Rangeland Ecological and Physical Modeling in a Spatial Context

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Abstract

The Simulation of Production and Utilization of Rangelands (SPUR) model has been in use and revision since 1987 in diverse rangelands including Texas and the Great Plains. The model's applicability to semi-arid rangelands of the southwest is under evaluation at the USDA-ARS Southwest Watershed Research Center in Tucson, Arizona. As part of this effort, a spatially explicit implementation of SPUR (SESPUR) has been developed with the long-term goal of incorporating distributed hydrologic information from GIS-based hydrologic models such as the Soil and Water Assessment Tool (SWAT) and KINEROS, as well as remotely sensed soil moisture. Ease of model use has been improved with the ability to display output with a GIS, and linkage to a database of input parameters will improve the user's experience. Validation of the updated model is in progress with data obtained at the Walnut Gulch Experimental Watershed near Tombstone, Arizona. The original focus of SPUR included prediction of hydrologic and erosion changes resulting from management decisions, as well as simulation of forage growth and its utilization by grazing animals. Its usefulness for other biophysical and ecological modeling has been substantially enhanced with the SESPUR spatial implementation.

Keywords: SPUR, spatial modeling, rangeland ecology, hydrologic modeling

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Introduction

Rangelands form an important part of the natural resources of the western United States. There is growing interest in detailed inventories of rangeland ecosystems and physical processes, such as carbon sequestration and release (Hanson et al. 2001). Computer simulation of rangeland systems provides a means to integrate existing data and understanding of these areas and processes and to extrapolate beyond present conditions, in the generation of "what-if" scenarios that can aid stakeholders in land management decisions.

The SPUR model (Simulation of Production and Utilization of Rangelands) has been under continuing development since its initial release in 1987 (Wight and Skiles 1987). SPUR contains components that model plant growth, carbon and nitrogen cycling, soil moisture flux, surface hydrology and erosion, foraging by wildlife, and economics of beef production. There have been ongoing efforts to incorporate improved understanding of landscape processes and to make model components interactive during simulation runs, allowing dynamic changes in system states (Carlson and Thurow 1992, Hanson et al. 1992, Foy 1993, Carlson and Thurow 1996, Foy et al. 1999, Pierson et al. 2001).

SPUR climate driving variables include daily precipitation and temperature maximum and minimum. Additional driving variables that are more difficult to obtain include incoming solar radiation, wind velocity and direction, and dew point. These parameters can be simulated using a routine such as CLIGEN, a stochastic weather generator developed for the WEPP hydrological model (Flanagan and Livingston 1995). SPUR runs on a daily time-step, with output summaries available monthly, annually and at other user-set intervals. Model results comprise text reports of vegetation, soil, hydrologic, and grazing animal numeric outputs (Carlson and Thurow 1992).

Because SPUR is point-based, it is applicable only to small homogeneous areas at the scale of a pasture or smaller, with a basic modeling unit of one soil and one vegetation type. In regions such as the Great Plains these conditions may be applicable over larger areas, but in the southwestern U.S. climate and landscape are characterized by high spatial variability. Such variability suggests that point-based model results may not generalize well over areas of any significant size in this region. Even at pasture scale, differential use of areas by grazing animals can cause spatial heterogeneity that is not well represented by a uniform field (Foy et al. 1999, Teague and Foy 2002).

Recent work at the USDA-ARS Southwestern Watershed Research Center (SWRC) has included development of a raster-based, spatially explicit implementation of SPUR (SESPUR) that can simulate areas composed of mosaics of soils, vegetation, and topography. Model parameterization, calibration and validation will use the Walnut Gulch Experimental Watershed as a study area, with historical data sets and ongoing studies providing data to evaluate SESPUR under southwestern semi-arid conditions. Descriptions of changes to the original SPUR model and initial results from the prototype spatial implementation are presented here.

Methods

The most recently published SPUR upgrade, SPUR2000 (Pierson et al. 2001), was used as the basis for SESPUR. Extensive Fortran code modification was required to allow simultaneous simulation of areas with differing soils, vegetation, and topography including slope and aspect. Additional subroutines were added to handle spatial data processing. Spatial data for input are converted to ASCII text files outside SESPUR and read by the program, and output text files are formatted for import into a geographic information system (GIS) for display and further analysis.

A 70 by 70 meter test area within the Kendall sub-watershed of Walnut Gulch was selected for prototype application development. The Kendall area is primarily grassland, with scattered shrubs, forbs, and small mesquite trees. Some spatial input data for the test area were obtained from GIS layers developed at SWRC for Walnut Gulch, including the 1993 soil survey digital map (Breckenfield n.d.) and a 10 meter resolution digital elevation model (DEM). The test area had two soil units and a variety of slopes and aspects (Figure 1).

Detailed soils information, including layer structure and properties, were obtained from the soil survey and linked to the soils spatial data. Some soil parameters were estimated from textural information (Cosby et al. 1984). A mix of modeled vegetation types--including C4 mid-height grasses, C4 short grasses, annual forbs, perennial forbs, sub-shrubs and shrubs--was assumed to be distributed uniformly in the test area. Vegetation data were acquired in field surveys in 2003, as existing vegetation maps did not provide adequate detail for model needs. Vegetation parameters included species or functional group composition, abundance, cover, and species- or group-specific physiological parameters. Many physiological parameters had to be estimated from the literature (e.g. Carlson and Thurow 1992, Larcher 2003), as detailed information is not available for many southwestern species. Topographic data including slope and aspect were derived with GIS functions from the 10-meter DEM. Climate data were simulated using CLIGEN, based on a CLIGEN-formatted summary file of long-term means and averages of climate parameters for the Tombstone climate station. A one-year simulation was performed for the test area.

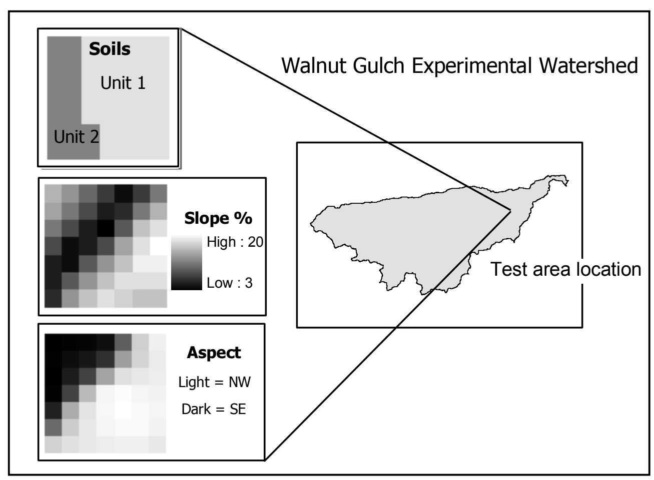

Figure 1. Spatial data for Kendall test area. Test area cell size = 10 meters; total size = 70 x 70 meters.

Results

SESPUR results for one vegetation variable, total monthly biomass production, are shown as a time series in Figure 2. Sensitivity of this variable to soil properties is suggested by the coincidence of higher production with the soil unit on the left side of the test area. This may indicate a need for adjustment of soil properties, as such large differences in production over a relatively small area are rarely seen in the field in this area. An array of additional outputs is available on a daily or monthly basis.

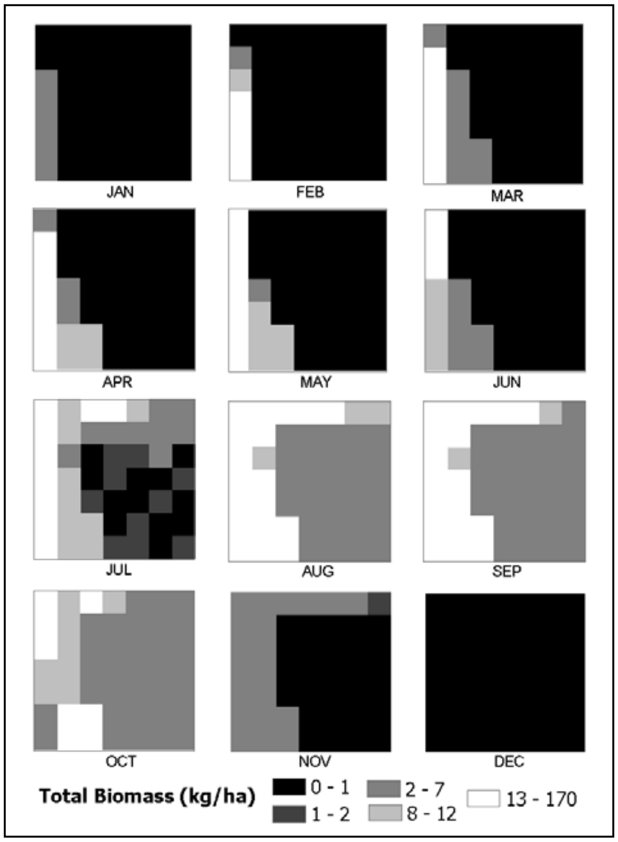

Figure 2. Time series of total monthly biomass production from SESPUR simulation.

The timing of net vegetation peak production in July (not clearly visible in Figure 2) shows a very strong influence of monsoonal precipitation on modeled vegetative growth. However, peak production generally occurs closer to September in this area, also indicating the need for parameter adjustment. SPUR was developed for areas with a well-defined growing season demarcated by last and first frost, and is known to perform less well in warm regions where extended or multiple growing seasons are possible (Carlson and Thurow 1992). This may be an area for future software modification, perhaps using a degree-day and soil moisture combined index to define growing season(s) during the year. Comparison of biomass production results with limited field data from May 2001 suggest model underestimation by at least one order of magnitude, but more field data will be needed to test this result.

Conclusions

The spatial implementation of SPUR opens up many possibilities for more accurate simulation of rangeland processes. The spatial distribution of daily vegetation growth and its impact on soil moisture may provide a valuable adjunct to a variety of physically based models. These include hydrologic models that focus on spatial routing of precipitation runoff, such as SWAT and KINEROS; and soil-vegetation-atmosphere (SVAT) models that examine overall water, carbon and energy balances. Increased understanding of other issues such as the shift to woody plant dominance in southwestern rangelands, and its implications for carbon cycling (Archer et al. 2001), will be facilitated by this kind of spatially detailed modeling.

The SESPUR model's potential is associated with a significant burden of data needs for parameterization, calibration and validation that may be complicated by the addition of spatial variability. It is anticipated that the model can be simplified and customized for southwestern rangelands, thus reducing data requirements. Immediate research data needs include a map of vegetation structure or composition with fractional cover estimates (i.e. percent woody vegetation cover and percent grass cover). Field data compiled during the 2003 growing season will be compiled with existing vegetation production data for further calibration and validation. Modeled soil moisture will be validated against in-situ measurements from the Walnut Gulch sensor network and estimates from remotely sensed data (see Bryant et al., this volume).

Significant effort is also presently required simply to assemble data for model runs. A user-friendly GIS-based interface is under development, which will assist in model parameterization and visualization of results. The improved interface and simplification of data requirements will support our efforts to make SESPUR a decision support tool that can be used by southwestern rangeland stakeholders as well as researchers.

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