Modeling the Impacts of Storm Intensities and Rainfall Time Increments on Flooding

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Introduction:

With TS Lee in 2011 and since, Penn State Harrisburg's campus entrance (as well as parts of Middletown Borough) have experienced flash flooding (Figure 1).

- TS Lee (Sept 5-9, 2011): 120 min; 2.80 in of rain. 14.29 in total (Figure 1).
- July 23, 2017: 87 min and 4.71 in of rain. (Figure 1)
- October 31, 2019: 66 min and 2.22 in of rain.
- July 9, 2021: 17 minutes and 0.95 inches of rain.

These floods are not in the FIRM areas and damage does not rise to a state or federal disaster declaration, but these storms are becoming more common.

RESEARCH QUESTION: In small urban watersheds with compacted soils, what is the impact of the rainfall time increment on modeling flood conditions (1 minute vs 15 minutes vs 1 hour)?

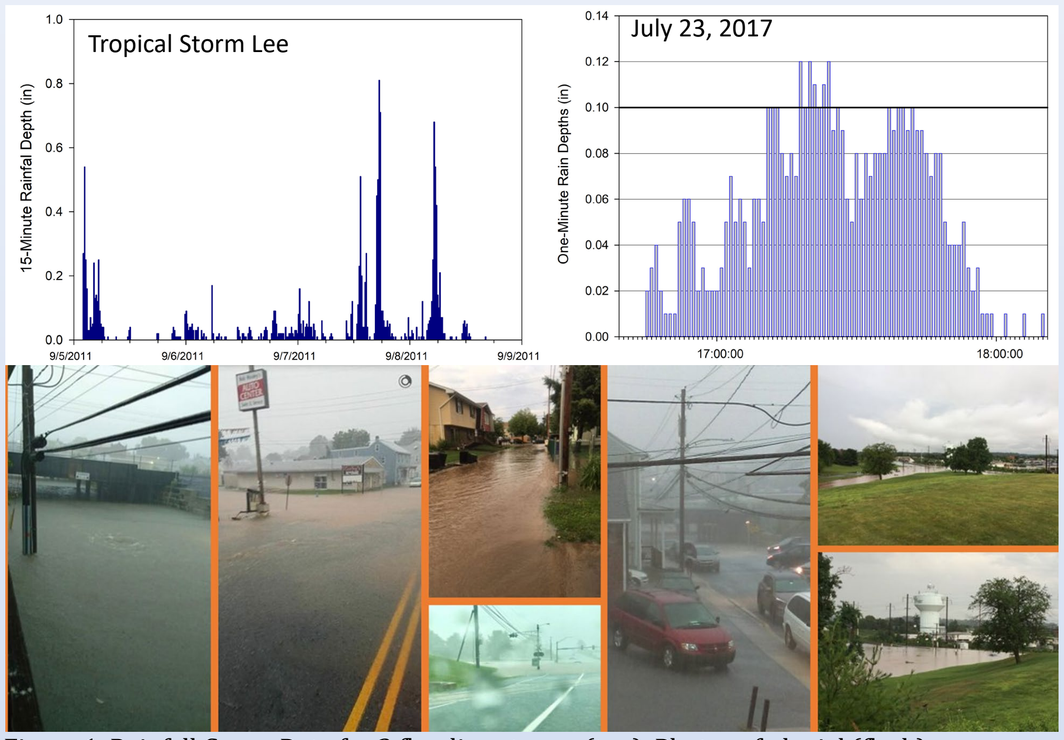

Figure 1. Rainfall Gauge Data for 2 flooding storms (top). Photos of pluvial (flash) flooding in Middletown Borough and Penn State Harrisburg.

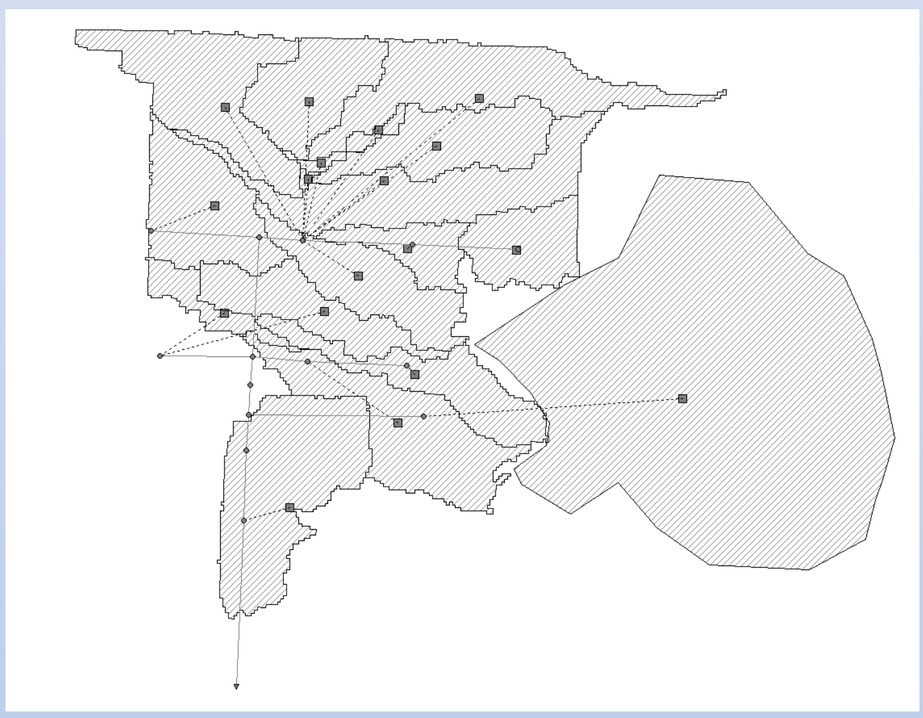

Figure 2. SWMM Model Subcatchment Map.

Methods:

- Model: Storm Water Management Model (SWMM) version 5.2.
- 50.5 acre watershed, 20 subcatchments, slopes 1-12%, 700 ft^2 ponded area per node (Figure 2).
- Horton infiltration data: Max Rate = 21 in/hr; Min Rate = 4.62 in/hr; k = 0.944 h^{-1}; 7 day drying time; Max Infiltration Depth of Water = 1.5 in (3 in compaction layer and assuming a porosity of approximately 50%).
- Created 6 different time series.
  - SCS Type II design storm (6-minute and 15-minute increments) – 4.38 inches
  - Tropical Storm Lee (15-minute and 1-hour increments) – 14.29 inches
  - July 23, 2017 (1-minute and 1-hour increments) – 4.71 inches
- Evaluated runoff coefficient, number of nodes surcharged, maximum node surcharge time, number of nodes flooded, depth of flooding, and maximum node flood time. Conduit surcharging not included.

Results (Figure 3):

- The runoff coefficients were the same for each storm event regardless of the rainfall time increment.
- The runoff coefficient was highest during TS Lee.
- Node surcharging occurred for all depth/time increment combinations but TS Lee hourly. Maximum surcharge time associated with TS Lee 15-minute.
- Flooding not seen by model for any TS Lee time increment or for the 1-hour time increment for the July 2017 storm.
- For depths similar to the SCS Type II 10-year storm, the 1-minute time increment resulted in more nodes flooded, more time flooded, and a substantially greater depth of flooding.

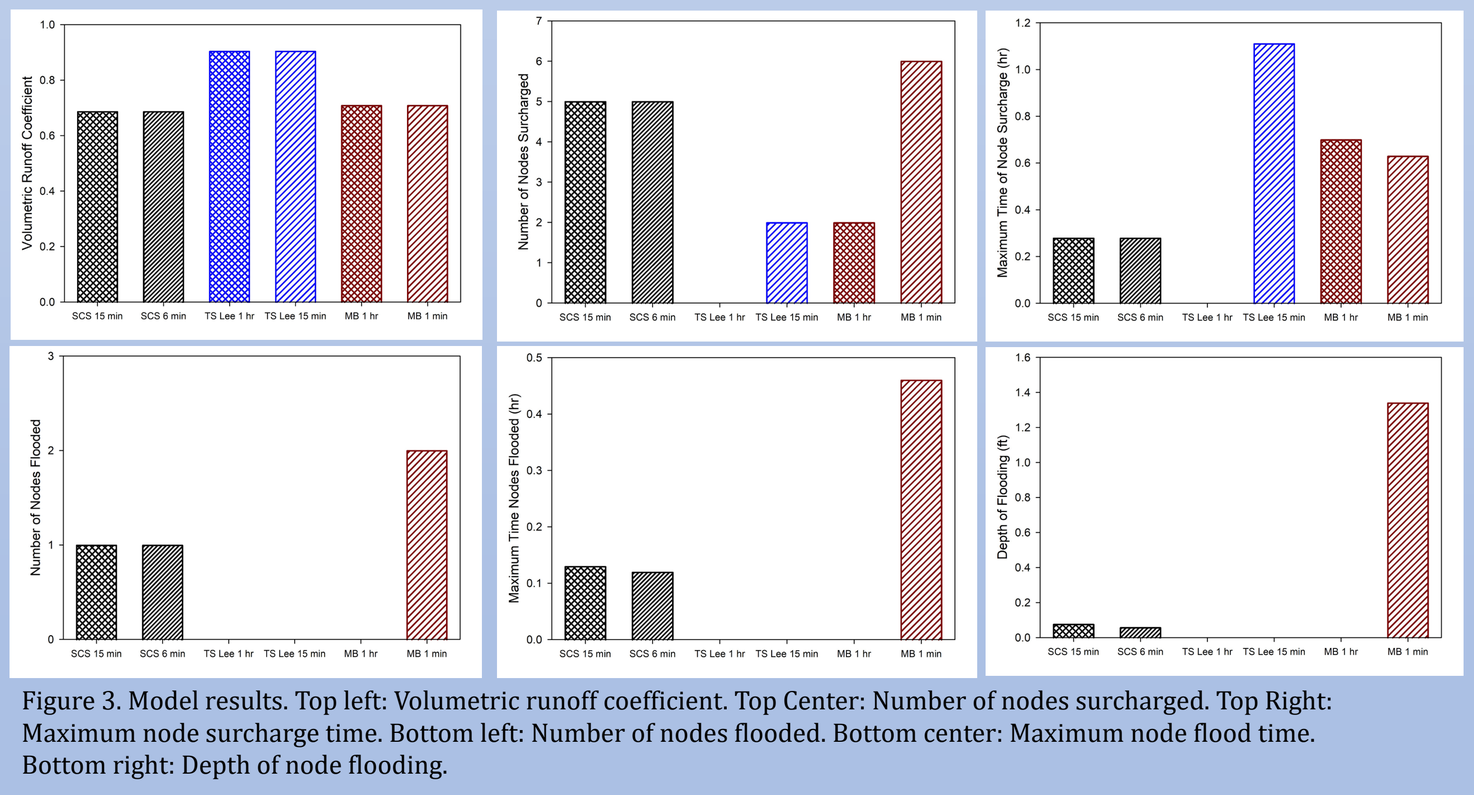

Figure 3. Model results. Top left: Volumetric runoff coefficient. Top Center: Number of nodes surcharged. Top Right: Maximum node surcharge time. Bottom left: Number of nodes flooded. Bottom center: Maximum node flood time. Bottom right: Depth of node flooding.

Conclusions and Research Significance:

- The runoff coefficient was influenced by the total depth of the rainfall and not by whether the rainfall time increment was hours or minutes.
- Modeling TS Lee with hourly data resulted in no nodes surcharging, indicating that the system drained sufficiently between inputs of rainfall. TS Lee, with its highest intensity of 2.8 inches in 2 hours on an hourly time increment did not trigger node surcharging. For the 15-minute increment for the same rainfall distribution, TS Lee triggered the longest time for node surcharging.
- For the July 2017 microburst, more nodes were surcharged with a 1-minute increment than the 1-hr increment. Importantly, the node flooding time was substantially larger than for any other scenario and more reflective of what happened.
- To model short duration, high-intensity storms, we need to use 1 – 5 minute rainfall data.
- This research will connect to a bigger project that can be used by the borough and the campus to help predict and prevent future damage from severe storms.

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