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Comparative modelling of large watershed responses between Walnut Gulch, Arizona, USA, and Matape, Sonora, Mexico

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Abstract Data collected from 1967 to 1977 on the intensively gauged Walnut Gulch Experimental Watershed near Tombstone Arizona are used to calibrate the Simulator for Water Resources on Rural Basins – Water Quality (SWRRBWQ) model. The Walnut Gulch data base includes topography, soils, vegetation and land use characteristics, as well as measured precipitation and runoff data. Results of the SWRRBWQ modelling effort are extended to the upper subarea of the Matape watershed in Sonora, Mexico to evaluate the practical aspects of extending natural resource models validated on small, data rich watersheds to larger watersheds with sparse data where comparably intense validation is impossible. Available data characterizing the Matape watershed include water yield, stream channel network, and vegetation, land use, and soils characteristics developed from remotely sensed data. Model calibration results from a small, intensively gauged watershed, and modelling limitations on larger, complex watersheds are discussed.

INTRODUCTION

The use, conservation, and preservation of rangelands and marginal dryland farming areas are constrained in part by lack of knowledge and technology bases that come from continued, long-term research and technology development and transfer. By evaluating the practical aspects of extending natural resource models validated on small, data-rich watersheds to larger watersheds with sparse data where comparably intense validation is impossible, progress can be made in developing knowledge and technology to assist land managers in selecting the best from among alternative management practices.

Hydrologic response is affected by vegetation, soils, climate, and management activities. Although implementing, evaluating, and monitoring alternative management practices is expensive and time consuming, the hydrologic response of various management practices can be modelled inexpensively and quickly. In addition, modelling efforts can expose data collection needs as well as future research needs.

The objective of this research is to calibrate the Simulator for Water Resources in Rural Basins – Water Quality (SWRRBWQ) (Arnold *et al.*, 1990) model using data collected on Walnut Gulch to simulate hydrologic and related processes on the watershed. Results of the SWRRBWQ modelling effort are extended to the upper subarea of the sparsely gauged Matape watershed in Sonora, Mexico.

STUDY SITES

Walnut Gulch Experimental Watershed

The 150 km^2 Walnut Gulch Experimental Watershed in southeastern Arizona is representative of approximately 60 million hectares of rangeland found throughout the semiarid Southwest. Precipitation data have been collected on the recording raingauge network on Walnut Gulch since its completion in 1961. These data have been used to evaluate the spatial and temporal properties of precipitation. In addition to precipitation, the Walnut Gulch data base includes topography, soils, vegetation and land use characteristics, as well as runoff data. Additional information on the Walnut Gulch Experimental Watershed, its data base, and observations and research findings are given by Renard *et al.* (1993).

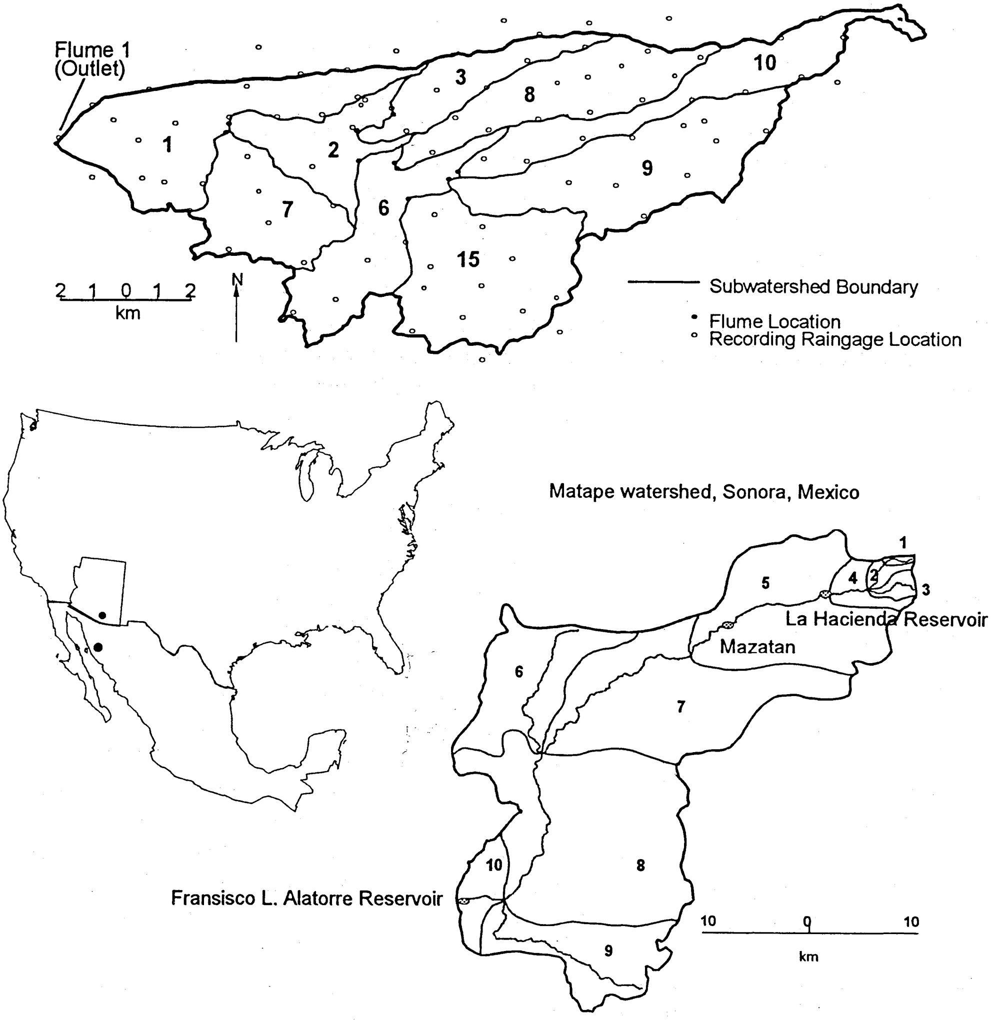

Fig. 1 Location map showing USDA-ARS Walnut Gulch Experimental Watershed, Arizona, USA, and Matape watershed, Sonora, Mexico, subwatershed discretization for SWRRBWQ modelling.

Upper Matape watershed

The 3140 km^2 Rio Matape watershed is typical of millions of hectares of Lower Sonoran desert and grasslands (Brown, 1982) in northern Mexico. The watershed drains into the Fransisco L. Alatorre Reservoir. Elevation of the watershed ranges from approximately 240 m above mean sea level at the reservoir to about 1680 m at the headwaters, about 34 km northeast of Mazatan. Available data for model calibration consists of limited streamflow records and sparse precipitation data. Subwatershed and stream channel network characteristics were developed from remotely sensed data and information digitized in a geographic information system (GIS).

METHODS AND ANALYSES

Distributed watershed modelling with SWRRBWQ

SWRRBWQ is a long-term water and sediment yield simulator that was developed for simulating hydrologic responses in rural basins. The model can be used to predict the effect of management decisions on water and sediment yields, as well as water quality, for ungauged rural basins. Large, complex watersheds can be modelled with SWRRBWQ because large basins can be subdivided based on soils, land use, or management and each subwatershed can be modelled with different precipitation, temperature, soils and management input values. The three major components of the model are weather, hydrology, and sedimentation. Processes considered in the model include surface runoff, return flow, percolation, evapotranspiration, transmission losses, pond and reservoir storage, sedimentation, and crop growth. Detailed descriptions of these processes can be found in Arnold *et al.* (1990).

Model input values – Walnut Gulch Experimental Watershed

Watershed characteristics The Walnut Gulch watershed was divided into nine subwatersheds (Fig. 1). A supercritical measuring flume (Smith *et al.*, 1981) is located at the outlet of each subwatershed, allowing for comparison of observed and simulated water yield at interior points (subwatersheds 3, 7, 8, 9, 10 and 15), and thus model calibration. Subwatershed sizes, channel lengths, average land slope, and length of overland flow were determined from 1:24 000 scale topographic maps. Soil parameters for each subwatershed were based on a soil survey of Walnut Gulch (Gelderman, 1970). Effective hydraulic conductivity of channel alluvium was estimated as 25 mm h^{-1}. Return flow travel time was set high to minimize calculated subsurface flow. Initial runoff curve numbers (CN2) for each subwatershed were estimated based on soil groups and were adjusted during model calibration. Subwatershed topographic characteristics are summarized in Table 1.

Weather Precipitation, air temperature, and solar radiation values are used in the model. Daily precipitation data were Theissen weighted for each subwatershed to create a single, aerially averaged daily precipitation record for each subwatershed. Daily maximum and minimum air temperatures are simulated by the model using normal

Table 1 Walnut Gulch Experimental Watershed subwatershed characteristics.

Subwatershed	Size (ha)	Main channel length (km)	Average land slope
1	2210	6.76	0.020
2	963	4.12	0.020
3	898	7.24	0.022
6	1545	3.86	0.020
7	1352	5.92	0.041
8	1550	9.48	0.021
9	2359	14.45	0.027
10	1663	18.29	0.038
15	2393	4.91	0.034

distribution equations and the daily mean and standard deviation of maximum and minimum temperature for each month. Solar radiation is also simulated by the model using normal distribution equations and the daily mean and standard deviation of daily solar radiation for each month. General weather data including the TP-40 10 year frequency rainfall amounts for 0.5 h and 6 h were taken from the Rainfall Frequency Atlas of the United States (Hershfield, 1961).

Vegetation and land use The rangelands at Walnut Gulch are primarily used for domestic animal grazing and were modelled as perennial crops with no tillage. The lower portion of the watershed is dominated by shrubs and the upper portion of the watershed is grassland with some shrub invasion.

SWRRBWQ model calibration using data from Walnut Gulch Experimental Watershed

The model calibration procedure consisted of varying input values including Condition 2 curve number, soil properties, and return flow travel time within reasonable ranges of uncertainty and comparing observed and simulated mean annual water yields. Subwatersheds 3, 7, 8, 9, 10 and 15 were individually calibrated for the eleven year period 1967-1977 (Fig. 2). To compute basin outflow, the SWRRBWQ model sums subwatershed outflows. In addition to water yield, observed and simulated maximum peak flow were compared (Table 3). Basin peak flow rates are computed in the model by a modified rational equation. Although it is possible to accurately simulate water yield, the observed and simulated peak flow values do not agree, with significant underprediction in all cases (Fig. 3).

Runoff calculations in the SWRRBWQ model are based on daily precipitation. Because of the short duration of storms characteristic of Walnut Gulch, the peak flow estimation procedures in SWRRBWQ need further evaluation and may need additional modification to accurately model peak runoff. Because subwatershed peak rates are used in the model to estimate subwatershed sediment yields, no attempt was made to model sediment yields.

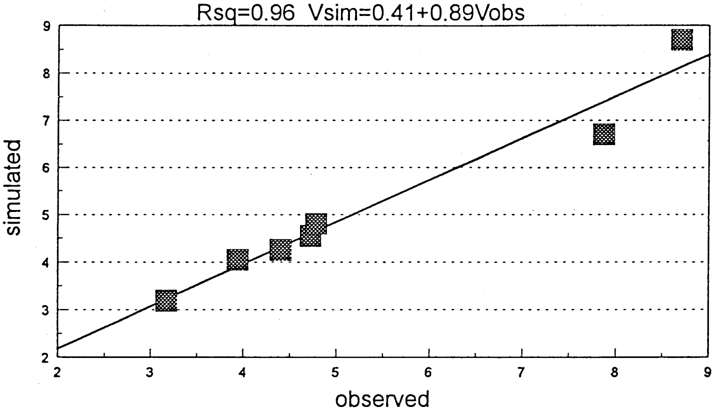

Fig. 2 Walnut Gulch Watershed observed and SWRRBWQ simulated average annual runoff (mm) 1967-1977, subwatersheds 1, 3, 7, 8, 9, 10 and 15.

Results of model simulation on the Upper Matape watershed

The Matape watershed was divided into 10 subwatersheds based on topography and soil type (Fig. 1). Subwatershed topographic and stream channel characteristics were determined using a GIS that incorporates data from 1:50 000 and 1:250 000 scale maps. Subwatershed topographic characteristics are summarized in Table 2.

Limited measured precipitation data are available for three locations on the Matape watershed. Average annual precipitation from 1980-1992 at La Hacienda Reservoir was 662 mm. Average annual precipitation at the Fransisco L. Alatorre Reservoir is approximately 390 mm. At Mazatan average annual precipitation is 503 mm. Because the monthly precipitation pattern at Mazatan follows the precipitation distribution pattern at Tombstone, Arizona, with a dominance of precipitation in July-September, and lower winter maximums during December-March, precipitation data from Walnut Gulch were

Table 2 Matape watershed subwatershed characteristics.

Subwatershed	Size (ha)	Main channel length (km)	Average land slope
1	1 607	4.1	0.10
2	1 618	8.2	0.10
3	3 647	10.8	0.10
4	5 614	5.9	0.05
5	60 899	33	0.05
6	38 674	31.6	0.05
7	67 156	37.2	0.05
8	95 192	32.5	0.03
9	30 475	39.5	0.03
10	9 035	8.8	0.03

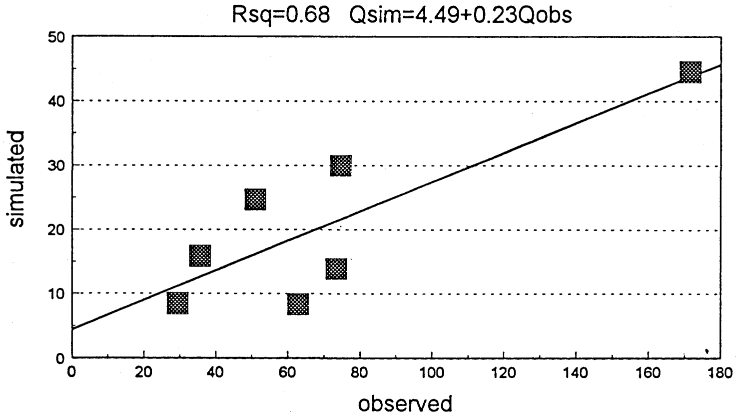

Fig. 3 Walnut Gulch Watershed observed and SWRRBWQ simulated maximum peak flow ($m^3\ s^{-1}$) 1967-1977, subwatersheds 1, 3, 7, 8, 9, 10 and 15.

used as input to model the Matape watershed. The SWRRBWQ model includes a rainfall adjustment factor that is used to multiply precipitation input values by a constant for each subwatershed. By applying rainfall adjustment factors to the weighted daily precipitation data from Walnut Gulch, calculated average annual precipitation agreed well with observed precipitation for the three subwatersheds on the Matape watershed where precipitation was recorded (subwatersheds 4, 5, and 10).

Table 3 Comparison of observed and SWRRBWQ simulated peak rates and average annual runoff for the 1967-1977 period of record.

		Peak rates ($m^3\ s^{-1}$):			Average annual runoff (mm):	
		Mean	Std. dev.	Max.	Mean	Std. dev.
Flume 1	observed	68.41	50.89	171.51	3.17	1.42
	simulated	7.30	8.66	44.57	3.19	3.18
Flume 3	observed	8.45	10.04	29.43	4.72	6.04
	simulated	2.15	2.49	8.48	4.55	6.84
Flume 7	observed	24.66	27.11	73.46	3.94	3.9
	simulated	3.91	3.79	13.89	4.05	7.13
Flume 8	observed	22.37	16.44	50.99	7.87	6.4
	simulated	2.21	4.08	24.67	6.7	7.76
Flume 9	observed	29.78	26.62	74.64	8.7	6.31
	simulated	3.27	4.96	29.99	8.7	7.69
Flume 10	observed	16.84	18.27	62.92	4.4	4.03
	simulated	1.46	1.90	8.39	4.26	4.24
Flume 15	observed	16.69	11.86	35.64	4.78	3.28
	simulated	4.88	4.68	15.89	4.81	6.14

Average monthly temperature, as well as maximum and minimum temperature, recorded at Mazatan were used to simulate daily temperature for each subwatershed. Monthly solar radiation values were calculated based on the latitude of the watershed. Soil parameters for the Matape watershed were estimated based on limited field data and soil texture. Because the model is sensitive to many of the soil parameters, additional data collection to accurately characterize soils is needed.

Limitations from available data on the Upper Matape watershed

Lack of observed data limited model calibration to annual water yield. Although a gauging station is located approximately 9 km upstream from the Fransisco L. Alatorre Reservoir, measured annual water yield data collected at the station is limited to eight discontinuous years of record (1960-1962, 1977, 1982-1985) with an average of 9.77 mm and standard deviation of 1.63 mm. By varying the runoff curve numbers, return flow travel time, and soil parameters over a reasonable range of values, a simulated mean annual water yield of 9.75 mm and standard deviation of 11.15 mm were calculated. The simulated water yield is based on precipitation input for the 11 years from 1967 through and including 1977 when high amounts of precipitation were recorded. If simulated water yield for 1977 is not included in the analysis, the standard deviation of simulated annual water yield is 3.08 mm and is in closer agreement with the standard deviation of observed water yield. This result indicates that caution must be observed when using short records and sparse data for calibrating the model.

DISCUSSION

The SWRRBWQ model was calibrated to estimate water yield on the Walnut Gulch and Matape watersheds. Although the large size of the Matape watershed prohibits intensive data collection, comparative watershed studies provide the opportunities to transfer data from Walnut Gulch and to use the limited physiographic data on ungauged watersheds.

Once calibrated, a model like SWRRBWQ is a useful tool for evaluating the effects of management systems on water yield. The results of this modelling effort indicate that benefits of using the model to evaluate alternative management practices will depend on the collection of additional data such as precipitation, water yield, and soil parameters. Because sediment yield is an important criteria in evaluating the impact of management systems, additional modelling must be done to accurately model peak flow and thus sediment yield.

Continuing research to calibrate and validate the SWRRBWQ model will include simulations for time periods longer than 11 years. Future modelling plans include calibration and validation on a time step shorter than one year, such as monthly. In addition, individual components of the hydrologic balance such as evapotranspiration, transmission losses, and percolation will be evaluated in detail. Efforts to collect, organize, and validate topographic, climate, soils, and hydrologic data for the Matape watershed are ongoing. After the model is successfully calibrated to estimate water and sediment yield, crop and land use data will be included to evaluate alternative management practices on rangelands in the semiarid Southwestern United States and Mexico.

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REFERENCES

Arnold, J. G., Williams J. R., Nicks, A. D. & Sammons, N. B. (1990) *SWRRB: A Basin Scale Simulation Model for Soil and Water Resources Management*. Texas A&M Press, College Station, Texas.

Brown, D. E. (1982) *Desert Plants* **4**(1-4). University of Arizona, Tucson, Arizona.

Gelderman, F. W. (1970) *Soil Survey, Walnut Gulch Experimental Watershed, Arizona*. Special Report, USDA-SCS, USDA-ARS, and Arizona Agricultural Experiment Station.

Hershfield, D. M. (1961) Rainfall frequency atlas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years. *US Dept of Commerce Tech. Pap. no. 40.*

Renard, K. G., Lane, L. J., Simanton, J. R., Emmerich, W. E., Stone, J. J., Weltz, M. A., Goodrich, D. C. & Yakowitz, D. S. (1993) Agricultural impacts in an arid environment: Walnut Gulch studies. *Hydrol. Sci. & Tech.* **9**, 145-190.

Smith, R. E., Cherry, D. L., Jr, Renard, K. G. & Gwinn, W. R. (1981) Supercritical flumes for measuring sediment-laden flow. *US Dept of Agric. Tech. Bull. no. 1655.*