GROUNDPOINT
TECHNOLOGIES, LLC

# Ulster County Culvert Modeling

## Final Technical Report

## 1. Background

The Ulster County Department of the Environment (the County) provided GroundPoint with documentation of a modeling effort previously performed at Cornell University with the goal of applying the academic effort to “real world” conditions. The model documentation, referred to as the “Cornel Culverts Model”, uses culvert data in conjunction with other GIS information to:

delineate the watersheds of individual culverts,
compute peak flow entering each culvert for a range of storm events, and
evaluate the capacity of each culvert against predicted peak discharge estimates.

The purpose of this project has been to continue efforts at assessing both stream connectivity and aquatic passage through culverts across the county with the goal of better understanding which culverts may be undersized based on anticipated peak flow demands as well as which culverts may present a barrier to aquatic passage.

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## 2. Methods

***Data Preparation:***

Lidar data for the SawKill watershed was provided by the County, reportedly collected to meet the USGS QL2 specifications with an estimated Nominal Point Spacing (NPS) of 0.7ft. LiDAR points classified as Ground were evaluated using a workflow developed by GroundPoint Technologies to evaluate drainage pathways with specific attention on road crossings and roadside ditches. 522 stream centerlines from a geodatabase provided by Ulster County were reviewed to ensure road crossings and culverts were enforced in the data as they relate to existing mapped streams.

The LiDAR data was reclassified as necessary (e.g., from Ground to Class 20 or 21) in specific places to enhance the creation of a hydrologically-corrected digital elevation model (DEM) of the ground surface. In addition, breaklines were inserted to enforce flow through culverts and along ditches, and to route flow in appropriate directions. The combination of point classification and breakline integration resulted in an “artificial” DEM that is the basis for further derivative surface development supporting drainage analysis and catchment delineation. After testing various raster resolutions for the DEM, a 5ft (1.5m) raster was chosen as optimal for the level of detail desired. Higher resolutions are possible, with additional cost in processing time and associated increase in file sizes. Lower resolutions were determined to be NOT appropriate for the level of detail necessary. An example of a 5m resolution data product with associated derivatives is provided for comparative purposes.

The artificial DEM was then “filled” using an automated threshold to remove spurious and artificial sinks, and in some cases actual sinks that limit the utility of the surface to support drainage analysis. After testing various fill thresholds, 5ft was used as a value that provided the maximum benefit for reducing the number of digital sinks while not overly “smoothing” the data. In areas where the 5ft fill threshold may have significantly altered the surface model, the resulting flow direction and accumulation layers were evaluated, and adjustments made as necessary to ensure that flow was being routed appropriately. As filled areas are relatively easy to identify in the surface model, the approach relies on "over filling" and making subsequent corrections to the filled flow surface as a more efficient and cost-effective process than "under filling" and correcting for sinks. Where sinks in the digital surface model were filled, drainage pathways were evaluated to ensure that the resulting flow directions were appropriate to reflect real world drainage conditions.

The resulting "filled" DEM was then post-processed to create flow direction and flow accumulation raster datasets. An iterative process of evaluating these derivatives using visual inspection, interpretation, field checking, and editing resulted in a final digital surface that was used to generate drainage area polygons from selected points.

Points were selected using a NAACC formatted culvert database provided by Ulster County. An initial database of 199 culverts in the SawKill Watershed was reviewed with comments and initial spatial adjustments performed. Spatial adjustments ensured proper placement on the landscape for drainage area calculations. A copy of the point data was edited to move the points to their proper location for catchment delineation. The total number of culverts ultimately selected for use was reduced to 33 based on the assignment of a valid Survey_ID by Ulster County. Two points were subsequently removed as either duplicate or unknown. The subsequent 31 drainage area polygons were assigned the point Survey_ID to associate the drainage areas back to the original NAACC points.

***Model Preparation:***

Previous model content (code) from the Cornell Department of Biological and Environmental Engineering Soil and Water Lab (Cornell) were provided by Ulster County. The Cornell models were adapted to a new set of python code.

New python scripts were developed replicating the Kirpich (1940) equation for time of concentration ($t_c$) using new LiDAR based elevation model to calculate the longest flow path (L) and the average slope ($s_w$) in each drainage area.

$$t_c = (0.000325)L^{0.77}\, s_w^{-0.385}$$

Curve Number geospatial data were provided by Cornell. A Curve Number preparation script was developed to clip the New England CN data to the project boundary and adjust the cell size to match the reference raster (the new LiDAR based DEM).

Precipitation data was downloaded from the NOAA Atlas 14 website:
(https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html)

A new python script tool was developed to run from inside ArcGIS. The script tool iterates through the points to generate a watershed polygon and calculate the area, average CN, $t_c$, and finally, calculated peak flows for each precipitation input for each catchment.

## 3. Results

The results of internal data processing on the LiDAR terrain data (LAS files) include:

- Modified LAS data where some ground points were reclassified
- Breakline Enforced DEM – exported from the Modified LAS with artificial breaklines added and some re-classification of LiDAR points completed prior to export.
- Filled DEM- a version of the Breakline Enforced DEM where sinks are filled to a specific threshold. In this case the threshold used was 5ft.
- Flow Direction raster dataset
- Flow Accumulation raster dataset
- Sink raster dataset
- Hillshade raster dataset
- Updated Point file for 31 NAACC culverts with a valid SurveyID
- Polygons for drainage area associated with each point

## 4. Next Steps

**Additional Point Processing-** Additional surface model preparation is necessary to process a larger number of points against the derived surface model. Future plans include processing ALL the culvert inventory points, and identifying locations where the data indicates a culvert may exist but is not in the inventory.

**Curve Number (CN) updates-** It should be possible to update the CN inputs to the model by replicating the assumptions of the original data development but using more recent high resolution land cover data. The tables in Appendix A illustrate the land cover-soil group combinations used for the CN data developed by Cornell, along with a proposed construct for creating a new CN dataset for Ulster County based on an eight-class land cover dataset.

**Precipitation Data Updates-** The updated python script can be adapted to ingest data from the North East Regional Climate Center that provide similar precipitation frequency data to the NOAA tables, although in a transposed format. The NERCC data also include future precipitation frequency estimates based on upper and lower limits of climate change modeling.

In addition, the python scripts could be adapted to allow user input on the frequency/duration. The current default value is fixed for a 5 year, 24hr storm. User interface issues need to be addressed regarding data management and selection of precipitation frequency values as they are not something with which most people are intuitively familiar.

**Culvert Capacity Calculations-** No effort was expended adapting the culvert capacity calculations. These calculations are currently embedded in a legacy script that automatically compares capacity with predicted flow. These calculations should be de-coupled allowing for separate analysis of capacity calculations as well as comparison with multiple precipitation frequency estimates. It is anticipated this should be relatively straightforward to implement. It is relevant because the peak flow calculation component of this effort is not specific to culverts, but to any point of interest. The fact that a point represents a culvert inlet is a specific case study implementation.

**Interface Development-** It appears premature to focus on developing a user interface tool without adequate resource investment in the underlying data and the code that establishes the calculations, as well as defining more clearly an "typical" anticipated user.

A simple proof of concept user interface that compares culvert capacity with predicted flow for specific frequency/duration estimates would be helpful, however the results have significant potential to be misleading without adequate spatial data QC and review.

In addition, a web based tool that shows the catchment area polygons for each culvert (or any set of points) and allows local experts to mark up or suggest further evaluation/changes on particular locations as part of the catchment area/drainage QC process would be very useful.

# Appendix A- Curve Numbers

Cornell Curve Number Method

| | Hydrologic Soil Classification | | | |
|---|---|---|---|---|
| Land Cover Type | A | B | C | D |
| Water | 0 | 0 | 0 | 0 |
| Developed Open Space | 46 | 65 | 77 | 82 |
| Developed Low Intensity | 56 | 71 | 81 | 86 |
| Developed Medium Intensity | 77 | 85 | 92 | 92 |
| Developed High Intensity | 89 | 92 | 94 | 95 |
| Deciduous Forest | 36 | 60 | 73 | 79 |
| Evergreen Forest | 36 | 60 | 73 | 79 |
| Mixed Forest | 36 | 60 | 72 | 79 |
| Shrub | 35 | 56 | 70 | 77 |
| Grasslands | 30 | 58 | 71 | 78 |
| Pasture | 49 | 69 | 79 | 84 |
| Row crops | 72 | 81 | 88 | 91 |
| Wetlands | 0 | 0 | 0 | 0 |
| | | | | |

Land Cover Classification Translation

| New Class | Old Class |
|---|---|
| Water | Water |
| Impervious Surfaces | Developed High Intensity |
| Tree Canopy | Mixed Forest |
| Shrub | Shrub |
| Grass | Grasslands |
| Soil | Developed Open Space |
| | |

Proposed New Curve Number Method

| | Hydrologic Soil Classification | | | |
|---|---|---|---|---|
| Land Cover Type | A | B | C | D |
| 4-Water | 0 | 0 | 0 | 0 |
| 5-6-7 Impervious Surfaces | 89 | 92 | 94 | 95 |
| 1-Tree Canopy | 36 | 60 | 72 | 79 |
| 8-Shrub | 35 | 56 | 70 | 77 |
| 2-Grass | 30 | 58 | 71 | 78 |
| 3-Soil | 56 | 71 | 81 | 86 |

Based on the Cornell model documentation, the following applies:

Where hydrologic soil classification assignment is based on either artificially or naturally drained soils, the assumption is for naturally drained soils ("D"). Average antecedent soil conditions are assumed (i.e., $CN=CN_{II}$).