

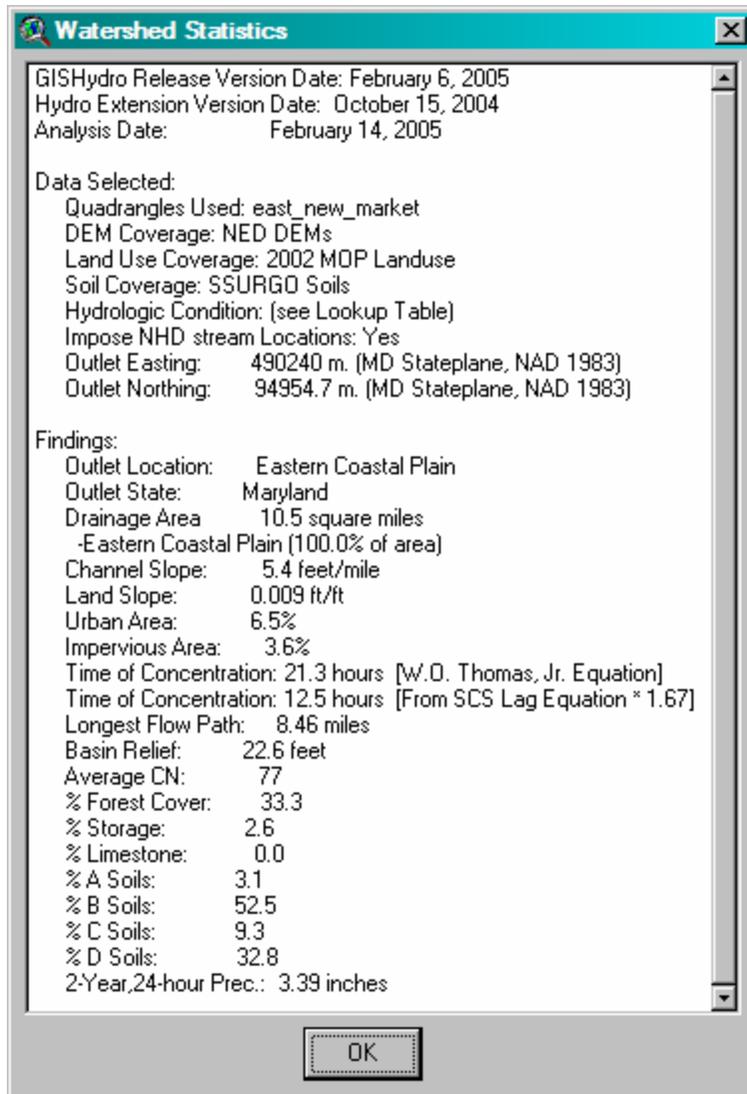
**Documentation for Velocity Method Segment Generator**  
**Glenn E. Moglen**  
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The purpose of this document is to provide guidance on the use of a new dialog box recently added to GISHydro2000 that allows the engineer to merge multiple pixels into single segments for computation of the time of concentration using the velocity method.

**Preliminaries**

Before reaching this new dialog box, the analysis proceeds in the standard way through the Hydro menu. Figure 1 shows the watershed statistics for an approximately 10 mi<sup>2</sup> watershed in the center of the East New Market quadrangle on Maryland's eastern shore. Note that the Thomas time of concentration is 21.3 hours while the SCS Lag equation produces a  $t_c$  estimate of about 12.5 hours. This is a large disparity, but it does convey the general sense of a 10 to 20 hour time of concentration. This is a long  $t_c$  given the watershed size, but note that the overall basin relief is only 22.6 feet.

Analysis may now move to the CRWR-PrePro menu. For direct comparison to the Watershed Statistics output, this example will treat the basin as a single watershed. We proceed through the CRWR-PrePro menu by specifying only a single stream within the overall watershed which has the effect of modeling the watershed as a single sub-basin. Again, this is only for direct comparability between the  $t_c$  calculated using the velocity method approach and the  $t_c$ 's determined earlier in the Watershed Statistics dialog by the Thomas and SCS lag equations.



**Figure 1.** Watershed Statistics dialog for example watershed analysis.

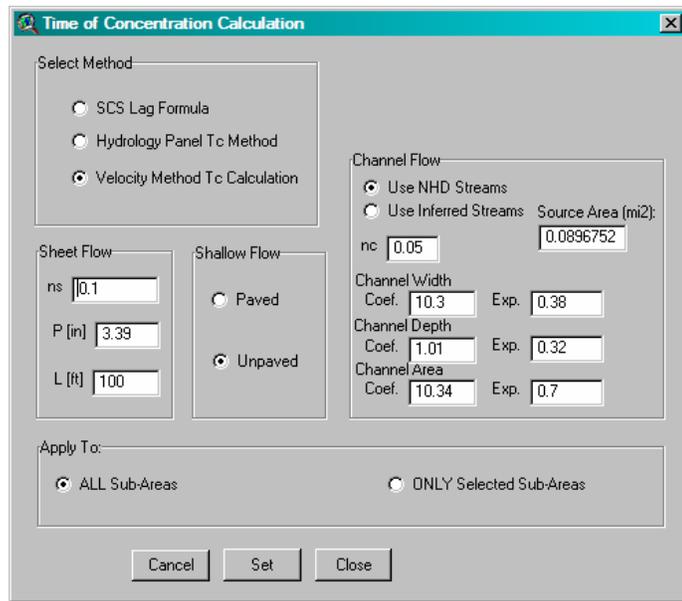
Figure 2 at right shows the standard “Time of Concentration Calculation” dialog as it appears for the analysis of this example watershed. Default values are chosen in all cases: this amounts to a 2-year, 24-hour precipitation depth of 3.39 inches as determined by the NOAA Atlas 14 dataset for the sheet flow portion of the time of concentration, unpaved conditions for the swale flow portion of the time of concentration and use of the National Hydrograph Dataset (NHD) streams to indicate the location (and onset) of channels for the channel flow portion of the time of concentration. Once these parameters are set and the dialog closed we select the “Calculate Attributes” menu choice which produces the raster theme, “Longest Path Sub 0”. Examining the table associated with this theme indicates an overall  $t_c$  of over 38.5 hours over 392 pixels along the longest flow path. This  $t_c$  is nearly twice the value determined using the SCS lag equation and more than three times the value determined using the Thomas equation.

This generally longer time of concentration is typical finding one is likely to encounter with the “pixel-based” approach to the calculation of the time of concentration within GISHydro2000. This finding is more likely to occur in relatively flat topography such as the eastern shore and is more likely to occur in larger watersheds (watersheds in excess of 5 mi<sup>2</sup>). It is with this problem in mind that the Velocity Method Segment Generator dialog/tool was developed.

**Background on Why Merging Pixels Reduces Time of Concentration**

It’s worthwhile to take a few moments 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. The elevation along the longest flow path is defined by the equation,

$$y = x^2 \tag{1}$$



**Figure 2.** The Time of Concentration Calculation dialog box. Shown are the choices used in this example watershed analysis.

where  $y$  is elevation  $x$  is position along the flow path, measured from upstream to downstream. 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,

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

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 just the incremental distance divided by the velocity,

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

where  $c$  is a constant that is dependent on roughness and channel geometry. The total travel time is just 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, let's assume that  $c=1$ , then the travel time over this unit length segment is just  $\sqrt{2}$ . For contrast, Table 1 shows the travel time if the channel is treated as having one, two, or three segments over the distance from  $x = 0$  to  $x = 1$ .

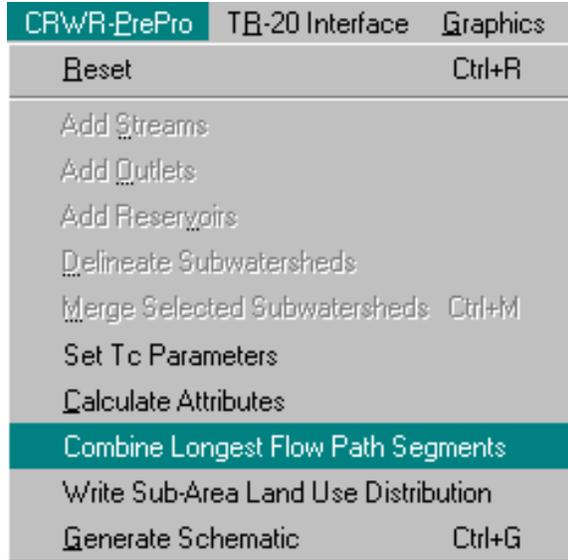
Table 1. Time of concentration in idealized system as a function of number of segments.

Number of Segments	$x$	$y=x^2$	$S = \frac{\Delta y}{\Delta x}$	$\Delta x$	$\frac{\Delta x}{\sqrt{S}}$	$t_c = \sum \frac{\Delta x}{\sqrt{S}}$
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	1.5	0.5	0.408	
	1.0	1.0				
	0.0	0.0	0.333	0.333	0.577	
3	0.333	0.111	1.0	0.333	0.333	1.146
	0.667	0.444	2.0	0.333	0.236	
	1.0	1.0				
	0.0	0.0				

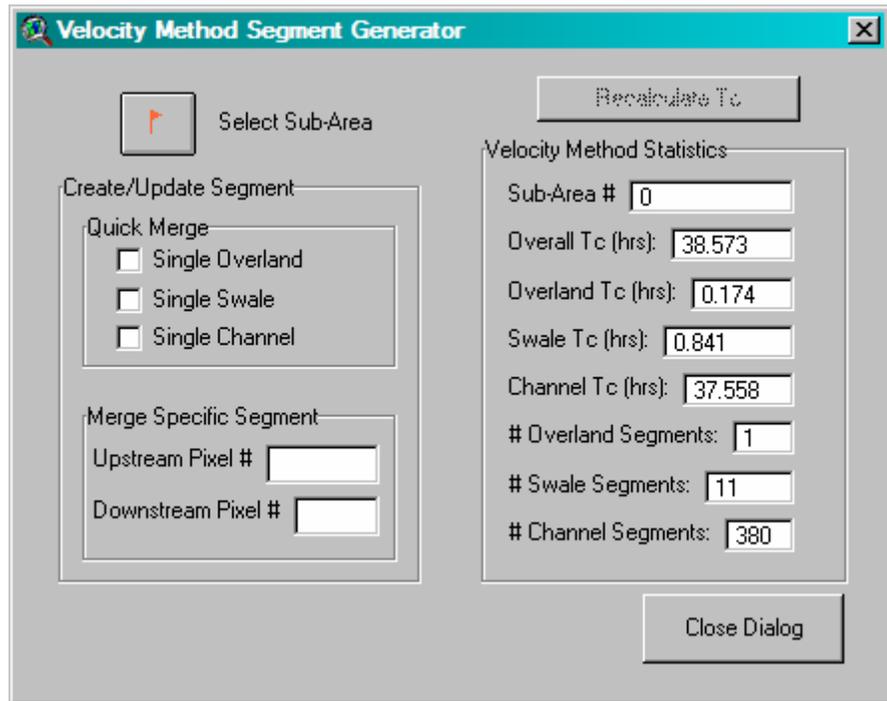
Clearly, as the number of segments increases, the estimated  $t_c$  increases. Note that from equation 5 the analytical limit to the  $t_c$  (for an infinite number of segments would be  $\sqrt{2}$ ).

**Using the Velocity Segment Generator Dialog/Tool**

In our example watershed analysis we left off at the pixel-based velocity method time of concentration calculation of about 38.5 hours. The new Velocity Segment Generator Dialog is accessed through a new menu choice on the CRWR-PrePro menu just beneath the existing “Calculate Attributes” choice. The new choice, shown at right is, “Combine Longest Flow Path Segments”. Selecting this choice produces the dialog shown below in Figure 3. The dialog initially appears “blank” when it is first opened so the first step is to use the “Select Sub-Area” tool



and select one sub-area from the watershed to be studied. In this case, the watershed is being treated as a single area so this tool is used only once. If the watershed has been sub-divided into multiple sub-areas then the tool will need to be used once for each sub-area, otherwise, the pixel-based time of concentration



**Figure 3.** The Velocity Method Segment Generator dialog shown after using the “Select Sub-Area” tool to select the example watershed.

determined simply from the “Calculate Attributes” menu choice will be used in writing the  $t_c$  to the TR-20 input file. Once the sub-area has been selected, the dialog box will update and will initially look as shown in Figure 3.

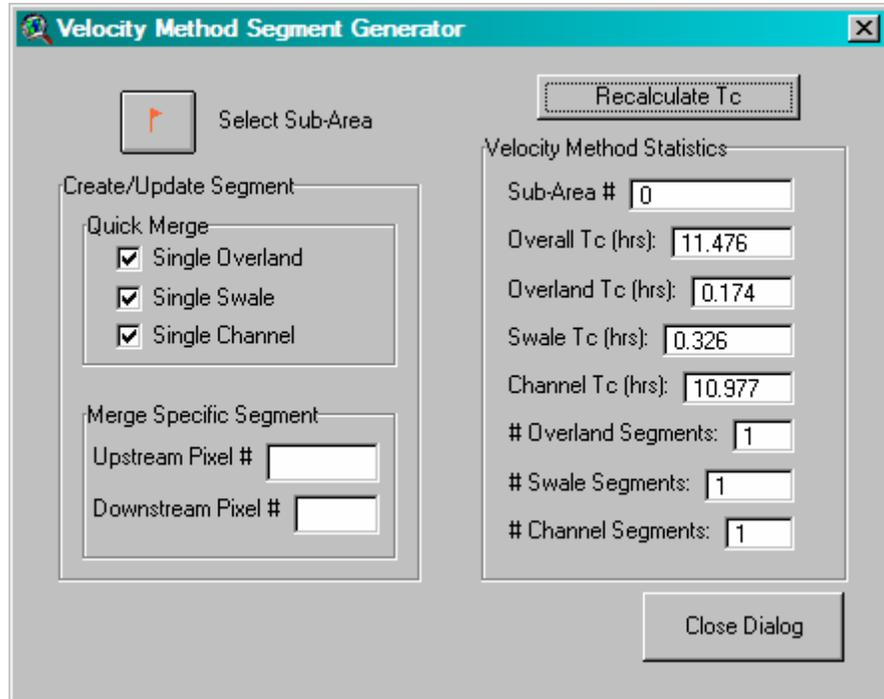
The Velocity Method Segment Generator can be divided into a left and right side. The left side is the “input” side while the right side is the “output” side. On the left side, the user can specify the merging of segments by individual pixel numbers (lower part) or the engineer can quickly merge all pixels of a particular flow type (i.e. overland, swale, or channel) into a single segment (upper part). Note that initially, there is 1 pixel

defining the overland flow part of the longest path, 11 pixels defining the swale, and 380 pixels defining the channel. This amounts to 392 individual segments over which incremental  $t_c$ 's are summed to produce the overall estimate of the time of concentration. As was shown in Table 1, as the number of increments segments defining the flow path are increased, the  $t_c$  tends to increase.

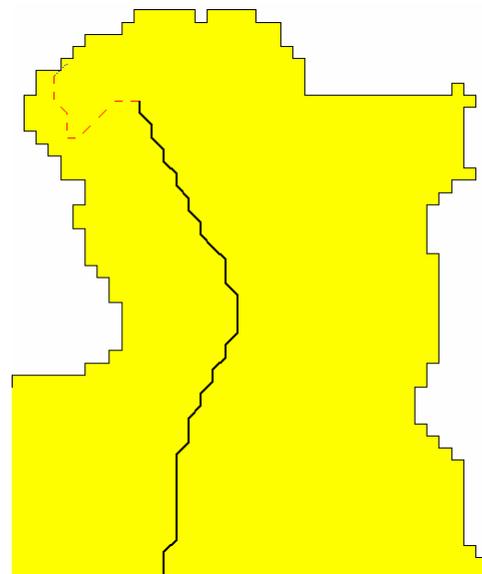
As a first step, let's examine the simplest case of a longest flow path with one overland flow segment, one swale segment, and one channel segment. This can be quickly created by selecting each of the check boxes under the "Quick Merge" area and then pressing the "Recalculate  $T_c$ " button. The result, is the updated dialog as shown in Figure 4.

Notice now that there is only 1 segment each for each of the 3 flow types and that the overall  $t_c$  has been reduced to about 11.5 hours. This is a huge reduction from the 38.5 hours originally calculated and is actually about 1 hour less than the value determined using the SCS lag equation as shown in the Watershed Statistics dialog.

There are other elements that merit examination apart from just the segment generator dialog. Let's examine the theme and associated table generated by this dialog. As stated in documentation elsewhere, selecting the "Calculate Attributes" menu choice produces the "Longest Path Sub x" raster theme where x is a number varying from 0 to  $n-1$  where  $n$  is the total number of sub-areas within the overall watershed. By initiating the segment generator dialog, a new theme is created for each sub-area



**Figure 4.** The Velocity Method Segment Generator dialog after "Quick Merge"-ing all overland, swale, and channel pixels.



**Figure 5.** The upstream end of the longest flow path for the example watershed.

that is refined. These themes are called, “Tcpathx.shp” where x is a number varying from 0 to  $n-1$  as above. This theme visually shows the longest flow path in sub-area x and also shows the 3 flow types of this longest flow path as shown in Figure 5. This figure focuses on the upstream end of the longest flow path. The solid black line corresponds to the channel portion of the longest flow path, the dashed red line corresponds to the swale, and the dotted blue line (barely visible at the extreme upstream end) is the overland portion of the longest flow path. Of course, much of the channel part of the flow path is truncated off in the figure. There is also a tabular representation of this theme as shown

Attributes of Tcpath0.shp																
Shape	UpPixel	SegName	Type	DownPixel	Avg_Area	UpElev	DownElev	Slope	Width	Depth	Xarea	L_Length	Tot_Length	Vel	L_Time	Tot_Time
PolyLine	1	M1	Mixed	2	0.00	44.3	43.2	0.007903	-1.00	-1.00	-1.00	139.2	139.2	0.22	0.174	0.174
PolyLine	2	S1	Swale	13	0.01	43.2	37.8	0.004334	-1.00	-1.00	-1.00	1245.7	1384.9	1.06	0.326	0.500
PolyLine	13	C1	Channel	393	4.35	37.8	-0.9	0.000894	18.01	1.62	28.94	43272.4	44657.3	1.10	10.977	11.476

**Figure 6.** Table for longest flow path corresponding to a single segment for each type of flow (condition of time of concentration consistent with Figure 5).

in Figure 6. Each row (record) in this table corresponds to an individual segment along the longest flow path. Segments are arranged in spatial order from the upstream end (record 1) to the downstream end (record m,  $m = 3$  in Figure 6). Segments may vary according to flow type or there may be multiple segments within a single flow type. The following is a description of the contents of the entries in this table:

- **Shape:** This is a GIS concept. “Polyline” means that this table entry literally contains the geographic information of where this segment of the longest flow path is in space.
- **UpPixel:** This is the pixel number of the most upstream pixel in the indicated flow segment. These numbers correspond directly to the “Value” field in the “Longest Flow Path Sub x” theme.
- **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:** This is 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 combined to make up the flow segment. The value reported is in  $\text{mi}^2$ .
- **UpElev:** This is the elevation at the upstream end of the segment in feet.
- **DownElev:** This is the elevation at the downstream end of the segment in feet.
- **Slope:** The slope of the segment in ft/ft.
- **Width:** The channel width (in feet) determined using the Avg. Area reported earlier in the U.S. Fish and Wildlife hydraulic geometry equations. 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 (in feet) determined using the Avg. Area reported earlier in the U.S. Fish and Wildlife hydraulic geometry equations. 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 (in ft<sup>2</sup>) determined using the Avg. Area reported earlier in the U.S. Fish and Wildlife hydraulic geometry equations. 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 length of the current flow segment in feet.
- **Tot\_Length:** The total “running length” from the upstream end of the overall flow path to the bottom of the current segment in feet
- **Vel:** the average flow velocity in the current segment in ft/s.
- **I\_Time:** the travel time of the current flow segment in hours.
- **Tot\_Time:** the total “running time” from the upstream end of the overall flow path to the bottom of the current segment in hours.

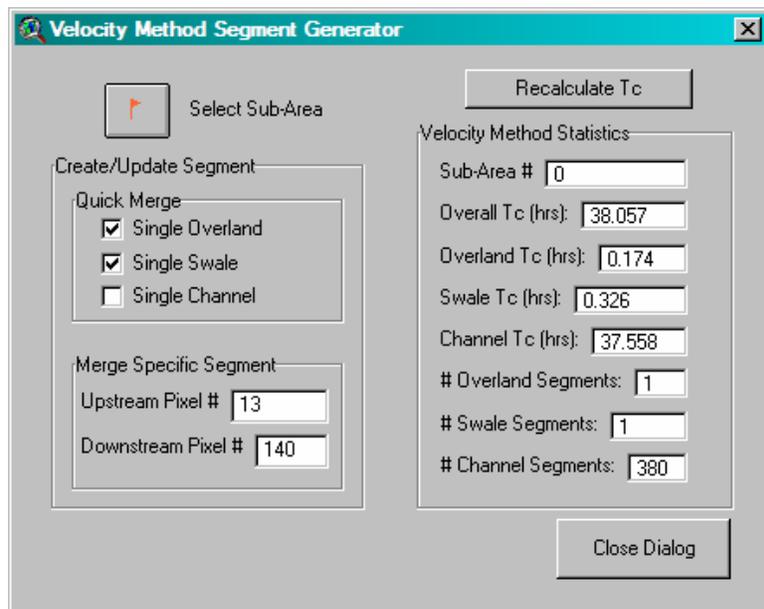
Let’s now consider performing more controlled merges. We note that the “Quick Merge” demonstrated earlier produced, if anything, too small of an estimate of the overall  $t_c$  value. Let’s imagine that our goal is to generate longest flow path segments such that:

- There is one (1) overland flow segment
- There is one (1) swale flow segment
- There are three (3) channel segments of roughly equal length

There is no “undo” tool for generating longest flow path segments. We can however “reset” the longest flow path to the original condition of each pixel representing a unique segment. This is done by again choosing the “Select Sub-Area” tool and selecting the sub-area for which we want to revise the  $t_c$  estimate.

The Velocity Segment Generator dialog will again appear as it did in Figure 3. As a first step, to obtain the one overland flow and one swale flow segment, we will choose the “Quick Merge” check boxes for just these two elements of the longest flow path. Although not shown, this results in a calculated  $t_c$  only slightly reduced from the default 38.57 hours to 38.06 hours.

We now take on the task of reducing the



**Figure 7.** Merging the first channel segment from upstream pixel 13 to downstream pixel 140.

channel flow portion of the longest flow path from 380 segments to 3 segments of roughly equal size. This would mean each segment is composed of roughly 380/3 or approximately 127 pixels. The very first channel pixel commences at UpPixel = 13, so the first segment would end at “DownPixel” = 140. This is shown in Figure 7 at the moment before pressing the “Recalculate Tc” button. After pressing that button, the overall  $t_c$  becomes 30.18 hours and the number of channel segments is reduced to 254. We repeat this process two more times: for “UpPixel = 140 and “DownPixel” = 267” and for “UpPixel” = 267 and “DownPixel” = 393. This results in the final condition of the Velocity Method Segment Generator shown in Figure 8, where the  $t_c$  is now 12.93 hours, about 1.5 hours greater than the  $t_c$  that

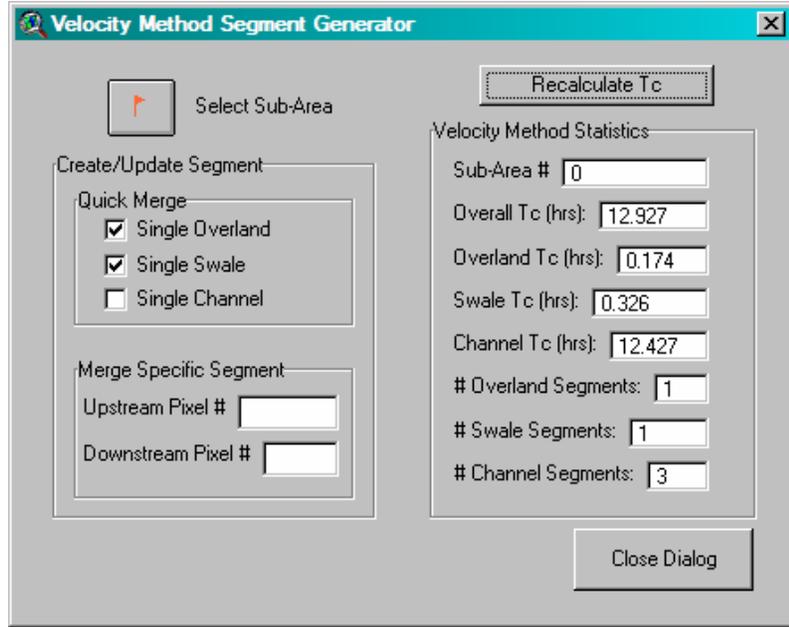


Figure 8. The Velocity Method Segment Generator after the channel portion of the longest flow path has been merged into 3 segments.

Attributes of Tcpath0.shp																
Shape	UpPixel	SegName	Type	DownPixel	Avg Area	UpElev	DownElev	Slope	Width	Depth	Xarea	L Length	Tot Length	Vel	L Time	Tot Time
PolyLine	1	M1	Mixed	2	0.00	44.3	43.2	0.007903	-1.00	-1.00	-1.00	139.2	139.2	0.22	0.174	0.174
PolyLine	2	S1	Swale	13	0.01	43.2	37.8	0.004334	-1.00	-1.00	-1.00	1245.7	1384.9	1.06	0.326	0.500
PolyLine	13	C1	Channel	140	0.86	37.8	18.2	0.001427	9.71	0.96	9.27	13763.8	15148.7	0.97	3.951	4.450
PolyLine	140	C2	Channel	267	3.97	18.2	5.8	0.000809	17.40	1.57	27.16	15231.6	30380.3	1.02	4.144	8.595
PolyLine	267	C3	Channel	393	8.25	5.8	-0.9	0.000472	22.97	1.98	45.30	14277.0	44657.3	0.92	4.332	12.927

Figure 9. Table for longest flow path corresponding to a single segment for each type of flow (condition of time of concentration consistent with Figure 5).

resulted from “Quick Merging” the channel into a single segment. Figure 9 shows the corresponding table for this flow path. This is just an example, but it illustrates how the engineer has complete control over the number and composition of longest flow path segments.

The engineer may wonder how and when the sub-area  $t_c$  values are recorded. Previously, the  $t_c$  values were set at the time that the “Calculate Attributes” menu choice was selected. This is still the case, however, if the engineer subsequently chooses to use the Velocity Method Segment Generator any merges performed using this dialog will result in instantly updated values for  $t_c$  for the selected sub-area. The last  $t_c$  determined in any sub-area is the  $t_c$  that will ultimately be written to the TR-20 input file. Again, if the engineer is not pleased with a particular merge, the merge cannot be undone, but the  $t_c$  for that sub-area can be reset to the original condition by using the “Select Sub-Area” tool.

## Guidance

We arrive now at the ultimate question of guidance. What is the “correct” value for  $t_c$ ? Here I believe 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 Will Thomas or SCS lag equations.
- Examine the “Attributes of TcPathx.shp” file and look for occurrences of unrealistically low velocities. For instance, consider Figure 10 which shows a

Attributes of Tcpath0.shp																
Shape	UpPixes	SegName	Type	DownPixes	Avgz Area	UpElev	DownElev	Slope	Width	Depth	Xarea	L Length	Tot Length	Vel	L Time	Tot Time
PolyLine	167	C155	Channel	168	2.50	17.9	17.9	0.000069	14.60	1.35	19.65	98.4	18597.7	0.27	0.101	16.514
PolyLine	168	C156	Channel	169	2.51	17.9	17.9	0.000069	14.60	1.36	19.67	139.2	18736.9	0.27	0.143	16.658
PolyLine	169	C157	Channel	170	2.51	17.9	17.9	0.000069	14.62	1.36	19.70	139.2	18876.1	0.27	0.143	16.801
PolyLine	170	C158	Channel	171	2.54	17.9	17.4	0.003592	14.68	1.36	19.87	139.2	19015.3	1.95	0.020	16.821
PolyLine	171	C159	Channel	172	2.55	17.4	16.7	0.005029	14.69	1.36	19.89	139.2	19154.5	2.31	0.017	16.838
PolyLine	172	C160	Channel	173	2.56	16.7	15.7	0.007184	14.72	1.36	19.95	139.2	19293.7	2.76	0.014	16.852
PolyLine	173	C161	Channel	174	2.56	15.7	15.3	0.002874	14.73	1.36	19.98	139.2	19432.9	1.75	0.022	16.874
PolyLine	174	C162	Channel	175	2.57	15.3	13.6	0.012213	14.74	1.37	20.01	139.2	19572.1	3.61	0.011	16.884

**Figure 10.** Part of the table for longest flow path with very small slopes and resulting very small travel velocities for the top three records shown.

small portion of a pixel-based channel flow path in which very small slopes are determined from the DEM (for the top three records shown) which result in very small velocities and resulting in long incremental travel times. If larger segments are generated by judicious merging of individual pixels, these very local features are “averaged out” and tend 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 GISHydro2000 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 to reflect 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 TR-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 TR-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.