AECOM

Mecklenburg County Floodplain Mapping 2008

PRELIMINARY YADKIN SUB-BASIN HYDROLOGY REPORT

5/14/2010

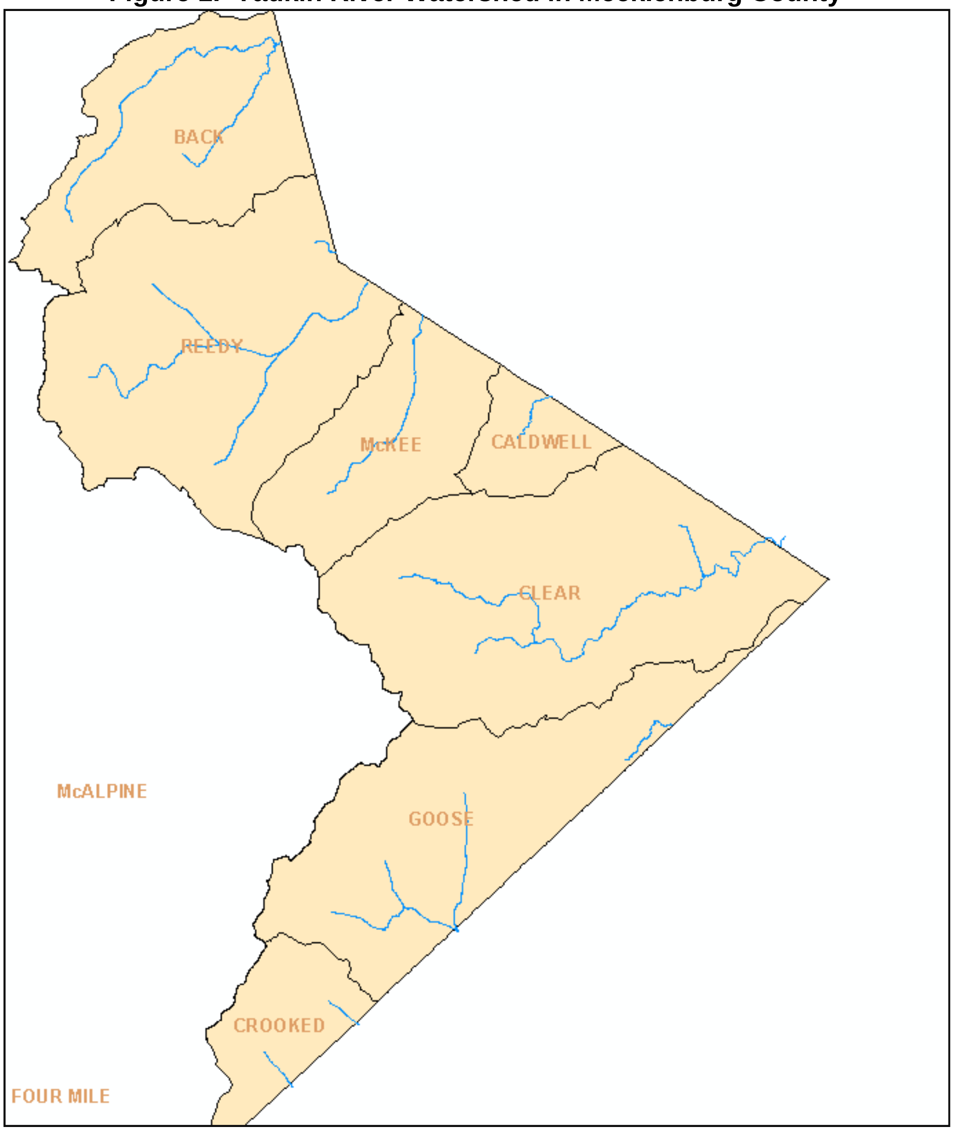
Updated 7/6/2010
Updated 11/09/2010
Updated 01/04/2011
Updated 02/09/2011
Updated 09/14/2011

Section 1 Watershed Description

1.1 Watershed Location

The Yadkin River Watershed in Mecklenburg County consists of the headwaters of Rocky River. The Rocky River Sub-basin 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 Mecklenburg County the Yadkin River watershed drains mostly rural areas in the east/southeast part of the county and contains the Back, Reedy, McKee, Caldwell, Clear, Goose, and Crooked Creek sub-basins. The sub-basins drain a small part Matthews, most of Mint Hill, and rural parts of Mecklenburg County.

Figure 1. Yadkin River Watershed in Mecklenburg County



Within Mecklenburg County the Yadkin River Watershed contains 38 miles of detailed study FEMA streams with 49 hydraulic structures. The study limits are summarized below in Table 1.

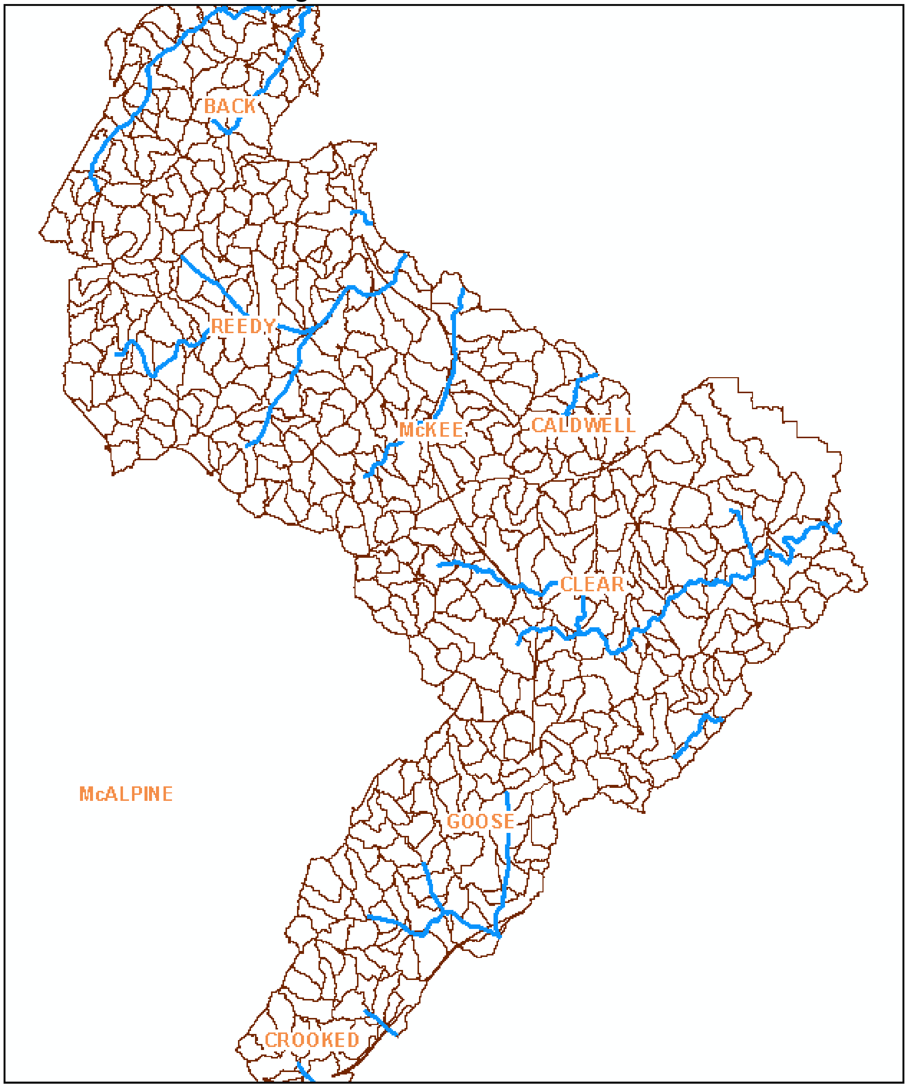
Table 1: Detailed Study Scope for the Yadkin Watershed			
Stream Name	**Downstream Limit**	**Upstream Limit**	**Length (mi.)**
Back Creek	County Line	Approx. 1,515 feet upstream of Rocky River Road	4.9
Back Creek Trib	Confluence with Back Creek	Approx. 1,515 feet upstream of Back Creek Church Road	2.5
Caldwell Creek	County Line	Approx. 1.0 mile upstream of County Line	1.0
Clear Creek	Approx. 2,020 feet downstream of County Line	Approx. 1,660 feet upstream of I-485	6.5
Clear Creek Trib	Confluence with Clear Creek	Approx. 1,650 feet upstream of Truelight Church Road	2.9
Duck Creek	County Line	Approx. 1.1 miles upstream of County Line	1.1
Goose Creek	County Line	Approx. 1.2 miles upstream of Lawyers Road	2.0
McKee Creek	County Line	Approx. 580 feet upstream of Denbur Drive	3.2
North Fork Crooked Creek	County Line	Approx. 880 feet upstream of Mt. Harmon Church Road	0.6
North Fork Crooked Creek Trib	County Line	Approx. 1,200 feet upstream of Stallings Road	0.5
Reedy Creek	County Line	Approx. 0.7 mile upstream of Plaza Road Extension	3.9
Reedy Creek Trib 1	County Line	Approx. 440 feet upstream of I-485	0.4
Reedy Creek Trib 2	Confluence with Reedy Creek	Approx. 1.2 miles upstream of Robinson Church Road	1.9
Reedy Creek Trib 3	Confluence with Reedy Creek	Approx. 119 feet upstream of Chapparal Lane	2.7
Sherman Branch	Confluence with Clear Creek	Approx. 0.6 mile upstream of Cabarrus Road	0.8
Stevens Creek	Confluence with Goose Creek	Approx. 0.5 mile upstream of Thompson Road	2.1
Stevens Creek Trib	Confluence with Stevens Creek	Approx. 0.5 mile upstream of Thompson Road	0.7

This study will add the Crooked Creek sub-basin as a new FEMA study. The North Fork of Crooked Creek and its Tributary were not studied in the previous effort for Mecklenburg County but will be included in this study.

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 was 72 acres. This includes the larger main reach basins and some large basins that lie mostly outside of the county boundary. So we feel that the headwaters are well represented with the smaller basin size. Figure 2 shows the sub-basins as delineated and as approved by the county.

Figure 2. Yadkin Sub-Basins



Basin delineations and drainage areas were determined using a 10' x 10' grid size digital elevation model (DEM) generated from 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.

1.3 Soils

Soils in the upper reaches of Yadkin River 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 Yadkin River 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 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 with land use-soil type lookup tables (provided by CMSWS) to develop curve number calculations for hydrologic modeling.

The existing land use layer was obtained from CMSWS and was used as the base layer for existing land use. It was reviewed and modified using the most recent aerial photography and any discrepancies were brought to the attention of CMSWS to resolve. A public task force was also involved in the QA/QC of the land use data and over a period of several months, reviewed and verified the data. The task force formerly approved the existing land use data on February 17, 2010. Please see the Floodplain Analysis and Mapping Standards Guidance Document (FAMSGD) for more detail. The existing land use layer contains 12 land use categories, for which, an *estimate* of percent impervious was assigned to each based on preliminary county research and testing. The land use designation relates directly to a curve number in the master curve number look up table. More details are provided in section 3.3.

The future land use layer was obtained from CMSWS for the City of Charlotte ETJ. The town of Matthews, and the town of Mint Hill submitted separate files as well. The separate future files were manipulated and then translated into one seamless layer and represented the same attributes as the existing layer. The future layer was then modified and verified using a similar process as the existing layer. The task force formally approved the future land use data on February 17, 2010. 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.

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

	Existing Land Use Layer	Future Land Use Layer
Field name	**Field Description**	**Field Description**
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

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 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 originally used in this study was a combination of the 2007 leaf-off imagery and the 2008 leaf-on imagery, both provided by CMSWS. The 2009 data was not ready for use at the beginning of the project but did become available near the beginning of 2010 and was used from that point forward.

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. 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 area reduction factors (presented in Table 3), 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) was also applied to the HEC-HMS models, a precipitation depth of 13.5 inches was provided by the county and applied to all 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 24 rain gages throughout the county. Data was received for the following storms:

- February 1, 2008

- April 26, 2008
- August 27, 2008
- November 30, 2008
- February 28, 2009
- July 27, 2009

It was determined that we would calibrate to the August 27, 2008 and the July 27, 2009 storms. Please see the calibration section for more detail.

The county also has an extensive stream gage network: flow and stage data was requested from 11 USGS stream gages throughout the county. Stream gage data in 15 minute increments was received for the same storms as mentioned above. In the final calibration, the Yadkin River Watershed used 2 stream gage and 6 rain gages in its calibration routine, which is discussed in further detail in the calibration section 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 Yadkin River 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 was 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 model 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 storage relationship, i.e. – discharge vs. stage chart.
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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 Yadkin 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 3 – Precipitation Depths for the Floodplain Mapping Project*. These depths were converted by HMS into a Type II rainfall distribution that was used in the modeling. The 1/3 PMP event of 13.5 inches of rain was also provided by the county and converted by HMS into a Type II distribution that was used in the modeling.

Drainage Areas: Drainage basin boundaries for the Yadkin 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 522 basins were delineated based on stream crossings and location in the watershed. The sub-basins averaged 72 acres in size and ranged from 3 acres to 720 acres. Each sub-basin was assigned a unique numeric identifier. See *Figure 2 – Yadkin Sub-Basins* above.

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 being 5% impervious. The adjusted look-up table can be seen in Table 4 below. A future conditions land use file was also created and approved by the Task Force. This file was used to create a future conditions curve number for each sub-basin. The future conditions land use was based on zoning designations and district/area plans and is considered to be fully "built out" conditions.

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

1. Sheet flow (T_S),
2. Shallow concentrated flow (T_{SC}), and
3. Channel flow (T_{CH}).

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.

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

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

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

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

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: $V = 20.3282 * S^{0.5}$
Assumes n=0.025 and r=0.2

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

Where: S = Slope

3. Channel Flow

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

Where: n = Manning's roughness based on drainage area
R = Hydraulic Radius based on drainage area
S = Slope

The flow paths and associated travel time calculations through ponds and lakes are calculated using a constant velocity of 1.0 ft/s, as recommended by the county.

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 database file Yadkin_TC_Database.mdb included in the submittal.

Channel / Structure Routings: The modified puls method was used for routing calculations in all stream channels because 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. 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%.

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 matches 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.

There are several USGS stream and rain gages for calibration of model parameters in the Yadkin River sub-basin portion of the study area (Tables 5 & 6). The stream gages are located on Reedy Creek and Clear Creek and have only been active since 2008 and 2003, respectively. The precipitation gages are located within or in close proximity to the Yadkin River sub-basin.

Table 5: Stream Gages used for Yadkin River sub-basin Model Parameter Calibration

Gage Station ID	Gaged Stream and Location	Latitude	Longitude	Drainage Area (square miles)
0212430293	Reedy Creek below I-485 near Pine Ridge, NC	35 15 30	80 39 45	12.6
0212466000	Clear Creek at SR 3181 near Mint Hill, NC	35 12 29	80 34 47	12.6

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

Gage Station ID	Gaged Stream and Location	Latitude	Longitude
351812080445545	CRN-01 Raingage at Fire Station 27 Charlotte, NC	35 18 10	80 45 00
351540080430045	CRN-16 Raingage at Reedy Creek Park Envir Center	35 15 41	80 43 07
351302080412701	CRN-23 Raingage at Charles T. Myers Golf Course	35 13 00	80 41 26
351218080331345	CRN-29 Raingage at Belk Scout Camp	35 12 19	80 33 07
351455080374445	CRN-30 Raingage at Rhyne Farm Mint Hill, NC	35 14 55	80 37 42
351028080385545	CRN-32 Raingage at Bain Elementary School	35 10 28	80 38 53
351536080410645	CRN-65 Raingage at Reedy Creek Elementary School	35 15 35	80 41 06
350857080383245	CRN-67 Raingage at Thompson Road Mint Hill, NC	35 08 56	80 38 31
351145080371945	CRN-68 Raingage at White Farm Mint Hill, NC	35 11 44	80 37 19

After initial evaluation of the gage data supplied by the USGS it was determined that the Clear Creek and Reedy Creek models would be used for calibration.

The precipitation and stream flow data for several large storms that occurred from 2008 and 2009 were reviewed and considered for use in model calibration procedure because the Reedy Creek stream gage has only been active since 2008. Criteria for selection of storm events were:

- Complete data sets;
- Simple, single peak hydrographs;
- Sufficient separation between storm events; and
- Some range in peak rainfall accumulation.

After review of available precipitation and stream flow data, two storm events were selected for use in the model calibration parameter exercise. The storm event peaks occurred near August 27, 2008 and July

29, 2009 (Table 7). These storm events were selected to include a representative range of peak discharges that varied from roughly the 50 percent annual chance event to the 0.2 percent annual chance event as measured in inches of rain for the specific event.

Although the July 2009 storm appears to be a 25 year event it is spread over 2 ½ days so it's very difficult to calibrate to. The August storm is a better representation of a hypothetical storm although it is only representative of a 10 year event in Clear Creek. On the other hand the August 2008 storm represents near a 500 year event in the Reedy Creek basin.

Table 7: HMS Control Specifications

Storm	Begin	End	Rainfall (In)	Hypothetical Storm Event
Clear Creek August 2008	8/26/2008 0:00	8/29/2008 0:00	4.89	~10-yr
Clear Creek July 2009	7/27/2009 0:00	7/30/2009 00:00	5.38	~25-yr
Reedy Creek August 2008	8/26/2008 0:00	8/28/2008 12:00	9.44	~500-yr
Reedy Creek July 2009	7/27/2009 12:00	7/30/2009 00:00	3.06	~2-yr

Each of the four peaks used in this calibration has been verified and published by the USGS and the entire dataset was reviewed for missing and/or incomplete data and there were no issues found.

The following observed runoff and flows were noted in the calibration runs:

Table 8: Peak Discharge Events used for Yadkin River sub-basin Model Parameter Calibration

Date	Gaged Stream and Location	Observed Runoff (inches)	Observed Peak Discharge (cubic feet/second)
8/27/08	Clear Creek at SR 3181 near Mint Hill, NC	0.97	1,110
7/28/09	Clear Creek at SR 3181 near Mint Hill, NC	2.20	1,380
8/27/08	Reedy Creek below I-485 near Pine Ridge, NC	3.69	4,350
7/28/09	Reedy Creek below I-485 near Pine Ridge, NC	0.55	677

4.1 Calibration Precipitation Input

An area-weighted, spatially distributed precipitation record was developed for use as precipitation input for the model calibration process. The observed point precipitation data at selected USGS precipitation gages (Table 6) was transformed to an area-weighted, spatially distributed precipitation record using an area weighted 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 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. As such, if a sub-basin is completely within a single rain gage polygon, the weighting for that rain gage is 1.0. In order to develop a weighted, distributed precipitation input, the weighted average was computed for each time step in the rain gage record.

4.2 Calibration Methodology

Calibration of the Clear and Reedy Creek sub-basins in the Yadkin River watershed 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 then apply an aspect of the calibration to each of the remaining un-gaged watersheds in the Yadkin watershed.

We began each calibration routine by running the models without any calibration and those results are noted below as compared to observed flow at the respective gages.

As shown below, un-calibrated results show that volumes range from 36.3% to 81.4% high and peak flows range from 47.7% to 90.9 % high. Also, the un-calibrated results of the 1% annual event are shown in Table 17 for comparison to effective and regression flows.

As suggested in the guidance document, we first reduced all curve numbers in each watershed by 4 and recalculated the initial abstraction using the default equation IA = 0.2*S, where S is based on the curve number. As seen in the calibration spreadsheets, this adjustment did not reduce the volume or the flow

Table 9: Initial Simulated and Observed Runoff and Peak Discharge for Stream Gages Used in Yadkin River Sub-basin before Calibration

Date	Gaged Stream and Location	Observed Runoff (inches)	Simulated Runoff (inches)	% Difference from Observed Runoff	Observed Peak Discharge (cubic feet/second)	Simulated Peak Discharge (cubic feet/second)	% Difference from Observed Peak
8/27/08	0212466000 (Clear Ck)	0.97	1.76	81.4%	1,110	1,824	64.3%
7/29/09		1.50	2.10	40.0%	1,380	2,064	49.6%
8/27/08	0212430293 (Reedy Ck)	3.69	5.03	36.3%	4,350	6427	47.7%
7/29/09		0.55	0.76	38.2%	677	1293	90.9%

enough for either watershed. A larger adjustment was needed, and in order to justify changing the curve numbers by more than the guidance document suggests, we initiated a direct percent impervious calculation of all drainage area draining to each stream gage. This calculation involved obtaining existing percent impervious layers from the county and supplementing them based on the 2009 aerials and the transportation layer. Using the 2009 aerials and the transportation layer, an updated impervious layer was created for all area that drained to the stream gages in Reedy and Clear Creeks, respectively. Once the impervious layer was complete a simple calculation of the impervious layer area divided by the total area draining to the gage supplied us with an actual percent impervious for Reedy and Clear Creeks. That comparison can be seen in Table 10 below.

The initial curve number for each sub-basin is a composite of the intersection of three layers; land use, soils, and sub-basins. This intersection file was used to calculate the overall percent impervious at each gage used in the original calculation. The land use file estimated a percent impervious from each land use polygon and this estimate was used in the composite calculation for curve numbers.

As shown in Table 10, the estimated percent impervious calculations from the land use layer results in 60% and 72% higher percent impervious calculations in Reedy and Clear Creek, respectively. This over-estimate of percent impervious should allow for the reduction of the curve numbers in calibration by more than +/- 4 as recommended in the guidance document.

The lag times in Clear Creek were not adjusted from the original calculations by using any global factor but original time of concentration flow paths did progress through several iterations to find the best fit for overall time to peak of the observed gage data. The time of concentration iterations included:

- a manual redraw of flow paths through pipes as noted in the inventory file, pipe flow was calculated using the open channel flow equations
- a velocity assumption of 1 ft/sec through ponds as recommended by the initial county review
- a redraw of the flow path to find a true longest time flow path. The overland or sheet flow calculations had the biggest impact on overall time of concentration calculations. Extra care was taken to find the longest time flow path versus the longest distance flow path.

Table 10: Percent Impervious Estimated vs. Calculated

Watershed	Original CN	% Imp from Land Use	% Imp from Imp Layer	Percent Difference
Reedy	70.42	19.61	12.24	60.2%
Clear	67.52	18.07	10.51	71.9%
Average	68.97	18.84	11.38	66.1%

Clear Creek - Several calibration iterations were performed in Clear Creek on both the August 2008 and July 2009 storms, as seen in the ***Clear Calibration*** spreadsheet. The initial simulations showed that the volume was 81.4% high and the peak flow was 66.4% high for the August 2008 storm. Similarly, for the July 2009 storm the initial simulated run showed that volume was 40.0% high and peak flow was 50.8% high. For the August 2008 storm a 11% reduction of curve numbers and an initial abstraction of 0.25*S resulted in the best fit of volume and peak flow to observed data.

The initial abstraction was increased from the default of 0.2*S to increase the reduction of the volume. We feel that 0.25*S is well within the acceptable range of initial abstraction values for this very rural sub-watershed. The July 2009 storm supplied more rain but it fell over a two day period and supplied two distinct peaks. Stepping through the iterations, a 10% reduction of curve numbers was used but the 0.2*S initial abstraction was all that was needed. The average curve number reduction and initial abstraction values of 10.5% and 0.225*S, respectively, were used in final calibration for the Clear Creek sub-watershed.

Reedy Creek – The iterations used in the calibration of Reedy Creek can be seen in the ***Reedy Calibrated*** spreadsheet. The July 2009 storm for Reedy Creek was very difficult to calibrate to because only 3.1 inches of rain fell which was separated by about 20 hours, creating two distinct peaks. The amount of rain was too small to consider in final calibration, therefore it is only shown for ancillary purposes. Initial simulation of the August 2008 storm resulted in a volume that was 36.3% high and a peak flow that was 49.6% high. Although the initial percentages were lower than found in Clear Creek, the shear amount of rainfall for the August 2008 storm in the Reedy Creek basin required larger reductions in curve number than we would have liked. Our initial calibration attempts had minimal impact and the hydrograph suggested that we could apply a lag time factor to assist in the calibration. This watershed has the largest continuous wooded area of any watershed we have studied and we believe that the time of concentration calculations may not do an adequate job of calculating through these areas. A lag factor of 1.75 was applied to the model and this assisted in lowering the peak flow and aligning the hydrograph peaks of the observed and simulated runs. In the ***Reedy Calibrated*** spreadsheet the third calibration is where we apply the lag time factor and this provided a 6% reduction of peak flow without affecting the volume. Our final calibration for Reedy Creek included a 14% reduction in curve numbers, an initial abstraction of 0.2*S, and a 1.75 lag factor.

4.3 Calibration Results

The model parameter calibration process for Clear and Reedy Creeks resulted in slightly different factor values for the respective storms events used in calibration. Final calibration for the Clear Creek sub-watershed was achieved computing an average CN factor and initial abstraction from each storm event and applying those values to the model (Table 12). The Reedy Creek model only used the August 2008 storm and also included a slight lag time factor as noted above.

Table 12: Results of Yadkin River Sub-basin Model Parameter Calibration

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	0212466000 (Clear Ck)	0.2*S	0.25*S	0.225*S	1.00	0.89	0.895
7/29/09		0.2*S	0.2*S		1.00	0.90	
8/27/08	0212430293 (Reedy Ck)	0.2*S	0.2*S	0.2*S	1.00	0.86	0.86
7/29/09		0.2*S	NA		1.00	NA	

When the above initial abstraction and curve number final values are applied to the respective models, the final simulated runoff and peak discharge values shown below in Table 13 are the result:

Table 13: Comparison of Simulated and Observed Runoff and Peak Discharge for Stream Gages used in Yadkin River sub-basin after calibration

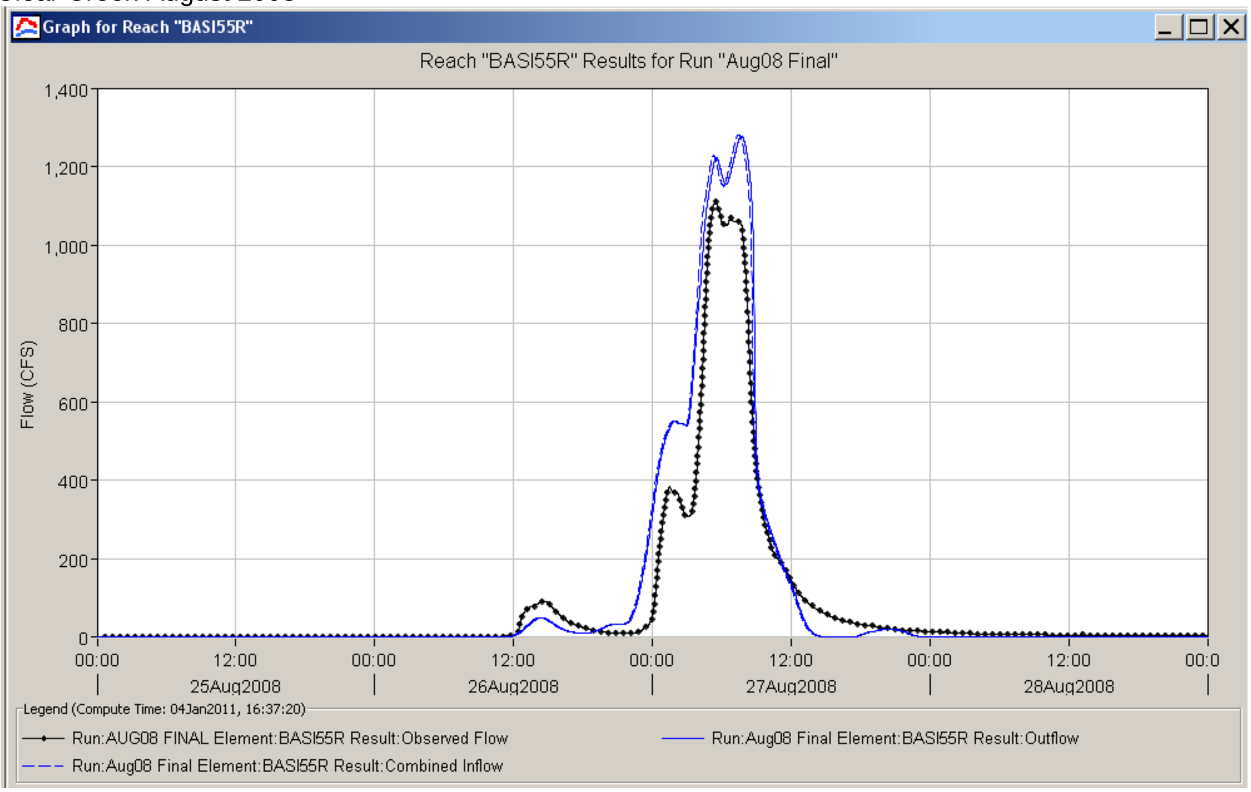
Date	Gaged Stream and Location	Observed Runoff (inches)	Simulated Runoff (inches)	% Difference from Observed Runoff	Observed Peak Discharge (cubic feet/second)	Simulated Peak Discharge (cubic feet/second)	% Difference from Observed Peak
8/27/08	0212466000 (Clear Ck)	1.17	0.97	20.6%	1,110	1,281	15.4%
7/29/09		1.50	1.45	-3.3%	1,380	1,491	8.0%
8/27/08	0212430293 (Reedy Ck)	3.69	3.85	4.3%	4,350	4,949	13.8%
7/29/09		0.55	0.36	-34.6%	677	707	4.5%

Specific hydrograph comparison for each storm in each basin is shown in the graphs below taken directly out of the HMS model results. The time to peaks for each storm and basin are as follows:

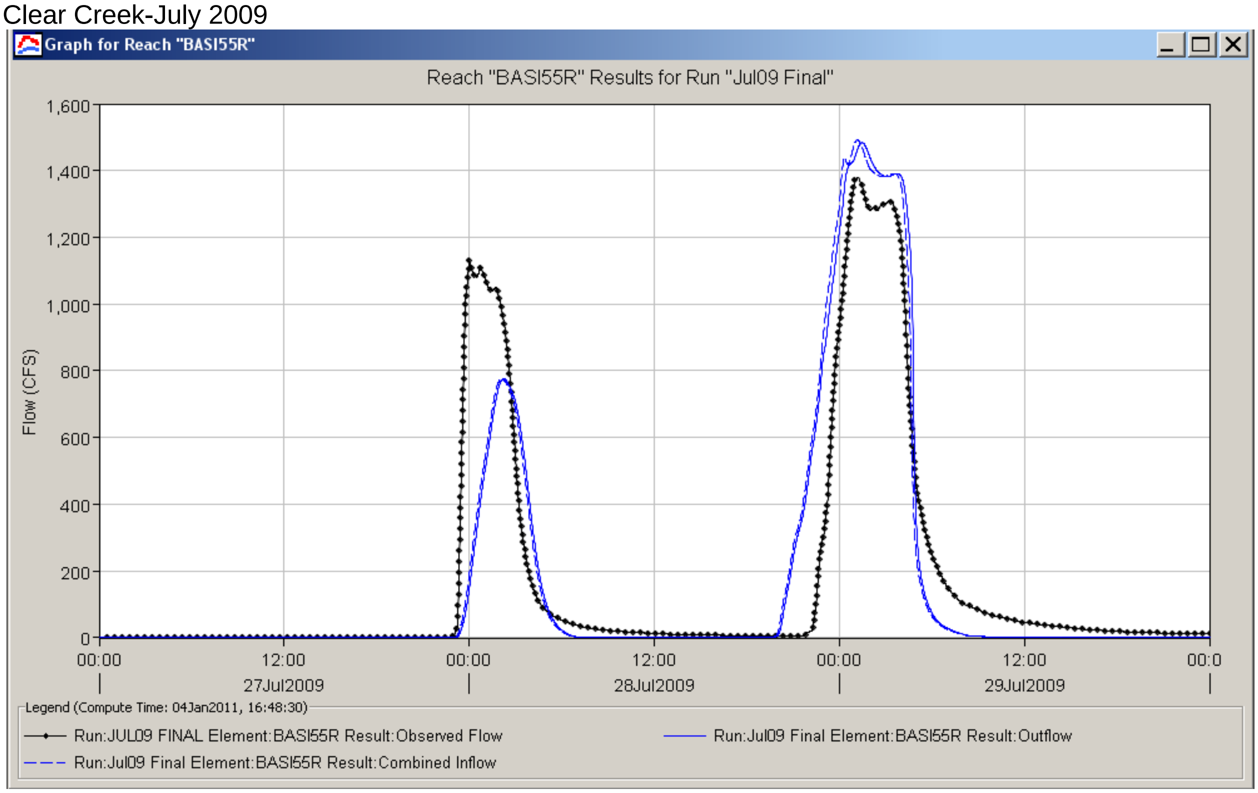
Table 14: Calibrated Time to Peaks

Date	Gaged Stream and Location	Observed Time to Peak	Simulated Time to Peak	Difference
8/27/08	0212466000 (Clear Ck)	27Aug08,05:30	27Aug08,05:29	-0:01
7/29/09		29Jul09,01:15	29Jul09,01:10	-0:05
8/27/08	0212430293 (Reedy Ck)	27Aug08,07:00	27Aug08,06:46	-0:14
7/29/09		29Jul09,01:30	29Jul09,01:56	0:26

Clear Creek-August 2008

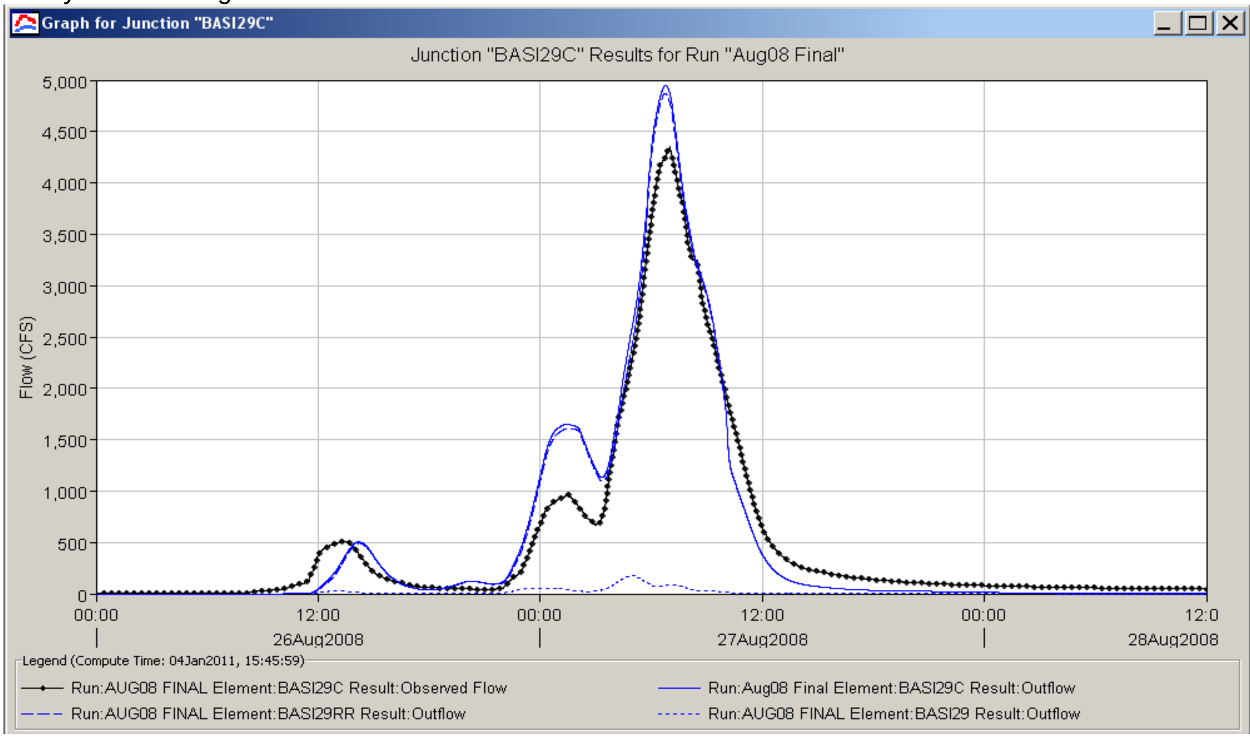


Clear Creek-July 2009

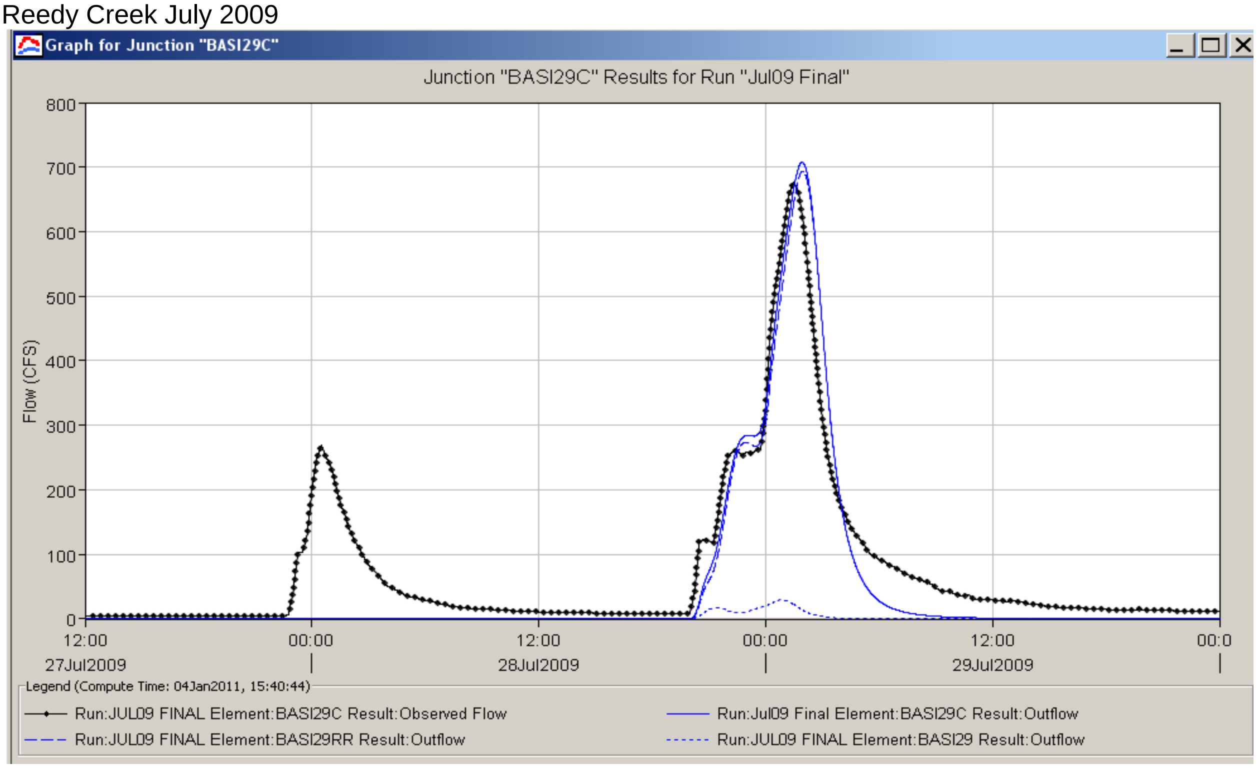


PRELIMINARY

Reedy Creek – August 2008



Reedy Creek July 2009



PRELIMINARY

High Water Mark Comparison: As another level of quality assurance, the final calibrated simulated flows from the August 2008 storm were input into the latest HEC-RAS models, these are not final models but our best representation of current stream geometry. The Reedy Creek watershed had two high water marks from the August 2008 event; both in the headwaters of the watershed. Clear Creek did not have any high water marks as the storm only produced the equivalent of a 10-year hypothetical event in that watershed. The results of our initial observations are below in Table 15.

Table 15: Preliminary Yadkin HWM Analysis

Reedy Creek			
XS Station	RAS Elev	HWM Elev	Diff
15000/15362	641.61	639.7	1.9
Reedy Creek Trib 3			
XS Station	RAS Elev	HWM Elev	Diff
14022	704.27	703.77	0.5

This initial high water mark comparison reveals that the hydrology calibration seems to be reasonable. Additional calibration will be required on the hydraulic model.

4.4 Model Comparison to the effective 1% Annual Storm and Regression

The 1% annual hypothetical storm was input into the calibrated and un-calibrated models and compared to effective flows in Table 17 below. In the Reedy Creek comparison the un-calibrated flows were slightly higher towards the downstream basins but definitely lower in the upper reaches as compared to effective flows. The calibrated flows for Reedy are slightly lower in the downstream basins and extremely lower in the upstream basins. Generally, the calibrated simulated flows were lower than effective flows at locations noted in the effective FIS. The calibrated simulated flows are generally lower than regression discharges as well but closer than effective flows.

The Clear Creek flows were on average about 25% lower than effective flows and the Reedy Creek flows were about 40% lower, on average, than effective flows. The effective study for both Reedy and Clear did not include any direct hydrologic gage calibration, only a calibration to high water marks. The effective study took more of a county-wide approach to the hydrology, whereas we have gone into more detail in these two specific watersheds. Although a 40% decrease in flows in the Reedy Creek watershed may seem excessive, there may be a couple of substantial reasons for the disparity, but all are based on a more exclusive look at the Reedy Creek basin, and taken together is the probable cause for the large disparity in flows. This more detailed review unveiled two specific grounds for the difference in flows compared to the effective study:

1. There are seven newly modeled reservoirs in the Reedy Creek headwaters that were not modeled in the original study, as none of them fall on modeled reaches. Several are quite large including Delta Lake dam, Linda Lake dam, and Reedy Creek Park Dam #3. These reservoirs attenuate a considerable amount of flow.

2. It appears that the effective Reedy Creek flows were generally on the high side. In a comparison to other effective flows with similar drainage areas, the Reedy Creek flows were from 5-39% higher than other flows in the Yadkin watershed. Also, in a direct comparison with the effective Clear Creek flows at the county line the effective Reedy Creek flow is 39% higher with a slightly smaller drainage area.

The updated calibrated flow on Reedy Creek at the county line now shows a 56% higher flow than that on Clear Creek. The effective flows show Reedy being 39% higher than Clear Creek at the county line.

Again, the general trend is, as you travel further upstream into the headwaters, our updated models display larger differences to the effective flows. And we believe that this is due to the more precise modeling of reservoirs in the headwater reaches that were not included in the effective study.

As compared to effective flows, the proposed flows are about 25% lower in the Clear Creek watershed and about 40% lower in the Reedy Creek watershed. Overall, we feel that we have calibrated to the August 2008 and July 2009 storms adequately and some initial high water mark comparisons back-up that assumption. Since our HMS model predicts about 14% more flow for the August 2008 storm at gage 212430293 and both water surface elevations are higher than the surveyed HWMs, we feel comfortable presenting flows that vary between 13% and 70% lower than effective values in the Reedy Creek watershed.

For Clear Creek, the proposed flows are closer to effective values, deviating between 12% and 44% lower than effective flow values. The calibrated Clear Creek HMS model results in a flow that is 15% higher than August 2008 storm at gage 212466000, there were no high water mark surveys in the Clear Creek basin because the August 2008 storm was only approximately a 10-yr hypothetical storm event and the July 2009 storm event was only approximately a 25-yr event, and was spread out over two days. The difference in effective and regression flows as compared to the calibrated flows in the Clear Creek model is similar to the Reedy model. The effective flows seem to closely resemble the regression flows, with the effective flows being consistently higher. The detail provided in this round of modeling contributes to the proposed flows being less than effective and even less than regression flows. The detailed modeling of 5 pond impoundments along with the detailed routing of much smaller sub-basins attributed to much higher attenuation overall in the watershed. This resulted in lower flows as compared to the effective and regression flows.

The final calibration factors, from data provided above are as follows:

Table 16: Final Calibration Factors Applied

Gaged Stream and Location	Lag Factor Applied	IA Applied	CN Factor Applied
0212466000 (Clear Ck)	None	0.225*S	0.895
0212430293 (Reedy Ck)	1.75	0.2*S	0.86

4.5 Calibration in Watersheds without Historical Stream Flow Data

A review of the un-calibrated peak flows as compared to the two observed gage peak flows for both storms reveals that original simulated estimates are high in every account. In Reedy we average 70% high for the two storms and in Clear the average initial over estimate is 58%. For a total of four individual events, the original un-calibrated models have over predicted peak flows and volumes. This leads to the plausible conclusion of applying calibration to the remaining un-gaged streams.

Table 17 displays a comparison of un-gaged, calibrated and un-calibrated flows, to Regression and effective flows. The un-calibrated simulated flows are consistently higher than regression flows but less so in the upper reaches and locations with smaller drainage areas. This contributes to the more detailed modeling of the upper reaches theory. There is obviously more attenuation modeled in this effort because of the extreme detail in capturing ponds and routing calculations. But as we progress downstream the difference becomes less pronounced.

These two observations led us to the conclusion that the un-gaged streams should be calibrated as well. It was determined that the most conservative calibration of the un-gaged streams would be to apply the 0.895 curve number adjustment from Clear Creek while maintaining the 0.2*S default initial abstraction. No lag factor was applied to the un-gaged streams.

Table 17: Simulated Peak Flows Compared to Effective and Regression Flows

	Eff DA (mi2)	Sim DA (mi2)	Sim Basin ID	Eff 1% (cfs)	Pre-Cal Sim 1% (cfs)	Urban Reg (cfs)	Ass. %Imp	Cal Sim 1%	% Change Eff	% Change Reg
Clear Creek										
county line	13.17	13.09	Basin34	3874	5189	3930	10	3037	-22%	-23%
100ft U/S of Ferguson Rd	11.27	11.25	Basin1231	3811	4971	3592	10	2919	-23%	-19%
1400ft D/S of Arlington Church	8.69	8.69	Basin71	3793	4701	3081	10	2750	-27%	-11%
50ft U/S of Bartlett Rd	1.57	1.66	Basin1182	1470	1538	1151	10	1161	-21%	1%
700ft U/S of Bartlett Rd	1.13	1.18	Basin69	1094	1344	1085	15	973	-11%	-10%
Clear Creek Trib										
550ft U/S of confluence	5.8	5.69	Basin1218	3217	3296	2770	15	2302	-28%	-17%
1500ft U/S of Bartlett Rd	4.38	4.2	Basin49	2696	2598	2313	15	1926	-29%	-17%
60ft U/S of Blair Rd (51)	2.21	2.15	Basin1179	1682	1643	1552	15	1164	-31%	-25%
Sherman Branch										
at confluence w/ Clear Creek	1.28	1.22	Basin33	1095	801	960	10	612	-44%	-36%
Reedy Creek										
county line	13.07	12.89	Basin30	5394	7250	3885	10	4715	-13%	21%
9800ft D/S of Hood Rd	7.68	7.78	Basin1224	4576	5269	3329	15	3314	-28%	0%
1600ft U/S of Hood Rd	2.69	2.69	Basin80	2141	2140	1773	15	1169	-45%	-34%
900ft U/S of Plaza Extension	1.62	1.64	Basin1180	1664	1352	1144	10	672	-60%	-41%
Reedy Creek Trib 2										
confluence w/ Reedy	2.75	2.74	Basin1201	2089	1780	1550	10	1124	-46%	-27%
200ft U/S of Robinson Church	2.05	2.01	Basin1190	1698	1484	1288	10	818	-52%	-36%
3200ft U/S of Robinson Church	1.43	1.42	Basin1171	1335	1232	1050	10	628	-53%	-40%
3900ft U/S of Robinson Church	1.13	1.09	Basin1155	1032	908	898	10	467	-55%	-48%
6000ft U/S of Robinson Church	0.5	0.51	Basin1081	604	406	568	10	164	-73%	-71%

	Eff DA (mi2)	Sim DA (mi2)	Sim Basin ID	Eff 1% (cfs)	Pre-Cal Sim 1% (cfs)	Urban Reg (cfs)	Ass. %Imp	Cal Sim 1%	% Change Eff	% Change Reg
Reedy Creek Trib 3										
confluence w/ Reedy	3.98	3.99	Basin64	2265	2821	1938	10	1781	-21%	-8%
4600ft D/S of Plott Rd	2.95	2.98	Basin2001	2022	2338	1883	15	1423	-30%	-24%
30ft U/S of Plott Rd	1.37	1.37	Basin1169	1106	932	1320	20	591	-47%	-55%
Back Creek										
@ county line	6.92	6.86	Basin1220	3397	4480	3713	25	3607	6%	-3%
400ft U/S of county line	4.67	4.6	Basin42	1971	2530	2932	25	1992	1%	-32%
3,100ft D/S of Katherine Kiker	2.82	2.83	Basin45	1829	1846	2198	25	1383	-24%	-37%
1,100ft D/S of McLean Rd	2.03	2.05	Basin1191	1706	1519	1812	25	1208	-29%	-33%
200ft U/S of McLean Rd	1.47	1.45	Baisn117	1477	1239	1478	25	1008	-32%	-32%
800ft U/S of West WT Harris	1.1	1.07	Baisn2	1395	1047	1234	25	841	-40%	-32%
Back Creek Trib										
at confluence	2.23	2.24	Basin1196	1779	1981	1908	25	1641	-8%	-14%
100ft D/S of Back Creek Church Rd	0.27	0.27	Basin969	1291	489	541	25	400	-69%	-26%
Caldwell Creek										
county line	1.5	1.52	Basin1177	1352	1423	1093	10	1004	-26%	-8%
900ft U/S of county line	1.14	1.15	Basin1158	1061	1102	928	10	794	-25%	-14%
Duck Creek										
county line	2.86	2.87	Basin1205	2045	1637	1592	10	1258	-38%	-21%
230ft U/S of county line	2.49	2.53	Basin5	1780	1531	1477	10	1166	-34%	-21%
1450ft U/S of county line	2.12	2.11	Basin1193	1634	1446	1328	10	1085	-34%	-18%
Goose Creek										
county line	7.29	7.36	Basin1222	4653	4849	3222	15	3898	-16%	21%
600ft U/S of county line	3.33	3.3	Basin66	2195	2349	2003	15	1860	-15%	-7%
250ft D/S of Lawyers Rd	1.94	1.86	Basin1187	1244	1494	1423	15	1232	-1%	-13%
McKee Creek										
county line	5.94	5.97	Basin28	2980	3420	3155	20	2665	-11%	-16%
2100ft D/S of Camp Stewart	4.44	4.44	Basin51	2300	2705	2646	20	2068	-10%	-22%
200ft U/S of Camp Stewart	3.5	3.44	Basin1211	1999	1987	2274	20	1628	-19%	-28%
2900ft U/S of Camp Stewart	2.74	2.78	Basin1202	1750	1542	2004	20	1191	-32%	-41%
D/S of East Lake Rd	1.27	1.24	Basin1164	1304	935	1241	20	688	-47%	-45%

	Eff DA (mi2)	Sim DA (mi2)	Sim Basin ID	Eff 1% (cfs)	Pre-Cal Sim 1% (cfs)	Urban Reg (cfs)	Ass. %Imp	Cal Sim 1%	% Change Eff	% Change Reg
North Fork Crooked										
at county line	N/A	1.25	Basin1165	N/A	1252	1126	15	1007	-11%	-11%
North Fork Crooked Trib										
at county line	N/A	1.72	Basin1185	N/A	1659	1360	15	1345	-1%	-1%
Reedy Creek Trib 1										
at county line	1.27	1.21	Basin1160	889	1568	1102	15	1259	42%	14%
Stevens Creek										
county line	7.29	7.36	Basin1222	4653	4849	3222	15	3898	-16%	21%
250ft U/S of county line	3.96	3.97	Basin62	2533	2518	2232	15	2024	-20%	-9%
3000ft U/S of 485	2.15	2.21	Basin50	1919	1560	1580	15	1247	-35%	-21%
300ft U/S of Thompson Rd	1.1	1.19	Basin1159	1629	759	1095	15	600	-63%	-45%
Stevens Creek Trib										
at confluence	1.42	1.43	Basin60	1053	1090	1221	15	844	-20%	-31%
2000ft U/S of Thompson Rd	0.71	0.67	Basin1118	764	574	776	15	436	-43%	-44%

Pre-Cal Sim 1% - Pre Calibration Simulated 1% annual flow

Cal Sim 1% - Calibrated Simulated 1% annual flow