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SPUR— Simulation of Production and Utilization of Rangelands:

A Rangeland Model for Management and Research

PREFACE

The application of modeling technology to problems of range research and resource management received considerable impetus through the Grassland Biome Study headquartered in Fort Collins, Colorado, during the late 1960's and early 1970's. Publication of the Grassland Simulation Model (ELM) demonstrated that the processes within a grassland ecosystem could be modeled and provided methodology and direction for future modeling efforts. ELM also demonstrated the utility of a model as a research tool and an aid to resource management.

A program entitled "Improved Management and Production of Western Rangelands Using Predicting Models and Remotely Acquired Data," submitted by C. H. Herbel and W. O. Willis, was perhaps the first formal step toward the development of a range modeling effort by the Agricultural Research Service (ARS). Subsequently, a Research Planning Workshop on Range Modeling was held in Fort Collins, Colo., April 20-21, 1978. The participants of this workshop recommended that a range modeling effort be initiated immediately within ARS. The major goals stated were: "(a) increased use of modeling among range scientists as a research technique to guide and improve on-going research and provide data bases and submodels for use in more comprehensive models; and (b) development of comprehensive models that can be used effectively as planning and decision-making tools in the management of rangeland resources and administrative and research programs."

The SPUR modeling effort was initiated in September 1980 with the organization of a coordinating committee composed of R. A. Evans, R. H. Hart, G. B. Hewitt, C. L. Hanson, L. J. (Kelvin) Koong, K. G. Renard, P. L. Sims, J. R. Wight (project coordinator), and G. E. Carlson and J. C. Ritchie representing the ARS National Program Staff. At coordinating committee meetings in November 1980 and February 1981, objectives, organization, and procedures were established.

Model components and lead scientists were identified as follows:

(a) Climate -- C. L. Hanson, Boise, Idaho
(b) Hydrology -- K. G. Renard, Tucson, Ariz.
(c) Plant -- R. H. Hart, Cheyenne, Wyo.
(d) Animals -- Kelvin Koong, Clay Center, Nebr.
(e) Insects -- J. A. Onsager, Bozeman, Mont.
(f) Economics -- E. B. Godfrey, Logan, Utah

A range model workshop was held in early May 1981. Organization of the range model workshop was similar to that of the initial CREAMS (A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems) Workshop. Workshop objectives were to: 1) review, refine, and adopt an approach; 2) establish lines of action and establish a timetable; 3) assign specific tasks; 4) identify data sets for validation and verification; and 5) complete a workgroup report.

A total of 54 persons, including participating scientists, administrators, user agency representatives, and interested visitors attended the workshop. The heterogeneous mix of scientific disciplines and management specialists, which is somewhat unique to range science and management, providing a stimulating environment for the discussion and development of modeling objectives and research plans.

Time tables of February 1, 1982, and October 1, 1982, were established for completio of the model components and component interfacing, respectively. With little exception, these timetables were met.

Everett Springer was hired as project modeler. Component interfacing and model testing and evaluation have been substantially enhanced through his efforts.

Spur components and their testing utilized existing data and knowledge. The help of non-USDA-ARS scientists, especially in the economic, animal, and plant components, i gratefully acknowledged. Suggestions and advice from potential user groups was continually sought and freely given throughout the course of the project.

At the time of this writing, an initial version of SPUR is operational and available for research. Documentation and user manuals will be completed in 1983, at which ti an operational version of SPUR is scheduled for public release. User manuals, documentation, and FORTRAN programs of SPUR and test data on magnetic tape will be available.

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SPUR HYDROLOGY COMPONENT: WATER ROUTING AND SEDIMENTATION

By L. J. Lane[1]

INTRODUCTION

Stream channels, and thus watersheds, combine in complex patterns to produce upland areas, channel networks, and interchannel areas. These features control the routes and rates of water and sediment movement as runoff occurs in response to precipitation. While many of the physical processes controlling water and sediment movement are common to the upland areas and the stream channels, channel processes are sufficiently complex and important to require special attention in formulating a simulation model. Of particular concern are the relationships among hydrologic processes, flow hydraulics, and sedimentation processes occurring in stream channels.

The objectives of this paper are to describe the development of simplified procedures to estimate runoff and sediment yield from rangeland watersheds by modeling streamflow and sediment transport in channels, to link these processes with the upland phase, and to identify future directions and research needs.

The models described herein are intended for application on small rangeland watersheds with well-defined channel systems where streamflow is ephemeral or intermittent. The procedures can also be applied to streams with base flow under conditions where the time constant in the subsurface flow component is known or can be estimated. Because the sediment yield calculations are based on computed transport capacity, the procedures are designed to compute transport capacity in alluvial stream channels composed of noncohesive sediments.

STRUCTURE OF THE MODEL

The logical and computational structure of the model follows the stream channel network from upland areas to the watershed outlet. Each exterior or primary channel receives runoff and sediment from any combination of an upland and two lateral flow areas. Interior or higher order channels can receive water and sediment from one or two upstream channels and from one or two interchannel or lateral flow areas. Computations proceed in the downstream direction until the watershed outlet is reached.

Linkage with the upland phase is accomplished by taking runoff and sediment yield from the upland and lateral flow areas as input to the channel system. (See the section on "SPUR Hydrology Component: Upland Phases.")

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Water Routing Component

The water routing component is based on a distributed hydrologic model (Lane 1982a),[2] and can include the influence of channel abstractions or transmission losses upon the volume and peak rate of runoff. Mean duration of flow is estimated using watershed characteristics following procedures developed by Murphey et al. (1977). Given estimates of runoff volume and flow duration, peak discharge, and hydrograph shape are estimated using a double-triangle hydrograph approximation (Ardis 1972, 1973; Diskin and Lane 1976).

When the stream channels are ephemeral, the model includes procedures to account for infiltration or transmission losses into the channel beds and banks. Under these conditions, runoff volumes and peak flow estimates include the influence of transmission losses in reducing runoff volumes and attenuating peak flow in the downstream direction. In the absence of significant transmission losses, peak runoff rates are also attenuated in the downstream direction, because hydrograph characteristics, such as time to the peak rate of runoff, increase with increasing drainage area.

The double-triangle hydrograph is broken into N intervals for the period [0, D], where D is the flow duration. This results in a piecewise-normal approximation where normal flow is assumed within each of the N time intervals, and the Manning equation is used to compute flow depth, velocity, and hydraulic radius throughout the duration of flow. The assumption of normal flow within each time interval, but changing flow rates between intervals, allows an approximation of unsteady flow. By changing the piecewise-normal hydrograph in the downstream direction, we approximate spatial variability. The combined results of these assumptions is an approximation to spatially varied and unsteady flow in the stream channels (Lane 1982b).

The water routing component was developed and tested using hydrologic data from Arizona, Kansas, Nebraska, and Texas. The transmission loss equations are based on analysis of runoff data from 14 channel reaches in Arizona, Kansas, Nebraska, and Texas, and have been tested using data from 14 other channel reaches in Arizona and seepage rates in unlined canals. The computations for runoff volume, time to peak, and peak discharge were evaluated using data from 260 rainfall-runoff events on 10 experimental watersheds in Arizona. The model reproduces trends in runoff rates and amounts and has been used to compute flood frequency distributions on small watersheds.

Additional research is underway to improve parameter estimation techniques and to improve individual components of the water routing model. However, based on available information contained in soils and topographic maps, and from channel characteristics based on field observations, the procedures outlined here can be used to estimate runoff rates and amounts from rangeland watersheds.

Sediment Routing Component

Based on flow hydraulics and sediment transport mechanics, the larger sediment particles are assumed to travel as bedload, with the smaller particles traveling as suspended sediment. The distribution of sediment is represented by up to 10 particle-size classes greater than 0.062 mm representing bedload, and one class of particles smaller than 0.062 mm representing suspended sediment. Transport capacity of bedload is computed using a modified form of Duboys' equation, and suspended

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[2] The author's name followed by the year underlined, refers to Literature Cited, p. 66.

sediment transport capacity is computed using a modified version of Bagnold's equation (Lane 1982b).

Sediment yield is computed by integrating water flow rates and sediment transport capacity through the N time intervals on the approximating hydrograph. Sediment yield calculations are made at channel cross sections representing each channel reach, so that net deposition or erosion in the reach can be computed with a continuity of mass equation.

The sediment transport capacity equations were evaluated using data from the Niobrara River in Nebraska. These data were used to assess the steady-state performance of the sediment transport equations, which explained over 90 percent of the variance in the observed data from the Niobrara River. The sediment yield model, using the piecewise-normal approximating hydrograph, was tested using data from 47 runoff events on five small watersheds in Arizona. The sediment yield model explained about 80 percent of the variance in these observed sediment yield data. Additional research is needed to test the combined hydrologic and sediment yield model using experimental data and to improve the parameter estimation techniques.

Selected References

Background material on hydrologic processes, model development, water routing, and sediment routing are summarized in table 1. While these references do not provide a complete picture, they do describe the processes and provide further reference material.

Table 1.--Selected references providing background information

Process or component	Comments	
Hydrology of rangelands	Basic source material and technical overview	Branson et al. (1981)
Hydrologic modeling	Emphasis on agricultural watersheds	Haan et al. (1982)
Upland processes	Hydrologic models for upland phase	Knisel (1980); SCS (1972); Murphey et al. (1977)
Channel processes	Open channel flow Sediment transport Basic source material	Chow (1959) ASCE (1975) Graf (1971)
Water routing	Distributed model Transmission losses	Lane (1982a) Babcock and Cushing (1941) Lane (1980)
Sediment routing	Development of procedure	Lane (1982b)

APPLICATIONS

Typical applications of the model include simulating flood frequency and predicting sediment yield for rangeland watersheds. The section "SPUR Hydrology Component: Upland Phases" discusses application on a small watershed in southeastern Arizona, including the influence of transmission losses on runoff and the importance of channel processes on sediment yield. Lane (1982a) describes the hydrologic model and presents examples of flood frequency estimation. Lane (1982b) presents results for flood estimation and sediment yield estimation for a number of small watersheds in Arizona. Lane and Hakonson (1982) describe applications in predicting sediment transport in alluvial stream channels in New Mexico and discuss the significance of differential sediment transport and particle sorting.

Important applications of the model include using it to evaluate the influence of land use and conservation measures upon water and sediment yield. The upland component of the hydrologic model contains infiltration and erosion parameters (for example, runoff curve numbers and Universal Soil Loss Equation factors) which are affected by land use and management practices. Given changes in runoff and sediment yield from the upland areas, as reflected in these parameters, the model can be used to estimate the response of the channel system to these changing inputs. By routing runoff and sediment through the channel network, it is possible to assess the influence of land use and management on the upland areas on runoff and sediment yield from complex watersheds. Without a component to represent the stream channel system, it is difficult to integrate the influence of land use and management practices upon water and sediment yield from areas larger than plots or individual pastures.

Taken together, the references cited earlier document development and applications of the water and sediment routing components of the SPUR Model. Additional testing, evaluation, and model applications are continuing, and will represent more broad-based applications with respect to climate, topography, soils, vegetation, land use, and watershed size.

FUTURE DIRECTIONS AND RESEARCH NEEDS

The channel component of the SPUR Model represents a simplified approximation to hydrologic, hydraulic, and erosion and sedimentation processes occurring in stream channel systems. As research continues to improve our knowledge and existing data, significant improvements can be anticipated. These include the dynamic relationship among hydraulic processes, channel erosion rates, and sediment deposition rates, and how they are affected by conservation measures, land use, and range management practices.

Future Directions

Improved linkage between the upland and channel phases will more accurately reflect the influence of range management practices on runoff and erosion from rangelands. Complex watersheds represent systems which exhibit complex interactions and feedback. For example, increases in sediment yield from the upland areas can be offset by increased sediment deposition in the stream channels. This can result in delayed or reduced increases in sediment yield at downstream locations. On the other hand, decreases in sediment yield from the uplands can result in increased channel erosion, which might delay or reduce decreases in sediment yield at downstream locations. Improved linkage between the upland and channel phases will allow more accurate representation of these interactions. Improved parameter estimation techniques are also needed to allow wider application of the model under varied climatic conditions.

Selected Research Needs

A recent report (ASCE 1982) discusses relationships between channel morphology and sediment yield and includes a statement of research needs. This state-of-the-art assessment documents research needed to improve the water and sediment routing component of the SPUR Model. Additional research needs are documented in the proceedings of a recent workshop on estimating erosion and sediment yields from rangelands (ARS 1982).

Research is needed to improve methods of modeling channel erosion and sediment deposition processes, especially as they are affected by land use and management practices. Research is needed to quantify channel bank erosion and erosion of cohesive sediments, including gully development. Improved models are needed for hydraulics of out-of-bank flow and the associated sediment deposition processes occurring in floodplains.

Hydrograph characteristics are estimated using geomorphic features of the watersheds and stream channel systems. These relationships need to be developed and tested in several land resource regions representing a wider range of climate, soils, vegetation, topography, and land use. Moreover, objective methods are needed to select the number of stream channel segments and upland areas required to accurately represent complex watersheds. The appropriate degree of lumping or simplification will depend on the required accuracy in water and sediment yield, which, in turn, depend upon the purpose of the model application. Objective criteria are needed to specify required accuracy of model predictions, and these specifications, in turn, need to be related to the degree of lumping or simplification assumed in formulating upland areas and channel segments in the hydrologic model.

SUMMARY STATEMENT

The water and sediment routing component of the SPUR model approximates hydrologic, hydraulic, and sedimentation processes controlling runoff and sediment yield from ephemeral and intermittent stream channels on rangeland watersheds. Background information for the model is summarized in table 1 and in the references cited earlier. Specific details, such as formulation of the equations, testing and evaluation, and applications have been published in the references cited. Additional details on parameter estimation and applications will be documented in subsequent publications, such as user manuals.

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