Predicting streamflow response to increased imperviousness in an urbanizing watershed using an integrated modeling approach

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• Urban development (built-up impervious surfaces) impacts the landscape, affecting the hydrologic regime, including runoff and streamflow.

• It is possible to look at past effects of urbanization and adapt to problems already at hand, but what about planning for the future?

• Quantitative estimates of future impacts of urbanization are needed to develop actionable information that can be used by land managers, planners, and policy makers.
Objective:

• The overall objective of this study was to use an integrated modeling approach to help address the problem.

• The approach involves using two models:

  1. An urban growth model that generates estimates of future impervious surface cover.

  2. A hydrologic model, that can use the output from the urban growth model to generate streamflow predictions.

Specific goal:

• Assess the hydrologic impacts of future impervious surface growth in Hinkson Creek watershed.
Study Area:

- Hinkson Creek watershed (HCW):
  - Designated impaired under section 303(d) of the Clean Water Act in 1998.
  - An urbanizing watershed.
Study Area:

- 59% of the city of Columbia, Missouri is situated in HCW.

- Columbia growing rapidly; population increased about 35% since 2000 (about 85,000 to 115,000).
The **Soil Water Assessment Tool (SWAT)** (Arnold et al., 1998), a deterministic, physically based, continuous-time model that can be used for long term hydrologic simulations to predict watershed management impacts.

SWAT uses spatially-referenced: **topographical**, **soil**, **climatic**, and **land-use** data to simulate the hydrologic balance in a watershed.

In SWAT, the watershed is divided into sub-basins, then into hydrologic response units (HRUs) comprised of unique land-use, soil, and topographical combinations.
In SWAT, the hydrologic cycle is based on following equation:

\[ SW_{\text{time-step}} = SW_{\text{begin}} - Q_{\text{surface}} - ET - Perc - Q_{gw} \]

Streamflow is based on the equation:

\[ FLOW_{\text{time-step}} = Q_{\text{surface}} + Q_{\text{lateral}} + \text{Baseflow} - \text{Trans.Loss} \]

And surface runoff \( (Q_{\text{surface}}) \) is based on the SCS runoff equation (SCS, 1972), which accounts for: canopy interception, surface storage, infiltration, soil permeability, land-use, slope, and antecedent soil water conditions.

(Adapted from Neitsch et al., 2011)
The Imperviousness Change Analysis Tool (I-CAT; Sunde et al., 2014). Simulates urban growth in terms of pixel-based imperviousness.

Uses urban growth drivers (elevation, slope, distance to water, road networks, and urban areas), along with past impervious surface growth trends, to predict where new development is likely to take place.

Growth allocated to locations with highest suitability values. And percent imperviousness (PIS) for each developed pixel is based on neighborhood analysis.
Soil
Land
- cover
Past impervious surface cover
Urban growth drivers
Conceptual schema:
I-CAT
Slope
Climate
Soil
Land-cover
SWAT
Streamflow estimates
Drivers of Urban Growth
Conceptual schema:
Slope
Climate
Soil
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Past impervious surface cover
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Imperviousness growth prediction:

Model validated using the relative operating characteristic (ROC).

**Calibration**: urban growth driver weights adjusted to generate suitability grid in best agreement with 1990-2000 growth grid (Zhou et al., 2012).

**Validation**: suitability grid from calibration accepted & compared with 2000-2011 growth grid (Zhou et al., 2012; NLCD, 2011).

Area under curve (AUC) for calibration & validation periods indicated that the model was effective for simulating future development.
Imperviousness growth prediction:


AUC (calibration) = 76
AUC (validation) = 73
Imperviousness growth prediction:
Baseline: 2011
Imperviousness growth prediction:

Prediction: 2031

In HCW:

2531.448 ha (2011)

3681.531 ha (2031)

Most important growth drivers:

1. Slope
2. Distance to secondary boundaries
SWAT - Streamflow simulation:

Calibration: Apr. 2007 – Dec. 2010  NSE = 0.84, $R^2 = 0.85$, RSR = 0.40

Validation: Jan. 2011 – May. 2014  NSE = 0.79, $R^2 = 0.79$, RSR = 0.46
19 years (1/1/1995 – 12/31/2013) of daily weather observations from Sanborn Field station were used in order to capture an array of possible hydrologic conditions in Hinkson Creek Watershed.

To compare only the effects of land use change, climate was held constant, and SWAT was run using the 2011 and 2031 land cover data.
SWAT - Results:

- 2011 mean discharge
- 2031 mean discharge
- 2031 avg. % diff.
SWAT - Results:

![Graph showing discharge rates for different years and months]
SWAT - Results:

![Graph showing average monthly surface runoff percentage change.](image-url)
SWAT - Results:

- Lateral flow

- Baseflow
Conclusions/Discussion

• Future impervious surface growth in the HCW will impact stream discharge.

• Simulation results suggest that the impact will be an average monthly discharge increase of approximately 4.2%.

• It was observed that the overall change was the result of alterations to various components of the simulated water yield, rather than a straightforward increase.

• The most greatly affected components were: surface runoff (increase), baseflow (decrease), and percolation (decrease).
Continued work:

- Analysis/comparisons of wet/dry years.
- Uncertainty analysis to estimate range of uncertainty for streamflow estimates.
- Statistical comparisons between land-use scenarios.
- Scenario analysis (implementation of controlled growth, rapid growth, uncontrolled growth).
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