Simulation Models and Management of Rangeland Ecosystems: Past, Present, and Future

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Rangeland ecosystems on public and private lands are subject to increasing pressures to meet multiple-use objectives, while managers, management techniques and plans on those same lands are subject to heightened public scrutiny. The most significant problem facing natural resource planners is that no uniform set of management guidelines fits all community types, pastures or units of land. Plant communities and associated environmental factors are multivariate in nature and interactions between plants, soils and environment are complex. Resource managers are faced with synthesizing an overwhelming amount of scientific information relative to ecology, soils, hydrology and range management principles. Innovative management tools, including simulation models and decision support systems, are needed to meet the multi-faceted challenges of rangeland ecosystems.

Models are abstractions of the real world or representations of the relationships under consideration. Simulation models have become important tools in the management of cultivated lands. However, simulation models have not been widely employed in the management of rangelands. Rangeland ecosystem process modeling has advanced to a level of sophistication, applicability and utility. The question remains whether such models are now viable management tools which could or should be more widely employed by land managers and agencies.

At the 50th Annual Meeting of the Society for Range Management, a symposium held in February, 1997 in Rapid City, S.D., addressed the use of simulation models in natural resource planning and management. This paper summarizes the symposium and provides a current reference for natural resources modeling activities associated with rangeland ecosystem management. Individual authors can be contacted for more detailed information.

Symposium Titles and Authors

ELM (Ecosystem Level Model): The beginning. Robert Woodmansee. Dept. Rangeland Ecosystem Science, Colorado State University, Fort Collins, Colo 80523

SPUR2 (Simulation of Production and Utilization of Rangelands): Its development and application. Jon Hanson. USDA-ARS, Great Plains Systems Research Center, Fort Collins, Colo 80522

SPUR-91 (Simulation of Production and Utilization of Rangelands): Its development and application. Tom Thurow. Dept. Rangeland Ecology and Management, Texas A&M University, College Station, Tex 77843

SPUR2.4 (Simulation of Production and Utilization of Rangelands): Its development and application. Richard Teague and Joelyn K. Foy. Dept. Texas Agricultural Experiment Station, The Texas A&M University System, Vernon, Tex 76385

RAPPS (RAngeland Plant ProfileS): Its development and application. Phillip L. Sims, Derek W. Bailey, Michiel B. Coughenour and James A. Bradford. USDA-ARS, Range and Pasture Research, Woodward, Okla 73801

WEPP (Water Erosion Prediction Project): Its development and application on rangelands. Mark Weltz. USDA-ARS, Southwest Watershed Research Center, Tucson, Ariz 85719

GEM (Generation of Weather Elements for Multiple Applications): Its application in the management of rangelands. Clayton L. Hanson and Greg Johnson. USDA-ARS, Northwest Watershed Research Center, Boise, Ida 83712

SHAW (Simulation of Heat And Water): Its application in the management of rangelands. Fred Pierson and Gerald Flerchinger. USDA-ARS, Northwest Watershed Research Center, Boise, Ida 83712

RANGETEK: Its development and application. Ross Wight. USDA-ARS, Northwest Watershed Research Center, Boise, Ida 83712

Use of simulation models in decision support systems. Jerry Stuth, Richard Conner and Wayne Hamilton. Dept. Rangeland Ecology and Management, Texas A&M University, College Station, Tex 77843

Factors that affect the adoption and use of simulation models as decision support tools. Ara Gardner. Dept. of Forest Resources, University of Idaho, Moscow, Ida 83843, and Ross Wight. USDA-ARS, Northwest Watershed Research Center, Boise, Ida 83712

Simulation models and rangeland management: The future. Will Blackburn. USDA-ARS, Northern Plains Area, Fort Collins, Colo 80525

Simulation models and rangeland health: Problems and Solutions. Ken Spaeth, USDA-NRCS, Northwest Watershed Research Center, Boise, Ida 83712, Fee Busby, USDA-NRCS, Little Rock, Ark 72201, Pat Shaver, USDA-NRCS, Corvallis, Ore 97331, Rhett Johnson, USDA-NRCS, Fort Worth, Tex 76115 and Dennis Thompson, USDA-NRCS, Washington, DC 20250

Synthesis and reflections. Herman S. Mayeux. USDA-ARS, Beltsville, Md 20705

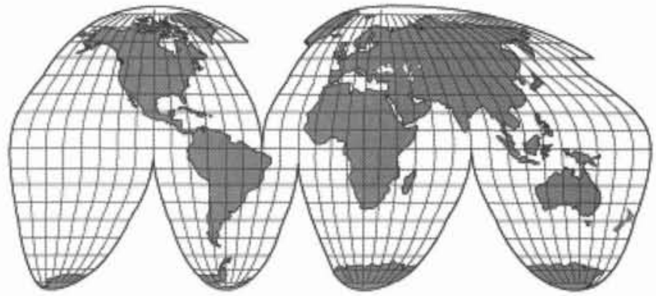
Rangeland Resource Models

Early modeling efforts began in 1965 with the development of ecosystem models via the International Biological Program (IBP). The IBP Grassland Biome study was "an experiment in big biology"dedicated to improve understanding of the structure and function of ecosystems. Through this effort, the Ecosystem Level Model (ELM) was developed. It was comprised of five basic components: 1) abiotic variables driven by temperature, water and carbon dioxide, 2) nutrients focused on nitrogen and phosphorus, 3) producers, 4) consumers, and 5) decomposers. ELM reasonably represented the biomass dynamics of IBP perennial grassland sites and their response to management alternatives.

The ELM effort provided important lessons to the future of ecosystem modeling: 1) modeling efforts require careful and detailed organization, 2) models require full documentation to facilitate future modification and user support, 3) models organize information and, if clearly described and explained, they are excellent communication devices, and 4) models both rely on and can guide field research because they integrate knowledge, guide the investigation of poorly understood mechanisms, and test hypotheses. The ELM provided a conceptual framework for much of the modeling progress over the last 25 years.

In 1987, the Simulation of Production and Utilization of Rangelands (SPUR) model was released as a general grassland simulation model composed of four basic components: hydrology, plant growth, animals (domestic and wildlife), and economics. The hydrology component in SPUR calculates a soil water balance, upland surface runoff volumes, peakflow, snowmelt, upland sediment yield, channel streamflow and sediment yield. In the plant component of SPUR, carbon and nitrogen are cycled through several compartments including standing live, standing dead, live roots, dead roots, seeds, litter and soil organic matter. The model simulates both competition between plant species and the impact of grazing on vegetation. The animal component of SPUR calculates domestic livestock physiology and forage harvesting by wildlife for all classes of animals including forage preference, palatability and utilization. Wildlife species, including insects, were considered as fixed consumers and were given first access to the available forage. SPUR was primarily designed to be used as a research and development tool.

The SPUR2 model is an enhancement of SPUR with modifications to the plant, animal, plant/animal interface and wildlife components. Modifications to the plant component include an improved method for calculating daily photosynthesis, and the ability to simulate plant response to elevated carbon dioxide. The animal component was enhanced by improving the energy dynamics for steers, the inclusion of a genetic-based cow/calf model, and the ability to design and test grazing systems. A new plant/animal interface was developed that incorporates the bite-count method of foraging. The wildlife component was improved by the addition of a grasshopper component. The SPUR2 model has been used to describe the impact of global warming and climate change on U.S. rangelands and the responses of arid and semiarid watersheds to increasing levels of carbon dioxide.



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The SPUR-91 model was a revision of the original SPUR model. The SPUR model worked well on the short-grass prairie, but did not represent sites with multiple growing seasons and both warm and cool season plant species. The modifications made to SPUR were therefore directed primarily at improving hydrology-plant intercommunication. Soil evaporation was linked to amount of vegetation cover which improved evapotranspiration predictions for low or no cover conditions, while permitting the original evapotranspiration model to remain unchanged for greater vegetative cover conditions. Plant growth was modified to provide accurate rates of plant dieback during seasonal dry periods, and generation of multi-modal growth curves. Better representation of the location of plant roots within the soil profile provided: 1) better timing of plant growth, 2) more accurate estimates of production for individual plant species, and 3) stability in long-term relative species composition.

The SPUR-91 model has potential for aiding in the assessment of various management practices on rangelands. Currently, however, the model is more reliably used to predict general trends rather than absolute values of management responses. At present, the model is not designed to simulate the growth processes of nonherbaceous vegetation. There are no algorithms for light attenuation, nor for woody growth or respiration of woody tissue. The modifications incorporated into SPUR-91 have improved the intercommunication between the hydrology, soils and plant components.

The SPUR2.4 version integrated all previous versions of SPUR and added a three-component soil organic carbon and nitrogen submodel which had been identified as a weak component in SPUR. The SPUR2.4 version improved both within- and between-season plant growth and long-term persistence of the key species.

The changes made to SPUR in creating SPUR-91, SPUR 2 and SPUR2.4 have improved the accuracy of the model. The model is now able to do more than just predict general trends of management responses. There is now potential for incorporating the assessment of various management strategies and practices in limited areas.

The ERHYM-II model is an enhanced version of the Ekalaka Rangeland Hydrology and Yield Model (ERHYM) which is a modification of an earlier crop yield model. It is a climate/water-balance model which provides daily simulation of soil water evaporation, transpiration, runoff and soil water routing for individual range sites. The model can utilize real-time climate data to simulate ongoing processes, or it can utilize long-term weather records or stochastically generated weather records to simulate runoff and herbage production (at peak standing crop) under a range of climatic conditions and management practices.

To address the need for readily-available climate data for any location, a stochastic climate simulation model has been developed which delivers accurate time series of daily or higher temporal resolution weather data.

Rangeland Plant Profiles (RAPPS) is a perennial, cool-season and warm-season, grass model that simulates for a single, average plant, and by extension for a monoculture, the following five plant functions: 1) phenology, 2) morphology, 3) chemical balance, 4) growth, and 5) tissue loss. The model calculates biomass production per unit area by plant part, digestibility, forage quality, plant dimensions, plant morphology and timing of phenological events. The construction of RAPPS in a modular format allows individual researchers to focus on modules appropriate to their research interests.

The Simultaneous Heat and Water (SHAW) model simulates the movement of water and heat through a vertical profile of vegetation, snow, soil surface residue and soil. The model looks at the plant-soil system as a series of layers starting from the top of the plant canopy and extending down through the soil to a depth specified by the user. Simulated processes include the influence of soil freezing and thawing, evaporation, transpiration, infiltration and surface runoff. The SHAW model provides hourly or daily predictions of temperature, water potential, ice and solutes at any specified point throughout the soil profile. The model simultaneously simulates the influence of several plant species and dead plant material on soil water and temperature conditions. After the required weather data are furnished to the model, it then predicts how much heat and water will move between layers or will be lost out the bottom of the soil profile or back into the atmosphere. The SHAW model is a very detailed process-based model; however, as a stand-alone management tool, it currently has limited use because it does not directly address management applications. The model must be coupled with other models or decision support tools to become useful for addressing practical rangeland management scenarios.

Water Erosion Prediction Project (WEPP) is a process-based model developed to replace the Universal Soil Loss Equation (USLE) for erosion prediction. It operates on a daily time step, allowing for the incorporation of temporal changes in soil infiltration, management practices, above- and below-ground biomass, litter biomass, plant height and canopy cover. The model is designed for use on a wide spectrum of grazing lands including rangelands, pastures, woodlands and alpine meadows. The WEPP model is intended to apply to all situations where soil erosion by water occurs, including that resulting from rainfall, snowmelt, irrigation and ephemeral gullies.

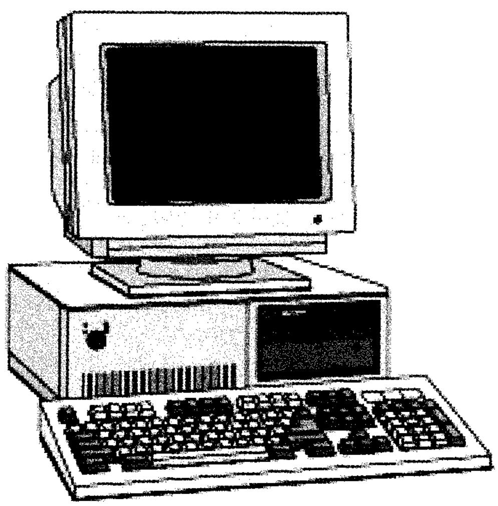
The hillslope version of WEPP can be conceptually divided into seven conceptual components: climate, topography, soils, hydrology, erosion, management, and plant growth and decomposition. A hillslope can be subdivided into 10 overland flow planes that represent different soil types, vegetation communities or management activities. The grazing option allows for 10 rotations of livestock within a year on each overland flow plane.

The watershed version of WEPP estimates soil loss and deposition from one or more hillslopes within a watershed. It computes sediment delivery from small watersheds and computes sediment transport, deposition and detachment in small channels and impoundments within the watershed. This includes erosion in ephemeral gullies and channels, but not "classical" gullies. The WEPP watershed model is limited to field-size areas, estimated to be approximately 800 acres for rangelands. To realize the full potential of WEPP as a management tool, requires improvements in the estimation procedures used to represent vegetation, soil, and management-induced temporal and spatial variability.

To address the need for readily-available climate data for any location, a stochastic climate simulation model has been developed which delivers accurate time series of daily or higher temporal resolution weather data. This model, Generation of weather Elements for Multiple applications (GEM), retains the basic internal structure of previous climate models, but has several significant improvements. The GEM model allows a user to select a location and request a simulated weather sequence for that location for as many months or years as needed. At present, GEM delivers a daily time series of maximum and minimum temperature, precipitation amount and solar radiation for any location, even in regions where no long-term climatic data exists.

Decision-Aid Software for Making Management Decisions

Contemporary ecosystem management, in which the land is viewed in a more holistic way, requires public land managers and consultants to be able to develop, justify and defend decisions with the assistance of computer systems. Computer software specifically designed



to aid in the decision-making process can enhance the ability of managers to view the greatest range of options and decide among them with greater confidence and insight. Decision-aid software includes: simulation models, databases, visualization systems and expert systems.

Because decision-aid software systems have not been extensively used by natural resource managers, a study was conducted to determine how significant certain perceived software characteristics are in affecting the potential user's intention to adopt these systems. Interviews were conducted with USDI-Bureau of Land Management, USDA-Forest Service, USDA-Natural Resources Conservation Service (NRCS) and Idaho Department of Agriculture managers. Each respondent that filled out the written questionnaire had tried at least one decision-aid software. Respondents commented on timber growth and yield simulation models, timber projection models, grazing land management decision-support-system models, pest and pathogen disturbance models and water quality models. Quantitatively, the variable "Compatibility" was the only variable that described how the respondents thought about the use of decision-support systems. Compatibility is the degree to which the user felt using the software was consistent with their past experiences, values, needs and job goals. The strongest qualitative predictor of adoption was "Participatory Design" which is how much the user of software is involved in the actual design of the software. Thirty out of 35 responses indicated that the end user should participate at a high level in an early stage of software development to create better, more usable software tools. This idea was summed by one respondent who stated that, "models don't get used at the ground level if field-level managers are not involved somehow."

To match software to end users' values, past history, needs and job goals, software developers must understand how end users think, how they do their jobs, and how they make decisions. For example, many respondents commented that they felt that software modelers/developers thought that the more calculations and/or more functions their models could perform, the better; actually field-level managers wanted only one or a few of these functions performed to really assist them in their decision-making process. Here, the first respondent hit a chord when she said, "Developers don't live in our environment where we make decisions on the ground; I don't think they have a clue how we make integrated decisions."

A summary of this study suggests that, even though respondents may have found that using the software was complex or frustrating, they still felt that if a decision-aid provided what they needed in their jobs and in their decision-making scenarios, it was a good tool. These findings send the strong message to software developers; that if software tools are going to be used in the decision-making process by natural resources managers, participation in development by the end user, and a thorough understanding of end user values, goals and needs, are crucial.

Examples of Decision-Aid Software

Decision support systems (DSS) are decision-aid software that are designed to represent complexity of a particular decision environment in an understandable manner. Grazing Lands Applications (GLA) is a comprehensive ranch-level planning system for nationwide application. The GLA was implemented in NRCS field offices across the U.S. in 1991 and represents the first comprehensive DSS ever developed and deployed for application on grazing lands.

The GLA maintains a database structure that allows information to be used for local problems. The DSS is designed to allow storage and retrieval of client-independent and client-dependent databases that support planning activities for assessment of forage supply, demand by animals and forage balance, nutritional status of grazing animals, economic feasibility of investments and grazing strategies for a given property. Client-dependent analysis involves creation of forage inventories, herd definition/profiling, grazing schedule/balance and combined long-term stocking responses. The GLA is essentially a forage budgeting framework relying on externally computed information, professional judgement of anticipated responses of vegetation and landholder interviews. Additional decision support tools include a module for long-term investment analysis linked to the combined stocking response.

Multiple Species Stocking Calculator (MSSC) was developed to address more complex planning issues. It utilizes a complex diet selection model with a limited input interface to determine stocking rates of multiple species of livestock in the presence of wild ungulate populations. The MSSC is a preference-based stocking system which shifts planning to understanding the diet-selection process and establishment of desired levels of utilization on target plant species. Plant species within the GLA plants database have to accommodate one of five major selection classes, depending upon the animal species of interest for each quarter in the year. The success of MSSC depends largely on the user's ability to properly characterize the forage on offer to the animals, assign an animal unit equivalent (AUE) value, understand the average population density of the wild herbivores, and feel comfortable with the assignment of the preference classes for plant-animal species.

The Nutritional Balance Analyzer (NUTBAL) was developed to meet GLA users' requests for a nutritional management module which allows more accurate assignment of animal-unit equivalent values throughout the production year. The NUTBAL provides representation of breedtypes and environmental conditions in a manner such that users are not forced to input information that is difficult to acquire. The use of NUTBAL has dramatically risen as its capabilities have been improved and a new fecal profiling service has become more widely used by professionals.

The Grazinglands Alternative Analysis Tool (GAAT) DSS was developed to overcome the problem of dynamic shifts in grazinglands enterprises (animal and non-animal) over longer planning horizons. The GAAT incorporates a dynamic economics model to assess net present value and internal rate of returns from an investment stream applied to a specified land unit. The GAAT accommodates analysis of a wide variety of animal and non-animal enterprises, either individually or in combination. It allows changes in any specific category of annual operating costs and/or product prices throughout the planning period. The GAAT accommodates breeding herd replacement from purchased or retained young animals. The GAAT can accommodate changes throughout the planning period in the proportion of available forage and/or feedstuffs allocated to each enterprise. The GAAT provides planners and consultants the capability to analyze complex situations where economic response must be tempered in ecological and biological reality.

The RANGETEK is decision-aid software designed for use at the field level. It makes extensive use of user-friendly menus, help screens, and expert system technology to organize input and output information and estimates values for input variables and parameters. The RANGETEK provides for the daily simulation of soil and plant evaporation and water routing through the profile. Minimum plant and soil parameters include dates of growth initiation and peak standing crop, average site herbage yield, and soil texture by horizon. The RANGETEK is intended for two main applications: 1) real-time simulation of daily soil and plant evaporation and soil water content, and 2) forecasting annual herbage production. Real-time simulations are used to monitor soil water and compute actual transpiration/potential transpiration ratios as indicators of current growing conditions. The calculated actual transpiration/potential transpiration ratios are used as yield indices to predict peak standing crop yields and to forecast herbage yields based on soil water content at the beginning of a growing season.

Phytomass Growth Model (PHYGROW) was developed to capture critical concepts from a wide array of models addressing hydrology, plant growth, diet selection, animal production and human decision making. The user can define plant communities with an unlimited number of species or functional groups of species. A module in PHYGROW allows the user to simulate various levels of risk in human decision making as it relates to destock/restock decisions. Currently, PHYGROW is being used primarily for policy analysis and drought monitoring systems.

Discussion and Conclusions

Changing societal demands for environmentally sustainable management practices and the growing trend to meet these demands through increased regulation requires improved prediction technology. While traditional rangeland research has led to the development of improved vegetation management practices, it has done little to enhance predictive capabilities of complex ecosystem processes. Rangeland plant communities are

Rangeland research has led to the development of improved vegetation management practices.

very unique and "rule of thumb" notions and "one equation fits all" approaches which depict linear attributes to be used ubiquitously for all rangeland plant community types do not result in models with much utility and robustness.

Natural resource planners and managers have encountered problems with the use of simulation models. Some models do not meet the needs of resource planners because considerable customization is needed to get information that is useful in the planning process. Input parameters are often ambiguous and not intuitive to the user. For example, the primary reasons for the lack of use of simulation models by the NRCS are complexity of software, availability of data, lack of validation for many rangeland communities, and models that incorporate the Universal Soil Loss Equation (USLE) and the Hydrologic Curve Number (HCN) are limited in scope for use on rangelands.

Natural resource planners and managers must account for interactions among soils, water, air, plants and animals. Rangeland simulation models can integrate these components of the rangeland ecosystem to facilitate evaluation of alternative management scenarios. Management alternatives can be evaluated in terms of how they affect hydrology, the plant community and soil stability. Rangeland simulation models, in theory, offer land management agencies planning assistance that is based on a high degree of science and technology. In order to successfully utilize this technology, the resource planner needs to know about many of the attributes in the rangeland plant community: plant community composition, soil information, climate, hydrology, and ecological attributes related to succession and plant composition. As rangeland simulation models evolve, potential applications for them may include evaluation of plant composition shifts, effects of grazing management strategies, and fire on plant communities and subsequent hydrologic trends.

Selection of simulation models to address problems on rangeland is difficult, given the potentially wide range of study objectives, data constraints, and spatial and temporal scales of application. Development of a Modular Modeling System for rangelands is needed. Modules and algorithms must be developed to specifically represent rangeland processes. The future of simulation models for rangeland management exists in our ability to selectively couple appropriate modules from a library of modules to create an optimal model for a desired application.

The development of viable simulation models is a long-term process. Decades, rather than months or years, may be needed to accomplish the comprehensive development, testing, validation, data collection, refinements and user simplifications necessary to make a model a viable, off-the-shelf management tool. This requires long-term commitment by individuals and organizations. It means commitment to collect basic data and to test, validate and maintain the model.

The process of model development, in and of itself, is valuable in studying ecosystem processes and how they function and interact. Simulation models can provide useful management information throughout their development, with the kinds and amount of information provided being consistent with their stage of development. While the application of simulation models may seem intuitive, more effort is needed on development of formalized procedures for using models as decision support tools; GLA is one example.

The transfer and acceptance of science-based technology to rangeland resource managers has been difficult. Success will depend on a team approach between model developers and model users and the commitment by both to stay the course. Such teamwork will result in the development of technologies for using these models as decision support tools.

Simulation models, used independently and as components of computerized decision support systems, will play an increasingly important role as decision support tools in the management of rangeland ecosystems. Through their ability to simulate plant community dynamics, runoff and erosion, they will also find application in dealing with trend analyses and rangeland health issues. The complexity and litigious nature of today's natural resource management problems require such tools.

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