Scenario Analysis in Two Western U.S. Watersheds: Evaluating Hydrological Response to Forecasted Land-use Change

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Introduction

Envisioning and evaluating future scenarios has emerged as a critical component of both science and social decision-making. The ability to assess, report, map, and forecast the life support functions of ecosystems is absolutely critical to our capacity to make informed decisions to maintain the sustainable nature of our environment now and into the future. Important advances in the integration of remote imagery, computer processing, and spatial-analysis technologies have been used to develop landscape information that can be integrated with hydrologic models to determine long-term change and make predictive inferences about the future. Two diverse case studies in northwest Oregon (Willamette River Basin) and southeastern Arizona (San Pedro River) were conducted to determine the impact of future land-use scenarios on surface-water conditions (e.g., sediment yield, surface runoff, and nutrients) using hydrologic process models associated with the Automated Geospatial Watershed Assessment (AGWA) tool. AGWA is a Geographical Information Systems interface that was developed to rapidly apply the Soil and Water Assessment Tool (SWAT) and KINematic Runoff and EROSion (KINEROS2) models for the purpose of conducting watershed assessments at multiple temporal and spatial scales (Miller et al. 2007). The two studies provide examples of integrating hydrologic modeling with a scenario analysis framework to evaluate plausible future forecasts and understand the potential impact of landscape change on water provisioning, a vital ecosystem service in the western U.S.

Materials and Methods

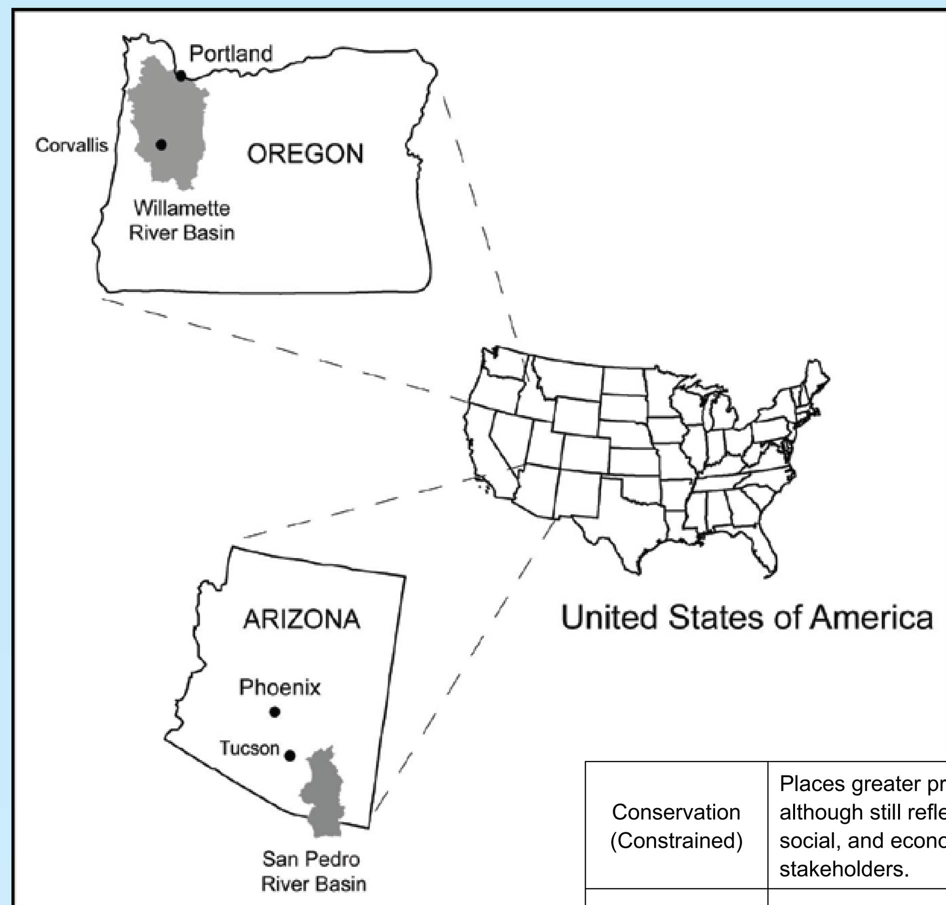
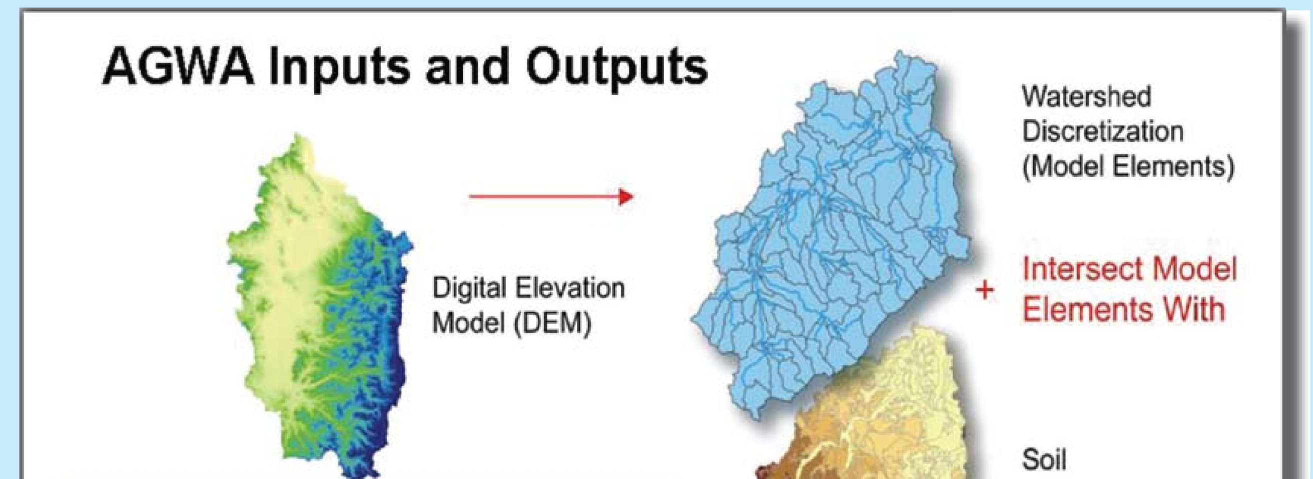


Figure 1. Location of the Willamette and San Pedro River basins.

The early 1990s and the year 2000 were used as a baseline for two western U.S. study basins, the Willamette River in Oregon, and the San Pedro River on the U.S./Mexico border, respectively (Figure 1). Land use was then projected 60 years (Willamette) and 20 years (San Pedro) into the future for three development options related to conservation, existing land-use and planning trends, and full open urban development (Table 1). The three scenarios for both watersheds reflect changes in population, patterns of growth, and development practices and constraints. Typically, as in these examples, scenario (or alternative futures) analysis uses a model-based approach to identify the key variables that reflect environmental change or to examine landscape change relative to specific issues or ecosystem services (Mohammed et al. 2009; Liu et al. 2008a; Liu et al. 2008b). The hydrologic responses resulting from the three development scenarios for both the Willamette and San Pedro River basins were evaluated using AGWA. The environmental endpoints related to surface hydrology were selected because they represent fundamentally important ecosystem services (Farber et al. 2006, MEA 2005). Initially the study areas were examined and reported separately (Kepner et al. 2008a, Kepner et al. 2004), although the approach is largely similar for both locations. The land cover/use scenarios were obtained from Steinitz et al. (2003) and Baker et al. (2004), in which the alternative courses of action were developed in consultation with local stakeholders for the three basic options listed in Table 1. The present research provides an integrated approach to identify areas with potential water-quality problems as a result of land cover change projected by stakeholders within the two river basins (Kepner et al. 2008b, Kepner et al. 2009). It was our hypothesis that land-cover changes associated with potential future development will alter the hydrology of each basin and that these changes could be quantified and graphically displayed using subwatersheds as a comparative unit.

Conservation (Constrained)	Places greater priority on ecosystem protection and restoration, although still reflecting a plausible balance between ecological, social, and economic considerations as defined by citizen stakeholders.
Plan Trend	Assumes existing comprehensive land use plans are implemented as written, with few exceptions, and recent trends continue.
Development (Open)	Assumes current land use policies are relaxed and greater reliance on market-oriented approaches to land and water use.

Table 1. Alternative-Future Scenarios for the San Pedro and Willamette River basins.



KINEROS Outputs	SWAT Outputs
Channel Infiltration (m^3/km)	Precipitation (mm)
Plane Infiltration (mm)	ET (mm)
Runoff (mm or m^3)	Percolation (mm)
Sediment Yield (kg)	Surface Runoff (mm)
Peak Flow (m^3/s or mm/hr)	Transmission Losses (mm)
Channel Scour (mm)	Water Yield (mm)
Sediment Discharge (kg/s)	Sediment Yield (t/ha)
	Nitrate in Surface Runoff (kg N/ha)
	Phosphorous in Surface Runoff (kg P/ha)

Figure 2. AGWA Input/Output variables. SWAT example for surface runoff in Willamette River Basin, OR.

A key feature of AGWA is that it uses commonly available GIS data layers to fully parameterize, execute, and spatially visualize results from both SWAT and KINEROS2 (Figure 2). Through an intuitive interface, users select a watershed outlet from which AGWA delineates and discretizes the watershed using a Digital Elevation Model. The watershed model elements are then intersected with soils and land cover data layers to derive the requisite model input parameters. AGWA can currently use both national (e.g., STATSGO) and international (e.g., FAO) soils data and available land-cover/use data such as the National Land Cover Data datasets. Users are also provided the functionality to easily customize AGWA for use with any classified land-cover/use data. The chosen hydrologic model is then executed, and the quantitative results are imported back into AGWA for visual display. This allows decision-makers to identify potential problem areas where additional monitoring can be undertaken or mitigation activities can be focused. AGWA can compare results from multiple simulations to compare changes predicted for each alternative future scenario. There are currently two versions of AGWA available: AGWA 1.5 for users with Environmental Systems Research Institute (ESRI) ArcView 3.x GIS software, and AGWA 2.0 for users with ESRI ArcGIS 9.x. AGWA 2.0 utilizes new features in ArcGIS 9.x that are not available in ArcView 3.x to make the tool more powerful, flexible, and easier to use. Both versions have been retained to reach the widest available audience and are provided to users free of charge from both the EPA and USDA/ARS Web sites:
http://www.epa.gov/esd/land-sci/agwa/index.htm
http://www.tucson.ars.ag.gov/agwa/

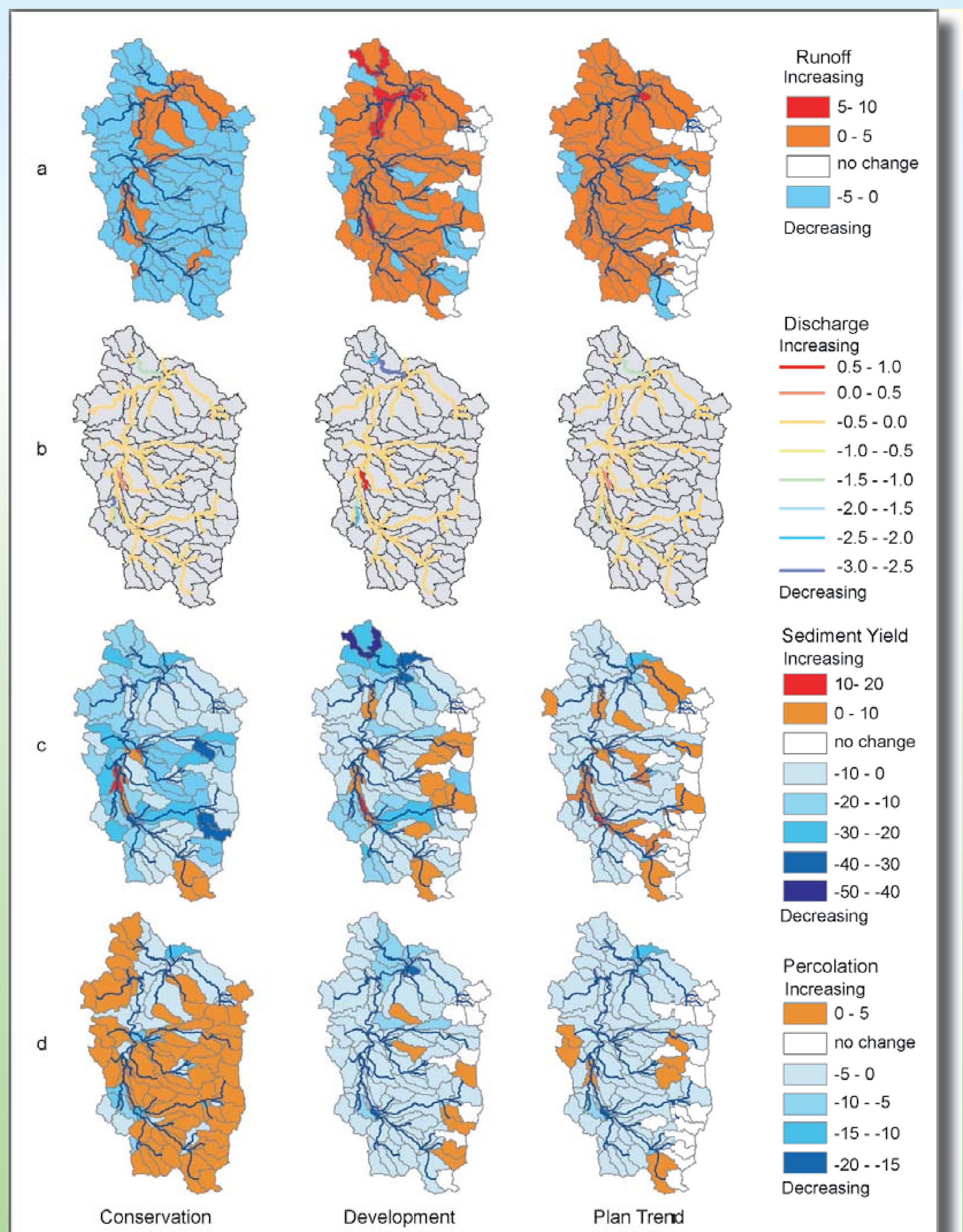


Figure 3. Percent change in average annual surface runoff, channel discharge, sediment yield, and percolation for each of the three alternative future (2050) scenarios for the Willamette River Basin (n = 111 subwatersheds). Modified after Kepner et al. (2008a).

Results

For the purpose of the studies, negative impacts to water ecosystem services are considered to be increases in surface runoff, channel discharge, sediment concentration, nitrogen and phosphorous loadings and decline of percolation volume. The impacts were summarized graphically by percent change relative to the 1990 and 2000 reference conditions for each of the alternative futures using subwatersheds as the comparative unit (Figures 3, 4, 5, and Tables 2 and 3). Urbanization and agriculture are presumed to be the major environmental stressors affecting watershed condition in both river basins.

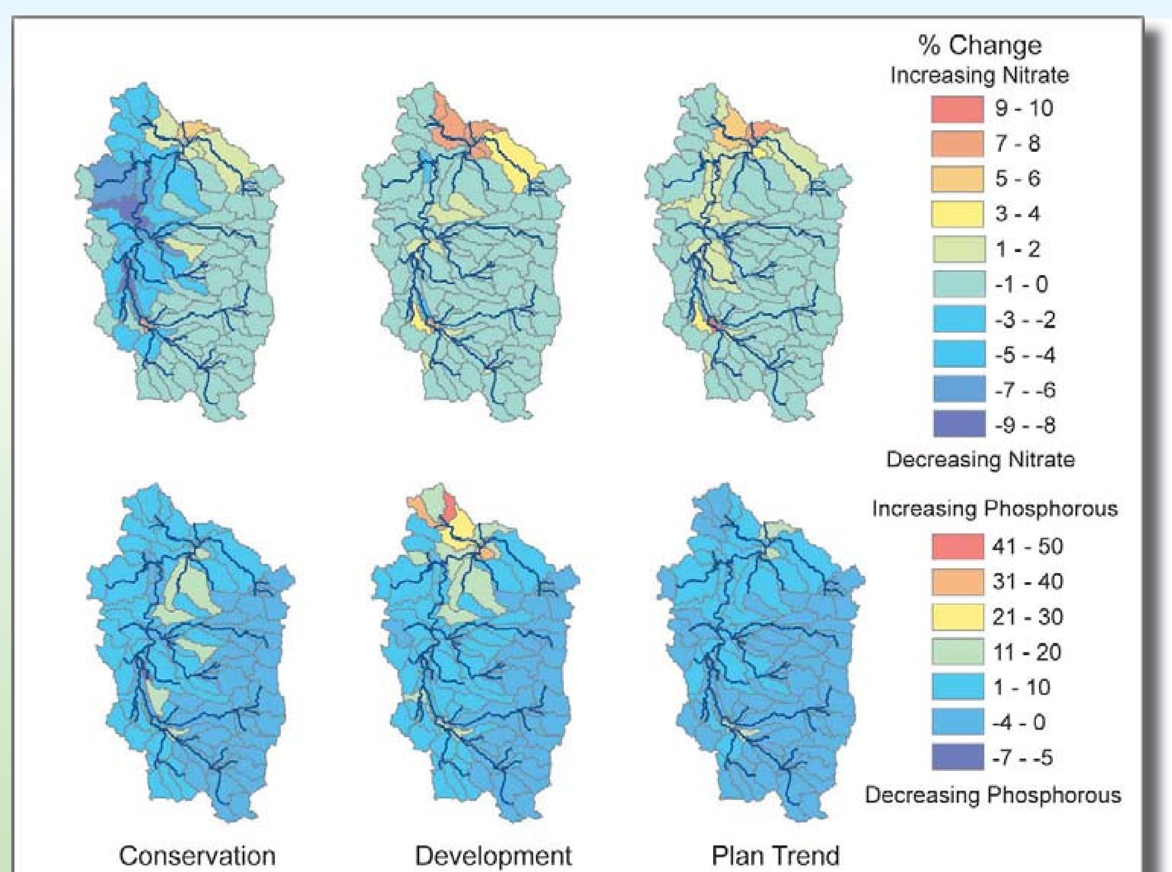


Figure 4. Percent change in average annual nitrate and phosphorous transported with surface runoff for each of the three alternative future (2050) scenarios for the Willamette River Basin (n = 111 subwatersheds).

Water Balance Component	Baseline 1990	Simulated Relative Change 1990-2050		
		Conservation	Development	Plan Trend
Sediment Yield (t/ha)	36.69	32.22	33.70	36.42
		-12.18%	-8.15%	-0.74%
Surface Runoff (mm)	330.98	327.59	334.81	334.18
		-1.02%	+1.16%	+0.97%
Percolation (mm)	655.12	656.27	650.28	653.04
		+0.18%	-0.74%	-0.32%
Nitrate (kg/ha)	0.785	0.772	0.788	0.789
		-1.66%	+0.38%	+0.51%
Soluble Phosphorous (kg/ha)	0.025	0.025	0.026	0.025
		0.0%	+4.00%	0.0%

Table 2. Simulated average annual sediment yield, surface runoff, percolation, nitrate, and phosphorous for the 1990 baseline and future conditions and predicted relative change for each of the three development scenarios at the watershed outlet, Willamette River, OR (29,738 km^2 drainage area).

The hydrologic modeling results indicate that negative impacts are likely under all three of the future scenarios as a result of predicted human development; however, there is a small variation in their specific hydrologic responses, particularly between Development and Conservation scenarios.

In general, the Development scenario has the greatest negative impact on surface hydrology and water quality and results in greater simulated surface runoff, flow discharge, and sediment concentration. Additionally, percolation and thus groundwater recharge is most reduced under this scenario. Lastly, under the Development scenario in the Willamette River Basin, nitrate and phosphorous loadings are increased in subwatersheds close to the outlet of the basin. This scenario favors development and allows for the largest future population increase within the watershed.

The Conservation and Plan Trend alternative futures have the least negative impacts to the surface water hydrology; however, considerable spatial variability for simulated hydrological response was demonstrated for all three scenarios in both study locations.

Water Balance Component	Baseline 2000	Simulated Relative Change 2000-2020		
		Conservation	Development	Plan Trend
Sediment Yield (t/ha)	0.47	0.50	0.51	0.49
		+6.4%	+8.5%	+4.3%
Surface Runoff (mm)	8.49	8.86	9.07	8.80
		+4.4 %	+6.8%	+3.7%
Percolation (mm)	1.95	1.89	1.86	1.89
		-3.1%	-4.6%	-3.1%

Table 3. Simulated average annual sediment yield, surface runoff, and percolation for the 2000 baseline and future conditions and predicted relative change for each of the three development scenarios at the Redington, AZ USGS Gage, San Pedro River, U.S./Mexico (8019 km^2 drainage area).

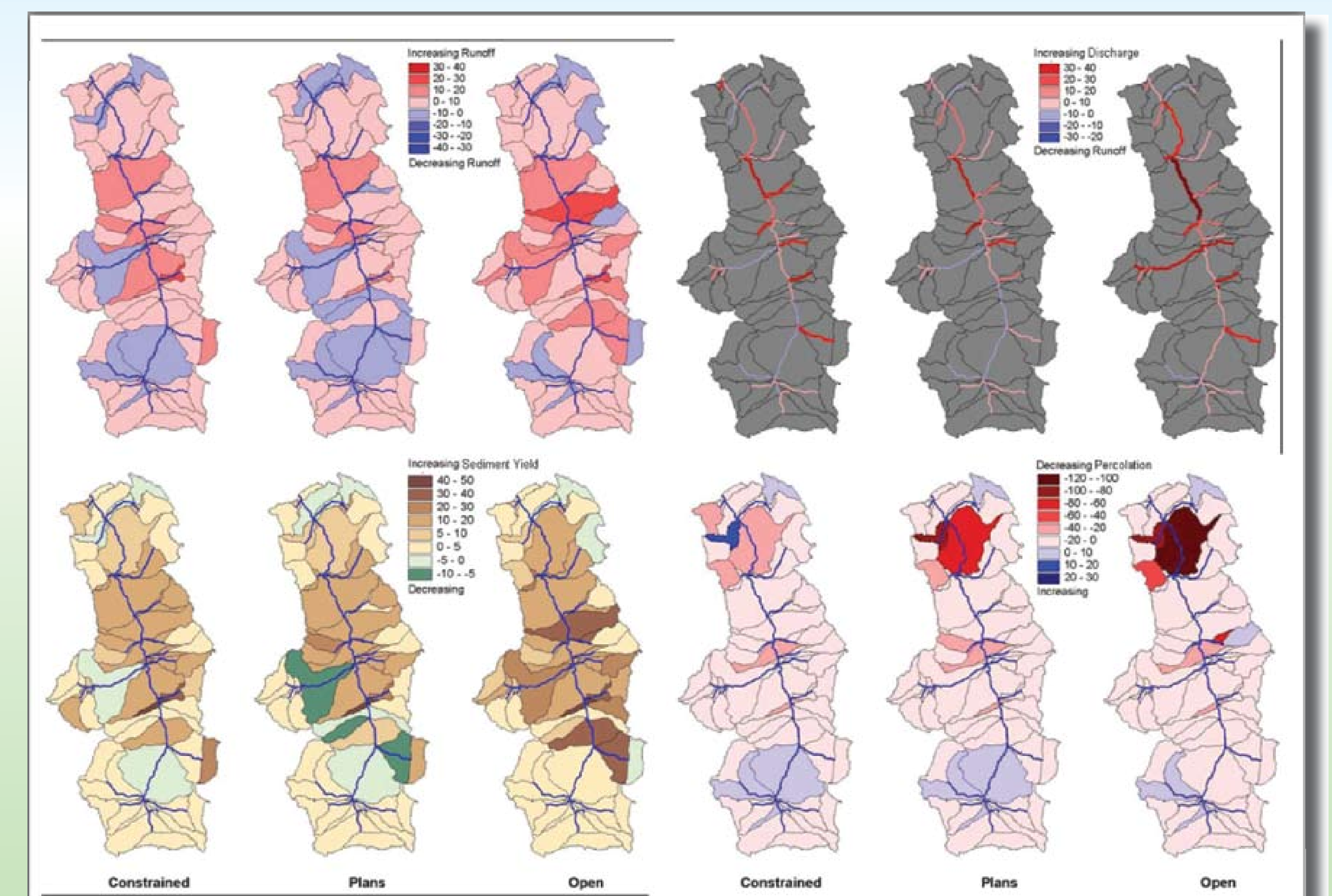


Figure 5. Percent change in average annual surface runoff, channel discharge, sediment yield, and percolation for each of the three alternative future (2020) scenarios for the San Pedro River Basin (n = 68 subwatersheds). Modified after Kepner et al. (2004).

Summary and Conclusions

The studies demonstrate the ability of integrating digital land-cover information (typically derived from satellite sensors) with hydrological process models in the AGWA tool to explore and evaluate options for a future environment. They provide a scientific underpinning for analyzing one set of ecosystem services related to surface hydrology, and undoubtedly the approach and technologies may apply to other services as well. Spatial modeling and analysis tools, such as AGWA, provide one of the most powerful approaches to quantify and forecast the relative impacts to ecosystem services, and thus improve our collective decision-making for the future. *For more information see: http://cfpub.epa.gov/crem/knowledge_base/crem_report.cfm?deid=75821*

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