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Comparative Evaluation of two Modeling Approaches of Urban Flooding in Ottawa, Canada

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Abstract

Urbanization and climate change have heightened urban flooding, necessitating stormwater modeling approaches tailored to urban contexts. This study compares two modeling approaches using PCSWMM for an urban catchment in Ottawa, Canada: (1) a topographic model, which simulates drainage patterns based on a 0.25-meter DEM, and (2) a lot-level model, which represents idealized drainage by routing runoff directly to roads. While the topographic approach reflects conventional subcatchment delineation, the lot-level approach is designed to evaluate impacts of property-level actions on flooding. Both models, provided by the City of Ottawa, were calibrated using flow and precipitation data for 11 storm events and validated for 6 events. Calibration showed correlations ranging from 0.61 to 0.97 (average 0.84) and KGEs averaging 0.49, while validation achieved correlations of 0.84–0.86 and KGEs between 0.42 and 0.34. A 69-mm storm event was simulated to assess flood distribution differences. The topographic model identified greater backyard flooding due to terrain-driven routing, whereas the lot-level model predicted higher street inundation caused by direct routing to roads. While no surface water level data were available for model calibration, results reflect relative differences due to routing assumptions. This analysis informs targeted flood management strategies by aligning modeling methodologies with specific mitigation objectives.

Highlights

- Evaluation of two common urban flood modeling approaches to inform mitigation objectives
- Similar calibration and validation accuracy across approaches
- Distinct spatial inundation patterns due to differences in runoff routing

Introduction

Introduction

Urbanization has significantly altered land use patterns, resulting in increased impervious surfaces and reduced stormwater infiltration, which, combined with the impacts of climate change, has intensified urban flooding risks (Bell et al. 2016; Du et al. 2012). Extreme rainfall events are becoming more frequent due to the warming climate, increasing flood risks and challenging aging stormwater infrastructure (Bush and Lemmen 2019; IPCC 2013; Jeong et al. 2020). Traditional grey infrastructure is not designed to address the complexities introduced by these changes (Fletcher et al. 2013; Guan et al. 2015).

Process-driven hydrological modeling is critical for understanding stormwater dynamics. PCSWMM, an advanced version of SWMM, enables simulation of drainage systems and evaluation of management interventions (CHI Water 2024). This study compares two PCSWMM-based models—topographic and lot-level—for an Ottawa catchment. The topographic model delineates subcatchments based on terrain and routes runoff through backyards. The lot-level model assigns subcatchments to individual properties and routes runoff to adjacent roads, representing engineered drainage logic. By calibrating and validating these models using observed flows and rainfall data, the study explores trade-offs between routing assumptions and predicted flood distributions.

Methodology

Model Setup

This study focuses on the Crystal Beach neighborhood, located in Ottawa's west end near the National Capital Commission's Greenbelt. Crystal Beach spans 77 hectares and features 42% impervious surface coverage with an average slope of 9%. Its aging stormwater infrastructure, designed without modern dual drainage principles, is prone to surcharging during storms with return periods of 2 years or greater. The overland flow systems also lack the capacity to manage larger storm events. A flow monitor in the catchment is located 7.5 km from the nearest City rain gauge. Figure 1 shows the location of the study area within Ottawa, showing the flow monitor and the two PCSWMM models with subcatchments, stormwater networks, and outfalls.

For the topographic model, 0.25-meter digital elevation model (DEM) provided by the City was used to delineate the area into 721 subcatchments based on slope and drainage. The lot-level model assigned runoff routing subcatchments to individual parcels, with additional division into front and back yard units where applicable. Key attributes, such as impervious surface percentages, subcatchment slopes, and widths were derived using the DEM. Land cover, stormwater system, bounding, obstruction (buildings), road centerlines, and downstream flow path layers were further refined during calibration.

Infiltration was modeled using the Horton equation, with the City of Ottawa's standard values for maximum infiltration (76.2 mm/hr) and minimum infiltration (18.1 mm/hr). Depression storage depths were set at 1.57 mm for impervious areas and 4.67 mm for pervious areas. Manning's roughness coefficients were adjusted to 0.013 for impervious surfaces and 0.25 for pervious surfaces, reflecting local conditions. Dynamic wave routing with a routing time step of 0.5 seconds was used, ensuring accurate simulation of overland and sewer flows. Both models have 1D-2D capabilities with dual-mesh setup: a directional mesh with a resolution of 2 meters for road corridors and a hexagonal mesh with a 5-meter resolution for open areas. The 2D model incorporated the bounding layer to define study extents and a DEM layer to assign elevation data to the mesh.

a) Crystal Beach - topographic b) Crystal Beach – lot level

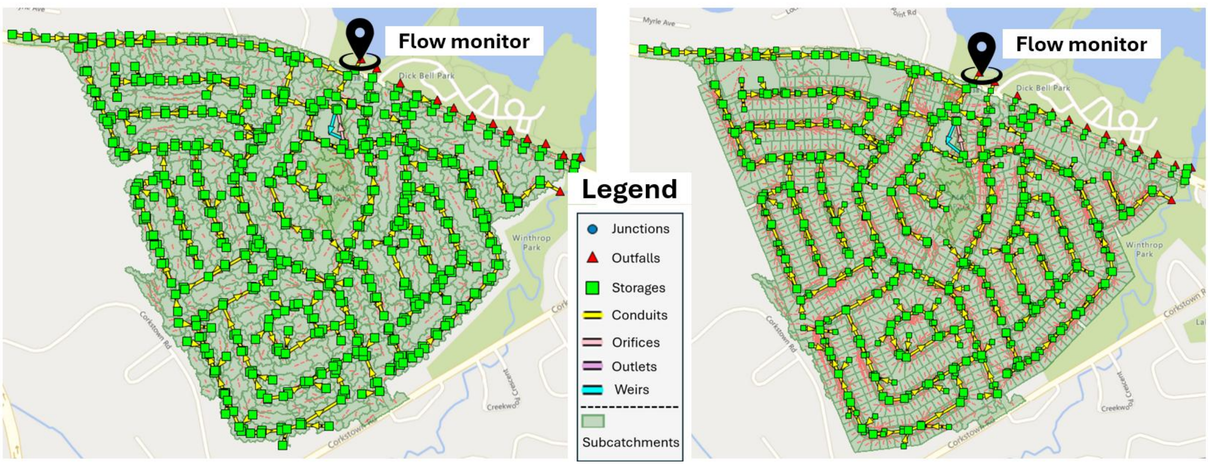

Figure 1. Map of the study area (Ottawa, Canada) showing the rain gauge, flow monitor, subcatchments, stormwater networks, and outfalls.

Calibration and Validation

Both models were calibrated and validated using flow data from a monitoring station and precipitation records from a nearby weather station. Key model parameters, reflecting imperviousness, subcatchment widths, infiltration rates, and depression storage depths, were refined during calibration to align simulated and observed flows. The Sensitivity-based Radio Tuning Calibration (SRTC) tool in PCSWMM was employed to systematically optimize parameter values and assess their impact on model performance. These procedures ensured the models accurately represented the study area's hydrological behavior under various rainfall conditions, providing a reliable foundation for further analysis.

2D Maximum Inundation Comparison

To evaluate inundation patterns, the 2D cell output of maximum inundation depths from PCSWMM was exported as a shapefile. These data were analyzed using an R script to calculate statistical metrics that quantify differences and correlations between the outputs of two models and the observed data. Key metrics included Pearson correlation coefficient, Kendall's tau, Kling-Gupta Efficiency (KGE), Mean Absolute Error (MAE), and Root Mean Square Error (RMSE). Pearson correlation coefficient measures the strength and direction of the linear relationship between the observed and the model predicted inundation depths. Kendall's tau evaluates the rank correlation, reflecting how well the relative order of predicted values matches with that of observations. Similarly, higher (lower) values of KGE indicate better (poor) resemblance between the observed and model predicted values. MAE and RMSE provide measures of the average and squared differences, respectively, between the predicted and observed inundation depths. While observed surface water levels were not available, these analyses quantified the relative agreement and spatial patterning between models, offering insights into the impact of differing runoff routing assumptions.

Results and Discussion

The calibration and validation of the topographic and lot-level PCSWMM-based models demonstrated strong performance, with the lot-level model showing slightly higher correlation values and consistency. For calibration, the topographic model achieved correlation values ranging from 0.61 to 0.94 and KGE values ranging from -0.24 to 0.79, while the lot-level model produced correlation values between 0.60 and 0.95 and KGE values ranging from 0.04 to 0.86. Validation metrics were similarly robust, with the topographic model showing correlation coefficient values ranging from 0.64 to 0.96 and KGE values ranging from 0.10 to 0.84. The lot-level model achieved correlation coefficient values ranging from 0.64 to 0.96 and KGE values between 0.07 and 0.66. Figure 2 illustrates these differences by comparing hydrographs from observed data and the topographic and lot-level model simulated data for two storm events, which respectively occurred on June 6 and July 24-25, 2017.

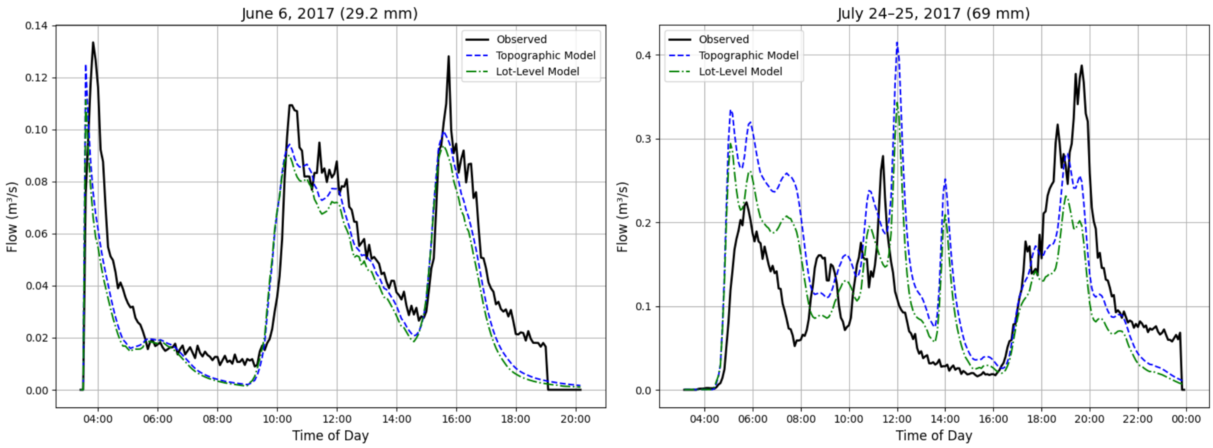

Figure 2. Comparison of hydrographs obtained from observed data and model outputs for the topographic and lot-level PCSWMM-based models for two storm events that occurred respectively on June 6 and July 24-25, 2017.

The comparison of maximum inundation depths revealed moderate agreement between the two models, with the Pearson correlation coefficient of 0.45, Kendall's tau of 0.41, MAE of 0.017 m, and RMSE of 0.043 m. While average inundation depths were similar, distinct spatial patterns were noted. The topographic model predicted more backyard flooding, while the lot-level model indicated greater street inundation. These differences are illustrated in Figure 3, for the largest event of the study period (i.e., 69-mm rain event of July 24–25, 2017), calculated as the differences between the values simulated by the topographic model minus those from the lot-level model.

a) Topographic b) Lot-level c) The difference

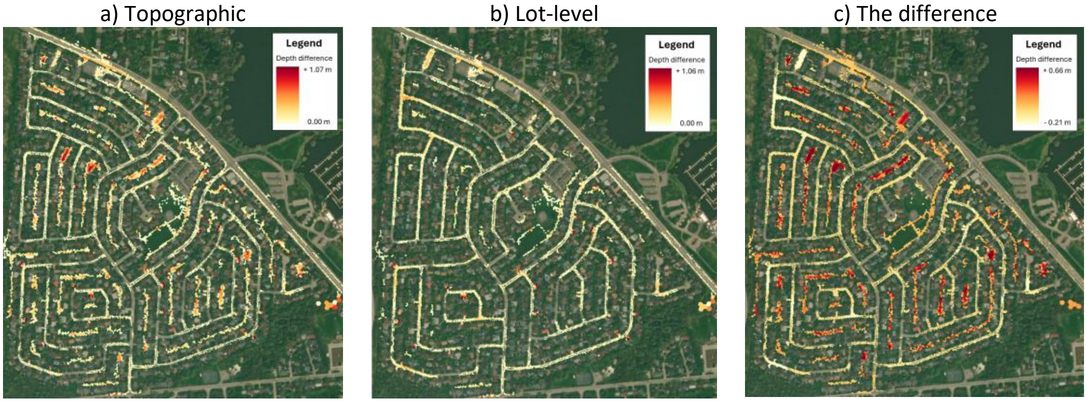

Figure 3. Comparison of inundation depths simulated by the (a) topographic (H_{topo}) and (b) lot-level (H_{lot}) models for the largest event of the study period (i.e., 69 mm rain event of July 24–25, 2017). The differences between the values simulated by both model (H_{topo} - H_{lot}) are shown in (c).

Conclusions and future work

This study demonstrates that routing assumptions in PCSWMM influence spatial flood predictions. While both models showed similar hydrograph performance, inundation patterns differed: the topographic model predicted more backyard flooding, and the lot-level model more road inundation. Future studies should deploy additional flow monitors, use distributed rainfall data, and validate surface flooding to improve confidence in spatial predictions. Work is ongoing to expand this approach to other neighborhoods and to simulate NBS scenarios. A journal publication is forthcoming.

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