Integrating a Landscape /Hydrologic Analysis for Watershed Assessment

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Abstract

Methods to provide linkages between a hydrologic modeling tool (AGWA) and landscape assessment tool (ATtILA) for determining the vulnerability of semi-arid landscapes to natural and human-induced landscape pattern changes have been developed. The objective of this study is to demonstrate the application of ATtILA and AGWA to investigate the spatial effects of varying levels of anthropogenic disturbance on runoff volume and soil erosion in the San Pedro River Basin. Results were particularly useful for assessing the effects of land cover change in the watershed and highlighting subwatersheds that require careful management.

Keywords: watershed assessment, landscape analysis, hydrologic models, sediment yield

Introduction

Empirical studies have established the significant causal relationship between watershed characteristics and sediment loads. Agriculture on slopes of greater than 3% increases the risk of soil erosion (Wischmeier and Smith 1978), and this can lead to increases in sediment loadings to surface waters. A decrease in natural vegetation indicates a potential for future water quality problems (Hunsaker and Levine 1995; Jones et al. 2001).

This study presents an integrated approach to identify areas with potential water quality problems in particular high sediment loadings as a result of land cover change. Landscape metrics describing spatial composition and spatial configuration were computed using the Analytical Tools Interface for Landscape Assessments (ATtILA) (Ebert et al. 2002). These landscape metrics were used along with the Automated Geospatial Assessment Tool (AGWA) (Miller et al. 2002) to examine the contribution of land cover type to sediment yield and identify subwatersheds with high sediment production for the period 1993 to 1997.

Study Area

The San Pedro Basin is located in the northern portion of Sonora, Mexico and southeastern Arizona. The Upper San Pedro Basin contains approximately 7598 km2.

The Upper San Pedro Basin is bounded by generally north-northwest trending mountains, which range in elevation from 1524 m to nearly 3048 m (Figure 1).

Figure 1. Location of the Upper San Pedro River Basin

The San Pedro River enters the basin at the International Boundary near Palominas, Arizona, and flows northwest for about 120 km before leaving the basin at Redington. The San Pedro River is mostly ephemeral and only flows in response to local rainfall. The river does have a perennial stretch of about 29 km between Hereford and a point just south of Fairbanks. The Upper San Pedro Basin represents a transition area between the Sonoran and Chihuahuan deserts and topography, climate, and vegetation vary substantially across the watershed. Annual rainfall ranges from 300 to 750 mm. Biome types include riparian forest, coniferous forest, oak woodland, mesquite woodland, grasslands, desertscrub, and agriculture.

Methods

The general approach used in this study was carried out in three steps:

1) the watershed was subdivided into sub-watersheds and landscape metrics were computed with ATtILA to quantify the percent cover and spatial pattern on each subwatershed

2) the AGWA tool was employed to parameterize the Soil Water Assessment Tool (SWAT) (Arnold et al. 1994) and calibrate it using the USGS stream flow gage at Redington.

3) Subwatersheds were identified with high potential of water quality problems based on sediment load for the period 1993-1997.

ATtILA

The U.S. Environmental Protection Agency, Landscape Ecology Branch has developed a user-friendly interface (ArcView extension) ATtILA (Ebert et al. 2002) to compute a wide variety of landscape metrics for categorical map patterns. Four families of metrics are included in the software: landscape characteristics, riparian characteristics, human stressors, and physical characteristics.
ATtILA is available at www.epa.gov/nerlesd1/ land-sci/html2/ATtILA/

AGWA

The AGWA tool uses widely available standardized spatial data sets to develop input parameter files for two watershed runoff and erosion models: KINEROS and SWAT. Using digital data in combination with the automated functionality of AGWA greatly reduces the time required to use these two watershed models. AGWA is an ArcView extension designed to provide qualitative estimates of runoff and erosion relative to landscape change.
AGWA is available at www.tucson.ars.ag.gov/agwa

Landscape Metrics

Landscape metrics for each patch and cover class within a subwatershed on the 1997 analysis map (Figure 2) were calculated using the ATtILA extension. Metrics included in the analysis are listed in Table 1.

Table 1 Landscape metrics

Category	Index Name
Spatial Composition	Land use proportions
	Shannon's diversity index
Spatial Configuration	Number of patches
	Patch density
	Largest patch index
	Average patch size
	Connectivity

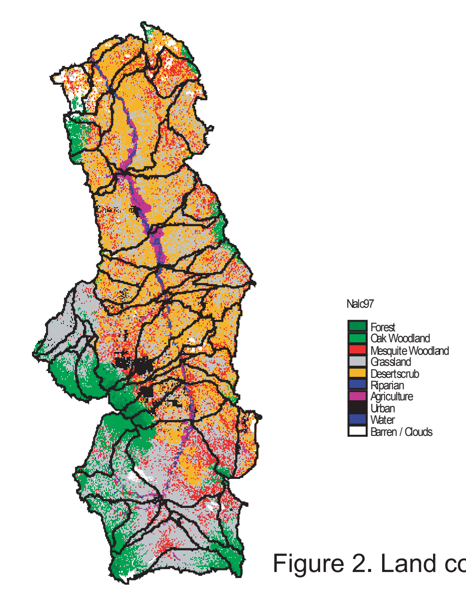

Figure 2. Land cover 1997

Hydrologic Simulation

The purpose of the simulation model was to assess the contribution of different land cover types to surface runoff and sediment yield for the period 1993 to 1997. The modeling was based on the subdivision of each of the 68 subwatersheds into Hydrologic Response Units (HRUs).
The characterization of each HRU within each subwatershed was established based on the landscape metrics computed with ATtILA. In particular we used proportion of land use, slope, number of patches, and average patch size. The total number of HRUs was 384.

Calibration

The SWAT model was calibrated separately against observed surface runoff and base flow for the period 1993 to 1997. The calibration results show that the average annual total water yield at the USGS Redington stream flow gage was calibrated to within 12% of the observed flow. SWAT was calibrated to within 13% and 4% for surface runoff and base flow, respectively. No attempt was made to calibrate the model against measured sediment concentration because insufficient data were available at Redington.

Results

The relationship between sediment yield and mean annual surface runoff for Agriculture, Desertscrub, Grassland, and Mesquite Woodland land cover classes is shown in Figure 3. Land use significantly affected the magnitude of sediment through its influence on the degree of protection afforded by the

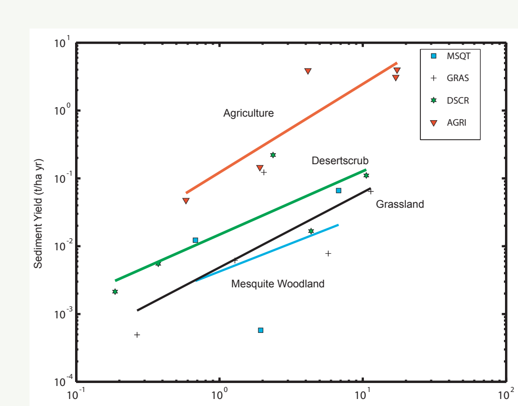

Figure 3. Relationship of sediment yield to mean annual surface runoff

Because SWAT is a distributed model, it is posible to view model output as it varies across the San Pedro Basin. Figure 4 depicts the spatial variability of average surface runoff and average sediment yield for the period 1993 to 1997. The spatial variability of sediment yield shown in Figure 4(b) is being controlled primarily by the spatial distribution of surface runoff shown in Figure 4(a).

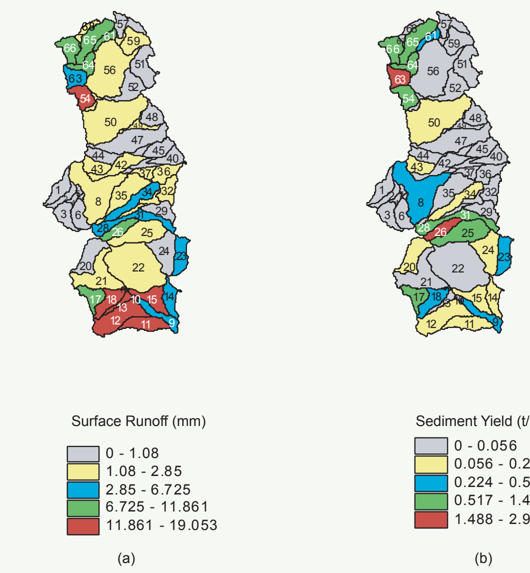

Figure 4. Spatially distributed (a) average surface runoff and (b) average sediment yield

Assessment

We ranked the HRUs according to high contributing sediment yield areas using the relationship between sediment yield to mean annual surface runoff as a function of land cover type, and the landscape metrics. We used as cutoff criteria the average slope (9%) and the average sediment yield (0.8 t/ha) of all HRUs for the period 1993 to 1997.The selection process yielded 8 HRUs; six are classified as agriculture and two as desertscrub. The six agricultural HRUs are located within the subwatersheds 54, 61, 65, 28, 52, and 20. The two HRUs with desertscrub land cover are located within the subwatersheds 63 and 66.

Figure 5. High sediment load subwatersheds

Table 2. Sensitive subwatersheds

Rank	Sub (Id)	Slope (%)	Syld. (t/ha)	Ave patch size (ha)	Sed. load (ton)
1	54	15	24.87	13.30	330.84
2	61	19	14.01	8.10	113.48
3	65	19	19.23	4.94	95.10
4	28	18	1.44	33.61	48.41
5	52	13	0.84	47.70	40.07
6	20	13	2.21	8.37	18.51
7	63	24	0.94	5.07	4.77
8	66	21	0.82	3.67	3.01

The ranking of the eight subwatersheds was carried out based on the average sediment load produced during the period 1993 to 1997. We computed tha average sediment load based on the average patch size computed with ATtILA and the average sediment yield computed with AGWA . The outcome of the ranking process is listed in Table 2 and depicted in Figure 5.

Conclusions

Methods for developing integrated planning and management strategies need to be spatially explicit, refer to specific areas, and utilize basic biophysical information together with assessments of both potential uses of individual land units and the potential levels threats in each. The integrated approach presented here allows resource managers to integrate landscape spatial analysis with hydrological modeling to identify problem areas.

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