NEW MODELING CAPABILITIES IN HEC-HMS APPLIED TO THE MILL CREEK BASIN

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Abstract

The Hydrologic Engineering Center (HEC) was contracted by the U. S. Army Corps of Engineers, Nashville District (LRN), to perform a hydrologic analysis of the Mill Creek Basin. Mill Creek, located in middle Tennessee, has a drainage area of 108 square miles at its confluence with the Cumberland River. The main objective of the hydrologic analysis was to develop both event and continuous simulation models of the Mill Creek Basin using the Hydrologic Modeling System (HEC-HMS). As requested by LRN and the study sponsor, the city of Nashville, the hydrologic models were built using a 200 meter grid, which is approximately equivalent to a 10-acre parcel.

New capabilities were added to HEC-HMS in support of the Mill Creek study. A gridded version of the deficit and constant loss method was added along with the Priestly-Taylor evapotranspiration method, which can be used in conjunction with a lumped or gridded basin model. The gridded deficit and constant loss method contains a storage layer to account for the moisture state in each grid-cell, thus allowing for continuous simulation of the rainfall-runoff process. The loss method parameters were estimated using geographic information systems (GIS). Event and continuous simulation models were calibrated using historic precipitation and stream flow data and frequency based precipitation and flow-frequency curves developed at gaged locations within the watershed. The Priestly-Taylor evapotranspiration method can account for daily atmospheric conditions, such as solar radiation and temperature, which effect evapotranspiration. This method provides more flexibility over the constant monthly evapotranspiration method which models evapotranspiration as a constant rate throughout the month. The Priestly-Taylor evapotranspiration method was used in the continuous models to remove moisture from each grid-cell during periods without precipitation.

INTRODUCTION

The Hydrologic Engineering Center (HEC) was contracted by the U. S. Army Corps of Engineers, Nashville District (LRN), to perform a hydrologic analysis of the Mill Creek Basin. This analysis is part of a scope of work to evaluate the existing flood control system and its project performance, determine the feasibility of raising existing levees, and to assess the potential of implementing environmental restoration sites and their impact on levee performance. The main objective of this hydrologic analysis was to generate both event and continuous simulation hydrologic models of the Mill Creek Basin. As requested by the Nashville District and the study sponsor, the city of Nashville, gridded or distributed models were built with a 200 meter grid-cell resolution (approximately equal to the size of a 10-acre parcel). An additional request was to keep subbasin size to a minimum. The largest subbasin had a drainage area of 1.3 square miles.

The hydrologic models were constructed using the Hydrologic Modeling System (HEC-HMS) Version 3.0. Single event models were developed for simulating current conditions in the Mill Creek Basin. Current condition models were built for three historic floods and for specific flows on flow-frequency curves developed at gaged locations in the watershed. Optimal parameters and initial conditions were found through model calibration using radar-rainfall data and measured stream flow hydrographs for the historic events. Frequency-based rainfall from the National Weather Service and flow-frequency curves were used when calibrating models to specific frequency events. The hydrologic models will be used for accessing changes to the Mill Creek Basin. The same model and storms can be adjusted for future land-use conditions to estimate future-condition flows (historic events and frequency events).

STUDY AREA

Mill Creek flows approximately 27 miles in a northerly direction from its headwaters in Williamson County, Tennessee, to its confluence with the Cumberland River in Davidson County, Tennessee. The Mill Creek Basin has a total drainage area of 108 square miles and is located in Central Tennessee (Figure 1). Topography in the Mill Creek basin varies from flat to moderately sloping along the main stem to rolling and hilly uplands, which form the watershed divide. Elevations range from approximately 385 feet above mean sea level at the mouth to approximately 1200 feet. Land use in the Mill Creek Basin varies greatly and is experiencing very rapid changes. Land use in the lower end of the basin is a mixture of residential, commercial, and industrial development. The middle portion of the basin is moderately developed, but is experiencing rapid and intense growth. The upper portion of the Mill Creek Basin, mostly in Williamson County, is presently rural with several isolated areas of heavy residential development.

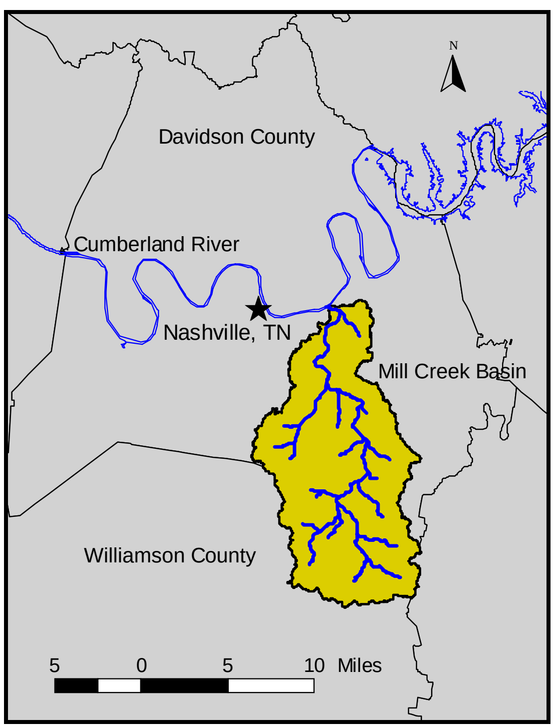

Figure 1 Study area.

METHODOLOGY

New capabilities were added to HEC-HMS in support of this study. These capabilities are available in Version 3.0 of the program. The following paragraphs describe these new capabilities and how HEC-HMS was used to develop both event and continuous models for the Mill Creek Basin.

The GIS tool, Geospatial Hydrologic Modeling Extension (HEC-GeoHMS), was used to delineate subbasins and river reaches in the Mill Creek Basin (HEC, 2003). Because gridded models were required, HEC-GeoHMS was used to develop a grid-cell file for the Mill Creek Basin. For this study, the grid was based on the Standard Hydrologic Grid (SHG) coordinate system (HEC, 2003). In effect, HEC-GeoHMS intersects a grid, in this case the grid size is 200 meters, with the watershed boundary. A grid-cell file is generated that contains each subbasin and a list of grid-cells located within each subbasin. Grid-cell area and distance from the centroid of the grid-cell to the subbasin outlet are also included in the grid-cell file.

A gridded approach to hydrologic modeling lets the modeler increase the level of detail in the hydrologic analysis. Instead of averaging model parameters for an entire subbasin, parameters are averaged for each grid-cell. The 200 meter SHG and one of the subbasins in the Mill Creek Basin can be seen in Figure 2, as well as different land use types. Approximately half of the grid-cells are located in residential areas while the rest are located in commercial and undeveloped areas. Once a current conditions model has been developed for this subbasin, parameters for those grid-cells located in undeveloped areas can be modified to reflect some type of development in the subbasin. A simulation can be computed to estimate the change in runoff due to the development.

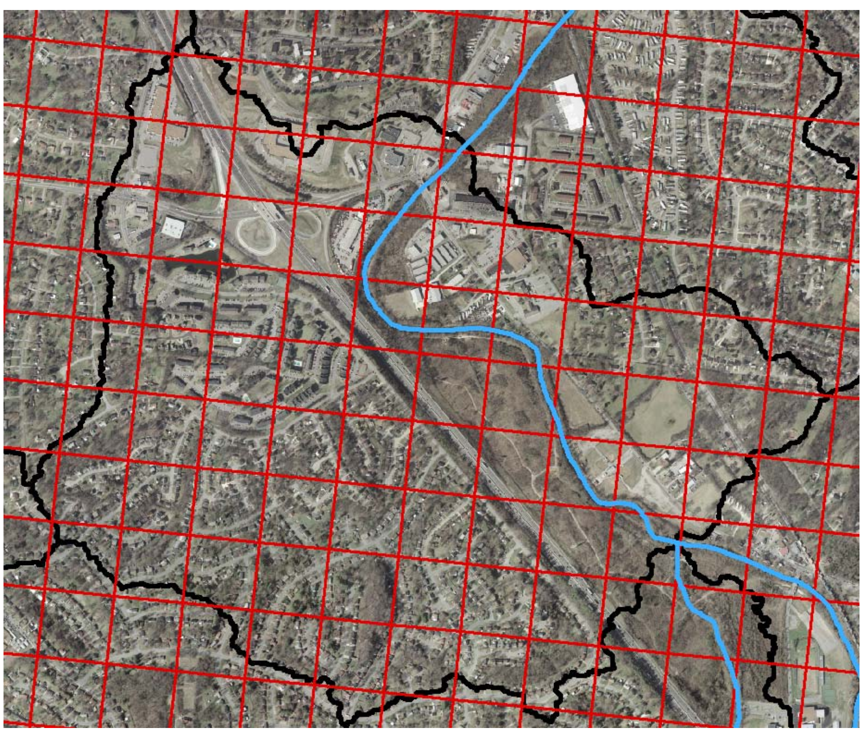

Figure 2 200 meter SHG superimposed on the Mill Creek Basin.

Gridded Deficit and Constant Loss Method

The gridded deficit and constant loss method was added to HEC-HMS in support of this study. This method is similar to the deficit and constant loss method, but loss calculations are computed separately for each grid-cell in a subbasin. The gridded deficit and constant loss method is a simple, 1-layer soil moisture accounting model. The program tracks the moisture deficit of each grid-cell. The moisture deficit increases during periods of no precipitation. The rate at which moisture leaves is determined by the evapotranspiration method defined in the meteorologic model. Previous versions of the program required that the recovery rate, or rate at which water leaves the storage layer, be defined inside the loss method. Only a constant monthly recovery rate could be entered. The Priestly-Taylor evapotranspiration method was added to the program in support of this study. This method uses meteorologic data to calculate potential evapotranspiration. The moisture deficit is reduced during periods of precipitation. Precipitation must fill the moisture deficit before precipitation excess is calculated. When the moisture deficit is filled, precipitation loss and excess is determined based on the constant loss rate for the grid-cell. Each grid-cell also contains a percent impervious area. Precipitation falling onto impervious area is routed directly to the subbasin outlet.

Four parameter grids must be developed in order to use the gridded deficit and constant loss method. A parameter grid is a new data type in HEC-HMS Version 3.0. A parameter grid is a gridded record stored in a DSS file. Previous versions of the program required that gridded parameters be stored in the grid-cell parameter file. The gridded deficit and constant loss method requires an initial deficit grid, maximum deficit grid, constant loss grid, and percent impervious area grid. These parameter grids were created using a GIS. First, a raster coverage was created for each grid type. For example, a 200 meter raster coverage was created where each grid-cell contained a percent impervious area value. Then, the raster coverage was exported from the GIS as an ASCII file. A program called "asc2dssGrid.exe" was used to convert the ASCII file to a gridded record in a DSS file.

Only one parameter grid was created for both the initial deficit and maximum deficit. All grid-cells had a value of 1 inch. The gridded deficit and constant loss method contains a grid ratio option for each parameter grid. The program will multiply the value in each grid-cell by the user specified grid ratio. This option was added to reduce the number of parameter grids needed when calibrating a model. The initial deficit grid ratio was adjusted during calibration of both the event and continuous simulation models. The initial deficit is dependent on the moisture state of the watershed at the beginning of a simulation. The maximum deficit grid ratio was only adjusted during calibration of the continuous simulation models. The maximum deficit is a measure of the amount of precipitation needed before runoff will occur when a watershed is at its driest. When calibrating a model using this loss method it is important to find periods in the precipitation record when no precipitation fell on the watershed for a length of time. The maximum deficit should be its largest at the end of these periods.

The constant loss grid was estimated using soil information from the State Soil Geographic (STATSGO) database (STATSGO, 1994). The database includes a GIS coverage (polygons of different soil types) and attribute tables. Figure 3 shows the STATSGO GIS coverage for the Mill Creek Basin. As a precipitation event occurs, the infiltration capacity of the soil reaches a constant rate. The saturated hydraulic conductivity was used as an estimate for the constant loss rate. A saturated hydraulic conductivity was calculated for each STATSGO polygon using information in the attribute tables. One of the GIS layers generated by HEC-GeoHMS was a vector polygon coverage of the 200 meter SHG. The SHG coverage was used to intersect the STATSGO soil coverage. The result was a new coverage with STATSGO polygons in each grid-cell of the 200 meter SHG. Using the new vector coverage, an average saturated hydraulic conductivity was calculated for each grid-cell (Figure 4). The vector coverage was converted to a raster coverage so that a gridded DSS record could be created. The constant loss grid ratio option was adjusted during model calibration; peak flow was very sensitive to this parameter.

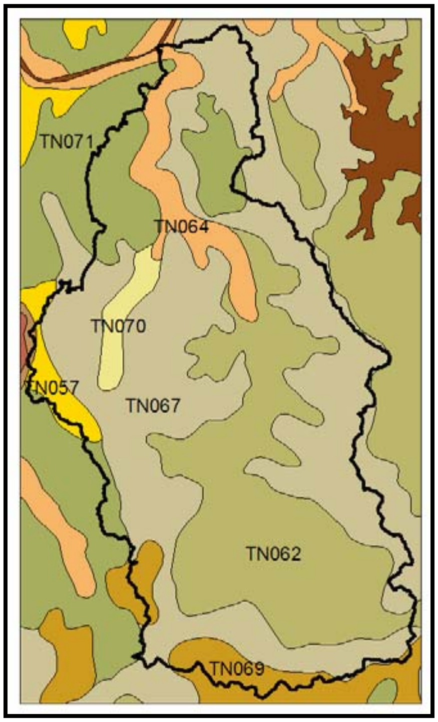

Figure 3 STASTGO coverage.

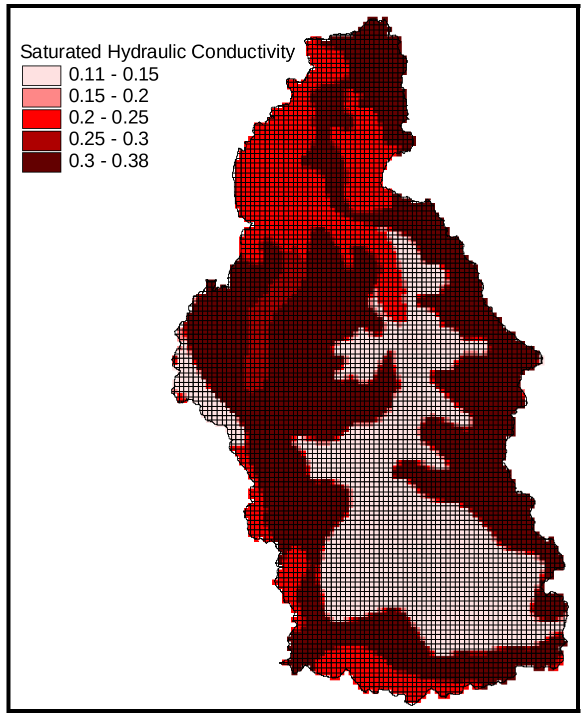

Figure 4 Saturated hydraulic conductivity.

The percent impervious area grid was estimated using hyperspectral data. Hyperspectral sensors collect image data in many spectral bands. Because reflectance is measured for many spectral bands, a detailed spectral reflectance curve can be developed for each pixel in the hyperspectral image. Spectral profiles for 5 pixels located within the Mill Creek Basin are shown in Figure 5. Land coverage types of these pixels include trees, grass, soil, roads, and rooftops. The processed hyperspectral data contained 57 spectral bands and had a resolution of 4 square meters.

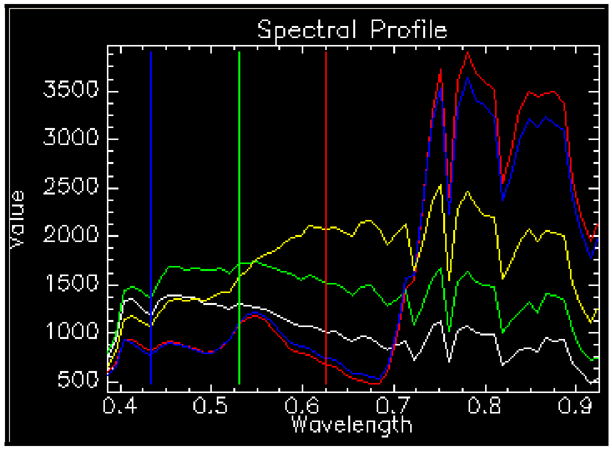

Figure 5 Spectral profiles for 5 locations in the Mill Creek Basin.

The ENVI program was used to process the hyperspectral data. In general, regions of interest were defined and the program extracted statistics and an average spectral profile of the pixels located within region of interest. Regions of interest were created by digitizing polygons over specific land coverage types in the hyperspectral image. The program was used to classify each pixel in the hyperspectral image by comparing the spectral profile of the pixel to the statistics generated when defining regions of interest. The end result was a raster coverage of land use at a 2 meter resolution. This coverage and the vector grid coverage generated by HEC-GeoHMS were used to determine the percent impervious area in each grid-cell of the 200 meter SHG. As is evident in Figure 6, the upper half of the Mill Creek Basin is less developed than the lower half.

The percent impervious area grid developed using hyperspectral data defines the total impervious area in the basin. However, impervious area in HEC-HMS is the impervious area connected directly to the subbasin outlet; all precipitation falling on this area will runoff. Precipitation falling on a rooftop or parking lot may flow onto the ground and infiltrate into the soil. In this case, the impervious area is not considered to be directly connected. Therefore, the impervious area grid ratio option was adjusted during model calibration. It was important to find rainfall-runoff events where runoff from directly connected impervious areas was the main cause of streamflow. These type of events generally occurred when the watershed was dry and no direct runoff was generated.

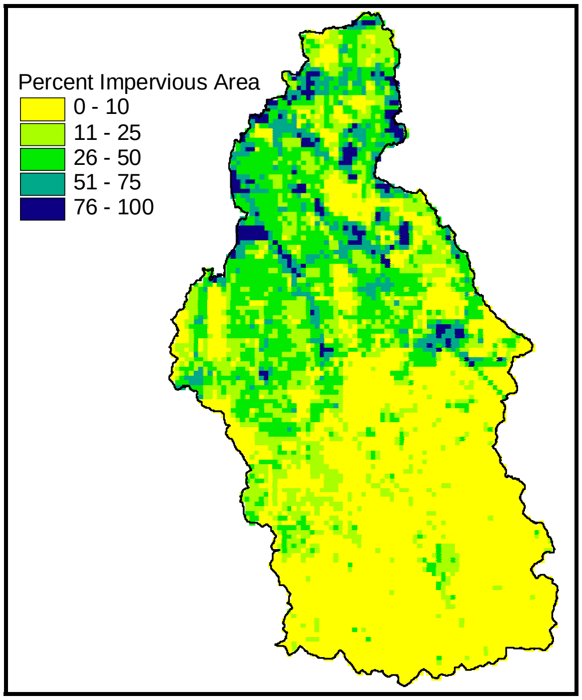

Figure 6 Percent impervious area in the Mill Creek Basin.

Priestly-Taylor Evapotranspiration Method

Evapotranspiration is an important element of continuous simulation modeling. Up to 70 percent of precipitation is returned back to the atmosphere (Gupta, 1989). The Priestly-Taylor evapotranspiration method was added to HEC-HMS in support of this study. A gridded version of this method was used for the continuous simulation models. The Priestly-Taylor method calculates potential evapotranspiration using meteorologic data. This method provides more flexibility over the constant monthly evapotranspiration method which models evapotranspiration as a constant rate throughout the month. The parameters required for this method are time series of net solar radiation, temperature, a crop coefficient, and a dryness coefficient.

A gage measuring net solar radiation was not found for the simulation period; therefore, net solar radiation was calculated using:

- daily minimum and maximum temperature,
- actual vapor pressure (minimum and maximum relative humidity),
- actual sunshine duration,
- latitude,
- longitude,
- day of the year.

Daily minimum and maximum temperature and relative humidity data were downloaded from the National Climatic Data Center (NCDC) website: http://www.ncdc.noaa.gov/oa/climate/stationlocator.html. Measured sunshine duration was available for part of the simulation period and was obtained from the National Weather Service.

An empirical approach was used to calculate actual sunshine duration using daily minimum and maximum air temperature for the remaining simulation period (Allen et al., 1998).

The crop coefficient is useful for scaling the calculated potential evapotranspiration. Factors such as the changing characteristic of vegetation and soil moisture conditions affect actual evapotranspiration. A crop coefficient curve was applied to the Mill Creek Basin to simulate the annual growing cycle of vegetation, where a value of 0.5 was used when the vegetation was dormant and a value of 0.9 was used when transpiration was at the maximum rate.

CONCLUSION

New capabilities were added to HEC-HMS in support of the Mill Creek study. The new gridded deficit and constant loss method is a simple, 1-layer soil moisture accounting method that tracks the moisture state in each grid-cell. Parameters for this new loss method can be estimated using GIS and must be stored in a gridded record in a DSS file. The grid ratio option is a convenient way to adjust grid-cell values in parameter grids without having to create a new parameter grid record. The new Priestly-Taylor evapotranspiration method can use daily meteorologic data, such as solar radiation and temperature, to calculate a potential evapotranspiration rate. This method provides more flexibility over the constant monthly evapotranspiration method, which models evapotranspiration as a constant rate throughout the month. The Priestly-Taylor evapotranspiration method was used in the continuous models to remove moisture from each grid-cell during periods without precipitation.

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