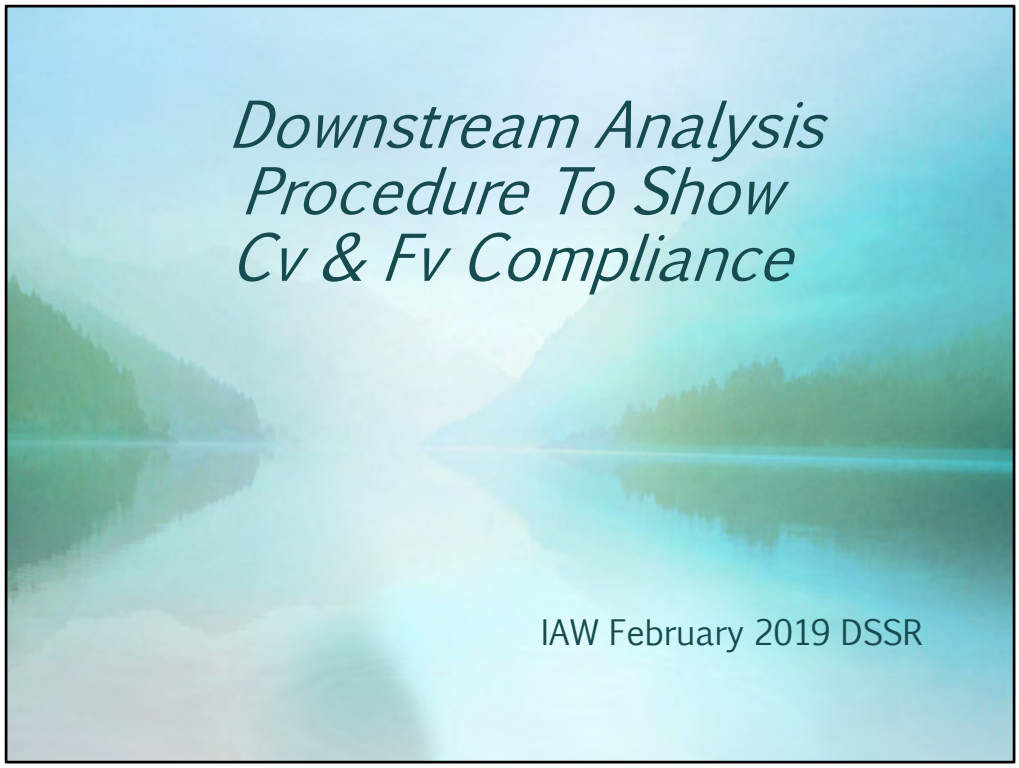


THIS TUTORIAL HAS BEEN PREPARED BY THE SEDIMENT & STORMWATER PROGRAM WITHIN THE DELAWARE DEPARTMENT OF NATURAL RESOURCES

Cv[1] & Fv[2] Compliance Criteria

Demonstration that the location of a project within a watershed would aggravate flooding or channel erosion by the imposition of peak control requirements, as evidenced by a downstream analysis that shows the inflection point of the site hydrograph occurs prior to and is less than the peak of the upstream hydrograph.

[1]2019 DSSR, Section 5.3.3.4
[2]2019 DSSR, Section 5.4.3.4

- The 2019 Delaware Sediment & Stormwater Regulations (DSSR) include provisions for complying with the "no adverse impact" requirements for the Cv (10-YR storm) and/or Fv (100-YR storm) by performing a downstream analysis.
- This tutorial has been prepared to outline the steps necessary to complete this analysis in accordance with the Department's guidelines.

Compliance Criteria: Downstream Analysis

- ✓ Developed site hydrograph peak less than peak of upstream hydrograph

AND…

- ✓ Developed site hydrograph inflection point occurs before peak of the upstream hydrograph

HOW?

In order to meet the Cv and Fv compliance requirements under DSSR Sections 5.3.3.4 and 5.4.3.4 respectively, two (2) conditions must be met:

1. The peak discharge of the site hydrograph for the developed condition must be less than the peak discharge of the upstream hydrograph, AND
2. The time of the inflection point of the site hydrograph must occur before the time of the peak for the upstream hydrograph

THE REMAINDER OF THIS TUTORIAL WILL EXPLAIN HOW THE ANALYSIS IS DONE TO DEMONSTRATE COMPLIANCE.

Compliance Criteria: Downstream Analysis

"Broadkill Estates"
Sussex County
Post-Developed Condition

- Open Space
  - HSG A: 8.06 ac
  - HSG B: 2.26 ac
- 1-ac Residential (20% imp)
  - HSG A: 21.17 ac
  - HSH B: 0.73 ac
- RCN: 49
- Tc: 0.2 hr

Point of Analysis (POA) is most downstream site discharge point to existing channel

The analysis will be based on a fictitious single family residential project located in Sussex County, Delaware known as Broadkill Estates. The site has the following post-developed conditions for the hydrologic analysis:

- Open Space
  - HSG A: 8.06 ac
  - HSG B: 2.26 ac
- 1-AC Residential (20% assumed imperviousness)
  - HSG A: 21.17 ac
  - HSG B: 0.73 ac
- Runoff Curve Number: 49
- Time of Concentration: 0.2 hr

Procedure

1. Hydrograph Calibration
   a. Consult MD Hydrology Panel Report
   b. Delineate upstream watershed
   c. Edit watershed boundary (optional)
   d. Generate Basin Characteristics Report
   e. Estimate watershed Time of Concentration (Tc)
   f. Determine Tc method based upon watershed size
   g. Generate Tc flow path in StreamStats
   h. Estimate slope and distance using elevation profile tool
   i. Calculate Tc [and Travel Time (Tt) if necessary]
   j. Estimate runoff volume
2. Downstream Analysis
   a. Enter hydrologic data into hydrologic model
   b. Determine site time to inflection point (Tinf)
   c. Compare site and watershed peak discharges (q_p), watershed time to peak (Tp) and site inflection point time (Tinf)

The procedure involves the following steps:

1. Hydrograph Calibration
   a. Consult MD Hydrology Panel Report
   b. Delineate upstream watershed
   c. Edit watershed boundary (optional)
   d. Generate Basin Characteristics Report
   e. Estimate watershed Time of Concentration (Tc)
   f. Determine Tc method based upon watershed size
   g. Generate Tc flow path in StreamStats
   h. Estimate slope and distance using elevation profile tool
   i. Calculate Tc [and Travel Time (Tt) if necessary]
   j. Estimate runoff volume
2. Downstream Analysis
   a. Enter hydrologic data into hydrologic model
   b. Determine site time to inflection point (Tinf)
   c. Compare site and watershed peak discharges (q_p), watershed time to peak (Tp) and site inflection point time (Tinf)

Step 1: Hydrograph Calibration

1a – Consult the MD Hydrology Panel Report

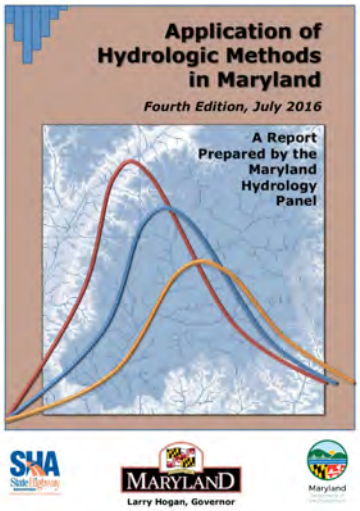
http://www.gishydro.eng.umd.edu/panel.htm

- The first step of the process is to develop a calibrated hydrograph for the upstream watershed.
- The documentation for this is available for download from the Maryland Hydrology Panel Report website:

  http://www.gishydro.eng.umd.edu/panel.htm

Step 1: Hydrograph Calibration

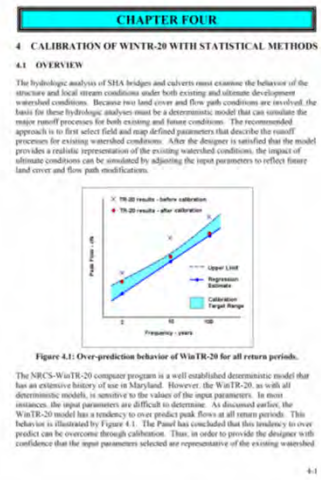
1a – Consult the MD Hydrology Panel Report



- *Application of Hydrologic Methods in Maryland* was prepared by the Hydrology Panel convened by the Maryland State Highway Administration and the Maryland Department of the Environment.
- The Fourth Edition of this publication was used for the preparation of this tutorial.

Step 1: Hydrograph Calibration

1a – Consult the MD Hydrology Panel Report



CHAPTER FOUR

4 CALIBRATION OF WINTR-20 WITH STATISTICAL METHODS

4.1 OVERVIEW

The hydrologic analysis of SHA bridges and culverts must examine the behavior of the structure and local stream conditions under both existing and ultimate development watershed conditions. Because two land cover and flow path conditions are involved, the basis for these hydrologic analyses must be a deterministic model that can simulate the major runoff processes for both existing and future conditions. The recommended approach is to first select field and map defined parameters that describe the runoff processes for existing watershed conditions. After the designer is satisfied that the model provides a realistic representation of the existing watershed conditions, the impact of ultimate conditions can be simulated by adjusting the input parameters to reflect future land cover and flow path modifications.

Figure 4.1: Over-prediction behavior of WinTR-20 for all return periods.

The NRCS-WinTR-20 computer program is a well established deterministic model that has an extensive history of use in Maryland. However, the WinTR-20, as with all deterministic models, is sensitive to the values of the input parameters. In most instances, the input parameters are difficult to determine. As discussed earlier, the WinTR-20 model has a tendency to over predict peak flows at all return periods. This behavior is illustrated by Figure 4.1. The Panel has concluded that this tendency to over predict can be overcome through calibration. Thus, in order to provide the designer with confidence that the input parameters selected are representative of the existing watershed

4-1

Hydrograph calibration procedures are contained in Chapter 4.

Step 1: Hydrograph Calibration

1a – Consult the MD Hydrology Panel Report

Table 4.2: Table of WinTR-20 Variable Adjustment Limits

Variable	Error Type	Error Source Variable	Common Error Trend	Effect On Peak Q	Note	Adjustment Limits of variable in column 3
Area	Random	Area	High or Low	Increase or Decrease		Not Recommended, check for non-contributing areas
RCN	Random	Table Selection	High or Low	Increase or Decrease	4	± 10% for each category and within the limits of the NRCS guidelines
T_c (Overland)	Systematic	n_o, L	Low	Increase	3	n_o up to 25%, L max = 100'
T_c (shallow conc.)	Systematic	Length, n	Low	Increase	3	Increase L up to 25%; n to ± 50%
T_c (channel)	Systematic	Length, n	Low	Increase	3	Increase L up to 25%; n to ± 50%
Representative X-section	Systematic	Area, n	Low	Increase	3	Area to ± 25%, n to ± 50%
Reach Routing Length	Systematic	Length	Low	Increase	3	Up to 50% for 1:24,000 maps, up to 15% for 1:2,400 maps
Storage at culverts	Systematic	Volume	Low	Increase	1	Up to 15%
ARC	Random	N/A	N/A	N/A	2	ARC = 2 is base value. See note below.
Dimensionless Unit Hydrogr.	Systematic	Peak Factor K	High or Low	Increase or Decrease		Regional values of K in Maryland
Rainfall Tables	Systematic	Increment, intensity, & duration	High or Low	Increase or Decrease		48, 24, 12 and 6 hr. distributions

Definitions:
Random (errors) = either high or low from an expected mean value.

Systematic (errors) = always higher or always lower than the calculated value.

Low = calculated value lower than probable "actual" value.

High = calculated value higher than probable "actual"

Notes:
1. If the total volume of "reservoir" storage in the watershed is less than 10% of the total runoff volume, the effects of storage may be ignored.
2. ARC = 2 may be more appropriate for conveying the 10-year or more frequent storms. ARC = 2 may be appropriate for severe storms of 200-year and above.
3. Primary calibration variable.
4. Do not adjust the weighted RCN.

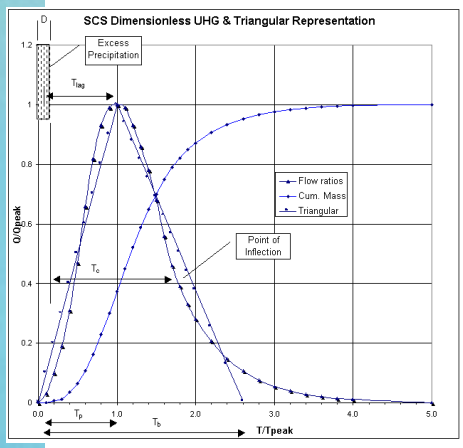
Table 4.2 is presented as a guide to assist the designer in the recalibration of WinTR-20 input parameters that might be causing the peak discharges to fall outside the recommended regional regression equation bounds. The table is a guide suggesting that, because of the difficulties in the estimation process, the parameters of column 1 could be in error by as much as the value listed in the last column. The selected values of all parameters in column 3 must be supported by field and map investigations, be consistent with standard hydrologic practice and documented.

4-11

- Table 4.2 summarizes the variables that affect hydrograph calibration and potential sources of error.
- The last column in the table contains recommended limits for adjusting these variables to achieve calibration.

Step 1: Hydrograph Calibration

1a – Consult the MD Hydrology Panel Report

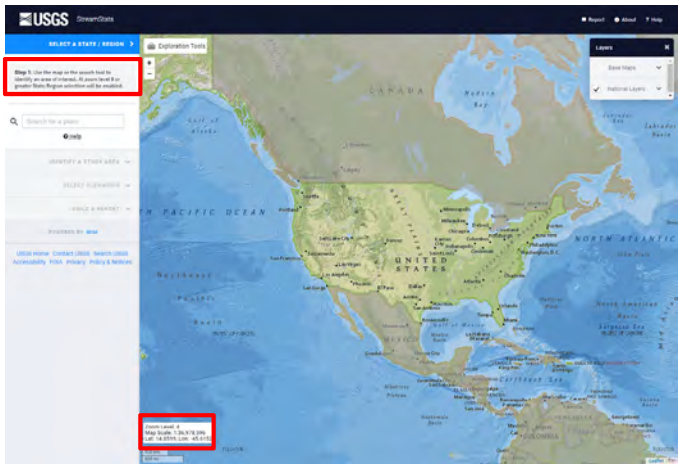


- 3 Parameters Needed
  - Peak discharge (q_p)

- There are three (3) parameters needed to develop a calibrated hydrograph for the upstream watershed.
- The first parameter is the peak discharge (q_p).

Step 1: Hydrograph Calibration

1b – Access StreamStats to delineate upstream watershed



https://streamstats.usgs.gov/ss/

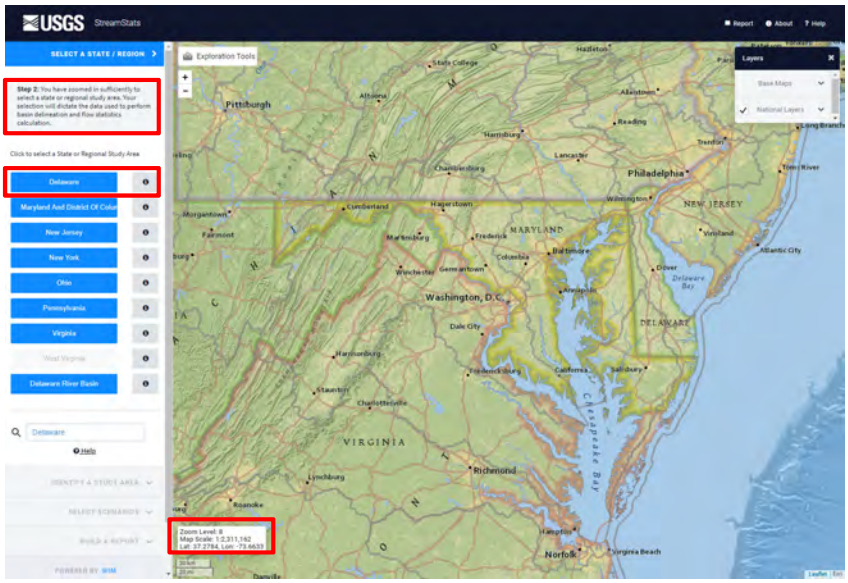
- The United States Geological Survey (USGS) online *StreamStats* application will be used to determine the target peak discharge for the calibrated hydrograph.
- The *StreamStats* application is available at the following link:

  https://streamstats.usgs.gov/ss/

- Once the application has been accessed, zoom into the area of interest to at least Zoom Level 8 as indicated in the zoom level window in the lower left corner.

Step 1: Hydrograph Calibration

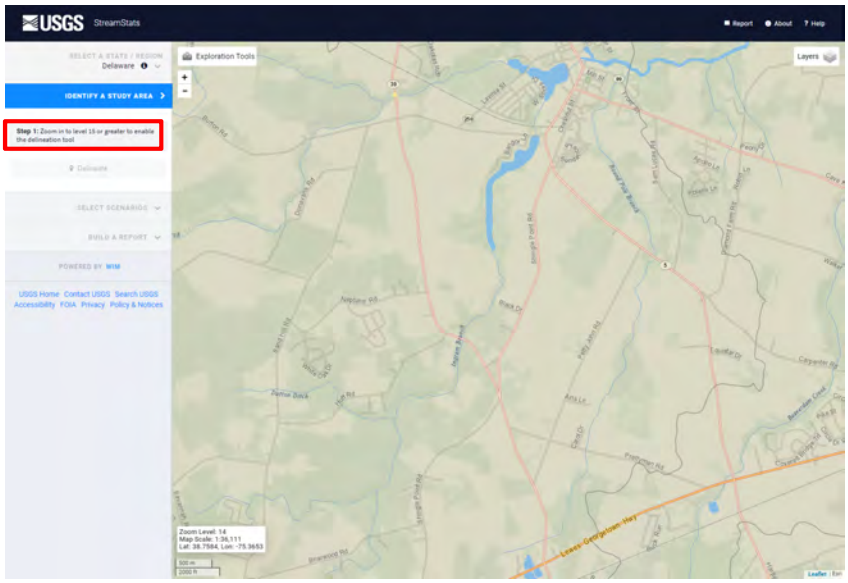
1b – Access StreamStats to delineate upstream watershed



- At zoom level 8, a list of State or Regional Study Areas will be displayed.
- Select the “Delaware” button.

Step 1: Hydrograph Calibration

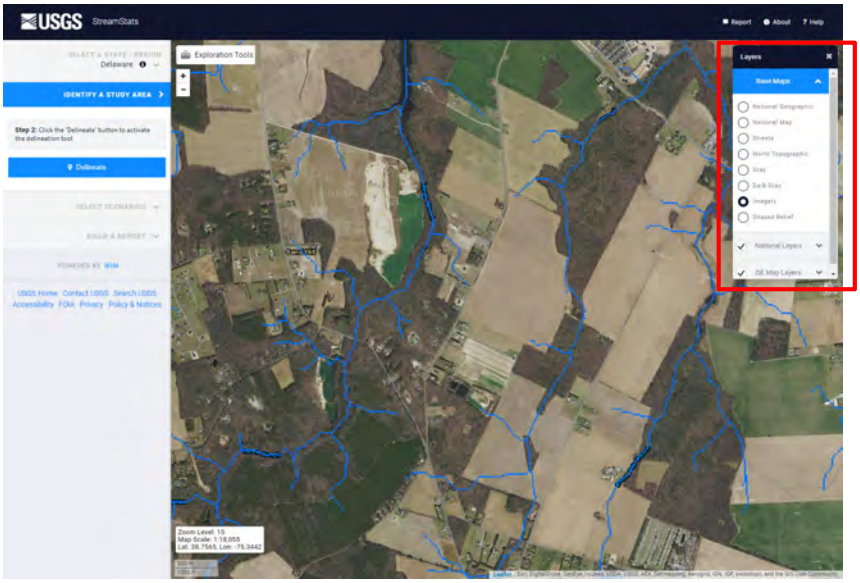
1b – Access StreamStats to delineate upstream watershed



- Continue to zoom into the area of interest to level 15 or greater to enable the delineation tool.

Step 1: Hydrograph Calibration

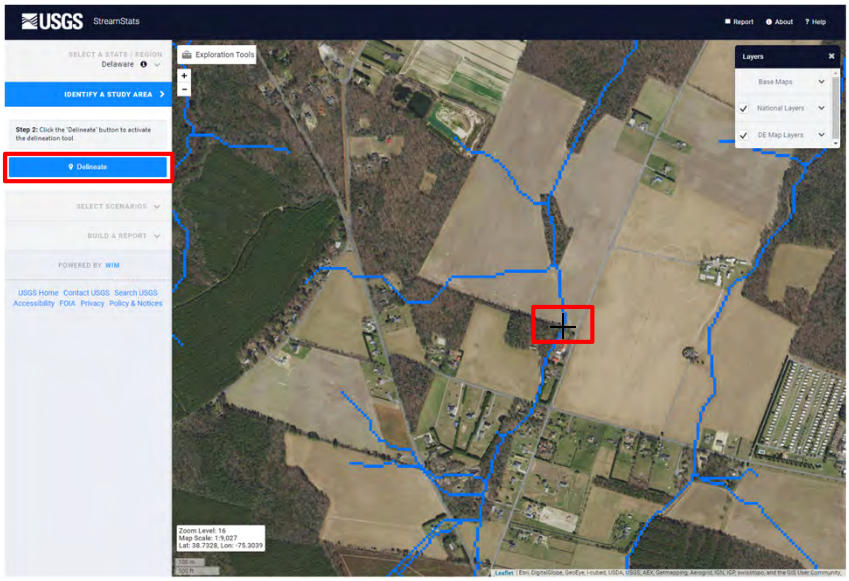
1b – Access StreamStats to delineate upstream watershed



- At zoom level 15 or greater, a raster image of the flowline network will appear.
- It is also helpful to turn on the imagery layer in the “Layers” menu to locate the appropriate point of analysis for the watershed delineation.

Step 1: Hydrograph Calibration

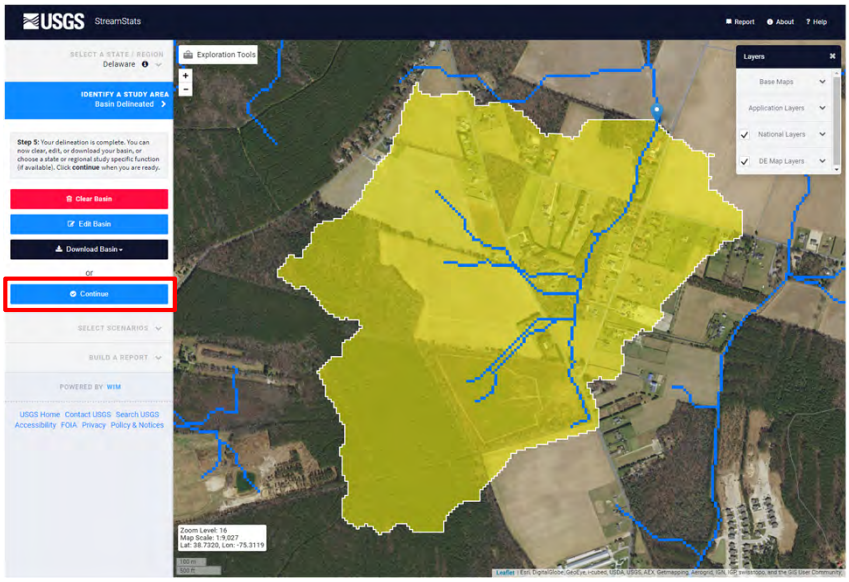
1b – Access StreamStats to delineate upstream watershed



- Locate the Point of Analysis (POA) of interest within the field of view
- Click on the "Delineate" button; the cursor will then change to a cross hair
- Click the cross hair on the flowline raster pixel that is closest to the POA
- *StreamStats* will begin the process of delineating the watershed area that drains to the POA based on the underlying Digital Elevation Model (DEM)

Step 1: Hydrograph Calibration

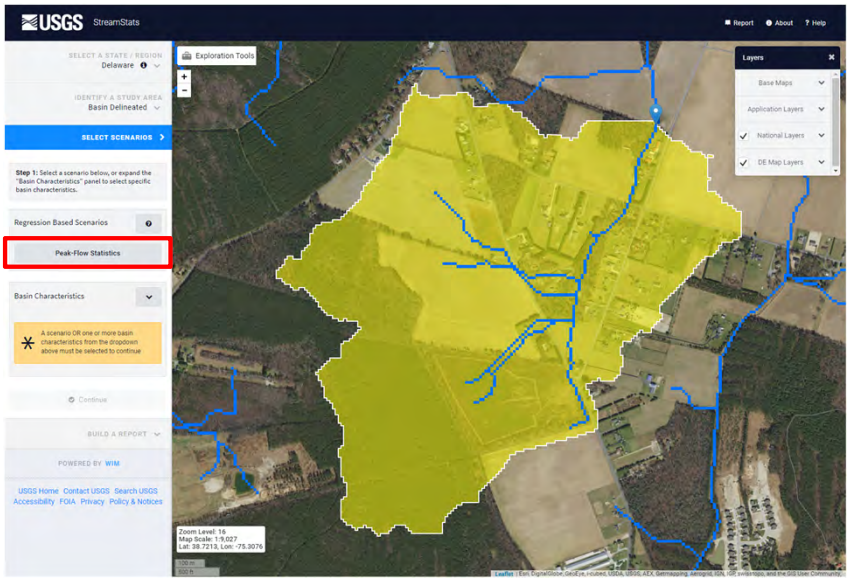
1c – Edit watershed boundary (optional)



- If the delineated watershed boundary appears to be incorrect, click the “Clear Basin” button to try delineating using a different flowline pixel
- If there are known areas within the watershed that are either missing or incorrectly included, click the “Edit Basin” button to manually adjust these areas
- If the delineated watershed boundary is acceptable, click the “Continue” button; this will bring up the “Select Scenarios” menu

Step 1: Hydrograph Calibration

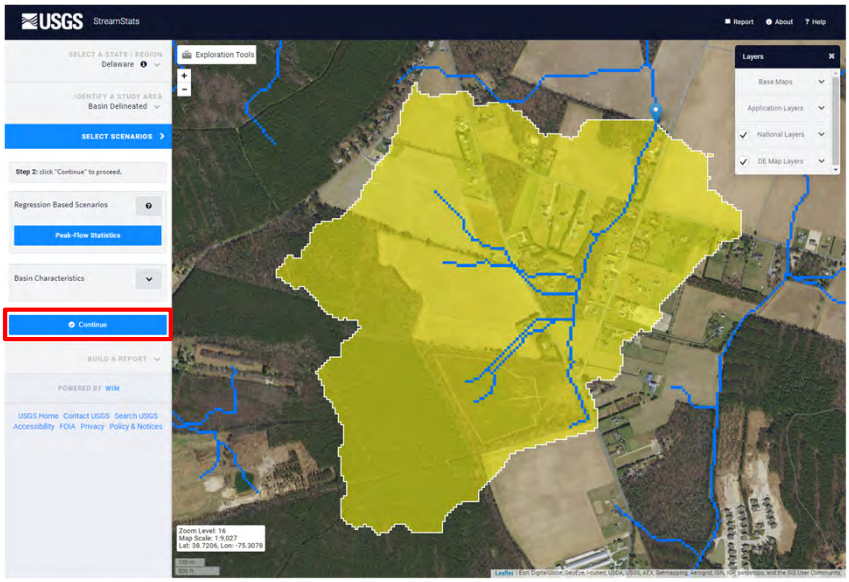
1d – Generate Basin Characteristics Report



- From the "Select Scenarios" menu, select the "Peak-Flow Statistics" option

Step 1: Hydrograph Calibration

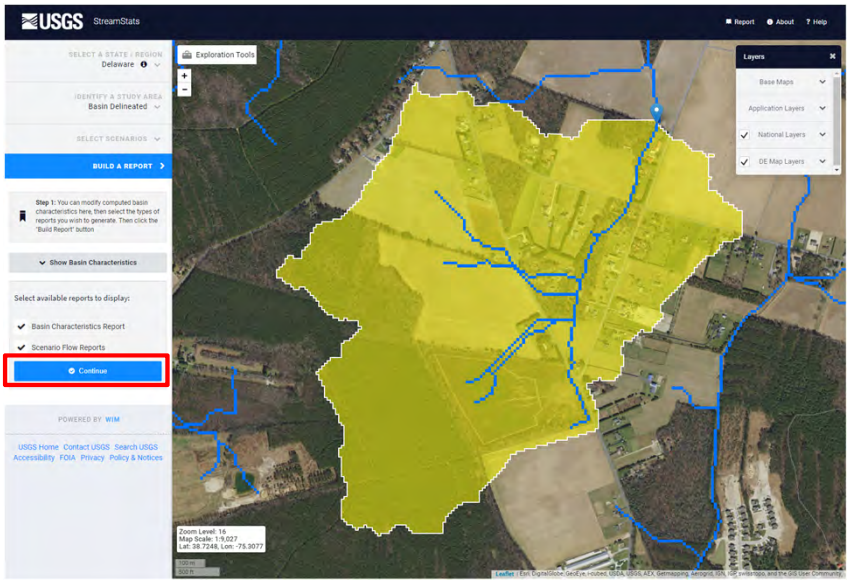
1d – Generate Basin Characteristics Report



- Click the "Continue" button

Step 1: Hydrograph Calibration

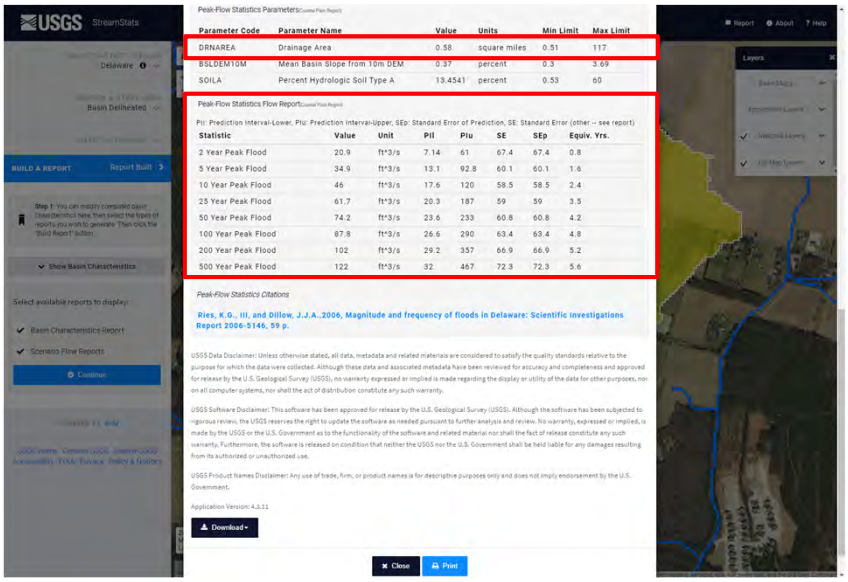
1d – Generate Basin Characteristics Report



- The "Select Scenario" menu will show a check next to "Basin Characteristics Report" and "Scenario Flow Reports"
- Click the "Continue" button

Step 1: Hydrograph Calibration

1d – Generate Basin Characteristics Report



Peak-Flow Statistics Parameters

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	0.58	square miles	0.51	117
BSLDEM10M	Mean Basin Slope from 10m DEM	0.37	percent	0.3	3.69
SOILA	Percent Hydrologic Soil Type A	13.4541	percent	0.53	60

Peak-Flow Statistics Flow Report

Pil: Prediction Interval-Lower, Piu: Prediction Interval-Upper, SEp: Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	Pil	Piu	SE	SEp	Equiv. Yrs.
2 Year Peak Flood	20.9	ft^3/s	7.14	61	67.4	67.4	0.8
5 Year Peak Flood	34.9	ft^3/s	13.1	92.8	60.1	60.1	1.6
10 Year Peak Flood	46	ft^3/s	17.6	120	58.5	58.5	2.4
25 Year Peak Flood	61.7	ft^3/s	20.3	187	59	59	3.5
50 Year Peak Flood	74.2	ft^3/s	23.6	233	60.8	60.8	4.2
100 Year Peak Flood	87.8	ft^3/s	26.6	290	63.4	63.4	4.8
200 Year Peak Flood	102	ft^3/s	29.2	357	66.9	66.9	5.2
500 Year Peak Flood	122	ft^3/s	32	467	72.3	72.3	5.6

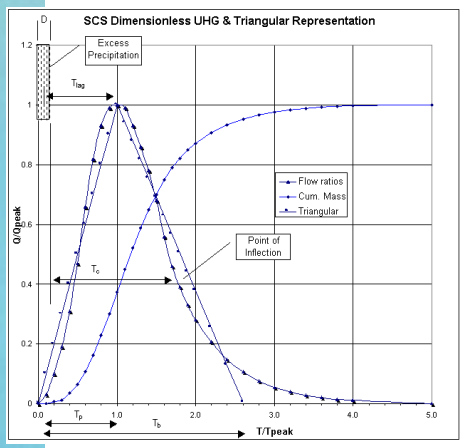
Peak-Flow Statistics Citations

Ries, K.G., III, and Dillow, J.J.A.,2006, Magnitude and frequency of floods in Delaware: Scientific Investigations Report 2006-5146, 59 p.

Application Version: 4.3.11

- *StreamStats* will generate the Basins Characteristic Report; ensure the drainage area is within the minimum and maximum recommended limits
- The Report also includes the peak flows for various return periods based on the USGS regression equations for that region; these will be used as the target peak flows for the calibrated upstream hydrograph
- The Report can be downloaded or printed for future reference

Step 1: Hydrograph Calibration



- 3 Parameters Needed
  - Peak discharge (q_p)
    - StreamStats
  - Time of concentration (T_c)

The second parameter needed to generate the calibrated upstream hydrograph is the Time of Concentration (Tc)

Step 1: Hydrograph Calibration

1e – Estimate watershed Tc

- Appendix 6 from the Maryland Hydrology Panel Report contains regression equations for estimating Tc

Step 1: Hydrograph Calibration

1e – Estimate watershed Tc

$$T_c = 0.133(CL^{.475})(SL^{-.187})(101-FOR)^{-.144}(101-IA)^{.861}(ST+1)^{.154}(10^{.19AP})(10^{.366CP})*$$

Where:

Tc = time of concentration (hrs)
CL = channel length (mi)
SL = channel slope (ft/mi)
FOR = forest cover (%)
IA = impervious area (%)
ST = lakes & ponds in watershed (%)
AP = 1 if Appalachian Plateau, 0 otherwise
CP = 1 if Coastal Plain, 0 otherwise
AP and CP = 0 if Piedmont Region

**Hydrologic Panel Report, Appendix 6, Eq. 1*

- The variables in the Tc regression equation are derived from the basin characteristics
- The physiographic region is also a variable in the equation

Step 1: Hydrograph Calibration

1e – Estimate watershed Tc

Table A6-3: Upper and lower limits for watershed characteristics for the time of concentration regression equation for each hydrologic region.

Region	Variable	Upper limit	Lower limit
Appalachian Plateau	Drainage area (mi^2)	295	1.6
Appalachian Plateau	Channel length (mi)	40.8	2.1
Appalachian Plateau	Channel slope (ft/mi)	195	6.1
Appalachian Plateau	Storage (%)	3.2	0.0
Appalachian Plateau	Forest cover (%)	89	54
Appalachian Plateau	Impervious area (%)	1.25	0.0
Piedmont	Drainage area (mi^2)	494	2.1
Piedmont	Channel length (mi)	70	2.2
Piedmont	Channel slope (ft/mi)	336	11
Piedmont	Storage (%)	1.16	0.0
Piedmont	Forest cover (%)	92	2.0
Piedmont	Impervious area (%)	41	0.0
Coastal Plain	Drainage area (mi^2)	113	2.0
Coastal Plain	Channel length (mi)	18.3	2.0
Coastal Plain	Channel slope (ft/mi)	41.8	1.5
Coastal Plain	Storage (%)	26.0	0.0
Coastal Plain	Forest cover (%)	79	5.0
Coastal Plain	Impervious area (%)	35	0.0

In summary, Equation 1 is based on estimates of T_c computed from rainfall-runoff events at 78 gaging stations in Maryland. The computed values of TC tend to be larger than similar estimates based on SCS (1986) procedures. However, Equation 1 can be used to evaluate the reasonableness of T_c estimates from SCS (1986) procedures. Further research is needed to improve the estimation of T_c in Maryland that would ultimately provide for more accurate estimates of design discharges from hydrological models such as TR-20.

- Table A6-3 shows the Upper and Lower Limit drainage areas that these regression equations are considered valid based on physiographic region
- For Delaware, there are two (2) physiographic regions; Piedmont and Coastal Plain

Step 1: Hydrograph Calibration

1e – Estimate watershed Tc

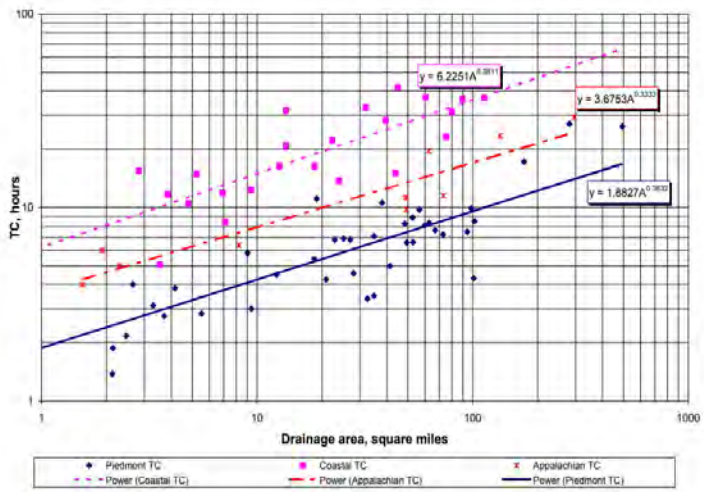


Figure 4-2: Time of concentration versus drainage area in Maryland.

- Figure 4-2 from Chapter 4 of the Maryland Hydrologic Panel Report is a plot of the Tc regression equation calculated for 78 USGS stream gages in Maryland
- The plot also shows the "best fit" line for each of the physiographic regions and the resultant equation for each

Step 1: Hydrograph Calibration
1e – Estimate watershed Tc

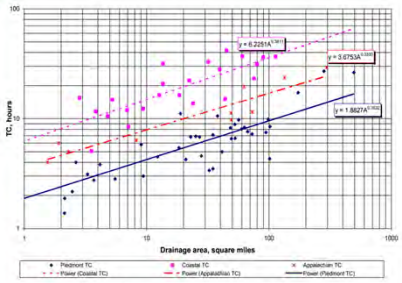


Figure 4-2: Time of concentration versus drainage area in Maryland.

- Coastal Plain
  $y = 6.2251A^{0.3811}$
- Piedmont
  $y = 1.8827A^{0.3532}$

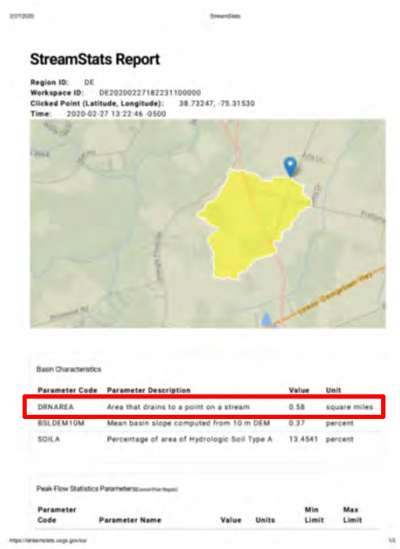
Where:
y = Tc (hrs)
A = Drainage Area (sq. mi.)*

- The equation for the Coastal Plain Region is:
  $y = 6.2251A^{0.3811}$
- The equation for the Piedmont Region is:
  $y = 1.8827A^{0.3532}$
- Where:
  y = Tc (hrs)
  A = Drainage Area (sq. mi.)
- These equations can be used with the drainage area from the *StreamStats* Basin Characteristics Report to estimate the watershed Tc*

((*NOTE: From Table A6-3, the Lower Limit is 2.0 sq. mi. for Coastal Plain and 2.1 sq. mi. for Piedmont watersheds; for drainage areas below the lower limit use the NRCS velocity method for estimating Tc.))

Step 1: Hydrograph Calibration

1f– Determine Tc method based upon watershed size



StreamStats Report

Region ID: DE
Workspace ID: DE20200227182231100000
Clicked Point (Latitude, Longitude): 38.73247, -75.31530
Time: 2020-02-27 13:22:46 -0500

Basin Characteristics

Parameter Code	Parameter Description	Value	Unit
DRNAREA	Area that drains to a point on a stream	0.58	square miles
BSLDEM10M	Mean basin slope computed from 10 m DEM	0.37	percent
SOILA	Percentage of area of Hydrologic Soil Type A	13.4541	percent

Peak Flow Statistics Parameters

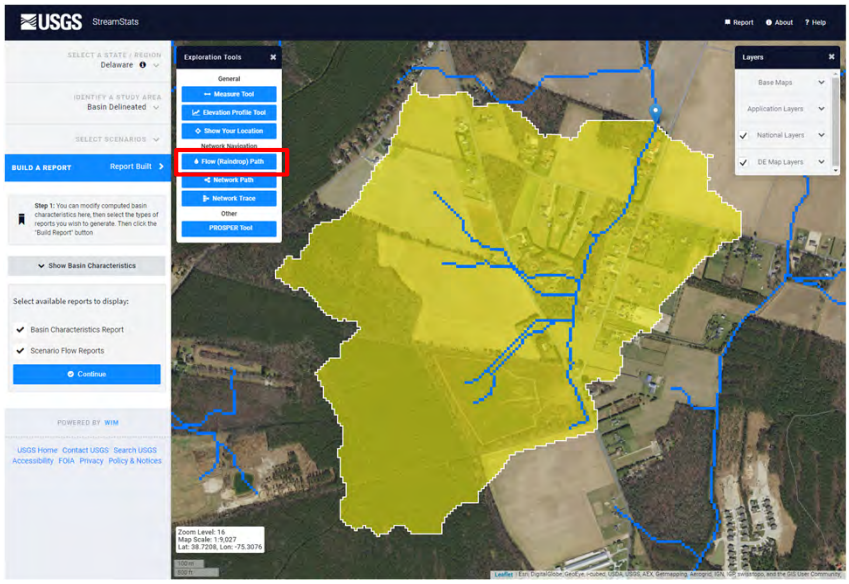
Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit

- StreamStats Report
  - DA = 0.58 sq. mi.
  - 0.58 sq. mi. < 2.0 sq. mi. Lower Limit for Tc Regression Equation
  - Must use NRCS Velocity Method

- Checking the *StreamStats* report it is noted that the delineated watershed is 0.58 sq. mi., which is below the 2.0 sq. mi. Lower Limit for the Coastal Plain Region
- The NRCS Velocity Method must therefore be used to estimate the watershed Tc in this case

Step 1: Hydrograph Calibration

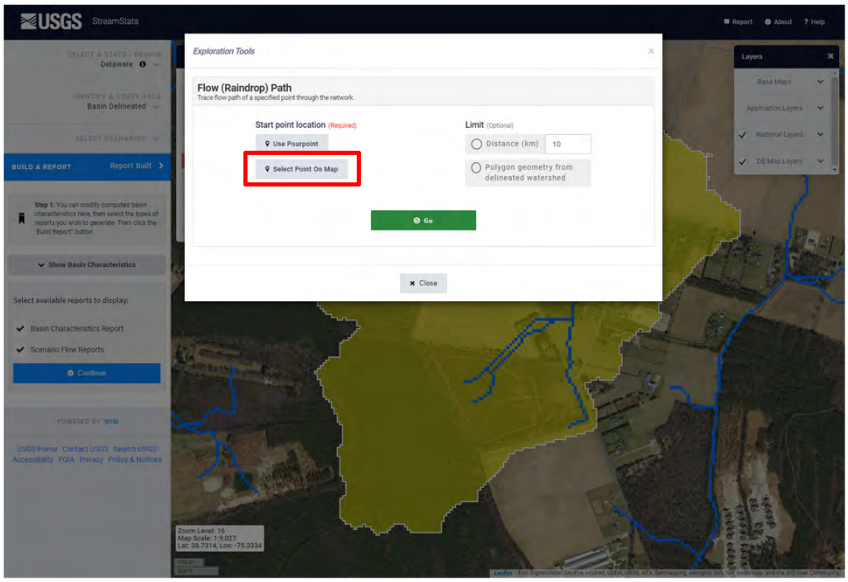
1g– Use StreamStats to generate flow path



- The *StreamStats* application also includes tools that can be used to estimate some of the parameters to be used in the NRCS Velocity Method equations
- One such tool is the "Flow (Raindrop) Path" tool that can be accessed from the "Exploration Tools" drop down menu

Step 1: Hydrograph Calibration

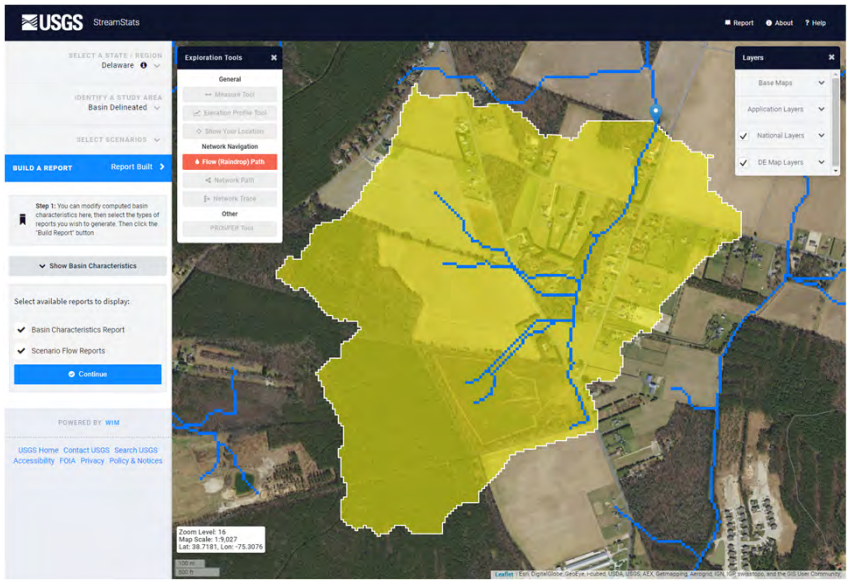
1g– Use StreamStats to generate flow path



- Once the “Flow (Raindrop) Path” tool has been selected, click on the “Select Point on Map” button

Step 1: Hydrograph Calibration

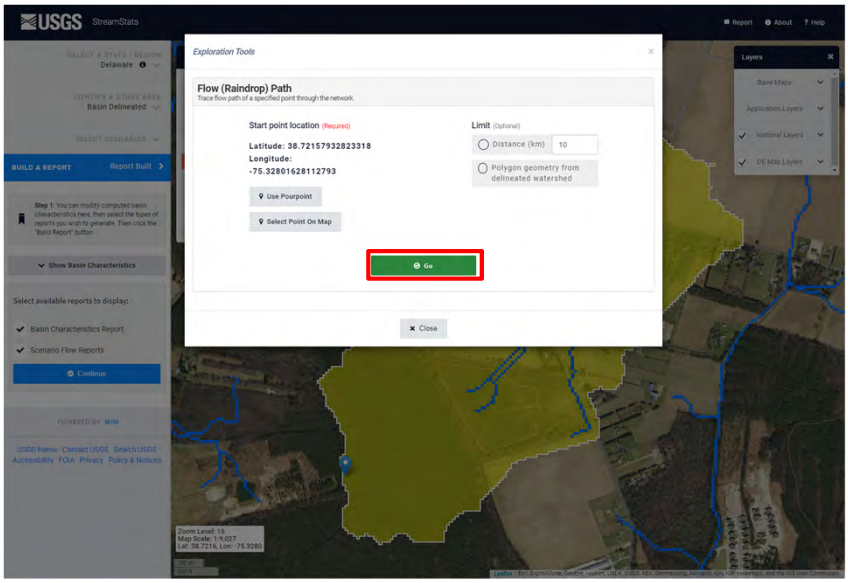
1g– Use StreamStats to generate flow path



- Place the cursor in a location within the delineated watershed that is estimated to be the most hydraulically distant point in the watershed

Step 1: Hydrograph Calibration

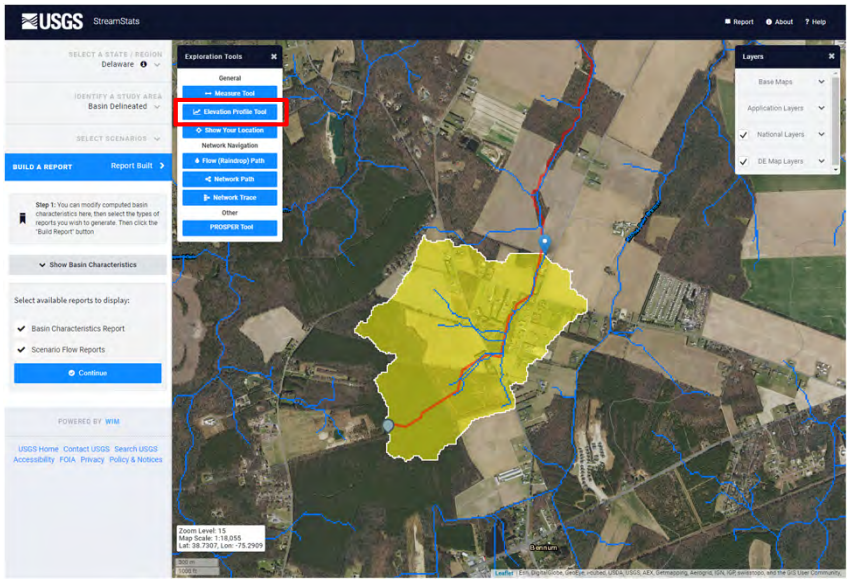
1g– Use StreamStats to generate flow path



- *StreamStats* will determine the Latitude and Longitude of the selected starting point for the flow path
- Click the “Go” button

Step 1: Hydrograph Calibration

1g– Use StreamStats to generate flow path

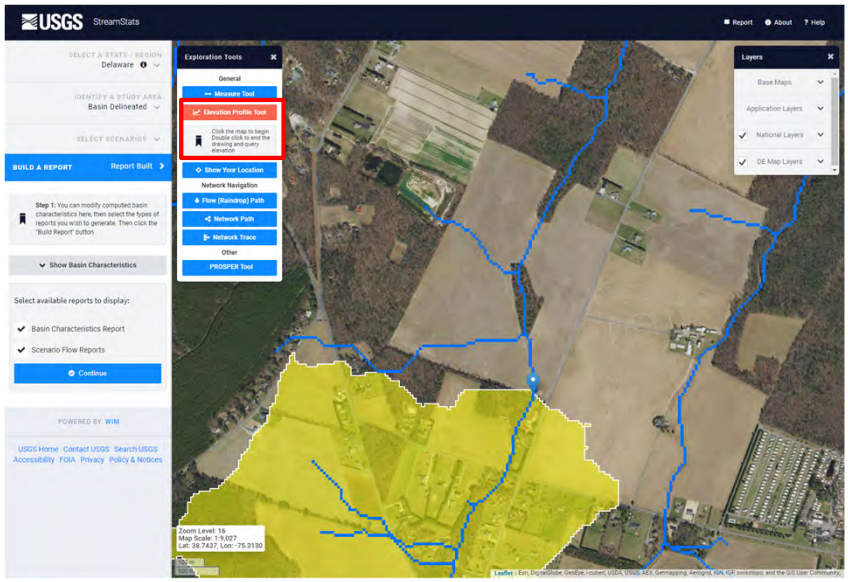


- *StreamStats* will display the flow path from the point selected. The generated flow path will extend to the ultimate discharge point and is intended to provide a guide for the flow path through the site only.
- Repeat the process until satisfied with results (NOTE: Close the "Exploration Tools" dropdown menu to start a new flow path.)
- Once satisfied with results, Sheet Flow and Shallow Concentrated Flow segments used for the NRCS Velocity Method can be estimated from aerial photography and contour maps based on the flow path thus determined
- The "Elevation Profile Tool" can be used to estimate the slope and distance of the Channel Flow segment

((NOTE: The flow path will be removed from the view once the Elevation Profile Tool is selected.))

Step 1: Hydrograph Calibration

1h – Estimate slope and distance of flow path

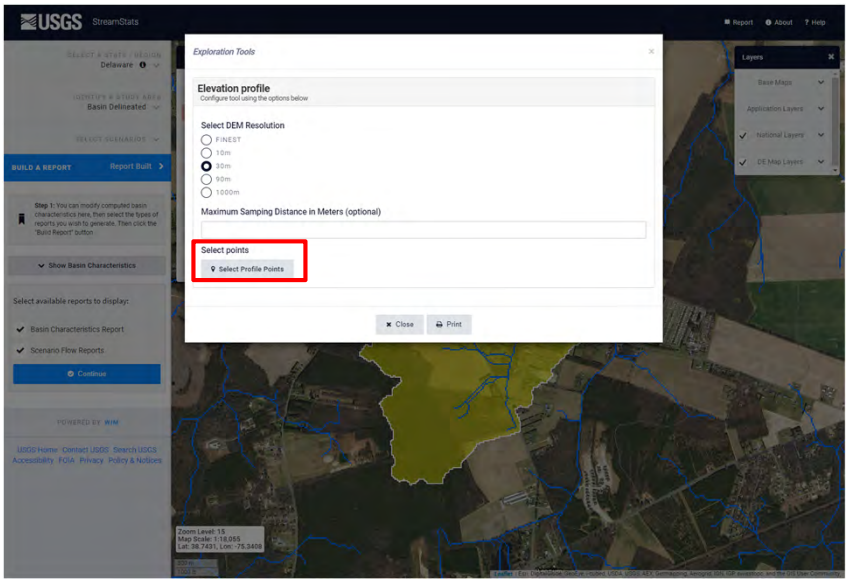


- The "Elevation Profile Tool" will allow the user to click points along the previously determined flow path to generate an elevation-distance plot

((NOTE: The previously determined flow path will not be viewable for this.))

Step 1: Hydrograph Calibration

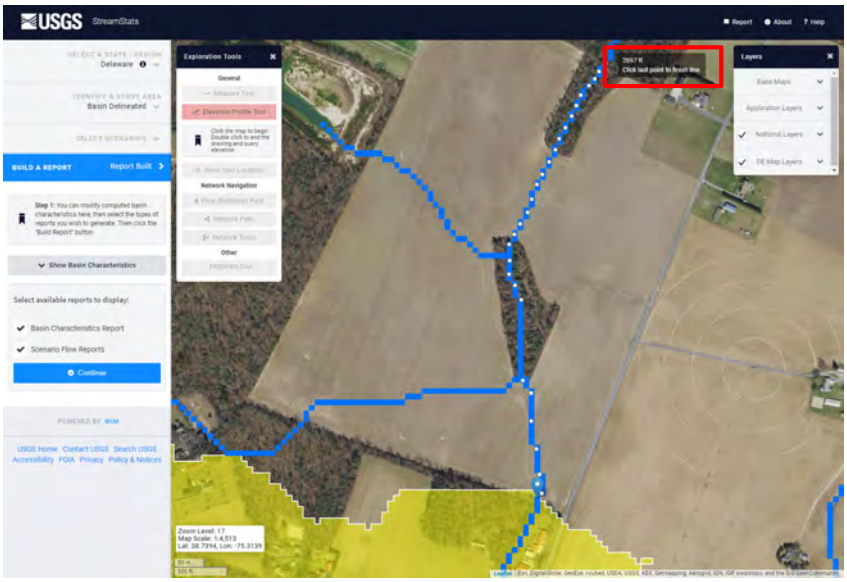
1h – Estimate slope and distance of flow path



- Click the “Select Points” button and begin clicking on the desired section of the flow path

Step 1: Hydrograph Calibration

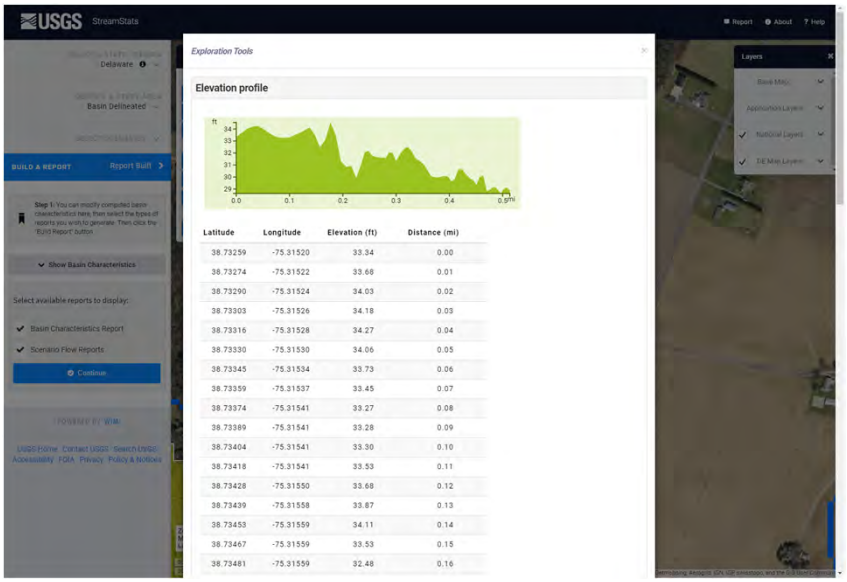
1h – Estimate slope and distance of flow path



- For this example, the profile tool is used to estimate the slope and distance of the main channel flow path previously determined to calculate the Travel Time (Tt) through the site to the main POA
- Once the desired flow path for the main channel has been digitized to the POA, double-click to finish

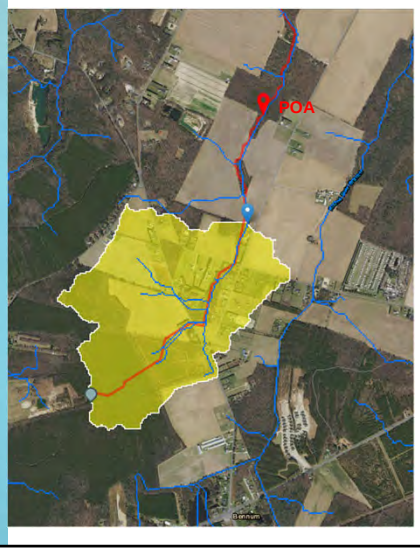
Step 1: Hydrograph Calibration

1h – Estimate slope and distance of flow path



- After the channel has been fully digitized, *StreamStats* will create an elevation-distance plot and table
- The starting and final elevations and distances are used to calculate the length and slope of the channel
- Irregularities in the elevation plot between the start and end points can be ignored for the purposes of this analysis

Step 1: Hydrograph Calibration
1i – Calculate Tc and Tt



Tc derived from delineated watershed:

- Sheet flow segment
  - 100', woods, dense, 1.0 % slope
- Shallow conc. flow segment
  - 2843', cultivated, 1.0% slope
- Tc = 1.68 hr

Travel Time (Tt) derived from elevation-profile:

- Channel flow segment
  - 2693', 0.17% slope, v = 1.70 fps
- Tt = 0.44 hr

StreamStats has generated enough information at this point to calculate the Time of Concentration (Tc) and Travel Time (Tt) to the POA for the upstream hydrograph

Time of Concentration (Tc)

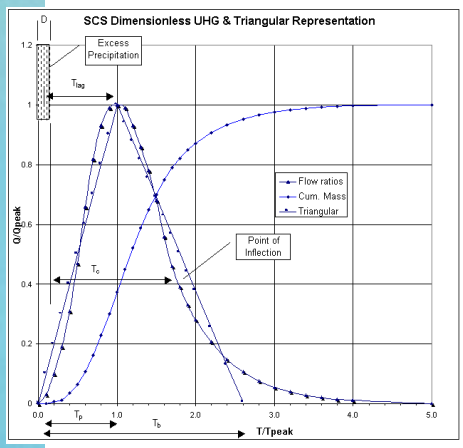
- Sheet flow segment: 100', woods, dense, 1% slope
- Shallow conc. flow segment: 2843', cultivated, 1% slope
- Tc = <u>1.68 hr</u>

Travel Time (Tt) through site to main POA

- From *StreamStats* profile tool
  - Channel flow segment: 2693'
  - 0.17% slope
- From external hydraulic calculations
  - Channel geometry: Trap, 20' BW, 3:1 SS, 3' D, s = 0.0017
  - Manning's "n": 0.035
  - Velocity = 1.70 fps
- Tt = (2693'/1.70 fps)/3600 = <u>0.44 hr</u>

Step 1: Hydrograph Calibration

1j – Estimate runoff volume using RCN as calibration parameter

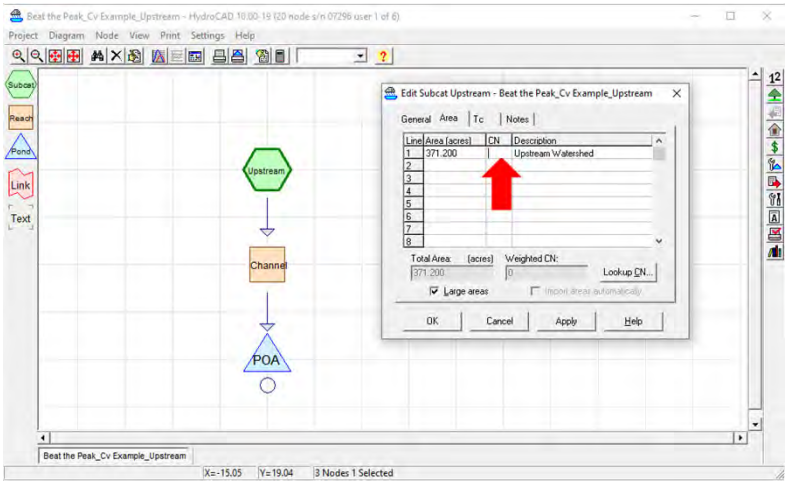


- 3 Parameters Needed
  - Peak discharge (q_p)
    - StreamStats
  - Time of concentration (T_c)
    - Hydro Panel Report, Fig. 4-2; OR NRCS Velocity Method
  - Runoff volume (Q)
    - RCN

- The final parameter need for hydrograph calibration is an estimate of the runoff volume
- Under the NRCS methodology, runoff volume is a function of the Runoff Curve Number (RCN)
- Normally, the RCN is derived from the various land covers and Hydrologic Soil Groups (HSG) within the watershed. The RCN and Tc are then used to calculate a peak discharge and hydrograph.
- In this case, the peak discharge and Tc are known. Thus it is not necessary to perform a land cover/HSG analysis for the watershed. Instead, the RCN will be used as a calibration parameter.

Step 1: Hydrograph Calibration

1j – Estimate runoff volume using RCN as calibration parameter

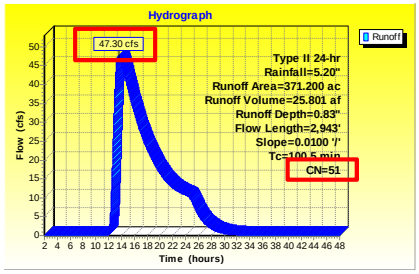


- The process for determining the appropriate RCN is essentially an iterative process using hydrologic software, such as HydroCAD, to test various RCN values until the calculated peak discharge is within acceptable range of the peak discharge determined from the *StreamStats* regression curves.

THE TUTORIAL WILL CONTINUE WITH THE PROCEDURE FOR CALIBRATING THE UPSTREAM HYDROGRAPH FOR THE CV (10-YR) STORM EVENT

Step 1: Hydrograph Calibration

1j – Estimate runoff volume using RCN as calibration parameter



Peak Flow Statistics Flow Report [Coastal Plain Region]

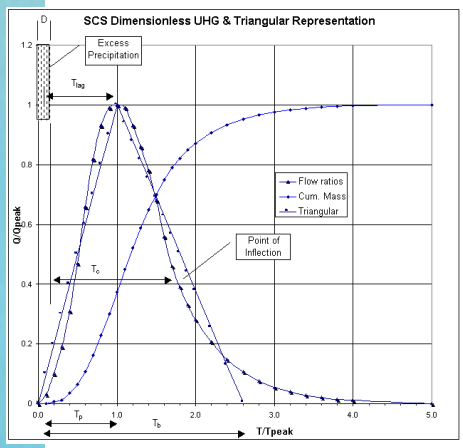
PII: Prediction Interval-Lower, PIu: Prediction Interval-Upper, SEp: Standard Error of Prediction, SE: Standard Error (other – see report)

Statistic	Value	Unit	PII	PIu	SE	SEp	Equiv. Yrs.
2 Year Peak Flood	20.9	ft^3/s	7.14	61	67.4	67.4	0.8
5 Year Peak Flood	34.9	ft^3/s	13.1	92.8	60.1	60.1	1.6
10 Year Peak Flood	46	ft^3/s	17.6	120	58.5	58.5	2.4
25 Year Peak Flood	61.7	ft^3/s	20.3	187	59	59	3.5
50 Year Peak Flood	74.2	ft^3/s	23.6	233	60.8	60.8	4.2
100 Year Peak Flood	87.8	ft^3/s	26.6	290	63.4	63.4	4.8
200 Year Peak Flood	102	ft^3/s	29.2	357	66.9	66.9	5.2
500 Year Peak Flood	122	ft^3/s	32	467	72.3	72.3	5.6

- After several HydroCAD trials testing various RCN values it was found that using an RCN of 51 resulted in a peak discharge of 47.30 cfs.
- This agrees favorably with the estimated 10-YR peak discharge of 46 cfs determined using the regression equations from the *StreamStats* analysis

Step 1: Hydrograph Calibration

1j – Estimate runoff volume using RCN as calibration parameter



- 3 Parameters Needed
  - Peak discharge (q_p)
    - 47.30 cfs
  - Time of concentration (T_c)
    - Tc = 1.68 hr
    - Tt = 0.44 hr
  - Runoff volume (Q)
    - RCN = 51

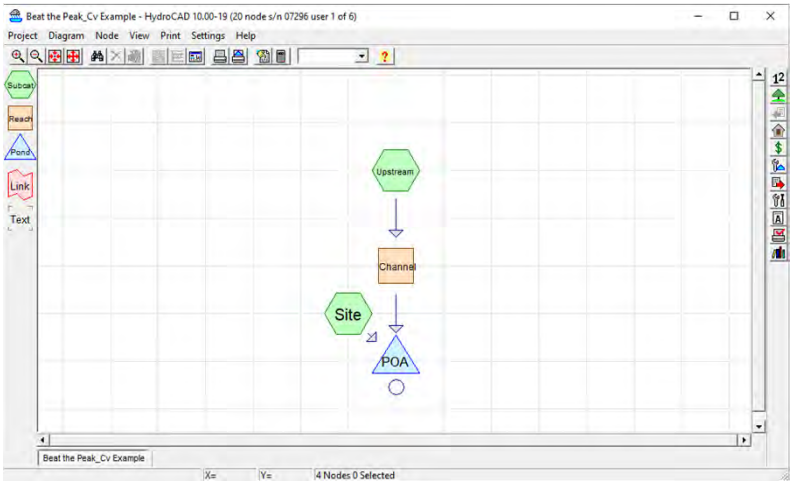
All the parameters needed for a calibrated hydrograph for the upstream watershed have now been determined.

- Peak discharge = 47.30 cfs
- Time of concentration = 1.68 hr
- Travel time = 0.44 hr
- Runoff curve number = 51

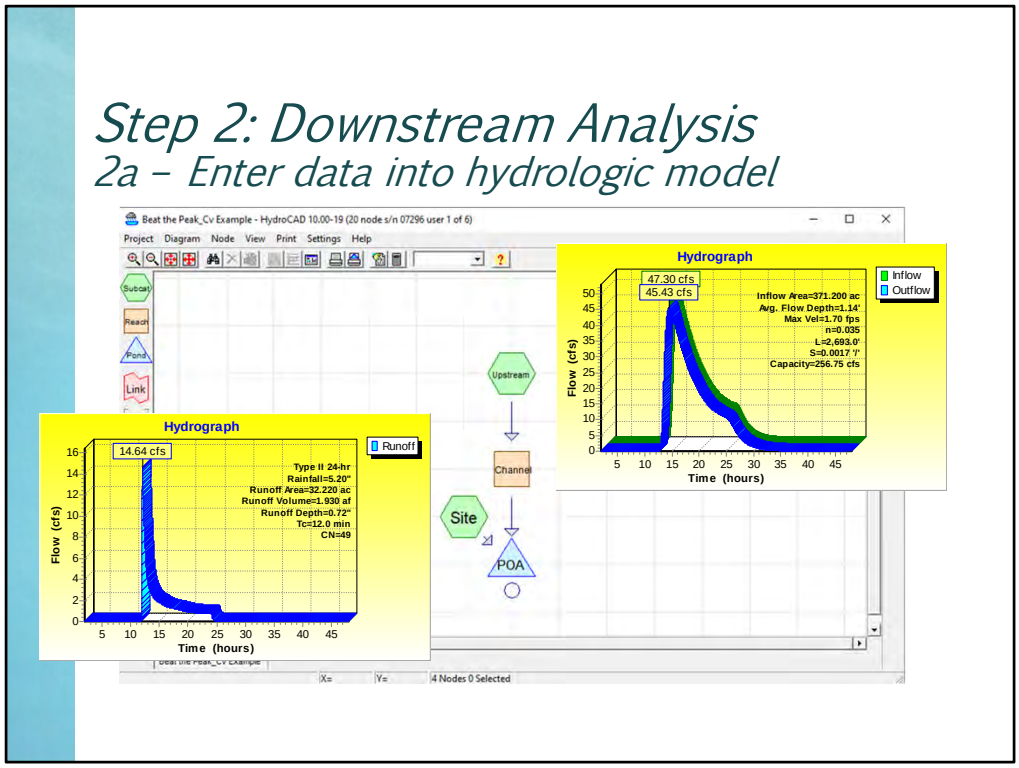
THIS COMPLETES STEP 1. THE TUTORIAL WILL CONTINUE WITH STEP 2 TO COMPLETE THE DOWNSTREAM ANALYSIS FOR THE CV (10-YR) STORM EVENT.

Step 2: Downstream Analysis

2a – Enter data into hydrologic model



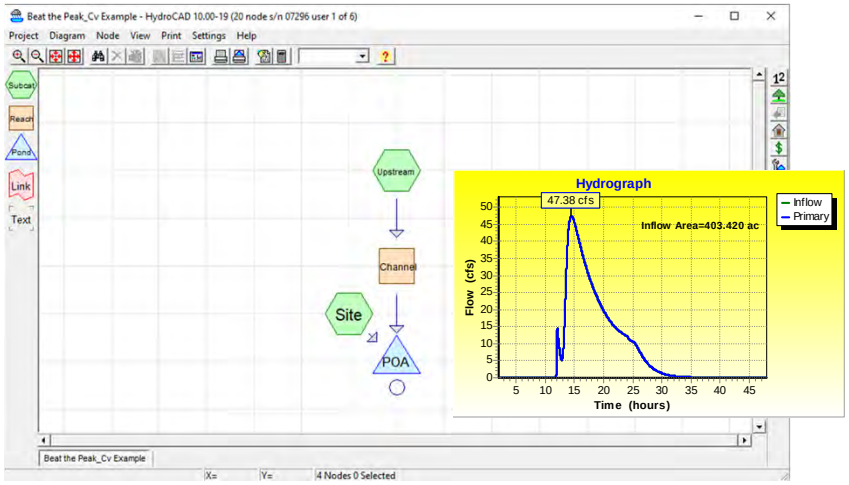
- The hydrologic data for the site and upstream subareas are entered into a hydrologic model, in this case HydroCAD, to perform the downstream analysis at the POA.



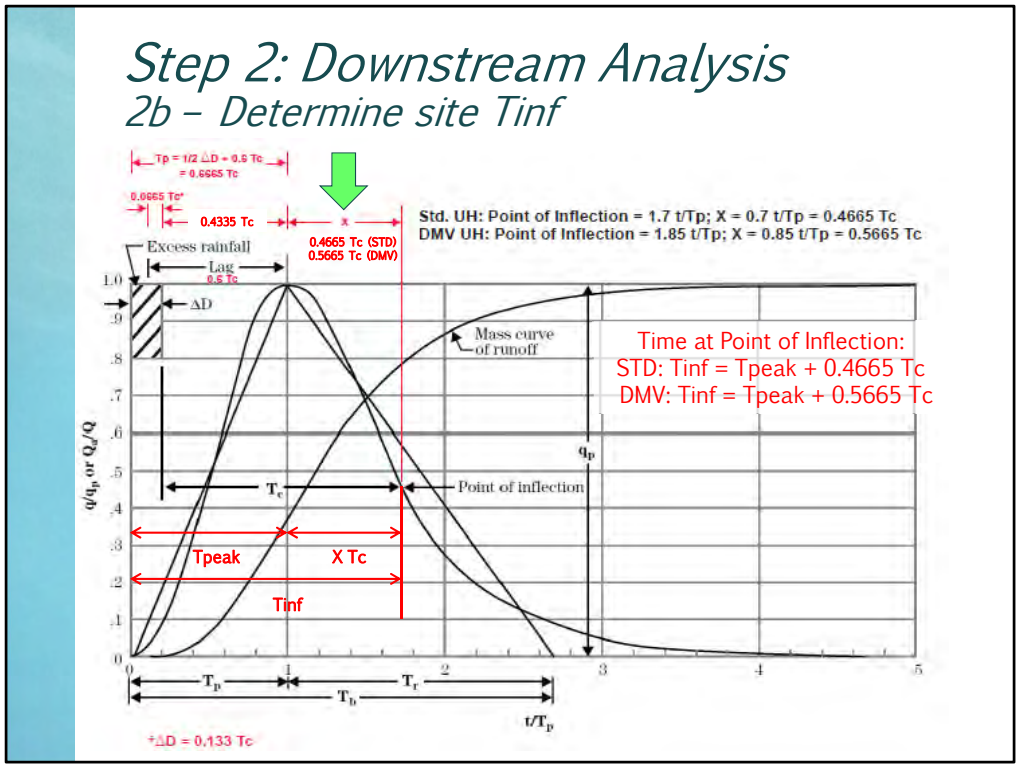
- Although there is some attenuation of the upstream hydrograph in the channel, the computed hydrographs indicate the peak discharge for the site is significantly less than the peak discharge for the upstream watershed.

Step 2: Downstream Analysis

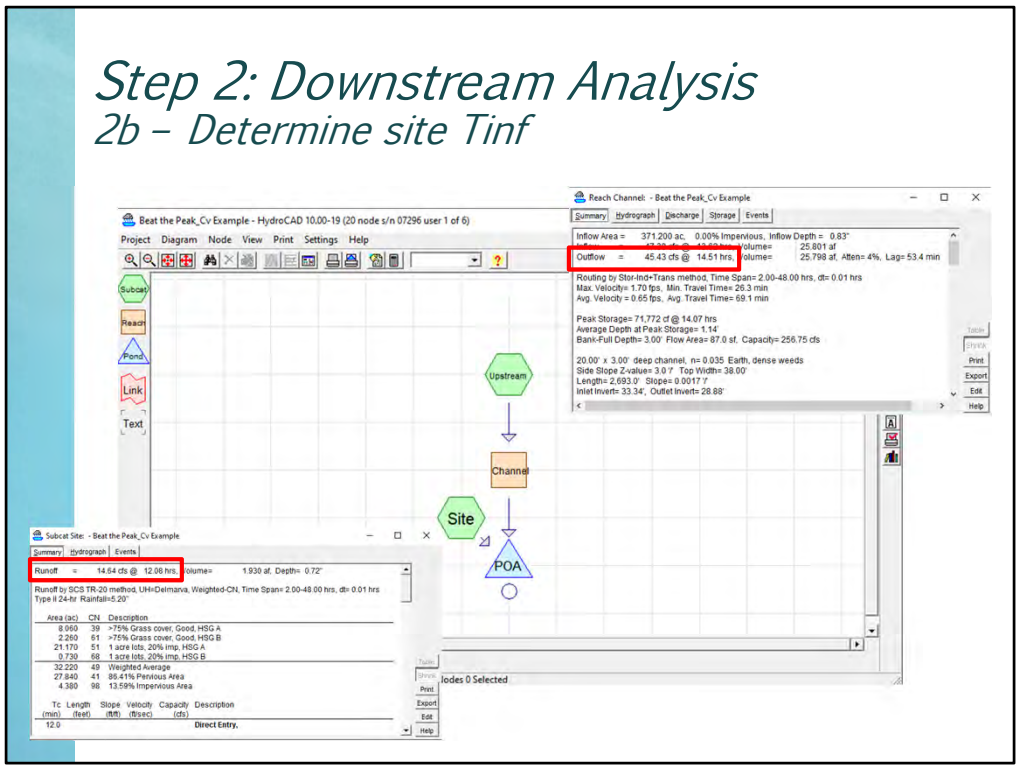
2a – Enter data into hydrologic model



- This can be seen clearly in the combined hydrograph at the POA.
- It cannot be determined from the hydrograph alone, however, whether the time of the inflection point for the site hydrograph occurs before the time of the peak for the upstream hydrograph.
- This will require additional analysis based on hydrograph theory.



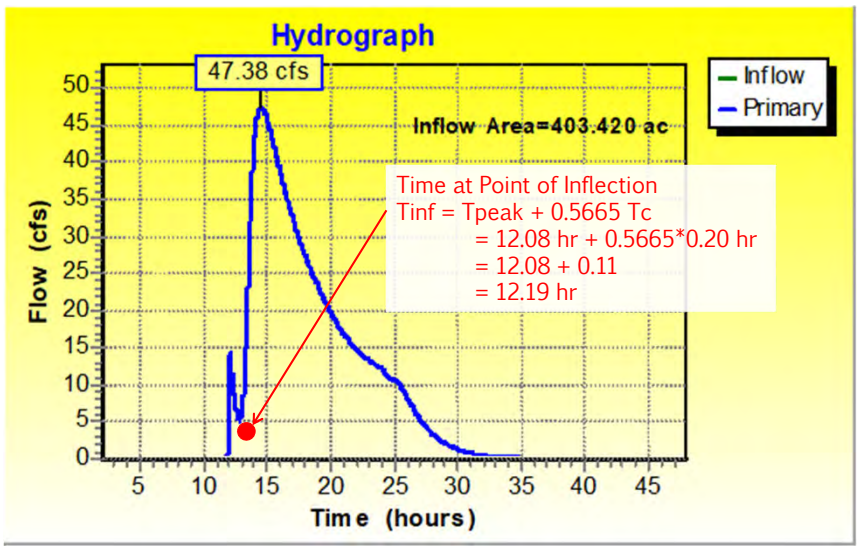
- Based on NRCS Hydrograph theory, Time of Concentration (Tc) is the time from the end of excess rainfall to the inflection point on the recession limb of the curvilinear hydrograph.
- By analogy using the geometry of the NRCS triangular hydrograph, it is possible to determine the time of the point of inflection in relation to the Tc and Time to Peak (Tp).
- The time to the point of inflection on the recession limb (X) varies depending on the unit hydrograph:
    - STD: Point of Inflection (X) = 1.7 t/Tp = 0.4665 Tc
    - DMV: Point of Inflection (X) = 1.85 t/Tp = 0.5665 Tc
- Therefore, the time to the point of inflection (Tinf) can be calculated by summing the time to peak (Tp) and the point of inflection time (X):
    - STD: Tinf = Tp + 0.4665 Tc
    - DMV: Tinf = Tp + 0.5665 Tc



- The Time to Peak of the site and upstream subareas are summarized in the HydroCAD report:
    - Tp Upstream: 14.51 hrs*
    - Tp Site: 12.08 hrs

*The reach routed hydrograph is identified as the "Outflow" hydrograph in the HydroCAD report and represents the hydrograph at the POA

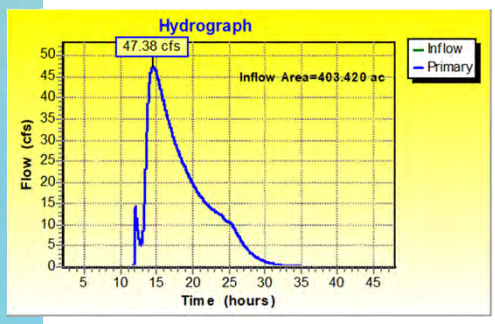
Step 2: Downstream Analysis
2b – Determine site Tinf



- The time to the point of inflection for the site hydrograph can now be calculated:

Site Tinf = 12.08 + (0.5665*0.20)
= 12.08 + 0.11
= 12.19 hr

Step 2: Downstream Analysis
2c – Compare q_p, Tp and Tinf



✓ Developed site hydrograph peak less than peak of upstream hydrograph

AND…

✓ Developed site hydrograph inflection point occurs before peak of the upstream hydrograph

- Comparing the peak discharges:

q_p Site		q_p Upstream
14.64 cfs	<	45.43 cfs

- Comparing the time of the inflection point of the site hydrograph to the time to peak for the upstream hydrograph:

Tinf Site		Tp Upstream
12.19 hr	<	14.51 hr

- The downstream analysis verifies that the site complies with the Cv requirements of the 2019 DSSR without additional management.
- The same procedure can be used to check for compliance with the Fv requirements by performing a downstream analysis with the upstream hydrograph calibrated for the 100-YR storm event. (NOTE: The RCN used for Fv calibration may or may not be the same as that used for Cv calibration.)

THIS CONCLUDES THE TUTORIAL

Downstream Analysis Procedure To Show Cv & Fv Compliance

IAW February 2019 DSSR

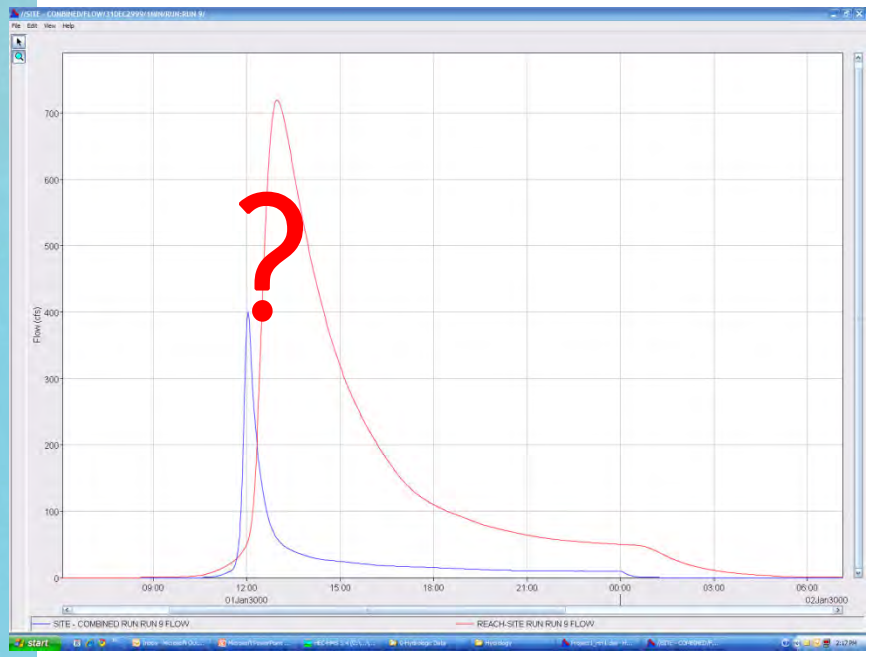
Cv[1] & Fv[2] Compliance Criteria

Demonstration that the location of a project within a watershed would aggravate flooding or channel erosion by the imposition of peak control requirements, as evidenced by a downstream analysis that shows the inflection point of the site hydrograph occurs prior to and is less than the peak of the upstream hydrograph.

[1]2019 DSSR, Section 5.3.3.4

[2]2019 DSSR, Section 5.4.3.4

Compliance Criteria: Downstream Analysis



✓ Developed site hydrograph peak less than peak of upstream hydrograph

AND…

✓ Developed site hydrograph inflection point occurs before peak of the upstream hydrograph

HOW?

Compliance Criteria: Downstream Analysis

"Broadkill Estates"
Sussex County
Post-Developed Condition

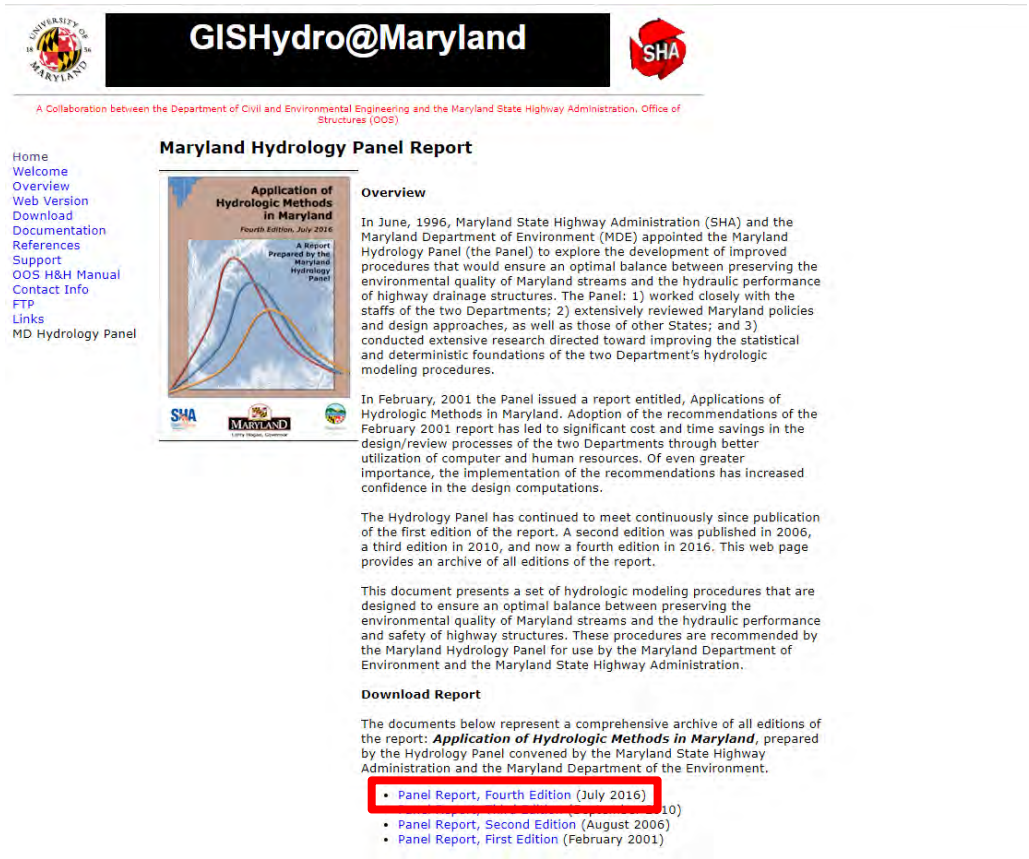
- Open Space
  - HSG A: 8.06 ac
  - HSG B: 2.26 ac
- 1-ac Residential (20% imp)
  - HSG A: 21.17 ac
  - HSH B: 0.73 ac
- RCN: 49
- Tc: 0.2 hr

Point of Analysis (POA) is most downstream site discharge point to existing channel

Procedure

1. Hydrograph Calibration
   a. Consult MD Hydrology Panel Report
   b. Delineate upstream watershed
   c. Edit watershed boundary (optional)
   d. Generate Basin Characteristics Report
   e. Estimate watershed Time of Concentration (Tc)
   f. Determine Tc method based upon watershed size
   g. Generate Tc flow path in StreamStats
   h. Estimate slope and distance using elevation profile tool
   i. Calculate Tc [and Travel Time (Tt) if necessary]
   j. Estimate runoff volume
2. Downstream Analysis
   a. Enter hydrologic data into hydrologic model
   b. Determine site time to inflection point (Tinf)
   c. Compare site and watershed peak discharges (q_p), watershed time to peak (Tp) and site inflection point time (Tinf)

Step 1: Hydrograph Calibration
1a – Consult the MD Hydrology Panel Report



GISHydro@Maryland

A Collaboration between the Department of Civil and Environmental Engineering and the Maryland State Highway Administration, Office of Structures (OOS)

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Contact Info
FTP
Links
MD Hydrology Panel

Maryland Hydrology Panel Report

Overview

In June, 1996, Maryland State Highway Administration (SHA) and the Maryland Department of Environment (MDE) appointed the Maryland Hydrology Panel (the Panel) to explore the development of improved procedures that would ensure an optimal balance between preserving the environmental quality of Maryland streams and the hydraulic performance of highway drainage structures. The Panel: 1) worked closely with the staffs of the two Departments; 2) extensively reviewed Maryland policies and design approaches, as well as those of other States; and 3) conducted extensive research directed toward improving the statistical and deterministic foundations of the two Department's hydrologic modeling procedures.

In February, 2001 the Panel issued a report entitled, Applications of Hydrologic Methods in Maryland. Adoption of the recommendations of the February 2001 report has led to significant cost and time savings in the design/review processes of the two Departments through better utilization of computer and human resources. Of even greater importance, the implementation of the recommendations has increased confidence in the design computations.

The Hydrology Panel has continued to meet continuously since publication of the first edition of the report. A second edition was published in 2006, a third edition in 2010, and now a fourth edition in 2016. This web page provides an archive of all editions of the report.

This document presents a set of hydrologic modeling procedures that are designed to ensure an optimal balance between preserving the environmental quality of Maryland streams and the hydraulic performance and safety of highway structures. These procedures are recommended by the Maryland Hydrology Panel for use by the Maryland Department of Environment and the Maryland State Highway Administration.

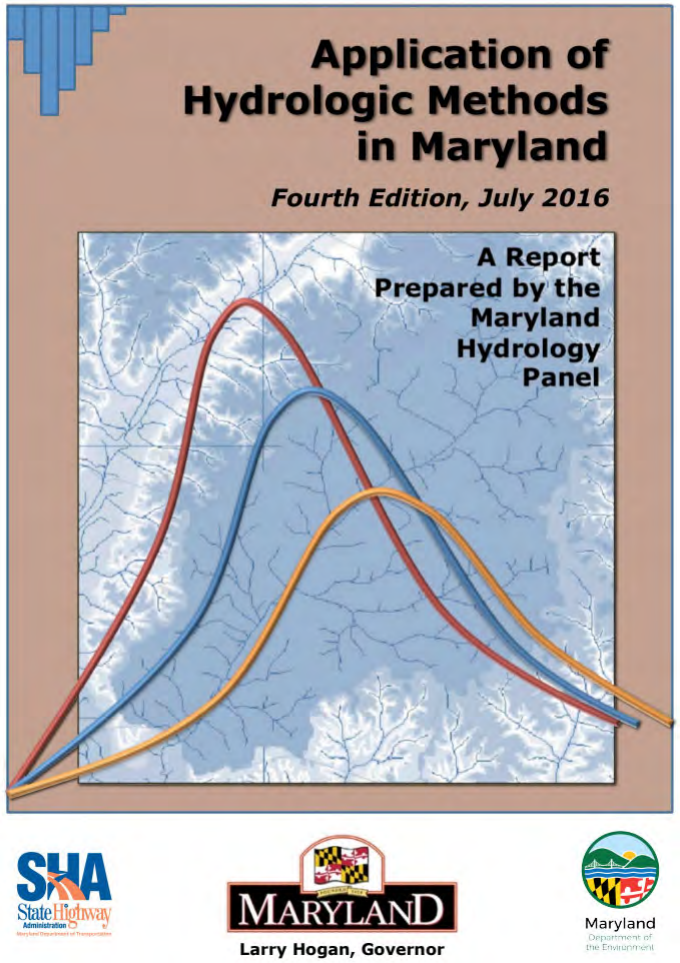
Download Report

The documents below represent a comprehensive archive of all editions of the report: ***Application of Hydrologic Methods in Maryland***, prepared by the Hydrology Panel convened by the Maryland State Highway Administration and the Maryland Department of the Environment.

- Panel Report, Fourth Edition (July 2016)
- Panel Report, Third Edition (September 2010)
- Panel Report, Second Edition (August 2006)
- Panel Report, First Edition (February 2001)

http://www.gishydro.eng.umd.edu/panel.htm

Step 1: Hydrograph Calibration
1a – Consult the MD Hydrology Panel Report



Step 1: Hydrograph Calibration
1a – Consult the MD Hydrology Panel Report

CHAPTER FOUR

4 CALIBRATION OF WINTR-20 WITH STATISTICAL METHODS

4.1 OVERVIEW

The hydrologic analysis of SHA bridges and culverts must examine the behavior of the structure and local stream conditions under both existing and ultimate development watershed conditions. Because two land cover and flow path conditions are involved, the basis for these hydrologic analyses must be a deterministic model that can simulate the major runoff processes for both existing and future conditions. The recommended approach is to first select field and map defined parameters that describe the runoff processes for existing watershed conditions. After the designer is satisfied that the model provides a realistic representation of the existing watershed conditions, the impact of ultimate conditions can be simulated by adjusting the input parameters to reflect future land cover and flow path modifications.

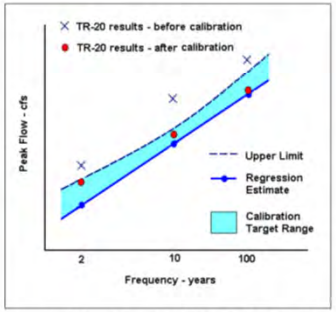


Figure 4.1: Over-prediction behavior of WinTR-20 for all return periods.

The NRCS-WinTR-20 computer program is a well established deterministic model that has an extensive history of use in Maryland. However, the WinTR-20, as with all deterministic models, is sensitive to the values of the input parameters. In most instances, the input parameters are difficult to determine. As discussed earlier, the WinTR-20 model has a tendency to over predict peak flows at all return periods. This behavior is illustrated by Figure 4.1. The Panel has concluded that this tendency to over predict can be overcome through calibration. Thus, in order to provide the designer with confidence that the input parameters selected are representative of the existing watershed

Step 1: Hydrograph Calibration
1a – Consult the MD Hydrology Panel Report

Table 4.2: Table of WinTR-20 Variable Adjustment Limits for Calibration

Variable	Error Type	Error Source Variable	Common Error Trend	Effect On Peak Q	Note	Adjustment Limits of variable in column 3
Area	Random	Area	High or Low	Increase or Decrease		Not Recommended, check for non-contributing areas
RCN	Random	Table Selection	High or Low	Increase or Decrease	4	± 10% for each category and within the limits of the NRCS guidelines.
T_c (Overland)	Systematic	n_o, L	Low	Increase	3	n_o up to 25%, L max = 100'
T_c (shallow conc.)	Systematic	Length, n	Low	Increase	3	Increase L up to 25%, n to ± 50%
T_c (channel)	Systematic	Length, n	Low	Increase	3	Increase L up to 25%, n to ± 50%
Representative X-section	Systematic	Area, n	Low	Increase	3	Area to ± 25%, n to ± 50%
Reach Routing Length	Systematic	Length	Low	Increase	3	Up to 30% for 1:24,000 maps, up to 19% for 1:2,400 maps
Storage at culverts	Systematic	Volume	Low	Increase	1	Up to 15%
ARC	Random	N/A	N/A	N/A	2	ARC= 2 is base value. See note below.
Dimensionless Unit Hydrogr.	Systematic	Peak Factor K	High or Low	Increase or Decrease		Regional values of K in Maryland
Rainfall Tables	Systematic	Increment, intensity, & duration	High or Low	Increase or Decrease		48, 24, 12 and 6 hr. distributions

Definitions:
Random (errors) = either high or low from an expected mean value.

Systematic (errors) = always higher or always lower than the calculated value.

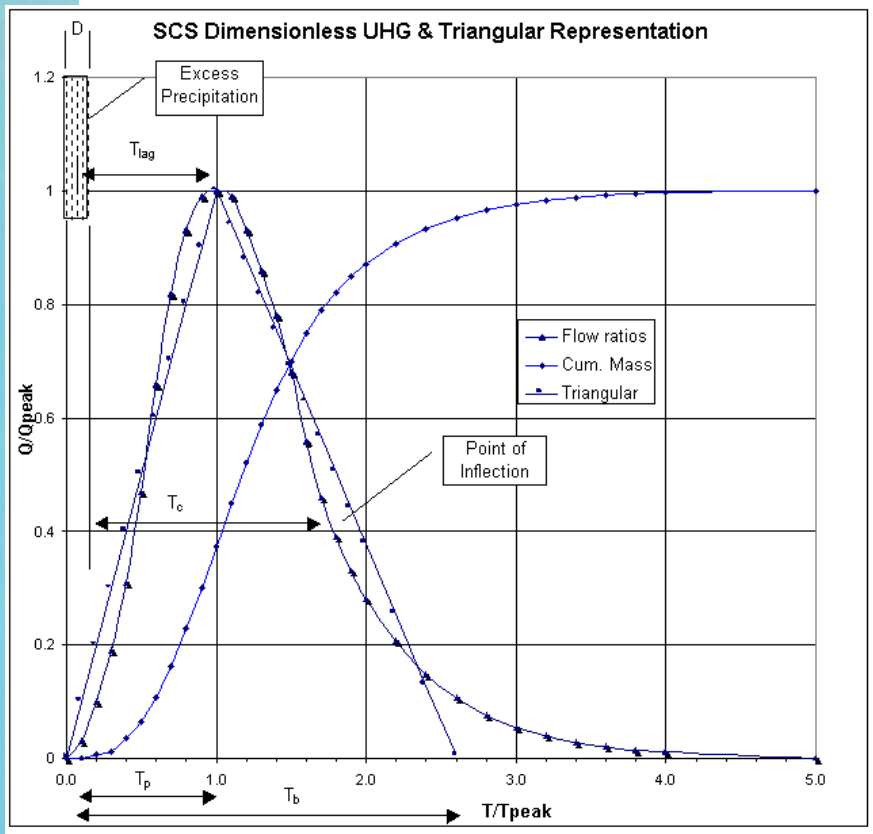
Low = calculated value lower than probable "actual" value.

High = calculated value higher than probable "actual"

Notes:
1. If the total volume of "reservoir" storage in the watershed is less than 10% of the total runoff volume, the effects of storage may be ignored.
2. ARC < 2 may be more appropriate for estimating the 10-year or more frequent storms. ARC > 2 may be appropriate for severe storms of 200 year and above.
3. Primary calibration variable.
4. Do not adjust the weighted RCN.

Table 4.2 *is presented as a guide to assist the designer in the reevaluation of WinTR-20 input parameters that might be causing the peak discharges to fall outside the recommended regional regression equation bounds. The table is a guide suggesting that, because of the difficulties in the estimation process, the parameters of column 3 could be in error by as much as the value listed in the last column. The selected values of all parameters in column 3 must be supported by field and map investigations, be consistent with standard hydrologic practice and documented.*

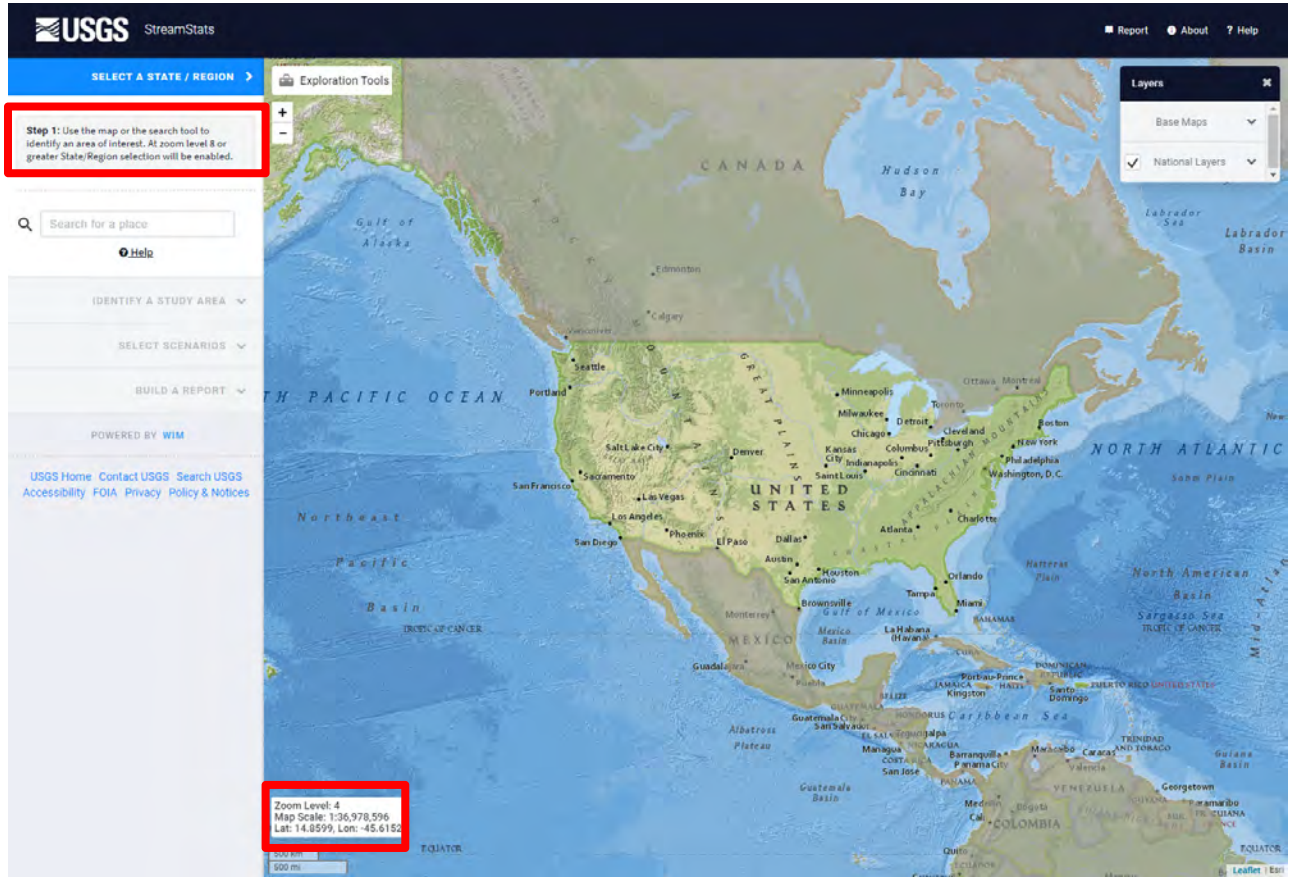
Step 1: Hydrograph Calibration
1a – Consult the MD Hydrology Panel Report



- 3 Parameters Needed
  - Peak discharge (q_p)

Step 1: Hydrograph Calibration

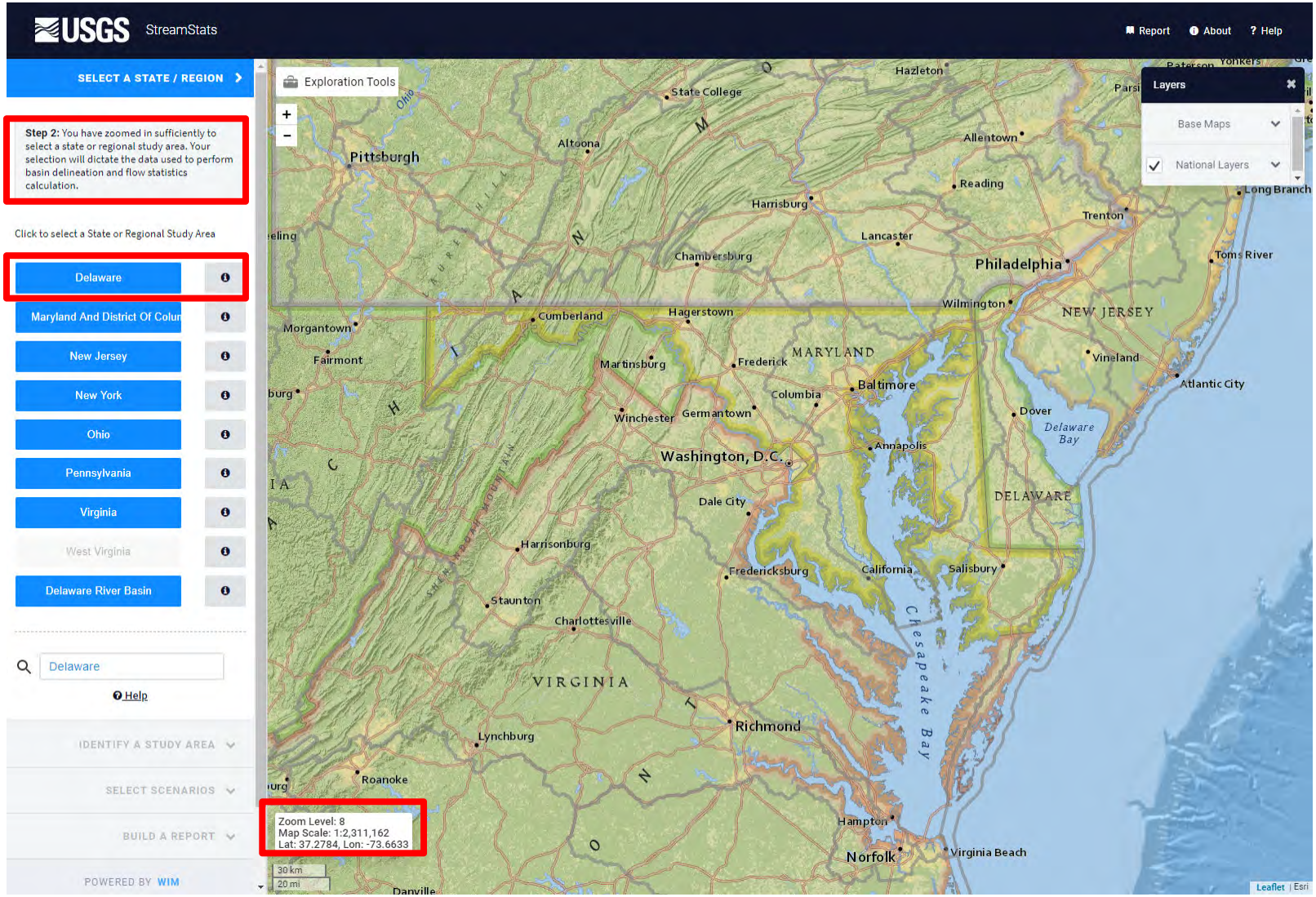
1b – Access StreamStats to delineate upstream watershed



https://streamstats.usgs.gov/ss/

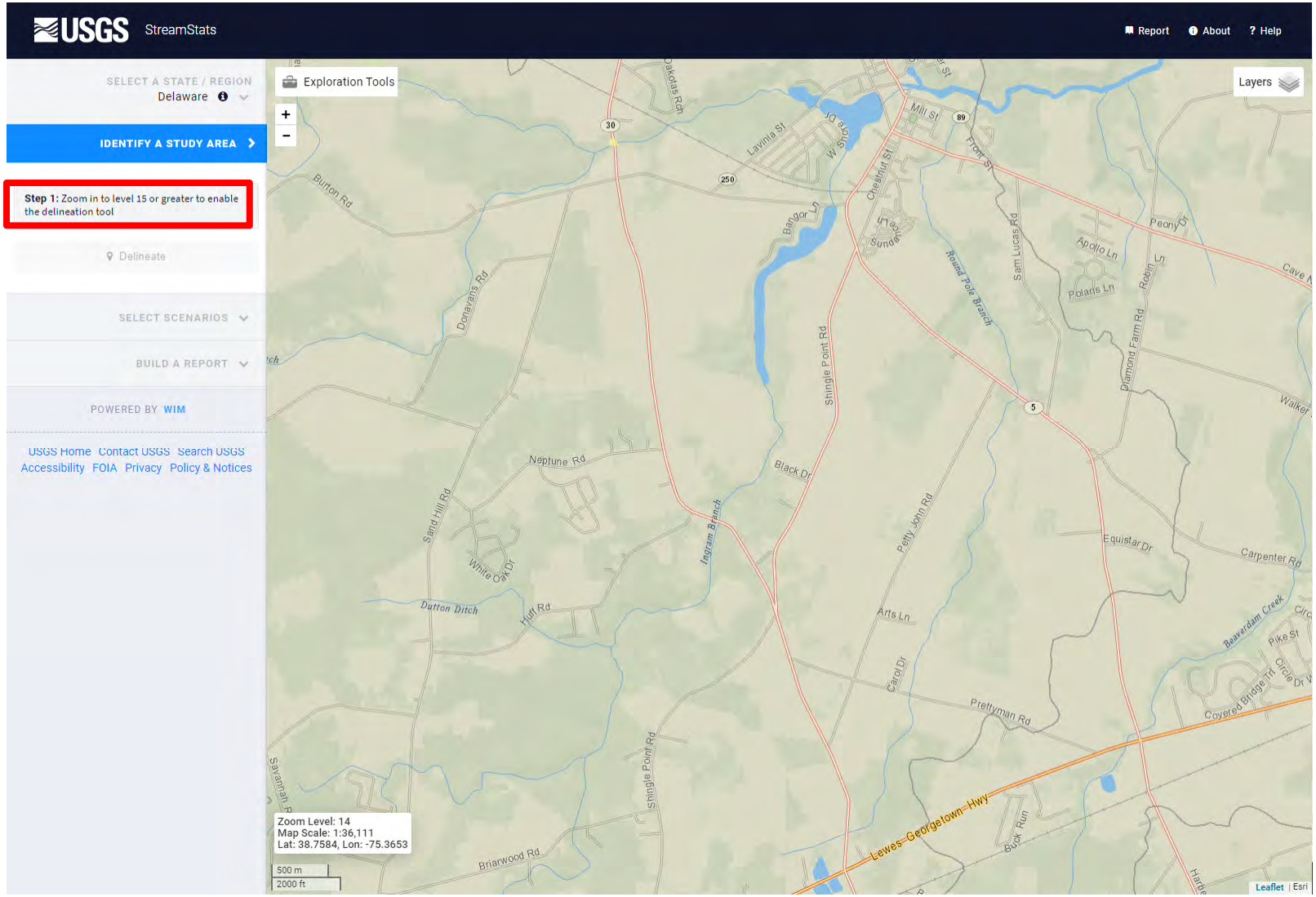
Step 1: Hydrograph Calibration

1b – Access StreamStats to delineate upstream watershed



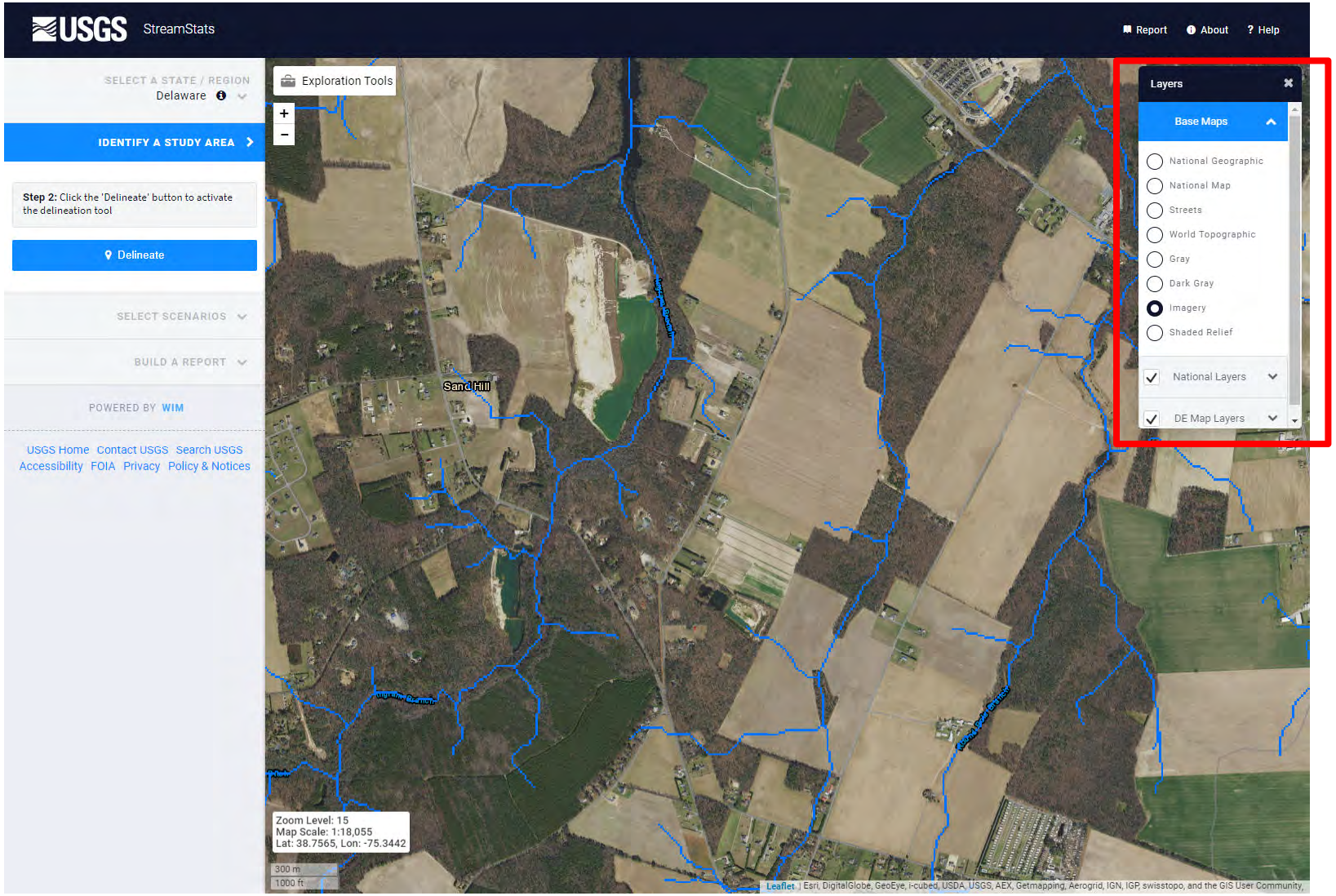
Step 1: Hydrograph Calibration

1b – Access StreamStats to delineate upstream watershed



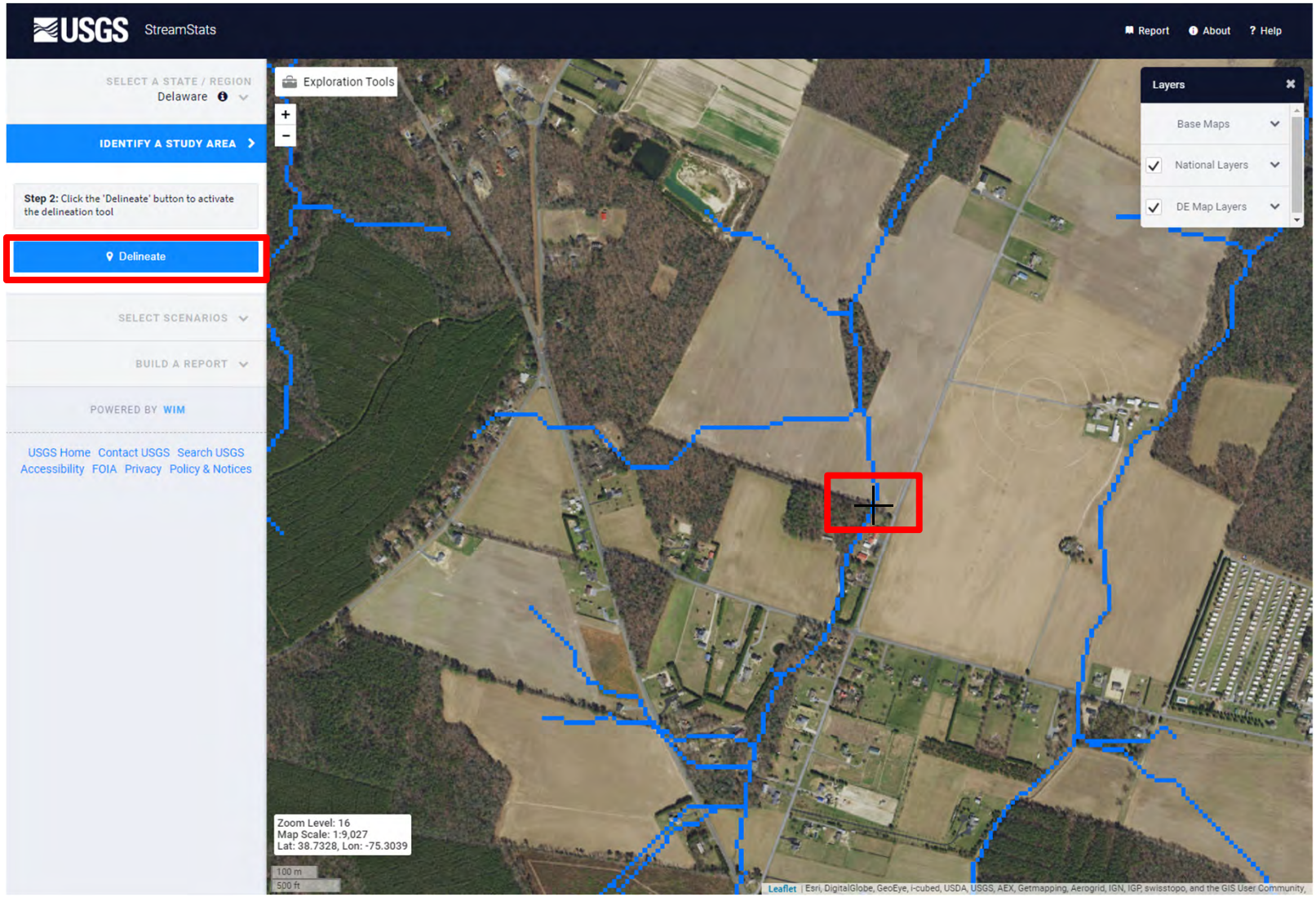
Step 1: Hydrograph Calibration

1b – Access StreamStats to delineate upstream watershed

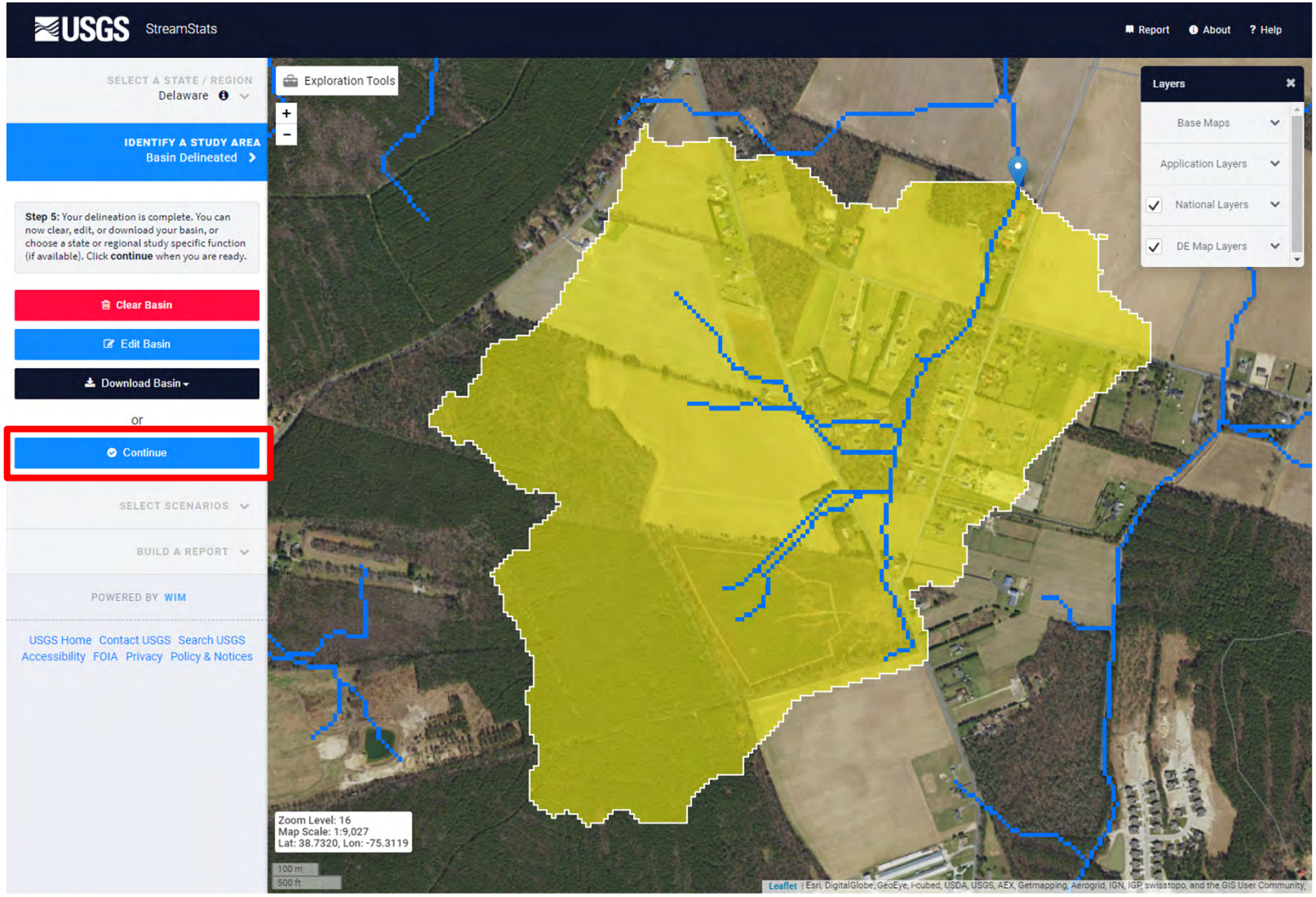


Step 1: Hydrograph Calibration

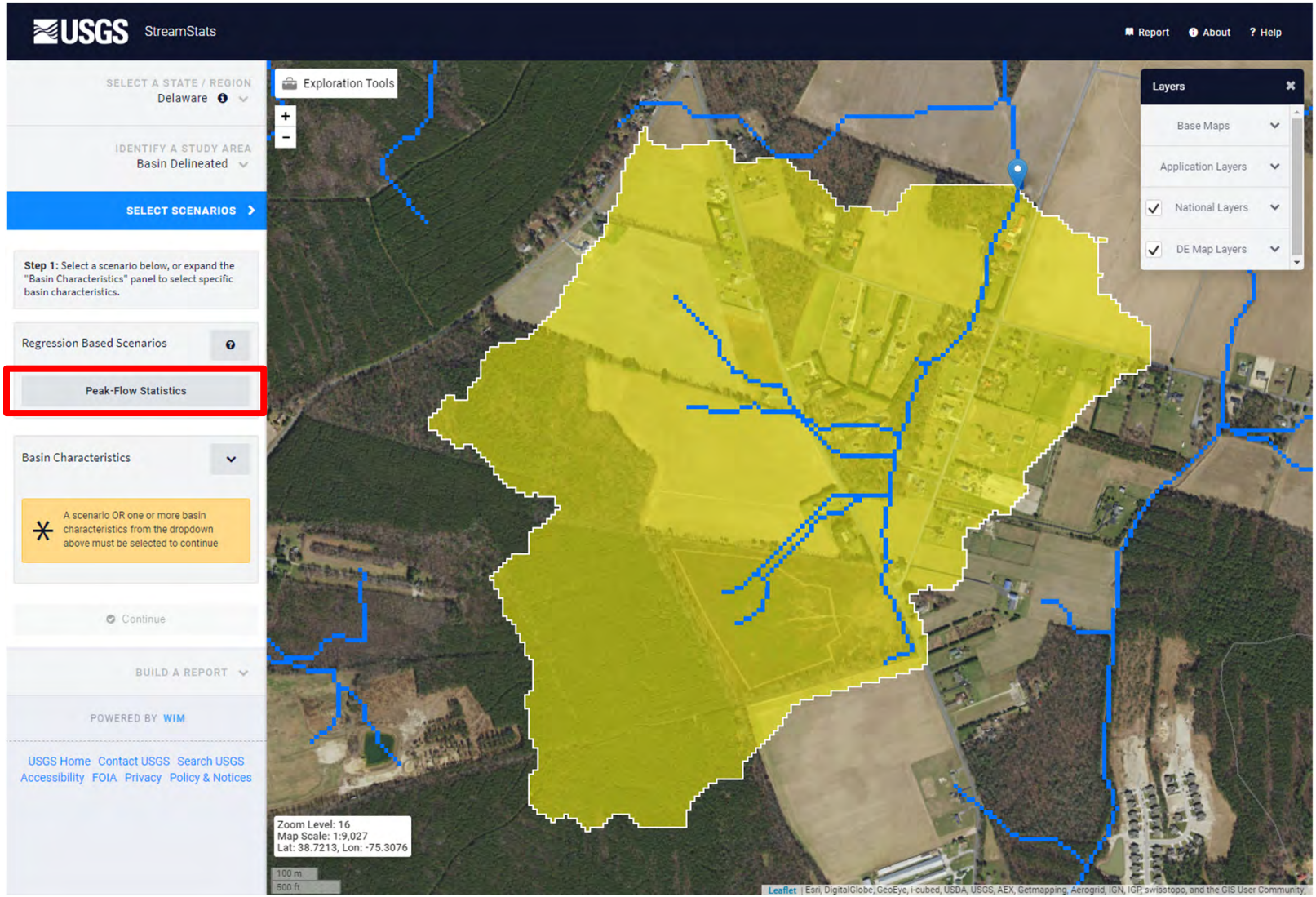
1b – Access StreamStats to delineate upstream watershed



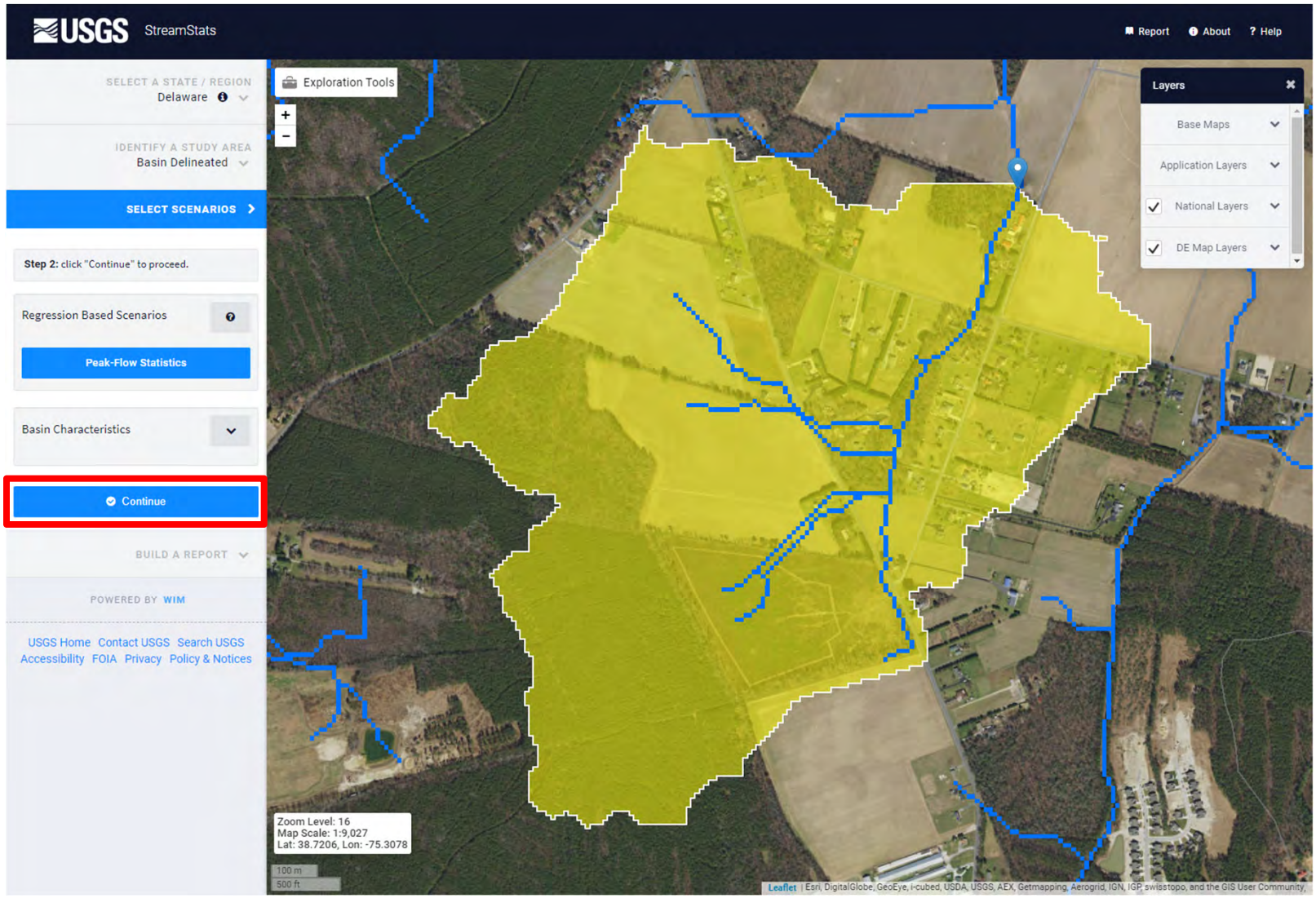
Step 1: Hydrograph Calibration
1c – Edit watershed boundary (optional)



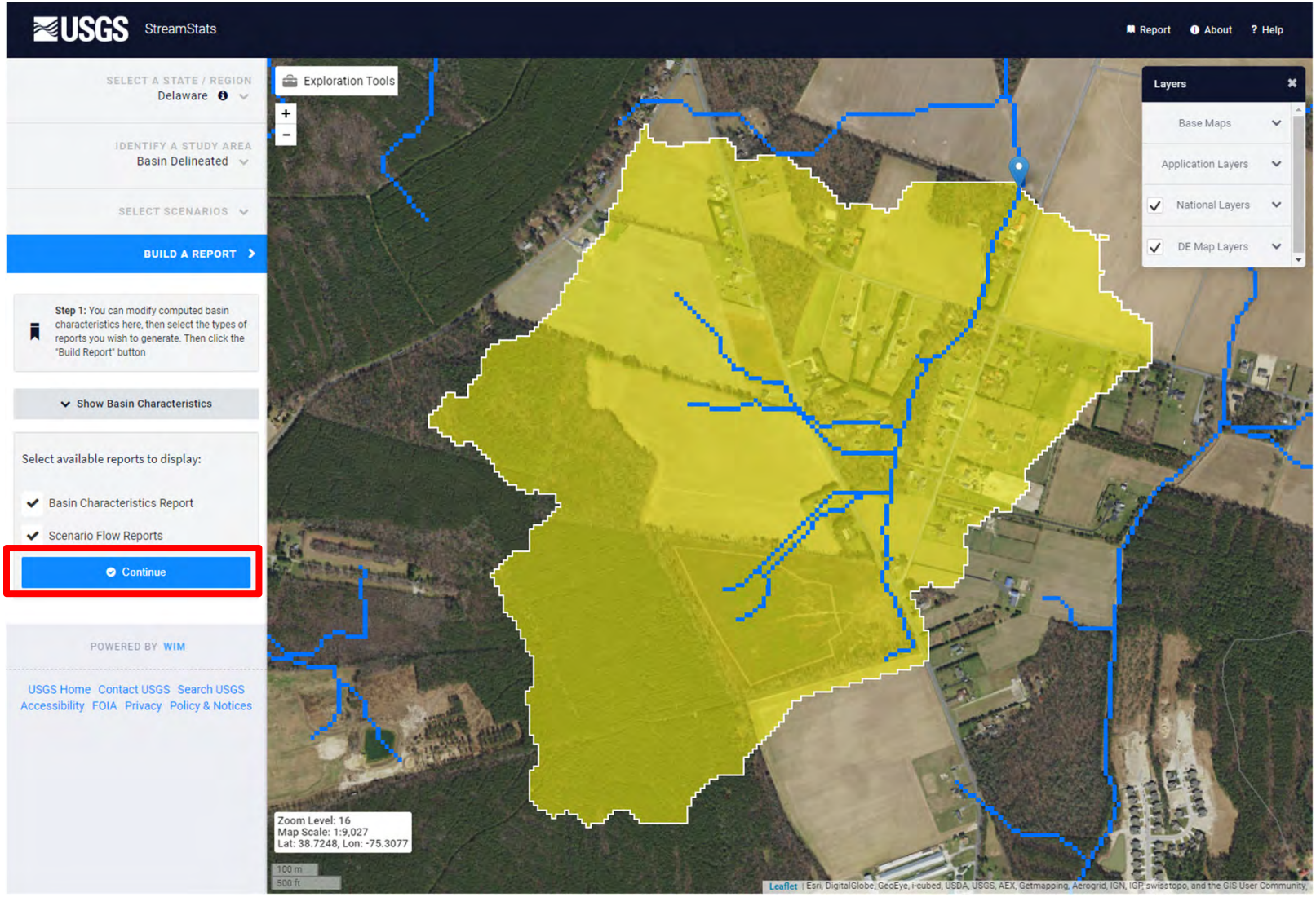
Step 1: Hydrograph Calibration
1d – Generate Basin Characteristics Report



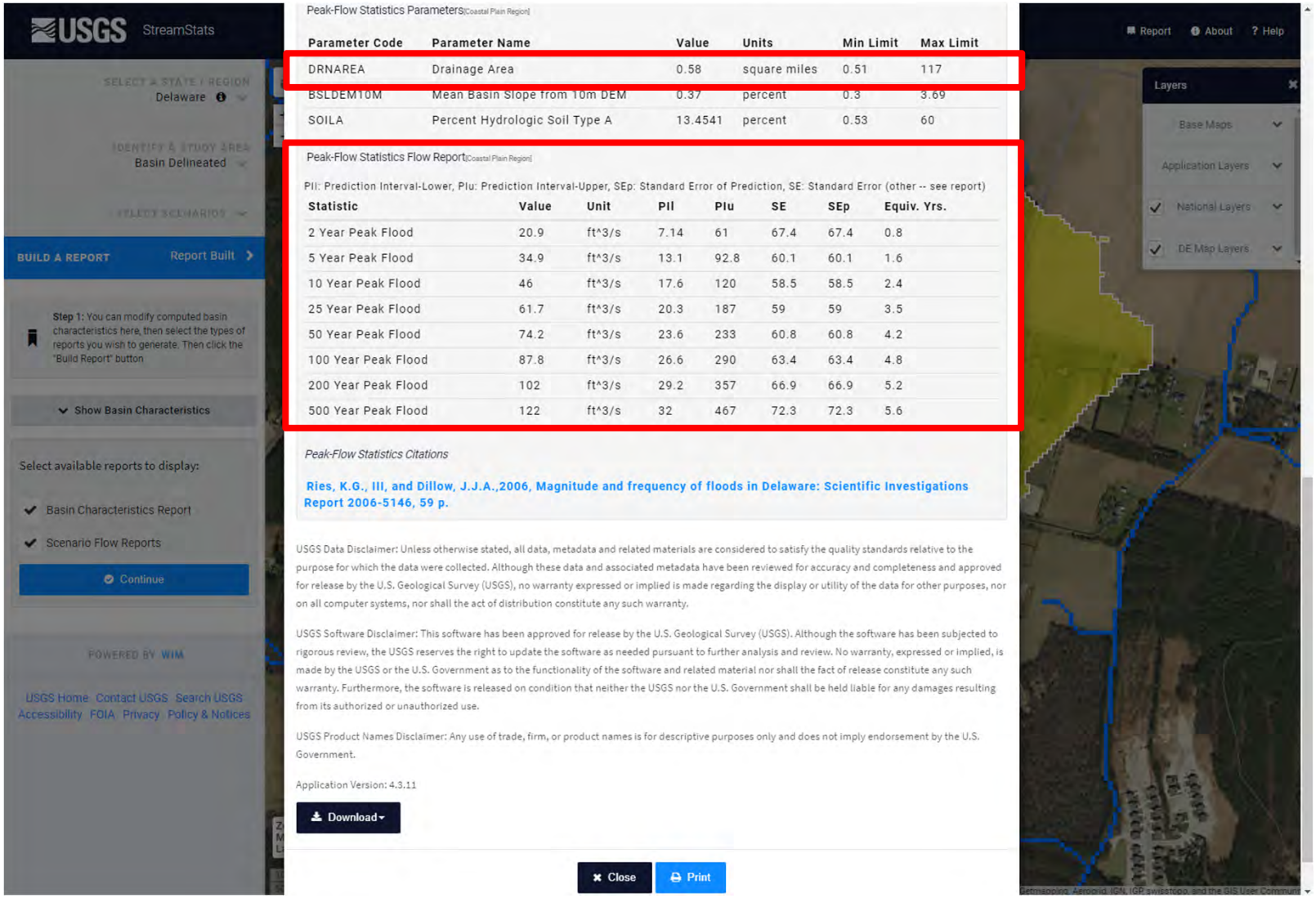
Step 1: Hydrograph Calibration
1d – Generate Basin Characteristics Report



Step 1: Hydrograph Calibration
1d – Generate Basin Characteristics Report



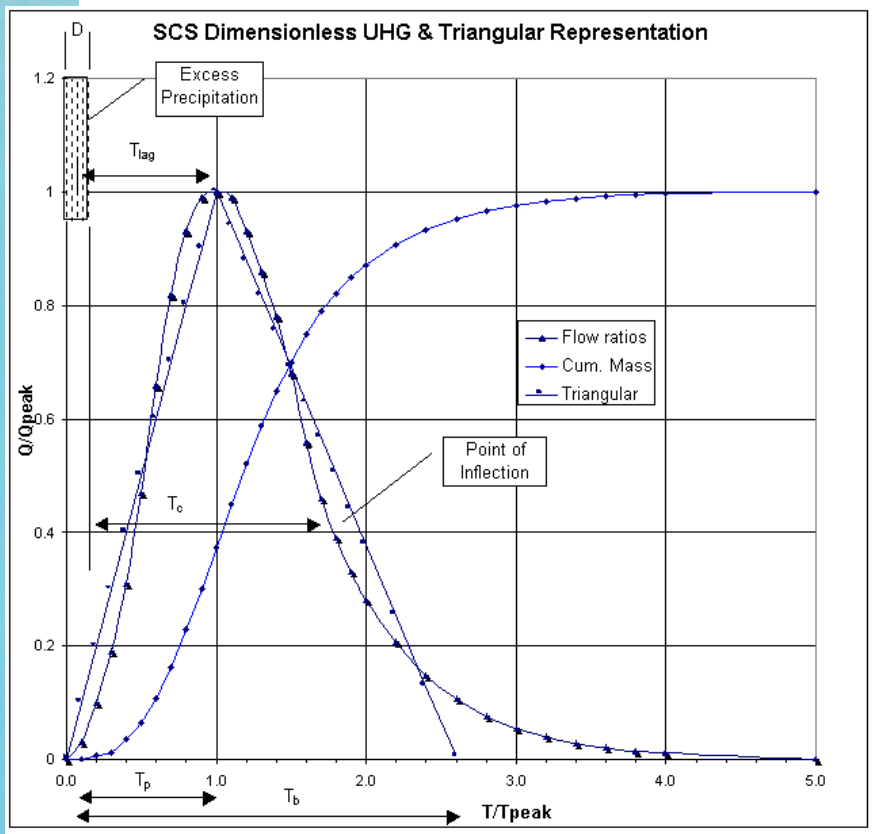
Step 1: Hydrograph Calibration
1d – Generate Basin Characteristics Report



Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	0.58	square miles	0.51	117
BSLDEM10M	Mean Basin Slope from 10m DEM	0.37	percent	0.3	3.69
SOILA	Percent Hydrologic Soil Type A	13.4541	percent	0.53	60

Statistic	Value	Unit	PIl	Plu	SE	SEp	Equiv. Yrs.
2 Year Peak Flood	20.9	ft^3/s	7.14	61	67.4	67.4	0.8
5 Year Peak Flood	34.9	ft^3/s	13.1	92.8	60.1	60.1	1.6
10 Year Peak Flood	46	ft^3/s	17.6	120	58.5	58.5	2.4
25 Year Peak Flood	61.7	ft^3/s	20.3	187	59	59	3.5
50 Year Peak Flood	74.2	ft^3/s	23.6	233	60.8	60.8	4.2
100 Year Peak Flood	87.8	ft^3/s	26.6	290	63.4	63.4	4.8
200 Year Peak Flood	102	ft^3/s	29.2	357	66.9	66.9	5.2
500 Year Peak Flood	122	ft^3/s	32	467	72.3	72.3	5.6

Step 1: Hydrograph Calibration



- 3 Parameters Needed
  - Peak discharge (q_p)
    - StreamStats
  - Time of concentration (T_c)

Step 1: Hydrograph Calibration
1e – Estimate watershed Tc

APPENDIX 6
REGRESSION EQUATIONS FOR ESTIMATING THE TIME OF CONCENTRATION

Step 1: Hydrograph Calibration
1e – Estimate watershed Tc

$$T_c = 0.133(CL^{.475})(SL^{-.187})(101-FOR)^{-.144}(101-IA)^{.861}(ST+1)^{.154}(10^{.19AP})(10^{.366CP})*$$

Where:

Tc = time of concentration (hrs)
CL = channel length (mi)
SL = channel slope (ft/mi)
FOR = forest cover (%)
IA = impervious area (%)
ST = lakes & ponds in watershed (%)
AP = 1 if Appalachian Plateau, 0 otherwise
CP = 1 if Coastal Plain, 0 otherwise
AP and CP = 0 if Piedmont Region

**Hydrologic Panel Report, Appendix 6, Eq. 1*

Step 1: Hydrograph Calibration
1e – Estimate watershed Tc

Table A6-3: Upper and lower limits for watershed characteristics for the time of concentration regression equation for each hydrologic region.

Region	Variable	Upper limit	Lower limit
Appalachian Plateau	Drainage area (mi^2)	295	1.6
Appalachian Plateau	Channel length (mi)	40.8	2.1
Appalachian Plateau	Channel slope (ft/mi)	195	6.1
Appalachian Plateau	Storage (%)	3.2	0.0
Appalachian Plateau	Forest cover (%)	89	54
Appalachian Plateau	Impervious area (%)	1.25	0.0
Piedmont	Drainage area (mi^2)	494	2.1
Piedmont	Channel length (mi)	70	2.2
Piedmont	Channel slope (ft/mi)	336	11
Piedmont	Storage (%)	1.16	0.0
Piedmont	Forest cover (%)	92	2.0
Piedmont	Impervious area (%)	41	0.0
Coastal Plain	Drainage area (mi^2)	113	2.0
Coastal Plain	Channel length (mi)	18.3	2.0
Coastal Plain	Channel slope (ft/mi)	41.8	1.5
Coastal Plain	Storage (%)	26.0	0.0
Coastal Plain	Forest cover (%)	79	5.0
Coastal Plain	Impervious area (%)	35	0.0

In summary, Equation 1 is based on estimates of T_c computed from rainfall-runoff events at 78 gaging stations in Maryland. The computed values of TC tend to be larger than similar estimates based on SCS (1986) procedures. However, Equation 1 can be used to evaluate the reasonableness of T_c estimates from SCS (1986) procedures. Further research is needed to improve the estimation of T_c in Maryland that would ultimately provide for more accurate estimates of design discharges from hydrological models such as TR-20.

Step 1: Hydrograph Calibration
1e – Estimate watershed Tc

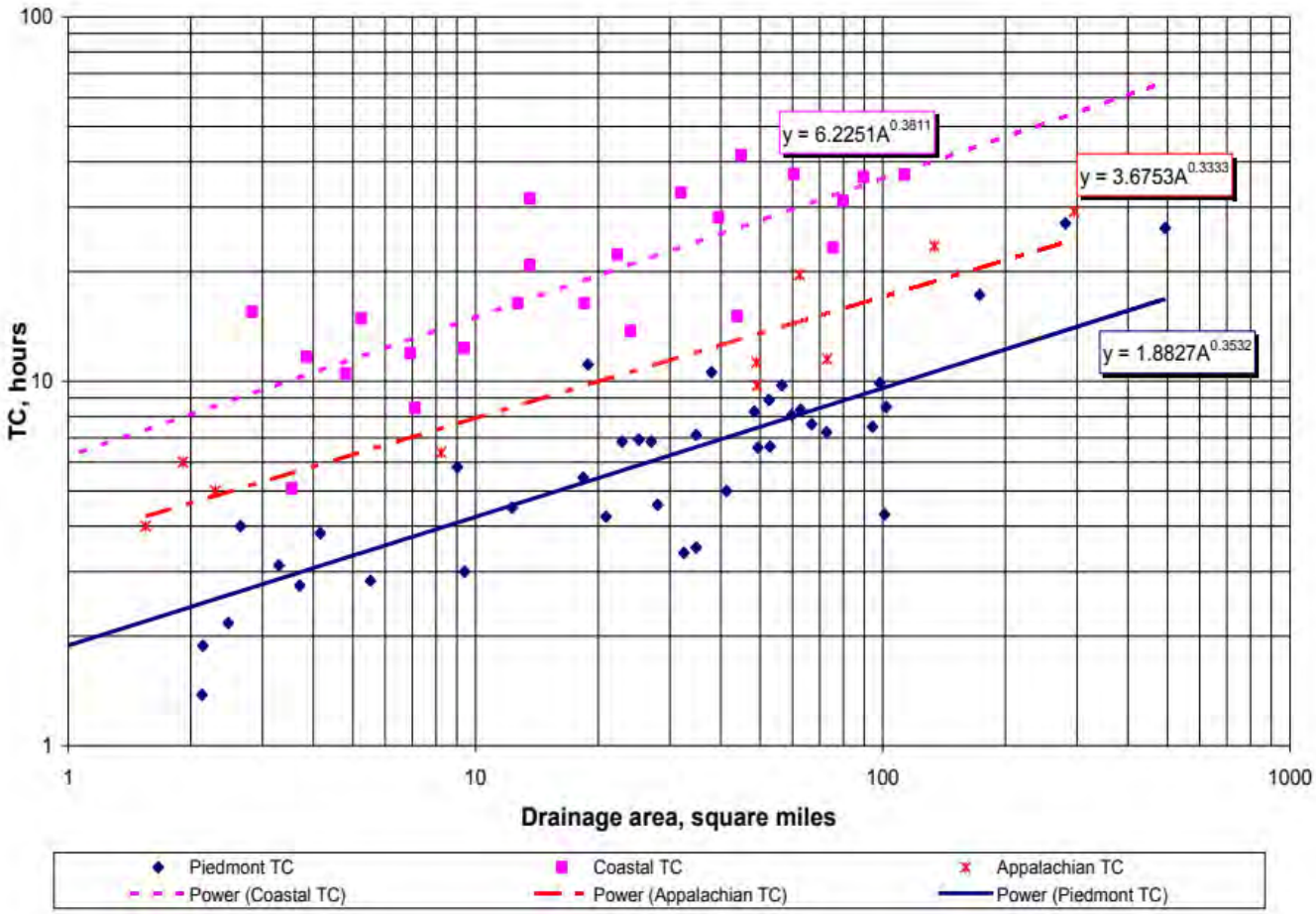


Figure 4-2: Time of concentration versus drainage area in Maryland.

Step 1: Hydrograph Calibration
1e – Estimate watershed Tc

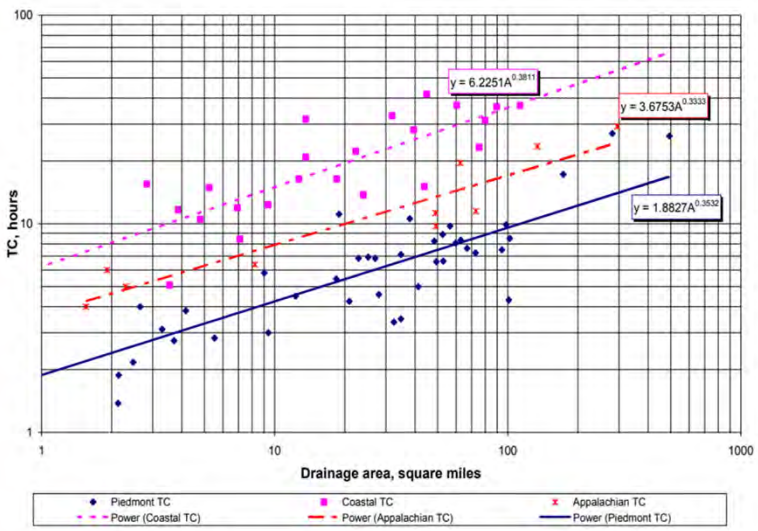


Figure 4-2: Time of concentration versus drainage area in Maryland.

- Coastal Plain

  $y = 6.2251A^{0.3811}$

- Piedmont

  $y = 1.8827A^{0.3532}$

Where:

y = Tc (hrs)

A = Drainage Area (sq. mi.)*

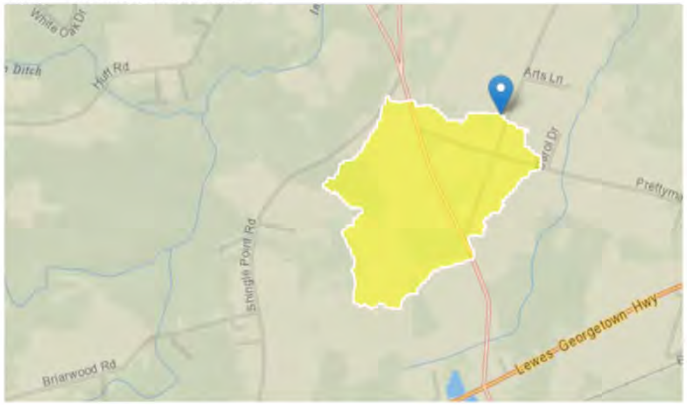
Step 1: Hydrograph Calibration

1f– Determine Tc method based upon watershed size

2/27/2020 StreamStats

StreamStats Report

Region ID: DE
Workspace ID: DE20200227182231100000
Clicked Point (Latitude, Longitude): 38.73247, -75.31530
Time: 2020-02-27 13:22:46 -0500



Basin Characteristics

Parameter Code	Parameter Description	Value	Unit
DRNAREA	Area that drains to a point on a stream	0.58	square miles
BSLDEM10M	Mean basin slope computed from 10 m DEM	0.37	percent
SOILA	Percentage of area of Hydrologic Soil Type A	13.4541	percent

Peak-Flow Statistics Parameters[Coastal Plain Region]

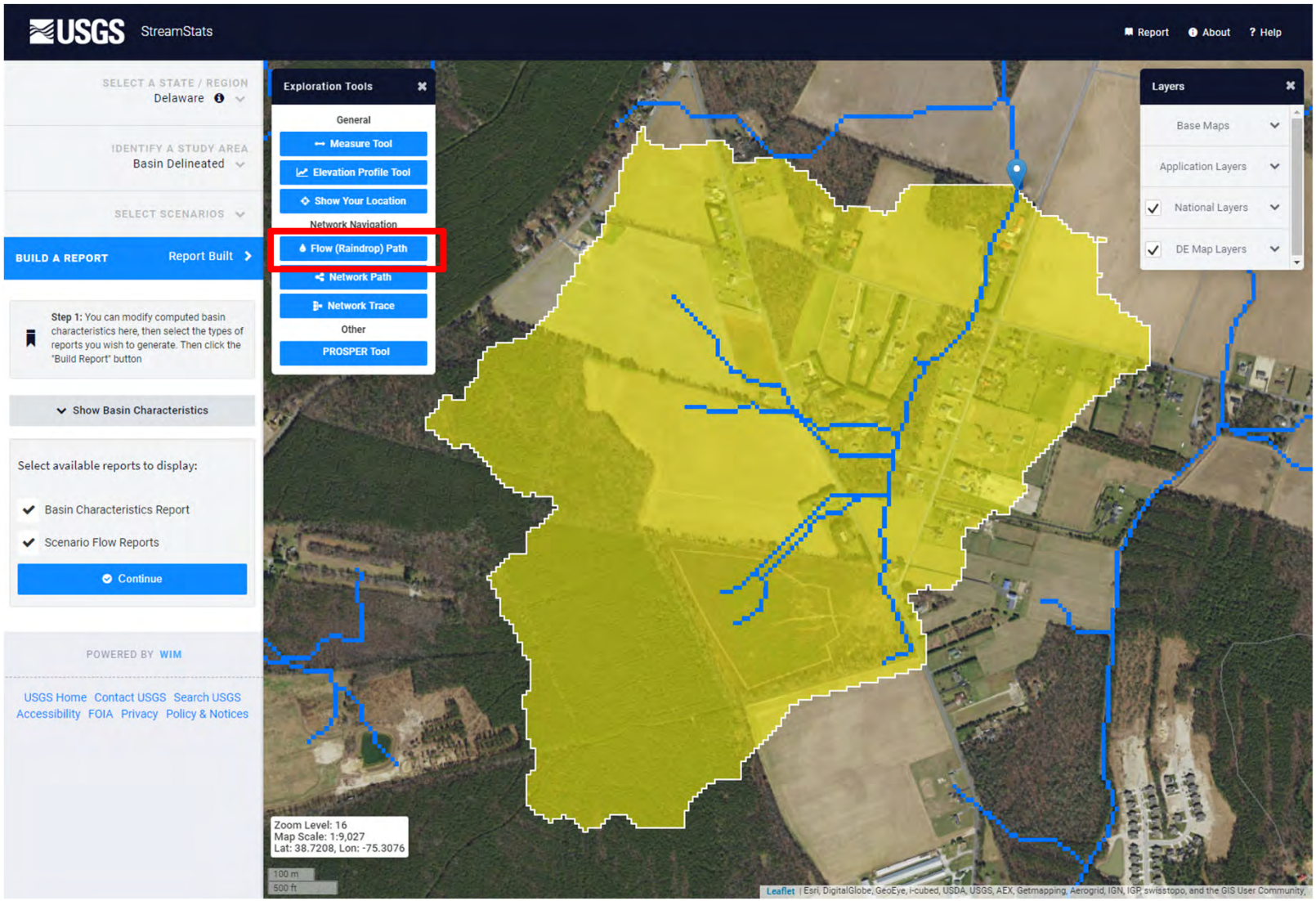
Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit

https://streamstats.usgs.gov/ss/ 1/3

- StreamStats Report
  - DA = 0.58 sq. mi.
  - 0.58 sq. mi. < 2.0 sq. mi. Lower Limit for Tc Regression Equation
  - Must use NRCS Velocity Method

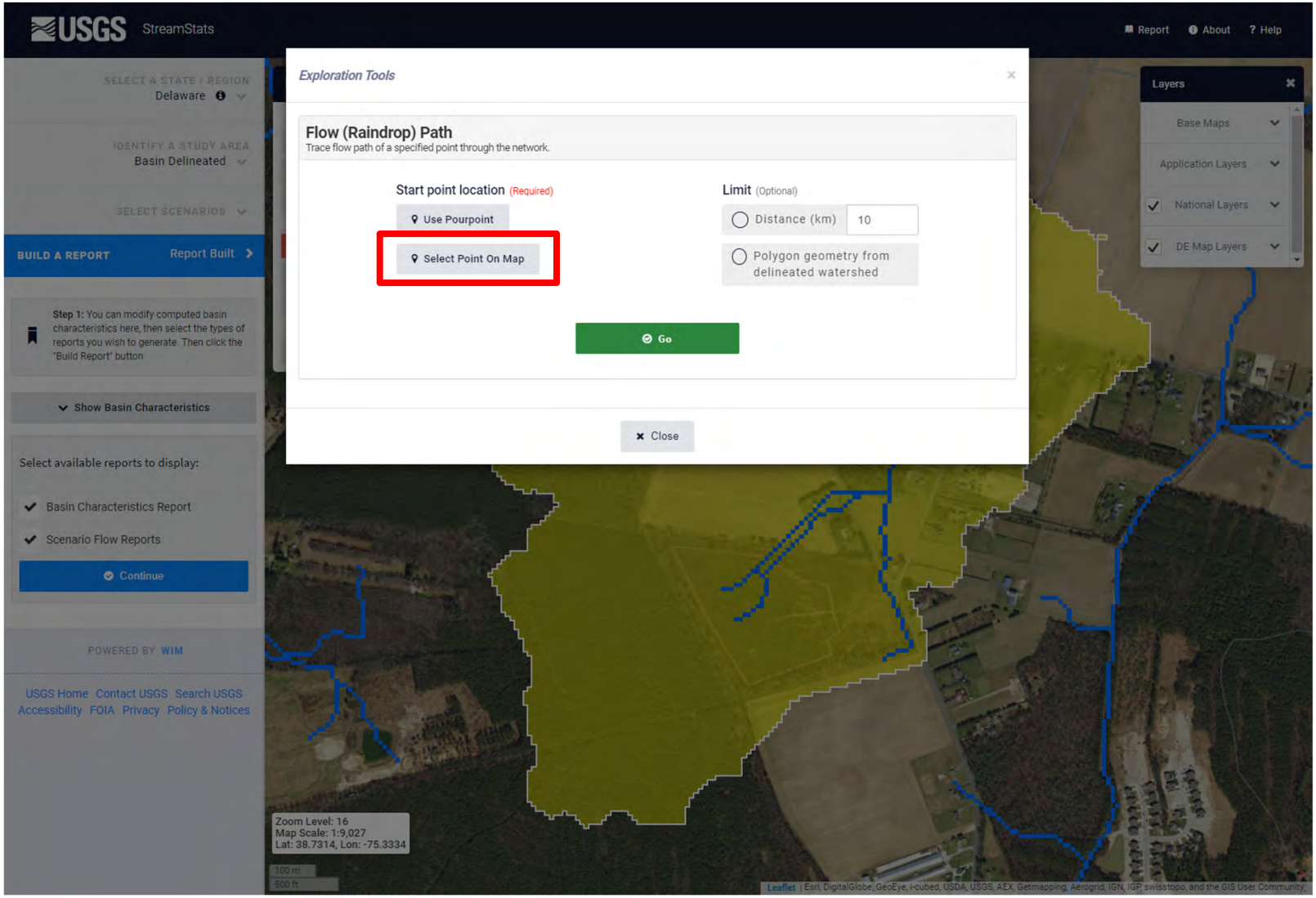
Step 1: Hydrograph Calibration

1g– Use StreamStats to generate flow path



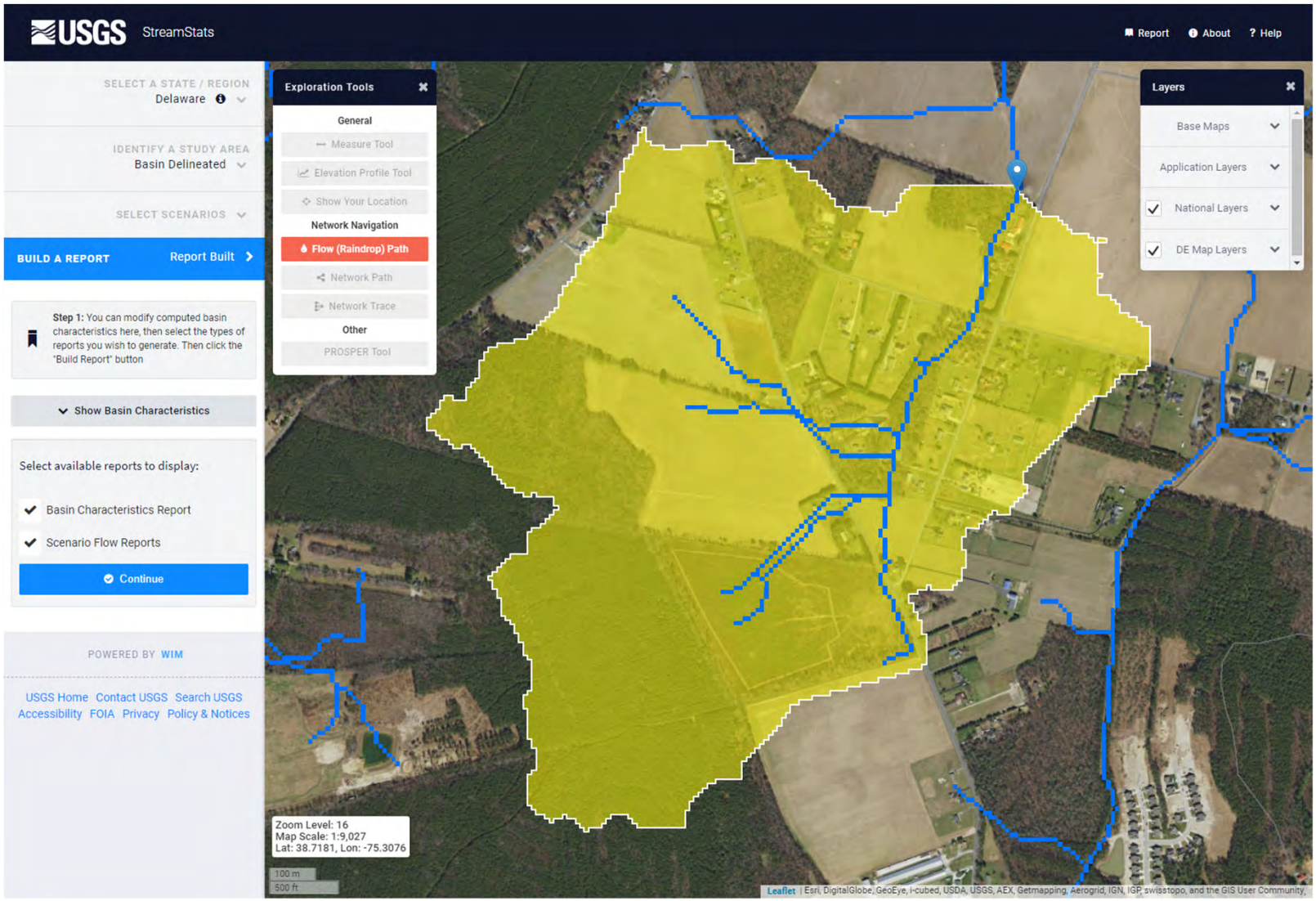
Step 1: Hydrograph Calibration

1g– Use StreamStats to generate flow path



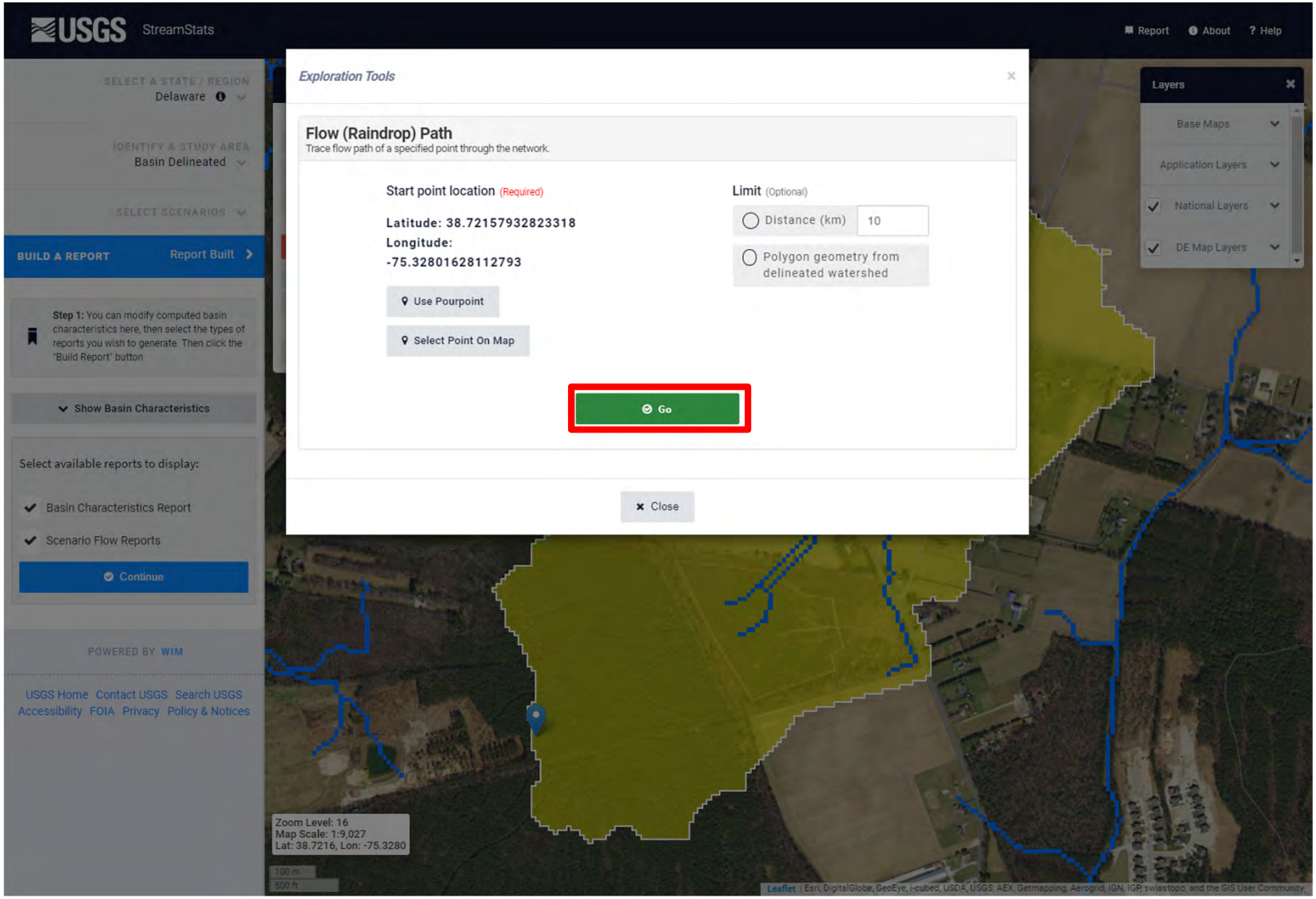
Step 1: Hydrograph Calibration

1g– Use StreamStats to generate flow path



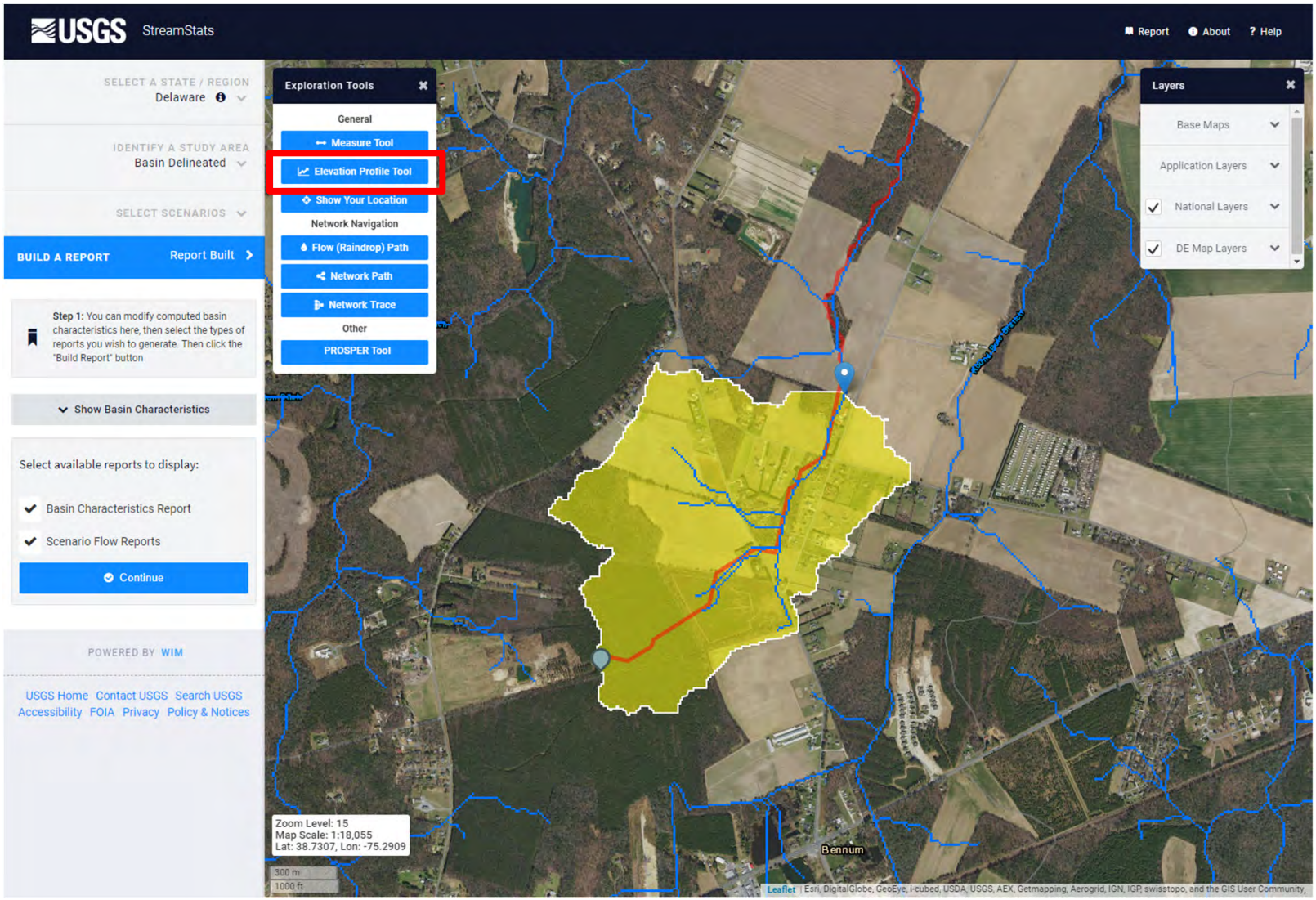
Step 1: Hydrograph Calibration

1g– Use StreamStats to generate flow path



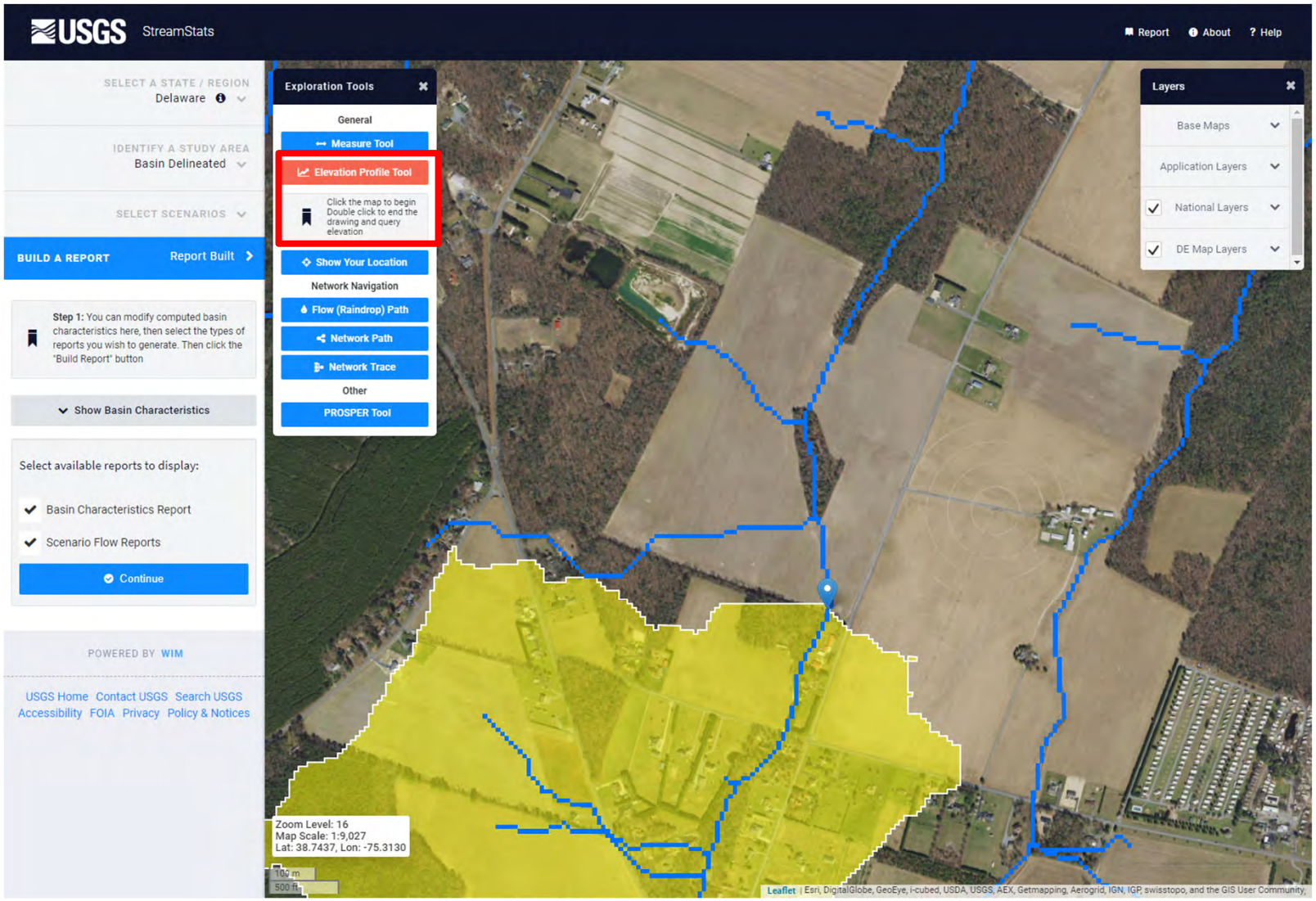
Step 1: Hydrograph Calibration

1g– Use StreamStats to generate flow path



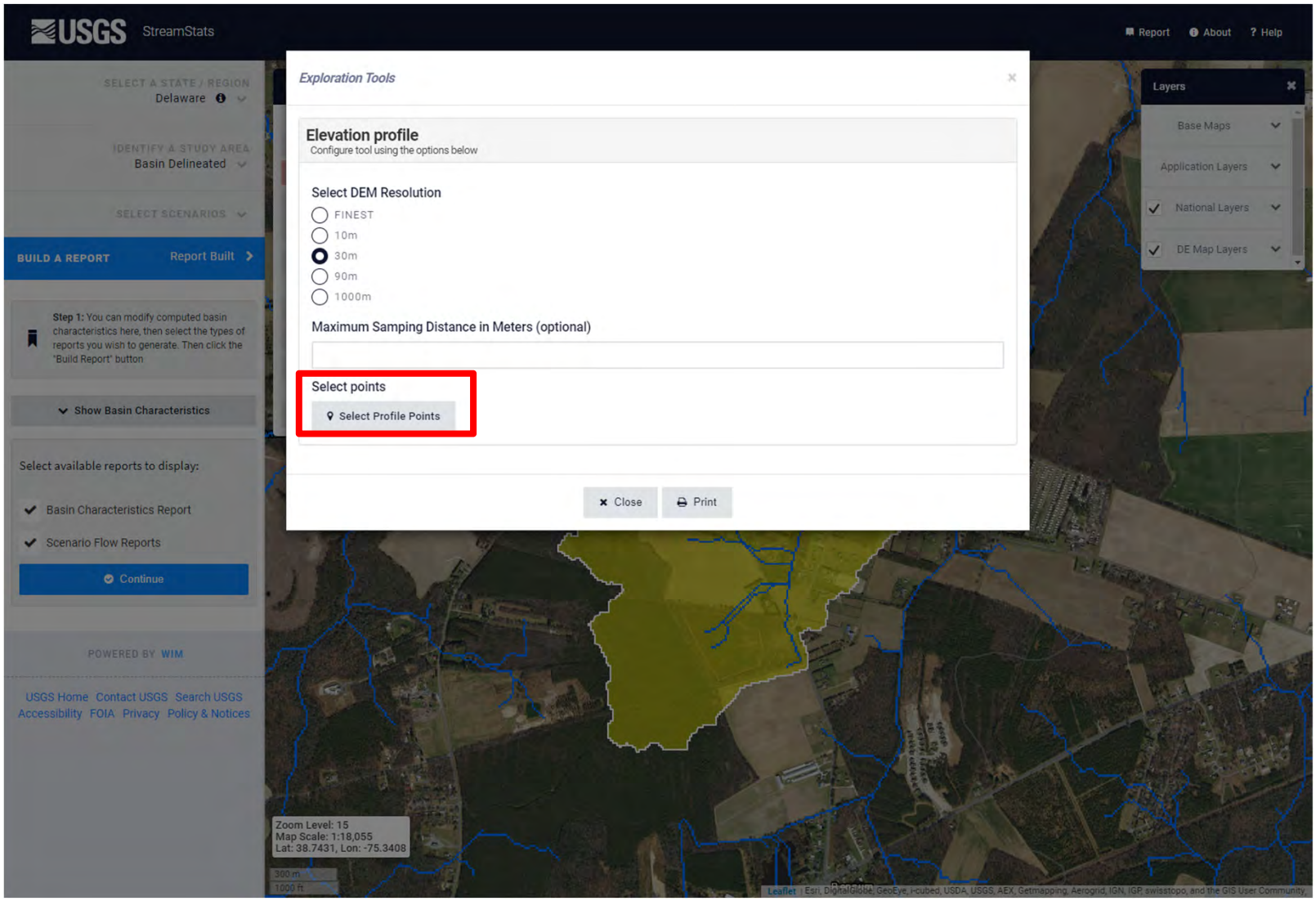
Step 1: Hydrograph Calibration

1h – Estimate slope and distance of flow path



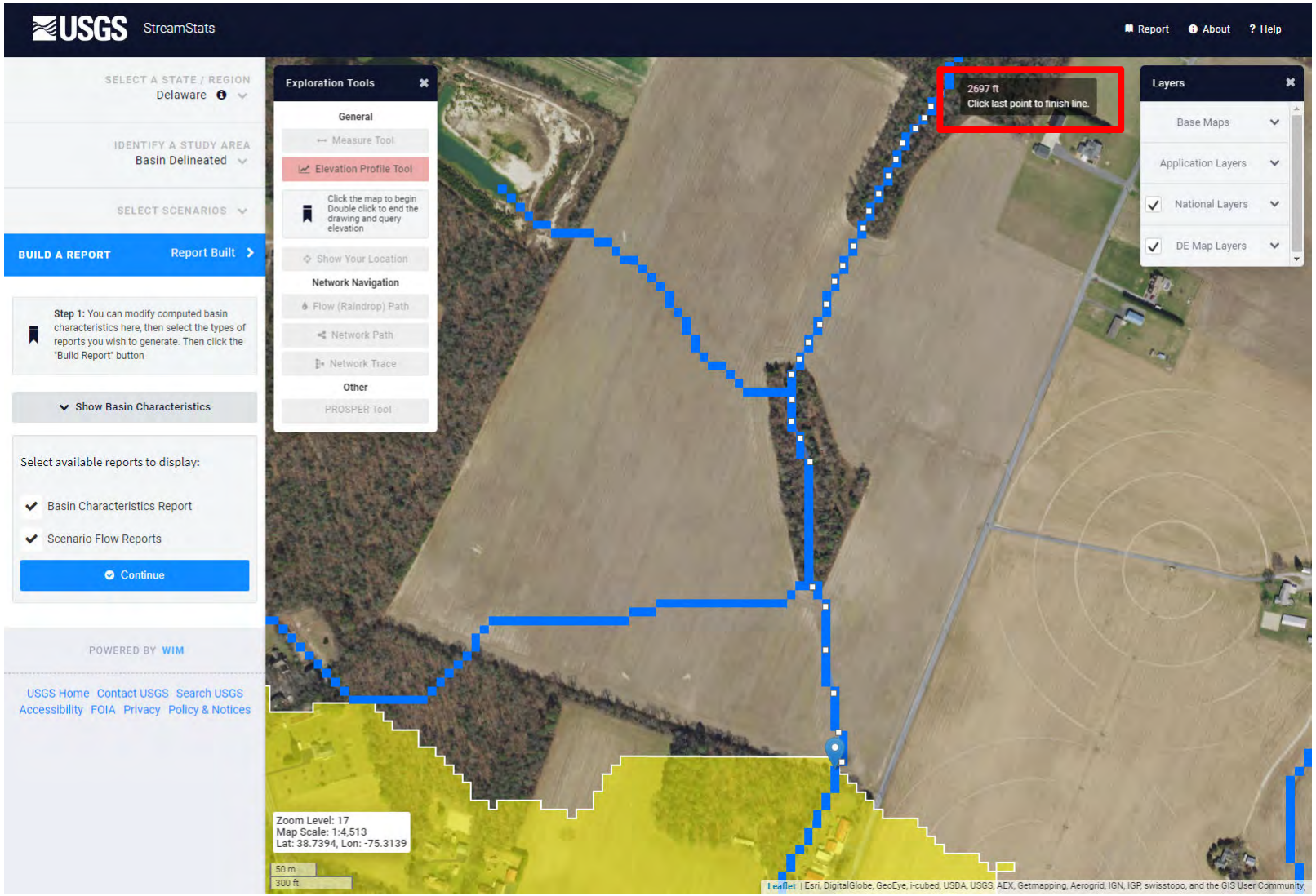
Step 1: Hydrograph Calibration

1h – Estimate slope and distance of flow path



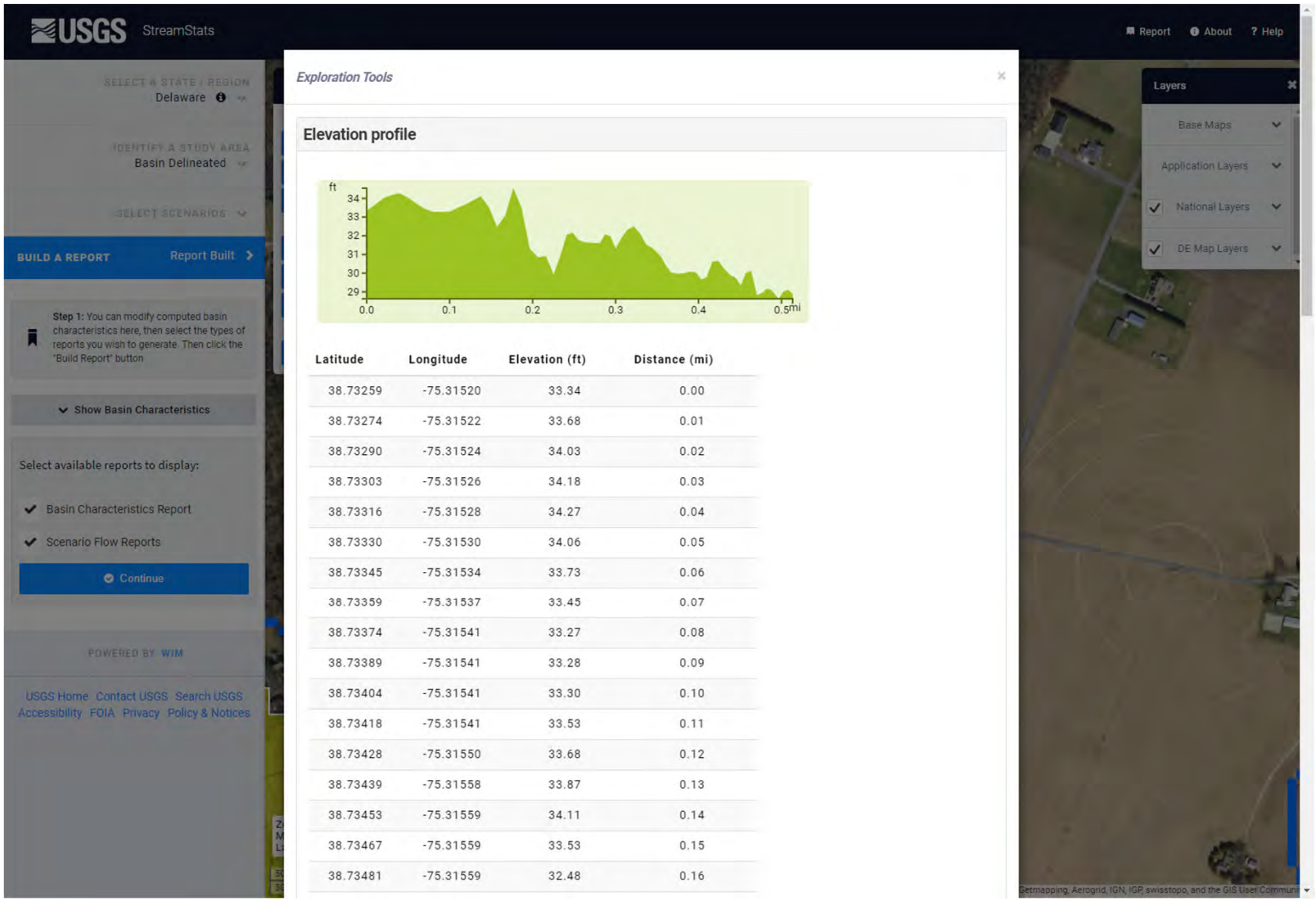
Step 1: Hydrograph Calibration

1h – Estimate slope and distance of flow path



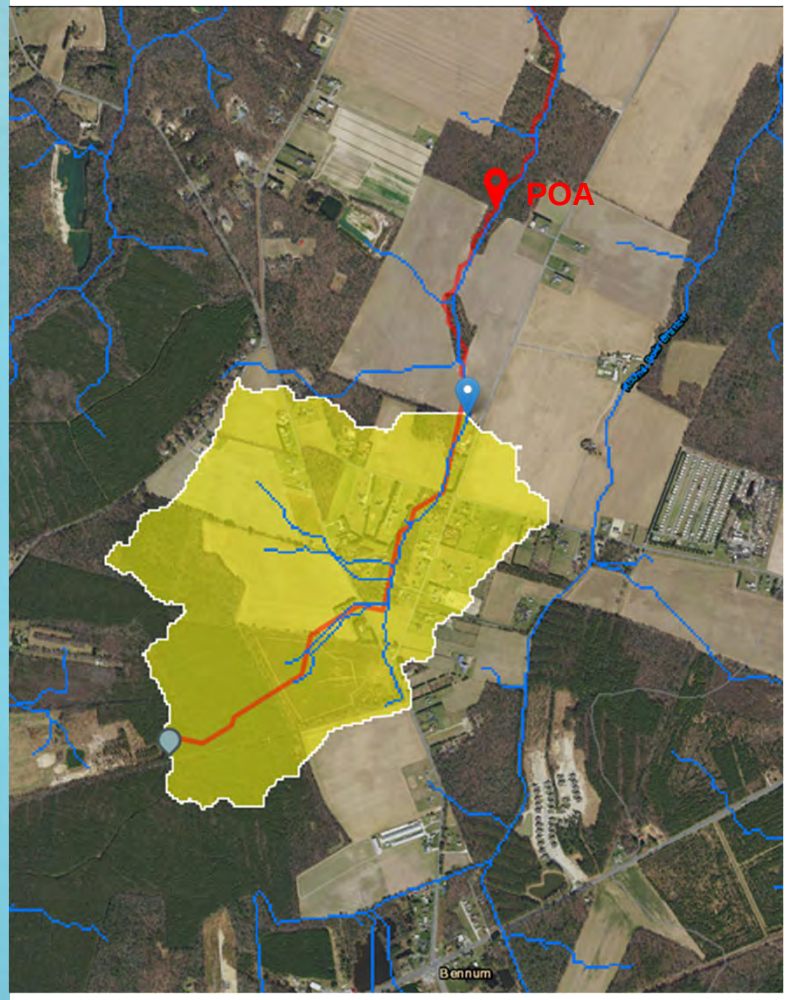
Step 1: Hydrograph Calibration

1h – Estimate slope and distance of flow path



Latitude	Longitude	Elevation (ft)	Distance (mi)
38.73259	-75.31520	33.34	0.00
38.73274	-75.31522	33.68	0.01
38.73290	-75.31524	34.03	0.02
38.73303	-75.31526	34.18	0.03
38.73316	-75.31528	34.27	0.04
38.73330	-75.31530	34.06	0.05
38.73345	-75.31534	33.73	0.06
38.73359	-75.31537	33.45	0.07
38.73374	-75.31541	33.27	0.08
38.73389	-75.31541	33.28	0.09
38.73404	-75.31541	33.30	0.10
38.73418	-75.31541	33.53	0.11
38.73428	-75.31550	33.68	0.12
38.73439	-75.31558	33.87	0.13
38.73453	-75.31559	34.11	0.14
38.73467	-75.31559	33.53	0.15
38.73481	-75.31559	32.48	0.16

Step 1: Hydrograph Calibration
1i – Calculate Tc and Tt



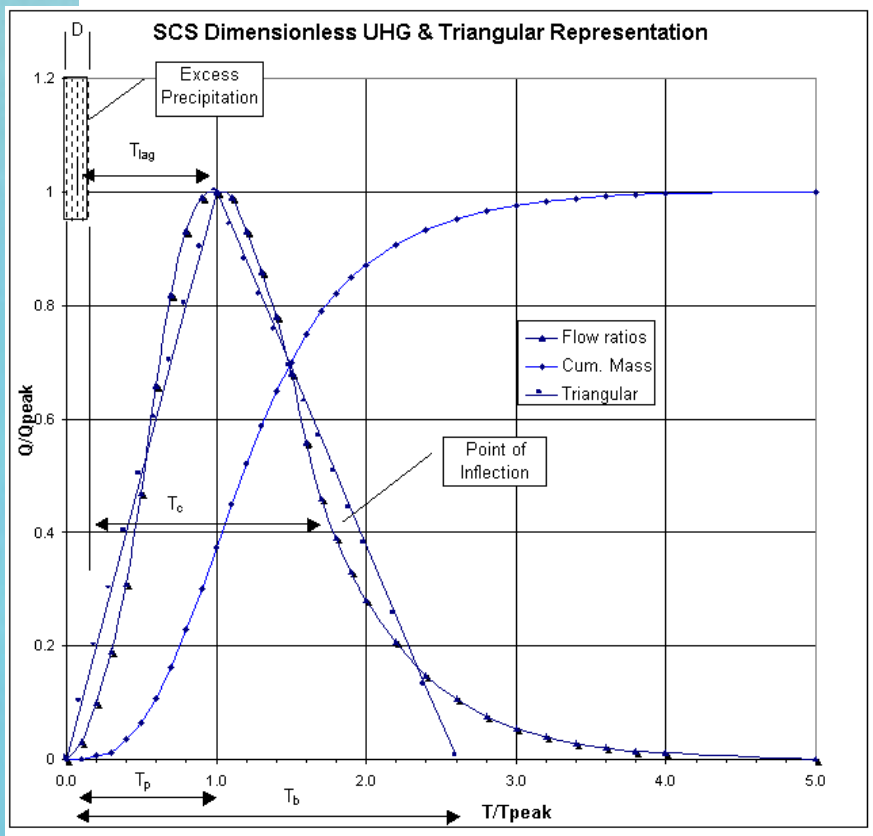
Tc derived from delineated watershed:

- Sheet flow segment
  - 100', woods, dense, 1.0 % slope
- Shallow conc. flow segment
  - 2843', cultivated, 1.0% slope
- Tc = 1.68 hr

Travel Time (Tt) derived from elevation-profile:

- Channel flow segment
  - 2693', 0.17% slope, v = 1.70 fps
- Tt = 0.44 hr

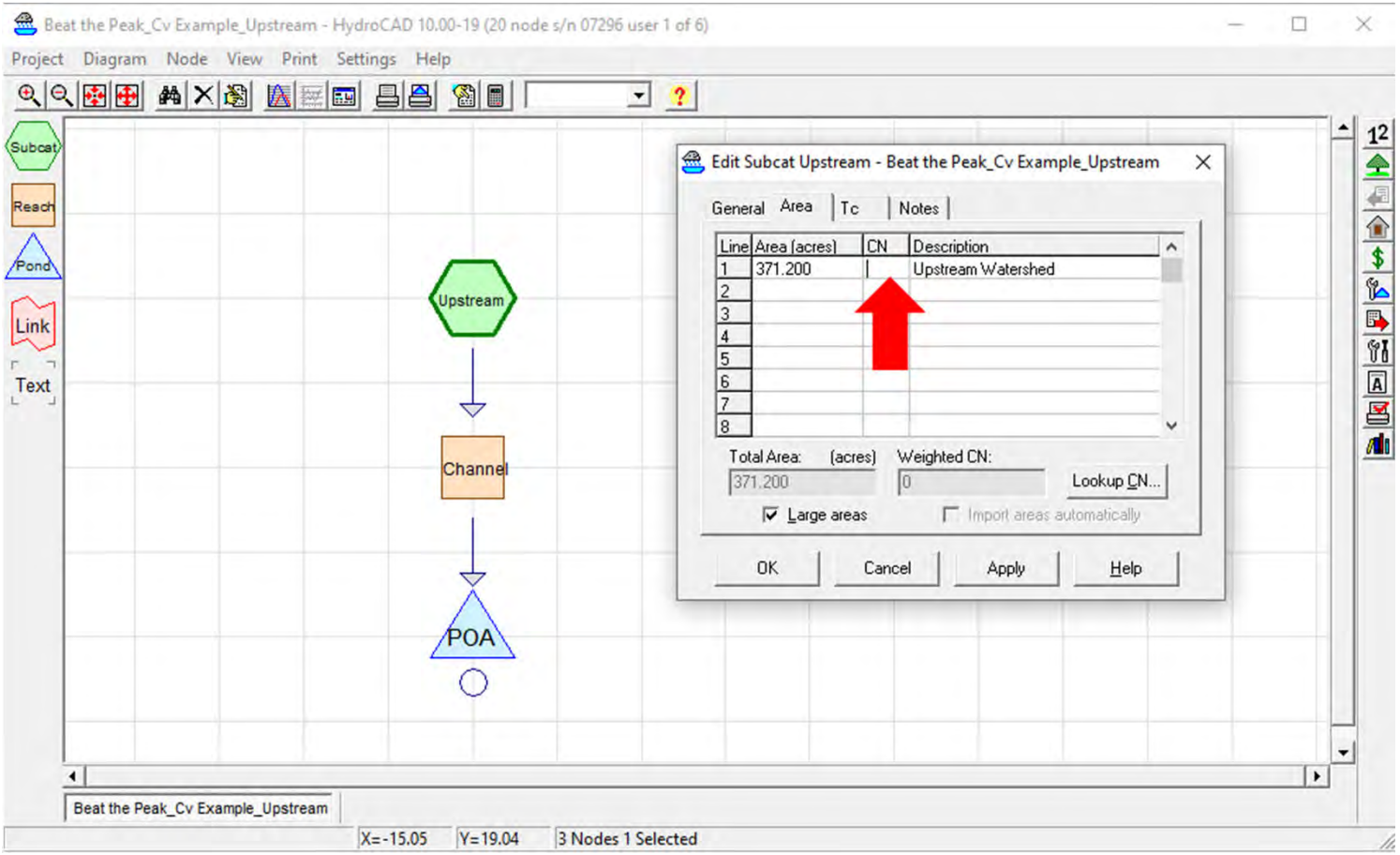
Step 1: Hydrograph Calibration
1j – Estimate runoff volume using RCN as calibration parameter



- 3 Parameters Needed
  - Peak discharge (q_p)
    - StreamStats
  - Time of concentration (T_c)
    - Hydro Panel Report, Fig. 4-2; OR NRCS Velocity Method
  - Runoff volume (Q)
    - RCN

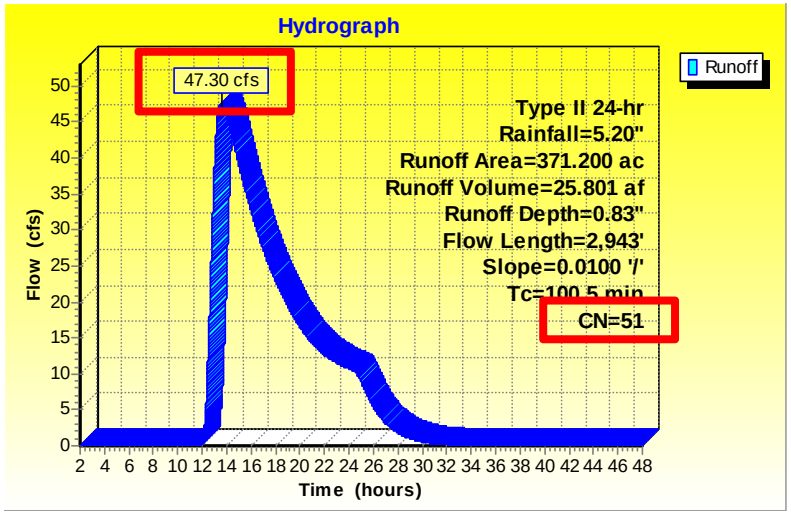
Step 1: Hydrograph Calibration

1j – Estimate runoff volume using RCN as calibration parameter



Step 1: Hydrograph Calibration

1j – Estimate runoff volume using RCN as calibration parameter



Peak-Flow Statistics Flow Report[Coastal Plain Region]

PII: Prediction Interval-Lower, PIu: Prediction Interval-Upper, SEp: Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	PII	PIu	SE	SEp	Equiv. Yrs.
2 Year Peak Flood	20.9	ft^3/s	7.14	61	67.4	67.4	0.8
5 Year Peak Flood	34.9	ft^3/s	13.1	92.8	60.1	60.1	1.6
10 Year Peak Flood	46	ft^3/s	17.6	120	58.5	58.5	2.4
25 Year Peak Flood	61.7	ft^3/s	20.3	187	59	59	3.5
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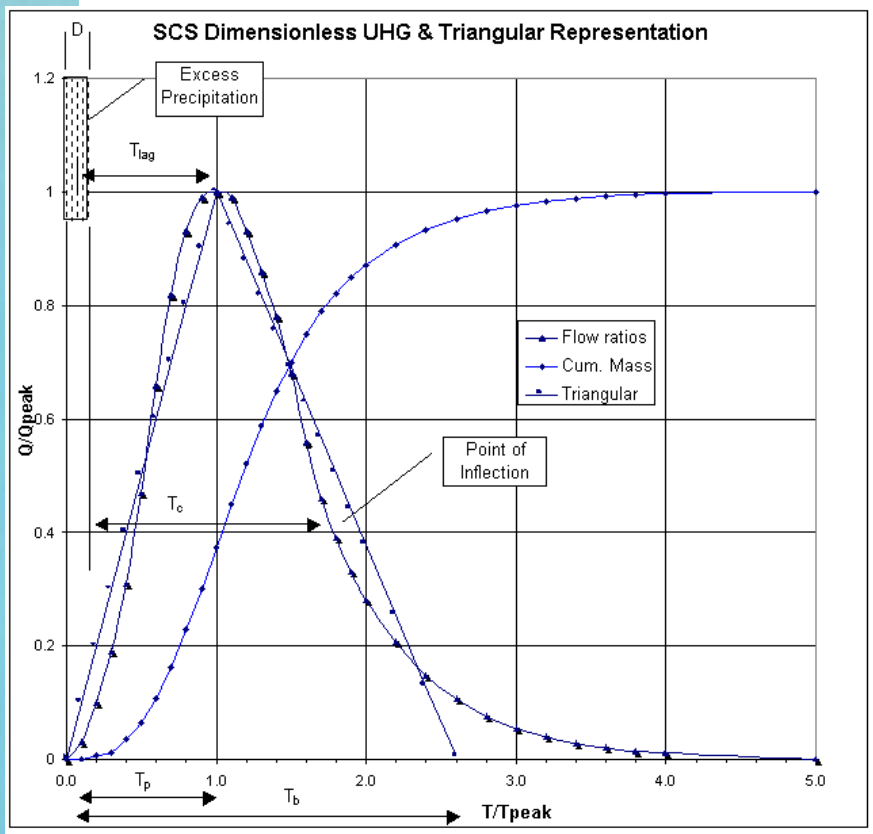
100 Year Peak Flood	87.8	ft^3/s	26.6	290	63.4	63.4	4.8
200 Year Peak Flood	102	ft^3/s	29.2	357	66.9	66.9	5.2
500 Year Peak Flood	122	ft^3/s	32	467	72.3	72.3	5.6

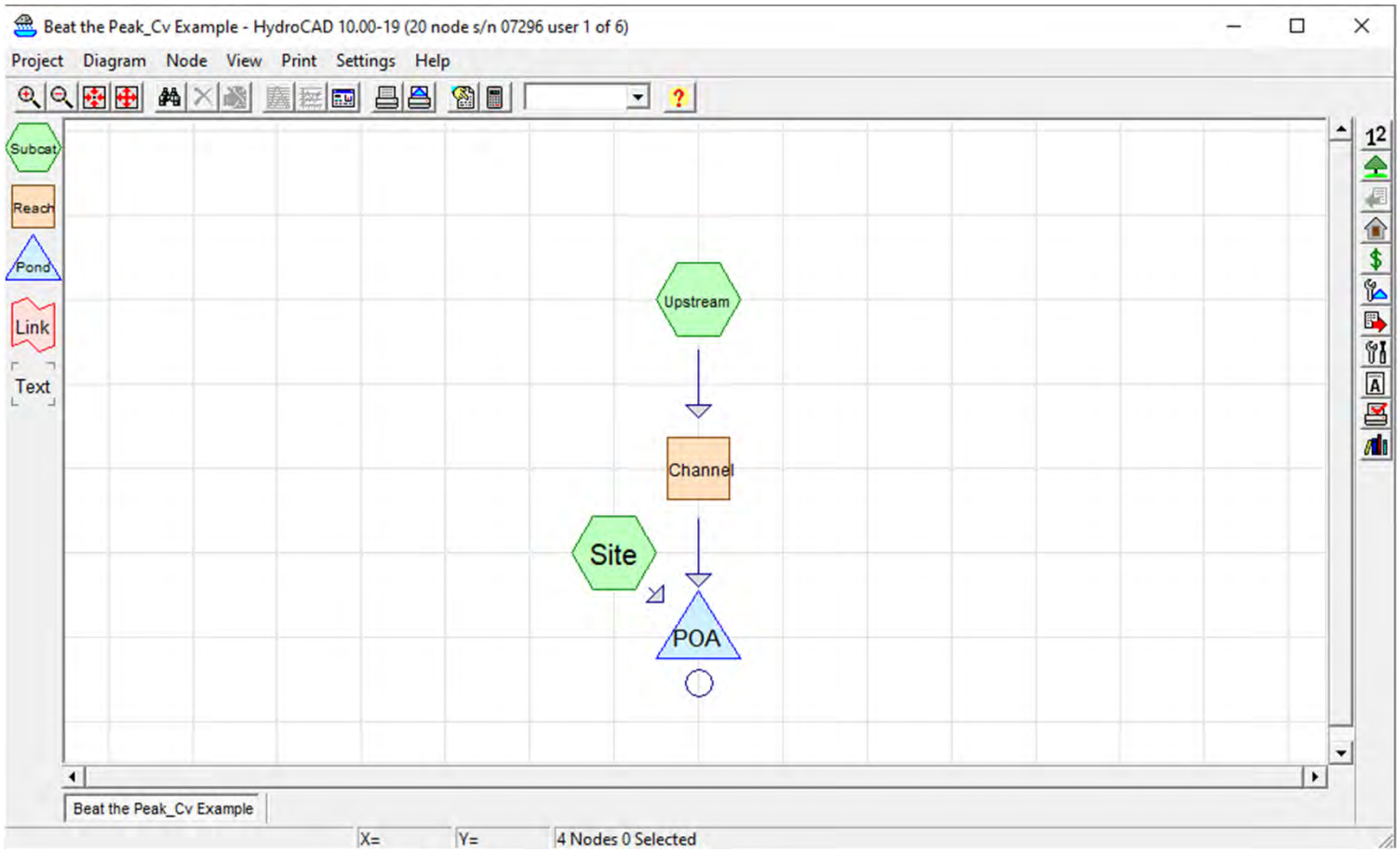
Step 1: Hydrograph Calibration

1j – Estimate runoff volume using RCN as calibration parameter

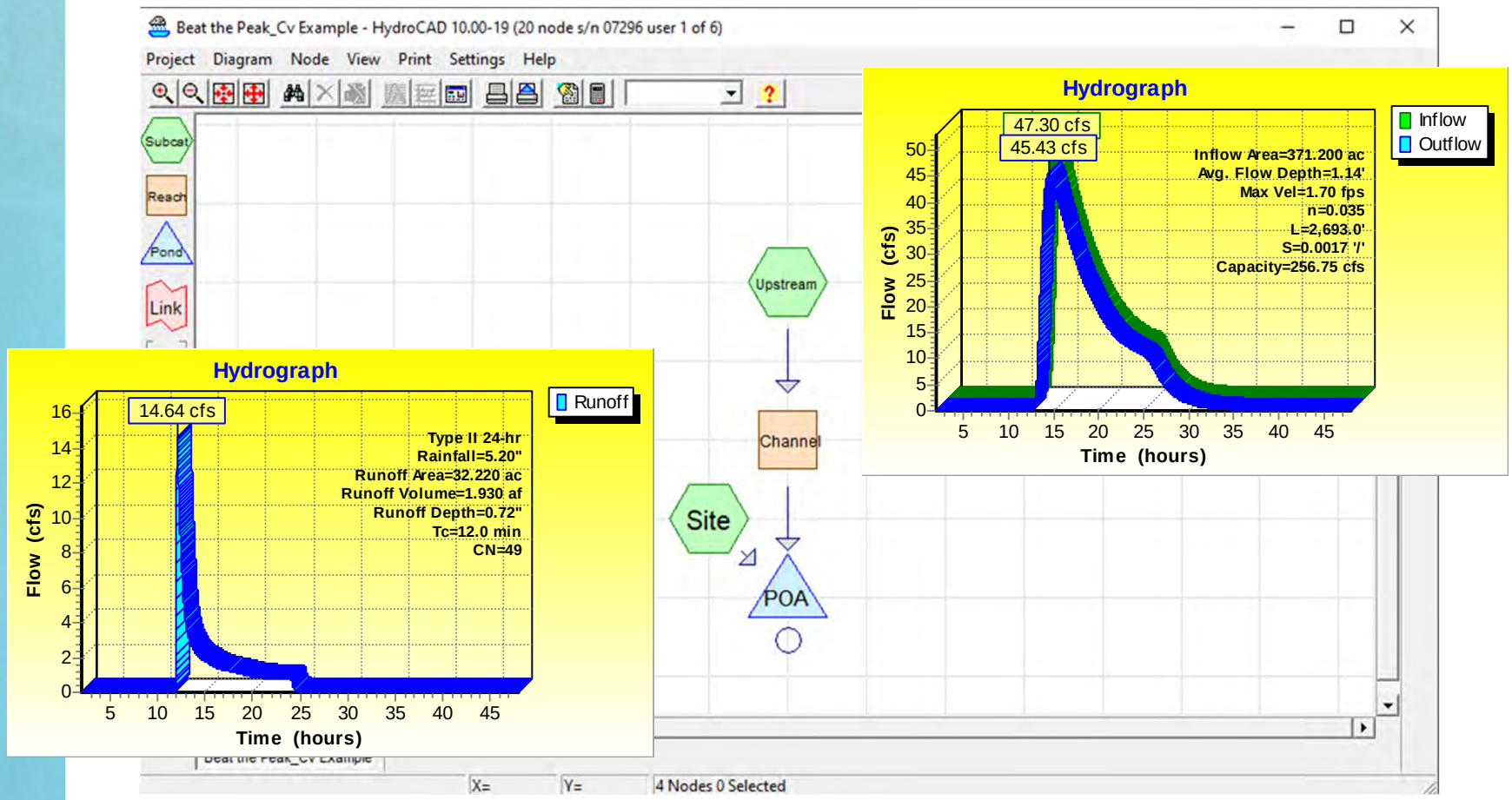


- 3 Parameters Needed
  - Peak discharge (q_p)
    - 47.30 cfs
  - Time of concentration (T_c)
    - Tc = 1.68 hr
    - Tt = 0.44 hr
  - Runoff volume (Q)
    - RCN = 51

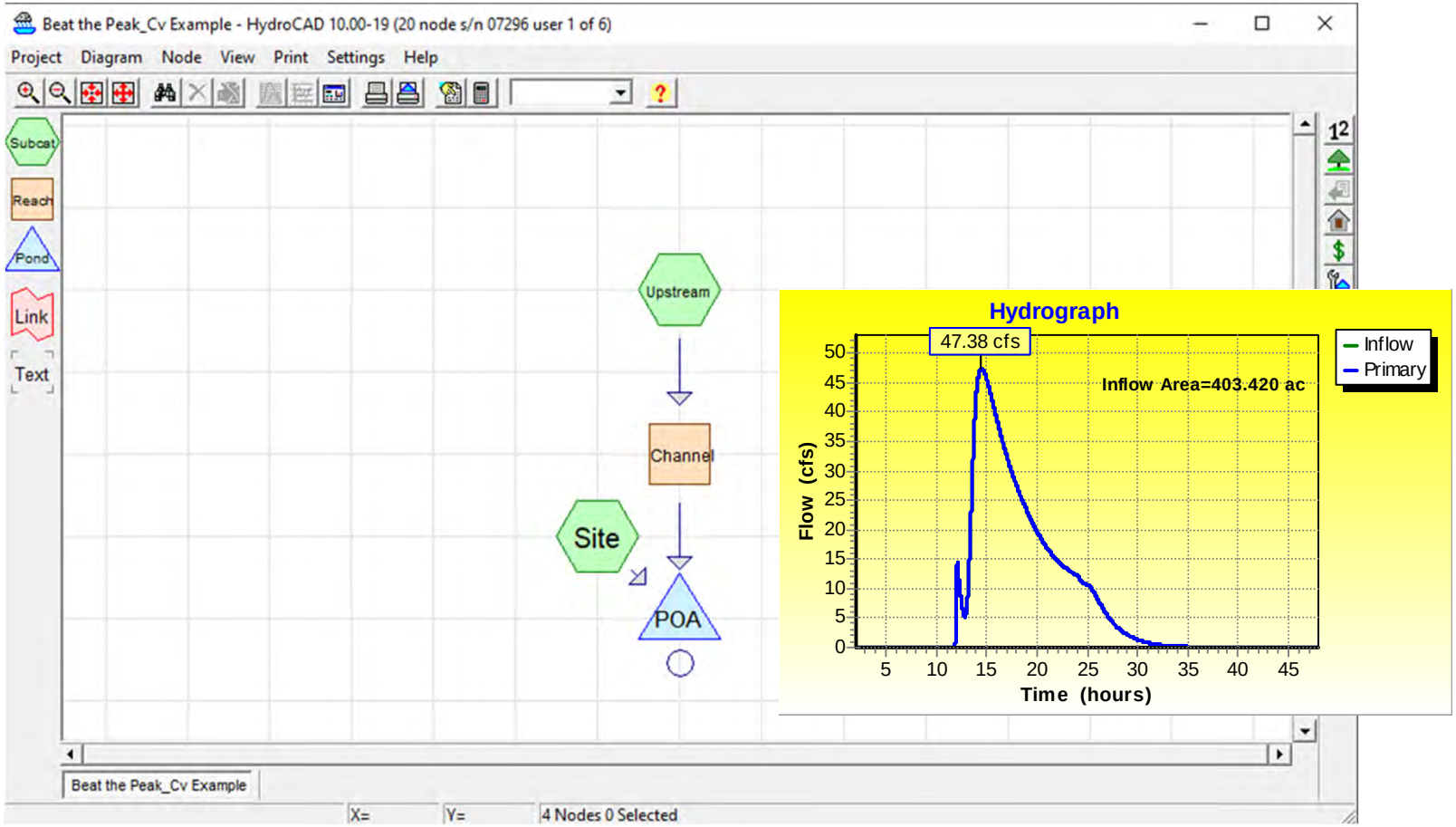
Step 2: Downstream Analysis
2a – Enter data into hydrologic model



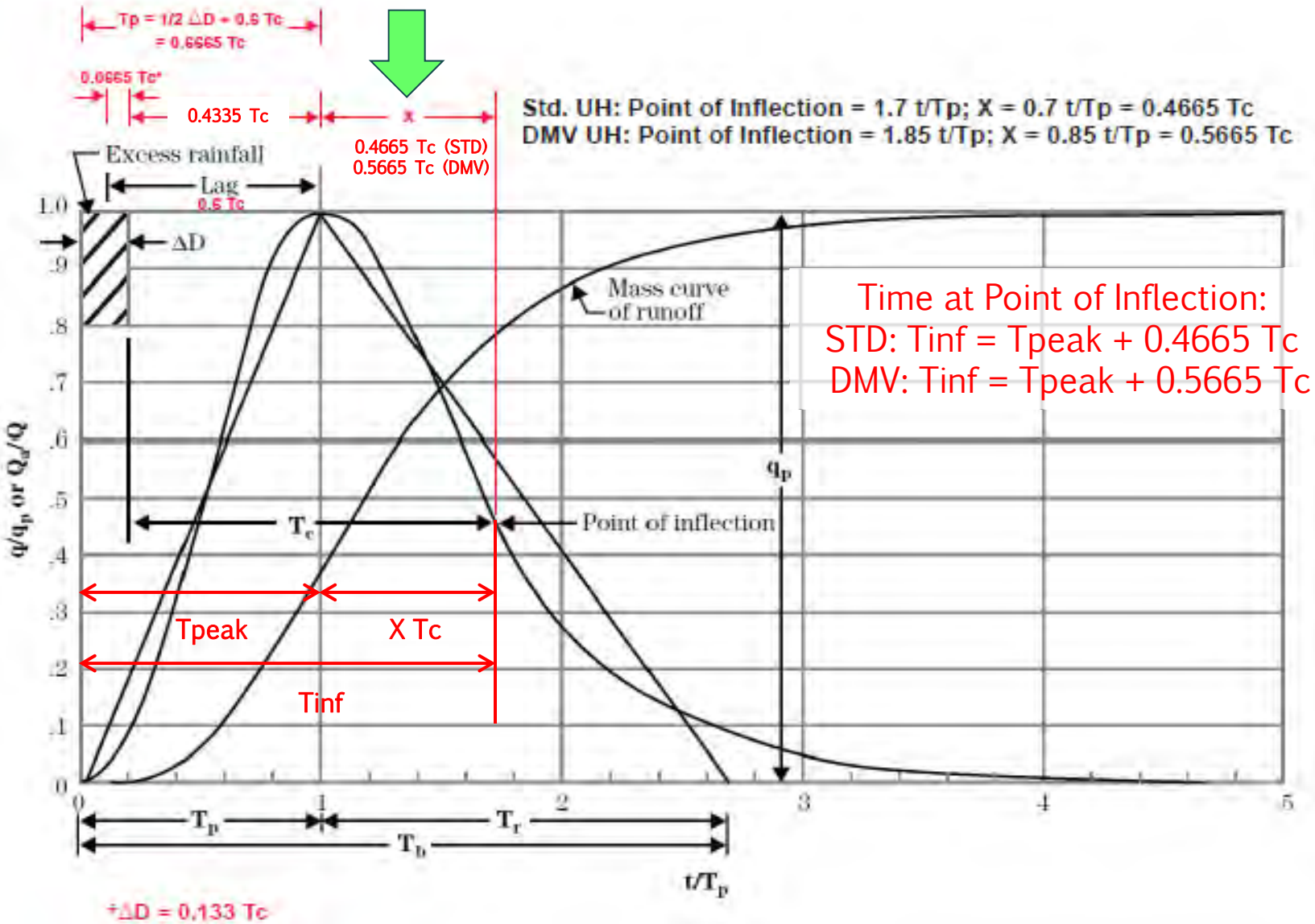
Step 2: Downstream Analysis
2a – Enter data into hydrologic model



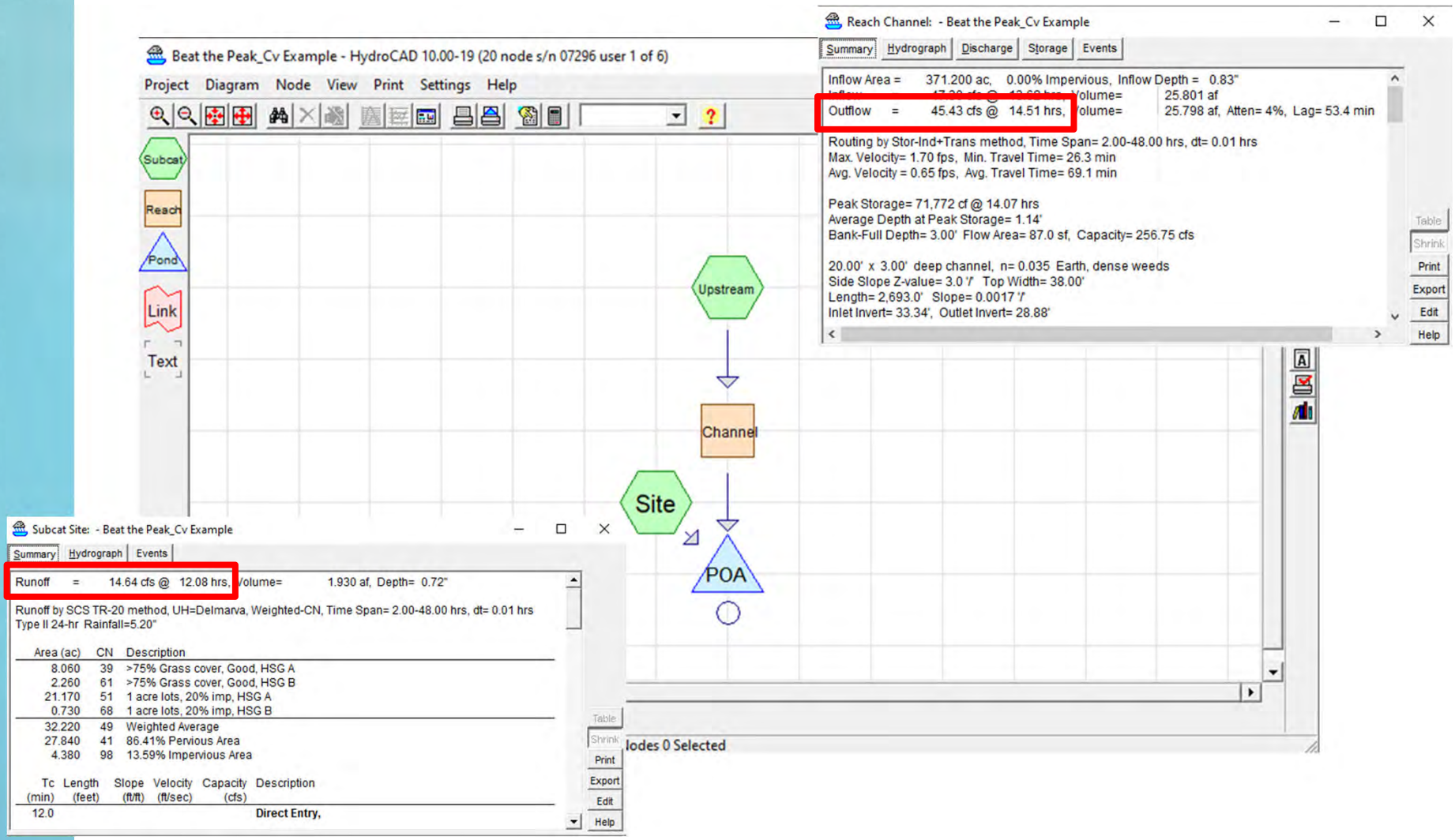
Step 2: Downstream Analysis
2a – Enter data into hydrologic model



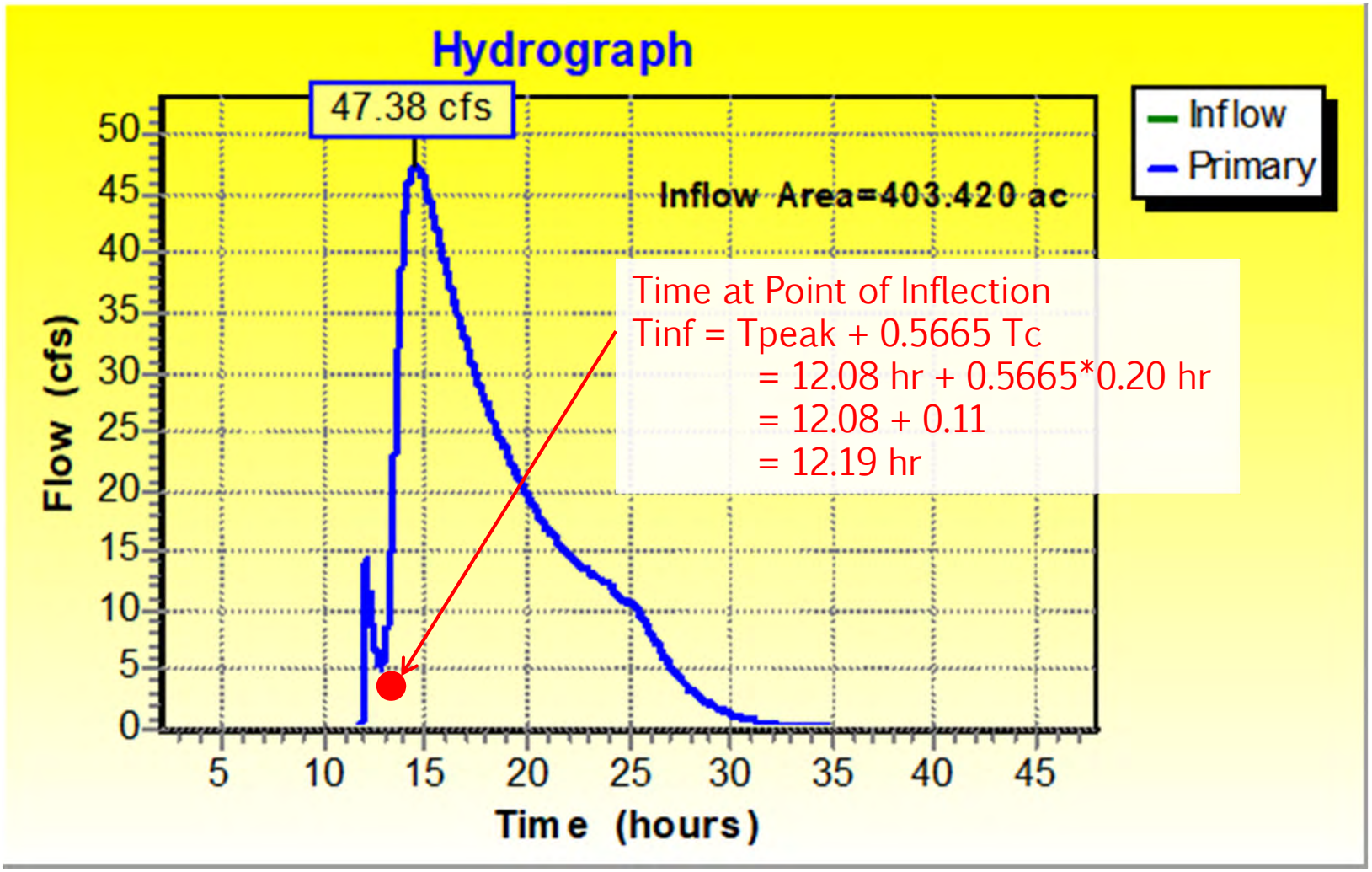
Step 2: Downstream Analysis
2b – Determine site Tinf



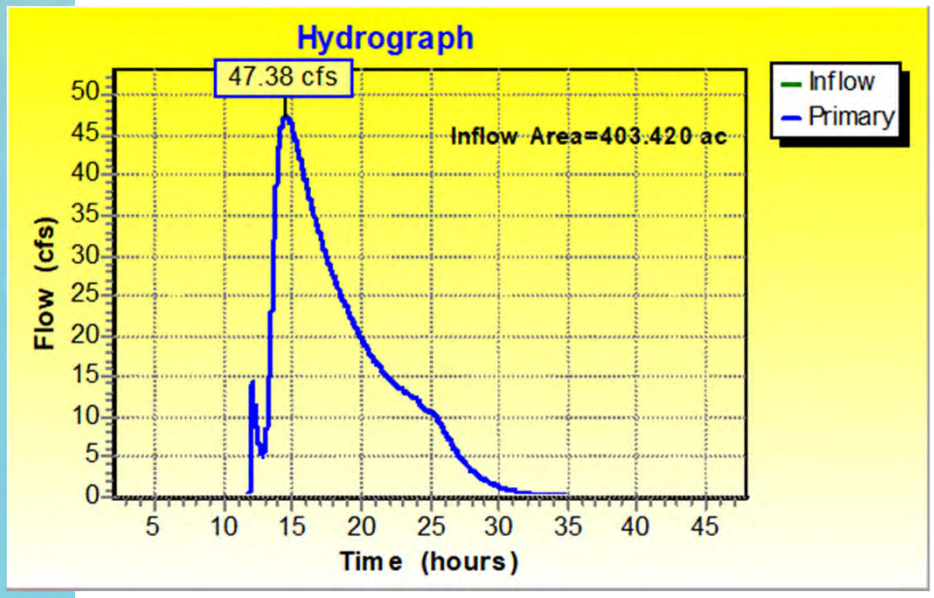
Step 2: Downstream Analysis
2b – Determine site Tinf



Step 2: Downstream Analysis
2b – Determine site Tinf



Step 2: Downstream Analysis
2c – Compare q_p, Tp and Tinf



✓ Developed site hydrograph peak less than peak of upstream hydrograph

AND…

✓ Developed site hydrograph inflection point occurs before peak of the upstream hydrograph