STORMWATER RUNOFF – MODELING IMPACTS OF URBANIZATION AND CLIMATE CHANGE

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Development pressure throughout the coastal areas of the United States continues to build, particularly in the southeast (Allen and Lu 2003, Crossett et al. 2004). It is well known that development alters watershed hydrology: as land becomes covered with surfaces impervious to rain, water is redirected from groundwater recharge and evapotranspiration to stormwater runoff, and as the area of impervious cover increases, so does the volume and rate of runoff (Schueler 1994, Corbett et al. 1997). Pollutants accumulate on impervious surfaces, and the increased runoff with urbanization is a leading cause of nonpoint source pollution (USEPA 2002). Sediment, chemicals, bacteria, viruses, and other pollutants are carried into receiving water bodies, resulting in degraded water quality (Holland et al. 2004, Sanger et al. 2008).

Climate change will likely amplify the impact of urbanization on stormwater runoff, further increasing the quantity of polluted runoff. Climate change predictions point to scenarios for heavy precipitation events to increase in frequency and intensity (Bates et al. 2008, Karl et al. 2008). A study modeling the impacts of urbanization and climate change produced results showing that increased rainfall intensity and increased impervious surfaces will cause flashier runoff periods, greater peak flows and heightened risk of flooding (Semadeni-Davies et al. 2008). Within this context, a science-based system for evaluating the relative impacts of both urbanization and climate change on stormwater runoff at the local scale is warranted.

We developed a fairly simple method to model the impacts of urbanization and climate change on stormwater runoff based on United States Department of Agriculture (USDA), Natural Resources Conservation Services (NRCS) modeling methods. USDA-NRCS methods to quantify volume and generate hydrographs of rate and time are provided in Part 630 of the National Engineering Handbook and in NRCS Technical Release 55. We used 13 watersheds in coastal South Carolina to test the models.

Runoff volume was calculated using the flow curve number method which is based upon the relationship between rainfall, runoff, and retention (i.e., rain not converted to runoff). The underlying hypothesis is that the ratio of actual retention to the potential maximum retention is similar to the ratio of actual direct runoff to potential maximum runoff (i.e., total rainfall. The flow curve number (CN) is a representation of the potential maximum retention and reflects the drainage characteristics of a watershed's soil and land cover. CN is determined by identifying the proportional composition of land cover categories and hydrologic soil groups within a watershed.

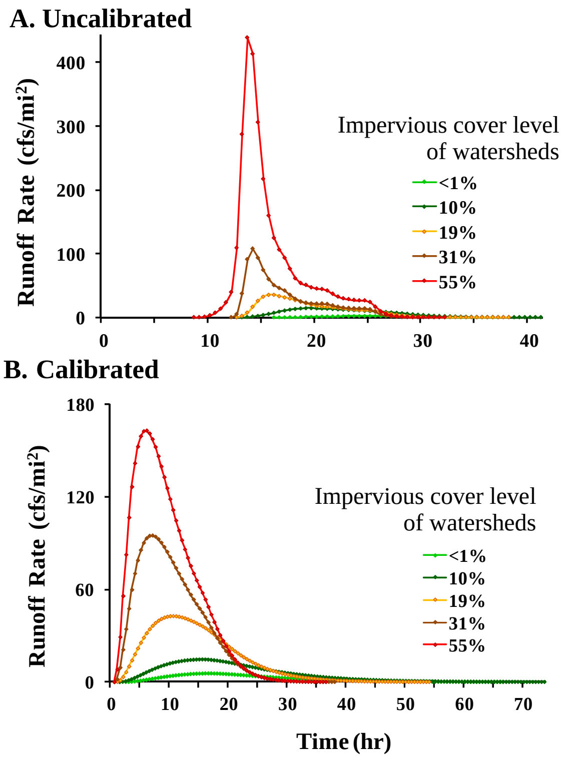


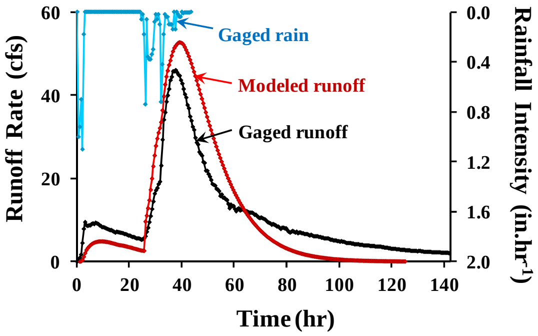
Figure 1. Hydrographs showing runoff from 5 of the 13 test watersheds at different levels of development (based on impervious cover). Y-axis shows runoff rate, and x-axis shows time. Curves are based on a 24-hour 4.5-inch storm event.
A. Hydrographs generated by uncalibrated USDA-NRCS models.
B. Hydrographs generated by calibrated models.

Runoff rate and time were calculated by constructing hydrographs using a three step process: 1) dimensionless unit hydrograph to 2) unit hydrograph to 3) direct runoff hydrograph. A hydrograph represents a watershed's drainage response to a rain event by graphically presenting stormwater runoff discharge rates over time. The hydrograph provides a broader view of runoff from a storm event: in addition to volume (area under the hydrograph curve), hydrographs show time runoff begins, time to peak rate, peak rate, and time runoff ends. Calibrations to the runoff volume and hydrograph models were made to reflect coastal southeastern US conditions generally. They were based upon literature reviews, examination of default values and formulas used for the NRCS methods, discussions with hydrologists, and an evaluation of model output compared to expected relative differences among watersheds based upon knowledge gained from past watershed research (Blair 2008, Figure 1).

The calibrated models were validated using U.S. Geological Survey (USGS) gaged precipitation and discharge measurements (Figure 2). USGS gaged data were recorded at 15-minute intervals from August 2002 through September 2003 in three South Carolina creeks with watersheds similar to our test sites (Smith 2005).

Templates were developed to provide modeling flexibility, and applications include using various urbanization and climate change scenarios. This allows us to investigate relative differences in runoff among watersheds at existing development levels. In addition, we can forecast the impact of development within a forested / undeveloped watershed by building up the percent of impervious cover to higher levels. For example, the current level would be <1%, 10% would represent light development, 30% would be a suburban watersheds, and 50% would be a highly developed or urban watersheds (Figures 3). Different rainfall amounts and storm durations can be modeled to simulate the changes in climate (Figure 4). Annual runoff can be modeled and forecasts made for various urbanization and climate change conditions. This modeling method can be developed into a tool that would benefit decision makers, research scientists, and the public.

Figure 2. Validation of calibrated model with USGS gaged rain and runoff. Y-axis shows runoff rate, and x-axis shows time. Curves are based on a 4.6 inch storm event at Old House creek watershed on 4/7-8/2003.



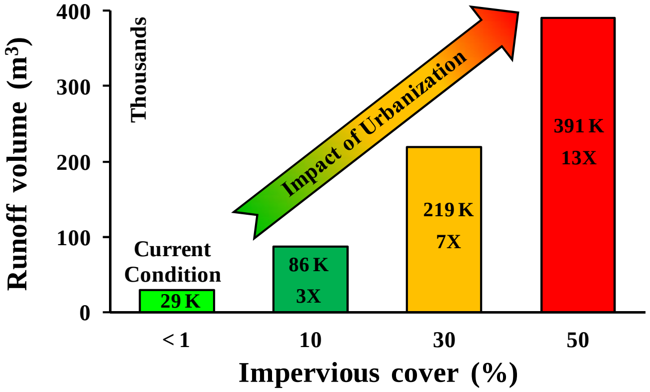
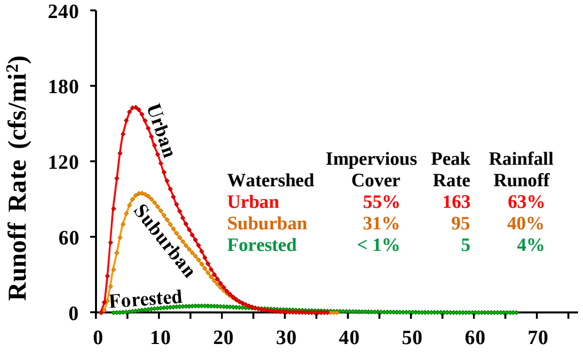


Figure 3. Bar chart showing predicted impact on runoff as a forested test watershed is developed. Volume is shown on the y-axis in thousands of cubic meters. Percent of impervious cover is shown on the x-axis. Volumes are based on a 4.5 inch storm event.

A. Impact of Urbanization



B. Impact of Urbanization & Climate Change

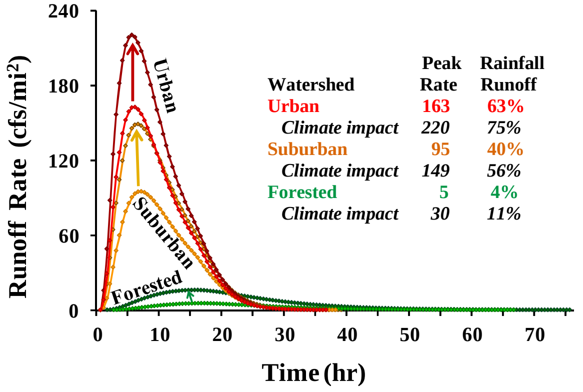


Figure 4. Hydrographs showing runoff from 3 test watersheds at different levels of development (based on impervious cover). Y-axis shows runoff rate, and x-axis shows time.

A. Hydrographs illustrate the impact of urbanization on runoff. Curves are based on a 24-hour 4.5-inch storm, average runoff conditions.

B. Hydrographs illustrate the impact of urbanization and climate change on runoff. Climate impact curves are based on a 24-hour 5-inch rain, semi-saturated runoff conditions.

Citations

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