Appendix B
Hydrology and Hydraulics

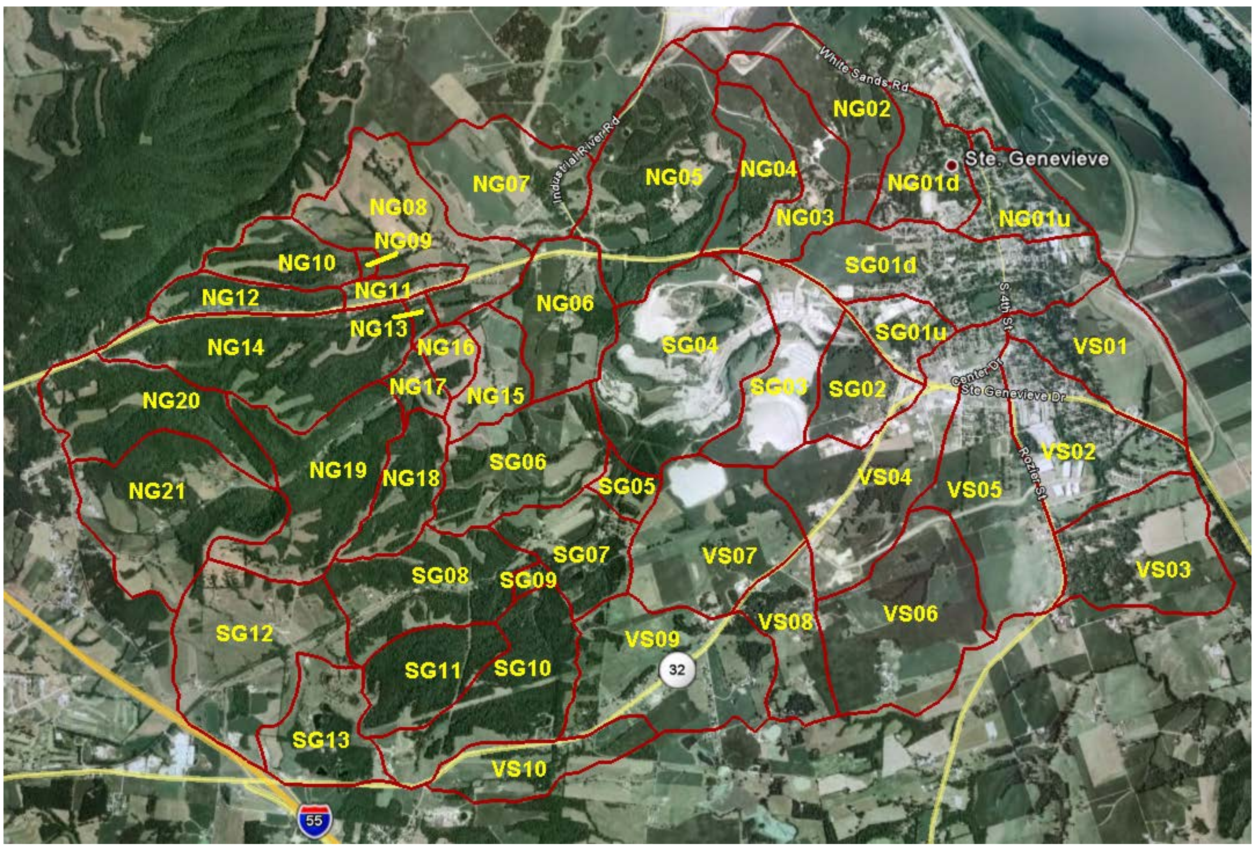
B-1. Hydrologic Analysis Methods

This section will describe the data and methods for developing the rainfall-runoff relationships, which were used to determine the flow frequencies at significant points along North and South Gabouri Creeks. The type of hydrologic model is discussed, as well as a verification of the validity of the results. Topographic data from 1994 is referenced in the following section, but it should be noted that more recent terrain data is available, in the form of Ste. Genevieve County Light Detection and Ranging (LiDAR). However, the hydrologic modeling results were deemed to be valid, and watershed characteristics have not changed significantly over the past 20 years. Therefore, the LiDAR terrain data has only been used for updating the hydraulic models. The hydrologic methods described below were completed in about 2009 and have not been modified.

B-1.1 Source Data

A topographic survey of the city of Ste. Genevieve was made for this project in 1994, but the extents of the survey did not cover the entire drainage basin for each creek. Instead, 7.5-minute Quad maps from the USGS were used to determine drainage areas and flow paths for each basin. The overall watersheds for North and South Gabouri Creeks were broken into smaller compartments, or subbasins, to develop the flow frequency values at points of interest on each stream. The subbasin delineation map is shown in **Figure B-1** below.

Figure B-1: Subbasin Map for Ste. Genevieve Tributaries

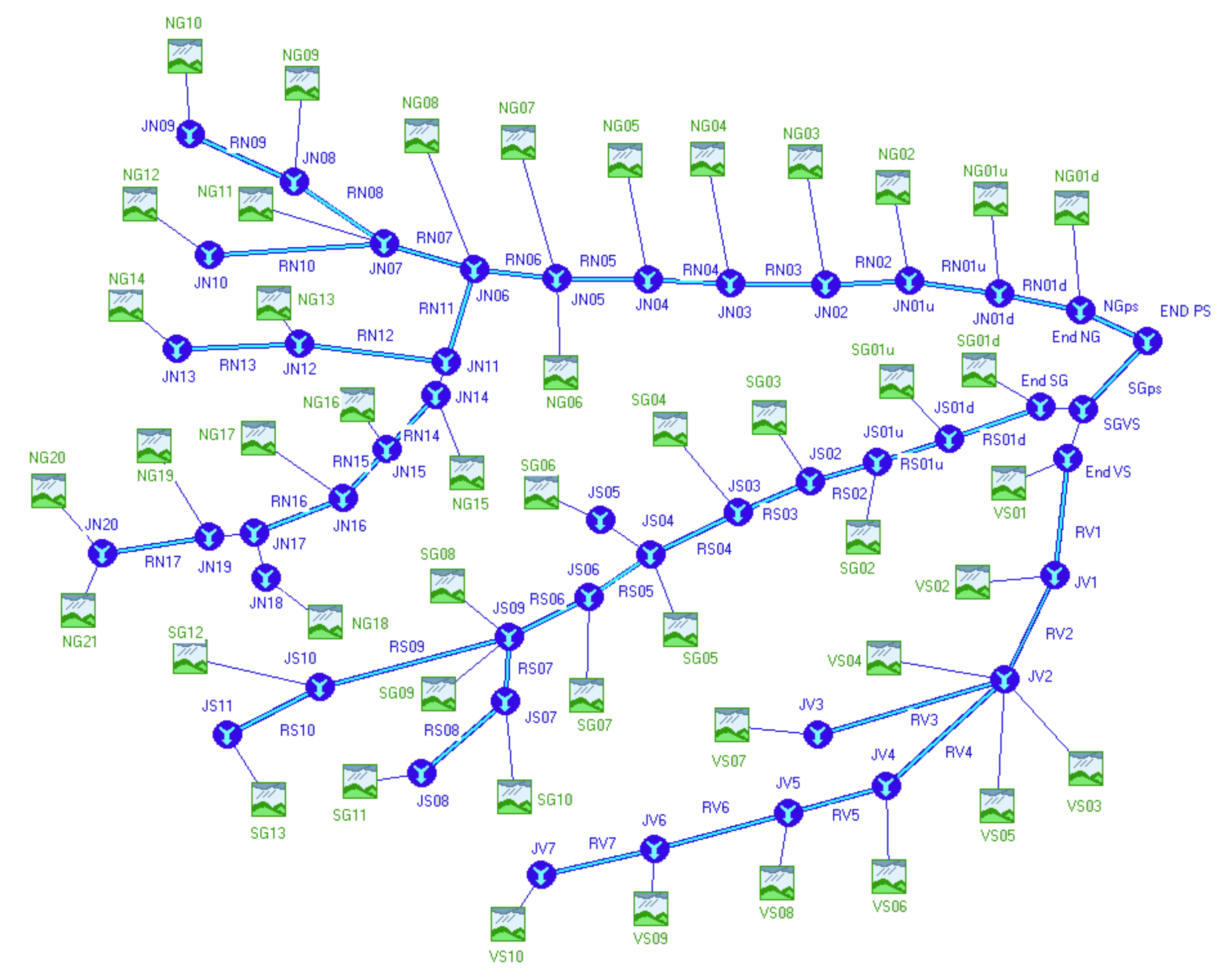


B-1.2 Modeling Methods

The hydrologic analysis was performed using the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) computer model, developed by the HEC research center of the Corps of Engineers. The model was initiated using Version 2.1 of the program, and later runs utilized Version 3.5. Selection of parameters for this hydrologic model is discussed in the following sections.

There are two main branches in the Gabouri Creek system, North Gabouri Creek and South Gabouri Creek. There is a significant unnamed tributary on the North Gabouri Creek, which enters upstream of the populated portion of the town of Ste. Genevieve. South Gabouri Creek has a significant tributary, Valle Spring Branch, which enters downstream of Main Street, near the Burlington and Northern Railway. For reference purposes, all subbasins, reaches, and junctions in the HEC-HMS model are named by the main creek branch they are part of: "NG", for North Gabouri; "SG" for South Gabouri; and "VS", for Valley Spring. The HEC-HMS model schematic for the connection of the subbasins follows in **Figure B-2**.

Figure B-2: HEC-HMS Model Schematic for Ste. Genevieve Tributaries



B-1.2.1 Basin Characteristics and Parameters

The National Resource Conservation Service (NRCS) Curve Number method was used for the loss rate of the subbasins. The Curve Numbers were chosen based on available land use data from the USGS and the Ste. Genevieve County Soil Survey maps. TR-55 methods were used to compute the Time of Concentration for the subbasins. Baseflow was determined for each month of the year using a regional average low flow rate per acre of drainage area.

The NRCS hydrograph transform method was also used, with Lag Times computed as 0.6 times the TC, or Time of Concentration. Reach routing was accomplished with the Muskingum method. The values for “K” and “x” were estimated using the expected travel times and storage capability of each stream reach. **Table B-1** and **Table B-2** below show the parameters that were selected for model computations.

Table B-1: Subbasin Parameters for HEC-HMS

Subbasin Name:	Area (sq.mi.)	Curve Number	Initial Abstraction	Percent Impervious	SCS Lag Time (min)
NG01d	0.256	76	0.5	35	16
NG01u	0.317	74	0.6	20	16
NG02	0.418	72	0.6	8	28
NG03	0.355	71	0.6	8	18
NG04	0.27	70	0.6	10	18
NG05	0.813	72	0.6	10	29
NG06	0.4	72	0.6	5	23
NG07	0.51	70	0.6	3	34
NG08	0.593	68	0.7	3	37
NG09	0.017	67	0.7	1	6
NG10	0.231	66	0.8	2	18
NG11	0.094	70	0.6	2	17
NG12	0.188	70	0.6	6	30
NG13	0.032	70	0.6	5	8
NG14	0.711	68	0.7	5	38
NG15	0.216	69	0.7	5	18
NG16	0.094	70	0.6	5	11
NG17	0.082	72	0.6	6	9
NG18	0.264	67	0.7	2	29
NG19	0.609	68	0.7	2	45
NG20	0.493	68	0.7	2	35
NG21	0.69	70	0.6	6	37
SG01d	0.699	75	0.5	30	32
SG01u	0.167	71	0.6	20	15
SG02	0.249	72	0.6	5	19
SG03	0.161	72	0.6	5	30
SG04	0.444	75	0.5	20	50
SG05	0.088	72	0.6	5	12
SG06	0.509	68	0.7	4	28
SG07	0.321	72	0.6	8	21

Table B-1: Subbasin Parameters for HEC-HMS (Continued)

Subbasin Name:	Area (sq.mi.)	Curve Number	Initial Abstraction	Percent Impervious	SCS Lag Time (min)
SG08	0.514	72	0.6	8	37
SG09	0.029	68	0.7	2	7
SG10	0.545	68	0.7	2	53
SG11	0.332	66	0.8	1	24
SG12	0.718	72	0.6	6	42
SG13	0.347	72	0.6	10	43
VS01	0.466	69	0.8	5	60
VS02	0.563	71	0.7	10	46
VS03	0.558	65	0.9	4	71
VS04	0.743	69	0.7	5	67
VS05	0.635	68	0.7	6	53
VS06	0.74	65	0.9	5	52
VS07	0.624	65	0.9	5	54
VS08	0.303	65	0.8	3	53
VS09	0.711	68	0.8	4	53
VS10	0.293	66	0.8	3	53

Table B-2: Muskingum Routing Parameters for HEC-HMS

Routing Reach	Muskingum K (hours)	Muskingum X	Number of Subreaches
NGps	0.056	0.2	2
RN01d	0.227	0.3	7
RN01u	0.229	0.3	7
RN02	0.078	0.2	2
RN03	0.118	0.2	4
RN04	0.128	0.2	4
RN05	0.467	0.2	14
RN06	0.228	0.2	7
RN07	0.186	0.2	6
RN08	0.281	0.2	8
RN09	0.081	0.2	2
RN10	0.38	0.2	11
RN11	0.151	0.2	5
RN12	0.324	0.2	10
RN13	0.097	0.2	3
RN14	0.203	0.2	6
RN15	0.213	0.2	6
RN16	0.204	0.2	6
RN17	0.634	0.2	19
RS01d	0.351	0.3	11
RS01u	0.147	0.3	4
RS02	0.097	0.2	3

Table B-2: Muskingum Routing Parameters (continued)

Routing Reach	Muskingum K (hours)	Muskingum X	Number of Subreaches
RS03	0.135	0.2	4
RS04	0.629	0.2	19
RS05	0.121	0.2	4
RS06	0.319	0.2	10
RS07	0.157	0.2	5
RS08	0.269	0.2	8
RS09	0.871	0.2	26
RS10	0.249	0.2	7
RV1	0.324	0.2	10
RV2	0.472	0.2	14
RV3	0.731	0.2	22
RV4	0.342	0.2	10
RV5	0.796	0.1	24
RV6	0.361	0.1	11
RV7	0.683	0.1	20
SGps	0.065	0.2	2

B-1.2.2 Meteorologic Model Parameters

Regional rainfall frequencies were determined with the National Weather Service's "Rainfall Frequency Atlas of the Midwest", more commonly known as Bulletin 71. The 50, 20, 10, 4, 2, and 1% Annual Chance Exceedance (ACE) rainfall frequencies for Region 5, Southeastern Missouri, were applied to the watershed models for North and South Gabouri Creek. For the analysis of detention reservoir alternatives, the Probable Maximum Precipitation (PMP) was utilized, and a study from nearby Cape Girardeau, Missouri was referenced to find these rainfall amounts. **Table B-3** contains the Bulletin 71 rainfall values for the range of frequencies required for the project.

Table B-3: Bulletin 71 Rainfall Frequencies for Southeastern Missouri (Region 5)

	Annual Chance Exceedance (ACE) Rainfall, in inches					
Duration	**50% ACE**	**20% ACE**	**10% ACE**	**4% ACE**	**2% ACE**	**1% ACE**
5 min	0.42	0.53	0.60	0.71	0.80	0.89
15 min	0.95	1.19	1.36	1.60	1.79	2.00
1 hr	1.65	2.06	2.36	2.79	3.12	3.49
2 hr	2.04	2.55	2.92	3.45	3.85	4.30
3 hr	2.25	2.81	3.22	3.80	4.25	4.75
6 hr	2.63	3.29	3.77	4.45	4.98	5.57
12 hr	3.05	3.82	4.37	5.17	5.78	6.46
1 day	3.51	4.39	5.03	5.94	6.64	7.42

B-1.3 Calibration/Verification

Unfortunately, there are no stream gages or rainfall gages in the Gabouri Creek system. This made it impossible to employ a traditional calibration method for the HEC-HMS model. Instead, regional regression equations were used as the basis for verification of the model results.

USGS regression equations for the southern region of the State of Missouri were compared to peak flows computed from the HEC-HMS model. Although the computed HMS results averaged about 25% lower than the USGS estimates, the results were still determined to be satisfactory. This is because the USGS estimates for the region are known to be overly conservative, judging by the experience of USACE hydraulic engineers. The verification of the final HEC-RAS results, as discussed in a later section of this report, was used to further validate the results of the hydrologic analysis.

B-1.4 Results of Hydrologic Analysis

The final HEC-HMS simulations were produced using the data parameters and rainfall inputs discussed in the above sections. The resulting flood hydrographs for each frequency event were automatically exported in HEC-DSS (Data Storage System) format. Peak flows from the DSS data file are referenced for the HEC-RAS Hydraulic Analysis. **Table B-4** below shows the resulting peak flows for the range of frequency events, at the lower end of both North and South Gabouri Creeks, near Main Street. The HEC-HMS model files and output data are on file in the Hydraulics Branch of the St. Louis District of USACE.

Table B-4: Peak Flows from HEC-HMS for North and South Gabouri Creeks

Location:	**Peak Discharge in cubic feet per second (cfs) for each Frequency Event, by Annual Chance Exceedance (ACE)**					
	50%	**20%**	**10%**	**4%**	**2%**	**1%**
North Gabouri Creek @ Main St.	877	1,605	2,173	2,940	3,530	4,209
South Gabouri Creek @ Main St.	635	1,111	1,480	1,976	2,358	2,796

Note: *This South Gabouri Creek location does not include inflow from Valle Spring Branch, which enters South Gabouri Creek downstream of Main Street.*

B-2. Hydraulic Analysis Methods

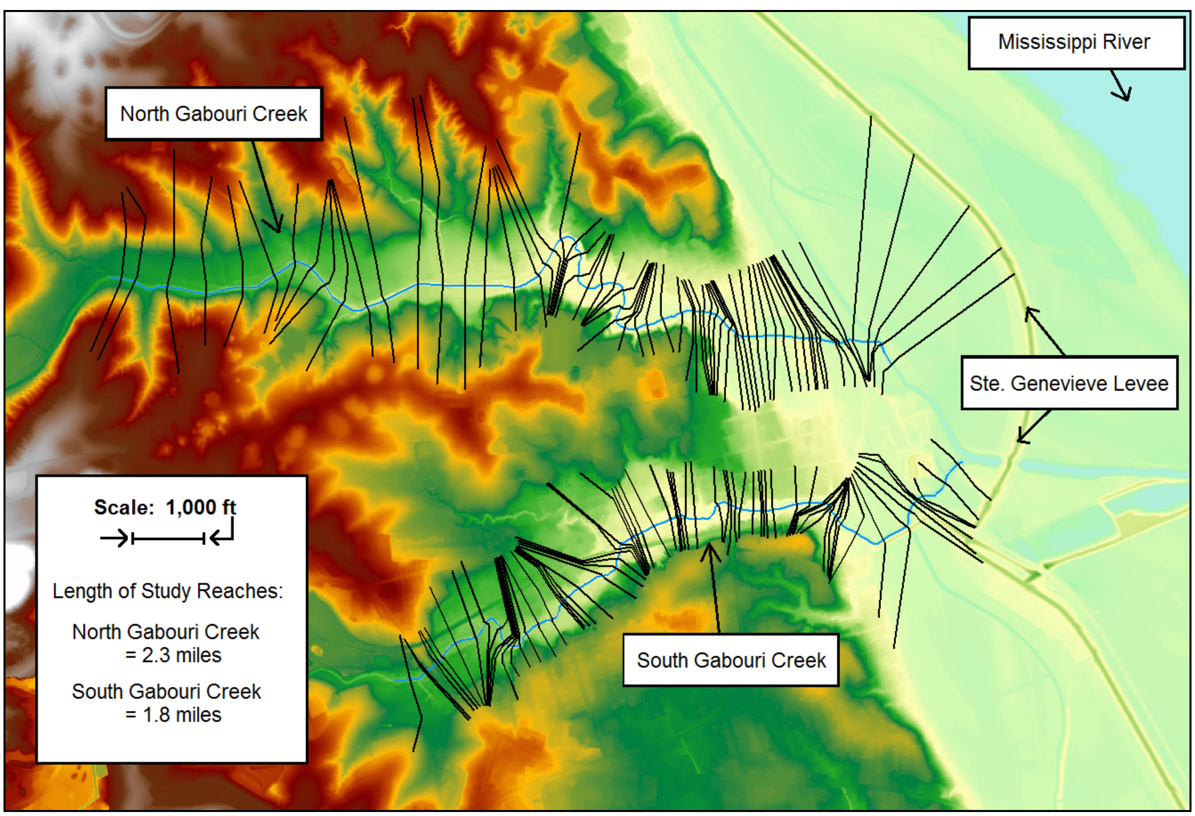
This section describes the data and methods for developing water surface profiles for various storm frequencies for the existing conditions on North and South Gabouri Creeks. It also covers the evaluation of various project alternatives with the hydraulic model. The model type and data inputs are also discussed, as well as a verification of the validity of the results. Key outputs from the study are the water surface profile plots for various hypothetical flood events and the number of structures flooded with and without the potential project alternatives.

Earlier studies of the Ste. Genevieve Tributaries utilized older source for terrain data which dated back to 1994 and were only accurate enough for 2-foot contours. This 2014-2015 efforts were able to take advantage of a much more precise and newer LiDAR data source. All discussion and analysis of alternatives in this section refer to the newest data sources, except where specifically indicated. Please note that the elevation datum of the LiDAR data is NAVD88, and therefore the HEC-RAS output data is also in NAVD88.

B-2.1 Source Data

The geometry for the final hydraulic modeling effort for North and South Gabouri Creeks was obtained from Ste. Genevieve County LiDAR (Light Detection and Ranging) from 2012. The grid cell size for the data was 1 meter, and the coverage was sufficient for all areas of interest on both creeks. The extents of North and South Gabouri Creeks studied in this modeling effort can be seen in **Figure B-3** below.

Figure B-3: Modeling Extents and Source Data for North and South Gabouri Creeks



Prior topographic surveys and USGS maps were not accurate enough to define the channel geometry for the earlier studies, so a cross-section survey contract was performed in 2000. Cross sections were surveyed at specific locations along North and South Gabouri Creeks, and bridge surveys were also completed. Although the channel cross sections were not needed since LiDAR is now available, the bridge surveys were still useful for providing bridge geometry in HEC-RAS. All remaining data requirements were met through site visits, and photographs were used to help estimate channel and overbank roughness coefficients.

B-2.2 Modeling Methods

Version 4.1 of the Hydrologic Engineering Center's River Analysis System (HEC-RAS) was used for the hydraulic analysis of the existing conditions and all alternatives. The HEC-RAS models for North and South Gabouri Creeks were created with the use of GIS (Geographic Information Systems). The HEC-produced ArcGIS extension called HEC-GeoRAS was used to extract terrain data from LiDAR to produce cross sections for the extents of both creeks where modeling was required. The GIS-exported HEC-RAS geometry was completed within the HEC-RAS program, by defining bank stations, bridge geometry, Manning's Roughness coefficients, Expansion and Contraction coefficients, and ineffective flow areas. The range of Manning's n values for the channel and overbank areas is shown below in **Table B-5**.

Table B-5: Range of Manning's n Roughness Coefficients

Parameter:	Channel	Overbanks
North Gabouri Creek Maximum Values	0.050	0.075
North Gabouri Creek Minimum Values	0.045	0.050
South Gabouri Creek Maximum Values	0.050	0.065
South Gabouri Creek Minimum Values	0.035	0.050

After all the geometric details were completed, the steady flow data was developed. For the existing conditions and all alternatives on North and South Gabouri Creeks, the flow frequency computations from the HEC-HMS model were used to define the peak flow rates at several locations in the HEC-RAS model. Flow change locations were defined by the subbasin boundaries in the HEC-HMS model. **Table B-6** below shows discharge values for all locations on North Gabouri Creek. **Table B-7** shows the same for South Gabouri Creek.

Table B-6: North Gabouri Creek Peak Discharge Inputs for HEC-RAS modeling

	Peak Discharge in cubic feet per second (cfs), by Annual Chance Exceedance (ACE)							
River Station (ft)	50%	20%	10%	4%	2%	1%	0.5% (extrapolated)	0.2% (extrapolated)
14,224	743	1,402	1,919	2,621	3,159	3,783	4,330	5,105
12,597	764	1,435	1,962	2,675	3,223	3,857	4,415	5,200
10,612	790	1,476	2,014	2,741	3,301	3,947	4,520	5,325
9,572	829	1,540	2,096	2,847	3,425	4,091	4,680	5,495
5,200	851	1,572	2,135	2,895	3,481	4,155	4,755	5,580
3,083	877	1,605	2,173	2,940	3,530	4,209	4,810	5,660

Table B-7: South Gabouri Creek Peak Discharge Inputs for HEC-RAS modeling

	Peak Discharge in cubic feet per second (cfs), by Annual Chance Exceedance (ACE)							
River Station (ft)	50%	20%	10%	4%	2%	1%	0.5% (extrapolated)	0.2% (extrapolated)
9,820	548	983	1,330	1,794	2,148	2,556	2,920	3,500
6,919	555	996	1,346	1,814	2,171	2,582	2,980	3,600
2,745	635	1,111	1,480	1,976	2,358	2,796	3,250	3,900
1,428	1,229	2,257	3,068	4,172	5,025	6,012	6,800	7,800

As shown in the two discharge input tables, the 0.5% and 0.2% annual chance exceedance events had to be extrapolated from the HEC-HMS output data, which only ranged from the 50% to the 1% chance rainfall. These two highest magnitude events were not used for the design of alternative plans, but were simply provided as a placeholder for the HEC Flood Damage Analysis model (HEC-FDA), which requires 8 flood profiles. Although the flow inputs are not based on hydrologic modeling output, they are still useful for determining project resiliency, or how each alternative performs for a storm event that is greater than the design level.

Geometric changes were made to the HEC-RAS model to evaluate each structural flood damage risk reduction alternative. These alternatives consisted of levees and channelization. Prior versions of this study also considered detention reservoirs, bridge replacements, and minor excavation of the main channels of the two creeks. More information about the evaluation of the alternatives considered can be found in **Section B-3**.

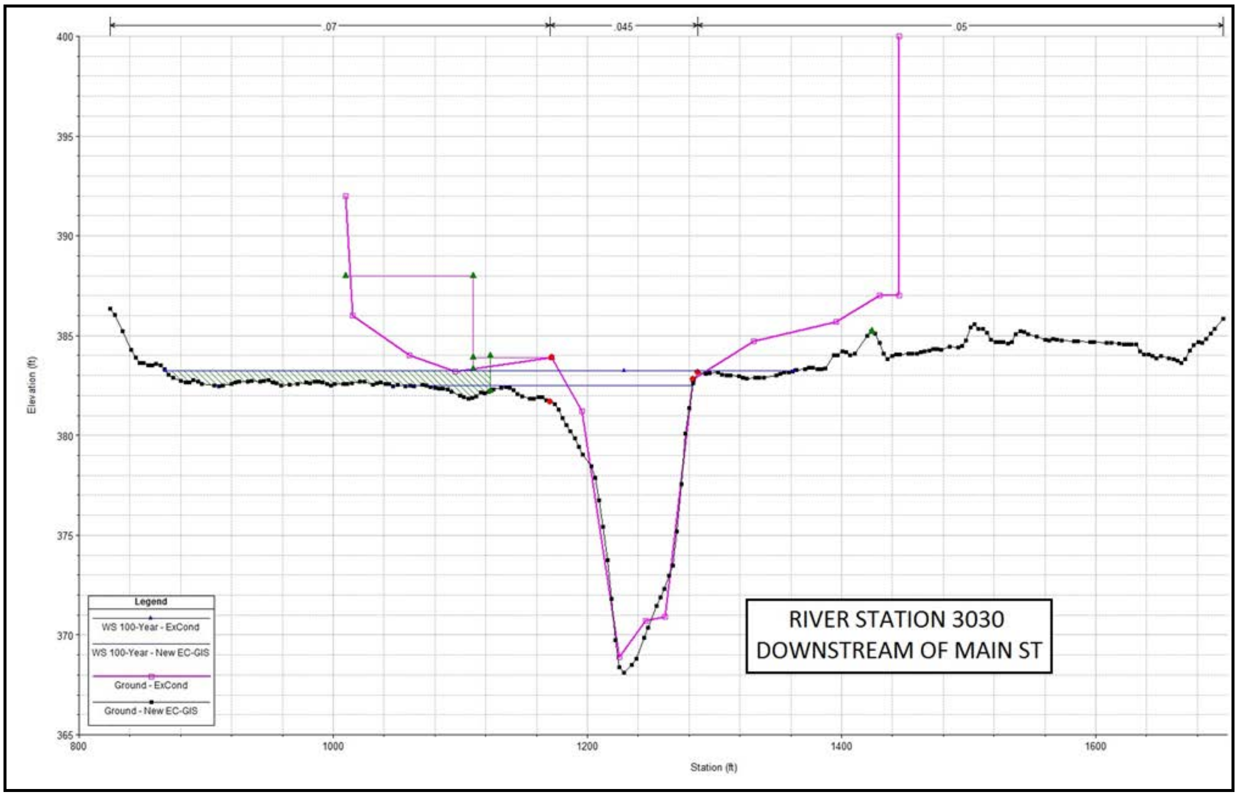
B-2.3 Calibration/Verification

As stated in **Section B-1.3** above, no stream gages were available to calibrate the hydraulic model. There was a significant flood documented in the year 1956, but little or no useful information could be found, such as approximate peak flood elevations. The only reasonable method of verification available was the comparison to other model results.

The computed water surface elevations for the existing conditions runs on North and South Gabouri Creeks were compared to the previous HEC-RAS models, computed in the late 1990's and 2000's with older topographic data in the NGVD 29 vertical datum. The newer HEC-RAS water surface profile results for the existing conditions were about 1-2 feet lower on average than the previous model results. Based on the conversion from NGVD29 to NAVD88 (approximately -0.2 feet), the new HEC-RAS results were still coming up 0.8 to 1.8 feet lower than the previous modeling showed.

These newer HEC-RAS results were found to be reasonably verified, because there is evidence of significant erosion and possible head-cutting in the channel. An incised or head-cut channel would result in lower channel invert elevations, and therefore lower computed water surfaces should be expected. The method of geo-referencing cross-sections with the ArcGIS program also lends itself to greater accuracy than the older hydraulic models utilized. A cross section geometry comparison from North Gabouri Creek is shown below in **Figure B-4**. The greater definition of the overbank areas can be seen in the newer geometry (black dots and lines), when compared to the older geometry (pink dots and lines). It is also noticeable that the old geometry actually cut short the potential carrying capacity of the overbank areas (outside the channel). The reason for the potential overbank width of several cross sections being reduced in this manner is unknown. It is just another example of how the hydraulic modeling was improved with the use of LiDAR and GIS. Because of these factors, the project alternative evaluation process was further validated.

Figure B-4: HEC-RAS Model Geometry Comparison on North Gabouri Creek



B-3. Hydrology and Hydraulics Summary

As stated above, the terrain data from recent LiDAR surveys and surveyed cross sections add a significant amount of validity to the most recent hydrologic and hydraulic analyses. The detailed hydrologic analysis represents a great improvement for the computation of peak flow rates, considering that the original design memorandum only utilized approximate methods. The HEC-RAS model made it much easier to evaluate a large number of structural alternatives, and about 70 different HEC-RAS model runs have been evaluated to date, including prior versions of hydraulic modeling. The geo-referenced HEC-RAS hydraulic model will also make it easier to model future changes to the Gabouri Creek system and produce accurate floodplain maps.

The HEC-RAS water surface profiles were compared for the various alternatives that were considered. A detailed list of these alternatives is presented in **Appendix C**. The results of the HEC-RAS analysis are shown in **Tables B-8** and **B-9** below. **Table B-8** shows a detailed comparison of water surface elevations for the final alternatives at important locations on North

Gabouri Creek. **Table B-9** shows the Existing Conditions results for South Gabouri Creek. The water surface profile plots for these alternatives are shown in **Figure B-5** and **Figure B-6**.

Table B-8: Comparison of Peak Stages at Key Locations on North Gabouri Creek

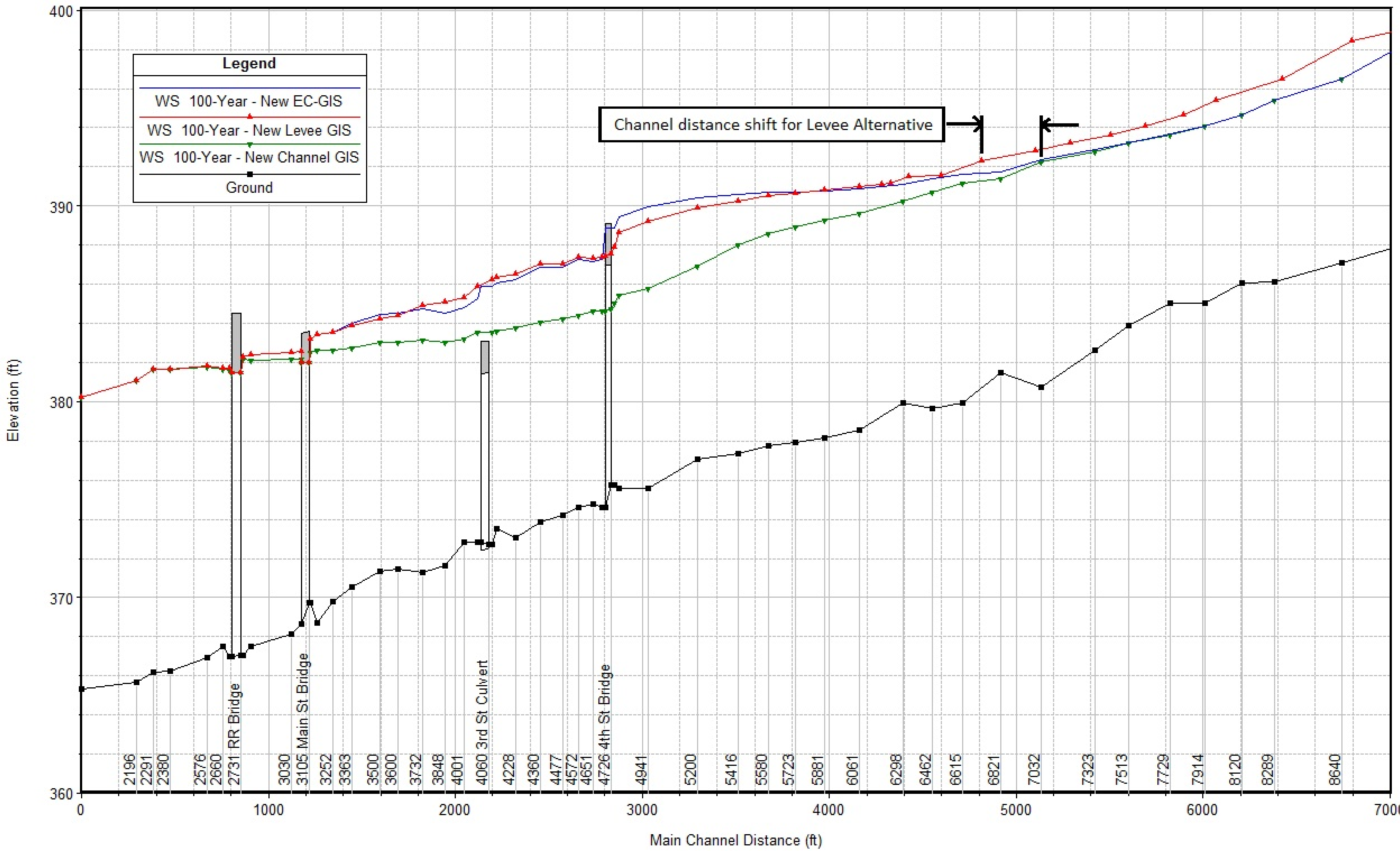
		North Gabouri at Upper End of Flood Damages (Station 8,640) Peak Water Surface Elevation (feet, NAVD88)				
Shorthand Name	**Alternative Full Name**	**5-year**	**10-year**	**25-year**	**50-year**	**100-year**
NG:EC-GIS	Existing Conditions (no action)	394.7	395.1	395.7	396.1	396.5
NG:Channel	Authorized Plan (channel widening)	394.7	395.1	395.7	396.1	396.5
NG:Levee	North Gabouri Levee	394.7	395.1	395.7	396.1	396.5
		North Gabouri at 4th Street Bridge (Station 4,751) Peak Water Surface Elevation (feet, NAVD88)				
Shorthand Name	**Alternative Full Name**	**5-year**	**10-year**	**25-year**	**50-year**	**100-year**
NG:EC-GIS	Existing Conditions (no action)	385.2	386.3	388.0	388.6	388.9
NG:Channel	Authorized Plan (channel widening)	380.6	381.8	383.2	384.1	385.0
NG:Levee	North Gabouri Levee	384.4	385.7	386.7	387.3	387.9
		North Gabouri at 3rd Street Culvert (Station 4,091) Peak Water Surface Elevation (feet, NAVD88)				
Shorthand Name	**Alternative Full Name**	**5-year**	**10-year**	**25-year**	**50-year**	**100-year**
NG:EC-GIS	Existing Conditions (no action)	383.1	383.3	384.4	384.7	385.9
NG:Channel	Authorized Plan (channel widening)	378.4	380.0	381.6	382.5	383.6
NG:Levee	North Gabouri Levee	381.2	382.6	384.2	385.3	386.2
		North Gabouri at Main Street Bridge (Station 3,130) Peak Water Surface Elevation (feet, NAVD88)				
Shorthand Name	**Alternative Full Name**	**5-year**	**10-year**	**25-year**	**50-year**	**100-year**
NG:EC-GIS	Existing Conditions (no action)	377.5	379.3	381.0	382.5	383.2
NG:Channel	Authorized Plan (channel widening)	376.9	378.8	380.6	381.4	382.5
NG:Levee	North Gabouri Levee	377.5	379.3	381.0	382.5	383.2

Table B-9: Peak Stages for Existing Conditions at Key Locations on South Gabouri Creek

		South Gabouri at Upper End of Flood Damages (Station 8,534)				
		Peak Water Surface Elevation (feet, NAVD88)				
Shorthand Name	**Alternative Full Name**	**5-year**	**10-year**	**25-year**	**50-year**	**100-year**
SG:EC-GIS	Existing Conditions (no action)	405.3	405.7	406.1	406.4	406.7
		South Gabouri at MO-IL Railroad Bridge (Station 5,980)				
		Peak Water Surface Elevation (feet, NAVD88)				
Shorthand Name	**Alternative Full Name**	**5-year**	**10-year**	**25-year**	**50-year**	**100-year**
SG:EC-GIS	Existing Conditions (no action)	395.0	395.5	396.0	396.3	396.7
		South Gabouri at 4th Street Bridge (Station 4,212)				
		Peak Water Surface Elevation (feet, NAVD88)				
Shorthand Name	**Alternative Full Name**	**5-year**	**10-year**	**25-year**	**50-year**	**100-year**
SG:EC-GIS	Existing Conditions (no action)	389.0	389.7	390.6	391.1	391.7
		South Gabouri at Main Street Bridge (Station 2,836)				
		Peak Water Surface Elevation (feet, NAVD88)				
Shorthand Name	**Alternative Full Name**	**5-year**	**10-year**	**25-year**	**50-year**	**100-year**
SG:EC-GIS	Existing Conditions (no action)	384.5	385.0	385.6	386.0	386.5

Note: Non-structural floodproofing was the selected plan for South Gabouri Creek, and the Existing Conditions results will apply to that plan, because there are no changes to the stream geometry.

Figure B-5: Water Surface Profile Plot for 1% Annual Chance Exceedance (ACE) Flood Event, North Gabouri Creek, Existing Conditions and Alternatives



Notes: *1. The profile plot for the Levee plan is shifted to the left of the Existing Conditions profile, because it also includes a channel realignment that shortens the main channel distance by about 300 feet.*
2. The Levee plan does not increase the water surface upstream of station 5,881; the increased profile near 3rd and 4th streets is contained between levees on both sides of the creek (no floodplain impacts).

Figure B-6: Water Surface Profile Plot for 1% Annual Chance Exceedance (ACE) Flood Event, South Gabouri Creek, Existing Conditions