water capacity were \$37 million, with timber losses at \$34 million. Other accumulated costs easily double these calculations (Graham, 2003). The fire created severe sedimentation of Cheesman Lake an important reservoir for Denver Water for a clean-up cost of \$5.5 million. Additionally, the heat of the fire created hydrophobic soil conditions that resist water absorption. This can foster a dramatic pulse of overland flow and increase the hydraulic force of runoff, thus creating favorable conditions for flash-flooding and serious erosion during heavy rainfalls (Denver Water, 2000).

Jurisdiction and Area Restrictions

The study site is predominately National Forest land of the PSI (Table 3) (Appendix A, Figure e). The Denver Water Board is the largest private landowner, but contracts management of its forested lands to the State of Colorado, Forestry Service. Chuck Dennis (2005), Colorado State Forest Service (CSFS) Forester, is interested in managing these and state inholdings similarly to the PSI in accordance to their restoration and fuel treatment plans. This allows a degree of freedom to modeling treatments for natural processes that heed no jurisdictional bound.

Table 3. Major landowners of study site (author's calculation from Theobald and others (2005))

Jurisdiction	Acres
PSI	79,356
Private non-ind	8,817
Denver Water	3,399
Jefferson Cnty	239
State of CO	90
Sum Total	91,901

There are several areas with special federal designations and restrictions; in the western portion of the study area is the Lost Creek Wilderness (Appendix A, Figure b). There are also several sites of Inventoried Roadless Areas. The PSI currently seeks to replace the current (1984) Forest plan. It is hoped that this study will assist in the development of a new plan, which is expected to include fuel management. Therefore, fuel treatments are modeled in this study for all areas accessible from the current road network, including prescribed burning in areas beyond the physical limits of mechanical thinning.

2.3 Development of the dynamic vegetation site sub-model

SIMPPLLE team cooperator Thad Jones conducted an extensive literature review of vegetation *species, density, size class*, and successional characteristics (by *habitat type*) encompassing all of Colorado. Extensive disturbance process information, subsequent post-disturbance states and successional pathways were developed. Defined were 195 vegetation species, 6 habitat types, 20

size classes, four density classes and 19 disturbance processes (Appendix G). MAGIS uses these attributes and classifications, so I imported these states and pathways for continuity and convenience.

2.4 Building the site sub-model

The following is a discussion of the development of the current vegetation dataset needed for MAGIS modeling. Other data layers namely hydrography, topography, and soils, as well as erosion and social issues are discussed as they become relevant.

Initial manipulation of the Current Vegetation data

The nfork/splatte R2VEG dataset was maintained by both the SIMPPLLE and MAGIS teams in its original amorphous-polygonal configuration until requests from the PSI forced us to reconsider this format. Maintaining stand-bound integrity is important to data accuracy so the original data format was retained for many months leading to model completion. For compelling reasons discussed in the following section "Complications and trade-offs of CV format" attributes were assigned to both the original polygons (discarded) and then to a newly created coverage in a 5-ac polygonal pseudo-grid. The SIMPPLLE team used the ArcInfo "pseudo-grid" method, facilitated by an AML routine, to convert this vector format into a 5-ac MMU raster. The AML then populated the newly created pseudo-grid layer by calculations similar to those performed by the Zonal Statistics.

The SIMPPLLE team performed a number of *crosswalk* conversions of terms within the dataset, as well as class assignments of continuous and integer variables to match "legal" terminology (Appendix G). This study is only concerned with fuel treatment of forested stands dominated by ponderosa pine, Douglas-fir or mixes of both (Figure 6). This was requested by Patten of the PSI

and is more for site invigoration than for fuel treatment. MAGIS and SIMPPLLE are capable of distinguishing a mix of dominant and co-dominant species as a unique combination and these are represented through the naming convention. To the imported data I added topographic attributes of elevation, slope and aspect via ArcMap's Spatial Analyst feature and the NED 30-m raster. I attributed CV stands with a code for the sub-watershed (HUC6th) by ArcMap's select by location function (have center in) (Table 4).

Table 4. Code assignment by 6th-code Hydrologic Unit

Watershed name	HUC 6th	Code assigned
Deer Creek (incidental inclusion)	101900020402	0
Pine-Rowland	101900020401	1
lowest north fork	101900020405	2
Buffalo Creek	101900020404	3
Waterton-Deckers	101900020407	4

Complications and trade-offs of CV format

Two formats were considered for the CV. Its native format was vector polygon—stands with a homogeneous mix of characteristics. These map units varied widely (some over 100-acres) in both size and shape with some polygons being very sinuous—usually indicative of riparian corridors. This original format was deemed unsuitable due to its irregular nature (Appendix A, Figure f). SIMPPLLE models several processes involving spread logic and those outputs lose significant resolution when forced to model for irregular polygons. The SIMPPLLE and MAGIS teams maintained, but ultimately abandoned a hybrid data format for several months that retained original stand boundaries, but split the larger units to a maximum of 30-acres. The compromise also failed to meet the SIMPPLLE team's spatial needs it too degraded SIMPPLLE's contagion modeling. Converting the CV to a pseudo-grid format best solves this problem and others, but dilutes the precision of the original data through summarization, especially via methods altering stand boundaries.

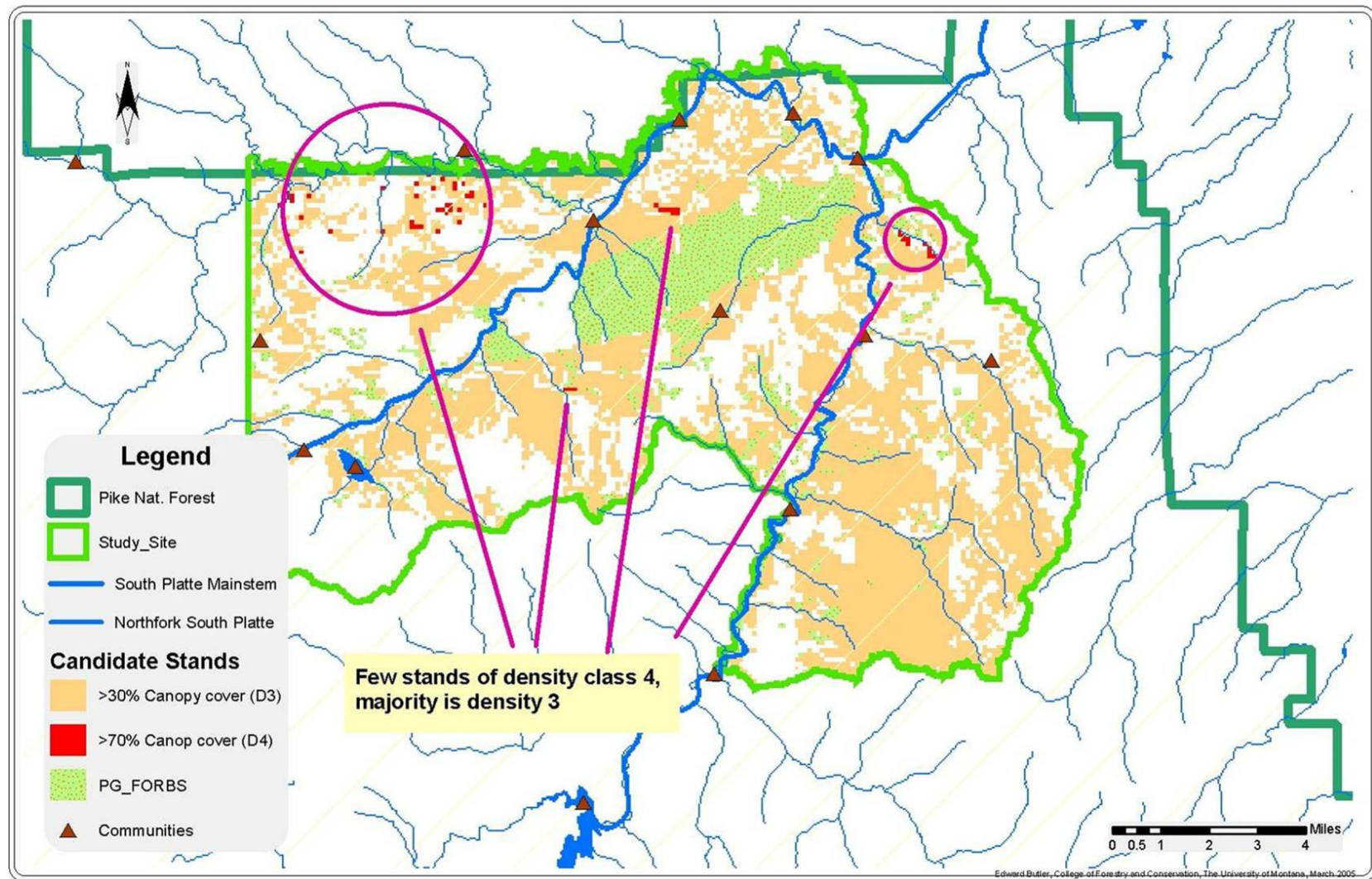


Figure 6. Map of stands (mostly in density class 3) eligible for treatment within the site.

Kaufmann, acted as the landscape architect of this study. According to Kaufmann's summary of his and other's related research the desired condition for the site includes scattered openings (10% or less crown closure) of 2 to 40-acres in size with the distribution notably skewed towards the smaller openings. Kaufmann expressed that the treatments should yield these openings on 25–35% of the entire site. I considered the obstacles to modeling these treatments and commented that such treatments would be very difficult to model based on the spatial limitations of the CV in its native format. I left Kaufmann with the idea that this would be something that the fuel managers could determined on-site, at the time of a treatment, with the benefit of COPPER modeling. Kaufmann seemed content. Months later several key foresters expressed dissent that the openings were not being modeled. The SIMPPLLE team revealed that the data format must be of a pseudo-grid format in order that the conversion of "stands" to "openings" could be modeled over time. A pseudo-grid format would also facilitate better resolution of "spread" process modeling. The SIMPPLLE team had produced from the outset a pseudo-grid version of the CV and now informed us of this fact. With an impending deadline and concern for the possible loss of SIMPPLLE support, we agreed on the pseudo-grid format (Figure 7). See also "Data format resolution trade-off" (Appendix E). The acceptance of this dataset and the "random-like" pattern of openings forced my thought on how to aggregate these small units into to contiguous treatment units to fulfill the subordinate purpose of fire breaks—discussed further in the section "Producing a Treatment Site Coverage."

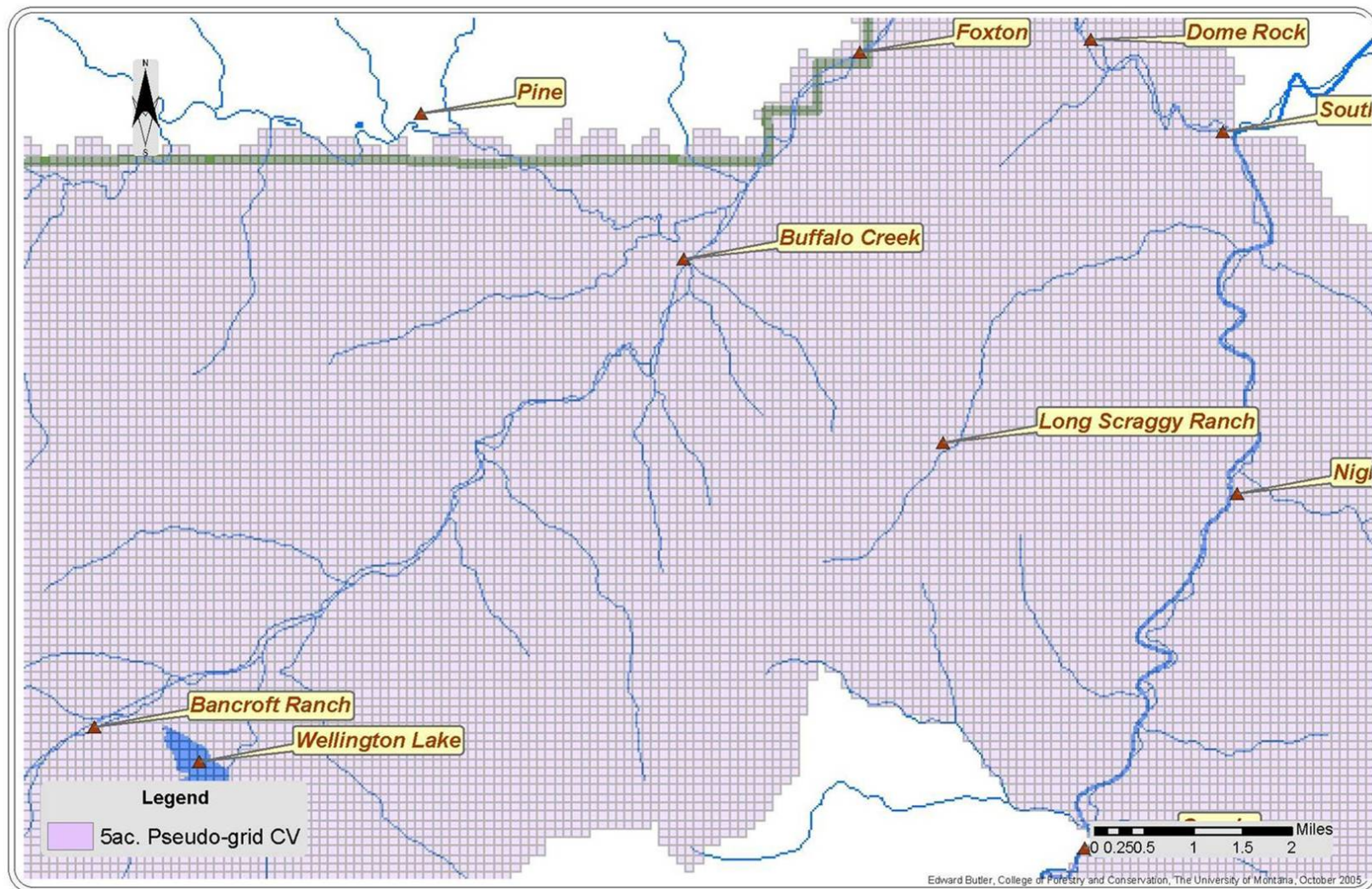


Figure 7. Map of SIMPPLLE supplied pseudo-grid format of R2veg dataset—selected for modeling

Updating the data for changes on the landscape

Between the collection of the CV data (1996) and the AVIRIS data (2002) the Hi-meadows fire burned 6% of the study site, also since 2002, the PSI conducted treatments on 13% of study area; both caused data error (Figure 5). I updated the original CV data, to reflect the current states in the treated stands according to a rule-set provided by Patton, PSI Fuel Treatment Project Leader (Appendix F, Table d). I also changed any multi-story forest structure to single story, but made no change to size class. I set all post-treatment densities to 2, per Patton's description.

For the Hi meadows burn, I used the (post-burn) AVIRIS data to update the states via Spatial Analyst's "zonal statistics" feature (Zonal Statistics). As mentioned, the AVIRIS data lacked sufficient detail for direct use in MAGIS or SIMPPLLE, so by my interpretation, I developed a cross-walk based on my experience with the burned area (Appendix F, Table e).

I observed that the vast majority of the original states were a mix of PSME and PIPO. The AVIRIS data provided only single species classification; consequently mixes were presented in the AVIRIS data as PSME dominated stands. Believing PSME to suffer higher mortality than PIPO for a given fire intensity, I made the cross-walk biased, favoring PIPO in the post-burn state (Appendix F, Table a). The AVIRIS dataset has no size class. I made the assumption that all CV multi-story states would convert to single story states as a result of the burn, but without size change. Without a generic "shrub" input for species, I used CEMO2_ARUV, a common shrub mix in the vicinity of the burn, where AVIRIS indicated a post-fire "shrub" state. I adopted the AVIRIS densities where a new state was provided by the cross-walk. I did not attempt any alteration on map units shown as barren "BA" in the CV dataset—they remain barren—nor did I update any stands that AVIRIS showed as "shadow."

Intermix Defense Zones (IDZ)

Using the subjective weighting and broader scheme of the previously mentioned PSI "Bowne study" (2002 unpub.) for guidance, I developed a slightly different plan for prioritization in the study site. The housing density portion of Bowne's study was a derivative of housing density analysis done by Theobald and Kneeland of Colorado State University, (2002 unpub.). The output of this analysis work was a 100m MMU raster data layer, derived primarily from parcel, well and census data. In the vicinity of the study site, values ranged from 0 to nearly 1 home per acre. In the PSI study, this data layer was reclassified into four density levels that included a 2-mile buffer (all buffers in Bowne's and this study reflect radii) of density clusters. The distribution of structures in the study site is arranged more in a pattern indicative of intermix rather than a consolidated WUI. Because of this widespread arrangement of structures the PSI density analysis resulted in a nearly complete coverage of the area, thus negating much of the value of prioritization. The Healthy Forest Restoration Act sets the precedence for treating forested areas up to a maximum of a 1-1/2-mile radius from a WUI in the absence of any declared "Communities at Risk" (CAR) with an approved "wildland fire plan." Discussions with Moore, the Forest Service Fire Management Officer FMO with jurisdiction over the study site, resulted in a decision to model fuel treatments in the absence of detailed wildland fire plans for the present—CAR needs can be planned for post-modeling. I therefore proceeded to develop a housing-density based analysis.

I re-created the Bowne density analysis from the "Theobald base density raster (Theobald and Kneeland, 2002 unpub.) (Figure 8). This I combined with a USGS structures (point) layer of the National Map Project, which derives its points by analysis of Digital Raster Graphic, USGS 1:24,000 scale topographic maps. In this area of rapid housing development, no structures layer will be current, but these two combined, provide the best data available for our purposes.

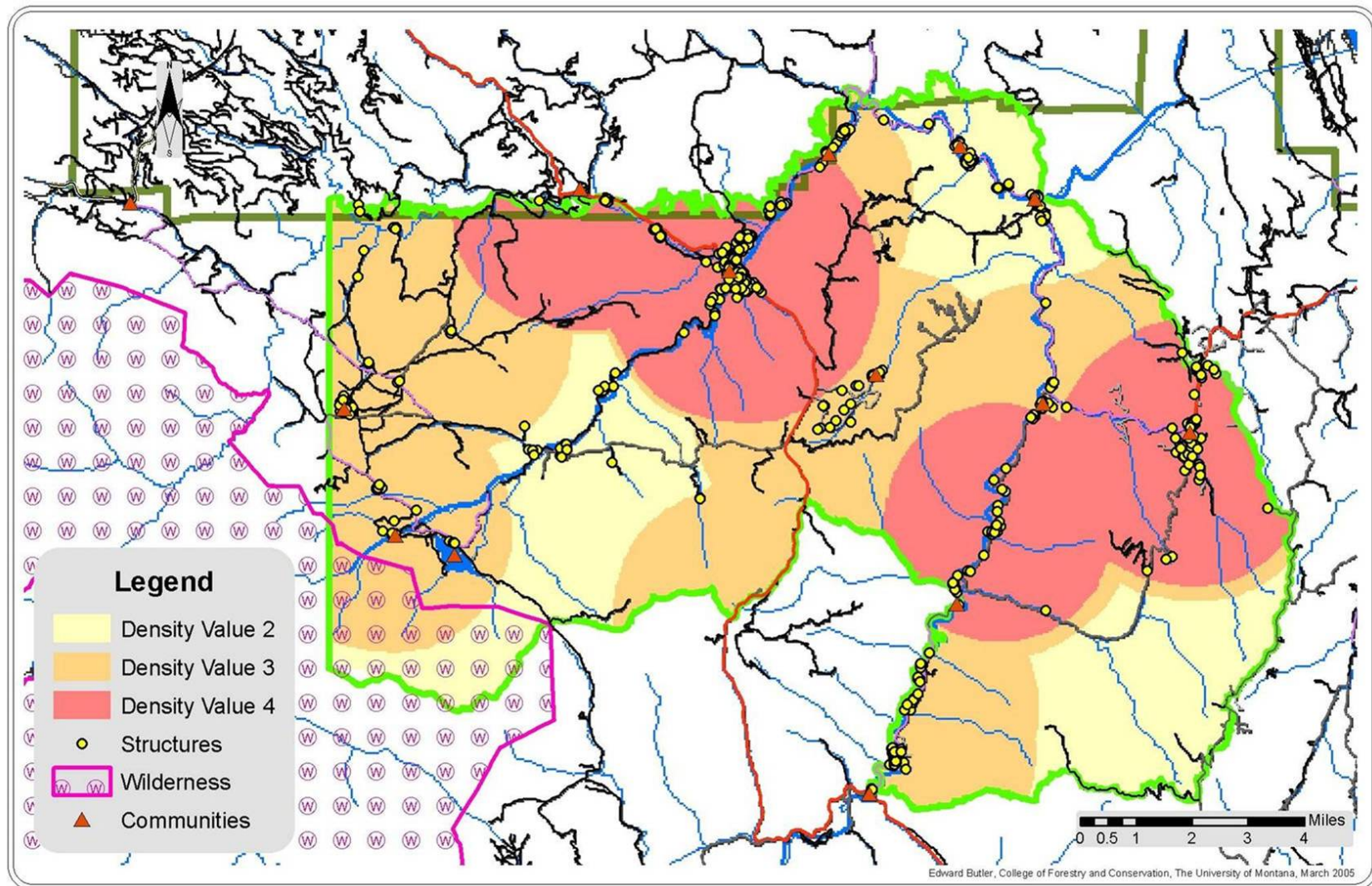


Figure 8. Map of re-creation of Bowne's PSI study housing density buffer zones

The structures and density layers were visually compared with an ownership layer, Digital Ortho Quarter (DOQ) layers and a roads layer and found to be accurate. I buffered the structure points to a half-mile radius. The majority of the points were coincident with the PSI's study class 2 rating. I retained the PSI's rating of 1 to 4, but changed the absence of housing to 0, thus 0-4 (Figure 9 and Table 5). In both studies, with overlapping buffers, each valuation assignment is exclusive and represents of the highest value assigned. Knowing these points could be structures of any status (dilapidated, removed or active residences) I felt they deserved some base level valuation for prudence. I assigned a 1-1/2-mi buffer of all structures with a value of 2. This step replaced the PSI's value of 1, but the values of 2, 3 and 4 were retained to a half-mile buffer and joined with the structure layer's values. I anticipate the alteration having the most effect between the PSI study and this study will be the valuation of a half-mile buffer of density classes 2-4 rather than the 2-mi buffer used previously. This half-mile buffer is supported by the FMO, (Moore, 2005).

Table 5. Adaptation of PSI's subjective ranking of housing density

PSI Rating	PSI Buffer	Housing Density	MAGIS Rating assigned	MAGIS Buffer
1	none	No homes in data	0	none
1	2-miles of density cluster	Up to a maximum of 1 home per 2500-acres	1	each structure buffered 1-1/2-mile
2	2-miles of density cluster	1 home per 40-acres maximum	2	1/2mile + union w/ 1/2-mile buffer of structures
3	2-miles of density cluster	1 home per 10-acres maximum	3	1/2mile
4	2-miles of density cluster	Up to 5 homes per-acre	4	1/2-mile

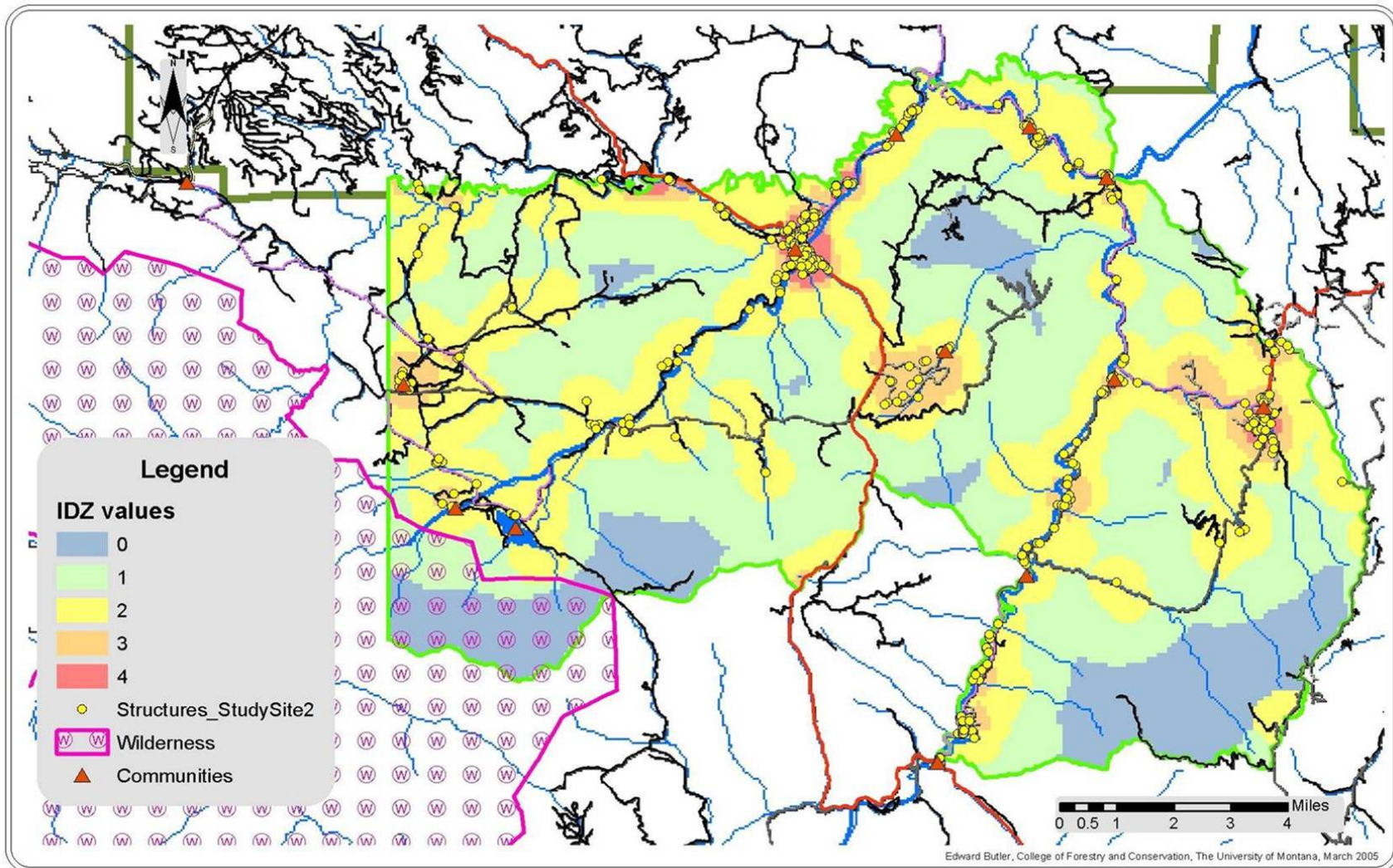


Figure 9. Map of new Intermix Defense Zones for optimization weighting in MAGIS based on PSI's study and a USGS structures layer

Species of Concern Habitat Zones

MAGIS modeler and Biologist Silverstein provided a data layer of habitat zones for species of concern (Appendix C). These habitat layers were added as attributes to the CV layer by using ArcMap's "select by location" feature (Appendix A, Figure c).

Prioritizing per PSI fuel treatment study (in-house study)

Bowne and others (2002 unpub.), (section on intermix defense zones) developed a model comprised of nested sub-models. All information I used in my reconstruction of their work was derived from direct discussions with Bowne or obtained from her compiled report (2002 unpub.). The primary model and each sub-model had separate schemes for weighting index values—the critical attributes of the primary model are based on hazard + risk + value.

Hazard – by hazardous fuel conditions, slope and aspect

Risk – related to human traffic—represented ignition potential

Value – composed of housing density, erosion potential and habitat for wildlife of concern – represented values at risk by catastrophic wildfire

In this study SIMPPLLE's disturbance modeling and the fire behavior modeling encompasses ignitions, aspects of topography and fuels and thus serves as a substitute for Bowne's "hazard modeling." I was without subjective weighting for "value" and therefore the "value sub-model" offered great utility. The methods I used for adding attributes to the MAGIS site sub-model with the components of the PSI "value" schema are discussed previously in this section. Here I develop methods for converting these attributes into a basic classification on a scale of 0-4.

The Bowne study weighting scheme was: housing density 0.45, erosion 0.40 wildlife 0.15 (45:40:15) = 100. Housing density needs no further manipulation and was used to populate a field called WUIVAL. Species of concern habitat zones are classified here in a method similar to that used by the PSI in-house study. Bowne (2002 unpub.) prefaces the weighting with, "'Value' in this context is not considered to be the inherent worth of one species or its habitat vs. another, rather it is used as a scale for assessing which habitats/species are most likely to be significantly impacted by stand-replacing wildfire". Bowne's study does not use area of zonal overlap cumulatively due to negligible overlap on the entire PSI expanse, but mentions that cumulative summation could be favorable where overlap exists on smaller sites—as with this study. Silverstein (biologist on the MAGIS team) and I agreed to model cumulatively in areas of overlap. He maintained the PSI's original zone values, but whereas the PSI had modeled the PMJM habitat as two separate zones (“potential” and “proposed critical”) Silverstein chose to combine the two for simplicity (Table 6). This recoding created a possible range of values from 0-21, consequently he created five classes to convert the values to the 5 point scale: 0 = 0pts; (1 to 5) = 1pts; (6 to 10) = 2pts; (11 to 15) = 3pts; (16 to 21) = 4 points—thus putting the cumulative point scale in the desired 0-4 range. I used this data to populate the field WILDCUM.

Table 6. PSI and MAGIS weights assigned to species

Species	PSI and MAGIS weight
Mexican Spotted Owl (MSO)	6
Pawnee montane skipper (PMSB)	9
Preeble's meadow jumping mouse (PMJM)	4 combined
Canadian lynx	2

Erosion by the Bowne study was modeled as "effective drainage rating," (linear units of roads + linear units of stream) assigned to map units. Also a soil layer was analyzed by Ken Kanaan, soil scientist for the PSI, and assigned an "erosion hazard rating" from his experience with the site. Bowne used these two rating systems in a matrix to select the map units at greatest risk of "soil

movement potential." I improved on this method by substituting outputs from the WEPP erosion modeling plus the coincidence of roads and streams as with the original study—erosion modeling discussed in section on WEPP erosion modeling.

I added the field RCZXROAD to the CV, which following WEPP modeling, will be used to identify stands coincident with the *riparian contribution zone* (RCZ) where it is intersected by roads. I assigned RCXROAD a value "2", with "1" assigned to all other stands in the RCZ—a value of 0 outside the zone. This value is used in the equation: $WEPPSED \times RCZXROAD = EROSION$. EROSION serves as the output value for prioritization within the *spatial priorities* weighting scheme. This makes road/stream proximity a factor of sediment yield, effectively doubling the estimated EROSION predicted by WEPP in those stands.

I applied Bowne's weightings to my new attributes $(WUIVAL \times .45) + (WILDCUM \times .15) + (EROSION \times .40) = SPATPRIO$. Bowne used spatial priorities (SPATPRIO) with fire hazard and risk on a 1:1:1 ratio. In COPPER there are numerous indices to choose for fire hazard input, but only SIMPPLLE's attribute FIRERISK, accounts for ignition probability in addition to spread and intensity, so to account for all of Bowne's "risk and hazard" components combined, the equation is: $SPATPRIO + (2 (FIRERISK \times .08)) = SPFRRISK$. The ".08" factor converts FIRERISK to a 0-4pt classification and "2" accounts for the combined contribution of Bowne's hazard and risk. From here on, I refer to this as the PSI's spatial priorities scheme (SP).

Fire Regime Current Condition Class attribution

FRCC classification was discussed in the site characterization section. Spatial data at a 1km resolution was readily available on-line as a raster dataset (USDA FS, 2001). I used the Zonal

Statistics function on this layer to populate the field FRCC in the CV (Appendix A, Figure d).

MAGIS will report total acres of activities by FRCC class in scenarios run.

Addition of estimates of biomass, timber volumes, stewardship values etc.

Economics Unit cooperator Dan Loeffler modeled biomass, timber volume cost and revenue for all candidate stands. Biomass and timber volume estimates were produced only for stands medium size class or larger using the FVS model with extensions. He gathered FIA data from five counties surrounding the site and categorized them by the critical variables of species, size class and density to derive estimates of total biomass; this he cross-walked into SIMPPLLE's classes. In FVS, stand growth was simulated over the planning periods and volumes, costs and revenues supplied to MAGIS in the form of a table. MAGIS will average these numbers for all like-stands when mechanical thinning is applied. Modeling assumptions and values: biomass 50% moisture content; in relation to costs, 1,000-ft average skidding distance and 20% slope; stumpage values for saw-logs (≥ 9 " DBH) as an average of \$8.44-ccf (mix of the target species.)

Currently no market for biomass chips exists near the site, with little market for timber.

Therefore no value for biomass is assigned, only the costs. Stewardship contracting is the exchange method which often facilitates work on the PSI. To facilitate this exchange the values must be tabulated. Often prescribed burning is not part of stewardship work due to the potential liability, so stewardship calculations include no burning costs—they are reported separately.

The above estimates are ubiquitous in the MAGIS modeling, but explicitly occur in outputs of the following estimates and associated revenues and costs.

BIOMAS — merchantable biomass produced (in tons), by thinning activity

CSTBIO – total costs involved with delivering BIOMAS to landings in chip form (dollars)

BIOSAV – estimated net revenue for BIOMAS (in thousands of dollars)

MAST9 – cost of mastication by thinning activity (as an alternative to merchantable biomass)

STEW – net stewardship values by period (without burning costs)

CSTBRN – cost of burning for all activities

2.5 Incorporating Companion Modeling

WEPP erosion modeling

Unlike other companion models, WEPP's functionality was internalized in MAGIS. This assimilation required extensive thought from me, Janet Sullivan (MAGIS developer) and demanded great cooperation from Elliot, WEPP's Project Leader. Methods of incorporation are novel and original and therefore recorded in great detail.

Determining critical variables and modeling assumptions

Erosion modeling employs complex variables interacting at different scales; the WEPP project is no exception, but meets a modelers needs for scale and complexity with different interfaces:

- GEO WEPP is the watershed scale or aggregated hillslope desktop interface of WEPP that uses a GIS data layer to supply the independent variables—the processor intense modeling of this interface limits project size to about two square-miles (Elliot, 2004).
- WEPP for Windows is a desktop application for individual hillslope modeling.
- FS WEPP is an on-line tool available through several modeling interfaces, each with a specific modeling function.

All of these interfaces access the same core WEPP modeling program, but each, insightfully advances to a higher degree of modeling complexity to match a user's abilities and needs. This study uses the core WEPP program without any interface. Here, I model for treated hillslopes

and aggregate to 6th code HUC's. A temporal limitation between WEPP and MAGIS warrants consideration.

Because erosion by water is driven by runoff, the process is sensitive to episodic extreme precipitation events. WEPP is best used to predict the erosion response post-treatment and to predict the likelihood and estimates of rill, inter-rill erosion and sediment delivery following extreme events. Modeling for average erosion tends to underestimate, since under average weather little erosion occurs, especially in the semi-arid mountains of central Colorado. WEPP will however, use a climate file to interject historical variability in precipitation, via daily increments. From WEPP's related CLIGEN database, recorded data by one or several weather stations is used to build a distribution of precipitation events (among other outputs). The longer the projected distribution, the more likely the extremes are captured (Elliot, 2004); I use a suggested 50-year distribution. This ability to model for daily events makes WEPP a valuable prediction tool, but there is an enormous disparity between the temporal scale of episodic erosion response and the decadal planning periods of this study. This degrades MAGIS's prediction of absolute values. I therefore decided to use WEPP to model not for absolute erosion values, but for relative accuracy, in order to examine trade-offs with erosion. I discussed this limitation with Deb Entwistle, Region (2005) 2 (R2) and PSI hydrologist and suggested using WEPP for tactical-level planning at the site of treatment implementation—she agreed.

Sullivan developed an interface "MAGWEPP" to build and populate a table with all combinations of WEPP-critical variables occurring on the site. She included a batch processing routine that ran WEPP on all the combinations, which populated a WEPP output look-up table for MAGIS runs. Since erosion becomes a concern when sediment is transported to a stream (Elliot, 2004), I chose this single WEPP output as the dependent variable (more on this in the sub-section "The

mechanics of WEPP"). I discussed critical variables for WEPP modeling with Kevin Hyde (2005), the hydrologist resident to the Economics Unit and Elliot (2005). I confirmed their opinions via informal analysis of sensitivity. This confirmation and the deliberate selection of the WEPP model by the client from the outset made further testing of the WEPP model was superfluous. Gross variables for site were determined to be (ordinal):

- climate
- gradient
- ground cover
- soil texture
- aspect

WEPP's associated CLIGEN database provided the packaged climate file for all climate variables and aspect is easily derived from the National Elevation Dataset, (NED-30m) (USGS, 1999), via ArcMap's Spatial Analyst module. Climate file, I held constant for all modeling, but made aspect a stand variable. I elaborate on gradient, ground cover and soil texture in the section The mechanics of WEPP.

The choice of a climate file, representative of a weather station (or composite of several) can be significant, but the stations around the site showed little variance. I examined weather stations in the vicinity of the study site via the Western Regional Climate Center web-site (2005) and chose three stations that were representative of the site proper (Table 7); I did this with a deliberate effort to represent the range of elevations for the site. I chose the station of "Bailey."

Table 7. Description of three weather stations examined in study area

Site	Elevation (feet)	Precipitation (inches)	Snowfall (inches)	Approximate distance and bearing from site
Cheesman	6890	16.1	58	4m-south
Bailey	7700	15.7	78	4m-west
Grant	8690	15.7	95	15m-west

Modeling of gradient, ground cover and soil texture proved complex and required simplifying modeling assumptions to accommodate modeling design, labor, and data limitations. Hyde, in addition to his position as hydrologist, is the primary modeler to a mature MAGIS study—the Bitterroot NF (BEMERP project). The BEMERP project also employs WEPP modeling for sediment prediction. Hyde consequently provided valuable feedback to my adaptation of WEPP.

Hyde felt that erosion modeling should be limited to stream proximity. A literature review of “sediment transport” indicated that transport is greatly limited by distance from a disturbance (Burroughs, 1990, Belt et al., 1992). These empirical studies concluded that sediment was transported less than 100m (328-ft) from the studied disturbances in most events ($p=0.95$ per Burroughs). Further, these were studies of road erosion; there were no studies on transport from slope disturbance. Roads being more erosion prone than disturbed slopes, modeling for erosion from a 100m (328-ft) buffer should yield prudent estimates. From these studies with further discussions between Hyde and Snook (2005), FS hydrologist related to the BEMERP project, I chose to model with a 328-ft (100m) (horizontal) buffer of the stream corridor (stream corridor assumed to be 5-m (16ft) buffer of the National Hydrologic Dataset (USGS, 2004)). This buffer I call the *riparian contribution zone* (RCZ). The referenced studies refer to slope distance for sediment transport, but I used horizontal as a simplifying assumption because WEPP requires horizontal input. The disparity is believed to be negligible and any effort to compensate would be disproportionate to the theoretical gain in accuracy. For modeling, most treatments are allowed in the RCZ. The RCZ is a modeling construct and should not be confused with Colorado's Best Management Practices (BMPs)—as they will apply to any treatment implementation (Figure 10).

Mechanics of WEPP

WEPP primarily uses the textural properties of soil for modeling. I received a spatial soil layer (SITESOILS) from Ken Kanaan, soil scientist for the PSI, to analyze the site, which produced a simple summary (Appendix H). Over 95% of the site was classified as "sandy loam" so for simplicity, I assumed the entire site should be considered "sandy loam." As a component of soil texture WEPP uses "rock fragment" as a percentage soil content to adjust infiltration, which as a result, affects runoff and erosion estimates. These data were available from the (SITESOILS) layer.

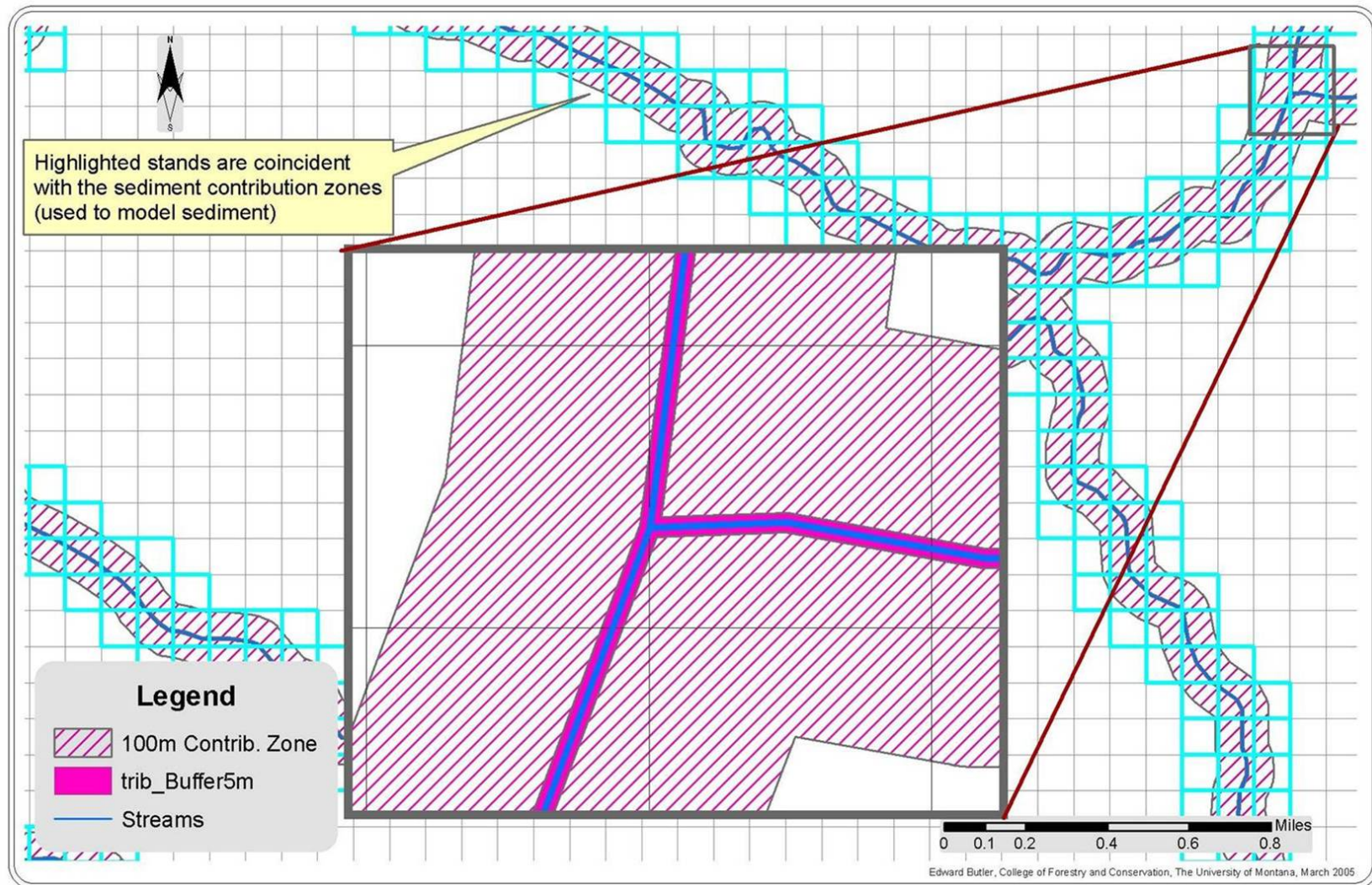


Figure 10. Map of zoomed area showing stands coincident with the riparian contribution zone (RCZ) for WEPP erosion modeling.

I already dismissed the value of modeling for average or "background" erosion for this study, so there is no modeling for average erosion (for simplification, background erosion assumed to be zero). The treatments (discussed in section on "Prescribed treatments") reduce density values 2-4 to 1 or 2. One would think there will be different levels of work intensity across the fuel treatments depending on the beginning state of the fuel loading, so a modeler might plan to model for different conditions in compaction and soil disturbance by density levels. Thinning with mastication will be the initial treatment for nearly all candidate stands (except standalone burning). Germaine to erosion modeling is the mastication's production of an irregular, but significant layer of chips (est.1-2" deep) that will cover the majority of the surface (Loeffler, 2005). This established PSI thinning process has been in use on similar projects and is discussed in a recent study on the effects of thinning and wildfire to the immediate south of the site. Libohova (2004), states clearly that thinning with mastication, did not change erosion rates (further study in Appendix K):

The amount of ground cover is important because this protects the soil from the kinetic energy of raindrops [Osborne, 1953] and provides resistance to surface runoff. Wright et al. [1982] found that 60% to 80% ground cover provided effective protection from surface erosion. In Arizona thinning did not cause a measurable increase in sediment yields despite the observed ground disturbance and compaction [Ffolliott, 1975]. The thinning in Trumbull is not expected to cause any erosion, as nearly 80% of the ground surface after thinning was covered with litter, chips, downed wood and live vegetation.

Each thinning is completed by an underburn designed to reduce fine fuels and therefore will reduce the chip load and other "dynamic" ground cover. Standalone burns may be used as initial treatments in some cases. I believe that erosion in the interval between the mastication and follow-up underburn will be negligible, but significant erosion could occur following burning, so erosion modeling proceeded on that thought. Rather than model the treated sites with heavy chip cover, I modeled the site with a single post-treatment state of "low severity burn." Elliot provided

soil and cover files to mimic the cover of this state, complete with manipulations reflective of mildly water repellent soil conditions across 25% of the surface.

Exposed rock (outcrop) affects erosion differently than "dynamic" surface cover. It does not contribute to sediment through detachment and it greatly inhibits infiltration, with the ability to affect runoff—therefore erosion. These are important variables affecting both surface cover and runoff. (SITESOILS) again provided data, which I employed as a WEPP input.

To build soil-variable attribution in the CV, I started by assigning each stand a soil type by Map Unit ID (MUID) a unique key, as provided by Kanaan's PSI soil layer. MUID was populated by using the data layer and ArcMap's "select by location feature". With the MUID in place as the key, I joined the soil attributes of: (1) rock content in soil by volume and (2) rock outcrop as area of the surface (both in percentage).

WEPP at its basic level, models hillslope profiles comprised of one or more slopes or *overland flow element(s)* (OFE)s and predicts erosion and deposition rates for horizontal increments across each OFE (in sequence of descent). Each OFE is assigned the critical variables and any erosion exceeding deposition, WEPP tabulates as sediment delivery to the stream. Elliot believed that two OFEs would suffice for our purposes with the upper acting as the disturbed site and the lower acting as a stream buffer, which I expected to be an area of deposition. I made the upper 100m (328-ft) buffer OFE1 and the lower 5-m (16-ft) OFE2. I assigned a single gradient to both from the portion of each stand coinciding with RCZ, which ranged from 0 to 96%, mean 29.0%, left-skewed. To select the contributing portions of the CV layer as the RCZ, I buffered the stream layer to a 5-m (16-ft) corridor (OFE2). I buffered OFE2 to 100-m (328-ft) to form OFE1. To a clip of this buffer, I assigned slope from the NED 30-m data via Spatial Analyst's slope feature.

To develop measurement of the area of the intersection of CV stands and the RCZ, I calculated the area of intersection and populated the attribute (SEDZN_PC) with it. SEDZN_PC provides a percentage of overall stand area that may contribute sediment output if treated.

Completing these steps, I ran Sullivan's MAGWEPP routine and populated the look-up table with the unique combinations of aspect, gradient, rock content and rock cover. To reduce the resultant matrix size, I condensed the data from integer format into classes:

- aspect — 8 cardinal points, 45, 90, 135, 180, 225, 270, 315, 360 degrees
- gradient — class intervals 10%, max of 100% (steepest RCZ grade was 96%)
- both rock content and rock cover — class intervals of 20%, max of 100%
- OFE1 — held constant as "low severity burn" as an input state
- OFE2 — held constant as healthy forest at 100% ground cover

The estimates from this modeling I used to populate WEPPSED, which is used with SEDZN_PC to calculate a total sediment contribution in pounds per RCZ-coincident-stand. This output is aggregated to 6th-code HUCs into output SEDWAT and representing the entire site as SEDTOT.

SIMPPLLE vegetation and disturbance modeling

As mentioned, SIMPPLLE's primary output used by MAGIS is a spatial risk index for each stand. I chose the incidents of "stand-replacing fire" (without the confounding fire suppression option) as the metric. The SIMPPLLE team produced 20 model runs for each decade based on the CV. I summed each stand for all runs and appended the index to the CV's stands.

Fire behavior outputs

Patten and Moore named crown fire activity (CFA) and rate of spread (ROS), both available from the fire behavior team, as their preferred fire behavior indices. They were also interested in

optimizing treatment configuration based on the fire behavior team's treatment optimization model (TOM). As previously mentioned TOM modeling is done iteratively with the treatment placement, configuration or size changing in each scenario until fire progression is diminished to an optimal level (within a given set of constraints, e.g. budget of acres to treat)(Stratton, 2005). Stratton reviewed wind patterns and fire history and then conferred with Moore about social concerns of the worst case scenario for extreme fire behavior. Based on this information Stratton produced outputs of CFA, ROS and TOM treatment configurations. Due to the extensive iterative processing required to build gridded winds for TOM modeling, Stratton decided to limit TOM treatment sites to the heavily populated South Platte corridor. A sustained prevailing wind of 270 degrees at 30 mph (20-ft above average crown) was used with a DEM to provide a gridded wind pattern; fuel moistures were set for the 97th percentile. All outputs were provided to me in 30-m map units. TOM treatments pixels are binary values of presence or absence (Stratton, 2005).

FlamMap provided ROS in feet (travel) per minute (fpm); range for the site 0 to 299 fpm. The disparity of the MMU of the CV (5-ac) with the fire behavior team's outputs (30-m) made summarization by the Zonal Statistics function necessary when populating the CV data. Stands of grass, forbs and shrubs can have very high rates of spread as can some non-candidate tree stands; these could confound modeling thus, making it important to remove non-candidate stands from ROS and also CFA valuation. I populated the CV attribute CANDATE to represent target stands, based only on the parameters of DOM_SP, SZ_CLASS, and DENSITY. I then removed ROS and CFA from further consideration in non-candidate stands. By this definition 6,748 of 18,406 stands were not candidates for treatment. The modeled candidate stands had a mean ROS of 41.9 fpm with the distribution skewed towards the slower values. I populated "CFA" in the same manner as ROS. CFA is valued with a range of 0-3: 0 = fire is not expected to carry; 1 =

surface fire only; 2 = passive crown fire (torching); 3 = active crown fire (crowning) expected. These terms are subjective, but CFA at a value of 2 or greater indicates that fire is predicted to spread rapidly with some, if not many, of the trees burning (Stratton, 2005). Based on this discussion with Stratton, conversion of this metric from integer classes to a summarized mean should not diminish its accuracy as a reporting value. Mean CFA in modeled candidate stands was 1.270, standard deviation 0.288.

2.6 Building the model specification framework

The "building blocks" of the model framework e.g., activities, management regimes, state groups, zones, etc. were developed in the manner described in the section on MAGIS anatomy and functions (Figure 2). For brevity, the section to follow on prescribed treatments sums up the working relationships of activities, lacking only discussion on continued stand maintenance. Due to the state of the site, few stands are eligible for burning as the initial treatment, though the model is set to consider that choice. All management regimes have activity "underburning" set to repeat in alternating decades following all instances of initial stand treatment e.g. the treatment "ThinHvBurn" is preformed in the second decade to stand 1726 and has activity "underburn" scheduled for the third and fifth periods following implementation (decades four and presumably decade six [if the regime were to continue beyond the 5 decades of this project]). Kaufmann and Patten, both expressed that once a stand was reduced density class 2, underburning every other period would be sufficient to keep the conditions maintained. Because of the structure of the management regimes borne from that logic, MAGIS uses a simple formula for post-treatment risk. A beginning stand with associated risk value is treated, therefore risk of stand replacing fire goes to zero and is kept at zero by repetitive maintenance.

Producing a practical treatment unit coverage

At the scale of this study, fuel treatments implemented in plots of individual stands of 5-acres would be ineffective in slowing fire growth and spread (Finney, 2001, 2002a, b). MAGIS with so many pertinent variables requires that variables and functions be tracked to the stand level, but MAGIS modelers often aggregate stands with shared critical characteristics to reduce the complexities for the client. I reduced the 18,406 stands to 8,027 treatment units with a resultant mean size of 11.5-ac, standard deviation of 26.9-ac—outliers ranging to 985-acres (Appendix I).

Candidate prescribed treatments

In the early stage of this study I had discussions with the PSI District Silviculturalist with responsibility over the study site. The silviculturalist shortly thereafter, transferred to a new district, leaving no replacement. I developed treatment logic based on Kaufmann's landscape vision tempered with hands-on understanding of fire and fuels management from Moore, Patten and Dennis (the fuel managers). Without a silviculturalist to interpret the fuel managers' desires and then provide a sanctioned set of prescriptions, I acted as compiler and editor for the ideas of the parties.

Creating random openings by thinning to density 1 across 25 to 35% of the treated landscape treatment (ThinDens1) was a condition Kaufmann and the fuel managers stated was necessary. Currently less than 2% of the area is in density class 1 (Table 1) (Kaufmann, 2005c). I developed the logic for this selection process after the WEPP erosion modeling and noted that, this aggressive treatment could cause notable error in the outputs. To avoid this concern and to avoid possible sedimentation of streams, I chose model for these treatments in candidate stands not intersecting the RCZ. The RCZ is ~10% of the site, so by using the random number generator to select 1 of every 3 stands to receive "ThinDens1" treatment (outside of the RCZ) the total area of

the population of candidate stands will still be within the target range of 25 to 35%. Scattering treatments in a random-like fashion, I used a random-number generator to select 33% of the eligible stands to receive this "ThnDens1" treatment. Kaufmann and the fuel mangers wished to mimic the natural distribution of opening sizes, which they stated was ~2 to ~40-ac, skewed with an average of size of ~5-ac. A histogram of the treatment assignment showed that the frequency of treatment sizes (by random junction) were heavily skewed towards the 5-ac minimum size; notable in the 10-ac class, but negligible in the larger classes. Selection of these stands is triggered by MAGIS' choice of either of the mechanical thinning treatments (discussed in the following section). This link insures that these random-like treatments will always be a subset of the treatment units rather than independent, thus augmenting fire-break effect. Estimates of timber, chips, biomass, costs and revenues were adjusted to include this "ThinDens1" treatment, but are combined with the overall estimates and tabulated by treatment unit acreage.

Eligible Prescriptions Summary — unabridged version in Appendix J

Prescriptions apply only to treatment units dominated by ponderosa pine and Douglas-fir or mixes of both. The primary objective of all treatments is to remove ladder fuels and attain a density class of 2 or less. Stands with a dominant multi-story crown structure, usually indicative of "ladder fuels" are identified in SIMPPLLE's density classes as (multi-story) of each diameter class. For an overview of the specifics of vegetation density classes as they relate to crown closure see "CFR legals" (Appendix G). IDZ valuation can be found in Table 5 and Figure 9.

Eligible management regime–ThinHvBn: (combined activity treatment)

Available for assignment to stands qualified as:

- intersecting a 2500-ft buffer of mapped roads
- size classes – seedling-sapling (SS), medium (M), medium multi-story (MMU), large (L), large multi-story (LMU) and very large multi-story (VLMU)
- vegetation density classes 3 or 4

- gradient classes $\leq 50\%$
- any IDZ value
- not classified as Wilderness

This is a heavy equipment density reduction to class 2, with no addition of permanent roads; therefore this treatment is limited to stands intersecting a 2500-ft buffer of an existing road. This treatment uses understory thinning to reduce ladder fuels, combined with overstory thinning to reduce canopy closure to density class 2 (Kaufmann, 2005b). Costs and volumes tabulated from all activities with revenue tabulated from boles harvested ≥ 9 " DBH; trees thinned other than saw-logs contribute to tabulated mastication or biomass costs. Mechanical thinning activities are followed by an in-period underburn—costs tabulated. Old growth trees are to be excluded from harvest (Kaufmann, 2005b) and are not accounted for in the model (expected to be an insignificant to the estimates) .

Sequence of activities:

1. Thin understory targeting ladder fuels (< 9 "DBH) with mastication by Hydro-axe or equivalent heavy equipment—scatter chips if not marketable.
2. Thin overstory with opportunistic harvest of boles ≥ 9 "DBH; skid to landing via whole-tree yarding with limbs and tops to be piled or chipped at landing.
3. Perform in-period underburn with pile burning (where necessary) to control surface and understory fine fuels and kill regenerating vegetation ~ 3 -8 years following thinning. Latitude in timing for manager's discretion regarding fuel conditions and regeneration.

Eligible management regime—ThinBn (combined activity treatment)

Available for modeling to stands:

- beyond a 2500-ft buffer of mapped roads
- size classes — SS, M, MMU, L, LMU and VLMU
- vegetation density classes 3 or 4
- gradient classes $\leq 50\%$
- any IDZ value
- not classified as Wilderness

This is done same as ThinHvBn, but no harvest of thinned material due to the hazards and difficulties posed by the remote stands. Trees are masticated up through 14" DBH. (Patten, 2005).

Eligible management regime–Underburn (single activity treatment)

Available for modeling to stands:

- without road consideration
- size classes — SS, M, L, VL (single story only)
- vegetation density classes ≤ 2
- gradient classes $\leq 100\%$ (no practical limitation on this site.)
- IDZ values ≤ 2
- not classified as Wilderness

Single activity – underburn to control surface / understory fine fuels

Eligible management regime–RxBurn (broadcast burn) (single activity treatment)

Treatment applied to same conditions as Underburn, but only valid in the Wilderness. Increased attention to detail by manger is required; mixed severity post-treatment conditions expected.

Auxillary treatment–ThinDens1a and ThinDens1b (combined activity treatment)

Previously mentioned in this section, this treatment is the same as ThinHvBn except the goal is density class 1: (1a) applied to stands intersecting the 2500-ft road buffer; (1b) beyond.

3 RESULTS

Building a large MAGIS model such as this one creates innumerable relationships among variables and allowable actions; the modeler must keep these in mind when performing scenario runs. A point that is can be explained, but has been enigmatic to non-modelers is that MAGIS, an inanimate entity, is incapable of "driving" itself, i.e. selecting an objective with constraints to get

a desired outcome. I also use the term "driver" to describe the choice of modeler's objective function and/or constraints. The CFR model built within MAGIS is an organizational tool of grand scale. MAGIS provides the platform for model assembly, while the model itself becomes the structure and protocol for scenario development. Within these plans, a single objective function is chosen, e.g. minimize cost; minimize one of the fire indices or maximize acres treated in a particular IDZ; typically, constraints are necessary to get an acceptable answer, since real-world forest planning is bound by constraints. The human modeler is the driving force behind results from scenario runs—the model just defines the maximum "decision space." Optimization at the root-level of planning can affect placement, timing or method of actions and is the alternative choice to direct control by the modeler. Control of scenario outcomes is performed via numeric operators ($=$, $<$, $>$, or R [limiting range]) and can be very direct, such as: forcing treatment to all stands in a given watershed; or treating 40,000-acres of the stands least expensive to treat (before considering others). Direct control of the results can obviate some of the value of optimization function, making the absolute minimal level of control favorable. When outputs must be controlled, for social acceptability (as an example), the modeler may still derive great value from the other aspects of optimization. In periods of the scenarios presented in the following section, quantity of acres treated is limited, but treatment placement is left for optimization. By directly controlling treatment in select periods the modeler may force MAGIS to optimize acres treated in the unconstrained periods via a differential effect.

The fuel mangers, Kaufmann and others all provided necessary direction for this study. The stated objectives and more subtle desires of the client I use to guide the results of this thesis in the demonstrations to follow. This demonstration I hope will serve as an example for feedback, adapted runs and as an impetus for end-user modeling by the client.

The site contains 55,190-acres (60% of the site) in treatable stands and there is no overlap in treatment options for a given stand (this was unplanned) (Table 8).

Table 8. Acreage of candidate stand by IDZ value assigned

		Candidate Acreage
Management regime	ThinHvBn	30,810
Management regime	ThinBn	10,115
(above) combined mechanized thinning	<i>Combined</i>	40,925
Management regime Thin	Underburn	14,265
Total		55,190

Concerns guiding these scenarios, in order of importance are:

1. rapid reduction of risk indices (indirect relation to acres treated)
2. the priority placed on named values at risk
3. providing a balanced plan (I elaborate further)
4. providing general efficiency within the above parameters

All fire indices were considered in initial model runs. TOM modeling produces no fire index and is not considered as a driver for scenario runs; further, the TOM output provided by the fire behavior team is unusable for two reasons. It was produced for a minority portion of the study site. For this issue alone I would not have eschewed TOM outputs for demonstration, this did however, make site-wide prioritization wide impossible with TOM. Unlike previous TOM outputs seen by this RMRS Economics Unit, the areas selected for treatment were very disaggregated and irregular, numerous treatment units being less than 60-meters². The message from Finney's ongoing study of spatial patterns as fire breaks has been that breaks must be aggregated and sufficiently large (in relation to fire size) to diminish fire spread (Finney, 2001, 2002a, b). Stratton of the fire behavior team supplied the dataset with commentary that he believed the "pixilated" nature of the TOM output was due to the very high resolution of the

AVIRIS CV data and that apparently TOM had difficulty working with it. Of the fire behavior indices proper, crown fire activity is selected for demonstration here. Rate of spread was examined, but is dismissed since it does not represent stand replacing fire—ROS values represent only spread rate of all fire types.

Prior to productive runs, initial scenarios are created to identify the model's parameters e.g. upper and lower bounds for totaled fire index values, expenditures and area calculations. Management regime RxBurn is not included; there are currently no stands eligible on-site. For simplicity, the initial runs examined here are for treatments in the first period only. Monetary calculations are in current dollars for single periods and discounted dollars for aggregated periods. The upper bound for net cost is \$18.6 million for period 1, obtained from a scenario that applies treatment to all candidate area with no regard for cost or revenue efficiency. The market for timber and biomass is negligible for the site and plans for the forest to sell timber ≥ 9 " DBH will reduce the net cost by ~10%. I do, however, minimize net cost to drive these scenarios, because I will produce subsequent runs based on speculative (higher) market values for comparison.

The client throughout this study expressed the desire to prioritize treatments in areas of higher housing density, so I provide simple IDZ weighting (recall section on Intermix Defense Zones), derived from trial and error, to the various indices used. I multiplied each stand's fire index values by the following factors for weighting: IDZ 1, factor of 1.2; IDZ 2, factor of 1.4; IDZ 3, factor of 1.6; IDZ 4, factor of 1.8 respectively. Lower factors had little effect in adding prioritization because treatment is notably more expensive in the denser IDZ's, due primarily to the liability posed by underburning. These factors slightly exceed the threshold posed by the higher costs, thus giving balance between the higher costs in the dense IDZ's and high index values outside of the developed areas. I summarize the incidence of candidate stands in each

zone in Figure 11 to frame the issue. This scheme is an example of subtle control through the common practice of subjective data weighting, but does not preclude MAGIS optimization

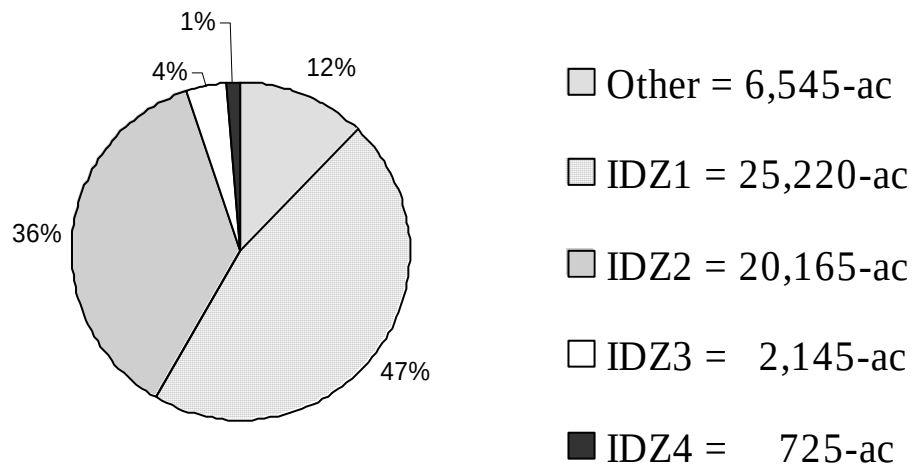


Figure 11. Proportion of total candidate treatment area placing in each Intermix Defense Zone.

I determined the costs involved with no action and also, full treatment of the site—this is all costs less revenues for period 1. I normalized each fire index against its own possible range of values (by no action / full treatment) and recorded respective net costs at fixed points along the range. This response curve (Figure 12) indicates there is minor difference in effectiveness among indices and that return on net cost diminishes noticeably above 90% effectiveness. However, from the same scenarios, Figure 13 indicates that there is some spatial variance in treatment placement—Figure 11 provides a reference of proportion of candidate area on-site.

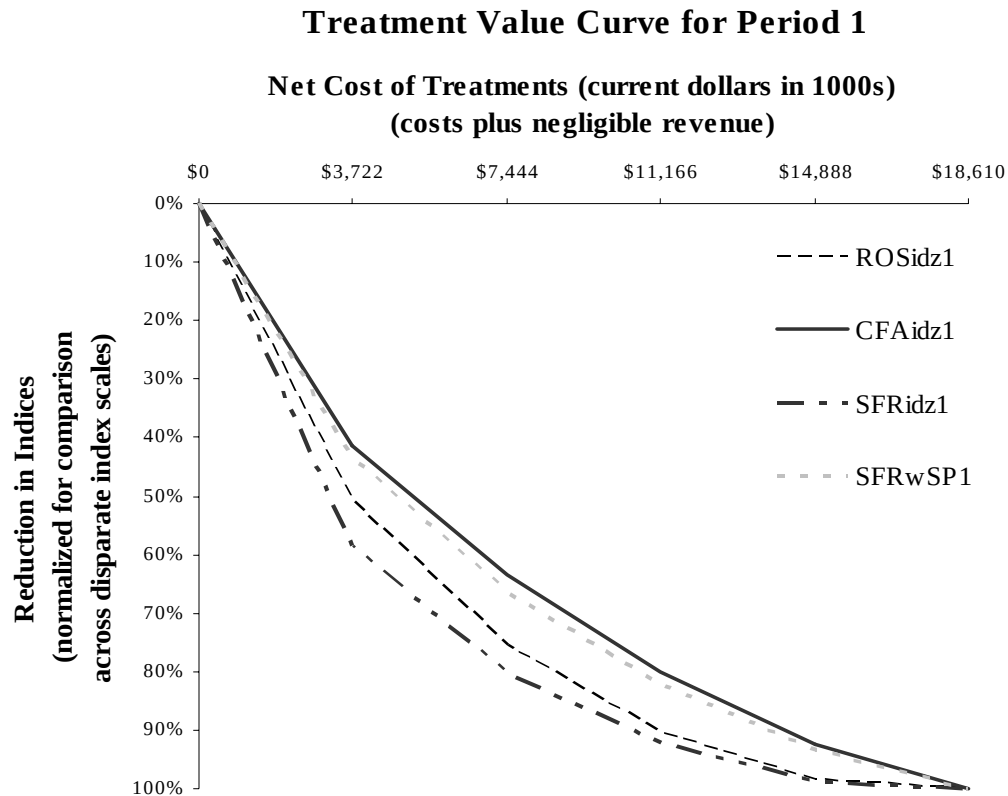


Figure 12. Response curve of net cost to reduction of indices, runs based on fire index values weighted (as indicated) by either IDZ or the PSI's "SP" scheme

A debate over the preferred index value is reserved for the client, but I note that the index value "SFRwSP1", (the blend of SIMPPLLE fire risk with the PSI's adapted value weighting system, (see section *Prioritizing per PSI's fuel treatment study [in-house study]*), generally schedules more total area of treatment than the other indices for a given net cost. (Figure 14).

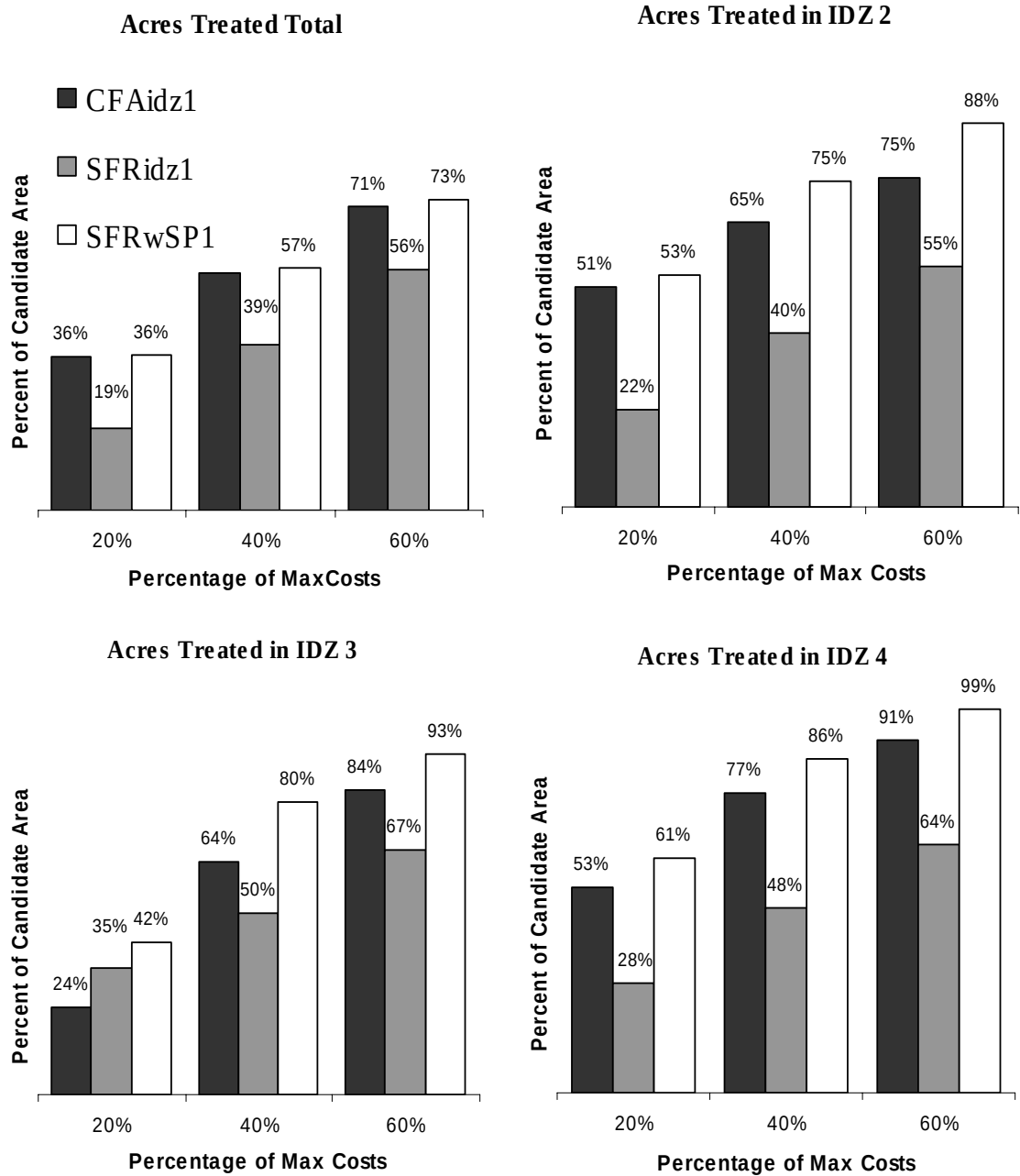


Figure 13. Initial test scenarios, run to examine distribution and type treatments scheduled by each index: run A constrained to 20% of normalized net cost, run B—40%, and run C—60%.

Investigation showed that this is the result of the PSI's weighting scheme favoring sites hospitable to "Underburn" as an initial treatment (Figure 14), and underburning is much less expensive than

mechanical thinning. I use this index as an option to my simple IDZ weighting scheme and as previously discussed, propose that having a subjective weighting scheme from the client is favorable to anything I can contrive. The PSI's weighting scheme could easily be applied to the other fire indices if desired by the client, I suspect with similar results; since the critical variable seems to be the weighting scheme and not the fire indices themselves (note the differences between SFRidz1 and SFRwSP1) (Figure 14).

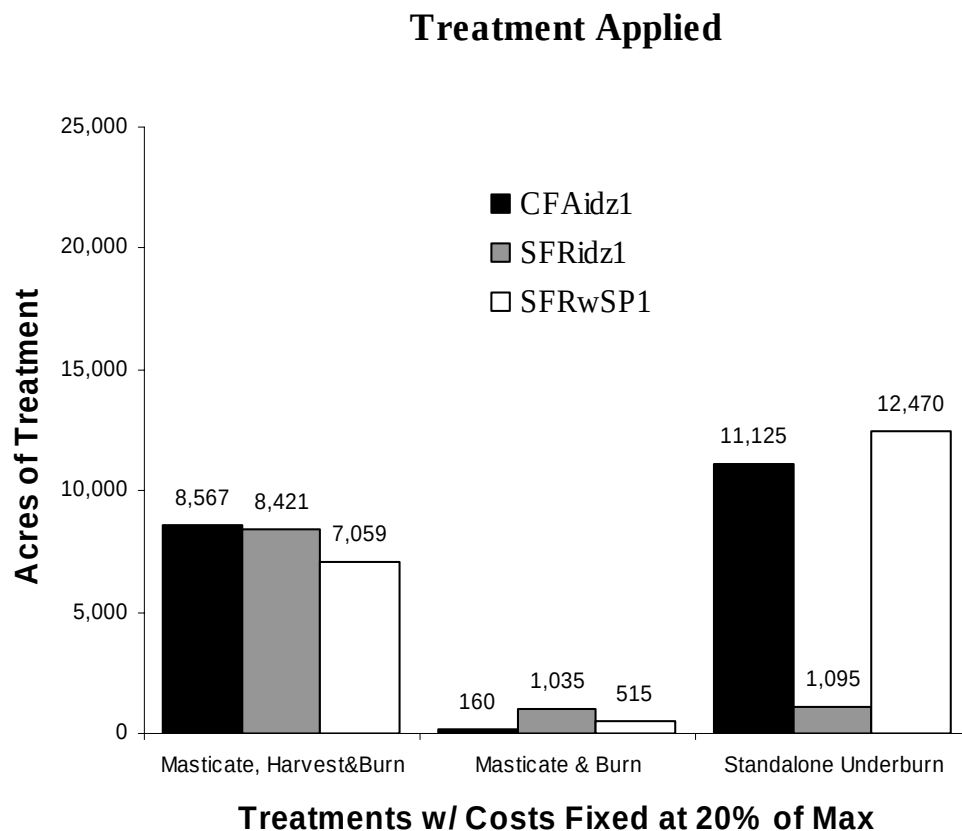


Figure 14. SFRwSP1 selected more stands (area) suitable for standalone underburn treatment in all three initial scenarios—20% of maximum net costs scenario summarized here.

To balance a scenario, the modeler must put the optimization function in-check with some well chosen constraints; otherwise by optimization, the run may schedule all the treatment into the first or last period depending on the objective function (for example). For the CFR study attempting to deliver the desired conditions in one decade is likely infeasible due to budget constraints,

manpower, and social and environmental concerns. Further, since little market exists for the forest products, a plan with treatment over several decades could potentially be used to offset costs by stimulating long-term demand, employment and local commerce. There is also a long-term concern about smoke production and limitations on burning-days. The management regimes of this model are reliant on maintenance burning in alternate periods to keep the treated stands in "mitigated" status. If an inordinate proportion of the site was treated in a single period, the result would be alternating periods of intense activity (and smoke) followed by inactivity—therefore with lessons from the initial runs, I expand the scenarios to plan for all five decades, while giving very strong emphasis to the mitigation efforts in the first three periods.

Culmination of Thesis Goal: Scenario: nSFRwSP4b

The (optimized) objective function is "maximize *present net value* (PNV)" i.e., sum of all costs, plus all revenues, in discounted dollars. Constraints found from trial and error are:

- limit activity acres of ThinHvBn to <7,000 for period 1
- limit activity acres of ThinHvBn to = 13,000 for period 2
- limit activity acres of maintenance Underburn to < 25,000 for any period
- limit outputs of total sediment to < 3,000-lbs for any period
- reduce SFRwSP index value to < 12,000,000 for period 1 (43% reduction)*
- reduce SFRwSP index value to < 9,000,000 for period 2 (82% reduction)*
- reduce SFRwSP index value to < 8,000,000 for period 3 (95% reduction)*

* Having no control over non-candidate stands, I reference the reduction against the range of possible values for the aggregate of candidate stands.

Recall that treatment ThinHvBn harvests accessible timber and note the limitation on "activity acres" above. Combined, these constraints ramp-up production of timber and bio-mass to allow development of markets, before the heavy harvest (13,000-ac) of the second decade arrives.

Another 7000-ac are treated by ThinHvBn in the third decade, which by this plan, allows periods 1 and 3 to sum roughly to the area treated in period two, i.e. balance. With this design rely on treatments ThinBn and Underburn, which produce no marketable goods, to provide a major

portion of index reduction in period 1. The value I use to constrain Underburn, derived by trial and error acts as a "check" against a "boom-and-bust" cycle of treatment application. What appears to be a ridiculously low constraint of 3,000-lbs (total site contribution per decade) I use only for demonstration. For reasons already discussed in the section on WEPP sediment modeling, the proposed fuel treatments deliver negligible estimates of sediment to streams (total sediment estimated for treatment to all candidate acres is 8,622lbs.) Finally, from trial and error, the index values set are known to be roughly attainable and the objective function driving the solution assures general economic efficiency, optimized within the parameters. These scenarios do not begin to infringe on the benchmark of \$10 million per decade (Patten, 2005) (given for current market values) and are therefore aggressive, but constrained (both drive up costs).

The possible range for index value **SFRwSP** (across all periods) is 15.3 million to 7.5 million. The constraint "reduction to 12 million" is a 43% decrease in relation to the "risk" index's possible range. I refer to index values when I use the term "risk" unless otherwise mentioned. Periods two and three drop an additional 39% and 13% respectively (94.7% all total)—same metric. Totaled for all periods, 89% of the candidate stands receive treatment, with 31% in the first decade to start. Further break-down shows reductions of 49% of IDZ2, 48% of IDZ3 and 77% of IDZ4 (of possible range). Stands with high IDZ values continue to be treated in remaining decades as well. PNV of proposed treatment is a net loss of \$10.4 million (discounted, five decades) and a net loss of \$4.2 million (current) for the first period.

As mentioned in the Introduction, efficiency for optimization modeling is relative to constraints. The expanse of the "decision space" is governed by the degree of constraint on a scenario. To frame the problem I ran scenarios at points across the range of PNV and I used an objective function minimizing and then maximizing the index over all periods (Figure 15). The idea of

modeling to examine trade-offs suggests an enormous range of "efficiency;" further, defining what type of efficiency (by the variables and their function) to scrutinize elucidates even more dimensions to the question, i.e. (costs x sediment), (treatment acres x index values). Efficiency in these scenarios is "economic efficiency" and is important, but subordinate to other constraints for this demonstration. The "decision space" for a scenario rapidly decreases with each additional constraint. The scenario **nSFRwSP4b** has a "decision space" that is a small fraction of the area of the unconstrained parameters (Figure 16) and the point created by **nSFRwSP4b** is notably skewed towards the maximum value; I argue that intersection for **nSFRwSP4b** would be further left (higher value) were it not for the constraints used, which come at a cost.

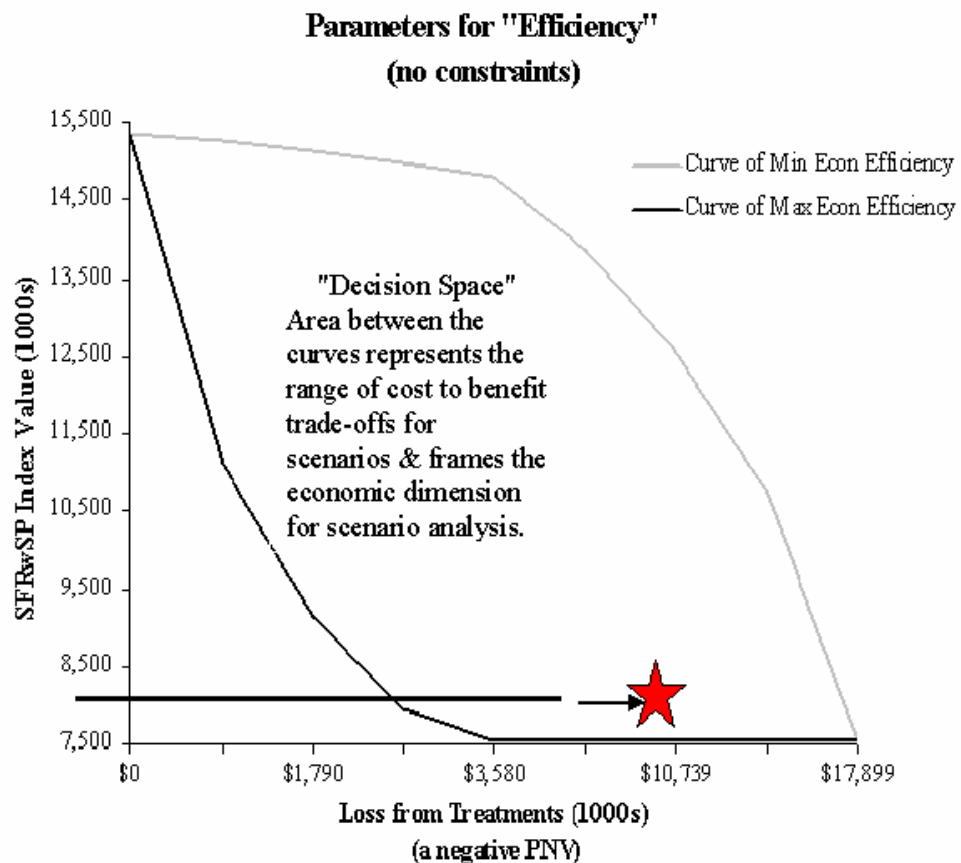


Figure 15. Curves derived by running scenarios minimizing and maximizing SFRwSP index at points within the possible PNV range. The star is the point for scenario **nSFRwSP4b**.

Having framed economic "efficiency" and having intimate familiarity with the model, there is no point in attempting to define efficiency further for the scenario (more in Discussion section). This scenario presents a 95% reduction of the specified risk in the first three decades. With fewer constraints the objective function of the runs tends to delay treatments to the later periods to reduce the repetitive burning costs (the optimizer attempts to maximize PNV). I and the client argue that postponement of treatment (by decades) for economic savings would be a poor solution. To illuminate the difficult task for forest planners, consider that if MAGIS has selected 89% of the candidate stands to reach 95% of maximum index reduction, imagine how poor of a return (for the investment) the remaining stands must provide. Manual treatment scheduling with just a small portion of these stands could have a dramatic effect on PNV.

The 15,048 computer generated iterations producing this optimal scenario were supported by a matrix with 283 million cells—each a unique variable combination. The scenario run with tabular output took less than a minute; GIS imagery was provided in five additional minutes (via Pentium IV, 2.4Ghz, .5Gb RAM).

Scenario nSFRwSP4c (increased market value scenario)

Kaufmann requested that I use higher market values for timber and biomass to see what effects it would have on total treatment costs and site selection. Silverstein and Loeffler also of the Economics unit, suggested new market prices of \$50 to replace the \$8.44 per CCF for timber and \$26 bone-dry ton for biomass where the previous price had been zero. There was no change to harvest bole minimum DBH. I re-ran the previous scenario on the new values.

This scenario produced no revelations, but did show that the change would increase the PNV from an average of <\$212> per acre to <\$109> per acre for a total investment of \$5.7 million,

indicating that if the forest were to shift the mastication / harvest threshold of the ThinHvBN treatment down through the medium size class, this treatment may pay for itself. Treatment placement was little changed, likely due to the large proportion of eligible stands treated in both scenarios.

As mentioned, an important part of the combined COPPER project is the ability to re-run a vegetation coverage that has been revised by the modeled treatments. MAGIS supplied the new states reflective of the post-treatment modeled landscape. The manual treatment ThinDens1 was applied to every third eligible stand and those states manually adjusted as discussed in section on prescribed treatments. This dataset was run in SIMPPLLE in the same manner as the initial simulations (also without fire suppression) and the cumulative change in fire behavior analyzed. Comparing the untreated landscape to the treated version subtly reveals the change from a spatial perspective (Figure 16 and 17), but comparison of mean probability of stand replacing fire summarizes the change. Recall the metric—simple occurrence or absence, aggregated for all candidate stands, by five decades (20 simulations were run for a significant sample for “no action” and then post-treatment **nSFRwSP4b**).

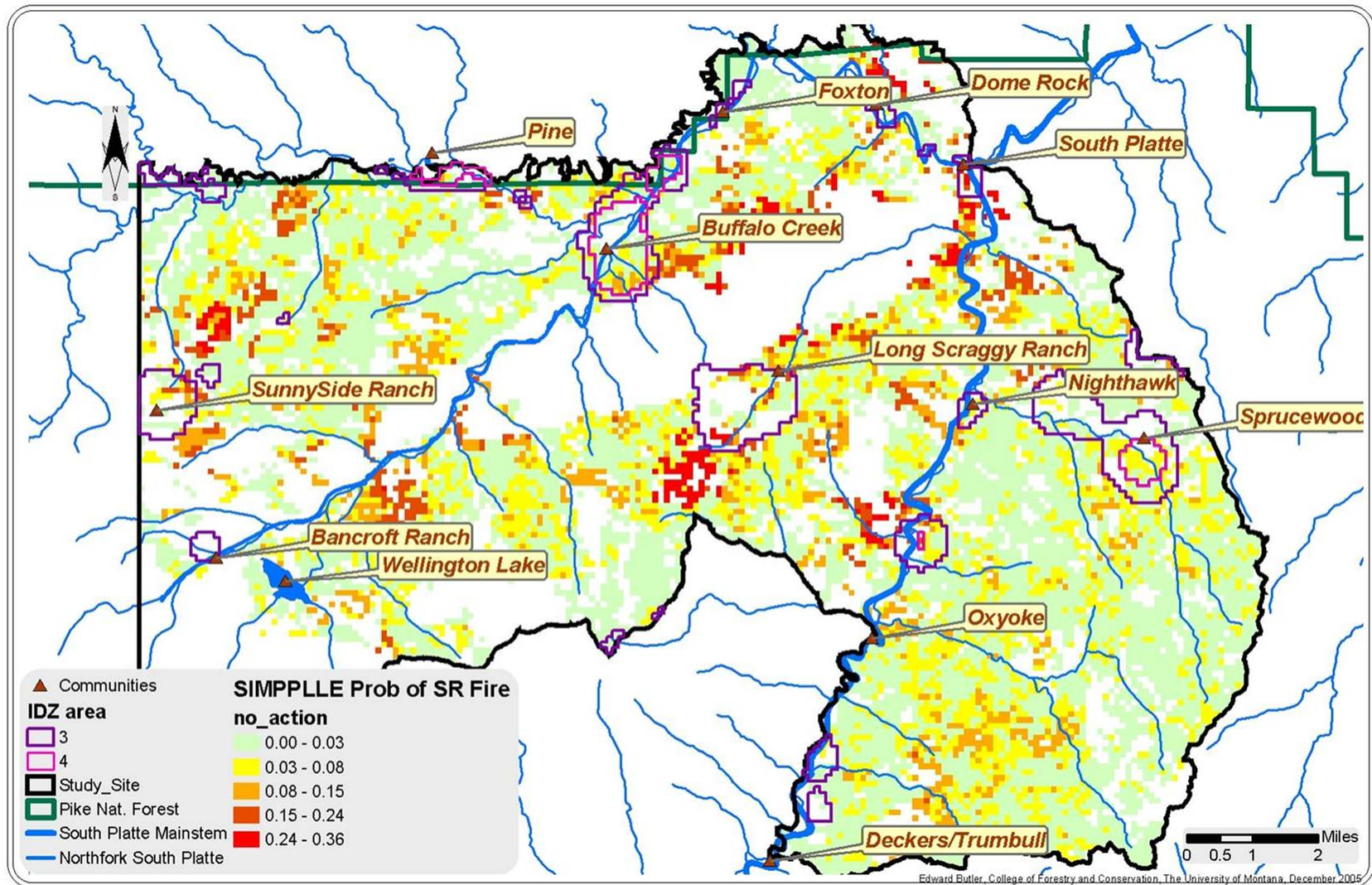


Figure 16. Map of SIMPPLLE's index of stand replacing fire expressed as a mean probability for all five decades (with no action).

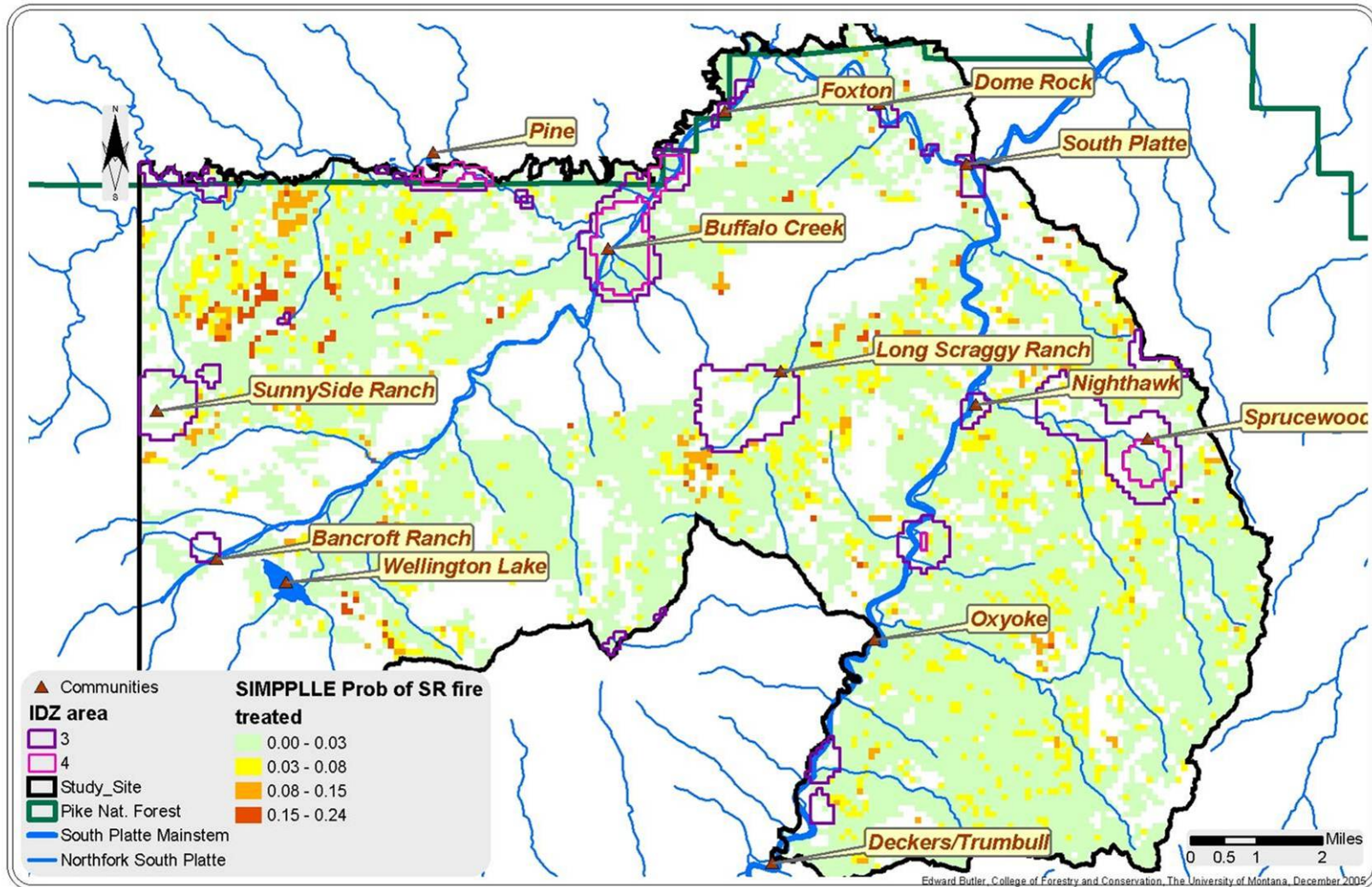


Figure 17. Map of SIMPPLLE's index of stand replacing fire, as a mean probability for all five decades, post **nSFRwSP4b** treatment.

4 DISCUSSION

This thesis changed my thought about fire ecology metrics and raises interesting questions for future study. Though not incorporated into this MAGIS model, I believe it is important to show, not just the reduction of stand replacing fire, but the change the proposed scenario will have on the site's overall mix of fire (Figure 18). Scenario nSFRwSP4b could make a major change in fire mix and an overall increase in fire favored by the goal this study.

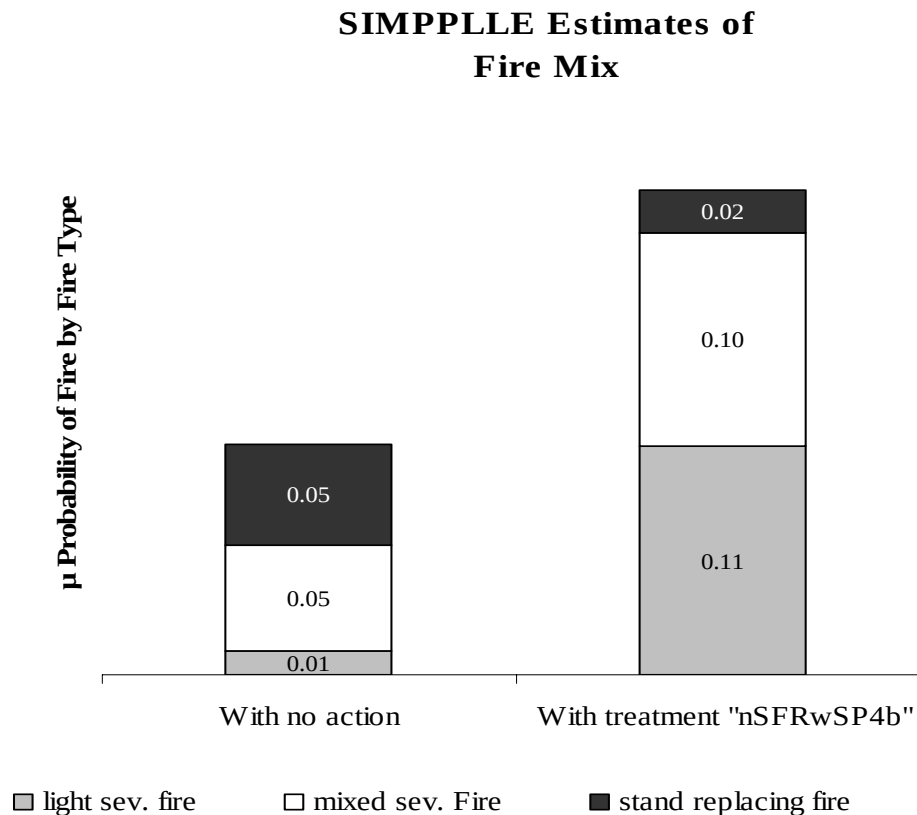


Figure 18. SIMPPLLE fire projections (all fire types) for the untreated landscape (no action) and the landscape post-treatment by scenario "nSFRwSP4b."

I have no feedback from the SIMPPLLE team on this comparison, so I present the analysis on face value—for future study. As presented, I have some thoughts. Figure 18 does not account for perpetual maintenance of the site by controlled burning; I propose that SIMPPLLE's estimates of

low and mixed severity fire will be greatly supplanted by controlled burning as long as the client extends the repetitive burning schedules set forth. Human development in and around the site has greatly altered the natural fire processes that have kept the ponderosa pine / Douglas-fir forest in balance. If the client successfully returns the site to the desired conditions, but continues with fire suppression to protect the development, aggressive maintenance burning will be a necessary component of continued wildfire hazard mitigation. The burning cost for this site (per decade) is estimated to be slightly more than \$2 million (current) and must be budgeted with necessary increases for inflation—the alternative would be to move the values at risk from harms way. From the outset of a plan such as this, all parties must be aware that success can be achieved long-term, but that long-term success involves perpetual burning, either by man or nature. "No action" does not mean inaction, since natural fire process will eventually restore the balance, likely with undesirable results to the public.

Numerous simplifications, abstractions or "modeling assumptions" are inherent in this and all models. This study could not have been accomplished with current resources without simplifications and many would argue that it is quite complex as is, but so is the site and the client's concerns. Major assumptions are that individual stands can be modeled in aggregate to landscape scale or that stands can be dynamically modeled by a pathway approach with statistics of natural processes correctly estimated; I am told that validations with the SIMPPLLE model were made with burns in the site vicinity (Schreiner, 2005). Studies (Libohova, 2004, Brown and MacDonald, 2005) indicate that due to chip cover, negligible erosion will occur after mechanical thinning, but what will the results be from follow-up underburning of the chips layer and other fine fuels? Via WEPP I estimate that even with underburning, sediment delivery to a stream will be negligible, due in-part to the low precipitation levels and very porous soils of the site—Brown and MacDonald (2005) support that my modeling may be accurate (appendix K). This study did

not model mortality incidental to the treatment process itself. No road traffic or road erosion was modeled, but this inclusion in the modeling process would be greatly beneficial, if this plan were taken beyond the demonstration stage. Background fire is not modeled in this exercise due to a number of constraints, but I argue that this study and fuel treatment projects in general, give an incomplete perspective by not making the comparison. Furthermore, since this study assumes background fire to be zero, i.e. there is no attempt to compare the modeled landscape with the probability or intensity of fire (possibly extreme), that doing so could only strengthen the argument for this type of study and fuel treatments in general.

For this study I decided to analyze and report only on the candidate stands and this gives something less than a full view of the issues. There were limitations that forced this decision. SIMPPLLE models stand-replacing fire for stands of trees, as well as, stands of shrubs and grass/forbs. With the majority of non-candidate stands given a nominal "dominant species" category of shrubs, grass/forbs, water or barren, I saw little point in attempting to model and report on all stands since it would have confounded the results for the target stands with little benefit to the overall study.

In this study the site is modeled without regard to jurisdiction other than tabulating effects by ownership class, leaving the difficulties of implementation across jurisdictions to the client. It should comfort the client that minor inconsistencies between the scenario and plan implementation are unlikely to have notable effect on landscape scale vegetation and fire dynamics, especially for the long-term.

This is a resource modeling project and data must exhibit landscape scale, "resource-grade" accuracy. Forest planners and those implementing the fuel treatments are expected to evaluate

the vegetation patterns within their site before beginning any treatments and must adapt to minor inconsistencies of spatial accuracy as the fuel treatments progress. GIS, resource mapping and modeling is not designed for survey grade accuracy. Should this study go beyond the demonstration stage, I expect comments, manual manipulation of treatment unit boundaries and notable conflicts with private landowners to drive modeling revisions.

The major modeling parameters, as well as the current vegetation layer (and other data) were provided by the client or the PSI NF (a party of the "client")." In this study it is assumed that the client is satisfied with the quality and accuracy of the data provided and will suffer or benefit from their own data quality control.

Modeling assumptions are necessary to facilitate the abstraction of natural dynamics. All assumptions made were based on the best knowledge and science available at the time and I can defend the choices without trepidation.

It is hoped that not only will the client use and comment from the given scenario, but run the model themselves. The iterative running of scenarios is a valuable learning experience for the modeler, giving great insight into the complexity of forest planning. Forest managers should not miss the epiphany that may come from running the model themselves, for doing so will illuminate how the model—and the forest—is a dynamic "tapestry," often producing unexpected results from seemingly inconsequential actions.

Even though this study uses sediment estimates from WEPP on a relative basis, plan development can greatly benefit from understanding the sediment potential for a given stand or stream reach as presented. Incorporation of WEPP modeling has greatly enhanced MAGIS' utility. There was a

surprise however. The riparian zone had been expected to act as an area of sediment deposition, but instead WEPP modeled erosion at rates similar to that of OFE1. Well after the conclusion of WEPP modeling, Elliot commented that he suspected I had used an OFE2 (the riparian buffer) that was below a width threshold; therefore I had compromised OFE2's expected filtration effect. This failure of my theory in no way degrades the relative accuracy among treatment sites.

Over the span of this study I have noticed a great interest in research that seeks to inventory hazardous forest fuels and predict extreme fire behavior. This is encouraging, but my concern is that forest managers can seize this data without considering the necessary related issues. The Forest Service is mandated to manage fuel treatment projects with broad concern for ecosystem health and all the social implications of "multiple use" (NFMA and NEPA). This concept of holistic planning is not addressed by the simplistic process of targeting problem areas and simply treating them. Proper project planning is a large and complex undertaking that I believe fills forest planners with angst to the point where important issues are often not fully explored in the name of expediency. MAGIS can organize the confusion and provide optimal options for natural resource planners.

Further study with this model is planned. The RMRS Economics Unit will conduct a biomass utilization study—the format is unknown. Also I suggest an examination of mature fuel treatment implementation projects (that were manually scheduled) to derive a comparison metric for use against the optimization modeling of this study. This metric (or metrics) would provide a basis for an efficiency study or cost justification for planning with MAGIS. Estimating sediment production from roads is a logical extension of MAGIS that is yet to be explored with MAGWEPP. The Economics Unit desires to follow through with a study, but has not chosen a particular MAGIS (site) model to apply the MAGWEPP functionality.

5 SUMMARY

Over the course of this study a great many interactions of forest variables were organized and examined. Through the COPPER paradigm, companion models provided expertise via datasets for prioritizing fuel treatments and SIMPPLLE provided runs on the post-treatment landscape for a second perspective of effectiveness. The demonstration scenario schedules fuel treatments with relative efficiency, while restoring the landscape to conditions representative of a mixed-severity fire regime. The demonstration scenario models the effective wildfire risk mitigation to housing density, water quality (erosion) and species of concern. The chosen scenario was produced by 15,048 (automated) iterations and considered 283 million unique combinations of variables influencing the decision process in some way. This level of complexity would be difficult—likely impossible—for managers to consider effectively and efficiently without the aid of optimization modeling provided by an SDSS such as MAGIS. Further, anyone criticizing the assumptions inherent in this study may wish to contemplate the simplifications used to manually scheduled fuel treatments. To make the complexities considered in this thesis workable for conventional planning methods, simplifications would be bold and extensive or the extent of the study would have to be greatly condensed.

If one agrees that the constraints for rapid risk reduction should not be sacrificed in the name of economy and from Figure 15, that the area to the left of the point **nSFRwSP4b** represents the costs of those constraints, then less than optimal fuel treatment choices would result in cost/index intersect points placing to the right of point **nSFRwSP4b**. As shown in figure 15, scenarios delivering similar results could have a maximum discounted (net) cost of \$17.9 million and at this extreme **nSFRwSP4b** would provide savings of \$7.5 million; offered only for anecdotal comparison, the costs of this study—in its entirety—is less than 4% of that savings calculation.

Further investigation is underway to provide a comparison metric for a future cost justification study.

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APPENDICES

A. Ancillary figures

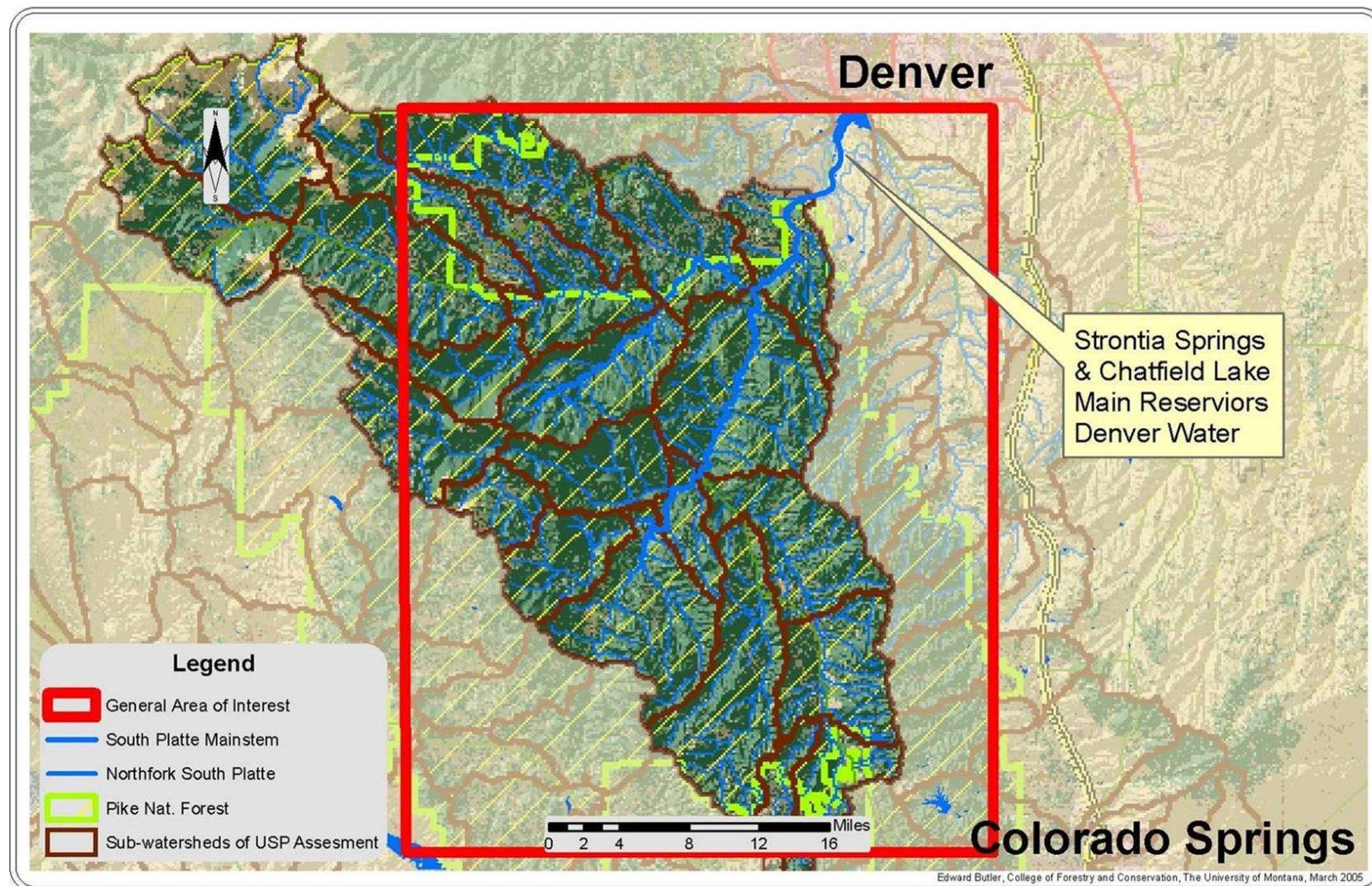


Figure a. Topographic map of extent of the Foster-Wheeler landscape assessment and headwaters of the South Platte River

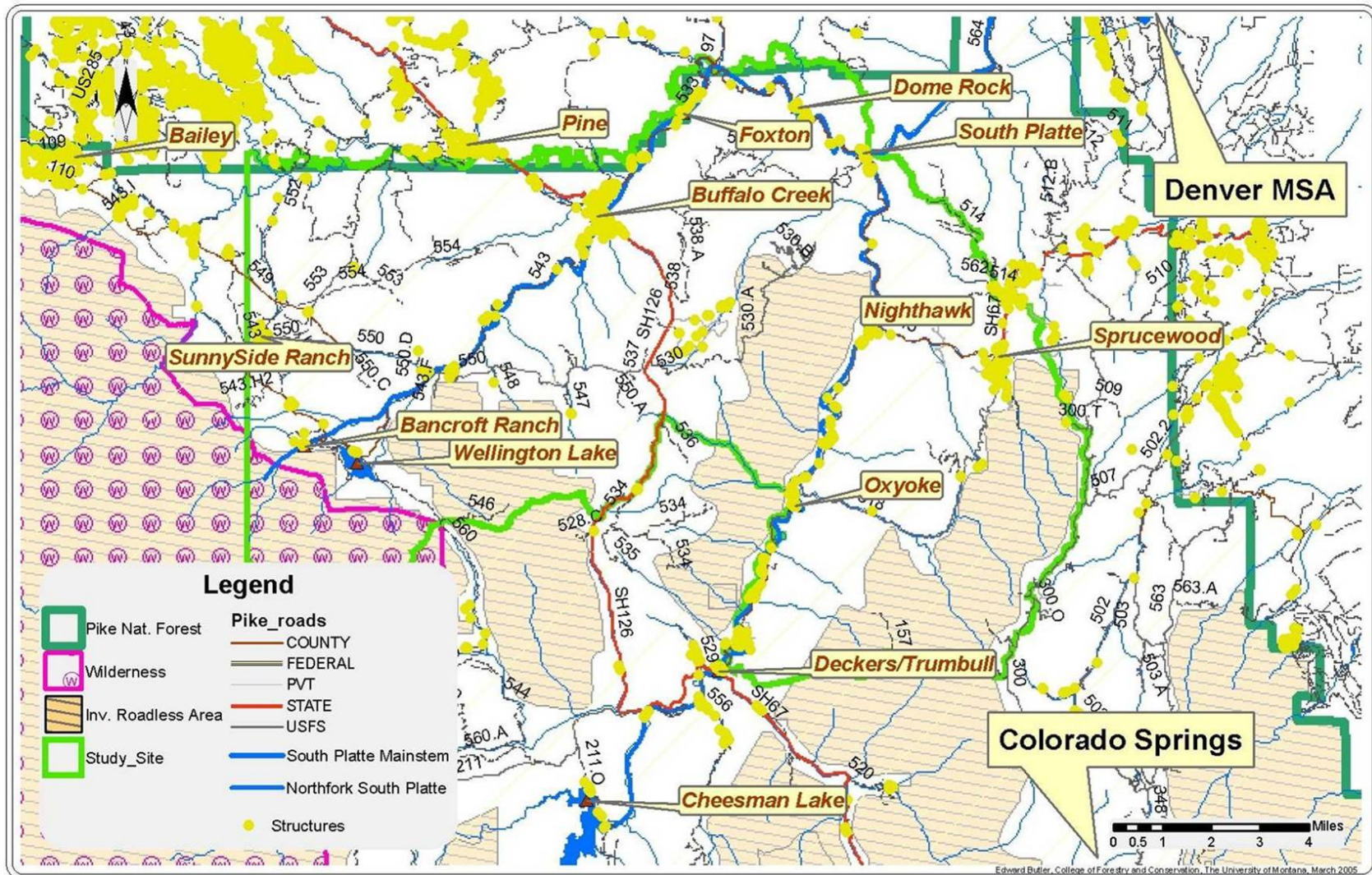


Figure b. Map of special areas and road network in the vicinity of the study site

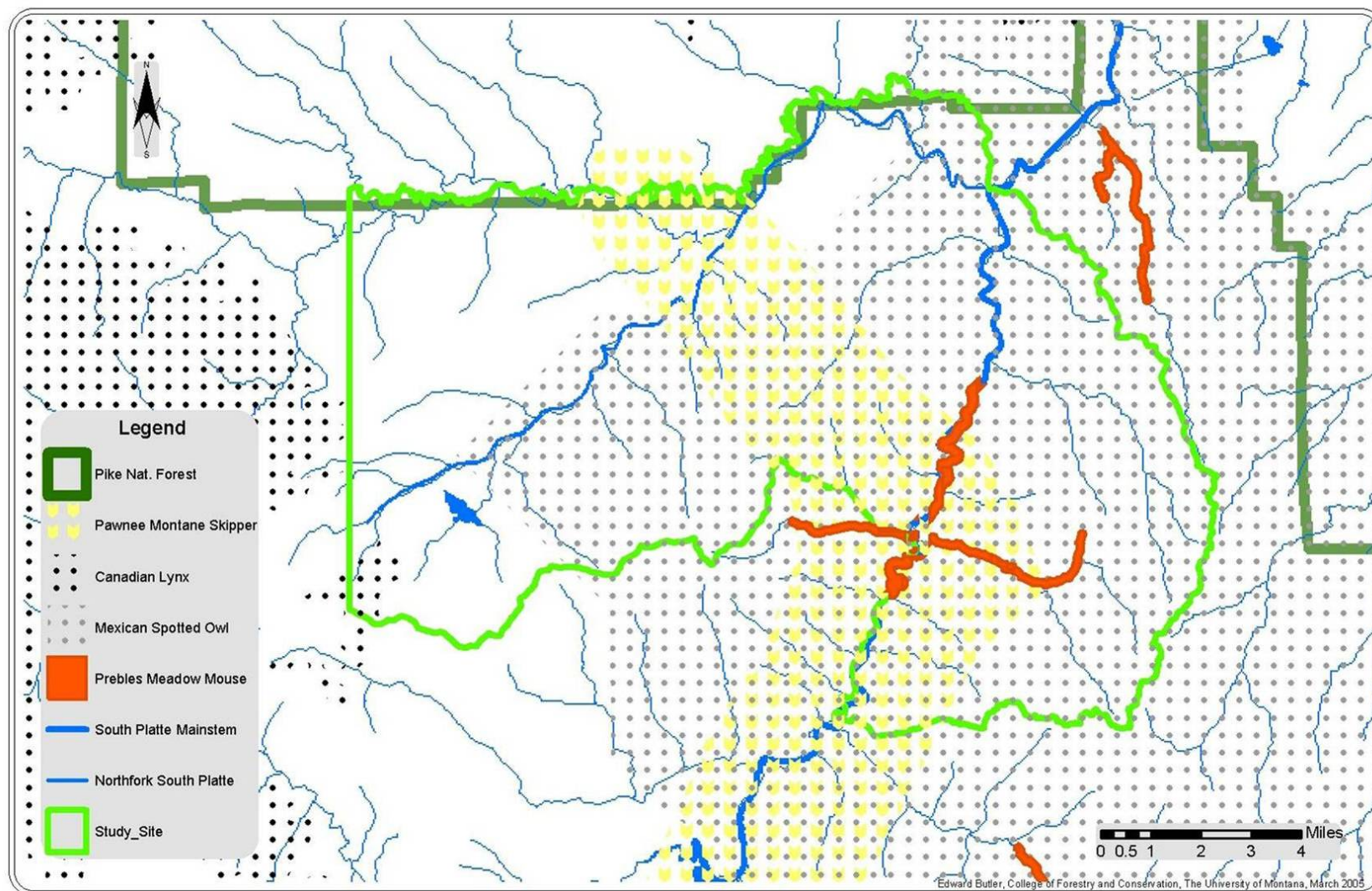


Figure c: Map of habitat zones delineated for four species of concern (fauna).

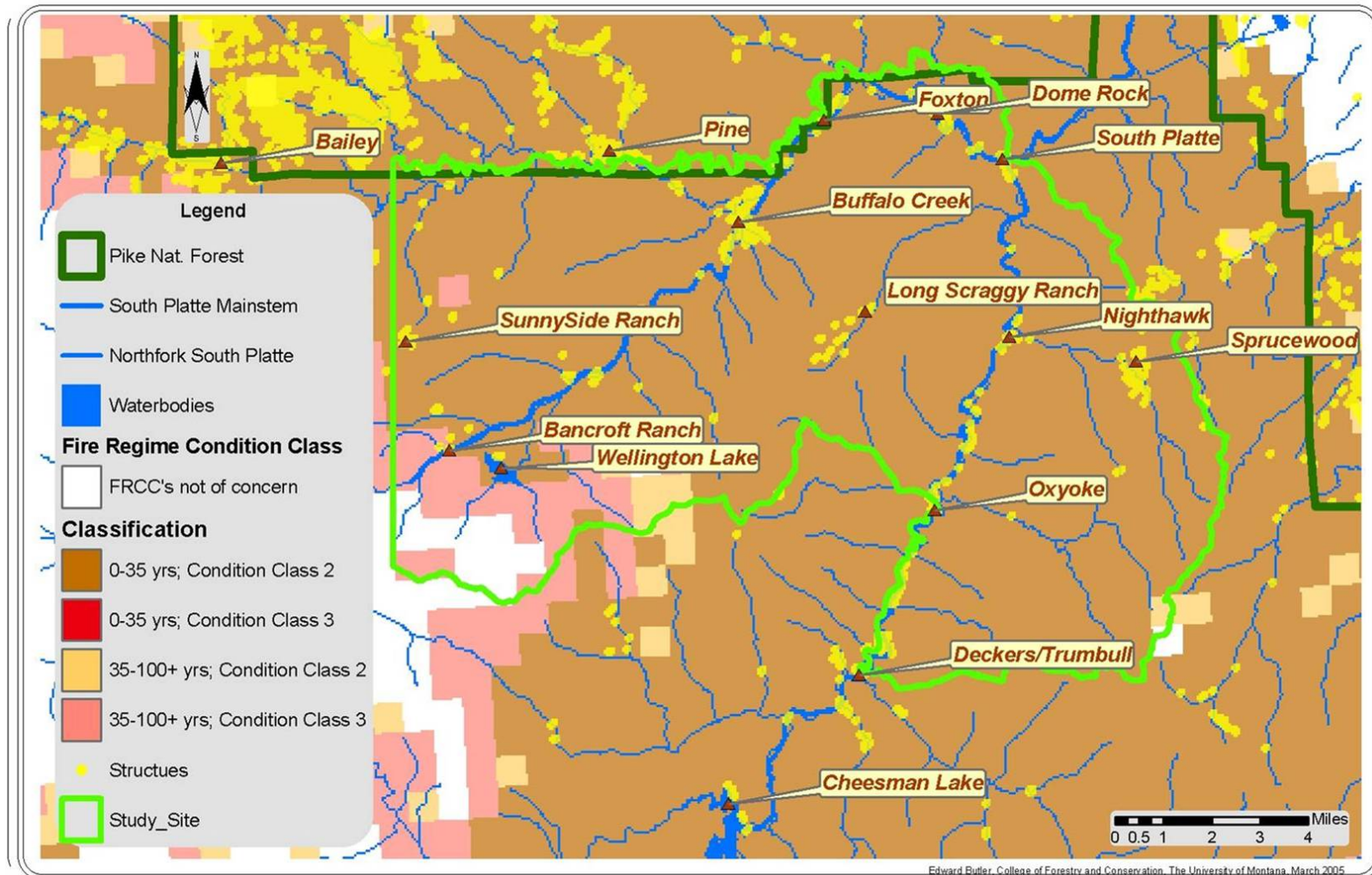


Figure d. Map of spatial distribution of Fire Regime Current Condition (FRCC) classes and structures in the study area.

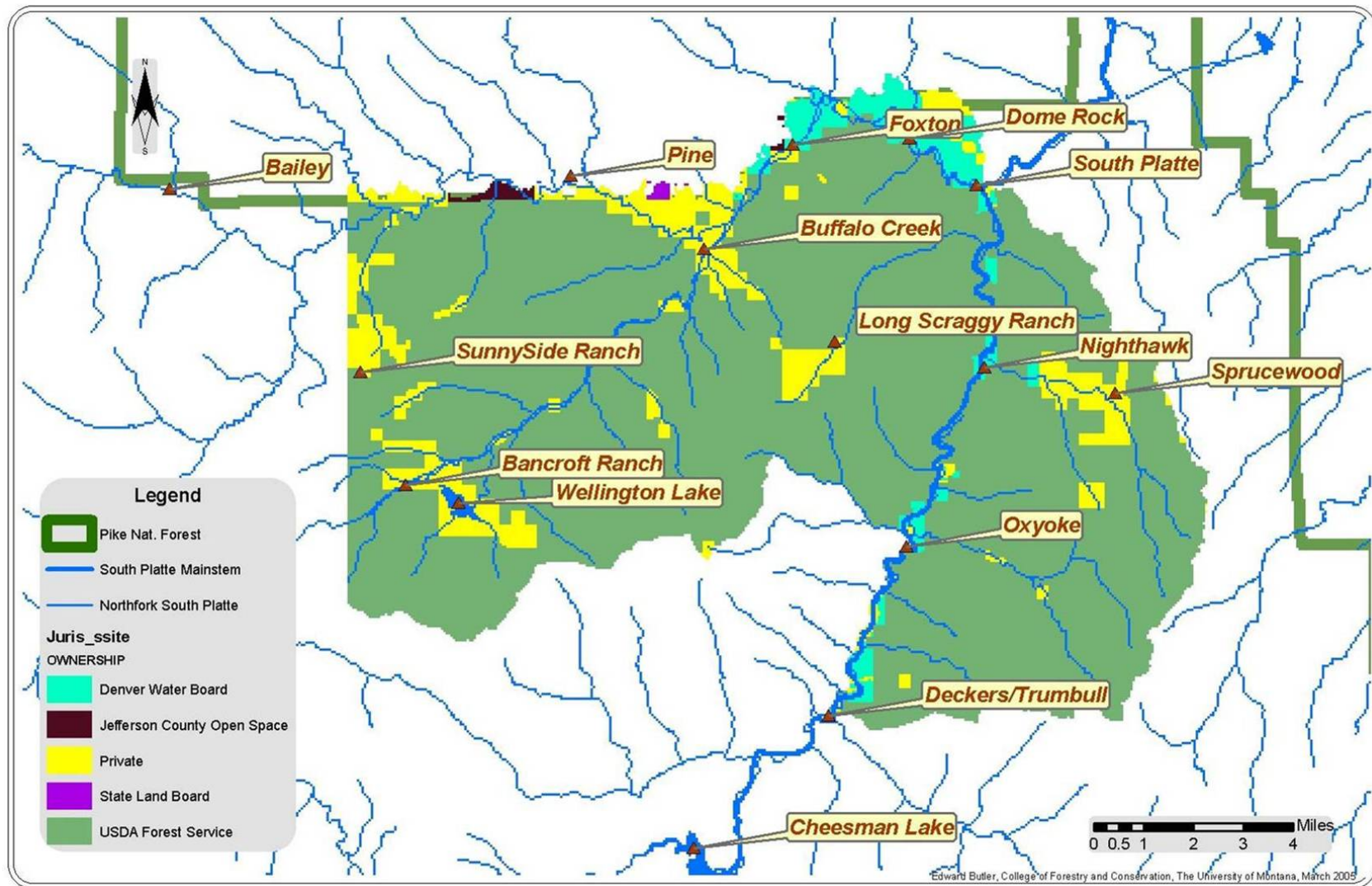


Figure e. Map of land ownership in study site

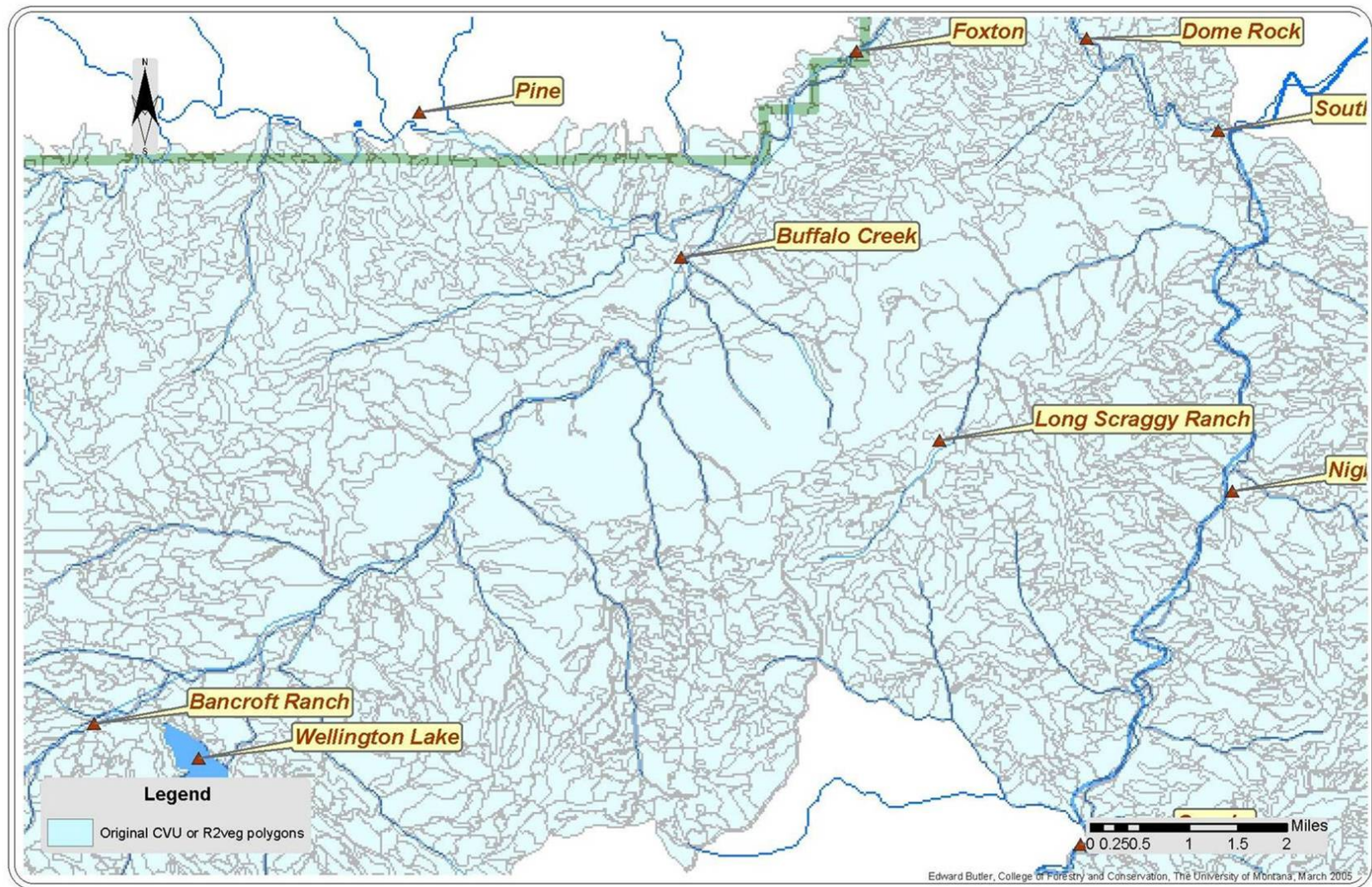


Figure f. Map of unaltered current vegetation CVU "R2" (timber stand polygons) coverage.

B. Summary CVU protocol and user's guide

Purpose and summary, CVU:

To provide guidelines, hierarchy, and structure for mapping all existing vegetation and ground cover.

Existing vegetation and other ground cover is described on the landscape, through a consistent protocol (Integrated Resource Inventory IRI, specifically Common Vegetation Unit CVU).

Basic information on existing vegetation is provided in a common format using standard terms, definitions, and measurements. The vegetation unit layer is consistent throughout the Rocky Mountain Region and is compatible with Forest Service National systems.

Delineates existing vegetation as it actually occurs on the landscape irrespective of non-vegetative boundaries such as ownership or administrative boundaries.

Contains polygons that accurately describe the existing vegetation resource and other ground cover current as of the date of survey.

(Green et al., unpub)

My interpretation of the "irrespective of ... ownership or administrative boundaries" is that stands must be delineated without regard to jurisdictional bounds; the data is not intended to extend more than an incidental distance from the Forest bounds. The extent of the R2 dataset supports this idea since it exceeds the PSI boundary by only a nominal margin.

Details of Delineation:

Vegetation polygons are delineated based on identifiable changes in vegetation characteristics as seen on project imagery, generally 1:24,000 scale natural color aerial photos. Aerial photos are interpreted using tonal contrasts or colors, texture, and patterns. Polygon boundaries are drawn around homogenous vegetation conditions and obvious changes in the delineation criteria. Delineation criteria can be subtle, but most often are readily seen on a stereo view of the photo. The vegetation characteristics used for delineation criteria are lifeform, species, percent crown cover, size, vertical structure and crown condition.

(Green et al., unpub)

Because vegetative timber stands are represented by common map units some summarization of components is inherent. Cover percent by area and corresponding statistics are calculated for

cover types of tree, shrub, grass/forb, barren/water. All stand boundaries are shared or coincident. If the cover percentage for tree meets a (SAF) minimum of 25% or if the trees appear to occupy a plurality of the stand, then the major lifeform is assigned as "tree."

Table a. Summarized excerpt of CVU terminology (Green et al., unpub)

Attribute	Codes	Description
LF_GSC (Lifeform/Ground, Surface Characteristic)	T,S,G,F,B,W	Tree, Shrub, Grass, Forb, Barren, Water
SPECIES_MIX	NRCS coding	PIEN:ABLA:POTR ranked, up to 3 species from dominant lifeform (MAGIS uses max. of 2 for this study)
COVER_PCT	<= 100%	Of lifeform
COVER_TYPE	SAF / SRM	National Cover Types
LAYERING	S or M	Single or Multiple
SIZE_CLASS	E,S,M,L,V by DBH	If Tree Lifeform (for the polygon)
HAB_STRUCT_STAGE	1M, 1T, 2S, 2T, 3A, 3B, 3C, 4A,4B,4C	As defined in <i>Managing Forested Lands for Wildlife</i>
COVER_PCT	(For each Lifeform) <= 100 (If crown%)	For each lifeform

The CVU attribution begins with delineation of stands by LF_GSC. Photos are interpreted per cover type, i.e. interpreters see ponderosa pine (PIPO)–Douglas-fir (PSME) mix (cover type), not PIPO and PSME by stem. To fit cover types into the NRCS class, a system of composites is used. The interpreter sees a cover type, but codes the appropriate species for that type based on ancillary data and field validation. If field verification is available, species coding is more reliable. Flora are delineated uniformly by group, e.g. an area with a mixture of tree and shrub would typically be delineated into separate polygons (assuming each group meets the minimum polygon size criteria). Areas not covered by vegetation are classed as either water or barren. From photo interpretation, supporting data and field visits, attributes of layering, size class and

major life form cover percent are derived. The general minimum polygon size is 5-acres (minimum of 160-ft wide), but 2-acres (minimum of 80-ft wide) for riparian stands.

Quality Control Protocol for the construction of CVU data

Photo interpreters are expected to be adequately trained, experienced with photos and photo interpretation procedures, and knowledgeable of the vegetation in the area that will be delineated.

Field calibration is mandatory and the amount needed depends on the interpreter's familiarity with the area, vegetation photo characteristics and the need based on the review of the interpreter's work. An initial field overview is generally done as each interpreter encounters new vegetation characteristics or areas. Interpreters visit the area to visually recognize delineation criteria as it appears on the photo. Field calibration includes taking tree and shrub size measurements and notes on vegetation characteristics in representative reference areas or areas of concern (e.g. understory species and density). Calibration notes on photo overlays should be maintained with the photo set and used by the interpreters as field reference data (ancillary data) to make interpretations. Photo interpreters work closely together and review each others work (including polygon delineations and interpretations) to calibrate to each other. Interpretation rules and assumptions are developed and shared among the interpreters. As new situations are encountered, the rules are updated. Prior to completion of each quad map, delineations and interpretations are reviewed by the Vegetation Unit Leader or interpretation leader. Areas where interpreters disagree are reinterpreted or settled by consensus.

(Green et al., unpub)

C. Summary of species of concern

The decline of the Mexican spotted owl, listed as a threatened species in 1993, occurred primarily because of the alteration of its habitat due to historical timber management practices, specifically the proliferation of even-aged silviculture and the effects of catastrophic wildfire on this altered landscape. The owls prefer more mature, mixed species stands of Douglas-fir and suffer from large scale, intense wildfire. For this reason, their core habitat should be managed for conditions indicative of a mixed severity fire with retention of trees greater than 9-inches DBH.

The Pawnee montane skipper was listed as federally threatened in 1987. This species is of special concern to this study because its total known habitat is 37.9-square-miles (est.) and is largely coincident with the site. PMSB inhabit dry, open Ponderosa pine woodlands with sparse understory between 6,000 to 7,500-feet with moderately steep slopes. Blue grama grass (*Bouteloua gracilis*), the larval food plant and prairie gayfeather (*Liatris punctata*), the primary nectar plant, constitute two necessary components of the ground cover. The most recent population estimation (1987) totaled 116,000 individuals. Fire suppression activities have lead to conifer encroachment of grasslands and reduction of *Liatris*, reducing habitat, leading to the listing of the Pawnee montane skipper (Silverstein, 2005 unpub.). The Schoonover and Hayman fire of 2002 consumed 40% of the PSMB's entire range; following these fires populations dipped to ~5% of their known historical average (Colorado Forestry Advisory Board, 2005).

The Preble's meadow jumping mouse is threatened by extensive human development throughout their limited range. A rapid population decline resulted in the species being listed by the U.S. Fish and Wildlife Service as threatened (1998) under the Endangered Species Act (ESA). Catastrophic fire is a major threat to the Preble's jumping mouse.

The Canadian lynx is a specialist depending on snowshoe hare as prey. The suitable habitat delineated for lynx showed negligible overlap with the site, but is was considered due to the proximity. Federal guidelines suggest conducting fire use activities to restore ecological processes and improve lynx habitat. Canadian lynx were listed as a federally threatened species in 2000.

The MSO (critical habitat) is an adaptation, by Silverstein, of a USDI, Fish and Wildlife Service (FWS), GIS layer (2003). Due to lack of data, Silverstein created a coverage for the PMSB

butterfly based on his study of a USDI, FWS, Recovery Plan (1998). The PMJM GIS layer is a USDI, FWS layer of critical habitat (2004), plus a 100m (328-ft) buffer of streams; Silverstein added the buffer because of the extremely narrow, riparian, critical habitat zone. The lynx zone was developed as potential habitat—lynx introductions have been made near the western edge of the study site, but with scant evidence found on the site proper (Colorado Division of Wildlife, 2004). There was no occurrence of Greenback trout in the site (Silverstein, 2005).

This information was provided in its entirety by the RMRS, Economics Unit's Biologist Robin Silverstein.

D. Fire Regime Current Conditions Reference

Table b: Guide to fire regime current conditions (FRCC) classification (Schmidt et al., 2002, Hann and Strohm, 2003)

Fire regime class	Frequency (mean fire return interval)	Severity	Modeling assumptions
I	0 – 35+ years, Frequent	Surface and mixed	Open forest, woodland, and savannah structures maintained by frequent fire; also includes frequent mixed severity fires that create a mosaic of different age post-fire open forest, woodland, shrub, or herb patches that make a mosaic of structural stages. Mean fire interval can be greater than 35 in systems with high temporal variation.
II	0 – 35+ years, Frequent	Replacement	Shrub or grasslands maintained or cycled by frequent fire; fires kill non-sprouting shrubs which typically regenerate and become dominant within 10-15 years; fires remove tops of sprouting shrubs which typically resprout and dominate within 5 years; fires typically remove most tree regeneration.
III	35 – 100+ years, Infrequent	Mixed and surface	Mosaic of different age post-fire open forest, early to mid-seral forest structural stages, and shrub or herb dominated patches generally <40 hectares, maintained or cycled by infrequent fire. Interval can range up to 200 years.
IV	35 – 100+ years, Infrequent	Replacement	Large patches generally >40 hectares, of similar age post-fire shrub or herb dominated structures, or early to mid-seral forest cycled by infrequent fire. Interval can range up to 200 years.
V	200+ years	Replacement, mixed, and surface	Variable size patches of shrub or herb dominated structures, or early to mid to late seral forest depending on the type of biophysical environment. Cycled by rare fire or other disturbance events. Often have complex structures influenced by small gap disturbances and understory regeneration.

Class	NRV or HRV departure	Description
Condition class 1	Low	Vegetation composition, structure, and fuels are similar to those of the natural regime and do not predispose the system to risk of loss of key ecosystem components. Wildland fires are characteristic of the natural fire regime behavior, severity, and patterns. Disturbance agents, native species habitats, and hydrologic functions are <u>within the natural range of variability</u> .
Condition class 2	Moderate	Vegetation composition, structure, and fuels have moderate departure from the natural regime and predispose the system to risk of loss of key ecosystem components. Wildland fires are moderately uncharacteristic compared to the natural fire regime behaviors, severity, and patterns. Disturbance agents, native species habitats, and hydrologic functions are outside the natural range of variability.
Condition class 3	High	Vegetation composition, structure, and fuels have high departure from the natural regime and predispose the system to high risk of loss of key ecosystem components. Wildland fires are highly uncharacteristic compared to the natural fire regime behaviors, severity, and patterns. Disturbance agents, native species habitats, and hydrologic functions are <u>substantially outside the natural range of variability</u> .

E. Trade-off between data formats

Resolution of a grid is determined by size of the map unit. The trade-off to increased resolution is larger storage size of the coverage. The pseudo-grid CV at 18,406 units, pushes the limits of the MAGIS teams' processing speed in some instances (Pentium IV, 1.8Ghz, 0.5G RAM), thus suggesting a practical size limit with factors of modelers patience, project schedule and the inevitable increase in human errors due to increased size of the job. Faster computers of the Economics Unit (Pentium IV 3.4Ghz, 2G RAM), however processed the same tasks in a fraction of the time.

Table c. Summary dataset statistics from ESRI ArcMAP, NHD and NED 30-m

Study Site Dataset	Polygon total count	Polygon mean size (ac)	Stand. dev.
OriginalR2 data	3,555	25.8	49.0
Modified R2	6,708	13.7	9.8
5ac Pseudo-grid	18,406	5.0	0.0

By watershed	Total Acres	Mean Gradient	Std Dev
Modified R2			
Pine-Rowland	11,768	25.7%	17.3%
Lowest N.Fork	7,392	34.6%	16.7%
Buffalo Cr.	27,752	25.6%	15.8%
Waterton/Deckers	44,819	26.7%	15.0%
Incidental inclusion	163		
All combined	91,894	27.0%	16.0%
Pseudo-grid			
Pine-Rowland	11,430	25.3%	14.9%
Lowest N.Fork	7,080	34.9%	13.3%
Buffalo Cr.	28,020	25.5%	14.0%
Waterton/Deckers	45,395	26.7%	12.7%
Incidental inclusion	105		
All combined	92,030	26.9%	13.7%

F. Detail of burned and treatment area updates

Table d. Revised vegetation states for stands treated by PSI NF

Original CV Species (in treatments)	Adjusted Post- treatment Species	States present in treatments
PG_FORBS	PG_FORBS	103
QUGA	PG_FORBS	1
PIPO_PSME	PIPO	1078
PIPO_PIPU	PIPO	18
PSME_PIPO	PIPO	681
PIPO_JUSC	PIPO	4
PICO_PSME	PICO	19
PIPO_PICO	PIPO	9
PIPO_POTR5	PIPO	362
POTR5_PIPO	PIPO	9
PSME_PICO	PICO	3

Table e. Revised current vegetation states for stands in Hi-meadow burn of 2000

AVIRIS description and density	Adjusted post- burn species	States present in burn
PSME density 4	PSME_PIPO	26
PSME density 3	PSME_PIPO	234
PSME density 2	PSME_PIPO	211
PSME density 1	PSME_PIPO	5
PIPO density 4	PIPO	2
PIPO density 3	PIPO	76
PIPO density 2	PIPO	106
PIPO density 1	PIPO	330
Shrub	CEMO2_ARUV	42
Grass	PGFORBS	3
Bare soil	NF	2

G. "CFR legals" valid nomenclature for CV data attributes

Table f. Field names, nomenclature common to both SIMPPLLE and MAGIS

Description	Mandatory MAGIS Attribute name	Ancillary attribution for SIMPPLLE
species (grass shrub, tree)	dom_sp	habitat group
size class	sz_class	ownership
density class	density	roads
stand id	slink	fire management zone
acres	acres (GIS derived)	special area

Table g. "Legal" nomenclature for target species used by SIMPPLLE and MAGIS

Target Stand	MAGIS class name	SIMPPLLE class name	Description
ponderosa pine	pipo	pipo	Pinus ponderosa
Douglas-fir	psme	psme	Pseudotsuga menziesii
mix of both	pipo-psm	pipo-psme	mix—pipo dominant
mix of both	psme-ppo	psme-pipo	mix—psme dominant
perennial grass & forbs	pg/forbs	pg/forbs	mix—grass / forbs

Table h. Tree size class definitions as used by SIMPPLLE and MAGIS

Size Classes	MAGIS attribute classes	DBH
Sapling	SS	1 to 4.9"
Medium	M	5 to 8.9"
Medium multi-story	MMU	5 to 8.9"
Large	L	9 to 15.9"
Large multi-story	LMU	9 to 15.9"
Very Large	VL	16"+
Very Large multi-story	VLMU	16"+

Table i. Density class definitions as used by SIMPPLLE and MAGIS

Density by Crown Cover	MAGIS and SIMPPLLE Density Classes
0 to 10%	1
11 to 30%	2
30 to 70%	3
70 to 100%	4

H. Summary of soil textural properties on-site

Table j. Percentage of soil types on-site

Area of Site	Soil Type
95.3%	sandy loam
00.2%	silt loam
00.8%	loam
00.8%	water
03.1%	unknown

I. Producing a practical treatment unit coverage and inherent trade-offs

I expect that fuel managers and planners receiving MAGIS scenarios will aggregate treatment units by using their own judgment, in order to gain a more synergistic effect for fire breaks. Of course the modeling can be adapted and re-run based on their new-found constraints and desires, but in any case, aggregating stands at the earliest opportunity decreases complexity for modelers and decision makers without limiting practical flexibility. There is a trade-off when aggregating treatment units as with any summarization. Aggregated stands must be homogeneous across all MAGIS spatial variables and relevant *state groups* if the modeler desires no loss of attribute

resolution; this may however, produce treatment units with a mean size only moderately larger than the stands. If a modeler aggregates stands into increasingly larger treatment units, any heterogeneous mix of attributes will force MAGIS to assign treatments based on majority values. MAGIS can, through its linear processing (LP) optimization function, produce proportional mixed treatments to address each stand's characteristics. Though optimized correctly, these solutions still use the MMU of the treatment unit and therefore lack the resolution to indicate which stands of the unit receives what treatment. This trade-off may be very favorable for the client as opposed to numerous man-hours that could be spent manually aggregating treatment units.

I produced a numeric string (key code) for each unique combination of attributes; I did this by adding to the CV coverage several additional numeric fields and populated them with integers 0-9—each digit representing one variant of a critical attribute. I then used the calculator tool to multiply each integer by the appropriate number of place-holding digits and once aligned, to sum the inputs. I used the Geoprocessing tool to dissolve the stands per this key. The original 18,406 5-ac stands were reduced to 8,027 treatment units with a resultant mean size of 11.5-ac, standard deviation of 26.9-ac with extreme outliers ranging up to 985-acres.

J. Unabridged prescribed treatments

Eligible Prescriptions

All prescriptions apply only to treatment units recorded as being ponderosa pine and Douglas-fir or mixes of both. The primary objective of all treatments was to remove ladder fuels and attain a density class of 2 or less. Stands with a dominant multi-story crown structure, usually indicative of "ladder fuels" are identified in SIMPPLLE's density classes as (multi-story) of each diameter class. For an overview of the specifics of vegetation density classes as they relate to crown closure see table x (appendix). Housing density can be found in table y.

Eligible treatment–ThinHvBn:

Available for modeling to stands:

- < 2500' of a road
- Seedling-Sapling, Medium, Medium (multi-story), Large, Large (multi-story) and Very large (multi-story)
- veg density classes 3 and 4
- gradient classes $\leq 50\%$
- all housing densities
- not eligible in Wilderness

This is a heavy equipment density reduction to class 2, with no addition of permanent roads; therefore this treatment is limited to stands intersecting a 2500-ft buffer of an existing road. This treatment will use understory thinning to reduce underbrush and ladder fuels (via visual discrimination) combined with overstory thinning to reduce canopy closure to density class 2—equally-across size classes until the desired density goal is achieved (Kaufmann, 2005b). Revenue is generated when stems $\geq 9"$ DBH are harvested; material other than saw-logs will be masticated (Dennis, 2005, Kaufmann, 2005b, Patten, 2005). The mechanical thinning is to be followed by an in-period underburn. Old growth trees are to be excluded on a stem-by-stem basis (via visual discrimination) (Kaufmann, 2005b). Some standing snags should be left, favoring those 14"DBH or more that are suspected of being hollow or of critical value to a species of concern (Colorado Forestry Advisory Board, 2005, Silverstein, 2005). Treatment removes PSME to the exclusion of PIPO in stands with dominant species mix "DOM_SP" as PIPO-PSME, but in all other stands trees are removed proportionally to existing levels (Chew, 2004). "Leave trees" should be left in groups when possible to avoid even spacing (Colorado Forestry Advisory Board, 2005).

Sequence:

4. Thin understory targeting ladder fuels ($< 9"$ DBH) with mastication by Hydro-axe or equivalent heavy equipment—scatter chips if not marketable.
5. Overstory thinning with opportunistic harvest of boles $\geq 9"$ DBH; skid to landing via whole tree yarding with limbs and tops to be piled or chipped at landing.
6. In-period underburn with pile burning (where necessary) to control surface and understory fine fuels and kill regenerating vegetation (regen) ~3-8 years following thinning. Latitude in timing gives managers discretion regarding fuel conditions and regeneration rates.

Eligible treatment–ThinBn

Available for modeling to stands:

- $\geq 2500'$ of a road
- SS, Medium, Medium (multi-story), Large, Large (multi-story) and Very large (multi-story)
- veg density classes 3 and 4
- gradient classes $\leq 50\%$
- all housing densities 0-4
- not eligible in Wilderness

This treatment is the same as ThinHvBn, with no harvest of thinned material due to the hazards and difficulties posed by the remote nature of the stands. With no harvest, trees are masticated up through 14" DBH via "Bo'hog," (or equivalent) attachment for Hydro-axe (Patten, 2005). If the vegetation density 2 goal cannot be attained without cutting 14"DBH or larger, the planned treatment would fail and trees $\geq 14"$ DBH would be left—this is expected to be infrequent.

Sequence

1. Thin understory targeting ladder fuels ($\leq 14"$ DBH) via mastication—scatter chips evenly.
2. In-period underburn to control surface and understory fine fuels and kill regenerating vegetation (regen) ~3-8 years following thinning; latitude in timing to give project manager discretion over fuel conditions and regen rates.

Eligible treatment—Underburn

Available for modeling to stands:

- without road consideration
- SS, Medium, Large, Very large
- veg density classes 1 and 2
- gradient classes $\leq 100\%$ (no practical limitation on this site.)
- housing density 1 or 2 or less
- not eligible in Wilderness

Single activity prescription— underburn to control surface and understory fine fuels and destroy emerging vegetation.

Eligible treatment—P_Burn (broadcast burn)

Available for modeling to stands:

- no restriction for road proximity
- all stand size classes, but no multi-story
- veg density classes 1 and 2
- gradient classes $\leq 100\%$
- not valid treatment for housing density 3 and 4
- housing density 0 to 2: can be applied as initial treatment at Project Manager's discretion
- only treatment valid in Wilderness

This is a single activity prescription—broadcast burning to produce mixed severity fire conditions.

Interjected treatment—ThinDens1a

Available for modeling to stands:

- randomly selected from candidate stands

- selection excluded from the contribution zone
- < 2500' of a road
- veg density classes 3 and 4
- housing density not a consideration
- gradient class $\leq 50\%$

This treatment is the same as ThinHvBn except the goal is density class 1.

Interjected treatment–ThinDens1b

Same as ThinDens1a except that it applies to all stands ≥ 2500 -ft of a road. Methods and sequence of activities same as ThinBn.

K. Summary Brown and MacDonald—continuation Libohova's erosion response study

Brown and MacDonald continued Libohova's study (2004). They stated that even with soil disturbance from thinning, the slopes (several in a range of 40-44% gradient) failed to produce erosion; further, that even though the year 2004 produced an intense and erosive, 25-year return interval storm, the swales produced no overland flow (2005). Brown and MacDonald cite the combination of very porous soil and negligible change in cover percentage between thinned and control sites, as the suspected cause (2005).

They further state (2005) "In the absence of any overland flow, the thinning activities in the Upper South Platte River Watershed appear unlikely to increase erosion rates except under the most extreme rain events." Significant to overall erosion could be additional traffic or maintenance on roads used to access the treatment sites (Reid and Dunne, 1984, MacDonald and Stednick, 2003, Brown and MacDonald, 2005). COPPER is not modeling for road traffic or related outputs.

L. CFR MAGIS model build documentation

(including modeling logic and definitions)

October 27, 2005

Author: Robin Silverstein

While this appendix may not be of interest to a general reader; it is included to aid further research with the CFR model. The Butler thesis generalizes the detail of this documentation for the sake of readability and clarity.

(*) indicates documentation for the model using higher market values for the timber and biomass.**

Non-spatial attributes:

Attribute name: FIRERISK

Type: continuous

RISK of wildfire from SIMPPLLE

(FIRERISK = “risk” of stand replacing fire from SIMPPLLE, which was the number of times each polygon received a stand replacing fire in each decade of 20 simulations. So theoretical value of 0 to 100, actual 0 to 48)

Attribute name: SPFRRISK

Type: continuous

Spatial priority times wildfire risk

(with wildfire risk on a 1 to 4 scale to have equal weight as spatial priority).

Equals the value of:

$SPATPRIO + (FIRERISK \times 16)$

(So, theoretical values of 0 to 1200, actual 40 to 907)

Attribute name: SPATPRIO

0 to 400, weighted point values assigned from wui, erosion and wildlife zones. (See scenarios description for more details on how SPATPRIO is calculated) (original values were multiplied by 100)

Attribute name: ROS

Type: continuous

Rate of spread result from FlamMap output used as a risk index

Attribute name: ROSPST

Type: continuous

Rate of spread result from FlamMap output post treatments

Attribute name: TOMW1

Type: continuous

Treatment optimization model output, ranking of polygons, wind 1

Attribute name: ASPECT

Type: continuous

Sediment attribute used in lookup tables for producing WEPPSED

Attribute name: SLOPEP

Type: continuous

Sediment attribute used in lookup tables for producing WEPPSED

Attribute name: ROCKCOV

Type: continuous

Sediment attribute used in lookup tables for producing WEPPSED

Attribute name: ROCKPER

Type: continuous

Sediment attribute used in lookup tables for producing WEPPSED

Attribute name: SEDZN_PC

Type: continuous

Percentage of polygon that contributes to sediment (based on 300 foot buffer of streams)

Attribute name: CFA

Type: continuous

Crown Fire Activity (x 100 to make an integer) result from FlamMap output used as a risk index

Attribute name: WTDWUI

Type: continuous

Weighted WUI used to prioritize WUI zones

Spatial attributes:

<u>Zone name</u>	<u>zone class</u>	<u>description</u>
Wildlife zones:		
MSO	1	critical Mexican spotted owl habitat
PMSB	1	Pawnee montane skipper butterfly range
PMJM	1	Preble's meadow jumping mouse
LYNX	1	Lynx habitat
ROADPOLY	1	Within 2500 feet of Road
	0	Not within 2500 feet of road
WUIVAL	4 (= high housing density) to 0 (= low housing density)	
WUIZONE requirement)	for treatment coverage(same as above, different type for MAGIS	
WTRSHED	0 to 4 – major watersheds	

SLOPECLS	10	$\leq 10 \%$
	20	$> 10 \%$ and $\leq 20\%$
	30	$> 20 \%$ and $\leq 30\%$
	40	$> 30 \%$ and $\leq 40\%$
	50	$> 40 \%$ and $\leq 50 \%$
	60	$> 50 \%$ and $\leq 60 \%$
	70	$> 60 \%$ and $\leq 70 \%$
	80	$> 70 \%$ and $\leq 80 \%$
	100	$> 80 \%$ and $\leq 100 \%$

SLOPEZN (same as above)

FRCC	12	FR 0-35 yrs, CC2
	32	FR 35-100 years, CC2
	33	FR 35-100 years, CC3
	51	FR 200+ years, CC1

OWNER
NFS
STATE
PRIVATE
DENVWATR
COUNTY

WILDNESS 1 = yes, 0 = no for wilderness

MODVEG 1= yes, 0 = no (vegetation modified from the original veg coverage based on recent fuel treatments or fires not reflected in original veg data)

Costs: (difficulty levels from Fred Patten)

<u>Cost name</u>	<u>amount *</u>	<u>veg density</u>	<u>slope</u>	cost w/ burn: <u>wui 3/4</u>	<u>wui 0/1/2</u>
ThinHvBn	\$295	3	$\leq 30\%$	475	375
(KJRTHB)	\$554	3	$> 30\%$	734	634
	\$475	4	$\leq 30\%$	655	555
	\$647	4	$> 30\%$	827	727

*(Mastication only. Assume harvest cost "0", as stumpage price used as revenue)

ThinBn : (Same costs apply to ThinBn)
(KJRTHB)

		<u>description</u>	<u>housing density (wui val)</u>
UBurn	\$180	understory burn	3
	\$80	understory burn	1 or 2
PBurn	\$180	prescribe burn	3
	\$80	prescribe burn	1 or 2

MainBurn	\$150	maintenance burn	3
	\$50	maintenance burn	1 or 2

Activities:

<u>Activity name</u>	<u>Cost item</u>	<u>description</u>
ThinHvBn	ThinHvBn	thin, chip, underburn, harvest (thin (mastication) and harvest, $\leq$ 2500 feet of a road, followed by burn)
ThinBn	ThinBn	thin, chip, underburn (thin (mastication), $>$ 2500 feet of a road, followed by burn)
UBurn	UBurn	understory burn (understory burn)
PBurn	Pburn	prescribe burn (prescribe burn)
MainBurn	MainBurn	Maintenance burn
KJRTHB	Dummy activity to allow calculations on the veg condition prior to treatment, to be paired with activity ThinHvBn	
KJRBTB	Dummy activity to allow calculations on the veg condition prior to treatment, to be paired with activity ThinBn	

Management Regimes:

<u>Regime name</u>	<u>activities planned</u>	<u>period following implementation</u>
MR_THB	KJRTHB	0
	ThinHvBn	0
	UBurn	2
	UBurn	4
MR_TB	KJRBTB	0
	ThinBn	0
	UBurn	2
	UBurn	4
MR_UB	UBurn	0
	UBurn	2
	UBurn	4
MR_PB	PBurn	0
	PBurn	2
	PBurn	4
MR_MB	MainBurn	0
	MainBurn	2
	MainBurn	4

Assigning Management Regimes:

<u>Regime name</u>	<u>Specifications for regime as an option</u>
<u>State group THIN:</u>	
MR_THB	species – PIPO, PSME, PIPO_PSM, PSME_PPO; sizeclass - SS, MEDIUM, LARGE, LMU, VLMU, MMU; density - 3, 4; Near existing road (2500 feet buffer) – ROADPOLY = 1 Only in WILDNESS = 0 SLOPEZN <= 50
MR_TB	species – PIPO, PSME, PIPO_PSM, PSME_PPO; sizeclass - SS, MEDIUM, LARGE, LMU, VLMU, MMU; density - 3, 4; Not near existing road – ROADPOLY = 0 Only in WILDNESS = 0 SLOPEZN <= 50
<u>State group BURN:</u>	
MR_UB	species – PIPO, PSME, PIPO_PSM, PSME_PPO; sizeclass - SS, MEDIUM, LARGE, VERY_LAR; density = 1, 2 WUIZONE = 0 or 1 or 2 WILDNESS = 0
MR_PB	species – PIPO, PSME, PIPO_PSM, PSME_PPO; sizeclass - SS, MEDIUM, LARGE, VERY_LAR; density = 1, 2 WUIZONE = 0 or 1 or 2 WILDNESS = 1
MR_MB	species – PG_FORBS sizeclass - all density = all WUIZONE = 0 or 1 or 2 WILDNESS = 1

Outputs:

Name: ACT_RED

Description: Risk reduction following activities

No Action Amount: Equals 1

Post-Activity Amounts: Equals 0 for activities.

This is done using the MAGIS table option. For each activity, enter zero for time units 1-9, and .01 for time unit 10.

Price: none.

Name: RISK_RED

Description: reduced risk of Simpplle SRF values.

Use equation for quantity:
 $ACT_RED * FIRERISK$
Price: none.

Name: SPFR_RED
Description: reduced risk of spatial wildfire values.
Use equation for quantity:
 $ACT_RED * SPFRRISK$
Price: none.

Name: WEPPSED
Description: Sediment accumulation per polygon:
((in tons (u.s. short)/ acre) * 100) - converted from WEPP output by multiplying .446 by original metric tons/ hectares output – times 100 used to avoid unwanted truncation at two decimal places in Magis lookup table dbf (_47/_48).
No Action Amount: Equals zero
Post-Activity Amounts: Equals post-activity erosion value from WEPP lookup
Activities included: UBurn, PBurn, ThinHvBn, ThinBn (all with identical sediment production based on “burn” amount from WEPP.)
Price: none.

Name: SEDIMENT
Description: Contributing sediment per polygon
Use equation for quantity:
 $(WEPPSED * SEDZN_PC) / 5$
note: equation results in output in lbs/acre since tons/acre not calculating, can multiply result by 2000 for tons/acre
Activities included: UBurn, PBurn, ThinHvBn, ThinBn (all with identical sediment production based on “burn” amount from WEPP.)
Price: none.

Name: SPAT_RED
Description: reduced risk of spatial wildfire values.
Use equation for quantity:
 $ACT_RED * SPATPRIO$
Price: none.

Name: BIOMAS
Description: BIOMAS from treatment ThinHvBn
No Action Amount: 0
Post-Activity Amounts: data from Dan’s table, lookup table BIOMAS.dbf
Price: none. (***\$13/ton 50% mc)
(= Average green tons/acre (50% mc) of trees 1 - 9" DBH, and tops above 4.5" and limbs of trees >9" DBH)

Name: BIOCST
Description: BIOCST from treatment ThinHvBn
No Action Amount: 0
Post-Activity Amounts: data from Dan’s table, lookup table of biomass cost
Price: -1.00 (to use in net revenue effects function BIOSAV).

(OLD = Average of harvest costs per acre for all removed materials at 1000 foot skidding using a whole tree system, NEW = Replace with costs of biomass only to get biomass to truck,)

Name: MRCCUT

Description: MRCCUT from treatment ThinHvBn

No Action Amount: 0

Post-Activity Amounts: data from Dan's table, lookup table MRCCUT.dbf

Price: 8.44. (***50)

(= Average cubic foot volume of merchantable trees cut; boles to 4.5" top from trees >9" DBH)

Name: MAST9

Description: Cost of mastication only in ThinHvBn treatment (done on trees <9" DBH)

No Action Amount: 0

Post-Activity Amounts: see mastication only costs in cost table

Price: 1.00 (to use in net revenue effects function BIOSAV)

Name: THBSS

Description: acres of ThinHvBn done in ss size_class to account for no harvesting in this sizeclass (can subtract later for harvest acres)

No Action Amount: 0

Post-Activity Amounts: 1.0 for ss size_class only

Price: none

Name: ROS_RED

Description: reduced risk of ROS.

Use equation for quantity:

$$(\text{ACT_RED} * \text{ROS}) + ((1 - \text{ACT_RED}) * \text{ROSPST})$$

Price: none.

Name: TOM1_RED

Description: reduced risk of TOMW1.

Use equation for quantity:

$$\text{ACT_RED} * \text{TOMW1}$$

Price: none.

Name: CFA_RED

Description: reduced risk of CFA.

Use equation for quantity:

$$\text{ACT_RED} * \text{CFA}$$

Price: none.

Name: FIRE_WW

Description: reduced risk of wui weighted FIRERISK (SIMPPLLE risk of SRF).

Use equation for quantity:

$$\text{ACT_RED} * (\text{WTDWUI} * \text{FIRERISK})$$

Price: none.

Name: ROS_WW

Description: reduced risk of wui weighted ROS.

Use equation for quantity:

$$\text{ACT_RED} * (\text{WTDWUI} * \text{ROS})$$

Price: none.

Name: CFA_WW

Description: reduced risk of wui weighted CFA.

Use equation for quantity:

$$\text{ACT_RED} * (\text{WTDWUI} * \text{CFA})$$

Price: none.

Name: BURNCST

Description: cost of burning for all treatments

From lookup table:

Housing density (wuival @ 0,1,2 = \$80, wuival @ 3,4 = \$180)

Price: \$1

Name: MASTCST

Description: cost of mastication

From lookup table:

<u>Cost</u>	<u>veg density</u>	<u>slopecls</u>
\$295	3	≤ 30%
\$554	3	> 30%
\$475	4	≤ 30%
\$647	4	> 30%

Price: -\$1

Name: HAULCST

Description: cost of hauling per distance to Denver at a rate of \$2.28/ton/mile of biomass.

Use equation for quantity:

$$2.28 * \text{DNVRDDST} * \text{BIOMAS}$$

Price: -\$1

Effects Functions:

1. Name: **ATOTi** Type: activity acres

Description: Tabulates the total acres of activities

Items Included: All treatment activities

Zone Name: NA

Zone Classes: NA

2. Name: **CSTTOT** Type: cost (discounted)

Description: Tabulates the discounted total activity costs. (excluding biomass)

Items Included: all cost items

Zone Name: NA

Zone Classes: NA

3. Name: **RSKTOTi** Type: output

Description: Tabulates the total reduced fire risk (RISK_RED).

Items Included: NA

Zone Name: NA
Zone Classes: NA

4. Name: **ATHBi** Type: activity acres
Description: Tabulates the total acres for activity ThinHvBn.
Items Included: ThinHvBn
Zone Name: NA
Zone Classes: NA
5. Name: **MRTHBi** Type: activity acres
Description: Tabulates the total acres for management regime MR_THB.
Items Included: management regime MR_THB
Zone Name: NA
Zone Classes: NA
6. Name: **ATBi** Type: activity acres
Description: Tabulates the total acres for activity ThinBn.
Items Included: ThinBn
Zone Name: NA
Zone Classes: NA
7. Name: **MRTBi** Type: activity acres
Description: Tabulates the total acres for management regime MR_TB.
Items Included: management regime MR_TB
Zone Name: NA
Zone Classes: NA
8. Name: **AUBi** Type: activity acres
Description: Tabulates the total acres for activity UBurn.
Items Included: UBurn
Zone Name: NA
Zone Classes: NA
9. Name: **MRUBi** Type: activity acres
Description: Tabulates the total acres for management regime MR_UB.
Items Included: management regime MR_UB
Zone Name: NA
Zone Classes: NA
10. Name: **AWUIxi** Type: activity acres
Description: Tabulates the total acres of activities in each WUI zone.
Items Included: All treatment activities.
Zone Name: WUIZONE
Zone Classes: 0,1,2,3,4
11. Name: **AMSOi** Type: activity acres
Description: Tabulates the total acres of activities in the MSO zone.
Items Included: All treatment activities.
Zone Name: MSO

Zone Classes: 1

12. Name: **APMSBi** Type: activity acres
Description: Tabulates the total acres of activities in the PMSB zone.
Items Included: All treatment activities.
Zone Name: PMSB
Zone Classes: 1
13. Name: **APMJMi** Type: activity acres
Description: Tabulates the total acres of activities in the PMJM zone.
Items Included: All treatment activities.
Zone Name: PMJM
Zone Classes: 1
14. Name: **SEDTOTi** Type: output
Description: Tabulates the total sediment (SEDIMENT).
Items Included: NA
Zone Name: NA
Zone Classes: NA
15. Name: **SPFTOTi** Type: output
Description: Tabulates the total reduced spatial fire risk (SPFR_RED).
Items Included: NA
Zone Name: NA
Zone Classes: NA
16. Name: **SPTTOTi** Type: output
Description: Tabulates the total reduced spatial Priorities (SPAT_RED).
Items Included: NA
Zone Name: NA
Zone Classes: NA
17. Name: **BIOMASi** Type: output
Description: Tabulates the total biomass (output = BIOMAS) from activity ThinHvBn – information taken from lookup table BIOMAS.dbf.
Items Included: activity ThinHvBn (since only those are done within roads where biomass could be taken out)
Zone Name: NA
Zone Classes: NA
18. Name: **CSTBIOi** Type: output
Description: Tabulates the costs of biomass, from output BIOCST from Dan's table.
Items Included: activity ThinHvBn
Zone Name: NA
Zone Classes: NA
19. Name: **SEDWATxi** Type: output
Description: Tabulates the total sediment (SEDIMENT) by watershed.
Items Included: NA
Zone Name: WTRSHED

Zone Classes: 0 - 4

20. Name: **CSTDECI** Type: cost (discounted)
Description: Tabulates the discounted total activity costs (excluding biomass) by decade
Items Included: all cost items
Zone Name: NA
Zone Classes: NA
21. Name: **FRCCxxi** Type: activity acres
Description: Tabulates the total acres of activities in each FRCC class.
Items Included: All treatment activities.
Zone Name: FRCC
Zone Classes: 12,32,33,51
22. Name: **OWNxi** Type: activity acres
Description: Tabulates the total acres of activities in each OWNER class.
Items Included: All treatment activities.
Zone Name: OWNER
Zone Classes: NFS = N
PRIVATE = P
STATE = S
DENWATR = D
COUNTY = C
23. Name: **OWNHxi** Type: activity acres
Description: Tabulates the total acres of activity ThinHvBn in each OWNER class.
Items Included: activity ThinHvBn
Zone Name: OWNER
Zone Classes: NFS = N
PRIVATE = P
STATE = S
DENWATR = D
COUNTY = C
24. Name: **OWNTxi** Type: activity acres
Description: Tabulates the total acres of activity ThinBn in each OWNER class.
Items Included: activity ThinBn
Zone Name: OWNER
Zone Classes: NFS = N
PRIVATE = P
STATE = S
DENWATR = D
COUNTY = C
25. Name: **OWNUBxi** Type: activity acres
Description: Tabulates the total acres of activity Burn in each OWNER class.
Items Included: activity Burn
Zone Name: OWNER
Zone Classes: NFS = N
PRIVATE = P

STATE = S
DENWATR = D
COUNTY = C

26. Name: **WILD**i Type: activity acres
Description: Tabulates the total acres of activity Burn in wilderness.
Items Included: activity Burn (only option in wilderness)
Zone Name: WILDNESS
Zone Classes: 1
27. Name: **LYNX**i Type: activity acres
Description: Tabulates the total acres of activities in LYNX zone.
Items Included: all treatment activities
Zone Name: LYNX
Zone Classes: 1
28. Name: **WUIUB**xi Type: activity acres
Description: Tabulates the total acres of activity UBurn in each WUI zone.
Items Included: UBurn.
Zone Name: WUIZONE
Zone Classes: 0,1,2,3,4
29. Name: **WUIPB**xi Type: activity acres
Description: Tabulates the total acres of activity PBurn in each WUI zone.
Items Included: PBurn.
Zone Name: WUIZONE
Zone Classes: 0,1,2,3,4
30. Name: **WUITB**xi Type: activity acres
Description: Tabulates the total acres of activity ThinBn in each WUI zone.
Items Included: ThinBn.
Zone Name: WUIZONE
Zone Classes: 0,1,2,3,4
31. Name: **WUITH**xi Type: activity acres
Description: Tabulates the total acres of activity ThinHvBn in each WUI zone.
Items Included: ThinHvBn.
Zone Name: WUIZONE
Zone Classes: 0,1,2,3,4
32. Name: **BIOSAV**i Type: net revenue
Description: Tabulates the costs savings of utilizing biomass over mastication, assuming both treatments included harvesting merchantable timber within prescription and included a followup burning. Biomass costs are to the truck, not including haul costs and any revenues.
Items Included: ThinHvBn.
Computes from outputs: $(1 * \text{MAST9}) + (-1 * \text{CSTBIO})$
33. Name: **REVI** Type: net revenue
Description: net revenue from harvest per period
Items Included: MRCCUT.

Computes from output: $8.44 * MRCCUT$

34. Name: **REVTOTi** Type: net revenue
Description: total net revenue from harvest, discounted
Items Included: MRCCUT.
Computes from output: $8.44 (**50) * MRCCUT$
35. Name: **EFFTOT** Type: net revenue
Description: efficiency function: total net revenue from harvest, including costs items
Items Included: ouput: MRCCUT; costs: ThinHvBn, ThinBn, Uburn, Pburn, MainBurn
Computes from output: $8.44 (**50) * MRCCUT - costs$
36. Name: **EFFi** Type: net revenue
Description: efficiency function: net revenue per period from harvest, including costs items
Items Included: ouput: MRCCUT; costs: ThinHvBn, ThinBn, Uburn, Pburn, MainBurn.
Computes from output: $8.44 (**50) * MRCCUT - costs$
37. Name: **ATHBSSi** Type: net revenue
Description: net revenue from harvest per period
Items Included: output: THBSS.
Computes from output: 1 for each “ss” sizeclass acre treated with ThinHvBn.
38. Name: **ROSTOTi** Type: output
Description: Tabulates the total reduced rate of spread (ROS_RED).
Items Included: NA
Zone Name: NA
Zone Classes: NA
39. Name: **TOMW1i** Type: output
Description: Tabulates the total reduced TOM values (TOM1_RED) based on wind condition 1.
Items Included: NA
Zone Name: NA
Zone Classes: NA
40. Name: **APBi** Type: activity acres
Description: Tabulates the total acres for activity PBurn.
Items Included: PBurn
Zone Name: NA
Zone Classes: NA
41. Name: **MRPBi** Type: activity acres
Description: Tabulates the total acres for management regime MR_PB.
Items Included: management regime MR_PB
Zone Name: NA
Zone Classes: NA
42. Name: **MERChi** Type: output
Description: Tabulates the total MRCCUT.

Items Included: NA
Zone Name: NA
Zone Classes: NA

43. Name: **CFAi** Type: output
Description: Tabulates the total crown fire activity reduction (CFA_RED).
Items Included: NA
Zone Name: NA
Zone Classes: NA
44. Name: **FIREWWi** Type: output
Description: Tabulates the total wui weighted FIRERISK (FIRE_WW).
Items Included: NA
Zone Name: NA
Zone Classes: NA
45. Name: **ROSWWi** Type: output
Description: Tabulates the total wui weighted ROS (ROS_WW).
Items Included: NA
Zone Name: NA
Zone Classes: NA
46. Name: **CFAWWi** Type: output
Description: Tabulates the total wui weighted CFA (CFA_WW).
Items Included: NA
Zone Name: NA
Zone Classes: NA
47. Name: **MODVEGi** Type: activity acres
Description: Tabulates the total acres treated to modveg
Items Included: Uburn, Pburn, ThinHvBn, ThinBn
Zone Name: MODVEG
Zone Classes: 1
48. Name: **STEWi** Type: revenue
Description: net stewardship value by period
Items Included: MRCCUT, MASTCST
Computes from output: $(8.44 (**50) * MRCCUT) - (1 * MASTCST)$
49. Name: **CSTBRNi** Type: output
Description: cost of burning for all activities, from output BURNCST
Items Included: Uburn, Pburn, ThinHvBn, ThinBn, MainBurn
Zone Name: NA
Zone Classes: NA
50. Name: **AMBURNi** Type: activity acres
Description: Tabulates the total acres for activity MainBurn.
Items Included: MainBurn
Zone Name: NA
Zone Classes: NA

51. Name: **MRMBi** Type: activity acres
Description: Tabulates the total acres for management regime MR_MB.
Items Included: management regime MR_MB
Zone Name: NA
Zone Classes: NA
52. Name: **HAULi** Type: activity acres
Description: Tabulates the haul costs of biomass from output HAULCST
Items Included: activity ThinHvBn
Zone Name: NA
Zone Classes: NA
53. Name: **MSTBIOi** Type: net revenue
Description: Tabulates the costs savings of utilizing biomass over mastication, assuming both treatments included harvesting merchantable timber within prescription and included a followup burning. Biomass costs are to the truck, including haul costs but not any revenues.
Items Included: ThinHvBn.
Computes from outputs: $(1 * MAST9) + (-1 * CSTBIO) + (-1 * HAULCST)$
54. Name: **BIOHLCi** Type: net revenue
Description: Tabulates the costs of biomass costs to the truck and hauling, but not any revenues. NOTE: Cost will come out as a negative value, so must maximize effects function to minimize costs. (BIOHLC without a number is total discounted).
Items Included: ThinHvBn.
Computes from outputs: $(-1 * CSTBIO) + (-1 * HAULCST)$
55. Name: **MASTCSi** Type: net revenue
Description: Tabulates the costs of mastication for all thinning treatments. NOTE: Cost will come out as a negative value, so must maximize effects function to minimize costs.
Items Included: ThinHvBn, ThinBn.
Computes from outputs: $(-1 * MASTCST)$
- *****BIOREVi** Type: net revenue
Description: Tabulates the total revenue from biomass
Items Included: ThinHvBn.
Computes from outputs: $13 * BIOMASS$
- *****MSTBIRi** Type: net revenue
Description: Tabulates the costs savings of utilizing biomass over mastication, assuming both treatments included harvesting merchantable timber within prescription and included a followup burning. Biomass costs are to the truck, including haul costs and revenues.
Items Included: ThinHvBn.
Computes from outputs: $(1 * MAST9) + (-1 * CSTBIO) + (-1 * HAULCST) + (13 * BIOMASS)$
- *****BIOPNVi** Type: net revenue
Description: Tabulates the revenues and costs of Biomass.
Items Included: ThinHvBn.
Computes from outputs: $(-1 * CSTBIO) + (-1 * HAULCST) + (13 * BIOMASS)$

*****TBPVNi**

Type: net revenue

Description: Tabulates the revenues and costs of Biomass plus revenues of merch.

Items Included: ThinHvBn.

Computes from outputs: $(-1 * CSTBIO) + (-1 * HAULCST) + (13 * BIOMASS) + (50 * MRCCUT)$

Fuel Treatment Scenarios:

(To be determined.....)

Spatial Priorities: (needs updating....)

Spatial priorities designed according to system used in Pike National Forest:

WUI (Housing Density) – 45%, Watershed (Erosion) – 40%, Wildlife (T&E) – 15%

WUI – Values given: from housing density WUIVAL 4 highest, 0 lowest.

Watershed – Values determined from EROSION – 4 = high, 3 = moderate, 0 = low, Erosion hazard rating from Ken Kanaan

Wildlife – MSO = 1, give score of 6; PMSB = 1, give score of 9; PMJM = 1, give score of 4, Lynx gives score of 2, then add scores, so total score of 0 – 5 = 1 pt, 6 – 10 = 2 pts, 11 – 15 = 3 pts, 16 – 21 = 4 pts.

So final Spatial priority = $.45(\text{WUI pts.}) + .40(\text{Watershed pts}) + .15(\text{wildlife pts})$, and calculated into a GIS attribute of SPATPRIO. For Spatial wildfire risk, times SPATPRIO by FIRERISK, giving GIS attribute of SPFRRISK.

Treatments:

ThinHvBn

Apply to: species: all PIPO- and PSME- combinations.

Size_class: SS, MEDIUM, MMU, LARGE, LMU, VLMU

Density: 3, 4

To all polygons intersecting 2500 foot buffer of roads.

Resulting states:

Density: goes to 2

Species: PIPO-PSME combination goes to PIPO

Size_class: MMU to MEDIUM, LMU to LARGE, VLMU to VLARGE

Time_inc to 1

others remain the same

ThinBn

Apply to: species: all PIPO- and PSME- combinations.

Size_class: SS, MEDIUM, MMU, LARGE, LMU, VLMU

Density: 3, 4

To all polygons not intersecting 2500 foot buffer of roads.

Resulting states:

Density goes to 2
Species: PIPO-PSME combination goes to PIPO
Size_class: MMU to MEDIUM, LMU to LARGE, VLMU to VLARGE
Time_inc to 1
others remain the same

Burn

Apply to: species: all PIPO- and PSME- combinations.
Size_class: SS, MEDIUM, LARGE, VLARGE
Density: 1, 2

Resulting states:
Time_inc to 1
Others remain the same

Post MAGIS openings applied in SIMPPLLE:

For every stand identified to be thinned (ThinHvBn or ThinBn), a random number application was applied to decide which of these stands would receive the THIN-DENSITY1 SIMPPLLE treatment of creating an opening. **1/3 of the non-riparian stands** were randomly assigned this treatment.