MODELING THE RESPONSE OF RUNOFF TO CHANGES IN URBANIZATION OF THE UPPER DELAWARE RIVER BASIN

Scott J. Goetz[1], Mindy Sun[1], Claire A. Jantz[2]

SUMMARY

Urbanization and associated increases of impervious cover in the Delaware River watershed (figure 1) have been extensive over the past two decades, resulting in a number of water quality impacts. To assess the scope of these changes, we used a spatial predictive model to quantify the amount and configuration of impervious cover by the year 2030 under three alternative land use scenarios: (1) future growth consistent with business as usual, (2) rapid growth exceeding current trends, (3) planned growth emphasizing low impact development. The resulting impervious cover maps were used to inform a hydrological model (SWAT) to simulate the response of stream flow variables. This exercise documented reduced infiltration, thus reduced baseflow, and increased the flashiness of runoff with greater impervious cover across the watershed.

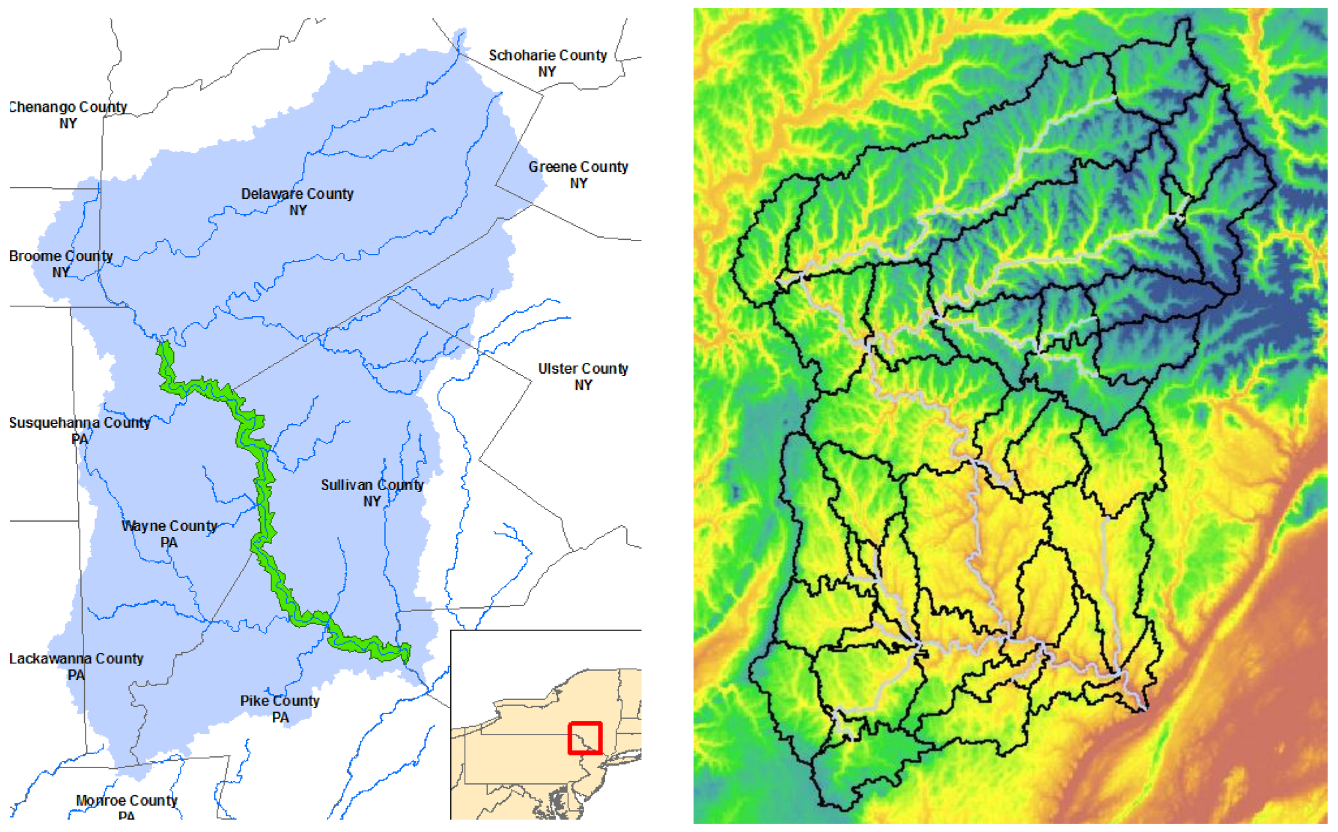

Fig 1. The Upper Delaware Scenic River is located along the boundary of New York and Pennsylvania. A digital elevation model was used to delineate smaller watersheds within the larger catchment.

PROCESS

DELINEATE WATERSHEDS
Break up the study area into hydrologic units

DEFINE LANDSCAPE
Discretize spatial inputs for soil, landuse, & vegetation

CALIBRATION
Select optimal model parameters and validate with observed data.

DEFINE IMPERVIOUS COVER
Using development scenarios

RUN SWAT
Using impervious cover and model parameters

MODELING FUTURE IMPERVIOUS COVER WITH AN URBAN GROWTH MODEL

Our predictions of future impervious cover were generated using the SLEUTH model under each of the different land use scenarios. The SLEUTH model outputs a probability of development for each 30m grid cell. These probabilities were translated to impervious cover by assuming any grid cell with a probability greater than 50% was likely to be developed (we also varied this threshold to test sensitivity of the outputs, not shown here). The results of the SLEUTH modeling are shown in figures 2 and 3. These maps were then used as input to the hydrological model (SWAT).

	CURRENT	CONSERVE	TREND	GROW
Developed	363	422	448	479
Barren Land	18	17	17	17
Forest	6,212	6,181	6,168	6,152
Scrub/Shrub	35	35	35	35
Grasslands	42	41	41	40
Agricultural	927	904	892	880
Wetlands	189	187	186	185

Fig 2. This table enumerates the area within the watershed study area (in km^2) that undergoes development according to each scenario relative to the present (current) time period (i.e. 2005).

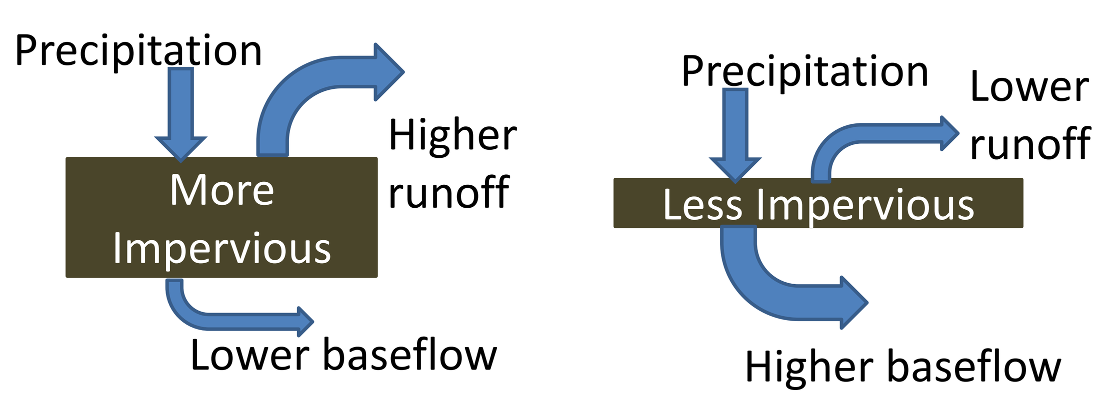

Fig 4. A more impervious landscape would be expected to reduce the amount of precipitation infiltrating into the surface, thus lowering baseflow (subsurface flow to streams) while increasing runoff (overland flow to streams).

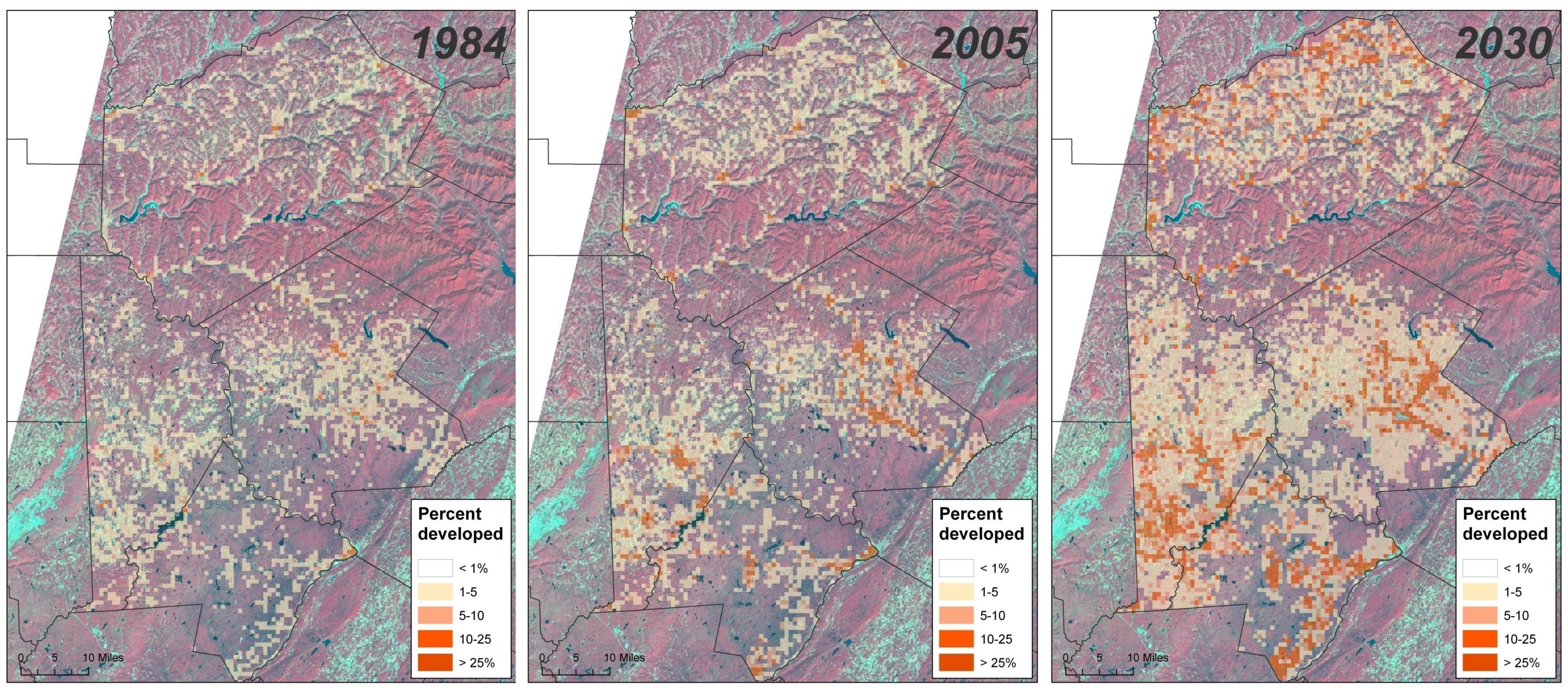

Figure 3. Maps showing past, current, and future development of the Upper Delaware Basin at 1km spatial resolution. The 1984 and 2005 maps were generated from Landsat imagery and the predicted map was generated from the SLEUTH model under a current trends scenario (Jantz, C. A., S. J. Goetz, P. Claggett, and D. Donato. 2010. Modeling regional patterns of urbanization in the Chesapeake Bay watershed. Computers, Environment and Urban Systems **34**:1-16.).

SWAT MODELING

To assess the hydrologic effects of impervious cover we used the Soil Water Assessment Tool (SWAT) model, part of the Automated Geospatial Watershed Assessment (AGWA). SWAT is a quasi-distributed model developed by the USDA Agricultural Research Service to predict the impact of land management practices on water, sediment and agricultural chemical yields in complex watersheds with varying soils, land use and management conditions. SWAT is a continuous-time model, i.e. a long-term yield model, using daily average input values, and is not designed to simulate detailed, single-event flood routing.

CALIBRATION

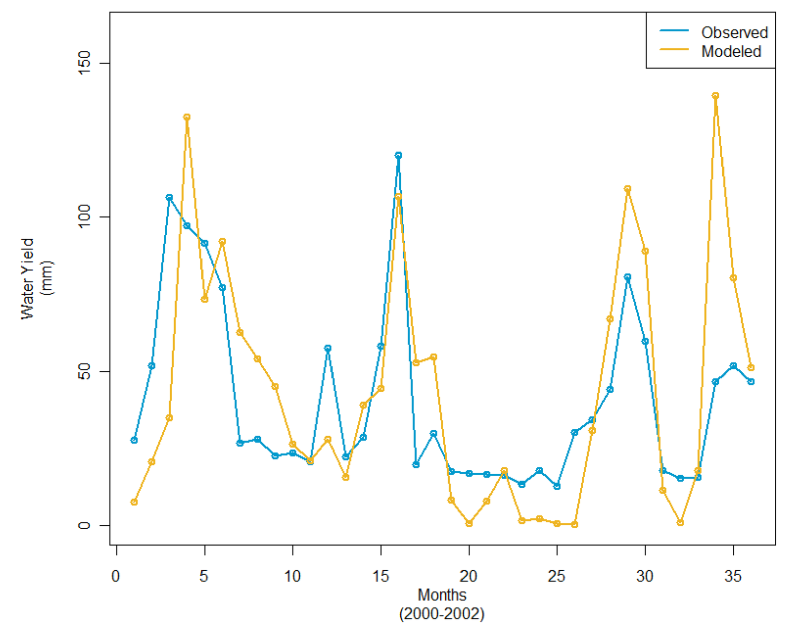

Figure 5 (left) . Calibration is the process by the which the model parameters are selected to optimize the fit between the predicted streamflow and observed (stream gauge) data. We used monthly total streamflow from the USGS Port Jervis station for the years 2000-2002. The SWAT model parameters (SCS curve numbers and groundwater parameters) were adjusted until a reasonable fit was achieved. These optimized parameters were used for subsequent predictive model runs.

RESULTS

Once the model has been calibrated, the model is run for the current, high growth, trend, and conservation scenarios. The results of each run are predictions for total water yield, surface flow, and base flow (in mm). These results can be analyzed both over time, and spatially throughout the basin. We would expect to see base flow decreases and surface runoff increases as the level of development intensifies (figure 4). For high runoff events, it also appears that the difference between the scenarios is even greater.

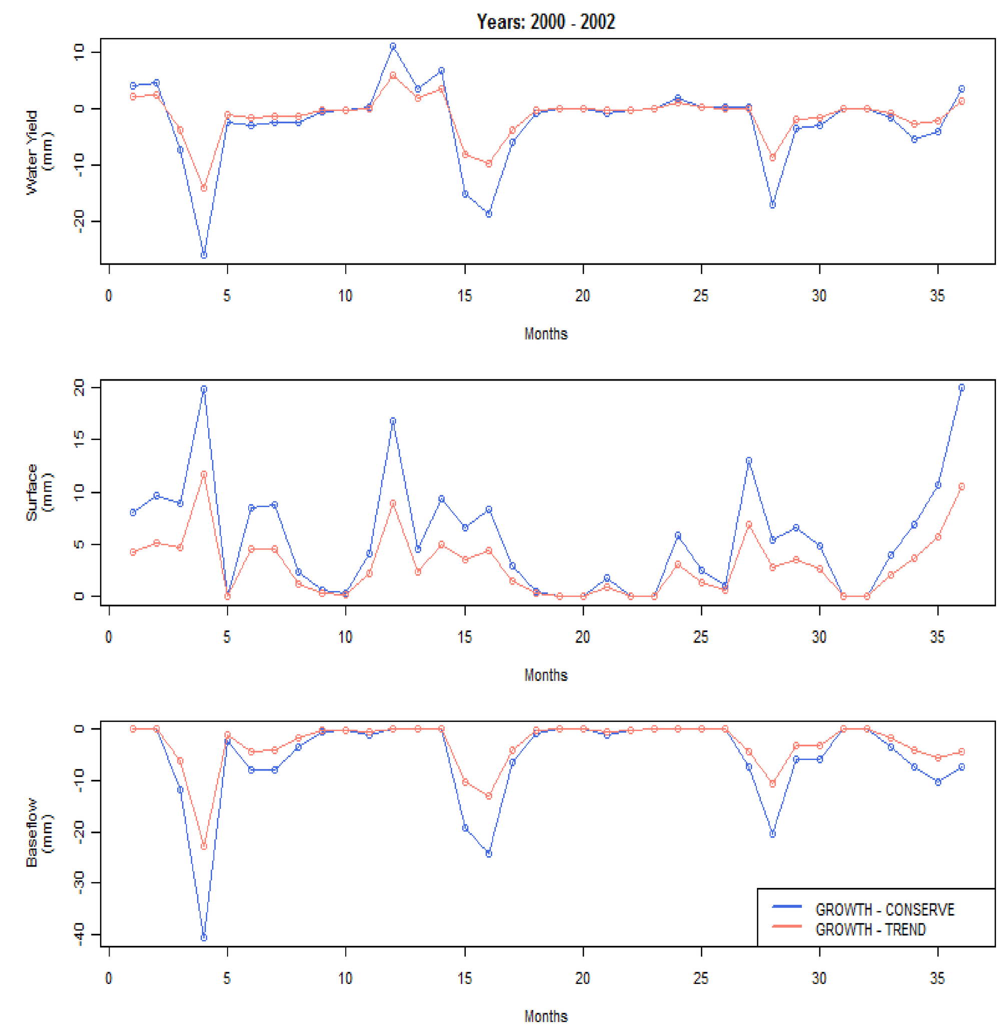

Fig 6 (above). Hydrograph showing differences between the rapid and planned growth scenarios (blue line) and the rapid and current trend scenarios (red line) for the modeled water yield (top), surface (middle), and base flows (bottom). The y-axis value represents the mm of water passing through the outlet point (gauge station) per month, as normalized to the catchment area. The high growth scenario produces higher amounts of surface flow while base flow is lowered, both due to decreased infiltration as a result of increased impervious cover.

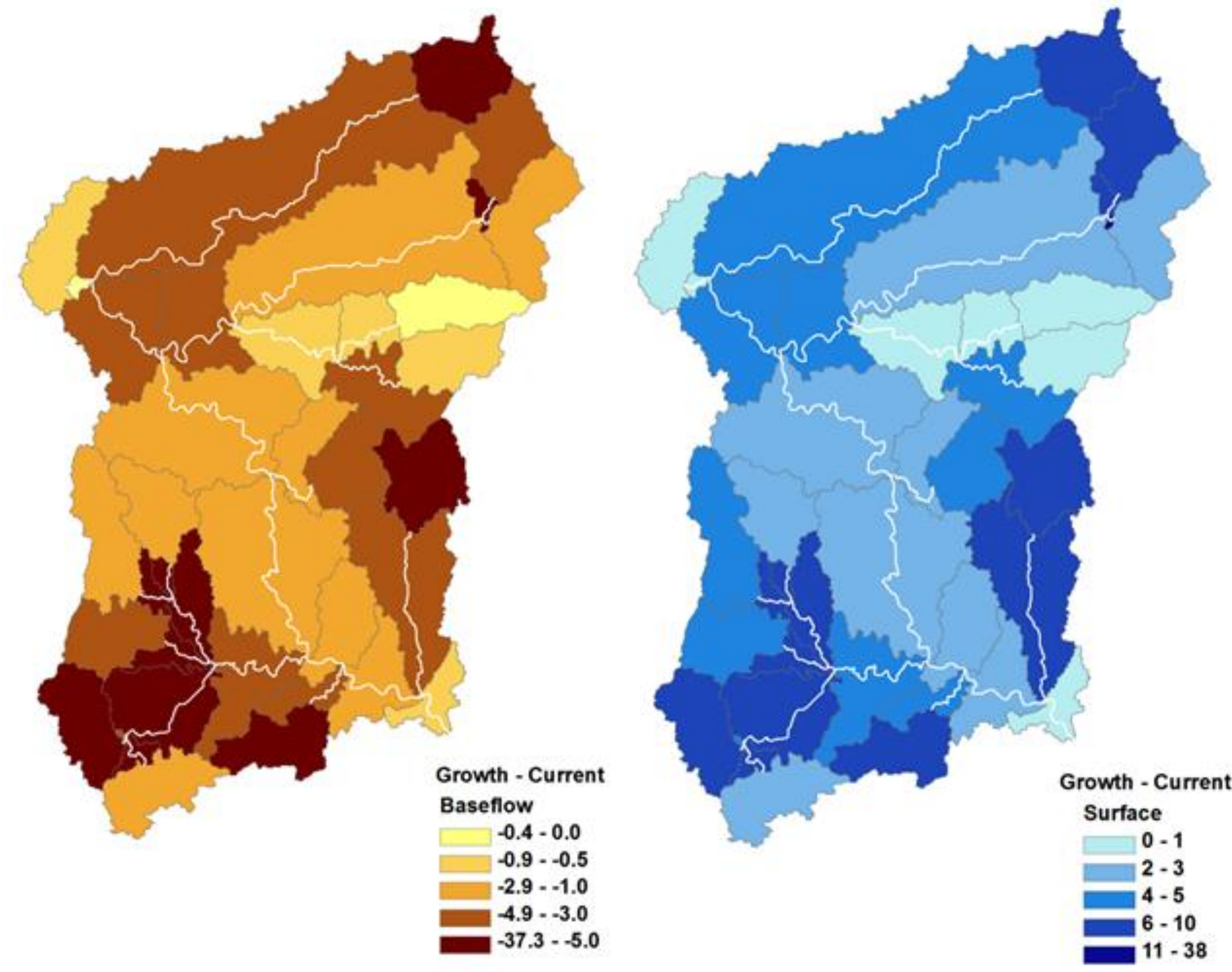

Fig 7 (left). Maps showing the difference in the average annual surface and base flow (in mm) for each basin within the Upper Delaware River watershed. Those basins with the greatest expected development (i.e. the greatest predicted increases in impervious cover) experience the greatest changes in hydrology. Note that in every case baseflow decreased while runoff (water yield) increased.

CONCLUSION

A number of studies have documented increased stream flow and decreased baseflow as the amount of impervious cover within a watershed increases (figure 4). In this context, we used the SWAT model to simulate hydrologic implications of our independent predictions of future urbanization patterns in the study area. The calibrated SWAT model predicted systematic decreases in baseflow and increases in overland flow of the watershed catchments resulting from observed (past) and predicted (future) urbanization. These results indicate substantial infrastructure costs will need to be incurred in order to mitigate impacts on water quality, stream biota and scenic & recreational river resources under increased urbanization. They also indicate, via the different scenarios, that low impact development techniques could be used to mitigate a substantial portion of those costs.

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(1) The Woods Hole Research Center, (2) Shippensburg University, (3) Science Systems Applications Inc. Please direct queries to <sgoetz@whrc.org>