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INFLUENCE OF GIS-BASED WATERSHED CHARACTERIZATION ON THE PREDICTION OF RUNOFF FROM SOUTHWEST RANGELANDS

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INTRODUCTION

A high-resolution geographic information system (GIS) was used to derive parameters for a basin-scale hydrologic simulation model for the prediction of runoff from a semi-arid watershed. The ARiD BaSIN (ARDBSN) model was tested on gauged rangeland watersheds within the USDA-ARS Walnut Gulch Experimental Watershed in southeastern Arizona. GIS techniques were used to subdivide the areas under investigation into flow elements and to extract from these elements relevant model parameters. Two gauged watersheds were configured to different levels of complexity by modifying the number of channels and overland flow elements used to characterize the basin. This paper describes the impact of GIS-based watershed characterization on runoff simulation and accuracy of annual runoff prediction from rangelands.

Model Description

The ARDBSN model is a distributed, continuous simulation runoff model originally written as the basin scale model for SPUR (Simulation of Productivity and Utilization of Rangelands; Wight and Skiles, 1987). A watershed can be divided into upland, lateral, and channel elements. Water can be routed to a channel from up to three upland and lateral elements and two channels. The hydrology component for the planes is computed using a daily water balance with the runoff volume computed by a modified SCS Curve Number method. Channel runoff volume and peak are adjusted for transmission losses as a function of basin characteristics, channel width, length, and hydraulic conductivity (Lane, 1982). Peak discharge is computed as a function of runoff volume and basin characteristics using regression relationships derived from semi-arid watersheds (Lane, 1982). This study is concerned only with volume runoff calculation.

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Description of the Study Area

Located in southeastern Arizona and surrounding the town of Tombstone, the USDA-ARS Walnut Gulch Experimental Watershed is densely gauged with a nested subwatershed design (Figure 1). Vegetation in the watershed is representative of the transition zone between the Chihuahuan and Sonoran deserts. Climate has been classified as semi-arid or steppe, with the majority of rainfall and runoff occurring during summer monsoon from convective thunderstorms (~60%), and the remainder occurring during the winter from low-pressure frontal systems. Two subwatersheds, 63.223 (44 ha) and 63.011 (785 ha), representative of brush- and grassland-dominated areas of the watershed respectively were chosen for intensive study. Soils within the study regions are comprised mainly of gravelly sandy loams.

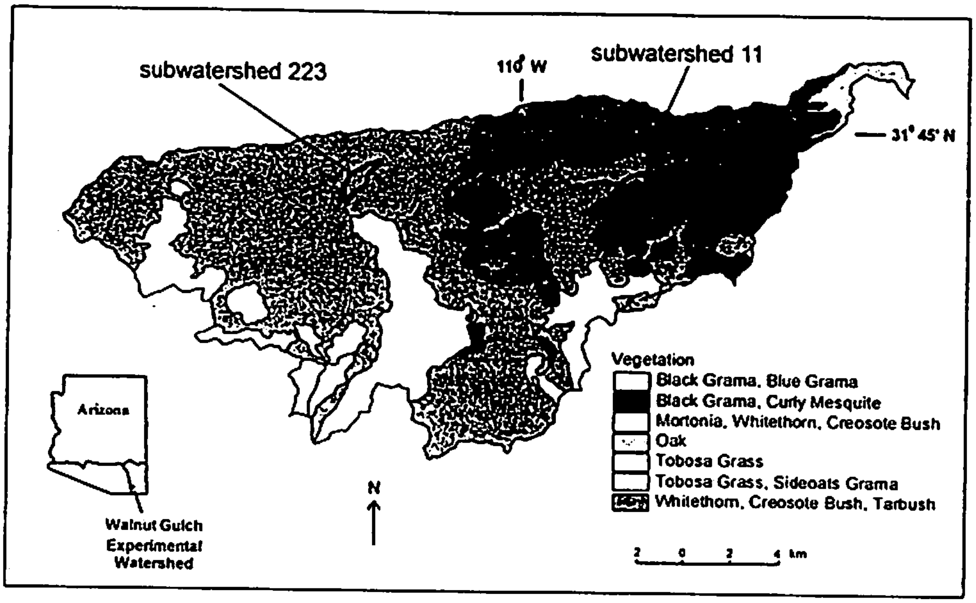

Figure 1. Locations of the Walnut Gulch Experimental Watershed and the nested subwatersheds used in this report.

METHODS

A quasi-automated link between the ARDBSN model and a GIS was created to ease the formulation of complex parameter input files. This link is still in development, but already is a significant improvement over creating these files by hand, and will allow future studies to be carried out more efficiently across a range of watershed scales and complexity.

GIS data has been assembled for Walnut Gulch with low-level aerial orthophotographs and abundant ground surveying. A digital elevation model with 10m resolution (0.7m absolute elevation error) was used for topographic characterization and automated subwatershed delineation. This DEM served as the basis for channel and plane articulation using flow direction and accumulation algorithms in Arc/Info (ESRI, 1998; names are necessary for factual reporting; however, the USDA neither guarantees nor warrants the standards of this product, and the use of the name by the USDA implies no approval of the product to the exclusion of others that may be suitable). Precipitation records from three and ten rain gauges were used with Thiessen mapping techniques to distribute rainfall across watersheds 223 and 11 respectively.

In order to investigate the influence of network and geometric complexity on model efficiency as defined by accuracy of simulated annual runoff, watersheds 11 and 223 were subdivided into planes and channels using different thresholds in the subdividing algorithm. The GIS-ARDBSN parameterization tool subdivides the watershed based solely on topography; uplands are defined as those areas contributing to the end of a first order channel, and lateral elements are those which contribute along the length of stream channels.

In the automated GIS techniques, network complexity and drainage density is determined by the threshold of flow accumulation (critical source area), which dictates the presence or absence of a stream. Increasing the threshold reduces the length and/or number of stream channels, which affects the number and size of lateral and upland elements. Four arbitrary thresholds were chosen for subdivision of the study areas as a function of the percentage of total watershed area: 1.5, 2.5, 5, and 10% (Table 1).

Table 1. Subwatershed characteristics for the ARDBSN model as a function of channel threshold. Increasing threshold percentage decreases complexity by reducing plane and channel elements.

	watershed 11 (786 ha)				watershed 223 (47.9 ha)			
Threshold (%)	*1.5*	*2.5*	*5*	*10*	*1.5*	*2.5*	*5*	*10*
Threshold (ha)	11.8	19.6	39.3	78.6	0.72	1.20	2.40	4.80
Number of channels	21	11	5	5	21	15	9	5
Drainage length (km)	13.8	12.0	10.0	8.16	3.19	2.64	2.09	1.53
Number of planes	51	27	12	12	46	37	19	13

Decreasing watershed complexity results in an increase in upland element areas and averaging of spatial characteristics, including infiltration and rainfall variability. Decreasing complexity also results in reduced channel length (Figure 2), which is critical to runoff modeling in semi-arid regions due to the importance of accurately assessing transmission losses. In order to account for the interaction between upland area and channel length for the different thresholds, the curve number method in the model was modified. A power function following Simanton et al. (1996) was developed from optimized runoff curve numbers for a range of watershed areas as: $CN = CN_b(A)^{-0.014}$, where CN_b is a baseline curve number and A is watershed area in acres. The physical basis for reducing the curve number by area is that with the aggregation of runoff processes into larger elements point rainfall raingage depths are averaged over larger areas decreasing the amount for a given sub-basin and transmission losses are decreased due to the reduction in channel length. Without adjusting the curve number, decreasing watershed complexity results in the overestimation of runoff. Given that network complexity is a function of both the research objective and basin scale, it is desirable to reduce the effects of simplification on runoff prediction.

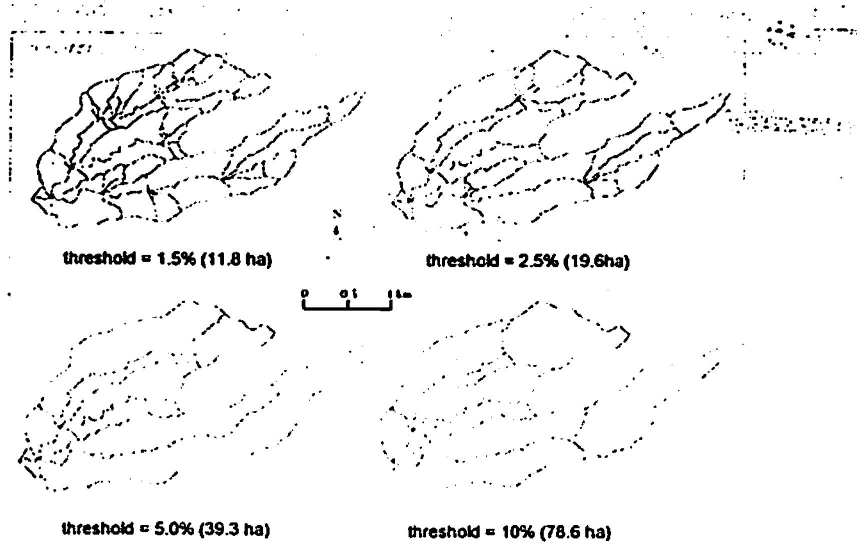

Figure 2. Plane and channel watershed configurations for subwatershed 11. Note that the uppermost contributing area contributing was removed from the analysis because a stock tank captured all runoff that occurred during the simulation period.

Strategic models such as ARDBSN are useful tools for investigating the effects of management decisions on runoff and erosion. Convenient measures for management decision support are annual runoff and sediment yield. Total annual runoff predictions were evaluated using the Nash-Sutcliffe coefficient, mean square error, and the correlation coefficient following Martinez (1999).

RESULTS AND CONCLUSIONS

Model results for both watersheds are displayed in Table 2. Note that in all cases there is a decline in efficiency with a reduction in watershed complexity ANOVA testing revealed that none of the results was statistically different from the observed data. These results indicate that the ARDBSN model is capable of predicting with reasonable accuracy average annual runoff for small watersheds. The model performed well on both study areas, which were considerably different in size. The ability to accurately simulate watershed response at a range of scales is critical for distributed modeling. In the absence of internal validation, models may be highly calibrated to a runoff gauging station (often located at the outlet of large basins), but still not produce viable interior results. These results indicate the effects of watershed configuration on runoff estimation.

Table 2. Model efficiencies for annual runoff volume.

	watershed 11				watershed 223			
Threshold (%)	*1.5*	*2.5*	*5*	*10*	*1.5*	*2.5*	*5*	*10*
Nash-Sutcliffe r^2	0.915	0.900	0.804	0.805	0.943	0.934	0.923	0.919
Mean-Square Error	0.003	0.003	0.007	0.008	0.037	0.040	0.046	0.046
Correlation	0.958	0.958	0.902	0.901	0.869	0.857	0.831	0.829

Figure 3 shows the results of seven years of simulation for both watersheds; note how increasing the complexity tends to pull the simulated results closer to the 1:1 line.

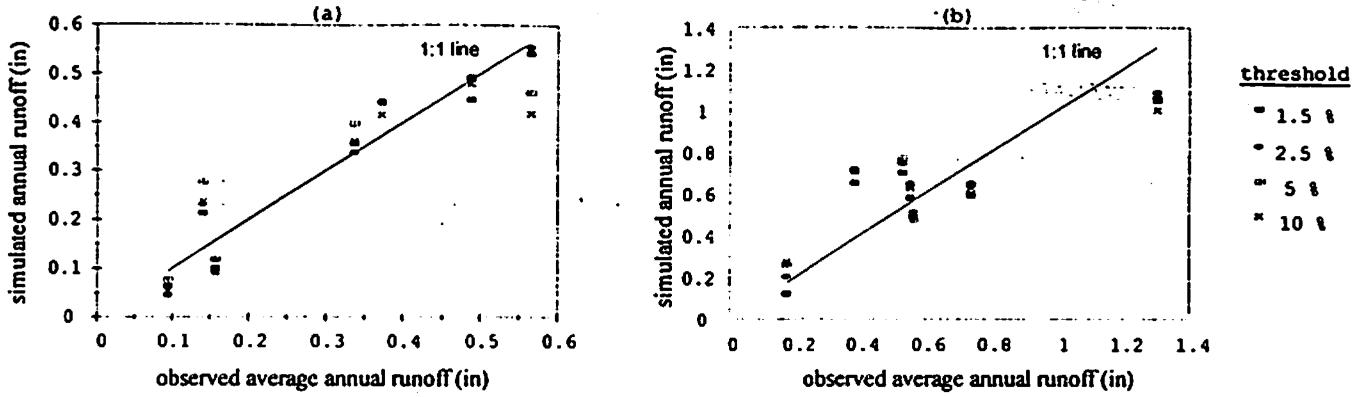

Figure 3. Annual runoff simulation results for watersheds 11 (a) and 223 (b) for a range of configuration thresholds.

It is somewhat surprising that, given its larger area, model efficiencies as measured with the correlation coefficient and mean square error are higher on watershed 11. Some technical difficulties were encountered during the modeling process that may help to explain some of the model behavior. Watershed configurations were based solely on topography, yet conventional hydrologic modeling calls for watershed elements to be homogeneous units and thereby reflect the inherent spatial complexity. With the very small runoff elements of watershed 223, the automated delineation produced spurious planar elements and overly complex basin routing, a direction for improvement in the GIS-ARDBSN link. However, these results are encouraging and efforts are underway to expand this research to a range of larger basin scales.

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