7.0 STREAM CARRYING CAPACITY MODEL

For this project, the HEC-GeoHMS/HEC-HMS software package developed by the U.S. Army Corps of Engineers' Hydrologic Engineering Center was utilized to predict streamflow in each subwatershed. The software package consists of two components, the HEC-GeoHMS preprocessing software, which is an extension for ArcView, and the HEC-HMS (Hydrologic Modeling System) software which is a stand-alone program that models runoff for the watershed. HEC-GeoHMS processes the geometry of the basin to develop the majority of the input parameters for the HEC-HMS software. This project is a GIS intensive analysis, so it was felt that the GeoHMS approach would be an efficient method to assess a basin of this size. It is also a standardized approach that allows for analysis of predicted land use scenarios.

7.1 GeoHMS Methods

As mentioned above, there are two primary phases of this portion of the analysis. The first is the derivation of the basin geometry from available GIS data, while the second is the use of this data to model runoff in the watershed. The following sections pertain to the HEC-GeoHMS processing portions, which derives basin geometry.

Watershed Delineation and Stream Network Development

A terrain model was developed, which defines the geometry of the subwatersheds and channels within the watershed. The preparation of the terrain model followed an 8-step process.

1. The Digital Elevation Model (DEM) data were loaded.
2. Depressions in the DEM data were filled to accommodate watershed modeling. The resulting grid was called "fill".
3. A flow direction grid was developed. The elevation of the surrounding grid cells defines the direction of flow leaving any specific grid cell within the model.
4. Each grid cell was assigned a stream flow accumulation value. This value represents the tributary area upstream of each specific grid cell. Calculations are made for each grid cell within the grid.
5. A stream grid was developed from a user-defined flow accumulation area. The threshold for a GIS stream to be created was 10,000 grid cells or approximately 25 square miles. This means that the flow accumulation area for a particular cell must exceed the 25 square mile threshold value before a stream segment can be generated in the stream model. This means that the first grid cell defined on a stream section in a headwater watershed will have approximately a 25 square mile tributary area.
6. A stream link grid was generated to define the individual stream reaches in the model. Beginning with a streams threshold grid cell, the first reach extends downstream to the first confluence. Stream reaches are defined from the first grid cell to the first confluence and then from confluence to confluence thereafter.

7. A watershed subwatershed grid is generated from the stream link grid and the flow direction grid. The threshold stream size is implied in the stream link grid which defines the watershed boundaries.
8. Vector files of the stream reaches and the watershed subwatersheds are generated from their respective grids (Stream link grid and watershed subwatershed grid).

Because of the relatively coarse elevation data for the study area (30 meter resolution), refinements and adjustments to the watershed boundaries are not supported. When higher quality elevation data are availalable the client may want to consider merging or subdividing basins to relate to physiographic changes in the study area such as major stream grade breaks. A watershed may also be subdivided into smaller areas to test the significance of development in a small subwatershed.

Stream and Watershed Characteristics

Following creation of the terrain model, processing was performed that defines the flow path lengths and relative slopes. This information is used for development of the time of concentration and basin lag values, which defines how long it takes water to travel through each subwatershed.

1. River length of the centerlines was extracted from the stream network described above. A length was calculated for each river reach. The lengths are stored in the river shape file.

2. River slope was calculated for each stream reach. An upstream and downstream elevation are extracted from the DEM. A slope value in percent is calculated for each reach. The river slope, along with the upstream and downstream elevations, is stored in the river shape file.

3. A basin centroid is required in the development of the HMS model. The basin centroid is a point representation for the specific subwatershed. There are several options for the calculation of the basin centroid. The method used in this study is the flow-path method. This method generates the longest flow path within the basin and locates the centroid at the midpoint of this path. A vector representing the longest flow path is generated during this process. The elevation for the basin centroid is stored in both the basin centroid shape file as well as the watershed basin shape file.

4. Longest flow path is required for the time of concentration calculations. For downstream basins, the longest flow path does not necessarily link the basin outflow to the basin inflow (i.e. the longest flow path may not follow the main channel through the basin). The length of the longest flow path is stored in both the longest flow path shape file and the watershed basin shape file.

5. The final watershed characteristic calculated is the centroidal flow path. The centroidal flow path represents the midpoint of the longest flow path to the

subwatershed outlet. The length of the centroidal flow path is stored in the centroidal flow path shape file and the subwatershed shape file.

Channel Parameters

Field data were collected for the stream channels of each subwatershed (see Appendix X for these data). Field values for bottom width, side slope and Manning’s n are added to the river shape file for each reach. These are utilized in the time of concentration derivation, explained below. Figure 7.1-A Field Points shows the points where channel cross-sectional information was obtained. It should be noted that geometric information was not obtained for the Middle Bonne Femme and Smith Creek subwatersheds, due to lack of access.

Time of Concentration

The time of concentration is estimated in accordance with the Natural Resource Conservation Service's Technical Release 55 (TR55) methodology. Time of concentration is defined as the travel time for water that falls on the subwatershed divide to reach the subwatershed outlet. According to TR55, water moves through a watershed as sheet flow, shallow concentrated flow, open channel flow, or some sequential combination of these. The initial runoff flow type is sheet flow, which is flow over plane surfaces. After a maximum of 300 feet, sheet flow usually becomes shallow concentrated flow, which is flow on the surface of soil, within rills or gullys. Open channel flow begins when a stream or creek is encountered, which is dependent on the specific subwatershed. The NRCS equations are based on a 2-year, 24-hour rainfall event.

To differentiate the three flow types, the longest flow path is broken into segments. By default, the first 300 feet from the upstream end of the longest flow path is defined as the break point between sheet flow and shallow concentrated flow. The second point is the break point between shallow concentrated flow and open channel flow, which occurs when the longest flow path reaches the river length derived in the previous section. The slope and length of each section between these break points is calculated and stored in the longest flow path shape file.

A spreadsheet is generated that summarizes the time of concentration parameters and calculations. The purpose of the spreadsheet is to allow the user to review and refine the automatically derived parameters. Manning's n values are refined to match field observations. Once all edits have been made to the parameters, the refined time of concentration values are exported back to the subwatershed shape file.

Curve Number Grid Derivation

Curve Number (CN) is an indicator of runoff potential for a given surface. The method was developed by the Soil Conservation Service (SCS), now known as the NRCS. The SCS-CN grid is the land-based component used in the computation of surface runoff in the HEC-HMS model. The values of SCS-CN were developed using the TR55 methodology. The SCS-CN method provides a rapid means for estimating runoff change with repect to changes in land use. The SCS-CN method is well established and used commonly to evaluate the runoff impacts of existing or proposed land use change.

The SCS-CN grid is developed from the union of land use and soil data. This union generates polygons or grid cells that have a specific land use and a specific hydrologic soil group value. TR55 land use categories and their related CN values are assigned to the LULC data by the user. The hydrologic group assignments (A to D) are assigned by the NRCS soil scientists during the soil mapping process and are defined for every soil type. Minimum annual steady ponded infiltration rate for a bare ground surface determines the hydrologic soil groups. Table 7.1-i contains criteria for class placement.

Table 7.1-i. Criteria for placement of hydrologic soil groups.

Hydrologic Soil Group	Criteria[a]
A	Saturated hydraulic conductivity is *very high* or in the upper half of high and internal free water occurrence is *very deep*
B	Saturated hydraulic conductivity is in the lower half of *high* or in the upper half of *moderately high* and free water occurrence is *deep* or *very deep*.
C	Saturated hydraulic conductivity is in the lower half of *moderately high* or in the upper half of *moderately* low and internal free water occurrence is deeper than *shallow*.
D	Saturated hydraulic conductivity is below the upper half of *moderately low*, and/or internal free water occurrence is *shallow* or *very shallow* and *transitory* through *permanent*.

a. The criteria are guidelines only. They are based on the assumption that the minimum saturated hydraulic conductivity occurs within the uppermost 0.5 m. If the minimum occurs between 0.5 and 1 m, then saturated hydraulic conductivity for the purpose of placement is increased one class. If the minimum occurs below 1 m, then the value for the soil is based on values above 1 m using the rules as previously given.

Reference: Soil Survey Manual - *Chapter Three Examination and Description of Soils* (*http://soils.usda.gov/technical/manual/print_version/chapter3.html*)

Since there are no definitive or current land use/land cover maps for Boone County, a composite of multi-date and multi-resolution map data was developed for this study. National Land Cover Data (NLCD) were used to describe the rural lands in the study area. Urban areas were identified from county property (cadastral) maps. Rights of way, also identified from county cadastral data, were used to represent the transportation network. SSURGO soils were used to enhance “urban area” and “water body” classes. National Hydrologic Data (NHD) waterbodies were used as the primary water body classification data source. IKONOS classified satellite imagery was used to identify impervious surface in the entire watershed.

Each land use file was unioned to develop the Land Use Land Cover GIS theme. The union of the various files allows the datafile to maintain all of the classification values of the original data. No final land use land cover theme was generated from this composite, although the land use is implied with the assignment of the SCS-CN values. Additional fields were added to maintain the present and future use SCS-CN values.

TR55 assignments were made following a data-quality hierarchy. The hierarchy generally follows from general to specific and from least current to most current.

1) The National Land Cover Data (NLCD) data provide total coverage of the study areas but is the least-resolved data. Though coarse, the NLCD classifications provide a good representation of large rural acreage. It should be noted that large clear cuts, fire, changing agricultural planting strategies, etc. may have occurred since the satellite data were captured in the early 1990s.

2) NLCD data often underestimates urban area, as tree canopies can obscure roads, buildings and other developed features. The poorly resolved data can not easily define urban boundaries. Conversely, the county cadastral data (parcel boundaries) define a region's "urban area" very well. The tax-use classes match closely with the TR55 land use categories. Small parcels generally represent intensive land use and a single use, and small parcels rarely represent multiple land uses. Tax use classifications, for example, of small residential, commercial and industrial parcels are very accurate because the data are used for tax appraisal purposes. The cadastral data have other benefits. The data are updated annually and can be used to update urban area or change to urban uses. As a result of these strengths, cadastral data and tax use attribute data were used in this model to classify urban areas. These updates can then be used to refine the SCS-CN grid on an annual basis.

3) Small parcels, less than or equal to 5 acres, were used to identify various urban area classes. "Rights of way" (the space between the parcels where streets and rail corridors are found) were incorporated to represent urban and rural developed transportation corridors. TR55 assignments for parcel data replaced those assigned to NLCD data.

4) SSURGO soils were used to supplement "urban area" classes. Because soils types are based on rigorous field analysis, soil classifications representing "urban area" are likely to be more accurate than modeled boundaries found in NLCD classifications. The urban soils found in Boone County (Keswick-Urban land complex, Mexico-Urban land complex, Urban land-Harvester complex, Weller-Urban land complex, Wrengart-Urban land complex) have been severely altered through excavation and development. These soils are represented as "urban area" land use for SCS-CN calculations.

5) The waterbody polygons found in the National Hydrographic Data (NHD) datasets were used in the development of the SCS-CN curve grid. NHD represents a "comprehensive set of digital spatial data that contains information about surface water features such as lakes, ponds, streams, rivers, springs and wells" (http://nhd.usgs.gov/). The high-resolution NHD waterboundaries used in this project were developed from 1:24,000/1:12,000 scale and represent the best water boundary data available for this study.

Two NHD subregion (NHDH1030 and NHDH0711) geodatabases were required to cover Boone County. (FTP location nhdftp.usgs.gov). The two geodatabases were merged and clipped at the Boone County line. The resulting waterbody map data were unioned with the other land use datasets described above. An SCS-CN value of 100 was assigned to the waterbody polygons.

IKONOS multi-band satellite imagery was collected and processed in November 2004 and represents the most current impervious surface data available for the study area. The high-resolution data provide the best estimates for impervious surface in the study area. The data represent actual "impervious surface" as opposed to an estimate of impervious surface based on land use/lot size. The SCS-CN values for the impervious surfaces were adjusted to reflect this additional accuracy.

The TR55 estimates were established to address a specific land use for a specific parcel size. The resulting TR55 value averages the various impervious and pervious surfaces on the property such as the building footprint, driveway, sidewalk, grassed yard, and wooded areas for a residential property. The use of the IKONOS data requires that the single residential class is divided into 2 or more use classes—those features of the property that are impervious (defined by IKONOS classification) and those that are pervious. The IKONOS impervious surface features were classified as *"Impervious areas: Paved parking lots, roofs, driveways, etc (excluding right-of-way)."* The remaining yards and open space were classified as *"Open space (lawns, parks, golf courses, cemeteries, etc.) Good condition (grass cover > 75%)"* Conventional classification assignments were used where IKONOS data were not available.

Three different sets of SCS-CN assignments were required. The first SCS-CN assignments covered the gaged Hinkson Creek Watershed. This watershed was used because it has a stream gage, and this was done to calibrate the model since there are no active USGS stream gages in the Bonne Femme Watershed. Because the data were available for the entire county, SCS-CN assignments were made for the entire county. As a result, these data could be used to model other watersheds in the county if desired. The IKONOS data were not used in these assignments because the coverage is limited to the primary study area. Second, the first assignments were adapted to incorporate the higher quality IKONOS impervious-surface data for the study area. Third, the future land use assignments were made based on parcel coding provided by the client. There were 180 properties marked for future land use change, see Table 7.1-i for a summary of the additional parcels and associated acreage. Of these, the land use classification of parcels falling into the "Park and Conservation" and "Unlikely to Develop" categories will not change. TR55 assignments for the remaining parcels were made based on the future land use category and proposed building density.

Table 7.1-i. Future Land Use Parcel Summary

#	Future Land Use	Parcel Count	Total Acreage
1	Commercial	22	1,085.6
2	Industrial	8	411.3
3	Park or Conservation	32	4,237.0
4	Residential	65	2,704.7
5	Residential-Low Density	28	1,481.6
6	Unlikely to develop	25	1,039.4
	TOTALS	180	10,959.6

The future SCS-CN assignment is performed at the parcel level. As a result the higher resolution NHD waterbody and IKONOS impervious surface values were overridden at the parcel level. As a result, NHD waterbodies and IKONOS SCS-CN values were re-assigned.

The data fields containing these three assignments are as follows.

1. ***Pres_CW_SCS_CN*** (present land use, county-wide, does not include IKONOS data)
2. ***Pres_SA_SCS_CN*** (present land use, study area only, includes IKONOS data)
3. ***Fut_SA_SCS_CN*** (future land use, study area only, includes IKONOS data)

Note: SCS-CN values developed for the Hinkson Creek watershed can be used to generate SCS-CN grids anywhere in the county. In contrast, since the IKONOS data only cover the Bonne Femme Watershed and the assignments for the IKONOS data are only appropriate for the Bonne Femme subwatersheds, assignment values for IKONOS data outside of the Bonne Femme study area are invalid.

All assignments were performed within the GIS geodatabase MS ACCESS file. The assignment queries are preserved in the ACCESS database as queries. Should the client feel inclined to change or adjust the assignments, the data are easily edited.

ModClark Grid

A ModClark grid was used as a means of incorporating distributed data into the modeling process. The watershed is essentially divided into several grids to allow for more resolved land use distributions and to utilize the radar precipitation data for specific events (NEXRAD Stage 3 data). It is important to note that distributed models work best to identify internal distributions within a subwatershed. According to the National Weather Service, "few studies have specifically addressed the improvement of distributed models over lumped models for predicting basin outflow hydrographs." At this time we can not state that higher-resolution distributed data "will lead to more accurate hydrograph simulations." (http://www.nws.noaa.gov/oh/hrl/dmip/intro.html)

The ModClark gridded model imposes the HRAP (Hydrologic Rainfall Analysis Project) grid on the subwatersheds. HRAP is a grid coordinate system used within the National Weather Service and represents the resolution of the radar data used in the HEC-HMS model. The ModClark grid intersects the subwatersheds with the rainfall grid generating summarized areas of unique subwatershed SCS-CN and rainfall data. Additional information on the HRAP coordinate system can be found at the following web addresses.
http://www.nws.noaa.gov/oh/hrl/distmodel/hrap.htm
http://www.pubs.asce.org/WWWdisplay.cgi?9901408

Once the ModClark grid has been generated, the average CN value for each ModClark polygon is calculated. This parameter is defined as BCN, which is the average curve number value for the ModClark grid cell. These data are placed into the BCN field in the ModClark polygon file.

HMS Parameter Export

Following creation of the data files described above, several functions are performed to ready the data for export into the HMS model structure. They are as follows.

1) Reach autoname and basin autoname assigns unique names to all stream reaches and subwatersheds analyzed in the study area.
2) Map units are converted to the desired units for HMS processing.
3) A check of the several project characteristics is made to verify that there are no conflicting names, stream reaches are within a watershed boundary, each subwatershed has one and only one centroid, all stream reaches are connected, and that the outlet point is valid.
4) A schematic of the HMS model is generated which represents the subwatersheds, stream network, stream junctions, reservoirs, diversions and sinks. HMS coordinates are added to these features for use in the HMS model.
5) Geo-HMS does not generate all of the parameters required to run the HMS model. The *Standard HMS Processes* function is used to populate these parameters with default values. The user can edit the fieldmap.fmf file to allow more control of the HMS extraction.
6) The background map file used in the HMS model is generated in Geo-HMS. The file contains HMS coordinates for the subwatershed polygons. A grid cell parameter file transfers area, length and CN values to the HMS model. A distributed basins file transfers the HMS schematic, the various features and their connectivity, from Geo-HMS to the HMS model.
7) There is an option to develop a single Meteorological export model. If the model is generated, it must be replaced in the HMS model.
8) The final step in the HMS setup process is to setup the project files. The HMS project Setup function generates the final *.hms file and then copies the required HMS file into a default HMSPROJ file folder.

7.2 HMS Methods

Following characterization of the watershed and stream characteristics in the study area using HEC-GeoHMS, the next step is configuration of the HMS model. The HMS program operates with three primary components: a basin model, a meteorologic model, and control specifications. The basin model is the geometric definition of the watershed and stream network. The meteorological model defines the rainfall that will be applied to the basin model. The control specifications define the timing of the rainfall event.

Basin Model

The basin model represents the spatial configuration of the watershed. The following figures summarize the parameters derived from the GeoHMS processing. Figure 7.2-A Drainage Areas presents the subwatersheds used for the basin model, their main channel configuration, and the subwatershed's associated surface area. Figure 7.2-B Hydrologic Soil Groups defines the layout of hydrologic soil groups within the watershed. Figure 7.2-C Existing Land Use summarizes existing land use within the watershed. Figure 7.2-D Existing Curve Number is an exhibit showing the existing gridded curve number for each subwatershed, derived by combining existing land use and hydrologic soil groups. Figure 7.2-E Predicted Land Use summarizes predicted land use within the watershed, with those parcels predicted to change highlighted. Figure 7.2-F Predicted Curve Number is an exhibit showing the predicted gridded curve number for each subwatershed, derived by combining predicted land use and hydrologic soil groups. It should be noted that Predicted Curve Number assumes conventional methods of construction.

The basin model is practically complete following export from the GeoHMS software. Aside from checking the input values for accuracy and reasonableness, the storage coefficient for each subwatershed must be entered. The storage coefficient is used for unit hydrograph derivation along with the time of concentration (using the Clark Method). It is a measure of the flow retention occurring in each subwatershed due to storage within the soil, on the surface, and within the channels. The primary factors affecting its value are storage and flow length within the subwatershed. The storage coefficient is derived through empirical methods. For this study, the USGS Water Resources Investigations Report 00-4184 "Equations for Estimating Clark Unit-Hydrograph Parameters for Small Rural Watersheds in Illinois" was utilized to estimate the storage coefficient. This was a recent study from a similar physiographic region that was felt to be the most reasonable method for estimation of these values. Table 7.2-i summarizes the Clark Unit Hydrograph parameters used in the basin model.

Table 7.2-i. Clark Unit Hydrograph Parameters.

Sub basin Identification	Time of Concentration (hr)	Storage Coefficient (hr)
Gans Creek North	4.2	1.9
Missouri River Tributary	not modeled	
Gans Creek South	3.9	1.8
Gans Creek	4.7	1.7
Clear Creek	3.3	1.2
Upper Little Bonne Femme	1.4	0.5
Upper Bonne Femme	8.7	3.1
Middle Little Bonne Femme	1.3	0.4
North Branch Little Bonne Femme	2.9	1.0
South Branch Little Bonne Femme	2.6	1.3
Lower Little Bonne Femme	4.5	1.5
Turkey Creek	6.7	2.8
Bonne Femme	2.3	0.9
Turkey/Bass Confluence	0.9	0.3
Bass Creek	6.2	2.2
Smith Creek	2.7	0.9
Middle Bonne Femme	2.8	0.9
Lower Bonne Femme	0.9	0.1
Fox Hollow Branch	2.5	0.6

For the purposes of this study, baseflow was assumed to be zero for all cases. Based on field observations this is felt to be a realistic assumption. All routing calculations were performed using the Muskingum Cunge standard method, using geometry measured in the field or derived through GIS analysis.

To model the characteristics of the karst systems present in this watershed, the runoff model was adjusted to account for defined subsurface flow between the Upper Bonne Femme subwatershed and the Pierpont subwatershed. Boone County estimates (Terry Frueh, personal communication) that the maximum flow capacity of the Devil's Icebox conduit is approximately 400 cfs. The surface water model was altered to divert up to 400 cfs from the Upper Bonne Femme subwatershed to the confluence of Devil's Icebox outflow with Gans Creek. The results presented in later sections account for this diversion.

Meteorologic Model

HEC-HMS has several options for specifying a rainfall event to apply to the basin model. The majority of these are not useable when the basin processing is performed with GeoHMS (HEC-HMS can be used without GeoHMS). Since the basin model is divided into grids, the gridded precipitation model was used in the HMS modeling process. This required the use of an actual rainfall event so spatially distributed rainfall amounts could be obtained from the National Weather Service. Next Generation Radar data (NEXRAD) is available from the National Weather Service for November 1994 to present. NEXRAD data was obtained from http://dipper.nws.noaa.gov/hdsb/data/nexrad/mbrfc_stageiii.php. The Missouri Basin River Forecast Center (MBRFC) provides NEXRAD one-hour precipitation (OHP) digital radar data. Although no metadata was provided with the data, additional information about the NEXRAD products can be found at http://www.ncdc.noaa.gov/oa/radar/radarproducts.html. A search was performed for all recorded flooding events in Boone County. Table 7.-ii presents the results of that search.

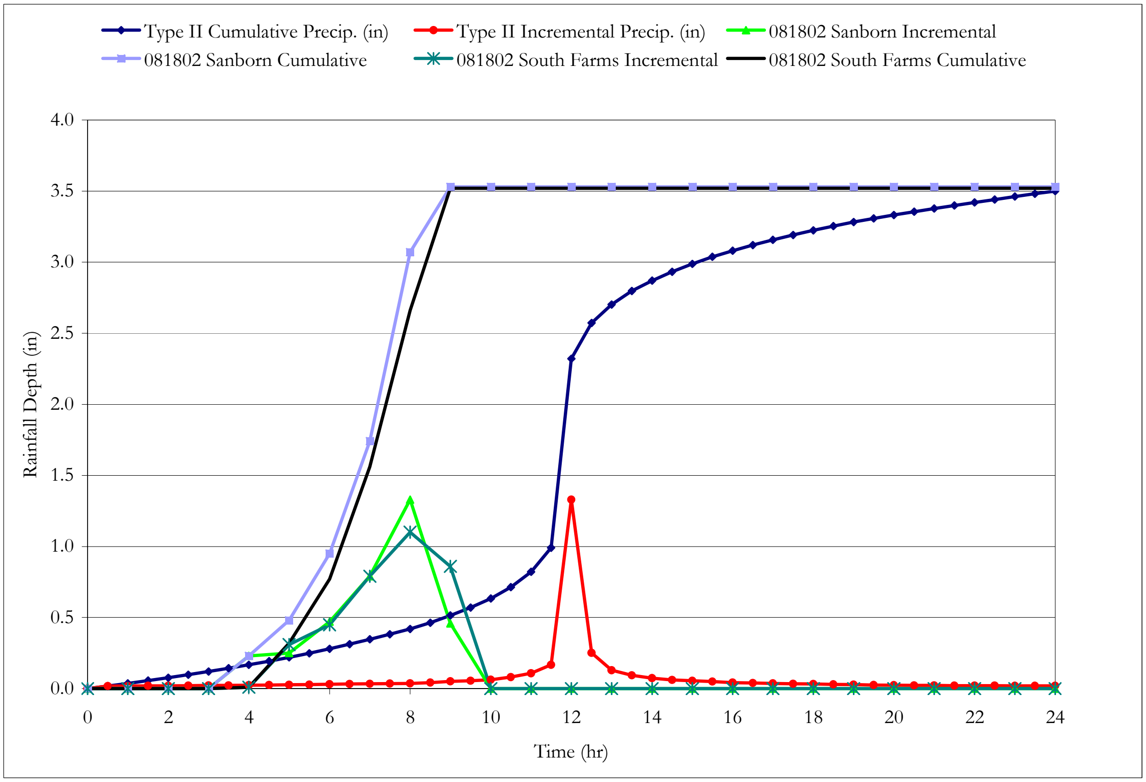
Table 7.2-ii. Flooding in Boone County, MO

Location within Boone County, MO	D	Type
1 Columbia	9/19/1993	Urban Flood
2 Columbia	9/22/1993	Flash Flood
3 Central And	4/11/1994	River Flood
4 Columbia And	4/11/1994	Flash Flood
5 Centralia	5/7/1995	Rural Flood
6 BOONE	5/17/1995	Flash Flood
7 MOZ010 - 019 - 027 - 035>036 - 041 - 047>051 - 059>065 - 075 - 084 - 099	5/1/1996	Flood
8 Countywide	6/22/1997	Flash Flood
9 Countywide	6/29/1998	Flash Flood
10 Central Portion	7/4/1998	Flash Flood
11 Countywide	10/5/1998	Flash Flood
12 MOZ041 - 047>051 - 059>063	10/6/1998	Flood
13 North Portion	6/12/1999	Flash Flood
14 South Portion	5/27/2000	Flash Flood

15 North Portion	8/7/2000	Flash Flood
16 Columbia	5/17/2001	Flash Flood
17 MOZ041 - 047>051 - 059>063	6/4/2001	Flood
18 Columbia	7/19/2001	Flash Flood
19 Countywide	5/7/2002	Flash Flood
20 MOZ041 - 048>051 - 059 - 061>063	5/8/2002	Flood
21 Countywide	5/9/2002	Flash Flood
22 Countywide	5/12/2002	Flash Flood
23 South Portion	8/18	Flash Flood
24 Columbia	8/20/2002	Flash Flood
25 North Portion	6/12/2003	Flash Flood
26 North Portion	6/25/2003	Flash Flood
27 Countywide	3/26/2004	Flash Flood
28 Countywide	8/26/2004	Flash Flood
29 Countywide	1/12/2005	Flash Flood

The rainfall totals for these storms were examined to determine candidates for use in the model. After analysis of several events, it was judged that the precipitation event of 18 August 2002 closely resembled the theoretical intensity-duration-frequency characteristics of a 2 year design rainfall event for this area of the country. Figure 7.2-iii compares the actual hourly rainfall data collected at the Sanborn and South Farms Weather Stations to a theoretical Type II distribution with a total precipitation of 3.5 inches.

Table 7.2-iii. Precipitation on 18 August 2002 compared to a Theoretical Type II Distribution (2 Year Return Interval, 24 Hour Duration).



As shown in Table 7.2-iii, the precipitation event of 18 August 2002 closely resembles a theoretical 2 year return event for this area. There was a similar total amount of precipitation and time distribution during the two events. For this reason, it was selected as an appropriate storm to use for the hydrologic modeling. A 2 year event is approximately equal to the bankfull discharge, which is also known as the channel forming event. The channel-forming event is extremely important because that is what maintains the stream channel in dynamic equilibrium; when this is maintained, aquatic habitat remains intact, and infrastructure is protected. The data for this event were transformed into the required format for the HMS model, which is distributed both temporally and spatially throughout the basin.

Control Specifications

The control specifications file determines the period that the model is run. In this case the event began at 23:00 on 17 August 2002 and ended at 23:00 on 18 August 2002, with a time interval of one hour.

7.3 Results

Table 7.3-i. For each subwatershed in the watershed, the HEC-HMS model predicts a maximum flow, time of maximum flow, and total runoff volume. Following are these values for each subwatershed in the watershed for existing and future conditions.

	Existing Conditions			Future Conditions		
Subwatershed Identification	**Maximum Discharge (cfs)**	**Time of Maximum Flow**	**Total Runoff Volume (a**	**Maximum Discharge**	**Time of Maximum**	**Total Runoff olu ac-**
Gans Creek North	893	18 Aug 02 1700	307	893	18 Aug 02 1700	307
Missouri River Tributary						
Gans Creek South	947	18 Aug 02 1700	355	947	18 Aug 02 1700	355
Gans Creek	3944	18 Aug 02 1800	2246	3999	18 Aug 02 1800	2279
Clear Creek	1120	18 Aug 02 1700	349	1206	18 Aug 02 1700	382
Upper Little Bonne Femme	3818	18 Aug 02 1800	2221	3883	18 Aug 02 1800	2254
Upper Bonne Femme	1569	18 Aug 02 2100	585	1634	18 Aug 02 2100	613
Middle Little Bonne Femme	4209	18 Aug 02 1800	2463	4273	18 Aug 02 1800	2496
North Branch Little Bonne Femme	884	18 Aug 02 1700	279	917	18 Aug 02 1700	291
South Branch Little Bonne Femme	524	18 Aug 02 1700	186	524	18 Aug 02 1700	186
Lower Little Bonne Femme	5508	18 Aug 02 1800	3025	5689	18 Aug 02 1800	3097
Turkey Creek	1489	18 Aug 02 2200	573	1489	18 Aug 02 2200	573
Bonne Femme Middle	3777	18 Aug 02 2100	1883	3837	18 Aug 02 2100	1906
Turkey/Bass Confluence	3823	18 Aug 02 2100	1686	3888	18 Aug 02 2100	1711
Bass Creek	2131	18 Aug 02 1900	816	2131	18 Aug 02 1900	816
Smith Creek	589	18 Aug 02 1600	157	589	18 Aug 02 1600	157
Bonne Femme Lower I	2866	18 Aug 02 1600	91	2914	18 Aug 02 1600	91
Bonne Femme Lower II	2849	18 Aug 02 2200	1334	2897	18 Aug 02 2200	1351
Fox Hollow Branch	234	18 Aug 02 1700	50	234	18 Aug 02 1700	50

To gain insight on the relative importance of the modeled flows, several interpretive figures have been prepared. Figures 7.3-A Existing Flow (cfs/sq mi) and 7.3-B Predicted Flow (cfs/sq mi) show the discharge in each subwatershed normalized to the tributary area upstream of each subwatershed for both existing and future conditions. When these figures are compared to the curve number figures, which indicate runoff potential, there is a strong correlation, as would be expected. Figure 7.3-C Flow Increase graphically depicts those subwatersheds that are predicted to experience an increase in flow when future build out conditions occur.

The channel geometry and bed material observed during the field work was used to calculate hydraulic values for the subwatershed outlets. For each subwatershed, velocity, shear stress, and a theoretically stable grain size was determined. Manning's equation (Brater, 1976) was used to determine velocity in the channels and DuBois equation (Rosgen, 2000) was used to determine shear stress. A third model run was also made to assess what effect an additional 10% increase in impervious area would have on runoff and channel discharge in the subwatersheds. Table 7.3-ii presents the results of the hydraulic calculations for all three model runs. Figure 7.3-D Velocity Increase shows the subwatersheds that are predicted to experience an increase in discharge velocity when future build out conditions occur.

As mentioned above, there were a total of three scenarios modeled, which were existing conditions, future conditions, and a 10% increase in impervious area in addition to the future conditions land use. It was felt that an appropriate way to evaluate and summarize the model results is through a shear stress analysis. The theoretical shear stress was compared to the observed grain size in the channels. Figure 7.3-E Shear Stress depicts those subwatersheds that are predicted to have shear stresses that exceed the stability threshold of the materials observed in representative cross sections of each subwatershed during a 2-Year precipitation event. "Acceptable" shaded subwatersheds are predicted to be stable for present and future conditions. "Existing" shaded subwatersheds are predicted to be unstable during conditions currently present. "Predicted" shaded subwatersheds are predicted to be unstable during conditions expected in the 25-year buildout analysis. "10% Incr. in Impervious" shaded subwatersheds are predicted to become unstable when 10% additional impervious area is added to the future build out conditions.

Table 7.3-ii. Velocity, Shear Stress, and Stable Grain Size by Subwatershed.

	Existing Conditions			Future Conditions			10% Increase in Impervious		
Subwatershed Identification	Velocity (fps)	Shear Stress (lb/ft²)	Stable Grain Size (in)	Velocity (fps)	Shea Stress (lb/ft²)	Grain Size (in)	Velocity (fps)	Shear Stress (lb/ft²)	Stable Grain Size (in)
Turkey Creek	6.5	1.4	4.9	6.5	1.4	4.9	6.7	1.5	4.9
Bass Creek	8.2	1.7	5.7	8.2	1.7	5.7	8.5	1.7	6.1
Turkey/Bass Confluence	8.4	1.1	3.1	8.5	1.1	3.1	8.8	1.1	3.7
Upper Bonne Femme	7.1	0.8	2.0	7.1	0.8	2.0	7.2	0.9	2.0
Bonne Femme Middle	5.4	0.5	0.9	5.4	0.5	1.2	5.6	0.5	1.2
Fox Hollow Branch	3.8	0.3	0.5	3.8	0.3	0.5	4.4	0.3	0.7
Bonne Femme Lower II	7.0	0.7	1.5	6.9	0.7	1.7	7.3	0.8	1.7
Gans Creek North	7.3	0.5	1.2	7.3	0.5	1.2	7.3	0.5	1.2
Gans Creek South	8.3	0.7	1.5	8.3	0.7	1.5	8.7	0.7	1.7
Clear Creek	8.6	0.9	2.0	8.9	0.9	2.6	9.2	0.9	2.6
Gans Creek	9.9	1.3	4.1	10.0	1.3	4.1	10.2	1.3	4.5
Middle Little Bonne Femme	6.1	0.7	1.7	6.1	0.7	1.7	6.3	0.8	1.7
Upper Little Bonne Femme	6.1	0.7	1.5	6.1	0.7	1.5	6.4	0.7	1.5
South Branch Little Bonne Femme	2.0	0.0	0.0	2.0	0.0	0.0	2.0	0.0	0.0
North Branch Little Bonne Femme	6.5	0.3	0.7	6.6	0.3	0.7	6.6	0.3	0.7
Lower Little Bonne Femme	14.3	2.3	8.8	14.4	2.4	8.8	15.0	2.5	9.8

7.4 Discussion

Based on the stream modeling results, several conclusions can be made about the watershed's present condition and possible implications for the future. The watershed is essentially composed of two drainage basins, the Bonne Femme in the south and the Little Bonne Femme in the north. Figure 7.3-E Shear Stress indicates that in both drainage basins, allowable shear stress is currently being exceeded in the downstream subwatersheds (the Lower Bonne Femme and Fox Hollow Branch in the south and the Little Bonne Femme subwatersheds in the north) and the Gans Creek South subwatershed. This was observed in the field and confirmed by the results of the modeling. As development occurs in the watershed, the model predicts that there will be increased total runoff in nine (9) of nineteen (19) subwatersheds (Figure 7.3-C Flow Increase) and a channel velocity increase in five (5) of nineteen (19) subwatersheds (Figure 7.3-D Velocity Increase). Aside from those subwatersheds already exceeding allowable shear stress, the Gans Creek subwatershed is predicted to experience channel instability for predicted conditions and the Bonne Femme, Clear Creek, and Gans Creek North subwatersheds will become unstable as urbanization continues beyond the level currently predicted. As a general trend, it appears that the instability issues are migrating upstream, most notably in the northern Little Bonne Femme drainage basin. This is felt to be critical to address as the City of Columbia continues to expand. It should be noted that the Upper Bonne Femme, Turkey Creek, and Bass Creek subwatersheds are predicted to be stable for all model runs. This is a determination based on runoff for the entire subwatershed using the channel characteristics at the subwatershed outlet. The outlets of these subwatersheds had channels that were lined with large diameter material (at least 4"), so these currently are and should remain stable. Field observations revealed that there were several channels in the upstream portions of these subwatersheds exhibiting instability. The channels in the upstream areas (primarily east of Highway 63) were composed of finer loess material that is less stable. This is a concern most notably for the karst recharge areas that comprise most of the Upper Bonne Femme and Bass Creek subwatersheds. If material is actively being transported into these conduits, this could be impacting these sensitive systems. Sediment transport into cave ecosystems could have an impact on macroinvertebrate populations, as well as vegetation communities that are adjusted to long term average nutrient inflow levels. More discussion of these issues follows in subsequent sections.