**Quick reference for using the Culvert Toolbox once you have the burned DEM:**

* Dem\_prep tool
  + Change the Projected DEM blue circle to your burned DEM, and the blue workspace to your DEM folder
  + ~ 15 minutes for 1034 culverts in four NY counties
* Culvert Watershed Delineation - Right-click to Edit Culvert\_ws\_delineation tool
  + Points layer blue circle 🡪 Projected culvert points
  + Iterate Feature selection. Input Features = Points Layer UTM. Field = BarrierID.
  + Flow accumulation bubble 🡪Select your flow accumulation raster (DEM\_burnfacc).
  + Snap pour point rectangle.
    - Input raster or feature pour point data = Selected\_point
    - Ensure that the pour point field exists for the layer (e.g. FID or NAACC\_ID)
    - Input accumulation raster = flow accumulation
    - Set “output raster” file path to your GIS\_files/Temp folder. Keep Snap%code% as the file name.
    - Set snap distance at the bottom to 20 m (or desired snap distance).
  + flow direction bubble 🡪 select your flow direction raster
  + Watershed square.
    - Input flow direction raster = flow direction
    - Input raster or feature pour point data = Snap%code%
    - Pour point field (optional) = VALUE
    - Set output raster path to your GIS\_files/Temp folder, keeping the default file name (Snap%code%ws.tif)
  + Double click on the Raster to Polygon yellow rectangle
    - Input raster = ws raster
    - Field (optional) = Value
    - Output polygon features = Navigate to your WS\_Poly folder and then add %code%ws.shp
  + Took >12 hours for 1034 culverts in four NY counties
* Append WS
  + Check attribute table of the All\_Culvert shapefile is empty
  + Edit append\_ws tool
  + Watershed folder blue ellipse 🡪 WS\_Poly folder
  + Dissolve yellow rectangle 🡪 set temp path to GIS\_files/Temp, keep file name, input feature should be “selected watershed”
  + All\_Culverts 🡪 All\_Culverts shapefile
  + Run 🡪 all watersheds into one shapefile

**Step 12: Prepare the All\_Culverts shapefile for export**

1. Add empty columns to the All\_Culverts file for Area, Time of Concentration and Curve Number
   1. In the table of contents, right click on the All\_Culverts and select “open attribute table”
   2. Click on the drop down in the top left corner of the attribute table and select “Add Field”
      1. Title the new field “Area\_sqkm” and select “float” as the type. Leave the defaults for precision and scale.
   3. Add another field titled “Tc\_hr” with type “float”
   4. Add a third field titled “CN” with type “float”
   5. Right click on the heading of the Area\_sqkm field and select “Calculate Geometry” and hit “yes” when the dialogue box pops up
      1. Ensure that “area” is listed in the property field
      2. Select square kilometers for the units
      3. Hit “ok”

**Explanation:** In this step we are setting up our watershed data file to be exported. In order to calculate the peak discharge, we will need the area, time of concentration (Tc) and Curve Number (CN) for each culvert watershed. The area is calculated in this step. Tc and CN will be calculated in the next two steps. The python code to be run later on relies on column order to track inputs, so following the order above when you add fields is important.

**Step 13: Calculate the Tc for each culvert watershed**

1. Calculate the watershed slope using the Slope tool
   * 1. Create a filled version of the NYS DEM (or clipped county DEM). Use the Fill tool under Spatial Analyst.
     2. Arctoolbox🡪 Spacial Analyst🡪Surface🡪Slope
     3. Select the filled DEM you just created. NOT the filled *burned* DEM created in Step 7.
     4. Select percent rise for type
     5. Save the new raster to your DEM folder
2. Calculate the watershed flow lengths (For a county, on the new computer, this step takes about 5 min)
   * 1. Arctoolbox🡪 Spacial Analyst🡪Hydrology🡪Flow length
     2. Select the flow direction. This can be the burned flow direction raster from Step 7.
     3. Ensure that method is set to “UPSTREAM”
     4. Save the new raster to your DEM folder
3. In the Culvert Toolbox, right click on the Tc tool and select “edit”
   * 1. Double click on the blue ellipse furthest to the left and select the “All\_Culverts” file as model input
     2. Double click on the flow length ellipse and select the newly created flow length raster
     3. Double click on the slope ellipse and select the newly created slope raster
     4. Double click on both yellow Clip squares and ensure the path to your Temp folder is correct. Keep the default file name (flen\_temp.tif for the flow length clip, and slope\_temp.tif for the slope clip).
4. Validate and run the model . No new files will be created. The Tc field in All\_Culverts will be filled in.

**Explanation:** This tool uses the Kripitch equation to calculate time of concentration for each culvert watershed. The slope of each watershed is taken by clipping the slope raster for the entire watershed to the boundaries of each culvert watershed, then calculating the average slope for each watershed. The flow length is taken by clipping the flow length raster of the entire watershed to each culvert watershed and selecting the longest flow path inside each culvert watershed.

**Step 14: Calculate the weighted CN for each culvert watershed**

1. Add a raster of curve numbers for your area of interest to the table of contents
   1. A curve number raster has been created for NY by Rebecca Marjerison for use in this model. It is based on 2006 landuse and 2010 soils data from New York State. It is available from the Cornell Soil and Water Lab.
2. Project Curve Number raster (Project Raster (Data Management)) to your UTM coordinate system from Step 3 (NAD\_1983\_UTM\_Zone\_18N for Eastern NY)
   1. Save as “CN\_UTM.tif”
3. Clip(Data Management) “CN\_UTM.tif” by “All\_culverts” to get “CN\_UTMclip”

a. Check “Use Input Features for Clipping Geometry”

1. Resample (Tools/Data Management Tools/Raster/Raster Processing/Resample) “CN\_UTMclip” to the size of the DEM, call it CN\_UTMclipRes
2. In the Culvert Toolbox, right click on the CN tool and select “edit”
   1. Double click on the blue ellipse farthest to the left and select the “All\_culverts” layer
   2. Double click on the blue ellipse that has an arrow going to the yellow “clip” ellipse and select the resampled CN\_UTMclip.tif as the input file
   3. Double click on the yellow rectangle labeled “Clip”
      1. Input raster = CN\_UTMclipRes (the resampled CN raster)
      2. Output extent = I\_fc\_2m\_merge\_BarrierID
      3. Ensure the Output Raster Dataset path exists in your system. Keep the default file name (cn\_temp)
   4. Verify and run the model *(If error results, see note below)*
   5. Ensure that the temporary files are being saved to a proper location on your machine

**Explanation:** The NY\_Curve\_Number.tif file is a raster image created by Rebecca Marjerison that combines 2006 landuse and 2010 soils data from New York State into a single Curve Number raster file. Each pixel value in the raster represents a curve number, the CN tool clips the raster to each individual culvert watershed and then finds a weighted average of the curve number of that watershed and adds it to the attribute table.

**Note:** This step has trouble on small watersheds. Occasionally, in the middle of a run, the script will stop, with an error message. If this happens, exit the model, open the attribute table of the All\_Culverts layer and, skipping the entry with the area that was too small, select all of the remaining culverts that haven’t been analyzed. Do this each time the script has an error. If possible, next, go back through the layer at the end, zoom to each culvert that wasn’t analyzed and use the “identify” cursor to determine the value of the CN raster beneath the culvert watershed:

1. Turn back on the statewide CN raster:
2. Use the identify cursor  to determine the CN value(s) under the watershed, and estimate an average.
3. Right click on the All\_Culverts shapefile and open the attribute table.
4. Start an editing session, and change the value of the CN field for the watershed to the estimated average.

**Step 15: Export watershed data from ArcGIS**

1. Export data as text file from ArcGIS
   * 1. Right click on the All\_culverts shapefile and select “open attribute table”
     2. In the Table Options drop down in the top left corner of the attribute table, selected “Export”
     3. Ensure that the Export is set to “all data”
     4. Save the script as a .txt file into the “CulvertEvaluation” folder as All\_culverts.txt
2. Open the text file in Excel
   1. First open excel, then load the file, ensuring that “all files” is selected in the “open” window
   2. Once opened, a Text Import Wizard should open automatically in Excel.
      * 1. In step one of the Text Import Wizard dialogue box, ensure that the bubble for “Delimited” is selected as the file type
        2. Hit “Next”
        3. In step two of the Text Import Wizard dialogue box, select “Comma” as the delimiter and ensure that no other boxes are selected.
        4. Hit “finish”
3. Save the file in yourwatershedname subfolder within the “CulvertEvaluation” folder as a .csv

**Explanation:** Once all of the relevant data has been added to the All\_Culverts attribute table, it is ready to be exported for use in the Cornell Culverts Evaluation Python script. This script will use this data in conjunction with NRCC precipitation data (downloaded in the next step) to determine the peak discharge from various storm events for each culvert. In order for the data to be accepted by Python, it must be saved in CSV format in the same folder as the Python script.

**Step 16: Download NRCC precipitation data**

1. Go to: <http://precip.eas.cornell.edu/>
2. Select the “Data and Products” tab
3. In the “Select Product” column on the left hand side, select “Extreme Precipitation Tables-Text/CSV”
4. Type the name of the county that contains the study watershed.
5. Click the “Submit” Box in the center of the screen below the map, a text file called “output” will then download automatically
6. Follow the procedure in step 15.II to open and save the output text file in excel as a CSV file.

**Explanation:** The North Eastern Regional Climate Center (NRCC) provides estimates of the precipitation values for a range of return period storms of varying durations. This step locates the data for the study watershed and exports it to a .csv file that will be used in the peak discharge calculations in the next step.

**Part 3: Use the python script to compute the peak discharge, capacity and max return periods**

**Step 17: Run Cornell\_Culverts\_Evaluation python script**

1. Ensure that the yourwatershedname data folder contains the exported data from the GIS in step 15, the precipitation CSV file exported from NRCC in step 16 and the exacted culvert data file from step 2.
2. Open “county\_list.csv”, located within the “CulvertEvaluation” folder, and include the names of all input files located in your data folder, ensuring “.csv” follows each file name you enter. Put this file in your data folder
   1. Example input is below:

|  |  |  |  |
| --- | --- | --- | --- |
| county\_abbreviation | watershed\_data\_filename | watershed\_precipitation\_filename | field\_data\_filename |
| Your three-letter abr. (e.g. ALB) | All\_culverts.csv | ALB\_precip.csv | ALB\_field\_data.csv |

1. Right click on the Cornell\_Culverts\_Evaluation.py file in your “CulvertEvaluation” folder
   * 1. Select “Edit with IDLE”
     2. Once the script is open, hit F5 (This will open the python shell)
2. Follow the script’s instructions.

This script will perform the following operations:

1. Calculate peak discharge for both current and future storm events. Events evaluated include the 1, 2, 5, 10, 25, 50, 200 and 500 year storms.
2. Calculate the cross sectional area of each culvert and assign each culvert minor loss coefficients based on culvert material and geometry.
3. Calculate the capacity of each culvert
4. Compare the capacity and peak discharges for each culvert and assign each culvert a maximum return period storm that it can safely pass
5. Summarize the data output in a single .csv file titled “model\_output”

Script inputs:

1. Watershed data CSV file (final output from steps 2-15)
2. Field data collection file (product of the extraction in step 2)
3. Precipitation file (product of step 16)

Script Outputs (same as model outputs!):

1. culv\_geometry: a csv file containing the areas of each culvert and assigned coefficients used in the capacity calculations
2. capacity\_output: a CSV file containing the maximum capacity of each culvert before the headwater overtops the road surface
3. current\_runoff: a CSV file containing the calculated runoff of each culvert watershed under the 1, 2, 5, 10, 25, 50, 100, 200 and 500 year storm events with current precipitation data
4. future\_runoff: a CSV file containing the calculated runoff of each culvert watershed under the 1, 2, 5, 10, 25, 50, 100, 200 and 500 year storm events with projected 2050 precipitation data
5. return\_periods: a CSV file containing the maximum return period storm that each culvert can safely pass for the current and projected 2050 precipitation data.
6. model\_output: a CSV file containing a summary of the above 5 outputs. The file contains the maximum return period that each culvert can safely pass, the capacity of each culvert and information about culvert geometry. This file can be viewed as the final output of this model.

**Explanation:** The Cornell\_Culvert\_Evaluation script does not actually perform any calculations by itself; instead, it serves as a command center to call on various functions that each performs a certain task.

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**Optional Step 18: Use R script to append Survey\_ID numbers**

1. This step was created to append Survey\_ID numbers onto the model\_output file created by the Cornell\_Culvert\_Evaluation python script. It requires the R script survey\_id\_v2.R, available from Allison Truhlar.
2. The R script requires the yourwatershedname.csv file, yourwatershedname\_field\_data.csv, yourwatershedname\_not\_extracted.csv, yourwatershedname\_export.csv, and yourwatershedname\_model\_output.csv.

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