Hydrologic Evaluation of the Blanchard River

Hancock County Flood Risk Reduction Program

Prepared for:
Maumee Watershed
Conservancy District
1464 Pinehurst Dr.
Defiance, Ohio 43512

Prepared by:
Stantec Consulting Services Inc.
11687 Lebanon Road
Cincinnati, Ohio 45069

November 8, 2017

Revision	Description	Author		Quality Check		Independent Review	
0	FINAL	E. Caudill	Nov. 8, 2017	SP	11/8		

Sign-off Sheet

This document entitled Hydrologic Evaluation of the Blanchard River was prepared by Stantec Consulting Services Inc. ("Stantec") for the account of Maumee Watershed Conservancy District (the "Client"). Any reliance on this document by any third party is strictly prohibited. The material in it reflects Stantec's professional judgment in light of the scope, schedule and other limitations stated in the document and in the contract between Stantec and the Client. The opinions in the document are based on conditions and information existing at the time the document was published and do not take into account any subsequent changes. In preparing the document, Stantec did not verify information supplied to it by others. Any use which a third party makes of this document is the responsibility of such third party. Such third party agrees that Stantec shall not be responsible for costs or damages of any kind, if any, suffered by it or any other third party as a result of decisions made or actions taken based on this document.

Prepared by _____
(signature)
Erman Caudill, PE (KY #23451), CFM

Reviewed by _____
(signature)
David Hayson, PE

Approved by _____
(signature)
Scott Peyton, PE

Stantec

Table of Contents

LIST OF APPENDICES

Stantec

Executive Summary

The Blanchard River system near the City of Findlay, in Hancock County, Ohio floods often. When intense convective storms move over the watershed, or rain falls on areas with sparse vegetation that may still have snow cover or wet/frozen ground, runoff from the predominantly agricultural watershed quickly fills the river and tributaries beyond the channel's capacity. Overbank flooding can lead to significant damages and economic impacts to the community, similar to the near flood of record that happened to the City of Findlay in August 2007.

The 2007 event renewed interest in flood mitigation for the area, and the U.S. Army Corps of Engineers Buffalo District (USACE) studied the river system and proposed a 9.2-mile long flood diversion channel upstream of Findlay to help reduce the impacts of future floods. The diversion channel was to connect Eagle Creek to the Blanchard River and divert potential flood flows to the south and west around Findlay. As USACE completed preliminary engineering and design, it became apparent the proposed Federal project was becoming an increasingly expensive undertaking with a marginal benefit-cost ratio.

In 2016, the local community accepted responsibilities for the project from USACE. The Maumee Watershed Conservancy District (MWCD), in cooperation with the Hancock County Commissioners and the City of Findlay, tasked Stantec Consulting Services Inc. (Stantec) with reviewing the USACE proposed project and continuing the planning and design efforts. Stantec's work was described in a conceptual report entitled: "*Final Report: Data Review, Gap Analysis, USACE Plan and Alternatives Review, and Program Recommendation*" dated April 3, 2017, referenced herein as the *Stantec Concept Report*. Stantec identified a number of gaps or questions from the prior USACE efforts and identified several areas where additional data was necessary for the project. After further reviewing the function and conceptual design of the proposed diversion channel, Stantec recommended alternate flood mitigation measures consisting of channel improvements to the Blanchard River within the City of Findlay and dry storage basins at three upstream locations (Eagle Creek, Blanchard River, and Potato Run).

Several portions of the *Stantec Concept Report* discussed gaps or questions from the hydrologic analyses performed by USACE. The following hydrologic data gaps have been addressed and resolved by Stantec as explained and documented herein:

Gage Frequency Analyses – Prior documentation for gage-based flood flow frequency analyses of the Blanchard River system was limited. Stantec performed an updated statistical frequency analysis for the USGS stream gage on the Blanchard River a short distance downstream of Findlay to determine peak discharge values for a variety of recurrence intervals. Methodology and results of those analyses are presented herein. The results indicate, from a strictly statistical perspective, the 100-year, 24-hour flood discharge at the gage location could range from about 12,040 to 16,120 cubic feet per second (cfs), within a 95-percent confidence limit, with a recommended value of about 13,700 cfs.

Spatial Storm Patterns – Previous hydrologic simulations of hypothetical events conservatively assumed a single point precipitation value over the entire watershed. Storms that occur over an area larger than about 10-square miles seldom have uniform precipitation over their spatial extent and often resemble an elliptical shape. Procedures outlined in publications by NOAA, including: *Atlas 2*, *Atlas 14*, and *HMR-52*, describe common spatial patterns and areal reduction factors used to account for larger scale spatial variability. Stantec worked with a meteorological consulting group, Applied Weather Associates (AWA), to study spatial and temporal patterns from actual large historic storms that have occurred throughout the United States and which could reasonably be transposed to the Blanchard River location. Characteristics such as storm orientation, major to minor axis variability, and areal reduction factors, were used to model the spatial variability that would likely occur across the Blanchard River watershed. As an example, the central 10-square mile portion of the watershed may experience a full point-precipitation value of 5.26-inches for a 100-year, 24-hour storm event as predicted by *NOAA Atlas 14*; however, the outer portions of the approximate 350-square mile watershed may experience only about 80-percent of that value, or 4.18-inches based on the spatial variation observed from the historic storms.

Storm Centering – When areal reduction factors are applied to a geographically fixed storm, the center of the storm becomes an important factor in runoff simulations. Four different locations were considered as the center of the storm to determine critical placement for the purposes of runoff simulations. A storm centered over the centroid of the upstream watershed, near the headwaters of Lye Creek and middle of Eagle Creek and the Blanchard River watersheds, was determined to result in the greatest average peak discharge and runoff volume in Findlay. Conversely, a storm centered over Main Street in Findlay produced the lowest peak discharges and volumes of the four locations considered.

Temporal Pattern - Previous hydrologic simulations of hypothetical events assumed an SCS Type II storm distribution. The SCS Type II event is valid, but more recent studies indicate it may be overly conservative, as it results in more runoff during the intense middle portion of the storm. Publications such as *NOAA Atlas 14* and *Bulletin 71* include additional analyses of historic precipitation gage records that indicate a less intense storm pattern that is more evenly spread over the duration of the storm is more common to the Blanchard River watershed geographic area. AWA reviewed the temporal patterns of the historic storm events and derived a custom temporal distribution that was similar to that of a less intense, more uniform Huff 3rd Quartile event. Stantec applied the custom temporal pattern to hypothetical model simulations to simulate storm timing.

HEC-HMS Model Updates – Stantec refined and updated the USACE HEC-HMS model to the extent possible. The watershed delineation was verified based on LiDAR based topographic mapping from the Ohio Statewide Imagery Program (OSIP). Subbasins were created based on dividing the watershed at locations significant to the flood risk reduction project and areas of 10 square-miles or smaller. Model parameters were selected to support calibration and for correlation with the updated and revised HEC-RAS model, which was completed during development of the previously submitted *Stantec Concept Report*.

Calibration Storms – Stantec reviewed historic stream and precipitation records for the area to identify events that were hydrologically similar to the August 2007 flood with sufficient data available for calibration purposes. Events in September 2011 and June 2015 were identified as calibration events. Stantec worked with AWA to obtain calibrated radar data for those events (and the August 2007 event) which were then used to create individual calibration geometries in the HEC-HMS model for all three events.

Based on the calibration and gage frequency results, Stantec determined the September 2011 geometry adequately represents typical conditions in the watershed. The HEC-HMS model using the September 2011 geometry with hypothetical grid-based precipitation patterns produces a reasonable approximation of the watershed's hydrologic response (hydrograph shapes and durations) to various return period events and predicts peak discharge values at the USGS Gage 04189000 location similar to the gage frequency estimates.

Note storms with a duration of 24-hours and point precipitation values from *NOAA Atlas 14* were previously discussed and recommended as a part of the *Stantec Concept Report.* Those values were retained for the simulations described herein.

The HEC-HMS model was used to simulate hypothetical events for various annual chance of exceedances (recurrence intervals). Peak discharge values at Main Street in Findlay and the five USGS gage locations are presented in Table E-1.

The HEC-HMS model that was developed as a part of this study and discharges listed in Table E-1 are based on more analyses than previous hydrologic studies of the area. The magnitude and trends predicted by the results are consistent with prior efforts and, therefore, do not invalidate the previous hydrologic modeling. Stantec does not recommend updating the *Concept Report, which was a* planning level document, but would recommend this revised and updated hydrologic model and results presented herein be used for future flood mitigation planning and design efforts in the area to the extent applicable.

Stantec

Table E1 – Peak Flood Discharge Values

Location	Average Recurrence Interval (Years)							
	2	5	10	25	50	100	200	500
Main Street in Findlay	5,680	7,643	9,321	11,634	13,595	15,652	17,902	21,130
USGS Gage 04189000 Blanchard River DS of Findlay	5,730	7,715	9,413	11,734	13,574	15,652	17,951	21,106
Gage Analyses (-/+ 5% Confidence)	*5,086* *6,020*	*7,319* *8,918*	*8,625* *10,788*	*10,111* *13,037*	*11,113* *14,619*	*12,039* *16,120*	*12,903* *17,552*	*13,964* *19,351*
USGS Gage 04188400 Blanchard River US of Findlay	3,825	4,650	5,218	5,997	6,578	7,148	7,743	8,633
USGS Gage 04188337 Blanchard River DS of Mt. Blanchard	3,356	4,249	4,988	6,186	7,094	8,008	8,991	10,489
USGS Gage 04188496 Eagle Creek Above Findlay	1,741	2,323	2,839	3,577	4,223	4,915	5,690	6,732
USGS Gage 04188433 Lye Creek Above Findlay	533	752	942	1,217	1,451	1,699	1,967	2,344

Notes:
- Discharges are reported in cubic feet per second (cfs).
- Values from HEC-HMS model simulations using the September 2011 calibration geometry developed by Stantec.
- Gage Frequency Estimates for USGS Gage 04189000 are provided for comparison purposes.

Stantec

Abbreviations

ACE	Annual Chance Exceedance
AC-FT	Acre Feet
ARCGIS	ESRI geographic information system software (version 10.5)
AWA	Applied Weather Associates
CFS	Cubic Feet per Second
DDF	Depth - Duration - Frequency
GIS	Geographic Information System
HEC-HMS	USACE Hydrologic Engineering Center Hydrologic Modeling System Software (version 4.2)
HEC-RAS	USACE Hydrologic Engineering Center River Analysis System Software (version 5.0.3)
HEC-GeoHMS	USACE Hydrologic Engineering Center Geospatial Hydrologic Modeling Extension for ArcGIS
HEC-GridUtil	USACE Hydrologic Engineering Center Grid Utility Software Package (version 2.0)
HEC-SSP	USACE Hydrologic Engineering Center Statistical Software Package (version 2.1)
IDF	Intensity - Duration - Frequency
LiDAR	Light Detection and Ranging
MWCD	Maumee Watershed Conservancy District
NOAA	U.S. Department of Commerce, National Oceanic and Atmospheric Administration
NRCS	U.S. Department of Agriculture, Natural Resources Conservation Service
OGRIP	Ohio Geographically Referenced Information Program
OSIP	Ohio Statewide Imagery Program
SCS	U.S. Department of Agriculture, Soil Conservation Service (now the NRCS)
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WSEL	Water Surface Elevation
YR	Year as in return period.

Stantec

1.0   INTRODUCTION & BACKGROUND

The Blanchard River system drains an area of about 343 square miles as it flows through the City of Findlay, in Hancock County, Ohio. Except for the area around Findlay and some smaller upstream communities, the majority of the watershed is characterized by agricultural (row-crop) land uses with a smaller percentage being urbanized or having stands of deciduous trees. When intense convective storms move over the watershed or when rain and snow melt runs off from frozen and sparsely vegetated ground, runoff from the predominantly agricultural area quickly fills the river and tributaries beyond the channel capacity. Overbank flooding occurs frequently and can lead to significant damages and economic impacts to the community.

In August 2007, a large flood impacted the City of Findlay and resulted in a great deal of interest in flood mitigation for the area. The U.S. Army Corps of Engineers Buffalo District (USACE) studied the river system and proposed a 9.2-mile long flood diversion channel upstream of Findlay to help reduce future adverse flood impacts. The diversion channel was to connect Eagle Creek to the Blanchard River and divert potential flood flows to the south and west around Findlay. As USACE completed preliminary engineering and design of the diversion channel, it became apparent the proposed Federal project was going to be an increasingly expensive undertaking with a marginal benefit cost ratio. Hancock County, the City of Findlay, and the Maumee Watershed Conservancy District (MWCD) agreed to take over and continue the project as it changed from one guided by Federal interests and economic measures to one led by the local community.

In July 2016, Hancock County retained Stantec Consulting Services Inc. (Stantec) to perform a gap analysis on the USACE work and complete design and permitting for the Western Diversion of Eagle Creek project recommended by the USACE. In Phase 1, Stantec reviewed existing data and analyses completed by USACE and identified potential data gaps and further analyses necessary to support the design work. Phase 2 was administered by the MWCD and attempted to resolve a number of those data gaps and questions. Findings were outlined in the Stantec report entitled: "*Final Report: Data Review, Gap Analysis, USACE Plan and Alternatives Review, and Program Recommendation*" dated April 3, 2017, referenced herein as the *Stantec Concept Report.*

Several key data gaps related to the proposed diversion channel were identified as described in the *Stantec Concept Report,* including: a poorly defined flood mitigation/management objective, incomplete economic evaluation of benefits, technical questions related to the hydrologic and hydraulic analyses, and an incomplete assessment of residual risk associated with the proposed diversion channel.

On the residual risk issue, USACE did not provide a complete accounting of the risks involved with the construction and operation of the Eagle Creek diversion channel. There was a recognized, yet significant, risk that the proposed channel would not appreciably reduce flood risk in Findlay if the source of flooding was from Lye Creek or the upstream portion of the

Blanchard River. Eagle Creek at the diversion location drains about 15-percent of the watershed area upstream of Findlay, but USACE had not estimated the reliability of the proposed diversion for flood control purposes.

Additionally, the recommended operating range for the diversion was up to and including the 4-percent annual-chance-exceedance (ACE) or 25-year average return period event. For floods larger than that, the ones that cause extensive damages in Findlay, a large portion of the flood discharge would bypass the diversion structure and could still potentially cause flooding downstream and in Findlay.

The initial hydrologic and hydraulic analyses performed by USACE in support of the diversion channel were conceptual and conservative. More analyses were needed to support the design. Stantec performed additional hydrologic and hydraulic modeling to resolve some of the identified gaps and questions with the USACE modeling.

After further reviewing the initial design for the proposed diversion channel, its economic benefits and costs, and hydrologic and hydraulic results, Stantec ultimately recommended alternate flood mitigation measures consisting of channel improvements to the Blanchard River within the City of Findlay and dry storage basins at three upstream locations (Eagle Creek, Blanchard River, and Potato Run). The recommendations were supported by a revised HEC-RAS hydraulic model as described in the *Stantec Concept Report*, but also included preliminary results from the hydrologic modeling. The final results from the hydrologic modeling are presented in greater detail herein and should be used for future work on the project, as described in section 6.1.

1.1   HYDROLOGIC DATA GAPS

Several portions of the *Stantec Concept Report* discussed gaps in the hydrologic analyses. The purpose of this report is to further explain and document how Stantec has addressed hydrologic gaps associated with the following topics:

- Observations & predictions of flood discharges based on area stream gage data

- Spatial variability in storms and differences in results based on where they might occur over the watershed

- Timing of storm accumulation

Also discussed are revisions and updates to the USACE HEC-HMS model and more complete documentation of the calibration of the revised model.

2.0 STATISTICAL ANALYSIS OF STREAM GAGE DATA

The U.S. Geological Survey (USGS) operates five stream gages in the portion of the Blanchard River watershed that is a part of the current study:

- Gage 04189000 – Blanchard River Downstream of Findlay

- Gage 04188400 – Blanchard River Upstream of Findlay

- Gage 04188337 – Blanchard River Downstream of Mt. Blanchard

- Gage 04188496 – Eagle Creek Above Findlay

- Gage 04188433 – Lye Creek Above Findlay

Figure 1 illustrates the locations of active USGS stream gages in the watershed.

A minimum of 10-15 years of continuous data is typically recommended to perform a statistically valid flood frequency analysis. Gage 04189000 is located on the Blanchard River a short distance downstream of Findlay, approximately 2 miles west, on the upstream side of the County Road 140 bridge. This gage has been in nearly continuous operation since October 1923, with a short data gap of 5 years between December 1935 and October 1940. A total of 89 years of reliable stage-discharge data suitable for this type of analysis is available. Unfortunately, the other four gages weren't established until after the 2007 flood event. Data from those gages isn't sufficient for flood flow frequency analyses, but records of events occurring since 2007 are useful for validating and calibrating the hydrologic model.

Procedures described in the "*Guidelines for Determining Flood Flow Frequency – Bulletin 17B*" from the U.S. Department of the Interior Geological Survey Interagency Advisory Committee on Water Data (1981) were used to perform a flood flow frequency analysis for Gage 04189000. Application of procedures from that document, referred to here as *Bulletin 17B*, are further described in a technical memo included in Appendix A. Stantec used the USACE Hydrologic Engineering Center Statistical Software Package (HEC-SSP) as a tool to perform the study and evaluate sensitivity to parameters such as data skew, hydrologic modifications in the watershed, and varied lengths of the period of records.

Note these analyses were completed prior to the flooding that occurred along the Blanchard River on July 13, 2017. Inclusion of that data point would likely skew the results slightly toward higher discharges on a more frequent basis (the 1% annual chance discharge estimate would be higher).

Figure 2 illustrates a trace of the historic observations from USGS Gage 04189000, while Figure 3 illustrates the frequency of various discharge values graphically. Lastly, Table 1 presents a summary of the results of the *Bulletin 17B* flood flow frequency analyses for USGS Gage 04189000.

Figure 1 - USGS Stream Gage Location Map
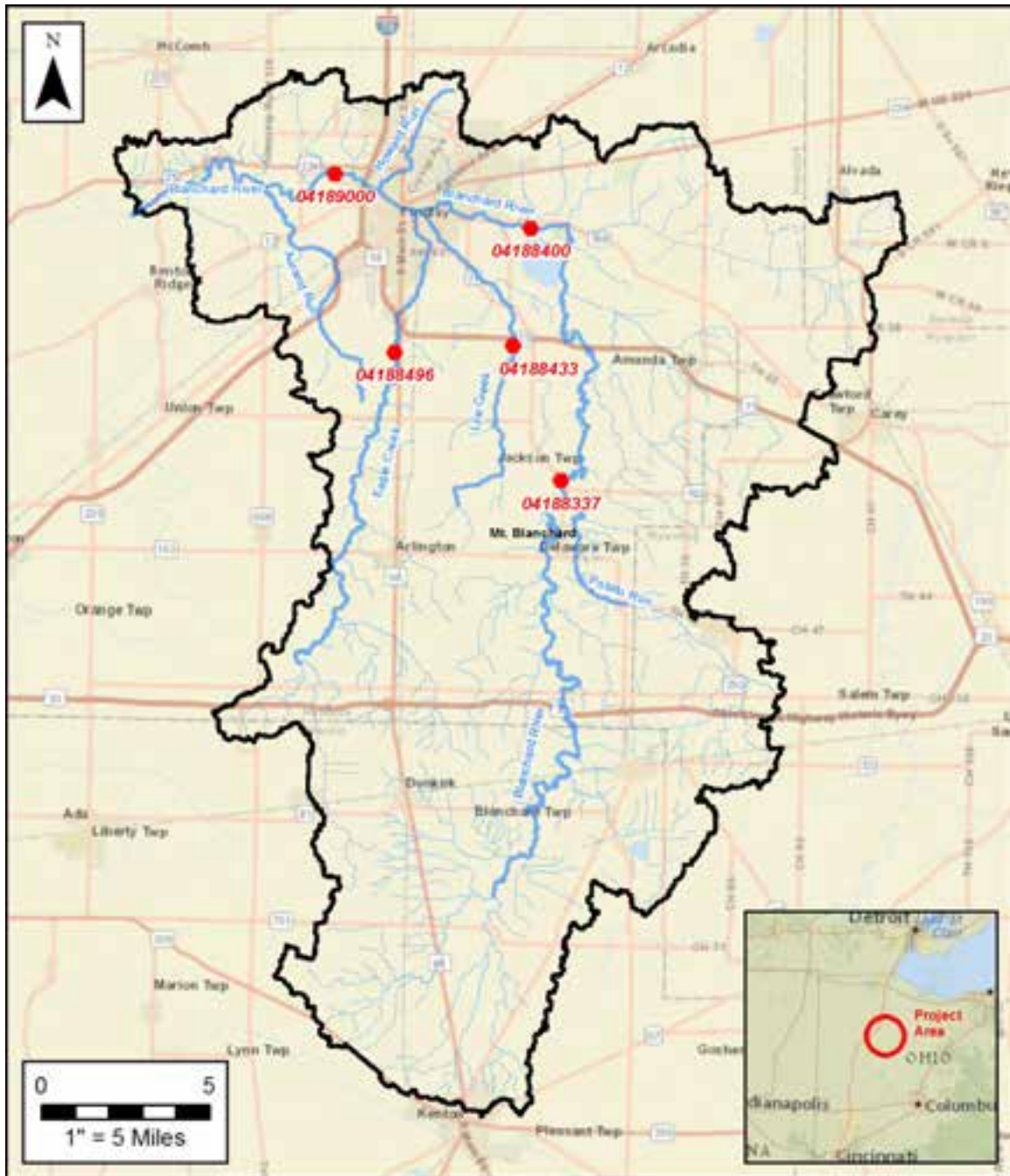
Data Sources: ESRI Online Map Services, USGS NHD Streams, USGS Gage Locations

Statistical Analysis of Stream Gage Data
November 8, 2017

Figure 2 - USGS Gage # 04189000 Historic Data

USGS Gage 04189000 Daily Data
Blanchard River Downstream of Findlay, Ohio
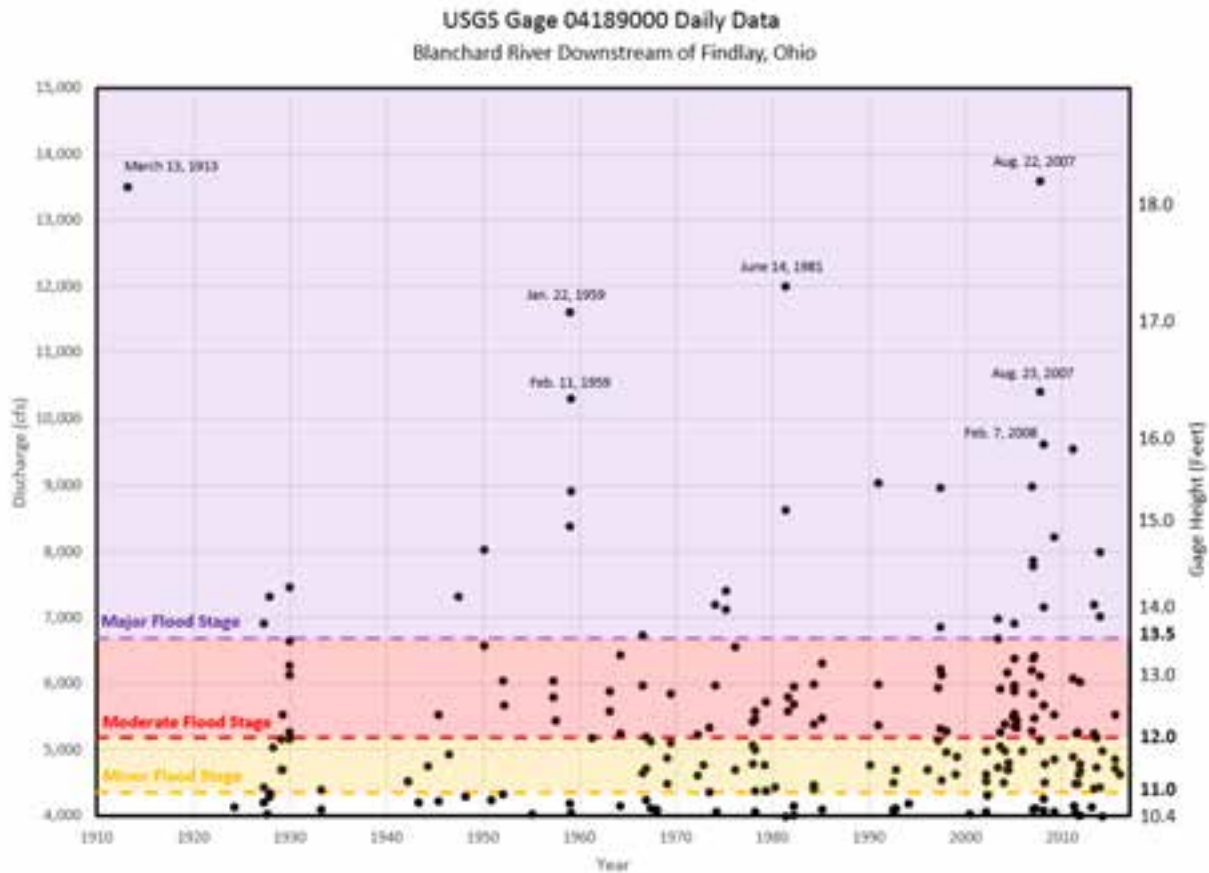
* Flood Stages identified by the National Weather Service.

Statistical Analysis of Stream Gage Data
November 8, 2017

Figure 3 - USGS Gage # 04189000 Data Trends
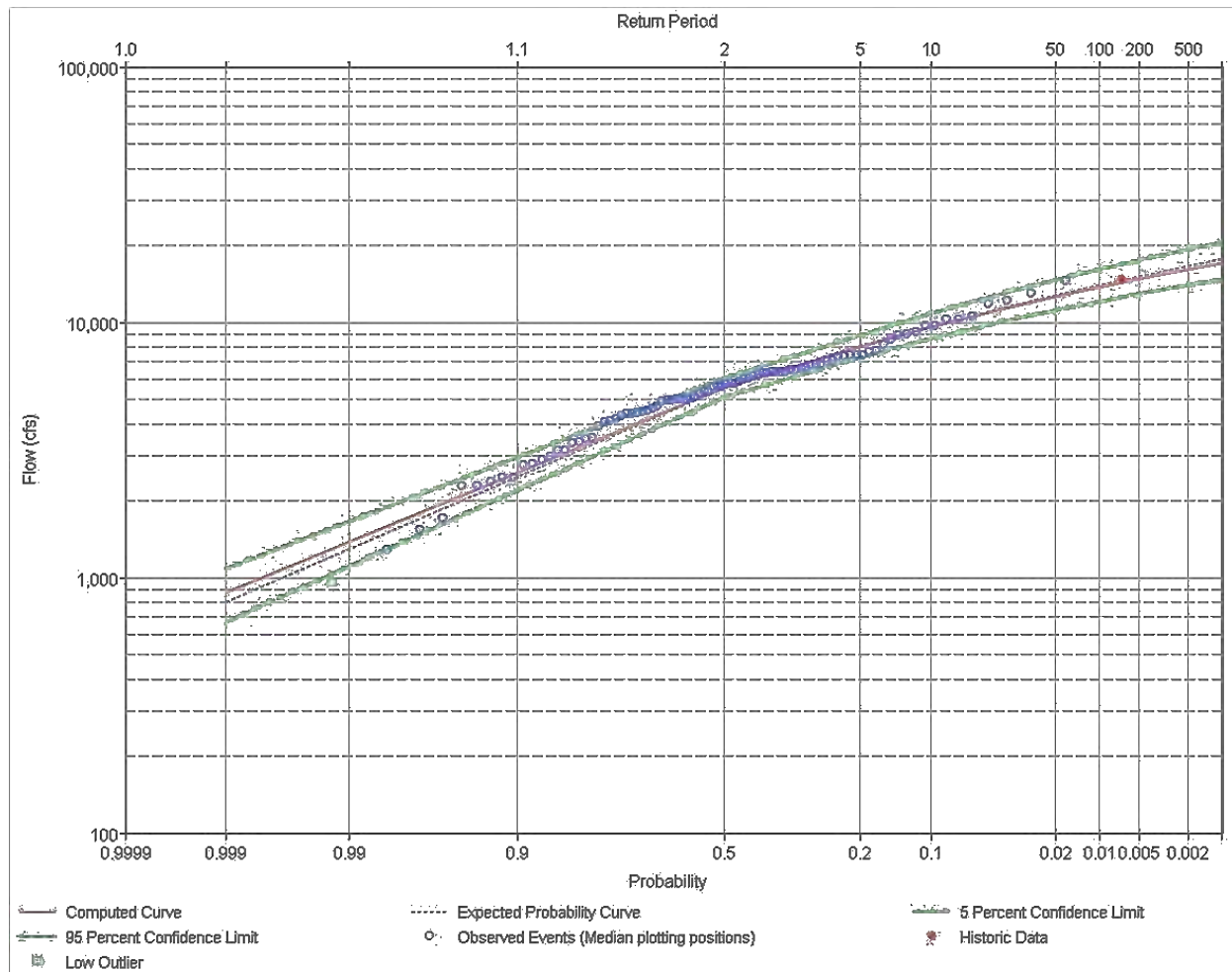
Table 1 – USGS Gage 04189000 Bulletin 17B Flood Frequency Analysis Results

Percent Chance Exceedance	Average Recurrence Interval (years)	Computed Discharge (cfs)	Confidence Limits 0.05	Confidence Limits 0.95
0.1	1000	17,117	20,649	14,715
0.2	500	16,156	19,351	13,964
0.5	200	14,811	17,552	12,903
1.0	*100*	*13,727*	16,120	12,039
2.0	50	12,576	14,619	11,113
4.0	25	11,346	13,037	10,111
10.0	10	9,559	10,788	8,625
20.0	5	8,028	8,918	7,319
50.0	2	5,530	6,020	5,086
99.9	1	875	1,084	667

An interesting trend was noted during the flood flow frequency analyses. As discussed in the memo in Appendix A, by limiting the period of record from the 89 years of available data, to only the last 40 years, and finally only the last 20 years, it would appear that the magnitude and frequency of flood discharges on the Blanchard River are increasing as a trend. Whether or not this increase is attributable to modifications to the hydrologic conditions within the watershed, changes to land use, or changes to the regional precipitation patterns cannot be determined from these analyses. Resolving that question is beyond the scope of the current study.

Refer to Appendix A for additional information pertaining to the Flood Flow Frequency Analyses for the USGS gage data.

3.0   SPATIAL DISTRIBUTION

In the initial planning and design efforts for the proposed Eagle Creek diversion channel, USACE developed a simulation of hydrologic conditions in the watershed using a HEC-HMS model. The HEC-HMS model included simulations for hypothetical events representing the 50%-, 20%-, 10%-, 4%-, 2%-, 1%-, 0.4%-, and 0.2%-annual-chance-exceedance (ACE) (2-, 5-, 10-, 25-, 50-, 100-, 250-, and 500-year average recurrence interval) storms.

For the hypothetical storm simulations, the USACE HEC-HMS model used the Frequency Storm approach and point precipitation depths obtained from *NOAA Atlas 14.* For the Frequency Storm approach, USACE assumed a storm area of 100-square miles for each of the subbasins. This resulted in an areal reduction factor of approximately 95% of the *NOAA Atlas 14* point based precipitation depth. The resulting precipitation depth was then applied uniformly to all of the subbasins in the watershed. Spatial variation was not considered. *NOAA Atlas 14* and publications such as *NOAA's Atlas 2* and *HMR 52* indicate for storms having a spatial area greater than about 10 square miles, a spatial or areal reduction factor should be applied. *HMR*

52 relates the areal reduction factors to a spatial pattern having an elliptical shape. This assumption of a storm's spatial pattern is well correlated to historic data and simplifies implementation in a GIS-based modeling environment. A typical example of such a storm is shown in Figure 4. By not applying the full areal reduction factors and not considering spatial variability of the hypothetical storms, the USACE simulations were overly conservative in terms of how much precipitation the watershed would receive for a given hypothetical storm event.

For the present hydrologic study updates, Stantec accounted for the spatial variability in the watershed. To understand how the hypothetical storms might occur, Stantec worked with a meteorological consulting group, Applied Weather Associates (AWA), to study actual large historic storms that have occurred throughout the United States and which could reasonably be transposed to the Blanchard River location. Based on 22 actual storm events, AWA developed spatial characteristics of storms that could occur in this area such as orientation, major to minor axis variability, and point rainfall reduction factors as a function of storm area. AWA found the historic storms fit relatively well to an ellipsoid type pattern commonly assumed. The average orientation of the ellipse pattern was about 262-degrees based on a north azimuth of 0-degrees for the major axis and clockwise angle measurement. The ratio of major to minor axis dimensions was found to average 3.82.

AWA also analyzed the spatial variability of the historic storms by studying the radar data and observed precipitation accumulations at various locations. AWA compared the precipitation at the center of the storm to the outer bands and developed spatial reduction factors based on proximity to the center. These "areal" reduction factors were based on the area of the ellipsoid pattern through a given point located away from the center of the storm. The *NOAA Atlas 14* point based precipitation values shown in Table 2 are applicable to a given storm that occurs within the Blanchard River watershed; however, the areal reduction factors shown in Figure 5 and elliptical geometric characteristics described above were applied to create more accurate storm simulations similar to the one shown in Figure 4. Of note, the minimum recommended areal reduction factor is 0.795 based on AWA's analyses, so all of the watershed receives at least 79.5% of the *NOAA Atlas 14* point precipitation value for a given storm event.

The composite precipitation accumulation pattern for each storm simulation was applied to the HEC-HMS model using gridded precipitation input files. In order to create the gridded precipitation files, a temporal pattern was applied to disaggregate the storm into a series of time steps. Temporal patterns are discussed further in Section 4 of this report. The process of creating the precipitation gridsets required extensive geoprocessing and data manipulation using the *ESRI ArcGIS* software application. Geoprocessing steps included developing a custom Python script to create the ellipsoid pattern on a grid basis, dissecting the precipitation into a series of time steps, setting values for the grid cells for each of those time steps, reprojecting the data into the correct Standard Hydrologic Grid (SHG) projection used by HEC and NOAA, then exporting the data in an acceptable ASCII file format that can be imported into a HEC-DSS database file. The HEC-HMS model also required a grid cell parameter file that related the subbasin locations in coordinate space to the precipitation grid locations. This file was created in ArcGIS using the HEC-GeoHMS extension and a series of geoprocessing routines and a custom Python script that

Stantec

Stantec created to format the file. Lastly, the HEC-DSS Vue and HEC-GridUtil programs were used to help visualize and organize the data.

Figure 4 - Typical Storm Pattern
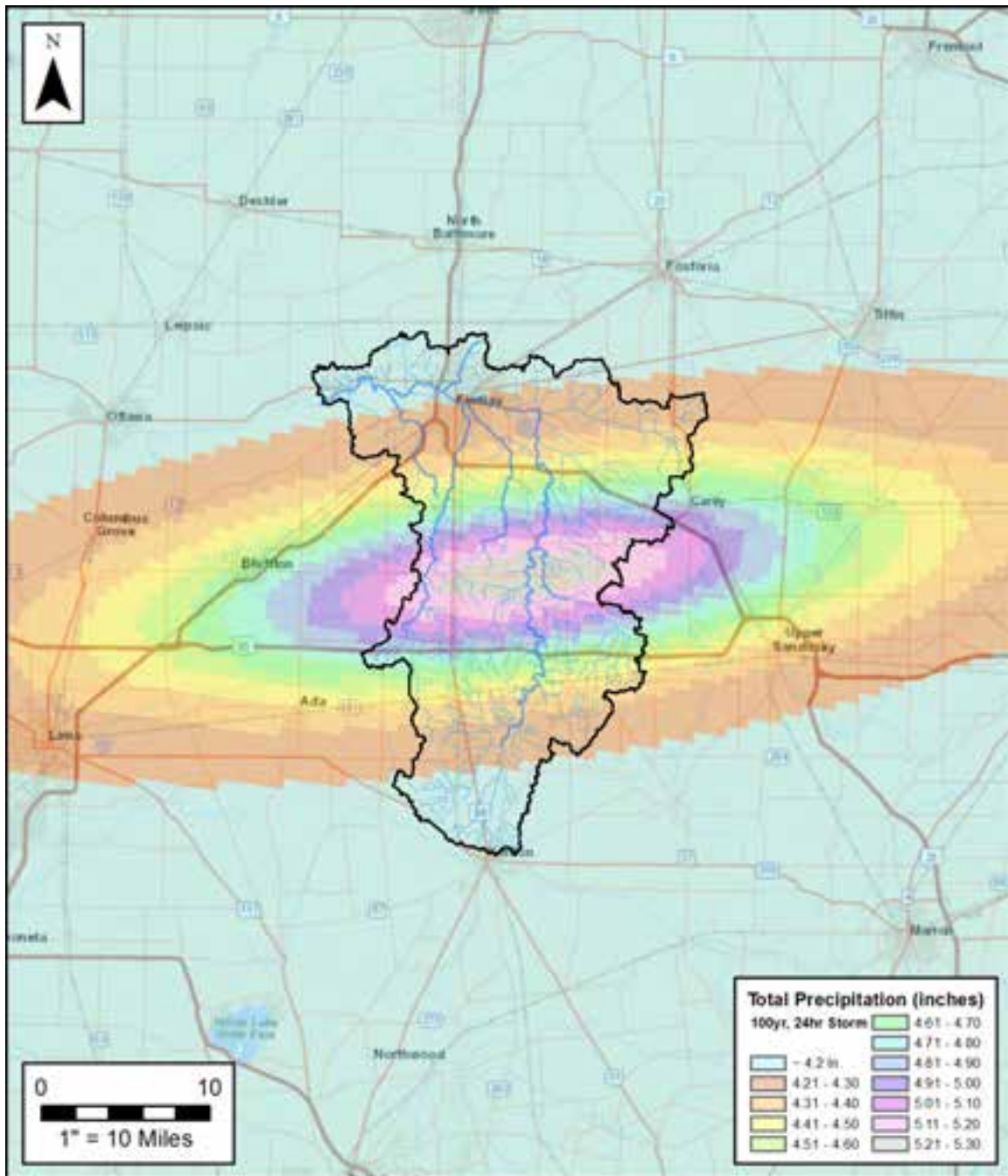
Data Sources: ESRI Online Map Services, USGS NHD Streams, USGS Gage Locations

Table 2 - NOAA Atlas 14 Point Precipitation Values

Average Recurrence Interval (years)	90% Confidence Interval (inches)		Recommended Value (inches)
1	1.90	2.20	*2.04*
2	2.28	2.64	*2.44*
5	2.81	3.25	*3.01*
10	3.23	3.75	*3.48*
25	3.83	4.46	*4.14*
50	4.32	5.05	*4.69*
100	4.82	5.68	*5.26*
200	5.33	6.34	*5.87*
500	6.04	7.30	*6.72*
1000	6.61	8.08	*7.42*

All events are 24-hour duration.

Figure 5 - Areal Reduction Factors
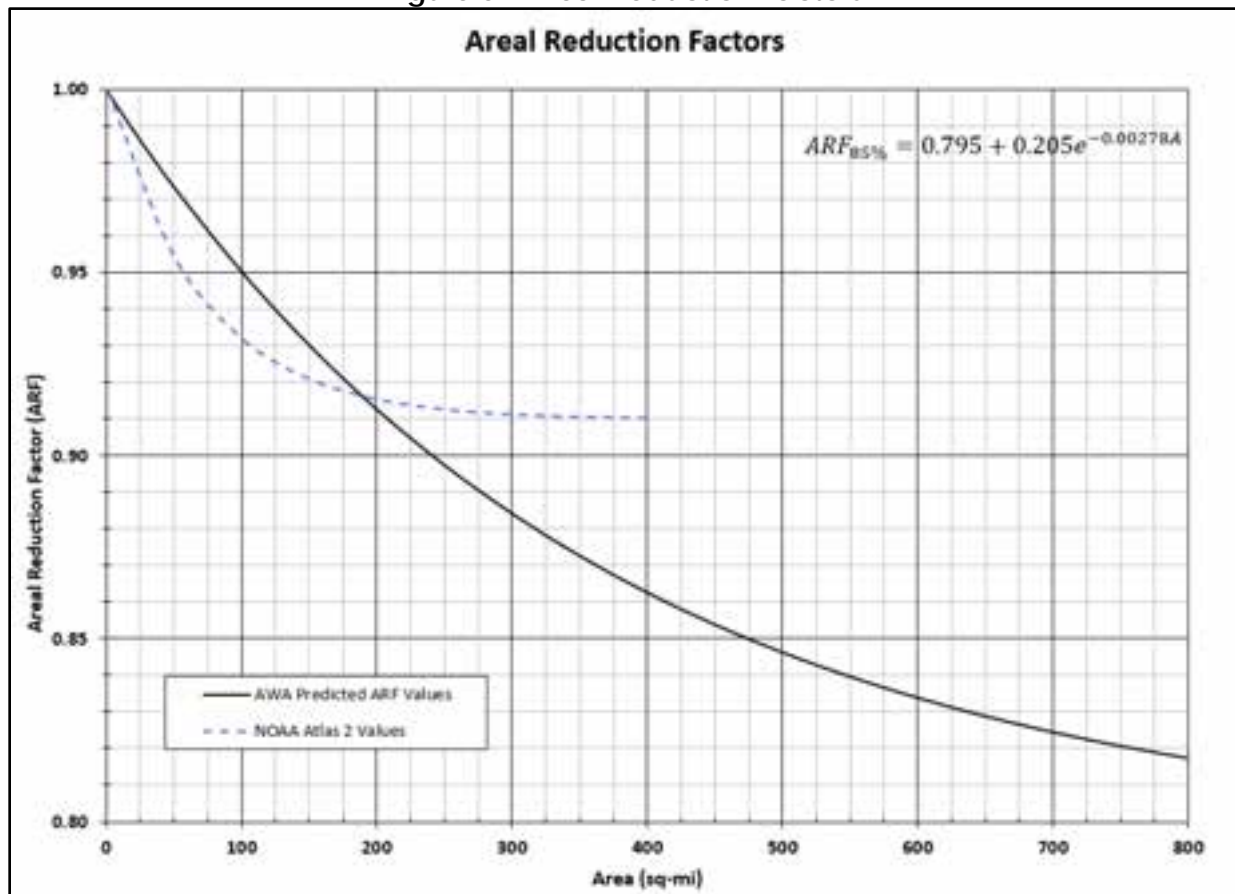
$$ARF_{85\%} = 0.795 + 0.205e^{-0.0027RA}$$

Graph adapted from Applied Weather Associates

Stantec

3.1   STORM CENTERING

When areal reduction factors and a spatial storm distribution are applied to a geographically fixed storm simulation, the location of the storm in relation to the watershed, the center of the ellipse, becomes an important factor in the hydrologic modeling. Four different locations were considered as the center of the storm to determine the appropriate placement for the purposes of runoff simulations. These locations are illustrated in Figure 6.

A storm centered over the centroid of the upstream watershed, near the top of Lye Creek and middle of Eagle Creek and the Blanchard River watershed, was determined to result in larger average peak discharges and larger volume of discharge. Conversely, a storm centered over Main Street in Findlay produced the lowest peak discharges and volumes for the four locations considered. Table 3 summarizes the simulation results at select locations based on storm center assuming Stantec's calibrated September 2011 geometry and a 100-year, 24-hour storm event.

Table 3 – 100-Year, 24-Hour Simulation Results based on Storm Center

Location / Storm Center	Discharge (cfs)	Volume (ac-ft)
Blanchard River at Main Street in Findlay		
Watershed Centroid	15,652	70,927
Headwaters	14,945	70,352
Lower Watershed	14,985	70,432
Over Main Street	14,192	67,627
Eagle Creek Outlet		
Watershed Centroid	4,797	12,235
Headwaters	4,588	11,718
Lower Watershed	4,245	11,387
Over Main Street	4,048	10,770
Lye Creek Outlet		
Watershed Centroid	3,398	12,582
Headwaters	3,325	12,552
Lower Watershed	3,039	11,799
Over Main Street	2,650	10,643

Figure 6 - Storm Centers Considered
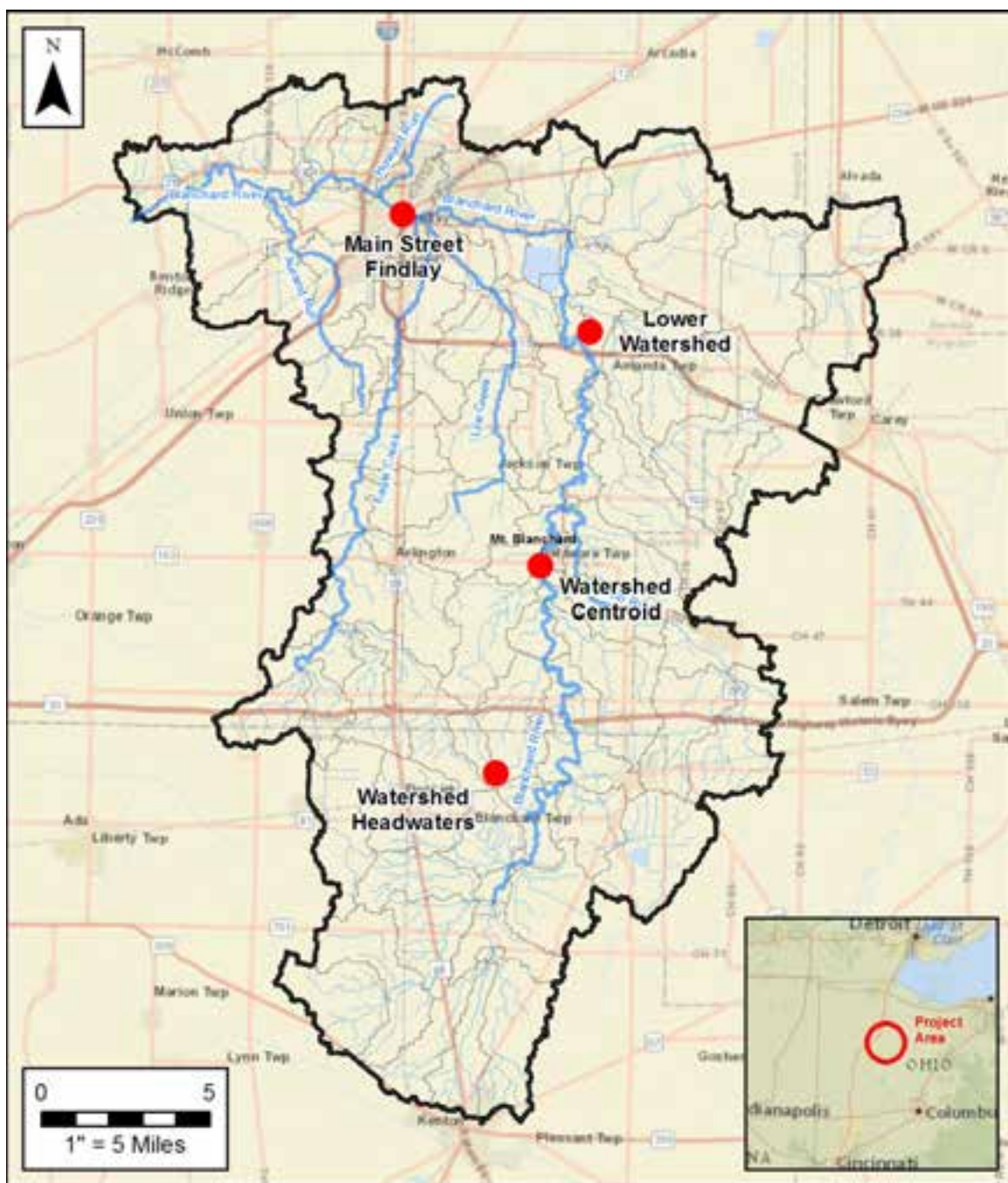
Data Sources: ESRI Online Map Services, USGS NHD Streams, USGS Gage Locations

4.0 TEMPORAL PATTERNS

Previous hydrologic simulations of hypothetical events by both Stantec and USACE assumed an SCS Type II storm distribution. The SCS Type II temporal pattern is a synthetic rainfall event first identified by the Natural Resources Conservation Service (NRCS) as a result of "*Technical Publication 40, Rainfall Frequency Atlas of the United States*" (TP-40) that was published in 1961 and followed by "*Technical Publication 149, A Method for Estimating Volume and Rate of Runoff in Small Watersheds*" in 1968. SCS Type II events have been used for engineering analyses in the eastern U.S. for many years.

The "*NOAA Rainfall Frequency Atlas of the Midwest, Bulletin 71*" was an initial update to TP-40 with the goal of identifying rainfall patterns specific to the Midwest. The "*NOAA Atlas 14 Rainfall Frequency Atlas of the United States*" is a newer update that takes into account approximately 40 years of additional precipitation records throughout the U.S. *NOAA Atlas 14* includes precipitation estimates and temporal patterns for various hypothetical frequency (return period) based storms and various durations. The *Bulletin 71* Huff Quartile Temporal Distributions and *NOAA Atlas 14* Temporal Distributions, which are also presented on a quartile basis, have rainfall more evenly distributed throughout the duration of the storm. Stantec's observations from using the *NOAA Atlas 14* temporal pattern indicates it is a less conservative approach than the SCS Type II rainfall, but more appropriate for simulating storms in a watershed of this size and in this geographic region for the purposes of flood mitigation.

Stantec asked AWA to review the temporal patterns associated with the historic storms used in the spatial analyses. AWA found most of the storms closely resembled that of a Huff 3rd Quartile storm from *Bulletin 71* or a NOAA 3rd Quartile storm from *Atlas 14*. Stantec applied the average temporal pattern determined by AWA to hypothetical model simulations used in the HEC-HMS model. Figure 7 illustrates the storm patterns described here.

Figure 7 - Storm Temporal Pattern
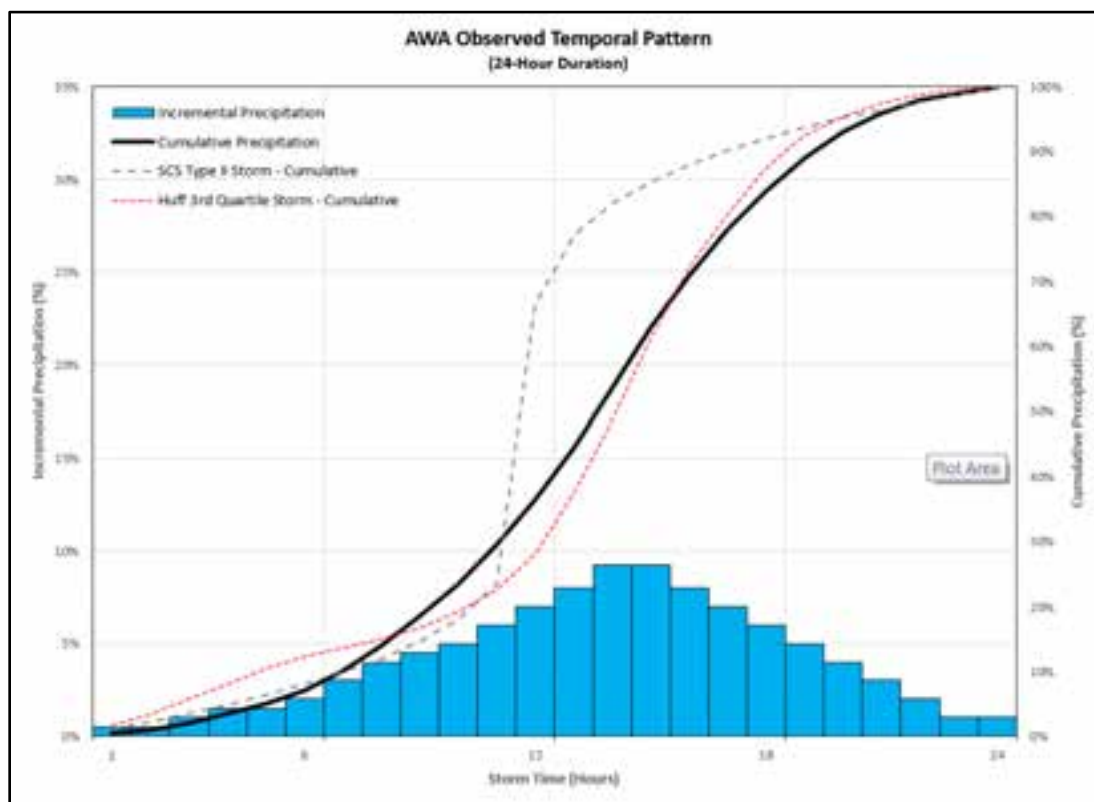
Graph adapted from Applied Weather Associates

5.0   HEC-HMS MODEL UPDATES

In order to simulate potential flood mitigation measures in the Blanchard River watershed, Stantec implemented a number of changes and updates to the USACE HEC-HMS model. First the watershed boundary and subbasin delineations were modified to fit the extent of the study and areas of interest for the proposed flood mitigation measures. Watershed and subbasin delineations were accomplished using the HEC-GeoHMS and ArcHydro plugins for ESRI ArcGIS. Terrain data used in the analyses was based on LiDAR based topographic mapping from the Ohio Statewide Imagery Program (OSIP). Subbasins were created based on dividing the watershed at locations significant to the flood risk reduction project and areas of 10 square-miles or smaller. Stream data used in the analyses was based on the USGS National Hydrologic Dataset (NHD). Figure 8 illustrates the watershed and subbasin delineation. Appendix B contains tabular summaries of the subbasin and reach parameters used in the HEC-HMS model.

Subbasin runoff was modeled in HEC-HMS using the SCS Curve Number approach applied on a grid basis. The SCS Curve Number approach was selected based on data availability and common acceptance within the industry for this type of modeling. More robust soil moisture

accounting methods or Green-Ampt soil infiltration methods could have been used, but those methods introduce additional model uncertainty and are more appropriate to longer term simulations. The curve number grid was created using landcover data from the USGS National Land Cover Database (NLCD) and soils data from the NRCS SSURGO soils database. Land cover and soil hydrologic groups were linked to SCS Curve Number values by selecting compatible pairs from the NRCS *"TR-55 Urban Hydrology for Small Watersheds"*. The initial abstraction ratio and retention factors were used as calibration parameters as described below.

The selected subbasin transform method was the ModClark grid method. The ModClark grid method was used because it was one of the only methods compatible with the gridded precipitation inputs and produces results with a finer resolution. Associated parameters with that approach are the time of concentration and subbasin retention storage coefficient, which were both determined initially using HEC-GeoHMS, then used as calibration parameters. Time of concentration was initially determined using the TR-55 segmental approach (overland, shallow concentrated, channel flow) with assumed velocities for channel segments. The velocities were cross-checked against reach routing velocities as applicable.

The selected baseflow methodology was recession baseflow. Recession baseflow was selected because it could be used to simulate conditions leading up to the modeled historic storm events and the trailing limb of the discharge hydrographs after the events occurred. Parameters used in the recession baseflow included the initial discharge per unit area, recession constant, and discharge limb threshold ratio to peak. The recession constant was not changed, but the other two parameters were used as calibration values.

Stantec

Figure 8 - Subbasin Delineation
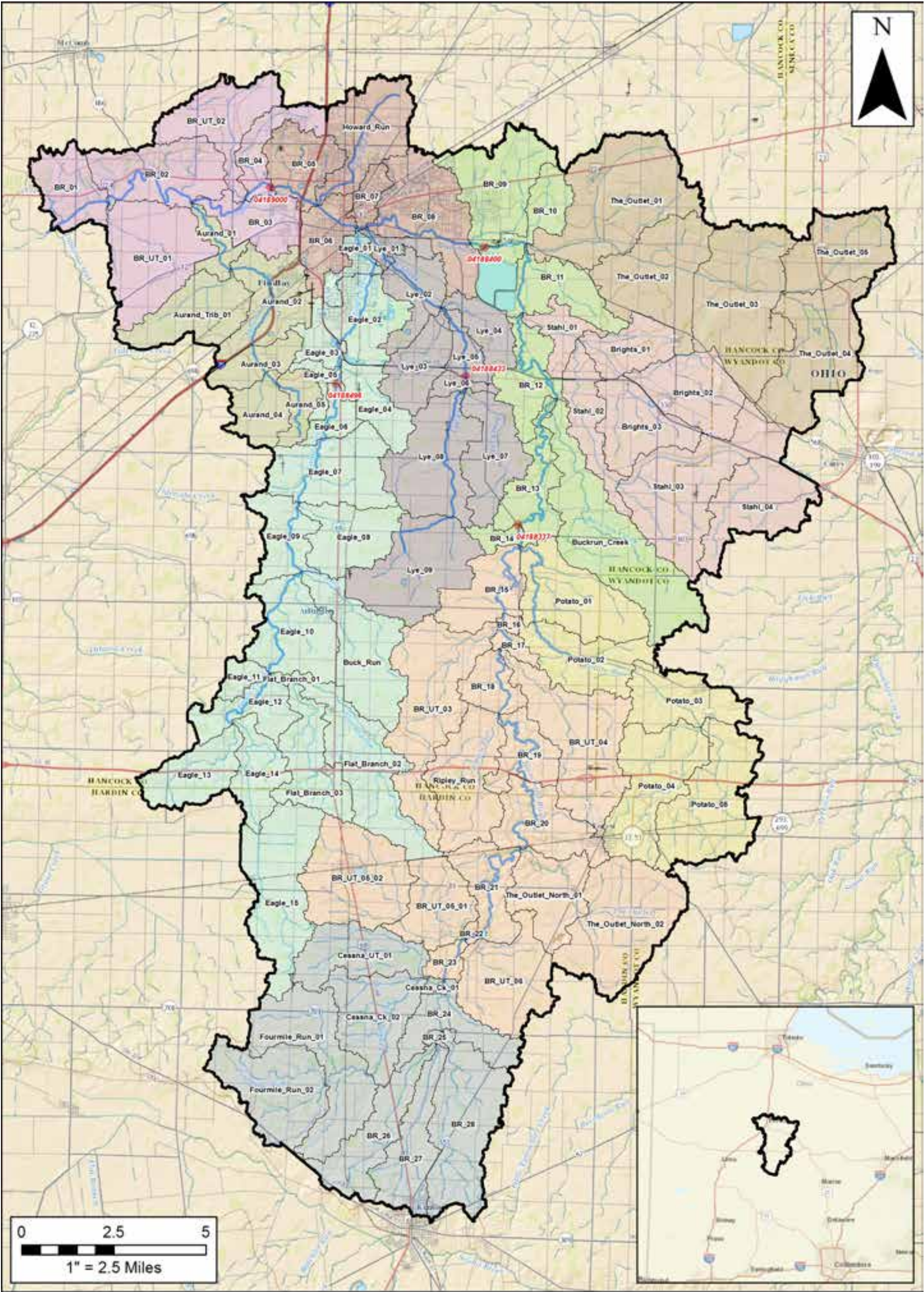
Data Sources: ESRI Online Map Services, USGS NHD Streams, USGS Gage Locations

Reach routing was accomplished using Modified Puls storage-discharge functions in areas with cross sections common to the HEC-RAS model. The storage-discharge data was calculated from rating curves developed from the HEC-RAS model. Note the HEC-RAS model updates were previously described in the *Stantec Concept Report*. Routing times and reach attenuation was compared to the HEC-RAS routing results for validation.

For areas that did not have cross sections in the HEC-RAS model, simple lag routing was applied. Initial values for the lag were calculated using an assumed velocity for the length of the stream calculated from the NHD stream data. These lag times, with reasonable limits on velocities, were later used as model calibration parameters.

5.1 CALIBRATION EVENTS

As a part of the initial gap analysis for the USACE hydrologic study, Stantec noted the calibration approach for the hydrologic model was not well documented. Gridded precipitation records for a number of historic storm events were included in the USACE HEC-HMS model, but it appears USACE calibrated the model to a single event that occurred in October 2011.

After Stantec further refined and updated the HEC-HMS model, the model results for the October 2011 event did not seem to correlate well to gage based discharge observations. The timing of the storms and runoff did not correctly align and the volume of runoff seemed different. The USACE model parameters also seemed inconsistent and varied widely between adjacent subbasins and reaches. Upon further investigation, it appears USACE used raw NEXRAD radar data from NOAA and did not correct the data using precipitation gage data. NEXRAD radar data captures reflectivity, which doesn't necessarily result in a correct estimate of direct rainfall. To best use the radar data, the resulting precipitation estimates must be compared and scaled on a time-step basis to precipitation gages in the area. The result from the USACE model was a model geometry that reasonably replicated gage results, but that was based on an uncalibrated October 2011 input storm and inconsistent calibration parameters. Stantec sought to recalibrate the updated model using precipitation corrected radar data.

The first assumption in model calibration was that the model geometry should represent an "average" antecedent condition where the ground was not overly saturated, frozen, or covered with snow accumulation. The model results would thus reflect runoff commensurate with those conditions. In addition, since the USGS Gage 04189000 has an abundance of reliable data, the model should also reasonably replicate the results of the gage frequency analyses.

Stantec started by reviewing stream discharge records for the USGS gage 04189000 prior to the August 2007 event. A trace of daily mean discharges is shown in Figure 9. One observation from Figure 9 was there was nearly four months of drier than normal conditions, as the stream discharge was well below the historical mean values for the gage published by USGS.

Figure 9 - August 2007 Storm Preceding Conditions
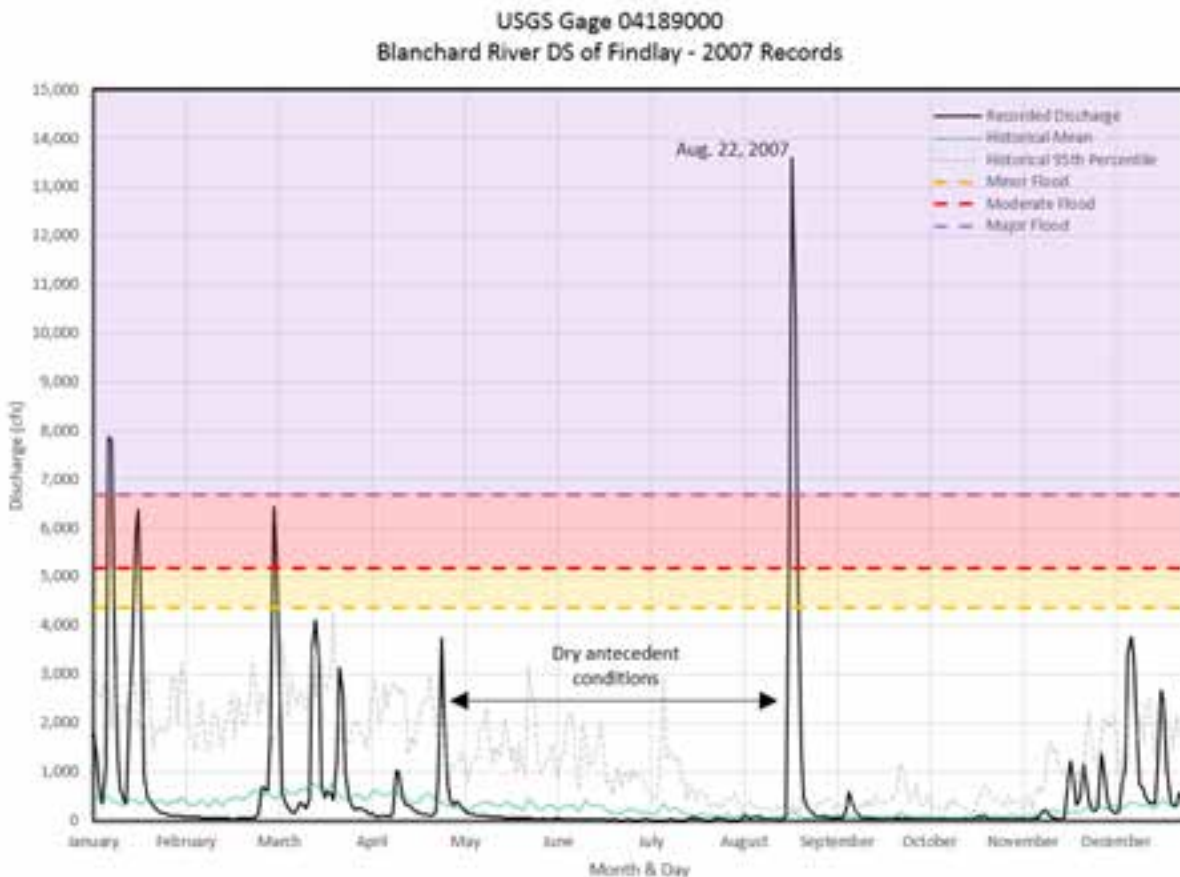
To further evaluate the August 2007 event, Stantec reviewed precipitation gages in the area and found very little accumulation during that preceding 4-month period. Not only was the stream discharge low, the watershed was also relatively dry. Stantec worked with AWA to obtain precipitation gage corrected radar data for the August 2007 storm. Total precipitation accumulations for the period between August 18 and August 22 of 2007 are shown in Figure 10. Note portions of the watershed received over 11 inches of rainfall during that time, making it an extremely abnormal hydrologic event. In fact, the Annual Chance of Exceedance (ACE) for a storm event with a depth and duration similar to the one in August 2007 was estimated to be less than 0.2% (greater than a 500-year return period) for much of the watershed. The intense rainfall with significant volume falling onto a dry watershed led to what would nearly approximate the flood of record for the City of Findlay.

Also note from Figure 10 the nearly elliptical shape of the storm and spatial distribution outward from a central precipitation band. These patterns are additional validation for the assumptions on spatial storm distribution and areal reduction described in Section 3 above.

Stantec

Figure 10 - August 2007 Storm Spatial Pattern
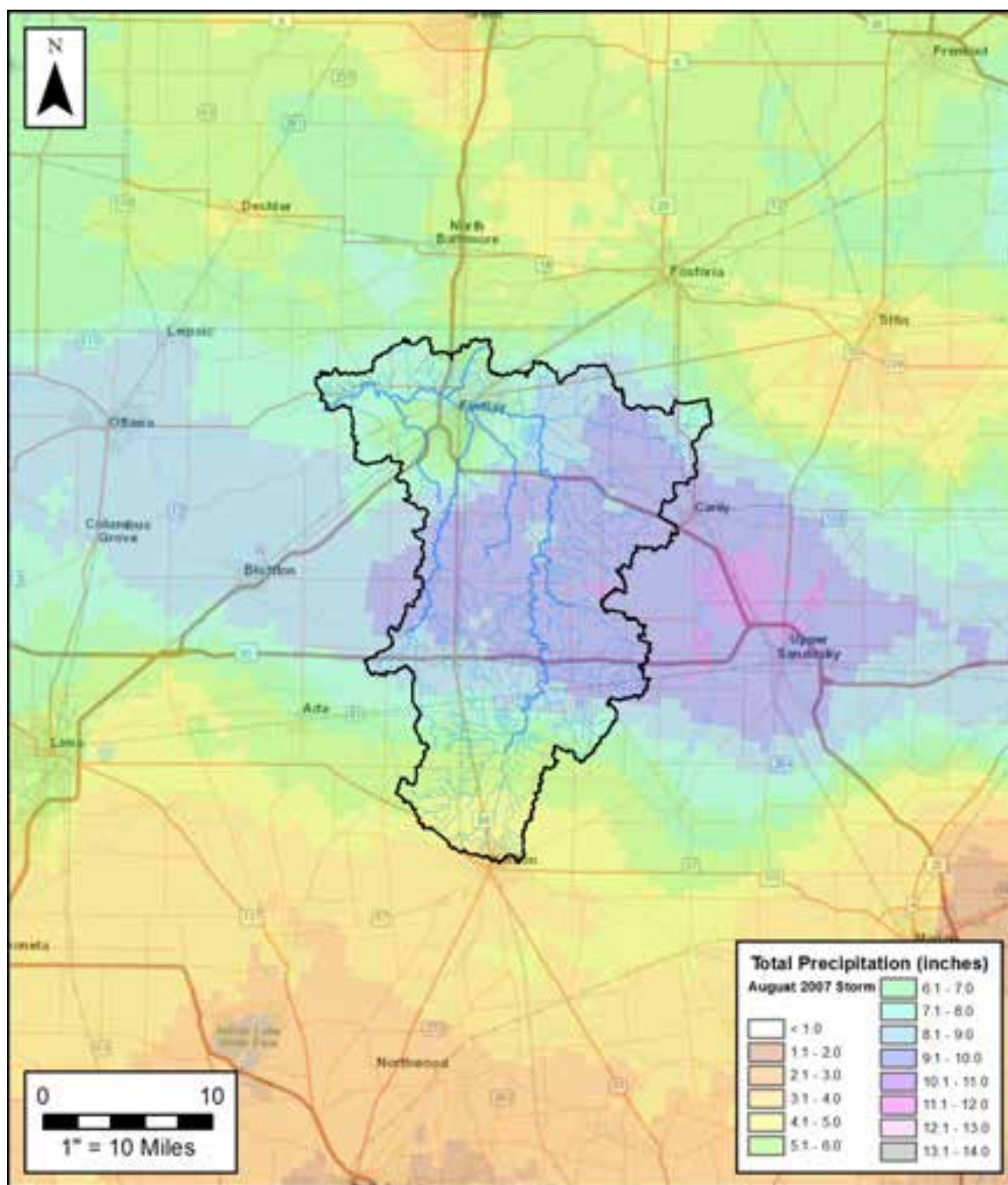
Data Sources: ESRI Online Map Services, USGS NHD Streams, USGS Gage Locations

For calibration purposes, Stantec sought to identify one or more storm events that were independent and distinct occurrences; that were not affected by saturated conditions, frozen ground, or snow accumulation; and which produced large discharges in Findlay like the August 2007 event. The calibration events were limited to the availability of stream gage records on all five USGS gages, which meant the events must occur after 2007.

A few larger runoff events were noted during 2011. One particularly promising event in March 2011 produced a large discharge in Findlay; however, upon further review of the precipitation gage data and temperature data for the area, it was found to be partially due to snow melt. Additionally, runoff from much of the watershed would have been affected by frozen ground with limited crop and tree cover. For that reason, the focus was placed mainly on events occurring between late spring and fall that were more similar to the August 2007 event.

Early June of 2011 indicated another significant runoff event, but that spring was particularly wet and antecedent conditions did not represent typical conditions in the watershed. An event was identified on September 22 of 2011 that met most of the criteria. It was a late summer convective storm, with a uniform and distinct rainfall, falling on a relatively dry watershed that had not received a great deal of rain in the preceding 3-4 months, and vegetative cover would have been similar to 2007. Figure 11 shows the trace of runoff during 2011, while Figure 12 shows the precipitation gage corrected radar for the September 2011 event.

Using the same process, Stantec identified another similar event in June 2015. A trace of the runoff during 2015 and precipitation gage corrected radar data for the June 2015 event are included in Figures 13 and 14 respectively.

Observed runoff hydrographs at the USGS 04189000 gage for all three storm events are illustrated in Figure 15.

Figure 11 - September 2011 Storm Preceding Conditions
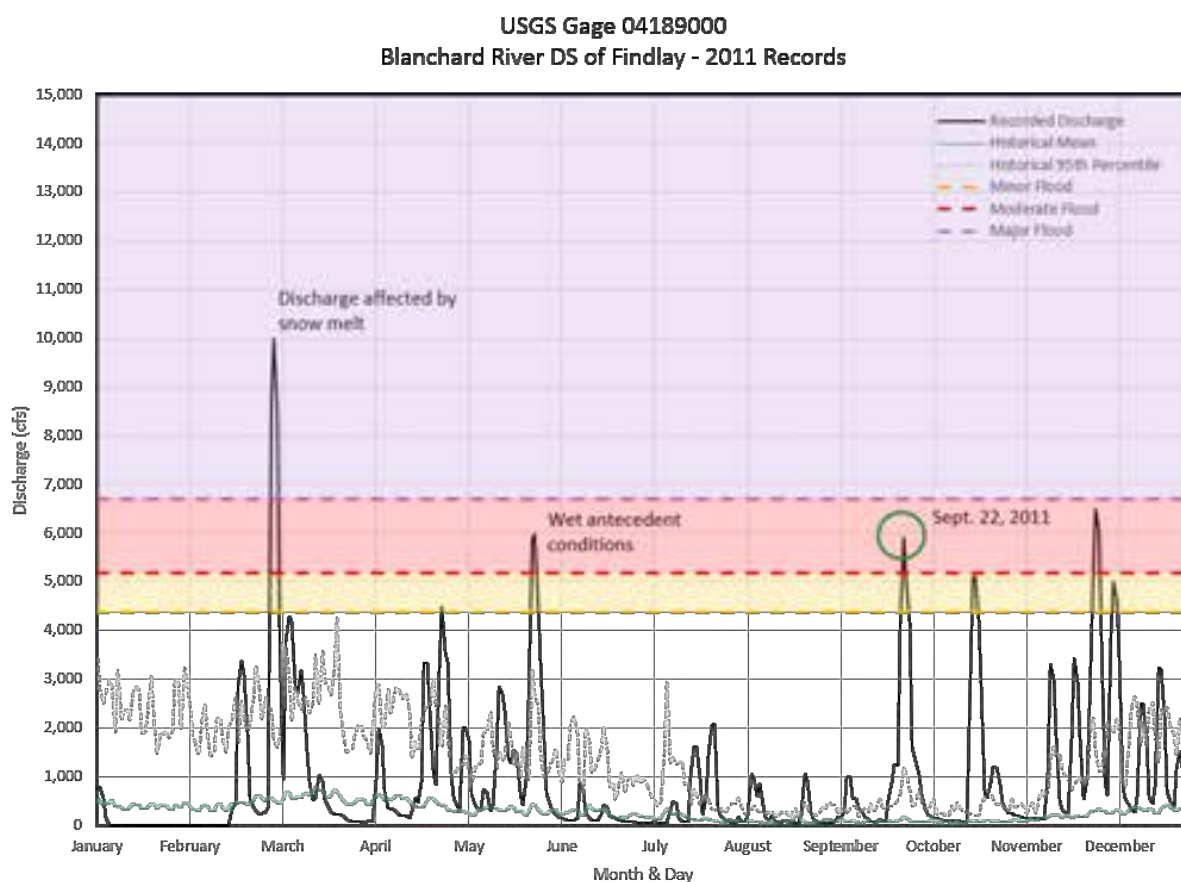
USGS Gage 04189000
Blanchard River DS of Findlay - 2011 Records

Figure 12 - September 2011 Storm Spatial Pattern
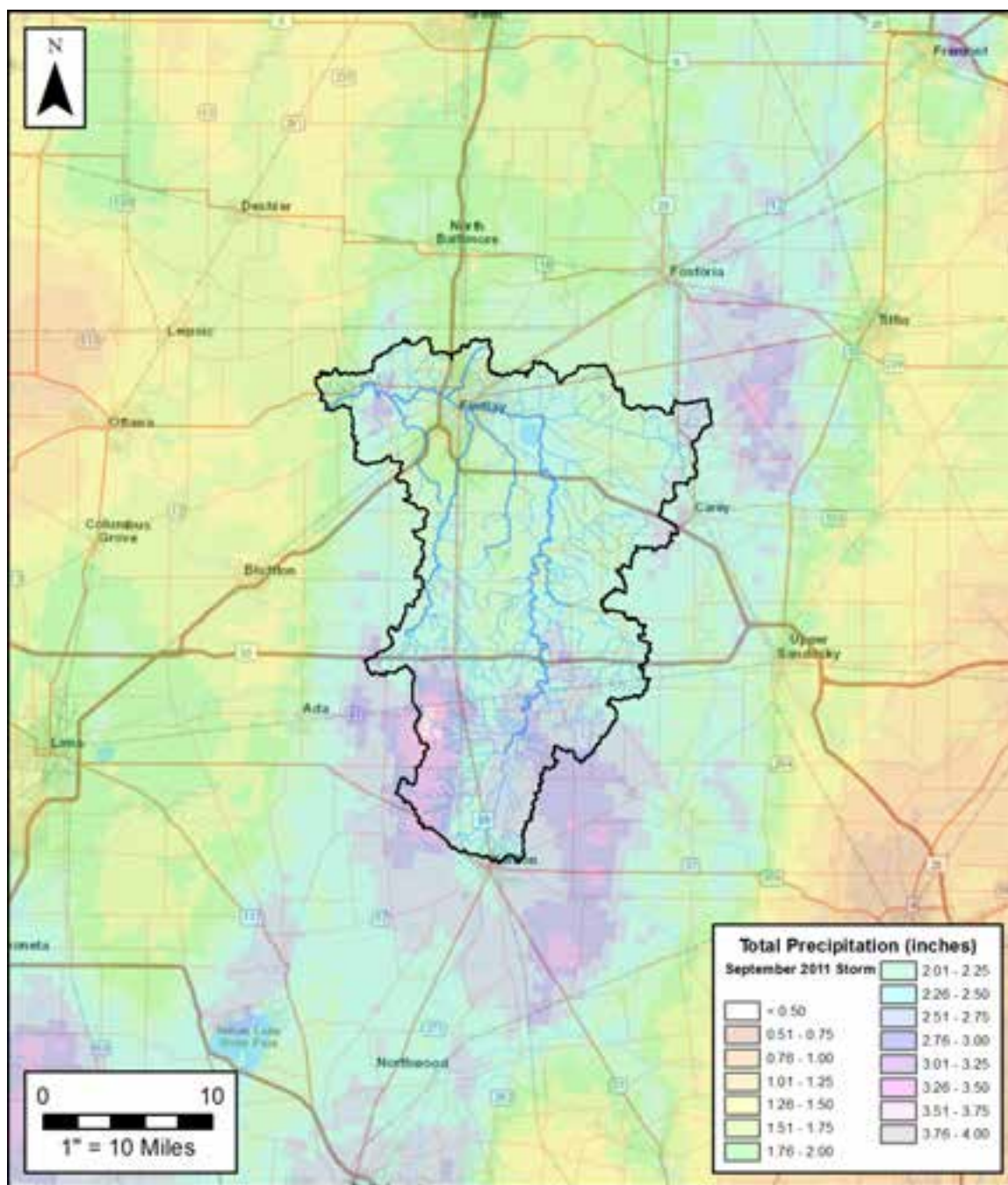
Data Sources: ESRI Online Map Services, USGS NHD Streams, USGS Gage Locations

Figure 13 - June 2015 Storm Preceding Conditions
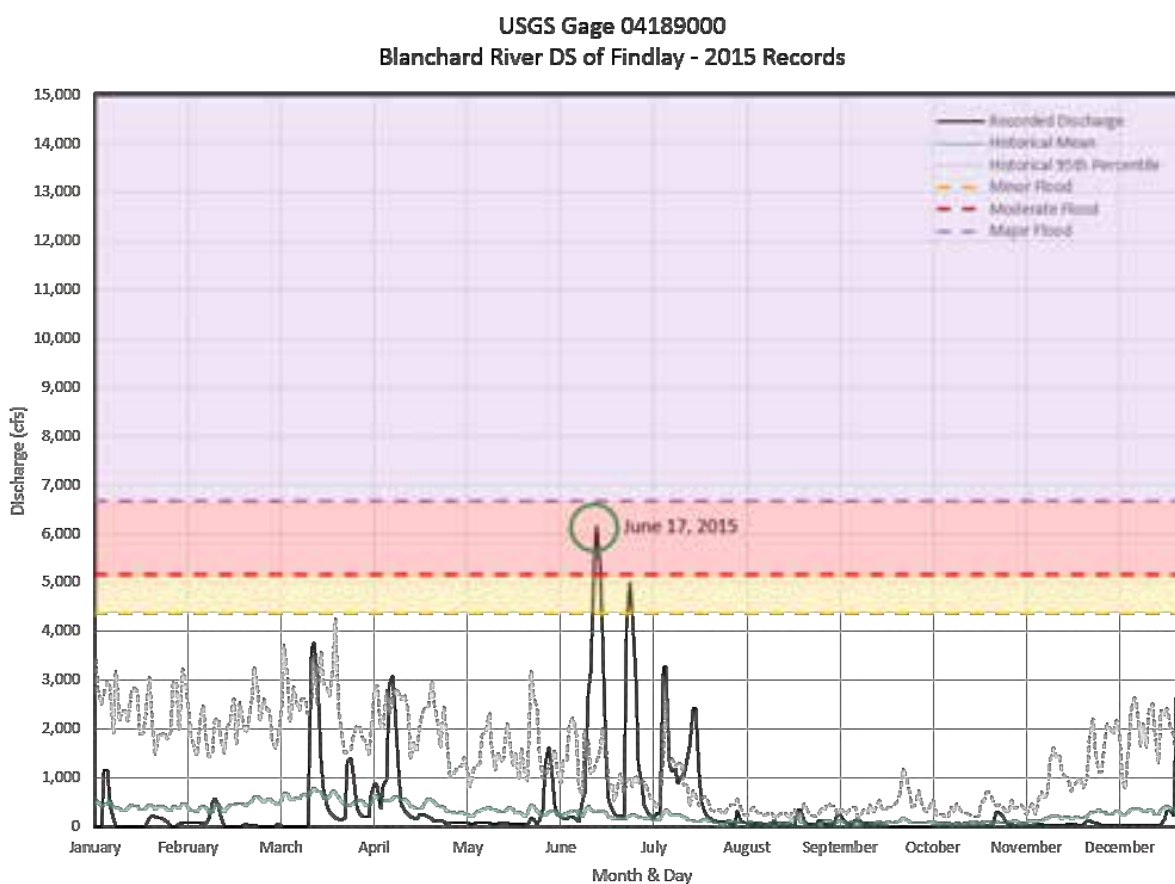
USGS Gage 04189000
Blanchard River DS of Findlay - 2015 Records

Figure 14 - June 2015 Storm Spatial Pattern
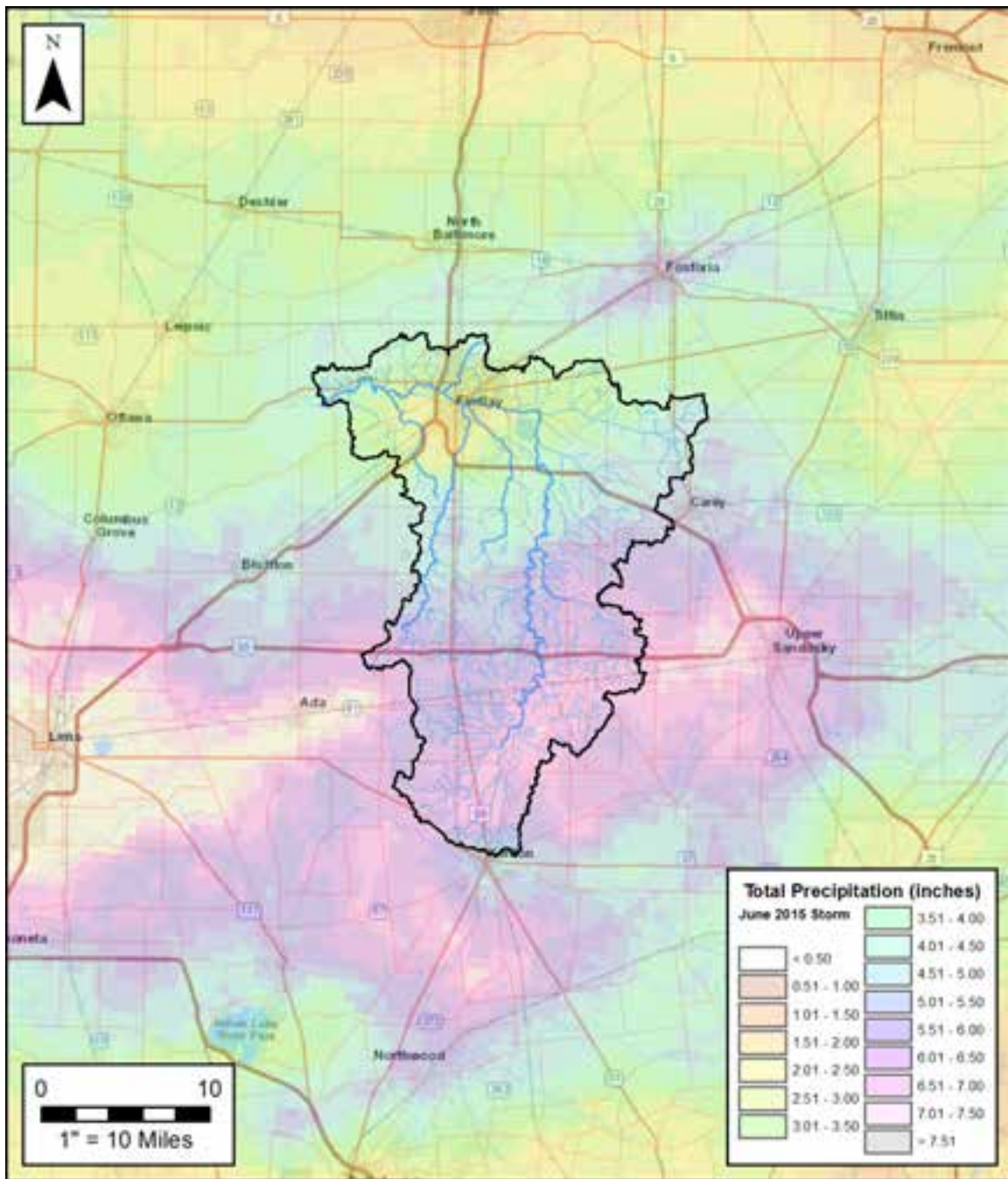
Data Sources: ESRI Online Map Services, USGS NHD Streams, USGS Gage Locations

Figure 15 - USGS Gage 04189000 Hydrographs
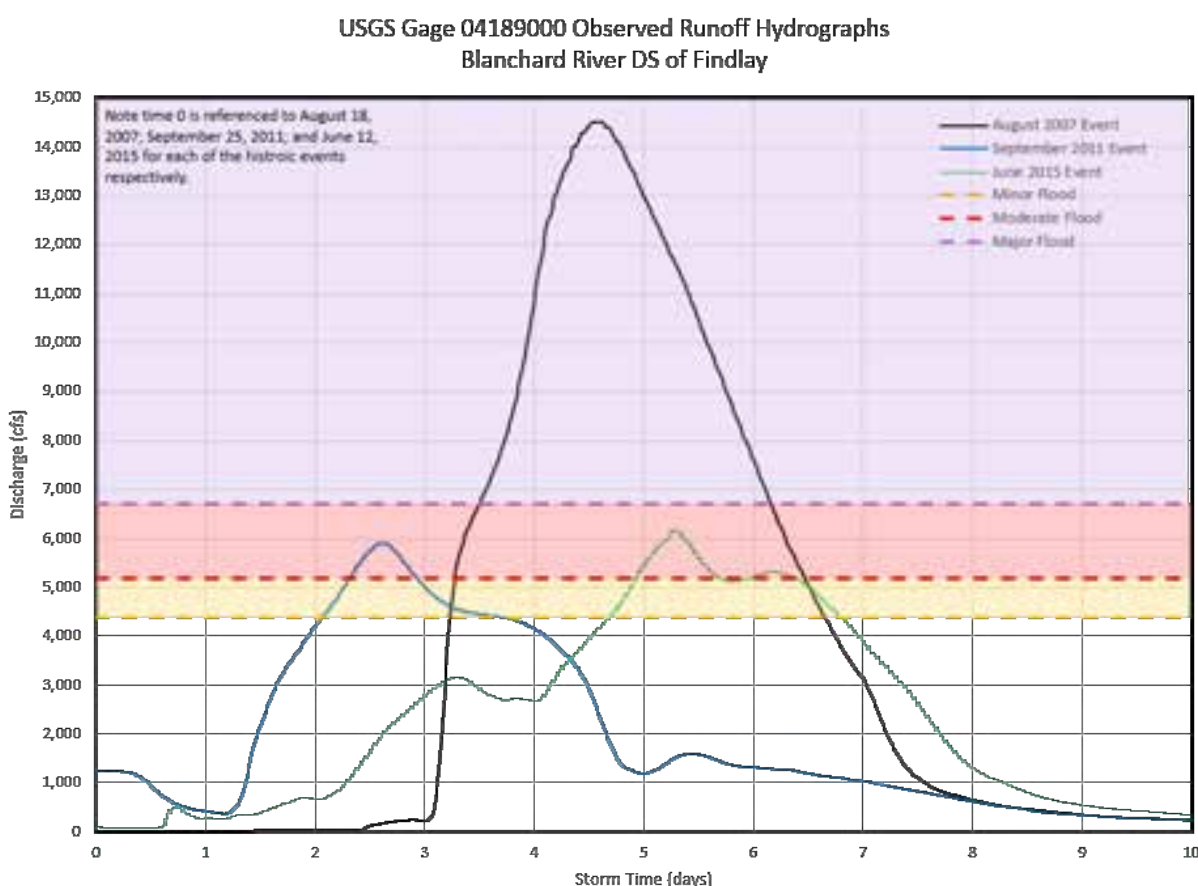
5.2   HEC-HMS MODEL CALIBRATION APPROACH

To calibrate the HEC-HMS model, Stantec started by creating calibrated geometry datasets for each of the September 2011 and June 2015 events. USGS gage data was available at five locations for these events. To accomplish the calibration, Computation Points were assigned to the nodes in the HEC-HMS model that represented the five USGS gage locations. Subbasins and reaches upstream of each gage (Computation Point) were then divided into 2-3 zones based on approximate travel time to the gage locations. The Forecast Analysis tools in HEC-HMS were then used to uniformly vary parameters within the zones. Lastly, parameter groupings and adjustments were checked for consistency between zones and within nearby spatial areas using GIS and an Excel spreadsheet.

Using the adjustments made for the September 2011 and June 2015 calibration events as a guide, Stantec then used the base model geometry to create a third calibration geometry dataset that simulated the result of the August 2007 flood event. The geometries for each of

these three calibration events were somewhat different due to variations in antecedent conditions.

Stantec then used the three calibrated geometries to simulate hypothetical storm events in the watershed. The September 2011 geometry produced results in Findlay for various return period events that were within the acceptable range of values determined from the gage frequency analyses at the USGS Gage 04189000 location. The September 2011 geometry was therefore deemed more appropriate for simulation purposes.

The base geometry and calibration adjustments are included in Appendix C. Some additional notes on specific calibration parameters and results follow.

5.2.1   Subbasin Losses - SCS Curve Number Grid Adjustment

Typically, SCS Curve Numbers originally computed using procedures in TR-55 would be transformed into area weighted composite values for each subbasin and then slightly adjusted to account for antecedent moisture conditions (AMC). Table 10.1 in the NRCS National Engineering Handbook, Part 4, Hydrology (NEH 4) and Table 3 in NRCS Technical Publication 149 (TP-149) describes adjustments to the curve number for antecedent conditions. As an example, a watershed with an average curve number of 85 under AMC II (average) conditions can have a curve number that ranges from 70 for AMC I (dry conditions) to 94 for AMC III (wet conditions).

When using the gridded curve number approach in HEC-HMS, the grid values are direct representations of average curve number for each grid cell, assuming AMC II conditions. Runoff is calculated on a cell by cell basis and then accumulated at the subbasin outlet. The curve number grid is not typically adjusted to account for antecedent conditions. Instead, the initial abstraction and retention factors are adjusted individually for each subbasin. A 1-square-kilometer curve number grid was used to match the radar based precipitation grid data sets.

The calculation of runoff using the SCS Curve Numbers is described in Equations 2-1 to 2-4 from TR-55.

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \text{ (Eq. 2-1)} \qquad I_a = 0.2S \text{ (Eq. 2-2)} \qquad S = \frac{1000}{CN} - 10 \text{ (Eq. 2-4)}$$

Where Q is the direct runoff, P is the precipitation for a given time period, I_a is a term describing the initial abstraction or precipitation loss, and S is a term defining the potential maximum retention.

In the HEC-HMS solution scheme for a gridded curve number approach, the 0.2 factor in Eq. 2-2 is replaced with a variable Abstraction Ratio. This allows for changes to the initial loss rates due to antecedent conditions, without artificially modifying the curve number grid. For calibration purposes, this value was adjusted within the range of 0.05 to 0.30, with an average of about 0.09.

In addition, the S in equation 2-1 is replaced in the HEC-HMS solution scheme with a term that has a multiplier Retention Factor that can account for additional (or less) subbasin storage that

wouldn't otherwise be apparent with the curve number. This factor was adjusted within the range of 0.3 to 2.5 during calibration, with an average of about 0.79.

5.2.2   Subbasin Transform – ModClark Time Parameters

Two factors are included in the ModClark transform method: time of concentration and storage coefficient. Time of concentration (Tc) was initially calculated using the segmental approach (overland, shallow concentrated, and channel flow) described in TR-55. For calibration purposes, the times of concentrations were multiplied by a factor that ranged from 0.7 to 1.9 with a maximum variation of 3 hours from the calculated value. The 3-hour limiting value was chosen based on the expected possible error in the initial time of concentration calculation. The average adjusted value was about 90% of the original determination.

The ModClark storage coefficient (R) was calculated based on a ratio to the time of concentration. Many references, including the *HEC-HMS Technical Reference Manual* and *USGS Water-Resources Investigations Report 00-4184* indicate the ratio of R / (Tc + R) is nearly constant for an area. For calibration purposes, this ratio was initially assumed as 0.6, then assumed to be relatively fixed for given group of subbasins assigned to a common computation point and forecast zone.

5.2.3   Subbasin Recession Baseflow

The initial discharge per unit area ratio and ratio of the recession threshold to peak discharge were adjusted during calibration based on hydrograph observations. Initial discharge varied from 0.1 to 1.5, while the recession ratio varied from 0.01 to 0.05. The average values were 0.93 and 0.026 respectively.

5.2.4   Reach Lag Times

The lower reaches of the Blanchard River watershed were previously included in the updated HEC-RAS model. For those reaches, the Modified Puls storage routing method was applied using storage discharge rating curves developed from the HEC-RAS model. The assumed number of subreaches was set to 1 to produce the maximum amount of attenuation within the reaches. No other parameters were included with those reaches and they were not included in the calibration process.

For upstream reaches and larger tributaries that were not included in the HEC-RAS model, simple lag time routing was applied within the HEC-HMS model. Lag time routing does not replicate attenuation within a reach, but allows for adjustments of timing of runoff from various parts of the watershed. Lag time was initially calculated by assuming a fixed velocity of 2 feet per second over the length of the reach as calculated from the NHD stream centerlines. During calibration, the velocity values were modified within the range of 0.9 to 2 feet per second and lag times calculated accordingly. The average selected velocity was about 2.0 feet per second.

5.3   CALIBRATION RESULTS

Peak discharge and volumetric results for the HEC-HMS calibration are summarized in Table 4. Graphical hydrograph comparisons are provided in Appendix C.

Table 4 - USGS Gage Observation Comparison – "Calibrated" Geometries

Location	September 2011		June 2015		August 2007	
	Peak Q (cfs)	Volume (ac-ft)	Peak Q (cfs)	Volume (ac-ft)	Peak Q (cfs)	Volume (ac-ft)
USGS Gage 04189000 Blanchard River DS of Findlay	6,232 *5,900*	33,499 *38,258*	8,277 *6,180*	53,392 *46,256*	14,290 *14,500*	77,809 *74,412*
USGS Gage 04188400 Blanchard River US of Findlay	4,556 *4,440*	25,646 *29,809*	5,105 *5,400*	36,485 *38,006*	7,320 *N/A*	46,820 *N/A*
USGS Gage 04188337 Blanchard River DS of Mt. Blanchard	4,571 *4,720*	18,073 *20,143*	5,670 *5,830*	28,438 *28,112*	6,215 *N/A*	29,179 *N/A*
USGS Gage 04188496 Eagle Creek Above Findlay	2,010 *2,090*	4,264 *5,997*	2,808 *2,760*	9,154 *10,988*	3,361 *N/A*	13,427 *N/A*
USGS Gage 04188433 Lye Creek Above Findlay	519 *520*	1,150 *1,471*	699 *682*	2,948 *3,173*	1,497 *N/A*	5,139 *N/A*

Notes:

- *Values in small typeface and italics are gage observations.*
- *Gage data not available for the August 2007 event except for gage 04189000*

After completing calibration and comparing the model geometries calibrated from the September 2011 and June 2015 storm events, Stantec observed the two events were slightly different hydrologically.

For the September 2011 event, a separate small rainfall event occurred about two days prior. The results of the calibration indicate less initial abstraction and retention storage. Runoff occurs more slowly as times of concentration are longer and the velocities are slower. The storage coefficients are lower as much of the retention storage is thought to be partially filled from the prior rainfall event.

For the June 2015 event, the preceding period was very dry. The results of the calibration indicate a higher initial abstraction and more retention storage. Runoff occurs more rapidly though as the times of concentration and velocities are shorter. The storage coefficients are higher as more of the retention storage is available.

Stantec

These trends were used to create a separate geometry specific to the August 2007 event that reasonably replicated gage observations from USGS gage 04189000 during that event. The antecedent conditions for the August 2007 event were drier than normal. Calibration parameters were therefore adjusted accordingly within a reasonable range based on the input data.

For the purposes of modeling hypothetical storm events, the September 2011 geometry was found to produce results similar to the frequency analyses for USGS gage 04189000 and was therefore deemed appropriate for the simulations. Results are reflected in Section 6 of this report.

6.0   RESULTS

The HEC-HMS model was used with the September 2011 calibration geometry to simulate several storm events using the spatial and temporal patterns described herein. The upstream watershed centroid was assumed as the center of the storm events. Peak discharge values at Main Street in Findlay and the five USGS gage locations for various return periods (recurrence intervals) are presented in Table 5.

6.1   APPLICABILITY AND RECOMMENDATIONS

The HEC-HMS model that was developed as a part of this study and discharges listed in Table 5 are based on more analyses than previous hydrologic studies of the area. The magnitude and trends predicted by the results are consistent with prior efforts and, therefore, do not invalidate the previous hydrologic modeling. Stantec does not recommend updating the *Concept Report, which was a* planning level document, but would recommend this revised and updated hydrologic model and results presented herein be used for future flood mitigation planning, benefit to cost ratio work, and design efforts in the area to the extent applicable.

Based on review of historic gage data and hydrologic modeling of historic storm events, the results of these analyses show that antecedent conditions will factor substantially into the resulting runoff volumes and peak discharges within the Blanchard River watershed. Stantec recommends that subsequent users of this model thoroughly review antecedent conditions and exercise caution when applying the model to varied hydrologic events.

Table 5 – Peak Flood Discharges

Location	Average Recurrence Interval (Years)							
	2	5	10	25	50	100	200	500
Main Street in Findlay	5,680	7,643	9,321	11,634	13,595	15,652	17,902	21,130
USGS Gage 04189000 Blanchard River DS of Findlay	5,730	7,715	9,413	11,734	13,574	15,652	17,951	21,106
Gage Analyses *(-/+ 5% Confidence)*	*5,086* *6,020*	*7,319* *8,918*	*8,625* *10,788*	*10,111* *13,037*	*11,113* *14,619*	*12,039* *16,120*	*12,903* *17,552*	*13,964* *19,351*
USGS Gage 04188400 Blanchard River US of Findlay	3,825	4,650	5,218	5,997	6,578	7,148	7,743	8,633
USGS Gage 04188337 Blanchard River DS of Mt. Blanchard	3,356	4,249	4,988	6,186	7,094	8,008	8,991	10,489
USGS Gage 04188496 Eagle Creek Above Findlay	1,741	2,323	2,839	3,577	4,223	4,915	5,690	6,732
USGS Gage 04188433 Lye Creek Above Findlay	533	752	942	1,217	1,451	1,699	1,967	2,344

Notes:
- Discharges are reported in cubic feet per second (cfs).
- Values from HEC-HMS model simulations using the September 2011 calibration geometry developed by Stantec.
- Gage Frequency Estimates for USGS Gage 04189000 are provided for comparison purposes.

7.0   REFERENCES

Stantec Concept Report: Stantec 2017, "Hancock County Flood Risk Reduction Program, Final Report: Data Review, Gap Analysis, USACE Plan and Alternatives Review, and Program Recommendation", April 3, 2017.

NOAA Atlas 2: Miller, J.F., R.H. Frederick and R.J. Tracy, 1973: "*Precipitation-Frequency Atlas of the Western United States. NOAA Atlas 2*", 11 vols., National Weather Service, Silver Spring, Maryland.

NOAA Atlas 14: Bonnin, G.M.; Martin, D.; Bingzhang L.; et-al, 2004: "*Precipitation-Frequency Atlas of the United States, Volume 2*", National Weather Service, Silver Spring, Maryland.

NOAA HMR 52: Hansen, E.M.; Schreiner, L.C.; Miller, J.F., August 1982: "*NOAA Hydrometeorological Report No. 52, Application of Probably Maximum Precipitation Estimates – United States East of the 105th Meridian*", Hydrometeorological Branch, Office of Hydrology, National Weather Service, Washington, D.C.

Bulletin 71: Huff, Floyd A. and Angel, James R. 1992: "*Bulletin 71, Rainfall Frequency Atlas of the Midwest*", Midwestern Climate Center, National Weather Service, and Illinois State Water Survey, Champaign, Illinois.

Bulletin 17B: Interagency Advisory Committee on Water Data 1982: "*Guidelines for Determining Flood Flow Frequency, Bulletin #17B of the Hydrology Subcommittee*", U.S. Department of the Interior Geological Survey, Office of Water Data Coordination, Reston, Virginia.

HMS Technical Reference Manual: U.S. Army Corps of Engineers, Hydrologic Engineering Center: "Hydrologic Modeling System HEC-HMS Technical Reference Manual", March 2000.

HMS User's Manual: U.S. Army Corps of Engineers, Hydrologic Engineering Center: "Hydrologic Modeling System HEC-HMS User's Manual, Version 4.2", August 2016.

USGS WRIR 00-4184: Straub, T.D.; Melching, C.S.; Kocher, K.E.: "Equations for Estimating Clark Unit-Hydrograph Parameters for Small Rural Watersheds in Illinois", U.S. Geological Survey in cooperation with the Illinois Department of Natural Resources, Office of Water Resources, 2000, Urbana, Illinois.

TP-149: Kent, K.M.: "*Technical Paper No. 149, A Method for Estimating Volume and Rate of Runoff in Small Watersheds*", U.S. Department of Agriculture, Soil Conservation Service, April 1973.

TP-40: Hershfield, David M.: "*Technical Paper No. 40, Rainfall Frequency Atlas of the United States*", U.S. Department of Commerce, Weather Bureau, Washington, D.C., January 1963.

TR-55: NRCS: "Technical Release 55, Urban Hydrology for Small Watersheds", U.S. Department of Agriculture, Natural Resources Conservation Service, Conservation Engineering Division, June 1986.

NEH 4: NRCS: "Part 630 Hydrology, National Engineering Handbook, Part 4, Hydrology", U.S. Department of Agriculture, Natural Resources Conservation Service, Conservation Engineering Division, September 1997.

ArcGIS: Environmental Systems Research Institute, Inc. (ESRI), 2015: ArcGIS version 10.4.1. for Desktop Redlands, California.

HEC Software (RAS, HMS, SSP, GridUtil, GeoHMS, DSSVue): U.S. Army Corps of Engineers Hydrologic Engineering Center. Refer to http://www.hec.usace.army.mil/ for versioning and citation information.

USGS Gage Data: United States Geological Survey, Gage ID #'s 0418900, 04188400, 04188337, 04188496, 0418433. Refer to https://waterdata.usgs.gov/nwis/rt to access individual sites.

USGS NHD: United States Geological Survey National Hydrography Dataset. Refer to https://nhd.usgs.gov/data.html for data access.

NOAA NEXRAD Radar Data: National Centers for Environmental Information, National Oceanic and Atmospheric Administration. Refer to https://www.ncdc.noaa.gov/data-access/radar-data/nexrad for data access.

National Land Cover Database (NLCD): Multi-Resolution Land Characteristics Consortium. Refer to https://www.mrlc.gov/ for data access.

SSURGO NRCS Soils Database: USDA Natural Resources Conservation Service. Refer to https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/ for data access.

Ohio Statewide Imagery Program (OSIP) and Ohio Geographically Referenced Information Program (OGRIP): Refer to http://ogrip.oit.ohio.gov/Home.aspx for additional information and data access.

Appendix A GAGE ANALYSIS SUPPORT DATA

Stantec

Memo

To:	Project Files	From:	Matthew Armstrong, Erman Caudill
	Cincinnati, Ohio		Lexington, KY
File:	174316204	Date:	June 16, 2017

Reference: **Stream Gage Frequency Analyses**
USGS Gage # 04189000 Blanchard River
Hancock County Flood Risk Reduction Program

Stantec has completed a hydrologic study for the Blanchard River and its tributaries in the vicinity of Hancock County and the City of Findlay, Ohio. As part of the study, Stantec completed a flood flow frequency analysis using many years of data from a stream gage located a short distance downstream of Findlay on the Blanchard River. This memo summarizes the flood flow frequency analysis and results.

Stream gage 04189000 on the Blanchard River is operated cooperatively by the U.S. Geologic Survey (USGS), the City of Findlay, and the U.S. Army Corps of Engineers (USACE). It is located approximately 2 miles west of the City of Findlay, on the upstream side of County Road 140 bridge. The gage location has 346 square miles of contributing watershed area. The gage's period of record includes daily mean discharges since October 1923; however, there is a gap in the data between December 1935 and October 1940. Instantaneous readings on a 30-minute interval have also been collected since the early 2000's. Lastly, a historical peak height/discharge value has been appended to the gage record: in March 1913, a gage height of 18.5 feet was reported and a discharge of 22,000 cubic-feet-per-second (cfs) was estimated.

Figure 1 from the USGS website for the gage illustrates the gage location.

Figure 1 – USGS Gage 04189000 Location

Design with community in mind

elc u:\174316204\technical_production\working_report\hydrology\appendix a - gage analysis support data\final memo blanchard river gage analyses.docx

1.0   METHODOLOGY

The methods used to perform this analysis are outlined in "*Guidelines for Determining Flood Flow Frequency – Bulletin 17B*" from the U.S. Department of the Interior Geological Survey Interagency Advisory Committee on Water Data (USDOI, 1981). This document is abbreviated herein as *Bulletin 17B*.

1.1   SOURCE DATA

Stream gage data consisting of daily mean discharge values was obtained from the USGS (USGS, 2017). The gage's daily data includes two time windows: October 1, 1923 to December 31, 1935 and October 1, 1940 to the present. (January 25, 2017 was the date of the download.) Annual maximum daily discharge values, on a water year basis, were also obtained for the *Bulletin 17B* analyses. The largest annual peak occurred on August 22, 2007 with a discharge of about 14,500 cubic feet per second (cfs). The lowest annual peak occurred on January 2, 1941 with a discharge of 958 cfs. The average daily value for the available period of record is about 280 cfs. One additional historical peak discharge is included with the gage data. A large event occurred around March 1913 that was estimated to have a magnitude of 22,000 cfs with a similar gage height as the August 2007 event. A listing of the annual peaks is included in the attached HEC-SSP output (see below), but Figure 2 shows a general plot of larger historic daily peaks from the gage.

1.2   GENERALIZED SKEW

In the *Bulletin 17B* procedure, the skew variable is used to account for the tendency of the data to vary from the mean. This skew or "spread" is similar to the standard deviation in classical statistical analyses. A "station skew" can be calculated directly from the input data; however, this can be inaccurate if there isn't a sufficient population of data or the data is not well represented due to one or more atypical events. To formulate a better estimate of the skew coefficient, the station skew can be combined with a generalized skew factor to create a weighted skew value. The generalized skew is based on other gage data from the region and was previously pre-computed and published in map form in *Bulletin 17B*. For this analysis, a generalized skew factor of -0.4 and mean skew error of 0.302 from *Bulletin 17B* (Interagency Advisory Committee on Water Data, 1982) were used to produce a weighted skew value. The sensitivity of the analyses to the skew coefficient selection was also evaluated.

Design with community in mind

elc u:\174316204\technical_production\working_report\hydrology\appendix a - gage analysis support data\final memo blanchard river gage analyses.docx

Stantec

Reference:
USGS Gage # 04189000 Blanchard River
Hancock County Flood Risk Reduction Program

Figure 2 – USGS Gage 04189000 Daily Peaks

Design with community in mind

elc u:\174316204\technical_production\working_report\hydrology\appendix a - gage analysis support data\final memo blanchard river gage analyses.docx
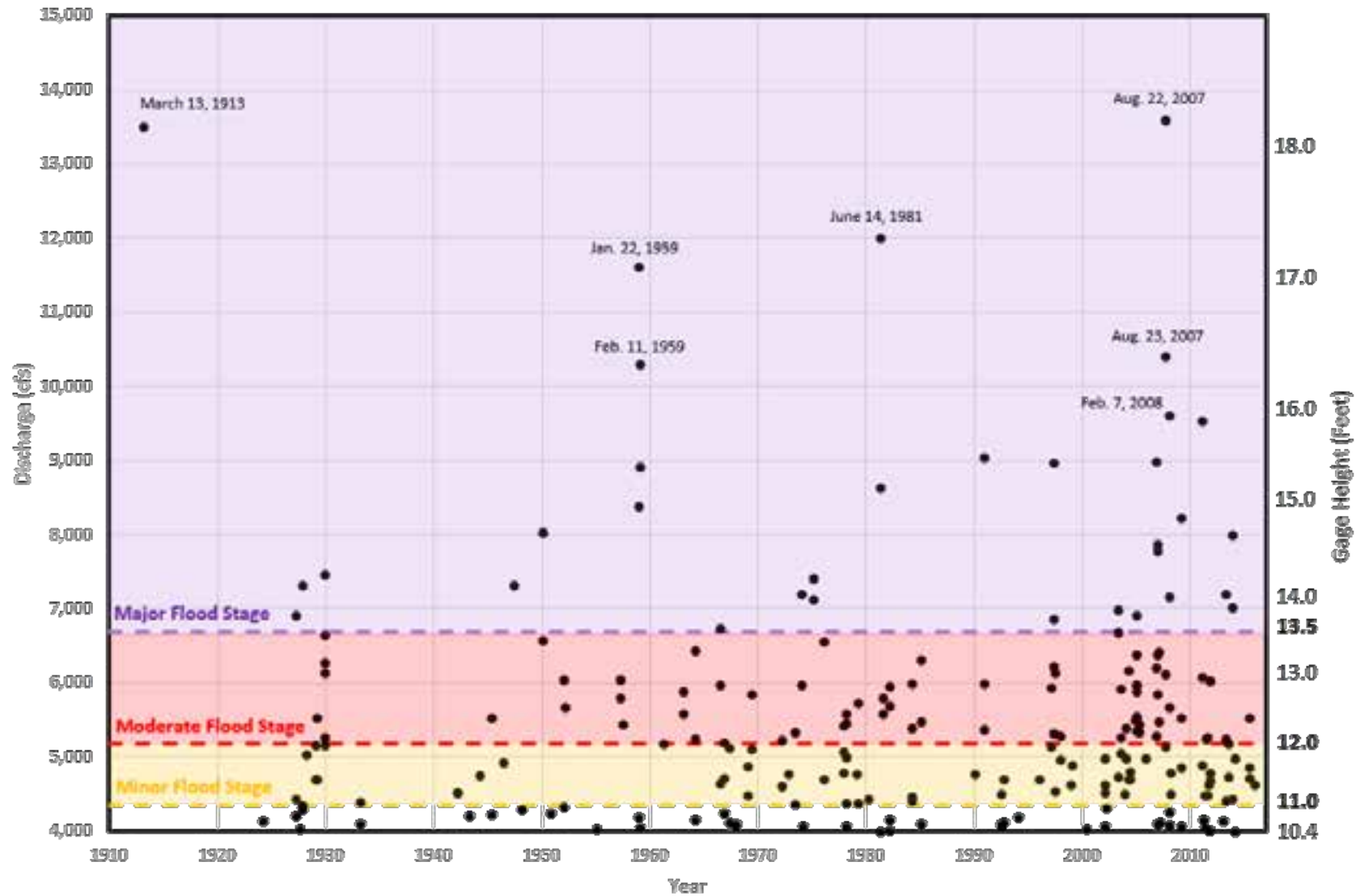
1.3   HISTORICAL PERIOD DATA

Historical period data is defined in the *Bulletin 17B* procedure as flood information outside of the continuous or systematic record. It is used to extend the range of the largest events at a gage, but can introduce uncertainty in the frequency aspect of the results because it omits the lower annual peak events that may have occurred between when the historic event happened and the continuous period of record began.

When including flood information outside of the systematic record it is important to evaluate the reliability of the data. Erroneous historic data will lead to errors in the flood flow frequency curve. For the March 1913 event a gage height of 18.5 feet was estimated with a corresponding discharge of 22,000 cfs. This value was estimated based on extrapolation from a rating curve with a previous peak discharge of 9,500 cfs (Weld, Asselstine, & Johnson, 1959). A similar gage height was recorded in August 2007, 18.46 feet; however, the recorded discharge during that event was only 14,500 cfs. For analysis purposes, the March 1913 discharge value was corrected to 14,590 cfs to be more consistent with the rating curve for the gage and 2007 observations.

Figure 3 illustrates the current rating curve for the gage that was obtained from the USGS and the relationship between the reported and corrected 1913 peak discharge values.

1.4   HYDROLOGIC MODIFICATIONS

One of the most important assumptions of flood flow frequency guidance is that no major hydrologic changes have occurred during the period of record used. Incremental increase in urbanization over time and discharge modification due to storage can have a significant impact on the runoff characteristics of the watershed. Urbanization, for the purpose of this analysis, is creation of new impervious area within the watershed that is not directly offset with mitigation measures (i.e. designed detention). Only records which represent relatively constant hydrologic conditions in the watershed should be used to perform a frequency analysis.

Historical records of impervious areas were not available for most of the 89 years of gage records; but based on current landuse in the watershed, development appears to be limited to the Findlay area and is not occurring over a large percentage of the watershed. For the analyses it was assumed that the percent of impervious area within the watershed was constant. To further test this assumption, three data subsets were evaluated to see if there may be changes in response during certain periods of time using:

1. The entire gage record

2. The most recent 40-years of gage records (about ½ the available data)

3. The most recent 20-years of gage records (about ¼ the available data)

Design with community in mind

elc u:\174316204\technical_production\working_report\hydrology\appendix a - gage analysis support data\final memo blanchard river gage analyses.docx

Figure 3 – USGS Gage 04189000 Rating Curve

Design with community in mind

elc u:\174316204\technical_production\working_report\hydrology\appendix a - gage analysis support data\final memo blanchard river gage analyses.docx
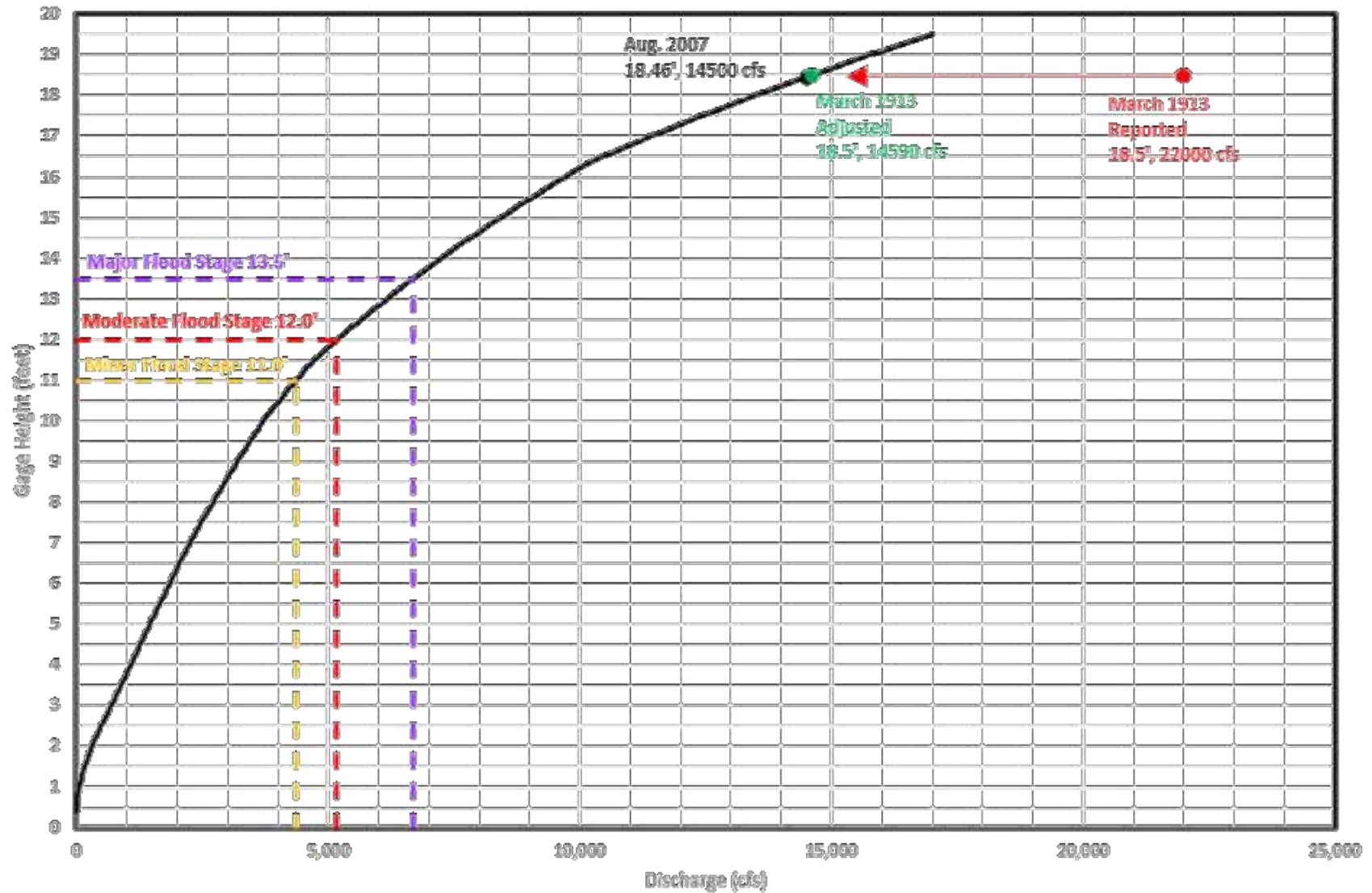
1.5   MODELING SOFTWARE

The analyses were performed using the USACE Hydrologic Engineering Center Statistical Software Package (HEC-SSP) v2.1 (USACE, 2016). Unless noted, the model parameter settings used during the analyses were:

- Bulletin 17B Methods

- Use Station Skew or Weighted Skew (depending on the simulation)

- Regional Skew = -0.4, Reg. Skew MSE = 0.302

- Compute expected probability curve

- Low Outlier Test – Single Grubbs-Beck

- Plotting Position - Median

- Confidence Limits – Default (0.05, 0.95)

- Time Window Modification Start Date – Checked, set to 01JAN1924

- Historic Period Data – Checked, 1913 to 1914, Corrected Value

- Frequencies Computed: 99.9%, 50%, 20%, 10%, 4%, 2%, 1%, 0.5%, 0.2%, 0.1%

2.0   RESULTS

Table 1 summarizes the computed discharges for various probabilities based on the weighted skew factor, corrected historical discharge value in 1913, and using all of the available data. Figure 4 presents the results graphically. Lastly, a detailed HEC-SSP output is included as an attachment. Further discussion of the skew factor and potential hydrologic modifications is discussed in terms of sensitivity in section 2.1.

Table 1 – Flood Flow Frequency Analysis Results

USGS Gage 04189000 Blanchard River Downstream of Findlay, Ohio					
Percent Chance Exceedance	Avg. Recurrence Interval (years)	Computed Curve Flow (cfs)	Expected Flow (cfs)	Confidence Limits	
				0.05	0.95
0.1	1000	17116.5	17627.6	20649.2	14715.0
0.2	500	16156.2	16576.7	19351.4	13964.1
0.5	200	14810.6	15119.5	17552.0	12902.8
1.0	*100*	*13726.8*	13964.6	16120.2	12039.4
2.0	50	12576.4	12749.5	14619.1	11113.4
4.0	25	11346.2	11464.9	13037.1	10110.5
10.0	10	9558.6	9618.5	10787.9	8625.4
20.0	5	8027.7	8055.9	8918.1	7319.4
50.0	2	5530.2	5530.2	6020.3	5085.9
99.9	1	874.5	804.9	1083.6	667.1

Design with community in mind

elc u:\174316204\technical_production\working_report\hydrology\appendix a - gage analysis support data\final memo blanchard river gage analyses.docx

Figure 4 – USGS Gage 04189000 Flood Flow Frequency Analysis Results

Design with community in mind

elc u:\174316204\technical_production\working_report\hydrology\appendix a - gage analysis support data\final memo blanchard river gage analyses.docx
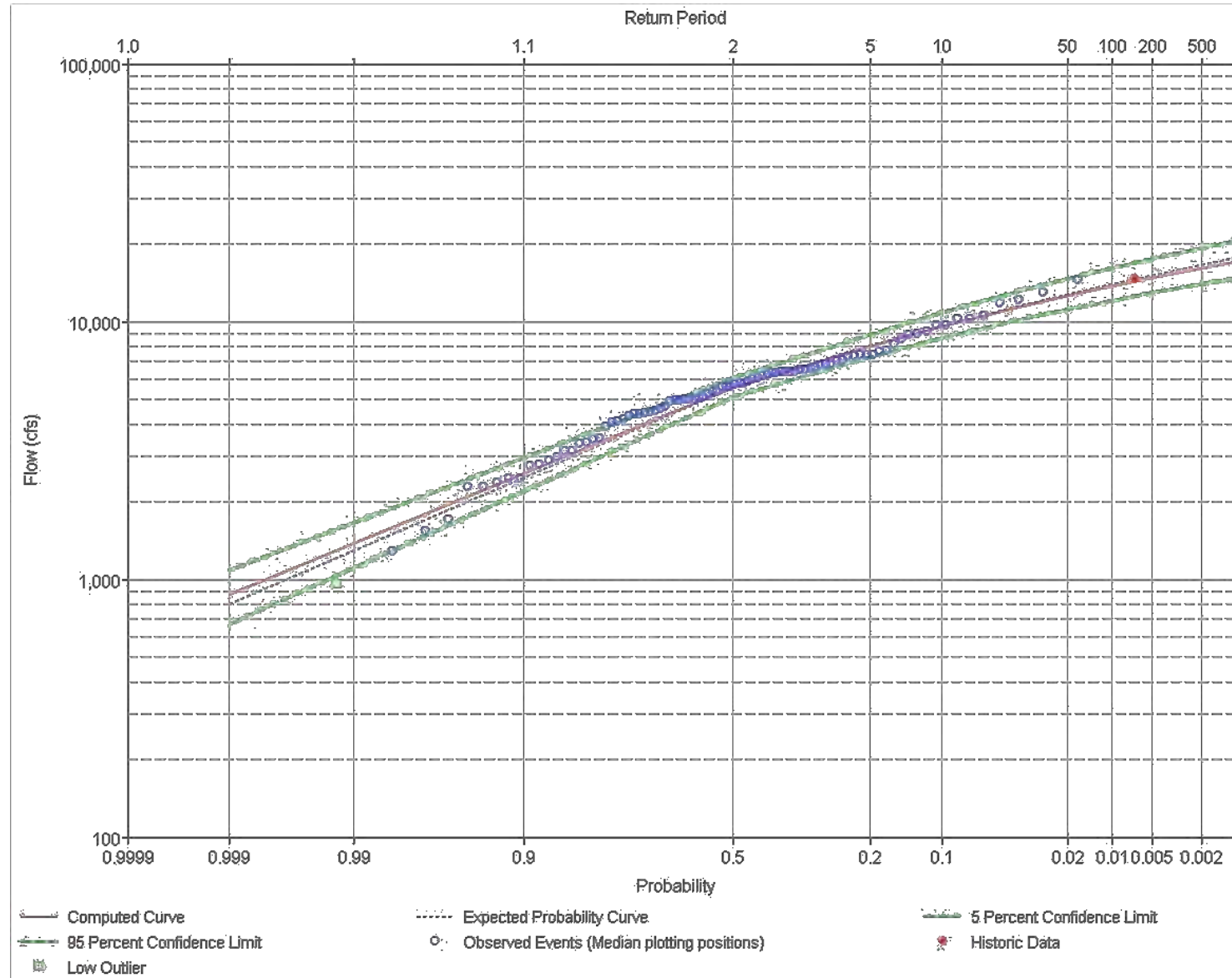
2.1   SENSITIVITY

As part of the analyses the sensitivity of the results to three variables were evaluated in order to quantify their impact on the flood flow frequency curve. The three variables evaluated were:

- Station Skew -vs- Weighted Skew

- Hydrologic Modifications

- Draft Bulletin 17C Procedural Guidance

2.1.1   Skew

As a basis of comparison, the 1-percent-chance exceedance (100-year recurrence) interval discharge in Table 1 above was calculated as 13726.8 cfs. This value assumed a weighted skew factor based on regional data previously published. If the "station skew" factor is selected instead, the calculated value is 13869.1, a difference of only +142.3 cfs or 0.01%. Other frequencies had similar results leading us to conclude using the weighted skew values do not significantly affect the results. This is also valid intuitively as the 04189000 gage has many years of data to support computing an accurate station based skew coefficient.

2.1.2   Hydrologic Modifications

To test the assumption that the hydrologic conditions in the watershed have remained relatively constant over the period of record, the analyses were split into 3 subsets: the entire record, the last 40 years, and the last 20 years. The 1913 event was omitted from the shorter duration simulations.

Again as a basis of comparison, the 1-percent-chance exceedance (100-year recurrence) interval discharge in Table 1 above was calculated as 13726.8 cfs using the entire period of record. If the data is limited to the last 40 years, the calculated value is 14694.1 cfs. If limited to the last 20 years, the calculated value is 15154.9 cfs. Table 2 summarizes the results for each of the frequencies.

Table 2 – Flood Flow Frequency Analysis Results Using Partial Records

USGS Gage 04189000 Blanchard River Downstream of Findlay, Ohio				
		Calculated Discharges (cfs)		
Percent Chance Exceedance	Avg. Recurrence Interval (years)	Entire Period of Record	Last 40 Years of Records	Last 20 Years of Records
0.1	1000	17116.5	19482.5	18273.9
0.2	500	16156.2	18035.8	17410.0
0.5	200	14810.6	16132.5	16173.3
1.0	100	13726.8	14694.1	15154.9
2.0	50	12576.4	13249.8	14051.7
4.0	25	11346.2	11789.5	12845.5
10.0	10	9558.6	9804.1	11042.7
20.0	5	8027.7	8213.5	9448.4
50.0	2	5530.2	5789.1	6736.8
99.9	1	874.5	1408.3	1184.3

From Table 2, it would appear that the magnitude and frequency of flood discharges on the Blanchard River are increasing as a trend. Whether or not this increase is attributable to

Design with community in mind

elc u:\174316204\technical_production\working_report\hydrology\appendix a - gage analysis support data\final memo blanchard river gage analyses.docx

modifications to the hydrologic conditions within the watershed or changes to the regional precipitation patterns cannot be determined from these analyses and are beyond the scope of this study. Further study of historic trends may be warranted. For now the entire period of record is used for the flood flow frequency analysis results.

2.1.3 Draft Bulletin 17C Guidance

The procedures described in *Bulletin 17B* were last updated in 1981. In 2016 the USGS released a draft version of proposed revisions termed *Bulletin 17C* (England Jr., et al., 2016). The new *Bulletin 17C* guidance includes a number of changes to the *Bulletin 17B* process.

One of the changes in *Bulletin 17C* is the generalized skew factor isoline map is no longer available to support weighting the station skew. The new guidance discontinues the country-wide map and directs the user to either generate their own regional skew factor or utilize regional skew data developed by others. The USGS has not published a regional skew analysis for this region or the state of Ohio. From the discussion in Section 2.1.1 above, this particular gage has sufficient data such that using only the station skew does not appear to significantly alter the results.

A second change centers around filling in gaps in systematic gage records using perception thresholds. *Bulletin 17C* discusses statistically valid ways to synthetically generate data that make the data sets more complete and lead to better frequency estimates.

HEC-SSP has implemented the DRAFT *Bulletin 17C* guidance and was used to compare the results. For the *Bulletin 17C* analysis the following modeling parameters were used as recommended in the *HEC-SSP Users Manual* (USACE 2016):

- Use Station Skew (no weighted skew)

- Low Outlier Test – Multiple Grubbs-Beck

- Plotting Position – Hirsch/Stedinger

- Confidence Limits – Default (0.05, 0.95)

- Frequencies Computed: 99.9%, 50%, 20%, 10%, 4%, 2%, 1%, 0.5%, 0.2%, 0.1%

- Perception Thresholds:
  - 1913 to 1924 and 1935 to 1940: Low Threshold = 4,365 cfs (discharge at minor flood stage) and High Threshold = 14,590 cfs (discharge during 1913 event)

Results of the *Bulletin 17C* analyses are slightly lower in that the 1-percent-chance exceedance (100-year recurrence) interval discharge was calculated as 12614.8 cfs, as opposed to the 13726.8 cfs in Table 1 above. The values in Table 1 are within the confidence limits of the *Bulletin 17C* results as shown in Table 3.

Design with community in mind

elc u:\174316204\technical_production\working_report\hydrology\appendix a - gage analysis support data\final memo blanchard river gage analyses.docx

Table 3 – Flood Flow Frequency Analysis Results Using Bulletin 17C

USGS Gage 04189000 Blanchard River Downstream of Findlay, Ohio					
		Calculated Discharges (cfs)			
Percent Chance Exceedance	Avg. Recurrence Interval (years)	Bulletin 17B Results	Bulletin 17C Results	Bulletin 17C 0.05 Confidence	Bulletin 17C 0.95 Confidence
0.1	1000	17116.5	14685.1	19260.5	12312.5
0.2	500	16156.2	14140.4	17889.4	12085.4
0.5	200	14810.6	13322.0	16110.6	11692.2
1.0	100	13726.8	12614.8	14779.5	11297.3
2.0	50	12576.4	11815.9	13447.7	10781.3
4.0	25	11346.2	10904.9	12094.8	10092.2
10.0	10	9558.6	9473.9	10236.8	8820.5
20.0	5	8027.7	8144.8	8754.3	7563.9
50.0	2	5530.2	5768.1	6256.5	5305.2
99.9	1	874.5	793.2	1209.3	290.3

Since the *Bulletin 17C* guidance is still in DRAFT form at this point, values predicted using Bulletin 17B are within the confidence limits, and more conservative, the Bulletin 17B values in Table 1 are recommended.

3.0   CONCLUSION & RECOMMENDATIONS

Flood flow frequency analyses for USGS gage 04189000 were carried out using procedures in *Bulletin 17B*. The gage data was found to be sufficient to support the analyses and results are shown in Table 1 and Figure 1.

Sensitivity analyses were carried out for skew coefficient, hydrologic modifications, and the draft *Bulletin 17C* guidance.

- Using the station skew coefficient in-lieu of a weighted skew coefficient was found to have limited impact on the analyses.

- Considering partial periods of record as a surrogate for hydrologic modifications indicated there is an increasing trend in terms of frequency and magnitude of flood events; however, additional study is necessary to adequately characterize the changes. For now using the entire period of record is recommended.

- The Bulletin 17C guidance results in a slightly lower prediction of flood flow frequency values, but the Bulletin 17B values are within the confidence levels of the analysis and considered appropriate.

At this time Stantec recommends the results of the Bulletin 17B analyses described in Table 1 and Figure 1 be used for planning and design efforts as applicable. Should additional analysis of regional trends be performed by the USGS or others, this analysis may need to be reviewed and revised as necessary.

Design with community in mind

elc u:\174316204\technical_production\working_report\hydrology\appendix a - gage analysis support data\final memo blanchard river gage analyses.docx

Stantec

Reference:
USGS Gage # 04189000 Blanchard River
Hancock County Flood Risk Reduction Program

Stream Gage Frequency Analyses

Page 11 of 11

4.0 REFERENCES

England Jr., J. F., Cohn, T. A., Faber, B. A., Stedinger, J. R., Thomas Jr., W. O., Veilleux, A. G., . . . Mason, R. R. (2016). "*DRAFT Guidelines for Determining Flood Flow Frequency – Bulletin 17C*": U.S. Geological Survey Techniques and. US Department of the Interior, US Geological Survey, Reston. Retrieved from http://dx.doi.org/10.3133/tm4–BXX/

Interagency Advisory Committee on Water Data. (1982). "*Generalized skew coefficients of logarithms of annual maximum streamflow, Plate 1*".

USACE. (2016, 07 12). Hydrologic Engineering Center Statistical Software Package (HEC-SSP) v2.1. Davis, California: United States Army Corps of Engineers, Institute for Water Resources.

USDOI. (1981). "*Guidelines for Determining Flood Flow Frequency, Bulletin 17B*". United States Department of the Interior, Geological Survey, Hydrology Subcommittee, Reston.

USGS. (2017, April 03). "*USGS 04189000 Blanchard River near Findlay OH*". Retrieved April 03, 2017, from USGS National Water Information System: https://nwis.waterdata.usgs.gov/oh/nwis/peak/?site_no=04189000&agency_cd=USGS

Weld, B. A., Asselstine, E. S., & Johnson, A. (1959). Geological Survey Circular 415, Reports and Maps of the Geological Survey Released Only in the Open Files, 1958. United States Department of the Interior, Geological Survey, Washington, D.C.

STANTEC CONSULTING SERVICES INC.

Matthew Armstrong, PE
Project Engineer
Phone: (859) 422-3000
matt.armstrong@stantec.com

Erman Caudill, PE (KY #23451), CFM
Civil Engineer
Phone: (859) 422-3000
erman.caudill@stantec.com

Attachment: HEC-SSP Output File

Design with community in mind

elc u:\174316204\technical_production\working_report\hydrology\appendix a - gage analysis support data\final memo blanchard river gage analyses.docx

```
-------------------------------
Bulletin 17B Frequency Analysis
    16 Jun 2017   12:14 PM
-------------------------------


--- Input Data ---

Analysis Name: Stream Gage Frequency Analysis
Description: USGS Gage 04189000 Blanchard River downstream of Findlay, Ohio
LOCATION.--Lat 41°03'21", long 83°41'17", Hancock County, OH, Hydrologic
Unit 04100008, on left bank at upstream side of county road bridge, 2 mi west
of Findlay, 3 mi downstream from Eagle Creek, and 3 mi upstream from Aurand Run.
DRAINAGE AREA.--346 mi2.
PERIOD OF RECORD.--October 1923 to December 1935, October 1940 to current year.
Monthly discharge only for October 1923, published in WSP 1307.
REVISED RECORDS.--WSP 974: 1942. WSP 1054: 1927-1930, 1933(M), 1945. WSP 1387: 1926,
1928(M), 1930(M), 1952. WSP 1912: Drainage area. WDR-OH-81-2: 1959, 1975(M).
WDR-OH-97-2: 1996(M).
REMARKS.--Water is diverted upstream from station into Findlay Reservoir. All water
returns to stream upstream from station. Water quality and sediment data previously
collected at this site.

Data Set Name: Blanchard River-Findlay OH-FLOW-ANNUAL PEAK
DSS File Name:
C:\Users\ecaudill\Documents\Project_Files\HEC_SSP\Blanchard_River_near_Findlay_OH\Blanchard_River
_near_Findlay_OH.dss
DSS Pathname: /Blanchard River/Findlay OH/FLOW-ANNUAL PEAK/01jan1900/IR-CENTURY/USGS/

Report File Name:
C:\Users\ecaudill\Documents\Project_Files\HEC_SSP\Blanchard_River_near_Findlay_OH\Bulletin17Resul
ts\Stream_Gage_Frequency_Analysis\Stream_Gage_Frequency_Analysis.rpt
XML File Name:
C:\Users\ecaudill\Documents\Project_Files\HEC_SSP\Blanchard_River_near_Findlay_OH\Bulletin17Resul
ts\Stream_Gage_Frequency_Analysis\Stream_Gage_Frequency_Analysis.xml

Start Date: 01 Jan 1924
End Date:

Skew Option: Use Weighted Skew
Regional Skew: -0.4
Regional Skew MSE: 0.302

Plotting Position Type: Median

Upper Confidence Level: 0.05
Lower Confidence Level: 0.95

Use Historic Data
Historic Period Start Year: 1913
Historic Period End Year: 1914
Year: 1913   Value: 14,590

Use non-standard frequencies
Frequency: 99.9
Frequency: 50.0
Frequency: 20.0
Frequency: 10.0
Frequency: 4.0
Frequency: 2.0
Frequency: 1.0
Frequency: 0.5
Frequency: 0.2
Frequency: 0.1

Display ordinate values using 1 digits in fraction part of value

--- End of Input Data ---
```

Stantec

```
--- Preliminary Results ---

<< Plotting Positions >>
Blanchard River-Findlay OH-FLOW-ANNUAL PEAK
-------------------------------------------------------------------------
|     Events Analyzed       |          Ordered Events                   |
|                   FLOW    |       Water       FLOW      Median         |
| Day Mon Year       CFS    | Rank  Year         CFS     Plot Pos        |
|---------------------------|-------------------------------------------|
|  30 Mar 1924    4,280.0   |   1   2007     14,500.0     0.78           |
|  19 Dec 1924    2,980.0   |   2   1981     13,000.0     1.90           |
|  05 Sep 1926    4,380.0   |   3   1959     12,100.0     3.02           |
|  21 Mar 1927    7,460.0   |   4   1928     11,800.0     4.14           |
|  01 Dec 1927   11,800.0   |   5   2008     10,500.0     5.26           |
|  19 Jan 1929    6,010.0   |   6   2011     10,200.0     6.38           |
|  15 Jan 1930    8,580.0   |   7   1950     10,200.0     7.49           |
|  03 Apr 1931    1,290.0   |   8   1991      9,670.0     8.61           |
|  18 Jan 1932    3,400.0   |   9   1997      9,630.0     9.73           |
|  14 Mar 1933    5,760.0   |  10   2014      9,110.0    10.85           |
|  29 Mar 1934    1,700.0   |  11   2009      8,930.0    11.97           |
|  04 May 1935    2,900.0   |  12   1975      8,860.0    13.09           |
|  27 Feb 1936    6,660.0   |  13   1930      8,580.0    14.21           |
|  02 Jan 1941      958.0   |  14   1947      8,160.0    15.32           |
|  10 Apr 1942    5,760.0   |  15   2003      7,710.0    16.44           |
|  18 May 1943    4,520.0   |  16   1963      7,660.0    17.56           |
|  12 Apr 1944    5,340.0   |  17   1927      7,460.0    18.68           |
|  20 Jun 1945    6,140.0   |  18   1974      7,410.0    19.80           |
|  18 Jun 1946    6,400.0   |  19   1966      7,410.0    20.92           |
|  08 Jun 1947    8,160.0   |  20   2013      7,350.0    22.04           |
|  22 Mar 1948    4,930.0   |  21   2005      7,290.0    23.15           |
|  16 Feb 1949    3,900.0   |  22   1976      7,070.0    24.27           |
|  15 Feb 1950   10,200.0   |  23   1952      7,020.0    25.39           |
|  21 Nov 1950    4,900.0   |  24   1973      6,850.0    26.51           |
|  27 Jan 1952    7,020.0   |  25   1964      6,830.0    27.63           |
|  18 May 1953    2,370.0   |  26   2004      6,750.0    28.75           |
|  17 Apr 1954    2,470.0   |  27   1936      6,660.0    29.87           |
|  04 Mar 1955    5,100.0   |  28   1957      6,580.0    30.98           |
|  26 Feb 1956    4,700.0   |  29   1984      6,510.0    32.10           |
|  06 Apr 1957    6,580.0   |  30   2012      6,480.0    33.22           |
|  07 Dec 1957    2,470.0   |  31   1969      6,410.0    34.34           |
|  11 Feb 1959   12,100.0   |  32   1978      6,400.0    35.46           |
|  11 Feb 1960    3,370.0   |  33   1946      6,400.0    36.58           |
|  26 Apr 1961    5,620.0   |  34   1985      6,380.0    37.70           |
|  27 Jan 1962    4,380.0   |  35   1982      6,320.0    38.81           |
|  06 Mar 1963    7,660.0   |  36   1979      6,300.0    39.93           |
|  22 Apr 1964    6,830.0   |  37   2015      6,180.0    41.05           |
|  05 Mar 1965    2,290.0   |  38   1945      6,140.0    42.17           |
|  13 Jul 1966    7,410.0   |  39   1929      6,010.0    43.29           |
|  08 May 1967    5,710.0   |  40   1998      5,990.0    44.41           |
|  30 Jan 1968    4,590.0   |  41   1972      5,850.0    45.53           |
|  19 May 1969    6,410.0   |  42   1942      5,760.0    46.64           |
|  05 Mar 1970    4,180.0   |  43   1933      5,760.0    47.76           |
|  23 Feb 1971    3,540.0   |  44   1967      5,710.0    48.88           |
|  23 Apr 1972    5,850.0   |  45   1961      5,620.0    50.00           |
|  27 May 1973    6,850.0   |  46   1992      5,610.0    51.12           |
|  20 Jan 1974    7,410.0   |  47   2002      5,590.0    52.24           |
|  24 Feb 1975    8,860.0   |  48   1996      5,340.0    53.36           |
|  17 Feb 1976    7,070.0   |  49   1944      5,340.0    54.47           |
|  17 Sep 1977    3,150.0   |  50   2006      5,260.0    55.59           |
|  17 Mar 1978    6,400.0   |  51   1955      5,100.0    56.71           |
|  14 Apr 1979    6,300.0   |  52   1999      5,060.0    57.83           |
|  22 Mar 1980    4,980.0   |  53   1993      5,020.0    58.95           |
|  14 Jun 1981   13,000.0   |  54   2016      5,010.0    60.07           |
|  13 Mar 1982    6,320.0   |  55   1980      4,980.0    61.19           |
|  03 May 1983    3,140.0   |  56   1990      4,960.0    62.30           |
|  23 Apr 1984    6,510.0   |  57   1948      4,930.0    63.42           |
|  24 Feb 1985    6,380.0   |  58   1951      4,900.0    64.54           |
|  05 Feb 1986    4,060.0   |  59   1956      4,700.0    65.66           |
|  03 Dec 1986    2,780.0   |  60   1968      4,590.0    66.78           |
|  02 Feb 1988    1,530.0   |  61   1943      4,520.0    67.90           |
```

Stantec

```
|  26 May 1989    4,080.0  |  62   2000    4,450.0   69.02  |
|  17 Feb 1990    4,960.0  |  63   1994    4,420.0   70.13  |
|  31 Dec 1990    9,670.0  |  64   1962    4,380.0   71.25  |
|  15 Jul 1992    5,610.0  |  65   1926    4,380.0   72.37  |
|  13 Nov 1992    5,020.0  |  66   1924    4,280.0   73.49  |
|  29 Jan 1994    4,420.0  |  67   1970    4,180.0   74.61  |
|  12 Apr 1995    3,480.0  |  68   1989    4,080.0   75.73  |
|  20 Jan 1996    5,340.0  |  69   1986    4,060.0   76.85  |
|  02 Jun 1997    9,630.0  |  70   1949    3,900.0   77.96  |
|  08 Jan 1998    5,990.0  |  71   1971    3,540.0   79.08  |
|  24 Jan 1999    5,060.0  |  72   1995    3,480.0   80.20  |
|  19 Jun 2000    4,450.0  |  73   1932    3,400.0   81.32  |
|  21 Apr 2001    2,290.0  |  74   1960    3,370.0   82.44  |
|  01 Feb 2002    5,590.0  |  75   1977    3,150.0   83.56  |
|  10 May 2003    7,710.0  |  76   1983    3,140.0   84.68  |
|  22 May 2004    6,750.0  |  77   1925    2,980.0   85.79  |
|  13 Jan 2005    7,290.0  |  78   1935    2,900.0   86.91  |
|  03 Jan 2006    5,260.0  |  79   1987    2,780.0   88.03  |
|  22 Aug 2007   14,500.0  |  80   2010    2,750.0   89.15  |
|  07 Feb 2008   10,500.0  |  81   1958    2,470.0   90.27  |
|  09 Mar 2009    8,930.0  |  82   1954    2,470.0   91.39  |
|  11 Mar 2010    2,750.0  |  83   1953    2,370.0   92.51  |
|  01 Mar 2011   10,200.0  |  84   2001    2,290.0   93.62  |
|  30 Nov 2011    6,480.0  |  85   1965    2,290.0   94.74  |
|  12 Apr 2013    7,350.0  |  86   1934    1,700.0   95.86  |
|  23 Dec 2013    9,110.0  |  87   1988    1,530.0   96.98  |
|  17 Jun 2015    6,180.0  |  88   1931    1,290.0   98.10  |
|  29 Dec 2015    5,010.0  |  89   1941      958.0*  99.22  |
|--------------------------|---------------------------------|
                                               * Outlier
```

```
<< Skew Weighting >>
-----------------------------------------------------------------
Based on 89 events, mean-square error of station skew =     0.11
Mean-square error of regional skew =                       0.302
-----------------------------------------------------------------
```

```
<< Frequency Curve >>
Blanchard River-Findlay OH-FLOW-ANNUAL PEAK
-----------------------------------------------------------------
| Computed     Expected  |  Percent  |   Confidence Limits     |
|   Curve     Probability |  Chance   |    0.05        0.95     |
|     FLOW, CFS          | Exceedance |    FLOW, CFS            |
|------------------------|-----------|-------------------------|
|  15,324.8    15,646.1  |    0.1    |  18,335.9    13,247.9   |
|  14,691.6    14,970.0  |    0.2    |  17,489.1    12,748.4   |
|  13,749.2    13,967.3  |    0.5    |  16,239.0    12,000.1   |
|  12,943.1    13,121.1  |    1.0    |  15,179.8    11,354.9   |
|  12,041.4    12,177.9  |    2.0    |  14,006.7    10,626.9   |
|  11,024.1    11,123.5  |    4.0    |  12,699.6     9,796.9   |
|   9,449.8     9,503.4  |   10.0    |  10,715.5     8,490.7   |
|   8,013.4     8,040.0  |   20.0    |   8,953.2     7,269.8   |
|   5,511.0     5,511.0  |   50.0    |   6,029.7     5,046.1   |
|     655.6       591.3  |   99.9    |     835.9       481.9   |
|------------------------|-----------|-------------------------|
```

```
<< Systematic Statistics >>
Blanchard River-Findlay OH-FLOW-ANNUAL PEAK
-----------------------------------------------------------------
|      Log Transform:       |                                   |
|        FLOW, CFS          |        Number of Events           |
|---------------------------|-----------------------------------|
| Mean             3.716    | Historic Events           0       |
| Standard Dev     0.219    | High Outliers       0             |
| Station Skew    -0.809    | Low Outliers        0             |
| Regional Skew   -0.400    | Zero Events         0             |
| Weighted Skew   -0.700    | Missing Events      0             |
| Adopted Skew    -0.700    | Systematic Events        89       |
|---------------------------|-----------------------------------|
```

```
--- End of Preliminary Results ---
```

Memo: Stream Gage Frequency Analyses, USGS Gage # 04189000 Blanchard River
Hancock County Flood Risk Reduction Program
Attachment: HEC-SSP Results

Stantec

Note: High outlier threshold is set to lowest historic value.

```
---------------------
<< Low Outlier Test >>
---------------------
 Based on 89 events, 10 percent outlier test deviate K(N) = 2.977
                   Computed low outlier test value = 1,155.82

         1 low outlier(s) identified below test value of 1,155.82


     Statistics and frequency curve adjusted for 1 low outlier(s)
```

```
<< Systematic Statistics >>
Blanchard River-Findlay OH-FLOW-ANNUAL PEAK
-----------------------------------------------------------------
|        Log Transform:        |                                 |
|          FLOW, CFS           |        Number of Events         |
|------------------------------|---------------------------------|
|  Mean              3.729     |  Historic Events           1    |
|  Standard Dev      0.210     |  High Outliers             0    |
|  Station Skew     -0.506     |  Low Outliers              1    |
|  Regional Skew    -0.400     |  Zero Events               0    |
|  Weighted Skew    -0.700     |  Missing Events            0    |
|  Adopted Skew     -0.700     |  Systematic Events        89    |
|                              |  Historic Period         104    |
|------------------------------|---------------------------------|
```

```
----------------------
<< High Outlier Test >>
----------------------
 Based on 88 events, 10 percent outlier test deviate K(N) = 2.973
                  Computed high outlier test value = 22,559.21

    0 high outlier(s) identified above input threshold of 14,590

   Statistics and frequency curve adjusted for 0 high outlier(s)
                               and 1 historic event(s)
```

```
<< Systematic Statistics >>
Blanchard River-Findlay OH-FLOW-ANNUAL PEAK
-----------------------------------------------------------------
|        Log Transform:        |                                 |
|          FLOW, CFS           |        Number of Events         |
|------------------------------|---------------------------------|
|  Mean              3.728     |  Historic Events           1    |
|  Standard Dev      0.209     |  High Outliers             0    |
|  Station Skew     -0.514     |  Low Outliers              1    |
|  Regional Skew    -0.400     |  Zero Events               0    |
|  Weighted Skew    -0.700     |  Missing Events            0    |
|  Adopted Skew     -0.700     |  Systematic Events        89    |
|                              |  Historic Period         104    |
|------------------------------|---------------------------------|
```

Note: Statistics and frequency curve were modified
using conditional probablity adjustment.

--- Final Results ---

<< Plotting Positions >>
Blanchard River-Findlay OH-FLOW-ANNUAL PEAK

```
-----------------------------------------------------------------------
|     Events Analyzed       |        Ordered Events                   |
|                    FLOW    |       Water      FLOW     Median        |
| Day Mon Year        CFS    | Rank  Year        CFS    Plot Pos       |
|---------------------------|------------------------------------------|
|  01 Jan 1913   14,590.0   |    1  1913    14,590.0     0.67          |
|  30 Mar 1924    4,280.0   |    2  2007    14,500.0     1.70          |
|  19 Dec 1924    2,980.0   |    3  1981    13,000.0     2.81          |
|  05 Sep 1926    4,380.0   |    4  1959    12,100.0     3.92          |
|  21 Mar 1927    7,460.0   |    5  1928    11,800.0     5.03          |
|  01 Dec 1927   11,800.0   |    6  2008    10,500.0     6.14          |
|  19 Jan 1929    6,010.0   |    7  2011    10,200.0     7.25          |
|  15 Jan 1930    8,580.0   |    8  1950    10,200.0     8.35          |
|  03 Apr 1931    1,290.0   |    9  1991     9,670.0     9.46          |
|  18 Jan 1932    3,400.0   |   10  1997     9,630.0    10.57          |
|  14 Mar 1933    5,760.0   |   11  2014     9,110.0    11.68          |
|  29 Mar 1934    1,700.0   |   12  2009     8,930.0    12.79          |
|  04 May 1935    2,900.0   |   13  1975     8,860.0    13.90          |
|  27 Feb 1936    6,660.0   |   14  1930     8,580.0    15.01          |
|  02 Jan 1941      958.0   |   15  1947     8,160.0    16.11          |
|  10 Apr 1942    5,760.0   |   16  2003     7,710.0    17.22          |
|  18 May 1943    4,520.0   |   17  1963     7,660.0    18.33          |
|  12 Apr 1944    5,340.0   |   18  1927     7,460.0    19.44          |
|  20 Jun 1945    6,140.0   |   19  1974     7,410.0    20.55          |
|  18 Jun 1946    6,400.0   |   20  1966     7,410.0    21.66          |
|  08 Jun 1947    8,160.0   |   21  2013     7,350.0    22.77          |
|  22 Mar 1948    4,930.0   |   22  2005     7,290.0    23.87          |
|  16 Feb 1949    3,900.0   |   23  1976     7,070.0    24.98          |
|  15 Feb 1950   10,200.0   |   24  1952     7,020.0    26.09          |
|  21 Nov 1950    4,900.0   |   25  1973     6,850.0    27.20          |
|  27 Jan 1952    7,020.0   |   26  1964     6,830.0    28.31          |
|  18 May 1953    2,370.0   |   27  2004     6,750.0    29.42          |
|  17 Apr 1954    2,470.0   |   28  1936     6,660.0    30.53          |
|  04 Mar 1955    5,100.0   |   29  1957     6,580.0    31.63          |
|  26 Feb 1956    4,700.0   |   30  1984     6,510.0    32.74          |
|  06 Apr 1957    6,580.0   |   31  2012     6,480.0    33.85          |
|  07 Dec 1957    2,470.0   |   32  1969     6,410.0    34.96          |
|  11 Feb 1959   12,100.0   |   33  1978     6,400.0    36.07          |
|  11 Feb 1960    3,370.0   |   34  1946     6,400.0    37.18          |
|  26 Apr 1961    5,620.0   |   35  1985     6,380.0    38.29          |
|  27 Jan 1962    4,380.0   |   36  1982     6,320.0    39.39          |
|  06 Mar 1963    7,660.0   |   37  1979     6,300.0    40.50          |
|  22 Apr 1964    6,830.0   |   38  2015     6,180.0    41.61          |
|  05 Mar 1965    2,290.0   |   39  1945     6,140.0    42.72          |
|  13 Jul 1966    7,410.0   |   40  1929     6,010.0    43.83          |
|  08 May 1967    5,710.0   |   41  1998     5,990.0    44.94          |
|  30 Jan 1968    4,590.0   |   42  1972     5,850.0    46.04          |
|  19 May 1969    6,410.0   |   43  1942     5,760.0    47.15          |
|  05 Mar 1970    4,180.0   |   44  1933     5,760.0    48.26          |
|  23 Feb 1971    3,540.0   |   45  1967     5,710.0    49.37          |
|  23 Apr 1972    5,850.0   |   46  1961     5,620.0    50.48          |
|  27 May 1973    6,850.0   |   47  1992     5,610.0    51.59          |
|  20 Jan 1974    7,410.0   |   48  2002     5,590.0    52.70          |
|  24 Feb 1975    8,860.0   |   49  1996     5,340.0    53.80          |
|  17 Feb 1976    7,070.0   |   50  1944     5,340.0    54.91          |
|  17 Sep 1977    3,150.0   |   51  2006     5,260.0    56.02          |
|  17 Mar 1978    6,400.0   |   52  1955     5,100.0    57.13          |
|  14 Apr 1979    6,300.0   |   53  1999     5,060.0    58.24          |
|  22 Mar 1980    4,980.0   |   54  1993     5,020.0    59.35          |
|  14 Jun 1981   13,000.0   |   55  2016     5,010.0    60.46          |
|  13 Mar 1982    6,320.0   |   56  1980     4,980.0    61.56          |
|  03 May 1983    3,140.0   |   57  1990     4,960.0    62.67          |
|  23 Apr 1984    6,510.0   |   58  1948     4,930.0    63.78          |
|  24 Feb 1985    6,380.0   |   59  1951     4,900.0    64.89          |
|  05 Feb 1986    4,060.0   |   60  1956     4,700.0    66.00          |
```

Memo: Stream Gage Frequency Analyses, USGS Gage # 04189000 Blanchard River
Hancock County Flood Risk Reduction Program
Attachment: HEC-SSP Results

Stantec

```
| 03 Dec 1986     2,780.0 |  61    1968     4,590.0   67.11  |
| 02 Feb 1988     1,530.0 |  62    1943     4,520.0   68.22  |
| 26 May 1989     4,080.0 |  63    2000     4,450.0   69.32  |
| 17 Feb 1990     4,960.0 |  64    1994     4,420.0   70.43  |
| 31 Dec 1990     9,670.0 |  65    1962     4,380.0   71.54  |
| 15 Jul 1992     5,610.0 |  66    1926     4,380.0   72.65  |
| 13 Nov 1992     5,020.0 |  67    1924     4,280.0   73.76  |
| 29 Jan 1994     4,420.0 |  68    1970     4,180.0   74.87  |
| 12 Apr 1995     3,480.0 |  69    1989     4,080.0   75.98  |
| 20 Jan 1996     5,340.0 |  70    1986     4,060.0   77.08  |
| 02 Jun 1997     9,630.0 |  71    1949     3,900.0   78.19  |
| 08 Jan 1998     5,990.0 |  72    1971     3,540.0   79.30  |
| 24 Jan 1999     5,060.0 |  73    1995     3,480.0   80.41  |
| 19 Jun 2000     4,450.0 |  74    1932     3,400.0   81.52  |
| 21 Apr 2001     2,290.0 |  75    1960     3,370.0   82.63  |
| 01 Feb 2002     5,590.0 |  76    1977     3,150.0   83.73  |
| 10 May 2003     7,710.0 |  77    1983     3,140.0   84.84  |
| 22 May 2004     6,750.0 |  78    1925     2,980.0   85.95  |
| 13 Jan 2005     7,290.0 |  79    1935     2,900.0   87.06  |
| 03 Jan 2006     5,260.0 |  80    1987     2,780.0   88.17  |
| 22 Aug 2007    14,500.0 |  81    2010     2,750.0   89.28  |
| 07 Feb 2008    10,500.0 |  82    1958     2,470.0   90.39  |
| 09 Mar 2009     8,930.0 |  83    1954     2,470.0   91.49  |
| 11 Mar 2010     2,750.0 |  84    1953     2,370.0   92.60  |
| 01 Mar 2011    10,200.0 |  85    2001     2,290.0   93.71  |
| 30 Nov 2011     6,480.0 |  86    1965     2,290.0   94.82  |
| 12 Apr 2013     7,350.0 |  87    1934     1,700.0   95.93  |
| 23 Dec 2013     9,110.0 |  88    1988     1,530.0   97.04  |
| 17 Jun 2015     6,180.0 |  89    1931     1,290.0   98.15  |
| 29 Dec 2015     5,010.0 |  90    1941      958.0*   99.25  |
|-------------------------|-------------------------------------|
|     Note: Plotting positions based on historic period (H) = 104 |
|          Number of historic events plus high outliers (Z) = 1   |
|            Weighting factor for systematic events (W) = 1.1573   |
-------------------------------------------------------------------
                                              * Outlier


<< Skew Weighting >>
------------------------------------------------------------------
Based on 104 events, mean-square error of station skew =    0.076
Mean-square error of regional skew =                        0.302
------------------------------------------------------------------


<< Frequency Curve >>
Blanchard River-Findlay OH-FLOW-ANNUAL PEAK
------------------------------------------------------------------
| Computed    Expected  |  Percent  |   Confidence Limits      |
|   Curve    Probability |  Chance  |     0.05        0.95     |
|     FLOW, CFS          | Exceedance|     FLOW, CFS           |
|-----------------------|-----------|--------------------------|
|  17,116.5   17,627.6  |    0.1    |  20,649.2    14,715.0    |
|  16,156.2   16,576.7  |    0.2    |  19,351.4    13,964.1    |
|  14,810.6   15,119.5  |    0.5    |  17,552.0    12,902.8    |
|  13,726.8   13,964.6  |    1.0    |  16,120.2    12,039.4    |
|  12,576.4   12,749.5  |    2.0    |  14,619.1    11,113.4    |
|  11,346.2   11,464.9  |    4.0    |  13,037.1    10,110.5    |
|   9,558.6    9,618.5  |   10.0    |  10,787.9     8,625.4    |
|   8,027.7    8,055.9  |   20.0    |   8,918.1     7,319.4    |
|   5,530.2    5,530.2  |   50.0    |   6,020.3     5,085.9    |
|     874.5      804.9  |   99.9    |   1,083.6       667.1    |
|-----------------------|-----------|--------------------------|
```

```
<< Synthetic Statistics >>
Blanchard River-Findlay OH-FLOW-ANNUAL PEAK
------------------------------------------------------------------
|         Log Transform:          |                                |
|           FLOW, CFS             |         Number of Events       |
|---------------------------------|--------------------------------|
|  Mean               3.726       |  Historic Events           1   |
|  Standard Dev       0.208       |  High Outliers       0         |
|  Station Skew      -0.490       |  Low Outliers        1         |
|  Regional Skew     -0.400       |  Zero Events         0         |
|  Weighted Skew     -0.472       |  Missing Events      0         |
|  Adopted Skew      -0.472       |  Systematic Events        89   |
|                                 |  Historic Period         104   |
|---------------------------------|--------------------------------|

--- End of Analytical Frequency Curve ---
```

Appendix B HEC-HMS MODEL SUPPORT DATA

Table 6 - HEC-HMS Model NLCD/TR55 Landuse Linkage

NLCD Landuse		TR-55 Landuse Translation	% of Watershed	SCS Curve Number Hydrologic Soil Group			
Code	Description	Description		A	B	C	D
11	Open Water	Impervious Area	0.6%	98	98	98	98
21	Developed, Open Space	Open Space, Poor Condition	6.9%	68	79	86	89
22	Developed, Low Intensity	Residential, 1/2 acre lots	3.7%	54	70	80	85
23	Developed, Medium Intensity	Residential, 1/4 acre lots	1.3%	61	75	83	87
24	Developed, High Intensity	Residential, 1/8 acre lots	0.6%	77	85	90	92
31	Barren Land (Rock/Sand/Clay)	Newly Graded Areas	0.1%	77	86	91	94
41	Deciduous Forest	Woods, Fair Condition	6.1%	36	60	73	79
42	Evergreen Forest	Woods, Good Condition	0.0%	30	55	70	77
43	Mixed Forest	Woods, Poor Condition	0.0%	45	66	77	83
71	Grassland / Herbaceous	Pasture, Good Condition	1.8%	39	61	74	80
81	Pasture / Hay	Pasture, Fair Condition	1.5%	49	69	79	84
82	Cultivated Crops	Row Crops, Straight, Good Condition	76.9%	67	78	85	89
90	Woody Wetlands	Brush, Poor Condition	0.1%	48	67	77	83
95	Emergent Herbaceous Wetlands	Brush, Poor Condition	0.3%	48	67	77	83
			% of Watershed	0.6%	0.6%	2.8%	96.1%

Stantec

Table 7 - HEC-HMS Model Parameter Summary – Subbasins (Hypothetical Geometry)

Subbasin	Area (sq-mi)	Loss Method SCS CN (Grid)		Transform Method ModClark		Baseflow Method Recession - Discharge / Unit Area		
		Ratio	Factor	Time of Concentration (hours)	Storage Coefficient (hours)	Initial Discharge Ratio	Recession Constant	Ratio to Peak
Aurand_Trib_01	4.49456	0.100	0.800	7.5	15.8	0.90	0.90	0.02
Aurand_01	1.35477	0.100	0.800	5.0	10.6	0.90	0.90	0.02
Aurand_02	4.65369	0.100	0.800	8.1	17.0	0.90	0.90	0.02
Aurand_03	2.05036	0.100	0.800	8.0	16.9	0.90	0.90	0.02
Aurand_04	2.48329	0.100	0.800	7.0	14.9	0.90	0.90	0.02
Aurand_05	1.61275	0.100	0.800	7.7	16.3	0.90	0.90	0.02
Brights_01	2.83366	0.100	0.800	6.6	32.9	1.50	0.90	0.05
Brights_02	4.58726	0.100	0.800	6.7	33.7	1.50	0.90	0.05
Brights_03	4.16126	0.100	0.800	4.7	23.6	1.50	0.90	0.05
BR_UT_01	6.87143	0.100	0.800	11.6	24.5	0.90	0.90	0.02
BR_UT_02	4.71974	0.100	0.800	9.9	20.9	0.90	0.90	0.02
BR_UT_03	8.47815	0.050	0.250	10.0	23.3	1.00	0.90	0.01
BR_UT_04	7.87170	0.050	0.250	8.2	19.2	1.00	0.90	0.01
BR_UT_05_01	3.90651	0.050	0.250	4.1	10.8	1.00	0.90	0.01
BR_UT_05_02	6.97983	0.050	0.250	5.8	15.4	1.00	0.90	0.01
BR_UT_06	5.80165	0.050	0.250	6.3	16.9	1.00	0.90	0.01
BR_01	3.33344	0.100	0.800	7.1	14.9	0.90	0.90	0.02
BR_02	5.43133	0.100	0.800	9.8	20.6	0.90	0.90	0.02
BR_03	3.17725	0.100	0.800	8.8	18.5	0.90	0.90	0.02
BR_04	2.49105	0.100	0.800	11.8	25.0	0.90	0.90	0.02
BR_05	3.40561	0.200	1.500	6.4	9.6	0.50	0.90	0.05
BR_06	2.85738	0.200	1.500	8.2	12.3	0.50	0.90	0.05
BR_07	1.12919	0.200	1.500	7.2	10.7	0.50	0.90	0.05
BR_08	6.34916	0.200	1.500	9.9	14.9	0.50	0.90	0.05
BR_09	5.75170	0.200	1.500	8.7	13.1	0.50	0.90	0.05
BR_10	3.55180	0.100	0.800	3.5	17.6	1.50	0.90	0.05
BR_11	3.79895	0.100	0.800	5.9	29.5	1.50	0.90	0.05
BR_12	3.33920	0.100	0.800	4.0	19.8	1.50	0.90	0.05
BR_13	3.41588	0.050	1.200	10.1	53.6	1.50	0.90	0.05
BR_14	0.86954	0.050	0.250	3.5	8.1	1.00	0.90	0.01
BR_15	3.63388	0.050	0.250	6.4	14.8	1.00	0.90	0.01
BR_16	0.25546	0.050	0.250	1.0	2.4	1.00	0.90	0.01
BR_17	0.64167	0.050	0.250	2.7	6.2	1.00	0.90	0.01

Appendix B HEC-HMS Model Support Data
November 8, 2017

| Subbasin | Area (sq-mi) | Loss Method SCS CN (Grid) | | Transform Method ModClark | | Baseflow Method Recession - Discharge / Unit Area | | |
		Ratio	Factor	Time of Concentration (hours)	Storage Coefficient (hours)	Initial Discharge Ratio	Recession Constant	Ratio to Peak
BR_18	2.01279	0.050	0.250	2.6	6.0	1.00	0.90	0.01
BR_19	2.79108	0.050	0.250	4.9	11.5	1.00	0.90	0.01
BR_20	4.31911	0.050	0.250	5.6	13.1	1.00	0.90	0.01
BR_21	3.30564	0.050	0.250	6.4	17.2	1.00	0.90	0.01
BR_22	0.20520	0.050	0.250	1.2	3.2	1.00	0.90	0.01
BR_23	0.91675	0.050	0.250	2.8	7.4	1.00	0.90	0.01
BR_24	3.39536	0.050	0.250	6.5	17.4	1.00	0.90	0.01
BR_25	0.18619	0.050	0.250	1.6	4.2	1.00	0.90	0.01
BR_26	4.41753	0.050	0.250	6.7	19.0	1.00	0.90	0.01
BR_27	4.19643	0.050	0.250	5.4	15.3	1.00	0.90	0.01
BR_28	7.30912	0.050	0.250	7.3	20.6	1.00	0.90	0.01
Buckrun_Creek	9.87749	0.050	1.200	15.1	90.6	1.50	0.90	0.05
Buck_Run	5.86944	0.050	1.200	12.8	4.3	0.70	0.90	0.01
Cessna_Ck_01	0.23087	0.050	0.250	1.3	3.4	1.00	0.90	0.01
Cessna_Ck_02	5.09014	0.050	0.250	4.3	11.6	1.00	0.90	0.01
Cessna_UT_01	4.41856	0.050	0.250	5.5	14.6	1.00	0.90	0.01
Eagle_01	1.29007	0.200	1.500	8.7	13.0	0.50	0.90	0.05
Eagle_02	3.82090	0.200	1.500	9.5	14.2	0.50	0.90	0.05
Eagle_03	1.38015	0.200	1.500	7.6	11.5	0.50	0.90	0.05
Eagle_04	2.47872	0.200	1.500	8.3	12.4	0.50	0.90	0.05
Eagle_05	0.78482	0.200	1.500	7.2	10.8	0.50	0.90	0.05
Eagle_06	1.28442	0.050	1.000	2.6	3.8	0.70	0.90	0.01
Eagle_07	5.65467	0.050	1.000	5.3	8.0	0.70	0.90	0.01
Eagle_08	3.99742	0.050	1.000	4.6	6.8	0.70	0.90	0.01
Eagle_09	2.98628	0.050	1.000	4.3	6.5	0.70	0.90	0.01
Eagle_10	5.16309	0.050	1.000	6.1	9.2	0.70	0.90	0.01
Eagle_11	0.93828	0.050	1.000	2.7	4.1	0.70	0.90	0.01
Eagle_12	2.83092	0.050	1.200	7.4	2.5	0.70	0.90	0.01
Eagle_13	3.64121	0.050	1.200	8.1	2.7	0.70	0.90	0.01
Eagle_14	2.96949	0.050	1.200	8.1	2.7	0.70	0.90	0.01
Eagle_15	7.29972	0.050	1.200	11.5	3.8	0.70	0.90	0.01
Flat_Branch_01	0.14956	0.050	1.200	1.2	1.8	0.70	0.90	0.01
Flat_Branch_02	6.67580	0.050	1.200	13.1	4.4	0.70	0.90	0.01
Flat_Branch_03	4.21592	0.050	1.200	10.0	3.4	0.70	0.90	0.01

Stantec

Appendix B HEC-HMS Model Support Data
November 8, 2017

Subbasin	Area (sq-mi)	Loss Method SCS CN (Grid)		Transform Method ModClark		Baseflow Method Recession - Discharge / Unit Area		
		Ratio	Factor	Time of Concentration (hours)	Storage Coefficient (hours)	Initial Discharge Ratio	Recession Constant	Ratio to Peak
Fourmile_Run_01	7.23825	0.050	0.250	6.8	19.3	1.00	0.90	0.01
Fourmile_Run_02	6.23404	0.050	0.250	4.9	13.9	1.00	0.90	0.01
Howard_Run	5.13442	0.200	1.500	7.9	11.8	0.50	0.90	0.05
Lye_01	0.98623	0.200	1.500	12.4	18.7	0.50	0.90	0.05
Lye_02	2.93308	0.200	1.500	11.4	17.0	0.50	0.90	0.05
Lye_03	3.09764	0.200	1.500	8.8	13.1	0.50	0.90	0.05
Lye_04	2.14784	0.200	1.500	10.1	15.2	0.50	0.90	0.05
Lye_05	1.38881	0.200	1.500	7.9	11.8	0.50	0.90	0.05
Lye_06	0.71725	0.100	1.000	3.8	12.8	0.50	0.90	0.03
Lye_07	4.26122	0.100	1.000	9.1	26.3	0.50	0.90	0.03
Lye_08	6.10663	0.100	1.000	6.8	19.6	0.50	0.90	0.03
Lye_09	6.76232	0.200	1.500	9.7	3.2	0.50	0.90	0.03
Potato_01	5.84167	0.050	0.250	7.4	17.3	1.00	0.90	0.01
Potato_02	4.48842	0.050	0.250	5.4	12.6	1.00	0.90	0.01
Potato_03	4.12563	0.050	0.250	4.7	11.0	1.00	0.90	0.01
Potato_04	6.36293	0.050	0.250	5.2	12.0	1.00	0.90	0.01
Potato_05	7.16129	0.050	0.250	5.8	13.6	1.00	0.90	0.01
Ripley_Run	5.73986	0.050	0.250	5.3	12.4	1.00	0.90	0.01
Stahl_01	1.75367	0.100	0.800	3.8	18.8	1.50	0.90	0.05
Stahl_02	3.20619	0.100	0.800	6.3	31.6	1.50	0.90	0.05
Stahl_03	8.99017	0.050	1.200	9.4	48.0	1.50	0.90	0.05
Stahl_04	5.29128	0.050	1.200	9.4	47.9	1.50	0.90	0.05
The_Outlet_North_01	4.19666	0.050	0.250	5.8	15.4	1.00	0.90	0.01
The_Outlet_North_02	8.31070	0.050	0.250	6.1	16.3	1.00	0.90	0.01
The_Outlet_01	9.77788	0.100	0.800	6.8	33.8	1.50	0.90	0.05
The_Outlet_02	6.95405	0.100	0.800	5.9	29.5	1.50	0.90	0.05
The_Outlet_03	9.67070	0.100	0.800	5.0	25.2	1.50	0.90	0.05
The_Outlet_04	7.30965	0.100	0.800	4.6	23.1	1.50	0.90	0.05
The_Outlet_05	4.96085	0.100	0.800	6.2	31.0	1.50	0.90	0.05

Stantec

Table 8 - HEC-HMS Model Parameter Summary – Reaches (Hypothetical Geometry)

Reach	Name	Length	Slope	Routing Method	Velocity	Lag Time
R_01	Blanchard River	10,800	0.0001	Modified Puls	N/A	N/A
R_02	Blanchard River	25,400	0.0001	Modified Puls	N/A	N/A
R_03	Blanchard River	11,000	0.0003	Modified Puls	N/A	N/A
R_04	Blanchard River	4,900	0.0003	Modified Puls	N/A	N/A
R_05	Blanchard River	7,900	0.0001	Modified Puls	N/A	N/A
R_06	Blanchard River	6,700	0.0012	Modified Puls	N/A	N/A
R_07	Blanchard River	1,500	0.0004	Modified Puls	N/A	N/A
R_08	Blanchard River	18,600	0.0001	Modified Puls	N/A	N/A
R_09	Blanchard River	2,100	0.0004	Modified Puls	N/A	N/A
R_10	Blanchard River	6,200	0.0004	Modified Puls	N/A	N/A
R_11	Blanchard River	11,700	0.0001	Modified Puls	N/A	N/A
R_12	Blanchard River	20,400	0.0001	Modified Puls	N/A	N/A
R_13	Blanchard River	31,600	0.0001	Modified Puls	N/A	N/A
R_14	Blanchard River	3,300	0.0006	Modified Puls	N/A	N/A
R_15	Blanchard River	19,100	0.0001	Modified Puls	N/A	N/A
R_16	Blanchard River	2,200	0.0009	Modified Puls	N/A	N/A
R_17	Blanchard River	5,500	0.001	Modified Puls	N/A	N/A
R_18	Blanchard River	12,700	0.0012	Modified Puls	N/A	N/A
R_19	Blanchard River	22,600	0.0001	Lag	1.05	360
R_20	Blanchard River	18,800	0.0005	Lag	1.03	305
R_21	Blanchard River	27,000	0.0003	Lag	1.02	440
R_22	Blanchard River	2,900	0.0001	Lag	1.93	25
R_23	Blanchard River	8,300	0.0006	Lag	1.02	135
R_24	Cessna Creek	3,000	0.0029	Lag	2.00	25
R_25	Cessna Creek	20,900	0.0004	Lag	1.07	325
R_26	Fourmile Run	12,100	0.0004	Lag	1.06	190
R_27	Aurand Run	14,400	0.0015	Modified Puls	N/A	N/A
R_28	Aurand Run	17,700	0.0012	Modified Puls	N/A	N/A
R_29	Aurand Run	4,600	0.0002	Modified Puls	N/A	N/A
R_30	Aurand Run	2,800	0.0009	Modified Puls	N/A	N/A
R_31	Eagle Creek	8,400	0.0012	Modified Puls	N/A	N/A
R_32	Eagle Creek	12,000	0.0008	Modified Puls	N/A	N/A
R_33	Eagle Creek	4,000	0.0014	Modified Puls	N/A	N/A
R_34	Eagle Creek	3,200	0.0001	Modified Puls	N/A	N/A
R_35	Eagle Creek	10,200	0.0001	Modified Puls	N/A	N/A

Stantec

Appendix B HEC-HMS Model Support Data
November 8, 2017

Reach	Name	Length	Slope	Routing Method	Velocity	Lag Time
R_36	Eagle Creek	12,000	0.0003	Modified Puls	N/A	N/A
R_37	Eagle Creek	12,900	0.001	Lag	1.26	170
R_38	Eagle Creek	21,500	0.0009	Lag	1.30	275
R_39	Eagle Creek	14,400	0.0015	Lag	0.79	305
R_40	Eagle Creek	21,700	0.0005	Lag	0.79	455
R_41	Flat Branch	5,300	0.0012	Lag	0.80	110
R_42	Lye Creek	6,900	0.0007	Modified Puls	N/A	N/A
R_43	Lye Creek	10,100	0.0002	Modified Puls	N/A	N/A
R_44	Lye Creek	12,100	0.0011	Modified Puls	N/A	N/A
R_45	Lye Creek	1,600	0.0002	Lag	0.59	45
R_46	Lye Creek	21,500	0.0004	Lag	N/A	N/A
R_47	The Outlet	15,700	0.0001	Lag	0.62	580
R_48	The Outlet	10,700	0.0001	Lag	2.38	110
R_49	The Outlet	13,000	0.0001	Lag	2.38	75
R_50	Stahl Run	9,300	0.0003	Lag	2.41	90
R_51	Stahl Run	25,500	0.0011	Lag	2.38	65
R_52	Stahl Run	21,600	0.0005	Lag	2.36	180
R_53	Brights Run	8,900	0.0001	Lag	2.32	155
R_54	Potato Run	19,200	0.0002	Modified Puls	2.47	60
R_55	Potato Run	18,300	0.0003	Lag	N/A	N/A
R_56	Potato Run	13,300	0.0005	Lag	1.36	225
R_57	The Outlet (North)	21,300	0.0013	Lag	1.34	165
R_58	Unnamed Trib 05	13,000	0.0001	Lag	1.31	270
R_59	Blanchard River	11,400	0.0005	Lag	1.31	165
R_60	Blanchard River	2,400	0.0021	Lag	1.27	150

Stantec

HYDROLOGIC EVALUATION OF THE BLANCHARD RIVER

Appendix B HEC-HMS Results

USGS Gage 04189000 Blanchard River Downstream of Findlay (Using September 2011 Calibrated Geometry)

Hypothetical Event Hydrograph Plot
USGS Gage 04189000 Blanchard River Downstream of Findlay
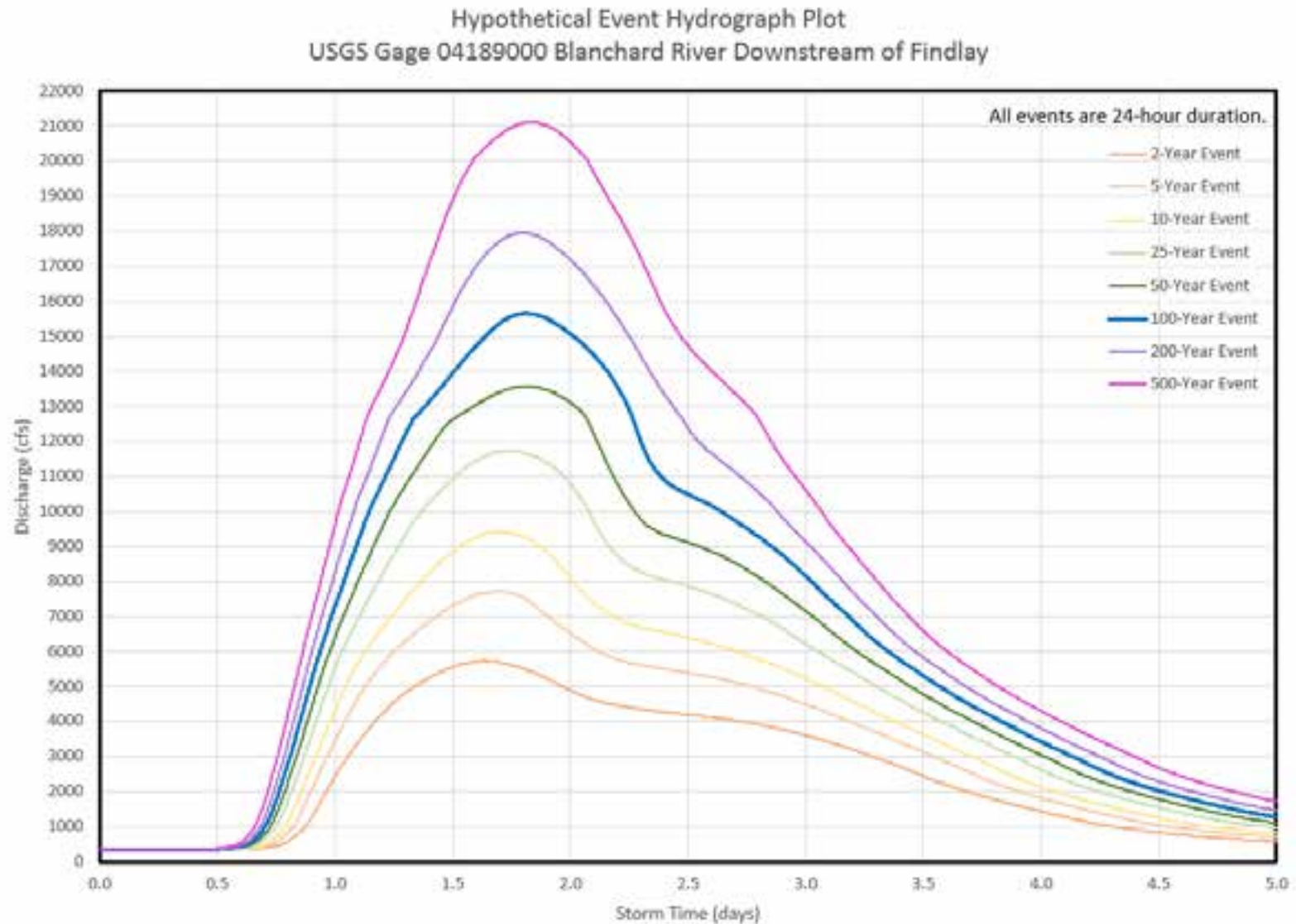
HYDROLOGIC EVALUATION OF THE BLANCHARD RIVER

Appendix B HEC-HMS Results

USGS Gage 04188400 Blanchard River Upstream of Findlay (Using September 2011 Calibrated Geometry)

HYDROLOGIC EVALUATION OF THE BLANCHARD RIVER
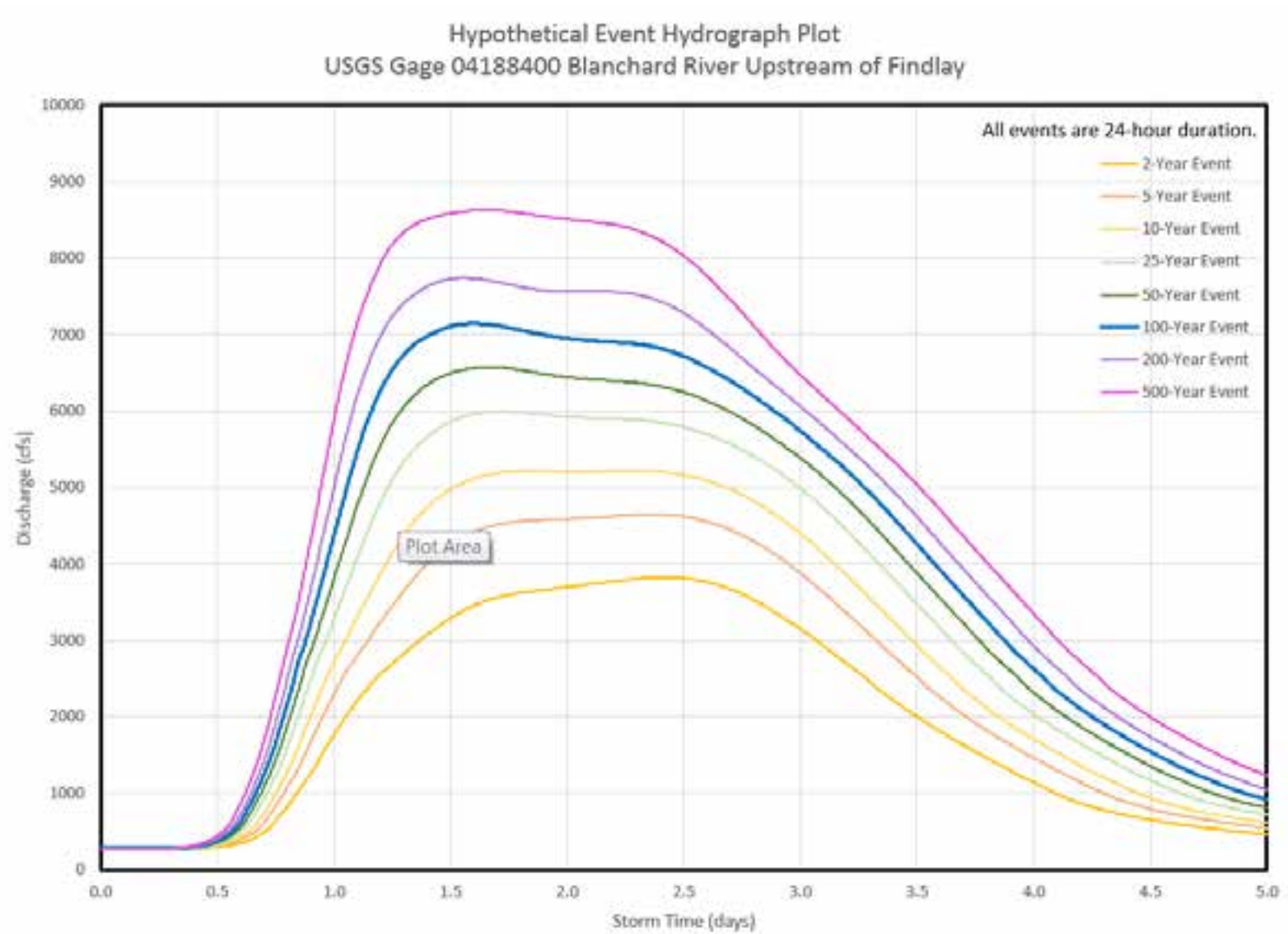
Appendix B HEC-HMS Results

USGS Gage 04188337 Blanchard River Downstream of Mt. Blanchard (Using September 2011 Calibrated Geometry)

Hypothetical Event Hydrograph Plot
USGS Gage 04188337 Blanchard River Downstream of Mt. Blanchard

Stantec
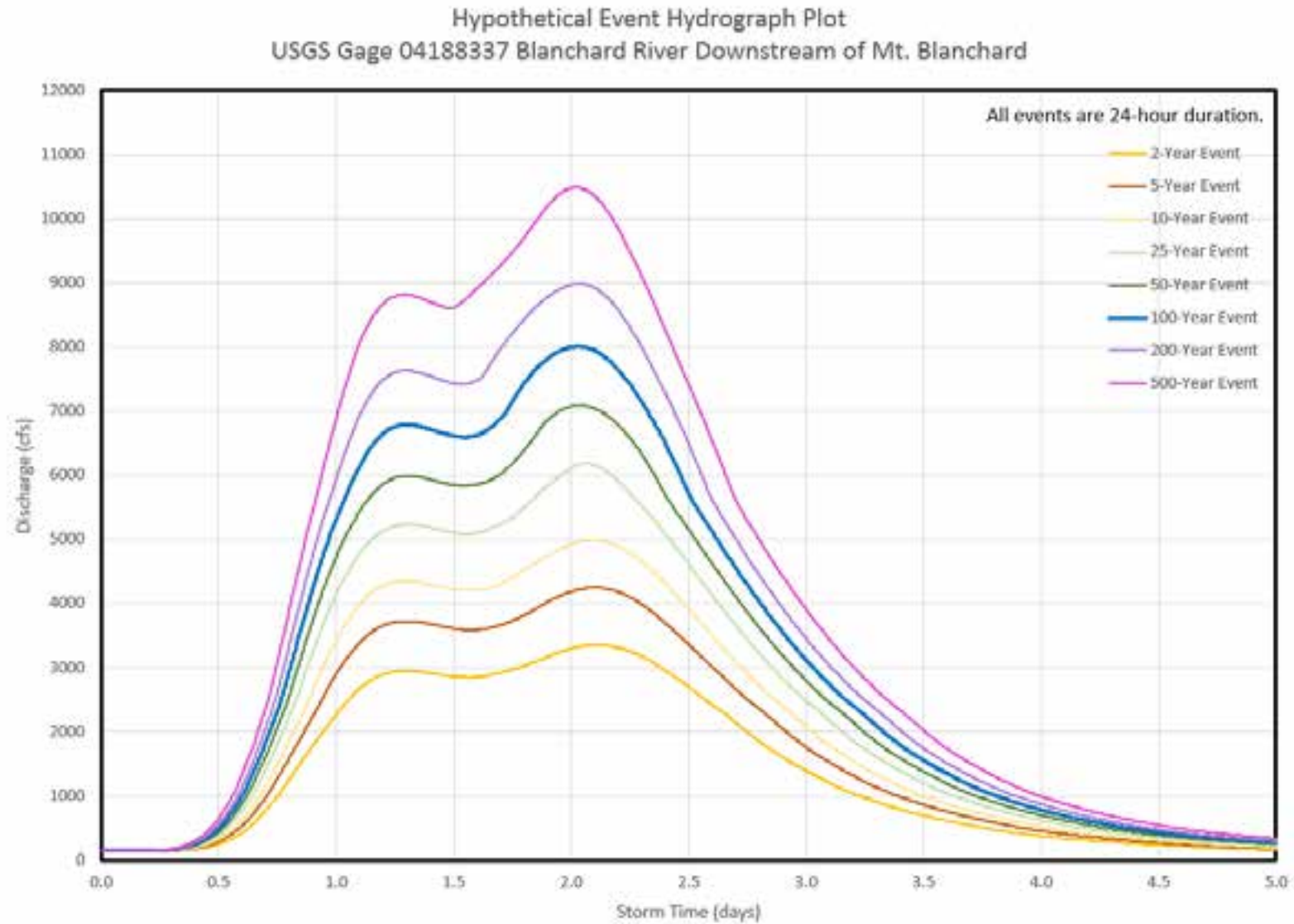
HYDROLOGIC EVALUATION OF THE BLANCHARD RIVER

Appendix B HEC-HMS Results

USGS Gage 04188496 Eagle Creek Above Findlay (Using September 2011 Calibrated Geometry)

Hypothetical Event Hydrograph Plot
USGS Gage 04188496 Eagle Creek Above Findlay
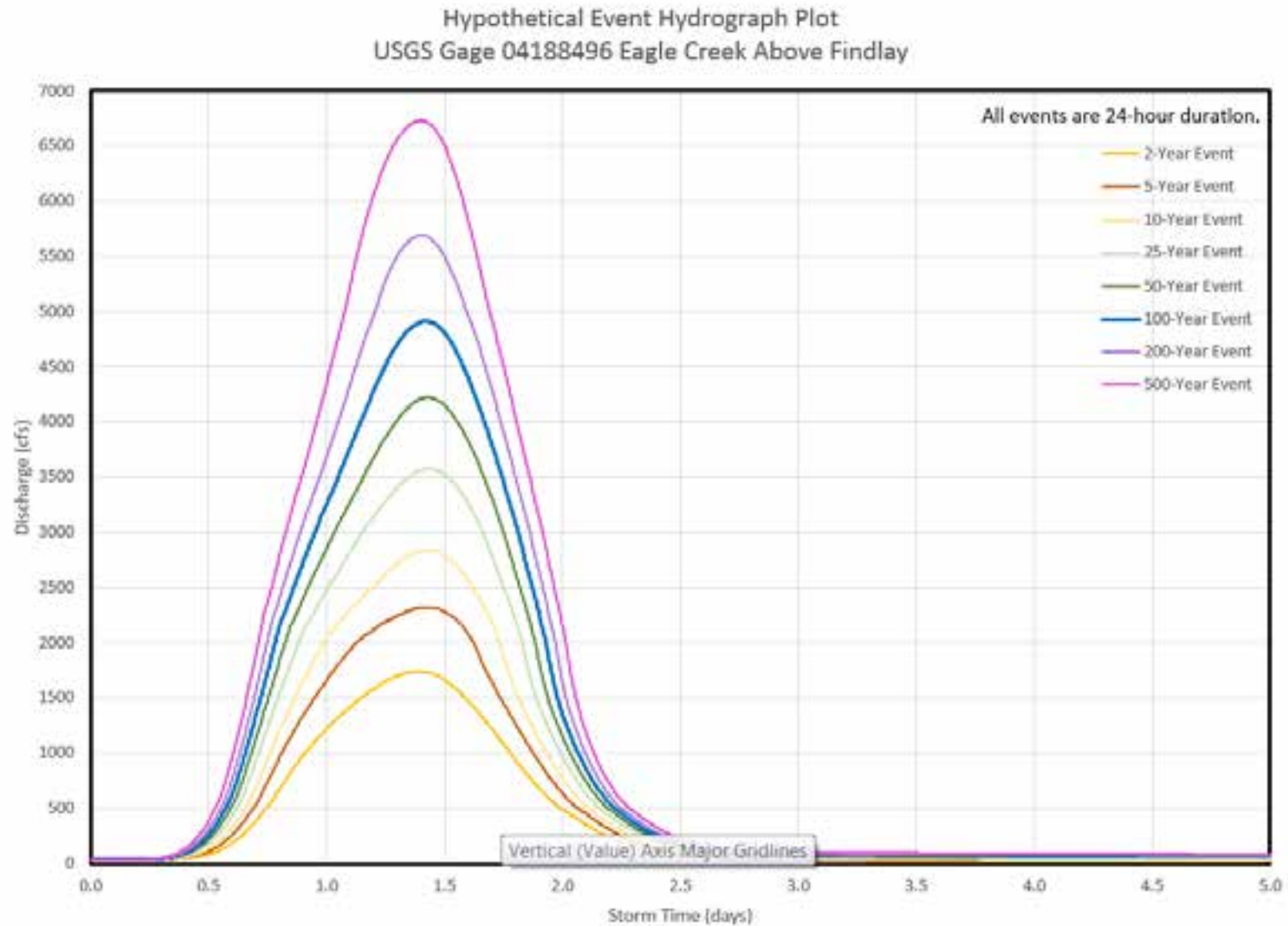
HYDROLOGIC EVALUATION OF THE BLANCHARD RIVER

Appendix B HEC-HMS Results

USGS Gage 04188433 Lye Creek Above Findlay (Using September 2011 Calibrated Geometry)
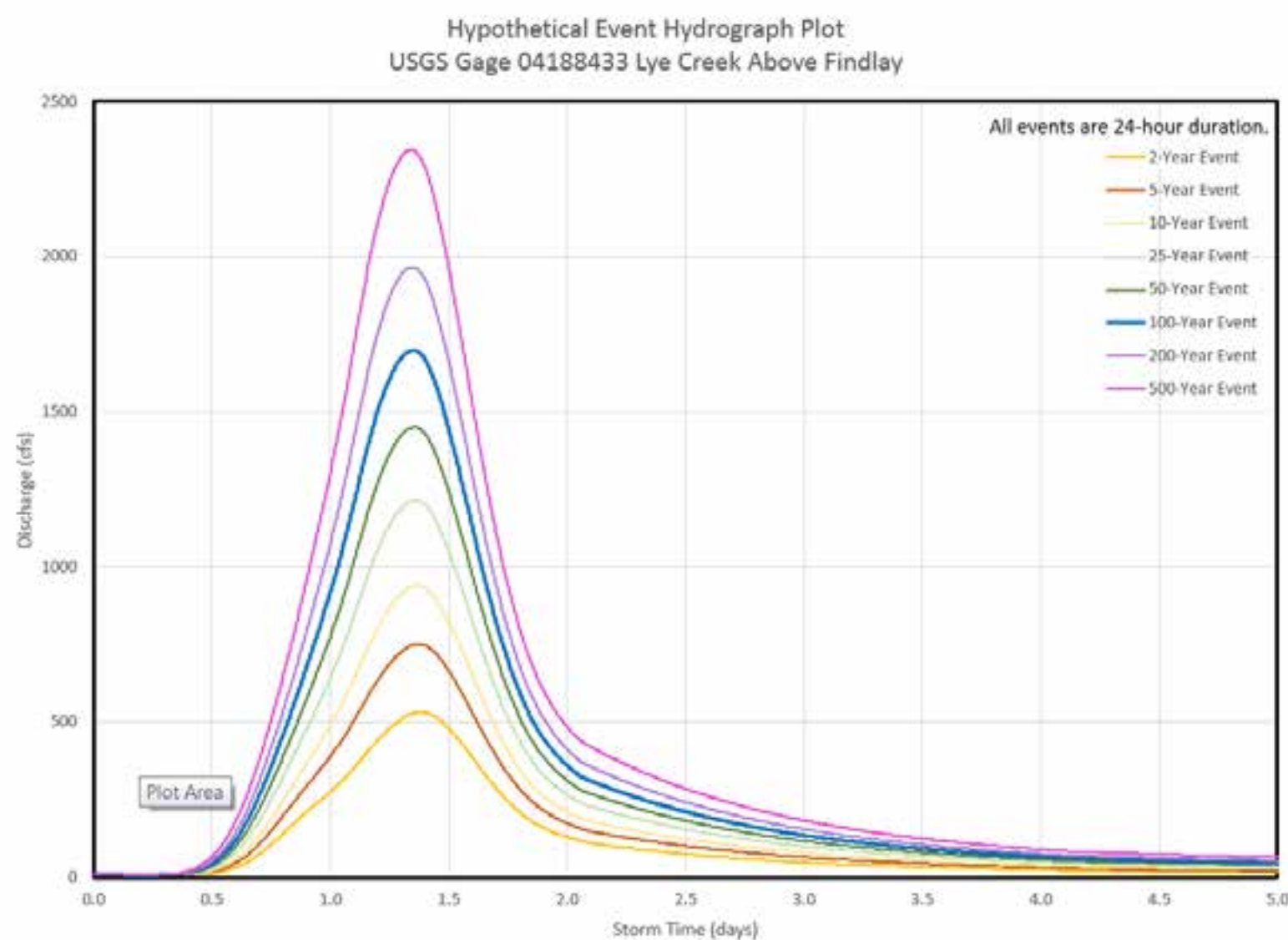
Appendix C   CALIBRATION DATA

Subbasin Parameter Calibration – September 2011

Subbasin	Original Values							September 2011 Calibration						
	Loss (Gridded CN)		Transform		Baseflow			Loss (Gridded CN)		Transform		Baseflow		
	Ratio	Factor	Time of Concentration	Storage Coefficient	Initial Discharge Ratio	Recession Constant	Ratio to Peak	Ratio	Factor	Tc Multiplier	R Multiplier	Initial Discharge Ratio	Recession Constant	Ratio to Peak
Average	0.20	1.00			0.50	0.90	0.05	0.09	0.79	1.14	1.81	0.93	0.90	0.026
Aurand_Trib_01	0.20	1.0	5.53	8.30	0.5	0.9	0.05	0.10	0.8	1.35	1.90	0.9	0.9	0.02
Aurand_01	0.20	1.0	3.72	5.58	0.5	0.9	0.05	0.10	0.8	1.35	1.90	0.9	0.9	0.02
Aurand_02	0.20	1.0	5.98	8.97	0.5	0.9	0.05	0.10	0.8	1.35	1.90	0.9	0.9	0.02
Aurand_03	0.20	1.0	5.93	8.90	0.5	0.9	0.05	0.10	0.8	1.35	1.90	0.9	0.9	0.02
Aurand_04	0.20	1.0	5.21	7.82	0.5	0.9	0.05	0.10	0.8	1.35	1.90	0.9	0.9	0.02
Aurand_05	0.20	1.0	5.73	8.60	0.5	0.9	0.05	0.10	0.8	1.35	1.90	0.9	0.9	0.02
Brights_01	0.20	1.0	7.32	10.98	0.5	0.9	0.05	0.10	0.80	0.90	3.00	1.5	0.9	0.05
Brights_02	0.20	1.0	7.48	11.22	0.5	0.9	0.05	0.10	0.80	0.90	3.00	1.5	0.9	0.05
Brights_03	0.20	1.0	5.24	7.86	0.5	0.9	0.05	0.10	0.80	0.90	3.00	1.5	0.9	0.05
BR_UT_01	0.20	1.0	8.59	12.89	0.5	0.9	0.05	0.10	0.8	1.35	1.90	0.9	0.9	0.02
BR_UT_02	0.20	1.0	7.34	11.01	0.5	0.9	0.05	0.10	0.8	1.35	1.90	0.9	0.9	0.02
BR_UT_03	0.20	1.0	11.07	16.61	0.5	0.9	0.05	0.05	0.25	0.90	1.40	1.0	0.9	0.01
BR_UT_04	0.20	1.0	9.16	13.74	0.5	0.9	0.05	0.05	0.25	0.90	1.40	1.0	0.9	0.01
BR_UT_05_01	0.20	1.0	4.51	6.77	0.5	0.9	0.05	0.05	0.25	0.90	1.60	1.0	0.9	0.01
BR_UT_05_02	0.20	1.0	6.40	9.60	0.5	0.9	0.05	0.05	0.25	0.90	1.60	1.0	0.9	0.01
BR_UT_06	0.20	1.0	7.03	10.55	0.5	0.9	0.05	0.05	0.25	0.90	1.60	1.0	0.9	0.01
BR_01	0.20	1.0	5.23	7.85	0.5	0.9	0.05	0.10	0.8	1.35	1.90	0.9	0.9	0.02
BR_02	0.20	1.0	7.24	10.86	0.5	0.9	0.05	0.10	0.8	1.35	1.90	0.9	0.9	0.02
BR_03	0.20	1.0	6.50	9.75	0.5	0.9	0.05	0.10	0.8	1.35	1.90	0.9	0.9	0.02
BR_04	0.20	1.0	8.75	13.13	0.5	0.9	0.05	0.10	0.8	1.34	1.90	0.9	0.9	0.02
BR_05	0.20	1.0	3.42	5.13	0.5	0.9	0.05	0.20	1.50	1.88	1.88	0.5	0.9	0.05
BR_06	0.20	1.0	5.19	7.79	0.5	0.9	0.05	0.20	1.50	1.58	1.58	0.5	0.9	0.05
BR_07	0.20	1.0	4.16	6.24	0.5	0.9	0.05	0.20	1.50	1.72	1.72	0.5	0.9	0.05
BR_08	0.20	1.0	6.91	10.37	0.5	0.9	0.05	0.20	1.50	1.43	1.43	0.5	0.9	0.05
BR_09	0.20	1.0	5.70	8.55	0.5	0.9	0.05	0.20	1.50	1.53	1.53	0.5	0.9	0.05
BR_10	0.20	1.0	3.91	5.87	0.5	0.9	0.05	0.10	0.80	0.90	3.00	1.5	0.9	0.05
BR_11	0.20	1.0	6.56	9.84	0.5	0.9	0.05	0.10	0.80	0.90	3.00	1.5	0.9	0.05
BR_12	0.20	1.0	4.40	6.60	0.5	0.9	0.05	0.10	0.80	0.90	3.00	1.5	0.9	0.05
BR_13	0.20	1.0	7.14	10.71	0.5	0.9	0.05	0.05	1.20	1.42	5.00	1.5	0.9	0.05

Appendix C Calibration Data
November 8, 2017

Subbasin	Original Values							September 2011 Calibration						
	Loss (Gridded CN)		Transform		Baseflow			Loss (Gridded CN)		Transform		Baseflow		
							Ratio to Peak					Initial Discharge Ratio		Ratio to Peak
	Ratio	Factor	Time of Concentration	Storage Coefficient	Initial Discharge Ratio	Recession Constant		Ratio	Factor	Tc Multiplier	R Multiplier		Recession Constant	
BR_14	0.20	1.0	3.87	5.81	0.5	0.9	0.05	0.05	0.25	0.90	1.40	1.0	0.9	0.01
BR_15	0.20	1.0	7.06	10.59	0.5	0.9	0.05	0.05	0.25	0.90	1.40	1.0	0.9	0.01
BR_16	0.20	1.0	1.14	1.71	0.5	0.9	0.05	0.05	0.25	0.90	1.40	1.0	0.9	0.01
BR_17	0.20	1.0	2.97	4.46	0.5	0.9	0.05	0.05	0.25	0.90	1.40	1.0	0.9	0.01
BR_18	0.20	1.0	2.87	4.31	0.5	0.9	0.05	0.05	0.25	0.90	1.40	1.0	0.9	0.01
BR_19	0.20	1.0	5.49	8.24	0.5	0.9	0.05	0.05	0.25	0.90	1.40	1.0	0.9	0.01
BR_20	0.20	1.0	6.23	9.35	0.5	0.9	0.05	0.05	0.25	0.90	1.40	1.0	0.9	0.01
BR_21	0.20	1.0	7.16	10.74	0.5	0.9	0.05	0.05	0.25	0.90	1.60	1.0	0.9	0.01
BR_22	0.20	1.0	1.34	2.01	0.5	0.9	0.05	0.05	0.25	0.90	1.60	1.0	0.9	0.01
BR_23	0.20	1.0	3.10	4.65	0.5	0.9	0.05	0.05	0.25	0.90	1.60	1.0	0.9	0.01
BR_24	0.20	1.0	7.26	10.89	0.5	0.9	0.05	0.05	0.25	0.90	1.60	1.0	0.9	0.01
BR_25	0.20	1.0	1.76	2.64	0.5	0.9	0.05	0.05	0.25	0.90	1.60	1.0	0.9	0.01
BR_26	0.20	1.0	7.44	11.16	0.5	0.9	0.05	0.05	0.25	0.90	1.70	1.0	0.9	0.01
BR_27	0.20	1.0	6.00	9.00	0.5	0.9	0.05	0.05	0.25	0.90	1.70	1.0	0.9	0.01
BR_28	0.20	1.0	8.07	12.11	0.5	0.9	0.05	0.05	0.25	0.90	1.70	1.0	0.9	0.01
Buckrun_Creek	0.20	1.0	12.08	18.12	0.5	0.9	0.05	0.05	1.20	1.25	5.00	1.5	0.9	0.05
Buck_Run	0.20	1.0	9.84	14.76	0.5	0.9	0.05	0.05	1.00	1.30	0.29	0.7	0.9	0.01
Cessna_Ck_01	0.20	1.0	1.43	2.15	0.5	0.9	0.05	0.05	0.25	0.90	1.60	1.0	0.9	0.01
Cessna_Ck_02	0.20	1.0	4.82	7.23	0.5	0.9	0.05	0.05	0.25	0.90	1.60	1.0	0.9	0.01
Cessna_UT_01	0.20	1.0	6.09	9.14	0.5	0.9	0.05	0.05	0.25	0.90	1.60	1.0	0.9	0.01
Eagle_01	0.20	1.0	5.67	8.51	0.5	0.9	0.05	0.20	1.50	1.53	1.53	0.5	0.9	0.05
Eagle_02	0.20	1.0	6.48	9.72	0.5	0.9	0.05	0.20	1.50	1.46	1.46	0.5	0.9	0.05
Eagle_03	0.20	1.0	4.63	6.95	0.5	0.9	0.05	0.20	1.50	1.65	1.65	0.5	0.9	0.05
Eagle_04	0.20	1.0	5.29	7.94	0.5	0.9	0.05	0.20	1.50	1.57	1.57	0.5	0.9	0.05
Eagle_05	0.20	1.0	4.19	6.29	0.5	0.9	0.05	0.20	1.50	1.72	1.71	0.5	0.9	0.05
Eagle_06	0.20	1.0	2.84	4.26	0.5	0.9	0.05	0.05	1.00	0.90	0.90	0.7	0.9	0.01
Eagle_07	0.20	1.0	5.91	8.87	0.5	0.9	0.05	0.05	1.00	0.90	0.90	0.7	0.9	0.01
Eagle_08	0.20	1.0	5.05	7.58	0.5	0.9	0.05	0.05	1.00	0.90	0.90	0.7	0.9	0.01
Eagle_09	0.20	1.0	4.82	7.23	0.5	0.9	0.05	0.05	1.00	0.90	0.90	0.7	0.9	0.01
Eagle_10	0.20	1.0	6.82	10.23	0.5	0.9	0.05	0.05	1.00	0.90	0.90	0.7	0.9	0.01
Eagle_11	0.20	1.0	3.04	4.56	0.5	0.9	0.05	0.05	1.00	0.90	0.90	0.7	0.9	0.01
Eagle_12	0.20	1.0	4.42	6.63	0.5	0.9	0.05	0.05	1.00	1.68	0.37	0.7	0.9	0.01
Eagle_13	0.20	1.0	5.13	7.70	0.5	0.9	0.05	0.05	1.00	1.58	0.35	0.7	0.9	0.01
Eagle_14	0.20	1.0	5.13	7.70	0.5	0.9	0.05	0.05	1.00	1.58	0.35	0.7	0.9	0.01
Eagle_15	0.20	1.0	8.49	12.74	0.5	0.9	0.05	0.05	1.00	1.35	0.30	0.7	0.9	0.01

Stantec

Subbasin	Original Values							September 2011 Calibration						
	Loss (Gridded CN)		Transform		Baseflow			Loss (Gridded CN)		Transform		Baseflow		
					Initial		Ratio					Initial		
			Time of	Storage	Discharge	Recession	to			Tc	R	Discharge	Recession	Ratio to
	Ratio	Factor	Concentration	Coefficient	Ratio	Constant	Peak	Ratio	Factor	Multiplier	Multiplier	Ratio	Constant	Peak
Flat_Branch_01	0.20	1.0	1.32	1.98	0.5	0.9	0.05	0.05	1.00	0.90	0.90	0.7	0.9	0.01
Flat_Branch_02	0.20	1.0	10.05	15.08	0.5	0.9	0.05	0.05	1.00	1.30	0.29	0.7	0.9	0.01
Flat_Branch_03	0.20	1.0	7.04	10.56	0.5	0.9	0.05	0.05	1.00	1.43	0.32	0.7	0.9	0.01
Fourmile_Run_01	0.20	1.0	7.55	11.33	0.5	0.9	0.05	0.05	0.25	0.90	1.70	1.0	0.9	0.01
Fourmile_Run_02	0.20	1.0	5.44	8.16	0.5	0.9	0.05	0.05	0.25	0.90	1.70	1.0	0.9	0.01
Howard_Run	0.20	1.0	4.87	7.31	0.5	0.9	0.05	0.20	1.50	1.62	1.61	0.5	0.9	0.05
Lye_01	0.20	1.0	9.43	14.15	0.5	0.9	0.05	0.20	1.50	1.32	1.32	0.5	0.9	0.05
Lye_02	0.20	1.0	8.36	12.54	0.5	0.9	0.05	0.20	1.50	1.36	1.36	0.5	0.9	0.05
Lye_03	0.20	1.0	5.75	8.63	0.5	0.9	0.05	0.20	1.50	1.52	1.52	0.5	0.9	0.05
Lye_04	0.20	1.0	7.12	10.68	0.5	0.9	0.05	0.20	1.50	1.42	1.42	0.5	0.9	0.05
Lye_05	0.20	1.0	4.85	7.28	0.5	0.9	0.05	0.20	1.50	1.62	1.62	0.5	0.9	0.05
Lye_06	0.20	1.0	3.41	5.12	0.5	0.9	0.05	0.10	1.00	1.10	2.50	0.5	0.9	0.03
Lye_07	0.20	1.0	7.01	10.52	0.5	0.9	0.05	0.10	1.00	1.30	2.50	0.5	0.9	0.03
Lye_08	0.20	1.0	5.22	7.83	0.5	0.9	0.05	0.10	1.00	1.30	2.50	0.5	0.9	0.03
Lye_09	0.20	1.0	6.69	10.04	0.5	0.9	0.05	0.20	1.50	1.45	0.32	0.5	0.9	0.03
Potato_01	0.20	1.0	8.24	12.36	0.5	0.9	0.05	0.05	0.25	0.90	1.40	1.0	0.9	0.01
Potato_02	0.20	1.0	5.99	8.99	0.5	0.9	0.05	0.05	0.25	0.90	1.40	1.0	0.9	0.01
Potato_03	0.20	1.0	5.23	7.85	0.5	0.9	0.05	0.05	0.25	0.90	1.40	1.0	0.9	0.01
Potato_04	0.20	1.0	5.72	8.58	0.5	0.9	0.05	0.05	0.25	0.90	1.40	1.0	0.9	0.01
Potato_05	0.20	1.0	6.47	9.71	0.5	0.9	0.05	0.05	0.25	0.90	1.40	1.0	0.9	0.01
Ripley_Run	0.20	1.0	5.89	8.84	0.5	0.9	0.05	0.05	0.25	0.90	1.40	1.0	0.9	0.01
Stahl_01	0.20	1.0	4.17	6.26	0.5	0.9	0.05	0.10	0.80	0.90	3.00	1.5	0.9	0.05
Stahl_02	0.20	1.0	7.02	10.53	0.5	0.9	0.05	0.10	0.80	0.90	3.00	1.5	0.9	0.05
Stahl_03	0.20	1.0	6.40	9.60	0.5	0.9	0.05	0.05	1.20	1.47	5.00	1.5	0.9	0.05
Stahl_04	0.20	1.0	6.38	9.57	0.5	0.9	0.05	0.05	1.20	1.47	5.00	1.5	0.9	0.05
The_Outlet_North_01	0.20	1.0	6.42	9.63	0.5	0.9	0.05	0.05	0.25	0.90	1.60	1.0	0.9	0.01
The_Outlet_North_02	0.20	1.0	6.77	10.16	0.5	0.9	0.05	0.05	0.25	0.90	1.60	1.0	0.9	0.01
The_Outlet_01	0.20	1.0	7.51	11.27	0.5	0.9	0.05	0.10	0.80	0.90	3.00	1.5	0.9	0.05
The_Outlet_02	0.20	1.0	6.55	9.83	0.5	0.9	0.05	0.10	0.80	0.90	3.00	1.5	0.9	0.05
The_Outlet_03	0.20	1.0	5.59	8.39	0.5	0.9	0.05	0.10	0.80	0.90	3.00	1.5	0.9	0.05
The_Outlet_04	0.20	1.0	5.14	7.71	0.5	0.9	0.05	0.10	0.80	0.90	3.00	1.5	0.9	0.05
The_Outlet_05	0.20	1.0	6.88	10.32	0.5	0.9	0.05	0.10	0.80	0.90	3.00	1.5	0.9	0.05

Stantec

Appendix C Calibration Data
November 8, 2017

Subbasin Parameter Calibration – June 2015

| | Original Values | | | | | | | June 2015 Calibration | | | | | | |
| | Loss (Gridded CN) | | Transform | | Baseflow | | | Loss (Gridded CN) | | Transform | | Baseflow | | |
Subbasin	Ratio	Factor	Time of Concentration	Storage Coefficient	Initial Discharge Ratio	Recession Constant	Ratio to Peak	Ratio	Factor	Tc Multiplier	R Multiplier	Initial Discharge Ratio	Recession Constant	Ratio to Peak
Average	0.20	1.00			0.50	0.90	0.05	0.20	1.68	1.20	2.12	0.32	0.90	0.025
Aurand_Trib_01	0.20	1.0	5.53	8.30	0.5	0.9	0.05	0.20	1.70	1.30	2.20	0.3	0.9	0.02
Aurand_01	0.20	1.0	3.72	5.58	0.5	0.9	0.05	0.20	1.70	1.30	2.20	0.3	0.9	0.02
Aurand_02	0.20	1.0	5.98	8.97	0.5	0.9	0.05	0.20	1.70	1.30	2.20	0.3	0.9	0.02
Aurand_03	0.20	1.0	5.93	8.90	0.5	0.9	0.05	0.20	1.70	1.30	2.20	0.3	0.9	0.02
Aurand_04	0.20	1.0	5.21	7.82	0.5	0.9	0.05	0.20	1.70	1.30	2.20	0.3	0.9	0.02
Aurand_05	0.20	1.0	5.73	8.60	0.5	0.9	0.05	0.20	1.70	1.30	2.20	0.3	0.9	0.02
Brights_01	0.20	1.0	7.32	10.98	0.5	0.9	0.05	0.20	2.00	1.41	3.00	0.5	0.9	0.05
Brights_02	0.20	1.0	7.48	11.22	0.5	0.9	0.05	0.20	2.00	1.40	3.00	0.5	0.9	0.05
Brights_03	0.20	1.0	5.24	7.86	0.5	0.9	0.05	0.20	2.00	1.50	3.00	0.5	0.9	0.05
BR_UT_01	0.20	1.0	8.59	12.89	0.5	0.9	0.05	0.20	1.70	1.30	2.20	0.3	0.9	0.02
BR_UT_02	0.20	1.0	7.34	11.01	0.5	0.9	0.05	0.20	1.70	1.30	2.20	0.3	0.9	0.02
BR_UT_03	0.20	1.0	11.07	16.61	0.5	0.9	0.05	0.20	1.80	0.90	2.50	0.1	0.9	0.01
BR_UT_04	0.20	1.0	9.16	13.74	0.5	0.9	0.05	0.20	1.80	0.90	2.50	0.1	0.9	0.01
BR_UT_05_01	0.20	1.0	4.51	6.77	0.5	0.9	0.05	0.20	1.80	0.90	2.50	0.1	0.9	0.01
BR_UT_05_02	0.20	1.0	6.40	9.60	0.5	0.9	0.05	0.20	1.80	0.90	2.50	0.1	0.9	0.01
BR_UT_06	0.20	1.0	7.03	10.55	0.5	0.9	0.05	0.20	1.80	0.90	2.50	0.1	0.9	0.01
BR_01	0.20	1.0	5.23	7.85	0.5	0.9	0.05	0.20	1.70	1.30	2.20	0.3	0.9	0.02
BR_02	0.20	1.0	7.24	10.86	0.5	0.9	0.05	0.20	1.70	1.30	2.20	0.3	0.9	0.02
BR_03	0.20	1.0	6.50	9.75	0.5	0.9	0.05	0.20	1.70	1.30	2.20	0.3	0.9	0.02
BR_04	0.20	1.0	8.75	13.13	0.5	0.9	0.05	0.20	1.70	1.30	2.20	0.3	0.9	0.02
BR_05	0.20	1.0	3.42	5.13	0.5	0.9	0.05	0.20	1.50	1.88	1.88	0.5	0.9	0.05
BR_06	0.20	1.0	5.19	7.79	0.5	0.9	0.05	0.20	1.50	1.58	1.58	0.5	0.9	0.05
BR_07	0.20	1.0	4.16	6.24	0.5	0.9	0.05	0.20	1.50	1.72	1.72	0.5	0.9	0.05
BR_08	0.20	1.0	6.91	10.37	0.5	0.9	0.05	0.20	1.50	1.43	1.43	0.5	0.9	0.05
BR_09	0.20	1.0	5.70	8.55	0.5	0.9	0.05	0.20	1.50	1.53	1.53	0.5	0.9	0.05
BR_10	0.20	1.0	3.91	5.87	0.5	0.9	0.05	0.20	2.00	0.80	0.80	0.5	0.9	0.05
BR_11	0.20	1.0	6.56	9.84	0.5	0.9	0.05	0.20	2.00	0.80	0.80	0.5	0.9	0.05
BR_12	0.20	1.0	4.40	6.60	0.5	0.9	0.05	0.20	2.00	0.80	0.80	0.5	0.9	0.05
BR_13	0.20	1.0	7.14	10.71	0.5	0.9	0.05	0.20	2.00	1.42	8.00	0.5	0.9	0.05

Stantec

Appendix C Calibration Data
November 8, 2017

Subbasin	Original Values							June 2015 Calibration						
	Loss (Gridded CN)		Transform		Baseflow			Loss (Gridded CN)		Transform		Baseflow		
	Ratio	Factor	Time of Concentration	Storage Coefficient	Initial Discharge Ratio	Recession Constant	Ratio to Peak	Ratio	Factor	Tc Multiplier	R Multiplier	Initial Discharge Ratio	Recession Constant	Ratio to Peak
BR_14	0.20	1.0	3.87	5.81	0.5	0.9	0.05	0.20	1.40	0.90	2.50	0.1	0.9	0.01
BR_15	0.20	1.0	7.06	10.59	0.5	0.9	0.05	0.20	1.40	0.90	2.50	0.1	0.9	0.01
BR_16	0.20	1.0	1.14	1.71	0.5	0.9	0.05	0.20	1.40	0.90	2.50	0.1	0.9	0.01
BR_17	0.20	1.0	2.97	4.46	0.5	0.9	0.05	0.20	1.40	0.90	2.50	0.1	0.9	0.01
BR_18	0.20	1.0	2.87	4.31	0.5	0.9	0.05	0.20	1.40	0.90	2.50	0.1	0.9	0.01
BR_19	0.20	1.0	5.49	8.24	0.5	0.9	0.05	0.20	1.80	0.90	2.50	0.1	0.9	0.01
BR_20	0.20	1.0	6.23	9.35	0.5	0.9	0.05	0.20	1.80	0.90	2.50	0.1	0.9	0.01
BR_21	0.20	1.0	7.16	10.74	0.5	0.9	0.05	0.20	1.80	0.90	2.50	0.1	0.9	0.01
BR_22	0.20	1.0	1.34	2.01	0.5	0.9	0.05	0.20	1.80	0.90	2.50	0.1	0.9	0.01
BR_23	0.20	1.0	3.10	4.65	0.5	0.9	0.05	0.20	1.80	0.90	2.50	0.1	0.9	0.01
BR_24	0.20	1.0	7.26	10.89	0.5	0.9	0.05	0.20	1.80	0.90	2.50	0.1	0.9	0.01
BR_25	0.20	1.0	1.76	2.64	0.5	0.9	0.05	0.20	1.80	0.90	2.50	0.1	0.9	0.01
BR_26	0.20	1.0	7.44	11.16	0.5	0.9	0.05	0.20	1.40	0.90	1.80	0.1	0.9	0.01
BR_27	0.20	1.0	6.00	9.00	0.5	0.9	0.05	0.20	1.40	0.90	1.80	0.1	0.9	0.01
BR_28	0.20	1.0	8.07	12.11	0.5	0.9	0.05	0.20	1.40	0.90	1.80	0.1	0.9	0.01
Buckrun_Creek	0.20	1.0	12.08	18.12	0.5	0.9	0.05	0.20	2.00	1.25	8.00	0.5	0.9	0.05
Buck_Run	0.20	1.0	9.84	14.76	0.5	0.9	0.05	0.20	1.60	1.40	0.60	0.5	0.9	0.01
Cessna_Ck_01	0.20	1.0	1.43	2.15	0.5	0.9	0.05	0.20	1.80	0.90	2.50	0.1	0.9	0.01
Cessna_Ck_02	0.20	1.0	4.82	7.23	0.5	0.9	0.05	0.20	1.80	0.90	2.50	0.1	0.9	0.01
Cessna_UT_01	0.20	1.0	6.09	9.14	0.5	0.9	0.05	0.20	1.80	0.90	2.50	0.1	0.9	0.01
Eagle_01	0.20	1.0	5.67	8.51	0.5	0.9	0.05	0.20	1.50	1.53	1.53	0.5	0.9	0.05
Eagle_02	0.20	1.0	6.48	9.72	0.5	0.9	0.05	0.20	1.50	1.46	1.46	0.5	0.9	0.05
Eagle_03	0.20	1.0	4.63	6.95	0.5	0.9	0.05	0.20	1.50	1.65	1.65	0.5	0.9	0.05
Eagle_04	0.20	1.0	5.29	7.94	0.5	0.9	0.05	0.20	1.50	1.57	1.57	0.5	0.9	0.05
Eagle_05	0.20	1.0	4.19	6.29	0.5	0.9	0.05	0.20	1.50	1.72	1.71	0.5	0.9	0.05
Eagle_06	0.20	1.0	2.84	4.26	0.5	0.9	0.05	0.20	1.80	1.60	0.60	0.5	0.9	0.01
Eagle_07	0.20	1.0	5.91	8.87	0.5	0.9	0.05	0.20	1.80	1.51	0.60	0.5	0.9	0.01
Eagle_08	0.20	1.0	5.05	7.58	0.5	0.9	0.05	0.20	1.80	1.59	0.60	0.5	0.9	0.01
Eagle_09	0.20	1.0	4.82	7.23	0.5	0.9	0.05	0.20	1.80	1.60	0.60	0.5	0.9	0.01
Eagle_10	0.20	1.0	6.82	10.23	0.5	0.9	0.05	0.20	1.80	1.44	0.60	0.5	0.9	0.01
Eagle_11	0.20	1.0	3.04	4.56	0.5	0.9	0.05	0.20	1.80	1.60	0.60	0.5	0.9	0.01
Eagle_12	0.20	1.0	4.42	6.63	0.5	0.9	0.05	0.20	1.60	1.40	0.60	0.5	0.9	0.01
Eagle_13	0.20	1.0	5.13	7.70	0.5	0.9	0.05	0.20	1.60	1.40	0.60	0.5	0.9	0.01
Eagle_14	0.20	1.0	5.13	7.70	0.5	0.9	0.05	0.20	1.60	1.40	0.60	0.5	0.9	0.01
Eagle_15	0.20	1.0	8.49	12.74	0.5	0.9	0.05	0.20	1.60	1.40	0.60	0.5	0.9	0.01

Stantec

Appendix C Calibration Data
November 8, 2017

Subbasin	Original Values							June 2015 Calibration						
	Loss (Gridded CN)		Transform		Baseflow			Loss (Gridded CN)		Transform		Baseflow		
	Ratio	Factor	Time of Concentration	Storage Coefficient	Initial Discharge Ratio	Recession Constant	Ratio to Peak	Ratio	Factor	Tc Multiplier	R Multiplier	Initial Discharge Ratio	Recession Constant	Ratio to Peak
Flat_Branch_01	0.20	1.0	1.32	1.98	0.5	0.9	0.05	0.20	1.80	1.60	0.60	0.5	0.9	0.01
Flat_Branch_02	0.20	1.0	10.05	15.08	0.5	0.9	0.05	0.20	1.60	1.40	0.60	0.5	0.9	0.01
Flat_Branch_03	0.20	1.0	7.04	10.56	0.5	0.9	0.05	0.20	1.60	1.40	0.60	0.5	0.9	0.01
Fourmile_Run_01	0.20	1.0	7.55	11.33	0.5	0.9	0.05	0.20	1.40	0.90	1.80	0.1	0.9	0.01
Fourmile_Run_02	0.20	1.0	5.44	8.16	0.5	0.9	0.05	0.20	1.40	0.90	1.80	0.1	0.9	0.01
Howard_Run	0.20	1.0	4.87	7.31	0.5	0.9	0.05	0.20	1.50	1.62	1.61	0.5	0.9	0.05
Lye_01	0.20	1.0	9.43	14.15	0.5	0.9	0.05	0.20	1.50	1.32	1.32	0.5	0.9	0.05
Lye_02	0.20	1.0	8.36	12.54	0.5	0.9	0.05	0.20	1.50	1.36	1.36	0.5	0.9	0.05
Lye_03	0.20	1.0	5.75	8.63	0.5	0.9	0.05	0.20	1.50	1.52	1.52	0.5	0.9	0.05
Lye_04	0.20	1.0	7.12	10.68	0.5	0.9	0.05	0.20	1.50	1.42	1.42	0.5	0.9	0.05
Lye_05	0.20	1.0	4.85	7.28	0.5	0.9	0.05	0.20	1.50	1.62	1.62	0.5	0.9	0.05
Lye_06	0.20	1.0	3.41	5.12	0.5	0.9	0.05	0.15	1.00	1.10	1.80	0.1	0.9	0.01
Lye_07	0.20	1.0	7.01	10.52	0.5	0.9	0.05	0.15	1.00	0.70	1.90	0.1	0.9	0.01
Lye_08	0.20	1.0	5.22	7.83	0.5	0.9	0.05	0.15	1.00	0.70	1.90	0.1	0.9	0.01
Lye_09	0.20	1.0	6.69	10.04	0.5	0.9	0.05	0.15	1.20	1.45	1.20	0.1	0.9	0.01
Potato_01	0.20	1.0	8.24	12.36	0.5	0.9	0.05	0.20	1.40	0.90	2.50	0.1	0.9	0.01
Potato_02	0.20	1.0	5.99	8.99	0.5	0.9	0.05	0.20	1.40	0.90	2.50	0.1	0.9	0.01
Potato_03	0.20	1.0	5.23	7.85	0.5	0.9	0.05	0.20	1.80	0.90	2.50	0.1	0.9	0.01
Potato_04	0.20	1.0	5.72	8.58	0.5	0.9	0.05	0.20	1.80	0.90	2.50	0.1	0.9	0.01
Potato_05	0.20	1.0	6.47	9.71	0.5	0.9	0.05	0.20	1.80	0.90	2.50	0.1	0.9	0.01
Ripley_Run	0.20	1.0	5.89	8.84	0.5	0.9	0.05	0.20	1.80	0.90	2.50	0.1	0.9	0.01
Stahl_01	0.20	1.0	4.17	6.26	0.5	0.9	0.05	0.20	2.00	0.80	0.80	0.5	0.9	0.05
Stahl_02	0.20	1.0	7.02	10.53	0.5	0.9	0.05	0.20	2.00	1.43	3.00	0.5	0.9	0.05
Stahl_03	0.20	1.0	6.40	9.60	0.5	0.9	0.05	0.20	2.00	1.47	8.00	0.5	0.9	0.05
Stahl_04	0.20	1.0	6.38	9.57	0.5	0.9	0.05	0.20	2.00	1.47	8.00	0.5	0.9	0.05
The_Outlet_North_01	0.20	1.0	6.42	9.63	0.5	0.9	0.05	0.20	1.80	0.90	2.50	0.1	0.9	0.01
The_Outlet_North_02	0.20	1.0	6.77	10.16	0.5	0.9	0.05	0.20	1.80	0.90	2.50	0.1	0.9	0.01
The_Outlet_01	0.20	1.0	7.51	11.27	0.5	0.9	0.05	0.20	2.00	0.80	0.80	0.5	0.9	0.05
The_Outlet_02	0.20	1.0	6.55	9.83	0.5	0.9	0.05	0.20	2.00	0.80	0.80	0.5	0.9	0.05
The_Outlet_03	0.20	1.0	5.59	8.39	0.5	0.9	0.05	0.20	2.00	1.50	3.00	0.5	0.9	0.05
The_Outlet_04	0.20	1.0	5.14	7.71	0.5	0.9	0.05	0.20	2.00	1.50	3.00	0.5	0.9	0.05
The_Outlet_05	0.20	1.0	6.88	10.32	0.5	0.9	0.05	0.20	2.00	1.44	3.00	0.5	0.9	0.05

Stantec

Subbasin Parameter Calibration – August 2007

Subbasin	Original Values							August 2007 Calibration						
	Loss (Gridded CN)		Transform		Baseflow			Loss (Gridded CN)		Transform		Baseflow		
	Ratio	Factor	Time of Concentration	Storage Coefficient	Initial Discharge Ratio	Recession Constant	Ratio to Peak	Ratio	Factor	Tc Multiplier	R Multiplier	Initial Discharge Ratio	Recession Constant	Ratio to Peak
Average	0.20	1.00			0.50	0.90	0.05	0.30	2.50	1.00	3.90	0.10	0.01	0.01
Aurand_Trib_01	0.20	1.0	5.53	8.30	0.5	0.9	0.05	0.30	2.50	0.99	3.90	0.1	0.01	0.01
Aurand_01	0.20	1.0	3.72	5.58	0.5	0.9	0.05	0.30	2.50	0.99	3.91	0.1	0.01	0.01
Aurand_02	0.20	1.0	5.98	8.97	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
Aurand_03	0.20	1.0	5.93	8.90	0.5	0.9	0.05	0.30	2.50	0.99	3.90	0.1	0.01	0.01
Aurand_04	0.20	1.0	5.21	7.82	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
Aurand_05	0.20	1.0	5.73	8.60	0.5	0.9	0.05	0.30	2.50	0.99	3.90	0.1	0.01	0.01
Brights_01	0.20	1.0	7.32	10.98	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
Brights_02	0.20	1.0	7.48	11.22	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
Brights_03	0.20	1.0	5.24	7.86	0.5	0.9	0.05	0.30	2.50	0.99	3.91	0.1	0.01	0.01
BR_UT_01	0.20	1.0	8.59	12.89	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
BR_UT_02	0.20	1.0	7.34	11.01	0.5	0.9	0.05	0.30	2.50	0.99	3.90	0.1	0.01	0.01
BR_UT_03	0.20	1.0	11.07	16.61	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
BR_UT_04	0.20	1.0	9.16	13.74	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
BR_UT_05_01	0.20	1.0	4.51	6.77	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
BR_UT_05_02	0.20	1.0	6.40	9.60	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
BR_UT_06	0.20	1.0	7.03	10.55	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
BR_01	0.20	1.0	5.23	7.85	0.5	0.9	0.05	0.30	2.50	0.99	3.90	0.1	0.01	0.01
BR_02	0.20	1.0	7.24	10.86	0.5	0.9	0.05	0.30	2.50	0.99	3.90	0.1	0.01	0.01
BR_03	0.20	1.0	6.50	9.75	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
BR_04	0.20	1.0	8.75	13.13	0.5	0.9	0.05	0.30	2.50	1.01	3.90	0.1	0.01	0.01
BR_05	0.20	1.0	3.42	5.13	0.5	0.9	0.05	0.30	2.50	0.99	3.90	0.1	0.01	0.01
BR_06	0.20	1.0	5.19	7.79	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
BR_07	0.20	1.0	4.16	6.24	0.5	0.9	0.05	0.30	2.50	1.01	3.89	0.1	0.01	0.01
BR_08	0.20	1.0	6.91	10.37	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
BR_09	0.20	1.0	5.70	8.55	0.5	0.9	0.05	0.30	2.50	1.00	3.89	0.1	0.01	0.01
BR_10	0.20	1.0	3.91	5.87	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
BR_11	0.20	1.0	6.56	9.84	0.5	0.9	0.05	0.30	2.50	1.01	3.90	0.1	0.01	0.01
BR_12	0.20	1.0	4.40	6.60	0.5	0.9	0.05	0.30	2.50	1.00	3.89	0.1	0.01	0.01
BR_13	0.20	1.0	7.14	10.71	0.5	0.9	0.05	0.30	2.50	0.99	3.90	0.1	0.01	0.01

Appendix C Calibration Data
November 8, 2017

Subbasin	Original Values							August 2007 Calibration						
	Loss (Gridded CN)		Transform		Baseflow			Loss (Gridded CN)		Transform		Baseflow		
	Ratio	Factor	Time of Concentration	Storage Coefficient	Initial Discharge Ratio	Recession Constant	Ratio to Peak	Ratio	Factor	Tc Multiplier	R Multiplier	Initial Discharge Ratio	Recession Constant	Ratio to Peak
BR_14	0.20	1.0	3.87	5.81	0.5	0.9	0.05	0.30	2.50	1.01	3.91	0.1	0.01	0.01
BR_15	0.20	1.0	7.06	10.59	0.5	0.9	0.05	0.30	2.50	1.01	3.90	0.1	0.01	0.01
BR_16	0.20	1.0	1.14	1.71	0.5	0.9	0.05	0.30	2.50	0.96	3.92	0.1	0.01	0.01
BR_17	0.20	1.0	2.97	4.46	0.5	0.9	0.05	0.30	2.50	1.01	3.90	0.1	0.01	0.01
BR_18	0.20	1.0	2.87	4.31	0.5	0.9	0.05	0.30	2.50	1.01	3.90	0.1	0.01	0.01
BR_19	0.20	1.0	5.49	8.24	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
BR_20	0.20	1.0	6.23	9.35	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
BR_21	0.20	1.0	7.16	10.74	0.5	0.9	0.05	0.30	2.50	1.01	3.90	0.1	0.01	0.01
BR_22	0.20	1.0	1.34	2.01	0.5	0.9	0.05	0.30	2.50	0.97	3.88	0.1	0.01	0.01
BR_23	0.20	1.0	3.10	4.65	0.5	0.9	0.05	0.30	2.50	1.00	3.89	0.1	0.01	0.01
BR_24	0.20	1.0	7.26	10.89	0.5	0.9	0.05	0.30	2.50	1.01	3.90	0.1	0.01	0.01
BR_25	0.20	1.0	1.76	2.64	0.5	0.9	0.05	0.30	2.50	1.02	3.90	0.1	0.01	0.01
BR_26	0.20	1.0	7.44	11.16	0.5	0.9	0.05	0.30	2.50	0.99	3.90	0.1	0.01	0.01
BR_27	0.20	1.0	6.00	9.00	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
BR_28	0.20	1.0	8.07	12.11	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
Buckrun_Creek	0.20	1.0	12.08	18.12	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
Buck_Run	0.20	1.0	9.84	14.76	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
Cessna_Ck_01	0.20	1.0	1.43	2.15	0.5	0.9	0.05	0.30	2.50	0.98	3.91	0.1	0.01	0.01
Cessna_Ck_02	0.20	1.0	4.82	7.23	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
Cessna_UT_01	0.20	1.0	6.09	9.14	0.5	0.9	0.05	0.30	2.50	1.00	3.89	0.1	0.01	0.01
Eagle_01	0.20	1.0	5.67	8.51	0.5	0.9	0.05	0.30	2.50	1.01	3.90	0.1	0.01	0.01
Eagle_02	0.20	1.0	6.48	9.72	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
Eagle_03	0.20	1.0	4.63	6.95	0.5	0.9	0.05	0.30	2.50	0.99	3.90	0.1	0.01	0.01
Eagle_04	0.20	1.0	5.29	7.94	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
Eagle_05	0.20	1.0	4.19	6.29	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
Eagle_06	0.20	1.0	2.84	4.26	0.5	0.9	0.05	0.30	2.50	0.99	3.90	0.1	0.01	0.01
Eagle_07	0.20	1.0	5.91	8.87	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
Eagle_08	0.20	1.0	5.05	7.58	0.5	0.9	0.05	0.30	2.50	1.01	3.91	0.1	0.01	0.01
Eagle_09	0.20	1.0	4.82	7.23	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
Eagle_10	0.20	1.0	6.82	10.23	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
Eagle_11	0.20	1.0	3.04	4.56	0.5	0.9	0.05	0.30	2.50	0.99	3.90	0.1	0.01	0.01
Eagle_12	0.20	1.0	4.42	6.63	0.5	0.9	0.05	0.30	2.50	1.00	3.91	0.1	0.01	0.01
Eagle_13	0.20	1.0	5.13	7.70	0.5	0.9	0.05	0.30	2.50	0.99	3.90	0.1	0.01	0.01
Eagle_14	0.20	1.0	5.13	7.70	0.5	0.9	0.05	0.30	2.50	0.99	3.90	0.1	0.01	0.01
Eagle_15	0.20	1.0	8.49	12.74	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01

Stantec

Appendix C Calibration Data
November 8, 2017

| Subbasin | Original Values | | | | | | | August 2007 Calibration | | | | | | |
| | Loss (Gridded CN) | | Transform | | Baseflow | | | Loss (Gridded CN) | | Transform | | Baseflow | | |
	Ratio	Factor	Time of Concentration	Storage Coefficient	Initial Discharge Ratio	Recession Constant	Ratio to Peak	Ratio	Factor	Tc Multiplier	R Multiplier	Initial Discharge Ratio	Recession Constant	Ratio to Peak
Flat_Branch_01	0.20	1.0	1.32	1.98	0.5	0.9	0.05	0.30	2.50	0.98	3.89	0.1	0.01	0.01
Flat_Branch_02	0.20	1.0	10.05	15.08	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
Flat_Branch_03	0.20	1.0	7.04	10.56	0.5	0.9	0.05	0.30	2.50	0.99	3.90	0.1	0.01	0.01
Fourmile_Run_01	0.20	1.0	7.55	11.33	0.5	0.9	0.05	0.30	2.50	1.01	3.90	0.1	0.01	0.01
Fourmile_Run_02	0.20	1.0	5.44	8.16	0.5	0.9	0.05	0.30	2.50	0.99	3.90	0.1	0.01	0.01
Howard_Run	0.20	1.0	4.87	7.31	0.5	0.9	0.05	0.30	2.50	1.01	3.90	0.1	0.01	0.01
Lye_01	0.20	1.0	9.43	14.15	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
Lye_02	0.20	1.0	8.36	12.54	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
Lye_03	0.20	1.0	5.75	8.63	0.5	0.9	0.05	0.30	2.50	1.01	3.90	0.1	0.01	0.01
Lye_04	0.20	1.0	7.12	10.68	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
Lye_05	0.20	1.0	4.85	7.28	0.5	0.9	0.05	0.30	2.50	1.01	3.90	0.1	0.01	0.01
Lye_06	0.20	1.0	3.41	5.12	0.5	0.9	0.05	0.30	2.50	1.00	3.91	0.1	0.01	0.01
Lye_07	0.20	1.0	7.01	10.52	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
Lye_08	0.20	1.0	5.22	7.83	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
Lye_09	0.20	1.0	6.69	10.04	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
Potato_01	0.20	1.0	8.24	12.36	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
Potato_02	0.20	1.0	5.99	8.99	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
Potato_03	0.20	1.0	5.23	7.85	0.5	0.9	0.05	0.30	2.50	0.99	3.90	0.1	0.01	0.01
Potato_04	0.20	1.0	5.72	8.58	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
Potato_05	0.20	1.0	6.47	9.71	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
Ripley_Run	0.20	1.0	5.89	8.84	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
Stahl_01	0.20	1.0	4.17	6.26	0.5	0.9	0.05	0.30	2.50	1.01	3.90	0.1	0.01	0.01
Stahl_02	0.20	1.0	7.02	10.53	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
Stahl_03	0.20	1.0	6.40	9.60	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
Stahl_04	0.20	1.0	6.38	9.57	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
The_Outlet_North_01	0.20	1.0	6.42	9.63	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
The_Outlet_North_02	0.20	1.0	6.77	10.16	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
The_Outlet_01	0.20	1.0	7.51	11.27	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
The_Outlet_02	0.20	1.0	6.55	9.83	0.5	0.9	0.05	0.30	2.50	1.01	3.90	0.1	0.01	0.01
The_Outlet_03	0.20	1.0	5.59	8.39	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01
The_Outlet_04	0.20	1.0	5.14	7.71	0.5	0.9	0.05	0.30	2.50	0.99	3.90	0.1	0.01	0.01
The_Outlet_05	0.20	1.0	6.88	10.32	0.5	0.9	0.05	0.30	2.50	1.00	3.90	0.1	0.01	0.01

Stantec

Reach Parameter Calibration

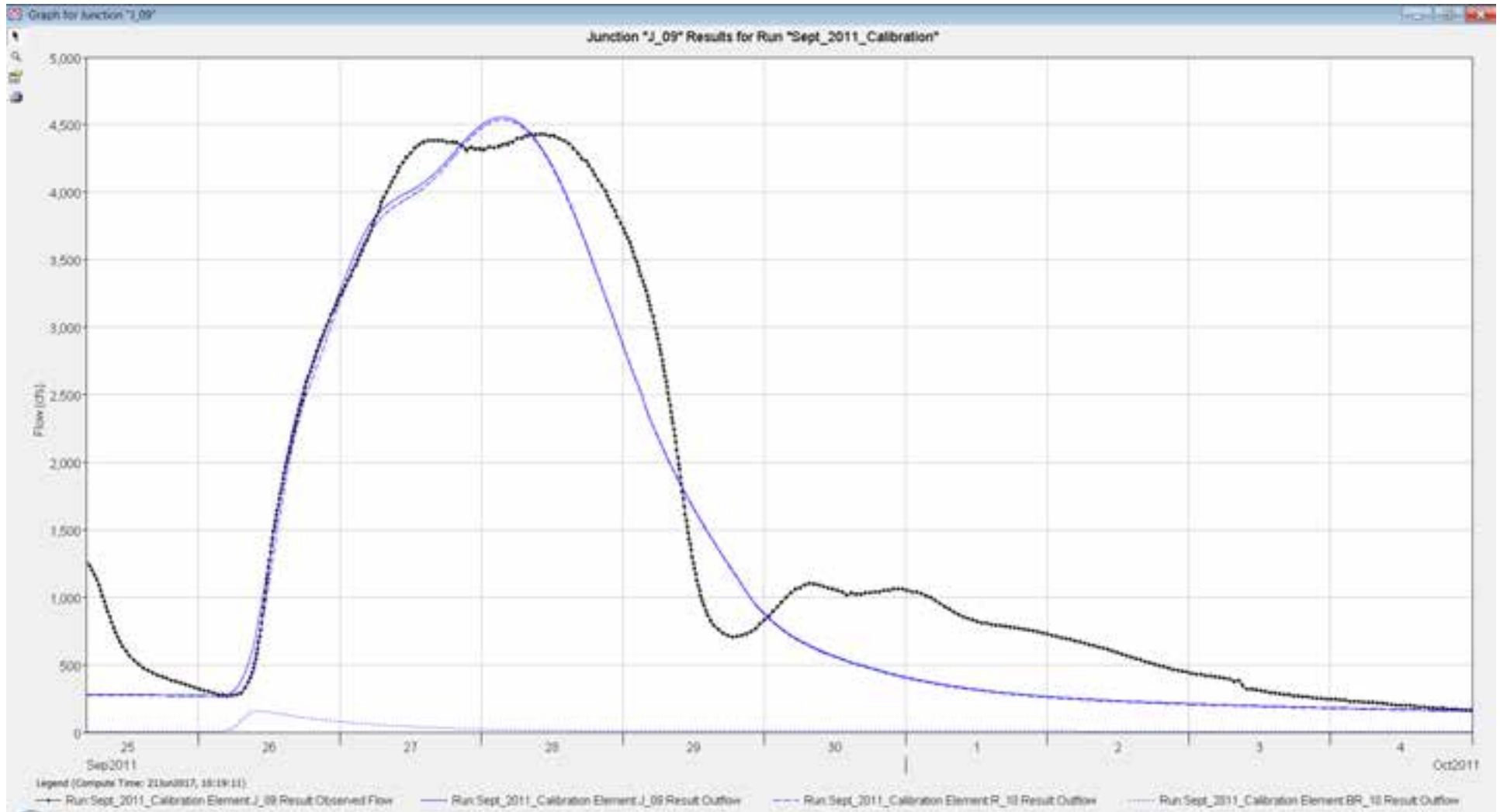| Reach	Length	Slope	Original Values		Sept. 2011 Calibration			June 2015 Calibration			August 2007 (Stantec)		
			Lag Time	Velocity	Lag Time	Velocity	Multiplier	Lag Time	Velocity	Multiplier	Lag Time	Velocity	Multiplier
			Average	2.01		1.49	1.49		1.80	1.15		2.03	1.00
R_19	22600	0.0001	190	1.98	360	1.05	1.89	190	1.98	1.00	190	1.98	1.00
R_20	18800	0.0005	160	1.96	305	1.03	1.91	160	1.96	1.00	160	1.96	1.00
R_21	27000	0.0003	230	1.96	440	1.02	1.91	230	1.96	1.00	230	1.96	1.00
R_22	2900	0.0001	20	2.42	25	1.93	1.25	25	1.93	1.25	20	2.42	1.00
R_23	8300	0.0006	70	1.98	135	1.02	1.93	70	1.98	1.00	70	1.98	1.00
R_24	3000	0.0029	25	2.00	25	2.00	1.00	25	2.00	1.00	30	1.67	1.20
R_25	20900	0.0004	170	2.05	325	1.07	1.91	170	2.05	1.00	170	2.05	1.00
R_26	12100	0.0004	100	2.02	190	1.06	1.90	100	2.02	1.00	100	2.02	1.00
R_37	12900	0.001	108	1.99	170	1.26	1.57	110	1.95	1.02	110	1.95	1.02
R_38	21500	0.0009	179	2.00	275	1.30	1.54	180	1.99	1.01	180	1.99	1.01
R_39	14400	0.0015	120	2.00	305	0.79	2.54	120	2.00	1.00	120	2.00	1.00
R_40	21700	0.0005	181	2.00	455	0.79	2.51	180	2.01	0.99	180	2.01	0.99
R_41	5300	0.0012	44	2.01	110	0.80	2.50	45	1.96	1.02	40	2.21	0.91
R_45	1600	0.0002			45	0.59		15	1.78		10	2.67	
R_46	21500	0.0004			580	0.62		215	1.67		180	1.99	
R_47	15700	0.0001	131	2.00	110	2.38	0.84	195	1.34	1.49	130	2.01	0.99
R_48	10700	0.0001	89	2.00	75	2.38	0.84	135	1.32	1.52	90	1.98	1.01
R_49	13000	0.0001	108	2.01	90	2.41	0.83	160	1.35	1.48	110	1.97	1.02
R_50	9300	0.0003	78	1.99	65	2.38	0.83	120	1.29	1.54	80	1.94	1.03
R_51	25500	0.0011	213	2.00	180	2.36	0.85	320	1.33	1.50	210	2.02	0.99
R_52	21600	0.0005	180	2.00	155	2.32	0.86	270	1.33	1.50	180	2.00	1.00
R_53	8900	0.0001	74	2.00	60	2.47	0.81	110	1.35	1.49	70	2.12	0.95
R_55	18300	0.0003	150	2.03	225	1.36	1.50	150	2.03	1.00	150	2.03	1.00
R_56	13300	0.0005	110	2.02	165	1.34	1.50	110	2.02	1.00	110	2.02	1.00
R_57	21300	0.0013	180	1.97	270	1.31	1.50	180	1.97	1.00	180	1.97	1.00
R_58	13000	0.0001	110	1.97	165	1.31	1.50	110	1.97	1.00	110	1.97	1.00
R_59	11400	0.0005	100	1.90	150	1.27	1.50	100	1.90	1.00	100	1.90	1.00
R_60	2400	0.0021	20	2.00	20	2.00	1.00	20	2.00	1.00	20	2.00	1.00

Stantec

Appendix C Calibration Results

September 2011 Event – USGS Gage 04189000 Blanchard River Downstream of Findlay (Using Sept. 2011 Calibrated Geometry)
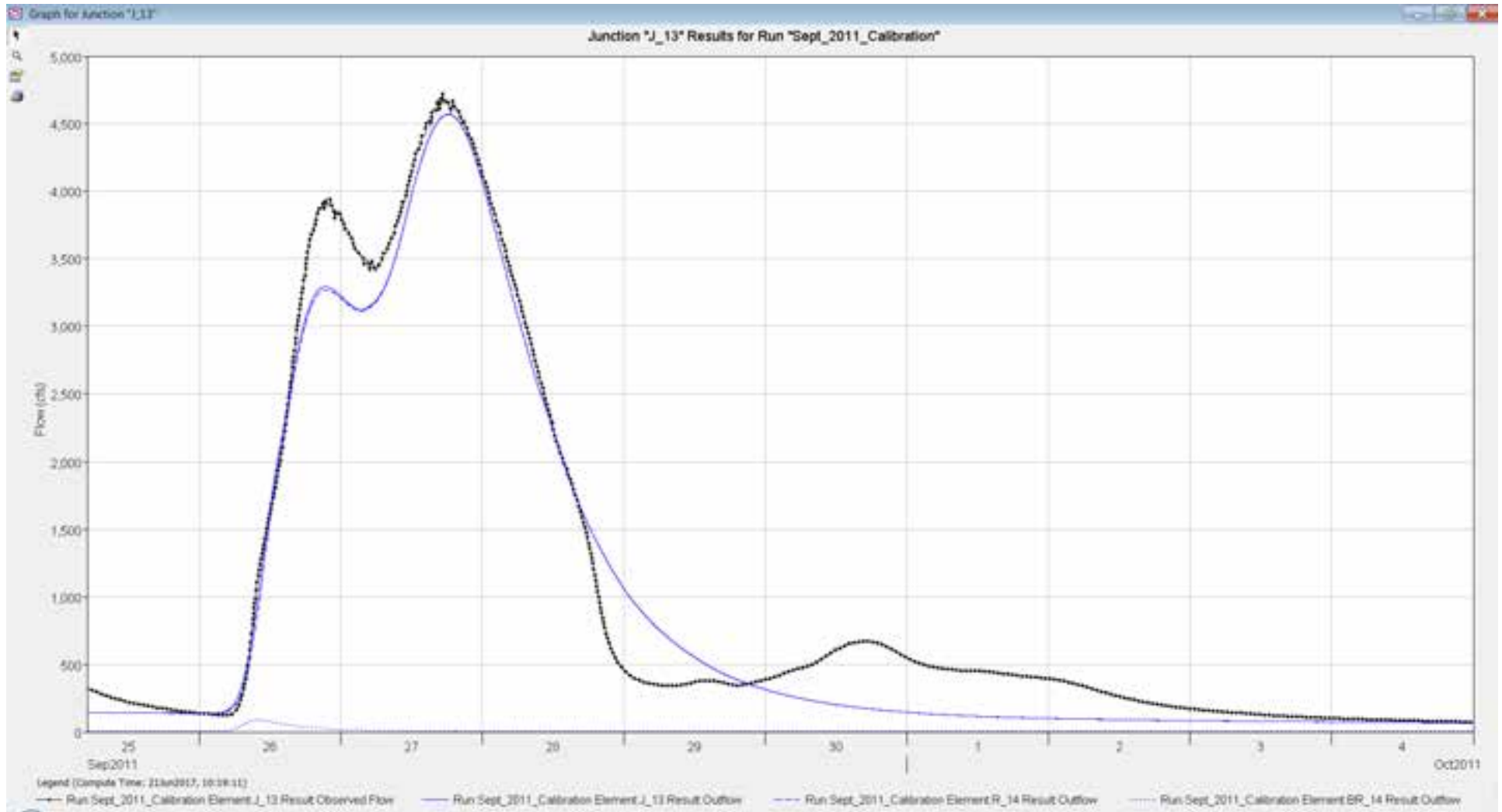
Appendix C Calibration Results

September 2011 Event – USGS Gage 04188400 Blanchard River Upstream of Findlay (Using Sept. 2011 Calibrated Geometry)

Appendix C Calibration Results

September 2011 Event – USGS Gage 04188337 Blanchard River Downstream of Mt. Blanchard (Using Sept. 2011 Calibrated Geometry)

Appendix C Calibration Results

September 2011 Event – USGS Gage 04188496 Eagle Creek Above Findlay (Using Sept. 2011 Calibrated Geometry)

Appendix C Calibration Results

September 2011 Event – USGS Gage 04188433 Lye Creek Above Findlay (Using Sept. 2011 Calibrated Geometry)

Appendix C Calibration Results

June 2015 Event – USGS Gage 04189000 Blanchard River Downstream of Findlay (Using June 2015 Calibrated Geometry)

Appendix C Calibration Results

June 2015 Event – USGS Gage 04188400 Blanchard River Upstream of Findlay (Using June 2015 Calibrated Geometry)

Stantec

Appendix C Calibration Results

June 2015 Event – USGS Gage 04188337 Blanchard River Downstream of Mt. Blanchard (Using June 2015 Calibrated Geometry)

Appendix C Calibration Results

June 2015 Event – USGS Gage 04188496 Eagle Creek Above Findlay (Using June 2015 Calibrated Geometry)

Stantec

Appendix C Calibration Results

June 2015 Event – USGS Gage 04188433 Lye Creek Above Findlay (Using June 2015 Calibrated Geometry)

Stantec

HYDROLOGIC EVALUATION OF THE BLANCHARD RIVER

Appendix C Calibration Results

August 2007 Event – USGS Gage 04189000 Blanchard River Downstream of Findlay (Using August 2007 Calibrated Geometry)