

Tool for Processing Hydrologic Parameters for HCFCD HEC-HMS Simulations

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Abstract

A key objective for the Harris County Watershed Master Plan was to develop a tool set for batch processing hydrologic parameters of existing and future landscape conditions across the watersheds and sub-watersheds in Harris County, Texas. The HEC-HMS Kinematic Wave tool extracts information from terrain, boundary and channel datasets and user input to build files that initialize a HEC-HMS hydrologic simulation for each sub-watershed. These parameters include the kinematic plane slope, length and roughness and kinematic wave main channel length, slope roughness, shape, width, and side slope. The Kinematic Wave tool is written for ArcGIS® in the VBA programming language utilizing ArcObjects®. The scheme of hydrologic features used by the tool, including watersheds, catchments, and drainage channels, follows the ArcHydro® data model.

Harris County Flood Control District Watershed Master Plan

Harris County, Texas, including the Houston metropolitan area, has a long history of disastrous floods caused by the combination of repetitive tropical storms, flat terrain and poorly draining soils. The overall mission of Harris County Flood Control District (<http://www.hcfcd.org>) is to devise flood damage reduction plans, implement the plans and maintain the infrastructure with proper regard for community and natural values.

The most recent watershed master plans developed by HCFCD were started in the early 1970's, for individual watersheds within the county. As a result of the recent damage from floods causing major economic loss, and new flood models as a result of the Tropical Storm Allison Recovery Project, and continued rapid development within Harris County, the district identified the need for a new countywide watershed master plan (WMP) incorporating new planning concepts, updated engineering methods and state-of-the-art technology.

The district realized the application of GIS techniques was necessary for the county-scale effort and scoped ESRI applications such as ArcMap 8.3 to handle data organization and modeling analyses outlined by the master plan. A modified version of the ArcHydro data model (Maidment 2002) was used to store and organize watershed attributes and spatial information important for the master plan. Many of the designs and model simulations were handled by software outside ESRI preprogrammed compatibility, thus creating a need for customized tools to link them.

The Kinematic Wave tool was developed to extend ArcMap Spatial Analyst® and ArcHydro® capabilities to develop kinematic wave runoff model parameters and then create an input file for the hydrologic simulation software, HEC-HMS 2.2.2 (USACE Hydrologic Engineering Center, 1993). Historically, HEC model parameters were

calculated by hand using United States Geological Survey topographic information from paper maps and digitized contours. GIS has become a standard method for post- and pre-processing data for hydrologic and hydraulic models (Djokic and Maidment 2000). However, much of this effort has been in the automation of soil and land-use characteristics for rainfall loss formulations (Smemoe et al. 2003).

The Kinematic Wave tool provides a standard automated process for calculating overland and channel flow path characteristics into model parameters so that the collection of water over the landscape can be simulated. The benefits of the Kinematic Wave tool to the planning effort include increased confidence in model parameter formulation, decreased labor time spent, repeatability, and a standard seamless transfer between database and model.

Study Area

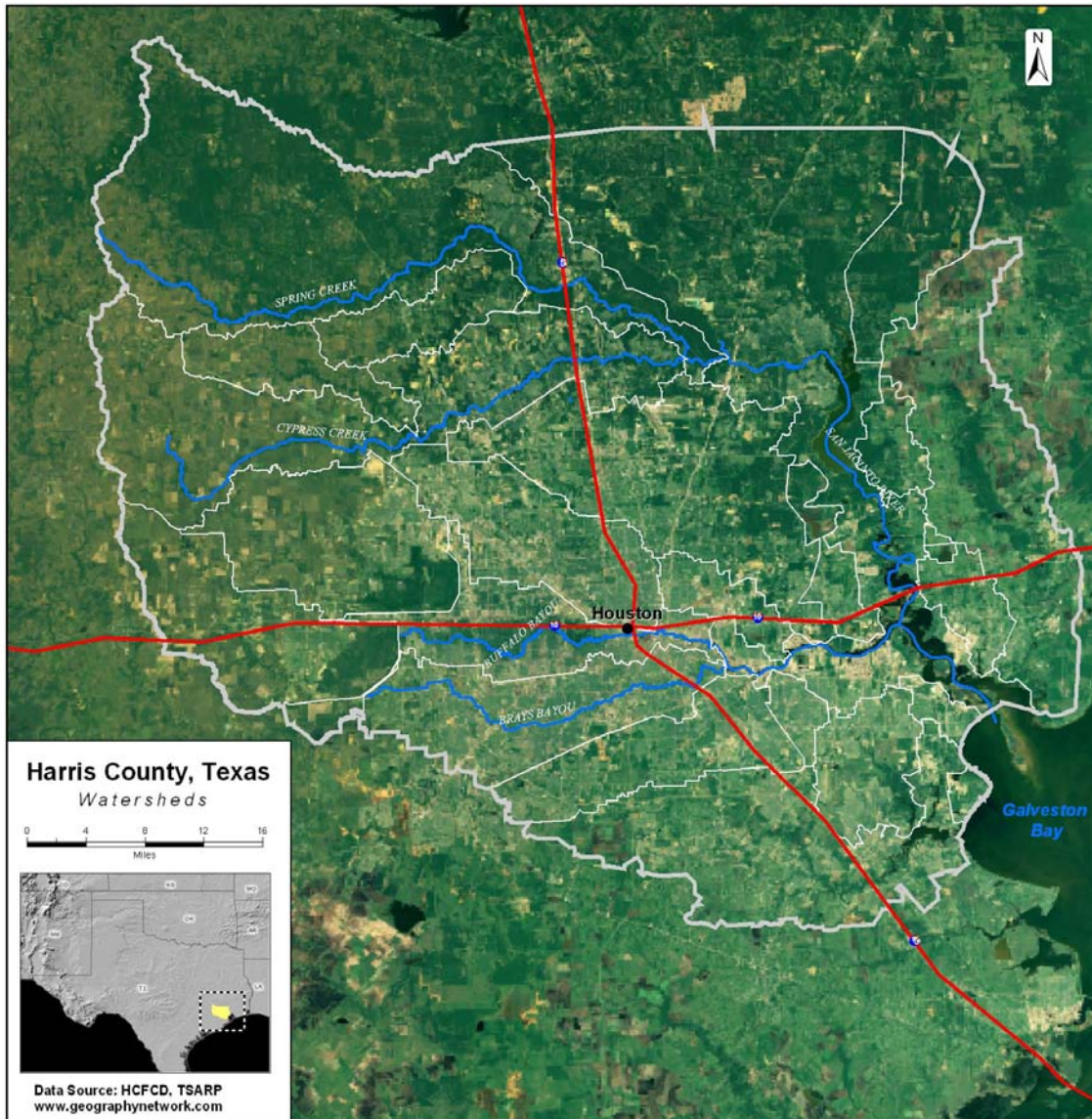
There are 22 watersheds in Harris County ranging from 15 to 475 square miles (mi^2). Figure 1 is a map of the study area. The county is 1700 mi^2 , thus the majority of the watersheds are under 200 mi^2 . The major channels that drain through the county are the San Jacinto River, Brays Bayou, Buffalo Bayou, and Cypress Creek, which eventually empty into Galveston Bay.

The terrain is mainly flat and low in Harris County as it is part of the Southeastern drainage area surrounding the Gulf of Mexico. Elevations do not exceed 300 feet (ft) above Mean Sea Level and clayey soils dominate. The Federal Emergency Management Agency (FEMA) is currently studying active subsidence within the county and estimates that the county has experienced a drop of 4.5 ft. over the last 25 years (http://www.fema.gov/fhm/mm_wip2f.shtm). The steepest slopes in the county occur along channel banks and other man-made structures such as highway abutments

Rapid landscape change is occurring in all 22 watersheds. The population of the county has grown by 25 percent in the past 10 years to around 3.6 million people. In 2002, the census bureau estimated 1,400,000 million housing structures in the county, only a third of which being multi-unit structures (<http://quickfacts.census.gov/qfd/states/48/48201.html>). This indicates that most county residents live in sprawling neighborhoods that were once farmland.

On average Harris County receives around 50 in. of rainfall per year. The majority of the rainfall occurs during the hurricane season from late June to October. Tropical cyclonic storms are quick and intense.

Figure1. The study area.



Tropical Storm Allison Recovery Project (TSARP)

In early June 2001, residents of Harris County were the victims of the most devastating rain event in U.S. history. Floods resulting from tropical storm Allison's rainfall intensities caused \$5 billion in property damage and claimed 22 lives. HCFCD teamed with the FEMA for the Tropical Storm Allison Recovery Project (TSARP) (<http://www.tsarp.org>) to assist in recovery from the flooding, and provide a greater understanding of flooding and flood risks.

The TSARP study produced a LiDAR topographic database for the entire county, watershed and sub-watershed boundaries, land-use and land-cover parameter estimates, and comprehensive maps of stream channel networks. Flood models for mapping new

FEMA digital flood insurance rate maps delineating high risk areas were the final end-product.

Harris County Hydro

The *Planning Strategies and Tools* document for the HCFCD Watershed Master Plan (HCFCD and J.F.Thompson, Inc. 2004) outlines the specific technical methodologies and strategies developed to implement the WMP, including the details for the design and implementation of an ESRI GeoDatabase® to store all information developed during the course of the project. The Harris County Hydro GeoDatabase® is sectioned by watershed level data and sub-watershed level data. The hydrologic features in the database are identified by the HydroID® schema defined by the ArcHydro® data model (Maidment 2002). The sub-watershed level database contains feature classes of hydro junctions, channels, cross sections, and catchments.

In addition, an ArcIMS® site was developed by HCFCD and J. F. Thompson for web access of WMP activities (<http://www.jfthompson-gis.com/Website/wmp4amap/viewer.htm>). The site includes access to updated spatial information developed and maintained by the WMP project team.

The Houston-Galveston Area Council (H-GAC) land-cover dataset was developed through image processing using Landsat 5 and Landsat 7 satellite imagery from July 22, 2001 and September 25, 2001, and January 15, 2002 and February 23, 2002. The land-cover data is in GRID format with 30-meter resolution (i.e. cell size). In January 2003, H-GAC Clean Rivers program staff completed the classification of the region's landscape into nine land cover categories.

To handle the large LiDAR dataset for the entire county, the DEM Conditioning Tool was developed (HCFCD, J. F. Thompson, Inc., and PBS&J, Inc. 2004) to build a customized gridded LiDAR DEM. The LiDAR datasets are organized into 200 tiles for the entire county. The tool was designed to allow the operator to select either one or many (regional) sub-watershed polygons from the HC Hydro GeoDatabase and then automatically identify each LiDAR tile associated with the area, merge the tiles together into one DEM grid, clip and buffer the selected region, and then raise a 1000-ft. wall around the perimeter of the new DEM. This process creates a DEM useful for analyzing generally flat terrain as runoff is prevented from draining out of the watershed boundary except through the outlet.

Hydrologic Model, HEC-HMS

The specification for the Kinematic Wave tool was to calculate parameters needed for a HEC-HMS simulation. The HEC-HMS is designed to simulate the precipitation to runoff transformation process in watersheds and sub-watershed systems. The program offers many different options for modeling these processes. HMS is a general solution for a wide range of problems for watersheds of different sizes, shapes and geographies. The results of HMS can be readily linked with other models.

Most of the description below was referenced from the HEC-HMS 2.1 User's Manual (USACE Hydrologic Engineering Center 2002). This information can be found at <http://www.hec.usace.army.mil/software/hec-hms/hechms-hechms.html>.

Physical Basis

Precipitation that does not infiltrate into the ground becomes excess precipitation. While excess precipitation can remain on the watershed in depressions and ponds, it typically moves downhill over the surface of the watershed and is routed into collector channels as runoff. To model this, a transform equation is used to compute runoff from excess precipitation.

Direct runoff can be modeled with the kinematic wave model. The kinematic wave method uses the continuity equation and the steady, uniform flow approximation of the momentum equation to transform precipitation to flow. More detailed descriptions of the kinematic wave model can be found in Training Document No. 10 (USACE Hydrologic Engineering Center 1993).

Kinematic Wave Model

The kinematic wave model divides overland flow within a catchment into planar and channel flow. The plane surface represents the behavior of the overland flow to the channel. The channel flow represents the concentrated flow through channels to the outfall of the catchment. HEC-HMS can simulate two (2) overland flow planes and three (3) channels. These are represented in HEC-HMS as two (2) collector channels and one (1) main channel. At a minimum, the kinematic wave model requires one (1) overland flow plane and a main channel. Following is a summary of the input information required for the different flow types.

Overland Flow Plane:

- Length in feet
- Slope in ft/ft
- Overland roughness coefficient
- Percent of catchment (100 percent if only one plane is used)

Channels (Collector & Main):

- Length in feet
- Slope in ft/ft
- Channel roughness coefficient (Manning n-value)
- Shape (trapezoid, deep, circular)
- Width or diameter in feet

- Side slope, H:V in ft/ft
- Contributing area in square miles per collector (not applicable for main channel)

The input parameters listed above will need to be generated in HEC-HMS basin format. For the HCFCD WMP, we will simulate one plane and a main channel for each catchment. Therefore, the actual syntax of the basin file will need to be created for input into the HEC-HMS. The following is an example of the catchment (i.e. Sub-basin in HEC-HMS) HEC-HMS basin file input format that will need to be created. The kinematic wave data are denoted by asterisks.

```

Subbasin: Subbasin-1
Canvas X: 259.124
Canvas Y: 856.448
Label X: 16
Label Y: 0
Area: 0.25

LossRate 1: Green and Ampt
Percent Impervious Area: 0.0
Initial Loss: 0
Moisture Deficit: 0.26
Wetting Front Suction: 20
Hydraulic Conductivity: 0.06

LossRate 2: Green and Ampt
Percent Impervious Area: 0.0

Transform: Kinematic Wave **

Plane: 1**
Length: 500**
Slope: 0.004**
Mannings N: 0.01**
Percent of Area: 100**
Number of Increments: 5**

Channel: Main**
Length: 500**
Slope: 0.005**
Mannings N: 0.03**
Shape: Trapezoid**
Width: 15**
Side Slope: 3**
Number of Increments: 2**
Route Upstream: Yes**

Baseflow: None
End:

```

KW Tool Procedure

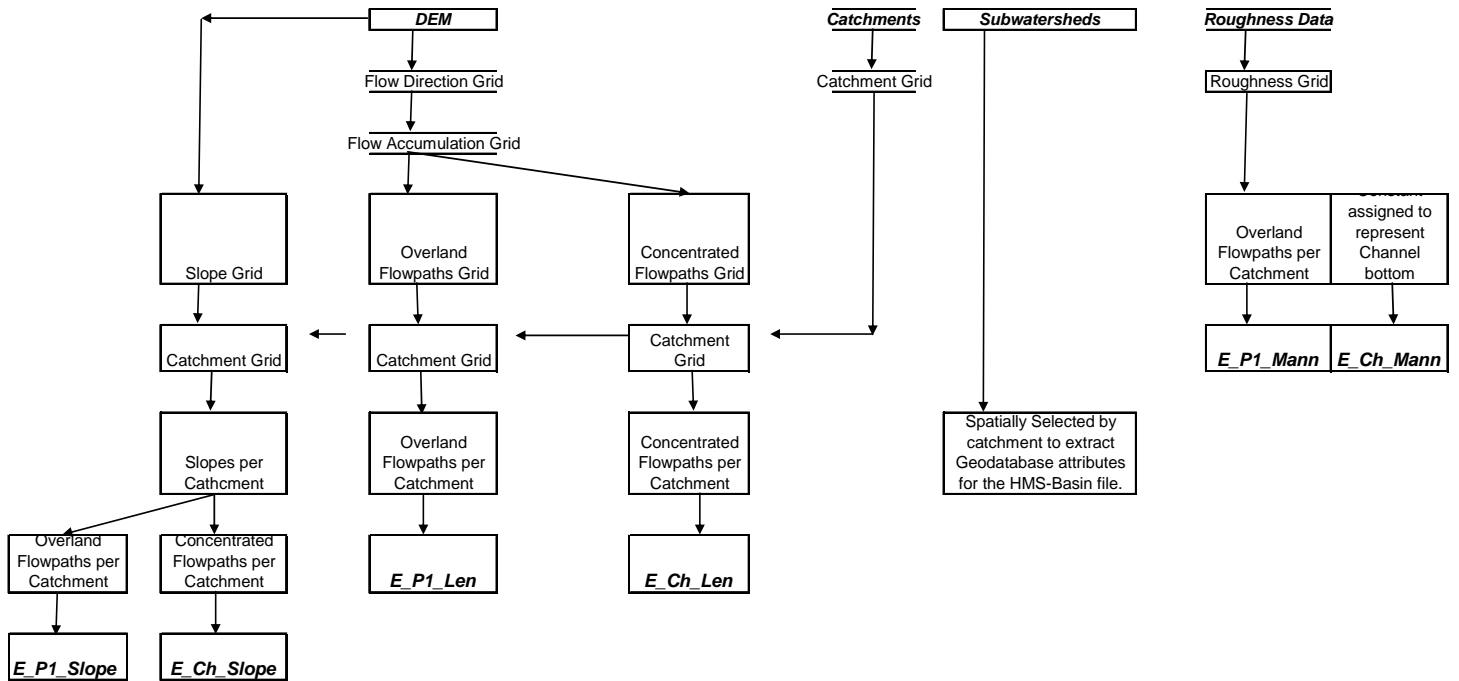
The KW Tool was developed using Visual Basic for Applications, ArcMap 8.3®, and Spatial Analyst 8.3®. The tool requires the following input layers:

- Catchments (GeoDatabase® featureclass)
- Sub-watersheds (GeoDatabase® featureclass)
- DEM (Raster)
- Roughness data (Raster)

The tool calculates six existing parameters, and six future parameters. The tool writes the parameters to a personal geodatabase and creates a file that can be loaded into HEC-HMS. Below is a list of the parameters calculated:

- **E_P1_Len** - Existing Plane 1 mean overland flow length.
- **E_P1_Slope** - Existing Plane 1 mean overland flow slope.
- **E_Ch_Len** - Existing Concentrated Channel mean length.
- **E_Ch_Slope** - Existing Concentrated Channel mean slope.
- **E_P1_Mann** - Existing Plane 1 overland flow mean roughness factor.
- **E_Ch_Mann** - Existing Plane 1 concentrated channel roughness factor.
- **P_P1_Len** - Future Plane 1 mean overland flow length.
- **P_P1_Slope** - Future Plane 1 mean overland flow slope.
- **P_Ch_Len** - Future Concentrated Channel mean length.
- **P_Ch_Slope** - Future Concentrated Channel mean slope.
- **P_P1_Mann** - Future plane 1 overland flow roughness factor.
- **P_Ch_Mann** - Future Concentrated Channel roughness factor.

Figure 2. The automation diagram of the KW process.



The automation diagram (Figure 1) illustrates how the existing parameters are derived. The future parameters are calculated based on the existing results with user interaction. The parameters are saved to the personal geodatabase. The HMS-basin file is created using the values from the geodatabase. Figures 2 and 3 are screenshots of the KW Tool illustrating the user interaction.

Figure 3. KW Tool Initialization Screen.

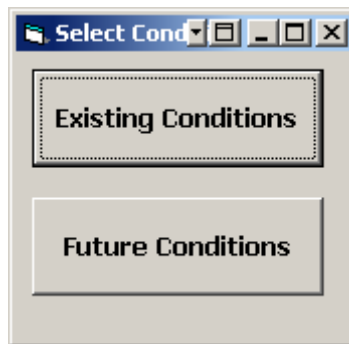


Figure 4. User input select input screen.

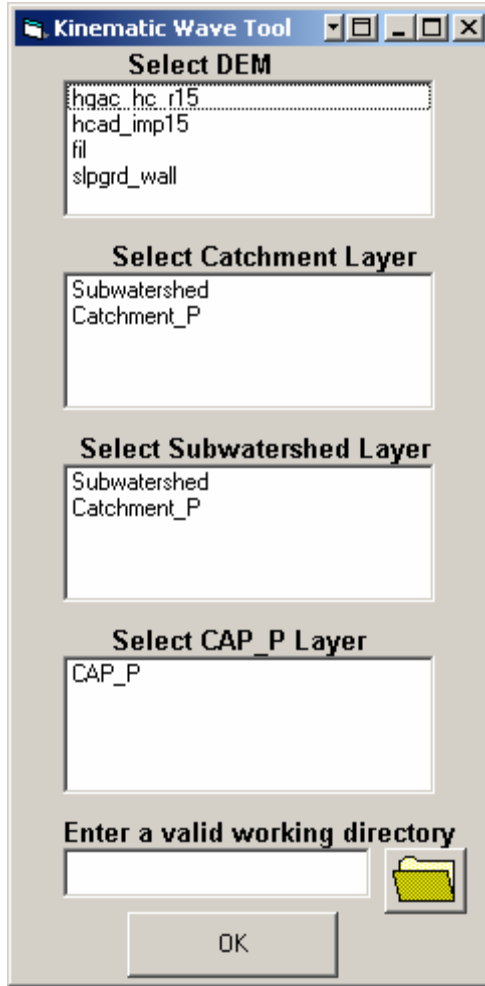


Figure 3 shows the dialog screen that allows the operator to opt between calculating parameters and write basin file or only write basin file. Figure 4 is the input screen for the HEC HMS basin file.

Figure 5. Option dialog screen.

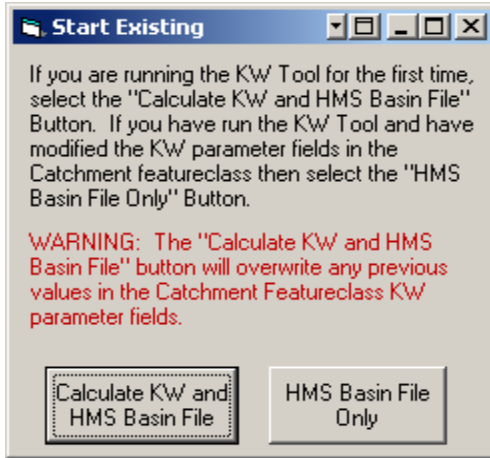
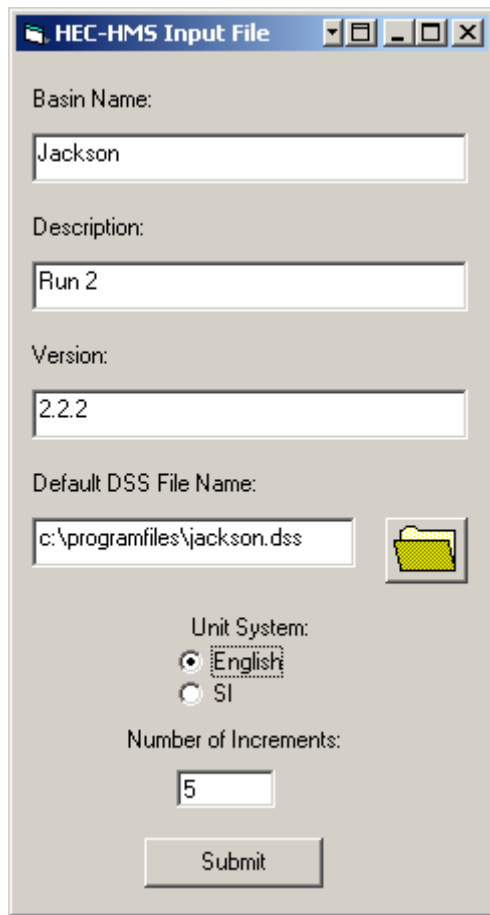


Figure 6. HEC-HMS basin file user input screen.



The H-GAC land-cover raster dataset was used to develop roughness parameters. Table displays the values used to reclassify the land cover dataset into the roughness dataset, *hgac_hc_r15*.

Table 1. Parameters used to calculate roughness.

Surface Description	Overland Flow Roughness
Low Intensity Developed	0.24
High Intensity Developed	0.11
Cultivated Land	0.15
Grassland	0.24
Woody Land	0.60
Open Water	Not Used
Wetlands	0.24
Woody Wetlands	0.42
Bare or Transitional Land	0.11

Discussion

The development of an automated GIS tool provides an efficient, confident and quantitative way for estimating kinematic wave parameters. There are four distinct advantages to the automated tool approach. First, the kinematic wave tool saves time and money. The specification of the WMP requires separate HMS Basin Input files for around 2200 catchments in Harris County. Estimating one hour per catchment to hand calculate the kinematic wave model parameters, this would cost the project over 1 year of raw engineering labor. While, the development of the KW tool took around 600 hours, one planning area averaging 300 catchments can be calculated in about 30 minutes.

Second, the tool presents a standard method for calculations. There are many different engineering firms that comprise the WMP project team. Each firm is responsible for calculating parameters for their assigned watershed. Many factors can bias techniques for measurements between the different firms and even within the firms. The GIS methods presented here allow for a standard method in which parameters are estimated. This in turn will give the technical project more confidence in the estimates.

Third, the kinematic wave tool allows the study to be documented more effectively so that it may be reproduced in the future. The documentation of hand calculations and engineering judgment requires meticulous, time-consuming detail. Previous studies that utilized hand calculations and large judgment calls have had difficulty reproducing the methods for estimating model parameters. The methodology of the kinematic wave tool is documented by the VBA code in which it is written, and the

English commentary. The tool can be rerun as many times as necessary, whenever needed.

Finally, the tool is expandable to estimate future kinematic wave parameters. The inputs and outputs have not been hard coded. HCFCD can rapidly model a developing watershed whose kinematic wave parameters have changed. This capability saves project time and taxpayer money for future studies.

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Appendix A.

Tool Technical Documentation

1.1 Required Inputs

1. ESRI raster dataset of LiDAR elevation (DEM) conditioned with the DEM Conditioning Tool.
2. ESRI raster dataset of the overland roughness values. The Harris County raster dataset for overland roughness is called '*hgac_hc_r15*'.
3. ESRI polygon feature class from the HCHydro geodatabase representing the catchments of interest. This feature class must contain a field called '*E_Pctlmp*' and '*HydroID*'.
4. ESRI polygon feature class from the HCHydro geodatabase representing the subwatershed of interest.

1.2. Procedure for Definition of Planes and Channels within the Catchments

1.2.1 Kinematic Wave Plane (*PI*)

Kinematic wave plane (*PI*) is represented as a network of overland flow paths. We define overland flow paths as cells that drain between 192 and 5227 15-foot grid cells.

1. A flow direction raster dataset is generated using the ESRI GRID function, FLOWDIRECTION from the selected DEM.

$$pGeoDirGrd = FLOWDIRECTION([DEM]) \quad (\text{Equation 1.2.1})$$

2. A flow accumulation raster dataset is generated using the GRID function, FLOWACCUMULATION from the flow direction grid.

$$pGeoAccGrd = FLOWACCUMULATION([pGeoDirGrd]) \quad (\text{Equation 1.2.2})$$

3. Overland flow paths are defined by using the GRID functions, CONDITION and SETNULL.

$$OFPath_X = CON([pGeoAccGrd] <= 192, 0,$$

$(\text{CON}([\text{pGeoAccGrd}] \geq 5227, 0, 1))$

$\text{OFPPath} = \text{SETNULL}([\text{OFPPath}_X]=0, [\text{OFPPath}_X])$ (Equation 1.2.3)

1.2.2. Kinematic Wave Channel (*Ch*)

Kinematic wave channel (*Ch*) is represented as a network of concentrated flow paths. We define concentrated flow paths as cells that drain greater than 5227 15-foot grid cells to the outlet of the catchment.

1. Concentrated flow paths are first identified by using the GRID functions, CONDITION and SETNULL with Equation 2.2.2.

$\text{CFPath}_X = \text{CON}([\text{pGeoAccGrd}] \geq 5227, 0, 1)$

$\text{CFPath} = \text{SETNULL}([\text{CFPath}_X] = 0, [\text{CFPath}_X])$ (Equation 1.2.4)

2. The concentrated flow paths are terminated at the catchment outlets by converting the boundaries of the catchment polygons into grid cells with values equal to 1.

`pCatchFCDescriptorC.Create catchFC, Nothing, "OBJECTID"`

`catchLineFC = pSurfaceOp.Contour
(pCatchFCDescriptorC, 1, 0)`

`catchLineGrd = pRstCovConSlp.ToRasterDataset
(catchLineFC, "GRID", pWorkspace, "CatchLineGrd")`

`catchLineGrd = catchLineGrd.CreateDefaultRaster`

$\text{catchLineGrd1} = ([\text{catchLineGrd}] \geq 0)$ (Equation 1.2.5)

3. Using a series of CONDITION and SETNULL statements, we make the intersections of concentrated flow paths and catchment boundaries null.

$\text{catchOut0} = ([\text{catchLineGrd1}] + [\text{CFPath}])$

$\text{catchOut1} = \text{CON}(\text{ISNULL}([\text{catchOut0}], 0), 0, [\text{catchOut0}])$

$\text{CFPathFin} = \text{SETNULL}([\text{catchOut1}] == 2, [\text{CFPath}])$ (Equation 1.2.6)

4. To prevent the channels from routing beyond the catchment boundaries, the flow direction raster from Equation 2.2.1 is terminated at the catchment boundary.

$\text{FlowDirNullCF} = \text{SETNULL}([\text{catchOut1}] == 2, [\text{pFlowDirRast}])$

(Equation 1.2.7)

1.3 Procedure for Estimating Parameters

1.3.1 Plane Length (*PI_Len*)

The plane length (*PI_Len*), or overland flow path length is estimated by averaging all the length values of the overland flow paths in a catchment. The following steps are used.

1. First a flowlength raster database is generated with the GRID command, FLOWLENGTH using the flow direction raster from Equation 2.2.1.

$$\text{ofPathLenx} = \text{FLOWLENGTH}([\text{FlowDir}], [\text{OFPathFin}], \text{UPSTREAM}) \quad (\text{Equation 1.3.1})$$

2. The length values are added to the overland flow paths and then averaged with the GRID function, ZONALMEAN.

$$\begin{aligned} \text{ofPathLen} &= [\text{ofPathLenx}] * [\text{OFPath}] \\ \text{ofPathLenMean} &= \text{ZONALMEAN}([\text{CatchGrid}], [\text{ofPathLen}]) \end{aligned} \quad (\text{Equation 1.3.2})$$

3. The average plane length values are converted back into a vector shapefile.

$$\text{ofPathMeanVFC} = \text{pRstCov.RasterDataToPolygonFeatureData}(\text{ofPathLenMean}, \text{pShapeWS}, \text{cfshapeName}, 0) \quad (\text{Equation 1.3.3})$$

4. The shapefile is joined to the catchment feature class based on the *HydroID* and calculated into *PI_Len* field. The join is removed.

$$\begin{aligned} \text{ofPathT} &= \text{OFPathMeanVFC} \\ \text{OFPathF} &= \text{ofPathT.Fields.FindField}(\text{"GRIDCODE"}) \\ \text{OFPathV} &= \text{pFeatOFPath.Value}(\text{OFPathF}) \\ \text{E_P1_LenF} &= \text{ptable.FindField}(\text{"E_P1_Len"}) \\ \text{pRow.Value}(\text{E_P1_LenF}) &= \text{OFPathV} \end{aligned} \quad (\text{Equation 1.3.4})$$

1.3.2. Plane Slope (*P1_Slope*)

The plane slope (*PI_Slope*) is estimated by determining the geometric mean of the overland flow paths' slope values in a catchment.

1. The elevations of the overland flow paths are extracted.

$$\text{ofPath_DEMx} = ([\text{OFPathFi nC}] * [\text{pRaster}]) \quad (\text{Equation 1.3.5})$$

2. The slope values are then calculated with the GRID function, SLOPE.

$$\text{ofGeoSI pGrd} = \text{pSurfaceOpS. SI ope}(\text{ofPath_DEMx}, \text{esri GeoAnal ysi sSI opePercentri se}) \quad (\text{Equation 1.3.6})$$

3. To compute the geometric mean, the slope values will be transformed to logarithmic values using the GRID function, LOG.

$$\begin{aligned} \text{ofGeoSI pGd_n} &= \text{CON}([\text{ofGeoSI pGrd}] == 0, 0.0000001, [\text{ofGeoSI pGrd}]) \\ \text{ofGeoSI pGd_lg} &= \text{LOG}([\text{ofGeoSI pGd_n}]) \end{aligned} \quad (\text{Equation 1.3.7})$$

4. The mean and standard deviation of the logarithm of the slope values per catchment are calculated and then transformed back to actual slopes with the GRID function, EXP10.

$$\begin{aligned} \text{ofGSI g_meanX} &= \text{ZONALMEAN}([\text{CatchGri d}], [\text{ofGeoSI pGd_lg}]) \\ \text{ofGS_meanEXP} &= \text{EXP10}([\text{ofGSI g_meanX}]) \end{aligned} \quad (\text{Equation 1.3.8a})$$

$$\begin{aligned} \text{ofGSI g_STDx} &= \text{ZONALSTD}([\text{CatchGri d}], [\text{ofGeoSI pGd_lg}]) \\ \text{ofGS_stdEXP} &= \text{EXP10}([\text{ofGSI g_STDx}]) \end{aligned} \quad (\text{Equation 1.3.8b})$$

5. High slope values beyond ½ of a standard deviation above the catchment average of the slopes are leveled with a CONDITION statement.

$$\text{ofSlope_HI} = [\text{ofGS_meanEXP}] + (.5 * [\text{ofGS_stdEXP}]) \quad (\text{Equation 1.3.9a})$$

$$\text{ofSlope} = \text{CON}([\text{ofGeoSlpGrd}] >= [\text{ofslope_HI}], [\text{ofslope_HI}], [\text{ofGeoSlpGrd}]) \quad (\text{Equation 1.3.9b})$$

6. These corrected slope values are then averaged again with ZONALMEAN.

$$\text{ofSI ope_mean} = \text{ZONALMEAN}([\text{CatchGri d}], [\text{ofSI ope}]) \quad (\text{Equation 1.3.10})$$

7. The average slope values are multiplied by 10,000 and then converted into integers with the GRID function, INT.

$$\text{ofSI ope_meanI} = \text{INT}([\text{ofSI ope_mean}] * 10000) \quad (\text{Equation 1.3.11})$$

8. The average plane slope values are then converted back into a vector shapefile.

$$\text{OFSI opeMeanVFC} = \text{pRstCov. RasterDataToPolygonFeatureData}(\text{ofSI ope_meanI}, \text{pShapeWS}, \text{ofSI opeshapeName}, 0)$$
 (Equation 1.3.12)

9. The shapefile is joined to the catchment feature class based on the *HydroID* and calculated into the *PI_Slope* field as true slope values.

$$\begin{aligned} \text{ofSI opeT} &= \text{OFSI opeMeanVFC} \\ \text{OFSI opeF} &= \text{ofSI opeT. Field. FindField("GRIDCODE")} \\ \text{OFSI opeV} &= \text{pFeatOFSI ope. Value(OFSI opeF)} \\ \text{E_P1_SI opeF} &= \text{ptable. Field. FindField("E_P1_SI ope")} \\ \text{pRow. Value(E_P1_SI opeF)} &= \text{OFSI opeV} / 10000 \end{aligned}$$
 (Equation 1.3.13)

1.3.3. Plane Manning N (*P1_Rough*)

1. The roughness values of the overland flow paths are extracted from the raster, *hgac_hc_r15*.

$$\text{ofpRough} = [\text{hgac_hc_r15}] * [\text{OFPATHFIND}]$$
 (Equation 1.3.14)

2. The median of the roughness values is then calculated using the GRID function, ZONALMEDIAN.

$$\text{ruf1000zonmed} = \text{ZONALMEDIAN}([\text{CatchGrid}], [\text{ofpRough}])$$
 (Equation 1.3.15)

3. The median plane Manning n values are then converted back into a vector shapefile.

$$\text{FRoughMedVFC} = \text{pRstCov. RasterDataToPolygonFeatureData}(\text{ruf1000zonmed}, \text{pShapeWS}, \text{ofRoughMedName}, 0)$$
 (Equation 1.3.16)

4. The shapefile is joined to the catchment feature class based on the *HydroID* and calculated into *PI_Rough* field. The join is removed.

$$\begin{aligned} \text{ofRoughT} &= \text{OFRoughMeanVFC} \\ \text{OFRoughF} &= \text{ofRoughT. Field. FindField("GRIDCODE")} \\ \text{OFRoughV} &= \text{pFeatOFRough. Value(OFSI opeF)} \\ \text{E_P1_MannF} &= \text{ptable. Field. FindField("E_P1_Mann")} \\ \text{pRow. Value(E_P1_MannF)} &= \text{OFRoughV} / 10000 \end{aligned}$$
 (Equation 1.3.17)

1.3.4. Channel Length (*Ch_Len*)

The channel length (*Ch_Len*), or concentrated flow path length is estimated by averaging all the lengths of the concentrated flow paths in a catchment. The following steps are used.

1. First a flowlength raster database is generated with the GRID command, FLOWLENGTH using the modified flow direction raster from Equation 2.2.7.

$$\text{CFPathLenx} = \text{FLOWLENGTH}([\text{FlowdirNullCF}], [\text{CFPathFin}], \text{UPSTREAM}) \quad (\text{Equation 1.3.18})$$

2. The lengths are added to the concentrated flow paths and then averaged with the GRID function, ZONALMEAN.

$$\begin{aligned} \text{CFPathLen} &= [\text{CFPathLenx}] * [\text{CFPath}] \\ \text{CFPathLenMean} &= \text{ZONALMEAN}([\text{CatchGrid}], [\text{CFPathLen}]) \end{aligned} \quad (\text{Equation 1.3.19})$$

3. The average channel lengths are then converted back into a vector shapefile.

$$\text{CFPathMeanVFC} = \text{pRstCov. RasterDataToPolygonFeatureData}(\text{CFPathLenMean}, \text{pShapeWS}, \text{cfshapeName}, 0) \quad (\text{Equation 1.3.20})$$

4. The shapefile is joined to the catchment feature class based on the *HydroID* and calculated into *Ch_Len* field. The join is removed.

$$\begin{aligned} \text{CFPathT} &= \text{CFPathMeanVFC} \\ \text{CFPathF} &= \text{CFPathT. Fields. FindField}(\text{"GRIDCODE"}) \\ \text{CFPathV} &= \text{pFeatCFPath. Value}(\text{CFPathF}) \\ \text{E_Ch_LenF} &= \text{ptable. FindField}(\text{"E_Ch_Len"}) \\ \text{pRow. Value}(\text{E_Ch_LenF}) &= \text{CFPathV} \end{aligned} \quad (\text{Equation 1.3.21})$$

1.3.5. Channel Slope (*Ch_Slope*)

The channel slope (*Ch_Slope*) is estimated by determining the geometric mean of the overland flow paths' slope values in a catchment.

1. The elevations of the concentrated flow paths are extracted.

$$\text{CFPath_DEMx} = ([\text{CFPathFi nC}] * [\text{pRaster}]) \quad (\text{Equation 1.3.22})$$

- The slope values are then calculated with the GRID function, SLOPE.

$$\text{CFGeoSI pGrd} = \text{pSurfaceOpS. Slope}(\text{ofPath_DEMx}, \text{esri GeoAnal ysi sSlopePercentri se}) \quad (\text{Equation 1.3.23})$$

- To compute the geometric mean, the slope values will be transformed to logarithmic values using the GRID function, LOG.

$$\begin{aligned} \text{CFGeoSI pGd_n} &= \text{CON}([\text{CFGeoSI pGrd}] == 0, 0.0000001, [\text{ofGeoSI pGrd}]) \\ \text{CFGeoSI pGd_lg} &= \text{LOG}([\text{CFGeoSI pGd_n}]) \end{aligned} \quad (\text{Equation 1.3.24})$$

- The mean and standard deviation of the logarithm of the slope values per catchment are calculated and then transformed back to actual slope values with the GRID function, EXP10.

$$\begin{aligned} \text{CFGSI g_meanX} &= \text{ZONALMEAN}([\text{CatchGri d}], [\text{CFGeoSI pGd_lg}]) \\ \text{CFGS_meanEXP} &= \text{EXP10}([\text{CFGSI g_meanX}]) \quad (\text{Equation 1.3.25a}) \\ \text{CFGSI g_STDx} &= \text{ZONALSTD}([\text{CatchGri d}], [\text{CFGeoSI pGd_lg}]) \\ \text{CFGS_stdEXP} &= \text{EXP10}([\text{CFGSI g_STDx}]) \quad (\text{Equation 1.3.25b}) \end{aligned}$$

- High slope values beyond ½ of a standard deviation above the catchment average of the slope values are leveled with a CONDITION statement.

$$\text{CFSlope_HI} = [\text{CFGS_meanEXP}] + (.5 * [\text{CFGS_stdEXP}]) \quad (\text{Equation 1.3.26a})$$

$$\text{CFSlope} = \text{CON}([\text{CFGeoSI pGrd}] >= [\text{CFSlope_HI}], [\text{CFSlope_HI}], [\text{CFGeoSI pGrd}]) \quad (\text{Equation 1.3.26b})$$

- These corrected slope values are then averaged again with ZONALMEAN.

$$\text{CFSI ope_mean} = \text{ZONALMEAN}([\text{CatchGri d}], [\text{CFSI ope}]) \quad (\text{Equation 1.3.27})$$

- The average slope values are multiplied by 10,000 and then converted into integers with the GRID function, INT.

$$\text{CFSI ope_meanI} = \text{INT}([\text{CFSI ope_mean}] * 10000) \quad (\text{Equation 1.3.28})$$

- The average channel slope values are then converted back into a vector shapefile.

$$\text{CFSI opeMeanVFC} = \text{pRstCov. RasterDataToPol ygonFeature Data}(\text{CFSI ope_meanI}, \text{pShapeWS},$$

$$\text{CFSI_opeShapeName, 0)} \quad (\text{Equation 1.3.29})$$

9. The shapefile is joined to the catchment feature class based on the *HydroID* and calculated into *Ch_Slope* field as true slope values.

$$\text{CFSI_opeT} = \text{CFSI_opeMeanVFC}$$

$$\text{CFSI_opeF} = \text{CFSI_opeT.Fiel ds.Fiel d("GRIDCODE")}$$

$$\text{CFSI_opeV} = \text{pFeat0FSI_ope.Val ue(CFSI_opeF)}$$

$$\text{E_Ch_SI_opeF} = \text{ptabl e.Fiel d("E_Ch_SI_ope")}$$

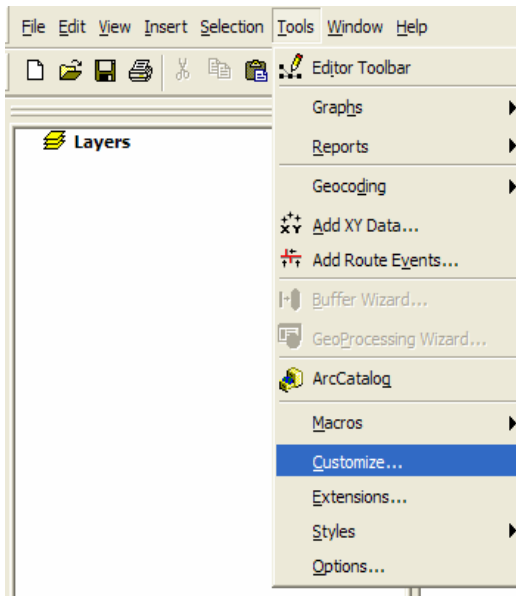
$$\text{pRow.Val ue(E_Ch_SI_opeF)} = \text{CFSI_opeV} / 10000 \quad (\text{Equation 1.3.30})$$

Appendix B

Kinematic Wave /HEC-HMS Basin Tool Instructions

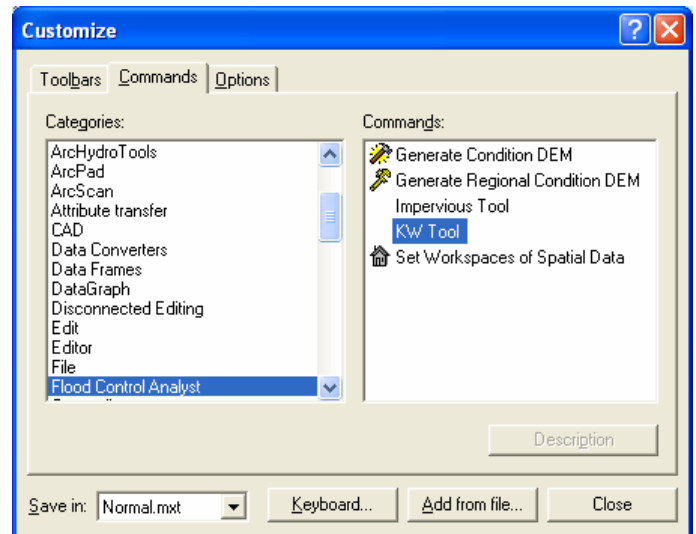
Open ArcMap

- Load the Spatial Analyst extension
 - Select Tool Menu and Extensions
 - Check the box next to Spatial Analyst
- Load Kinematic Wave/Basin Tool into any existing toolbar
 - Select Tool Menu and Customize



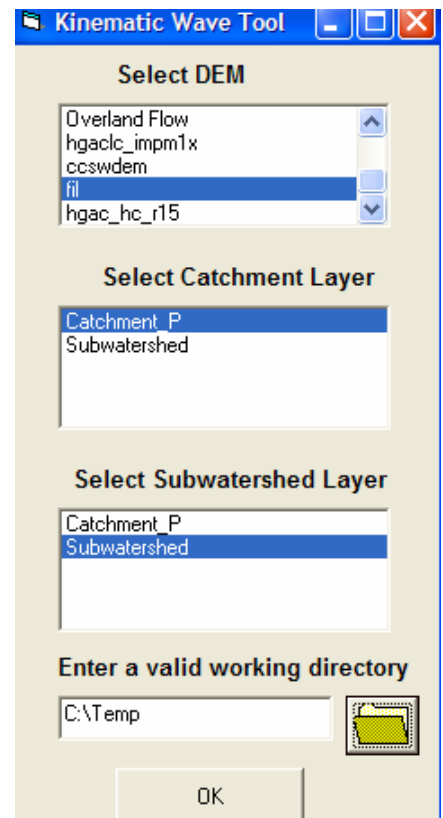
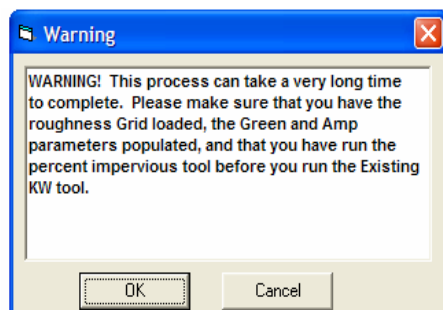
- Select Commands Tab
- Click "Add from file . . ."
- Browse to location of KWTool.dll
- Open KWTool.dll
- Select OK

- Scroll down to KW tool in the Commands List
- Drag & Drop the KW Tool from the commands list to any toolbar
- Close customized window



- Add the following data to the Map, which are needed to run the kinematic wave tool.

- Subwatershed dataset (Subwatershed) from the watershed geodatabase
- Catchment dataset (Catchment_P) from the Subwatershed geodatabase
- Conditioned Digital Elevation Model - Conditioning includes burning in the CAP_P streams and filling sinks
- Land Cover roughness grid (hgac_hc_r15). Note: Do NOT change the name of the roughness grid. The hgac_hc_r15 must be loaded into the ArcMap with this exact name, "hgac_hc_r15", for the tool to work properly.
- Before starting the KW tool it is recommended that the make newly added layers visible option is set to off. To turn off this option go to:
 - Tools -> Options -> Application and turn "Make newly added layers visible by default" **Off**.
- Select the "KW Tool" button located on the tool bar. An end user agreement will be displayed. Read the agreement and select "I agree" to use the tool. Check the do not display again box to keep the end user agreement from coming up again.
- The next window that opens gives the user the choice of running "Existing Conditions" or "Future Conditions". The user must run the existing conditions first before running the future conditions. If future conditions is chosen without running the existing conditions an error window will open prompting the user to run existing conditions first.
- If the user selects Existing Conditions, the user will see a warning box that lists out key items to consider before running existing conditions - click OK.



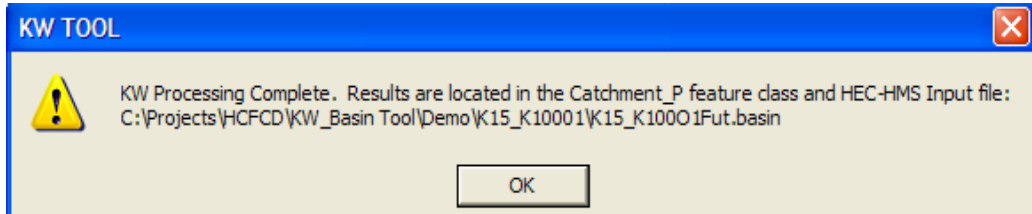
- Next the “Kinematic Wave Tool” window will be displayed. Within this window the following items can be selected.
 - Select the digital elevation model (DEM) that will be used from the list of all available grids in the ArcMap.
 - Select the catchment layer (Catchment_P) that is to be used from the list of all available polygon layers in ArcMap
 - Select the subwatershed layer (Subwatershed) that will be used from the list of all available polygon layers in ArcMap
 - Browse to an existing temporary directory by clicking on the folder. The temporary directory will be used to store temporary files that are generated during the kinematic tool process. The directory must be a valid working directory and available for read/writing before running the tool.
- The process time for the kinematic wave tool will vary, depending on computer speed, the number of catchments in the Catchment_P layer, and the size of subwatershed and DEM. During tool testing, process time averaged between 25 and 30 minutes for 33 catchments. While the tool is working several new ArcMap files will be added to the view, which will be located in the working directory specified above. These files can be removed after the tool is finished.
- Once the tool has finished its calculations, the “HEC-HMS Input File” window will be displayed.
- The user can enter the following data within the “HEC-HMS input file” window.

- Basin Name (Used for the HEC-HMS name only)
- Description (Used to Describe the HEC-HMS run)
- HEC-HMS version (Do Not Change)
- Default DSS File Name (Location to store DSS)
- Unit System (Choose English)

The screenshot shows the "HEC-HMS Input File" dialog box. It has a blue title bar with the text "HEC-HMS Input File" and a close button. The dialog contains the following fields and options:

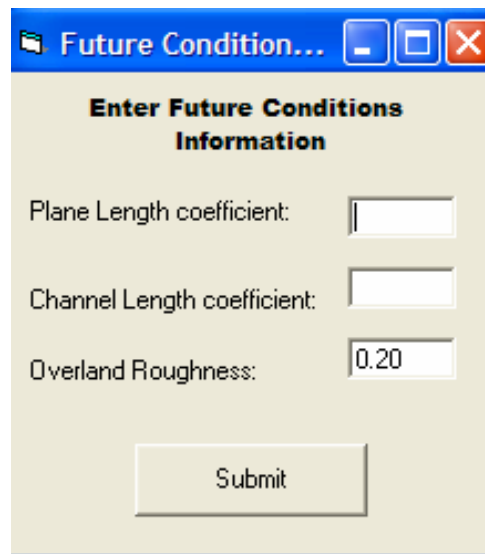
- Basin Name:** An empty text input field.
- Description:** An empty text input field.
- Version:** A text input field containing "2.2.2".
- Default DSS File Name:** An empty text input field.
- Unit System:** Two radio buttons, "English" (selected) and "SI" (unselected).
- Number of Increments:** A text input field containing "5".
- Submit:** A button at the bottom of the dialog.

- Number of Increments (Do Not Change)
- The HEC-HMS basin file (.basin) will be saved to the file folder that includes the geodatabase (.mdb) file that the catchment dataset is located in.



The HEC-HMS basin file then needs to be renamed and moved to the proper directory as follows:

- Basin file locations: \$WMP_WS_SERVER_PATH/Watershed Directory (e.g., A_Clear_Creek)/Models/WMP_HMS/BasinFiles
- Basin file name should start with E_sub or P_sub, for existing/proposed.
- For the HEC-HMS basin file for future conditions two coefficients must be entered into an input window: 1) Plane Length Coefficient and 2) Channel Length Coefficient. These two coefficients are used by the tool to adjust the future conditions plane length and channel length based on the existing percent impervious for a catchment.
Note: the existing percent impervious field (E_PctImp) in the Catchment_P layer must be populated.



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