Foreword

This training manual was developed to support training workshops on the use of GISHydro2000 software. It contains general information about ArcView, GIS-hydrologic modeling techniques, instructions on use of the software, detailed exercises, and supporting reference materials.

GISHydro2000 is an ArcView GIS-based application for conducting hydrologic analyses in the State of Maryland. Sponsored by the Maryland State Highway Administration, GISHydro2000 integrates a complete database of terrain, land use, and soils data with tools for assembling and evaluating hydrologic models including regional regression equations and TR-20. The program is designed to support the procedures for hydrologic analysis recommended by the Maryland Hydrology Panel.

This manual will not directly follow the lectures presented in the training workshop. Rather, it serves as a document for future reference when using the software and for further explanation of its concepts. Several exercises are included to reinforce the lecture material beginning with assembly of data for a hydrologic analysis and ending with application of calibration procedures recommended by the Maryland Hydrology Panel. The exercises will be performed during the course of the workshop to emphasize the step-by-step techniques used.

The GISHydro software is evolving continually and being enhanced. Recent additions include interactive tools for land use modification and for travel time estimation. Multiple peak discharge estimation methods have been included as well as tools for altering the hydrologic conditions of the area of interest. A CD-ROM with the current version of the software will be provided to the workshop participants; however this represents only a snapshot of the program. Users are encouraged to visit the GISHydro@Maryland website (www.gishydro.umd.edu) frequently so that you can always have the most up-to-date version of the software and data.

The Department of Civil and Environmental Engineering has a well established program of research and instruction in the field of GIS applied to hydrologic and hydraulic modeling. In addition to occasional training seminars and workshops, there are currently both undergraduate and graduate courses including: “ENCE301 – Geo-Metrics and GIS in Civil Engineering”, “ENCE688Z – GIS for Watershed Analysis”, and “ENCE688R – “River Engineering.”

We invite you to explore the training materials, courses, and research publications we have available. The GISHydro software initiative has been and continues to be a cooperation between academia, federal, state, and local government, as well as private consultants. This cooperation continues to produce powerful tools to support engineering, conservation, and planning efforts within the State.
Thank you for registering for the training workshop. For more information, please contact the author of this document:

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From the mid-1980’s through the present, Dr. Robert Ragan of the University of Maryland developed a QuickBasic-based program called GISHydro for use at the Maryland State Highway Administration and throughout the state. This program contained land use and soils data for the entire state of Maryland and enabled engineers to perform rapid and automated hydrologic analyses. The ArcView based project discussed in this document, GISHydro2000, was conceived in the spirit of GISHydro but designed to take advantage of a Windows-based operating system, the default industry-standard GIS, and further the automation capabilities of the original software with automated basin delineation based on DEMs. GISHydro2000 is continually evolving but it is an established program and provides hydrologic engineers with the tools and data necessary to perform a range of hydrologic analyses in the State of Maryland.

**Data / Files included**

GISHydro2000 includes many different types of files and coverages. We will briefly discuss each of these in turn. As an engineer, you should take special note of the extents and the relative quality of each coverage. There is redundancy among the included files so you may wish to repeat analyses several ways using different data sets to develop an appreciation for the potential range of “correct” answers. We will try to indicate which coverage in each category is of the most superior quality, but it is often the case that the higher quality data covers a much more limited extent of the state or...
region. The more extensive an area you set out to analyze, the more likely you will be forced to use poorer quality data over that area.

Data often comes in a variety of coordinate systems: UTM, State Plane, Geographic. For uniformity, we have projected all data sets to the Maryland State Plane (NAD ’83) coordinate system and datum. All raster data have been resampled at 30 meters resolution. The units of all data sets are in meters, although GISHydro2000 internally converts all calculations to be in English units.

Coverages of DEMs, Land Use, and Soils are organized into files named after the USGS 7.5-minute quadrangle maps. Each complete coverage is zipped-up into a single *.zip file to minimize storage needs. The file selection script within GISHydro2000 performs the necessary calls to the software to unzip and merge, if necessary, multiple quadrangles together.

**DEM – Digital Elevation Models**

We are all familiar with contour lines on topographic maps. A Digital Elevation Model (DEM) is simply a raster (or grid) representation of the same information. At each pixel a single representative number is used to indicate elevation over the pixel’s small extent.

We currently provide three different coverages of DEMs with GISHydro2000: NED DEMs, 30m DEMs, and 90m DEMs. All three coverages have their source origins as USGS products. In general, the higher the data resolution, the better the quality of answers derived from it although sometimes, there can be idiosyncratic artifacts in one coverage that do not appear in the other. We recommend the use first of the NED DEMs, followed by the 30m DEMS, and finally the 90m DEMs.

**USGS Data**

These data were either obtained directly from the USGS or from websites distributing USGS DEM data. Although the 90m data have been resampled to 30 meters their inherent quality still reflects their native 90m resolution. You will find these files in the following locations:

- \umdgism\dems\30m_dems\ned_dems.zip
- \umdgism\dems\30m_dems\30m_demms.zip
- \umdgism\dems\90m_dems\90m_demms.zip

**Land Use**

Land Use data have been obtained from a number of sources and their quality and resolution reflect those origins. We include nine different data sets: USGS (1970’s), Ragan (1985), Ragan (1990), Maryland Office of Planning (MOP) (1990), MOP (1994), MOP (1997), MOP (2000), Ultimate, and EPA – MRLC (~1992).

**USGS 1970’s Land Use**

This data set was obtained from the EPA BASINS web site as part of their “core” dataset. These data have their origins in the GIRAS dataset produced by the USGS during the 1970s. These files are distributed in 1° by 2° quadrangle blocks at a map scale of
1:250,000 with a resolution of 200 meters. The vintage of the files ranges from 1972 to 1977 depending on the quadrangle. You will find these files in the following location:

- `\umdgism\lu70\lu70m_grids.zip`

**Ragan, 1985 Land Use**

These data have been converted from their original GISHydro format to be compatible with GISHydro2000. These data have an inherent resolution of 400ft by 500ft so they will look patchy in comparison to other coverages of land use. These data were originally developed from paper maps that were scanned and digitized by hand. These data cover within the state of Maryland only. You will find these files in the following location:

- `\umdgism\ragan\l85_grids\l85m_grids.zip`

**Ragan, 1990 Land Use**

These data are similar to the Ragan, 1985 data but capture all updates to changes in land use between 1985 and 1990. You will find these files in the following location:

- `\umdgism\ragan\lan_grids\lanm_grids.zip`

**Maryland Office of Planning, 1990 Land Use**

These data were obtained from the Maryland Office of Planning and should be used only in a manner consistent with the following disclaimer:

*The LandUse/Land Cover data set you have selected has been provided courtesy of the Maryland Department of Planning. Any use of that data set outside of this application without the permission of the Department of Planning is prohibited. For more information on Department of Planning data, please visit the MDP web site http://www.mdp.state.md.us or call (410) 767-4500.*

These data were originally in vector format with a minimum mapping unit of 10 acres. These data were converted to a raster format and sampled at 30 meter resolution. You will find that these data are consistent with the Ragan, 1985 and 1990, but a visual inspection will quickly indicate a greater degree of detail is contained in these data. These data cover within the state of Maryland only. Please note that any analysis extending beyond the boundaries of Maryland will not have complete land use definition when using MOP data. You will find these files in the following location:

- `\umdgism\lu90\lu90m_grids.zip`

**Maryland Office of Planning, 1994**

These data are similar to the Maryland Office of Planning, 1990 data (and carry the same disclaimer) but capture all updates to changes in land use between 1990 and 1994. You will find these files in the following location:

- `\umdgism\lu94\lu94m_grids.zip`
Maryland Office of Planning, 1997
These data are similar to the Maryland Office of Planning, 1990 data (and carry the same disclaimer) but capture all updates to changes in land use between 1994 and 1997. You will find these files in the following location:
- \umdgism\lu97\lu97m_grids.zip

Maryland Office of Planning, 2000
These data are similar to the Maryland Office of Planning, 1990 data (and carry the same disclaimer) but capture all updates to changes in land use between 1997 and 2000. You will find these files in the following location:
- \umdgism\lu2000\lu2km_grids.zip

Maryland Office of Planning, 2002
These data are similar to the Maryland Office of Planning, 1990 data (and carry the same disclaimer) but capture all updates to changes in land use between 2000 and 2002. You will find these files in the following location:
- \umdgism\lu2002\lu2002m_grids.zip
These data were originally in vector format with a minimum mapping unit of 10 acres. These data were converted to a raster format and sampled at 30 meter resolution. Please note that any analysis extending beyond the boundaries of Maryland will not have complete land use definition when using MDP data.

Ultimate Landuse
This is a unique coverage of land use that reflects the most recent available data from the Maryland Department of Planning (formerly MOP) which currently is the 2002 land use. These data are updated according to zoning information obtained from each individual county. Where land has already been developed, the current and ultimate land use are the same. Where land is currently in agricultural or forested land uses, the land use has been updated to reflect any development that may occur according to the zoning at that location. For more specific details on this coverage, see the final report submitted by Moglen to MDSHA and appearing at the GISHydro2000 website at:


EPA – MRLC (Multi-Resolution Land Cover)
These data come from an EPA Region 3 data set with a native 30m resolution and a date of approximately 1992. These data were derived from unsupervised classification of satellite images including leaf-on and leaf-off images to distinguish between deciduous and coniferous forests. This data set is the only land use coverage that extends beyond the boundaries of the state of Maryland. As such, it will be the only coverage available to
you should your region of study extend beyond the state. (Users of this dataset are cautioned that, because this dataset reports land *cover* rather than land *use*, there is a tendency to over-estimate forest cover when using this dataset. Where this quantity is a predictor in regression equations, the over-estimation of forest cover would lead to a lower estimate of peak discharges.) You will find these files in the following location:

- \umdgism\mrlc\mrlcm_grids.zip

**Soils**

Hydrologic Soil type as defined by the NRCS is contained in three different provided coverages. These coverages are STATSGO, Ragan, and SSURGO and are discussed below. Since ArcView must work with numbers (not letters) we use A=1, B=2, C=3, and D=4 (and water =-1).

**STATSGO**

This coverage is actually stored as a vector format and converted to raster (100 foot resolution) on the fly within GISHydro2000. The resolution of this coverage is the poorest of the three, but these data cover the entire region of GISHydro2000, not just what lies within the Maryland borders. You will find the shapefile associated with this coverage at:

- \umdgism\maryland\statsgo_allm.shp

**Ragan**

This coverage is similar in quality to the Ragan, 1985 and 1990 land use coverages. These data were scanned from county soil maps and hand digitized and are identical to those found in the original GISHydro. The native resolution is a 400 ft by 500 ft pixel, but has been resampled to 30 meter resolution. These data cover only within the state of Maryland. You will find these data at:

- \umdgism\ragan\scs_grids\scsm_grids.zip

**SSURGO and Draft SSURGO Soils data** *(draft data are shown in italics)*

These data are of very high quality and resolution, but are not available in all counties within the state of Maryland. Counties where these data are available: Anne Arundel, Baltimore City, *Baltimore County*, *Caroline*, Carroll, *Cecil*, *Charles*, Dorchester, Frederick, Harford, Howard, Kent, Montgomery, Queen Annes, *Somerset*, St. Marys, *Talbot*, Washington, *Wicomico*, and Worceester. In addition, eight counties in Pennsylvania that are included in GISHydro2000 are: Adams, Bedford, Delaware, Franklin, Fulton, Lancaster, Somerset, and York counties. Two counties in Delaware that are included in GISHydro2000 are: Kent and Sussex counties. Finally, SSURGO soils for the Washington DC area are also included. These data were converted from vector format and sampled at 30 meter resolution. Extreme care should be taken when using this data that the watershed(s) being studied lies entirely within only the counties listed above. You will find these files in the following location:

- \umdgism\ssurgo\ssurgom_soils.zip
Draft SSURGO data carries the following disclaimer:

The SSURGO data set you have selected includes data that are currently in "Draft Copy" form and have been provided courtesy of the Natural Resources Conservation Service (NRCS). These data are the best estimates available at this time, but are subject to change without notice. Any estimates made from these data should be carefully evaluated. For more information on NRCS SSURGO data, please visit the Soil Data Mart web site at http://soildatamart.nrcs.usda.gov or contact the State Soil Scientist, James H. Brown at (443) 482-2913.

Precipitation
The NOAA Atlas 14, Volume 2 (Ohio River Basin and Surrounding States) dataset has been added since 2000. For details about the source of these data, please see: http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_gis.html
These data are included in GISHydro in grid format and are resampled at 30m resolution at the time of data extent specification. Data are available for the 1, 2, 5, 10, 25, 50, 100, 200, and 500 year storm events and for 6, 12, 24, and 48 hour durations.

Enlarged Data Extent
With new support from the Delaware Department of Transportation, the spatial extent of GISHydro was expanded in 2006 to include all land area in the state of Delaware and additional land area in Pennsylvania southwest of the Delaware River. In all, 30 new 7.5 minute quads were added to the spatial extent of GISHydro.
A new land use layer that represents a composite of Maryland Department of Planning 2002 land use and Delaware Planning 2002 land use. The link to the Maryland Data is:
http://www.mdp.state.md.us/zip_downloads_accept.htm
and the link to the Delaware data is:
These two datasets were fused along the MD/DE stateline and used to create a single continuous raster layer of land use. Land use codes from Delaware were multiplied by 1000 so as to keep the two coding schemes distinct. You will find these files in the following location:

Miscellaneous
There are a number of other odds and ends of files which make GISHydro2000 work or simply make it easier to work with. These are listed below.

National Hydrography Dataset (NHD) (formerly EPA River Reach (RF3))
The EPA publishes a data set termed “River Reach Files”, or because of a file naming convention, these files are often simply called “RF3 files”. We include these data only within the boundaries of our study region both for reference and as a tool to help guide the DEM drainage network determination (this will be discussed more later). These data are a vector shapefile format located at:

Miscellaneous
There are a number of other odds and ends of files which make GISHydro2000 work or simply make it easier to work with. These are listed below.
**Maryland and Adjacent Counties**

We provide a vector polygon coverage of the counties within Maryland and immediately bordering Maryland. This data set is located at:

- `\umdgism\maryland\mdcountystpm.*` (where `*` = “shp”, “shx”, and “dbf”)

**Maryland Physiographic Provinces**

The physiographic provinces of Maryland as defined in the USGS Peak Discharge Regression Equations report by Dillow (1996) are contained in a vector shapefile called:

- `\umdgism\maryland\mdprovm.*` (where `*` = “shp”, “shx”, and “dbf”)

**Maryland Major Road Network**

The centerlines of major roads within the region are contained in a vector shapefile called:

- `\umdgism\maryland\mjr-rds_stpm.*` (where `*` = “shp”, “shx”, and “dbf”)

**USGS Quads Coverage**

This quads data set illustrates the USGS 7.5-minute boundaries for all quadrangles within the study region. This is a very important data set as it keeps track of all the information contained within the overall database. If you use the identify button to click on any one random quad, you will quickly obtain the quad name, the state(s) that lie within it, and whether or not SSURGO data is available. This vector shapefile is located at:

- `\umdgism\maryland\quads83v3.*` (where `*` = “shp”, “shx”, and “dbf”)

**Digital Raster Graphics (DRG) Images**

Large scale digital raster graphics covering all but the extreme southern row of the 7.5 minute quads in the quads83v3 extent are available in GISHydro2000:

- `\umdgism\maryland\drgs\baltstpm`
- `\umdgism\maryland\drgs\cumbstpm`
- `\umdgism\maryland\drgs\salistpm`
- `\umdgism\maryland\drgs\washstpm`
- `\umdgism\maryland\drgs\wilmstpm`

These DRGs are stored as grids but serve only as pictures to provide a large scale background that may be useful for spatial reference in some cases.

**USGS Gage Network Coverage**

This shapefile provides the spatial location of all (current and inactive) USGS gages within the State of Maryland as well as other selected gages located in surrounding states. This vector shapefile is located at:

- `\umdgism\maryland\usgsgagesm.*` (where `*` = “shp”, “shx”, and “dbf”)

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Using GISHydro2000

Having completed this review of the data, we are now prepared to begin to use GISHydro2000 to extract data or perform hydrologic analyses.

The “Maryland View” Window

The first window you will see when entering GISHydro2000 is the “Maryland View” window shown at right. Before sitting down to a session with GISHydro2000 you should have a good notion of the approximate location and extent of the watershed you wish to study. A very good piece of information to have on hand is the approximate location of the watershed outlet relative to the (major) road network. Poor initial estimates of the watershed extent may require second and third iterations at the “select quadrangles” step described below.

The “Select Quadrangles” Dialogue Box

To begin the quadrangle selection process, make sure the “Quads Available” theme is active. Then click on the red, “Q” button which brings up the dialogue box shown at right. You will begin by selecting one or more quadrangles of data to be analyzed. If you know the quadrangle name, you can simply search for it in the “Quads Available” list at the upper left, or if you prefer to work more visually, you can click on the “Pick Tool” and add the quads to the “Quads Selected” list. Note that you must click the “Add” button if you are selecting quads by name from the “Quads Available” list.

The next step is to identify the data coverages you want (e.g. DEMs, Land Use, and Soils). Please note that depending on the particular quad(s) you have selected some of the choices enumerated earlier in the “Data Files Included” section, may not be available for your particular site. If this is the case, you should have seen information messages flash across the dialogue box indicating the lack of a particular type of data set. (For example, the above warning concerning the non-presence of SSURGO soils data within the entirety of the Sandy_Spring quad.) Within the confines of those data sets that are still available to you, you should use the scroll arrows for each desired data set and
blacken the choice you wish to make for each data type. You can actually select “None” for any data type, but not for all three. When choosing the data coverages you want you should try to select the best available coverage as determined from the commentary provided above in the “Data Files Included” section. You may also wish to try several variations to develop a sense of the variability in your derived answer.

The “Hydrologic Condition” are of this dialog is a vestige of previous versions of GISHydro2000 where the user could select either “Good” or “Fair” hydrologic conditions that would be universally applied across the entire extent of the selected data. This is no longer the case. “Good” hydrologic conditions are applied initially by default. After the data are selected, the user can invoke the change hydrologic conditions dialog and modify hydrologic conditions on a category-by-category basis. A separate section, discussing this dialog is provided elsewhere in this handout and can also be located at the GISHydro2000 documentation web page.

There remains to discuss two “check” mark boxes which toggle on and off. The leftmost box, “Perform DEM Processing” controls whether in GISHydro2000 the software will determine flow directions, and drainage areas from the provided DEM. If you click this box off, you will have to perform DEM processing at a later time should you wish to automatically delineate a watershed. If you simply wish to extract a quad or two of data for use elsewhere you should click the box off. Clicking this box off greatly speeds the process of simple data extraction. If you wish to perform DEM processing (i.e. the leftmost box is checked “on”), you additionally have the choice of “Burning Streams” or not. If you click this box off, flow directions and drainage areas will be determined from the DEM alone. If you leave the “Burn Streams” box checked “on”, the National Hydrography Dataset (NHD) files described earlier will be used to impose the known drainage network associated with the more major streams and rivers in the state. This is the suggested course as it does not add any significant compute time to the analysis and can greatly enhance the determined flow directions and drainage areas, especially in regions of flat relief, rivers with wide floodplains, and if poor resolution DEMs must be employed.

You have control of is the “Threshold Area” determination. This is the number of pixels required to form a stream. In essence you are being asked a question about the drainage density of the area you are studying. While the answer that you give will not affect any subsequent analyses, it will have a profound effect on the appearance of the inferred channel network that will be provided. The smaller the number you specify, the more channel network you will see. The value of 250 pixels provided by default has been found to be fairly representative of streams in this region. We suggest changing it only if you have a very special purpose in mind.

The bottom part of the dialog box indicates the path where all files associated with the planned analysis will be saved. The “c:\temp\” portion of this path is unchangeable, but you can control the final part of the path. A random 5-digit number will be placed here by default but can be replaced with more meaningful text by the user if desired. The last step in the process is to click the “Apply” button. Notice that you can “Cancel” completely out of the process or click the “Reset” button to redo the process from the beginning.
The “Area of Interest” Window

Once you select the “Apply” button you have initiated a process that can take under a minute to 10’s of minutes depending on the clock speed of the machine you are working on and the extent and nature of the selection process you have specified. For reference, a single quadrangle processed on a 1 GHz machine will require under a minute to complete. In any case, eventually, you will see the “Maryland View” window give way to the “Area of Interest” view window focused on the quad(s) you have identified. A typical “Area of Interest” view window (for the Kensington quad) is shown below:

Contents

There are a number of themes you will find automatically placed in the “Area of Interest” view window. These themes (from top to bottom) are: 2-yr Prec., MD Quads, MD Roads, Outlets(*), Stream Links(*), Inferred Streams(*), Curve Number, Soils, Land Use, Original DEM, Filled DEM(*), Flow Direction(*), Flow Acc.(*), one of more digital raster graphics (DRG) files, and Mdprov.shp. The items indicated with a (*) will only be present if DEM processing has been requested. Obviously if you chose “None” for any of the basic coverage types, then the theme associated with that coverage would be missing from this view.

Performing Watershed Analysis

One possible direction you will follow at this time is to perform a watershed analysis which will consist first of delineating a watershed within the bounds of the area
of interest. From there GISHydro2000 will guide you through the process of determining watershed parameters, ultimately leading to estimates of the Thomas (and other) Peak Discharge Equations. Details on following this course of action will appear in a later section.

**Extracting Data**

The other possible direction is that you will simply wish to extract data from the “Area of Interest” view and move on to an analysis outside of GISHydro2000. Extracting data is easy. You simply click on the red “E” tool and then drag a rectangular box over the subregion of the “Area of Interest” that you wish to extract. You will be prompted with two choices. The first choice is whether you wish to export to an ASCII Grid or ArcView Grid format. We suggest the ASCII Grid format for moving to WMS. The ArcView Grid format may be useful for subsequent analyses of these data external to the GISHydro2000 program but still using the ArcView GIS software. The second choice (actually three sub-choices) will be the file names and locations for all extracted data. Please be certain you control the destination of these files or you may have difficulty locating them later.

**Watershed Analysis**

Strictly speaking, the functionality discussed in this section is not part of GISHydro2000, but is rather a series of programs which exist as a “Hydro Extension” to ArcView. Some of these programs were developed originally by the creators of ArcView itself, and later modified at the University of Maryland, Department of Civil and Environmental Engineering to suit our needs. Most are codes generated entirely by us to facilitate the specific task of watershed characterization and peak discharge estimation.

**The “Hydro Menu”**

The “Hydro” menu choices are shown at right. Depending on whether DEM Processing has already been performed some or all choices but the “Properties” item may be grayed out and unavailable. As each step is performed in sequence, the next “Hydro” menu choice will become active. Let us examine, in turn, each of the choices in this menu.

**Setting “Properties”**

Clicking on the “Properties” item of the “Hydro” menu will produce the extended file naming dialogue shown at right. The “OK” button will remain grayed out until you have entered some form of text for the the “Project Identifier”. For all entries but the “Project Identifier” you should indicate the name of the theme that contains the property indicated. In some cases you will be telling the “Hydro” extension where to find the data it will need to work with, in other cases you will be controlling the names of output themes created by the “Hydro” extension. The provided default names are consistent with the naming scheme of GISHydro2000, but you can change any name to reflect particular studies you might wish to perform external from GISHydro2000.
• **Project Identifier:** For this item you may enter anything you want, but it is suggested you enter something meaningful to you as this information will be written so several output text files as a label.

• **Original DEM:** You should place here the name of the theme that contains the original DEM before any processing has occurred. This is a required input to the “Hydro” extension. It cannot be created by the extension.

• **Filled DEM:** This theme will be created by the “Hydro” extension should you select the “Fill” or “Process DEM” menu selections. The Filled DEM is much the same as the Original DEM except that certain low point anomalies in the topography have been “filled” to provide for drainage everywhere throughout the extent of the data set.

• **Flow Direction:** This theme will be created by the “Hydro” extension should you select the “Flow Direction” or “Process DEM” menu selections. The extension uses the Filled DEM theme to determine flow directions in one of eight directions (east, southeast, south, southwest, west, northwest, north, or northeast) for each pixel within the data set.

• **Flow Accumulation:** This theme will be created by the “Hydro” extension should you select the “Flow Accumulation” or “Process DEM” menu selections. The extension uses the Flow Direction theme to determine the cumulative area (in pixels) draining to each pixel within the data set.

• **Delineated Watershed:** Once the DEM has been processed, it is possible to delineate a watershed. The resulting theme is a raster quantity with every pixel within the basin set to a single value, and every pixel exterior to the basin set to “no data”. This theme will be created by the “Hydro” extension through the use of the “W” tool.

• **Land Use:** You should place here the name of the theme containing information of land use distributions over the area being studied. This theme must be present in the view from the outset of the analysis. This is a required input to the “Hydro” extension.

• **Soil Type:** You should place here the name of the theme containing information on the distribution of hydrologic soil type within the region being studied. This presence of this theme is optional to the “Hydro” extension, but it must exist for the “Basin Composition” menu choice to become active.

• **Curve Number:** This theme is the product of a table lookup operation given knowledge of the soils and land use distributions. GISHydro2000 creates this theme automatically when generating the “Area of Interest” view. This is a required input to the “Hydro” extension. It cannot be created by the extension.
• **Basin Relief:** This theme is generated by the “Hydro” extension given the “Original DEM” and “Flow Direction” themes. Selecting the “Hydro” menu choice, “Show Basin Relief” will add this theme to the view. Although basin relief is spatially distributed as indicated by the “Basin Relief” theme, in reality, the only value of any importance is the value of the “Basin Relief” theme at the watershed outlet.

**Delineating a Watershed**

Before attempting to delineate a watershed you must have successfully completed processing the DEM covering the basin you wish to study. We strongly suggest you also select the “Show Channels” item from the “Hydro” menu if they are not already included in your view. This will aid in the process of locating the pixel to select as your watershed outlet.

Say you are interested in delineating the watershed associated with the channel that is draining to the southwest as shown in the inset at right. To assure you select the correct pixel, it is a good idea to zoom in tightly on the vicinity of the outlet. Select the “W” Tool from the tool bar and then simply click the mouse on top of the pixel you wish to be the outlet of the basin. ArcView will perform some calculations for a little while, but will eventually return, having created a “Watershed” theme.

It cannot be stressed strongly enough that you closely and carefully inspect your delineated watershed to be sure it agrees well with the basin you were anticipating. You should be especially suspicious of any watershed which ends right at the border of selected data. Watersheds that extend to the border of the data often have straight boundaries. This indicates that more watershed lies beyond the boundaries of the data, and you should return to the “Select Quadrangles” dialogue box making sure to choose additional data along the area(s) where straight borders were observed.

Once you are satisfied with the watershed you have delineated you can proceed to the final steps of the analysis. The figure at above right shows the watershed delineated in this example.

**Basin Composition**

Selecting the “Basin Composition” item from the “Hydro” menu will generate two ArcView tables: “Distribution of Land Use by Soil Group” and “Distribution of Land Use and Curve Numbers Used” as shown below for the sample watershed shown on the previous page. These two tables are organized similarly to tables generated by the
original GISHydro program. A prompt is given by the software to additionally write out the contents of these two tables to a file specified by the user.

### Find Similar Gages

This menu choice is of value for rapidly determining the subset of all U.S.G.S. stream gages located in Maryland that hold similar watershed properties to the watershed that the user has delineated. Selecting the “Find Similar Gages menu” choice will produce the dialogue box shown above. By selecting the desired search attributes and adjusting the provided slider bars appropriately, the user can develop a query of the overall Maryland stream gage database to determine those gages that are most similar to the delineated watershed. Care should be taken not to make the search criteria too strict or too lenient, lest no gages, or too many gages satisfy the search criteria, respectively. At present, the only supported search attributes are drainage area and %Forest cover. The database to support more exhaustive queries is currently under construction. All U.S.G.S. stream gages satisfying a query generated with the above box will be indicated as highlighted entries in a pop-up table, and will also be highlighted in the USGSpages theme in the “Area of Interest” view.
Basin Statistics

Selecting the “Basin Statistics” item from the “Hydro” menu will produce a dialogue box like the one shown at right. The information contained in this dialogue includes all the data needed to estimate peak discharges given any of the available sets of peak discharge regression equations. Additionally, a prompt is given by the software to write out the contents of this dialogue box to a file specified by the user. Notice that a warning will be printed in the event that the impervious area exceeds 15% of the watershed area. In this case, it will be necessary to adjust any discharges estimated using the USGS Peak Flow regression equations with the USGS Urban Equations (Sauer et al, 1983). If the Thomas peak flow equations are selected, it is not necessary to adjust the discharges since the Thomas equations incorporate a measure of urbanization in their formulation.
Thomas Peak Discharge Estimation

The Q_{1.25} through Q_{500} discharges estimated from the Thomas (Moglen, et al., 2006) equations are computed by selecting the “Calculate Thomas Discharges” item from the “Hydro” menu. The regression equations that lead to these discharge estimates are the equations that 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 TR-20 model.

Dillow Peak Discharge Estimation

The Q_{2} through Q_{500} discharges estimated from Dillow (1996) are computed automatically by selecting the “Calculate Dillow Discharges” item from the “Hydro” menu. In addition to the peak discharge estimates, confidence intervals on these estimates corresponding to 50%, 67%, 90%, and 95% are also determined from a U.S.G.S. developed program developed by Gary Tasker. In the event the watershed spans more than one geographic province area weighted estimates of both the peak discharges and the confidence intervals are determined. Not shown in the dialogue box at left is the lower half of the output which details the exact output from the Tasker program. Once the “OK” button is selected, a prompt is given by the software to write out the contents of this dialogue box to a file specified by...
the user. (Note: peak discharge estimates can **not** be calculated with this menu choice if the watershed outlet is determined to be outside of the boundaries of Maryland.)

**U.S.G.S. Hydrograph Estimation**

A second publication by Dillow (1997) outlines a procedure to estimate hydrographs given a known flow peak (such as the peaks determined using the previous menu choice. Select the “Calculate Hydrograph” menu choice and you will be prompted by a dialogue box such as the one shown at right. You must select a hydrograph peak associated with one of the return intervals 2 through 500 years (the 2-year return interval is shown selected at right). Once you have selected a return interval, a second dialogue box will appear such as shown at right. This box shows the determined hydrograph time and discharge values. Notice that the calculated hydrograph peak (495 ft³/s) corresponds with the peak estimated from the previous menu choice and offered as a selection option in the previous dialogue box. Once the “OK” button is selected, a prompt is given by the software to write out the contents of this dialogue box to a file specified by the user. In this fashion, the user can quickly import this data into another program (such as Excel) and generate a plot of this discharge hydrograph.
**Compare Discharges**

The compare discharges menu choice allows the engineer to rapidly compare discharges from among five methods: Carpenter (former USGS equations), Dillow (current USGS equations), Thomas (fixed region equations – selected for design by Maryland Hydrology Panel), L-moment, and Region of Influence (ROI). The discharge estimates and the discharge estimates plus one standard deviation are provided for each method. Calibration of TR-20 is expected for the Thomas equations between the best estimate and the best estimate plus one standard deviation. For instance, in the table shown below, if the 100 year discharge is the design criteria, it will be necessary to calibrate TR-20 to produce estimates between 4,640 ft³/s and 6,070 ft³/s (see Thomas and Thomas +1SE columns in table).

<table>
<thead>
<tr>
<th>Return Period</th>
<th>Carpenter</th>
<th>Carpenter+1SE</th>
<th>Dillow</th>
<th>Dillow+1SE</th>
<th>Thomas</th>
<th>Thomas+1SE</th>
<th>L-Moment</th>
<th>L-Moment+1SE</th>
<th>ROI</th>
<th>ROI+1SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.25 Year</td>
<td>589.0</td>
<td>589.0</td>
<td>999.0</td>
<td>589.0</td>
<td>444.0</td>
<td>589.0</td>
<td>999.0</td>
<td>589.0</td>
<td>999.0</td>
<td>999.0</td>
</tr>
<tr>
<td>1.50 Year</td>
<td>589.0</td>
<td>589.0</td>
<td>999.0</td>
<td>589.0</td>
<td>612.0</td>
<td>589.0</td>
<td>999.0</td>
<td>589.0</td>
<td>999.0</td>
<td>999.0</td>
</tr>
<tr>
<td>1.75 Year</td>
<td>589.0</td>
<td>589.0</td>
<td>999.0</td>
<td>589.0</td>
<td>689.0</td>
<td>589.0</td>
<td>999.0</td>
<td>589.0</td>
<td>999.0</td>
<td>999.0</td>
</tr>
<tr>
<td>2 Year</td>
<td>582.0</td>
<td>587.0</td>
<td>495.0</td>
<td>580.0</td>
<td>757.0</td>
<td>580.0</td>
<td>757.0</td>
<td>580.0</td>
<td>757.0</td>
<td>757.0</td>
</tr>
<tr>
<td>5 Year</td>
<td>589.0</td>
<td>1030.0</td>
<td>934.0</td>
<td>1260.0</td>
<td>1370.0</td>
<td>1260.0</td>
<td>1370.0</td>
<td>1260.0</td>
<td>1370.0</td>
<td>1370.0</td>
</tr>
<tr>
<td>10 Year</td>
<td>589.0</td>
<td>1500.0</td>
<td>1340.0</td>
<td>1350.0</td>
<td>1930.0</td>
<td>1350.0</td>
<td>1930.0</td>
<td>1350.0</td>
<td>1930.0</td>
<td>1930.0</td>
</tr>
<tr>
<td>25 Year</td>
<td>1530.0</td>
<td>2300.0</td>
<td>1990.0</td>
<td>2360.0</td>
<td>2920.0</td>
<td>2360.0</td>
<td>2920.0</td>
<td>2360.0</td>
<td>2920.0</td>
<td>2920.0</td>
</tr>
<tr>
<td>50 Year</td>
<td>540.0</td>
<td>320.0</td>
<td>2570.0</td>
<td>2760.0</td>
<td>3650.0</td>
<td>2760.0</td>
<td>3650.0</td>
<td>2760.0</td>
<td>3650.0</td>
<td>3650.0</td>
</tr>
<tr>
<td>100 Year</td>
<td>500.0</td>
<td>460.0</td>
<td>3260.0</td>
<td>3500.0</td>
<td>4640.0</td>
<td>3500.0</td>
<td>4640.0</td>
<td>3500.0</td>
<td>4640.0</td>
<td>4640.0</td>
</tr>
<tr>
<td>200 Year</td>
<td>330.0</td>
<td>599.0</td>
<td>599.0</td>
<td>599.0</td>
<td>599.0</td>
<td>599.0</td>
<td>599.0</td>
<td>599.0</td>
<td>599.0</td>
<td>599.0</td>
</tr>
<tr>
<td>500 Year</td>
<td>330.0</td>
<td>599.0</td>
<td>5360.0</td>
<td>5360.0</td>
<td>7740.0</td>
<td>5360.0</td>
<td>7740.0</td>
<td>5360.0</td>
<td>7740.0</td>
<td>7740.0</td>
</tr>
</tbody>
</table>

**Export ROI Equations**

The Region of Influence method generates a unique set of regression equations for each watershed analyzed. For reporting purposes, it is necessary to write out these equations. By choosing this menu selection a file export dialog box is invoked and the engineer is prompted to enter the name of an output text file that will contain these regression equations. For the example shown here, the screen capture at right shows the ROI equations generated which may be useful for reporting purposes or if further analyses with the ROI equations are planned.
Exercise I-A: Beginning a Hydrologic Analysis with GISHydro2000

Every analysis performed using GISHydro2000 begins with the assembly of the necessary GIS data for the required extent. In this exercise, you will use GISHydro2000 to select data to begin a hydrologic analysis.

Task
Using GISHydro2000, begin a hydrologic analysis for the watershed upstream of USGS Stream Gage No. 01650500 near Randolph Road in Montgomery County, Maryland. Use the GIS themes in the Maryland View to locate the basin outlet and estimate the extent of the watershed. Select the USGS quadrangles covering the area of interest and choose the appropriate data layers (DEM, Land Use, and Soils) for further analysis.

Locate Outlet and Select Quads

*Note: The following Section describes how to find an outlet location to estimate which quad sheets are needed. If the quad sheets are already known, skip to the section below titled “Selecting Quads”.

The location of the watershed has been given at USGS Stream Gage No. 01650500 above Randolph Road. The Maryland View contains themes useful for finding this location. Select the theme called “MD Major Roads” and make it active, so that its legend “pops out” from the other legends. Open the Query Builder and select the Query option from the Theme Menu. The window on the left lists the field names in the MD Major Roads theme attribute table. The window on the right of the query builder lists the unique values for each field. Select the “Update Values” check box and build the following query by double-clicking on the [Hwynname] field, selecting the “=” relation, and scrolling through the value list to find Randolph Road.

( [Hwynname] = "RANDOLPH RD" )
Once the query expression is typed, press the “New Set” button to select Randolph Road from the MD Major Roads Theme. With the selection made, now we can zoom in to the selected area by pressing the button (Zoom-to-selected). When this button is pressed View window will zoom to the extent of the selected Randolph Road, which will be colored yellow.

Based on the location of the road, use the 1:250k Baltimore DRG theme (1:250,000 USGS topographic map) to estimate the overall size of the watershed (you may have to turn off, or re-order some themes to see it drawn correctly). Let’s assume that we have identified the quads that cover the drainage area of the Northwest Branch in the general facility of Randolph Road. They include:

- Kensington
- Beltsville
- Clarksville
- Sandy_Spring

We will now use the Select Quads Dialog Box to select these quads.

**Selecting Quads**

While in the Maryland View, open the **Select Quads Dialog Box** using the “Q” button from the button-bar. The dialog box shown below will open. Select the four quads above from the alphabetical list or visually using the pick tool. The quads are located just north of the northern-most part of Washington, DC. The graphic below shows the selected quads:
Select Data Types
The best resolution terrain data available in GISHydro2000 are the 30m USGS DEMs, which comprise the National Elevation Dataset (NED). Use this data for this exercise. Select 2000 MOP Land Use from the land use pull down menu. For soils data, select Ragan Soils. Note that a warning message has appeared in the center of the dialog. This is informing the user that, for the SSURGO data, there is only partial availability for the selected quads. This is because not all Maryland counties are available in SSURGO format at present. (in this case, Prince George’s County is unavailable SSURGO format.) If you are confident that the watershed you will later delineate is within the bounds of this data, you can proceed with SSURGO. But, if your watershed extends beyond the limits of this data, you will be forced to go back and select a different soils data type. This warning system also applies to watersheds that extend outside of the State. In cases where the selected quad is completely outside of the State or a SSURGO county, data choices will be removed from the soils and land use pull-down menus. The Ragan Soils database is available for all quads with land draining into the State of Maryland and is therefore recommended.

Select Processing Options
The last step before closing the Select Quads Dialog box is to set the desired processing options. In order to delineate streams and watersheds, the “Perform Processing” checkbox must be checked. It is recommended that the “Burn Streams” checkbox be checked to insure that the alignment of the extracted drainage network corresponds with known locations from the 1:100k blue lines (streams). The threshold drainage area, in pixels, controls the extent and amount of streams to be extracted from the DEM topography. A high value (>1000) will provide fewer streams while a low value (<250) will produce more streams. The default value of 250 corresponds roughly to the extent of the blue lines visible on a 1:24k topographic map.

Previous versions of GISHydro allowed the user to choose hydrologic conditions from the Select Quads dialog box. However, this functionality has been moved to a later step and will be shown in another exercise. When all data selections, data types, and processing options are complete, press “Apply” to begin the data extraction and processing process.

What happens next?
You will now see several DOS windows pop up followed by a sequence of processing steps while GISHydro assembles the data. GISHydro2000 stores terrain, land use, and soils data in zip archive files organized by quad sheet. The program dynamically extracts the necessary data and performs processing on a contiguous area determined by the selection of quads.

For this example, we have selected four quad sheets. For an average PC, processing will take 1-3 minutes. For a single watershed, processing typically less than 1 minute. During the processing stage, you will see a little blue bar move rapidly back and forth on the ArcView Window. This is normal. ArcView determines the flow directions and flow
accumulations for each cell in the **combined grid**; the four quads are extracted from the database and merged for the DEM, land use, and soils layers.

**The Area of Interest View**

When processing is complete, a new View will be created limited to the extent of the four quads. It is from this View that all further steps will take place (the Maryland View is closed automatically, but remains part of the gishydro.apr project.)
Exercise I-B: Watershed Delineation and Modifying Land Use and Hydrologic Conditions

In this exercise, you will define the watershed outlet and delineate the extent of the Northwest Branch watershed. You will then use interactive tools to modify the land use conditions for the area of interest. Finally, you will modify the hydrologic conditions for the study area. Note: This exercise will take a long time to complete. At a minimum, complete Part One.

Task
Delineate the watershed upstream of USGS Stream Gage No. 01650500 near Randolph Road in Montgomery County, Maryland (Northwest Branch watershed). The 2000 Maryland Office of Planning land use database indicates that a golf course in the northeast part of the watershed has low-density residential land use conditions, unlike similar golf courses located within the watershed. Use GISHydro2000 to modify the land use and curve number data for this area to more appropriate hydrologic conditions.

Part One – Delineate Watershed
In Exercise I-A, we showed how to use the Query Builder to locate a feature within a particular theme. Since we know that the outlet of the Northwest Branch watershed is located at USGS Stream Gage No. 01650500, we can use this theme to find our outlet point.

Load USGS Gage Network
To locate the gage, we must add the USGS stream gage network to the current view. Select the “Add Theme” option from the View Menu. Use the file browser to locate the file: usgsgagesm.shp located in the umdgism/maryland directory:

Now, make the gage theme active and open the query builder, as in Exercise I-A. Insure that the “update fields” box is checked, and then build the query:

( [Gage_id] = "1650500" )

Note that the leading “0” in the gage is not entered. Select the “New Set” button then close the Query Builder box. Use the “Zoom to selected” button to magnify the selected...
feature, in this case a gage. Make sure the theme is turned on (visible). You should see
the selected gage colored yellow. This will be the watershed delineation point.

Delineate the Watershed

Zoom-in to the selected gage and arrange the themes so that the “Inferred Streams” theme
is turned on (visible). Note that the selected gage is not shown directly on the drainage
network. This is OK. Use the tool to select the pixel (select the tool from the
toolbar, then click on the pixel in the display window), on the inferred streams, nearest to
the selected gage. The watershed will be delineated after some processing is completed.
Use the zoom-out feature to adjust the view extent to the boundary of the watershed. The
delineated watershed should look like:

The watershed theme is given an arbitrary name – “A Watershed.” Note that the color of
the watershed may be different for each user. Move the “Inferred Streams” layer to the
top of the View legend to have the streams draw on top of the watershed boundary.

Basin Composition

After the watershed has been delineated, from the
Hydro Menu, select the “Basin Composition” option.
You will be prompted to enter a name and location
for a text file that contains the land use composition
of the watershed by hydrologic soil type. This
information will not be displayed from within
GISHydro, however it can be opened in a text editor
such as “Notepad” where it can be printed or the text
can be copied/pasted into another document.
**Calculate Basin Statistics**

From the Hydro Menu, select the “Calculate Basin Statistics” option. After some processing, the dialog below will appear summarizing the physical properties of the watershed delineated in the previous section. Note the warning about the impervious level of the watershed. GISHydro relies on the engineering judgment of the user to decide the final appropriateness of the respective discharge estimation methods.

These data can be selected, copied, and pasted into a text editor or MS Word document for creating a watershed analysis report. You are also prompted to save this data as a text file if desired. **Note that although the GIS data are stored in SI/metric units, the calculated quantities (area, basin relief, slope, etc.) are reported in English units.**
Part Two – Modify Land Use Conditions

The Hampshire Greens Golf Club is located at the intersection of New Hampshire Avenue and Ednor Road in the northeast corner of the Northwest Branch watershed. The 2000 Maryland Office of Planning land use database uses land use categories to describe the land cover conditions. Unlike the other golf courses located within the watershed that are categorized as “18 – Urban Open Land”, the course of the Hampshire Greens Golf Club has a category of “11 – Low Density Residential.”

In this part of the exercise, we will modify the land use database to correspond with a more appropriate land use and hydrologic condition for the Northwest Branch watershed.

Step 1: Invoke the Land Use Modification Dialog

Press the “LU” button, located to the right of the “Q” button used earlier to initiate the analysis. This will bring up the dialog box shown below:
**Step 2: Entering the Land Use Category Name**
Enter in this box the text describing the land use category (e.g., “Golf Course land use”). This field is for informational purposes only and is not a required input.

**Step 3: Indicating the Major Land Use Category**
There exist three special classes of land use that need to be indicated for correct calculation of the “Basin Statistics” and/or the USGS regression equations. These categories are, “urban”, “forest”, and “storage”. The user simply needs to click on the category that applies to the new land use category being specified. If none of these categories apply, leave the selection set as the category, “none”. Choose this option.

**Step 4: Indicating the Curve Numbers and/or Imperviousness**
The default imperviousness is 0% as the dialog box opens. There are no default curve number values. So long as the major land use category is “urban” or “none” the imperviousness box is editable. Any numerical entry in imperviousness box will result in the calculation of the associated A, B, C, and D curve numbers according to the formulas:

\[
\begin{align*}
A \text{ Soil: } & \quad x \cdot 98 + (1 - x) \cdot 39 = CN_a \\
B \text{ Soil: } & \quad x \cdot 98 + (1 - x) \cdot 61 = CN_B \\
C \text{ Soil: } & \quad x \cdot 98 + (1 - x) \cdot 75 = CN_C \\
D \text{ Soil: } & \quad x \cdot 98 + (1 - x) \cdot 80 = CN_D
\end{align*}
\]

where \( x \) is the imperviousness expressed as a fraction of 1. All curve numbers are rounded to the nearest integer value. Please note that any manual entry in the imperviousness box after the curve number boxes have been filled out will undo entries manually entered in the curve number boxes. If you wish to manually specify both curve numbers and imperviousness, you should first specify the imperviousness and then the curve numbers. Enter an imperviousness value of 11%.
**Step 5: Load the Background Image**

An image of the area surrounding the Hampshire Greens Gold Club has been included in the workshop working directory. The path to this directory will be provided. From the ArcView View Menu, add a Theme and browse to the workshop directory. Select “Image Data” as the type and select the “mappoint.tif” image. We will on screen digitize the boundary of the golf course to revise the MOP land use database.

**Step 6: Digitizing the Land Use Polygon**

Press the “Digitize Polygon” button (.diag) and digitize on the computer screen the outline of the Hampshire Greens Gold Club. Two things to note: 1) To end the digitizing of the polygon, double-click rapidly at the last location of the polygon you are updating; 2) You can digitize multiple polygons for a given category simultaneously. If you have multiple polygons you wish to digitize that you wish to have the same land use, you can simply digitize multiple polygons by repeatedly selecting the “Digitize Polygon” tool and specifying multiple polygons in the view. When all polygons have been digitized, click the “Apply Polygon” button.

**Step 7: Applying the Polygon**

Only after both a polygon(s) has been digitized and curve number/imperviousness information has been entered will the “Apply Polygon” button become enabled (black). At the time this button is pressed, the text information indicated in the dialog box along with all polygon(s) (see Step 6 above) are written to disk. If the “Apply Polygon” button is not pressed and the dialog box is exited (through the use of the “Cancel” button or the “X” box at the upper-right corner of the dialog) then any information contained in the dialog box at the time of exiting is lost. The Land Use Modification Dialog may be opened once and multiple polygons of land use entered and applied, or the dialog may be opened multiple times each time specifying one or more polygons of land use.

**Step 8: Revising the Curve Numbers**

After one or more polygons of modified land use are entered and applied, the “Revise Curve Numbers” button becomes active “black”. Until this button has been pressed, the land use and curve number themes have not been revised to reflect any of the changes entered in this dialog. This button needs to be pressed only once, at the conclusion of the entry of all modified land use polygons, but may actually be pressed anytime after the first land use change polygon has been completely entered. Note that once this button has been pressed, the legend colors for the display of the “Land Use” and “Curve Number” themes are changed. Since it is impossible to anticipate what kinds of land use will be entered by the engineer, no effort has been made to control the color legends for these themes. For the land use theme, the engineer must manually modify the legends for these themes with the appropriate colors associated with all previously existing and new categories of land use. This is chronologically the last button you will press when using this dialog. Once you are finished with this dialog you can proceed with your hydrologic analysis as done previously.
Step 9: Using the “Cancel” Button

Pressing this button (or the “X” button at the upper-right corner of the dialog) cause the dialog box to close with any information contained in the dialog at the time of exiting being permanently lost. For instance, you may wish to use this button if you are unhappy with the polygon you have digitized. You could then re-open the dialog box by pressing the “LU” with no memory of any information entered previously (the defined polygon or other text information) being retained since the last time the “Apply Polygon” button was pressed.

Documenting Modified Land Use: The “Digitize Custom Land Use Polygon” dialog stores information in two places during and after use of this dialog is completed. Non-GIS information is stored in the landuse lookup table. The digitized polygons are stored in a shapefile (3 physical files make up 1 shapefile). Both of these entities are written to the c:\temp directory.

The Landuse Lookup Table: This table is visible within the GIS as one of the table called, “Landuse Lookup Table.” The file that contains the information in displayed in this table is located on the machines hard-drive at, “c:\temp\templutab.dbf”. The default version of this table corresponding to the selection of Maryland Department of Planning land use data is shown below:

The “Hyd_x” fields (columns) indicate the curve numbers that apply to this land use category for soil type “x.” The “Imp” field shows the default imperviousness associated with each land use category as a decimal fraction. The “Lucat” field indicates the major land use class (see Step 4) that applies to each land use category (“u”=urban, “f”=forest, “s”=storage, and “n”=none. The values and category descriptions appearing in the leftmost two fields will vary depending on the land use coverage selected by the engineer at the time the analysis is
initiated. Additional records (rows) starting with values of Lucode = 501 will be added to this table if the land use modification dialog is used to indicate new land use polygons. This table should be included as a standard part of all hydrologic analysis reports.

The “lumod” shapefile: This file is not loaded into the GIS. It exists only on disk as “c:\temp\lumod.xxx” (where xxx are the 3 file extensions: “shp”, “shx”, and “dbf” that make up a shapefile.) If land use is changed as part of a given analysis, this shapefile should be included electronically as a standard part of the reporting of that analysis.

Part Three: Modifying Hydrologic Conditions
From the Area of Interest view, the user/engineer is able to modify the hydrologic conditions for a study watershed in addition to land use. The “Modify Hydrologic Condition” dialog box is invoked when the button circled below is pressed/clicked.

From left to right across the table, this dialog shows the land use code, land use category, the A, B, C, and D curve numbers for each category, the current understood hydrologic condition, and then the letters “G,” “F,” and “P.” The engineer can update the hydrologic condition for any one category by pressing the appropriate letter “G” (Good), “F” (Fair), or “P” (Poor) as needed. If a wholesale change is desired, the buttons “Set All to ‘Good’”, “Set All to ‘Fair’”, and “Set All to ‘Poor’” change the hydrologic condition across all hydrologic conditions simultaneously.
From left to right across the table, this dialog shows the land use code, land use category, the A, B, C, and D curve numbers for each category, the current understood hydrologic condition, and then the letters “G,” “F,” and “P.” The engineer can update the hydrologic condition for any one category by pressing the appropriate letter “G” (Good), “F” (Fair), or “P” (Poor) as needed. If a wholesale change is desired, the buttons “Set All to ‘Good’,” “Set All to ‘Fair’”, and “Set All to ‘Poor’” change the hydrologic condition across all hydrologic conditions simultaneously.

Once all desired changes are made, the engineer should press, “Update and Close,” this will update all the indicated changes in the table and apply these changes to the “Curve Number” theme as it appears in the “Area of Interest” view. For reporting purposes, the “Write Lookup Table to File” behaves the same as the “Update and Close” button, but also provides a file browser dialog box for the engineer to direct an output text file for the updated lookup table. The “Cancel and Close” button exits the dialog with none of the changes that may have been entered taking effect.

A few cautionary words are necessary. If changes are made to the lookup table, then any previous calculations involving the curve number (e.g. selecting the “Basin
Statistics” choice from the “Hydro” menu or the “Calculate Attributes” from the “CRWR-PrePro” menu must be repeated (after modifying the lookup table) so as to incorporate the revised curve number values. Also, if any custom land uses are added using the “Digitize Custom Land Use Polygon” (obtained by pressing the “LU”) button, the curve numbers associated with any added special land uses will appear in the “Modify Hydrologic Condition” dialog. However, the curve numbers associated with such specialized land use categories will not be editable because GISHydro2000 has no way of knowing what the appropriate “Good,” “Fair,” and “Poor” hydrologic conditions for such polygons would be.
Exercise I-C: Discharge Estimation Using Regression Techniques and Graphical Comparison

GISHydro2000 includes the capability to calculate discharges using several regression techniques. These statistical predictions of peak flow are based on watershed parameters, land use, physiographic region, and other factors. The regression discharge estimates are used for comparison with discharges predicted by TR-20 in accordance with the recommendations of the MD Hydrology Panel. This exercise describes the use of GISHydro2000 to calculate peak flow regression estimates for the Northwest Branch watershed.

Task
Estimate the peak discharges ($Q_{1.25} - Q_{500}$) for the Northwest Branch watershed above USGS Gage 0160500 located in Montgomery County, Maryland. Use each of the regression methods in GISHydro2000 and compare your results.

Calculate Peak Discharges
After the Basin Statistics have been calculated, the next step is to calculate the peak discharges. Select “Calculate Thomas Discharges” from the Hydro Menu. The Thomas equations used a fixed region method to calculate peak discharges. The figure below depicts typical values for the study watershed. As with the Basin Statistics, the discharges shown can be output to a file.

### Fixed Region Estimated Discharges

<table>
<thead>
<tr>
<th>$Q$</th>
<th>Estimated Discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.25</td>
<td>962 cfs</td>
</tr>
<tr>
<td>1.50</td>
<td>1,300 cfs</td>
</tr>
<tr>
<td>1.75</td>
<td>1,500 cfs</td>
</tr>
<tr>
<td>2.00</td>
<td>1,630 cfs</td>
</tr>
<tr>
<td>3.00</td>
<td>2,600 cfs</td>
</tr>
<tr>
<td>4.00</td>
<td>4,440 cfs</td>
</tr>
<tr>
<td>5.00</td>
<td>5,700 cfs</td>
</tr>
<tr>
<td>5.00</td>
<td>5,110 cfs</td>
</tr>
<tr>
<td>100</td>
<td>1,200 cfs</td>
</tr>
<tr>
<td>200</td>
<td>1,563 cfs</td>
</tr>
<tr>
<td>500</td>
<td>2,100 cfs</td>
</tr>
</tbody>
</table>

Individual Province Predictions Follow:

Fixed Region Estimated Discharges for Piedmont region

<table>
<thead>
<tr>
<th>$Q$</th>
<th>Estimated Discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.25</td>
<td>962 cfs</td>
</tr>
<tr>
<td>1.50</td>
<td>1,300 cfs</td>
</tr>
<tr>
<td>1.75</td>
<td>1,500 cfs</td>
</tr>
<tr>
<td>2.00</td>
<td>1,630 cfs</td>
</tr>
<tr>
<td>3.00</td>
<td>2,600 cfs</td>
</tr>
<tr>
<td>4.00</td>
<td>4,440 cfs</td>
</tr>
<tr>
<td>5.00</td>
<td>5,700 cfs</td>
</tr>
<tr>
<td>5.00</td>
<td>5,110 cfs</td>
</tr>
<tr>
<td>100</td>
<td>1,200 cfs</td>
</tr>
<tr>
<td>200</td>
<td>1,563 cfs</td>
</tr>
<tr>
<td>500</td>
<td>2,100 cfs</td>
</tr>
</tbody>
</table>
Next, select “Calculate Dillow Discharges” from the Hydro menu. Since the watershed contains a USGS gage, you will be prompted to decide whether to perform a gage adjustment as permitted by the Dillow regression equations. (See http://md.water.usgs.gov/publications/wrir-95-4154/ for details). You may choose “None” to apply just the Dillow regression equations or you can choose gage 01650500 to perform a weighted average between the regression equation and gage flood frequency information. Choose both and experiment to see the effect on the calculated discharges. The figure below shows typical discharges that can also be saved to a file.
### U.S.G.S. Peak Flow Estimates

**GIS Hydro Release Version Date:** June 15, 2004  
**Hydro Extension Version Date:** May 10, 2004

#### Geographic Province:
- Fledermaus (100.0% of area)

| Q12% | 1230 cfs  |
| Q25% | 2530 cfs  |
| Q10% | 3290 cfs  |
| Q25% | 5130 cfs  |
| Q50% | 6320 cfs  |
| Q10% | 9190 cfs  |
| Q50% | 17200 cfs |

#### Area Weighted Prediction Intervals from Taskal

<table>
<thead>
<tr>
<th>Period</th>
<th>50 PERCENT</th>
<th>67 PERCENT</th>
<th>90 PERCENT</th>
<th>95 PERCENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1230</td>
<td>1330</td>
<td>1390</td>
<td>1470</td>
</tr>
<tr>
<td>5</td>
<td>2160</td>
<td>2500</td>
<td>2890</td>
<td>3370</td>
</tr>
<tr>
<td>10</td>
<td>3070</td>
<td>3590</td>
<td>4000</td>
<td>4410</td>
</tr>
<tr>
<td>25</td>
<td>4630</td>
<td>5700</td>
<td>6400</td>
<td>7270</td>
</tr>
<tr>
<td>50</td>
<td>6150</td>
<td>7770</td>
<td>8860</td>
<td>9830</td>
</tr>
<tr>
<td>100</td>
<td>8670</td>
<td>10500</td>
<td>11800</td>
<td>12800</td>
</tr>
<tr>
<td>500</td>
<td>14700</td>
<td>20200</td>
<td>23700</td>
<td>27600</td>
</tr>
</tbody>
</table>

#### Individual Province Taskal Analyses Follow:

**Flood frequency estimates for**

**REGION** Fledermaus region  
area = 21.30; forest = 24.90; snow = 0.53

<table>
<thead>
<tr>
<th>Return</th>
<th>Discharge</th>
<th>Standard Error</th>
<th>Equivalent Standard Error</th>
<th>Years of Record</th>
<th>Years of Prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1230</td>
<td>7.9</td>
<td>61.66</td>
<td>0.0344</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>2300</td>
<td>10.6</td>
<td>65.16</td>
<td>0.0361</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>3350</td>
<td>12.8</td>
<td>68.66</td>
<td>0.0295</td>
<td>0.0066</td>
</tr>
<tr>
<td>25</td>
<td>5130</td>
<td>15.4</td>
<td>72.76</td>
<td>0.0286</td>
<td>0.0126</td>
</tr>
<tr>
<td>50</td>
<td>6320</td>
<td>17.3</td>
<td>74.65</td>
<td>0.0276</td>
<td>0.0105</td>
</tr>
<tr>
<td>100</td>
<td>9190</td>
<td>19.3</td>
<td>76.16</td>
<td>0.0262</td>
<td>0.0075</td>
</tr>
<tr>
<td>500</td>
<td>17200</td>
<td>23.7</td>
<td>76.95</td>
<td>0.0238</td>
<td>0.0045</td>
</tr>
</tbody>
</table>

#### Prediction Intervals

<table>
<thead>
<tr>
<th>Return</th>
<th>50 PERCENT</th>
<th>67 PERCENT</th>
<th>90 PERCENT</th>
<th>95 PERCENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1230</td>
<td>1330</td>
<td>1390</td>
<td>1470</td>
</tr>
<tr>
<td>5</td>
<td>2160</td>
<td>2500</td>
<td>2890</td>
<td>3370</td>
</tr>
<tr>
<td>10</td>
<td>3070</td>
<td>3590</td>
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<td>4410</td>
</tr>
<tr>
<td>25</td>
<td>4630</td>
<td>5700</td>
<td>6400</td>
<td>7270</td>
</tr>
<tr>
<td>50</td>
<td>6150</td>
<td>7770</td>
<td>8860</td>
<td>9830</td>
</tr>
<tr>
<td>100</td>
<td>8670</td>
<td>10500</td>
<td>11800</td>
<td>12800</td>
</tr>
<tr>
<td>500</td>
<td>14700</td>
<td>20200</td>
<td>23700</td>
<td>27600</td>
</tr>
</tbody>
</table>

Estimates adjusted for proximity to station 16509500.
Having calculated regression estimates for peak discharge using the available methods, the next step is to select the “Compare Discharges” option from the Hydro menu. Some calculations are performed and a file dialog prompts the user to specify a location for an output file. Although not directly displayed, an ArcView table contains the discharge estimates and error bound for each respective regression method. The table is called “OVERALL Calculated Discharges” and can be viewed in the list of ArcView tables after the “Compare Discharges” option is selected from the Hydro menu.

A graphical comparison of the discharges may be created by clicking on the Chart button in the table view ( ). Select Return period as the field in the “Label series using” drop down list. Then, add each field to be included in the chart (e.g., Carpenter, Dillow, Thomas, L-Moment, ROI) by selecting it and pressing the add button. Click “OK” when finished. A chart similar to the one will be displayed. This chart may be labeled and printed for inclusion in a hydrologic analysis report.
Exercise II-A: Introduction to TR-20 Modeling and Subdivision

In this exercise we will begin the development of a TR-20 model for the prediction of the 100-year return period discharge occurring at the outlet of the Northwest Branch watershed at Gage 01650500.

Task
Use the GISHydro2000 program to define the elements of the Northwest Branch watershed for a TR-20 model. Subdivide the watershed into 5 sub-watersheds corresponding to the main channel segments and routing reaches.

Delineate Main Channels and Sub-watersheds
Inspection of the drainage network (the Inferred Streams theme) shows that there are a large number of short stream branches that extend from the main stream segments. These features are not typically seen on a 1:24k blue line coverage and are an artifact of the channel extraction process.

GISHydro2000 chooses as the default to subdivide the watershed at all stream confluence points. As you might expect, this would result in an extraordinarily large amount of subdivision. It is therefore necessary to modify the stream network to a more simple representation. For our purposes, we wish to model the watershed with three main channel segments which will result in 5 sub-watersheds and two routing reaches.

Select the tool from the tool bar and click on a point somewhere near the upper right divide of the watershed. You will see a single flow path delineated from the point you clicked on to the watershed outlet. Note that this segment isn’t necessarily the longest flow path in the watershed. That path will be determined later. Next, choose a point near the northwest divide and click again. Another flow path is traced to the outlet. Finally, choose the third main channel segment by clicking again near the divide of the southwest region of the watershed.

From the CRWR-PrePro menu, select “Add Streams”. This option is necessary to incorporate the delineated stream in the stream network. The following box appears:

Select NO to use only the single stream segment (default option). Important: You must select the “Add streams” option before choosing “Delineate Sub-watersheds.” Otherwise, the default subdivision based on the inferred streams will be used likely
resulting in more subdivision than desired. Once the streams are added, the modified stream network looks like:
Sub-watersheds

Now we will delineate sub-watersheds for the Northwest Branch watershed. GISHydro will create a subdivision at each stream confluence or at an outlet point placed in-line on a stream using the “O” tool. Although not illustrated as part of this exercise, this tool allows watersheds to be subdivided in series to describe abrupt changes in channel conditions, for example.

From the CRWR-PrePro Menu, select “Delineate subwatersheds.” After some processing, a new theme with 5 sub-watersheds should be displayed (see below). Note that the small sub-area near the basin outlet is created between the gage and the upstream confluence. TR-20 output (i.e., peak discharge or runoff hydrograph) can be reported at the confluence in this case as we would expect neither significant increase in runoff due to the small contributing area nor attenuation in the stream reach due to its short length (i.e., kinematic translation only will occur).

The raster stream and watershed themes are converted into new vector themes: subrivs.shp and subshefs.shp, respectively. Future processing of the model will be based on these themes.
Exercise II-B: Time of Concentration Determination

After subdividing the watershed, the next step is to assign a time of concentration to each sub-watershed in the Northwest Branch watershed. TR-20 uses the time of concentration in simulating the runoff hydrograph for each sub-area. GISHydro2000 includes an interactive tool to specify the method of calculation for Tc and to enter associated parameters such as lengths of sheet and channel flow.

Task
Use the GISHydro2000 Time of Concentration Calculation dialog box to specify the time of concentration for each of the 5 sub-areas in the Northwest Branch watershed. Choose to specify parameters individually or to all sub-areas at the same time. Set the time of concentration parameters for the sub-watersheds and generate the watershed schematic which forms the logical organization of the TR-20 input file.

Set Time of Concentration Parameters
After delineating the sub-watersheds in the previous exercise, we must now set the travel time for each of the 5 sub-watersheds. Open the Time of Concentration Calculator by selecting the “Set Tc Parameters” option on the CRWR-PrePro menu. The dialog box shown below will appear.
The user may select one of three methods to calculate Tc: the SCS Lag Formula, the MD Hydrology Panel Tc method, or the velocity method. The selected method can be applied to each sub-watershed individually, or to all sub-watersheds at the same time. To set Tc parameters for individual sub-watersheds, the user must first select a sub-watershed polygon using the ArcView select feature tool. Clicking the “Set” button in the above dialog will then apply the selected method and parameters only to that sub-watershed. Note that a Tc method must be chosen for all other sub-watersheds individually if one is entered in this manner. Once a method has been set for all sub-watersheds, press the close button on the dialog box.

**Calculate Attributes**

From the CRWR-PrePro menu, select the “Calculate Attributes” option. This step will determine the length of the longest flow path and apply time of concentration settings for the watershed. A message box will appear notifying you when the processing is complete.

This exercise is continued on page 58 using the velocity method for each subwatershed.
Refining Time of Concentration Calculation: Velocity Method Segment Generator

A tool to combine velocity method segments was developed in February 2005. This document provides guidance on the use of this tool 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 mi² 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 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$^2$). 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,

$$y = x^2$$

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,
\[ S = \frac{dy}{dx} = 2x \]  

(2)

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

\[ v \sim \sqrt{S} \]  

(3)

where \( v \) is the velocity. Incremental travel time, \( dt_c \) is just the incremental distance divided by the velocity,

\[ dt_c = c \frac{dx}{\sqrt{S}} = \frac{dx}{\sqrt{2x}} \]  

(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,

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

(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>
<thead>
<tr>
<th>Number of Segments</th>
<th>( x )</th>
<th>( y=x^2 )</th>
<th>( S = \frac{\Delta y}{\Delta x} )</th>
<th>( \Delta x )</th>
<th>( \frac{\Delta x}{\sqrt{S}} )</th>
<th>( t_c = \sum \frac{\Delta x}{\sqrt{S}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0</td>
<td>0.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>1</td>
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<td>0.5</td>
<td>0.5</td>
<td>0.707</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>1.5</td>
<td>0.5</td>
<td>0.408</td>
<td></td>
</tr>
<tr>
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<td>0.333</td>
<td>0.333</td>
<td>0.577</td>
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<tr>
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<td>2.0</td>
<td>0.333</td>
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<td>1.0</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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 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.
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 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 $\text{ft/ft}$.
- **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

<table>
<thead>
<tr>
<th>Shape</th>
<th>UpPixel</th>
<th>SegName</th>
<th>Type</th>
<th>DownPixel</th>
<th>Avg.Area</th>
<th>UpElev</th>
<th>DownElev</th>
<th>Slope</th>
<th>Width</th>
<th>DownD</th>
<th>X</th>
<th>Y</th>
<th>L</th>
<th>TL</th>
<th>V</th>
<th>Tt</th>
<th>Tt2</th>
</tr>
</thead>
<tbody>
<tr>
<td>FoxLine</td>
<td>1</td>
<td>M</td>
<td>Mixed</td>
<td>000</td>
<td>44.3</td>
<td>43.2</td>
<td>0.007903</td>
<td>1.00</td>
<td>1.00</td>
<td>139</td>
<td>138</td>
<td>0.22</td>
<td>0.174</td>
<td>0.174</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FoxLine</td>
<td>2</td>
<td>S</td>
<td>Swale</td>
<td>001</td>
<td>43.2</td>
<td>37.5</td>
<td>0.002341</td>
<td>1.00</td>
<td>1.00</td>
<td>124</td>
<td>158</td>
<td>1.06</td>
<td>0.256</td>
<td>0.256</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FoxLine</td>
<td>3</td>
<td>C</td>
<td>Channel</td>
<td>366</td>
<td>39.8</td>
<td>27.5</td>
<td>0.001584</td>
<td>16.01</td>
<td>16.01</td>
<td>432</td>
<td>455</td>
<td>10.4</td>
<td>10.977</td>
<td>11.476</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**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).
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 ft²) 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
tc 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 tc 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 tc
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.](image)
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 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 small portion of a pixel-based channel flow path in which very small slopes and resulting very small travel velocities for the top three records shown.

- 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.
Exercise II-B (continued from page 47): Merging Velocity Method Segments

We have identified five subwatersheds for the Northwest Branch Watershed. For all subwatersheds, we assume that the velocity method has been selected as the time of concentration calculation method. The “Calculate Attributes” processing step under the CRWR-PrePro should now be complete. We will now use the Velocity Method Segment Generator to refine the flow paths for each subwatershed (sub-area). Note: If you chose to use the Velocity Method Tc estimation technique for only certain sub-areas, they you will need to apply this method for only the sub-areas selected.

Part I – Quick Merge

As explained in the previous section, the velocity method determines a travel time along the longest flow path for each pixel lying on that flow path. The flow times for each pixel can be aggregated based on the classification of the pixel as channel, swale, or overland flow. Choose the “Combine the Longest Flow Path Segments” option from the CRWR-PrePro menu to open the Velocity Method Segment Generator Dialog box.

Task: Use the “Select Sub-Area” tool to choose the sub-area (subwatershed) in the upper-left corner of the watershed. When the mouse is clicked, a series of calculations are performed and the longest flow path for that sub-area is vectorized and added to the Area of Interest View. The attribute table is also displayed for your reference.

The Segment Generator dialog box remains open to allow the user to modify the flow paths. The current velocity method statistics (for the current sub-area) are shown on the right.

Note the overall Tc for the current sub-area in hours: __________________

Check the three check-boxes under “Quick Merge” notice that the “Recalculate Tc” button becomes enabled. Click the button to combine the flow times for all pixels on the longest flow path of that watershed based on their classification as overland, swale, channel, or a mixture. The attribute table will be re-computed and the velocity method statistics for that watershed updated.

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What is the overall Tc for the current sub-area after merging: ________________

Is it higher or lower than before? Why?

Click “Close Dialog” and repeat the “Quick Merge” procedure for the four remaining subwatersheds. Summarize the flow times below:

<table>
<thead>
<tr>
<th>Sub-area</th>
<th>SCS Lag Tc (hrs.)</th>
<th>Hydrology Panel Tc (hrs.)</th>
<th>Pre-Merge Overall Tc (hrs.)</th>
<th>Post-Merge Overall Tc (hrs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3.66</td>
<td>2.37</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>3.91</td>
<td>2.39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3.24</td>
<td>2.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.31</td>
<td>0.81</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>3.41</td>
<td>2.01</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

You should note that the “Quick Merge” procedure produces the shortest time of concentration that you can realize for each subwatershed. The pixel-by-pixel flow times generally produce the longest time of concentration for each subwatershed. In the next part, you will merge specific flow segments to generate Tcs in between these bounds.
Part-II – Merge Specific Segments

As shown on the GISHydro2000 flow chart on page 111, the modification of flow segments is one technique that can be used for calibrating peak discharges (see calibration re-entry point F6 and calibration advice beginning on page 68). If modeled peak discharges are too big, you can use this tool as a calibration mechanism to merge flowpaths into multiple segments (rather than single segments). This will result in longer time of concentration estimates and consequently reduce the peak discharge estimate.

**Task:** Repeat the Velocity Method time determination for the five sub-areas in the Northwest Branch Watershed. Your task is to collapse all of the swale flow pixels (and their associated travel times) into a single segment for each subwatershed. Begin by opening the Velocity Method Segment Generator dialog box and select the sub-area in the upper-right of the watershed.

For this sub-area, swale flow begins with Pixel Number 3 and ends with Pixel 24 (Note: you may not get the same exact pixel numbers or times for your sub-area). The Overall Tc for this sub-area is currently 5.826 hours. Enter the upstream and downstream pixel number in the “Merge Specific Segment” area of the dialog box and click the Recalculate Tc button.

You will notice that the swale flow segment is now collapsed into one segment with an overall Tc of 5.733 hours, a decrease of approximately 2%. Repeat the “Merge Specific Segment” technique for the swale segments for the other sub-areas in the watershed. Which sub-area exhibits the greatest decrease in overall Tc as a result of the swale segment aggregation?

Once all Tc values are finalized, choose: "CRWR-PrePro: Generate Schematic" to generate the connectivity between sub-areas required by the TR-20 model.
Exercise II-C: Calculating Routing Reach Cross Section Parameters

In order to perform the desired reach routings for the model schematic generated in the previous exercise, it will be necessary for us to define a cross section rating table for each. Recall that the cross section rating table contains the stage-discharge-end area relationship at a section along the stream reach chosen to be representative of the overall length. To determine the rating table relationship, we need to specify, for each cross section, the geometry and roughness for both the main channel and the cross section.

**Task**
Use the GISHydro2000 program to calculate reach routing tables for the reaches identified in the Northwest Branch watershed schematic. Use the draw transect tool to sample a cross section near the mid point of each reach. Use the Cross Section Editor dialog box to adjust the geometry, slope, or roughness characteristics of the sampled cross sections as needed.

**Draw Reach Routing Transects**

The procedure for gathering this information using GISHydro2000 is to use the tool to draw transects across each of the routing reaches. The transect lines are used to extract the profile of the floodplain at the selected point crossing the stream. At the intersection of the stream, a synthetic channel is incised since the DEM topography is too low resolution to capture the channel geometry. A surveyed cross section rating table may also be loaded.

Before drawing any cross sections, a useful step is to add the contour lines corresponding to the DEM. The contours aid in selecting the correct positioning of the transect line. To display the contour lines, make the “Original DEM” theme active. Next, select the Create Contours item from the Surface menu. A dialog box will ask you to specify the contour interval. Enter 20 meters and press OK. A new theme is created. Zoom-in to the northern-most routing reach, indicated by the light green lines in the schematic diagram. To draw a transect line, select the Add Transects Tool from the toolbar and drag a line across the routing reach. **Note: The transect line must cross the stream line (the schematic line does not reflect the alignment of the stream). The transect should be completely contained within the surrounding sub-watershed (i.e., don’t extend past the sub-watershed divide).**

When a transect line is drawn, the Cross Section Editor Dialog Box is displayed as shown below:
This dialog box allows the sample cross section data to be edited (in English units), the rating table to be recalculated based on those edits, and a 2-D plot of the sampled cross section to be displayed. The cross section station and elevation data may be exported to a text file using the “Export Cross Section” button. When you are satisfied with the cross section rating table, click OK. The table for each reach will be written to the TR-20 input file to be defined in the next exercise.

Repeat the transect drawing process for the remaining routing reach. For watersheds with more subdivisions, be sure that a transect line is drawn for each routing reach. If you wish to change the transects, simply delete the theme called “AddAsTransects.shp” and begin again.

When finished, there should be two transects drawn similar to those shown in the figure below:

As already mentioned, the short routing reach between the confluence of the two main stream segments and the downstream gage will likely have little effect on the simulated runoff created by TR-20. To test this hypothesis, compare the peak discharge and runoff volume at the confluence and at the outlet. Is the change insignificant? Routing is a flood wave attenuation process used to model the friction and storage in a stream reach. When the reach is very short relative to the size of the flood wave, attenuation does not occur, only kinematic translation as already discussed.
Exercise II-D: Creation and Execution of TR-20 Model

GISHydro2000 uses the divided sub-watersheds, reach rating tables, and calculated attributes to assemble the input for the TR-20 model. In this exercise, you will specify input and output files for TR-20, specify output options, and assign a rainfall distribution for rainfall/runoff calculations for the Northwest Branch watershed. You will then execute the TR-20 model and examine the output.

Task

Using TR-20, estimate the 100-year return period discharge for the Northwest Branch watershed. Use the 24-hr. duration storm. Compile the TR-20 input file, execute the program, and examine the output.

Precipitation Depth Selection

The engineer needs to indicate to GISHydro2000 all storm frequency/durations that are to be analyzed. Under the TR-20 Interface menu, is the menu choice, “Precipitation Depths”. Selecting this, the engineer is presented with the dialog box shown below. Simply check all storm frequencies and durations desired for analysis. Only those storms selected here will be available later for inclusion in a TR-20 input file.

![Precipitation Frequency & Duration Selector](image)

*Note: "Unselect All" button will not unselect storms that have already been determined.*
When all desired storms are determined, click the “Apply/Close” button. This will trigger GISHydro2000 to access the precipitation database for the same quadrangles selected at the beginning of the analysis.

A new feature was added to GISHydro2000 in Fall 2007 to determine precipitation depth based on spatially distributed precipitation from NOAA Atlas 14 precipitation data. The areal average storm depth over the domain of the watershed is now calculated directly. This is effectively a watershed-specific design storm with the storm distributions no-longer based on TP-40. This change of approach was reviewed and approved by the Maryland Hydrology Panel. Depending on the number of storms selected, the average storm depth and distribution will be determined and may take some time to compute. After computing is complete, a dialog box will report the selected storm depth with the distribution stored for subsequent analysis.

The depths and storm distributions will automatically be written into the TR-20 input file when selected by the user from the TR-20 control panel. Only the storms durations and return periods chosen with the precipitation selector dialog box will be available for inclusion in the TR-20 model. Note that if storms have already been identified for analysis at an earlier time (for instance, if the engineer is iteratively flowing between this dialog and the TR-20 Control Panel dialog) then these storms will appear selected when this dialog re-opens and the depths/distributions will still be available.

If the “Output Storm Depths to File” box is checked on, the engineer will also be given an output text box below. Only the storm depths selected will be indicated in this text box.

Configure TR-20 Control Panel

Once the watershed schematic, reach rating tables, and precipitation depths have been created/specified, the TR-20 model can be setup for execution. Open the TR-20 control panel from the TR-20 Interface Menu. Select a name and location for the TR-20 input file to be generated and also for the output file that TR-20 will create. Use either the workshop working directory or the c:\temp folder as shown below. Enter the optional Job and Title header information, which will be written into the TR-20 input file.
**Standard Control Output Options**

The Standard Control Output options allow the user to specify which data are reported for each watershed element (e.g., subwatershed, outlet, or reach). If only the overall watershed outlet discharge and volume are desired, leave the “Apply Output Options only to Watershed Outlet” box checked and select any additional output values desired. Un-checking this box will report all selected options for each watershed element.

**Set Simulation Parameters (Executive Control)**

The default time increment and staring time are recommended in most cases. The compute sequence can be specified directly if only portions of a complex watershed are to be analyzed (i.e., if a rainfall/runoff simulation is desired for only a sub-set of the overall model.)

The rainfall parameters are typically based on the 24-hr storm for Maryland. Use the rainfall depth corresponding to the 100-yr return frequency (8.47 inches). Choosing “Edit” will allow the user to edit the rainfall depths associated with each return period storm on the list. Finally, the antecedent rainfall condition (ARC) can be specified. Leave the default selected (ARC 2). When all of the simulation parameters are set, press ok. The following Dialog appears indicating that the input file has been created:

![Dialog Image]

**Execute the TR-20 Model**

To execute the TR-20 model for the current watershed, select the Execute option from the TR-20 Interface Menu or simply press Cntrl+E. You will be asked some questions related to TR-20 logging. These prompts have been carried over from the original program:

- Do you want an input list with the output? Choose No.
- Include the latest TR-20 user notes with the output? Choose No.
- Write all warnings and messages to a separate file? Choose No.
Finally, when asked, select yes to execute the TR-20 model.

**Evaluate and Compare Results**

TR-20 will execute automatically and return the generated output file in Notepad for review. The output file is shown below which reports that the peak discharge for the 100 year storm is approximately 11,612 cfs. Your results may vary.

Did you request that output be written for the confluence upstream of the Gage? Re-open the TR-20 control panel and un-check the box for “Apply output options only to watershed outlet.” Un-checking this box will produce output data for each watershed element in the model (i.e., each RUNOFF, ADDHYD, and XSECTION). Re-run TR-20 and consider the runoff generated by the small subarea near the outlet. Answer the following questions:

- How does the volume of runoff compare with the other subareas? The peak flow?
  Peak time?
- What is the effect of the reach routing in the last reach before the outlet? Does significant attenuation in the peak flow occur?
Exercise II-E: Comparing Results and Model Calibration

We are now in a position to compare discharges predicted by the regression techniques used in Exercise I-A at the end of Day One of the workshop with the discharges predicted by TR-20 in the previous exercise. The Maryland Hydrology Panel suggests that TR-20 discharges should fall within +1 standard error of the fixed region regression estimate. If the predicted TR-20 discharge is above or below this range, calibration is necessary.

Task
In this exercise we will compare discharges for the 100-year return period flood at the Northwest Branch watershed. Apply the Maryland Hydrology Panel calibration procedure using GISHydro2000 if the predicted TR-20 discharge is outside the range of the predicted regression equation estimate plus one standard error.

Evaluate and Compare Results
In Exercise I-C, the predicted 100-year return period discharge for the Northwest Branch watershed using the Thomas fixed region regression method was 12,000 cfs with an upper bound of 15,700 cfs (the expected value plus one standard error). The predicted TR-20 discharge from the previous exercise for the 100-year return period is 11,612 cfs. Since this is outside (i.e., below) the prescribed range as suggested by the Maryland Hydrology Panel, calibration is required.

Calibration Procedure
Follow the calibration procedure and flow chart in the training manual to adjust the TR-20 estimate to bring it within the acceptable range. The engineer should re-evaluate the decisions made in developing the watershed model with regard to land use, subdivision, travel time estimates, and reach routing parameters. This is an open ended exercise.
Calibration

Please refer to Table 4.2 from the “Application of Hydrologic Methods in Maryland” manual (Page 73) and the flow charts beginning on Page 111 in the back of this manual. This table indicates the parameters that may be adjusted in order to calibrate the TR-20 run to fall in the range between the peak discharge estimate and the peak discharge estimate plus one standard deviation determined from the regression equations.

As a practical matter, GISHydro2000 has been designed to ease the modification of some of these parameter values. Other parameter values are best adjusted manually using a text editor on the actual TR-20 input file. We will address both types of calibration here:

**Calibration from within GISHydro2000**

- **Drainage Area:** it’s not recommended that you modify this value. However, you should carefully check the watershed delineation provided by GISHydro2000. Does the drainage boundary touch the “edge” of the DEM extent at any location? Does the drainage area seem consistent with the NHD stream network? Is the river so wide that it has separate “shores” that seem to be causing trouble? Is there a significant tributary just upstream/downstream of your selected outlet? How much difference to the drainage area would result by moving your initial outlet location just upstream/downstream of the tributary create? Special care should be taken in watersheds delineated on the eastern shore where topography is very flat and delineation of drainage areas from DEMs is poorer. You should make an approximate estimate of the drainage area from other means and be sure that the GISHydro2000 estimate is consistent with this. If not, you might try using one of the alternative DEM layers. In extreme cases, you may need to manually enter the drainage area in the TR-20 input file. (Keep in mind that the peak flow regression equations are automatically calculated based on the drainage area determined by GISHydro2000. If the area reported in the watershed characteristics files is not correct, the regression equations’ output will likewise be incorrect. **Possible re-entry in several locations: F1 (if selecting new DEM layers or a revised DEM extent), F2 (if selecting a new outlet location).**

- **RCN:** this value can be modified by +/- 10% within each category and within the limits of NRCS guidelines. There are three ways to modify this number using GISHydro2000:
  1. **Modify land use:** Use the Land Use Modification dialog to modify land use polygons within your watershed. Note that when you specify a new land use you are prompted to indicate the A, B, C, and D soil curve numbers. The approach is especially merited if your watershed contains a good deal of low-density residential (MOP code LU=11) land use, or if it contains a good deal of institutional (MOP code LU=16) land use. The actual land cover in these two categories can differ significantly from the default values. Indicating your own curve number values in these areas to reflect either more or less intense urbanization may often be justified. **Re-entry at F3 (Modify Land Use? Yes).**
2. **Modify hydrologic condition:** Use the Modify Hydrologic Condition dialog to modify hydrologic conditions within your watershed. The default hydrologic condition is “Good” in all cases. With this dialog you can re-specify the condition in each land use category individually. Note that since the default value is “Good” changing to “Fair” or “Poor” will result in larger curve numbers and ultimately shorter $T_c$ values and larger peak discharges. *Re-entry at F4 (Modify Hydrologic Conditions? Yes).*

3. **Modify lookup table directly:** This is not recommended. However if necessary, you use a text editor to modify and re-save any of the following files:
   - **andlookup***.txt:** used for Ragan and MOP land uses
   - **usgslookup***.txt:** used for 1970’s USGS land use
   - **mrlclookup***.txt:** used for MRLC land use
   - **zoninglookup***.txt:** used for Ultimate land use
   where “***” is either “good”, “fair” or “poor” depending on the hydrologic condition you intend to apply. These files are located in the `/umdgism/mdinterface` directory. Be sure that you retain the use of “tab” characters to separate entries in these files. You should also retain an original copy of the lookup file before modifying it. *Re-entry at F1 – you will need to reselect your quads and data layers to have GISHydro2000 apply the modified lookup files.*

4. **$T_c$:** the time of concentration, $T_c$, is a function of many factors: flow length, roughness, slope, channel geometry, and other variables. The discussion that appears here applies primarily to the velocity method $T_c$ calculation, which is the recommended method. The engineer has considerable freedom to modify many different values, primarily through the Time of Concentration Calculation dialog.
   - **Overland Flow:** the engineer may choose to modify the sheet flow roughness by up to 25% and the flow length may be modified but can be no longer than 100 feet (approximately one 30m pixel). These changes can be entered directly in the “sheet flow” part of the dialog. Also located here is the 2-year, 24-hr precipitation depth in inches. The value is determined and indicated by the output of the “Basin Statistics” menu choice. 3.2 inches is the default although this value does vary somewhat across the state.
   - **Shallow Concentrated Flow:** there is only one parameter for the shallow concentrated flow portion of the calculation: paved vs. unpaved. However, the flow length attributed to the shallow concentrated flow is also a key determinant of this quantity. The shallow concentrated flow portion of the overall flow length is determined as the residual of flow that is neither overland (the first x feet – up to 100 feet) nor channel (the last y feet, beginning at the upstream extreme of the channel network). The engineer can control this residual length by moving the upstream extreme of the channel network up or down depending on the specified source area. This is the minimum area required to form a channel. The smaller this area,
the greater the drainage density and the greater the upstream extent of the channel network. In this fashion, the engineer can control how much of the total flow length is treated as shallow concentrated flow vs. channel flow by varying the source area. The default source area is about 0.09 mi². This number may reasonably vary from as little as 0.05 mi² to as much as 0.5 mi².

c. **Channel:** As with the shallow concentrated flow, the length of channel flow can be controlled by varying the source area. Keep in mind that as channel length goes up, shallow concentrated flow length goes down and vice-versa. As with overland flow, the Manning’s roughness may also be varied. Finally, the channel geometry may be varied – as indicated by the width, depth, or area coefficients and exponents. The default values that appear here come from those presented by the U.S. Fish and Wildlife studies in Maryland. If you know the channel for your particular watershed differs significantly from the representative geometry of these studies, you can control the geometry here. A smaller channel cross-section will lead to greater velocities and thus smaller Tc values.

*Re-enter at F5 (set Tc method).*

5. **Combining Flow Paths:** If the modeled peak discharge is too small, it may indicate that the calculated Tc is too large. This problem often occurs if you have not combined any segments along the longest flowpath. This can be overcome by using the “CRWR-Prepro: Combine Longest Flow Path Segments” menu choice. *Please note:* if your modeled peak discharge is too big, combining segments will not help – you need to try one of the other calibration techniques.


b. Try the segment generator “Quick Merge” tool by clicking to merge each of “overland”, “swale”, and “channel” flow paths into a single segment for each part of the flow path. Repeat for each sub-area.

c. Return to Control Panel and generate new input file. Execute TR-20. The modeled peak discharges under the single segment configuration for each part of the flow path represents the lower-bound to the Tc’s you can calculate, and the probable upper-bound to the peak discharges you can calculate with regards to the Tc parameter alone. If the new peak discharge you model is less than or falls within the calibration window then you’re in good shape. If combining segments lands you in the calibration window then you’re done. If combining segments lands you below the lower-bound of the calibration window then you need to back off the “Quick Merge” (single segment) approach, but return to the segment generator dialog and combine segments more judiciously. Trial and error should result in a Tc that produces a peak discharge within the desired range. If the modeled
peak discharge is still too small, you will need to combine this calibration approach with at least one of the other approaches. *Re-enter at F6 (Combine Longest Flow Path Segments).*

6. **Representative Cross-Section:** The Cross Section Editor dialog automatically detects the cross-section geometry, drainage area, and reach slope. Additionally, it applies the hydraulic geometry from the U.S. Fish and Wildlife equations for Maryland and applies default values for Manning’s n. These data are used to generate a rating table consisting of 20 measurements of stage, discharge, and cross-sectional area. In the context of calibration, the engineer may choose from two options:
   a. **Revise input to the editor:** such input may be revised reach slope, channel roughness, or channel geometry. Be sure to press the “Recalculate” button after revising these entries. *Re-enter at F7 by using the “XE” tool which re-initiates the Cross Section Editor.*
   b. **Load in a rating table from a file:** here the engineer has complete control by simply loading in a tab delimited text file with the column headings: “Elev”, “Dischg”, and “Area” followed by at most 20 records of the corresponding rating table data. *Re-enter at F7 by using the “XE” tool which re-initiates the Cross Section Editor.*

7. **Antecedent Rainfall Condition (ARC):** In the TR-20 Control Panel, choose AMC = 1, 2, or 3. Be careful if doing simulations for more than one frequency. If this is the case, ARC can only increase as the return period increases (i.e. ARC=1 would tend to apply to 2, 5, and 10 year events; ARC=3 would tend to apply to 100, 200, and 500 year events). *Re-enter at F8 (TR-20 Control Panel).*

8. **Rainfall Tables:** In the TR-20 Control Panel, choose 6, 12, or 24 hour events. Similar to ARC the duration must strictly increase with increasing return period. *Re-enter at F8 (TR-20 Control Panel).*
Calibration outside of GISHydro2000

1. **Tc (Flow Lengths):** Modification of flow lengths is constrained within the GISHydro2000 environment to be consistent with the data contained within the GIS. In some circumstances these data may be faulty. In this case, the engineer must use his/her knowledge of actual flow lengths to modify the Tc calculations for any/all of the overland, shallow concentrated, and channel flow segments of the time of concentration calculation. These updated Tc values would then be manually revised within the text input file to TR-20. Re-enter at F9 (Run TR-20).

2. **Reach Routing Length:** Similar to the Tc calculation in #1 above, the routing length can be manually updated within the text input file if the GIS fails to accurately determine this value. Re-enter at F9 (Run TR-20).

3. **Storage at Culverts:** GISHydro2000 does not determine this quantity. If culvert storage is significant in your watershed, you will need to manually reflect this storage in the TR-20 input file. Re-enter at F9 (Run TR-20).

4. **Dimensionless Unit Hydrographs:** the default peak rate factor in TR-20 is 484. Within the Coastal Plain (eastern and western) of Maryland, the suggested peak rate factor is 284 (see Table 3.1 in Hydrology Panel report). Revising the dimensionless hydrograph must be done manually at this time. Re-enter at F9 (Run TR-20).

5. **Other:** Ultimately, the TR-20 input file is just a text file. GISHydro2000 has been built to automate much of the construction of standard TR-20 input files. In unusual watersheds, you may find that it is simply easier to manually edit the input text file than try to have GISHydro2000 do these edits for you. The justification for such edits would be based on it being within the range of the parameter values indicated by the Hydrology Panel report and that it be consistent with your understanding of the watershed you are analyzing. Re-enter at F9 (Run TR-20).
### Recommended TR-20 Calibration Limits (Table 4.2)

#### Table of TR-20 Variable Adjustment Limits for Calibration

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

**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” value.

**Notes:**
1. 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.
2. ARC < 2 may be more appropriate for estimating the 10-yr or more frequent storms.
3. ARC > 2 may be appropriate for severe storms of 200 yr and above.
4. Primary calibration variable.
5. 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.
6. 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.
7. 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.
8. Do not adjust the weighted RCN.

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.
Exercise II-F: File Upload/Download within the GISHydro Web Server

GISHydro2000 functionality can be obtained in stand-alone form by downloading the GISHydro program from the download page at:

http://www.gishydro.umd.edu/download_sign_in.asp

The stand-alone program is available for download at no cost but you must have your own version of ArcView (version 3.2 or greater with the Spatial Analyst v1.1 extension) in order to use the program.

Alternatively, you can access the GISHydro2000 through a Web Server version at no cost. To do this, you must contact Glenn Moglen (moglen@umd.edu) for an account and a small (free) plug in program must be installed on each machine from which you plan to access the web server. More information on how to obtain web server access is available at:

http://www.gishydro.umd.edu/web.htm

The following is short exercise showing how you can upload/download files to/from the GISHydro web server.

1. Log into the web server.
2. Click on the “Windows Explorer” icon shown circled above.
3. You will then get the Citrix “Client File Security” Dialog shown at left. Under the question, “What access do you want to grant?”, choose “Full Access” as shown. Then click “OK”.

http://www.gishydro.umd.edu/download_sign_in.asp
4. You will see the windows explorer application appear as shown at right.

5. When working on the server, you should confine your activities to the “e:\temp\” directory, for example setting up a directory with your last name. In my case that would be: “e:\temp\moglen”.

6. Notice that the lower part of the windows explorer application shows “Network Drives” (circled and blown up at right). These are the drives on your local machine (the machine you are accessing the web server from). For instance, the drive labeled “D$ on ‘Client’ (U:)” is physically the “d:” drive on my laptop, but windows explorer, from the perspective of the web server, sees it as the “u:” drive. Using the windows explorer application shown above. If I had a file (or files) on my laptop’s “d:” drive that I wanted to upload to the web server, I could simply use windows explorer to cut/paste them. Here’s how.

   a. From the web server’s windows explorer application, navigate to the laptop “d:” drive (seen by the server as network drive “u:").
   b. Select the file (or files) to be copied. Type <Ctrl>-c to copy.
   c. From the web server’s windows explorer application, navigate to “e:\temp\moglen”. Type <Ctrl>-v to paste. The files are now uploaded to the server.
   d. Reverse the operation to download files created by the GISHydro web server to your local machine.

   Hint: close all other windows explorer applications that might be running on your local machine before starting. The copy/paste processes must be done only using windows explorer running on the web server.

   For more instructions on accessing the Web-based version, see page 116.
ArcView Tutorial

This brief tutorial will provide an overview of the organization and basic use of ArcView. To learn more, it is strongly recommended that you obtain a book on ArcView and/or read the on-line help.

Documents

ArcView allows the user to view and use a number of different types of “documents” in order to perform GIS-based analyses. The window at the right shows an “empty” ArcView project as you first enter the software. The different icons on the vertical bar indicate a number of the broad categories of documents that ArcView recognizes: views, tables, charts, layouts, and scripts. We will discuss only those documents which need to be understood to effectively use the MDInterface.

Views

The “View” window is the document you are most likely to think of when you think of a GIS. This is the window that visually displays the spatially distributed data that is being analyzed. Within the MDInterface there will be two view windows that are used extensively: the “Maryland View” and the “Area of Interest”. We will discuss the contents and functionality of these views later.

Themes

Strictly speaking, “themes” are not documents, but are rather “sub-documents” that appear within the “View” window. A theme is an areal coverage showing the distribution of a certain property such as county boundaries, the road network, land use, etc. Themes come in three types: feature, image, and grid. Feature data is ArcView’s name for the “Vector” data format in generic GIS terms. Image data is ArcView’s way of allowing the user to load in aerial photography or scanned maps to provide useful background context to a map. Although this data is a “Raster” data format in generic GIS terms (i.e. the picture is really a large matrix of pixels), there is no “intelligence” associated with the image, it is simply there to add context. Grid data is ArcView’s name for the “Raster” data format in generic GIS terms. The spatial analyst extension of ArcView must be installed and active for ArcView to handle this data type. Most of the important data manipulations taking place within the MDInterface take advantage of the grid data type and the functionality associated with it.

Tables

The true “power” of a GIS is its ability to associate tables with visually displayed information like land use, elevation, or soils maps. Within the MDInterface there will be two kinds of tables that are of particular interest. The first is a table that associates land use and soil type with a particular curve number. We have provided a standard lookup table, identical to the one used previously in the original “GISHydro”. The second table
(actually two tables) provides a breakdown of the land use distribution by soil type and shows the curve numbers used.

**Layouts**

For purposes of reports or simply conveying complex spatial relationships, you will often find that you would like to print a copy of the ArcView “View” window. This is best done using the Layout document type which automates much of the necessary labelling, orientation, and scale issues associated with producing a proper map.

**Scripts**

The script document type gives the user access to ArcView at a programming level. It allows the user to automate repetitive tasks or perform complicated operations simply by clicking a button. For example, the MDInterface is actually a series of scripts linked together to allow a variety of specific actions by the user.

**The View Window**

We will now discuss just a few of the most basic concepts within the ArcView “View” environment:

**Active vs. Visible Themes**

Shown at right is an ArcView “View” window with two themes loaded into it. The two themes are “Land Use” and “MD Counties” as shown in the “legend” portion of the window. You will note that the legend entry for a theme consists of three parts: a “visibility” box, an “information content” box, and (very subtle) simply the area occupied by the theme within the legend which we will call the “activity” box. You will notice that the visibility box is checked on for “MD Counties” which indicates to ArcView that this information should be displayed within the View window. You should also notice that the activity box of “Land Use” is “popped up” relative to “MD Counties”. This means that “Land Use” is the active theme (even though it is not visible). Many of the functions of ArcView are designed to work only on the active theme(s). To make a theme active, simply click anywhere within the legend box occupied by the theme. You should see that it seems to pop up relative to the other themes. If you want more than one theme active at a time, hold down the shift button and click on all the theme legends you want to have active. It is easy to think that the
displayed theme is the active one. As this example illustrates, this is not necessarily the case. Activity and visibility are two different properties of a theme.

**Navigating within the Window**

ArcView provides a number of buttons and tools to move around within the “View” window and inspect the data. At right, the top row of icons are “buttons” which allow you to easily zoom and pan the extent of the view window that you want to see. The second row of icons are “tools” that require some additional input from you to make the view window zoom or pan as you desire. From left to right the top row of buttons work as follows:

- **Zoom to the Extent of All Data:** This button zooms to the extent of all themes loaded into the view window. If you have themes of differing extent (for instance a theme covering only a single county) and another theme covering the entire state, this button will zoom to the extents of the state.

- **Zoom to the Extent of Active Data:** This button zooms to the extent of only active theme(s) in the view window. If your single county coverage is the only active theme, pressing this button will zoom to the extents of the county, regardless of the extents of other data in the view window.

- **Zoom to Selected Data:** When only some items of a vector theme have been selected, this button will zoom the view to only to the extents of these selected items.

- **Zoom In Incrementally:** This allows you to zoom in centered on the current condition of the view window a small amount. This button is good if you want to slightly nudge the view window to display the contents at center slightly larger. If you want to perform a more substantial zoom you should use the “magnifying glass tool (+)” described below.

- **Zoom Out Incrementally:** This button is the opposite of the one above, panning the view out by a small amount. If you want to perform a more substantial pan you should use the “magnifying glass tool (-)” described below.

You might also note that all of these functions can also be performed from the “View” menu choice as well. It is often the case that menu choices have corresponding buttons to speed the operation. In the case of navigating the view, you will probably find it easier to use the buttons than the menu choices.

We now move to the three “tools” that allow you to speed the window navigation process. From left to right the bottom row of tools work as follows:

- **Magnifying Glass Tool(+):** This tool allows you to draw a rectangle around the area you wish to zoom to. The rectangle can be as big or little as you wish and you can use this tool repeatedly to zoom in as tight to a location as you wish.

- **Magnifying Glass Tool(-):** This tool works like the one above except that the amount of “panning” performed is inversely proportional to the size of the
window you draw. If you draw a big rectangle within the View window, it works much like the “Zoom out incrementally” button. If you draw a very small window, the view will pan out to a very great degree.

- **Hand Tool:** This tool works by grabbing a point in the view window and dragging it a set degree up, down, to the left or right as desired to move the center of the view from one location to another.

- **The “Identify” Tool:** With any “grid” theme active, you can use the identify tool to inspect the contents of any pixel. Click on the theme(s) you want to be active, click on the identify tool, then click on the pixel or item you want to know more about. A dialogue box will appear providing information on the selected pixel or item.

- **The “Label” Tool:** When trying to orient yourself within the MDInterface, you may find it helpful to use the provided road network theme. By first selecting the Label tool and then clicking on any road in the vicinity of the desired watershed outlet, ArcView will label that road with a recognizable name such as I-495, MD 193, etc. This should help you feel very confident of your whereabouts when trying to find a specific location.

### The Table Window

As stated earlier, tables are an integral part of GIS operations. To look at the table associated with any theme in the View window you should make that theme active, then select “Theme: Table...” from the menu list. You should be able to look at the tables associated with any feature theme, and many grid themes. Grid themes of continuous data may not have viewable tables because they would simply have to many entries.

### The Layout Window

We will not discuss layouts at length here. We strongly suggest you consult additional tutorials or other documentation to learn more about the layout facility. You will want to use this facility for the creation of finalized maps associated with your GIS work.

To quickly generate a print-ready map, orient the view just as you would like for it to be displayed. From the “View” menu choice, choose “Layout...”. You will be asked to choose a basic orientation and style template and then a “Layout” window will appear. Everything in this window is potentially editable by double-clicking on the desired item to change its contents, size, orientation, etc.

### The Script Window

ArcView provides for the capacity to write programs that operate on the view, as well as themes, tables and other ArcView document types. The scripting language used by ArcView is called “Avenue” and is an object-oriented language. A script window allows you to edit, compile, run, and debug scripts. We will return to this topic and document type in much greater depth later when we begin to discuss and write scripts.
Vector and raster data models

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

Continuous surfaces can be represented using the grid or raster data Model in which a mesh of square cells 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 overlaying 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 and measured at particular points where there are climate stations.

Being able to move back and forth smoothly between raster and vector representations of data is an important feature of spatial hydrology.
TR-20 Structure and Operation

Technical Release 20: Computer Program for Project Formulation Hydrology (TR-20) (SCS, 1983) is a hydrologic model for simulation of direct runoff hydrographs resulting from natural or synthetic rainfall occurring over a watershed. The program can be used to model complex watersheds with multiple subareas, channel reaches, and reservoirs. Hydrographs are generated for subwatersheds, combined or separated at confluence points, and routed through downstream reaches or structures.

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 TR-20. The unit hydrograph is the transfer function used by TR-20 to transform the rainfall excess into direct runoff. The rainfall hyetograph is convolved with the unit hydrograph to produce the direct runoff hydrograph. This process is explained below.

For a specified rainfall depth and distribution, a hydrograph is developed for each subwatershed 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:

\[ Q = \frac{(p - 0.2S)^2}{p + 0.8S} \]
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:

\[
q_p = \frac{484AQ}{t_p} = \frac{726AQ}{tc}
\]

where \( t_p \) is the time to peak in hours, \( t_c \) is the time of concentration in hours, \( Q \) is the runoff of one inch for the unit hydrograph, and \( A \) is the drainage area in square miles.

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. The value 484 in the above equation is called the peak rate factor and represents an empirical constant.

Hydrographs generated from upstream subwatersheds can be 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, which TR-20 uses the storage-indication method to simulate.

**Simplified Example**

The best way to illustrate the overall process of developing a TR-20 model is to walk through a simplified example. The example that follows gives a 24.9 mi\(^2\) watershed divided into five subwatersheds. It contains two reach routings in the lower portion of the main channel. At the outlet, the peak discharge resulting from 4.25-in of rainfall is simulated for the 24-hr Type II storm.

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. In order to route upstream hydrographs to downstream locations, a representative cross section is needed from which a stage-discharge-end area relationship can be produced.
Watershed Configuration

Consider the following arrangement of subwatersheds for the example TR-20 model:

Hydrographs are generated for each of the subareas and are combined in time at the junction points. The difference in the timing of runoff for each subarea (i.e. time of concentration) controls how the peak discharge will be affected when the hydrographs are combined. If the times are very close, the times to peak of each of the hydrographs will be similar and a larger peak discharge will result. If the times are substantially different, the peaks will not coincide and a reduced peak will result. The consideration of increased peak does not ignore volume considerations. Regardless of the timing of runoff, the volume of runoff generated by a real or synthetic rainfall distribution will eventually be translated in time through the watershed.

Cross Sections

Cross sections control not only translation of upstream hydrographs but also attenuation. The attenuation is based on the storage available to runoff while in the channel/floodplain.

Two cross sections are identified in the watershed that will be used to route hydrographs. Cross Section 3 (L = 7985 ft.) will be used to route the combined hydrograph from subwatersheds 1 and 2. Cross Section 5 (L = 10424 ft.) will be used to route the combine hydrograph resulting from subwatersheds 3 and 4 and the routed hydrograph through Cross Section 3.

Representative cross sectional geometry was determined for each of the sections for the channel and overbank. Additionally, roughness characteristics, given in terms of Manning roughness coefficients were determined for Section 3 (channel n: 0.035, left n:
0.07, and right n: 0.09) and for Section 5 (channel n: 0.035, left n: 0.07, right n: 0.09). The sections are shown below:
**Rating Table Calculation**

For each of the cross sections shown above, a stage-discharge-end area relationship must be developed. This information is used by the TR-20 model in the Modified-Att-Kin reach routing procedure. At incremental depths, values of stage, discharge and end area are computed. The relationship below can be used to develop the reach rating table for a complex cross section involving a center channel, left and right overbank.

\[
Q = \sum \Delta Q = A_i V_L + A_r V_c + A_k V_R
\]

where \( V \) is the velocity from Manning’s Equation:

\[
V = \frac{1.49 \frac{2^\frac{2}{3} \frac{1}{2}}{n}}{R S^\frac{1}{2}}
\]
**Input File**

The TR-20 input file is arranged in cards of job and header information, structure and reach tables, standard control statements, and executive control statements. The input “cards” (they really aren’t cards anymore, although they used to be in the early days of the program) contain all of the configuration and parameter values necessary to produce a runoff hydrograph.

The formatting of the input files is somewhat rigid and may take some getting used to. Data is placed in specific fields based on horizontal column location. The following three figures are input forms for listing the contents of the input file:
### Stream Cross Section Data

**Cross Section No.**

<table>
<thead>
<tr>
<th>Section No.</th>
<th>Elevation, ft.</th>
<th>Discharge, cfs</th>
<th>Area, sq ft.</th>
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</tr>
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<tr>
<td>3</td>
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<td></td>
<td></td>
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<tr>
<td>9</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

**Executive Control for Watershed**

**Data Operation**

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<th>Data Field 2</th>
<th>Data Field 3</th>
<th>Record Ident.</th>
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</thead>
<tbody>
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</tr>
<tr>
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</tr>
</tbody>
</table>

**Examples**

- The record is used for control of subarea data and standard control that did not currently affect.
- The record is not used forcontrol of subarea data and standard control that did not currently affect.

**Instruments**

<table>
<thead>
<tr>
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<th>Notes</th>
<th>Rainfall Depth</th>
<th>Rainfall Duration</th>
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<tbody>
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</tr>
<tr>
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<tr>
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</tbody>
</table>

**Important:** Date No. 1 and 2 require decimal points.
When entered completely, the TR-20 input file for the sample watershed will look like:

<table>
<thead>
<tr>
<th>JOB</th>
<th>TR-20</th>
<th>FULLPRINT</th>
<th>NOPLOTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>TITLE</td>
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<td>OUTLET OF BASIN AT WATERSHED #5</td>
<td></td>
</tr>
<tr>
<td>2 XSECTN 003</td>
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<td>193.29</td>
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<td>20.071</td>
<td>8.203</td>
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<td>85.823</td>
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</tr>
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<td>8</td>
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<td></td>
</tr>
<tr>
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<td></td>
<td></td>
</tr>
<tr>
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<td>1</td>
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<tr>
<td>6 RUNOFF 1</td>
<td>2</td>
<td>2</td>
<td>5.5599</td>
</tr>
<tr>
<td>6 ADDHYD 4</td>
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<td>1 2 3</td>
<td></td>
</tr>
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<td>1</td>
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</tr>
<tr>
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</tr>
<tr>
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</tr>
<tr>
<td>7 COMPUT 7 001 010</td>
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<td>4.25</td>
<td>1.02 2 1 1</td>
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<tr>
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</tr>
<tr>
<td>ENDJOB 2</td>
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</tr>
</tbody>
</table>
Output File.
TR-20 creates an output file which reports the desired output options (hydrographs, peaks, elevations, volumes) at desired locations within the watershed. The output file for the sample watershed is shown below:

```
1
TR20 -----------------------------------------------------------------------------------------------
--- SCS -
OUTLET OF BASIN AT WATERSHED #5

VERSION
03/10/**
2.04TEST
13:10:42                    PASS   1   JOB NO.   1

PAGE   1

OPERATION ADDHYD XSECTION 10
INPUT HYDROGRAPHS 1,5 OUTPUT HYDROGRAPH 4

PEAK TIME(HRS) PEAK DISCHARGE(CFS) PEAK ELEVATION(FEET)
13.30            6818.4                       (NULL)

RUNOFF ABOVE BASEFLOW (BASEFLOW = .00 CFS)
1.85 WATERSHED INCHES;  29746 CFS-HRS; 2458.2

ACRE-FEET.
1
```

```
TR20 -----------------------------------------------------------------------------------------------
--- SCS -
OUTLET OF BASIN AT WATERSHED #5

VERSION
03/10/**
2.04TEST
13:10:42                    PASS   2   JOB NO.   1
```
Appendices

1. Sections of Maryland Hydrology Panel Report:
   b. Appendix 3: Fixed Region Regression Equations for Maryland

2. Flowcharts for Hydrologic Analysis in GISHydro2000

3. Links to Useful and Relevant Documents for GISHydro2000
2.1 INTRODUCTION

The Maryland State Highway Administration (MSHA) has a long history of using statistical methods for estimating flood discharges for the design of culverts and bridges in Maryland. MSHA has funded three regional regression studies over the last 25 years, Carpenter (1980), Dillow (1996) and Moglen and others (2006).

Carpenter (1980) developed regression equations for three hydrologic regions (North, South and Eastern) in Maryland by relating flood discharges based on Bulletin 17A (U.S. Water Resources Council, 1977) at 225 rural gaging stations (114 in nearby states) to watershed and climatic characteristics. Carpenter (1980) also used short-term rainfall-runoff data collected at eight small stream sites to calibrate a watershed model and simulate annual peak discharges at these stations using long-term rainfall data. The simulated annual peak discharges were analyzed using Bulletin 17A guidelines to estimate the design flood discharges at each station. For 17 other small stream stations in the Appalachian Plateau and Piedmont Regions with only observed data for the period 1965-76, Carpenter adjusted the flood discharges based on comparisons to nearby long-term stations to be more representative of a longer period of record.

Dillow (1996) developed regression equations for five hydrologic regions in Maryland (Appalachian Plateau, Blue Ridge, Piedmont, western and eastern Coastal Plains, see Figure 2.1). Dillow’s study superceded the study by Carpenter (1980). Dillow (1996) used flood discharges based on Bulletin 17B estimates (Interagency Advisory Committee on Water Data (IACWD), 1982) at 219 rural gaging stations (112 in nearby states) in developing his regression equations. Dillow (1996) also utilized the rainfall-runoff estimates for the small watersheds that were developed by Carpenter (1980). He chose not to use Carpenter’s (1980) adjusted design discharges for the small watersheds with observed data for the period 1965-76 but used design discharges based on the observed short-term record.

Moglen and others (2006) evaluated three approaches for regional flood frequency analysis using data for rural and urban (≥ 10% impervious) gaging stations: the Fixed Region approach, the Region of Influence method (Burn, 1990) and regional equations based on L-Moments (Hosking and Wallis, 1997). The Fixed Region approach is analogous to the approach taken by Carpenter (1980) and Dillow (1996) where regression equations are developed for a fixed geographic region and are based on Bulletin 17B estimates at the gaged sites. For the Region of Influence approach, regression equations are based on gaging stations that have the most similar watershed characteristics as the unaged site of interest. There are no geographic flood regions and the regression equations are different for each unaged site. For the gaged sites, flood discharges based on Bulletin 17B guidelines were used in the Region of Influence analysis. The L-
Moment approach (Hosking and Wallis, 1997) uses linear moments, a linear combination of the untransformed annual peak discharges (not the logarithms), to estimate the parameters of the frequency distribution. Several frequency distributions can be used in the L-Moment approach, but the Generalized Extreme Value distribution was shown to be most appropriate for Maryland streams. For estimation at an ungaged site, the L-Moment approach is analogous to an index flood approach where the mean annual flood is estimated from a regression equation based on watershed characteristics and design discharges such as the 100-yr discharge, are estimated as a ratio to the mean annual flood.

Carpenter (1980) and Dillow (1996) used the generalized skew maps in Bulletins 17A and 17B (same map) in developing the weighted skew estimates in defining the design discharges at the gaging stations. Moglen and others (2006) developed new estimates of generalized skew as described later and illustrated that these estimates of generalized skew were more accurate than those from the Bulletin 17B map.

Moglen and others (2006) compared estimates of flood discharges from the Fixed Region, Region of Influence, and L-Moment methods to Bulletin 17B estimates at the gaged sites and determined that the Fixed Region approach was most accurate. The Fixed Region approach uses the five hydrologic regions shown in Figure 2.1 plus there are separate rural and urban equations for the Piedmont Region (a total of six sets of equations). The Fixed Region regression equations are the recommended statistical approach for ungaged watersheds in Maryland and supercede the regression

Figure 2.1
equations developed by Dillow (1996). The Fixed Region regression equations are described in more detail in this chapter and are provided in Appendix 3.

The physiographic regions shown in Figure 2.1 appear as crisp lines separating one region from another, and thus one set of regression equations from another. Caution should be exercised by engineers when analyzing watersheds near these physiographic boundaries. For instance, the fall line which separates the Piedmont from the Western Coastal Plain region is more appropriately considered a region of some width, rather than a crisp line. Within this area close to physiographic region boundaries it is possible for a watershed that is strictly located within one region to exhibit flood behavior more consistent with the neighboring physiographic region. In GISHydro2000, the software automatically detects if the watershed comes within 5 km of the physiographic boundary and prints a warning if this is the case. Similarly, in the Blue Ridge physiographic region, underlying limestone geology is a predictor variable. The location of this limestone cannot be known with precision. In GISHydro2000, the software automatically detects if the watershed comes within 1 km of the limestone geology boundary and prints a warning if this is the case.

2.2 FLOOD DISCHARGES AT GAGING STATIONS

Estimates of design discharges, such as the 100-yr flood discharge, are made at gaging stations where there is at least 10 years of annual peak discharges by using Bulletin 17B (IACWD, 1982). These guidelines are used by all Federal agencies and several state and local agencies for flood frequency analysis for gaged streams. Bulletin 17B guidelines include fitting the Pearson Type III distribution to the logarithms of the annual peak discharges using the sample moments to estimate the distribution parameters and provide for (1) outlier detection and adjustment, (2) adjustment for historical data, (3) development of generalized skew, and (4) weighting of station and generalized (regional) skew.


If the gaged watershed has undergone significant change during the period of record, the annual peak data may not be homogeneous. The user should ensure that the data are homogeneous, and exhibit no significant trends due to land-use change before performing the frequency analysis. A simple way to check on this is to plot the annual peak discharges versus time and determine if there are any noticeable trends in the data. Statistical procedures for performing a more quantitative evaluation of trends and non-homogeneity in flood data are discussed by Pilon and Harvey (1992), McCuen and Thomas (1991) and McCuen (1993).
In the recently-completed regional flood frequency study, conducted in cooperation with the Maryland State Highway Administration, Moglen and others (2006) used Bulletin 17B and L-Moment procedures to estimate selected design discharges at gaging stations in Maryland and Delaware in the development of regional regression equations. A generalized skew study was performed for the Bulletin 17B analysis to obtain a new generalized skew (in lieu of the Bulletin 17B skew map) to weight with the station skew. An average generalized skew coefficient of 0.45 with a standard error of 0.41 was determined for stations in the Eastern Coastal Plains region. An average generalized skew coefficient of 0.55 with a standard error of 0.45 was determined for the rest of the state. The nationwide standard error of the Bulletin 17B skew map is 0.55.

Moglen and others (2006) developed estimates of the 1.25-, 1.50-, 1.75-, 2-, 5-, 10-, 25-, 50-, 100-, 200- and 500-yr peak discharges at 136 rural and 18 urban gaging stations in Maryland and Delaware using annual peak data through the 1999 water year. Data for the 154 stations were used in the regional regression analyses. Estimates of design discharges provided by Moglen and others (2006) are available to those users who choose not to perform their own Bulletin 17B analysis.

If the watershed characteristics of the gaging station are similar to those used in deriving the regression equations, then the best estimate of design discharges at the gaging station is considered to be weighted estimates based on gaging station data and the Fixed Region regression estimates. Moglen and others (2006) describe the flood discharges and the associated watershed characteristics used in the development of the Fixed Region regression equations. Watershed characteristics for USGS gaging stations in Maryland and Delaware used in the regional regression analyses are given in Appendix 1. Flood frequency estimates for USGS gaging stations in Maryland and Delaware are given in Appendix 2. The procedures for weighting the gaging station and regression estimates are described below.

In accordance with Appendix 8 of Bulletin 17B guidelines (IACWD, 1982), it is assumed that an estimate at a single gaging station is independent of the regional regression estimate. Assuming independence of estimates, Hardison (1976) has shown that a weighted estimate, obtained by weighting each estimate inversely proportional to its variance, has a variance less than either of the individual estimates. Hardison (1976) further demonstrated that weighting two estimates inversely proportional to their variances was comparable to weighting by the equivalent years of record. The following weighting equation described by Dillow (1996) should be used:

\[
LQ_w = \frac{(LQ_g \times N_g + LQ_r \times N_r)}{(N_g + N_r)}
\] (2.1)

where \(LQ_w\) is the logarithm of the weighted peak discharge at the gaging station, \(LQ_g\) is the logarithm of the peak discharge at the gaging station based on observed data, \(LQ_r\) is the logarithm of the peak discharge computed from the appropriate Fixed Region regression equation, \(N_g\) is the years of record at the gaging station, and \(N_r\) is the equivalent years of record for the Fixed Region regression estimate.
The equivalent years of record of the regression estimate is defined as the number of years of actual streamflow record required at a site to achieve an accuracy equivalent to the standard error of prediction of the regional regression equation. The equivalent years of record (Nr) is computed as follows (Hardison, 1971):

$$Nr = \frac{S}{SE_p}^2 R^2$$  (2.2)

where S is an estimate of the standard deviation of the logarithms of the annual peak discharges at the ungaged site, SE_p is the standard error of prediction of the Fixed Region regression estimates in logarithmic units, and R^2 is a function of recurrence interval and skewness and is computed as (Stedinger and others, 1993):

$$R^2 = 1 + G*Kx + 0.5 \times (1+0.75*G^2)*Kx^2$$  (2.3)

where G is an estimate of the average skewness for a given hydrologic region, and Kx is the Pearson Type III frequency factor for recurrence interval x and skewness G. Average skewness values G were defined using design discharges from Moglen and others (2006) and are as follows: 0.489 for the Appalachian Region, 0.484 for the Blue Ridge Region, 0.585 for the urban equations in the Piedmont Region, 0.553 for the rural equations in the Piedmont Region, 0.554 for the Western Coastal Plain Region and 0.477 for the Eastern Coastal Plain Region.

In order to estimate the equivalent years of record at an ungaged site, the standard deviation of the logarithms of the annual peak discharges (S in Equation 2.2) must be estimated. Average values of S were computed for each region and are as follows: 0.241 log units for the Appalachian Region, 0.292 log units for the Blue Ridge Region, 0.324 log units for the urban equations in the Piedmont Region, 0.299 log units for the rural equations in the Piedmont Region, 0.294 log units for the Western Coastal Plain Region and 0.304 log units for the Eastern Coastal Plain Region.

A computer program, developed by Gary Tasker, USGS, and modified by Glenn Moglen, University of Maryland, can be used to compute the weighted estimate given in equation 2.1 and for determining the equivalent years of record, and standard errors of prediction for these estimates. The equivalent years of record for the weighted estimate is assumed to be Ng+Nr (see Equation 2.1), the sum of the years of gaged record and equivalent years of record for the regression estimate. The Tasker program was updated and the regression equations developed by Dillow (1996) were replaced with the Fixed Region equations shown in Appendix 3.

An example of computing a weighted estimate at a gaging station, Northwest Branch Anacostia River near Colesville (station 01650500), a 21.2-square-mile urban watershed (impervious area = 20.1 percent) in the Piedmont Region is illustrated below. The flood discharges for station 01650500 (Qg in cfs) based on 62 years of record are taken from Appendix 2 and are given in Table 2.1. Also provided in Table 2.1 are the Fixed (Piedmont Urban) Region regression estimates (Qr in cfs) at station 01650500.
Table 2.1
Flood Frequency Estimates for Northwest Branch Anacostia River near Colesville (station 01650500) based on Gaging Station data, Regression Equations and a weighted estimate.

<table>
<thead>
<tr>
<th>Return period (years)</th>
<th>Station (Qg) (cfs)</th>
<th>Regression (Qr) (cfs)</th>
<th>Weighted (Qw) (cfs)</th>
</tr>
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<tbody>
<tr>
<td>2</td>
<td>1,250</td>
<td>1,550</td>
<td>1,270</td>
</tr>
<tr>
<td>5</td>
<td>2,260</td>
<td>2,920</td>
<td>2,360</td>
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<td>3,240</td>
<td>4,260</td>
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<td>4,960</td>
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<tr>
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<td>8,900</td>
<td>11,700</td>
<td>9,980</td>
</tr>
<tr>
<td>500</td>
<td>16,600</td>
<td>21,600</td>
<td>18,400</td>
</tr>
</tbody>
</table>

The Fixed Region regression estimates in log units (LQr) are weighted with the station estimates in log units (LQg) using Equation 2.1. The weighting factors are the years of record at station 01650500 (Ng = 62) and the equivalent years of record (Nr) for the regression equations are computed from Equation 2.2 and given in Appendix 3. The weighted estimates are shown in Table 2.1. For example, the 100-yr weighted estimate is computed from Equation 2.1 as follows using the logarithms of the flood discharges

\[ LQw = \frac{(LQg \times Ng + LQr \times Nr)}{(Ng + Nr)} = \frac{(3.94939\times62 + 4.06819\times45)}{(62+45)} = 3.999351 \text{ log units, where } Qw = 9,980 \text{ cfs.} \]

The equivalent years of record for the weighted estimate is assumed equal to the sum of the observed record length (62 years) and the equivalent years of record from the regression equation (45 years). Therefore, for the 100-yr weighted estimate, the equivalent years of record are 107 years.

Figure 2.2 illustrates the process of weighting station data with the regional regression estimates.
Figure 2.2
Regional Regression Equation Flow Chart

2.3 ESTIMATES FOR UNGAGED SITES NEAR A GAGING STATION

Procedures described by Dillow (1996) are recommended for obtaining estimates of design discharges for ungaged sites that are on the same stream as the gaging station, have similar watershed characteristics as the gaging station and are within 50 percent of the drainage area of a gaging station. Data provided by Moglen and others (2006) and shown in Appendix 1 can be used to determine if the gaged stream has watershed characteristics similar to those used in developing the regression equations. The procedure involves three steps:

1. Compute the ratio (R) of the weighted estimate to the Fixed Region regression estimate at the gaging station

\[ R = \frac{Q_w}{Q_r} \]  

(2.4)

where Qw and Qr are the weighted and regression estimates in cfs.
2. Scale the ratio $R$ based on the difference in drainage area between the ungaged site and the gaging station using the following equation (Sauer, 1974):

$$R_w = R - \frac{(2|A_g - A_u|)}{A_g} \times (R-1)$$

(2.5)

where $R_w$ is the scaled ratio, $A_g$ is the drainage area in square miles at the gaging station and $A_u$ is the drainage area in square miles at the ungaged location.

3. Compute the final estimate ($Q_f$) at the ungaged site as

$$Q_f = R_w \times Q_U$$

(2.6)

where $Q_U$ is the Fixed Region regression estimate in cfs at the ungaged site.

Equation 2.5 was developed with the limiting assumption that estimates would only be extrapolated upstream and downstream on the same stream to 0.50 or 1.50 times the drainage area of the gaging station. If Equation 2.5 is used beyond these limits, then irrational results may be obtained. If the gaged watershed has undergone significant change during the period of record, then the annual peak data may not be homogeneous and the extrapolation procedure may not be appropriate.

In the case where the ungaged site is between two gaging stations, estimates of $Q_g$ should be obtained by interpolating between the two gaging stations on the basis of a logarithmic plot of peak discharge versus drainage area. An estimate of $N_g$ is obtained as an arithmetic average of the record length at the two gaging stations using the differences in drainage area between the ungaged site and the gaging stations as the weighting factor. The values of $L_{Q_g}$ and $N_g$ so obtained should be used in Equation 2.1 to get a final weighted estimate for the ungaged site.

The weighted estimates at the Northwest Branch of the Anacostia River near Coleville (shown in Table 2.1), where the drainage area is 21.2 square miles, are extrapolated upstream to an ungaged location where the drainage area is 15.1 square miles and the impervious area is 25 percent. For this procedure to be applicable, the watershed characteristics at the ungaged site should be similar to those at the gaged site. For this example, the weighted ($Q_w$) and regression ($Q_r$) 100-yr flood discharge at station 01650500 are 9,980 and 11,700 cfs, respectively, and the regression estimate ($Q_u$) at the ungaged location is 9,940 cfs. The adjusted 100-yr flood discharge at the ungaged location on the Northwest Branch of the Anacostia River is computed to be 9,310 cfs using Equations 2.4 to 2.6 as follows:

$$R = \frac{Q_w}{Q_r} = \frac{9,980}{11,700} = 0.853$$

$$R_w = R - \left[ \frac{(2|A_g - A_u|)}{A_g} \times (R-1) \right] = 0.853 - \left[ \frac{(2|21.2-15.1|)}{21.2} \times (-0.147) \right] = 0.937$$

$$Q_f = R_w \times Q_u = 0.937 \times 9,940 = 9,310 \text{ cfs}.$$
The equivalent years of record are 71.4 years for the 100-yr flood discharge at the ungauged location. This value is interpolated between 107 years for the weighted station data at 21.2 square miles and 45 years for the Fixed Region regression equation estimate at 0.5 times the gaged drainage area. The computation is 107 – ((107-45)*6.1/10.6) = 71.4 years. The equivalent years of record for the Fixed Region regression equations are given in Appendix 3.

2.4 ESTIMATES AT UNGAGED SITES

Fixed Region regression equations developed by Moglen and others (2006) can be used for estimating the 1.25-, 1.50-, 1.75-, 2-, 5-, 10-, 25-, 50-, 100-, 200- and 500-yr peak discharges for rural and urban watersheds in Maryland which are not significantly affected by detention storage, urbanization, tidal marshes or changing land-use conditions such as mining, excavation or landfill activities. Equations applicable to urban watersheds are available for just the Western Coastal Plains and Piedmont Regions.

In addition, the watershed characteristics for the site of interest should be within the range of the watershed characteristics of the gaging stations used in the regional analysis. Watershed characteristics used in the development of the Fixed Region regression equations are given in Appendix 1. These data can be used to determine if the ungauged site has similar watershed characteristics as those used in developing the regression equations.

A computer program developed by Gary Tasker, USGS, was modified to facilitate the estimation of flood discharge estimates at ungauged sites using the Fixed Region regression equations documented in Appendix 3. The equivalent years of record, the standard errors of prediction and prediction intervals are also computed for these estimates using the Tasker program.

The standard error of prediction for the ungauged site is computed as the sum of the model and sampling error as described by Hodge and Tasker (1995). Given the standard error of prediction for an ungauged site, the equivalent years of record are computed by Equation 2.2. Prediction intervals are then computed as:

\[
\log Q_x + t(c/2, n-p)\sigma(S\varepsilon)^{2}(1+ho)^{0.5} \text{ upper value (2.7a)}
\]
\[
\log Q_x - t(c/2, n-p)\sigma(S\varepsilon)^{2}(1+ho)^{0.5} \text{ lower value (2.7b)}
\]

where \(Q_x\) is the flood discharge for recurrence interval \(x\), \(t\) is the critical value of students \(t\) for a 100 (1-c) percent prediction interval with \(n-p\) degrees of freedom, \(n\) is the number of gaging stations used in the regression analysis, \(p\) is the number of explanatory variables in the Fixed Region regression equation, \(ho\) is the leverage of the site. The standard error of prediction (SEp) estimated by the Tasker program is more accurate than using the standard error of estimate given in Appendix 3. The standard error of estimate given in Appendix 3 is a measure of the variability of the station data about the regression equation and is less than the standard error of prediction which is a measure of how well
00the equations predict flood discharges at an ungaged site. The standard error of prediction includes both the variability about the regression equation and the error in the regression coefficients or the bias in the regression estimate.

The leverage expresses the distance of the site’s explanatory variables from the center of the convex data set (called the Regressor Variable Hull) defined by the explanatory variables in the regression analysis (Montgomery and Peck, 1982). The prediction intervals are directly related to the magnitude of the leverage for a given site. The leverage is computed as (bold letters denote a matrix):

\[ h_0 = x_0 (X^T X)^{-1} x_0^T \] (2.8)

where \( x_0 \) is a row vector of the logarithms of the explanatory variables at a given site, \( (X^T X)^{-1} \) is the covariance matrix of the regression parameters (T means transpose), \( x_0^T \) is a column vector of the logarithms of the explanatory variables at a given site.

Equations 2.7 and 2.8 and the data in Appendix 1 are used to compute the prediction limits in the Tasker program. For plus and minus one standard error of prediction, there is a 68 percent chance that the true discharge lies between the upper and lower prediction limits.

The range of watershed characteristics for each hydrologic region is given in Table 2.2. The watershed characteristics were estimated using GIS data from several sources as described in the report by Moglen and others (2006). The Fixed Region regression equations for each hydrologic region are given in Appendix 3 along with the standard error of estimate and the equivalent years of record. The Fixed Region regression equations are based on 24 stations in the Eastern Coastal Plain (including 9 stations in Delaware), 22 stations in the Western Coastal Plain, 50 stations in the Piedmont (34 rural stations, 16 urban stations), 20 stations in the Blue Ridge and 23 stations in the Appalachian Plateau. A total of 139 stations out of the 154 stations were used to derive the Fixed Region regression equations. Fifteen stations were omitted from the analyses because they were outliers and not representative of any stations in the given region.

In developing the Fixed Region regression equations, forest cover and impervious area for 1985 land use conditions were used because these data tended to be most correlated with the flood discharges. The reason is that the 1985 land use conditions were closer to the midpoint of the period of record of the streamgage data particularly for the urban watersheds in the Western Coastal Plains and Piedmont Regions. In applying the regression equations, the analyst should use the current land use conditions to obtain estimates of the flood discharges for existing conditions.

The percent A soils \( S_A \) and D soils \( S_D \) are estimated using the “STATSGO Soils” layer obtained from the NRCS. \( S_A \) or \( S_D \) measured from the “Ragan soils” developed from the SCS County Soil Series publications by Robert Ragan at the University of Maryland and available in digital form through GISHydro2000 and from
SSURGO soils data obtained from the NRCS can (in some cases) vary widely from the estimate determined from the “STATSGO Soils”-derived measure. For this reason, it is preferable to use $S_d$ or $S_d$ estimated from the “STATSGO Soils” when using the Fixed Region regression equations.

### 2.5 FUTURE RESEARCH

The Fixed Region regression equations are applicable to both rural and urban watersheds in the Western Coastal Plains and Piedmont Regions. For the urban watersheds, a “relatively constant period of urbanization” was defined as a change in impervious area of less than 50 percent during the period of record. If a watershed had 20 percent impervious area at the beginning of record, it could have no more than 30 percent impervious area at the end of the time period (Sauer and others, 1983). No urban stations were eliminated from the analysis based on these criteria notably because several urban gaging stations were discontinued in the late 1980s. For future analyses, a more detailed approach should be developed for determining a homogeneous period for frequency analysis or for adjusting the annual peak data to existing conditions.

The Maryland Department of Planning (MDP) data were used to estimate land use conditions such as impervious area. The MDP approach is to assign a percentage of impervious area to various land use categories. For example, Institutional Lands are assigned an impervious area of 50 percent but there is considerable variation in impervious area for this land use category. Impervious area as estimated from the MDP data was statistically significant in estimating flood discharges for urban watersheds in the Western Coastal Plains and Piedmont Regions but this variable did not explain as much variability as anticipated. For future regression analyses, more accurate or detailed measures of urbanization (impervious area, percentage of storm sewers, length of improved channels, etc) should be used for characterizing urbanization and its affect on flood discharges. Improved measures of urbanization would likely provide more accurate regression equations in the future.

Many of the gaging stations on small watersheds (less than about 10 square miles) were discontinued in the late 1970s resulting in generally short periods of record for the small watersheds in Maryland. As described earlier, Carpenter (1980) and Dillow (1996) utilized estimates of flood discharges from a calibrated rainfall-runoff model for eight gaging stations in Maryland. Carpenter (1980) also adjusted flood discharges at 17 other small watersheds based on comparisons to nearby long-term gaging station data. Moglen and others (2006) utilized both of these adjustments in developing the Fixed Region regression equations in Appendix 3. There are many other short-record stations in Maryland for which no adjustment was made. For future regression analyses, a more systematic approach for adjusting the short-record stations should be developed. In addition, streamgaging activities should be resumed on several of the small watersheds.
where there are less than 15 years of record. Improving the data base of small watershed data would provide more accurate regression equations in the future.

Finally, only stations primarily in Maryland were used in developing the Fixed Region regression equations in Appendix 3 because the required land use data were not available in neighboring states. The exception was the inclusion of nine gaging stations in Delaware. More detailed land use data should be developed for the neighboring states like Pennsylvania, Virginia and West Virginia so that additional gaging stations could be included in the regional regression analyses.
## Table 2.2
Range of Watershed Characteristics for Each Hydrologic Region in Maryland.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Eastern Coastal Plain</th>
<th>Western Coastal Plain</th>
<th>Piedmont (Rural)</th>
<th>Piedmont (Urban)</th>
<th>Blue Ridge</th>
<th>Appal. Plateau</th>
</tr>
</thead>
<tbody>
<tr>
<td>DA</td>
<td>2.27 to 112.2 sm</td>
<td>0.1 to 349.5 sm</td>
<td>0.28 to 258.07 sm</td>
<td>0.49 to 102.05 sm</td>
<td>0.11 to 820 sm</td>
<td>0.52 to 293.7 sm</td>
</tr>
<tr>
<td>BR</td>
<td>5.1 to 43.5 ft</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>S_A</td>
<td>0 to 49.4 %</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>IA</td>
<td>---</td>
<td>0 to 36.8 %</td>
<td>---</td>
<td>10.9 to 42.8 %</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>S_D</td>
<td>---</td>
<td>2.4 to 26.4 %</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>FOR</td>
<td>---</td>
<td>---</td>
<td>4.4 to 75.3 %</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>LIME</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>0 to 100 %</td>
<td>---</td>
</tr>
<tr>
<td>LSLOPE</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>0.06632 to 0.22653 ft/ft</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DA</td>
<td>Drainage area in square miles measured on horizontal surface.</td>
</tr>
<tr>
<td>BR</td>
<td>Basin relief in feet. The difference between the elevation of the outlet point and the average basin elevation.</td>
</tr>
<tr>
<td>S_A</td>
<td>Percent of DA that is classified as NRCS Hydrologic Soil Group A.</td>
</tr>
<tr>
<td>IA</td>
<td>Percent of DA that is impervious as defined by the Maryland Department of Planning land use data.</td>
</tr>
<tr>
<td>S_D</td>
<td>Percent of DA that is classified as NRCS Hydrologic Soil Group D.</td>
</tr>
<tr>
<td>FOR</td>
<td>Percent of DA land cover that is classified as forest cover.</td>
</tr>
<tr>
<td>LIME</td>
<td>Percent of DA that is underlain by carbonate rock (limestone and dolomite), from map in Dillow (1996).</td>
</tr>
<tr>
<td>LSLOPE</td>
<td>Average land slope of the watershed in feet per feet.</td>
</tr>
</tbody>
</table>
APPENDIX 3

FIXED REGION REGRESSION EQUATIONS FOR MARYLAND
Fixed Region Regression Equations for the Eastern Coastal Plain Region

The new equations are based on 15 stations in Maryland and 9 stations in Delaware with drainage area (DA) ranging from 2.27 to 112.20 square miles, basin relief (BR) ranging from 5.1 to 43.5 feet, and percent A soils (SA) ranging from 0.0 to 49.4 percent. Basin relief is not statistically significant for discharges less than the 5-yr event but is included in the equations for consistency.

The standard errors range from 33.7 percent (0.142 log units) for Q1.50 to 50.8 percent (0.208 log units) for Q500.

<table>
<thead>
<tr>
<th>Eastern Coastal Plain Fixed Region Regression Equation</th>
<th>Standard error (percent)</th>
<th>Equivalent years of record</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1.25 = 19.85 DA&lt;sup&gt;0.796&lt;/sup&gt; BR&lt;sup&gt;0.066&lt;/sup&gt; (SA +1)&lt;sup&gt;-0.106&lt;/sup&gt;</td>
<td>34.2</td>
<td>4.5</td>
</tr>
<tr>
<td>Q1.50 = 20.48 DA&lt;sup&gt;0.795&lt;/sup&gt; BR&lt;sup&gt;0.156&lt;/sup&gt; (SA +1)&lt;sup&gt;-0.140&lt;/sup&gt;</td>
<td>33.7</td>
<td>4.1</td>
</tr>
<tr>
<td>Q1.75 = 20.81 DA&lt;sup&gt;0.799&lt;/sup&gt; BR&lt;sup&gt;0.197&lt;/sup&gt; (SA +1)&lt;sup&gt;-0.146&lt;/sup&gt;</td>
<td>34.2</td>
<td>4.1</td>
</tr>
<tr>
<td>Q2 = 20.95 DA&lt;sup&gt;0.803&lt;/sup&gt; BR&lt;sup&gt;0.222&lt;/sup&gt; (SA +1)&lt;sup&gt;-0.144&lt;/sup&gt;</td>
<td>34.9</td>
<td>4.1</td>
</tr>
<tr>
<td>Q5 = 25.82 DA&lt;sup&gt;0.793&lt;/sup&gt; BR&lt;sup&gt;0.368&lt;/sup&gt; (SA +1)&lt;sup&gt;-0.190&lt;/sup&gt;</td>
<td>36.9</td>
<td>6.8</td>
</tr>
<tr>
<td>Q10 = 31.17 DA&lt;sup&gt;0.777&lt;/sup&gt; BR&lt;sup&gt;0.439&lt;/sup&gt; (SA +1)&lt;sup&gt;-0.215&lt;/sup&gt;</td>
<td>38.2</td>
<td>9.5</td>
</tr>
<tr>
<td>Q25 = 40.26 DA&lt;sup&gt;0.751&lt;/sup&gt; BR&lt;sup&gt;0.511&lt;/sup&gt; (SA +1)&lt;sup&gt;-0.242&lt;/sup&gt;</td>
<td>40.0</td>
<td>13</td>
</tr>
<tr>
<td>Q50 = 50.00 DA&lt;sup&gt;0.732&lt;/sup&gt; BR&lt;sup&gt;0.549&lt;/sup&gt; (SA +1)&lt;sup&gt;-0.261&lt;/sup&gt;</td>
<td>41.7</td>
<td>16</td>
</tr>
<tr>
<td>Q100 = 63.44 DA&lt;sup&gt;0.711&lt;/sup&gt; BR&lt;sup&gt;0.576&lt;/sup&gt; (SA +1)&lt;sup&gt;-0.279&lt;/sup&gt;</td>
<td>44.0</td>
<td>18</td>
</tr>
<tr>
<td>Q200 = 79.81 DA&lt;sup&gt;0.689&lt;/sup&gt; BR&lt;sup&gt;0.601&lt;/sup&gt; (SA +1)&lt;sup&gt;-0.296&lt;/sup&gt;</td>
<td>46.5</td>
<td>19</td>
</tr>
<tr>
<td>Q500 = 108.7 DA&lt;sup&gt;0.660&lt;/sup&gt; BR&lt;sup&gt;0.628&lt;/sup&gt; (SA +1)&lt;sup&gt;-0.316&lt;/sup&gt;</td>
<td>50.8</td>
<td>21</td>
</tr>
</tbody>
</table>
Fixed Region Regression Equations for the Western Coastal Plain Region

The new equations are based on 22 stations in the Western Coastal Plain. Five stations were deleted as outliers: 01585100 and 01585300 (highly urban stations partly in the Piedmont), 01589500 and 01594800 (very low peaks), and 01661050 (data do not fit a Pearson Type distribution real well). The drainage area (DA) ranges from 0.10 to 349.50 square miles, the 1985 impervious area (IA) ranges from 0.0 to 36.8 percent, and percent D soils (SD) ranges from 2.4 to 26.4 percent. Although the 1985 impervious area was used to develop the equations, the current impervious area should be used when estimating flood discharges.

The standard errors range from 35.4 percent (0.149 log units) for Q2 to 65.7 percent (0.260 log units) for Q100. The standard for Q500 is 89.8 percent (0.334 log units) because there is one station that is an outlier at the 500-yr recurrence interval but reasonable for other recurrence intervals.

Forest cover and impervious area are about equally significant and have a correlation of –0.63 and are not both significant in the same equation. Impervious area was used because it is more related to ultimate development. Drainage area has a correlation of 0.86 with basin relief and -0.72 with channel slope. Therefore, neither basin relief or channel slope are significant parameters in this region. Land slope is not statistically significant either.

<table>
<thead>
<tr>
<th>Western Coastal Plain Fixed Region Regression Equation</th>
<th>Standard error (percent)</th>
<th>Equivalent years of record</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q_{1.25} = 18.62 DA^{0.611} (IA+1)^{0.419} (SD +1)^{0.165}</td>
<td>38.9</td>
<td>3.2</td>
</tr>
<tr>
<td>Q_{1.50} = 21.97 DA^{0.612} (IA+1)^{0.399} (SD +1)^{0.226}</td>
<td>36.3</td>
<td>3.2</td>
</tr>
<tr>
<td>Q_{1.75} = 24.42 DA^{0.612} (IA+1)^{0.391} (SD +1)^{0.246}</td>
<td>35.6</td>
<td>3.4</td>
</tr>
<tr>
<td>Q_{2} = 26.32 DA^{0.612} (IA+1)^{0.386} (SD +1)^{0.256}</td>
<td>35.4</td>
<td>3.7</td>
</tr>
<tr>
<td>Q_{5} = 42.64 DA^{0.607} (IA+1)^{0.347} (SD +1)^{0.340}</td>
<td>36.3</td>
<td>6.8</td>
</tr>
<tr>
<td>Q_{10} = 58.04 DA^{0.603} (IA+1)^{0.323} (SD +1)^{0.382}</td>
<td>40.6</td>
<td>8.4</td>
</tr>
<tr>
<td>Q_{25} = 86.25 DA^{0.582} (IA+1)^{0.295} (SD +1)^{0.421}</td>
<td>48.9</td>
<td>9.3</td>
</tr>
<tr>
<td>Q_{50} = 111.50 DA^{0.584} (IA+1)^{0.270} (SD +1)^{0.457}</td>
<td>54.7</td>
<td>9.9</td>
</tr>
<tr>
<td>Q_{100} = 143.56 DA^{0.586} (IA+1)^{0.260} (SD +1)^{0.469}</td>
<td>65.7</td>
<td>9.0</td>
</tr>
<tr>
<td>Q_{200} = 185.15 DA^{0.580} (IA+1)^{0.243} (SD +1)^{0.488}</td>
<td>75.5</td>
<td>8.7</td>
</tr>
<tr>
<td>Q_{500} = 256.02 DA^{0.573} (IA+1)^{0.222} (SD +1)^{0.510}</td>
<td>89.8</td>
<td>8.3</td>
</tr>
</tbody>
</table>
Fixed Region Regression Equations for the Piedmont Region

The new equations are based on 34 rural stations and 16 urban stations in the Piedmont Region. **Two sets of regression equations were developed for the rural and urban stations with the urban stations having 10 percent or greater impervious area and the rural stations less than 10 percent.** Across the two data sets, 9 stations were deleted as outliers: 01582510, 01583000, 01583495, 01583600, 01589000, 01589240, 01592000, 01650050 and 01650085. Therefore, 50 of the 59 stations in Piedmont Region were used in developing the following two sets of equations. For the rural equations, the drainage area (DA) ranges from 0.28 to 258.07 square miles, and forest cover (FOR) from 4.4 to 75.3 percent. For the urban equations, drainage area (DA) ranges from 0.49 to 102.05 square miles and impervious area (IA) from 10.9 to 42.8 percent. Basin relief and channel slope are highly correlated with drainage area and are not statistically significant in the regression equations.

**For the rural equations** (less than 10 percent impervious area), the standard errors range from 24.3 percent (0.104 log units) for \( Q_{10} \) to 39.7 percent (0.166 log units) for \( Q_{500} \).

<table>
<thead>
<tr>
<th>Piedmont (Rural) Fixed Region Regression Equation</th>
<th>Standard error (percent)</th>
<th>Equivalent years of record</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Q_{1.25} = 202.9 , DA^{0.682} (\text{FOR}+1)^{-0.222} )</td>
<td>39.0</td>
<td>3.3</td>
</tr>
<tr>
<td>( Q_{1.50} = 262.0 , DA^{0.683} (\text{FOR}+1)^{-0.217} )</td>
<td>33.8</td>
<td>3.8</td>
</tr>
<tr>
<td>( Q_{1.75} = 308.9 , DA^{0.679} (\text{FOR}+1)^{-0.219} )</td>
<td>32.1</td>
<td>4.3</td>
</tr>
<tr>
<td>( Q_{2} = 349.0 , DA^{0.674} (\text{FOR}+1)^{-0.224} )</td>
<td>31.3</td>
<td>4.8</td>
</tr>
<tr>
<td>( Q_{5} = 673.8 , DA^{0.659} (\text{FOR}+1)^{-0.228} )</td>
<td>25.6</td>
<td>14</td>
</tr>
<tr>
<td>( Q_{10} = 992.6 , DA^{0.649} (\text{FOR}+1)^{-0.230} )</td>
<td>24.3</td>
<td>23</td>
</tr>
<tr>
<td>( Q_{25} = 1556 , DA^{0.635} (\text{FOR}+1)^{-0.231} )</td>
<td>25.3</td>
<td>33</td>
</tr>
<tr>
<td>( Q_{50} = 2146 , DA^{0.624} (\text{FOR}+1)^{-0.235} )</td>
<td>27.5</td>
<td>37</td>
</tr>
<tr>
<td>( Q_{100} = 2897 , DA^{0.613} (\text{FOR}+1)^{-0.238} )</td>
<td>30.6</td>
<td>37</td>
</tr>
<tr>
<td>( Q_{200} = 3847 , DA^{0.603} (\text{FOR}+1)^{-0.239} )</td>
<td>34.2</td>
<td>37</td>
</tr>
<tr>
<td>( Q_{500} = 5519 , DA^{0.589} (\text{FOR}+1)^{-0.242} )</td>
<td>39.7</td>
<td>35</td>
</tr>
</tbody>
</table>
Fixed Region Regression Equations for the Piedmont Region

For the urban equations (10 percent or greater impervious area), the standard errors range from 26.0 percent (0.111 log units) for \(Q_{25}\) to 41.7 percent (0.174 log units) for \(Q_{1.25}\).

<table>
<thead>
<tr>
<th>Piedmont (Urban) Fixed Region Regression Equation</th>
<th>Standard error (percent)</th>
<th>Equivalent years of record</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Q_{1.25} = 17.85 DA^{0.652} (IA+1)^{0.635})</td>
<td>41.7</td>
<td>3.3</td>
</tr>
<tr>
<td>(Q_{1.50} = 24.66 DA^{0.648} (IA+1)^{0.631})</td>
<td>36.9</td>
<td>3.8</td>
</tr>
<tr>
<td>(Q_{1.75} = 30.82 DA^{0.643} (IA+1)^{0.611})</td>
<td>35.6</td>
<td>4.1</td>
</tr>
<tr>
<td>(Q_2 = 37.01 DA^{0.635} (IA+1)^{0.588})</td>
<td>35.1</td>
<td>4.5</td>
</tr>
<tr>
<td>(Q_5 = 94.76 DA^{0.624} (IA+1)^{0.499})</td>
<td>28.5</td>
<td>13</td>
</tr>
<tr>
<td>(Q_{10} = 169.2 DA^{0.622} (IA+1)^{0.435})</td>
<td>26.2</td>
<td>24</td>
</tr>
<tr>
<td>(Q_{25} = 341.0 DA^{0.619} (IA+1)^{0.349})</td>
<td>26.0</td>
<td>38</td>
</tr>
<tr>
<td>(Q_{50} = 562.4 DA^{0.619} (IA+1)^{0.284})</td>
<td>27.7</td>
<td>44</td>
</tr>
<tr>
<td>(Q_{100} = 898.3 DA^{0.619} (IA+1)^{0.222})</td>
<td>30.7</td>
<td>45</td>
</tr>
<tr>
<td>(Q_{200} = 1413 DA^{0.621} (IA+1)^{0.160})</td>
<td>34.8</td>
<td>44</td>
</tr>
<tr>
<td>(Q_{500} = 2529 DA^{0.623} (IA+1)^{0.079})</td>
<td>41.2</td>
<td>40</td>
</tr>
</tbody>
</table>
Fixed Region Regression Equations for the Blue Ridge Region

The new equations are based on 20 stations in Maryland with drainage area (DA) ranging from 0.11 to 820 square miles and percent limestone (LIME) ranging from 0.0 to 100 percent. Basin relief, land slope, forest cover and soils characteristics were all investigated as explanatory variables but were not statistically significant across all recurrence intervals in the regression equations.

The standard errors range from 51.6 percent (0.211 log units) for Q_{25} to 74.6 percent (0.289 log units) for Q_{1.25}.

<table>
<thead>
<tr>
<th>Blue Ridge Fixed Region Regression Equation</th>
<th>Standard error (percent)</th>
<th>Equivalent years of record</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q_{1.25} = 57.39 DA^{0.784} (LIME +1)^{-0.190}</td>
<td>74.6</td>
<td>1.0</td>
</tr>
<tr>
<td>Q_{1.50} = 81.45 DA^{0.764} (LIME +1)^{-0.193}</td>
<td>67.1</td>
<td>1.1</td>
</tr>
<tr>
<td>Q_{1.75} = 96.33 DA^{0.755} (LIME +1)^{-0.194}</td>
<td>65.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Q_{2} = 107.20 DA^{0.750} (LIME +1)^{-0.194}</td>
<td>64.0</td>
<td>1.3</td>
</tr>
<tr>
<td>Q_{5} = 221.28 DA^{0.710} (LIME +1)^{-0.202}</td>
<td>55.4</td>
<td>3.0</td>
</tr>
<tr>
<td>Q_{10} = 336.84 DA^{0.687} (LIME +1)^{-0.207}</td>
<td>52.5</td>
<td>4.9</td>
</tr>
<tr>
<td>Q_{25} = 545.62 DA^{0.660} (LIME +1)^{-0.214}</td>
<td>51.6</td>
<td>8.8</td>
</tr>
<tr>
<td>Q_{50} = 759.45 DA^{0.641} (LIME +1)^{-0.219}</td>
<td>52.5</td>
<td>9.7</td>
</tr>
<tr>
<td>Q_{100} = 1034.7 DA^{0.624} (LIME +1)^{-0.224}</td>
<td>54.4</td>
<td>11</td>
</tr>
<tr>
<td>Q_{200} = 1387.6 DA^{0.608} (LIME +1)^{-0.229}</td>
<td>57.4</td>
<td>13</td>
</tr>
<tr>
<td>Q_{500} = 2008.6 DA^{0.587} (LIME +1)^{-0.235}</td>
<td>62.3</td>
<td>13</td>
</tr>
</tbody>
</table>
Fixed Region Regression Equations for the Appalachian Plateau Region

The new equations are based on 23 stations in Maryland with drainage area (DA) ranging from 0.52 to 293.7 square miles and land slope (LSLOPE) ranging from 0.06632 to 0.22653 ft/ft. One station, 03076505, was an outlier and eliminated from the regression analysis. Basin relief, channel slope and basin shape have relatively high correlations with drainage areas of 0.78, -0.77 and 0.62, respectively, and were not statistically significant in the regression equations.

The standard errors range from 20.7 percent (0.089 log units) for Q₂ to 48.0 percent (0.198 log units) for Q₅₀₀.

<table>
<thead>
<tr>
<th>Appalachian Plateau Fixed Region Regression Equation</th>
<th>Standard error (percent)</th>
<th>Equivalent years of record</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q₁₀₀₀ = 1565.0 DA₀.784 LSLOPE₀.589</td>
<td>48.0</td>
<td>15</td>
</tr>
<tr>
<td>Q₅₀₀ = 1046.9 DA₀.793 LSLOPE₀.525</td>
<td>41.8</td>
<td>15</td>
</tr>
<tr>
<td>Q₂₀₀ = 766.28 DA₀.799 LSLOPE₀.478</td>
<td>37.4</td>
<td>15</td>
</tr>
<tr>
<td>Q₁₀₀ = 559.80 DA₀.806 LSLOPE₀.435</td>
<td>33.1</td>
<td>16</td>
</tr>
<tr>
<td>Q₅₀ = 404.22 DA₀.812 LSLOPE₀.393</td>
<td>29.1</td>
<td>15</td>
</tr>
<tr>
<td>Q₂₅ = 255.75 DA₀.821 LSLOPE₀.340</td>
<td>24.2</td>
<td>14</td>
</tr>
<tr>
<td>Q₁₀ = 179.13 DA₀.826 LSLOPE₀.314</td>
<td>21.6</td>
<td>12</td>
</tr>
<tr>
<td>Q₅ = 101.41 DA₀.834 LSLOPE₀.300</td>
<td>20.7</td>
<td>7.1</td>
</tr>
<tr>
<td>Q₂ = 96.37 DA₀.836 LSLOPE₀.307</td>
<td>21.2</td>
<td>6.4</td>
</tr>
<tr>
<td>Q₁.75 = 87.42 DA₀.837 LSLOPE₀.321</td>
<td>21.9</td>
<td>5.9</td>
</tr>
<tr>
<td>Q₁.25 = 70.25 DA₀.837 LSLOPE₀.327</td>
<td>23.6</td>
<td>5.7</td>
</tr>
</tbody>
</table>

The standard errors range from 20.7 percent (0.089 log units) for Q₂ to 48.0 percent (0.198 log units) for Q₅₀₀.
A

Modify Land Use Procedure

Start → Digitize Land Use Polygons → Specify Land Use Category → Specify CNs individually → Revise Land Use Layer Update CN Layer Update Lookup Table → End

B

Modify Hydrologic Condition Procedure

Start → Set all categories to same hydrologic condition? → Yes → Select "Good", "Fair", or "Poor" Set All Button → Output Lookup Table → Update and Close → End → No → Set individual categories to "Good", "Fair", or "Poor"
TR-20 Model Development and Execution Procedure

1. Start
2. Specify Input/Output Files
3. Specify Job and Title Info
4. Select Output Options
5. Choose Storm Type & Distribution
6. Execute TR-20 Model
7. Select Rainfall Depths
8. End

MD Hydro Panel Calibration Procedure

Start

Calibration steps inside GISHydro:
- Modify Tc
- Modify Runoff Curve Number
- Other (see discussion)

Calibration steps outside GISHydro:
- Modify Tc (flow lengths)
- Modify Unit Hydrograph
- Modify Reach Routing Length
- Other (see discussion)

Re-execute TR-20

End
Links to useful and relevant documents for GISHydro2000

(last revised: April 15, 2007)

• GISHydro Web Page:  http://www.gishydro.umd.edu
  o Documentation:  http://www.gishydro.umd.edu/document.htm
  o Data/Program Download:  http://www.gishydro.umd.edu/download_sign_in.asp
  o Online User’s Manual

• Application of Hydrologic Methods in Maryland – Maryland Hydrology Panel

• Bankfull Discharge and Channel Characteristics of Streams in the:
  o Piedmont
  o Allegheny Plateau and Valley and Ridge
  o Coastal Plain
  Link:  http://www.fws.gov/chesapeakebay/streampub.htm

• Evaluation of Alternative Statistical Methods for Estimating Frequency of Peak Flows
  in Maryland

• Technique for Estimating Magnitude and Frequency of Peak Flows in Maryland
  Link:  http://md.water.usgs.gov/publications/wrir-95-4154/

• NOAA Atlas 14 Precipitation Data
  Link:  http://hdsc.nws.noaa.gov/hdsc/pfds/index.html
Instructions for Using the Web-Based Version of GISHydro2000
Glenn E. Moglen
(last revised July 16, 2006)

There are several things you need to know to currently use GISHydro2000 from the web. These instructions will allow you to test the web-based version, however, the details of logging in may change over the next few weeks to months.

Step 1: Obtain Login Information
Access to the GISHydro2000 web version is free, however to control access to the web site is password protected. This is done for two reasons:
1. To provide added security to the server that is supporting the web version.
2. To help us document usage of the server.

To obtain a username and login, please contact Glenn Moglen (moglen@umd.edu) and request a login to the server. You should provide the following information with your username request:
- Your full name
- Your email address
- Your company or employer
- Your phone number

Step 2: Download Plug-in
The web-based version runs by using software from Citrix. In order to use this software, it is necessary to download and install a plug-in from this company. To do this, go to:


and download the file, “ica32t.exe. (There’s also a link to this at the GISHydro: Download page.)

Step 3: Install Plug-in
Once you have downloaded the plug-in, double click on its filename or icon and install. You should receive the following prompt window at the initiation of the installation:

Click on the “Yes” window and accept all the subsequent installation wizard boxes to complete the installation.
Step 4: Set Security in Internet Explorer

It is necessary to indicate to your computer that the server that is supporting the GISHydro2000 program is a “trusted site”. To do this, in Internet Explorer select: Tools: Internet Options. Click on the “Security” tab and then click on the “Trusted Sites” Icon. Then click on the “Sites” button. In the window to the left of the “Add” button, type the URL, http://129-2-71-200.umd.edu. Then click the “Add” button and you should see the URL for this site jump to the lower window labeled “Web Sites:”. Click the “OK” buttons to accept this site and close out the change of this internet option.

Step 5: Logging into Server

At the Internet Explorer address window, type:

http://129-2-71-200.umd.edu

(alternatively, you can simply follow the link from the main GISHydro web page and follow the link from there.)

You will then see the browser appear as shown at right. Enter your user name and password obtained earlier in Step 1. Now click the “Log In” button.
Step 6: Providing Remote File Access

Click on the Windows Explorer icon (shown circled at right) to launch the windows explorer application. This will result in the shown dialog from the Citrix software.

You want to choose “Full Access” to the first question. This will have the effect of mapping the drives on your local machine to the directory structure seen by the server. The effect will be as if the local drives on your machine become available drives to the server. GISHydro2000 will write all files during a given session to the “e:\temp\xxxxx” directory of the server. The value of “xxxxx” is randomly assigned but you can modify it as you wish. Thus, using Windows Explorer will allow you to copy and move files to/from the e:\temp\xxxxx directory on the server to your local machine as desired. More explanation on this temporary directory is contained under Step 8.
Step 6: Launching GISHydro2000

To launch GISHydro2000, simply click on the “GISHydro2000” icon (shown circled at right) and GISHydro2000 should start up. You are now logged in!

If you have not properly installed the plug in, when you click on the “GISHydro2000” icon, you will instead see the dialog box shown at right. If you get this dialog box, go back and review Steps 2 and 3 and make sure that they were done correctly and completely.
Step 8: File Management in GISHydro2000 Software

For security reasons and to keep files from different users and different projects separate, it is important to note a recent change to the GISHydro2000 software. As shown at right, the bottom part of the “Select Quads” dialog indicates the default path that GISHydro2000 has assigned for your analysis session. You may accept (and record) this number, or you can specify a more meaningful name of your own. Just be sure to retain the “e:\temp” (changed from “c:\temp” on June 23) part and to only use letters or numbers – do not use spaces or unusual characters such as “?”、“#”、“%” etc. All files you generate in this GISHydro2000 web session will be sent to this path or to directories located deeper along this path.

Step 9: Longevity of Files in the “e:\temp” Directory

Files written to the “e:\temp” directory should be considered temporary. You must make use of the windows explorer tool to move all work to your local machine from the server. At the time of this writing, files will be deleted from the “e:\temp” directory periodically and without warning (generally files less than one week old will not be deleted unless space requirements require otherwise). It is up to you as a user to copy your work promptly and maintain your own permanent version of all created files on your own local machine.

Final Comment:

The number of persons the server can simultaneously support is 10. So, (1) please log out promptly once you’ve completed your analysis, and (2) if you are unable to log in because all 10 of the licenses are already being used, please let me know. I’d like to know how often this license limit kicks in.

That’s it! I am still working on making this web-based version of GISHydro2000 work better and I expect there may be bugs because of some recent changes to make it web-compatible. Please let me know if you encounter any problems. Thank you.