SIMULATION OF RANGELAND RESOURCE DYNAMICS USING HISTORICAL RAINFALL DATA

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INTRODUCTION

This paper discusses a simulation methodology, SCALER (Simulating Climate And Land Effects on Ranges) which can be used to evaluate the dynamics of rangeland resources under the influence of climatic variations and management practices over time. Operation of this model requires information on daily rainfall data, daily solar radiation, soil type, range management practice, and vegetation type. This information is then applied to available mathematical techniques to derive other important variables. The concept of Range Quality Index (RQI) is introduced as a measure of the composite effect of output variables on rangelands over a period of interest. Application of this model can serve a useful purpose for long term planning.

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DESCRIPTION OF THE STUDY AREA

As a case, study area, the Santa Rita Experimental Range (SRER), located approximately 35 miles south of Tucson, Arizona, was selected to provide required input data. The topography is characterized by nearly level to gently sloping alluvial fans, which extend from the Santa Rita Mountains on the east to the Santa Cruz river on the west. Low foothills are found in the northeastern part of the area, changing to steep mountain slopes in the southeastern part. Short side drainages are common nearer to the higher elevation and in the more sloping country. Average annual precipitation varies from about 15 to 19 inches based on elevation.

Precipitation falls during a summer rainy season of July to September and a winter rainy season from December to April. About half of the total annual precipitation occurs during the summer growing season. A small percentage of the annual rainfall occurs during the dry months of May and June, when essentially all available soil water is removed by evapotranspiration.

CLIMATIC VARIABLES

Stochastic Rainfall Simulation.

Rainfall data were obtained from three available gauges for the period of 1958-1978. Daily rainfall was first classified into average monthly precipitation per event values. These values were then put into seasonal groups, as justified by their means, standard deviations and student-t test. Three seasons were characterized, including a wet summer, a long winter, and a dry pre-summer. The daily precipitation per event values of these groups were used to estimate seasonal means and variances. Also, probability of rain for a given day was computed, based on the number of rainy days in a given season. This information was used to generate daily rainfall events, assuming a Gamma distribution with a Probability Distribution Function(PDF) given by:

$$f(x) = (\lambda/\Gamma(K))(\lambda x)^{K-1} e^{-\lambda x} \qquad x > 0 \qquad (1)$$

The parameters (λ,K) were computed using the mean and standard deviation of seasonal precipitation per event values. one major problem with the Gamma is that its Cummulative Distribution Function (CDF) does not exist in closed form, making the variable transformation impossible. However, there are several techniques that can generate approximate Gamma distributed random variables. In this caes, an algorithm, explained in (Law and Kelton, 1981) was used.

Estimation Of A Runoff Event.

Surface runoff was estimated from the standard Soil Conservation Service (SCS) equation as follows:

$$Q=(P-aS)/(P+bS)**2 \qquad (2)$$

where:

Q = runoff (in),
P = rainfall (in),
S = potential maximum retention (in).

Based on the available data for small watersheds, a and b are estimated to be 0.2, 0.8 respectively (SCS, 1972). S is then calculated by using Curve Numbers(CN) related to soil and vegetation characteristics, as follows:

$$CN=(1000)/(10+S) \qquad (3)$$

Simulated daily precipitation was used as an input to estimate runoff events whenever the amount of rain exceed 0.2 S.

Estimation Of Sediment Yield.

The modified version of Universal Soil Loss Equation (MUSLE) developed by (Williams and Hann, 1973) was used to estimate sediment yield as a measure of erosion. The values of runoff developed previously was used to estimate peak flow as follows:

$$QFLOW=(484AwQ)/(0.5D+0.6Tc) \tag{4}$$

where:

QFLOW = peak flow (ft3/sec),
Aw = area of watershed (mi2),
Q = runoff volume (in),
D = duration of excess rainfall (hours),
Tc = time of concentration (hours).

QFLOW was then used to estimate sediment yield as follows:

$$Z=95(QFLW)^{0.95}K(LS)CP \tag{5}$$

where:

Z = storm sediment yield (tons),
LS = slope length and gradient factor,
C = cropping management factor,
P = erosion control practice factor.

SOIL WATER BUDGETING

A soil water budgeting developed by (Owtadolajam,1982) was applied.In this case, we are interested in the amount of water available for plant growth which can be estimated by considering different aspects of water movement in the soil. Mathematically, this can be represented as:

$$P = Q+SURP+AET+W2-W1 \tag{6}$$

where:

P = precipitation (in),
Q = surface runoff (in),
SURP = soil water surplus (in),
AET = actual evapotranspiration (in),
W1 = soil water begining of budgeting period (in),
W2 = soil water end of budgeting period (in).

Soil Water Surplus (SURP).

SURP is that portion of water that goes below the root zone by deep perculation. We can relate it to soil water content W, and precipitation as:

$$SURP= BPW/WM \tag{7}$$

where:

B = an empirical constant,
P = precipitation (in),
W = soil water (in),
WM = maximum water holding capacity of soil (in).

Evapotranspiration (ET).

The Actual Evapotranspiration (AET) is a function of the quantity of water within the soil and thus, will be equal or less than the Potential Evapotranspiration (PET). WK was defined as a piont where AET=PET by (Seller, 1965). As the soil dries, water is lost at the potential rate until the water content falls below WK, the critical water content. At that point the AET rate falls below the potential rate as expressed below:

$$AET=PET \qquad \bar{W} > WK \tag{8}$$

$$AET=(\bar{W}/WK)PET \qquad \bar{W} < WK \tag{9}$$

$$\bar{W}=0.5(W1+W2) \tag{10}$$

where:
W1 = initial soil water content (in),
W2 = next day soil water content (in).

These equations require certain conditions: the effect of snow accumulation in winter is ignored, temperature does not fall below $-1^{o}C$; and, water is removed from the top 10 to 20 cm of the soil.

The following equation was used to calculate PET from temperature and radiation:

$$PET = a + b*W'*Rs \tag{11}$$

where:
Rs = solar radiation (mm/day),
W' = weighing factor based on temperature and latitude,
a, b = based on relative humidity and wind speed.

The soil water budgeting equation was then used to estimate next day available soil water.

ABOVEGROUND BIOMASS PRODUCTION

Much of the information on plant biomass production is on an annual basis. Among the many references on the subject we can cite(Wittaker and Marks, 1975). For a simulation study, however, when weare interested in long term effects, this causes some problems. One reason is that plant growth is dependent upon the available soil water in the root zone, based on short time periods (hourly, daily, etc.).

By the same token, a semi-arid rangeland can experience extended periods of no rain, when virtually all of the available soil water is consumed by ET without being replenished. A typical example can be the pre-summer season, when the case study area (SRER) can go without rain for a period of two months or longer.

Thus, a model sensitive to daily variation in plant growth as a function of available soil water would be of interest. Among the many efforts in modelling and simulation of plant production some of the more recent works include (Innes, 1978), (Raynolds et al., 1980), and (Wight and Hanks, 1981). Some of the work geared towards modelling the production on short-grass prairie includes(Gilbert, 1975), (Detling, et al., 1978), (Parton et al., 1978), and (Detling, 1979).

The most recent work include (Lane and Stone, 1983), and (Hansen et al., 1983). The former effort concentrates on above ground net primary production as affected by various climatological factors, in particular water use efficiency and the latter model is based on phytomass and nitrogen flow analysis.

A methodology explained by (Gilbert, 1975) was used to establish the plant growth component. This daily model is dependent upon available soil water and temperature which were previously calculated. This dependency is rather important, since it avoids any unreasonable growth if soil water is limiting. According to this methodology, Net Primary Production (NPP) is assumed to be the difference between photosynthesis rate (PS) and the respiration rate (RS):

$$NPP = PS - RS \qquad (12)$$

The photosynthesis rate was assumed to depend primarily on available soil water and daily temperature:

$$\text{Photosynthesis rate(gm/m2/day)} = ETQ * ESMQ * QBM * QMAX \qquad (13)$$

where:

ETQ = effect of temperature on photosynthesis,
ESMQ = effect of soil moisture on photosynthesis,
QBM = above ground green plant biomass (gm/m2),
QMAX = Maximum PS (gm live plant biomass/day).

Respiration rate was assumed to depend only on the temperature term:

$$RS\text{(gm/m2/day)} = ETR * RBM * RMAX \qquad (14)$$

where:

ETR = effect of temperature on respiration,
QBM = above ground green plant biomass (gm/m2),
RMAX = maximum RS (gm respiration/day).

DISCUSSION OF RESULTS

After inputting the required information, 50 years of simulation was performed. Output included rainfall, runoff, sediment yield, solar radiation, and biomass production. All of these were generated on a daily basis and presented on a seasonal basis. The seasonal values were further ranked on (0-4) scale, based on their standing as compared to the minimum and maximum values of each category of the five above. These ranked values were then averaged out to arrive at a composite ranked value of each season which we are calling Range Quality Index (RQI) to demonstrate the dynamic behavior of the rangeland over time as shown in Figure 1. As it can be observed from the graph of Figure 1, the long winter season behaves rather consistently throughout the simulation period. However, the dry per-summer season maintains a lower trend which indicates a worse RQI than the winter season. This could be due to the very low percipitation for this season. The summer season shows the highest fluctuation among the three seasons which could be due to the short term, high intensity summer precipitations. As it is evident from Figure 1, a period of about 33 years is passed before RQI is restored to its best quality,(years 17-50).

Table 1 shows the statistics of various outputs variables of the simulation.Of particular interest is the period of April-June with long dry periods and little precipitation which can severly influence the quality of the rangeland.

Table 1.--Means and standard deviations of 50 years of simulation of output variables

output variable	season I (Oct.-March)	season II (April-June)	season III (July-Sept.)
max. dry days	29.0 + 7.0	63.0 + 21.0	7.3 + 2.2
no. rainy days	25.0 + 4.0	1.6 + 1.3	23.5 + 4.1
precipitation(in)	7.1 + 1.1	0.4 + 0.4	7.8 + 1.4
runoff(in)	0.01 + 0.0	0.0 + 0.0	0.07 + 0.0
sediment(tons/season)	0.4 + 0.4	0.4 + 0.2	3.0 + 2.2
production(gm/m2)	2.1 + 0.7	0.2 + 0.2	7.3 + 2.1

RANGE QUALITY INDEX (RQI)

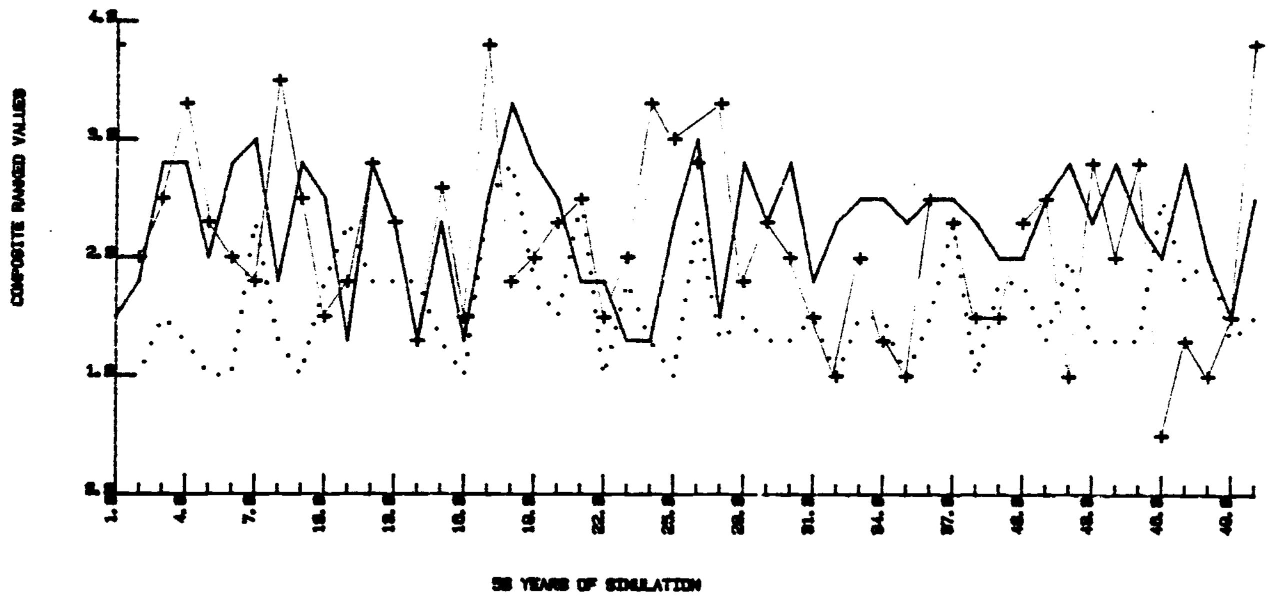

Figure 1. RQI values of seasons(I, II, III) by solid line, dotted line, and + line respectively, for 50 years of simulation. season(I) is Oct.-March, season(II) is April-June, season(III) is July-Sept.

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