Scenario Analysis for the San Pedro River: Analyzing Hydrological Consequences of a Future Environment

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1. Introduction

EPA's Office of Research and Development established a goal within the 2001 Strategic Plan "To anticipate future environmental issues." Studies of future management and policy options based on different assumptions provide a mechanism to examine possible outcomes and especially their likely benefits and consequences. The San Pedro River in Arizona and Sonora, Mexico (Figure 1), is an area that has undergone rapid changes in land use and cover, and subsequently is facing keen environmental crises related to water resources. It is the location of a number of studies that have dealt with change analysis, watershed condition, and most recently, alternative futures analysis. In the present study, previously defined future scenarios, in the form of land-use/land-cover grids, were examined relative to their impact on surface-water conditions. These hydrological outputs were estimated for the baseline year of 2000 and predicted 20 years in the future as a demonstration of how new geographic information system (GIS)-based hydrologic modeling tools can be used to evaluate the spatial impacts of urban growth patterns on surface-water hydrology.

2. Materials and Methods

In alternative futures analysis, potential impacts from a number of wide-ranging scenarios are compared to current conditions of a region in terms of a set of processes that are modeled in a GIS. Alternative future landscape analysis involves 1) describing the patterns and significant human and natural processes affecting a geographic area of concern; 2) constructing GIS models to simulate these processes and patterns; 3) creating changes in the landscape by forecasting and by design; and 4) evaluating how the changes affect pattern and process using models. In the present study, primary source data were developed for three land-cover/land-use grids representing alternative futures for the San Pedro River Basin in the year 2020. The year 2000 was used as baseline condition and a set of land-cover/land-use maps were developed for the year 2020 based on current land management and projected census growth. For the purpose of this study, the 2020 maps were selected for three scenarios which reflected important contradictions in desired future policy based on stakeholder input. The scenarios are listed in Table 1 and basically reflect changes in population within the watershed, patterns of growth, and development practices and constraints.

CONSTRAINED	Assumes lower population (78,500 inhabitants) than presently forecast for 2020. Development is concentrated in mostly existing developed areas (i.e., 90% urban). Removes all irrigated agriculture within the river basin.
PLANS	Assumes population increase as forecast for 2020 (95,000 inhabitants). Development is in mostly existing developed areas (i.e., 80% urban and 15% suburban). Removes irrigated agriculture within a 1-mile buffer zone of the river.
OPEN	Assumes population increase is more than the current 2020 forecast (111,500 inhabitants). Most constraints on land development are removed. Development occurs mostly into rural areas (60%) and less in existing urban areas (15%). Irrigated agriculture remains unchanged from current policy except for prohibiting new expansion near the river.

Table 1. Scenarios for future urbanization of the Upper San Pedro River Basin in the year 2020.

Figure 1. Location of the Upper San Pedro River Basin, Arizona/Sonora.

The watershed was discretized with a contributing source area of 9,200 ha, producing 67 sub-watershed elements (Figures 2-4) via the Automated Geospatial Watershed Assessment (AGWA) tool. AGWA is a GIS-based interface tool for watershed modeling and assessment that has been developed jointly by the U.S. EPA Office of Research and Development and the USDA Agricultural Research Service. AGWA combines hydrologic process models in an intuitive interface for performing multi-scale change assessment and is provided at no cost via the Internet as a modular, open-source suite of programs (www.tucson.ars.ag.gov/agwa/ *or* www.epa.gov/nerlesd1/land-sci/agwa/). The same simulation was performed using each of the three 2020 land-cover scenarios to develop parameter inputs. Average annual outputs from the three alternative futures were then differenced from the baseline values to compute percent change in average daily values over the 20-year period with a focus on the relative magnitude and spatial distribution of the computed changes.

3. Results

Surface runoff, percolation, and sediment yield were simulated within AGWA for the three 2020 scenarios. Results from the simulation runs are given in Table 2 and Figures 2, 3, and 4. The figures show the relative departure from the 2000 baseline year and illustrate the spatial variability of changes to the surface-water hydrology. In general, the simulation results indicate that land-cover changes associated with future development will significantly alter the hydrologic response of the watershed. Changes are primarily associated with increasing urbanization and the associated replacement of vegetated surfaces with impervious ones.

In the case of surface runoff, the simulations show average increases over the 20-year period commensurate with increases in urbanization. Although most sub-watershed elements exhibited an increase in runoff, other areas showed improvement or decreasing runoff (Figure 2).

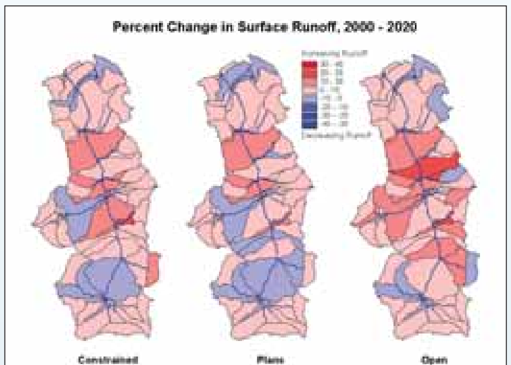

Figure 2. Percent change in surface runoff, 2000 - 2020, Upper San Pedro River Basin, Arizona/Sonora.

Sediment yield and erosion are directly related to runoff volume and velocity. The percent change in sediment yield simulated also displayed a high degree of spatial variability across the basin and between the three scenarios (Figure 3).

	Baseline 2000	Simulated Percent Relative Change 2000 - 2020		
		Constrained 2020	Plans 2020	Open 2020
Surface runoff (m^3/day)	186,538	4.3	3.7	6.9
Percolation (m^3/day)	42,760	-2.7	-3.0	-4.6
Sediment yield (t/day)	1,042	4.4	3.7	7.0

Table 2. Simulated average daily surface runoff, percolation, and sediment yield for the 2000 baseline conditions and predicted relative change for each of the three development scenarios.

Percolation is a hydrologic measure of the water volume that is able to infiltrate into the soil past the root zone to recharge the shallow and/or deep water aquifers. Figure 4 displays the simulated change in percolation for the three development scenarios. Although the model predicts some improvement in the watershed headwaters where human inhabitation is most dispersed, overall percolation is expected to decrease in all options as urban impervious surfaces are expanded, especially under the Open Scenario (Table 2).

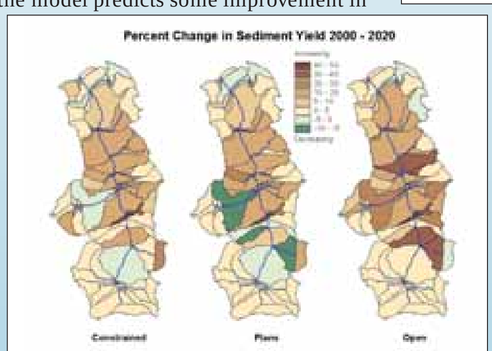

Figure 3. Percent change in sediment yield, 2000 - 2020, Upper San Pedro River Basin, Arizona/Sonora.

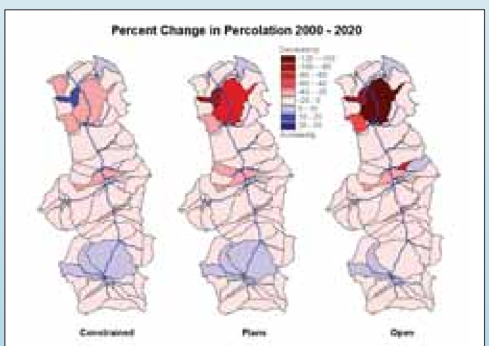

Figure 4. Percent change in percolation, 2000 - 2020, Upper San Pedro River Basin, Arizona/Sonora.

4. Summary and Conclusions

The hydrologic responses resulting from three development scenarios for the Upper San Pedro River Basin were evaluated using AGWA, a GIS tool developed to integrate landscape information with hydrological process models to assess watershed impacts. With this type of assessment, it is possible to rapidly evaluate likely changes in surface runoff throughout a basin, as well as the cumulative downstream change as widely distributed tributary impacts are felt in the main channel. In general, under a future urbanizing environment, the model simulation results appear to indicate that important impacts to the watershed hydrology can be expected. The most notable changes are likely to be increases in the amount of runoff, sediment discharge, and a loss of surface-water access to the groundwater table.

For the purpose of this study, negative impacts are considered to be any increase in surface runoff, sediment yield, and/or declines in groundwater percolation. The impacts are summarized graphically by percent change relative to the 2000 reference condition for each of the alternative futures using sub-watersheds as the comparative unit. The hydrologic modeling results indicate that negative impacts are likely under all three of the future scenarios as a result of predicted urbanization; however, there is remarkable variation in their specific hydrologic responses, particularly between the Constrained and Open Scenarios. In general, the Open Scenario has the greatest negative impact on surface water hydrology and results in greater simulated surface runoff and sediment yield than the other options, especially in the downstream reaches near Benson, Arizona. Additionally, percolation and thus groundwater recharge is most reduced under this option. This has particularly important bearing on the San Pedro which is the only unimpounded river in Arizona and where all municipal and most agricultural is water is derived from groundwater sources.

The present study endeavors to demonstrate the general potential of integrating spatial data and distributed modeling in environmental management. The combination of both landscape analysis with hydrological modeling can be widely applied on a variety of landscapes, watersheds, and regions and provides an important tool to assess vulnerability. The use of scenarios thus allows stakeholders and decision-makers to assess the relative impacts of several alternative sets of options and thus provides an important tool to help make better informed choices for an improved future.

For more information see:

Kepner, W.G., D.J. Semmens, S.D. Bassett, D.A. Mouat, and D.C. Goodrich. 2004. "Scenario Analysis for the San Pedro River, Analyzing Hydrological Consequences of a Future Environment." *Journal of Environmental Monitoring and Assessment*, 94: 115-127. Kluwer Academic Publishers (http://www.epa.gov/nerlesd1/land-sci/pdf/scenario_spedro.pdf).

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