SPECTRUM: AN ANALYTICAL TOOL FOR BUILDING NATURAL RESOURCE MANAGEMENT MODELS

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ABSTRACT.—This paper describes the functional capabilities of Spectrum: a software tool for constructing linear programming based forest management models. Spectrum contains a robust set of features that allow easy construction of the three components of a forest management model: current and future states of the forest and the natural processes that affect change; ecosystem management goals and objectives; and a range management actions that offer alternatives for achieving these goals. Flexible land stratification schemes allow the model to focus at the appropriate scale. Generalized Model 2 formulations enable representation of successional pathways and forest structure changes due to mortality and fire. Management goals, constructed as constraints in the model, can control any aspect of the model such as structural stage proportions, rates of harvest, critical habitat requirements, or budgetary limitations. Objectives can be created to minimize deviations from historical structural patterns, maximize joint species viability or minimize deviations from a variety of stakeholders' goals. Management actions that cover a wide range of treatment and timing options are easily constructed. Spectrum has been used to construct planning models for several National Forests and has been used in several research studies. Attendance at recent training sessions has shown keen interest from U.S. forest industries as well as forest managers in foreign countries.

OVERVIEW

Spectrum (USDA Forest Service, 1995) is a computer-based analytical tool designed to assist land managers with strategic planning. It is developed jointly by staff at the Ecosystem Management Analysis Center and researchers at the Rocky Mountain Forest and Range Experiment Station. With Spectrum, managers are able to model alternative resource management scenarios through time and use mathematical programming techniques to schedule activities which best meet their objectives. Although designed primarily for broad-scaled strategic planning, Spectrum is finding acceptance in smaller-scale tactical analyses pertaining to individual watersheds or similar project areas.

Spectrum is not a model per se, but a flexible tool that facilitates the model building process. It is analogous to an artist's blank canvas, brushes, and paints. Spectrum provides the building blocks to create a model, but like an artist's canvas it starts out blank. It has no inherent data or relationships, thereby providing the model builders with maximum latitude and flexibility. Many model builders can be involved in the construction of a single model. Ideally, an interdisciplinary team addressing integrated planning issues will use Spectrum to jointly build a model of the multiple-use interactions that exist or might exist in a forest environment. Once built, all members of the team can run the model and conduct sensitivity analyses relevant to their areas of interest.

Spectrum is similar to another analysis tool called FORPLAN (Johnson et al., 1986). FORPLAN served as the primary analysis tool for Forest Service land management planning since 1980 and its capabilities and limitations are well documented (Bailey, 1986; Hoekstra et al., 1987). The Land Management Planning Critique (Hoekstra et al., 1990) in particular, found that despite being basically sound and providing good analysis, FORPLAN:

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- is not user friendly;
- is difficult for analysts, managers, and the public to understand models and explain results;
- is expensive to run in terms of computer resources;
- is time consuming to learn the system, build models, and do analysis;
- does not adequately account for spatial relationships within the management problems being modeled;
- does not address uncertainty and risk surrounding resource information; and
- relies on linear optimization techniques that are an inadequate representation of real world natural systems and management objectives.

Criticisms of FORPLAN, the agency's adoption of an ecosystem-based management policy, and changing technology led to the decision to develop Spectrum. Earlier emphasis on economic efficiency has shifted toward ecosystem sustainability and changed the focal point of analysis. The historical range of variability within an ecosystem has replaced production capability as a benchmark for analysis. There is a need to embed natural disturbance and other ecological processes within our models and to evaluate management in the context of longer temporal scales and multiple spatial scales. What is left behind on the landscape through time (its desired condition) has become more important, instead of just what has been harvested or taken.

Models built with Spectrum are envisioned to fulfill many needs of the planning process and informed decision making. They can be used to formulate and evaluate alternative desired conditions for the various landscapes of the forest. A model can explore alternative pathways for achieving a specific desired condition. The resource interactions and effects of applying a variety of management actions to landscapes through time can be examined. Models can assist in developing feasible and sustainable management plans by scheduling activities subject to specific management objectives and constraints. The tradeoffs among alternative management plans can be explored in terms of ecological, environmental, and economic factors. Perhaps the greatest use of Spectrum models is for asking "what if" questions and doing sensitivity analysis on major assumptions and uncertain data. For example:

- what if we emphasize amenities over commodities?
- what if we allocate all suitable wildlife habitat to reserves?
- what if we have reduced budgets?
- what are the implications of our resource inventories being off 10%?
- how will our ability to provide the projected levels of goods and service be affected if insects impact 10% of specific landscapes?

SYSTEM COMPONENTS

Figure 1 portrays the components of Spectrum and their relationship to one another. Spectrum is accessed through a graphical user interface which presents sophisticated analytical capability for complex problem analysis in a user-friendly manner through "Windows-like" features such as point and click menus and pick lists. Within the interface the user will find:

- a data entry system with on-line help screens for model building and editing;
- a model manager to track multiple models;
- a run manager for executing models via the background analytical engine;
- a solution manager for creating customized solution reports;
- graphical display of certain model data and solution information;
- utilities for data import and solution export.

Spectrum uses relational database structures to store all model data and solution results. These structures are

xBase-compliant enabling a user to access them outside of Spectrum via popular database management systems such as dBase, FoxPro, or Access.

At the heart of Spectrum is the analytical engine, which generates a matrix for the linear programming algorithm, solves the matrix, and interprets the solution results into a series of reports and database files. Spectrum uses a commercial linear programming software package known as C-WHIZ (Ketron Management Science, 1994) to solve the matrix. The analytical engine provides for very flexible and robust problem specification.

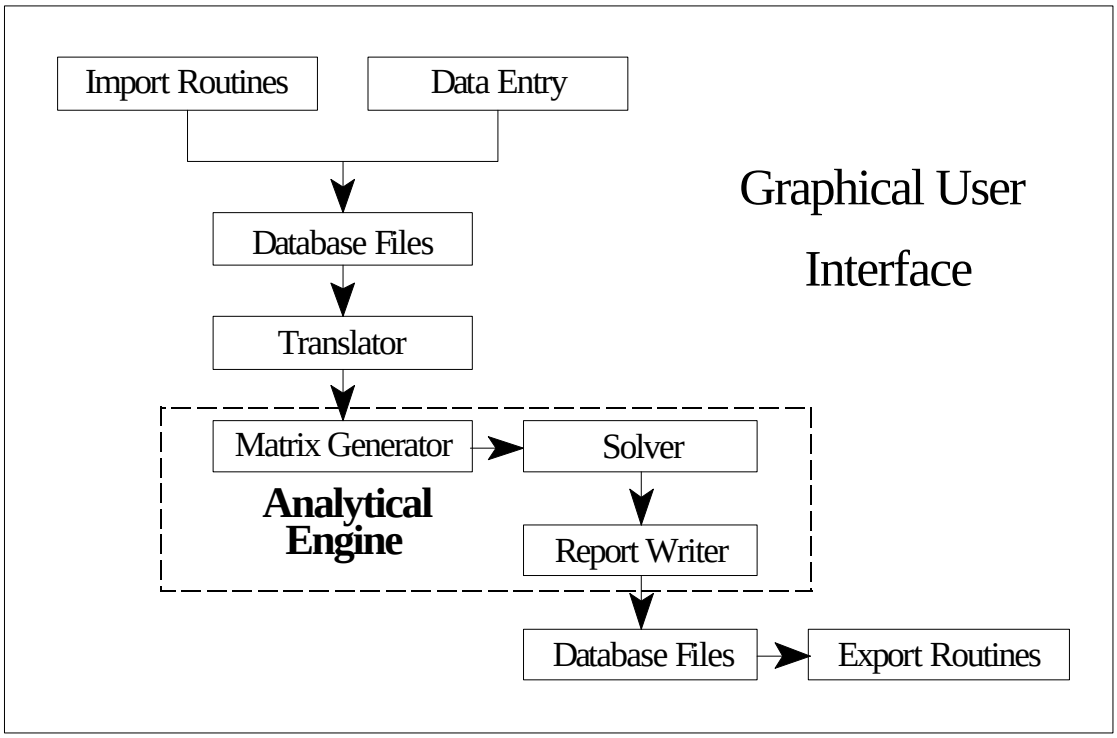

Figure 1.—Spectrum system components

Spatial Specification

The primary data units in Spectrum are areas of land or analysis units. Analysis units can be contiguous with similar characteristics, discontiguous with similar characteristics, or contiguous with dissimilar characteristics, depending upon the needs of the analysis. The user has up to six attributes to describe the characteristics of each area of land. The number of allowable analysis units for a given model is virtually unlimited.

Contiguous analysis units (or contiguous parts of analysis units) can be grouped together into zones. Zones are used to address a higher level of scale than analysis units; typically they represent logical management units. The management of the representative analysis units within a zone can be coordinated. For example, all the acres within a zone must be managed as a wildlife reserve. Zones can also be used to model activities and outputs that occur on an area basis instead of an acre basis (which is the case for analysis units). For example, it usually makes sense to associate the amount of road building with the management choice of an entire area. Furthermore the user can control the timing of these activities so that, for example, only 25% of the road building occurs during the first time period.

Temporal Specification

Each Spectrum model has a specified time frame called a planning horizon. The planning horizon is broken into equal length intervals called periods. The user specifies the number of periods (up to 90) and the period length depending upon the needs of the analysis. Exploring sustainability issues would dictate a model with a long time horizon, while a model with small periods may be used for a budget analysis.

Management Actions

Management actions are characterized by two attributes, typically management emphasis and management intensity. They consist of a set of activities that when applied to specific areas of land results in a set of outputs and/or conditions. These sets of activities and outputs are packaged together in what is called a yield composite. The resource coefficients associated with each member of a yield composite are either listed in tables or described as a relationship to another member. For example, the amount of logging costs may be directly related to the amount of timber volume removed.
The relationship may be discriminated by the type of management (emphasis and intensity), the type of land it is being applied to (via its attributes), and the type of vegetative treatment that is occurring. The habitat for a particular species of wildlife may be different following a shelterwood treatment than a clearcut.

Economic information can be applied to any of the activities or outputs as appropriate. The coefficients can be discriminated by the type of management, the land area, the type of vegetative treatment, and descriptors of the resource yields. For example, timber from 18" diameter logs may be more valuable than timber from 12" diameter logs. Economic information can also be trended through time and derived from price/quantity demand data.

Each management action has a schedule of timing options associated with it. The schedules can be either time-based or age-based. Time-based schedules specify when, during the planning horizon, the management action can first begin. Age-based schedules utilize the vegetation age for the same purpose. Spectrum facilitates defining schedules for uneven-aged, shelterwood, and clearcut management regimes.

Multiple Outcome Model 2 Formulations

In Model 1 formulations, each decision variable in the linear programming matrix represents possible management for a land area over the entire planning horizon. In traditional Model 2 formulations, each decision variable represents possible management for a land area over the life of the stand with a set of decision variables representing the generations of stands that can occur over the planning horizon (Johnson and Scheurman, 1977). However, each decision variable recognizes only one outcome at each age from regeneration of the stand to regeneration harvest. Spectrum improves upon traditional Model 2 in a number of ways. First, acres can split among multiple regeneration classes. This, for example, allows for the explicit recognition of regeneration failure. Second, acres can pass to regeneration classes any time during the rotation, allowing explicit recognition of mortality. Third, acres can move to other classes besides regeneration classes--that is, classes with stand ages other then zero. This allows embedding probabilistic outcomes into the model. For example, models can be built to represent multiple outcomes following commercial thinning or multiple outcomes of catastrophic events.

State and Flow Variables

To address ecosystem management issues, it is important to be able to embed simulation of ecological process and natural disturbance modeling within our planning models. Multiple outcome Model 2 formulations provide us with

some of this capability as does the use of state and flow variables. An example of a state variable is the number of animals of a particular species in a given watershed. An example of a flow variable is the number of animals moving into or out of that watershed. These variables are used in linear and non-linear equations (using linear approximation techniques) which can cross over all or just a subset of all management actions. The equations can have a temporal dimension as well as an initial condition. Once defined, the variables can be subsequently used in constraints and objective functions. State and flow variables make it possible to derive model solutions using non-linear ecological relationships as the basis for selecting among a range of possible management actions.

Constraints

Specifying constraints in Spectrum is as easy as writing a linear equation. The variables in the equation are called constraint variables, which are simply an activity or output for a subset of your model (specific land areas, management actions, vegetative treatments, stand ages). Constraints have a temporal dimension to them but it does not have to be the same for both variables. A few examples of constraints are:

- acres of elk habitat in period 7 must be at least 7000 acres.
- acres of early successional stage in periods 1 and 2 must be at least 42% of the acres of late successional stage in periods 2 and 3.
- timber volume cannot decrease by more than 10% in each successive time period.
- amount of recreation in area A in periods 1 and 2 must exceed the amount of recreation in area B in periods 2 through 5 by at least 100 units.

Mathematical Programming Options

Spectrum offers an array of optimization techniques and flexible specification of objective functions. In addition to traditional linear programming, cardinally weighted goal programming and mixed integer programming solution techniques are available. Linear programming optimizes a single objective either through maximization, minimization, MAX/MIN, or MIN/MAX. The MAX/MIN formulation maximizes the minimum level of a critical resource throughout the planning horizon, while MIN/MAX minimizes the maximum level of an undesirable outcome.

Goal programming tries to achieve several objectives simultaneously. A goal or target is specified for each objective and a solution is sought that minimizes the weighted sum of deviations from these targets. Individual objectives may have different degrees of importance reflected in the penalty weight attached to deviation from their targets. In addition, an individual objective may have different penalty weights depending upon the direction and magnitude from the target, as well as the time period. The user has the option of minimizing under-achievement of goals, over-achievement of goals, or both.

SPECTRUM APPLICATIONS

Spectrum has seen growing use since it initial release in February, 1996. Several models have been constructed for National Forests in the Pacific Northwest and the Rocky Mountains. Spectrum has also been adopted for use by private forest industry in the U.S. and by public forest managers in Australia. Typical of models being developed are goal programming formulations to try to create a mix of successional stages distributed spatially (generally by watersheds) throughout the forest and natural disturbance models showing the effects of change agents such as fire, insects, and disease based on historical and estimated probabilities.

Researchers at the Rocky Mountain Forest and Range Experiment Station have used Spectrum in a number of their studies. Hof et al. (1994) utilized a mixed integer formulation to optimize the spatial layout of management actions

for providing wildlife habitat over time. Bevers et al. (1994) developed wildlife species viability optimization models to convert a given set of initial forest conditions, through a combination of natural growth and management treatments, to a forest system which addresses the joint habitat needs of many wildlife populations over time.

Attendance at Spectrum training sessions and requests for software and training have shown keen interest in Spectrum throughout the world. Training sessions have been given in Bolivia and at the European Forest Institute in Finland. A number of National Forest offices have retrieved the software and have begun to use it for analysis in support of Forest Plan revisions. Other government agencies, universities, timber corporations, consulting groups, and several land management agencies in foreign countries have also requested Spectrum software and have participated in user training.

TECHNICAL SPECIFICATIONS

Spectrum requires a 386 or better PC with 16 megabytes of memory and a mouse. Large models can require up to 200 megabytes of free hard disk space. If you use a 386 machine a math coprocessor is required. C-WHIZ from Ketron Management Science is needed for solving models, otherwise the rest of the software is available from the Ecosystem Management Analysis Center free of charge. The mixed integer programming option requires the MIP module of C-WHIZ, which must be purchased separately from Ketron. A version of Spectrum is available that requires only 8 megabytes of memory but only 20 time periods can be used for analysis.

Spectrum Release 1.5 is currently available. For information on how to obtain the software or user documentation, please contact Kathy Sleavin. [Phone: (970) 498-1833] [Fax: (970) 498-1660] [Email: ksleavin/rm@fs.fed.us].

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