

GISHydroNXT

Technical Reference Manual

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Foreword

This technical document was developed to provide GISHydroNXT users with a detailed explanation of the processes and theory behind certain tools in the software.

GISHydroNXT is an ArcGIS-based application for conducting hydrologic analyses in the State of Maryland. Sponsored by the Maryland Department of Transportation State Highway Administration, GISHydroNXT integrates a complete database of terrain, land use, soils, and precipitation data with tools for assembling and evaluating hydrologic models including regional regression equations and WinTR-20. The program is designed to support the procedures for hydrologic analysis recommended by the Maryland Hydrology Panel.

This manual will serve as a document for reference when using the software and for further explanation of its concepts.

The GISHydro software is evolving continually and being enhanced. This software was originally written for use in ArcView 3.3 and some screen captures or references in this manual may still come from this version of the software. This manual (and associated training workshop) represents the first version of this software compatible with ArcGIS 10.x. The website will contain a downloadable stand-alone version of the GISHydroNXT software for users to employ on their own machines. Users will need to separately purchase and install ArcGIS 10.x. Users are encouraged to visit the GISHydro@Maryland website (www.gishydro.eng.umd.edu) frequently for updates on the GISHydro software and database.

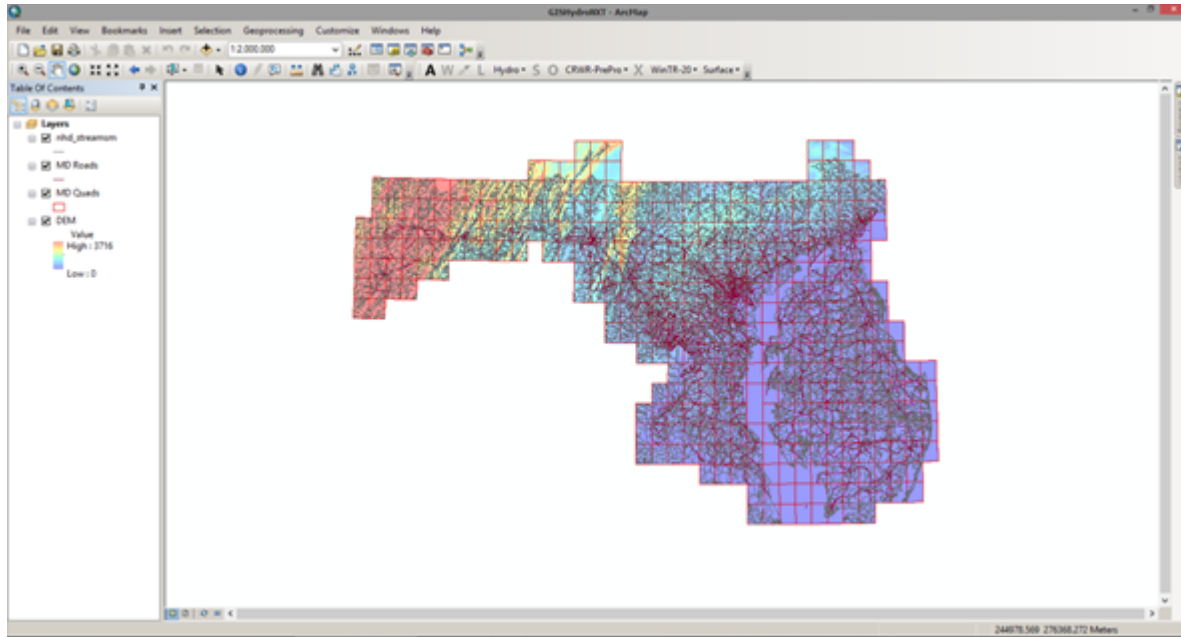
The GISHydro initiative has been and continues to be a cooperation among academia, federal, state, and local government, and private consultants. This cooperation continues to produce powerful tools to support engineering, conservation, and planning efforts within the State. The feedback we receive from all users has helped us to improve these tools and we encourage users to provide comments, bug reports, and suggestions for new features as they arise.

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Background: History and Lineage of GISHydroNXT

“A tool and database for aiding hydrologic analysis in Maryland.”



In the mid-1980s, Dr. Robert Ragan of the University of Maryland developed a QuickBasic-based program called GISHydro for use at the Maryland Department of Transportation State Highway Administration (MDOT SHA) and throughout the state. The program contained land use and soils data for the entire state of Maryland and enabled engineers to perform rapid, automated hydrologic analyses. From roughly 1998 to the present, MDOT SHA funded GISHydro2000, an ArcView-based program conceived in the spirit of GISHydro but designed to take advantage a true GIS software system. ArcGIS is now the default industry-standard GIS; GISHydroNXT, which is written for compatibility with this current GIS software, represents the newest version of the GISHydro family. GISHydroNXT will continue to evolve as data appear, methods change, and new features are added. Regardless, GISHydroNXT is constructed for compatibility with the methods and concepts described by the Maryland Hydrology Panel. GISHydroNXT provides engineers with the tools and data necessary to perform a range of hydrologic analyses in the State of Maryland.

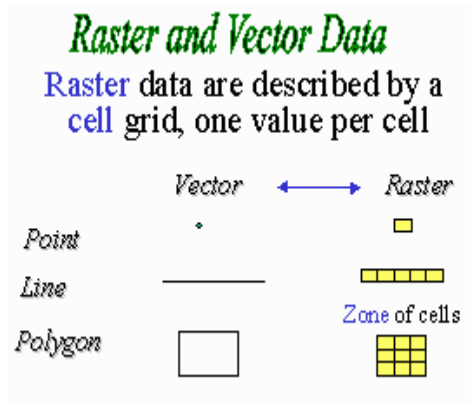
Vector and Raster Data Models in GIS

(based on David R. Maidment, “Introduction to Spatial Hydrology” – ESRI Campus)

The vector data model provides information at specified (x,y) locations in the landscape. The spatial coordinates, x and y , can be in any coordinate system, including (longitude, latitude). GISHydroNXT uses the Maryland State Plane coordinate system. A single (x,y) pair defines a point. Points can be connected to form line features, such as streams or roads. Polygons are lines that end at their starting point to enclose an area; this vector data type is used for states or counties.

Continuous surfaces can be represented using the grid or raster data model in which a mesh of square cells of equal size is laid over the landscape and the value of the variable defined for each cell.

As shown in the graphic below, a point in a vector representation can be approximately transformed to a single cell in a raster representation. Likewise, a vector line can be approximately transformed to a sequence of raster cells lying along that line, and a vector polygon can be approximately transformed to a zone of raster cells overlying the polygon area.



Spatial hydrology involves both spatial data development and hydrologic modeling, both of which require intensive computational functions. Those functions are usually offered by raster data models. However, most spatial data sources are in vector data format, which also provides unique visualization and geographic analysis benefits. Therefore, the connection between raster and vector data is critical in spatial hydrology, perhaps more so than in other applications of GIS.

Rivers are best represented as lines, and gaging stations and other control points on rivers like water right locations are best represented as points. However, the watershed areas draining to those points are best derived from Digital Elevation Models (DEM), which are raster representations of land surface terrain elevation considered as a continuous surface.

Moreover, precipitation, evaporation, and other climatic variables are defined continuously through space, but are measured at particular points (weather stations). GIS tools allow interpolation between point values to full coverage in a raster representation.

Being able to move back and forth smoothly between raster and vector representations of data is an important feature of spatial hydrology.

Performing Watershed Analysis: General Guidance

Before beginning a session with GISHydroNXT, the user should have a good notion of the approximate location and extent of the watershed to be studied or analyzed. A useful piece of information to have on hand is the precise or approximate location of the watershed outlet relative to the (major) road network. The road network and the National Hydrographic Dataset (NHD) are included in GISHydroNXT's spatial database; specific roads and/or streams can be identified using GIS search functions. The watershed outlet can also be located in GISHydroNXT using its geographic coordinates (Longitude, Latitude).

Basin Statistics (Hydro Menu)

The “Calculate Basin Statistics” item from the “Hydro” menu of the GISHydroNXT bar will produce (after a few moments) a text file, which is launched in a Notepad window as shown below. The filename will be “basinstat.txt”. The information contained in this window includes all the data needed to estimate peak discharges given any of the available sets of peak discharge regression equations.

Items appearing in the basinstat.txt file are numbered on the screen shot and explained below.

```

basinstat.txt - Notepad
File Edit Format View Help
1 GISHydro Release Version Date: July 5, 2018
2 Project Name: My Project
3 Analysis Date: July 22, 2018
Data Selected:
4 DEM Coverage: National Elevation Dataset
5 Land Use Coverage: 2010 MOP Landuse
6 Soil Coverage: SSURGO Soils
7 Hydrologic Condition: Good
8 Impose NHD stream Locations: Yes
9 Outlet Easting: 397481 m (MD Stateplane, NAD 1983)
Outlet Northing: 155259 m (MD Stateplane, NAD 1983)
Findings:
10 Outlet Location: Piedmont
11 Outlet State: Maryland
12 Drainage Area: 21.20 square miles
13 -Piedmont 100.00 percent of area
14 Channel Slope: 20.6 feet/mile (0.00391 feet/feet)
15 Land Slope: 0.057 feet/feet
16 Urban Area (percent): 52.9
17 Impervious Area (percent): 23.8
*****
18 Watershed is within 5km of physiographic
province boundary. You should consider
sensitivity of discharges to region location.
*****
19 Time of Concentration: 4.72 hours [W.O. Thomas, Jr. Equation]
20 Time of Concentration: 5.72 hours [From SCS Lag Equation * 1.67]
21 Longest Flow Path: 8.16 miles
22 Basin Relief: 147.38 feet
23 Average CN: 71.7
24 Forest Cover (percent): 22.9
25 Storage (percent): 0.2
26 Limestone (percent): 0.0
Selected Soils Data Statistics Percent:
27 A Soils: 0.0
B Soils: 80.1
C Soils: 6.1
D Soils: 13.6
SSURGO Soils Data Statistics Percent (used in Regression Equations):
28 A Soils: 0.0
B Soils: 80.1
C Soils: 6.1
D Soils: 13.6
29 2-Year,24-hour Prec.: 3.19 inches
30 Mean Annual Prec.: 43.86 inches
  
```


1. The date of the GISHydroNXT release/version used for the calculations.
2. Project name introduced by the user in Data Input Selection
3. The date the analysis was performed.
4. The data set used for the digital elevation (“coverage” is a term used in GIS practice), as selected by the user (in “Area of Interest” tool)
5. The Land Use data set selected by the user (in “Area of Interest” tool)
6. The Soils data set selected by the user (in “Area of Interest” tool)
7. The Hydrologic Condition specified by the user (in “Area of Interest” tool)
8. National Hydrographic Dataset (NHD) stream locations are automatically imposed.
9. The easting and northing (x and y coordinates) of the watershed outlet in Maryland State Plane coordinates [m].
10. The physiographic region in which the watershed outlet lies.
11. The state in which the watershed outlet lies
12. The watershed drainage area in square miles.
13. The watershed percentage by area lying within the specified physiographic region(s).
14. The average channel slope, calculated as rise/run.
15. The watershed average land slope, calculated on a pixel-by-pixel basis, then averaged.
16. The watershed percent urbanized, as identified from the selected land use.
17. Percent of the watershed area that is impervious.
18. The physiographic province boundaries in the data set are approximate. GISHydroNXT alerts the user if the delineated watershed lies near a province boundary.
19. The time of concentration calculated from W.O. Thomas’s regression equation for Maryland
20. The time of concentration calculated from the SCS Lag Equation:

$$t_c = 1.67 \text{Lag}$$
21. Length of longest flow path, as inferred from flow direction raster.
22. Basin relief is defined as the difference between basin mean elevation and outlet elevation.
23. Curve number is defined pixel-by-pixel; this is the watershed average.
24. Percent (by area) of the watershed covered by forest, based on the selected land use data set.
25. Percent (by area) of the watershed area that contributes water storage, rather than direct runoff.
26. Percent (by area) of the watershed area underlain by limestone, based on GISHydroNXT’s limestone raster data set.
27. Percent (by area) corresponding to each of the four hydrologic soil types, based on the soils data set selected by the user in the “Area of Interest” tool.
28. Percent (by area) corresponding to each of the four hydrologic soil types, based on the SSURGO soils data set (for consistency with the discharge regression equations). If the user selected SSURGO (in the Area of Interest tool), 25 and 26 are identical.
29. Precipitation depth [in] corresponding to 2-year return period, 2-hour duration. From the NOAA Atlas 14 raster data set included with GISHydroNXT.
30. Mean annual precipitation depth [in] (NOAA).

Thomas Peak Discharge Estimation (Hydro menu)

The discharges corresponding to 1.25- and 500-year return periods (Q1.25 through Q500), as estimated from the Thomas equations¹ are computed by selecting the “Calculate Thomas Discharge” item from the “Hydro” menu.

If a USGS streamgage lies within the watershed or within a specified distance of the outlet, the user is prompted to indicate whether gage adjustment should be carried out (See **Gage Adjustment of Discharge**). The results of this tool appear in a text file launched as a Notepad window (see below).

The regression equations that lead to these discharge estimates have been selected by the Maryland Hydrology Panel as being the most representative of discharge behavior for Maryland watersheds. The discharges estimated by these equations are to be used for guidance of the calibration of the WinTR-20 model.

As shown in the “Basin Statistics” output, this example watershed lies entirely in the Maryland Piedmont with an area of 21.44 mi² and an impervious area of 19.5 percent. For such a watershed, the Thomas urban equations for the Piedmont physiographic region apply. These equations are published in Appendix C of the Maryland Hydrology report. For example, the 2-year equation is copied below:

$$Q_2 = 37.01(DA)^{0.635} (IA + 1)^{0.588} \quad (1)$$

Items appearing in the frdischarges.txt are numbered in the screen shot and explained below.

¹ *Application of Hydrologic Methods in Maryland: 4th Edition, July 2016, A Report Prepared by the Maryland Hydrology Panel* (http://gishydro.eng.umd.edu/HydroPanel/July_2016_Hydrology_Panel_Report.pdf)

frdischarges.txt - Notepad

File Edit Format View Help

1 GISHydro Release Version Date: July 5, 2018
 2 Project Name: My Project
 3 Analysis Date: July 24, 2018
 4 Geographic Province(s):
 -Piedmont 100.00 percent of area

5 Q(1.25): 970 cfs
 Q(1.50): 1150 cfs
 Q(2): 1450 cfs
 Q(5): 2610 cfs
 Q(10): 3810 cfs
 Q(25): 5940 cfs
 Q(50): 8150 cfs
 Q(100): 11000 cfs
 Q(200): 13900 cfs
 Q(500): 20100 cfs

6 Area Weighted Prediction Intervals (from Tasker)

Return Period	50 PERCENT		67 PERCENT		90 PERCENT		95 PERCENT	
	lower	upper	lower	upper	lower	upper	lower	upper
1.25	925	1020	903	1040	863	1090	843	1120
1.5	1100	1210	1080	1230	1030	1290	1010	1320
2	1390	1520	1360	1560	1300	1630	1270	1660
5	2450	2770	2380	2860	2250	3030	2180	3120
10	3540	4090	3420	4240	3200	4540	3090	4700
25	5460	6460	5230	6730	4830	7300	4640	7600
50	7420	8940	7090	9360	6490	10200	6210	10700
100	9910	12200	9420	12800	8540	14100	8140	14800
200	12200	15800	11500	16800	10100	19000	9540	20200
500	17400	23300	16200	25000	14200	28700	13200	30700

7 Individual Province Tasker Analyses Follow: |

8 Flood frequency estimates for
 REGION: Blue Ridge & Piedmont
 area= 21.20:line = 0.00:forest = 22.95 :Impervious Area= 23.80 :skew= 0.48

9

Return Period	Discharge (cfs)	Standard Error of Prediction (percent)	Equivalent Years of Record	Standard Error of Prediction (logs)
1.25	970.	7.2	77.59	0.0311
1.50	1150.	6.7	77.99	0.0293
2.00	1450.	6.9	78.49	0.0301
5.00	2610.	9.1	83.98	0.0395
10.00	3810.	10.7	90.78	0.0465
25.00	5940.	12.6	99.77	0.0547
50.00	8150.	14.0	105.77	0.0603
100.00	11000.	15.4	108.76	0.0663
200.00	13900.	19.3	106.79	0.0831
500.00	20100.	21.8	104.79	0.0936

10 PREDICTION INTERVALS

Return Period	50 PERCENT		67 PERCENT		90 PERCENT		95 PERCENT	
	lower	upper	lower	upper	lower	upper	lower	upper
1.25	925.	1020.	903.	1040.	863.	1090.	843.	1120.
1.50	1100.	1210.	1080.	1230.	1030.	1290.	1010.	1320.
2.00	1390.	1520.	1360.	1560.	1300.	1630.	1270.	1660.
5.00	2450.	2770.	2380.	2860.	2250.	3030.	2180.	3120.
10.00	3540.	4090.	3420.	4240.	3200.	4540.	3090.	4700.
25.00	5460.	6460.	5230.	6730.	4830.	7300.	4640.	7600.
50.00	7420.	8940.	7090.	9360.	6490.	10200.	6210.	10700.
100.00	9910.	12200.	9420.	12800.	8540.	14100.	8140.	14800.
200.00	12200.	15800.	11500.	16800.	10100.	19000.	9540.	20200.
500.00	17400.	23300.	16200.	25000.	14200.	28700.	13200.	30700.

11 Estimates adjusted for proximity to station 1650500

1. The date of the release/version of GISHydroNXT used for the calculations.
2. Project name introduced by the user in Data Input Selection
3. The date the analysis was performed.
4. The geographic province(s) in which the watershed lies, and their respective percentage by area.
5. The discharge (Q_T) corresponding to the listed return periods, T [yr].
6. The prediction intervals (or confidence intervals) calculated for the listed discharges; 50, 67, 90, and 95 percent are the probabilities that the true Q_T lies within the given lower and upper bounds.
7. If the watershed lies within more than one physiographic province, the values provided in 4 and 5 are area-weighted averages. The remainder of the text document provides the calculations for each individual province. (In this example, only one province is included.)
8. The analyzed province is identified, and the properties of the portion of the watershed lying within that province are listed (Area, percent limestone, percent forest cover, percent impervious area, and the regional skew).
9. Detailed statistics of the regression estimate of discharge for each return period for the part of the watershed lying in this physiographic region.
10. Prediction intervals (confidence intervals) corresponding to the estimates in 8.
11. If the regression estimates were adjusted for proximity to a USGS gaging station, a statement is included. A discussion of the gage adjustment procedure follows.

Gage Adjustment of Discharge

GISHydroNXT uses a regression method to estimate the watershed discharge corresponding to selected annual probabilities. If one or more USGS streamflow gage(s) is (are) located in or near the watershed, the user has the option to adjust the regression estimates using measured data from the nearby gage(s). Here, the 50% probability (“2-year”) discharge, Q_2 , is used as an example.

Adjusted peak discharges are calculated using a five-step process.

First, the regression-based discharge, $Q_{2,gage,reg}$, as in (1), above, is evaluated at the gage location. All the required inputs are stored in GISHydroNXT’s database.

Second, the discharge from the gage flood record, $Q_{2,gage,ff}$ is retrieved from GISHydroNXT’s database.

Third, a weighted log discharge, which is a function of both the gage flood record and the gage regression estimate, is calculated using:

$$\log(Q_{2,gage,weighted}) = \frac{N \cdot \log(Q_{2,gage,ff}) + E \cdot \log(Q_{2,gage,reg})}{N + E} \quad (2)$$

where N is the years of record at the gaging station, and E is the equivalent years of record for the Fixed Region regression estimate.

Fourth, the ratio of the weighted gage discharge to the regression equation gage discharge is determined from the non-log values:

$$R_2 = \frac{Q_{2,gage,weighted}}{Q_{2,gage,reg}} \quad (3)$$

Finally, the adjusted 2-year peak discharge for the watershed is calculated as the product of this ratio and the regression estimate at the watershed outlet,

$$Q_{2,adjusted} = R_2 \cdot Q_{2,reg} \quad (4)$$

The user does not need to perform these adjustments for the gage manually. If the gage adjustment option is selected, these calculations will be automatically performed.

Compare Discharges (Hydro menu)

This tool is launched from the Hydro menu, using the command “Compare Discharges”.

The output of this tool is a text file, which is launched in a Notepad window, as shown. The numbered items are explained below

Return_Period	Carpenter	Carpenter+1SE	Dillow	Dillow+1SE	Thomas2006	Thomas+1SE_2006	Thomas_2010	Thomas+1SE_2010
1.25 year	-	-	-	-	1004.7	1423.7	1004.7	1423.7
1.50 year	-	-	-	-	1353.6	1853.1	1353.6	1853.1
1.75 year	-	-	-	-	1562.5	2118.8	-	-
2 year	1156.3	1694.0	1237.8	1703.2	1700.7	2297.6	1700.7	2297.6
5 year	2067.7	3093.3	2244.4	3050.1	3163.8	4065.5	3163.8	4065.5
10 year	2906.3	4464.1	3138.3	4321.4	4571.6	5769.4	4571.6	5769.4
25 year	4332.6	6936.5	4556.5	6520.4	6926.3	8727.1	6926.3	8727.1
50 year	5702.4	9454.6	5801.0	8655.1	9271.2	11839.3	9271.2	11839.3
100 year	7425.3	12786.4	7222.7	11318.0	12135.1	15860.6	12135.1	15860.6
200 year	-	-	-	-	15737.9	21214.7	15737.9	21214.7
500 year	-	-	11574.6	20475.5	21849.2	30851.1	21849.2	30851.1

1. List of Return Periods [yr] for which estimates are provided. In general, the regression equations provide estimates for some, but not all, of the Return Periods.
2. Discharge estimates calculated using Carpenter’s [1980] equation.
3. Upper one-standard-error confidence limit for Carpenter’s [1980] equation. Only the upper confidence limit is reported in this tool, following the Maryland Hydrology Panel’s guidance for calibration of WinTR-20 (ref).
4. Discharge estimates calculated using Dillow’s [1996] equation.
5. Upper one-standard-error confidence limit for Dillow’s [1996] equation.
6. Discharge estimates calculated using Thomas’s 2006 equation.
7. Upper one-standard-error confidence limit for Thomas’s 2006 equation.
8. Discharge estimates calculated using Thomas’s 2010 equation.
9. Upper one-standard-error confidence limit for Thomas’s 2010 equation.

Time of Concentration: Velocity Method

GISHydroNXT provides three different methods to estimate Time of Concentration (t_c) for a watershed or subwatershed:

- The NRCS Lag Method
- The Hydrology Panel regression method
- The Velocity Method

When the Velocity Method is selected, the user has the option to merge segments in the flow path that GISHydroNXT infers from the digital elevation model. This section explains why merging pixel-based flow path segments into longer line segments decreases the t_c , and provides some guidance on the use of this optional analysis tool

Segment Merging within the Velocity Method

It is worthwhile to understand how the merging of multiple pixels into a single segment of channel has the effect of reducing the calculated time of concentration. We begin by considering an idealized watershed in which the flow path controlling the time of concentration has uniform characteristics throughout. In this example, only slope will be varied, although the reader should recognize that channel characteristics such as roughness or geometry also vary spatially. For this example, assume that the elevation along the longest flow path is defined by the equation,

$$z = x^2 \quad (1)$$

where z is elevation and x is position along the flow path, measured from downstream to upstream. For simplicity, we will examine a unit length of the flow path from $x = 0$ to $x = 1$. Slope along the longest flow path is simply,

$$S = \frac{dz}{dx} = 2x \quad (2)$$

Assuming channel flow and either a Manning's or Chezy velocity relationship,

$$v \sim \sqrt{S} \quad (3)$$

where v is the velocity. Incremental travel time, dt_c is simply the incremental distance divided by the velocity,

$$dt_c = c \frac{dx}{\sqrt{S}} = c \frac{dx}{\sqrt{2x}} \quad (4)$$

where c is a constant that is dependent on roughness and channel geometry. The total travel time is the integral of equation (4),

$$t_c = \frac{c}{\sqrt{2}} \int_0^1 \frac{dx}{\sqrt{x}} = c \left[\sqrt{2x} \right]_0^1 = c\sqrt{2} \cdot (\sqrt{1} - \sqrt{0}) = c\sqrt{2} \quad (5)$$

For simplicity, assume that $c = 1$. Then the travel time over this unit length segment is $\sqrt{2}$. For contrast, Table 1 shows the travel time if it is calculated by difference, rather than integration, if the channel is subdivided into one, two, or three segments over the distance from $x = 0$ to $x = 1$, and the travel time estimated individually for each segment.

Table 1. Time of concentration in idealized system as a function of number of segments.

Number of Segments	x	$z = x^2$	$S = \frac{\Delta z}{\Delta x}$	Dx	$\frac{\Delta x}{\sqrt{S}}$	$t_c = \sum \frac{\Delta x}{\sqrt{S}}$
1	0.0	0.0	1.0	1.0	1.0	1.0
	1.0	1.0				
2	0	0	0.5	0.5	0.707	1.115
	0.5	0.25				
	1.0	1.0	1.5	0.5	0.408	
3	0.0	0.0	0.333	0.333	0.577	1.146
	0.333	0.111				
	0.667	0.444	1.0	0.333	0.333	
	1.0	1.0	2.0	0.333	0.236	

Clearly, as the number of segments increases, the estimated t_c increases. Note that from equation 5 the analytical limit to the t_c (for an infinite number of segments) would be $\sqrt{2}$ (equal to 1.414).

Velocity Method Attribute Table

When the Velocity Method t_c tool is run, a polyline shapefile and its corresponding attribute table are created. The flow path is created by drawing line segments between the centers of the flow path pixels. Each pixel is numbered, starting with 1 at the upstream end. The attribute table contains all the properties of each line segment in the flow path. The geometric locations (x,y) of each line segment are stored separately in ArcGIS's shapefile data format.

Each row in the attribute table corresponds to a line segment in the flow path. Each column corresponds to a property or attribute. The attributes are explained below.

Segment Attributes - Sub-area 1																
FID	UpPixel	SegName	Type	DownPixel	Avg. Area	UpElev	DownElev	Slope	Width	Depth	Xarea	I_Length	Tot_Length	Vel.	I_Time	Tot_Time
0	0	M1	overland	1	0.000173...	521.1	517.2	0.02737	-1.0	-1.0	-1.0	139.2	139.2	0.35	0.11	0.11
1	1	S1	swale	2	0.000521...	517.2	513.3	0.040565	-1.0	-1.0	-1.0	98.4	237.6	3.25	0.008	0.119
2	2	S2	swale	3	0.00086873	513.3	508.2	0.036551	-1.0	-1.0	-1.0	139.2	376.8	3.08	0.013	0.131
3	3	S3	swale	4	0.001216...	508.2	502.7	0.039066	-1.0	-1.0	-1.0	139.2	516.0	3.19	0.012	0.143
4	4	S4	swale	5	0.002432...	502.7	499.5	0.023446	-1.0	-1.0	-1.0	139.2	655.2	2.47	0.016	0.159
5	5	S5	swale	6	0.005907...	499.5	496.6	0.020612	-1.0	-1.0	-1.0	139.2	794.4	2.32	0.017	0.176
6	6	S6	swale	7	0.011467...	496.6	494.2	0.016944	-1.0	-1.0	-1.0	139.2	933.6	2.1	0.018	0.194
7	7	S7	swale	8	0.016679...	494.2	490.1	0.029529	-1.0	-1.0	-1.0	139.2	1072.8	2.77	0.014	0.208
8	8	S8	swale	9	0.019807...	490.1	485.1	0.036392	-1.0	-1.0	-1.0	139.2	1212.0	3.08	0.013	0.221
9	9	S9	swale	10	0.023629...	485.1	483.3	0.017473	-1.0	-1.0	-1.0	98.4	1310.4	2.13	0.013	0.233
10	10	S10	swale	11	0.026583...	483.3	477.7	0.056992	-1.0	-1.0	-1.0	98.4	1408.8	3.85	0.007	0.24
11	11	S11	swale	12	0.028146...	477.7	475.5	0.015881	-1.0	-1.0	-1.0	139.2	1548.0	2.03	0.019	0.259
12	12	S12	swale	13	0.030231...	475.5	471.8	0.037864	-1.0	-1.0	-1.0	98.4	1646.4	3.14	0.009	0.268
13	13	S13	swale	14	0.03301174	471.8	467.9	0.039488	-1.0	-1.0	-1.0	98.4	1744.9	3.21	0.009	0.277
14	14	S14	swale	15	0.039266...	467.9	465.3	0.026619	-1.0	-1.0	-1.0	98.4	1843.3	2.63	0.01	0.287
15	15	S15	swale	16	0.043610...	465.3	465.2	0.000579	-1.0	-1.0	-1.0	98.4	1941.7	0.39	0.07	0.358
16	16	S16	swale	17	0.047432...	465.2	466.2	0.002996	-1.0	-1.0	-1.0	139.2	2080.9	0.88	0.044	0.401
17	17	S17	swale	18	0.061506...	466.2	469.6	0.002996	-1.0	-1.0	-1.0	139.2	2220.1	0.88	0.044	0.445
18	18	S18	swale	19	0.07384205	469.6	468.4	0.002996	-1.0	-1.0	-1.0	98.4	2318.5	0.88	0.031	0.476
19	19	S19	swale	20	0.076100...	468.4	463.8	0.002996	-1.0	-1.0	-1.0	98.4	2417.0	0.88	0.031	0.507
20	20	S20	swale	21	0.07731697	463.8	462.6	0.011894	-1.0	-1.0	-1.0	98.4	2515.4	1.76	0.016	0.523
21	21	S21	swale	22	0.078359...	462.6	465.8	0.008636	-1.0	-1.0	-1.0	139.2	2654.6	1.5	0.026	0.548
22	22	C1	channel	23	0.08426681	465.8	465.4	0.008636	5.78	0.52	3.0	98.4	2753.0	1.6	0.017	0.565
23	23	C2	channel	24	0.090695...	465.4	459.4	0.008636	5.81	0.52	3.04	139.2	2892.2	1.61	0.024	0.589
24	24	C3	channel	25	0.092432...	459.4	449.7	0.069266	5.86	0.53	3.09	139.2	3031.4	4.58	0.008	0.598
25	25	C4	channel	26	0.094517...	449.7	438.4	0.081342	5.92	0.53	3.14	139.2	3170.6	4.99	0.008	0.606
26	26	C5	channel	27	0.102857	438.4	436.3	0.015014	6.25	0.56	3.48	139.2	3309.8	2.22	0.017	0.623

FID: Feature ID. This is the ArcGIS index for the line segment described in a given row. Numbering starts at 0.

UpPixel: This is the pixel number of the most upstream pixel in the indicated flow segment.

SegName: The segment name for the particular record in the table. A leading “O” means pure overland flow, “M” means mixed (some overland and some swale), “S” means swale, and “C” means channel. Segments are numbered consecutively from upstream to downstream so, for instance, “C2” corresponds to the second channel segment, immediately downstream from “C1”.

Type: The type of flow. Potential entries are “Overland”, “Mixed”, “Swale”, and “Channel”

Downpixel: This is the pixel number of the most downstream pixel in the indicated flow segment. These numbers correspond directly to the “Value” field in the “Longest Flow Path Sub x” theme. Notice that the downstream pixel from one segment is also the upstream pixel for the next segment in the downstream direction.

Avg. Area: This number reflects the arithmetic average of the drainage area to all pixels that make up the flow segment. The value reported is in mi².

UpElev: The elevation at the upstream end of the segment [ft].

DownElev: The elevation at the downstream end of the segment [ft].

Slope: The slope of the segment [ft/ft], calculated as

$$Slope = \frac{UpElev - DownElev}{I_Length}$$

where UpElev and DownElev are as described above and I_Length is the segment length [ft] (see below).

Width: The channel width [ft] determined using U.S. Fish and Wildlife Service hydraulic geometry equations [McCandless and Everett, 2002; McCandless 2003(a) and (b)], with “Avg. Area” as the input. If the segment is not a channel then “-1.00” appears for this entry, indicating that the quantity does not apply to this segment.

Depth: The channel depth [ft] determined using the U.S. Fish and Wildlife Service hydraulic geometry equations [McCandless and Everett, 2002; McCandless 2003(a) and (b)], with “Avg. Area” as the input. If the segment is not a channel then “-1.00” appears for this entry indicating that the quantity does not apply to this segment.

Xarea: The channel cross-sectional area [ft²] determined using the U.S. Fish and Wildlife Service hydraulic geometry equations [McCandless and Everett, 2002; McCandless 2003(a) and (b)], with “Avg. Area” as the input. If the segment is not a channel, then “-1.00” appears for this entry indicating that the quantity does not apply to this segment.

I_Length: The incremental length (pixel center to center) of the flow segment in feet.

Tot_Length: The total length from the upstream end of the overall flow path to the bottom of the segment [ft].

Vel: The average flow velocity in the segment [ft/s] calculated using Manning’s equation.

I_Time: the incremental travel time of the flow segment in [hr], calculated as

$$I_Time = \frac{I_Length}{Vel}$$

Tot_Time: the total travel time from the upstream end of the overall flow path to the bottom of the current segment [hr].

When flow segments are merged, either by the Quick Merge method or by custom specification, the individual pixel-to-pixel lengths are added, the areas are averaged, the reach representative width and depth are calculated by the USFWS regression equations using Avg Area, the velocity is calculated from the average geometry, and an average velocity is then calculated using Manning’s equation. At each stage of segment merging, a new attribute table is displayed, as shown below (for the result of a Quick Merge):

FID	UpPixel	SegName	Type	DownPixel	Avg. Area	UpElev	DownElev	Slope	Width	Depth	Xarea	I_Length	Tot_Length	Vel.	I_Time	Tot_Time
0	0	M1	overland	1	0.000173...	521.1	517.2	0.028017...	-1.0	-1.0	-1.0	139.2	139.2	0.356833...	0.108360...	0.108360...
1	1	S1	swale	22	0.033235...	517.2	465.8	0.020435...	-1.0	-1.0	-1.0	2515.2	2654.4	2.905990...	0.240422...	0.348783...
2	22	C1	channel	382	8.312709...	465.8	271.5	0.004809...	33.75779...	2.424345...	81.74482...	40401.6	43056.0	3.407645...	3.293378...	3.642161...

Note that the difference between the UpPixel and DownPixel values for each row (segment) are now greater than one because the flow segment contains more than one pixel-to-pixel line segment.

Guidance on Determining an Accurate Time of Concentration

We arrive now at the ultimate question of guidance. What is the “correct” value for t_c ? Sound engineering judgment should be the guiding principle. Some things to examine or ask include: How does the pixel-based t_c compare to the t_c values determined using the “Basin Statistics” menu choice? Merging of pixels into larger segments for the longest flow path is probably indicated if the pixel-based t_c is substantially greater than the t_c 's determined by the Thomas or NRCS lag equations.

Examine the “Attributes of TcPathx.shp” file and look for occurrences of unrealistically low velocities. Very small segment velocities result in long incremental travel times. If larger segments are generated by judicious merging of individual pixels, these very local features are averaged out, with a tendency to result in greater slopes, greater velocities, and smaller incremental travel times.

Use the “identify” tool to examine the DEM directly along the longest flow path. Is it genuinely very flat over long distances or are there only small “pockets” of flat areas? You might wish to use the “Create contours...” menu choice under the “Surface” menu in GISHydroNXT to create a contour map of the DEM for guidance in visualizing the topography. A genuinely flat area should be reflected by a segment that combines the pixels that span this area. The engineer should endeavor to merge pixels to create segments that reflect breaks in slope along the watershed.

Examine the overall drainage network as it interacts with the longest flow path. Are there locations where significant tributaries join with the longest flow path? This is especially likely along the “channel” portion of the flow path. In such locations, the channel geometry is likely to change quickly, reflecting the increased drainage area associated with the tributary. In such locations you should use the “identify” tool to identify the upstream/downstream pixel numbers along the longest flow path and then use the Velocity Method Segment Generator dialog to combine pixels into segments that begin/end at these large tributary junctions.

Ultimately, the decision of whether and to what degree to merge pixels must rest with the engineer. Simulated discharges using WinTR-20 (and other rainfall-runoff models) are very sensitive to measures of representative time scales for the watershed. The time of concentration is a powerful parameter the engineer might vary during the calibration step. Owing to the structure of DEM data and its tendency to produce small slopes at a pixel-based description of the longest flow path, the engineer should pay especially close attention to small peak discharges produced by the WinTR-20 model. Are these modeled discharges small because of t_c estimates that are much larger than those resulting from regression equations? If the answer to this question is “yes”, then the combining of pixel-based segments into larger flow segments using the Velocity Method Segment Generator is probably indicated.

WinTR-20 Interface

According to the Natural Resources Conservation Service (NRCS) (2018),

The Computer Program for Project Formulation Hydrology (WinTR-20) is a single event watershed scale runoff and routing model. It computes direct runoff and develops hydrographs resulting from any synthetic or natural rainstorm. Developed hydrographs are routed through stream and valley reaches as well as through reservoirs. Hydrographs are combined from tributaries with those on the main stream.... WinTR-20 may be used to evaluate flooding problems, alternatives for flood control (reservoirs, channel modification, and diversion), and impacts of changing land use on the hydrologic response of watersheds.

WinTR-20 is built on Technical Release 20: Computer Program for Project Formulation Hydrology (TR-20) (SCS, 1983), and employs the same conceptual representation of the watershed, stream reaches, and storage structures as the original TR-20.

GISHydroNXT allows the user to develop a WinTR-20 input file, using the data sets installed with GISHydroNXT. The interface does not use the full WinTR-20 Windows interface. Rather, a text input file is created. The user can run a command-line version of WinTR-20 from within GISHydroNXT, or may choose to save the created text input file for further development using an external installation of WinTR-20.

The capabilities of WinTR-20 are more extensive than the basic model generated in GISHydroNXT. Nonetheless, GISHydroNXT provides tools to automate the essential inputs. For complete guidance on WinTR-20, the reader is referred to NRCS (2018).

Conceptual Description

The program is designed to simulate the rainfall-runoff process for a watershed. Figure 2-1 depicts the rainfall-runoff process used by WinTR-20. The unit hydrograph is the transfer function used to transform the rainfall excess into direct runoff. The rainfall hyetograph is convolved with the unit hydrograph to produce the direct runoff hydrograph, as discussed below.

The watershed may be analyzed as a whole, or divided into subwatersheds. For a specified rainfall depth and temporal distribution, a hydrograph is developed for each subwatershed

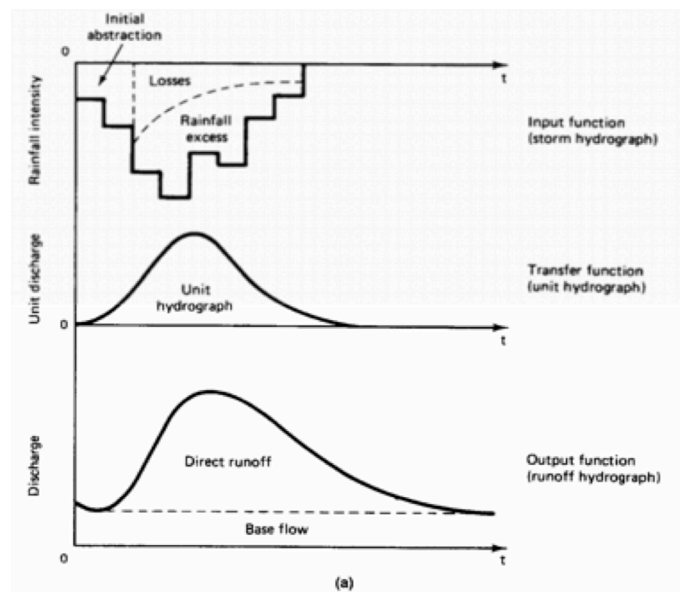


Figure 2-1: Rainfall-runoff process (McCuen, 1998).

given the drainage area, time of concentration, and curve number as input. The runoff resulting from a given rainfall depth is computed from the NRCS rainfall- runoff equation:

$$Q = \frac{P - 0.2S}{P + 0.8S}$$

where P is the precipitation in inches, Q is the runoff in inches, and S is the potential storage in inches, given by:

$$S = \frac{1000}{CN} - 10$$

where CN is the runoff curve number. The time to peak for the direct runoff hydrograph is equal to two-thirds the time of concentration. The peak discharge of the unit hydrograph, the SCS dimensionless unit hydrograph in this case, is computed using the equation:

$$q_p = \text{PRF} \frac{AQ}{t_p}$$

where PRF is the peak rate factor, t_p is the time to peak in hours, Q is event runoff (one inch for the unit hydrograph), and A is the drainage area in square miles. The standard unit hydrograph is defined with PRF equal to 484 (an empirical constant); the user may also select the DelMarVa unit hydrograph, for which the PRF equals 284.

The specified watershed event precipitation is converted to a rainfall hyetograph (precipitation as a function of time). The ordinates of the rainfall hyetograph are multiplied, translated, and added in time with the ordinates of the unit hydrograph to form the direct runoff hydrograph for each subwatershed. This process is called convolution.

Hydrographs generated from upstream subwatersheds are routed through channel reaches using the Modified Att-Kin (Attenuation – Kinematic) method. For a given stream reach, the routing procedure translates the upstream hydrograph along its length and attenuates the peak of the hydrograph to account for storage in the channel.

Hydrographs can also be routed through reservoirs or other storage structures. WinTR- 20 uses the storage-indication method to simulate reservoir routing.

In order to develop a simulated runoff hydrograph for each subwatershed, a minimum amount of information is required. The area, time of concentration, and curve number must be specified for each subwatershed. GISHydroNXT's tools automate the calculation of these input parameters.

The event precipitation depth and the temporal distribution of precipitation are required. GISHydroNXT allows the user to specify frequency(ies) and duration(s) of the event(s) to be modeled. The precipitation depths are retrieved from a spatial database of NOAA Atlas 14 precipitation. In building the WinTR-20 input file, GISHydroNXT uses NOAA's Type II design rainfall distributions corresponding to durations of 6, 12, 24, and 48 hours.

In order to route upstream hydrographs to downstream locations, a stage-discharge relationship (rating table) is required. GISHydroNXT allows the user to create a cross-section for each routing reach using the Cross-Section (Transect Line) tool, and then generates the rating table for the reach using Manning's equation.

GISHydroNXT creates the WinTR-20 input file as a text file incorporating all the required elements, as well as user preferences for detailed or summary output. A knowledgeable user can edit this text file to adjust the precipitation distribution(s), unit hydrograph(s), rating table(s), and other parameters.

The user may choose to run WinTR-20 from within GISHydroNXT using the "Execute WinTR-20" command, or may export the text input file for use in a full Windows installation of WinTR-20.

References

Natural Resources Conservation Service (NRCS), 2018. “WinTR-20 Project Formulation Hydrology,” <https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/null/?cid=stelprdb1042793> (short URL: <http://go.usa.gov/cZeg9>)

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