Elsevier Editorial System(tm) for Journal of Hydrology
Manuscript Draft

Manuscript Number: HYDROL10374

Title: Assessing Impacts of Landuse Changes on Hydrology for the Upper San Pedro Watershed

Article Type: Research Paper

Keywords: Hydrological Modeling; Multiple Regression Analysis; Hydrological Processes; Urbanization; Mesquite

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Title: **Assessing Impacts of Landuse Changes on Hydrology for the Upper San Pedro Watershed**

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Abstract

The assessment of landuse changes on hydrology is essential for the development of sustainable water resource strategies. Specifically, understanding how each land use influences hydrological processes will greatly improve predictability of hydrological consequences to landuse changes and thus can help stakeholders make better decisions. However, given the limited landuse data and simultaneous changes of multiple landuse classes, it is difficult to quantify impacts of individual land uses on hydrology. In this study, an integrated approach of hydrological modeling and multiple regression analysis was applied to quantify contributions of changes for individual land uses on hydrological processes. As a case study, hydrological modeling was conducted for four landuse scenarios (1973, 1986, 1992, and 1997) in the upper San Pedro watershed using the Soil and Water Assessment Tool (SWAT). Simulation results were used in a multiple regression analysis to quantify contributions for individual land uses to five major hydrological responses at the subbasinal scale. Results indicated that urbanization was the strongest contributor to the increased surface runoff and water yield from 1973 to 1997 and replacement of desertscrub/grassland by mesquite was the strongest predictor of decreased baseflow/percolation and of the increased ET. Increased runoff, declined percolation, and increased ET have a negative impact on the upper San Pedro River Basin, thus urbanization and mesquite invasion were characterized as two major environmental stressors affecting local watershed conditions. Approaches applied in this study successfully determined contributions of changes for individual land uses to hydrological processes, providing quantitative information for stakeholders to make better decisions for future landuse and/or water resource planning and management, thus it can be widely applied to a variety of watersheds to assess impacts of landuse changes on hydrology.

Keywords: Hydrological Modeling; Multiple Regression Analysis; Hydrological Processes; Urbanization; Mesquite

1. Introduction

Assessing impacts of landuse changes on hydrology is essential for watershed management and ecological restoration. The assessment usually includes evaluation of spatial patterns of hydrological consequences to different landuse scenarios, comparison of basinal values of simulated hydrological processes to landuse changes at the basinal scale, and examination of temporal responses in channel discharge with changes in landuse scenarios (e.g. Miller et al., 2002; Ghaffari et al., 2009; Franczyk and Chang, 2009). However, studies do not quantify contributions of change for individual land uses to different hydrological responses. Without accurate quantification, the impacts of changes for some landuse classes on hydrologic processes may be exaggerated or understated, or even misinterpreted. In this study, an integration approach of hydrological modeling and multiple regression analysis was applied in the upper San Pedro watershed to quantify contribution of changes for individual land uses on hydrological processes.

In the upper San Pedro watershed, major landuse changes in the period from 1973 to 1997 include mesquite invasion, declines of grassland and desertscrub, and increases of urban and agriculture area (Kepner et al., 2000). An increase of annual runoff, flashier flood response, and decreased water quality due to sediment loading simulated in the watershed was attributed to simultaneous changes of several land uses as described above (Miller et al., 2002). However, how each landuse class influences each hydrological process is still unknown. The answer to this question will improve predictability of hydrological consequences to landuse changes and thus is crucial for future landuse and/or water resource planning and management.

Objectives of this study include: 1) calibrate and validate the SWAT model in terms of streamflow for three USGS gages in the upper San Pedro watershed; 2) evaluate impacts of landuse changes on hydrology at the basinal scale; 3) quantify the contribution of changes in land uses to major hydrological processes at the subbasinal scale.

2. Study Site

The upper San Pedro Watershed originates in Sonora, Mexico and flows north into southeastern Arizona, USA (Figure 1). In this study, the investigation area is composed of the upper San Pedro Basin and a part of the lower San Pedro Basin to the Redington USGS gage (Figure 1). For convenience, the entire study area is referred as “upper San Pedro” in the text.

The upper San Pedro Watershed has an area of about 7,400 km^2, and lies between latitude 30°54′ and 32°30′ N and longitude -110°48′ to -109°45′ W. Elevations in the basin range from 900 to 2900 m, and annual rainfall from 300 to 750 mm. The landuse classes include woodland (oak and mesquite), desert shrub, grassland, forest, riparian, agriculture crops, urban, water, and barren (Kepner et al., 2000). Major cities along the San Pedro River from south to north are

Cananea (Mexico), Hereford, Sierra Vista, Ft. Huachuca, Charleston, Tombstone, St. David, Benson, and Redington (Figure 1).

3. Methods

The method we used are divided into two parts: 1) hydrological modeling to simulate hydrological processes for four landuse scenarios; 2) performing multiple regression analysis to determine the contribution of changes for several landuse classes on hydrological processes.

3.1 Hydrological Modeling

3.1.1 Model Description

The Soil and Water Assessment Tool (SWAT) 2005 (Neitsch et al., 2005) was applied in the upper San Pedro watershed to assess impacts of landuse changes on hydrological processes The SWAT model is a continuous, long-term, physically based distributed model developed to assess impacts of climate and land management on hydrological processes, sediment loading, and pollution transport in watersheds (Arnold et al., 1998). In the SWAT model, a watershed is divided into subwatersheds or subbasins. Subbasins are further divided into a series of uniform hydrological response units (HRUs) based on soil and landuse. Hydrological components, sediment yield, and nutrient cycles are simulated for each HRU and then aggregated for the subbasins.

Hydrological components simulated in the SWAT model include evapotranspiration (ET), surface runoff, percolation, lateral flow, groundwater flow (return flow), transmission losses, and ponds (Arnold et al., 1998). Evaporation and transpiration are simulated separately: evaporation is computed using exponential functions of soil depth and water content and transpiration is estimated using a linear function of potential evapotranspiration (PET) and leaf area index. Three methods used to estimate PET include: Hargreaves (Hargreaves et al., 1985), Priestley-Taylor (Priestlr.Ch and Taylor, 1972), and Penman-Monteith (Monteith, 1965). The surface runoff is estimated using a modification of the SCS (Soil Conservation Service) curve number method (USDA, 1972) with daily rainfall amounts. The curve number values are based on soil type, landuse, and land management conditions (Rallison and Miller, 1981) and are adjusted according to soil moisture conditions (Arnold et al., 1993). Percolation is calculated using the combination of a storage routing technique and a crack-flow model (Arnold et al., 1998). The lateral flow is estimated simultaneously with percolation using a kinematic storage model (Solan et al., 1983). The groundwater flow (baseflow) into the channel is calculated based on hydraulic conductivity of shallow aquifer, distance from subbasin to main channel, and water table height (Hooghoudt, 1940).

3.1.2 Model Inputs

The input data used in the SWAT model includes a digital elevation model (DEM), soil data, land cover land use (LULC) data, and climate data. The DEM was derived from the USGS National Elevation Dataset (NED) with a resolution of 1 arc-second (about 30 meters), and the soil data was from the State Soil Geographic (STATSGO) Database. The LULC data for the years1973, 1986, 1992, and 1997 used to assess the impact of landuse change on hydrology, was developed from the North American Landscape Characterization (NALC) project (Kepner et al., 2002). The land use scenarios in years1992 and 1997 were covered by 1.44% and 2.17% clouds, respectively (Kepner et al., 2002). Clouds in NALC 1992 were overlain by landuse in NALC 1986, and clouds in 1997 were replaced by NALC 1992. The impact of this replacement on hydrological simulation could be ignored because clouds were mainly distributed in non-urban areas where vegetation changes were not significant from 1986 to 1997. The climate data, including daily values of precipitation and minimum-maximum temperature in the period from 1960/01 to 2008/04, were derived from 12 meteorological stations located in the upper San Pedro watershed. The missing records of precipitation and temperature were interpolated by the method proposed by Di Luzio et al. (2008).

3.1.3 Model Calibration and Validation

Simulations set up using NALC 1992 landuse data were used to calibrate streamflow from 1991 to 1995 at two USGS gages (Redington and Charleston, Figure 1). The model was calibrated by manually editing input parameters to match simulation results with observations for annual streamflow. Different calibration values were applied to the upper-stream (subbasins 48-116) and down-stream (1-47), because the proportion of baseflow separated from streamflow by Baseflow Filter (Arnold et al., 1995) in upper-stream gages (i.e. Charleston and Tombstone) was much higher than that in the down-stream gage (i.e. Redington). After model calibration, simulations set up using NALC 1997 landuse data were used to validate streamflow from 1996 to 2000 at two stations (Charleston and Tombstone Figure 1).

Three criteria were used to evaluate the model's performance on calibration and validation: Nash-Sutcliff (NS) coefficient, coefficient of determination (R^2), and percent bias (PBIAS). The NS coefficient was calculated as the following equation (Nash and Sutcliffe, 1970; Gupta et al., 1999):

$$NS = 1 - \left[\frac{\sum_i^n (Q_{simi} - Q_{obsi})^2}{\sum_i^n (Q_{obsi} - Q_{avg})^2} \right] \quad (2)$$

where n is the number of time steps, Q_{simi} and Q_{obsi} the simulated and observed streamflow at time step i, and Q_{avg} the average observed streamflow over the simulation period. PBIAS was calculated based on equation 3:

$$PBIAS = \left[\frac{\sum_{i=1}^{n} (Y_i^{obs} - Y_i^{sim}) \times (100)}{\sum_{i=1}^{n} (Y_i^{obs})} \right] \quad (3)$$

where Y_i^{obs} and Y_i^{sim} are observed and simulated streamflow at time step *i*.

The calibration/validation performance for SWAT model is considered satisfactory when R^2 and NS are greater than 0.5 (Moriasi et al., 2007). When the absolute value of PBIAS is less than 15, the SWAT model is rated as good performance (Moriasi et al., 2007).

3.1.4 Model Application

To assess the impacts of landuse changes on surface water availability, the calibrated model was run for four landuse scenarios (1973, 1986, 1992, 1997) with constant DEM and soil data from Jan. 1960 to Apr. 2008 (48.3 years). The simulated results were used to evaluate impacts of landuse changes on hydrology at the basinal scale and to quantify contribution of changes for individual landuse classes on hydrological components at the subbasinal scale.

3.2 Multiple Regression Analysis

Multiple regression analyses were performed to determine the contribution of changes in land uses to hydrology. Changes were between NALC1997 and NALC1973 landuses and hydrological processes. Independent variables (predictors) are the changes for the five primarily varied landuse classes (i.e. Urban, Mesquite, Grassland, Desertscrub, and Agriculture). Dependent variables (responses) are changes for five hydrological processes (i.e. Surface Runoff, Baseflow, Water Yield, Percolation, and Evapotranspiration). Pair-wise correlations between variables were computed (Proc Corr, SAS® 9.2) and multiple regression analyses (Proc Reg, SAS® 9.2) were conducted to quantify contribution of each of the five land uses on hydrological processes. When all sites (subbasins) are included in the multiple step-wise regressions, residuals were not normal. Hence, sites were grouped into two to meet normality (Shapiro-Wilk test >0.974, p>0.052). The physical meaning behind this grouping stems from the combined effects of many landuses on hydrological processes, which are explained in the following results section.

4. Results and Discussion

The calibration/validation and simulation results are presented in this section. Impacts of landuse changes on hydrology at the basinal scale are discussed and quantification results of contributions of changes for five land uses on hydrological processes at the subbasinal scale are reported.

4.1 Calibration Results

The optimal values for model calibration are shown in Table 1. The comparison between simulated and observed annual streamflow values in the periods of calibration (1991/01 – 1995/12) and validation (1996/01 – 2000/12) is shown in Figure 2. A good match can be seen between simulated and observed values. The NS and R^2 values for the annual calibration and validation are listed in the Table 2. All NS and R^2 values are above 0.5, and PBIAS are in the range of $\pm 15\%$ (most PBIAS are in the range of $\pm 10\%$), suggesting satisfactory model performance (Moriasi et al., 2007).

The good match between simulation and observation, as well as high NS, R^2, and low absolute values for PBIAS indicates that yearly streamflow can be described by the calibrated model. Thus, SWAT models set up by the optimal parameters can be applied to evaluate hydrological consequences to land use changes.

4.2 Impacts of Landuse Changes on Hydrology at the Basinal Scale

A comparison of landuse scenarios of years 1973, 1986, 1992, and 1997 indicates that the most significant changes occurred in five landuse classes: Mesquite, Grassland, Desertscrub, Urban, and Agriculture (Table 3 and Figure 3). The proportional extent of mesquite increased from 2.81% to 14.33%, with 410% expansion (relative change) from 1973 to 1986, and mesquite invasion stopped after 1986 (14.00% - 14.33%). Conversely, from 1973 to 1986, the proportional extent of grassland and desertscrub decreased from 41.07% to 35.00%, and from 39.70% to 32.70%, respectively. After 1986, the grassland extent was relatively stable (34.57% – 35.00%) and the desertscrub decreased from 32.70% to 31.75%. The urban region was gradually expanded from 0.44% to 2.24% between 1973 and 1997, extending over 400%. The agriculture region gradually increased from 1.18% to 2.45% from 1973 to 1992 and then decreased to 1.96% in 1997.

The average annual basin values of total water yield, surface runoff, and baseflow for each landuse scenarios are shown in Figure 4. Compared to the landuse scenario in year 1973, the average annual water yield over the watershed is 0.07 mm higher in 1986, 0.13 mm higher in 1992, and 0.25 mm higher in 1997: increasing 1.90%, 3.54%, and 6.81%, respectively. Similar to water yield, average annual surface runoff with landuse in 1973 was 2.61 mm; it gradually increased to 2.93 mm with landuse in 1997: increasing 12.26%. On the contrary, the average annual baseflow for landuse in 1986 was 0.04 mm lower than that in 1973: it decreased 3.54%; but baseflow for landuse in 1992 or 1997 was similar with that in 1986. Similar to baseflow, average annual basin percolation decreased from 13.14 mm for landuse in year 1973 to 12.85 mm for landuse in 1986 and percolation values for the other two landuse scenarios were similar to that in 1986. Consequences of evapotranspiration (ET) to landuse changes, however, are more complicated than other hydrological processes. The average annual basin ET decreased from

385.3 mm for landuse in 1973 to 385.1 mm for landuse in 1986 and then increased to 385.7 mm for landuse in 1997.

The overall increase of runoff simulated in the upper San Pedro Watershed from landuse in 1973 to 1997 was also reported by Miller et al. (2002), who attributed it to the simultaneous increase of urban, agriculture and woody mesquite, and decrease of grassland and desertscrub. In this study, a very strong positive correlation was observed between surface runoff and proportional urban area (Figure 5), indicating that the increase of average annual basin surface runoff could be mainly attributed to the urban expansion from 1973 to 1997. Increased average annual basin runoff associated with urbanization may be due to the increase of impervious surfaces (Franczyk and Chang 2009).

The decrease of average annual basin baseflow and percolation from landuse scenario from 1973 to 1986 corresponds to biological conversions from grassland/desertscrub to mesquite, suggesting that a possible association exists between the decrease of baseflow/percolation and mesquite invasion. Invasion of mesquite by replacing grassland destroyed complete grassland canopy cover, which was a favored landscape for infiltration through lowering the effective energy of raindrops (Schlesinger et al. 1990), resulting in declines of percolation and baseflow.

4.3 Contribution of Changes for Individual Landuse Classes on Hydrological Processes

Figure 6 shows the spatial distribution of changes for five land uses (i.e. urban, mesquite, grassland, desertscrub, and agriculture) and five simulated hydrological processes (i.e. surface runoff, baseflow, water yield, percolation, and evapotranspiration) between landuse scenarios in 1997 and 1973. It shows that urban expansion mainly occurred at the middle-stream cities along the upper San Pedro Rive Basin, including Hereford, Sierra Vista, Charleston, Tombstone, and Benson, and also occurred for the city of Cananea (Mexico) in the upper-stream. Mesquite invasion occurred across almost the entire watershed by replacing grassland and desertscrub. The conversion between grassland and mesquite can be distinguished in the upper-stream (Mexico) where no apparent decrease of desertscrub was observed (Figure 6). The increased agriculture area was mainly distributed in the upper and lower-stream of the basin.

The most significant increases of surface runoff and water yield also mainly occurred in the middle-stream, largely matching the spatial distribution pattern of urban expansion, which was confirmed by the positive high correlation between urban expansion and increase of runoff/water yield (Table 4). The decrease of surface runoff and water yield in the southeast of the watershed spatially corresponds to subbasins where the majority of grassland was replaced by mesquite (Figure 6). Spatial patterns of baseflow and percolation are almost the same, with an apparent decrease in the southeastern and northern part of the watershed (Figure 6). This pattern partially matches the spatial distribution of mesquite invasion. In table 4, negative medium correlations were seen between mesquite with each of baseflow and percolation, indicating an association of mesquite invasion and decrease of baseflow/percolation. The spatial pattern of ET did not corresponding to any class of landuse change and no significant correlation between ET and other variables were examined (Table 4), suggesting a more complicated mechanism controlling the change of ET.

Results of multiple regression analyses are shown in Table 5. The 116 subbasins were divided into two groups (Figure 7) to meet normality of residuals. For the surface runoff, urban is the highest contributor (partial R^2=0.9991, positive) followed by desertscrub (partial R^2=0.0001, positive) in group 1. In comparison, although urban is still the highest contributor for the surface runoff in group 2 (partial R^2=0.7928, positive), the second significant contributor is grassland (partial R^2=0.1251, positive). Similar to the surface runoff, the highest contributor for both groups of water yield is urban (positive) and the second significant contributor for group 2 is grassland (positive). In addition, the mesquite (negative) and agriculture (positive) are also contributors to the changes of water yield (Table 5). For percolation and baseflow, the highest contributor for group 1 is desertscrub (positive) followed by urban (positive) and the highest contributor for group 2 is grassland (positive) followed by agriculture (positive). Both desertscrub and grassland were replaced by mesquite in the upper San Pedro watershed from 1973 to 1997 (Kepner et al., 2000), indicating that decrease of percolation/baseflow can be attributed to mesquite invasion. For the ET, the highest contributor in group 1 is urban (partial R^2=0.9098, negative) followed by mesquite (positive) and desertscrub (positive); and the highest contributor in group 2 is grassland (partial R^2=0.4436, negative) followed by desertscrub (partial R^2=0.1674, positive).

The responses of surface runoff to landuse changes can largely be attributed to the CN2 values for different landuses (Ghaffari et al., 2009). Urbanization was quantified as the strongest predictor for surface runoff, because the CN2 value for urban (98) is much higher than the other landuse classes (39–89). Compared to mesquite and desertscrub (CN2 ranges from 45 to 73 or from 39 to 81, respectively), grassland is characterized by relatively higher CN2 values (67-89). Hence, grassland was identified as the second strongest predictor (negative contribution) to the surface runoff in group 2. Surface runoff is the most significant component of water yield (more than 70%), thus the most significant predictors for water yield are the same as surface runoff.

Changes of desertscrub and grassland were quantified as the strongest predictor (positive) to the changes of percolation and baseflow, suggesting the primary decrease of percolation/baseflow was attributed to the decrease of grassland/desertscrub from 1973 to 1997. In the upper San Pedro watershed, the decreased grassland and desertscrub was replaced by mesquite, the invasion of which may lower the effective energy of raindrops (Schlesinger et al. 1990), consequently resulting in the decline of percolation and baseflow.

Changes of urban and grassland were identified as the strongest predictors (negative) for the change of ET from 1973 to 1997. The negative influence of urbanization on ET can be attributed to the increase of impervious area, where no water was returned back into the atmosphere through plant transpiration. The negative impact of grassland on ET is due to its relatively low transpiration demand compared to that of shrubs (desertscrub and mesquite). Mesquite and desertscrub have a shallow lateral root system and a deep vertical root system, which enables them to use water in the shallow and deep soil, as well as in the groundwater system (Heitschmidt et al., 1988; Scott et al., 2006). In the upper San Pedro watershed, the replacement of grassland by mesquite from 1973 to 1997 enhanced the transpiration demand, and thus resulted in the increase of ET.

5. Summary and Conclusions

Contributions of land uses to major hydrological processes in the upper San Pedro watershed were evaluated using a combination of hydrological modeling and multiple regression analyses. The impacts of landuse change on hydrology were evaluated; associations and contributions of landuse changes to hydrological processes were identified and quantified. We summarize our conclusions as follows:

1. Although mesquite invasion (2.81–14.33% from 1973-1986) was the most significant landuse change in the upper San Pedro watershed from 1973 to 1997, increased surface

runoff and total water yield were mainly attributed to urbanization (0.44 – 2.24% from 1973-1997).

2. The replacement of grassland by mesquite also contributed to the decrease of surface runoff and water yield.
3. The replacement of desertscrub or grassland by mesquite from 1973 to 1997 was identified as the strongest predictor for the declines of baseflow and percolation and for the increase of ET in the upper San Pedro watershed.

Increase in surface runoff was considered as a negative impact on the upper San Pedro River Basin (Kepner et al. 2004). It may further strengthen environmental stress through generating more sediment yield and erosion that were usually directly related to runoff volume and velocity. Thus, urbanization, the strongest predictor for surface runoff and water yield, was the major environmental stressor controlling watershed condition for the upper San Pedro River Basin. A decline of percolation would directly decreases recharge for the shallow and/or deeper aquifers and thus be considered a negative impact for watersheds (Kepner et al. 2004). Hence, mesquite invasion by replacing grassland/desertscrub was another important environmental stressor affecting watershed conditions in the upper San Pedro River Basin.

As described above, the approach used in this study successfully determined contributions of changes for land uses to hydrological processes, providing quantitative information for stakeholders and decision makers to make better choices for future landuse and/or water resource planning and management. This approach can be widely applied to a variety of watersheds to predict hydrological consequences to landuse changes.

References

Arnold, J.G., Allen, P.M., Bernhardt, G., 1993. A Comprehensive Surface-Groundwater Flow Model. J Hydrol, 142(1-4): 47-69.

Arnold, J.G., Allen, P.M., Muttiah, R.S., Bernhardt, G., 1995. Automated base flow separation and recession analysis techniques. Groundwater. 33(6),1010-1018.

Arnold, J.G., Srinivasan, R., Muttiah, R.S., Williams, J.R., 1998. Large area hydrologic modeling and assessment - Part 1: Model development. J Am Water Resour As, 34(1): 73-89.

Di Luzio, M., Johnson, G.L., Daly, C., Eischeid, J.K., Arnold, J.G., 2008. Constructing retrospective gridded daily precipitation and temperature datasets for the conterminous United States. Journal of Applied Meteorology and Climatology. 47:2, 475-497.

Franczyk, J., Changk, H., 2009. The effects of climate change and urbanization on the runoff of the rock creek basin in the Portland metropolitan area, Oregon, USA. Hydrological Processes. 23, 805-815.

Ghaffari G., Keesstra, S., Ghodousi, J., Ahmadi, H., 2009, SWAT-simulated hydrological impact of land-use change in the Zanjanrood Basin, Northwest Iran. Hydrological Processes. DOI: 10.1002/hyp.7530.

Hargreaves, G.L., Hargreaves, G.H., Riley, J.P., 1985. Agricultural Benefits for Senegal River Basin. J Irrig Drain E-Asce, 111(2): 113-124.

Heitschmidt, R.K., Ansley, R.J., Dowhower, S.L., Jacoby, P.W., Price, D.L., 1988. Some Observations from the Excavation of Honey Mesquite Root Systems. J Range Manage, 41(3): 227-231.

Hernandez, M., Miller, S.N., Goodrich, D.C., Goff, B.F., Kepner, W.G., Edmonds, C.M., Jones, K.G., 2000. Modeling Runoff Response to Land Cover and Rainfall Spatial Variability in Semi-arid Watersheds. Environmental Monitoring and Assessment. 64, 285-298.

Hooghoudt, S.B., 1940. Bijdrage tot de kennis van enige natuurkundige grootheden van de grond. Versl. Landbouwkd. Onderz., 46: 515-707.

Kepner W.G., Semmens, D.J., Bassett S.D., Mouat D.A., and Goodrich D.C. 2004. Scenario Analysis for the San Pedro River, Analyzing Hydrological Consequences of a Future Environment. Environmental Monitoring and Assessment. 94,115-125.

Kepner, W.G., Edmonds, C.M., and Watts, C. J. 2002. Remote Sensing and Geographic Information Systems for Decision Analysis in Public Resource Administration: A Case Study of 25 Years of Landscape Change in a Southwestern Watershed. EPA/600/R-02/039. 31pp.

Kepner, W.G., Semmens, D.J., Heggem, D.T., Evanson, E.J., Edmonds, C.M., Scott, S.N., Ebert, D.W., 2003. The San Pedro River Geo-Data Browser and Assessment Tools. CD-ROM (EPA/600/C-03/008 and ARS/152432), U.S. Environmental Protection Agency, Office of Research and Development, Las Vegas, NV, USA; U.S. Department of Agriculture, Agricultural Research Service, Tucson, AZ, USA.

Kepner, W.G., Watts, G. J., Edmonds, C. M., Maingi, J. K., Marsh, S. E., Luna, G., 2000. A landscape approach for detecting and evaluating change in a semi-arid environment. Environmental Monitoring and Assessment. 64, 179-195.

Li, K.Y., Coe, M.T., Ramankutty, N., De Jong, R., 2007. Modeling the hydrological impact of land-use change in West Africa. Journal of Hydrology. 337, 258-268.

Miller, S.N., Kepner, W.G., Mehaffey, M.H., Hernandez, M., Miller, R.C., Goodrich, D.C., Devonhold, K.K., Heggem, D. T., Miller, W. P., 2002. Integrating landscape assessment and hydrologic modeling for land cover change analysis. Journal of the American Water Resources Association. 38(4), 915-929.

Monteith, J.L., 1965. Evaporation and environment, 19th Symposia of the Society for Experimental Biology. Cambridge University, London, U.K., pp. 205-234.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R., Williams, J.R., Soil and Water Assessment Tool. Theoretical Documentation. Version 2005, USDA-ARS, Temple, TX, USA (2005) 494 pp.

Orr, P., Colby, B., 2004. Groundwater management institutions to protect riparian habitat. Water Resour Res, 40(12): -.

Priestlr.Ch, Taylor, R.J., 1972. Assessment of Surface Heat-Flux and Evaporation Using Large-Scale Parameters. Mon Weather Rev, 100(2): 81-82.

Rallison, R.E., Miller, N., 1981. Past, Present and future SCS runoff procedure. Rainfall runoff relationship. Water Resources Publication, Littleton, CO.

Schlesinger, W.H., Reynolds, J.F., Cunningham, G.L., Huenneke, L.F., Jarrell, W.M., Cirginla, R.A., Whitford, W.G., 1990. Biological feedbacks in global desertification. Science. 247, 1043-1048.

Scott, R.L., Goodrich, D., Levick, L., 2006. Determining the riparian groundwater use within the San Pedro Riparian National Conservation Area and the Sierra Vista Subwatershed, Arizona. In Hydrologic Requirements of and Consumptive Ground-Water Use by Riparian Vegetation along the San Pedro River, Arizona.

Solan, P.G., Morre, I.D., Coltharp, G.B., Eigel, J.D., 1983. Modeling surface and subsurface stormflow on steeply-sloping forested watersheds. Water Resource Inst. Report 142, University of Kentucky, Lexington.

USDA, S.C.S., 1972. National Engineering Handbook Section 4 Hydrology.

Winchell, M., Srinivasan, R.,, Di Luzio, M., Arnold J., 2007. ArcSWAT interface for SWAT 2005. User's Guide. Blackland Research Center, Texas Agricultural Experiment Station, Temple.

Figure

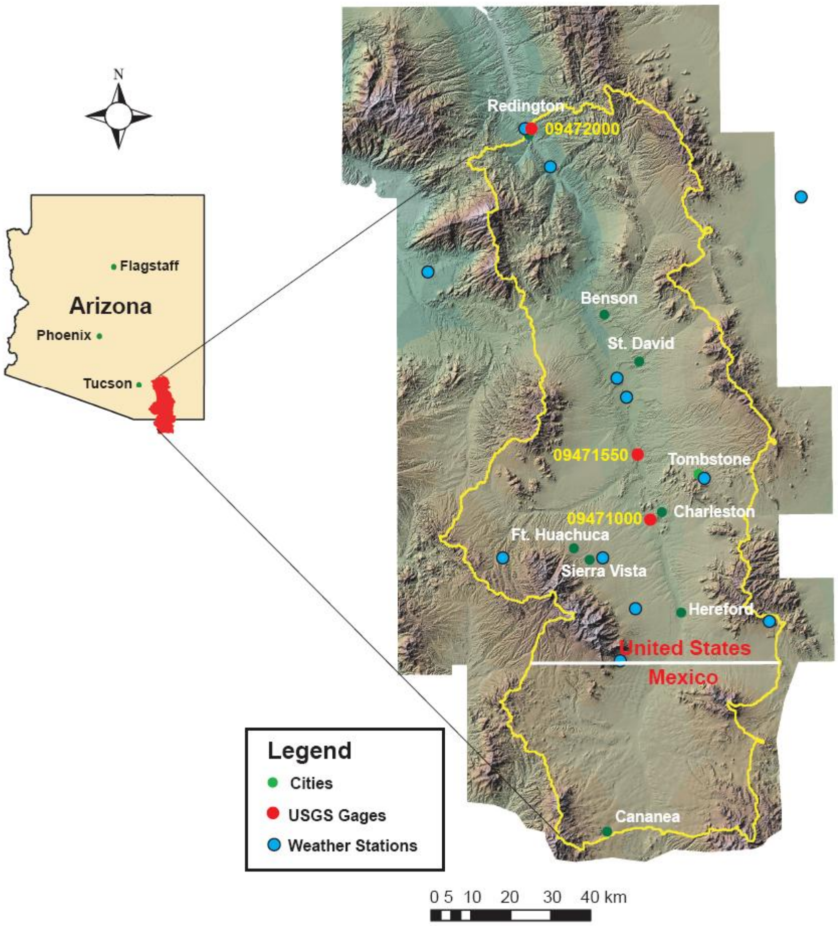
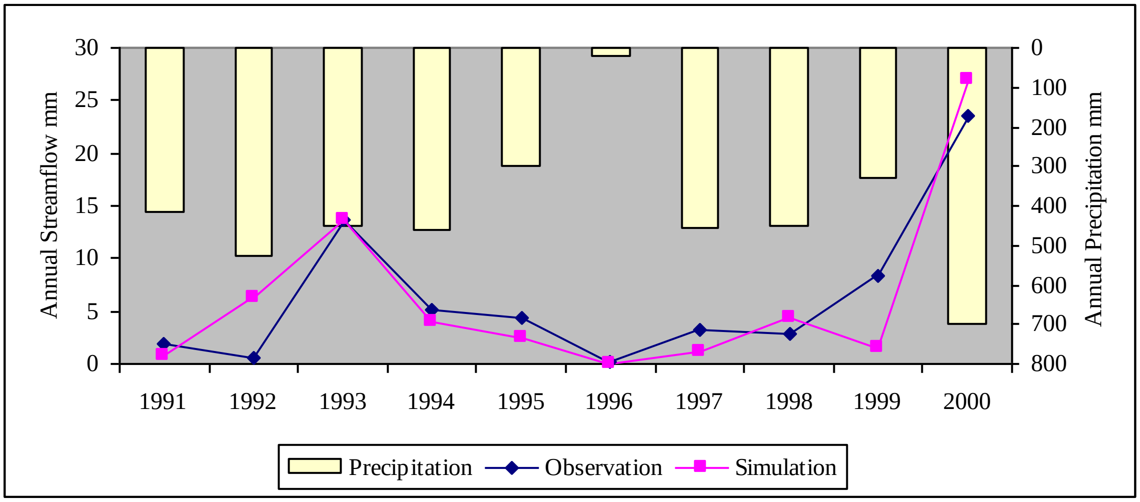


Figure 1. Locations of the cities, USGS monitoring gages, and weather stations and cities in the upper San Pedro watershed (modified from Kepner et al., 2000)



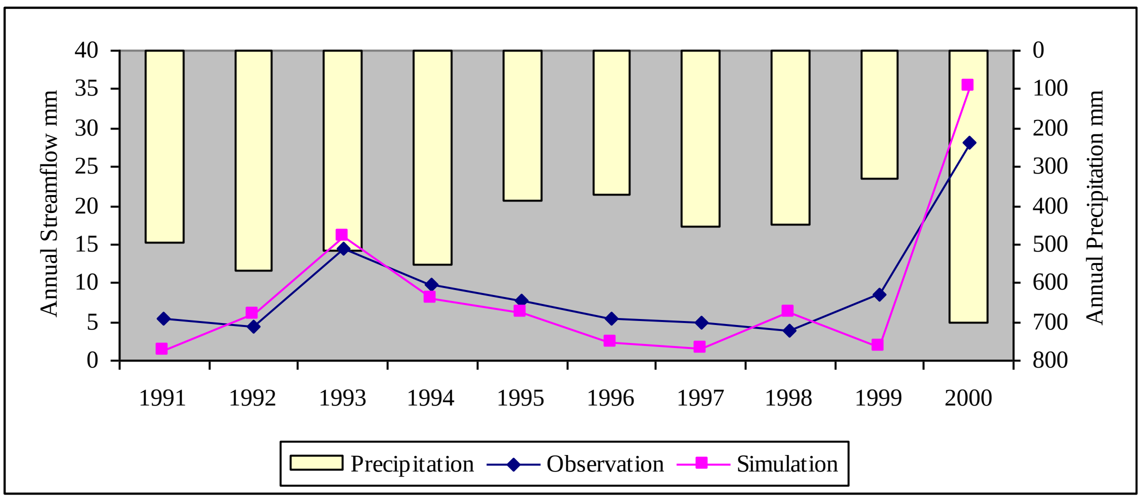


Figure 2. Annual precipitation simulated and observed streamflow in the upper San Pedro watershed. Upper: Redington (1991-1995) and Tombstone (1996-2000) gages; Lower: Charleston gage (1991-2000).

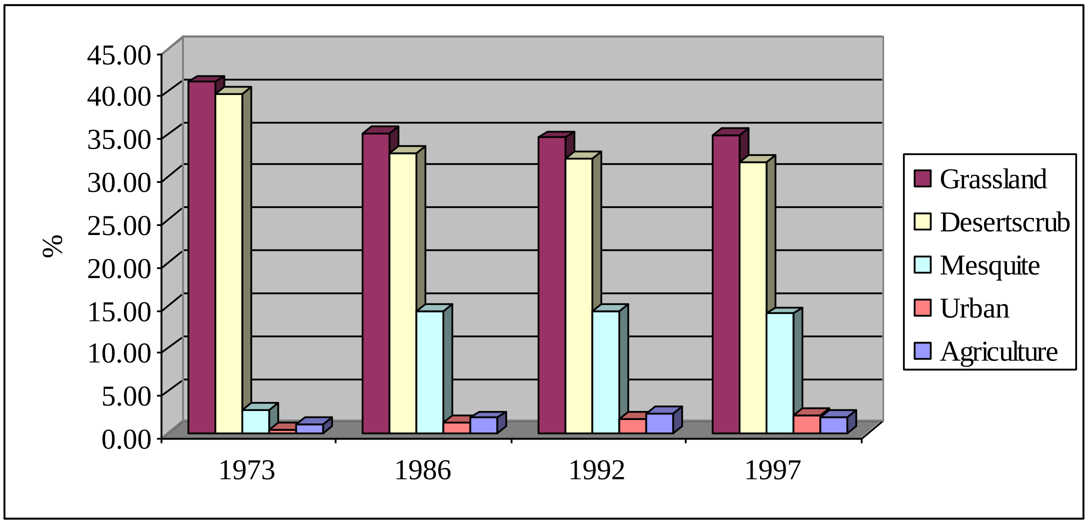


Figure 3. Changes in proportional extent for four landuse classes in the upper San Pedro watershed (1973-1997)

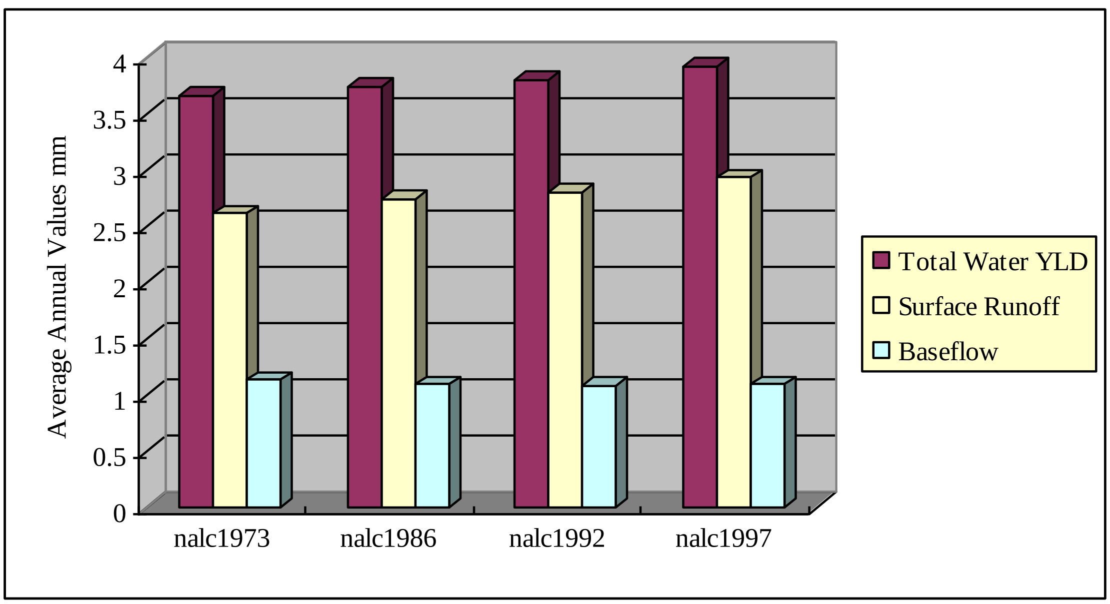


Figure 4. Average annual basin values of water yield (total flow), surface runoff, and baseflow for four past landuse scenarios in the upper San Pedro watershed.

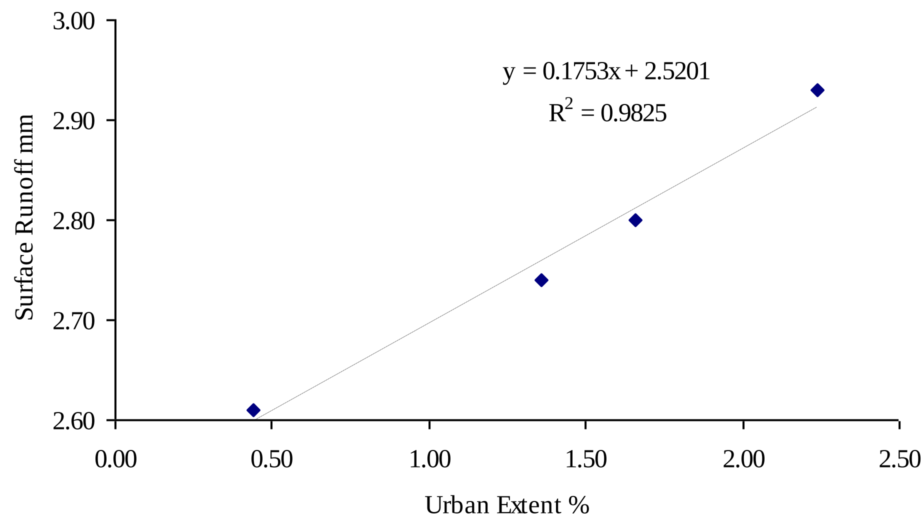


Figure 5. Relationship between proportional extent of urban and average annual surface runoff (1960-2008) for four landuse scenarios in the upper San Pedro Watershed

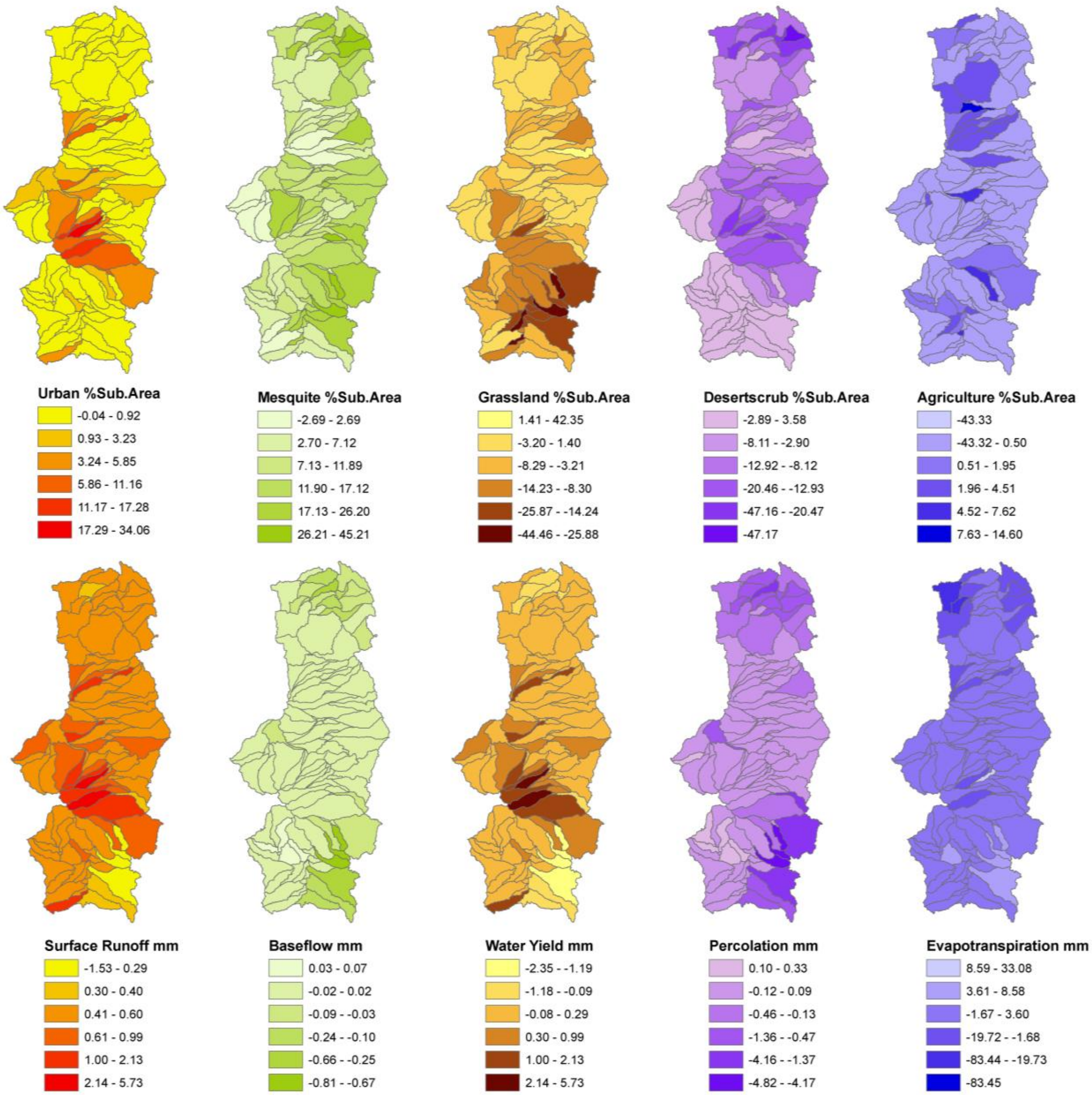


Figure 6. Spatial distribution of deviation of five landuse classes and hydrological processes between landuse scenarios in year 1997 and 1973

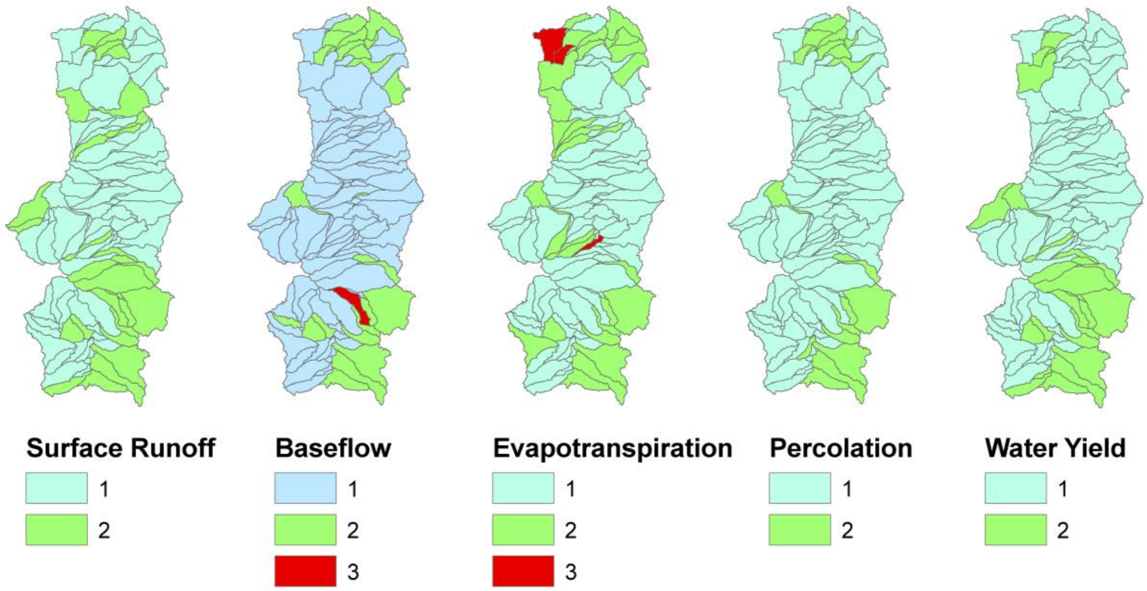


Figure 7. Spatial distribution of divided groups for five hydrological processes. Group 3 are outliers.

Table
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Table 1. Description, default and optimal values that used in the model calibration/validation (* , the multiple sign, means the default values of parameter are multiplied by the number following the "*").

Parameter	Default	Description	Optimal Value	
			Subbasin 1-47	48-116
Adjf_latq	1	Adjust factor for lateral flow	0.02	0.02
CN2	30-92	SCS runoff curve number for moisture condition II	*0.87	*0.83
ESCO	0.950	Soil evaporation compensation factor	0.050	0.050
SOL_AWC	0.01-0.19	Available water capacity of the soil layer	*1.4	*1.4
Alpha_BF	0.048	Baseflow recession constant	0.0852	0.0167
GW_Revap	0.02	Revaporation coefficient	0.20	0.20
Revapmn	1.0	Threshold water level in shallow aquifer for revap	0.0	0.0
GWQMN	0.0	Threshold water level in shallow aquifer for baseflow	20.0	25.0

Table 2. Criteria for examing the accuracy of the model calibration and validation

Index	Calibration (1991-1995)		Validation (1996-2001)	
	Redington	Charleston	Tombstone	Charleston
NS Coefficient	0.63	0.58	0.81	0.70
R^2	0.66	0.82	0.90	0.93
PBIAS	-5.10	9.56	10.70	7.94

Table 3. Proportional land cover extent and percent relative land cover change for the upper San Pedro watershed in the period of 1973 to 1997 (from Kepner et al., 2002).

LandUse	1973	1986	1992	1997	86-73	92-86	97-92	97-73
Mesquite	2.81	14.33	14.23	14.00	409.96	-0.70	-1.62	398.22
Grassland	41.07	35.00	34.57	34.94	-14.78	-1.23	1.07	-14.93
Desertscrub	39.70	32.70	32.20	31.75	-17.63	-1.53	-1.40	-20.03
Agriculture	1.18	1.84	2.45	1.96	55.93	33.15	-20.00	66.10
Urban	0.44	1.36	1.66	2.24	209.09	22.06	34.94	409.09

Table 4 Pair-wise Pearson correlation for the changes of five landuse classes and five hydrological processes between landuse scenarios in 1997 and 1973; ET: evapotranspiration.

	Surface Runoff	Baseflow	Water Yield	ET	Percolation	Urban	Mesquite	Agriculture	Grassland	Desertscrub
Surface Runoff	1.00									
Baseflow	**0.35**	1.00								
Water Yield	**0.99**	**0.48**	1.00							
ET	-0.04	-0.13	-0.06	1.00						
Percolation	**0.34**	**0.98**	**0.47**	-0.13	1.00					
Urban	**0.95**	0.09	**0.90**	0.01	0.09	1.00				
Mesquite	-0.12	**-0.47**	-0.18	0.08	**-0.48**	-0.01	1.00			
Agriculture	0.03	0.03	0.03	0.01	0.03	0.01	0.01	1.00		
Grassland	0.04	**0.50**	0.11	-0.18	**0.47**	-0.13	**-0.54**	-0.09	1.00	
Desertscrub	**-0.38**	0.00	**-0.35**	0.08	0.04	**-0.36**	**-0.54**	-0.07	**-0.23**	1.00

n = 116, bold numbers are for $p<0.05$

Table 5 Summary of multiple regression analyses of five land uses (predictors) with each hydrological process (responses), partial R^2 are listed with direction of influence (negative or positive). Bold numbers are for the strongest predictor.

Responses	Group	Number of Subbasins	Predictors					R^2
			Urban	Mesquite	Agriculture	Grassland	Desertscrub	
Surface Runoff	1	85	**0.9991(+)**				0.0001(+)	0.9992
	2	31	**0.7928(+)**			0.1251(+)		0.9179
Baseflow	1	89	0.1477(+)				**0.3793(+)**	0.5271
	2	26	0.0388(+)		0.1641(+)	**0.6791(+)**		0.8820
Water Yield	1	91	**0.9973(+)**	0.0006(-)				0.9978
	2	25	**0.6944(+)**		0.0274(+)	0.1505(+)		0.8724
Percolation	1	96	0.0841(+)				**0.3184(+)**	0.4025
	2	20			0.3053(+)	**0.5074(+)**		0.8127
ET	1	82	**0.9098(-)**	0.0352(+)			0.0035(+)	0.9484
	2	30				**0.4436(-)**	0.1674(+)	0.6110

$p<0.05$ for all F tests