

GISHydro2000: A Tool for Automated Hydrologic Analysis in Maryland

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Abstract

This paper presents a GIS-based program called GISHydro2000. This tool was developed by the author and is used extensively by state government and private consultants in the development of predictions for flood behavior in the state of Maryland. This paper presents a demonstration of the program's overall functionality and underlying spatial database. An actual example watershed will be analyzed to illustrate how GISHydro2000 works and the tools it provides.

Introduction

GISHydro2000 is a GIS-based program that automates hydrologic analysis of any watershed in the state of Maryland. This program has been developed under funding by the Maryland State Highway Administration (MDSHA). Engineers at MDSHA and consultants to MDSHA make extensive use of this program for all hydrologic analysis submitted for permits to the Maryland Department of the Environment. In the mid-1990's to the present, the state has convened a Hydrology Panel consisting of academics, government experts, and private consultants with experience in hydrology and hydraulics. This Panel has recently released its report providing recommendations on how to properly carry-out hydrologic analyses within Maryland (Ragan et al., 2004). GISHydro2000 was developed in concert with this report and is the tool recommended by the Panel for performing hydrologic analyses.

GISHydro2000 combines an extensive database of topography, land use, soils, rainfall frequency-depth, and other ancillary data with GIS-based tools that speed the analysis of many watershed characteristics, execute USGS and other flood-frequency regression equations, and acts as a graphical user interface to the NRCS TR-20 (SCS, 1984) rainfall-runoff model. The purpose of this paper is to provide an overview of the basic functionality of this tool through an example watershed analysis.

Selection of Data

Figure 1 presents the opening screen of GISHydro2000. The red rectangular outlines correspond to individual 7.5 minute USGS quadrangles. The quads shown comprise the entire set of quads necessary to account for all watersheds both in the state of Maryland and those watersheds which drain into the state of Maryland. The only exceptions to this are along the main stem of both the Potomac and Susquehanna

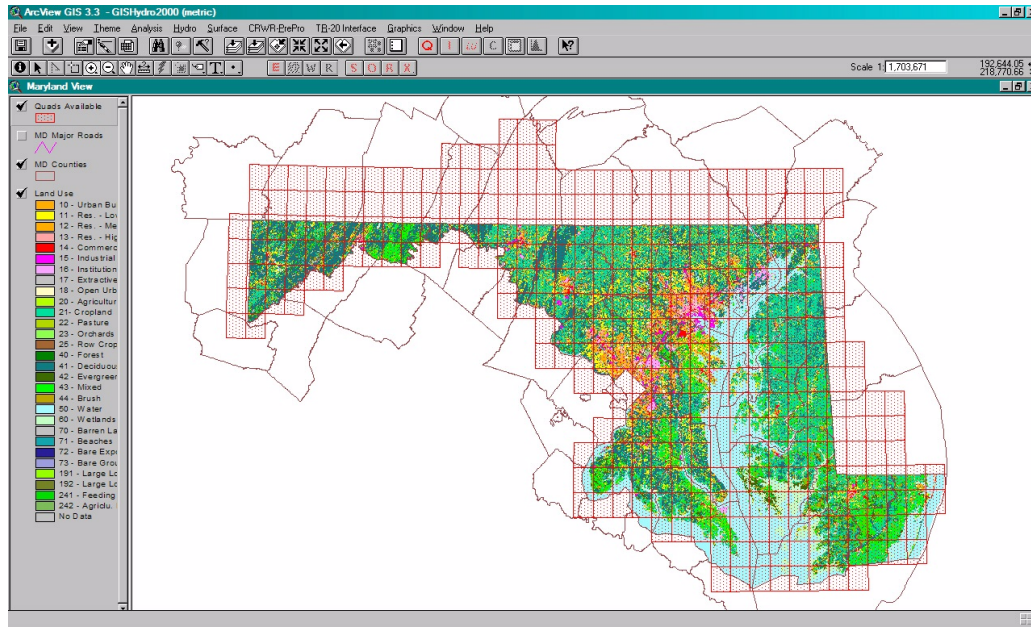


Figure 1. The opening “Maryland View” screen of GISHydro2000.

ivers which would necessarily include much of Virginia (in the case of the Potomac) and much of Pennsylvania and even New York (in the case of the Susquehanna).

Pressing the “Q” button initiates an analysis in which the first step is the specification of the planned spatial extent of the analysis. The user indicates this spatial extent by selecting one or more quads for analysis. This step is shown in Figure 2 which illustrates the “Select Quadrangle(s)” dialog box. Shown selected is a single (Kensington) quadrangle which defines the areal extent of the planned analysis. There are three categories of spatial data that must be selected by the user at this point: DEM data (topography), land use, and soils. GISHydro2000 contains three different sources of DEM data (with the shown NED – National Elevation Dataset (USGS, 2005a) data being the best quality), nine different sources of land use data which include recent satellite imagery from the national land cover dataset (USEPA, 2005) and several statewide generalized land use products from 1985 to 2000 (shown), and soils data are available in three different sources: SSURGO (NRCS, 2005a), STATSGO (NRCS, 2005b) and a homegrown layer developed from scanned county soil maps. Finally, the check boxes in the lower right concern whether the DEM will be interpreted for flow directions and flow accumulation (yes, if the “Perform Processing” box is selected) and whether streams should be imposed where they have been digitized in the National Hydrography Dataset – NHD (USGS, 2005b) (yes, if the “Burn Streams” box is selected). The value of 250 entered for the

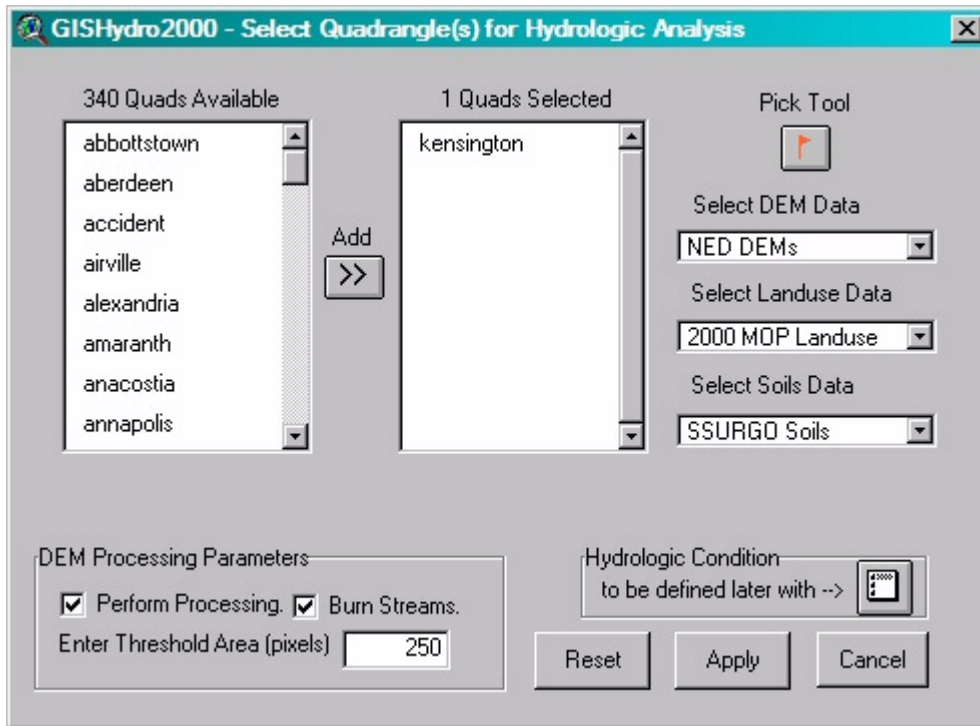


Figure 2. The “Select Quadrangle(s)” dialog box.

threshold area is simply a count in 30 meter x 30 meter pixels used to define the minimum area required to form a stream. This is a visualizing device that will be used to infer stream locations in the next part of the analysis. Once the “Apply” button is selected the data indicated in the dialog box are extracted from the GISHydro2000 database, and any indicated processing is performed.

Watershed Delineation, Characteristics, and Flood Frequency

At the completion of all data extraction and processing, GISHydro2000 creates the “Area of Interest” view as shown in Figure 3. Figure 3 shows the view window after the next step of watershed delineation has taken place. Watershed delineation is a task that is easily accomplished by the GIS, with the user only needing to indicate, with a mouse click, the location of the outlet of the watershed. In this example, a watershed has been delineated at the intersection of a road and the stream network. This is a typical application of GISHydro2000 since hydrologic engineers are concerned with such locations where bridges or culverts must be constructed at road/stream intersections.

The delineated watershed is now used by the GIS to overlap the existing data layers and determine a suite of watershed characteristics. These characteristics are determined by the user simply choosing the “Basin Statistics” menu choice which produces the dialog box shown in Figure 4. These statistics include estimates of all the watershed characteristics necessary to estimate flood frequency using the current USGS rural regression equations (Dillow, 1996) and some more recent regression equations based on USGS gage data but that also include measures of urbanization

where urbanization is sufficient to influence flood frequency relations (Ragan et al., 2004).

The two-year flood from regression equations by Dillow (1996) and Ragan et al. (2004) are provided in equations 1 and 2, respectively,

$$Q_2 = 451A^{0.635}(F + 10)^{-0.266} \quad (1)$$

where Q_2 is the 2-year peak discharge in ft^3/s , A is the drainage area in mi^2 and F is the percent forest cover, and,

$$Q_2 = 37.01A^{0.635}(IA + 1)^{0.588} \quad (2)$$

where IA is the percent impervious area. Figure 4 shows that the drainage area of the watershed shown in Figure 3 is 3.8 mi^2 with 6.9 percent forest cover and 39.4 percent impervious area. We insert these values into equations 1 and 2, respectively,

$$Q_2 = 451 \cdot (3.8)^{0.635} (6.9 + 10)^{-0.266} = 495 \text{ ft}^3/\text{s} \quad (3)$$

$$Q_2 = 37.01 \cdot (3.8)^{0.635} (39.4 + 1)^{0.588} = 760 \text{ ft}^3/\text{s} \quad (4)$$

The calculations shown in equations 3 and 4 do not need to be performed by hand. Instead, the user may simply choose two menu choices in GISHydro2000, “Calculate Dillow Discharges” and “Calculate Thomas Discharges”, respectively. The Dillow discharges response is shown in Figure 5. The Thomas discharges response is not shown, but is similar in spirit. As shown in this figure, GISHydro2000 determines the 2- through 500-year peak discharges along with confidence intervals around each of these discharges based on the standard errors of the USGS regression equations. It is worthwhile to pause momentarily here to note that with just a few mouse clicks to indicate analysis extent, desired data sets, and watershed outlet location, GISHydro2000 has allowed the rapid determination of watershed characteristics and flood frequency. Computation speed varies somewhat with analysis extent, but for illustrative purposes the results shown here can be produced within less than 5 minutes on a 650MHz CPU. These same calculations, performed by manual techniques, could easily consume many hours or even days depending on watershed size.

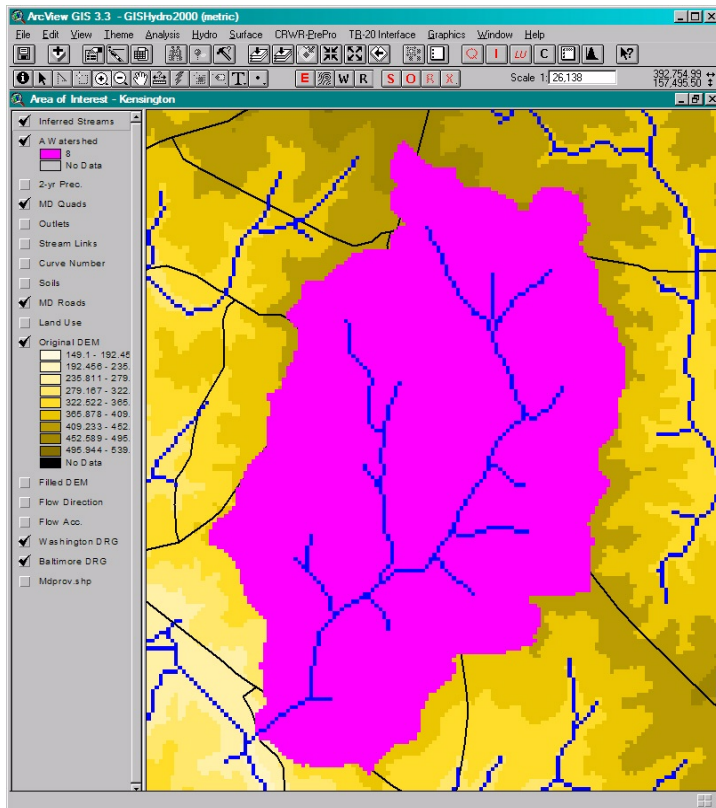


Figure 3. The “Area of Interest” view focused on a delineated example watershed.

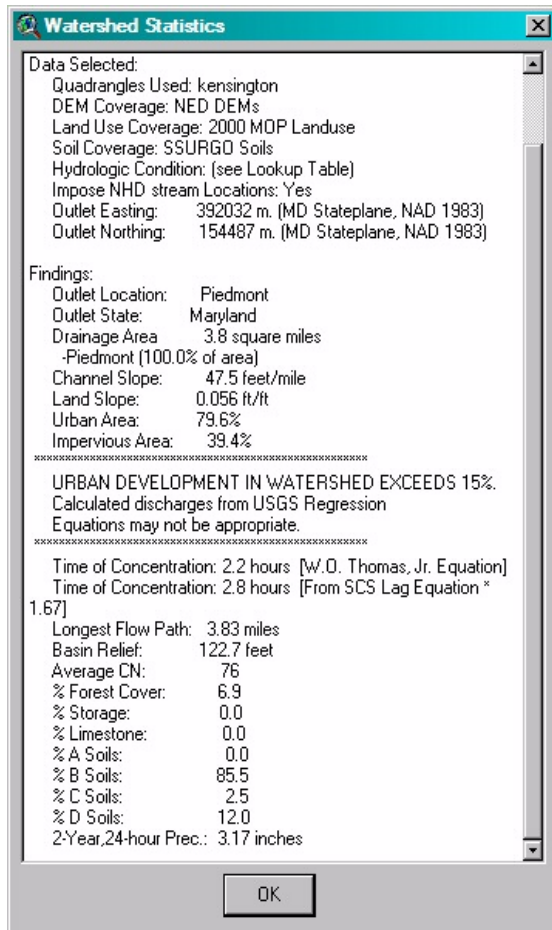


Figure 4. Watershed statistics for example watershed.

dating as far back as the 1960's and at least as recently as the 1980's means that today's engineers need to be fluent in both current technology and in material that is not quite so current. The reality is that regulatory agencies often still require watershed analyses to be based on these legacy programs. This is the case in Maryland where TR-20 (SCS, 1984) is a required analysis tool.

Building a TR-20 input file can be a time consuming undertaking.

Not shown here are additional capabilities within GISHydro2000. For example, this tool can readily determine the analogous flood frequency outcomes for the Ragan et al., (2004) regression equations. Further, GISHydro2000 has an ancillary supporting layer of the location of all USGS stream gages in and around Maryland. If the watershed outlet indicated by the user should correspond to a stream location within +/- 50 percent of the drainage area of a gaging location, GISHydro2000 will prompt the user as to whether he/she wishes to produce a weighted flood frequency estimate based on a combination of the regression equations for the observed flood frequency at this gage and the flood frequency that would result from the regression equations alone.

GISHydro2000 as a Front-End to TR-20

The legacy of card image-based hydrology and hydraulic programs

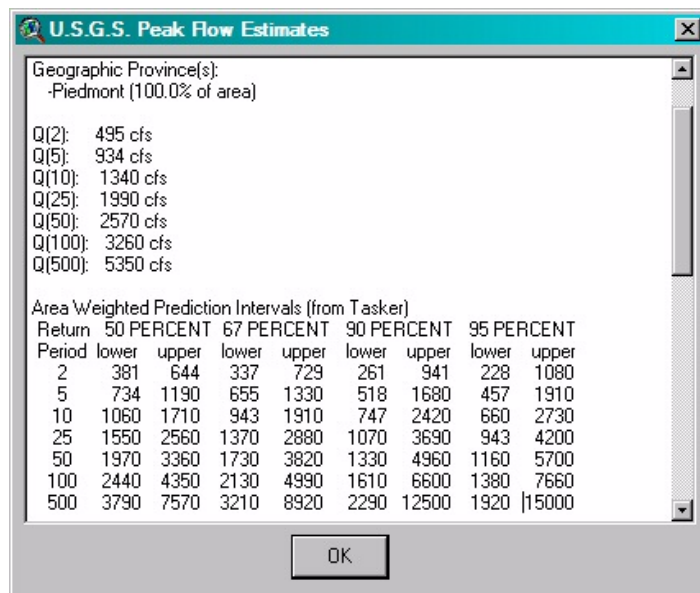


Figure 5. USGS flood frequency results and confidence intervals for example watershed.

The user must first sub-divide (if necessary) the watershed into an appropriate set of sub-areas, and symbolically name each sub-area so that the topological connectivity of each sub-area within the entire watershed can be correctly communicated to the program. Further, the user must determine a suite of characteristics: drainage area, average curve number, and time of concentration for all delineated sub-areas within the overall watershed.

GISHydro2000 has been constructed to streamline the development of a TR-20 input file. The tedium of sub-area delineation and sub-area characteristic determination is handled by GISHydro2000 so that the user can focus on the modeling decisions, such as where to sub-divide, and what parameters to choose to most appropriately characterize the flow path defining the time of concentration.

We begin with sub-area delineation. Figure 6 shows the study watershed sub-divided into three sub-areas. This sub-division is controlled by the user by indicating to GISHydro2000 the location of all significant stream sources. These sources are traced downstream where any confluence with other streams results in a point of sub-division. Figure 6 illustrates two upstream sub-basins which combine and then flow through a downstream sub-area to the overall watershed outlet. Additional sub-division can be indicated by the user through the specification of internal outlet points that might physically represent locations where structures such as bridges or detention basins exist or where the physical conditions change rapidly such as moving from an agricultural to an urban setting.

Once the watershed is sub-divided the user needs to define the conditions that will determine the time of concentration within each sub-area. This is accomplished with the “Time of Concentration Calculation” dialog box illustrated in Figure 7. The user is presented with three methods for determining the time of concentration. Two of these methods are regression-based but the third method, the velocity method (SCS, 1986), is the recommended method and depends on additional input information defining the sheet flow, shallow concentrated flow, and channel

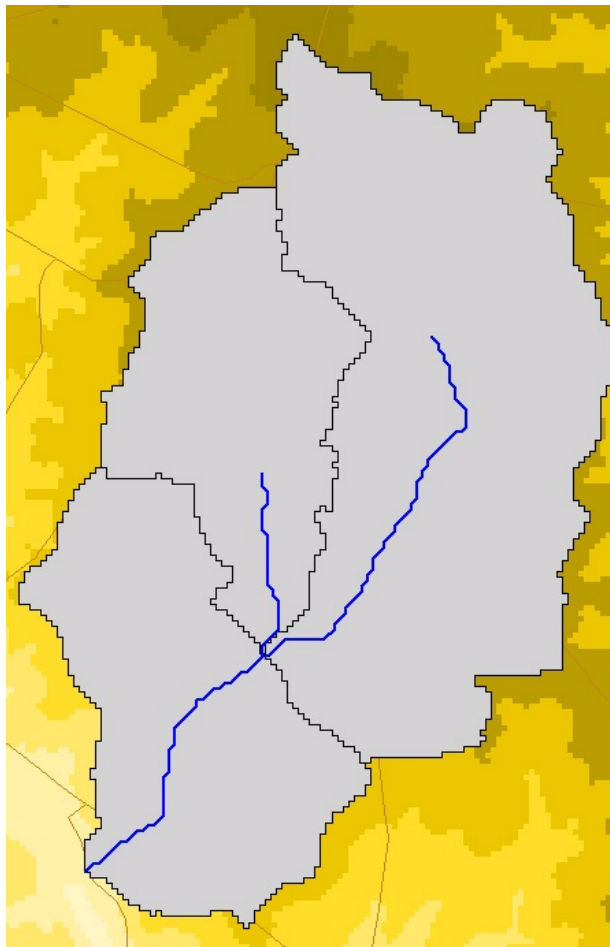


Figure 6. Sub-area delineation with the example watershed.

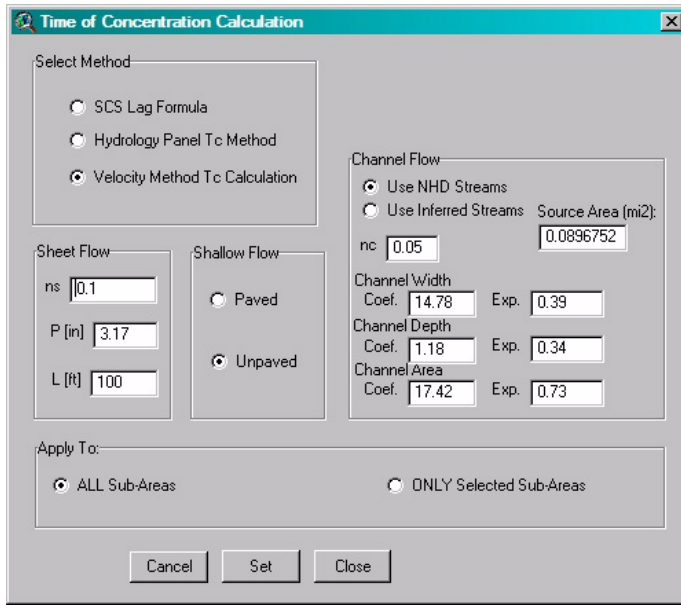


Figure 7. Dialog box to specify the parameters of the time of concentration calculation.

based on whether conditions are paved or unpaved. Channel flow is based on Manning's equation which requires information about Manning's n for the channel ($n = 0.05$, is the default). The channel geometry is based on hydraulic geometry relationships developed for the state of Maryland by the U.S. Fish and Wildlife Service (McCandless and Everett, 2002; McCandless, 2003a, McCandless 2003b). The upstream extent of the channel may be defined either by the 1:100,000 scale NHD streams (USGS, 2005b) or by a minimum source area. Slope is calculated directly from the DEM.

Once the parameters defining the time of concentration calculation have been selected, the GIS calculates the attributes for all sub-areas. This includes rigorously examining all possible flow paths within a sub-area to determine

flow portion of the longest flow path. These inputs are indicated by the entries shown in the boxes in Figure 7. In the case of sheet flow, default values for Manning's n ($n = 0.1$) and the maximum length of overland flow ($L = 100$ feet) are shown. The 2-year, 24-hour precipitation depth is determined from an embedded precipitation data layer in the GISHydro2000 database and is uniquely determined based on the areal extent of the delineated watershed. Shallow flow has only one input as shown

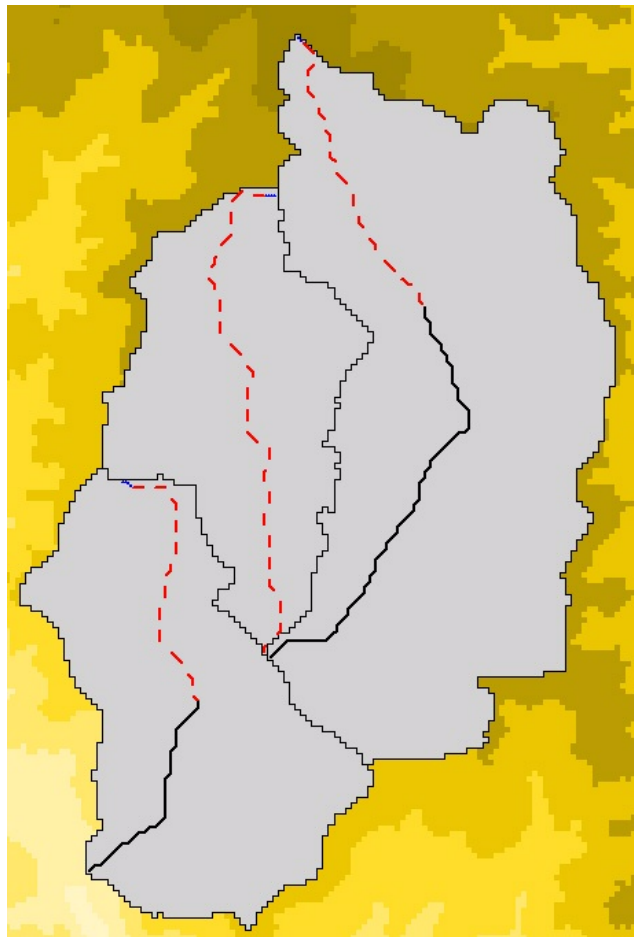


Figure 8. Time of concentration flow paths for each sub-area in example watershed.

the path with the longest overall travel time. The GIS adds a layer for each sub-area showing the actual longest flow path for each sub-area. These longest flow paths are shown in Figure 8 for the example watershed. The small dotted upland reach in each sub-area is the sheet portion of the time of concentration, the dashed red length of each flow path is the shallow concentrated portion of the flow path, and the solid black portion is the channel part of the flow path. (Note that the northwestern sub-area in the example watershed does not have a channel portion to its longest flow path because there is no channel in this sub-area according the NHD). The reader should be aware that since all these calculations are being done in the GIS, there are tabular attribute data being determined for all themes as the user defines the parameters that describe the watershed being examined. The GIS view window is useful for visualizing the spatial organization of the watershed, but it is ultimately these tabular attribute data that are used to write the input file required by TR-20.

The next step is to have the GIS define the topological connectivity of all sub-areas within the watershed. This is done by a simple menu choice selection and results in a “stick diagram” depicting the idealized representation of the watershed topology. This diagram is shown in Figure 9. Note that each sub-area has a source node as indicated by the blue dots at the watershed centroid. The red node indicates the overall watershed outlet location while the yellow node indicates an internal location where two sub-areas meet. Connectivity is indicated by black lines showing the location where locally-generated runoff from a sub-area will first appear. In this case, the two northern sub-areas will generate runoff that first appears at the internal node/confluence, while the southern sub-area will only appear at the overall watershed outlet. The red line indicates a routing reach that will transfer runoff from the internal node/confluence to the overall watershed outlet.

The user must now develop a rating table for the routing reach indicated in Figure 9. The user does this by choosing the cross-section tool from the GIS interface and physically drawing a line to indicate the location of a cross-section across the routing reach. Doing so produces the dialog box shown in Figure 10. The user can control the channel and overbank Manning’s n values (the values shown are default values) and the bankfull channel geometry (determined from the sampled drainage area at the cross-section location and the hydraulic geometry equations from the US Fish and Wildlife Service discussed earlier). Any change to these entries will cause the “Recalculate” button to become active. When this button is pressed, the stage-discharge-end area relationship shown in the large box on the right will update. This is the rating table that will be associated with this reach. Pressing

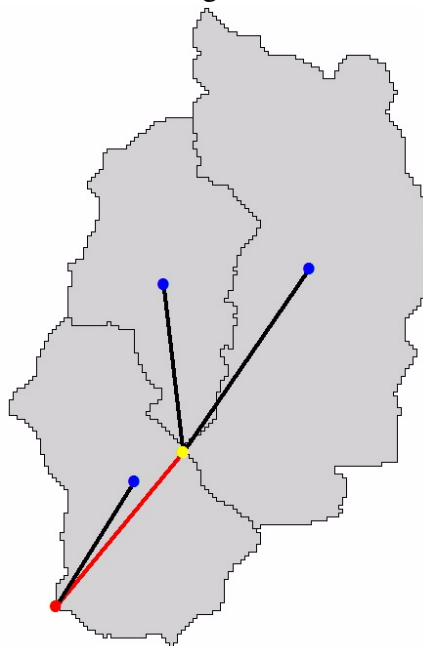


Figure 9. Topological description of the example watershed.

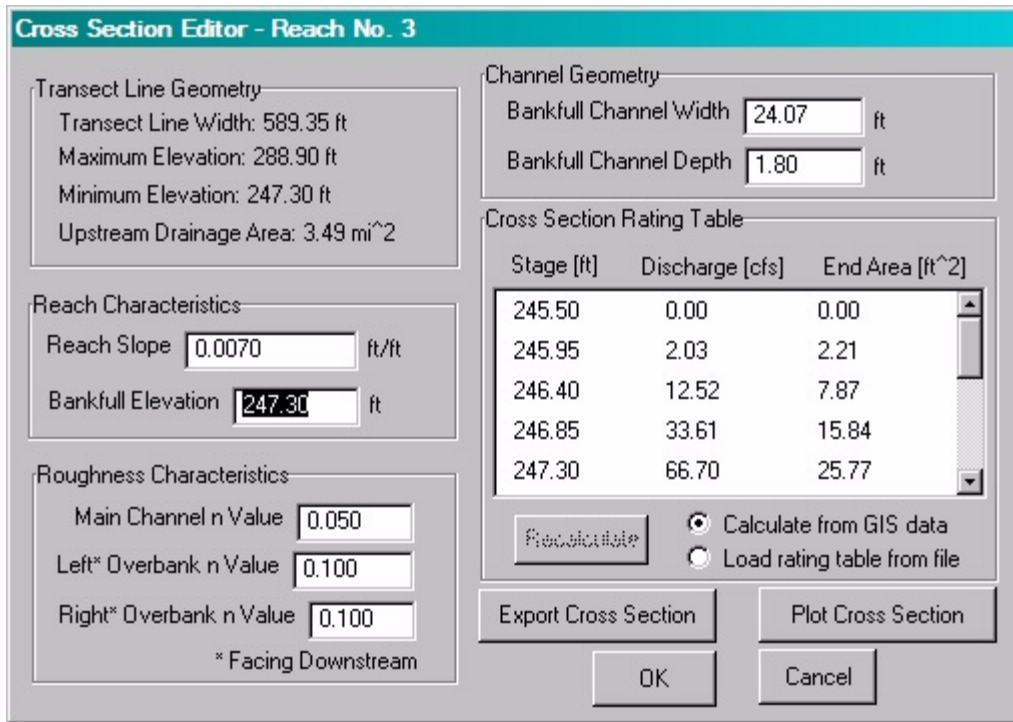


Figure 10. Cross-section editor dialog used for generating a rating table for the routing reach in the example watershed.

the “Plot Cross Section” button provides a graph of the sampled cross-section as shown in Figure 11. The reader should note that most of the cross-section shown in Figure 11 corresponds to overbank flow conditions and is determined directly from the DEM. However, the small incised channel visible at approximately (station=450 ft., elevation=247 ft.) is artificially introduced into the cross-section and corresponds to the geometry indicated in the “Channel Geometry” section of the dialog box shown in Figure 10.

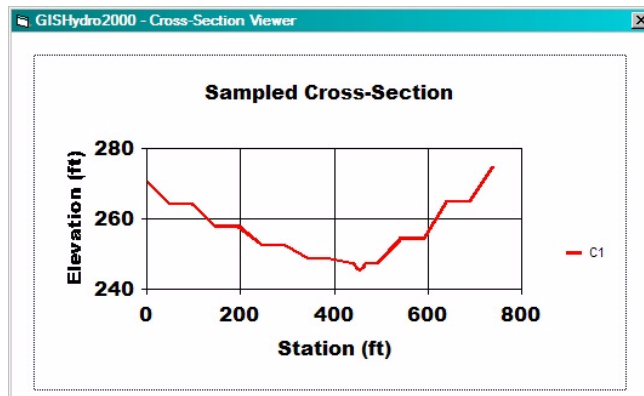


Figure 11. Sampled cross-section for routing reach in example watershed.

TR-20 requires the user to specify a storm depth for which a hydrograph will be simulated. Embedded within the GISHydro2000 database are 24 precipitation-frequency data layers from the NOAA Atlas 14 (NWS, 2005) study recently completed for the Ohio River Basin. The user need only click on any or all desired storms which he/she intends to model. (Shown in Figure 12 only the 2-year, 10-year, and 100-year, 24-hour storms are selected.) GISHydro2000 will determine the precipitation depths for these selected storms and make them available for modeling in the next and last step in the

development of a TR-20 input file. These depths are unique to the watershed being studied since the watershed outline is used to sample the data contained in the NOAA Atlas 14 database.

The last step to create a TR-20 input file is to indicate to GISHydro2000 all the information that is not “gis-able”. That is all information that can not somehow be determined by the GIS, but is necessary to execute TR-20. This information is conveyed to GISHydro2000 through the “TR-20 Control Panel” dialog box shown in Figure 13. This information includes input and output file names, the selection of various output options, the storm depth to be chosen and the antecedent conditions. (Shown in Figure 13, only the 2-year storm depth of 3.17 inches has been selected.)

Pressing the “OK” button in this dialog will initiate the writing of the TR-20 input file to the indicated location in the dialog (“c:\temp\tr20in.dat” in this case).

We can now actually execute the TR-20 program. This can be done from

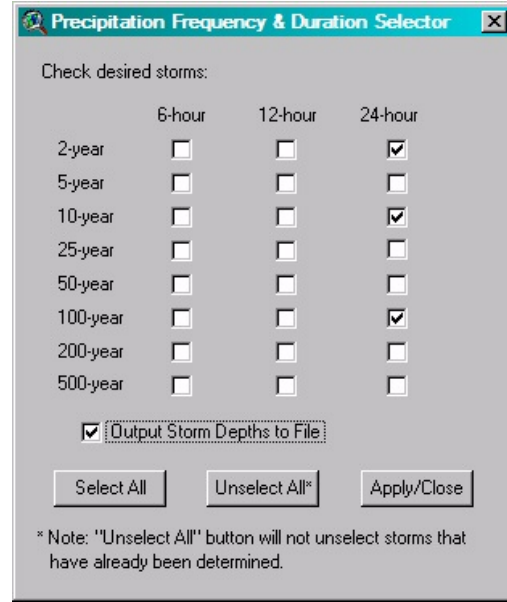


Figure 12. Dialog box for storm selection within TR-20.

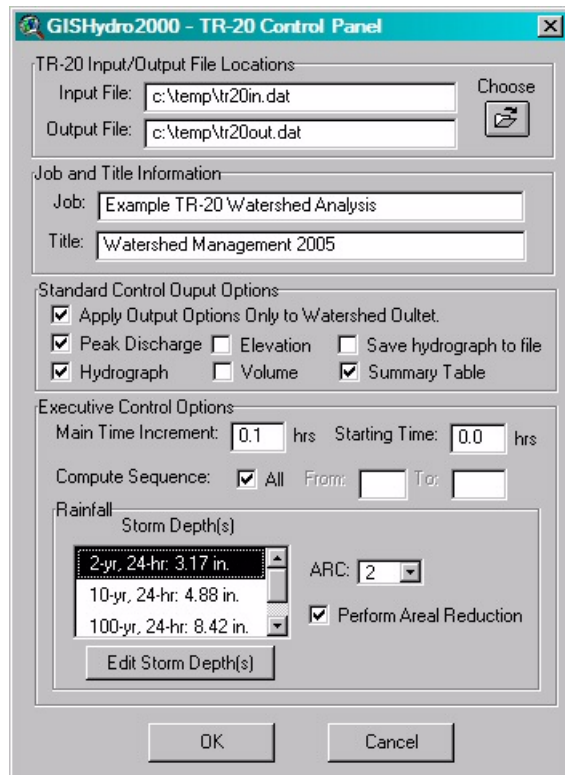


Figure 13. TR-20 Control Panel dialog box with sample inputs shown.

within the GISHydro2000 interface by selecting the “Execute TR-20” menu choice. The user will observe TR-20 executing from within a DOS window and then a text editor window will open up with the output from the TR-20 simulation loaded into this window as shown in Figure 14. At this point, the main function of GISHydro2000 has been completed but the user’s job is now to examine this output, compare it against, other information, and determine if further calibration is necessary. In this case, note that the circled area in Figure 14 indicates a simulated 2-year peak discharge of about 773 ft³/s (compare to the USGS regression equation value of 495 ft³/s determined in equation 3 and 760 ft³/s for the Ragan et al., (2004) regression equations). Given the highly non-rural nature of this watershed (which renders the use of USGS rural equations

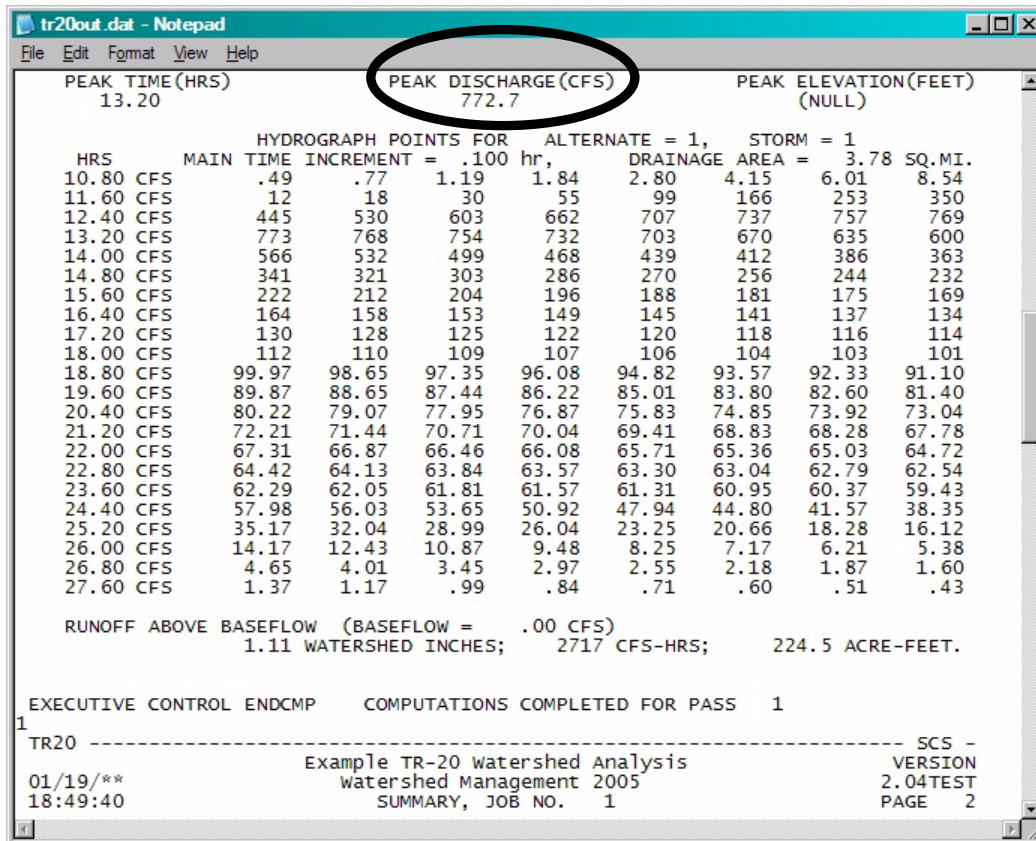


Figure 14. Sample portion of output from TR-20 simulation for example watershed.

inappropriate), the strong agreement between the TR-20 peak and the result from equation 4 would seem to indicate that little or no additional calibration is necessary. In other cases where the agreement is not so strong, the user might decide there is a need to cycle back and re-assess many of the choices made in developing the TR-20 input file. This might include the selections of Manning's n values, watershed subdivision choices, location where the routing table cross-section was determined, etc. GISHydro2000 provides a useful tool where such secondary or tertiary analyses are possible. Without such a tool time constraints may have otherwise precluded the performance of such subsequent analyses.

Summary

This paper presented the GISHydro2000 program which combines a large spatial database and numerous GIS-based tools to quickly perform hydrologic analyses anywhere in the state of Maryland. This presentation illustrated the primary functionality of the program in the context of the analysis of a small watershed. DEM, land use, and soils data were extracted from the database. A watershed was delineated and its characteristics were determined. These characteristics were used to drive two different sets of flood frequency equations. Next, a TR-20 model was constructed and several tools were illustrated that helped sub-divide the watershed, determine time of concentration within each sub-area, and generate a rating table for

the reach routing within the watershed. Final results for the 2-year flood based on TR-20 and one set of flood frequency regression equations (that accounted for urbanization) showed strong agreement.

The author invites interested readers to examine this GISHydro2000 more closely. It may be freely downloaded at:

<http://www.gishydro.umd.edu>

To use GISHydro2000 you must have ArcView (version 3.2 or higher) with the Spatial Analyst extension (version 1.1 or higher). Readers familiar with GIS software may be curious if this tool is compatible with the new ArcGIS 8.x or 9.x software. It is not. However, a project is currently underway between the author and MDSHA to port GISHydro2000 to this new GIS platform.

Acknowledgements

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