Loss of Street Trees Causes 10,000 L/Tree Increase in Leaf-on Stormwater Runoff for Great Lakes Urban Sewershed

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Highlights

- The model performed well in the validation period using both manual and automated calibration.
- Predicted runoff reduction was 106 L/m^2 of canopy (10,226 L/tree), 61% higher than field estimated 66 L/m^2 (6,376 L/tree).
- Additional field studies are needed to confirm or update model processes and parameter ranges.

Introduction

Urban forests are a nature-based solution for stormwater management, and computer models are a rapid and inexpensive way to assess tree impacts. This study modeled underlying processes and extent of runoff reduction due to street trees with a paired-catchment field experiment conducted in Fond du Lac, Wisconsin (Selbig et al., in press). The i-Tree Hydro model simulated site-level conditions from the field experiment, before and after mature green ash (Fraxinus pennsylvanica) and Norway maple (Acer platanoides) street trees were removed from one of the two catchments. Field observations were compared to simulation predictions to assess the validity of modeled stormwater benefits of trees.

Methodology

Model area characterization

Model inputs were prepared for two residential catchments (a control and test) in Fond du Lac, WI, USA (Figure 1). For each catchment, model inputs include area, land cover, topography, weather data, discharge data, and hydrologic parameters as described by Wang et al. (2008). Area, land cover, and topography were derived from standard Geographic Information System (GIS) data layers and analysis. Weather data was collected in situ with support from the weather station at Fond Du Lac County Airport

(USAF-WBAN ID#: 726506-04840). Discharge data was collected in situ using redundant sensors in the storm sewer pipe draining surface runoff from each catchment.

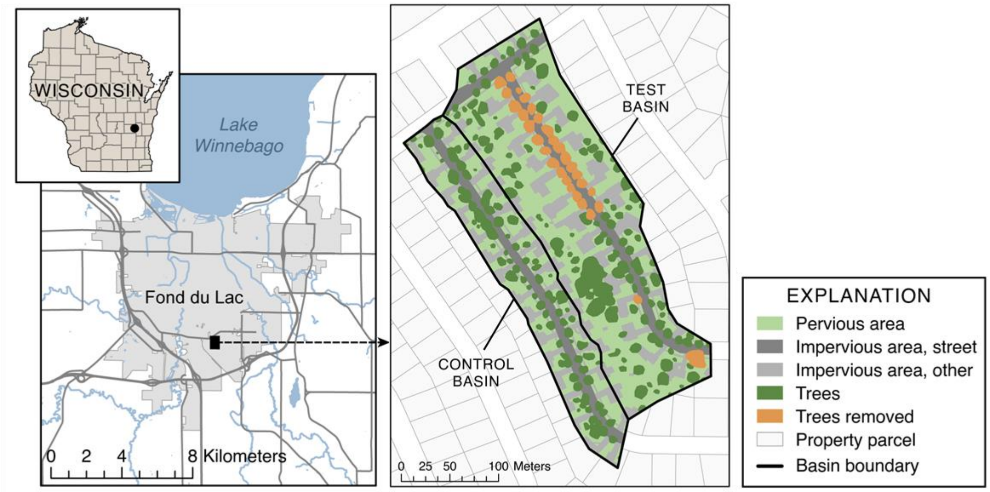

Figure 1. Map of paired catchment study area location.

Calibration and validation

Model hydrologic parameters were aligned with field conditions using automatic and manual calibration. Calibration was guided by field observations and model performance metrics comparing predicted and observed total weekly surface runoff (m^3) from 2019. Fit was judged using peak weighted Nash-Sutcliffe criteria, base flow weighted criteria, and balanced peak and base flow criteria. To validate predictions, model parameters calibrated with 2019 data were used to simulate conditions in 2020.

Change in runoff and water fluxes due to trees

Weather data for the post-treatment period was input with the post-treatment land cover to simulate a “Cut” scenario that corresponds with 2020 observations. To predict discharge had trees not been removed, a “No-cut” scenario was simulated using weather data for the post-treatment period and pre-treatment land cover. The difference in discharge simulated in Cut and No-cut scenarios describes the change in runoff due to tree cover. Change in runoff volume (m^3) was normalized to total canopy area (L/m^2 canopy) and total number of trees removed (L/tree). This approach used comparable metrics and a calibration time period consistent with those employed in the field study (Selbig et al., in press).

Results and discussion

Model performance values for calibration and validation are shown in Table 1. Calibration resulted in fits better than the average observed flow (>0.0) and, for peak flow, are near or above the threshold of 0.3 considered to be a good fit. Validation results are a mix of fits better (>0.0) and worse (<0.0) than the average observed flow. Calibrated parameters performed better during the validation period in the test catchment than in the control catchment. The control parameters are derived primarily from automated calibration, whereas test parameters relied significantly on manual calibration.

Table 1. Model performance in the control and test catchments for the calibration (2019) and validation (2020) periods.

Calibration metric	Control catchment results		Test catchment results	
	Calibration period	Validation period	Calibration period	Validation period
Peak weighted criteria	0.29	-0.23	0.25	0.76
Base flow weighted criteria	0.18	0.06	0.36	0.55
Balanced flow criteria	0.31	0.33	0.23	0.83

Calibrating the model to hyperlocal conditions presented unique challenges. Site-specific phenomena required additional data cleaning and coarser timesteps for automated calibration. In situ estimation of some parameters such as specific leaf storage exceeded their suggested model ranges. Overall, validation supports use of the model in scenario assessment but with the need for fine-tuned parameters and recognizing limitations in the observation data used for calibration. The substantial differences between calibrated and uncalibrated model predictions of runoff reduction and absolute runoff suggest the reliability of uncalibrated model outputs needs to be reevaluated.

Simulations demonstrated the anticipated increase in runoff after tree canopy was removed. Runoff reduction of the removed tree canopy is estimated to be 10,226 L/tree and 106 L/m^2 of canopy. The associated field study estimated lower runoff reduction and less total runoff for both land cover conditions. The difference between field results (6,376 L/tree and 66 L/m^2 of canopy) and model results could not be fully accounted for in the other water fluxes compared for this study. Model results are consistent with the ranges of runoff reduction from previous studies such as Xiao and McPherson (2002) (610 to 26,000 L/tree) and Center for Watershed Protection (2017) (3,200 to 7,570 L/tree). This overlap and agreement supports the upward adjustment of the 2017 GLRI runoff credit (233 L/tree; GLRI, 2017).

There are no consistent trends in modeled throughfall or interception values relative to field values. The largest of five pre-treatment storms had a modeled interception 44% lower than the field estimate. For the second largest of the five storms, modeled interception loss was 64% higher than the field estimate. Spatially-averaged interception data was limited to five storm events. Typical values of leaf storage in the literature are lower than in this hyperlocal setting. Even with model leaf storage increased to match field observations, other factors drive the field study to estimate substantially lower runoff reduction than i-Tree Hydro. These results emphasize the need for further study of leaf storage limits and variability, better understanding of subsurface fluxes and storage, and more extensive field monitoring of evaporation and ET.

Conclusions and future work

Study results show stormwater impacts of trees can be accurately predicted using i-Tree Hydro when calibrated manually. This model's predicted impacts of trees are within the range of other models and standards, but high relative to in situ estimates. Study limitations highlight the value of computer models and the need for quality field data. Model validation suggests study results could inform the uptake of trees as stormwater control measures at catchment scales across the Great Lakes basin. Further study of in situ phenomena may adjust model processes and improve predictions of tree stormwater benefits.

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