Monocacy Creek Streamflow Modeling Project

Miles Necker, Tara Troy, Ben Felzer

INTRODUCTION

Climate change is expected to result in more precipitation, and potentially more flooding, in the Lehigh Valley. In this project, I developed a hydrological model set-up of the Monocacy Creek to quantify potential future changes in flooding. Using HEC-HMS, a widely-used, publicly available hydrologic model, I first divided the Monocacy Creek into three sub-basins, allowing for some spatial variability in parameters. I selected 10 flooding events in the basin and associated the storm rainfall to have a catalog of storm events with hourly streamflow observations against which to calibrate and validate the model. In a series of sensitivity experiments, I found the model to be most sensitive to the curve number (which account for surface effects on flow), impervious surface, and canopy cover. Increasing the curve number or the impervious surface results in more streamflow, while increasing canopy cover reduces the streamflow. Ongoing work is focused on calibrating the model to match historical flood peaks, volume, and duration. After this is completed, I will use precipitation data from future climate model scenarios to determine how flooding may change in the future. The Monocacy Creek proved to be challenging to model, as a portion lies over large areas of limestone, which results in significant streamflow loss to groundwater.

HEC-HMS MODEL EXAMPLE (FIGURE 1)

Basic HEC-HMS model broken into subbasins

Junctions and reaches are used in HEC-HMS to represent stream segments or flow channels that connect different sub-basins of the drainage network. This figure shows how those sub-basins are represented in HEC-HMS.

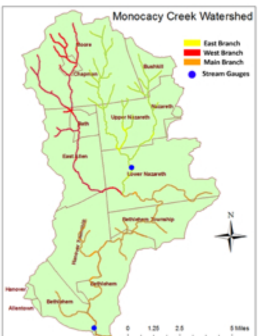
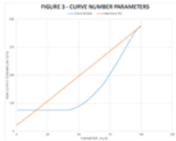


FIGURE 2 - MONOCACY CREEK WATERSHED MAP

Image sourced from the Watershed Coalition of the Lehigh Valley with permission

PARAMETER SENSITIVITY TESTING FOR CALIBRATION



MODEL RESPONSE TO INPUT PARAMETERS

Curve Number - The curve number is an empirical parameter used in hydrology for predicting direct runoff or infiltration from rainfall excess. A low curve number means that the ground can infiltrate more, and produces less runoff; a characteristic curve number for a forest is 30-40. Pavement has a curve number of 98.

This figure demonstrates the sensitivity of model flood peaks to variations in the curve number and percent impervious surface input parameters. Although the percent impervious surface plays a role in the curve number, it is also entered into the model as a seperate parameter as well.

$$P_e = \frac{(P - I_a)^2}{P - I_a + S}$$

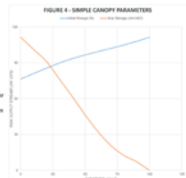
P_e = Accumulated precipitation excess at time T
P = Accumulated rainfall depth at time T
I_a = Initial loss
S = Potential maximum retention of soil

CANOPY STORAGE

Canopy interception represents precipitation that is captured on trees, shrubs, and grasses, and does not reach the soil surface. Only after this storage is filled does precipitation become available for filling other storage volumes (such as soil or the waterway itself).

This graph shows that as the maximum storage capacity for the canopy goes up, it keeps more water from reaching the soil and therefore reduces runoff in the Monocacy Creek model. The more water that is contained within the canopy to begin with (such as from prior rainfalls), the less it can capture in a new storm, therefore increasing runoff.

The parameters are in two separate units. I varied both between 0 and 100, the initial storage being 0 to 100 percent and the max storage being 0 to 100 mm of H2O that can be stored in the canopy.



MANNING'S N EQUATION FOR CHANNEL ROUTING

$$V = \frac{CR^{2/3}S^{1/2}}{n}$$

V = Average Velocity
R = Hydraulic radius (ratio of channel cross-section area to wetted perimeter)
S = Slope of the energy grade line
C = Conversion constant (1 in this case)
n = Manning's n variable

The model run shown in this graph is early on in the calibration process; as new parameters are added in, the model produces results that do not align well with the actual data. As the model development progresses, the graph's alignment will improve. The model uses a Manning's n routing method for any in-channel routing and a curve number for runoff routing. The storm used for this run is highlighted in the precipitation gauge table.

THE DATA ISSUE:

The USGS (United States Geological Survey) provides access to data from thousands of stream gauges throughout the country. However, about 0.57% of the time the gauge records a data point twice. I developed a program to remove the repeated data and average out the 15 minute data to hourly, which is the required resolution of HEC-HMS.

To determine which streamflow values caused flooding of the Monocacy, I matched historical flood records to storm events as identified in historical Lehigh Valley newspapers, and then searched for the relevant streamflow records.

Table 1: Storm Data from Allentown Rain Gauge	
Sourced from Weather.gov	
Date	Total Rainfall (mm)
01/19/96	67.818
05/17/02	35.48
07/01/07	44.523
12/10/08	64.262
04/01/09	46.428
06/17/09	42.418
08/02/09	36.83
10/24/09	38.354
12/02/09	49.784
04/16/11	46.99

STORM DATA:

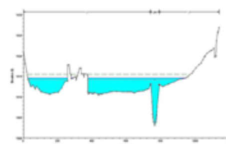
These storms were chosen due to them being relatively recent reflecting the modern urbanized watershed. Storms are of relatively similar magitude facilitating storm comparisoitn. In the future, some of these storms will be used for calibration and others for validation of the calibrated model. Moving forward some of the older storms may be replaced with more recent events as more data are collected.

Future Work

HEC-RAS CROSS SECTION (FIGURE 6)

A sample HEC-RAS cross section filled with streamflow.

HEC-RAS is a one-dimensional model that calculates water flow through streams and rivers and other channels.



CALIBRATION AND VALIDATAION

Calibration uses observed hydrometeorological data in a systematic search for parameters that yield the best fit of the computed results to the observed runoff. This search is often referred to as "optimization."

The next step is to break the entire watershed down into subasins and build cross sections of the creek using ARC GIS.

1) Calibrate HEC-HMS for each subbasin now that I have done the sensitivity
2) Validate HEC-HMS using different storms than the ones I use for validation
3) Create cross sections and running HEC-RAS
4) Apply future precipitation data from climate models to the finished model