2017 Update to Gridded Flash Flood Guidance at the Lower Mississippi River Forecast Center

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Table of Contents

1.0 Introduction

Gridded Flash Flood Guidance (GFFG) is the operational method used by the National Weather Service (NWS) for estimating the rainfall amount required to produce flash flooding. NWS River Forecast Centers (RFCs) update GFFG multiple times per day to reflect changing soil moisture conditions. This guidance is shared with the local NWS Weather Forecast Offices (WFOs). At the Lower Mississippi River Forecast Center (LMRFC), GFFG was most recently updated in fall of 2007. Changing land cover over time, including urban development, can alter the hydrologic response of small basins subject to flash flooding. These geomorphological changes necessitate the updating of GFFG periodically. This report documents the 2017 efforts to update GFFG produced by the LMRFC and highlights scripting methods developed to speed up the update process.

For detailed background information on GFFG and its assumptions, information about the process leading to the completion of this effort, and additional information about preparing the input files necessary for GFFG, read the immediately following sections. For a simpler overview of using the associated python scripts to update files for GFFG, start at "section 3.0 Semi-Automation of the GFFG File Creation Process".

1.1 Past Gridded Flash Flood Guidance

GFFG currently being produced by the LMRFC was developed using methods in the conference paper "Spatially-Variable, Physically-Derived Flash Flood Guidance" (Schmidt, Anderson, & Paul, 2007). The paper describes a method for determining a threshold amount of runoff that is likely to produce flash flooding based upon land cover, slope, near-surface soil texture, and rainfall frequency. Estimation of this runoff threshold is based upon the US Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS) Curve Number method and the NOAA Atlas 14 3-h, 5-yr rainfall event (NOAA NWS Hydrologic Design Studies Center, 2015).

The 3-hr, 5-yr rainfall event is used to calculate runoff at grid cell, using the predetermined standard curve number for the cell. Next, the NRCS peak streamflow equations to estimate peak streamflow for rainfall event at each cell. This discharge is then considered to be the bankfull capacity of the headwater stream within that grid cell. Multiple times per day, soil moisture values from the operational SAC-SMA model are used to establish a real-time CN that has been adjusted up or down based upon soil moisture conditions. This "real-time" CN and the NRCS equations are then used to calculate how much rainfall will be required in one, three, and six hours to fill the calculated channel to capacity (Q_s). A later development estimated how full the stream channel was during the effective period of the guidance and reduced the channel capacity to reflect that value.

1.1.1 Soils and Land Cover

Curve Number is estimated based upon land cover using a lookup table. Schmidt, Anderson, & Paul (2007) provided a lookup table for the 2001 land cover update (Table 1). The curve number for a particular land cover type differs based up on the soil texture, namely the particular soil's infiltration capacity. Hydrologic soil group is the classification scheme used by the NRCS (2004) and ranges from A to D with A having the lowest runoff potential (high infiltration) and D having the highest runoff potential (low infiltration).

The source for hydrologic soil group was originally in gridded format from Pennsylvania State University's Soil Information for Environmental Modeling and Ecosystem Management website, however this data has not been updated in several years and remains in a format that is difficult to use in current GIS software. The NRCS maintains updated versions of soil data on their web portals including software packages that will create the necessary GIS layers from the raw data.

Table 1. Curve number lookup table for 2001 Land Cover descriptions based upon hydrologic soil group (soil texture). From Appendix A of Schmidt, Anderson, & Paul (2007).

CLASS	DESCRIPTION	A	B	C	D
11	Open Water	100	100	100	100
12	Perennial Ice/Snow	100	100	100	100
21	Low Intensity Residential	57	72	81	86
22	High Intensity Residential	61	75	83	87
23	Commercial/Industrial/Transportation	89	92	94	95
30	Barren	77	86	91	94
31	Bare Rock/Sand/Clay	77	86	91	94
32	Quarries/Strip Mines/Gravel Pits	77	86	91	94
33	Transitional	43	65	76	82
41	Deciduous Forest	36	60	73	79
42	Evergreen Forest	36	60	73	79
43	Mixed Forest	36	60	73	79
50	Shrubland	35	56	70	77
51	Shrubland	35	56	70	77
60	Non-Natural Woody	35	58	71	78
61	Orchards/Vineyards/Other	35	58	71	78
71	Grasslands/Herbaceous	49	69	79	84
81	Pasture/Hay	49	69	79	84
82	Row Crops	67	78	85	89
83	Small Grains	63	75	83	87
84	Fallow	76	85	90	93
85	Urban/Recreational Grasses	39	61	74	80
91	Woody Wetlands	36	60	73	79
92	Emergent Herbaceous Wetlands	49	69	79	84

1.1.2 Rainfall Frequency

The calculation of threshold runoff attempts to estimate the 50% annual exceedance probability (AEP), or 2-year average recurrence interval (ARI), streamflow event. The 50% AEP/2-year ARI rainfall event has often been cited as the threshold for flash flooding onset (Carpenter, Sperfslage, Georgakakos, Sweeney, & Fread, 1999; Reed, Johnson, & Sweeney, 2002) because the same AEP value roughly corresponds to the streamflow AEP value associated with bankfull river conditions. Recent research, however, has shown the relationship between streamflow event AEP and onset of flooding to be widely varying between locations (Cosgrove, 2014; Erlingis, Gourley, & Hong, 2014). In Schmidt, Anderson, and Paul (2007) they instead chose the 20% AEP/5-year ARI *rainfall* event as the source for estimating bankfull *streamflow* because using the lower, 50% AEP rainfall often did not produce FFG values that met the calibration goals they had established (approximately 50% AEP streamflow) and they determined that their estimates of channel capacity were too low. (Anderson, 2017).

A review of the relevant literature was conducted to determine the basis for the 2-year streamflow ARI (50% AEP) assumption used for onset of flooding. As summarized by Wolman and Leopold (1957), 140 river locations were studied by Langbein (1949) and the median streamflow ARI for flood stage was 2.1 years. Wolman and Leopold also provided a table summary of a U.S. Army Corps of Engineers study (unknown year) of 71 river locations in Texas which had a median flood stage streamflow ARI of "about 2 years" (although a manual recalculation of values provided in the table suggested an ARI closer to 2.5 years). The vast majority (10th percentile to 90th percentile) of ARIs ranged from 1.3 to 6.5 years. Wolman and Leopold (1957) then provided a detailed table of streamflow data they collected from 37 locations across the contiguous U.S.; the data provided had a median bankfull streamflow ARI of 1.4 years (10th to 90th percentile values ranged from 1.0 to 12.6 years, respectively.

As summarized by a conference paper by Kennth V.H. Smith presented to the 2nd International Conference on Hydraulic Design in Water Resources Engineering (Smith, 1986), Dury (1959) concluded that bankfull streamflow ARI was approximately 1-2 years for the Nene and Great Ouse Rivers in the United Kingdom. The book Fluvial Processes in Geomorphology (Leopold, Wolman, & Miller, 1964) provided a data table of 20 locations which had a median bankfull streamflow ARI of 1.2 years (10th to 90th percentile values ranged from 1.1 to 2.3 years, respectively). Woodyer (1968) reported on bankfull streamflow ARIs for 12 river locations in New South Wales, Australia, which had median ARI of 2.8 years (10th to 90th percentile values ranged from 1.5 to 7.8 years, respectively). Williams (1978), which also was very critical of the concept of using streamflow ARIs as a proxy for bankfull, provided bankfull streamflow ARIs for 35 locations across the U.S. which had a median ARI of 1.8 years (10th to 90th percentile values ranged from 1.1 to 27.2 years, respectively). The landform regions and watershed areas for each of the river locations provided by the various studies varied greatly. The smallest known watershed size was 4.3 mi^2 and the largest was 13100 mi^2. Raw bankfull streamflow ARI values, when provided by these studies, are summarized in Figure 1.

Although many studies of widely varying basin sizes and physical characteristics concluded similar median ARIs for bankfull or flood stage streamflow, there are concerns over the usage of a single ARI value to represent bankfull. By the 1970s, a summary of work on these efforts by G.P. Williams (1978) concluded that generalizations of the relationships between bankfull stage and streamflow ARI were not very successful due to a "eleven possible definitions of 'bank-full' …used by various researchers." Williams also concluded that "[ARI] …is a poor estimate of bankfull discharge." A PhD thesis by J.W. Tilleard (2001) also provides a summary of issues trying to assign a particular streamflow ARI to bankfull or flood stage. Williams' summary of other studies in the 1950s and 1960s indicated that "only one variable, channel slope, even remotely related to the [ARI] of bankfull discharge."

Issues in determining a good approximation for threshold runoff go beyond concerns over using a single set streamflow ARI to approximate bankfull. The original GFFG implementation uses *rainfall*, not streamflow, to determine channel capacity, and thus, threshold runoff. Although the causative rainfall likely has some correlation to the resulting streamflow, there are numerous factors which contribute to weakening this relationship. Although impossible to mention all of these factors, they likely include soil moisture, rainfall duration, and land cover. The 2 year streamflow ARI, even if a good proxy for flood stage, and even if it could be estimated based upon a single ARI rainfall, will not necessarily indicate the onset of flash flooding. Variability in vulnerability to flooding as well as variability in what gets considered - and officially reported - as flash flooding add to the difficulty in using a single ARI for a warning threshold across the contiguous U.S. Based upon all of these concerns, much caution must be used when applying the one-size-fits all approach of rainfall ARI as a proxy for flash flood threshold runoff. The original developers of GFFG considered this in their original development; They considered ARI as a potential calibration variable that could be used to adjust the baseline FFG on a more site-by-site basis (Anderson, 2017).
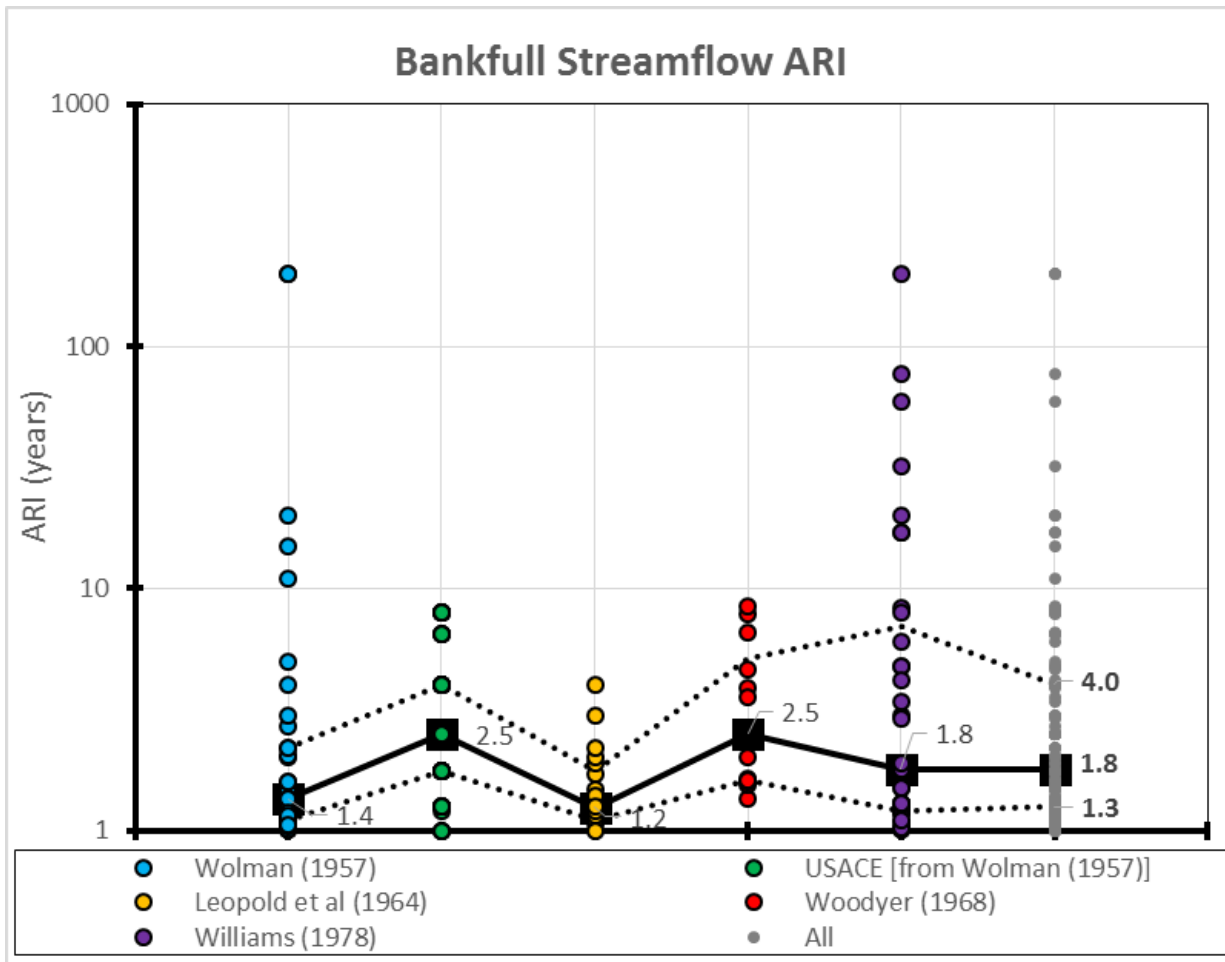
Figure 1. Bankfull streamflow ARI data from multiple studies, and all studies combined (far right). Median values for each study indicated by large black squares with thick black line and the 50th percentile range (25th percentile to 75th percentile) indicated by dotted lines.

2.0 Methodology

This section describes the methods used to update LMRFC's GFFG using the latest soil data, land cover data, and rainfall frequency data.

Requirements include:

- ArcGIS 10.x
- Python 2.5+
- Microsoft Access
- USDA NRCS Soil Data Viewer
  (https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/home/?cid=nrcs142p2_053620)

2.1 Retrieving and Preparing Soil Data

Soil surveys are completed by the USDA NRCS. The most recent, finest-scale soil survey data available at the time of this report are those available from the Soil Survey Geographic Database (SSURGO). The NRCS also produces a generalized soil map based upon SSURGO data referred to as the General Soil Map of the U.S. (STATSGO2) which supersedes data from the State Soil Geographic (STATSGO) dataset. STATSGO was the basis for prior version of GFFG at the NWS RFCs.

Due to the very high resolution of SSURGO, data availability is by each county individually (or larger areas if an external hard drive is sent to USDA). Processing files of that size also is very time and processor intensive. These limitations make usage of raw SSURGO data difficult, so STATSGO2 will be used instead for updating GFFG.

2.1.1 The USDA NRCS Web Soil Survey

Soil survey data is available from the USDA via the Web Soil Survey (https://websoilsurvey.nrcs.usda.gov/) (USDA NRCS Soil Survey Staff, 2017). Once in the Web Soil Survey application, choose "Download Soils Data" then "U.S. General Soil Map (STATSGO2)" then "entire data set." Although individual states of interest can be downloaded individually, downloading the entire data set ensures that multiple states are already mosaicked together, including survey areas that may cross state lines.

Figure 2. Steps for navigating the USDA NRCS Web Soil Survey to download STATSGO2 soil survey data for the entire United States.

2.1.2 Connecting the tabular data to the template database

Once the data is downloaded and extracted, the tabular data must be tied to the template database. This is done using Microsoft Access. Load the file with the Microsoft Access Database (.mdb) extension within the folder of extracted soil data. Click "enable content" if your security blocks Microsoft macros by default. In the "SSURGO Import" box, type the path to the tabular data folder. When using data for the entire U.S., this should likely end with something like "\wss_gsmsoil_DE_[2006-07-06]\tabular\". For large file sizes (such as the U.S. as a whole), this will take several minutes at a minimum and the progress bar may appear to hang for long periods of time and even start over on multiple occasions.
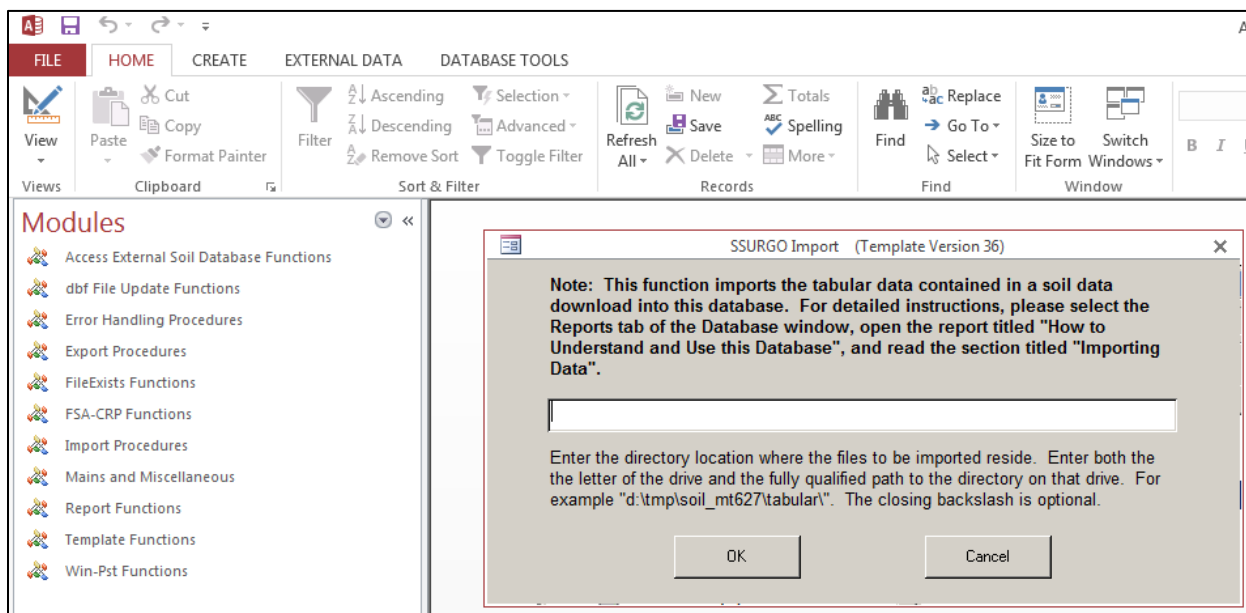
Figure 3. The tabular data import prompt seen when first opening soil data template databases.

2.1.3 USDA NRCS Soil Data Viewer in ArcGIS

Once the soil data's template database is tied to the tabular data, the soil survey information can be aggregated to the soil survey polygons to create gridded data. This is accomplished by using USDA NRCS's Soil Data Viewer and the plugin for ArcGIS. Once the add-on for ArcGIS has been activated, make sure that the toolbar is turned on by right clicking in the toolbar area and clicking "Soil Data Viewer Toolbar" such that it is checked.
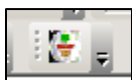

Figure 4. The USDA NRCS Soil Data Viewer toolbar in ArcMap.

Aggregating soil survey data on the national scale would be particularly time intensive, often unnecessary, and would likely exceed the limitations of the Soil Data Viewer. To work around this, select just the soil survey polygons that cover your study area and create a new clipped down shapefile. Use caution when manually selecting and deleting soil survey polygons – although most polygons are small in size, some polygons can be large and cover irregular areas such as 100 or more continuous miles of river floodplain. Selecting polygons that appear to be outside of the area of interest may inadvertently include a very large polygon that extends into the study area.
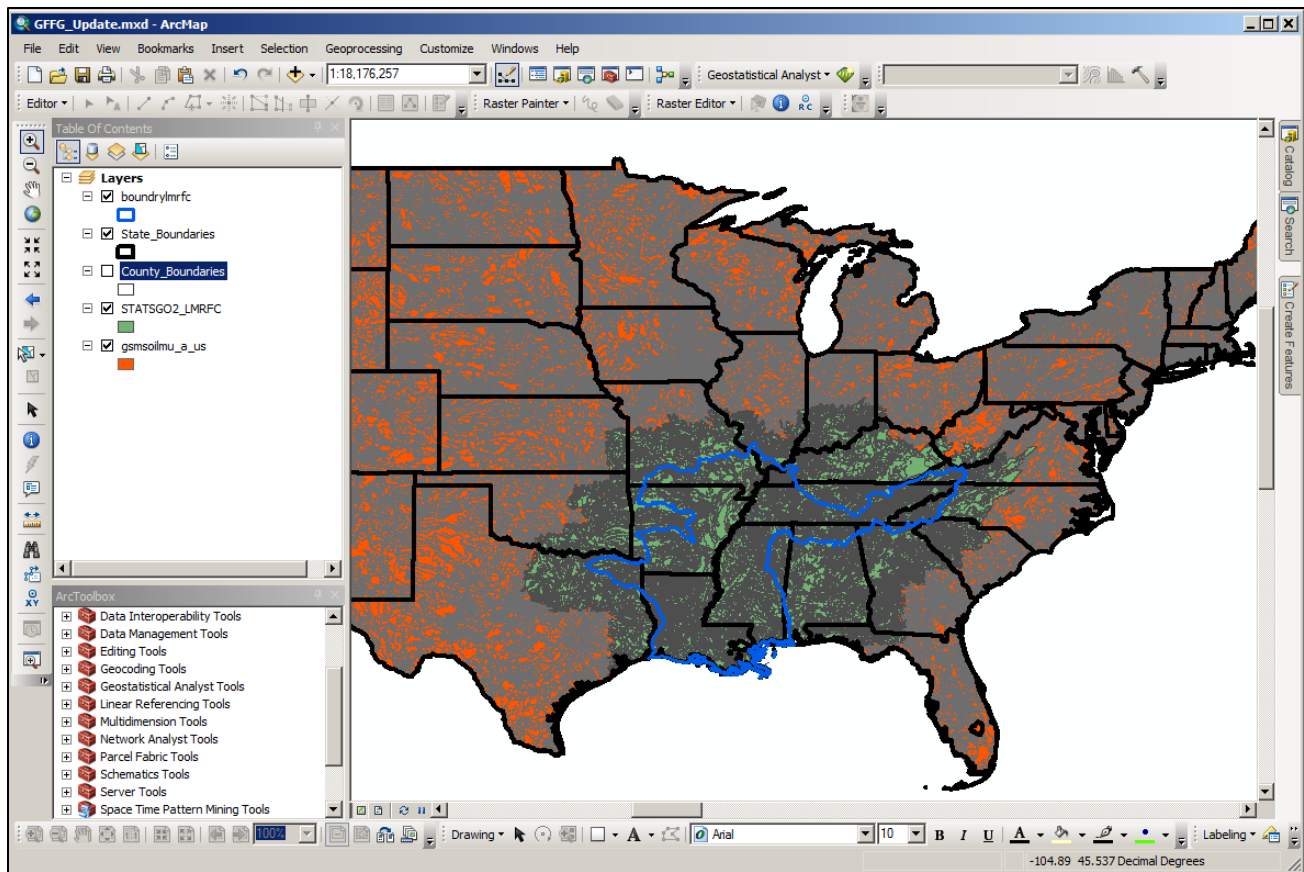
Figure 5. The raw soil survey data polygons from the extracted U.S. STATSGO2 data (orange) and the soil survey data polygons that were clipped down the LMRFC area (green).

Click the button in the toolbar to activate the Soil Data Viewer plugin. Select the template database (.mdb) that was tied to the tabular data. You will receive an error if the template database was not tied to the associated tabular data (see section "2.1.2 Connecting the tabular data to the template database"). The Soil Data Viewer will prompt you to select the polygon shapefile that you wish to use for soil survey data aggregation – select the shapefile that was clipped down to your analysis area.
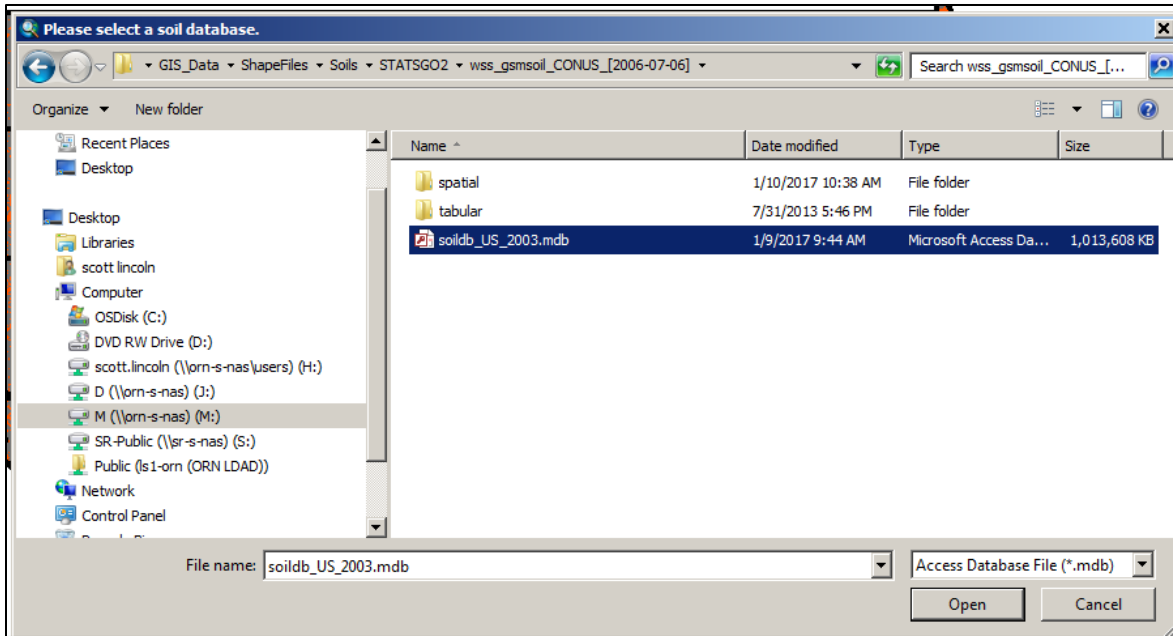
From the Soil Data Viewer menu "Attribute Folders" select "Hydrologic Soil Group" under "Soil Qualities and Features." Then click "Map" to aggregate the soil survey data and create a feature layer of hydrologic soil group by soil survey polygon. This process will take several minutes to complete. Make sure to save the feature layer as a separate shapefile if you are satisfied with the results.

Although not necessary for this particular method, the Soil Data Viewer can also create feature layers of other important soil information such as surface texture, saturated hydraulic conductivity (Ksat), and soil moisture capacity.
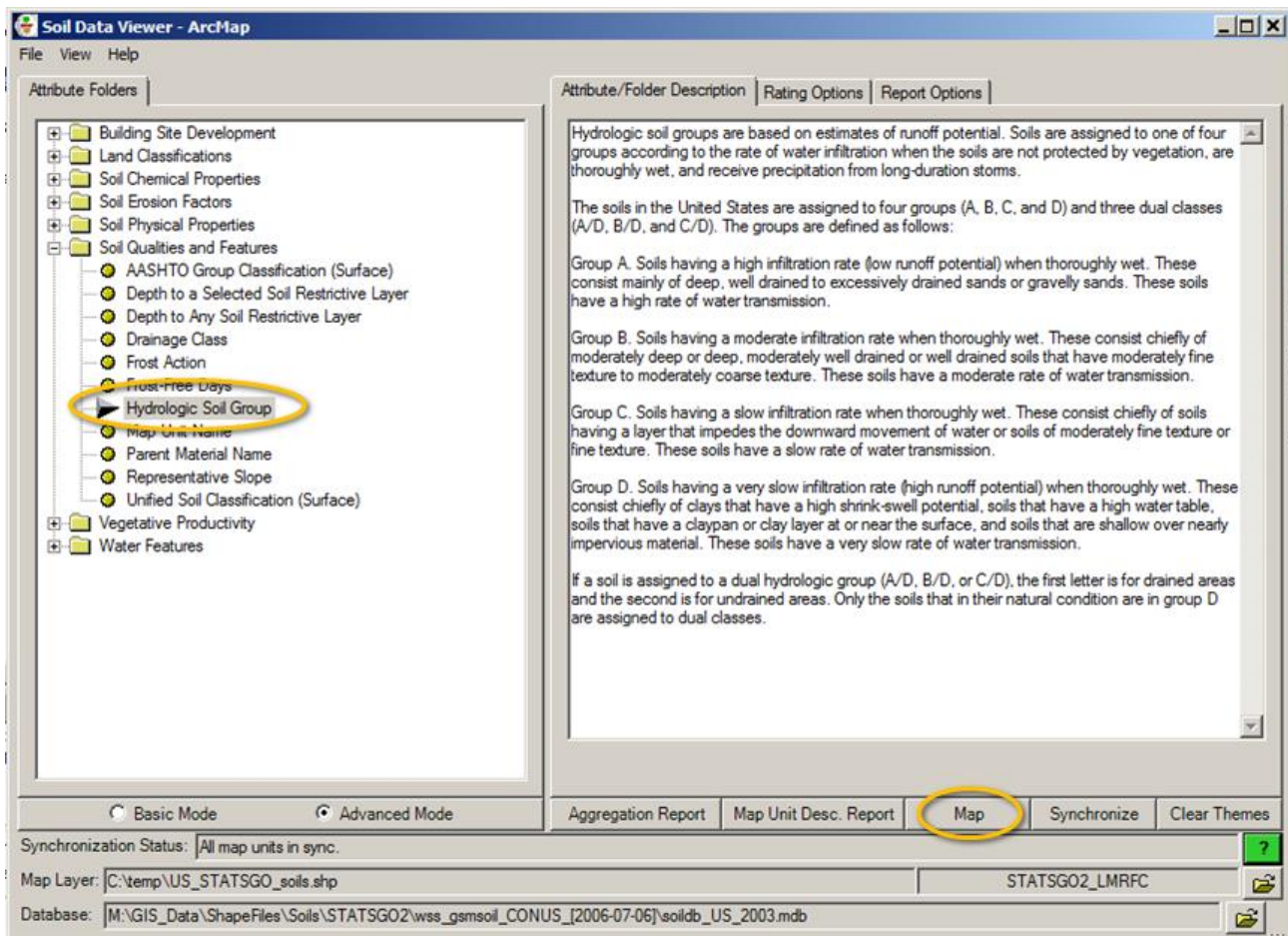
Figure 6. Steps for creating a hydrologic soil group feature layer using the USDA NRCS Soil Data Viewer addon to ArcGIS.

2.2 Retrieving Land Cover Data

Land Cover data is available from the National Land Cover Database, a product of the Multi-Resolution Land Characteristics Consortium (https://nationalmap.gov/landcover.html). The data can be downloaded from the USGS National Map (https://viewer.nationalmap.gov). Due to file size limitations of the National Map, land cover data may need to be downloaded in multiple pieces for areas smaller than an entire RFC, then mosaicked back together into a larger raster.

The 2001 land cover database has since been superseded by the 2006 and 2011 land cover databases (Homer, et al., 2015). The 2006 and 2011 updates use slightly different land cover classes, some of which have no direct correlation to a 2001 classification.

Land cover classifications for the 2006 and 2011 data were estimated, when necessary, based upon values from similar 2001 classifications and guidance from the USDA NRCS National Engineering Handbook (Natural Resources Conservation Service, 2004) as well as USDA Technical Release 55: Urban Hydrology for Small Watersheds (Natural Resources Conservation Service, 1986). The curve number lookup table used for the 2006 and 2011 land cover updates is shown by Table 2.

Table 2. Curve number lookup table for 2006 and 2011 Land Cover descriptions based upon hydrologic soil group (soil texture).

CLASS	DESCRIPTION	A	B	C	D
11	Open Water	100	100	100	100
12	Perennial Ice/Snow	100	100	100	100
21	Developed, Open Space	39	61	74	80
22	Developed, Low Intensity	57	72	81	86
23	Developed, Medium Intensity	61	75	83	87
24	Developed, High Intensity	89	92	94	95
31	Barren Land (Rock/Sand/Clay)	77	86	91	94
41	Deciduous Forest	36	60	73	79
42	Evergreen Forest	36	60	73	79
43	Mixed Forest	36	60	73	79
51	Dwarf Scrub	35	56	70	77
52	Shrub/Scrub	35	56	70	77
71	Grassland/Herbaceous	49	69	79	84
72	Sedge/Herbaceous	49	69	79	84
73	Lichens	49	69	79	84
74	Moss	49	69	79	84
81	Pasture/Hay	49	69	79	84
82	Cultivated Crops	65	77	84	88
90	Woody Wetlands	36	60	73	79
95	Emergent Herbaceous Wetlands	49	69	79	84

2.3 Retrieving Rainfall Frequency Data

This rainfall frequency data was derived from NOAA Technical Paper 40 (Hershfield, 1961) for the original flash flood guidance implementation. Over the last 5-10 years, TP-40 has been superseded by improved rainfall frequency information presented in NOAA Atlas 14 (NOAA NWS Hydrologic Design Studies Center, 2015). Gridded rainfall frequency data from NOAA Atlas 14 is being created by region instead of for the CONUS as a whole. Data for each region covering the LMRFC area, for the 20% AEP (5-yr ARI), was downloaded and mosaicked.

As of January 2017, rainfall frequency data for Texas was not yet completed. Although data from TP-40 was available for Texas, a finer-scale, newer analysis (SRCC TR 97-1) was completed by the Southern Regional Climate Center in the 1990s (Faiers, Keim, & Muller, 1997) which was used in place of NOAA Atlas 14. SRCC TR 97-1 included rainfall durations from 3 hours to 24 hours, but unfortunately did not include the 1 hour duration, which is important for flash flood guidance.

2.4 Calculating Curve Number

Because there are four (4) different curve numbers for each land cover classification (one for each hydrologic soil group), a simple raster re-classification is not sufficient for calculating curve number. To avoid the complexity and additional computation time of calculating curve number for each hydrologic soil group separately and then mosaicking the separate rasters back together, the hydrologic soil groups were mapped to an index. The index values were chosen such that there was a linear relationship between hydrologic soil group and curve number (Figure 7). HSG Index values of 1.0, 2.7, 3.6, and 4.0 were selected to correspond to hydrologic soil groups A, B, C, and D, respectively, which makes the relationship perfectly linear. The linear regression parameters for the HSG Index are listed in Table 3. It should also be noted that in some cases, dual HSGs (example: A/D) may exist for a particular area (Natural Resources Conservation Service, 2004). The first letter corresponds to the runoff potential of the *typically wet* soil if it were drained. The second letter corresponds to the runoff potential if the soil were not drained. Because the typical condition of the soil is undrained, the second letter will be used for instances of dual HSG values.

An ArcGIS "model" was created to simplify and partially-automate the processing of each of the steps necessary to create curve number from hydrologic soil group and land cover (Figure 8). "Models" in ArcGIS connect multiple, separate tools in a graphical flow-chart manner such that output from one is immediately used as input for another. First, the shapefile of hydrologic soil group is converted to a raster. The hydrologic soil group raster is converted to an index. Next, the land cover raster is re-classified into linear regression parameter "a" and then into linear regression parameter "b" (Table 3).

Finally, using the linear regression equation, the rasters for parameter "a", parameter "b", and hydrologic soil group are then utilized to create a raster of curve number.
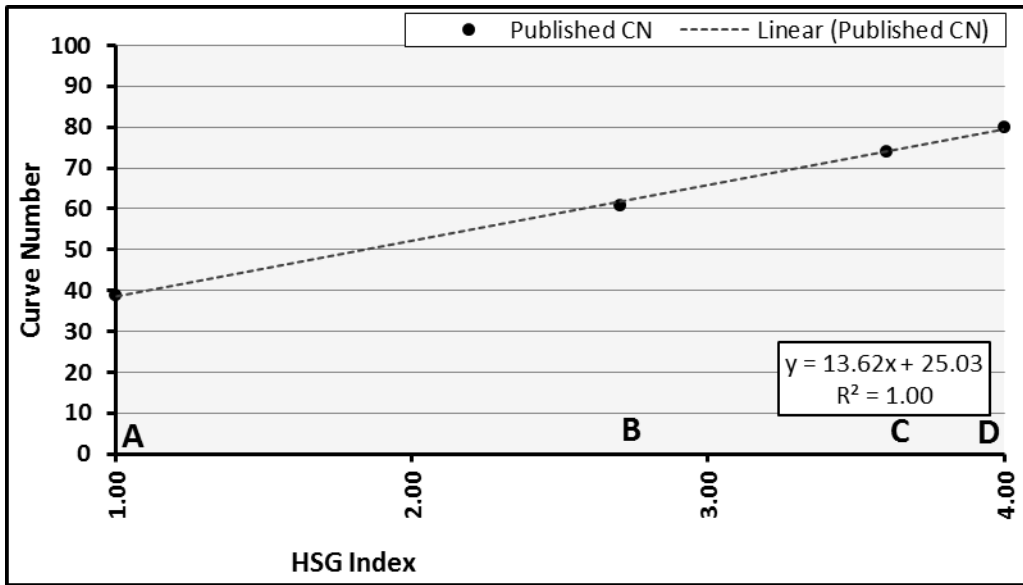

Figure 7. Example relationship between hydrologic soil group (expressed as an index) and curve number. The example above is for land cover class 21, "Developed, Open Space." HSG Index values of 1.0, 2.7, 3.6, and 4.0 correspond to hydrologic soil groups A, B, C, and D, respectively, which makes the relationship perfectly linear.
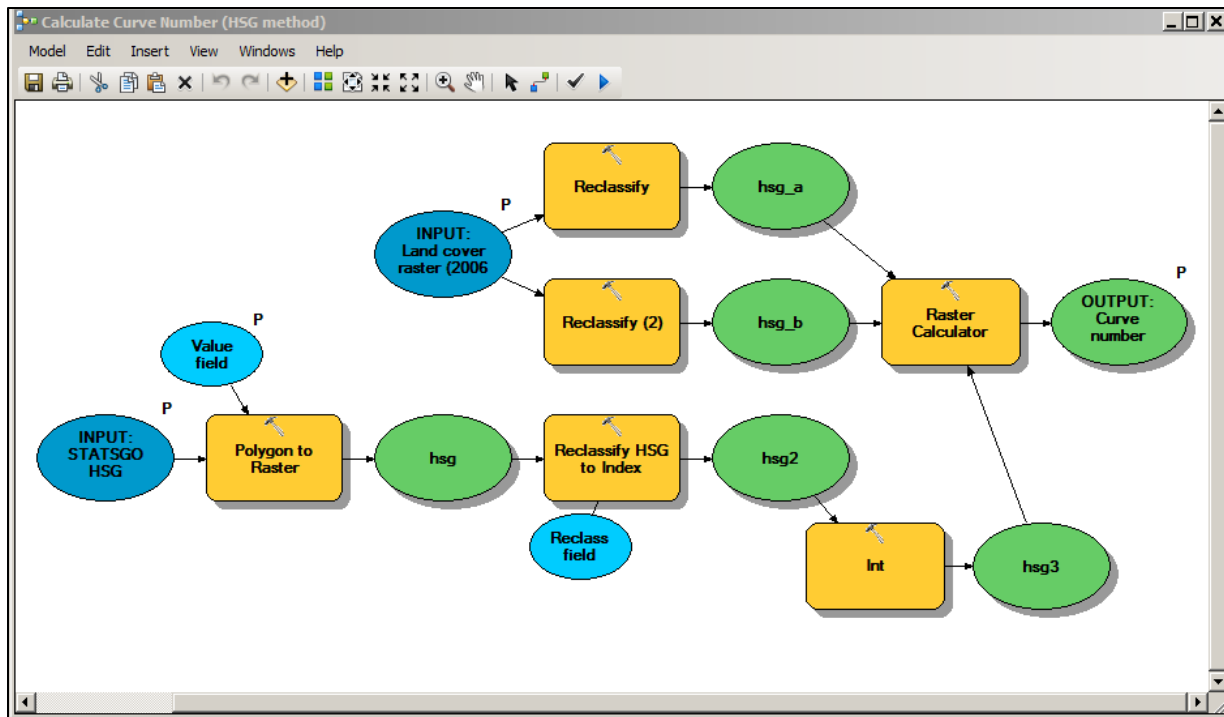
Figure 8. ArcGIS model used to create a raster of curve number from the hydrologic soil group and land cover rasters.

Table 3. Curve number values for each land cover class based upon hydrologic soil group. Linear regression parameters "a" and "b" used to create the linear relationship for curve number from HSG Index. Values are valid for the 2006 and 2011 USGS Land Cover datasets.

class	description	HSG A	HSG B	HSG C	HSG D		y = a x + b		
		1	2.7	3.6	4		a	b	r2
11	Open Water	100	100	100	100		0.0000	100.0000	
12	Perennial Ice/Snow	100	100	100	100		0.0000	100.0000	
21	Developed, Open Space	39	61	74	80	*	13.6180	25.0291	0.9995
22	Developed, Low Intensity	57	72	81	86	*	9.5354	47.0624	0.9984
23	Developed, Medium Intensity	61	75	83	87	*	8.6063	52.1872	0.9995
24	Developed, High Intensity	89	92	94	95	*	1.9803	86.9057	0.9974
31	Barren Land (Rock/Sand/Clay)	77	86	91	94		5.5748	71.2511	0.9987
41	Deciduous Forest	36	60	73	79		14.3031	21.5936	1.0000
42	Evergreen Forest	36	60	73	79		14.3031	21.5936	1.0000
43	Mixed Forest	36	60	73	79		14.3031	21.5936	1.0000
51	Dwarf Scrub	35	56	70	77		13.8620	20.3397	0.9974
52	Shrub/Scrub	35	56	70	77		13.8620	20.3397	0.9974
71	Grassland/Herbaceous	49	69	79	84		11.6143	37.4397	0.9999
72	Sedge/Herbaceous	49	69	79	84	*	11.6143	37.4397	0.9999
73	Lichens	49	69	79	84	*	11.6143	37.4397	0.9999
74	Moss	49	69	79	84	*	11.6143	37.4397	0.9999
81	Pasture/Hay	49	69	79	84		11.6143	37.4397	0.9999
82	Cultivated Crops	65	77	84	88	*	7.5551	57.1567	0.9985
90	Woody Wetlands	36	60	73	79		14.3031	21.5936	1.0000
95	Emergent Herbaceous Wetlands	49	69	79	84		11.6143	37.4397	0.9999

2.5 Calculating Threshold Runoff

Threshold runoff (also referred to as ThreshR) is the threshold amount of runoff above which flash flooding is expected to begin (Schmidt, Anderson, & Paul, 2007). The original GFFG technique first calculates an "initial abstraction" raster from the curve number grid (Figure 9). Initial abstraction refers to the rainfall that is captured by vegetation and imperfections in the soil surface during a rainfall event before infiltration into the soil surface can begin. The threshold runoff for 20% AEP (5-yr ARI) storm with a 3-hr duration is then calculated from the initial abstraction using the curve number runoff equation (Figure 10).

$$S_{sm} = \frac{1000}{CN_{sm}} - 10 \; ; \qquad (3)$$

Figure 9. The curve number initial abstractions equation presented as equation 3 in Schmidt, Anderson, & Paul (2007).

$$Q = \frac{(P - 0.2S_{sm})^2}{P + 0.8S_{sm}} \; ; \qquad (7)$$

Figure 10. The curve number runoff equation presented as equation 7 in Schmidt, Anderson, & Paul (2007).

ThreshR values for 1-hr and 6-hr storm durations are then calculated, somewhat indirectly, using the threshold for the 3-hr duration storm. The peak flow per 1-in of runoff is calculated using the SCS unit hydrograph equations. First, the lag time (in hours) is calculated from hydraulic length (for GFFG purposes assumed to be the diagonal length across one HRAP pixel, or 19131.5-ft), average watershed slope (for GFFG purposes the average slope by pixel, in percent), and initial abstraction (calculated from curve number previously, in inches). The lag time equation is show by Figure 11. Next, the time of rise (in hours) for the unit hydrograph is calculated from rainfall duration (set as 3-hr for the 3-hr ThreshR duration) and lag time (calculated previously). The time of rise equation is show by Figure 12. Finally, peak flow (in cfs) is calculated from basin area (for GFFG purposes assumed to be the area of one average HRAP pixel, or 6.564 mi^2) and time of rise (calculated previously). The peak flow equation is shown by Figure 13. This peak flow per 1-in of runoff for 3-hr of rainfall is multiplied by the 3-hr ThreshR raster to estimate the peak flow for a given HRAP pixel caused by a 20% AEP (5-yr ARI), 3-hr duration design storm. This "critical flow" is used as the basis for calculating ThreshR values for the other durations. ThreshR values for 1-hr and 6-hr durations are estimated by dividing the critical flow by the peak flow per 1-in of runoff for 1-hr of rainfall and 6-hr of rainfall, respectively. An ArcGIS "model" was again created to simplify and partially automate these processing steps (Figure 14).

$$t_p = \frac{l^{0.8}(S+1)^{0.7}}{1900y^{0.5}} \; ; \qquad (4)$$

Figure 11. The lag time equation presented as equation 4 in Schmidt, Anderson, & Paul (2007). Lag time (in hours) is calculated based upon hydraulic length (ft), average watershed slope (%), and initial abstraction (in).

$$T_R = \frac{D}{2} + t_p \; ; \qquad (5)$$

Figure 12. The time of rise equation presented as equation 5 in Schmidt, Anderson, & Paul (2007). Time of rise (in hours) is calculated based upon rainfall duration (hr) and lag time (hr).

$$Q_p = \frac{484A}{T_R} \; ; \qquad (6)$$

Figure 13. Unit hydrograph peak flow equation presented as equation 6 in Schmidt, Anderson, & Paul (2007). Peak flow (in cfs) is calculated based upon basin area (mi²) and time of rise (hr).
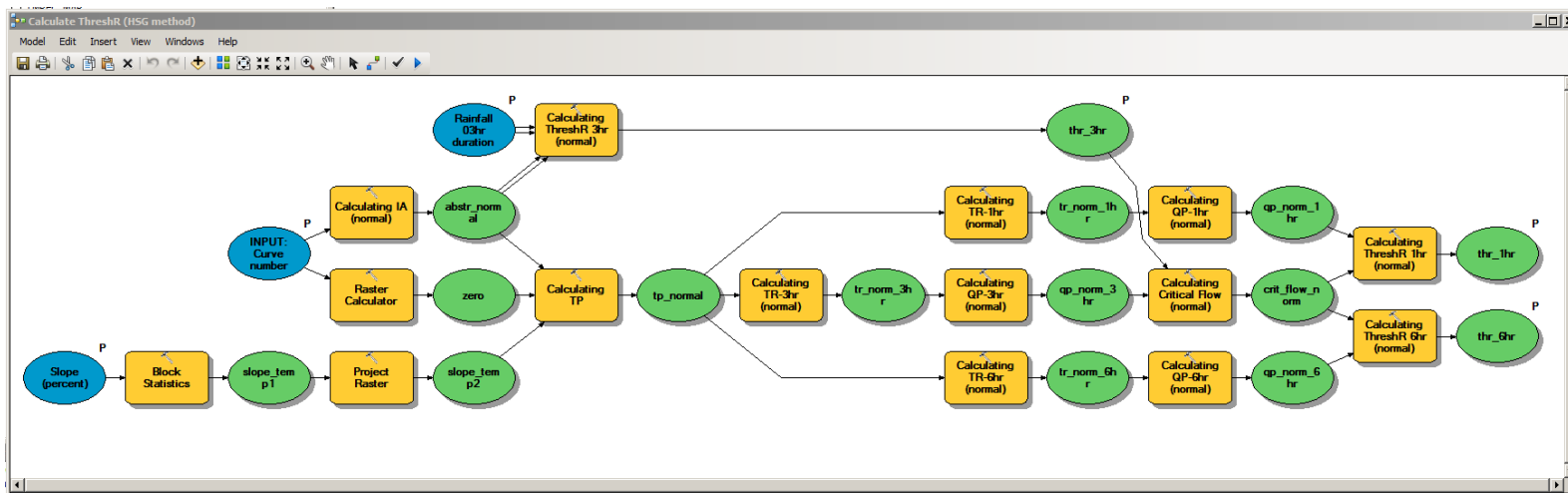

Figure 14. ArcGIS model used to create rasters of threshold runoff from curve number, slope, and rainfall frequency (design storm) rasters. This illustrates the steps which were ultimately automated by Python scripts.

2.6 Preparing threshold runoff raster for AWIPS

The files required by GFFG in AWIPS must be in "XMRGLike" format. Utilities exist on AWIPS as part of the RDHM product suite which can convert files to and from the XMRGLike format. These utilities require files in ASCII format which also must be in a specific HRAP-like projection. Several intermediate steps are required to get files from the native projection, file format, and resolution produced by the ArcGIS tools to the format required by the utilities.

1. Data gaps in the final ThreshR grid are filled using areal averages. Focal statistics using the 0.10 x 0.10 degree mean are calculated and then mosaicked with the original TheshR grid such that NoData values become the areal average value and areas with data are not changed.
2. The ThreshR grid is averaged by each HRAP grid pixel using Zonal Statistics. This requires a shapefile of HRAP polygons for the RFC that is updating their GFFG.
3. The HRAP-averaged ThreshR grid is then projected to a custom projection called "HRAP Stereographic North Pole" provided by Brian Cosgrove and Gene Derner.
4. The projected ThreshR grid finally converted to ASCII format using "Raster to ASCII."
5. The resulting ASCII file is transferred to AWIPS and converted to XMRGLike using the "asctoxmrglike" utility with the "ster" (stereographic) projection setting.

An ArcGIS "model" was created to simplify and automate these processing steps (Figure 15).
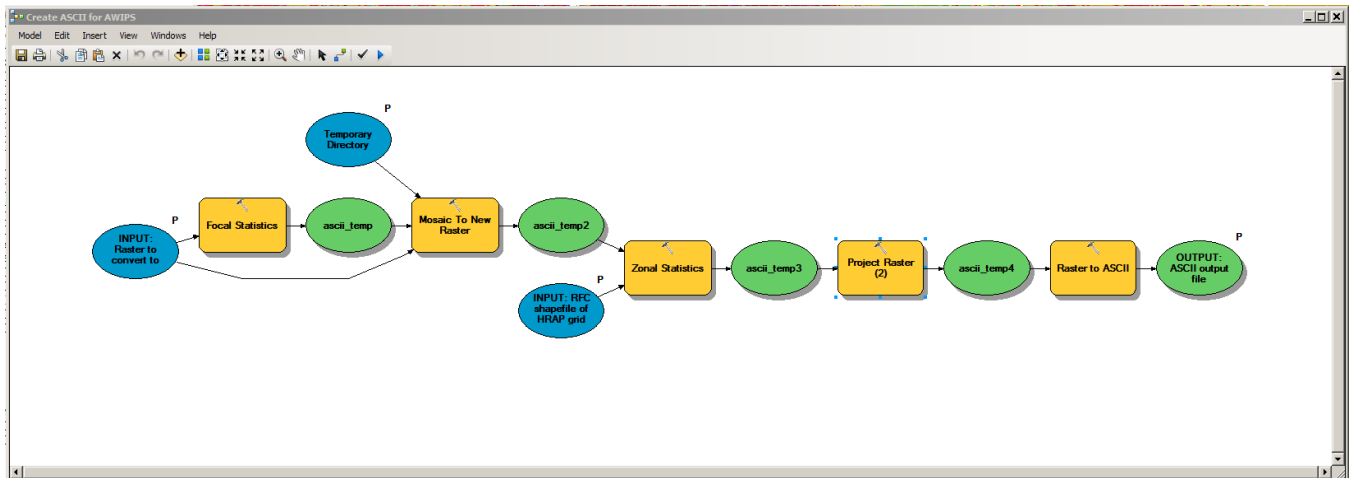

Figure 15. ArcGIS model used to create ASCII files of threshold runoff from ArcGIS rasters. The ASCII files can then be converted to XMRGLike in AWIPS. This illustrates the steps which were ultimately automated by Python scripts.

To complete the updating of GFFG, AWIPS also requires several additional files beyond just the 1-hr, 3-hr, and 6-hr threshold runoff. Table 4 lists the required files and their descriptions. These files are converted to ASCII using the same steps mentioned above for ThreshR.

Table 4. Required files for GFFG in AWIPS.

File Name	Description
cn_norms.xmrg	Curve number under "normal" conditions. That is, the default curve number before adjustments are made for wet antecedent conditions or dry antecedent conditions.
1hrqp.xmrg	1-hr peak flow
3hrqp.xmrg	3-hr peak flow
6hrqp.xmrg	6-hr peak flow
12hrqp.xmrg	12-hr peak flow *Note: The scripts documented here do not create 12-hr GFFG so, if required, these grids would be a copy of the 6-hr values*
24hrqp.xmrg	24-hr peak flow *Note: The scripts documented here do not create 24-hr GFFG so, if required, these grids would be a copy of the 6-hr values*
1hrtr.xmrg	1-hr time of rise (in hours).
qs.xmrg	Critical flow (in cfs).
1hrthreshr.xmrg	1-hr threshold runoff. Calculated indirectly from 3-hr threshold runoff.
3hrthreshr.xmrg	3-hr threshold runoff.
6hrthreshr.xmrg	6-hr threshold runoff. Calculated indirectly from 3-hr threshold runoff.
12hrthreshr.xmrg	12-hr threshold runoff. *Note: The scripts documented here do not create 12-hr GFFG so, if required, these grids would be a copy of the 6-hr values*
24hrthreshr.xmrg	24-hr threshold runoff. *Note: The scripts documented here do not create 24-hr GFFG so, if required, these grids would be a copy of the 6-hr values*

3.0 Semi-Automation of the GFFG File Creation Process

Section 2 outlines the process of creating the grids required by GFFG in ArcGIS raster format. These rasters must then be converted to ASCII format, transferred to AWIPS, and then converted to XMRGLike. To further automate this process and reduce processing time, the individual ArcGIS "models" described in previous sections were converted to python scripts and combined into a single script. This combined script was developed such that it would be tied in to an ArcGIS toolbox and run from within the program (as opposed to stand alone). This allows the user to prepare all of the required files and then immediately run the GFFG creation process.

This section outlines the entire process start-to-finish.

3.1 Automatic creation of GFFG files in ArcGIS raster format

Although the python scripted method removes some intermediary steps indicated in the previous sections and automates many of the other steps, the user must still manually prepare some of the required data. The input files that must be prepared manually are slope, rainfall frequency, land cover, and soil survey data (Table 5).

Table 5. Required input and data files for the python script which creates curve number, critical flow, time of rise, and threshold runoff rasters for GFFG in AWIPS.

Name	Units	Description
Temp Directory	-	A location to store temporary files produced by the python script. A good location is usually "C:\Temp"
Cell Size/Processing Resolution	Degrees	The processing resolution for the intermediate steps in GFFG input file creation. A smaller value may improve the final results, but will drastically increase processing time. A good default is "0.01".
Hydrologic Soil Group (HSG) Shapefile	-	Polygon shapefile containing the predominant hydrologic soil group in one of the fields of the attribute table. This file is created in section 2.1 Retrieving and Preparing Soil Data. Acceptable values are A, B, C, D, A/D, B/D, and C/D. For "HSG field" you must select the field from the shapefile that contains the predominant hydrological soil group of the features.
Land Cover	-	Raster indicating the predominant land cover classification based upon the format used by the 2011 USGS update. This file is discussed in section 2.2 Retrieving Land Cover Data. Acceptable values are integers from 0 to 99.
Slope	Percent (%)	Raster indicating the DEM slope in percent. Acceptable values are decimal of 0.0 and above. Resolution is assumed to be 30-meter.
3-hr Rainfall ARI/AEP	Inches (in)	Raster indicating the rainfall frequency data for a 3-hr duration storm to use for creating the threshold runoff. This creates the "baseline case" equivalent to the onset of flash flooding. Default value is the 20% AEP/5-yr ARI event (see section 2.3 Retrieving Rainfall Frequency Data), but could theoretically be changed across the domain or even basin-by-basin.

After indicating the location of the required input files and setting the output file names, the user is able to start the script from within ArcGIS (Figure 16). This script takes approximately 20-30 minutes to complete. Output files from this script can then be reviewed before conversion to ASCII for the transfer to AWIPS.
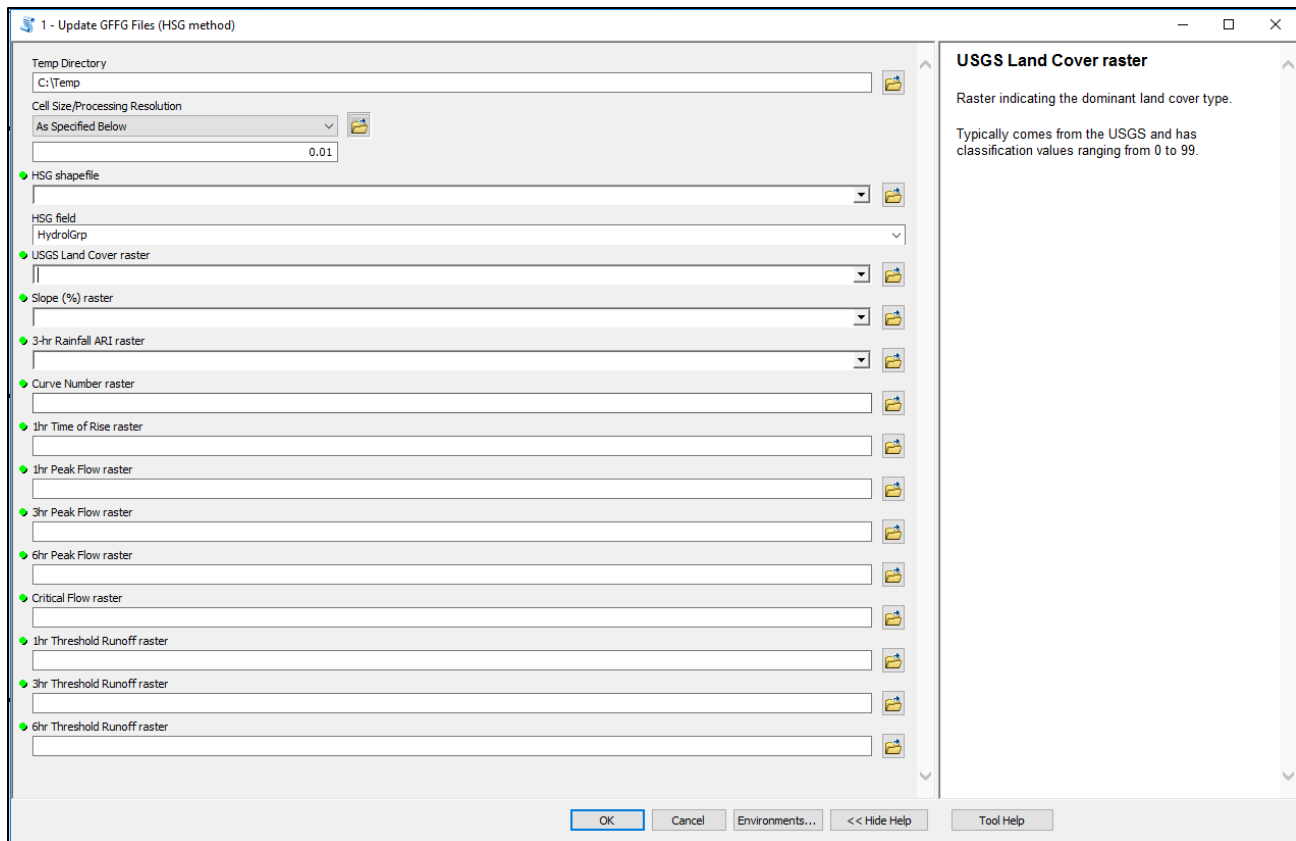
Figure 16. The data entry interface for the automatic creation of GFFG files via python script. Guidance on each input/output layer is provided on the right.

3.2 Conversion of GFFG files to ASCII

To prepare the output rasters for AWIPS and conversion to XMRGLike, they must be converted to ASCII format. A python script was created that could be tied to the ArcGIS toolbox which completes the necessary conversion steps. First, the raster values are averaged by HRAP pixel, then the data is projected to North Pole Stereographic projection, the data is mosaicked with a mask raster, and finally the resulting data is converted to ASCII. The required input files for this process are the raster file to convert, an HRAP grid shapefile, and a raster mask file (Table 6).

> NOTE: The data masking was a feature added after the original creation of the tool in ArcGIS Model Builder (section 2.6 Preparing threshold runoff raster for AWIPS). This step became required after initial testing of the new GFFG files in AWIPS. See section "3.2.1 Creation of a Raster Mask File" for more details.

Table 6. Required input and data files for the python script which converts raster to ASCII for GFFG in AWIPS.

Name	Units	Description
Temp directory	-	A location to store temporary files produced by the python script. A good location is usually "C:\Temp"
Raster File to Convert	-	A raster file representing a GFFG input file which needs to be converted to ASCII before subsequent conversion to XMRGLike
HRAP Grid Shapefile	-	A polygon shapefile of HRAP pixels covering the RFC. Must at least extend to, or just beyond, the RFC boundary
Raster Mask File	-	A raster file indicating which pixels should have data and which pixels should "have data" specifically indicated as NoData. This file makes sure that the extent of each ASCII file is consistent; failure to have consistent input files results in a GFFG crash (see "3.2.1 Creation of a Raster Mask File" for more details)

After indicating the location of the required input files and setting the output file names, the user is able to start the script from within ArcGIS (Figure 17). Instead of converting each file separately, it is recommended that the user right-click on the script in the tool box and run in batch. Each raster created from the previous sub-section can then be converted to ASCII all at once. Following the conversion, the ASCII files should be transferred to the AWIPS system.
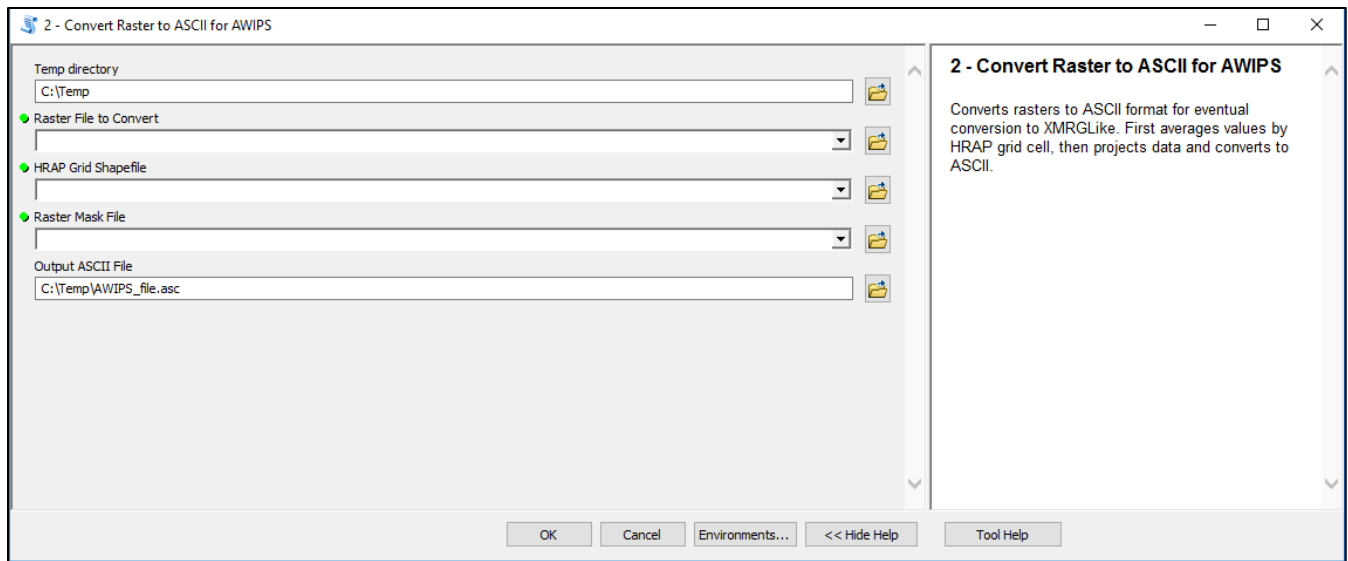
Figure 17. The data entry interface for the automatic conversion of GFFG input files to ASCII files via python script. Guidance on each input/output layer is provided on the right.

3.2.1 Creation of a Raster Mask File

The input data for GFFG in AWIPS must be averaged by HRAP pixel and then projected to the hybrid stereographic projection (similar to HRAP) for use in AWIPS by GFFG. The input data must also have the extent clipped, and/or extended, to specifically match the extent defined in the RFC's Apps Defaults. Cells with actual data (as opposed to cells with "data" that is labeled is indicated "NoData") must also match exactly between each of the input rasters. This is why a raster mask file is required. This step was found to be necessary after initial testing of the new GFFG files in AWIPS.

In this raster mask, areas where you desire data should be indicated by the value "1" and areas of NoData should be indicated by the value "-1" (Figure 18). A conditional argument in ArcPy uses these flags to clip and/or extend the data when making the ASCII files such that it meets the requirements of GFFG. One way to develop this mask file rather easily would be to take an existing GFFG data grid from AWIPS, convert to ASCII, and transfer to the windows environment. Using the Reclassify function in ArcGIS, set all cells with "NoData" or "-1" to "-1", and all other values to "1". Store this resulting raster with your other development files so it can be used as a mask later.
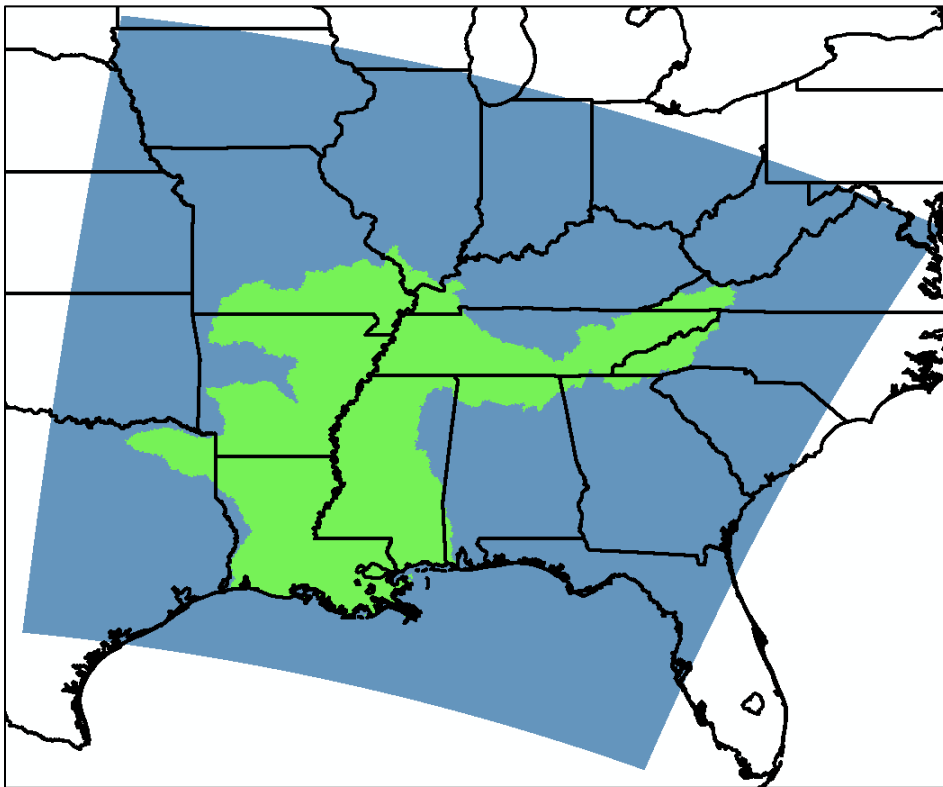

Figure 18. Example of a raster mask used to specify which pixels are "data" and which pixels are "NoData" for creation of the ASCII files.

3.3 Conversion of ASCII files to XMRGLike

For use by GFFG, the required files must be converted to XMRGLike format. The easiest way to accomplish this is to use the conversion utilities included in the DHM-TF package, an add-on to RDHM. The "asctoxmrglike" tool inside of the /rdhm32/bin/ folder of the DHM-TF package is used for the ASCII to XMRGLike conversion. The ASCII files must be in either HRAP or North Pole Stereographic coordinate systems for the conversion to be successful; the python script in the previous section uses North Pole Stereographic. Output is an XMRGLike file compressed into a GZ file.

The usage format for asctoxmrglike is:
```
asctoxmrglike <input file> <output file> <ster|HRAP>
```

Place the ASCII files from the previous step into same directory as the script. Example usage is:
```
asctoxmrglike curve_number.asc curve_number.xmrg ster
```

Then use "gunzip" on the output file to extract the XMRGLike file, which can then be used for GFFG.

3.4 Creation of Forced GFFG Override File

Although not necessary for the creating/updating of GFFG files, a python script is also available which aids in the creation of GFFG override files. A GFFG override file is utilized in AWIPS to force the resulting GFFG values to a set number, regardless of output from the GFFG program. This override file may be useful in situations where wildfires have drastically changed the rainfall required for flash flooding or in other unique hydrologic situations, but caution must be used. Because this override file is providing a *set value* instead of a *maximum* value, during times of recent rainfall which has drastically increased soil moisture and filled modeled channel capacities, neighboring HRAP pixels may actually have lower GFFG values than the target area. In many situations, this situation may be undesirable and cause unintended results, as such, use caution in implementation.

First, the polygons are converted to raster than then averaged by HRAP pixel, then the HRAP centroids shapefile is used to extract the HRAP-averaged values into a table which is tied to the HRAP X and Y coordinates. The required input files for this process are the polygon shapefiles of 1-hr and 3-hr forced GFFG values, an HRAP grid shapefile, and a HRAP centroids shapefile (Table 7).

Table 7. Required input and data files for the python script which creates the forced GFFG override file.

Name	Units	Description
Temp directory	-	A location to store temporary files produced by the python script. A good location is usually "C:\Temp"
1hr Forced GFFG Shapefile	Inches	A polygon shapefile delineating the area where 1-hr forced GFFG values should be applied. For "1hr Forced GFFG value field" you must select the field from the shapefile that contains forced GFFG values.
3hr Forced GFFG Shapefile	Inches	A polygon shapefile delineating the area where 3-hr forced GFFG values should be applied. For "3hr Forced GFFG value field" you must select the field from the shapefile that contains forced GFFG values.
HRAP Grid Shapefile	-	A polygon shapefile of HRAP pixels covering the RFC. Must at least cover the area where forced GFFG overrides are being applied.
HRAP Centroids Shapefile	-	A point shapefile of HRAP centroids covering the RFC. Must at least cover the area where forced GFFG overrides are being applied. This file must contain fields indicating the HRAP X and Y coordinates. This file can be retrieved from AHPS ("NWS All Points" shapefile). For "HRAPX field" and "HRAPY field" you must select the field containing the HRAP X and Y coordinates, respectively.

After indicating the location of the required input files and setting the output file name, the user is able to start the script from within ArcGIS (Figure 19). The resulting file should be sent to AWIPS to be utilized by GFFG.
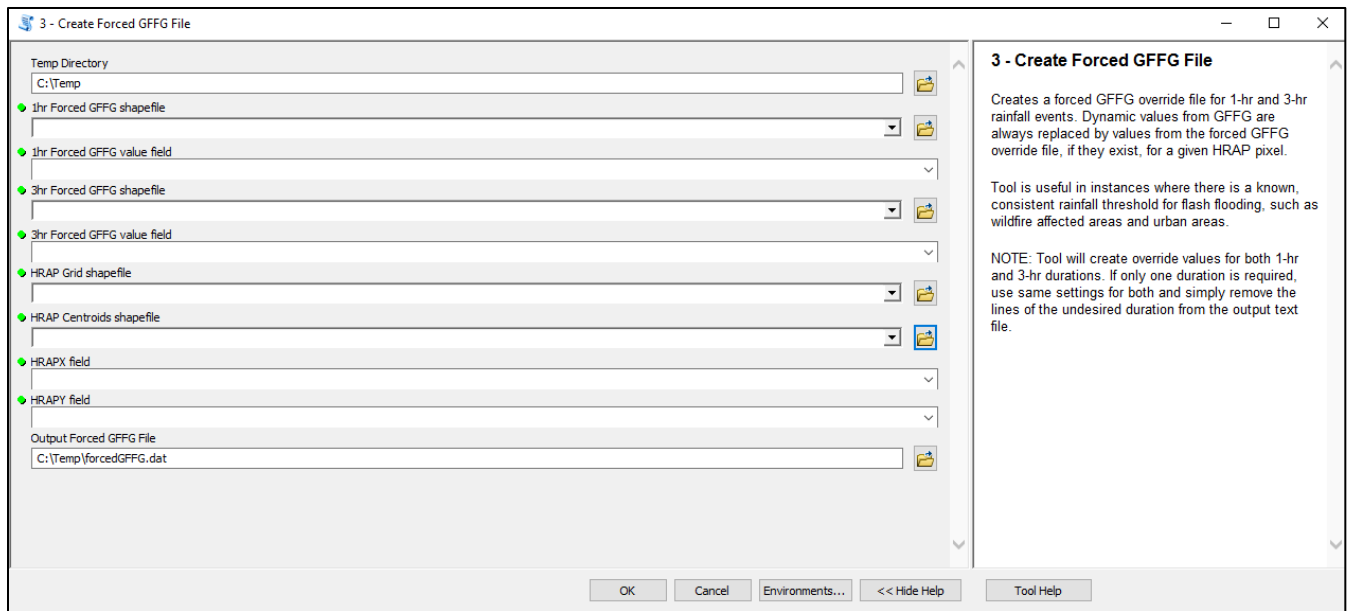
Figure 19. The data entry interface for the creation of a forced GFFG override file via python script. Guidance on each input/output layer is provided on the right.

4.0 Conclusions and Future Work

One limitation of the current technique used to create threshold runoff grids for gridded flash flood guidance is that soil runoff potential is lumped into only four groups (hydrologic soil group). This provides no means of differentiating runoff potential that differs within individual groups and may contribute to significant jumps between areas of different soil type. Because hydrologic soil group is closely tied to specific ranges of saturated hydraulic conductivity (K_{sat}) values, K_{sat} could hypothetically be used to determine curve number with more continuous values. Future work should evaluate the creation of curve number – and thus, threshold runoff – from K_{sat}.

Another limitation to current flash flood guidance techniques involves the assumption of a specific design storm (example: 5-yr, 3-hr rainfall) as the onset of flash flooding for all locations. Section 1.1.2 Rainfall Frequency provides further discussion on this assumption. One way to get around using a set ARI rainfall event for all areas would be to look at the frequency of flash flood reports for a given area and calculate the ARI of experiencing flash flood conditions. Rainfall ARIs used to calculate threshold runoff could then be changed on a watershed-by-watershed basis based upon how frequent flash flooding each for the local area. The Iowa Environmental Mesonet (IEM) at Iowa State University (ISU) maintains a GIS database of NWS flash flood local storm reports (LSRs; http://mesonet.agron.iastate.edu/request/gis/lsrs.phtml). Although caution would be advised due to the currently limited time frame of available reports (roughly 10 years as of this report), future work could evaluate methods of adjusting threshold runoff for GFFG based upon actual flash flood frequency. Metadata associated with these reports area prone to include errors, both spatial and temporal, so any analysis of flash flood report frequency should be used on a relative basis.

5.0 Acknowledgements

6.0 References

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Appendix A: Comparison of Legacy GFFG to Updated GFFG at LMRFC

Upon completion of the updated input data for GFFG at the LMRFC, a parallel run was set up so that the different versions could be compared before implementation. This parallel run was first completed at 1800 UTC 22 September, 2017. The GFFG run based upon updated parameters did show some differences when compared to the GFFG run based upon the original parameters (hereafter "legacy").

Looking at output from the 1800 UTC run of 22 September, 2017, differences were documented in the 1-hr GFFG (Figure 20). Most areas had at least slightly increased GFFG values, but the Appalachian Mountains had lowered values. The threshold runoff values (Figure 21) which are directly used to create the GFFG values were evaluated next; the pattern was the same. Curve number was evaluated next (Figure 22); increased values were noted in many areas, especially the Louisiana coast, with some decreased values noted in northern Arkansas and southern Missouri. Critical flow seemed to become more "noisy" in the updated values compared to legacy values (Figure 23), with lower critical flow in northern Arkansas and southern Missouri as well as the Appalachian Mountains. The values for 1-hr time of rise were also compared (Figure 24); updated values were also more "noisy" when compared to legacy values with an increase in time of rise noted in coastal Louisiana.

A number of factors may have contributed to changes in GFFG values as well as the components. Updated rainfall frequency data, land cover data, and soil texture data was used. Generally, land cover changes would be small in most areas except for near rapidly growing urban areas. Differences in rainfall frequency data with NOAA Atlas 14 compared to NOAA Technical Paper 40 may contribute to differences noted in critical flow data, and thus, threshold runoff. Differences in the calculation method for hydrologic soil group also may have contributed to differences in curve number.
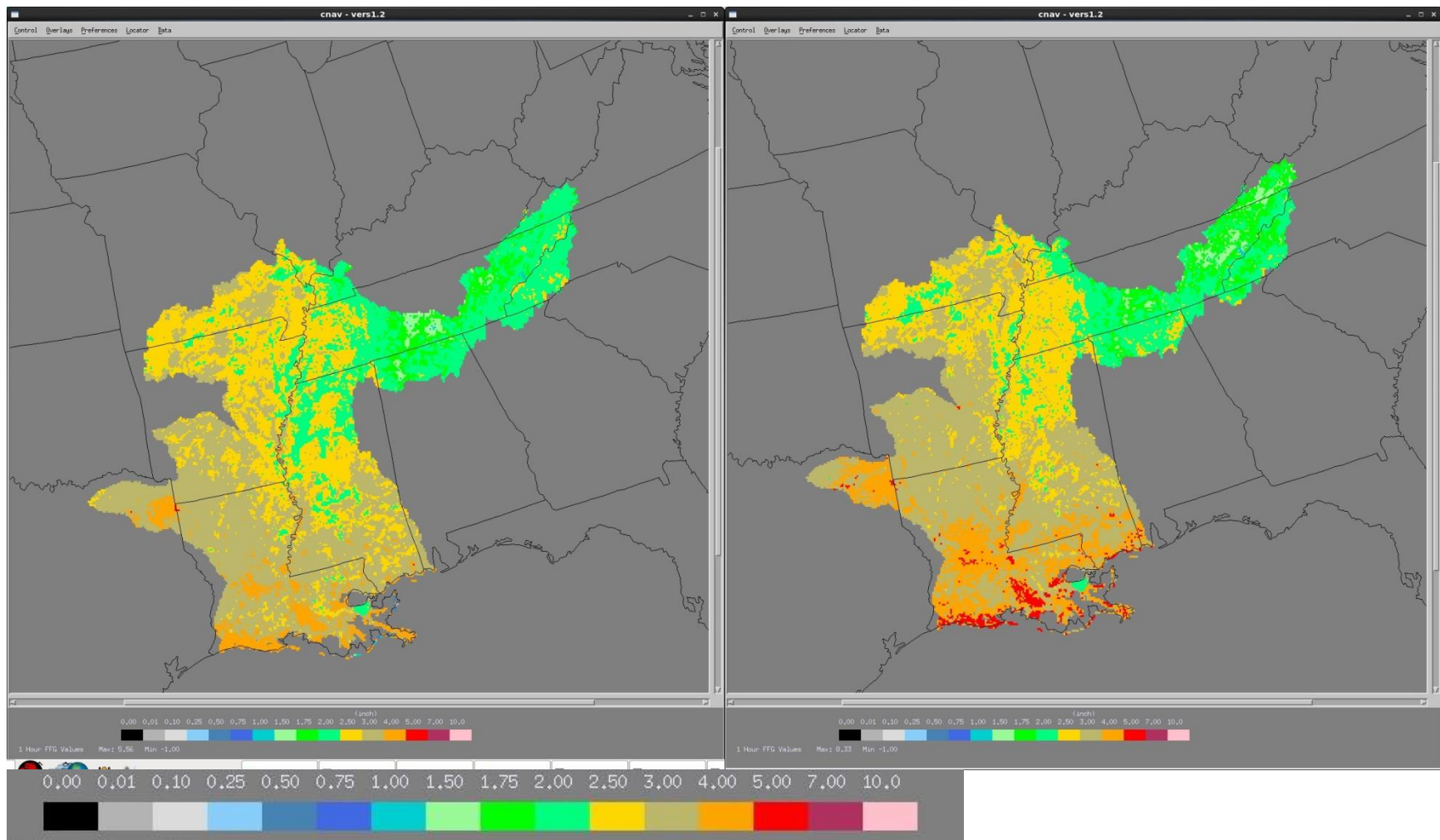
Figure 20. 1-hr GFFG values (in inches) for the legacy run (left) and the updated run (right).
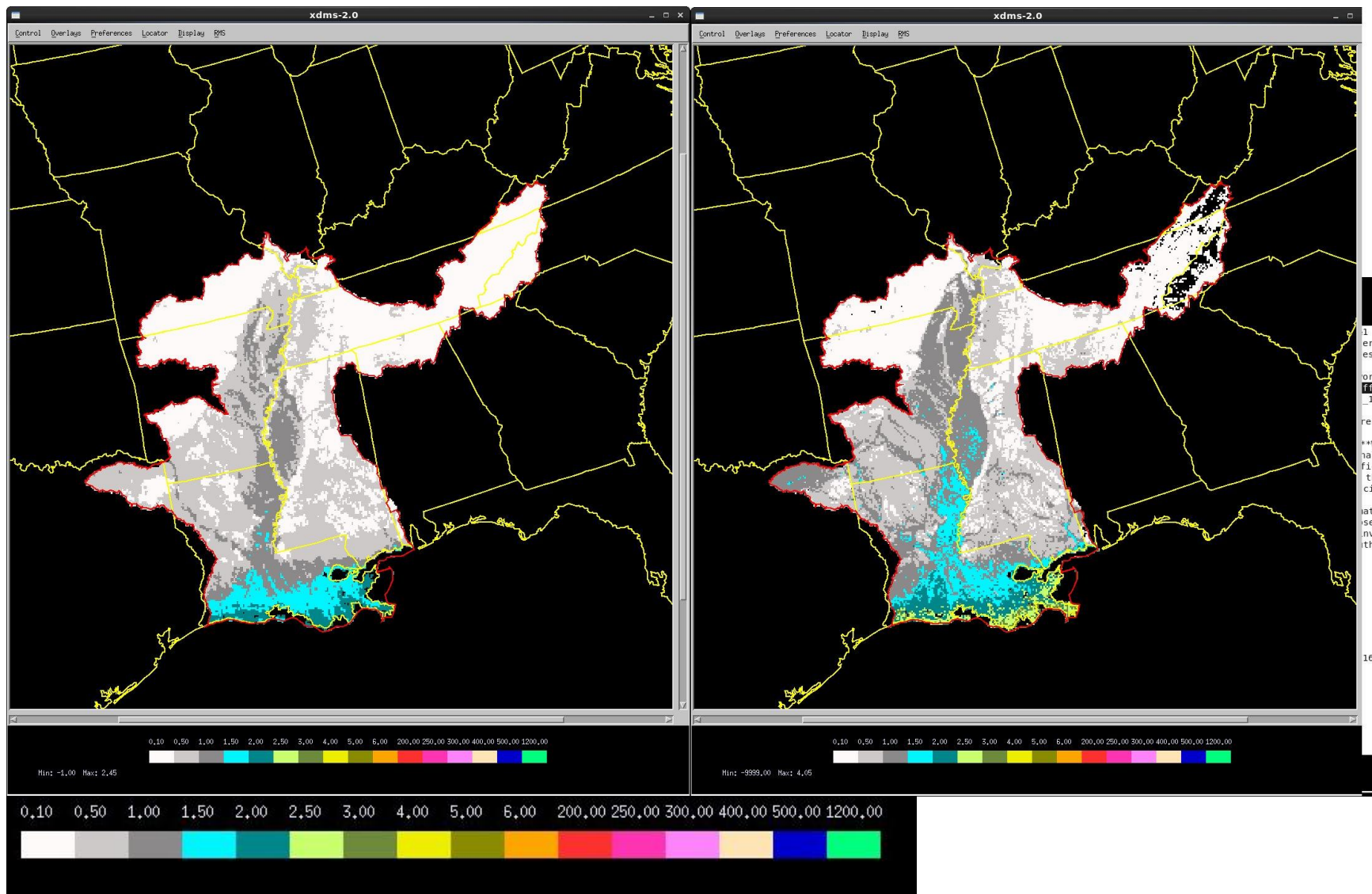
Figure 21. 1-hr threshold runoff values (in inches) for the legacy run (left) and the updated run (right).
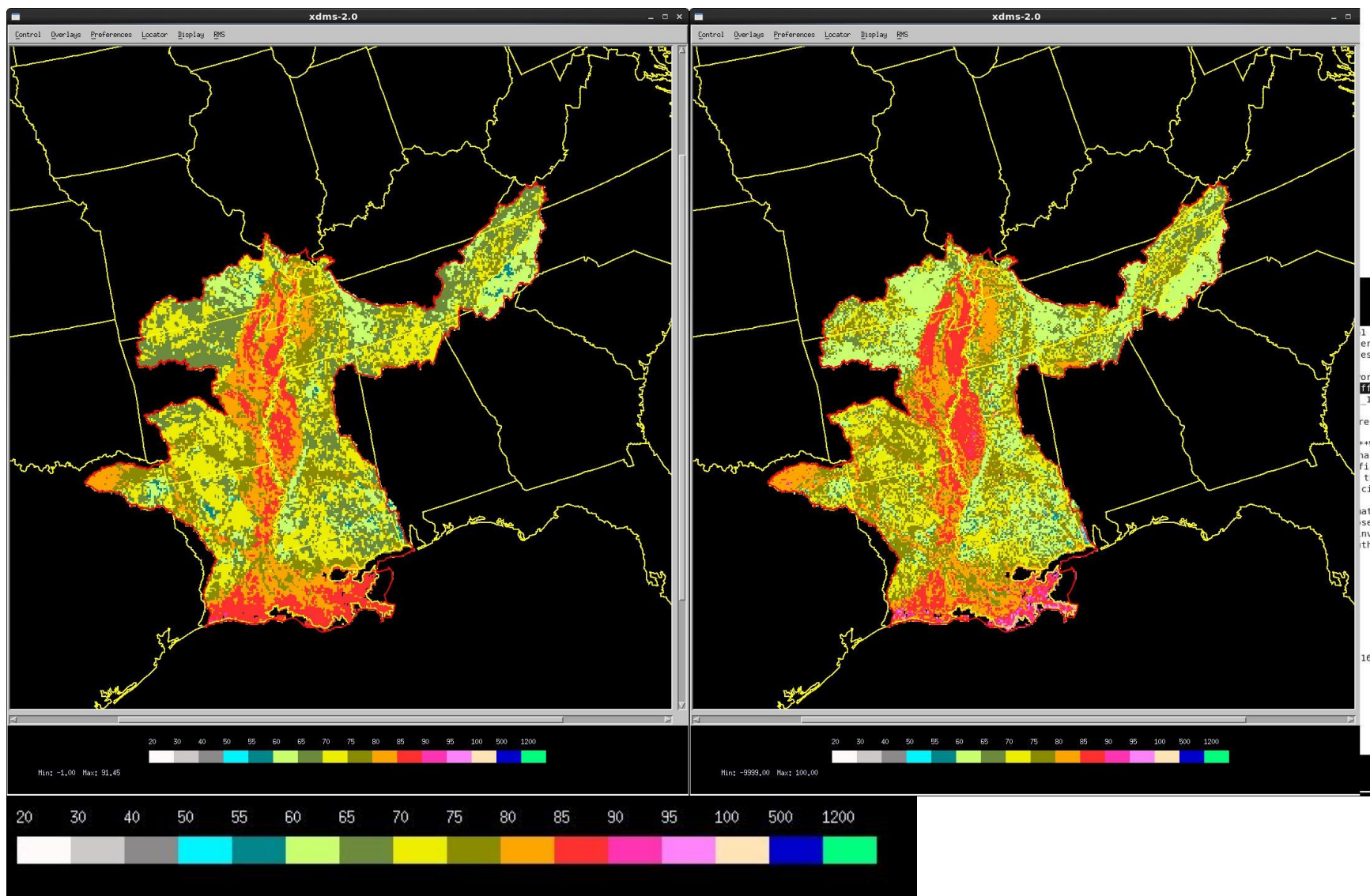
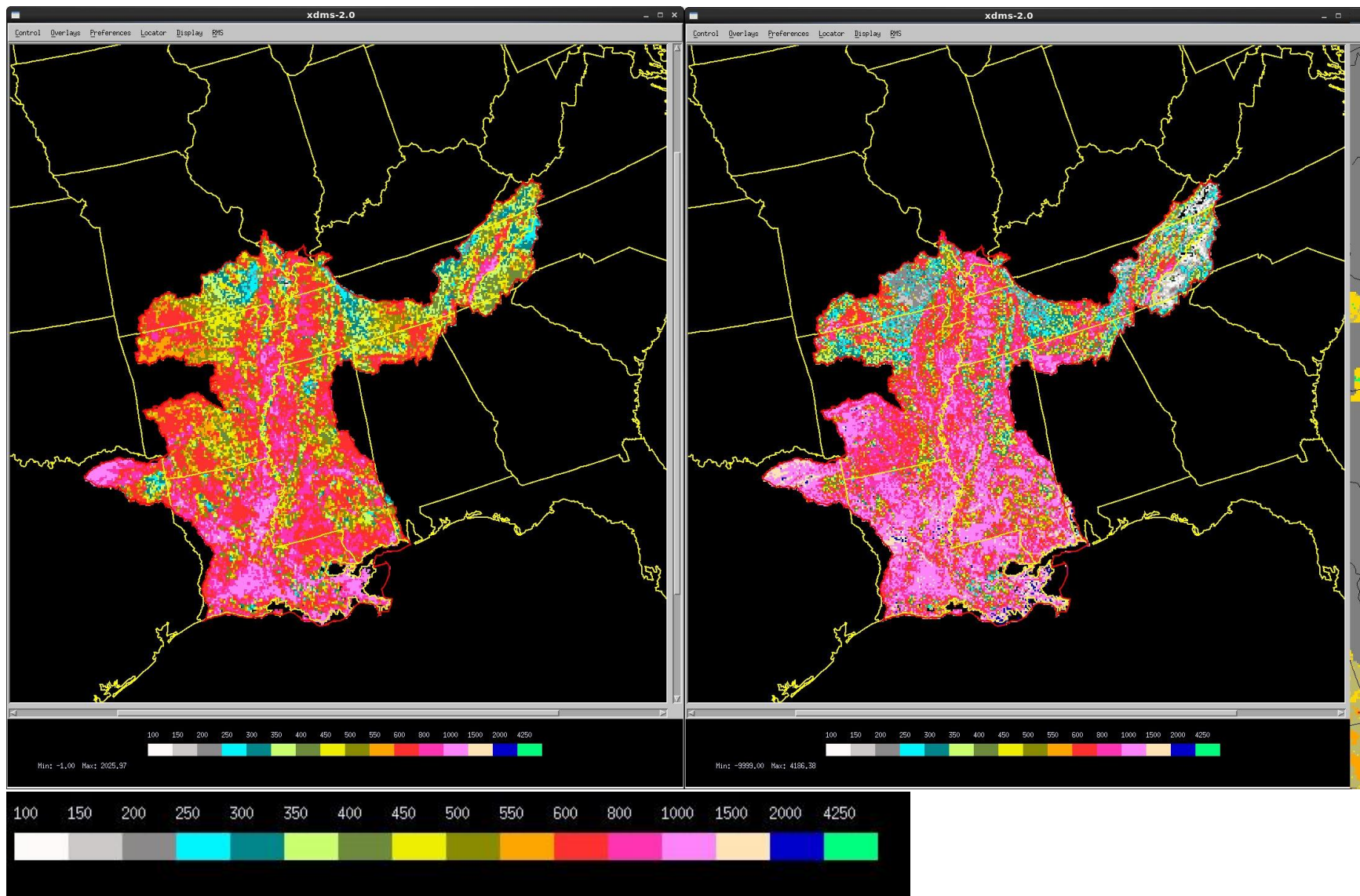Figure 22. Curve number values for the legacy run (left) and the updated run (right).

Figure 23. Critical flow values (in cfs) for the legacy run (left) and the updated run (right).
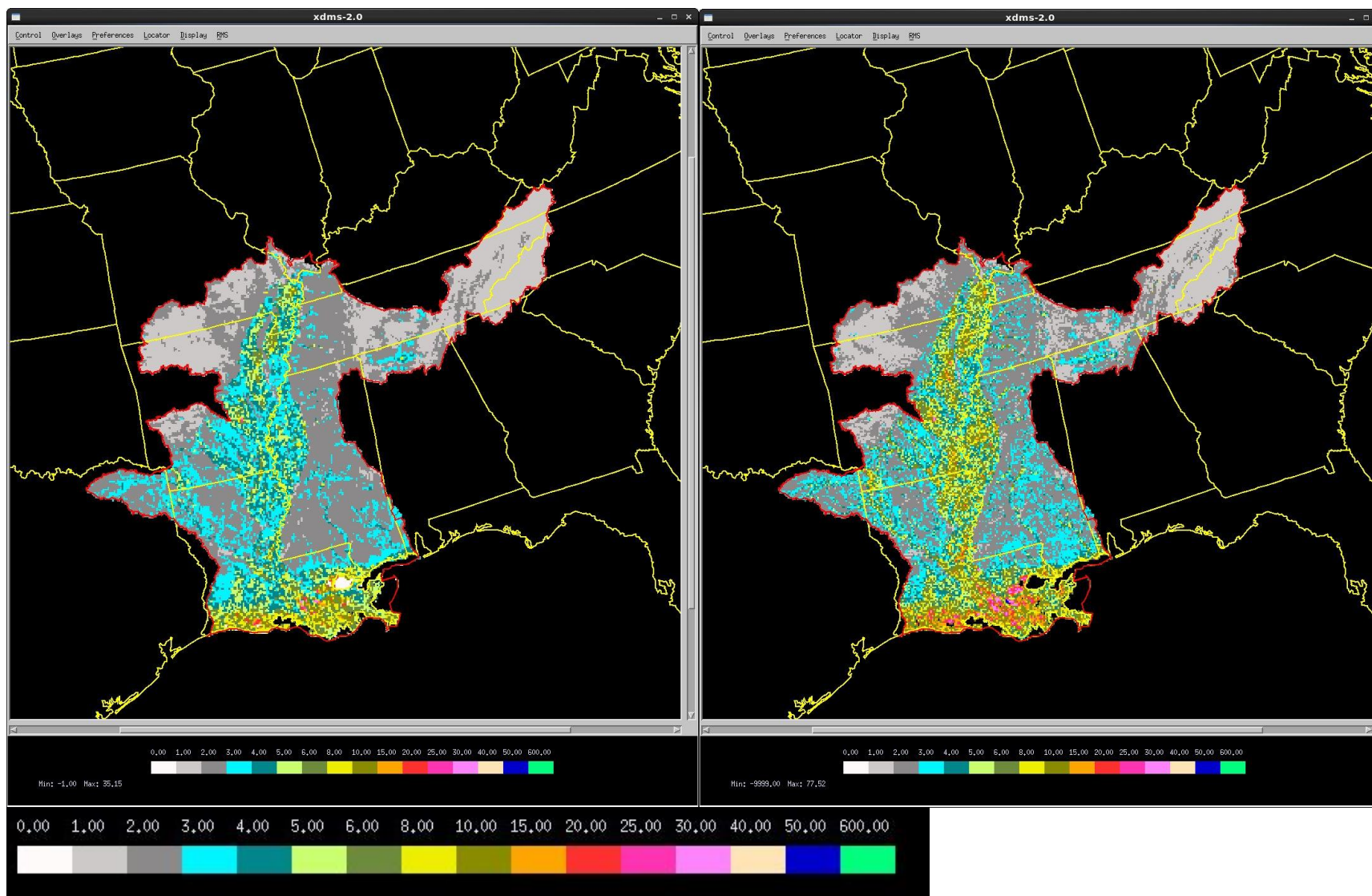
Figure 24. 1-hr time of rise values (in hours) for the legacy run (left) and the updated run (right).