AECOM

PRELIMINARY

Mecklenburg County Floodplain Mapping 2008

Sugar/Irwin Sub-Basin Hydrology Report

6/24/2011

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Updated 3/20/2012
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Section 1 Watershed Description

1.1 Watershed Location

The Sugar/Irwin watershed is part of the Catawba River basin and is located in the central area of the Blue Ridge/Piedmont hydrologic region of North Carolina. The sub-basin terrain is characterized by rolling hills with moderate relief and narrow, steep stream valleys in the northern portion and more level terrain in the south. Our study area drains mostly urban areas in the southern part of Mecklenburg County and contains the Blankmanship Branch, Steel Creek, and Sugar/Irwin sub-basins.

Figure 1. Sugar/Irwin River Watershed in Mecklenburg County

The study area of the Sugar/Irwin Watershed contains 61 miles of detailed study FEMA streams with 146 hydraulic structures. The study limits are summarized below in Table 1.

1.2 Hydrologic Subdivision of Watershed

The target sub-basin size for this study was determined by the county to be 60 acres. The intent was to reflect more localized hydrologic patterns in the headwaters of the streams to be studied. The overall average size of a sub-basin is 60 acres. This includes the larger main reach basins and basins located outside of the county that drain into the county. The headwaters are well represented with the smaller basin size. Figure 2 shows the sub-basins as delineated.

Table 1: Detailed Study Scope for Sugar/Irwin River Sub-basin

Stream Name	Downstream Limit	Upstream Limit	Length (mi.)
Blankmanship Branch	County Line	Approx. 100 feet upstream of Steele Creek Rd	0.7
Coffey Creek	Confluence with Sugar Creek	Approx. 0.7 miles upstream of West Blvd	6.3
Irwin Creek	Confluence with Stewart Creek	Approx. 0.9 miles upstream of Nevin Rd	10.7
Irwin Creek Trib 1	Confluence with Irwin Creek	Approx. 840 feet upstream of Pressley Rd Access Extension	0.8
Kennedy Branch	Confluence with Irwin Creek	Approx. 215 feet upstream of Slater Road	2.1
Kings Branch	Confluence with Sugar Creek	Approx. 300 feet upstream of I-485	4.4
McCullough Creek	Confluence with Sugar Creek	Approx. 415 feet upstream of Nations Ford Road	1.4
Polk Ditch	Confluence with Walker Branch	Approx. 300 feet upstream of S Tryon St	1.4
Steele Creek	County Line	Approx. 170 feet upstream of Brown Grier Rd	4.5
Stewart Creek	Confluence with Irwin Creek	Approx. 665 feet upstream of Capps Hill Mine Rd	5.3
Stewart Creek Trib 1	Confluence with Stewart Creek	Approx. 1,550 feet upstream of Berryhill Rd.	0.8
Stewart Creek Trib 2	Confluence with Stewart Creek	Approx. 275 feet upstream of I-85	1.6
Stewart Creek Trib 3	Confluence with Stewart Creek	Approx. 2,065 feet upstream of Hoskins Road	1.1
Sugar Creek	County Line	Confluence of Irwin and Taggart Creeks	12.1
Taggart Creek	Confluence with Sugar Creek	Approx. 445 feet upstream of Denver Ave	3.5
Walker Branch	Confluence with Steele Creek	Approx. 1,625 feet upstream of S Tryon St	2.2
Walker Branch Trib	Confluence with Walker Branch	Approx. 370 feet upstream of Steele Creek Road	0.8

Basin delineations and drainage areas were determined using a 10' x 10' grid size digital elevation model (DEM) generated from the Light Detection and Ranging (LIDAR) data collected by the county. Drainage areas from the current effective study were determined using a 50' x 50' grid cell so there may be some differences when compared directly. The effective study was also based on larger scale sub-basins with a typical size between 150 – 200 acres.

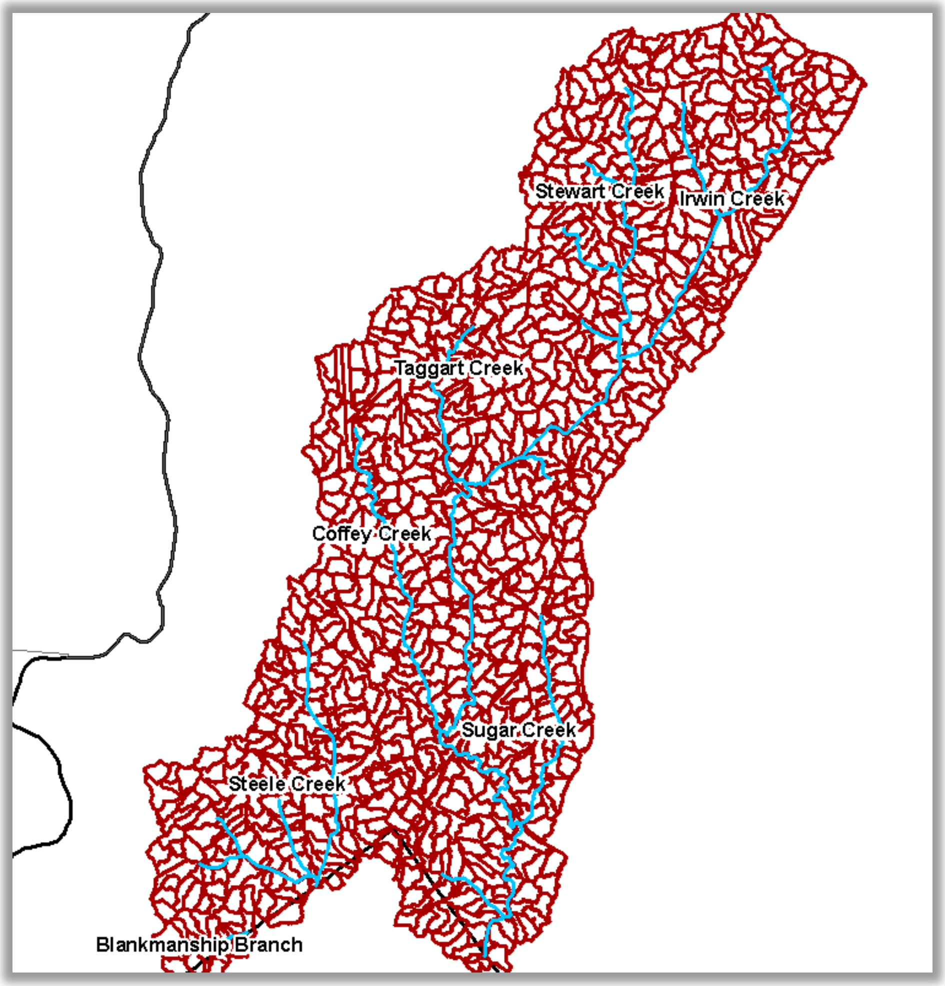


Figure 2. Sugar/Irwin Sub-Basins

1.3 Soils

Soils in the Sugar/Irwin Watershed fall in the central area of the Blue Ridge/Piedmont hydrologic region of North Carolina. These soils are predominately Cecil Sandy Clay Loams and are classified as Hydrologic Soil Group (HSG) B. The Cecil soils make up approximately 60% of the total watershed area.

Other soils located in the Sugar/Irwin watershed in Mecklenburg County are the Enon Sandy Loam (En Series), Monocam Loam (MO series), Vance Sandy Loam (Va series), all HSG-C soils. There are also areas of Wilkes soil (Wk series), which belongs to HSG-D.

1.4 Land Use

Land use is often used in floodplain analysis as an indicator of the percent imperviousness of a watershed, which has a significant effect on subsequent surface runoff and associated hydrologic peak flow calculations. The Mecklenburg County Effective Flood Insurance Rate Maps (FIRMs) include floodplain mapping based on both existing and future land use conditions. The existing and future land use layers were used within land use and soil type lookup tables (provided by CMSWS) to develop curve number calculations for hydrologic modeling.

The existing land use layer was obtained from the CMSWS. This layer was used as the base layer and it was reviewed and modified using the most recent aerial photography. Any discrepancies were brought to the attention of CMSWS to resolve. A task force will also be involved in the QA/QC of the land use data. Please see the Floodplain Analysis and Mapping Standards Guidance Document (FAMSGD) for more detail.

The future land use layer was obtained from CMSWS for the City of Charlotte ETJ. The town of Pineville submitted separate future land use files. The separate future files were manipulated and then translated into one seamless layer in order to have the same attributes as the existing land use layer. The future layer was then modified and verified using a similar process as the existing layer. Please see the Floodplain Analysis and Mapping Standards Guidance Document (FAMSGD) for more detail. A detailed description of the fields in the existing and future land use layers is presented in Table 2.

The southern part of the Sugar/Irwin watershed drains some areas in York and Lancaster Counties in South Carolina. As such, existing land use data was created using aerial data provided by Mecklenburg County. Zoning data from these counties were used as a basis for the future land use file. This data was translated to mimic the Mecklenburg County future land use file.

Section 2 Data Used in Analysis

2.1 Mecklenburg County GIS Data

Topographic data was furnished by Mecklenburg County in the form of LIDAR .las files. This data was used in boundary delineation, stream line editing, digital cross section generation, and delineation of the time-of-concentration flow paths. Planimetric data, including streets, streams, and a jurisdictional layer was also furnished by the county.

The storm drainage infrastructure inventory was obtained from archives of the effective study. This file was reviewed and QC'd by the county in the field and each structure survey was verified. If it was not verified in the field, it was flagged for a new survey. The 'new' surveyed structures were merged with the approved effective structure data and a new infrastructure inventory file was created.

The aerial photography was the 2009 leaf-off imagery provided by CMSWS.

2.2 SCS Soil Data

Soils information was obtained from the Mecklenburg County Soil Survey (US Department of Agriculture, October, 1975). This information was intersected with the basin and land use files, and then the look-up tables were applied to get a composite curve number for each sub-basin.

2.3 Rainfall Data

Intensity-Duration-Frequency (IDF) information presented in the Charlotte-Mecklenburg Storm Water Design Manual (CMSWDM) (dated 1993) specifies precipitation depths to be used for the various design storm events (e.g. 2- through 100-year storms) and patterns. The rainfall depths presented in CMSWDM were compared with results of a recent United States Geological Survey (USGS) precipitation study (SIR 2006-5017) prepared in 2006.

Table 2: Field descriptions for Existing and Future Land Use Layers		
	Existing Land Use Layer	**Future Land Use Layer**
Field name	**Field Description**	**Field Description**
FID	Field created by ArcGIS to provide a unique ID for each row in the table	Field created by ArcGIS to provide a unique ID for each row in the table
Shape	Field created by ArcGIS that indicates the type of geometry (i.e. Polygon)	Field created by ArcGIS that indicates the type of geometry (i.e. Polygon)
ObjectID	Field created by ArcGIS to provide a unique ID for each row in the table	Field created by ArcGIS to provide a unique ID for each row in the table
ACRES	Area of polygon	Area of polygon
LU_CODE	Number assigned based on 12 land use categories	Number assigned based on 12 land use categories
LU_DESC	Land use description (i.e. WOODS/BRUSH, etc)	Land use description (i.e. WOODS/BRUSH, etc)
LU_SOURCE	Source of land use description (i.e. TASKFORCE, etc)	Source for land use description (i.e. TASKFORCE, etc)
DATE_CRRNT	Contains the most recent date that the LU_DESC was edited.	Contains the most recent date that the LU_DESC was edited.
NOTES	Notes were inserted into the field if applicable.	Notes were inserted into the field if applicable.
PERCIMP	EXISTING percent of a catchment area that is made up of impervious surfaces such as roads, roofs, etc. (i.e. Transportation has 80% impervious area)	EXISTING percent of a catchment area that is made up of impervious surfaces such as roads, roofs, etc. (i.e. Transportation has 80% impervious area)
NOTES2	N/A	Notes were inserted into the field if applicable. NOTES2 was added if additional space was needed
PAST_DESC	N/A	Original Land Use description before translation, preserved for reference.
CRRNT_DESC	N/A	One of the twelve land use descriptions assigned after translation
Futr_Imper	N/A	FUTURE percent of a catchment area which is made up of impervious surfaces such as roads, roofs, etc. (i.e. Transportation has 80% impervious area)
ChngInImpe	N/A	Change in percent impervious area from Existing to Future Land Use

The USGS study developed several independent families of IDF curves based on different precipitation gage networks and data samples. Based on a comparison and evaluation of precipitation depth sources and recommendations in the USGS publication, it was deemed that the 24-hour precipitation depths from the combined "NOAA dataset plus aggregated USGS site representing the "CRN initial dataset" family with no areal reduction factors (presented in Table 3), hereafter referred to as the "combined" dataset, should be used for the Floodplain Mapping Project.

Table 3. Precipitation Depths for the Floodplain Mapping Project	
Storm Event	Precipitation Depth (inches)
50%	3.06
20%	4.08
10%	4.80
4%	5.76
2%	6.51
1%	7.29
0.2%	9.23
1/3 PMP	13.5

NOTES: Precipitation values taken from combined "NOAA dataset plus aggregated USGS site" IDF presented in SIR 2006-5017

The USGS combined precipitation depths are slightly higher in the 100-year storm, but equal to or slightly lower in the smaller (higher frequency) storms, than those presented in the CMSWDM for a 24-hour storm duration. The 1/3 Probable Maximum Precipitation (PMP) depth of 13.5 inches was provided by the county and applied to the HEC-HMS models.

2.4 USGS Stream / Rainfall Gages

Mecklenburg County has an extensive collection of USGS gages in and around the county. Rainfall data in 5 minute increments was requested from 14 rain gages that impact the Sugar/Irwin watershed. Data was received for the following storms:

August 28, 1995
July 24, 1997
August 27, 2008
July 27, 2009

The July 2009 storm event produced precipitation totals between 1.08 and 2.97 inches. The 2-yr precipitation is 3.06 inches. From previous experience with rainfall totals this low it was determined that we would calibrate only to the August 27, 2008 storm. The August 1995 and July 1997 storms were used to compare our calibrated models after the fact. Those historical events were not used directly in the calibration process. Please see the calibration section for more detail.

From the County's extensive stream gage network, flow and stage data were requested from 9 USGS stream gages in our study area. Stream gage data in 15 minute increments were received for the same storms as mentioned above. The stream gage on Stewart Creek at Morehead did not report any data for any of the storms. The gage was brought online in 2000, after the 1995 and 1997 events and it simply did not report any discharges for the August 2008 event. The stream gage on Sugar Creek at Arrowood Road is a stage only gage. Therefore, the Sugar/Irwin watershed will use only 7 stream gages and 14 rain gages in its calibration routine, which is discussed in section 4 below.

2.5 Time of Concentration / Lag Time

Time of Concentration values were calculated using the method described in Chapter 3, Urban Hydrology for Small watersheds (Technical Release 55), Natural Resource Conservation Service (1986). The time of concentration is computed using sheet flow, shallow concentrated flow, and channel flow. A maximum flow length for sheet flow in urban areas is 100 feet and in rural areas is 300 feet.

Section 3 Description of Hydrologic Modeling

3.1 Model Used

The hydrologic modeling for the Sugar/Irwin Watershed in Mecklenburg County was performed using the USACE Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS), Version 3.40. Peak flood discharges with 50%, 20%, 10%, 4%, 2%, 1%, and 0.2% annual chance exceedance were modeled for this study.

Future Conditions Model: A future conditions HEC-HMS model will be created in a similar fashion as the existing conditions model. The only parameter adjustment in the initial creation of the future conditions model was the use of the future land use layer to calculate future conditions curve numbers. These curve numbers were used in the model to create full build-out of the watershed. The time of concentration and initial abstraction used in the future conditions were taken from the calibrated existing conditions model.

3.2 HEC-HMS Model Assumptions and Limitations

The HEC-HMS model is a mathematical representation of the hydrologic process and it is to be used to perform the computations for three basic functions;

- Compute losses and generate a runoff hydrograph;
- Combine hydrographs;
- Route hydrographs through channels, structures, ponds, and detention basins.

These functions are combined in a logical manner to model a particular watershed. In order to use the HEC-HMS model correctly and evaluate the results, it is important to understand the limitations of the models use and its underlying theoretical assumptions. The general assumptions and limitations of the HEC-HMS model are as follows:

- Stream flow routings use hydrologic routing methods and do not reflect the full Saint-Venant equations;
- Simulations are limited to a single storm event. The model does not have the capability of accounting for soil moisture storage or depletion between rainfall events, and;
- Storage facilities must be described with a single stage – discharge and stage – storage relationship.

The theoretical assumptions that govern the model's applicability to a specific watershed are as follows:

- The watershed can be represented as an interconnected group of catchment areas;
- The hydrologic process can be represented by the model parameters which reflect average conditions within a catchment area;
- Model parameters represent temporal and spatial averages;
- Rainfall and losses are uniformly distributed across the catchments per a weighted gage analysis, and;
- All runoff from a catchment area (sub-basin, basin, and watershed) eventually goes to the same outfall point.

Additional model assumptions specific to the Sugar/Irwin River Watershed in Mecklenburg County are:

- The modeling procedure used in this project followed the “SCS Methodology”. This terminology covers a wide range of procedures relating to rainfall and losses, runoff and hydrograph routing, and use of the SCS Unit Dimensionless Hydrograph to develop runoff hydrographs.
- The 24-hour Type II rainfall distribution was used for all design frequency simulations.

3.3 HEC-HMS Model Parameter Development

Rainfall Data: Rainfall depths for the 50%, 20%, 10%, 4%, 2%, 1%, and 0.2% annual chance exceedance storm events were obtained from the FAMSGD and are listed above in Table 2. These depths were converted by HMS into a Type II rainfall distribution that was used in the modeling.

Drainage Areas: Drainage basin boundaries for the Sugar/Irwin River Watershed in Mecklenburg County were delineated using a 10’ x 10’ grid size digital elevation model (DEM) generated from the LIDAR data collected and processed in 2008 and supplemented with data from LIDAR flown in 2004. From this hydrologically correct DEM, a total of 888 basins were delineated based on stream crossings, storm water inventory, and location in the watershed. The sub-basins averaged 61.2 acres in size and ranged from 1.3 acres to 241.8 acres. There are several large sub-basins over 150 acres and most of these are due to extreme circumstances. There are three quarries located in the study area, one each in the Stewart, Sugar, and McCullough watersheds. Each sub-basin was redrawn so the entire quarry fit into one sub-basin to eliminate the routing and simplify the time of concentration calculations. In the Coffey Creek watershed, the airport posed a similar problem. There was limited existing inventory data and with the new runway just operational last year, we were limited in how we could model through the property. In order to try and simplify the process and eliminate some estimation, we redrew larger sub-basins and manually calculated the time of concentrations and the routing reaches. Sub-basin boundaries were revised to reflect the presence of existing storm drainage infrastructure in instances when these drainage structures were not reflected in the LiDAR data. Each sub-basin was assigned a unique numeric identifier (see Figure 2).

Runoff Curve Numbers: A weighted runoff curve number was calculated for each sub-basin by using an intersection of soils data, land use data, and sub-basin boundary data. The intersection references a ‘look-up’ table of curve numbers for various soil and land use category combinations and assigns a runoff curve number to each polygon within a sub-basin. For a given sub-basin, the individual runoff curve numbers are multiplied by the drainage area of the polygon they represent and the results are summed and divided by the total drainage area of the sub-basin. The resultant runoff curve number is the weighted runoff curve number for the sub-basin.

The ‘look-up’ table of curve numbers was created using TR-55 Table 2-2a ***Runoff Curve Numbers for Urban Areas*** as a base but then added in the percent impervious assumptions from the land use data, i.e. woods/brush is 5% impervious. The adjusted look-up table can be seen in Table 4 below.

Time of Concentration / Lag Time: Time of concentration is the time required for a drop of water (during a 50% chance event) to travel from near the hydraulically most remote part of a catchment to its outfall. The time of concentration has three associated flow path components:

1. Sheet flow,
2. Shallow concentrated flow, and
3. Channel flow.

These three components are calculated individually and summed to obtain the time of concentration for the sub-basin. The length of the sheet flow segment for a sub-basin is limited to 100 feet for urban areas and 300 feet for rural or undeveloped areas. The shallow concentrated flow segment extends from the downstream end of the sheet flow segment to a defined swale or pipe system.

The channelized flow segment extends from the downstream end of the shallow concentrated segment to the outfall of the sub-basin.

$T_C = T_S + T_{SC} + T_{CH}$

The time of concentration routine uses the triangular irregular network (TIN) and calculates the longest path for each sub-basin and stores them in a database and a shapefile. For each sub-basin this routine produces a single shallow concentrated flow path, categorized as either paved or unpaved. Each flow path therefore represents the area that it spends the most time traversing. The shallow concentrated flow paths were verified using aerials and contours to make sure they represent the majority of the sub-basin. However, if the shallow concentrated flow paths traveled over a different surface for greater than 20% of the total distance, an attempt was made to capture that change of land cover in the calculations by dividing the shallow concentrated flow path into separate sections of paved and unpaved, with subsequent calculations then being performed accordingly.

The equations used in the time of concentration calculations are as follows:

1. Overland Flow

$$\mathbf{T_i = [0.007(nL)^{0.8}] / [P_2^{0.5} * S^{0.4}]}$$

Where: n = sheet n based on land use
L = Length (100' or 300')
P_2 = 2yr. 24hr rainfall = 3.06
S = Slope

2. Shallow Concentrated Flow

Velocity Calculation for Paved Surfaces: $\mathbf{V = 20.3282 * S^{0.5}}$
Assumes n=0.025 and r=0.2

Velocity Calculation for Unpaved Surface: $\mathbf{V = 16.1345 * S^{0.5}}$
Assumes n=0.05 and r=0.4

Where: S = Slope

3. Channel Flow

Velocity Calculation: $\mathbf{V = (1.486/n) * R^{2/3} * S^{1/2}}$

Where: n = Manning's roughness based on drainage area
R = Hydraulic Radius based on drainage area
S = Slope (minimum allowable value = 0.005ft/ft)

The flow paths and associated travel time calculations through ponds and lakes are calculated using a constant velocity of 1.0 ft/s. Additionally, travel time calculations for flow paths through storm drain pipes have been calculated as open channel flow using a 0.02 n-value and a hydraulic radius of 0.5585 (corresponding to a 3' pipe).

Lag time (T_L), or the time which elapses between the center of mass of the rainfall and the peak runoff, is derived from the time of concentration based on the empirical relationship of $T_L = 0.6*T_C$ documented in the HMS User's Manual.

Time of Concentration results for individual basins can be seen in the attached database called '*Sugar/Irwin_TC_Database.mdb'.*

Table 4: Master Curve Number Table

		Curve Number for hydrologic soil group with AMC2 conditions						
Land Use Code	Land Use Description	A Ex/Fut	B Ex/Fut	C Ex/Fut	C/D Ex/Fut	D Ex/Fut	U Ex/Fut	W
1	Woods/Brush	33	57	71	75	78	57	98
2	> 2 ac Residential & Open Space	44	65	77	80	82	65	98
3	0.5 to 2 ac Residential	51/53	68/70	79/80	82/82	84/84	68/70	98
4	0.25 to 0.5 ac Residential	56/59	71/74	81/82	83/84	85/86	71/74	98
5	< 0.25 ac Residential	59/64	74/77	82/84	84/86	86/88	74/77	98
6	Institutional Areas	69	80	86	88	89	80	98
7	Industrial-Light	74	83	88	90	91	83	98
8	Industrial-Heavy	81	88	91	92	93	88	98
9	Commercial-Light	83	89	92	93	94	89	98
10	Commercial-Heavy	92	94	95	96	96	94	98
11	Standing Water	98	98	98	98	98	98	98
12	Transportation	86	91	93	94	94	91	98

Channel / Structure Routings: The modified puls method was used for routing calculations in all stream channels because we feel that it gives the modeler the most versatility. In streams that have an effective HEC-RAS model, the storage-outflow parameters were initially used to balance the new model. See the FAMSGD for more detail. In the upper headwater reaches of the watershed where no effective RAS model exists, Manning's equation is used to calculate a range of discharges based on a range of water depths in the routing cross section in that sub-basin. This routing cross section is considered to be an average or "representative" cross section, characterizing the general geometry of the floodplain in that sub-basin. In some cases more than one cross section was placed to get a better representation of the channel. In sub-basins where there is excessive piping of the routed flow, the routing length is represented by only the length of the reach that is open channel. We did not calculate losses through pipes as it is deemed insignificant for the purposes of this flood study. The maximum elevation along the cross section is divided by 10 to come up with a range of water surface elevations, with each elevation then being used to calculate an associated storage volume and discharge. From this, a storage / outflow rating curve for the sub-basin can be developed. New updated RAS models have been created and have been used to balance the HEC-HMS peak discharges with the HEC-RAS peak water surface elevation results, as recommended in the FAMSGD, until the difference between peak discharges in successive runs is less than 10%. In reaches where there is an updated RAS model the storage – discharge curves were taken from the RAS model itself and input into the HMS model.

Section 4 Model Calibration

Model calibration refers to adjustment of model parameters so that simulated stream flow computed using observed rainfall as inputs to the hydrologic model is in agreement with observed stream flow. Model calibration is outlined in a systematic procedure in the FAMSGD. For watersheds with historical precipitation and gage data this procedure suggests that curve numbers be adjusted by +/- 4 so that total runoff volume and discharge match as close as possible at measured locations. The next step is to adjust time parameters to help match time to peak and then cross check with regression equations. Finally, other hydrologic parameters can be considered if necessary and justifiable.

In order to compute simulated stream flow using observed rainfall as input there must be adequate historic rainfall and stream flow data collected. Mecklenburg County has a large dataset of stream and precipitation gages scattered throughout the county, with most of the gages being added after the historic 1995 and 1997 storms that produced severe flooding in the county. Specifically in the Sugar/Irwin watershed, there are currently nine stream gages; they are located on Irwin, Stewart, Taggart, Coffey, Steele, and Sugar Creeks. However, only two of those gages reported data during the 1995 and 1997 events. Therefore, the hydrologic calibration will be performed using mostly the 2008, 2009, and 2011 storm events and we will use the 1995 and 1997 storms after the calibration is performed to verify results.

Discharge and stage data was requested for the nine stream gages during the large storm events in August 2008, July 2009, and August 2011, we received complete data sets for seven of the nine gages requested. We did not receive any data for the gage on Stewart Creek at Morehead Street, and the gage on Sugar Creek at Arrowood Road is a stage only gage and can only be used in hydraulic model calibration. That leaves seven stream gages for direct hydrologic calibration and they are presented in Table 5.

Table 5: Active Stream Gages in the Sugar/Irwin Watershed for Hydrologic Calibration

Gage Station ID	Gaged Stream and Location	Start Date	End Date	Drainage Area (square miles)
02146211	Irwin Creek at Statesville Ave at Charlotte, NC	October 1981*	Present	6.0
0214627970	Stewart Creek at State St at Charlotte, NC	June 2000	Present	9.3
02146300	Irwin Creek near Charlotte, NC	May 1962	Present	30.7
02146315	Taggart Creek at State St at Charlotte, NC	July 1998	Present	5.7
02146348	Coffey Creek near Charlotte, NC	October 1998	Present	9.1
02146381	Sugar Creek at NC 51 near Pineville, NC	October 1994	Present	65.3
0214678175	Steele Creek at SR 1441 near Pineville, NC	May 1998	Present	6.7

* Period of record at Station 02146211 is discontinuous. The station was active from October 1981 to September 1994, November 1997 to September 2001, and June 2004 to present

The hydrologic calibration procedure is dependent on the availability of stream and precipitation gages as well as the homogeneousness of the watershed we are studying. If the watershed was relatively small, consistent, and homogeneous, one could apply the same assumptions throughout the model and calibrate using one HMS model. However, considering the amount of information available and the heterogeneous nature of the watershed, it was concluded that an individual sub-watershed approach to calibration, using the gages in each of the sub-watersheds independently, was the best option. This option allows for flexibility in calibrating the extremely urban Irwin and Stewart sub-watersheds differently than the rural Steele Creek sub-watershed. To that end we have set up seven independent HMS models and we will calibrate each model using the stream gage(s) that are contained therein. The sub-watersheds will be separated at the major confluences as such:

The Stewart Creek HMS model will begin at the confluence with Irwin Creek and will contain the three Stewart Creek tributaries;

The Irwin Creek model will begin at the confluence with Taggart Creek and will contain the Kennedy Branch and Irwin Trib 1 tributaries. It will also contain an input hydrograph for Stewart Creek that will be represented as a discharge gage;

The Taggart Creek model will begin at the confluence with Irwin Creek;

The Coffey Creek model will begin at the confluence with Sugar Creek;
The Sugar Creek model will begin at the county line and contain the Kings Branch and McCullough Creek tributaries. It will also contain three input hydrographs, represented by discharge gages, for Taggart, Irwin, and Coffey Creeks;
The Steele Creek HMS model will begin at the county line and will contain the Walker Branch, Walker Branch Trib, and Polk Ditch tributaries;
The Blankmanship Branch HMS model will begin at the county line.

4.1 Calibration Precipitation Input

Historic precipitation data was requested for the August 1995, July 1997, August 2008, and July 2009 storm events. Initial analysis of the precipitation data revealed that the July 2009 storm event provided rain gage totals between 1.08 and 2.97 inches, the August 2008 storm provided rain gage totals between 6.93 and 9.27 inches, while the August 2011 storm provided rain gage totals between 2.00 and 6.83 inches. From these totals it is apparent that the 2009 and 2011 storms were not all encompassing storms. The rainfall for those storms appears to be concentrated in certain basins. The rainfall for the 2008 storm is spread more evenly over each of the watersheds. But, the issue with the 2008 storm is that it was not a concentrated event, the total rainfall was spread out over two days and in most cases caused a double peak hydrograph. Double peak hydrographs can be very difficult to calibrate. We tried to use each of the three storms in each of the watershed calibration routines. The 1995 and 1997 data, where it is available, will be used later for comparison.

Historic rainfall data used in the simulation storm analysis was gathered for 14 precipitation gages in or near the Sugar Irwin watershed. Initial analysis of the data revealed that one of the gages supplied data that was not consistent with the others. The August 2008 total rainfall only summed to 0.38 inches for CRN-13. Since we have a plethora of data points and after consultation with our chief hydrologist, that gage was removed from the analysis. The gages used in the precipitation analysis are listed in table 6 below.

Table 6: Precipitation Gages used for Yadkin River sub-basin Model Parameter Calibration

Gage Station ID	Gaged Stream and Location	Latitude	Longitude
351633080493445	CRN-03 Raingage at Irwin Creek	35 16 33	80 49 34
351132080562345	CRN-04 Raingage at Fire Station 30	35 11 34	80 56 09
351642080533445	CRN-05 Raingage at CMU Admin Building	35 16 42	80 53 34
351331080525945	CRN-11 Raingage at Fire Station 10	35 13 29	80 53 14
350947080524945	CRN-13 Raingage at USGS Office	35 09 47	80 52 49
351320080502645	CRN-15 Raingage at Char-Meck Govt Center	35 13 17	80 50 23
350842080572801	CRN-21 Raingage at Kennedy Jr High	35 09 13	80 57 21
350623080583801	CRN-22 Raingage at Lake Wylie Elementary School	35 06 54	80 58 18
351604080470845	CRN-27 Raingage at Hidden Valley Elementary School	35 16 04	80 47 08
350657080544945	CRN-28 Raingage at Crompton Street	35 06 57	80 54 49
351502080512045	CRN-50 Raingage at Beatties Ford Rd	35 15 02	80 51 20
351412080541245	CRN-53 Raingage at Harding High School	35 14 12	80 54 08
351741080475045	CRN-54 Raingage at Turning Point Academy	35 17 43	80 47 46
351104080521845	CRN-60 Raingage at Collingswood Elementary	35 11 05	80 52 18

Precipitation totals for the August 2008 storm event are fairly consistent across the gage network. Storm totals range from 6.93 inches to 9.27 inches, with the average being 7.84 inches of rain. Instead of applying this average rainfall to all of the HMS models, it was decided to create an area-weighted, spatially distributed precipitation record using Thiessen polygons.

The area-weighted, spatially distributed precipitation record takes the observed point precipitation data at selected USGS precipitation gages (Table 6) and transforms them to an area-weighted, spatially distributed precipitation record using the Thiessen polygon method. Thiessen polygons are defined as a set of polygons that enclose the areas around a set of point locations (such as a group of rain gages) so that for a given point location, the associated Thiessen polygon includes all the area that is less than half way between the selected point and all the remaining points. As such, all locations within a given polygon are closer to the associated rain gage than to any of the other rain gages. Thiessen polygons for the selected precipitation gage location were developed using GIS tools.

The Thiessen polygons were then intersected with the drainage sub-basins for each studied watershed. The weighted precipitation for each sub-basin is computed as the weighted average of the observed rainfall at each gage for which the sub-basin intersects an associated polygon. The weighting factor for the associated rain gages is computed as the percent of the total area of the sub-basin that is contained in the associated rain gage polygon. In order to develop a weighted, distributed precipitation input, the weighted average was computed for each time step in the rain gage record. Each HMS model then has a spatially distributed average rainfall calculated from the gages that are nearest its sub-basins. Specific calculations for the weighted rainfall for each HMS model can be seen in the ***Meck.SugarIrwin.Precip.WeightedRainfall.xls*** spreadsheet. Figure 3 is a graphic representation of the summed precipitation values for each gage using the outlined Thiessen Polygon method. For example, there are four precipitation gages in the Stewart Creek sub-watershed. In the Stewart Creek meteorologic models, under the Precip-Weights icon, every sub-basin has the identical gage weights distribution. The four precipitation gages in the Stewart Creek model are weighted as follows:

CRN-05 – 0.494
CRN-11 – 0.109
CRN-50 – 0.281
CRN-53 – 0.116

The above gage weights are applied to each precipitation value at each time-step and then they are summed. The rain gage with the most impact on the area-weighted calculations is CRN-05, which is represented by the 7.59 inch precipitation total in the graphic below. The total precipitation for the Stewart Creek model using the area-weighted, spatially distributed calculation is 7.6 inches. The specific calculations for each storm event can be seen in the ***Meck.SugarIrwin.Precip.WeightedRainfall.xls*** spreadsheet.

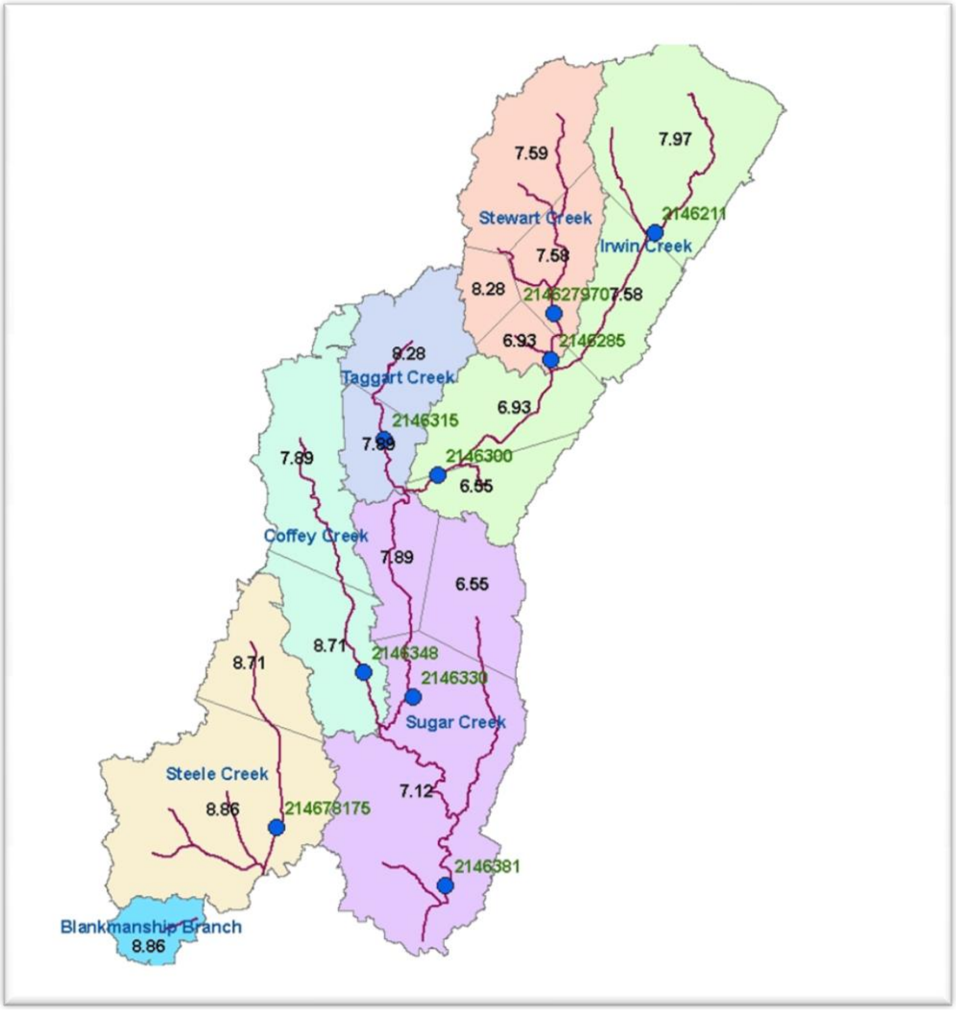


Figure 3. Sugar/Irwin Watershed Thiessen Polygon Precipitation Coverage – August 2008

The total amount of precipitation calculated by the area-weighted, spatially distributed method in each HMS model can be found in Table 7 below.

Table 7: Precipitation Totals by HMS Sub-Watershed

Stream/Model	Aug 2008 Weighted Precip (In)	Jul 2009 Weighted Precip (In)	Aug 2011 Weighted Precip (In)
Blankmanship Branch	8.86	1.92	2.37
Coffey Creek	8.23	2.23	2.23
Irwin Creek	7.46	2.05	6.12
Steele Creek	8.82	1.96	2.28
Stewart Creek	7.6	1.56	5.66
Sugar Creek	7.12	2.04	2.36
Taggart Creek	8.15	2.25	4.68

In observation of the calculated precipitation totals, it is apparent that slightly more rain fell in the southwest portion of the Sugar/Irwin watershed during the August 2008 storm. This is supported by the

Rainfall Distribution Map created by the USGS as seen in Appendix A. This storm would be ideal except for the fact that the duration of the event was over a 48-hour period and in all of the watersheds the storm hydrograph contains two separate and independent discharge peaks. This fact makes the August 2008 storm difficult to calibrate.

4.2 Calibration Methodology

Calibration of watersheds with stream gage data (Stewart, Irwin, Taggart, Coffey, Sugar, and Steele) was initiated by following the steps laid out in the FAMSGD. In general, "hydrologic calibration is typically performed by adjusting sub-basin lag times, initial abstractions, curve numbers, and/or peaking coefficients, as justifiable, to better match computed peak flows and hydrograph time to peaks with observed values or previous studies." In order to take advantage of the amount of gage data and to acknowledge that every sub-watershed reacts uniquely to each storm event, it was thought best to keep the calibration of each watershed separate and apply an average of the calibration to each of the remaining un-gaged watersheds in the Sugar-Irwin and Steele Creek watersheds. Each calibration routine began by running the models without any calibration and those results are noted below as compared to observed flow at the respective gages.

Table 8: Initial Simulated and Observed Runoff and Peak Discharge for Stream Gages Used in Sugar/Irwin Watershed before Calibration

		Runoff (inches)			Peak Discharge (cubic feet / sec)		
Event Date	Gage number (Stream Name)	Observed	Simulated	% Difference from Observed	Observed	Simulated	% Difference from Observed
08/08	0214627970 (Stewart)	4.19	5.2	24.1	2709	3040	-10.9
07/09		0.38	0.28	-26.3	383	968	-60.4
08/11		4.71	3.55	-24.6	5370	5130	-4.5
08/08	02146300 (Irwin)	4.00	4.87	21.8	1720	1662	-3.4
07/09		0.52	0.48	7.7	432	499	15.5
08/11		4.58	3.77	-17.7	4055	4217	4.0
08/08	0212430293 (Irwin)	3.52	5.18	47.2	5110	7250	41.9
07/09		0.61	0.46	-24.6	1950	1316	-32.5
08/11		3.92	3.87	-1.3	10600	11114	4.8
08/08	0212430293 (Taggart)	3.93	5.95	51.4	2250	2166	-3.7
07/09		0.83	0.75	-9.6	1170	827	-29.3
08/11		2.59	2.93	13.1	3160	3459	9.5
08/08	02146700 (Coffey)	3.54	5.75	62.4	1640	2369	44.5
07/09		0.43	0.59	37.2	390	577	47.9
08/11		0.9	0.79	-12.2	791	890	12.5
08/08	02146381 (Sugar)	3.95	5.42	37.2	6120	11182	82.7
07/09		0.25	0.61	144.0	552	2453	344.3
08/11		2.28	2.71	18.9	6110	13470	120.5
08/08	0214678175 (Steele)	3.99	6.98	74.9	1120	2723	143.1
07/09		0.39	0.59	51.3	436	555	27.3
08/11		0.75	1.11	48.0	900	937	4.1

As illustrated by table 8 above, the initial results of the simulated rainfall events generally compared favorably to the historical data (discharges and volumes) for Coffey, Taggart, Stewart, and Irwin. Pre-calibrated discharges and volumes for the August 2011 storm were within 24% of observed values. The August 2008 values were consistently high as compared to observed, generally between 20-60%. Pre-calibrated values for the July 2009 storm were generally lower than observed except in Coffey Creek.

The 2008 storm occurred over two days and that probably had an impact on the excessively high flow and volumes seen in the model comparison. In most watersheds, the storm produced double peaks and was difficult to simulate.

The August 2011 storm, on the other hand, displayed a very nice Type II curve of rainfall. It was an intense direct rainfall, especially for the Stewart and Irwin watersheds. Since this precipitation fell in a more predictable manner, the model responds much more favorably and initially produces discharges and volumes that are closer to observed.

The July 2009 storm event is a rather small but intense event, totaling a precipitation maximum of 2.25 inches in Taggart Creek. This event required the use of the baseflow parameter in HMS in order to obtain initial results. In larger events baseflow is not significant in the calculations, but with only between 1 - 2.25 inches of rain falling during this event, the baseflow was required. It was input into the model using the discharge per area recession method. The discharge per area was calculated by averaging 3 days of daily discharges produced before the peak for each storm. The USGS daily statistics were used for the calculations and can be seen in Table 9.

Table 9: USGS Daily Baseflow at Referenced Gages

Stream/Model	Jul09 Avg Baseflow (cfs)	Aug11 Avg. Baseflow (cfs)	DA at Gage (mi^2)	Avg Discharge per Area (cfs/mi^2)
Coffey Creek	1.2	0.8	9.1	0.1
Irwin Creek	9.7	11.0	30.7	0.3
Stewart Creek	8.9	10.0	9.3	1.0
Taggart Creek	0.8	0.3	5.7	0.1
Sugar Creek	0.51	0.48	65.3	0.5
Steele Creek	0.4	0.25	6.7	0.05

Specific calibration iterations for each gaged watershed can be seen in the respective spreadsheets named "***Watershed_Calibration***". For each watershed, we began by applying the curve number adjustments as recommended in the guidance document. Individually, each of the watersheds could be

calibrated within the standards set forth in the guidance document to match the observed data for the event. But, an average calibration was applied in the end to get a better representation for a wide range of storms. Using the three storms was beneficial because it gave us a look at several different depths, types and distributions of rainfall.

4.3 Calibration Results

The model parameter calibration process for Stewart, Irwin, Taggart, and Coffey Creeks resulted in slightly different initial abstraction (IA) and curve number (CN) scale factor values for the respective storms used in calibration. Each gaged stream has its own individual calibration routine because each watershed is unique and can have a significantly different response to a similar rainfall event. In most cases we used average calibration factors for curve number and initial abstraction as calculated for the August 2008, July 2009, and August 2011 storm events. Generally speaking, calibration for each individual storm event could be obtained while staying within the allowed parameters in the FAMSGD, the exception being the August 2008 storm that was spread over 2 days and caused double peaks in all of the hydrographs. An average curve number and initial abstraction calibration factor was calculated for each HMS model and are displayed below.

When the final initial abstraction and curve number values displayed in Table 10 are applied to the respective models, the final simulated runoff and peak discharge values shown below in Table 11 are the result.

Table 10: Initial and Final Calibration Factors

Date	Gaged Stream and Location	IA Starting Value	IA Calibrated Value	IA Final Value	CN Starting Value	CN Calibrated Value	CN Final Value
8/27/08	0214627970 (Stewart)	0.2*S	0.3*S (NA)	0.*1S	1.00	Raw + 4	Raw + 4
7/29/09		0.2*S	0.1*S		1.00	Raw + 4	
8/05/11		0.2*S	0.1*S		1.00	Raw + 4	
8/27/08	0212430293 (Irwin)	0.2*S	0.1*S (NA)	0.15*S	1.00	Raw + 2	Raw -0.25
7/29/09		0.2*S	0.15*S		1.00	Raw - 0.5	
8/05/11		0.2*S	0.15*S		1.00	Raw	
8/27/08	0212430293 (Taggart)	0.2*S	0.4*S(NA)	0.25*S	1.00	Raw	Raw + 2
7/29/09		0.2*S	0.2*S		1.00	Raw + 4	
8/05/11		0.2*S	0.2*S		1.00	Raw - 1	
8/27/08	02146700 (Coffey)	0.2*S	0.3*S (NA)	0.225*S	1.00	Raw - 3	Raw - 2
7/29/09		0.2*S	0.225*S		1.00	Raw - 2	
8/05/11		0.2*S	0.25*S		1.00	Raw - 1	
8/27/08	02146381 (Sugar)	0.2*S	0.2*S	0.2*S	1.00	Raw	Raw
7/29/09		0.2*S	0.2*S		1.00	Raw	
8/05/11		0.2*S	0.2*S		1.00	Raw	
8/27/08	0214678175 (Steele)	0.2*S	0.3*S	0.25*S	1.00	Raw - 4	Raw
7/29/09		0.2*S	0.25*S		1.00	Raw - 2	
8/05/11		0.2*S	0.25*S		1.00	Raw	

It was apparent in Stewart Creek that additional flow was needed for both the Type II storm events in August 2011 and July 2009. The August 2008 storm appeared to be the outlier, probably due to the rainfall pattern which resulted in a double peak. The maximum initial flow difference in Stewart Creek of - 60.4% was seen during the July 2009 storm event. The initial volumes were within 26.3% of observed. Therefore the emphasis was placed on the 2009 and 2011 storms for calibration. Looking at the initial un-calibrated results it was apparent that more volume and flow were needed. An increase of curve numbers by +4 and a corresponding initial abstraction reduction to 0.1*S provided the desired results.

Irwin Creek has two stream gages that reported for all three storm events. The initial un-calibrated simulated Irwin Creek results upstream of the confluence with Stewart Creek were very close to observed flow and volume values, the maximum percent difference was only 21.8%. Downstream of the Stewart Creek confluence, the difference of observed to simulated flows and volume increased. Although, this was due primarily to the low flow and volume from the initial Stewart Creek hydrograph, and once the Stewart Creek model was calibrated to increase flow and volume the gage downstream of the confluence agreed more readily with observed results. Again, using only the 2009 and 2011 storms, the volumes

Table 11: Simulated and Observed Runoff and Peak Discharge Post Calibration

		Runoff (inches)			Peak Discharge (cubic feet / sec)		
Event Date	**Gage number (Stream Name)**	**Observed**	**Simulated**	**% Difference from Observed**	**Observed**	**Simulated**	**% Difference from Observed**
08/08	0214627970 (Stewart)	4.19	5.91	41.1	3040	2975	-2.1
07/09		0.38	0.55	44.7	862	968	-21.3
08/11		4.71	4.18	-11.3	5370	5635	4.9
08/08	02146300 (Irwin)	4.00	4.98	24.5	1720	1648	-4.2
07/09		0.52	0.55	5.8	432	544	25.9
08/11		4.58	3.88	-15.3	4055	4231	4.3
08/08	0212430293 (Irwin)	3.52	5.51	56.5	5110	7408	45.0
07/09		0.61	0.64	4.9	1950	1868	-4.2
08/11		3.92	4.26	8.7	10600	11922	12.5
08/08	0212430293 (Taggart)	3.93	6.2	57.8	2250	2235	-0.7
07/09		0.83	0.86	-3.6	1170	954	-18.5
08/11		2.59	3.13	13.1	3160	3663	15.9
08/08	02146700 (Coffey)	3.54	5.37	51.7	1640	2116	29.0
07/09		0.43	0.46	7.0	390	424	8.7
08/11		0.9	0.64	-28.9	791	646	18.3
08/08	02146381 (Sugar)	3.95	5.4	36.7	6120	10806	76.6
07/09		0.25	0.63	152.0	552	2274	312.0
08/11		2.28	2.75	20.6	6110	13139	115.0
08/08	0214678175 (Steele)	3.99	6.81	70.7	1120	2553	127.9
07/09		0.39	0.52	33.3	436	492	12.8
08/11		0.75	0.99	32.0	900	807	-10.3

and flows needed to be adjusted slightly. The calibration factors applied were 0.15*S and raw CN – 0.25. This increased the difference of the 2009 storm to 25.9% but reduced the volume shortage for the 2011 storm slightly. The calibrated results at the gage downstream of Stewart Creek came within 12.5% of observed values.

The Taggart Creek initial un-calibrated simulated results revealed split results for the 2009 and 2011 events. Initial un-calibrated simulated flow and volume for the 2009 storm were lower than observed values, 32.5% lower flow value and a 24.6% lower volume. However, the 2011 event showed slightly higher simulated versus observed results. The calibration resulted in the application of a raw CN + 2 and an initial abstraction of 0.25*S. This split the difference and provided a calibrated flow difference of -18.5% for the 2009 event and a 15.9% difference for the 2011 event.

The initial un-calibrated simulated results for Coffey Creek were more consistent. Simulated flows and volumes for all three storms were up to 62.4% higher than observed data, except for the 2011 volume, which was 12.2% lower than observed volume. Therefore, overall we felt it necessary to increase initial abstraction and decrease curve numbers slightly. The final calibration factors of raw CN – 2 and IA*0.225 were applied and resulted in a 28.9% lower volume for the 2011 storm but the flow for the same storm was 18.3% high.

Sugar Creek is the main channel through this watershed and it accepts flows from Irwin, Coffey and Taggart Creeks. It has an interesting and well studied past but the stream flow gage data only goes back to 1994. Therefore, due to the lack of gage record, a specific gage analysis could not be performed. The initial un-calibrated simulated results show unusually high flows, almost double the observed flows in every storm event. The initial simulated volumes however are much closer to observed values for two out of the three events. The initial thought was that the hydrographs from the tributaries were combining incorrectly but even shifting some of the inflow hydrographs did not appear to help. Also, it seemed counter-intuitive to have the observed flow at the gage on Irwin Creek with a 30.7 mi^2 drainage area be consistently higher for the type II storm events of 2009 and 2011 than the observed flow at the gage on Sugar Creek, which has a drainage area of 65.3 mi^2. The 2008 storm event has been characterized as not being a type II rainfall event. The observed flow at the Sugar Creek gage is slightly higher than the Irwin gage for the 2008 storm.

Initially it was considered that there was too much rainfall input into the models for the 2009 and 2011 events. The 2011 event was not as homogeneous as the 2008 and 2009 events but from the rainfall totals in table 7 the non-uniform rainfall totals are captured well. For the 2011 event the majority of the rain falls in the Stewart and Irwin Creek watersheds, 5.66 and 5.68 inches, respectively. Only 2.36 inches of rain falls in the Sugar Creek watershed. For the 2009 event more rain falls in the Sugar Creek watershed than in the Stewart Creek watershed, 2.04 and 1.56 inches, respectively. Yet in these two storm events the observed flows at the Sugar Creek gage are significantly less than the observed flows at the Irwin Creek gage. Another reason to believe that our rainfall data is acceptable is the volume comparison of the simulated events versus the observed events. Sugar Creek simulated volumes are between 19 – 144% higher than observed, whereas simulated flow values are between 83 – 344% higher than observed. The 144% higher simulated volume occurs during the July 2009 storm event. The volume and peaks for the 2009 event are much more sensitive to calibration than the other storms due to the low observed volume and peak flow totals. Therefore, it is our conclusion that the Sugar Creek main channel provides an inexplicable amount of attenuation from the confluence of Irwin Creek downstream to the gage at Arrowood Road. A report by Smith et al, “The Regional Hydrology of Extreme Floods in an Urbanizing Drainage Basin” 2002 supports this conclusion and presents another possible reason for the odd peak flow totals at the Irwin and Sugar gages. This report states that “Attenuating reaches serve to mix the effects of upstream heterogeneities of flood response, resulting in rapid decline in the influence of urbanization on flood response with increasing drainage area.”

Table 13: Sugar and Irwin Creek Observed Flow Comparison

Event Date	Irwin Observed Flow/Vol	Sugar Observed Flow/Vol
Aug-08	5110/3.52	6210/3.95
Jul-09	1950/0.61	552/0.25
Aug-11	10600/3.92	6110/2.28

The other possible reason for the inconsistent peak flow totals could be the spatial and temporal patterns of heavy rainfall patterns in the Sugar Creek watershed. If the rainfall is uniform over the entire watershed it tends to be simpler to simulate that peak. Therefore smaller watersheds are easier to calibrate. Another factor that may be considered is the impact that the Irwin Creek Waste Water Treatment plant has on the peak discharges in the Sugar/Irwin watershed. The downstream gage on Irwin Creek (02146300) sits just upstream of the plant and the calibration at this gage is minimal for several storms. Charlotte Mecklenburg Utilities (CMU) has been contacted to investigate further.

The initial Steele Creek un-calibrated simulated results returned high volumes and discharges for the three storm events. Again, the 2008 storm was the most excessive probably due to the fact that the 8.82 inches of rainfall fell over a two day period and produced two separate and distinct peaks. As we have demonstrated, this type of event can be difficult to calibrate to. The 2009 and 2011 events were not large rainfall events but initial un-calibrated simulated volumes were within 50% of observed and peak discharges were within 27%. The simulated 2008 storm was 75% over in volume and 143% over in peak discharge. We began the calibration process by increasing the initial abstraction to 0.25*S because all of the volumes were high. This caused the expected drop in simulated volumes and peak discharges. The simulated 2011 storm peak discharge fell to 6% below the observed which appears to be the limiting factor in calibration. Any other adjustment to reduce volume will produce a simulated peak discharge 10% below the observed. A 1.25*Raw lag factor was also applied to smooth out some of the peak discharges.

Table 12: Pre and Post Calibrated Time to Peaks

Date	Gaged Stream	Observed Time to Peak	Simulated Time to Peak	Difference	Lag Factor Applied	Calibrated Time to Peak	Difference
08/08	0212466000 (Stewart)	04:15	03:47	-00:28	0.9	03:30	-00:45
07/09		00:15	00:48	00:33	0.9	00:33	00:18
08/11		15:00	14:51	-00:09	0.9	14:54	-00:06
08/08	02146300 (Irwin)	04:00	03:45	-00:15	1.25	03:47	-00:13
07/09		00:15	00:21	00:06	1.25	00:23	00:08
08/11		14:30	14:21	-00:09	1.25	14:19	-00:11
08/08	0212430293 (Irwin)	07:30	06:25	-01:05	1.125	06:29	-01:01
07/09		00:45	02:37	01:52	1.125	02:31	01:46
08/11		17:45	16:54	-00:51	1.125	16:48	-00:57
08/08	0212430293 (Taggart)	03:15	03:23	00:08	None	03:24	00:09
07/09		00:05	00:05	00:00	None	00:05	00:00
08/11		14:45	14:14	-00:31	None	14:15	-00:30
08/08	02146700 (Coffey)	07:00	06:15	-00:45	1.20	06:20	-00:40
07/09		03:30	03:19	-00:11	1.20	03:20	-00:10
08/11		19:00	17:34	-01:26	1.20	17:38	-01:22
08/08	02146381 (Sugar)	15:30	10:20	-05:10	0.75	10:17	-05:13
07/09		02:45	08:51	06:06	0.75	09:07	06:22
08/11		04:30	22:54	-06:06	0.75	23:27	-05:33
08/08	0214678175 (Steele)	13:10	10:47	-02:23	1.25	10:54	-02:16
07/09		00:45	01:14	00:29	1.25	01:21	00:36
08/11		14:45	15:55	01:10	1.25	15:54	01:09

The calibration of lag times was performed more so to offset some of the impacts of the curve number and initial abstraction calibration as well as to smooth out some of the time to peaks. Generally speaking, the lag time factors applied had limited effect on the overall time to peak of the larger watersheds. However, in the smaller watersheds the un-calibrated simulated time to peaks of Type II storm events of 2009 and 2011 compared favorably with the observed time to peaks. As mentioned previously, the double peak of the observed 2008 storm event makes calibration of the simulated 2008 event difficult at best. Also, it has been noted that the Sugar Creek gage is historically difficult to calibrate to for the reasons listed above. If the time to peaks for the 2008 event and the Sugar Creek model are ignored, there are four of twelve simulated time to peaks that are not within 37 minutes of the observed. The calibrated simulated and observed hydrographs at each of the gages can be seen in Appendix D. It is apparent that the 2008 storm and the Sugar Creek gage are not well calibrated. But, we believe that the Type II storm events of 2009 and 2011 are calibrated well in all of the other watersheds.

4.4 Model Flow Comparison

A 1% annual preliminary discharge comparison table can be found in Appendix B of this document. The preliminary discharges calculated for Stewart Creek have increased significantly when compared to effective and regression discharges. This result seems to confirm reports by the County in that watershed of severe flooding outside of the effective floodplain boundary. Preliminary discharges have increased from 77 – 220% in the main channel of the Stewart Creek watershed. The preliminary discharges are only slightly higher than the regression discharges, ranging from 11 – 30% higher.

Overall, the preliminary updated discharges are higher than effective; there are only 9 locations out of 40 where the preliminary discharge is less than the effective. In only one sub-basin are the preliminary discharges more than 10% lower than effective and that is in the headwaters of Taggart Creek, sub-basin 487C. But in general the preliminary discharges agree favorably with regression and vary from 40% less in some sub-basins to 40% higher in others.

Figure 4. US Face of Norfolk Southern RR Crossing on Taggart Creek

The preliminary discharges are 20% lower than effective at this location on Taggart Creek, probably due to the attenuation calculations upstream of Denver Avenue and the railroad crossing. The preliminary discharges are significantly, between 50 - 100% less than regression discharges in this area as well. Further investigation reveals that the railroad crossing acts like a dam here, attenuating a significant amount of flow due to the hydraulic inefficiencies of the apparently very old arch stone culvert. The effective RAS model uses a much more hydraulically efficient box culvert to model the opening. But, as seen in figure 4 below, the old culvert is clearly an arch, and when an arch is input into the updated RAS model, much more attenuation is seen. This attenuation causes the peak flows to decrease significantly downstream of this structure.

The preliminary peak discharges in the Steele Creek watershed are significantly higher than effective discharges, ranging from 90% to 280% higher. It appears that the effective peak discharges in this watershed are very low, as the regression discharges agree more favorably with the simulated preliminary discharges. The regression peak discharges range from 61% lower to 23% higher than preliminary discharges.

Historical Event Model Comparison: Historical storm events were input into the HMS models for observation. The summer storms of 1995 and 1997 are the storms that always come to mind when flooding events in Mecklenburg County are discussed. Rainfall and stream flow data from the USGS was obtained and incorporated into the HMS models to test the models versus other historical rainfall events. There was, however, some data missing or just not correct from the USGS data dump. The only stream gage that was active for the 1995 and 1997 events in the Sugar and Steele Creek watersheds was the Irwin Creek gage at the Irwin Creek Wastewater Treatment Plant. Table 14 displays the calibrated results of the historical storm event analysis.

Table 14: 1995 and 1997 Comparison of Runoff, Peak Discharge, and Time to Peak

Date	Gaged Stream and Location	Observed Runoff (inches)	Simulated Runoff (inches)	% Difference from Observed Runoff	Observed Peak Discharge (cfs)	Simulated Peak Discharge (cfs)	% Difference from Observed Peak	Observed Time to Peak	Simulated Time to Peak
Cal 95	02146300 Irwin Creek	4.02	3.93	-2.2%	5,510	4,426	-19.7%	27Aug95,17:30	27Aug95,19:03
Cal 97		7.36	6.75	-8.3%	11,600	11,123	-4.1%	23AJul97,08:00	23AJul97,08:06

Calibrated volumes were within 10% but the observed peak flow for the 1995 storm was about 20% higher than the simulated. 6.3 inches of rain fell over a 40-hour period during the 1995 event. The duration of the event may have some impact on the peak discharges. The 1997 storm is within all parameters and matches very well. The precipitation during 1997 storm event lasted only 24 hours and resulted in a total of 9.1 inches. One-and-half times more rainfall fell in the 1997 storm versus the 1995 storm but the peak discharge is more than double in the 1997 storm. The duration and intensity of the 1997 rainfall is the probable cause in the differences in the peak flows during the 1995 event and these factors are much more difficult to calibrate to. The 1997 storm appears to be more of a classic type II event, thus making it easier to simulate.

Gage Analysis Comparison: There are two gages in this study area that have a lengthy enough gage record to perform a statistical recurrence interval analysis, both are on Irwin Creek. Table 15 displays how simulated calibrated flows compare to the gage analyses. Simulated peak discharges are between 17.8 and 26.1 percent higher than the gage analysis in the Irwin Creek watershed. This analysis, along with the historical storm analysis of each of these watersheds provides confidence in the calibration procedure and the final flows in Appendix B.

Table 15: Comparison of AECOM Gage Analysis Results

Gage ID	Gaged Stream and Location	Dates Analyzed	DA (miles^2)	Q100 (cfs)	Calibrated Q100 (cfs)	% Diff
02146211	Irwin Creek at Statesville Ave at Charlotte, NC	1982-2010	5.97	3,236	4,081	26.1%
02146300	Irwin Creek near Charlotte, NC	1975-2010	30.7	10,480	12342	17.8%

Gage vs. Proposed HEC-HMS vs. USGS Urban Regression vs. Effective Discharges: The gage analysis results as listed in table 13 above have been compared to the proposed discharges determined by the calibrated HEC-HMS models in the charts displayed in Appendix C. In addition the USGS urban regression equation and effective study discharges are included on these charts. All these values are evaluated against the gage results for reasonability. It is shown that all major streams have proposed discharge values which lie within one standard error (68-percent confidence interval) of the gage results. Several streams, including most tributaries are shown to be of low significant drainage area including; Blankmanhip Branch, Irwin Creek Tributary 1, Kennedy Branch, Kings Branch, McCullough Creek, Polk Ditch, Stewart Creek Tributary 1, Stewart Creek Tributary 2, Stewart Creek Tributary 3, Walker Branch Tributary. However, simple observable placement on the charts in Appendix C, show that none appear to fall far from the approved standard error (68-percent confidence interval).

High Water Mark (HWM) Comparison: As an additional level of quality assurance, the final simulated calibrated flows from the August 2008 storm were input into updated preliminary HEC-RAS models. These models are not final calibrated models but do contain the most up to date stream geometry and structure information. The Sugar/Irwin study watershed contains 40 surveyed HWMs from the 2008 storm and 52 surveyed HWMs from the 2011 storm event.

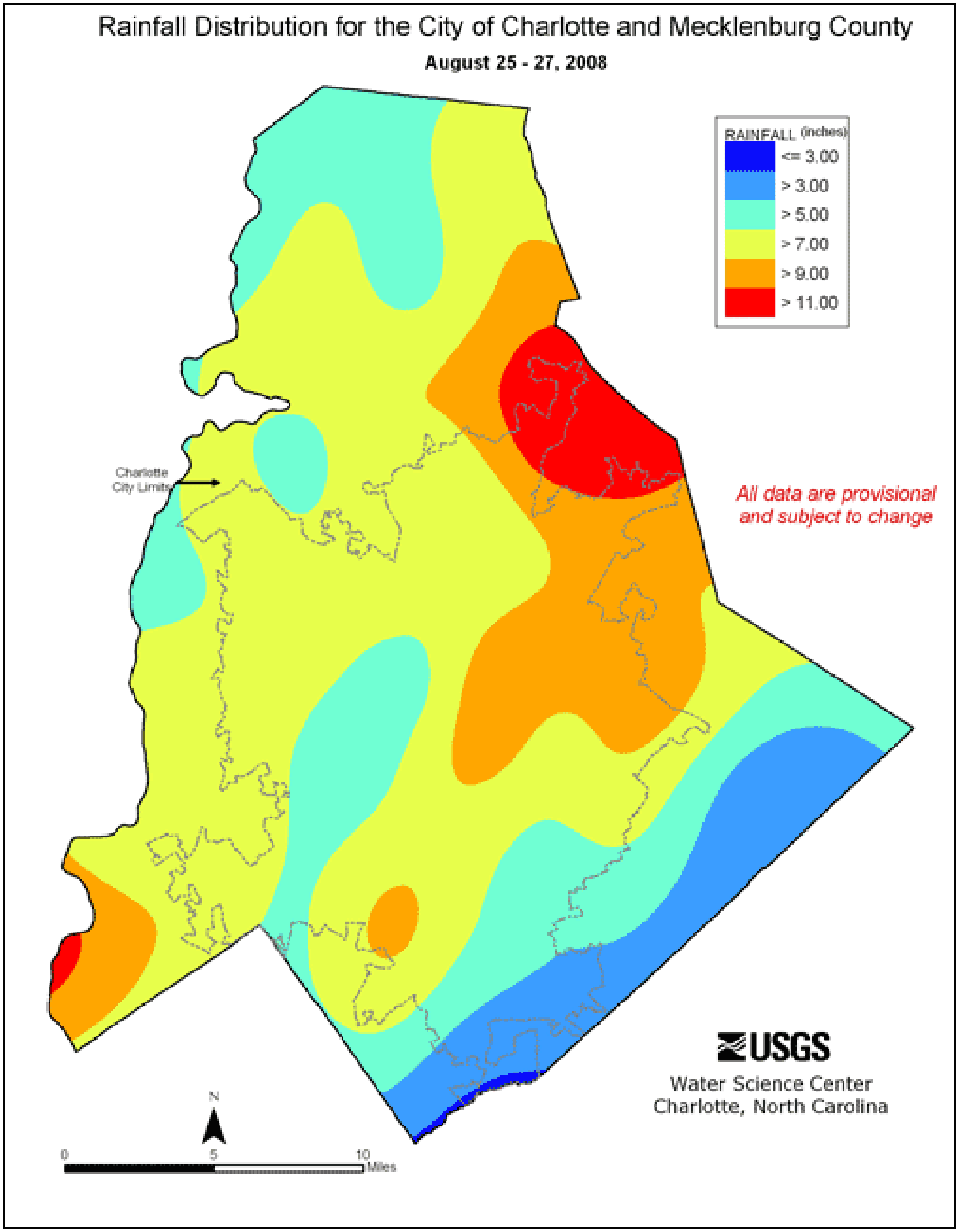
This ***initial*** high water mark comparison reveals that the calibrated hydrology appears reasonable. When the simulated peak flows were input into the preliminary RAS models only 6 of 40 initial water surface elevations (WSEL) were lower than measured HWMs for the 2008 storm event. Only 1 of those was over 2 feet lower, 2.02 feet lower to be exact. For the 2011 HWMs, initial RAS WSELs indicate that only 8 of 52 marks were initially found to be lower than measured. There appear to be several cases of the 8 where the difference in elevation could be attributed to backwater from the main reach that is not represented in our preliminary RAS models. Examples may be STE1_01_11 and STE3_01_11.

A more detailed HWM analysis will be completed when the preliminary discharges are approved and the RAS models are calibrated. The initial HWM comparison seems to indicate that the simulated water surface elevations are generally higher than measured marks. This is to be expected on Sugar Creek due to the rather inexplicable reduction in peak discharges seen at the stream gage at NC51 near Pineville. Please see the HWM spreadsheet for more detail. If it is found that approved discharges do in fact have to be updated then they will be updated. But currently, we feel that the peak discharges are reasonable.

4.5 Calibration in Watersheds without Historical Stream Flow Data

Blankmanship Branch is a free standing model because there is no stream gage and it drains to the county line. It does however drain into Steele Creek down past the county line. Therefore, the same calibration that was applied to the Steele Creek HMS model was applied to the Blankmanship Branch model. Similarly to Steele Creek, calibrated peak discharges for Blankmanship Branch were much higher than effective discharges but slightly lower than regression discharges.

Appendix A


Rainfall Distribution for the City of Charlotte and Mecklenburg County
August 25 - 27, 2008
RAINFALL (inches)
<= 3.00
> 3.00
> 5.00
> 7.00
> 9.00
> 11.00
Charlotte City Limits
All data are provisional and subject to change
N
0
5
10
Miles
USGS
Water Science Center
Charlotte, North Carolina

Appendix B

Flooding Source and Location	Basin ID	Updated DA (mi2)	Eff 1% (cfs)	Prelim 1% (cfs)	% Diff	Reg 1% (cfs)	% Diff
Irwin Creek Watershed							
Irwin Creek							
Approximately 4,700 feet upstream of Nevins Road	BASIN005C	1.14	1260	1378	9%	1162	16%
Approximately 1,200 feet upstream of Nevins Road	BASIN008C	2.05	1,580	1534	-3%	1649	-7%
Approximately 700 feet upstream of Dalecrest Drive	Basin010C	3.41	2,220	2570	16%	2370	8%
Approximately 1,200 feet upstream of Starita Road	Basin015C	4.90	2,870	3246	13%	3083	5%
Approximately 2,400 feet downstream of I-85 Service Road	BASIN016C	5.16	3,230	3663	13%	3191	13%
Approximately 400 feet upstream of I-277	Basin026C	11.24	6,400	6978	9%	5350	23%
Approximately 200 feet upstream of Remount Road	Basin033C	24.20	9,000	11676	30%	8698	25%
Confluence with Taggart Creek	Basin051C	30.97	12,300	12332	0%	10100	18%
Irwin Creek Tributary 1							
At confluence with Irwin Creek	Basin476C	1.16	2,570	2456	-4%	1588	35%
Kennedy Branch							
At confluence with Irwin Creek	Basin339C	3.29	3,001	3000	0%	2639	12%
Approximately 2,600 ft. upstream Confluence with Irwin Creek	Basin333C	1.77	1,774	1633	-8%	1704	-4%
Approximately 200 ft. downstream of Cindy Lane	Basin332C	1.60	1349	1568	16%	1603	-2%
Approximately 300 ft. downstream of Slater Road	Basin331C	1.43	948	1554	64%	1517	2%
Stewart Creek							
At Confluence with Irwin Creek	Basin384C	11.20	3,513	6184	76%	5502	11%
Approximately 400 ft. downstream of Rozzelles Ferry Road	Basin379C	9.00	2,636	5802	120%	4738	18%

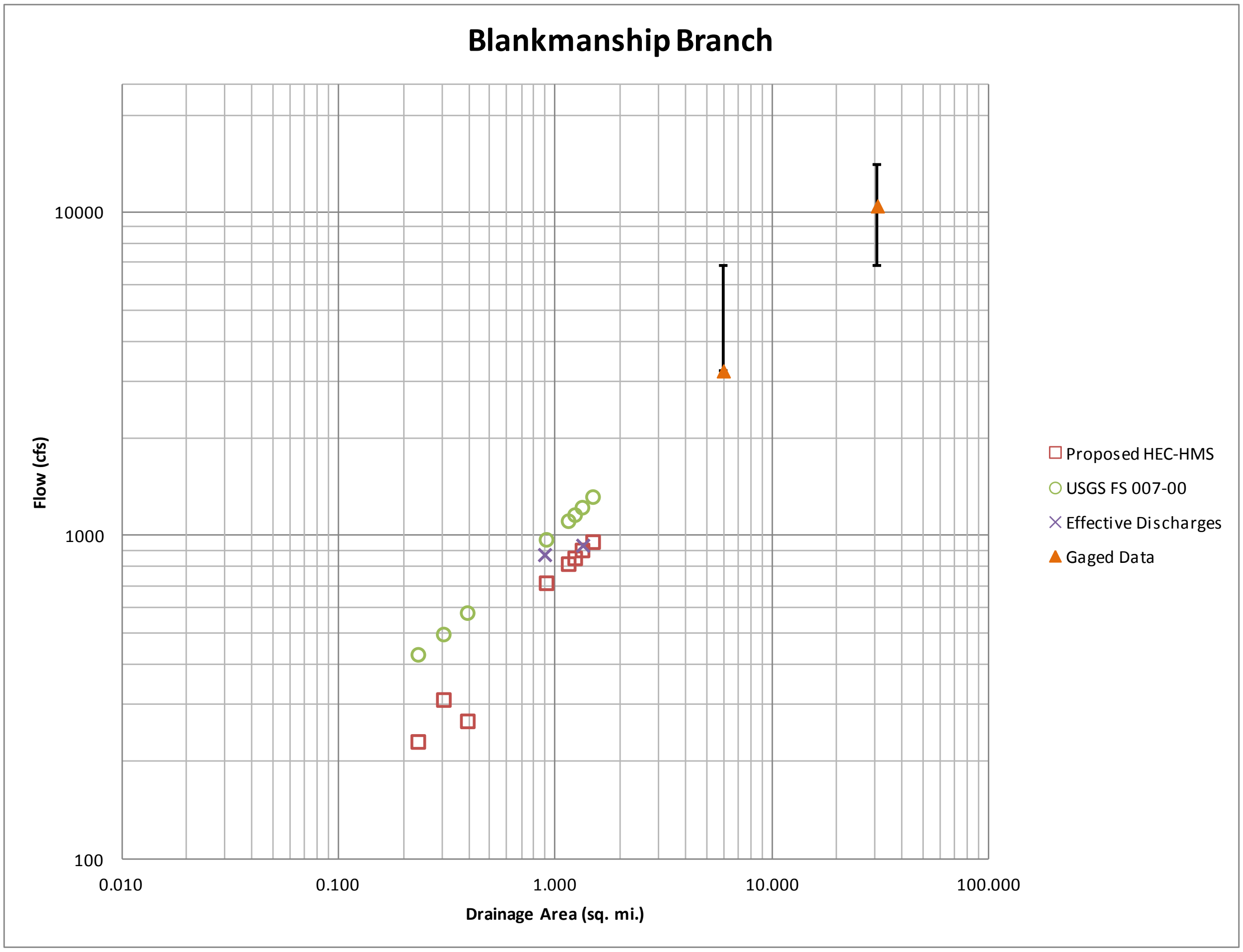
Flooding Source and Location	Basin ID	Updated DA (mi2)	Eff 1% (cfs)	Prelim 1% (cfs)	% Diff	Reg 1% (cfs)	% Diff
Approximately 300 ft. upstream of Southwest Boulevard	Basin370C	5.12	1536	4929	221%	3343	32%
Approximately 2,400 ft. upstream of Hoskins Road	Basin362C	1.29	802	1936	141%	1133	41%
Stewart Creek Tributary 1							
At confluence with Stewart Creek	Basin423C	1.44	2,544	2774	9%	1776	36%
Stewart Creek Tributary 2							
At Confluence with Stewart Creek	Basin444C	2.24	2,617	3472	33%	2112	39%
Approximately 200 ft. upstream of Barlowe Road	Basin438C	0.91	1068	1336	25%	1204	10%
Stewart Creek Tributary 3							
At Confluence with Stewart Creek	Basin461C	1.37	1,814	1626	-10%	1658	-2%
Approximately 100 ft. downstream of Hoskins Road	Basin459C	0.98	1198	1192	-1%	1309	-10%
Sugar Creek Watershed							
Coffey Creek							
Approximately 1,900 feet upstream of West Boulevard	Basin607C	2.32	2,774	2458	-11%	2771	-13%
Approximately 700 feet upstream of West Boulevard	Basin567C	2.87	2,931	2740	-7%	3012	-10%
Approximately 600 feet downstream of Piney Top Drive	Basin570C	4.02	3,024	3524	17%	3516	0%
Approximately 6,700 feet upstream of Shopton Road	Basin577C	6.07	3,359	3785	13%	4091	-8%
Confluence with Sugar Creek	Basin596C	10.63	3,452	4155	20%	5488	-32%
Kings Branch							
At Confluence with Sugar Creek	Basin698C	4.38	1,488	2941	98%	3225	-10%
Approximately 1,000 ft. downstream of Kings Branch Court	Basin688C	2.55	1,240	3166	155%	2425	23%
Approximately 200 ft. upstream of Archdale Drive	Basin681C	1.36	1,060	2241	111%	1734	22%

Flooding Source and Location	Basin ID	Updated DA (mi2)	Eff 1% (cfs)	Prelim 1% (cfs)	% Diff	Reg 1% (cfs)	% Diff
Approximately 200 ft. downstream of I-77	Basin679C	0.76	610	1148	88%	1159	-1%
McCullough Branch							
At Confluence with Sugar Creek	Basin732C	2.22	1,253	1391	11%	1970	-42%
Approximately 500 ft. downstream of Nations Ford Road	Basin727C	1.48	1,248	1220	-2%	1627	-33%
Sugar Creek							
At County Line	Basin102C	68.78	13,469	16994	26%	16214	5%
Approximately 2,800 ft. upstream of I-77	Basin076C	44.33	11,686	14367	23%	12460	13%
Taggart Creek							
At Confluence with Sugar Creek	Basin503C	6.59	2,346	5120	118%	4190	18%
Approximately 900 ft. downstream of West Boulevard	Basin498C	5.03	1,979	4532	129%	3617	20%
Approximately 1,600 ft. downstream of Morris Field Drive	Basin495C	3.96	1,856	3449	86%	3197	7%
Approximately 100 ft. upstream of Winston Container Road	Basin489C	2.70	1,682	1646	-2%	2464	-50%
Approximately 200 ft. downstream of Mulberry Church Road	Basin488C	1.87	1,168	1304	12%	1995	-53%
Approximately 100 ft. upstream of Mulberry Church Road	Basin487C	1.17	909	746	-18%	1561	-109%
Steele Creek Watershed							
Blankmanship Branch							
At County Line	Basin908C	1.50	356	954	168%	1358	-42%
Approximately 3,100 ft. upstream of County Line	Basin904C	0.92	354	712	101%	971	-36%
Polk Ditch							
At Confluence with Walker Branch	Basin871C	1.63	500	1383	177%	1665	-20%
Approximately 4,900 ft. upstream of Confluence	Basin867C	0.92	395	748	89%	1204	-61%

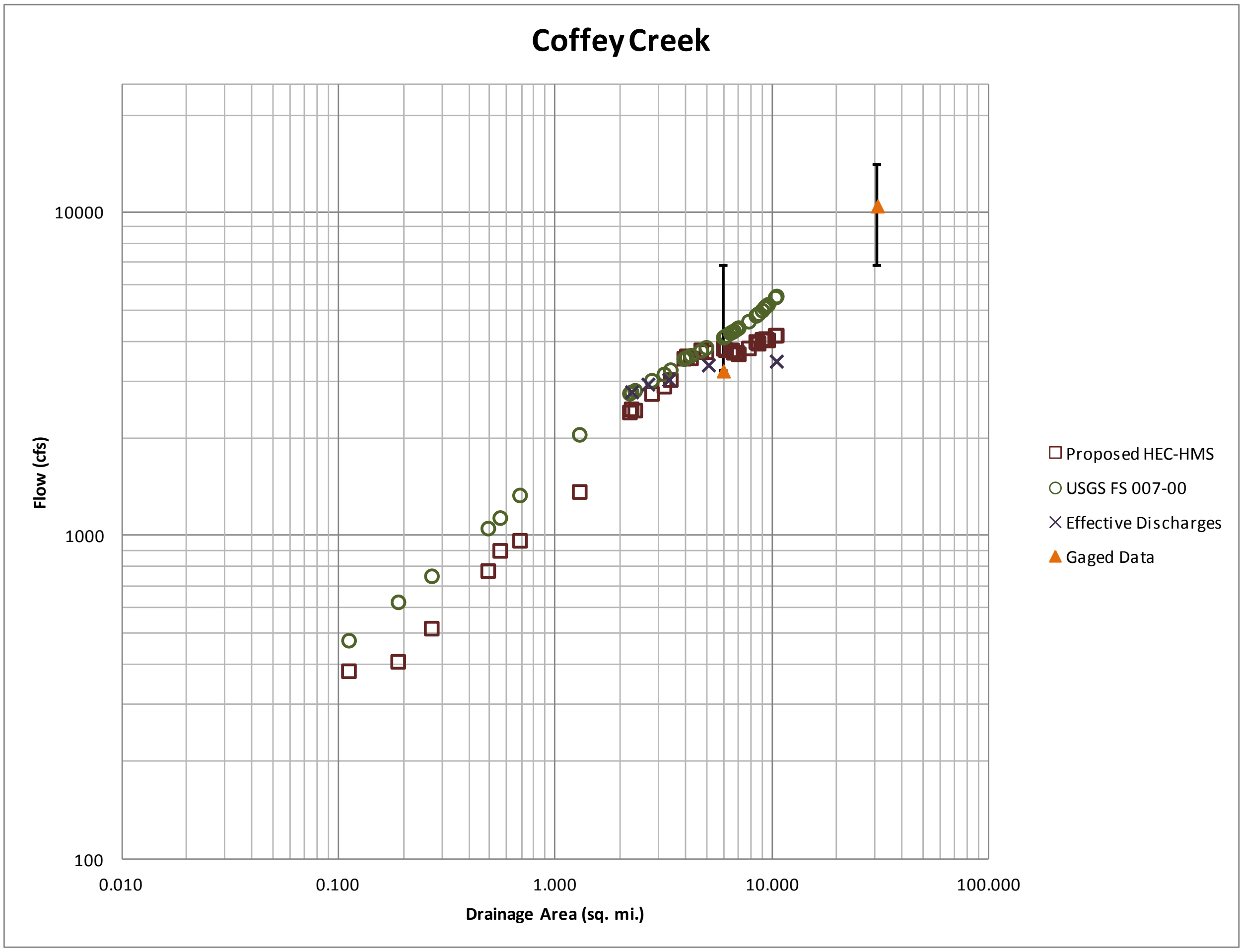
Flooding Source and Location	Basin ID	Updated DA (mi2)	Eff 1% (cfs)	Prelim 1% (cfs)	% Diff	Reg 1% (cfs)	% Diff
Steele Creek							
At County Line	Basin771C	14.63	2,791	7970	186%	6125	23%
Approximately 210 ft. upstream of County Line	Basin770C	7.54	1,700	3690	117%	4377	-19%
Approximately 800 ft. upstream of John Price Road	Basin756C	3.70	1,193	2376	99%	2749	-16%
Approximately 100 ft. upstream of Arrowwood Appt. Road	Basin755C	2.87	957	2032	112%	2285	-12%
Approximately 1,800 ft. downstream of Red Hickory Lane	Basin751C	1.59	639	1264	98%	1498	-19%
Approximately 600 ft. upstream of Red Hickory Lane	Basin750C	1.27	485	1124	132%	1250	-11%
Approximately 1,200 ft. downstream of Brown Grier Road	Basin749C	0.57	257	523	103%	712	-36%
Walker Branch							
At Confluence with Steele Creek	Basin841C	7.07	1,193	4551	281%	3701	19%
Approximately 750 ft. upstream of Confluence	Basin839C	4.93	997	3163	217%	2959	6%
Approximately 2,500 ft. downstream of Hwy 49	Basin834C	2.37	798	1760	121%	1960	-11%
Walker Branch Tributary							
At Confluence with Walker Branch	Basin886C	1.65	434	1549	257%	1513	2%

Appendix C

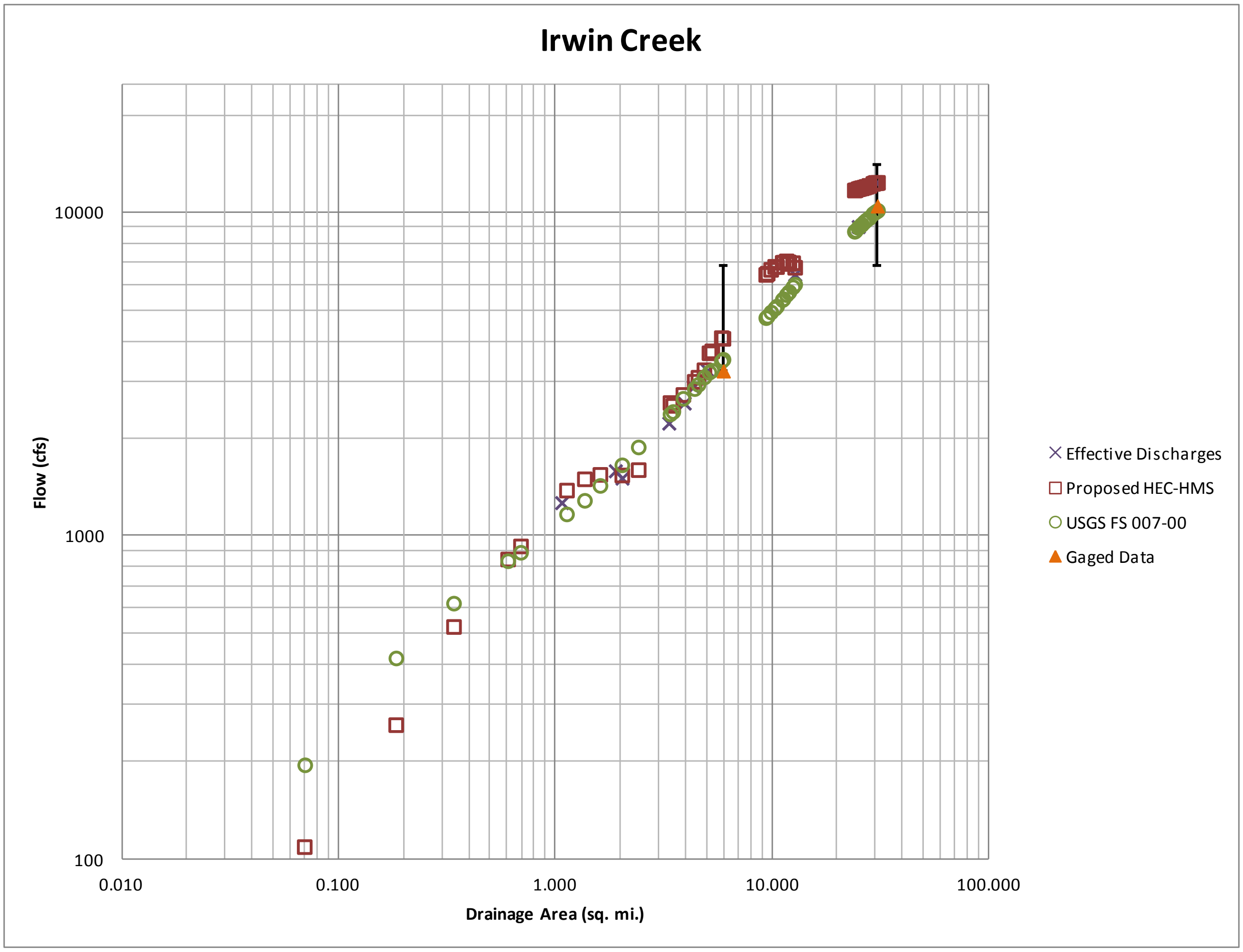
Main Channel HEC-HMS Model Discharges for the 1% Annual Event



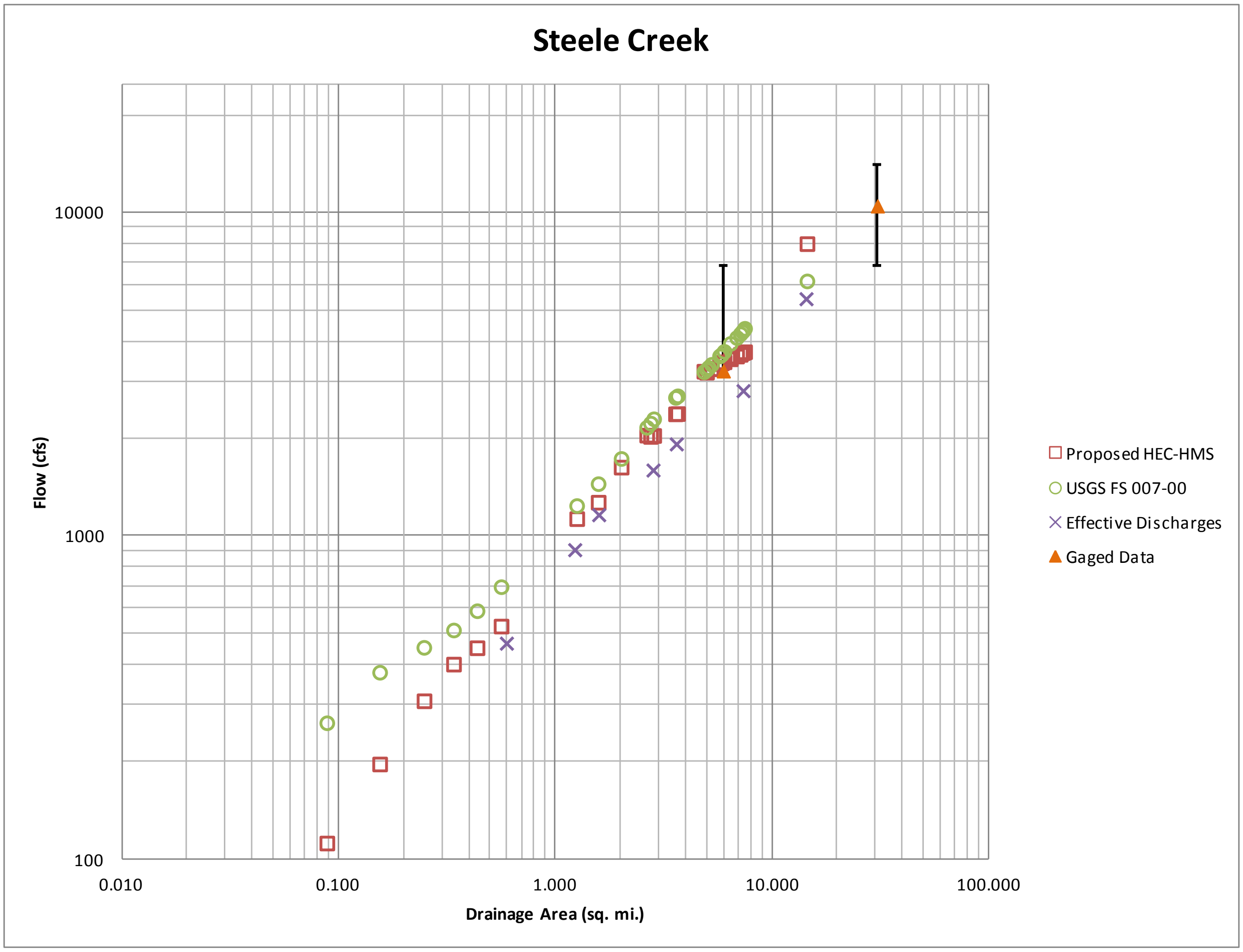
PRELIMINARY



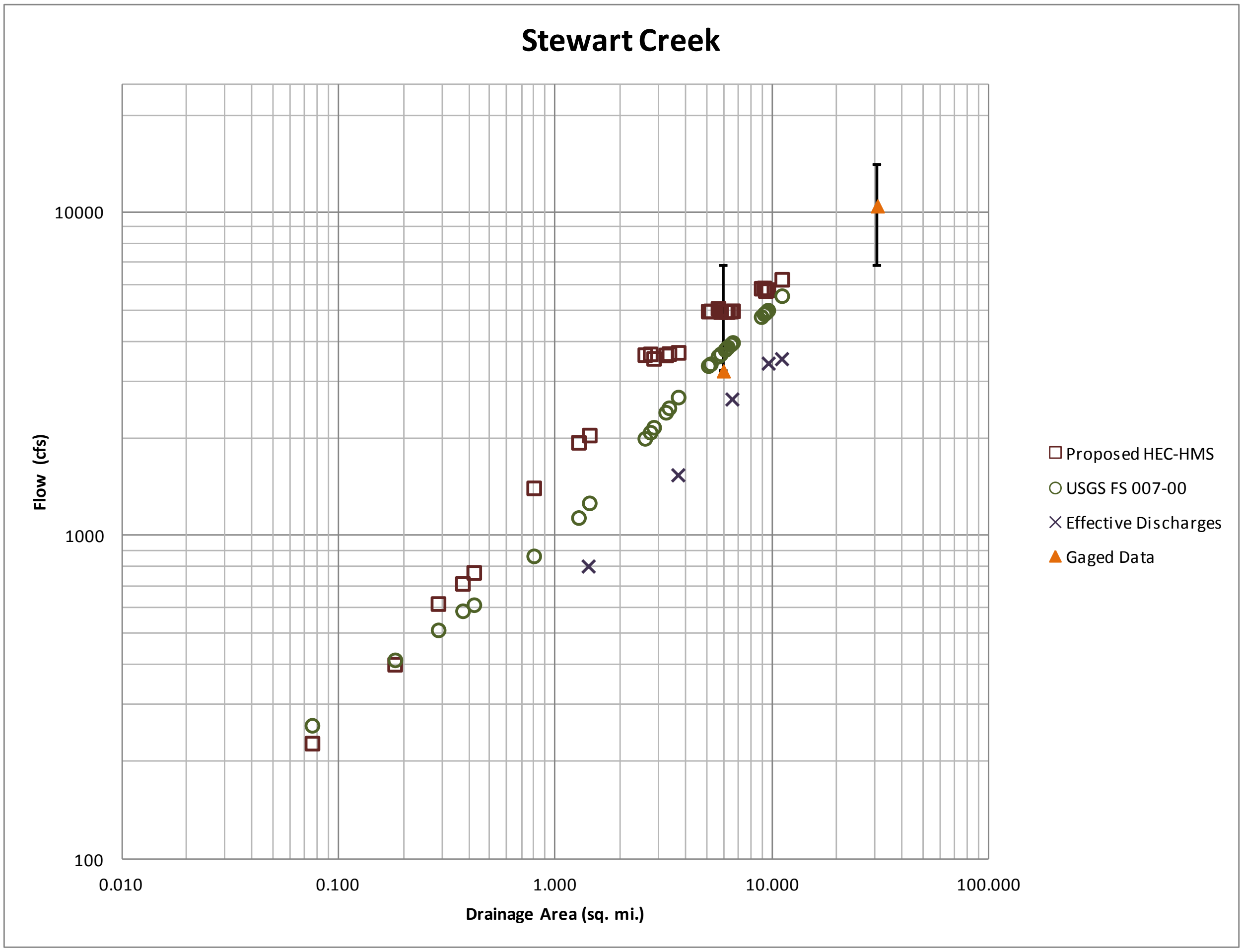
PRELIMINARY



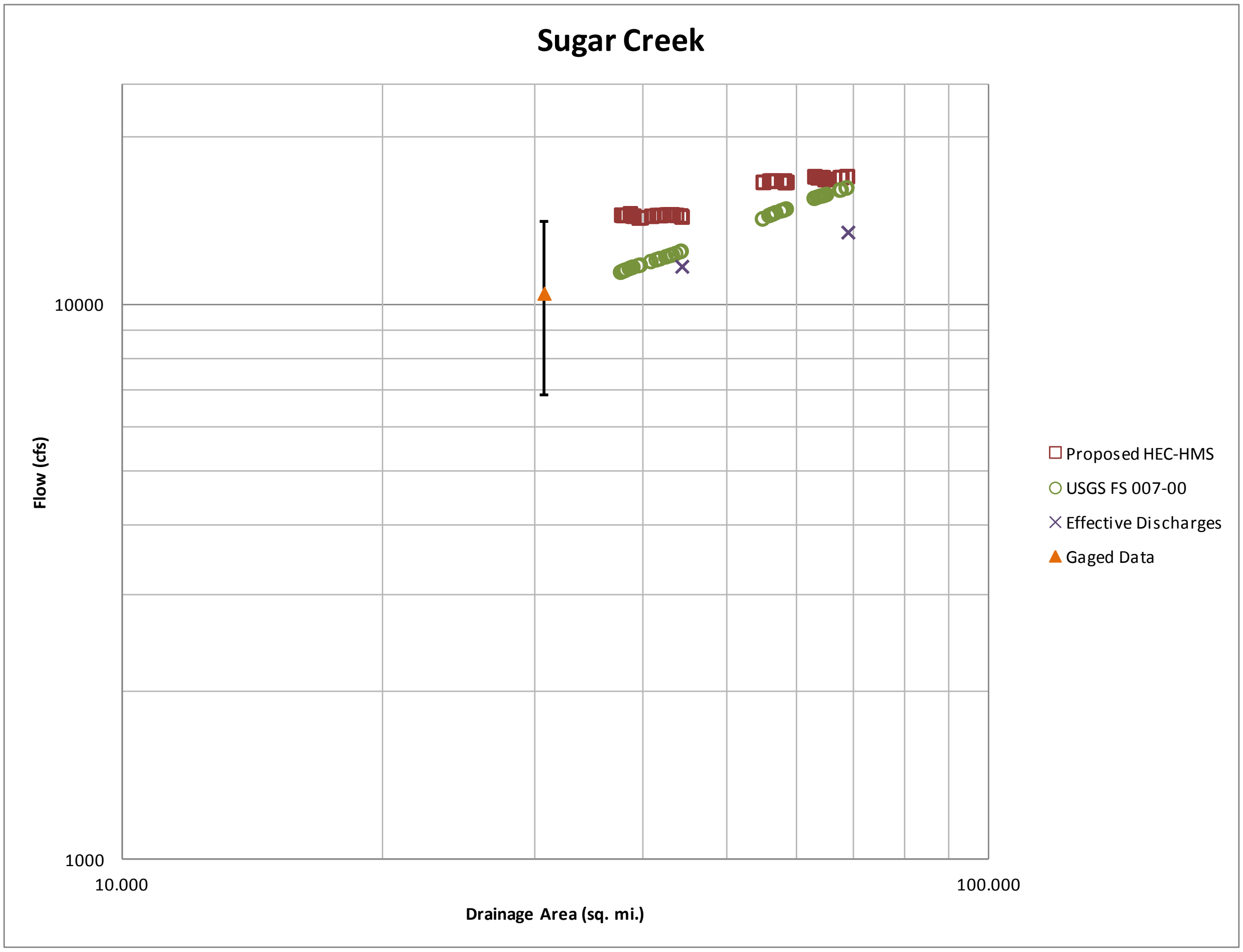
Irwin Creek
Flow (cfs)
10000
1000
100
0.010
0.100
1.000
10.000
100.000
Drainage Area (sq. mi.)
Effective Discharges
Proposed HEC-HMS
USGS FS 007-00
Gaged Data



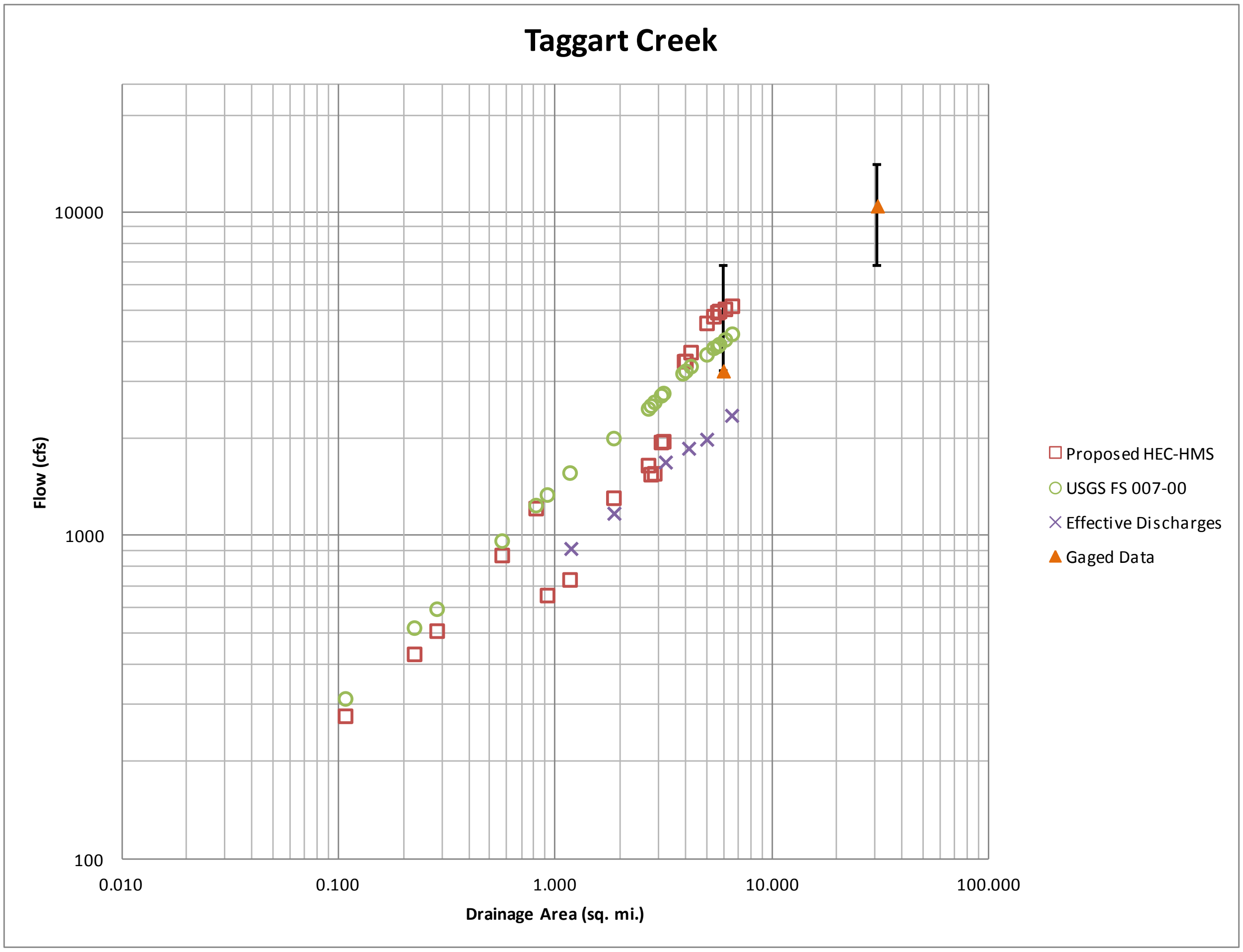
Steele Creek
10000
1000
100
Flow (cfs)
0.010
0.100
1.000
10.000
100.000
Drainage Area (sq. mi.)
Proposed HEC-HMS
USGS FS 007-00
Effective Discharges
Gaged Data



PRELIMINARY

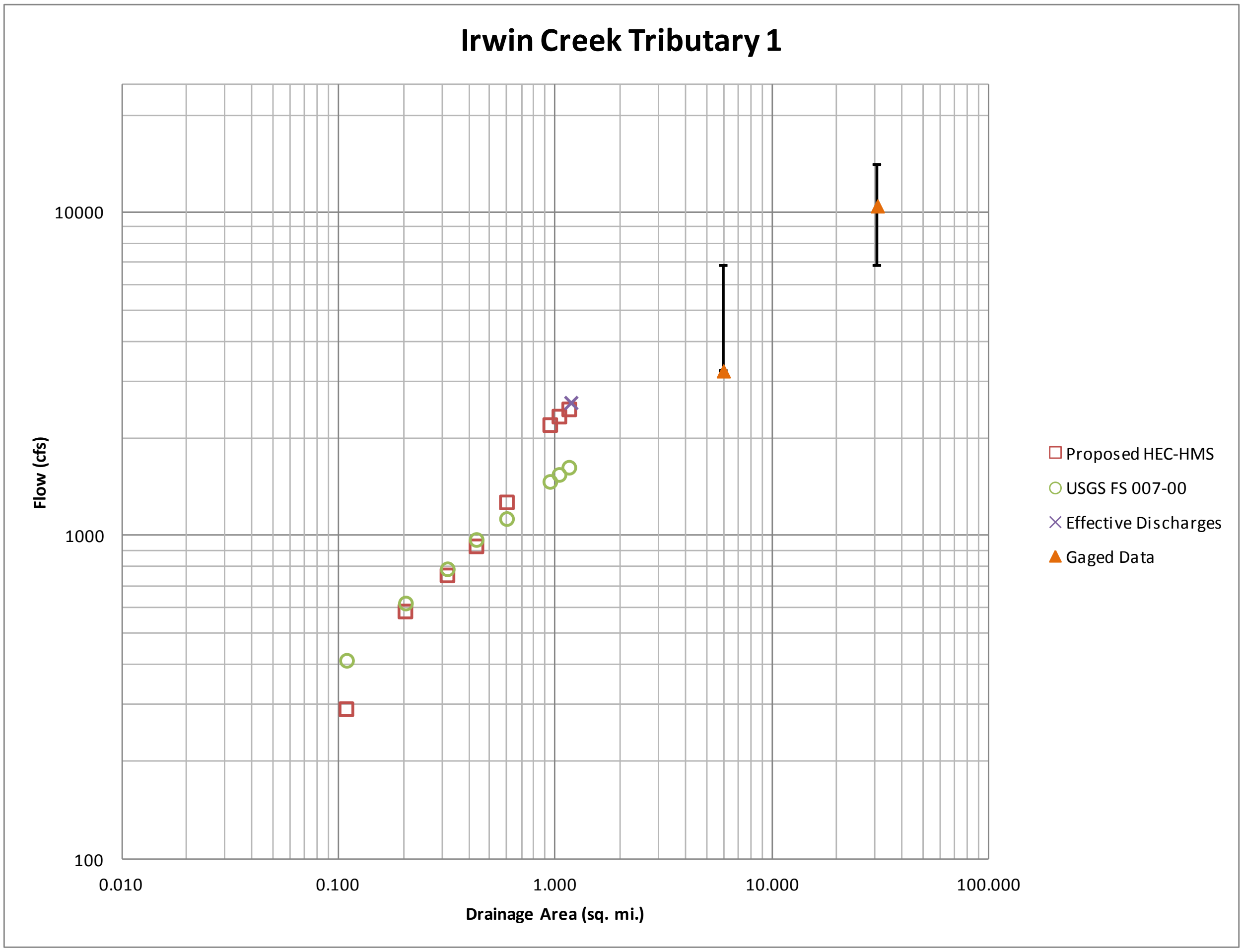


Sugar Creek
10000
1000
Flow (cfs)
10.000
100.000
Drainage Area (sq. mi.)
Proposed HEC-HMS
USGS FS 007-00
Effective Discharges
Gaged Data

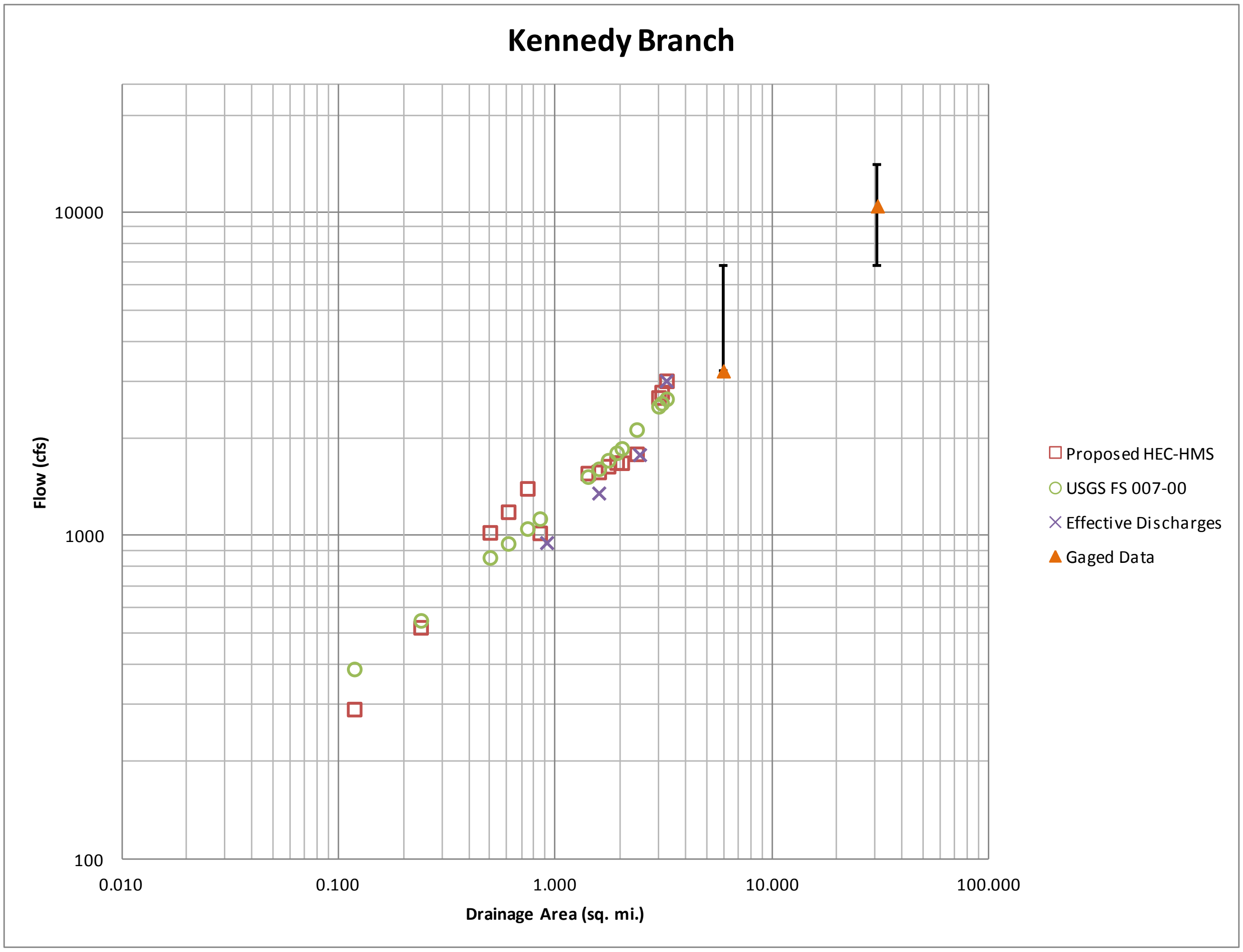


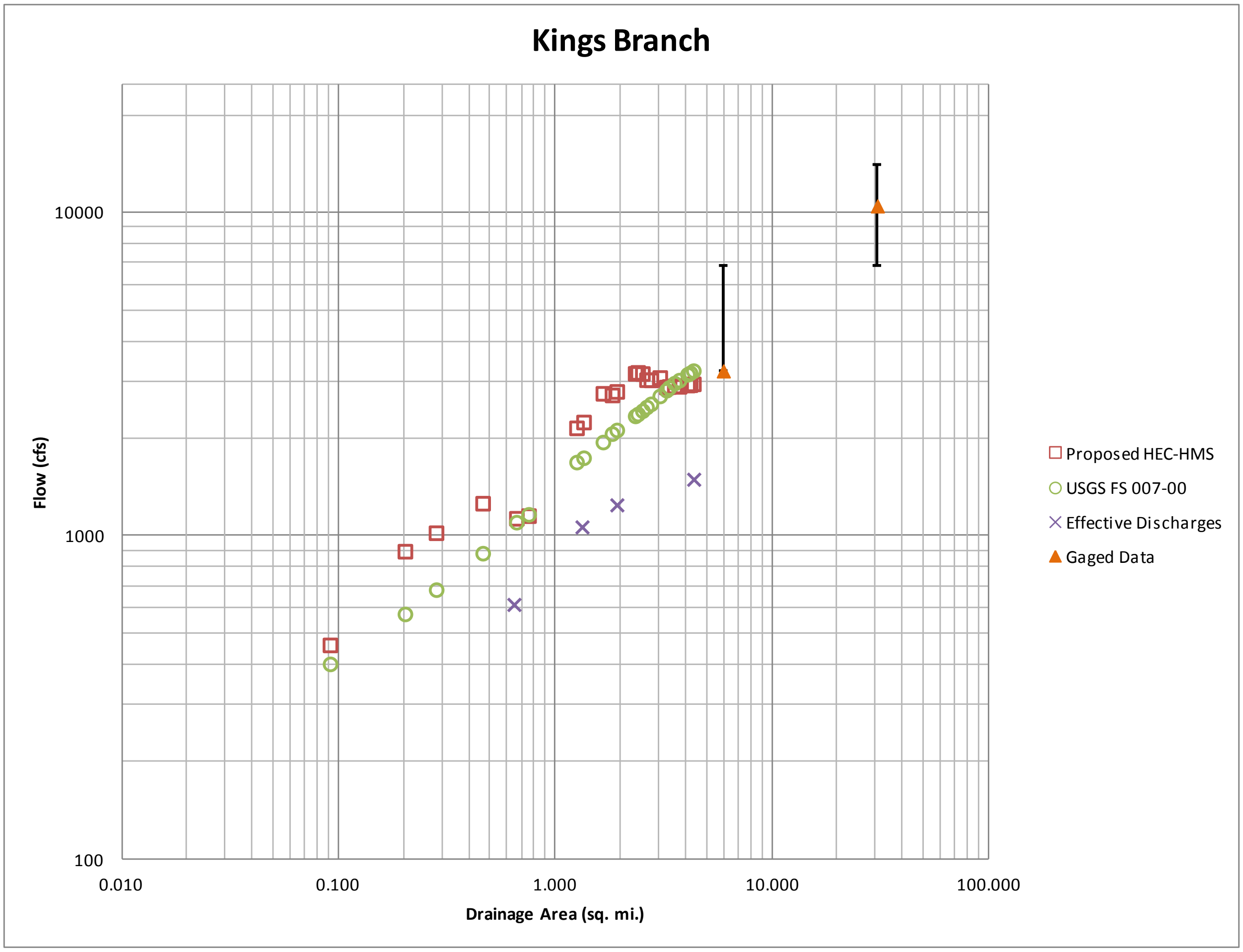
PRELIMINARY

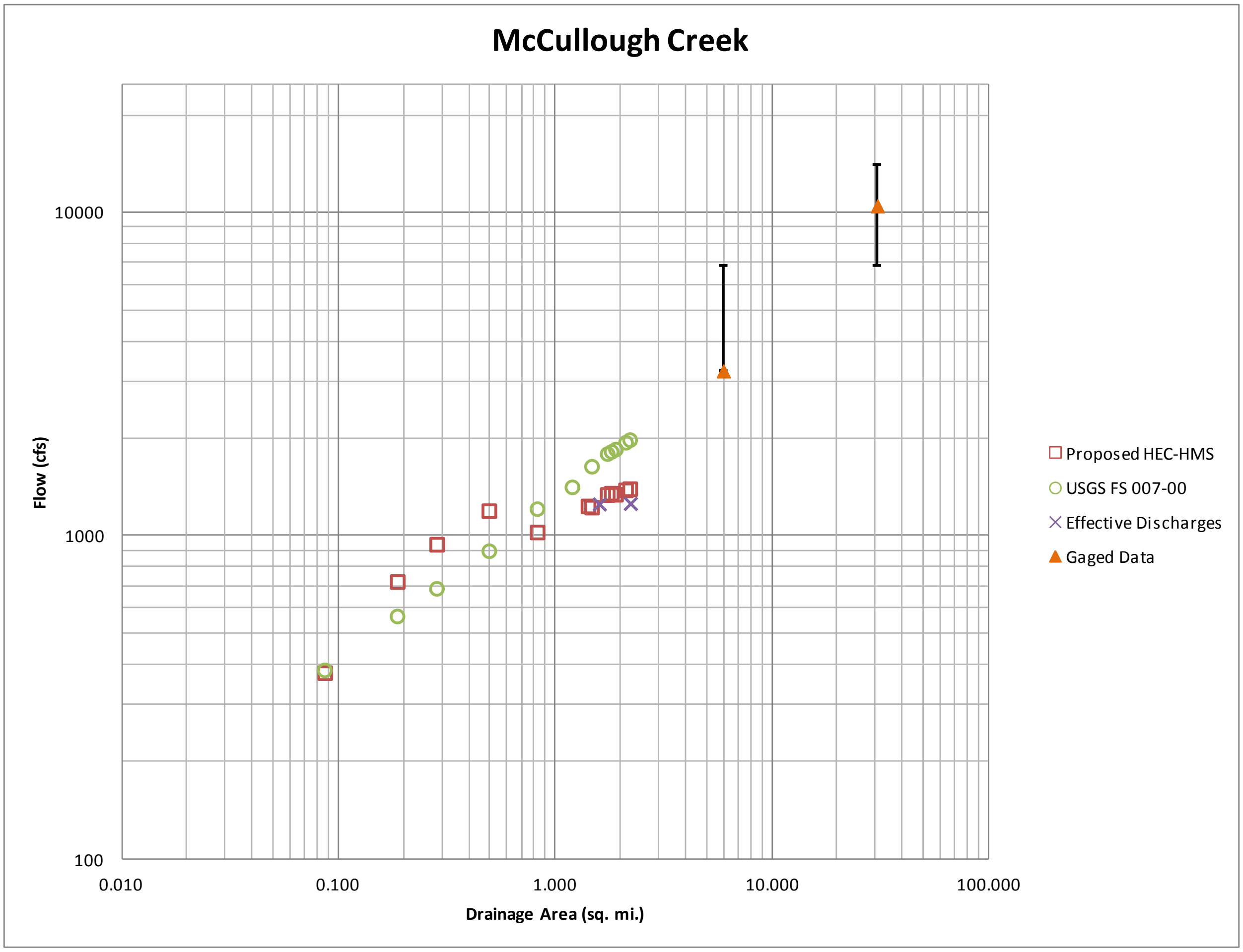
Tributary Streams HEC-HMS Model Discharges for the 1% Annual Storm Event

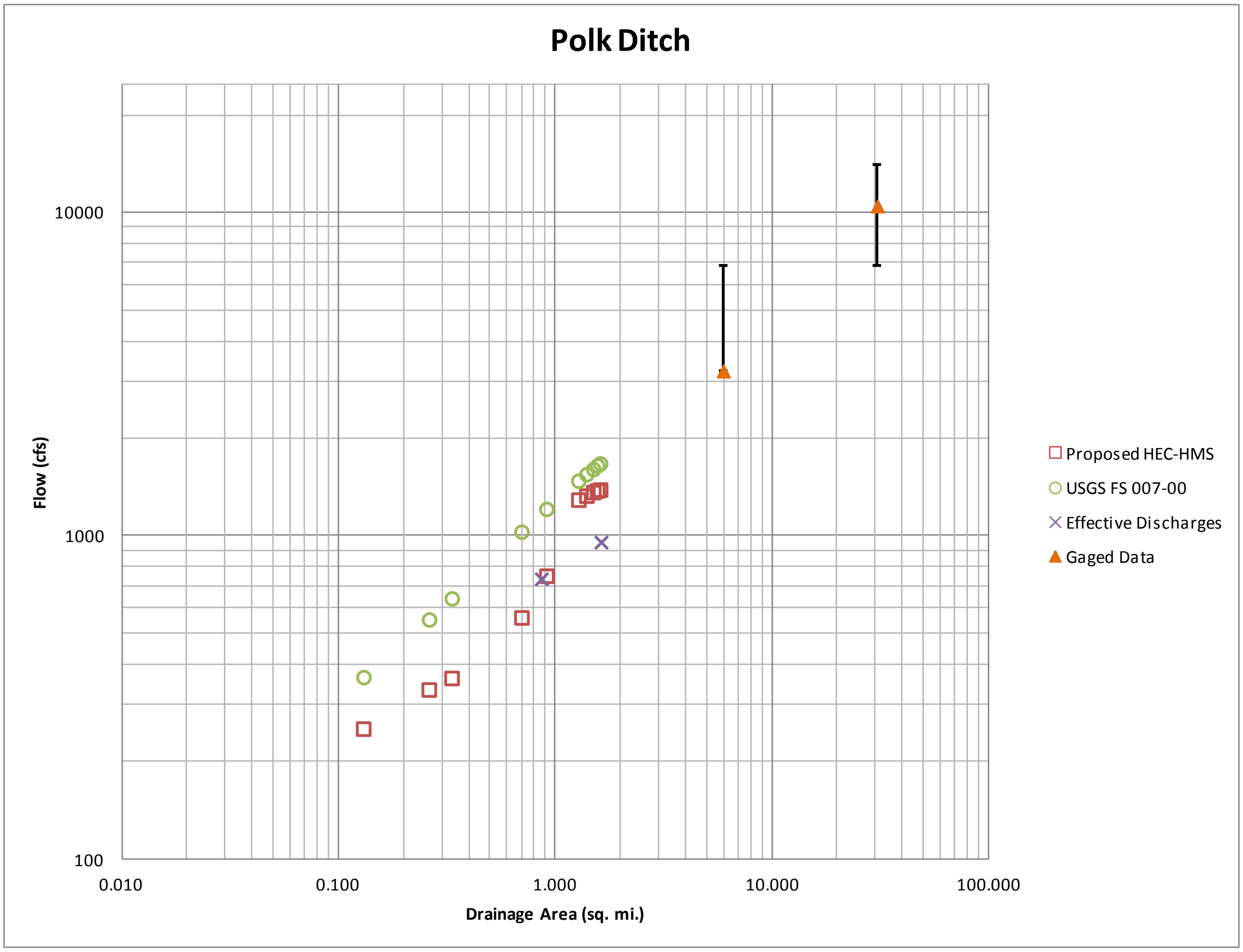


PRELIMINARY

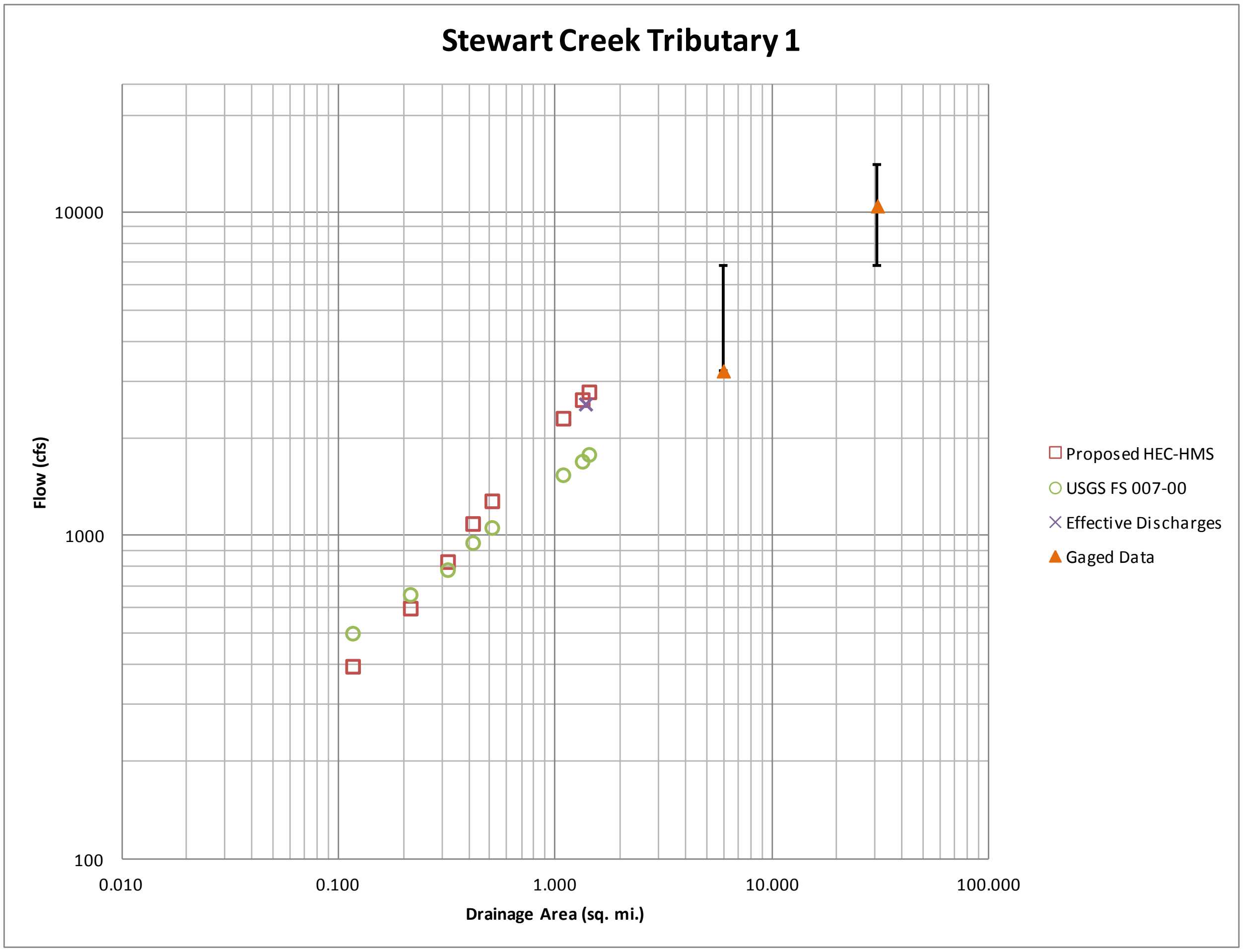

Kennedy Branch
10000
1000
100
0.010
0.100
1.000
10.000
100.000
Flow (cfs)
Drainage Area (sq. mi.)
Proposed HEC-HMS
USGS FS 007-00
Effective Discharges
Gaged Data


Kings Branch
Flow (cfs)
10000
1000
100
0.010
0.100
1.000
10.000
100.000
Drainage Area (sq. mi.)
Proposed HEC-HMS
USGS FS 007-00
Effective Discharges
Gaged Data

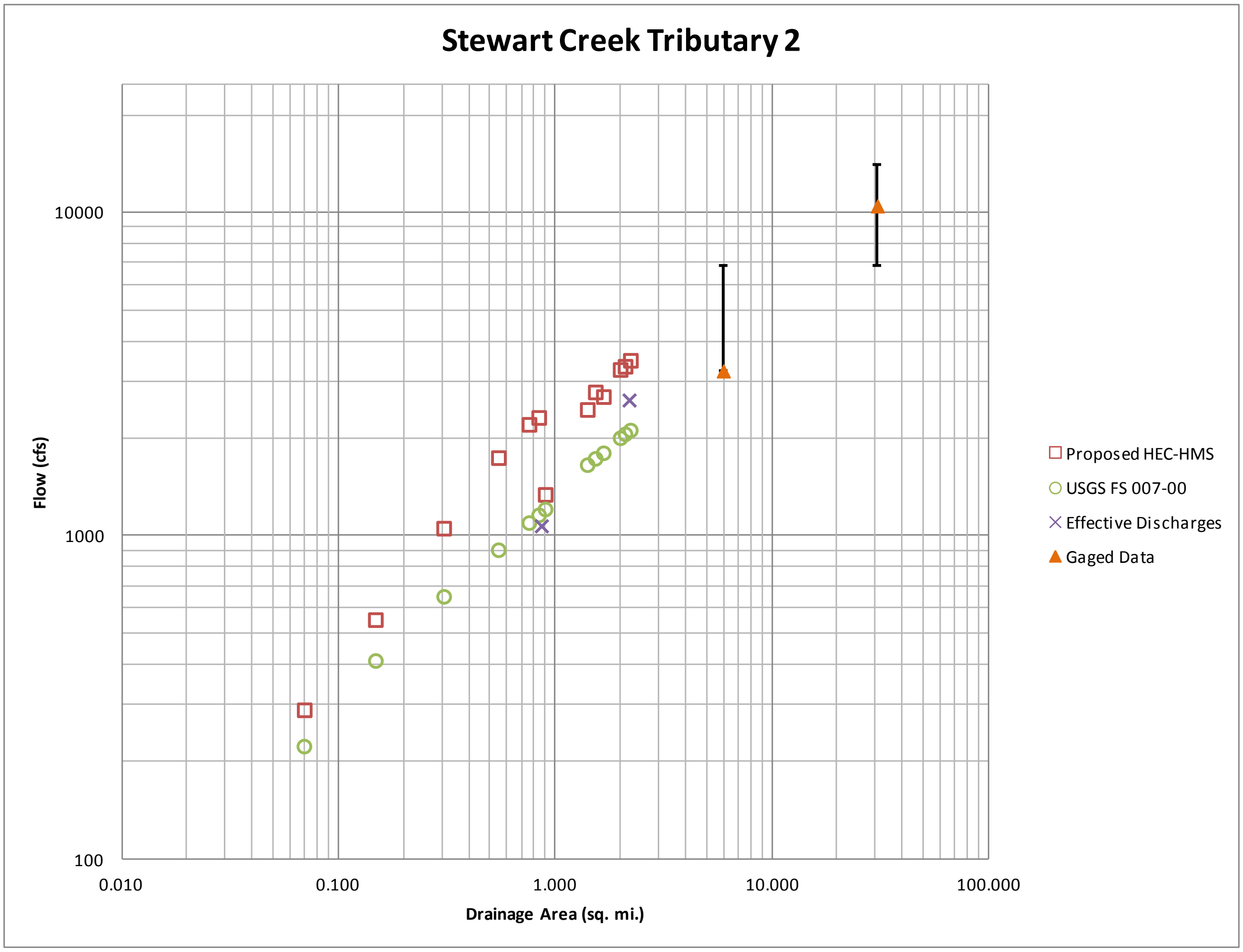

McCullough Creek
Flow (cfs)
10000
1000
100
0.010
0.100
1.000
10.000
100.000
Drainage Area (sq. mi.)
Proposed HEC-HMS
USGS FS 007-00
Effective Discharges
Gaged Data



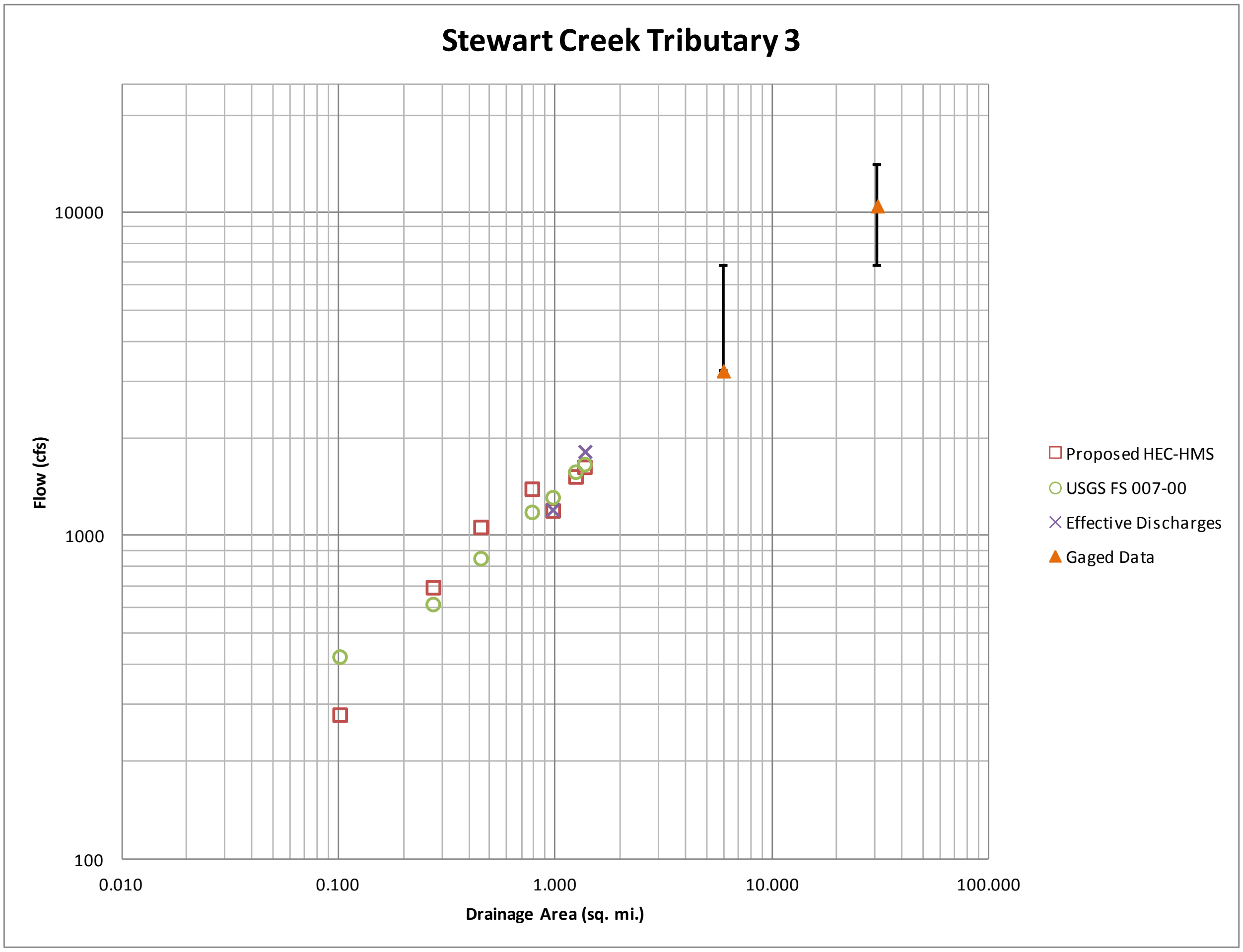
PRELIMINARY



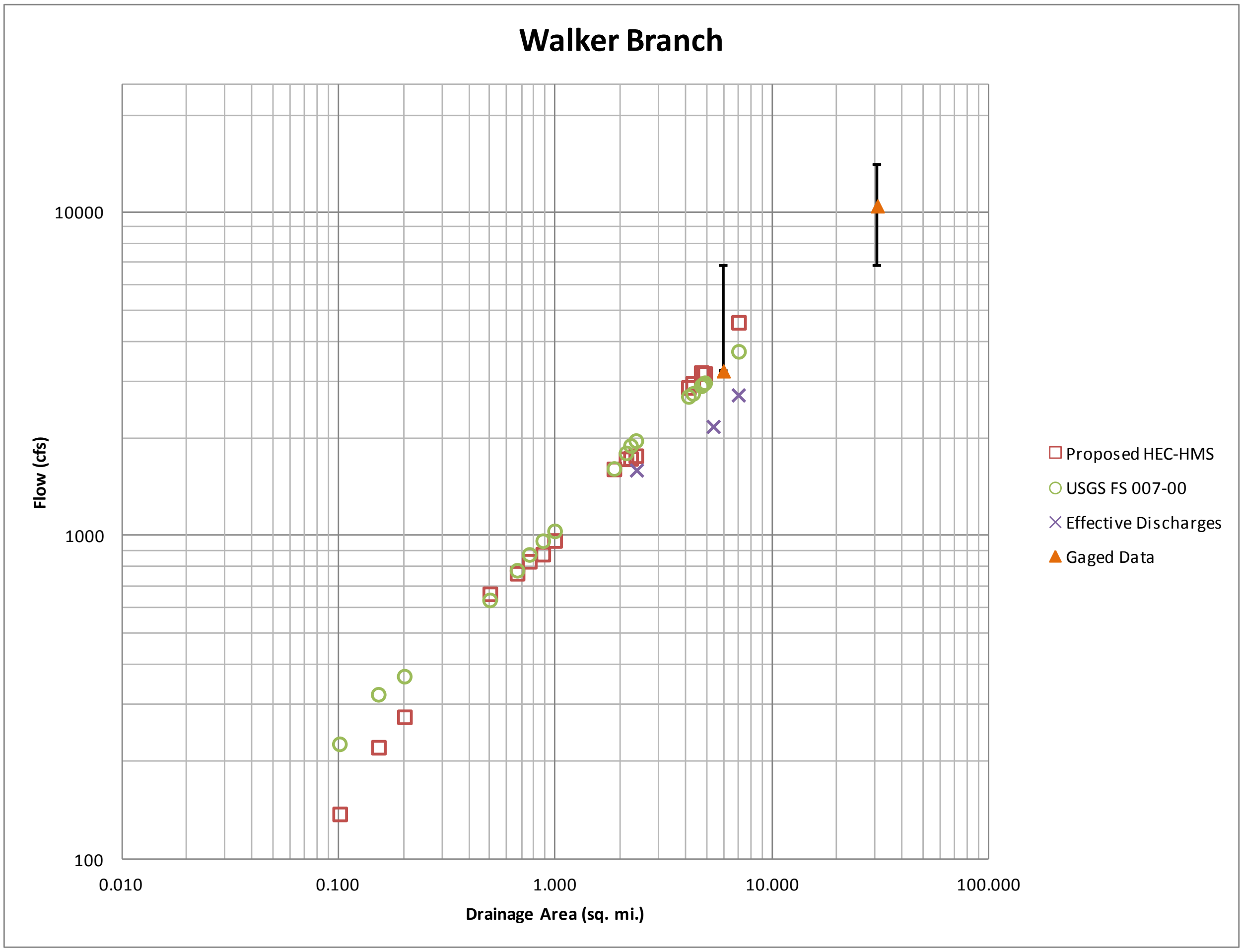
Stewart Creek Tributary 1
Flow (cfs)
10000
1000
100
0.010
0.100
1.000
10.000
100.000
Drainage Area (sq. mi.)
Proposed HEC-HMS
USGS FS 007-00
Effective Discharges
Gaged Data



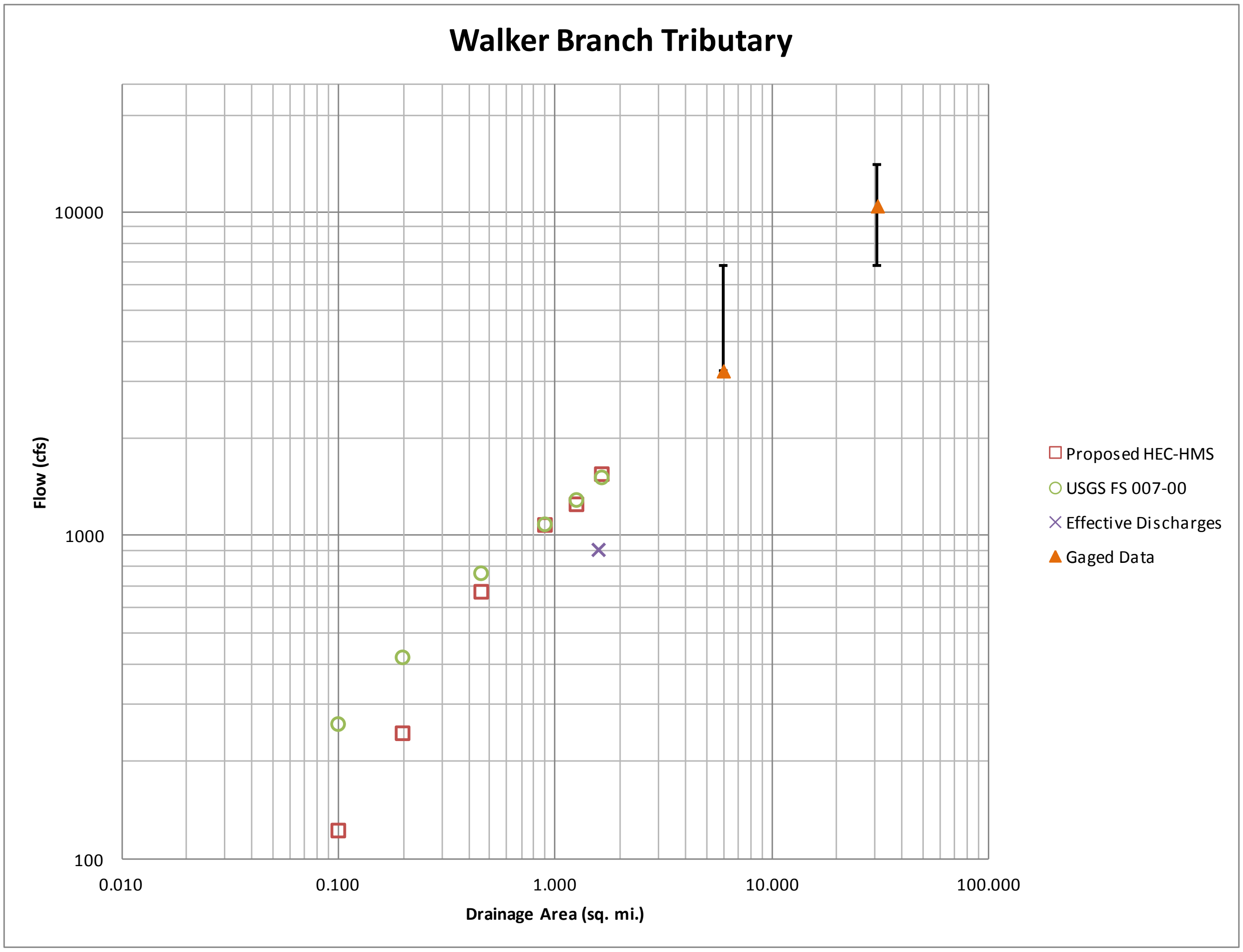
Stewart Creek Tributary 2
10000
1000
100
Flow (cfs)
0.010
0.100
1.000
10.000
100.000
Drainage Area (sq. mi.)
Proposed HEC-HMS
USGS FS 007-00
Effective Discharges
Gaged Data



PRELIMINARY



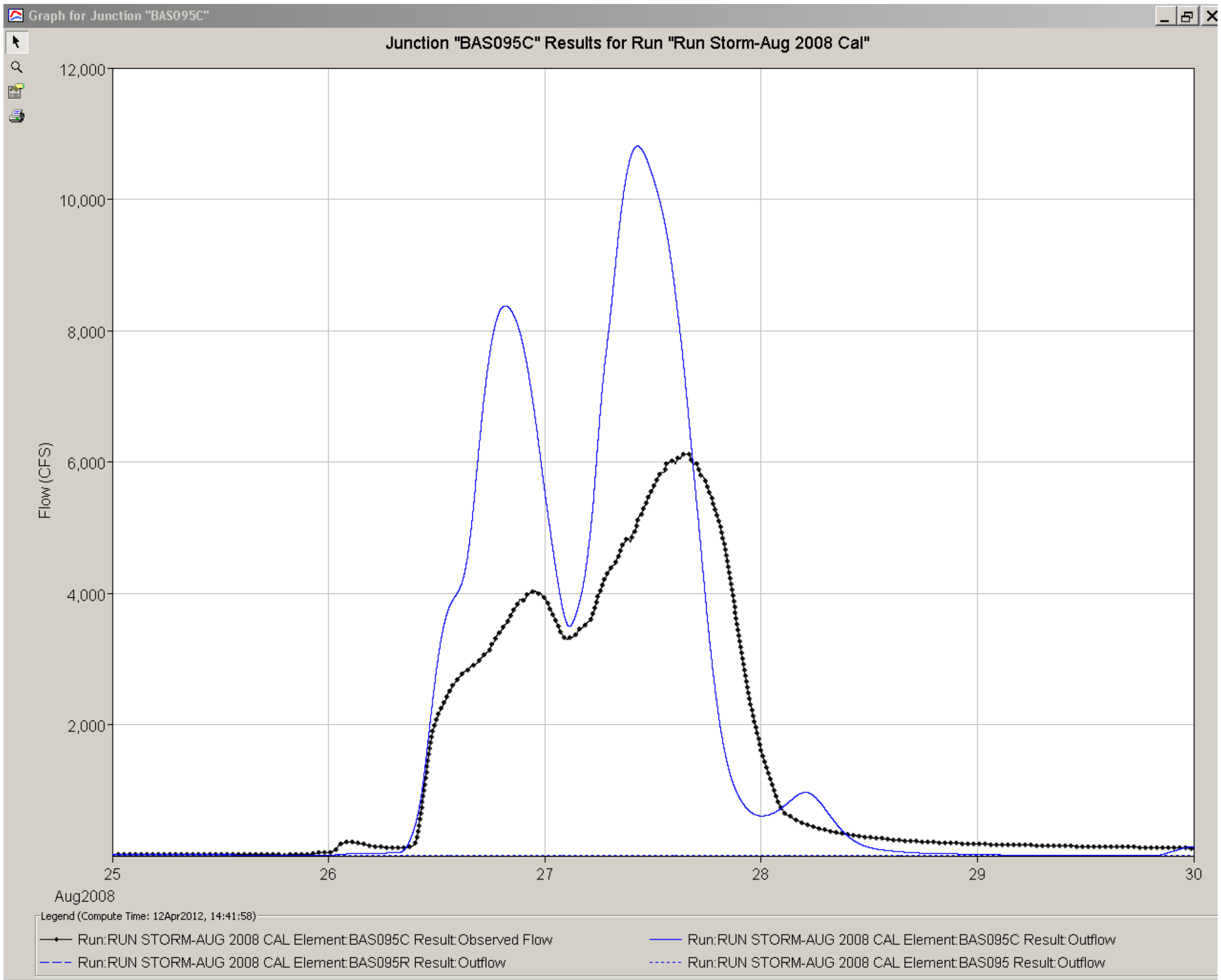
Walker Branch
Flow (cfs)
10000
1000
100
0.010
0.100
1.000
10.000
100.000
Drainage Area (sq. mi.)
Proposed HEC-HMS
USGS FS 007-00
Effective Discharges
Gaged Data



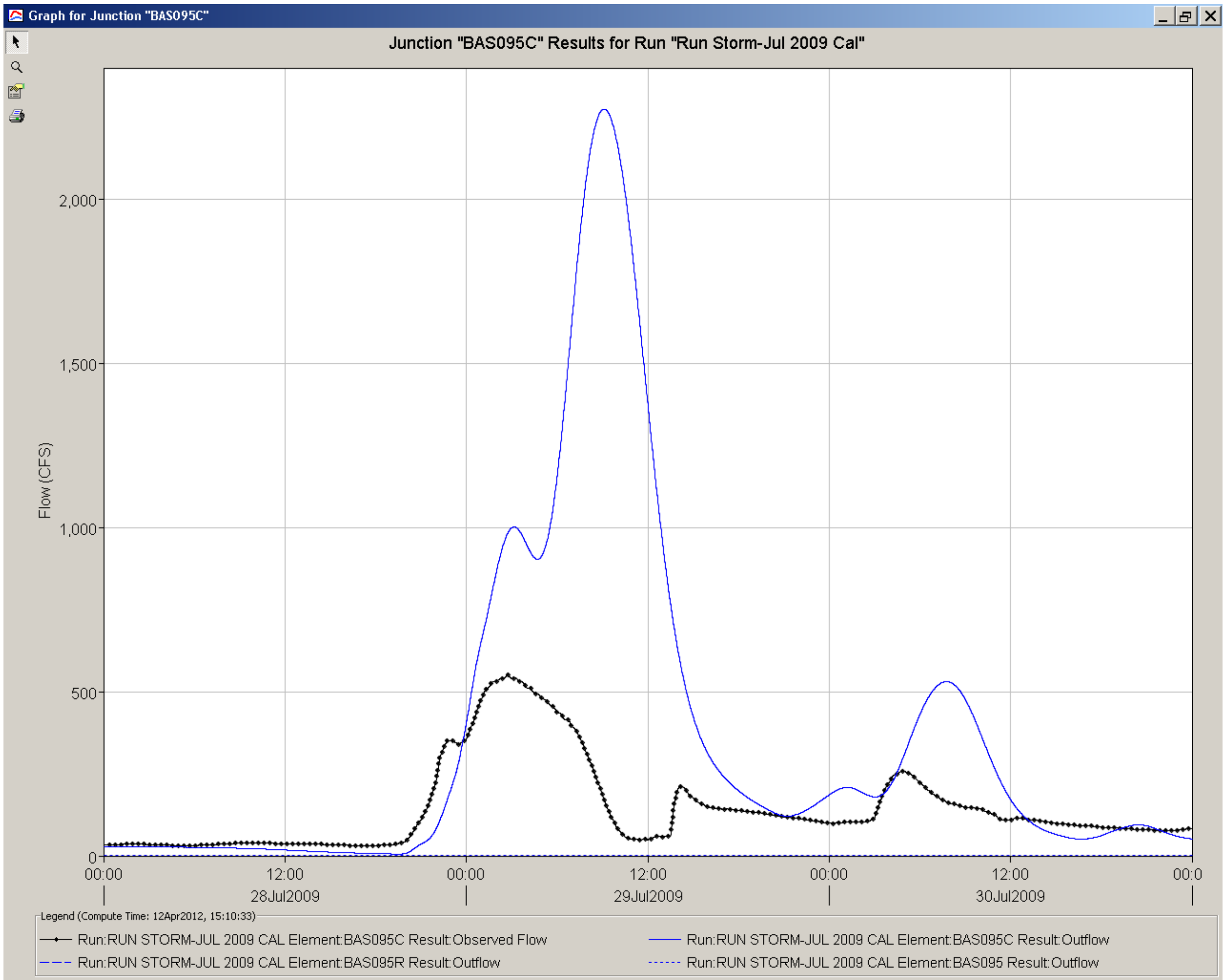
Walker Branch Tributary
Flow (cfs)
10000
1000
100
0.010
0.100
1.000
10.000
100.000
Drainage Area (sq. mi.)
Proposed HEC-HMS
USGS FS 007-00
Effective Discharges
Gaged Data

Appendix D

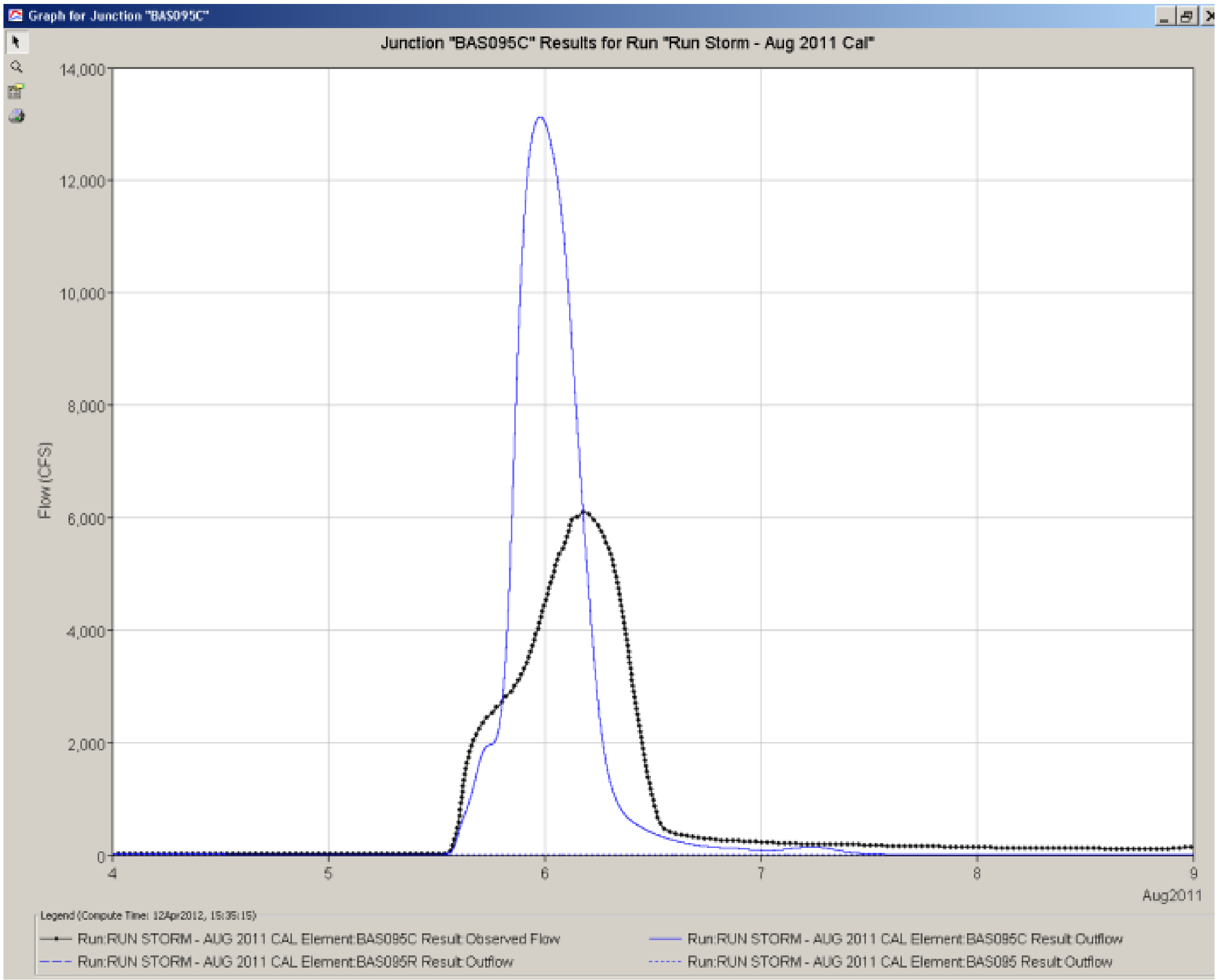
Sugar Creek



Aug 2008

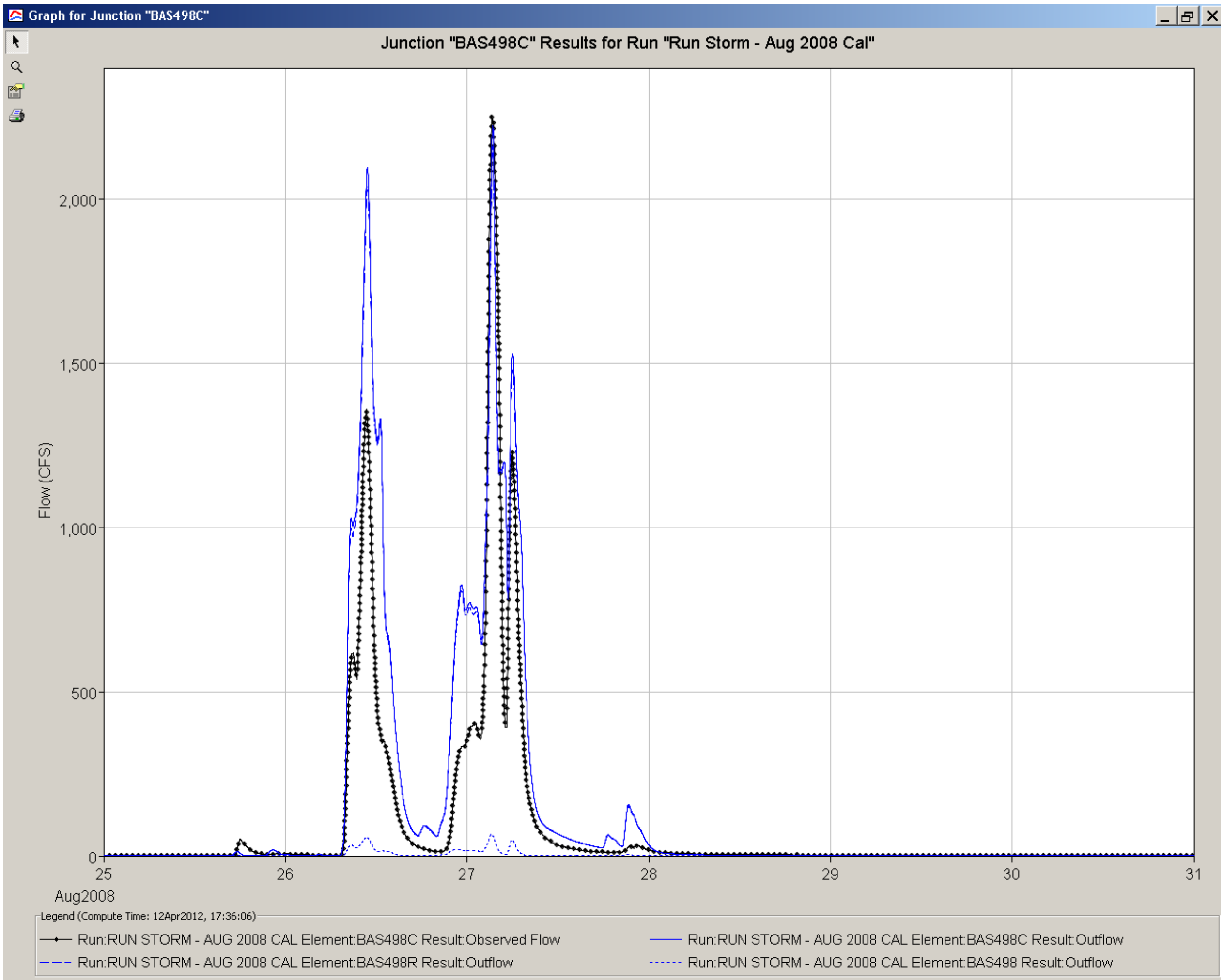

Graph for Junction "BAS095C"
Junction "BAS095C" Results for Run "Run Storm-Jul 2009 Cal"
Flow (CFS)
2,000
1,500
1,000
500
0
00:00
12:00
28Jul2009
00:00
12:00
29Jul2009
00:00
12:00
30Jul2009
00:0
Legend (Compute Time: 12Apr2012, 15:10:33)
Run:RUN STORM-JUL 2009 CAL Element:BAS095C Result:Observed Flow
Run:RUN STORM-JUL 2009 CAL Element:BAS095C Result:Outflow
Run:RUN STORM-JUL 2009 CAL Element:BAS095R Result:Outflow
Run:RUN STORM-JUL 2009 CAL Element:BAS095 Result:Outflow

Jul 2009

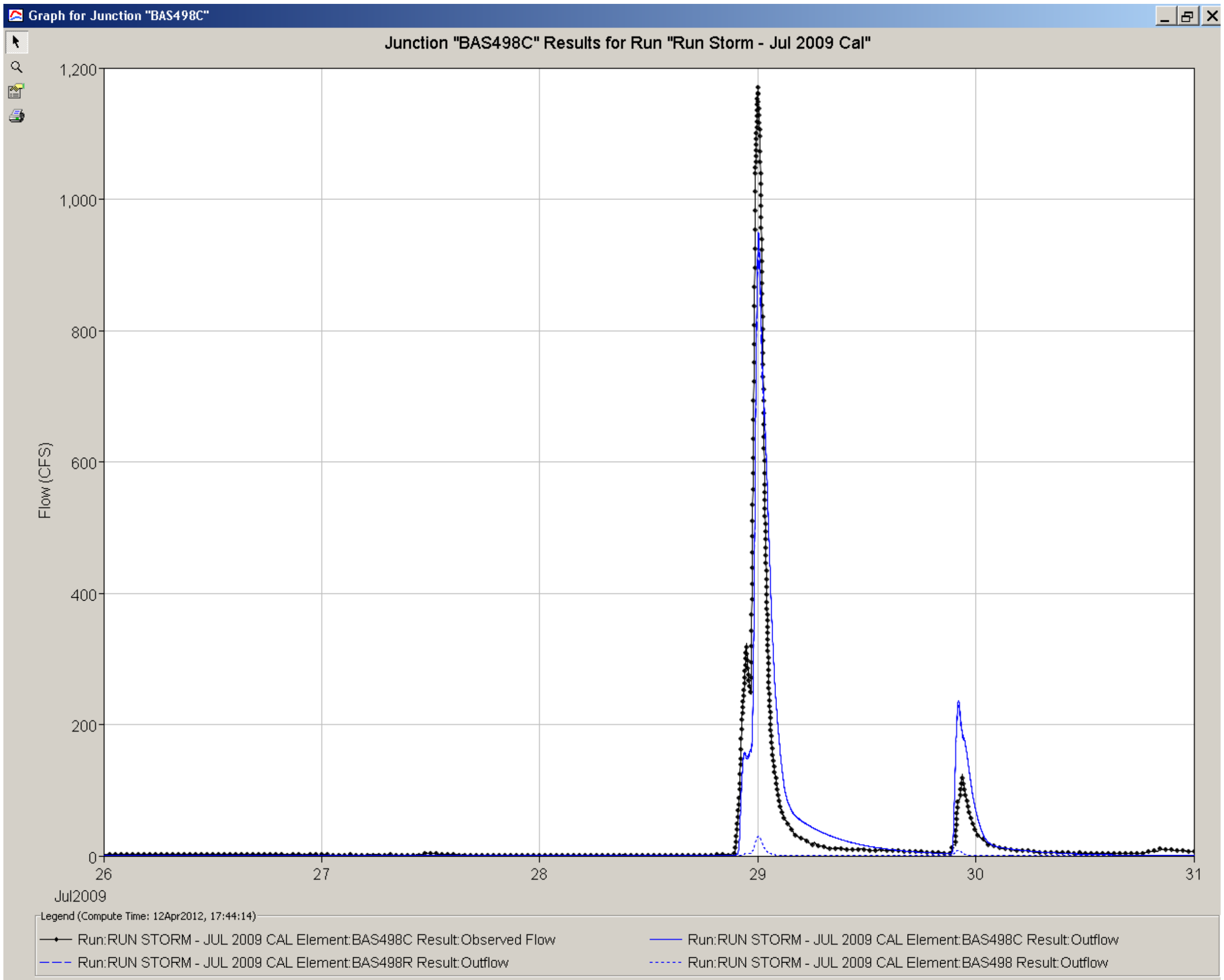

Graph for Junction "BAS095C"
Junction "BAS095C" Results for Run "Run Storm - Aug 2011 Cal"
Flow (CFS)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
4
5
6
7
8
9
Aug2011
Legend (Compute Time: 12Apr2012, 15:35:15)
Run:RUN STORM - AUG 2011 CAL Element:BAS095C Result:Observed Flow
Run:RUN STORM - AUG 2011 CAL Element:BAS095C Result:Outflow
Run:RUN STORM - AUG 2011 CAL Element:BAS095R Result:Outflow
Run:RUN STORM - AUG 2011 CAL Element:BAS095 Result:Outflow

Aug 2011

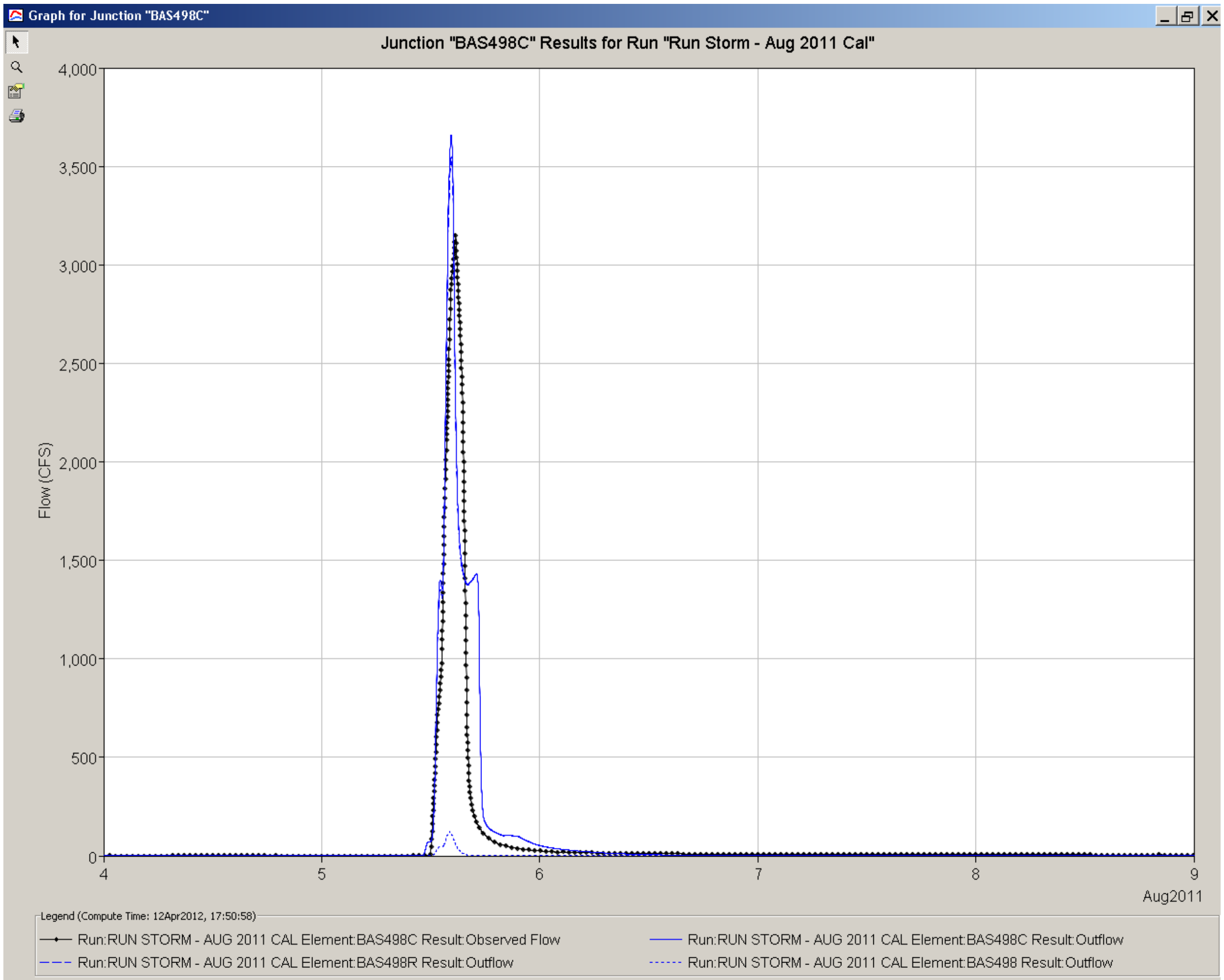
Taggart Creek



Aug 2008

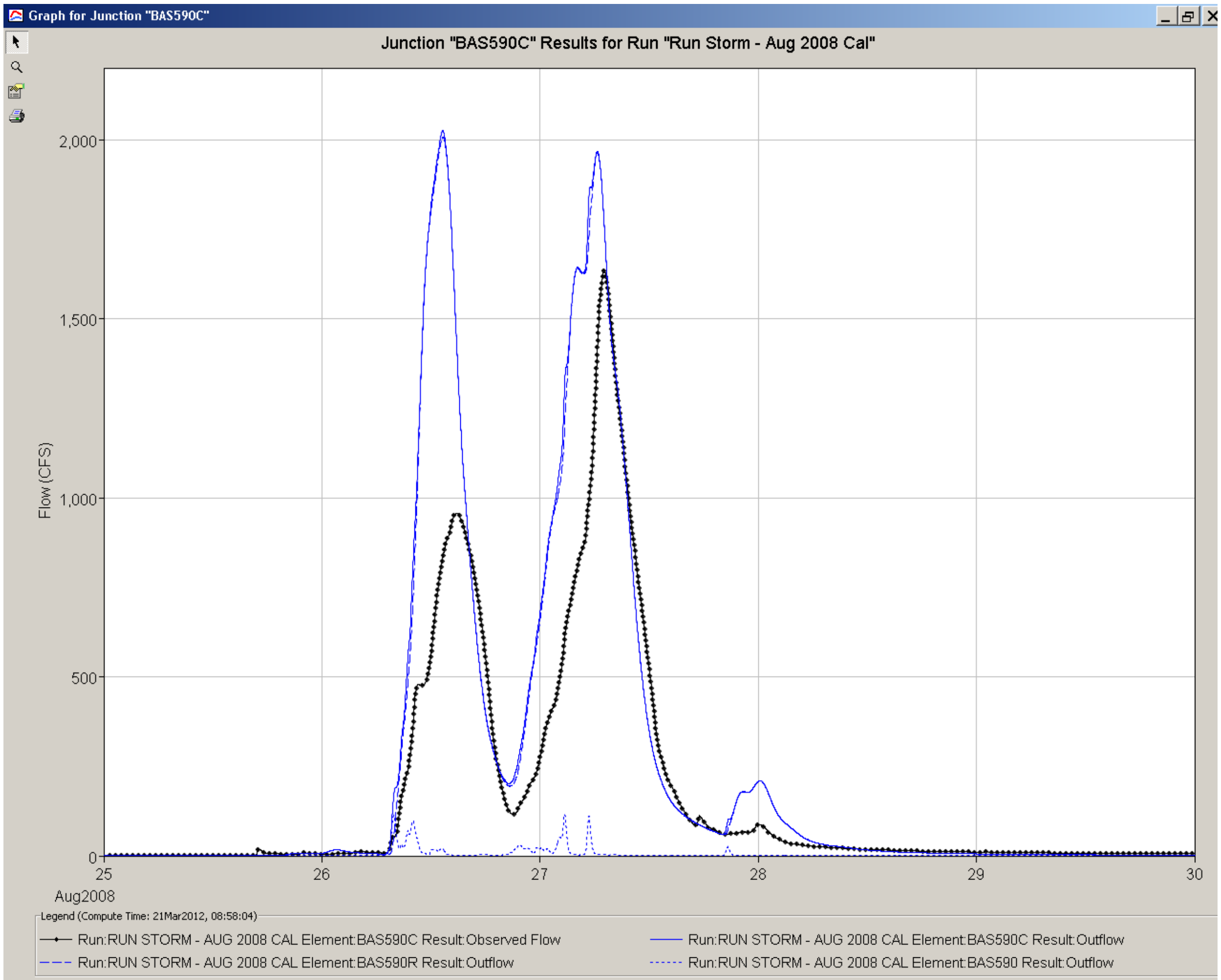

Graph for Junction "BAS498C"
Junction "BAS498C" Results for Run "Run Storm - Jul 2009 Cal"
Flow (CFS)
1,200
1,000
800
600
400
200
0
26
27
28
29
30
31
Jul2009
Legend (Compute Time: 12Apr2012, 17:44:14)
Run:RUN STORM - JUL 2009 CAL Element:BAS498C Result:Observed Flow
Run:RUN STORM - JUL 2009 CAL Element:BAS498C Result:Outflow
Run:RUN STORM - JUL 2009 CAL Element:BAS498R Result:Outflow
Run:RUN STORM - JUL 2009 CAL Element:BAS498 Result:Outflow

Jul 2009

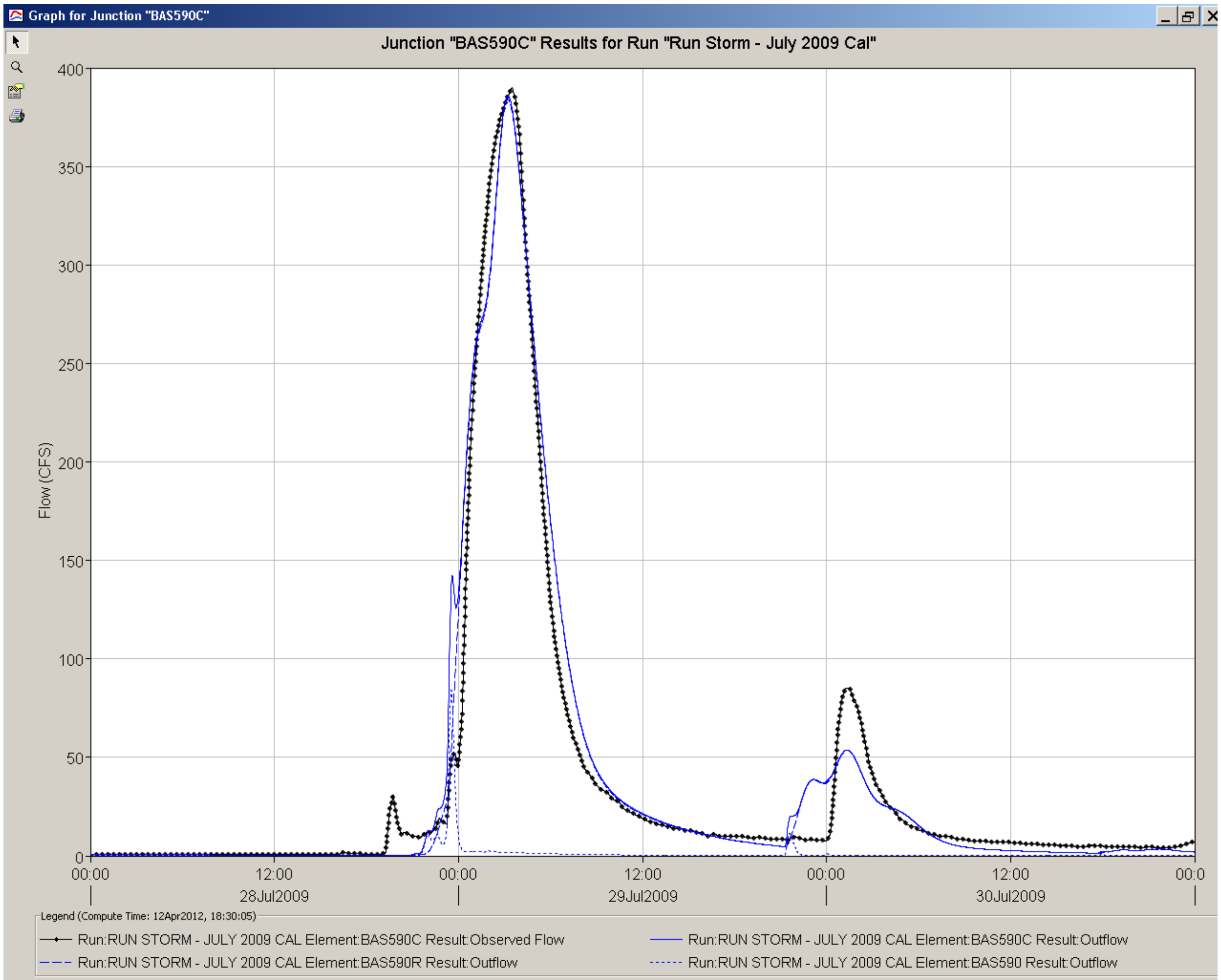

Graph for Junction "BAS498C"
Junction "BAS498C" Results for Run "Run Storm - Aug 2011 Cal"
Flow (CFS)
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
4
5
6
7
8
9
Aug2011
Legend (Compute Time: 12Apr2012, 17:50:58)
Run:RUN STORM - AUG 2011 CAL Element:BAS498C Result:Observed Flow
Run:RUN STORM - AUG 2011 CAL Element:BAS498C Result:Outflow
Run:RUN STORM - AUG 2011 CAL Element:BAS498R Result:Outflow
Run:RUN STORM - AUG 2011 CAL Element:BAS498 Result:Outflow

Aug 2011

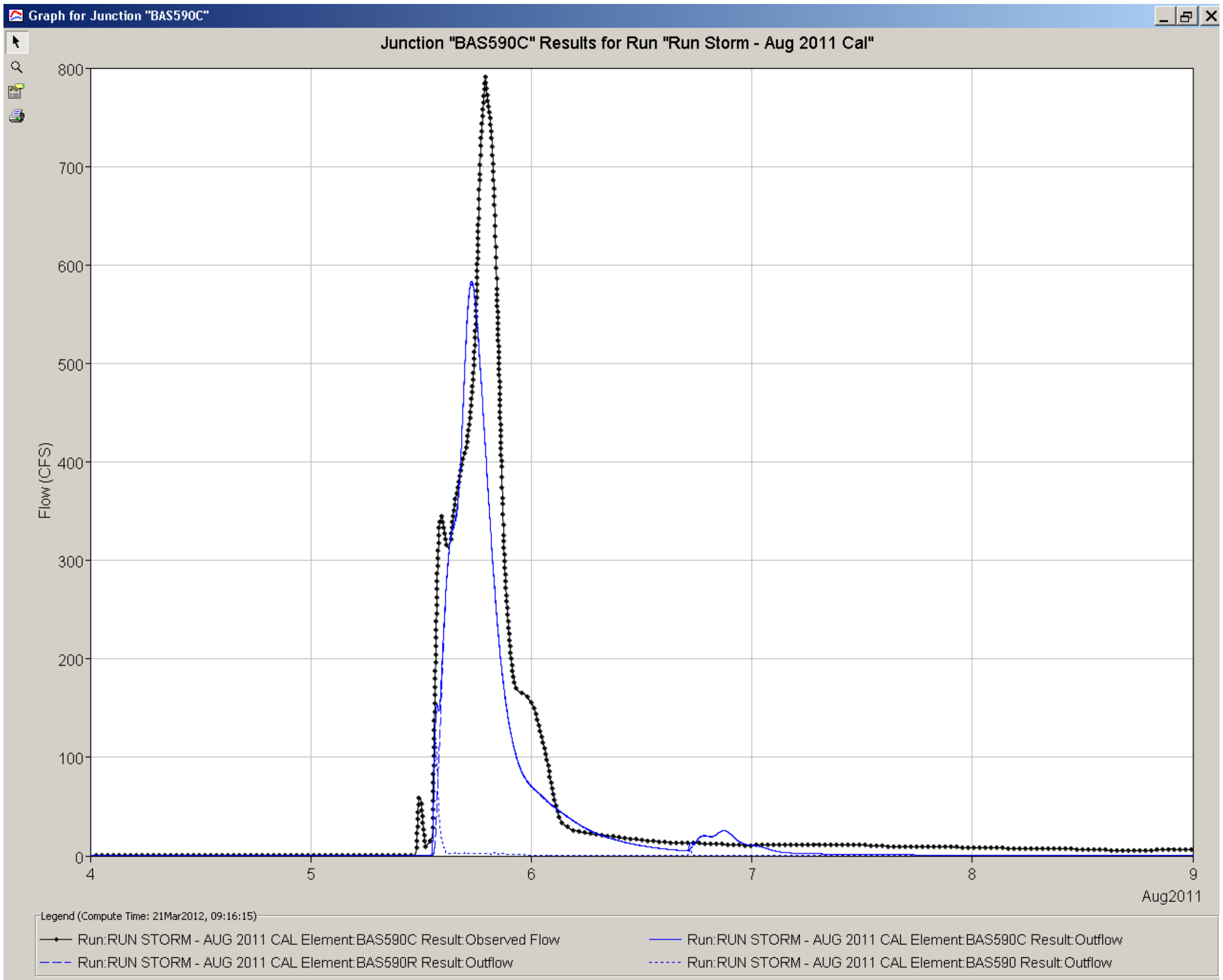
Coffey Creek



Aug 2008

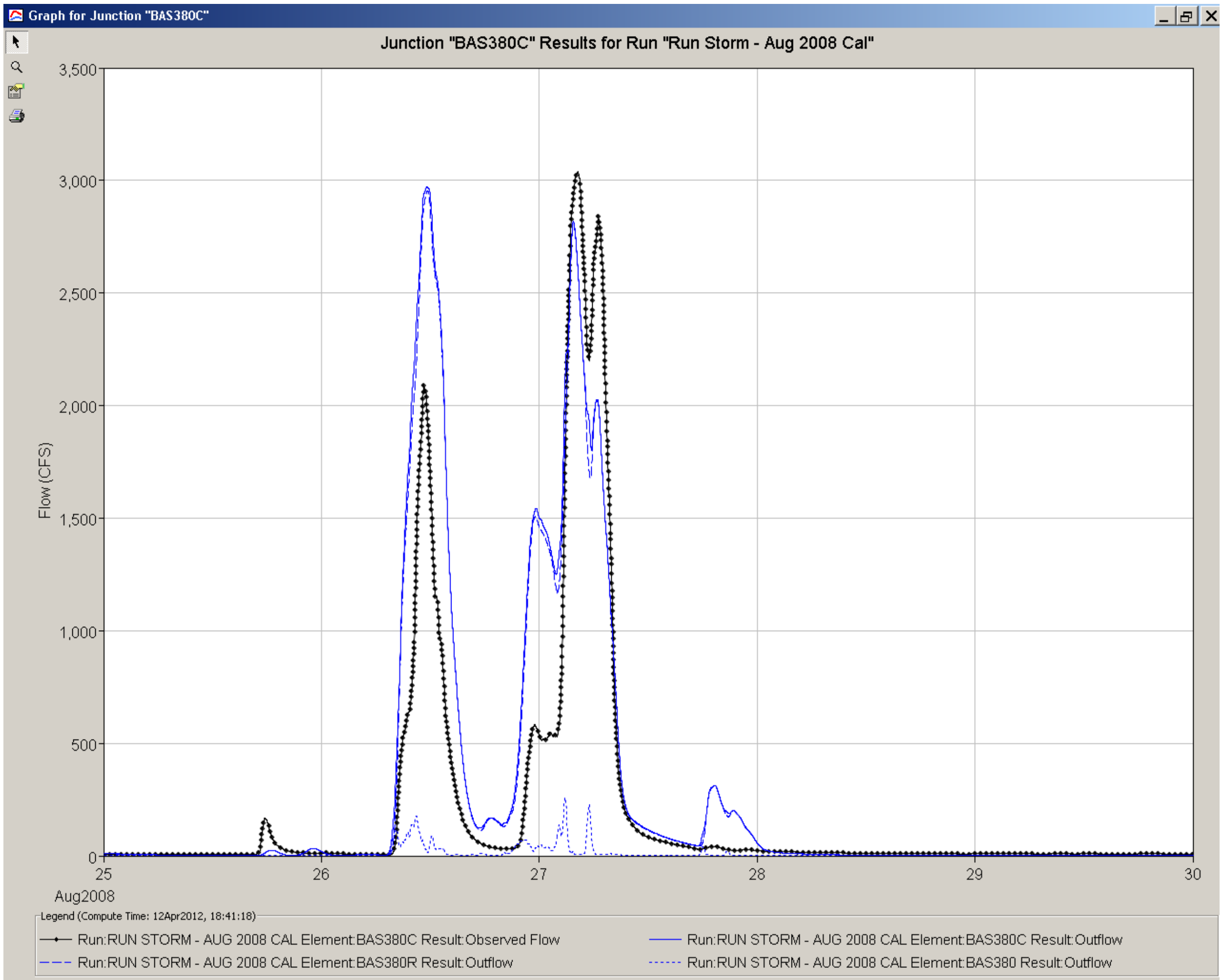

Graph for Junction "BAS590C"
Junction "BAS590C" Results for Run "Run Storm - July 2009 Cal"
Flow (CFS)
400
350
300
250
200
150
100
50
0
00:00
12:00
00:00
12:00
00:00
12:00
00:0
28Jul2009
29Jul2009
30Jul2009
Legend (Compute Time: 12Apr2012, 18:30:05)
Run:RUN STORM - JULY 2009 CAL Element:BAS590C Result:Observed Flow
Run:RUN STORM - JULY 2009 CAL Element:BAS590C Result:Outflow
Run:RUN STORM - JULY 2009 CAL Element:BAS590R Result:Outflow
Run:RUN STORM - JULY 2009 CAL Element:BAS590 Result:Outflow

Jul 2009

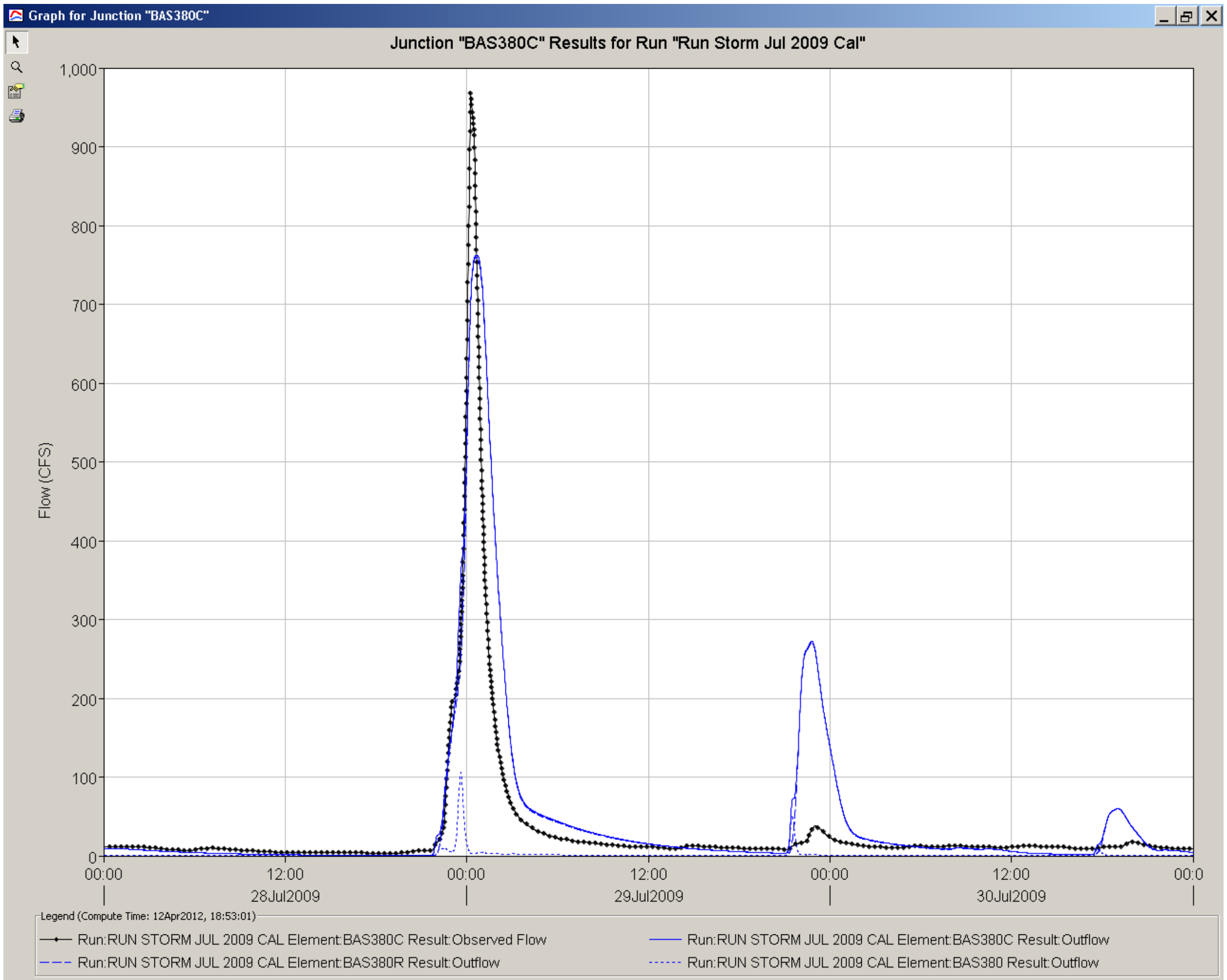

Graph for Junction "BAS590C"
Junction "BAS590C" Results for Run "Run Storm - Aug 2011 Cal"
Flow (CFS)
800
700
600
500
400
300
200
100
0
4
5
6
7
8
9
Aug2011
Legend (Compute Time: 21Mar2012, 09:16:15)
Run:RUN STORM - AUG 2011 CAL Element:BAS590C Result:Observed Flow
Run:RUN STORM - AUG 2011 CAL Element:BAS590C Result:Outflow
Run:RUN STORM - AUG 2011 CAL Element:BAS590R Result:Outflow
Run:RUN STORM - AUG 2011 CAL Element:BAS590 Result:Outflow

Aug 2011

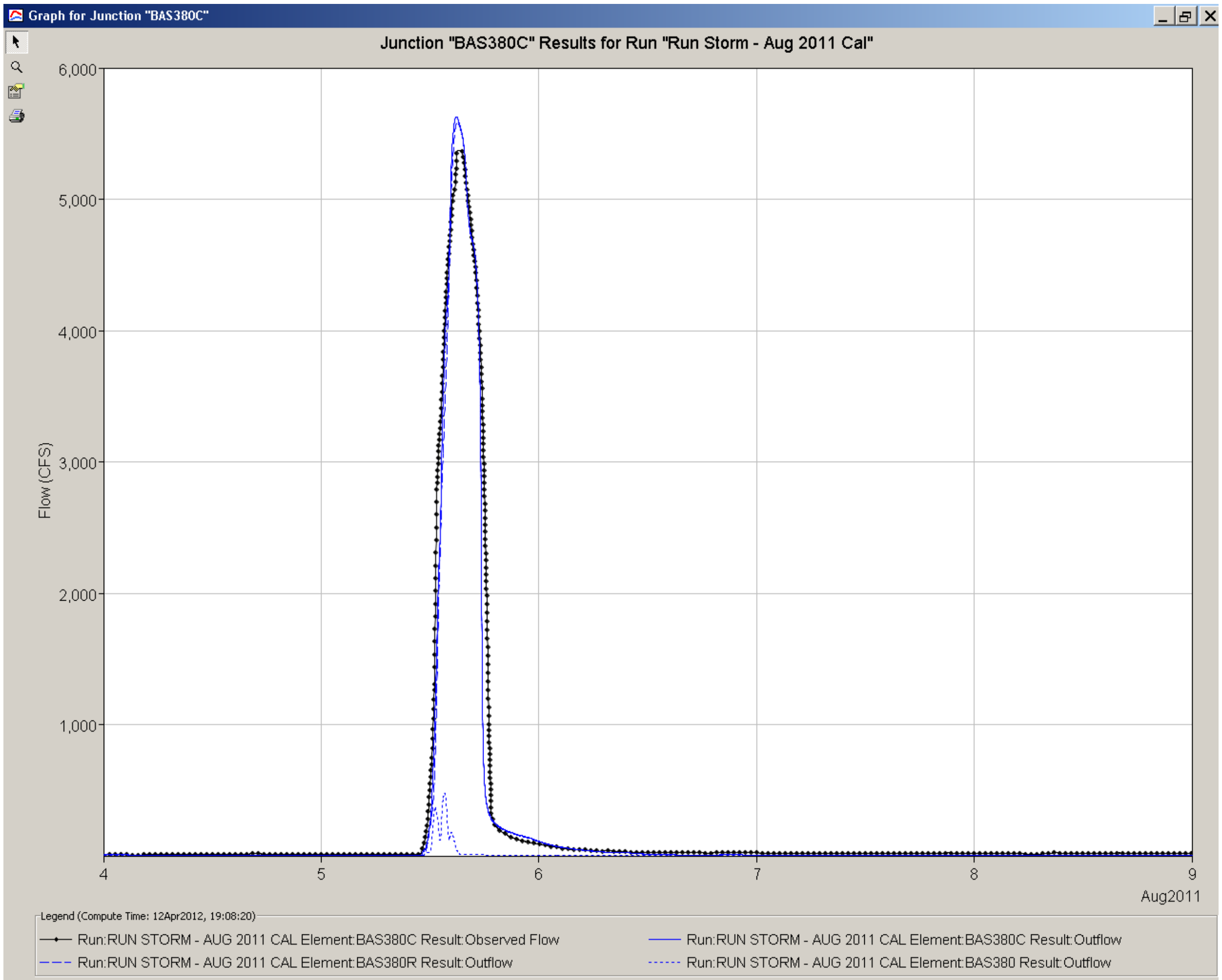
Stewart Creek



Aug 2008


Graph for Junction "BAS380C"
Junction "BAS380C" Results for Run "Run Storm Jul 2009 Cal"
Flow (CFS)
1,000
900
800
700
600
500
400
300
200
100
0
00:00
12:00
28Jul2009
00:00
12:00
29Jul2009
00:00
12:00
30Jul2009
00:0
Legend (Compute Time: 12Apr2012, 18:53:01)
Run:RUN STORM JUL 2009 CAL Element:BAS380C Result:Observed Flow
Run:RUN STORM JUL 2009 CAL Element:BAS380C Result:Outflow
Run:RUN STORM JUL 2009 CAL Element:BAS380R Result:Outflow
Run:RUN STORM JUL 2009 CAL Element:BAS380 Result:Outflow

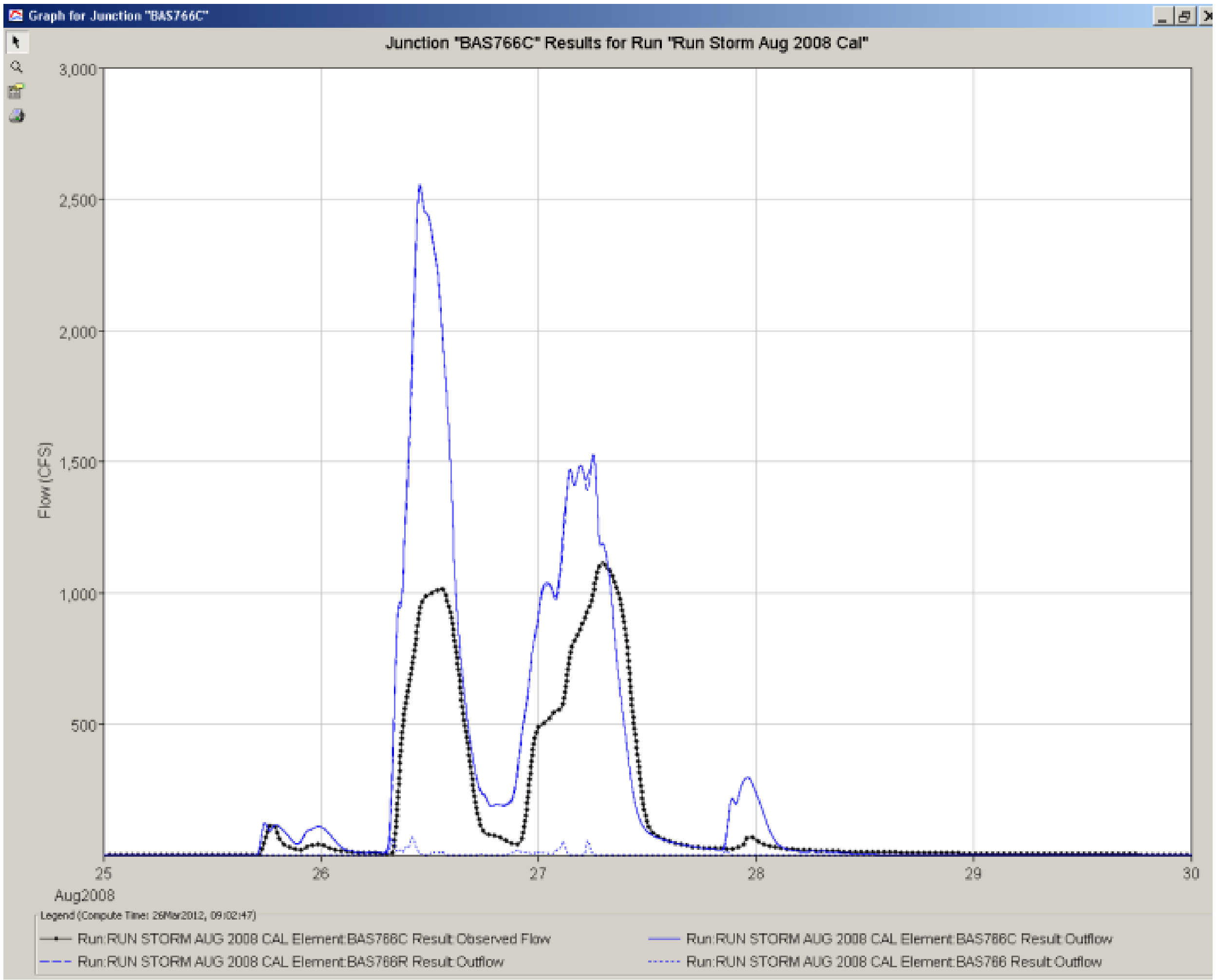
Jul 2009



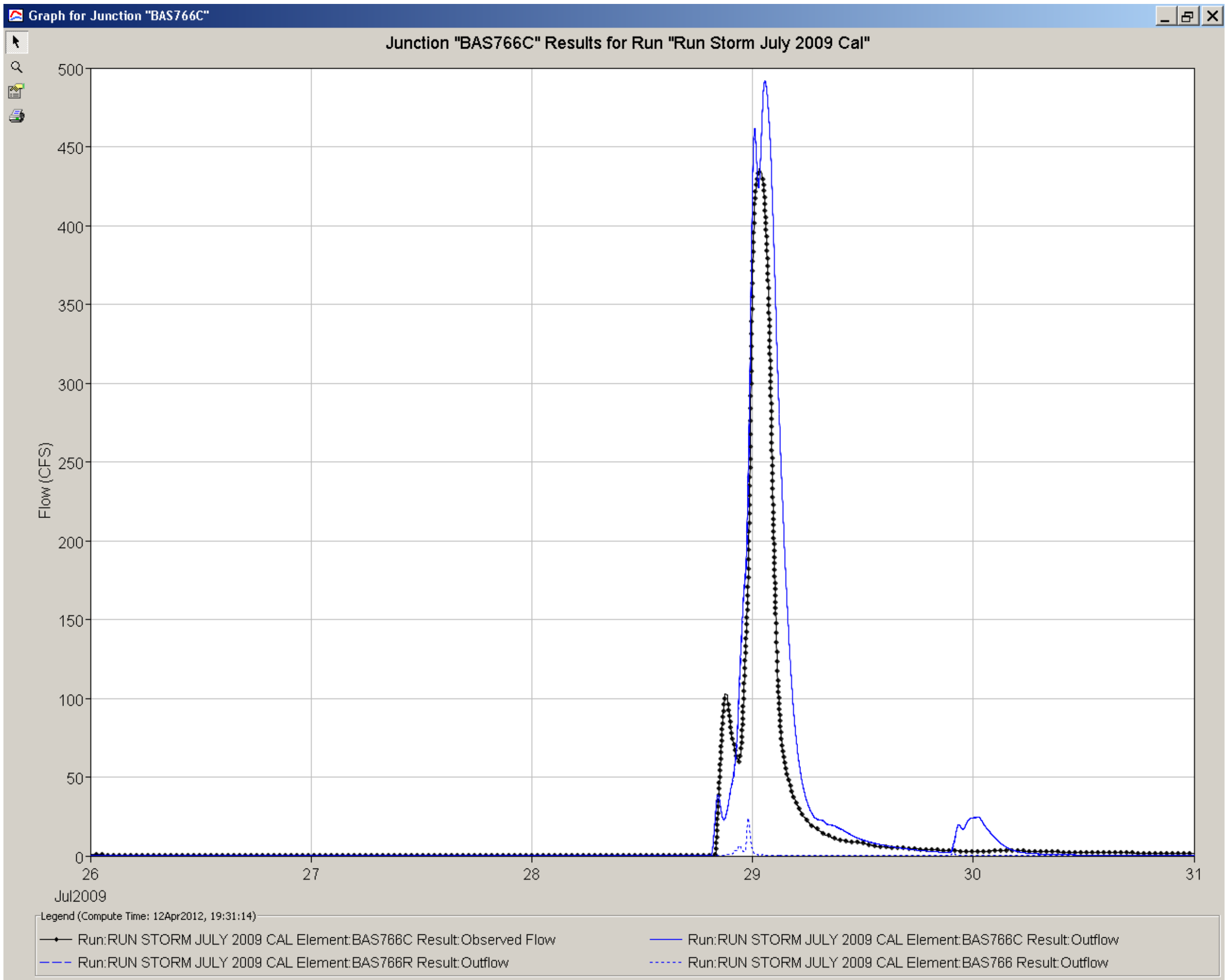
Graph for Junction "BAS380C"
Junction "BAS380C" Results for Run "Run Storm - Aug 2011 Cal"
Flow (CFS)
6,000
5,000
4,000
3,000
2,000
1,000
4
5
6
7
8
9
Aug2011
Legend (Compute Time: 12Apr2012, 19:08:20)
Run:RUN STORM - AUG 2011 CAL Element:BAS380C Result:Observed Flow
Run:RUN STORM - AUG 2011 CAL Element:BAS380C Result:Outflow
Run:RUN STORM - AUG 2011 CAL Element:BAS380R Result:Outflow
Run:RUN STORM - AUG 2011 CAL Element:BAS380 Result:Outflow

Aug 2011

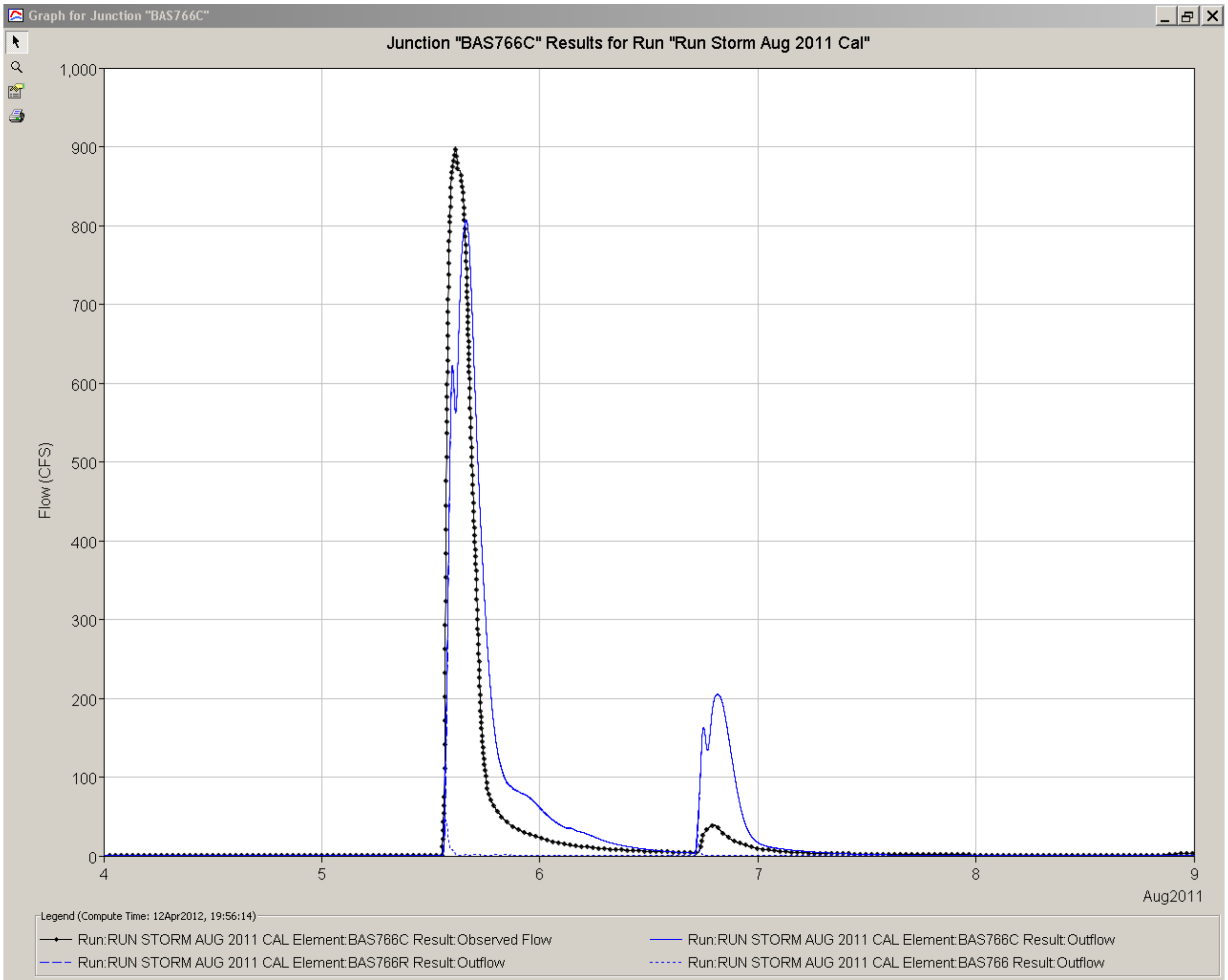
Steele Creek



Aug 2008


Graph for Junction "BAS766C"
Junction "BAS766C" Results for Run "Run Storm July 2009 Cal"
Flow (CFS)
500
450
400
350
300
250
200
150
100
50
0
26
27
28
29
30
31
Jul2009
Legend (Compute Time: 12Apr2012, 19:31:14)
Run:RUN STORM JULY 2009 CAL Element:BAS766C Result:Observed Flow
Run:RUN STORM JULY 2009 CAL Element:BAS766C Result:Outflow
Run:RUN STORM JULY 2009 CAL Element:BAS766R Result:Outflow
Run:RUN STORM JULY 2009 CAL Element:BAS766 Result:Outflow

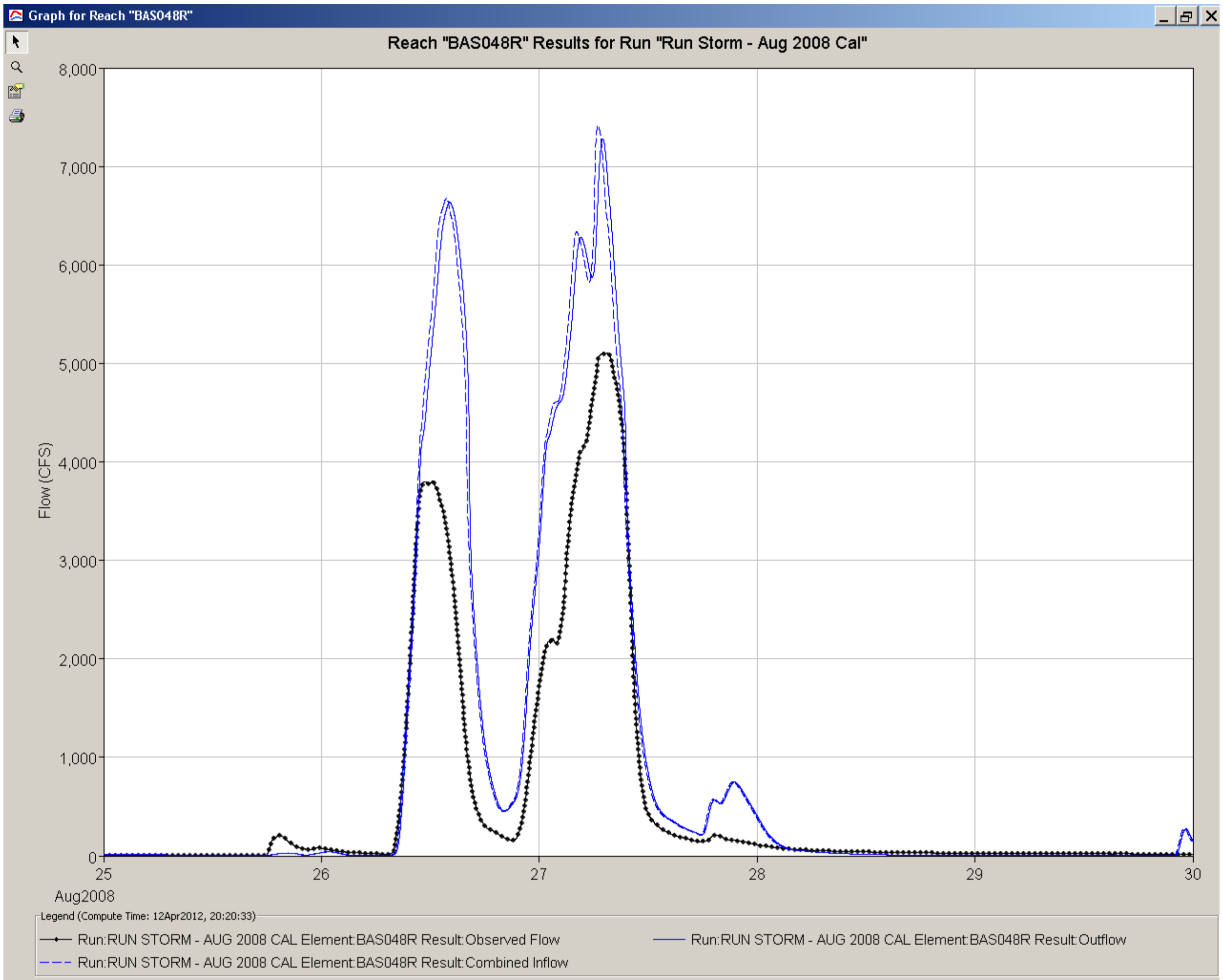
Jul 2009



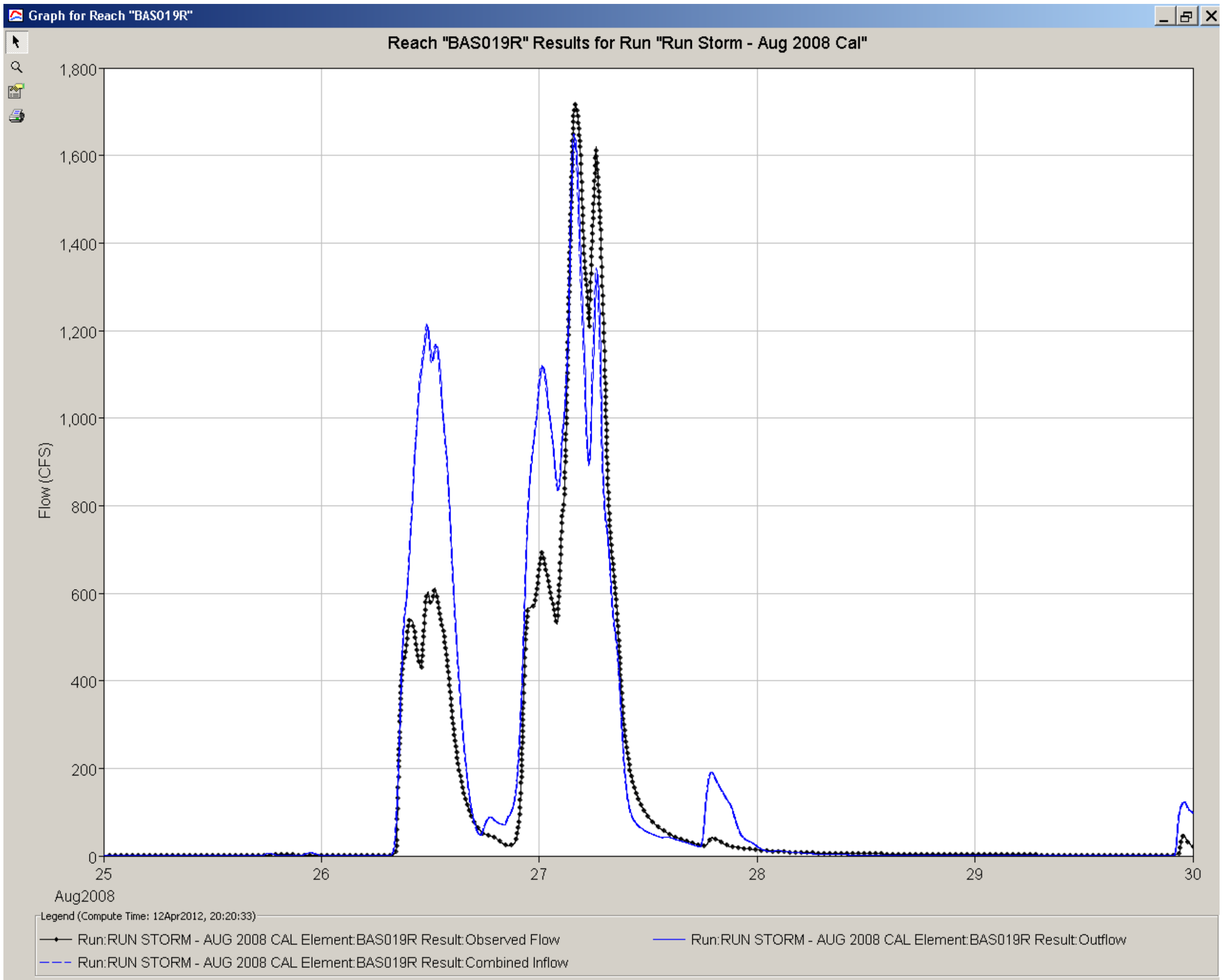
Aug 2011

PRELIMINARY

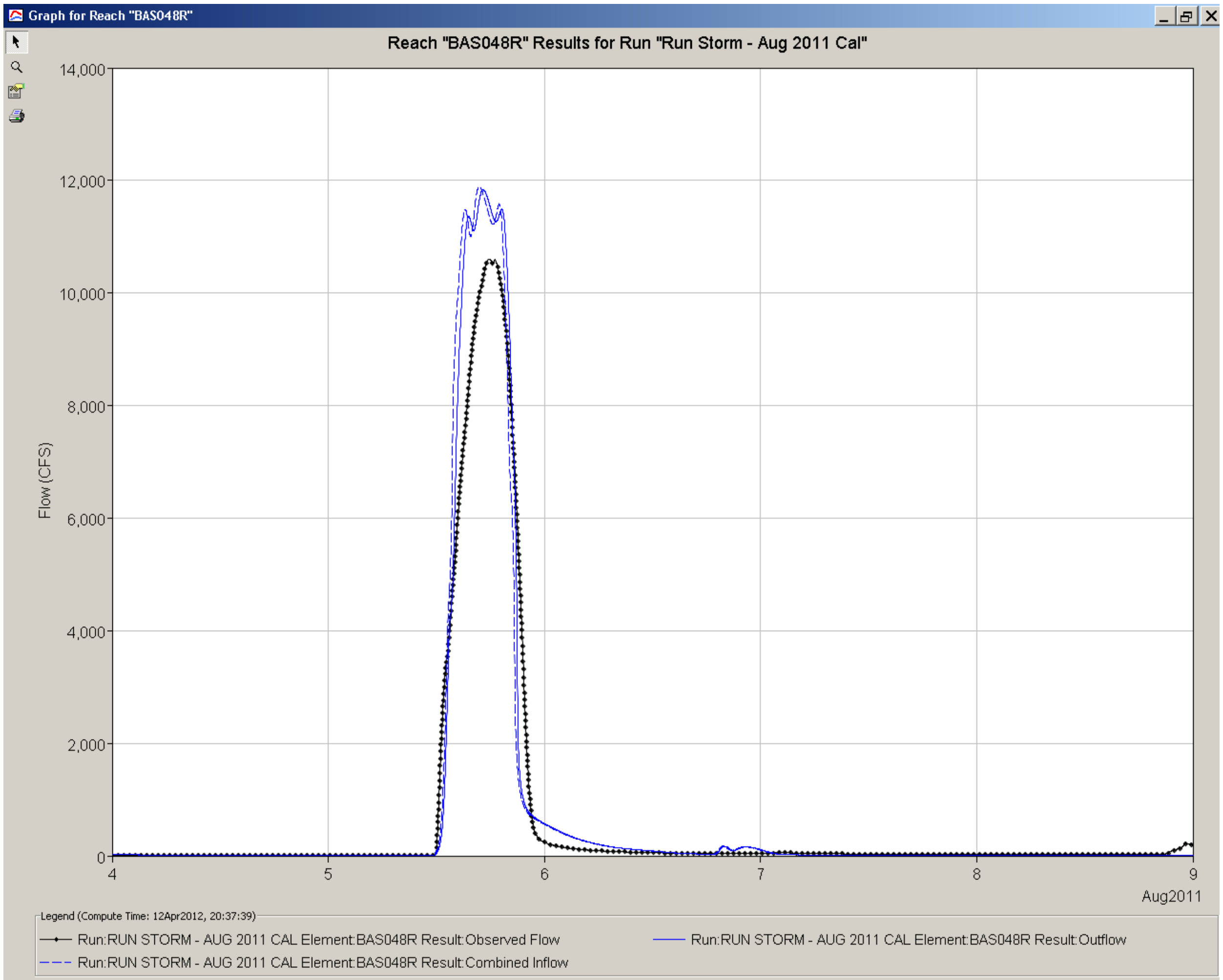
Irwin Creek



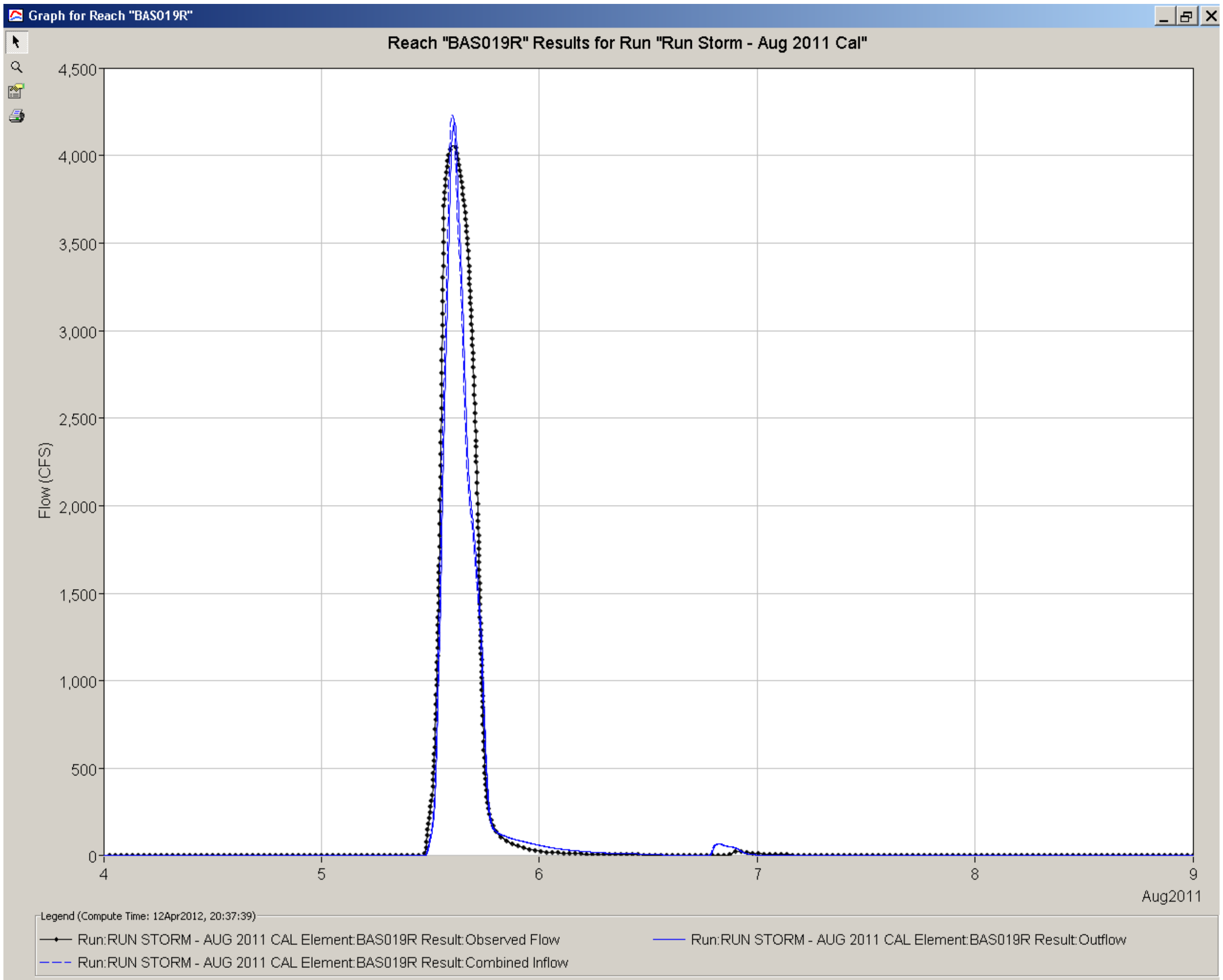
Gage 2146300 Aug 2008



Gage 2143211 Aug 2008



Gage 2146300 Aug 2011



Gage 2146211 Aug 2011

Appendix E

Database	Table	Table Description	Field	Field Description	Units
TC	TCS	Tabulation of basin times of concentration	BASIN_ID	Basin identification number	n/a
			BY	Engineer who calculated TC	n/a
			DATE	Date of TC calculation	n/a
			COMMENT	Comment	n/a
			TOTAL TIME	Sum of basin incremental times	hours
	LuLookup	Lookup table used to designate specific landuse classes as "rural" (for overland incremental TC calculations) and "paved" (for shallow concentrated incremental TC calculations)	Landuse	Landuse Code	n/a
			SCSSheetN	Sheetflow N value for overland flow	n/a
			Rural	Rural check for overland flow	n/a
			Paved	Paved check for shallow concentrated flow	n/a
	Chanlookup	Lookup table used to select geometric properties for open channel incremental TC calculations	LowerDA	Lower DA limit	acres
			UpperDA	Upper DA limit	acres
			Shape	Channel shape	n/a
			Depth	Channel depth	feet
			BottomWidth	Channel bottom width	feet
			SideSlope	Channel side slope	feet/feet
			ManningsN	Channel Mannings N	n/a
			HydRadius	Channel hydraulic radius	feet
CN	CNlookup	Lookup table used for translating landuse and soil types into curve number	Landuse	Landuse code	n/a
			Soil_Type	Soil hydrologic ID code	n/a
			CN	Basin composite curve number	n/a
	CNS	Tabulation of basin composite curve numbers	BASIN_ID	Basin identification number	n/a
			DA_SQMI	Basin drainage area	sq mi
			CN	Basin composite curve number	n/a
			BY	Engineer who calculated CN	n/a

Database	Table	Table Description	Field	Field Description	Units
			DATE	Date of CN calculation	n/a
RTC	POINTS	Tabulation of cross-sectional geometric takeoffs and parameters used in the computation of storage - discharge curves	XSECT	RTC cross section ID	n/a
			XS_STATION	Cross section vertex station	feet
			ELEVATION	Cross section vertex elevation	feet
			CODE	Vertex ID code	n/a
	ROUTING DATA	Tabulation of routing data for each basin	Route_ID	Routing reach ID	n/a
			TimeStep	Routing time step	n/a
			Option	Routing option	n/a
			Num_Reach	Number of routing reaches	n/a
			LEFT_N	Left overbank n-value	n/a
			CHAN_N	Channel n-value	n/a
			RIGHT_N	Right overbank n-value	n/a
			REACH_LN	Routing reach length	feet
			ENERGY_SL	Routing reach slope	feet/feet
	ROUTING SERIES	Tabulation of routing reach parameters used in the calculation of storage - discharge curves	Route_ID	Routing reach ID	n/a
			TYPE	Routing parameter type	n/a
			Option	Routing option	n/a
			Storage	"Storage" parameter of S-D curve	acre-feet
			Area	Routing cross-sectional flow area	sq ft
			Depth	Routing cross-sectional flow depth	feet
			Discharge	"Discharge" parameter of S-D curve	cfs
	ROUTINGS	Inventory of routing reaches	Route_ID	Routing reach ID	n/a
			TYPE	Routing method (modified puls for all reaches)	n/a
			DATE	Date of routing parameter calculation	n/a

Database	Table	Table Description	Field	Field Description	Units
			Option	Routing option	n/a
			BY	Engineer who calculated routing parameters	n/a
	RTCLookup	Lookup table used to select geometric properties for open channel hydraulic routing calculations	LowerDA	Lower DA limit	acres
			UpperDA	Upper DA limit	acres
			Shape	Channel shape	n/a
			Depth	Channel depth	feet
			BottomWidth	Channel bottom width	feet
			TopWidth	Channel top width	feet
			ChannelN	Channel n-value	n/a
			OverbankN	Overbank n-value	n/a