Forest Fuel Management

Photo by Kari K. Brown, courtesy of U.S. Forest Service

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A spatial decision-support system developed by the Rocky Mountain Research Station provides forest managers with the tools to effectively remove a build-up of fuels while adhering to principles of ecological multiple-use forest management and responding to public interests.

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Twentieth-century forest management practices of fire exclusion have caused a build-up of forest fuels that, combined with current weather patterns, threaten the ecological health of the Colorado Front Range. The year 2002 clearly demonstrated the potential for catastrophic wildfire in the area. During that year's fire season, the Hayman fire moved across 138,000 acres of the Pike National Forest, located south and west of Denver. The South Platte River watershed coincides with much of the Pike National Forest, and the urban and suburban populations of Denver — currently in an apparently deteriorating drought situation — are dependent on the South Platte watershed for their water supply. The Hayman and other wildfires in recent history put the forest's health and water quality in jeopardy.

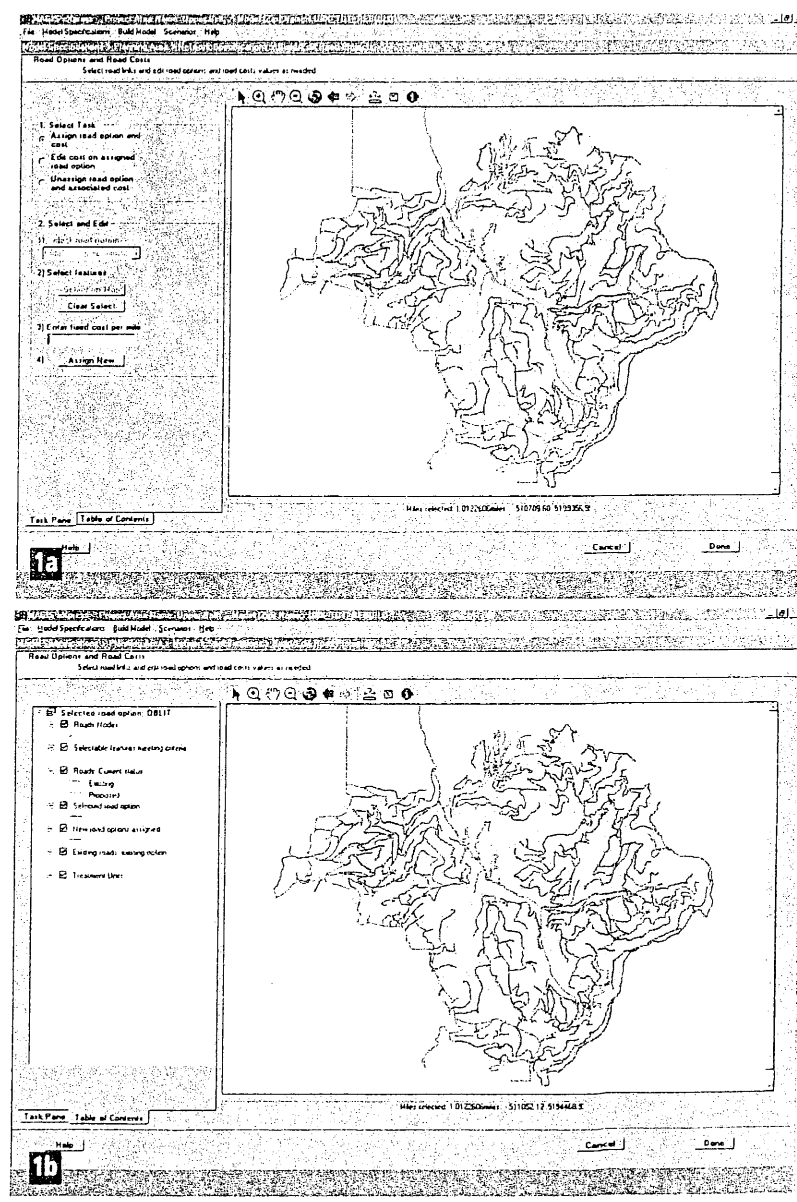
Of course, the Pike National Forest is not alone in being confronted with these difficult circumstances. In recent years, forest health as it affects the occurrence of catastrophic fire has become a well-publicized, central issue for forest-management decisions across the United States. And, although the remedy for the buildup of forest fuels may seem straightforward, forest managers may not have the proper planning tools to effectively remove fuels while adhering to wider principles of ecological multiple-use forest management, responding to public interests, working within budget, and planning transportation. In reducing fuels, several issues must be considered, including minimizing insects and disease, mitigating any sedimentation or smoke produced by forest treatment activities, reducing road density, and managing wildlife habitat. In meeting these objectives several questions must be addressed: Is it possible to determine locations that would most effectively lessen the risk of stand-replacing fire? Are treatments in those locations consistent with other objectives? Can costs be offset by incidental biomass or other utilization?

To aid natural-resource managers in answering these questions and analyzing similar complex management decisions, researchers of the U.S. Forest Service's (USFS's) Rocky Mountain Research Station (RMRS), located at the Missoula Forestry Sciences Lab, The University of Montana–Missoula (UM), and the USFS Inventory and Monitoring Institute (IMI) at Fort Collins, Colorado, have worked to develop a spatial decision-support system (SDSS) planning tool that combines GIS with modified versions of existing predictive models and optimization methods. Known as MAGIS (Multi-Resource Analysis and Geographic Information System), the tool is a powerful software package that enables natural-resource planners and decision makers to schedule management activities for five user-defined time periods (usually decades) and estimate the ecological and economic consequences of those activities. With MAGIS, planning-area resource models and management scenarios are first defined and then "solved" to optimize resource management and transportation (optional) on both a temporal and geographic basis. Any number of alternative scenarios may be specified by modelers (research staff or resource managers) and results compared.

Origins of an SDSS

RMRS is one of seven research stations of the Research and Development branch of USFS. The RMRS forest economics unit at the Missoula Forestry Services Lab conducts studies in resource valuation and use, serving the public as well as private landowners. The College of Forestry and Conservation at UM is a regional leader in forestry education and research using GIS. IMI is a USFS nationally chartered organization. IMI provides technical consultation to Forest Service units with responsibilities for on-the-ground inventory, monitoring, and planning activities.

RMRS, IMI, and UM developed MAGIS to focus on tactical forest planning at the landscape level. The premise behind MAGIS is to enable natural-resource managers to meet the challenges they face to fulfill many conflicting social, biological, and commodity-production objectives. These include reducing fire and other risks; providing habitat for terrestrial and aquatic organisms; producing such commodity outputs as forage, sawlogs, and biomass; monitoring changes to the land over time; studying the cumulative effects of actions taken over time and space on biodiversity and endangered species; maintaining old growth and mosaic structures over landscapes; and providing recreational access and use. MAGIS was also created with the knowledge that in order to use resources available for management activities wisely, it is not enough to consider only short-term costs and effects of management (fuel reduction, planting, or



Figures courtesy of Judy M. Troutwine

Figures 1a and 1b. A custom GIS interface facilitates quickly entering road-management options from which the MAGIS solver selects optimal actions (**1a**). Users can toggle between the task pane and the map's table of contents (**1b**).

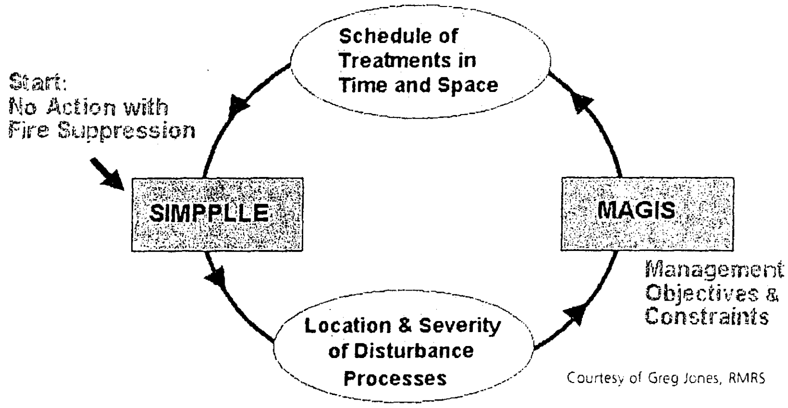


Figure 2. Natural-resource planners can take advantage of MAGIS to schedule management activities that reduce fire risks based on inputs derived from SIMPPLLE, a stochastic model developed by RMRS for projecting vegetative change over time due to natural processes. Activities proposed by MAGIS can also be fed back into SIMPPLLE to evaluate the effect of applying various forest management activities.

other forest treatments). Long-term, tactical spatial planning is needed to reduce risk, meet objectives, and minimize costs.

Realizing that local resource managers often have access to scientific data but may have limited time, technology, and knowledge to carry out a complex planning process, MAGIS provides advanced functionality to conduct complex analysis and allows managers a great deal of control in defining models and scenarios. The addition of custom GIS interfaces to MAGIS guides the user and streamlines tasks, facilitates processing, and improves the accuracy of data values, model specifications, and visual interpretation of solutions. Figures 1a and 1b (on page 23)show two of the GIS interfaces.

Two versions of MAGIS are available for modeling: MAGIS Pro and MAGIS Express. MAGIS Express has a timber and road emphasis, with numerous predefined variables to streamline the model-building process. MAGIS Pro has a wider range of flexibility in defining management issues and using spatial data to build a very complex planning problem. More specifically, MAGIS Pro employs mathematical programming techniques to solve a system of linear equations created indirectly by the user. The user selects one of two solvers, which then reports a feasible solution for the system of equations. In contrast, MAGIS Express relies on a heuristic solver that finds a solution to a system of equations on a trial-and-error basis. Through a controlled process, thousands of values for the unknowns are assigned and the resultant solutions are compared to one another to identify the "best" one. (MAGIS Express outputs are not intended to be the optimum solutions; this solver is best suited for quick, initial analyses.)

Both MAGIS Pro and Express solutions consist of a schedule of forest treatments and road projects in time and space and the various results of those treatments (costs, revenues, timber volume, and other outputs [Pro only]; risks of fire and insects; vegetative states; and traffic). Upon completion of the solution process, various feasible solutions can be displayed in tabular as well as visual form.

Keeping It SIMPPLLE. To assess the risk factors, RMRS researcher Jim Chew developed SIMPPLLE (Simulating Vegetative Patterns and Processes at Landscape Scales). SIMPPLLE is a stochastic simulation model for projecting vegetative change over time in the presence of natural processes, either with or without management treatments. The interaction of various natural processes, such as stand-replacing fires, on a landscape are modeled, making it a powerful tool for assessing forest health in time and space. SIMPPLLE can be used to project the frequency and location of natural disturbances for the "no action" management alternative with or without fire suppression. These results can be used to compute a risk index for each stand based on the most likely type of natural forest disturbance and the probability of its occurrence. This index can then be incorporated into MAGIS to address forest-health issues.

Using SIMPPLLE results, natural-resource planners can take advantage of MAGIS to schedule management activities that reduce fire risks, as well as address other management objectives relevant to the area of interest. In addition, managers can import the schedule of activities proposed by MAGIS into SIMPPLLE to perform additional simulations to evaluate the changes in location and extent of disturbances associated with applying those forest-management activities (see Figure 2). In this way, economic efficiency is gained by using SIMPPLLE and MAGIS iteratively to plan the optimal size and location of forest treatments that prove most effective in reducing large-scale crown fires and restoring ecological sustainability.

Using MAGIS

When used in actual practice by natural-resource managers, MAGIS allows them control at every step of the process, from specifying a planning framework to defining planning area models, building potential planning scenarios, and displaying scenario results.

MAGIS provides this flexibility because planning decisions are always based entirely on local situations, including natural and other resources, existing policies, and public concerns.

When commencing an analysis, the user first inputs information that conceptually defines a resource-planning problem. For example, it is at this stage that the manager would specify vegetative pathways and potential land-management actions. Attributes associated with land-management units and roads are either derived from geospatial databases or entered via the custom GIS interfaces or both. No spatial operations are performed on these geospatial databases by MAGIS. Special zones (watershed, wilderness, and population density, for example) may be included as attributes and used in the framework definitions, effects-functions definitions, and project-area specifications. Those same land-management (treatment) unit and roads databases form the base layers for the custom GIS interfaces. MAGIS currently handles coverage and shapefile formats. Through a comprehensive setup procedure, a planning model is then formulated from these databases, definitions, and specifications, and a matrix is generated for input to the solver.

A Framework. The planning model or economic-resource framework is composed of definitions of the parameters used for one or more project-area models, such as activity-costs, products and prices, nonproduct outputs (sedimentation for example), definition of zones and other attributes that are used to build cost and output relationships, management regime definitions and rules for assignation of the regimes to individual treatment units as options, road management option definitions, and the vegetation pathways definitions. (Users can assign cost/price changes to the inputs and outputs of the roads network and land-management area by time unit.) Vegetative pathways can be thought of as the sequence from a starting vegetative state (for example, dense, large-lodgepole forest), an activity applied to that state, and the resulting state (for example, moderately dense, large-lodgepole forest). Importantly, trajectories are determined by habitat-type group and length of time in a given state, and the selection of management actions can change the projected state in particular ways. For example, a selection harvest could reduce both the density and dominant species components of the forest stand.

Project-Area Specifications. For a particular planning area, the required geospatial databases include land management (treatment) units, stands (MAGIS Pro only), and the associated transportation network. If SIMPPLLE is being used in conjunction with MAGIS, results of that simulation process will have been incorporated into the land-management (treatment) unit attributes. Each land-management unit and road network link is assigned one or more potential management options in one or more time periods. These management options comprise the totality of the decision variables from which the solver may choose a schedule of treatments and projects. Figures 1a and 1b (on page 23) show examples of the GIS interfaces to ease these tasks.

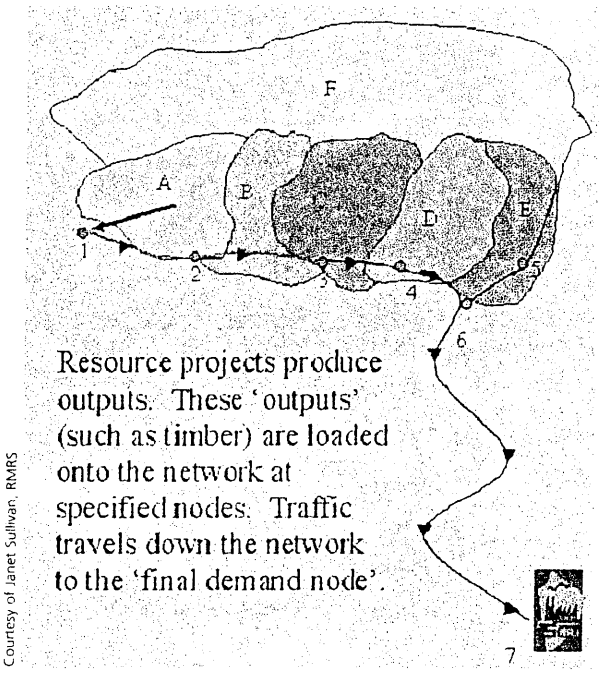
Effects Functions. The next step is to specify relationships between model components and set constraints to represent management objectives within a project-area model. This involves formulating management objectives as mathematical relations, or effects functions. In MAGIS, effects functions are specified as timber output, other output, acreage and length control, cost, and net revenue. Examples include the acreage in a specific successional stage; the acreage having unique stand characteristics (such as density, height, or diameter categories); the number of miles of open road; the acres in forage production or cover; wildlife security areas and corridors; the size of openings created by land-management activities; and timber harvest volumes by species. An effects function can be defined to apply to the entire planning area or portions thereof, such as drainages or wildlife zones. Similarly, the time periods during which a management objective may be potentially applied may include all periods or be limited by user selection.

Effects functions essentially quantify the relationships between model components (decision variables, traffic, and outputs) and control the selection of decision variables to meet a scenario's specifications. With MAGIS Pro, users can also include special effects functions to control solver results for adjacency.

Solving Scenarios

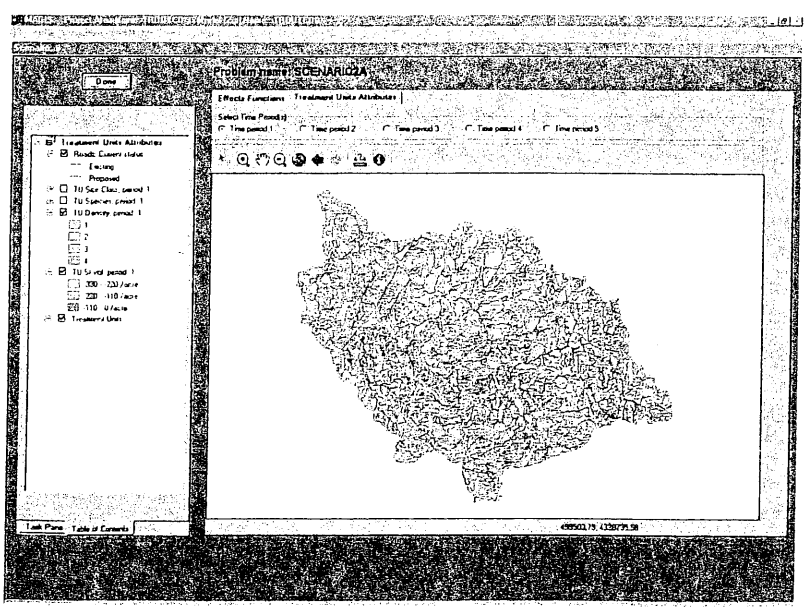
Once the model components and relationships among them are defined, one or more alternative management scenarios are defined. They involve specification of solution controls, objective function, management constraints, and presetting decision variables.

Solution controls refer to the solver/analysis type and the function (objective function) to be maximized or minimized. At this point, the user sets management constraints (upper or lower limits) as needed on any of the remaining defined effects functions. For



Courtesy of Janet Sullivan, RMRS

Figure 3. This image demonstrates how MAGIS "connects" each land-management unit to the road network via "loading nodes." If a loading point is on a proposed road or a road that requires reconstruction before it can carry traffic, MAGIS selects the road management options for those construction or reconstruction options.



Courtesy of Judy M. Troutwine

Figure 4. MAGIS can present results in the form of GIS maps displaying effects functions, vegetation-state quantities, and schedules for management options and road projects. A query tool is available for investigating solutions further, a custom legend categorizes land-management actions, and mousing over treatment units and road features displays more information in the status bar.

example, if the maximization of total net-present value is used as the objective function, MAGIS will search for a solution that generates the largest value based on the relationships between model components. However, this value could be constrained by setting limits (lower or upper bounds) on the amount of saw-timber size-class harvested, the number of miles of new road, or the number of acres untouched by harvesting.

Preselecting decision variables and setting spatial constraints provide two more avenues of control. With MAGIS Pro, users also have the ability to turn on or off each type of spatial constraint. It is important to keep in mind when selecting decision variables and specifying spatial constraints that the costs for road options and traffic flow are specific to each road segment. In addition, each treatment unit with management options has "connections" to the road network via "loading nodes" (see Figure 3). As units are selected for harvest, traffic from the harvest is loaded onto the network. If the loading point is on a proposed road or a road that requires reconstruction before it can carry traffic, MAGIS selects the road management options for those construction or reconstruction options as well. In this way, the solver selects for the least-cost route to the "exit" or final demand node (output and destination) and tracks the total amount of traffic (of each type) by road segment and time period.

Processing and Results. During the solution processing, MAGIS selects vegetation-treatment projects and road projects, calculates the resultant traffic routing and volume, projects vegetation changes through time based on succession and the selected activities, and calculates the values of all defined effects functions. As mentioned previously, the solution method is specific to whether MAGIS Express or Pro is being used for a particular model. Experienced users may further extract outputs from tables and feed them into SIMPPLLE to simulate reduced risk levels as a result of treatments recommended by MAGIS.

The software presents scenario results in two modes: tabular reports or GIS display maps (see Figure 4). The maps display effects functions, vegetation-state quantities, and schedules for management regimes and road projects. These schedules detail specific activities and traffic amounts for each time period. Customized displays include a query tool for land-management options, a custom legend dialogue that categorizes land-management functions, and mouse-over displays in the status bars.

An Empowering Technology

To date, MAGIS has been used to aid forest managers in the U.S. Department of Agriculture National Forest System, and research staff have assisted managers in defining models and scenarios for planning area objectives and constraints. A partial list of RMRS-assisted modeling projects hints at the range of resource-planning contexts for which MAGIS may be used:

- *Angeles National Forest* — Using MAGIS, Angeles National Forest in California was modeled to reduce the risk of fire in chaparral. Treatments included mechanical removal and prescribed burning. Spatial priorities were established based on housing density. Scenarios included treating with or without spatial priorities, in or out of wilderness areas, and for different amounts of total acres.
- *Southwestern Utah* — An area in southwestern Utah including Fishlake National Forest and adjacent Bureau of Land Management, private, and state lands was modeled for fuel treatments. The main management concerns involved restoring sagebrush habitat where pinyon-juniper had encroached and increasing the amount of aspen in areas where white fir and Douglas fir were overstocked. Scenarios included active versus passive management along with prioritization for sage-grouse habitat.
- *Kenai Peninsula* — A section of the Kenai Peninsula in Alaska was modeled for restoration of bark beetle–killed white spruce. Treatments included prescribed burning in a wildlife refuge, logging dead white spruce in the general forest, and logging with replanting in the wildland urban interface. The management options further involved solving for hazard reduction and improving wildlife habitat.

MAGIS is also currently being applied to analyze the Pike National Forest in the South Platte watershed in Colorado. RMRS and cooperating researchers are conducting an analysis on a watershed within a 500,000-acre planning area in that forest to help mitigate the impact of fires in the Colorado Front Range and their effects on the surrounding ecosystems, wildlife, and water quality.

All this illustrates MAGIS' capabilities as a custom SDSS that empowers natural-resource managers by guiding them through the modeling process. The addition of the interactive GIS interfaces enables managers possessing moderate GIS skills to effectively use MAGIS. The software handles the mundane and technical processing tasks behind the scenes and allows managers and planners to analyze and visualize large sets of spatial and nonspatial data, examining "what if" scenarios to estimate the effects of various alternative forest-management actions without actually carrying them out on the ground.

Courtesy of Bitterroot National Forest

MAGIS' tools enable natural-resource planners to analyze and study the cumulative effects of actions taken over time on biodiversity, wildlife habitat and corridors, and watersheds.

Manufacturers

MAGIS executes under **Microsoft** Windows 2000 or XP. Program execution and dialogues are controlled by a system of computer programs written in the Microsoft Visual FoxPro database software development language. MAGIS integrates a commercial mathematical software package and custom GIS interface. MPSIII/pc, 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 9.0 license is required to run MAGIS. FoxPro need not be installed to execute MAGIS. ⊕