Final

North Branch Chicago River

Middle Fork and Skokie Rivers

U.S. Army Corps of Engineers
Chicago District

Planning Assistance to States Report

July 2019

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Executive Summary

This Planning Assistance to States (PAS) Report documents the purpose, methods and findings of a watershed evaluation of the Middle Fork and Skokie River of the North Branch of the Chicago River in Lake County, Illinois. The study was completed by the United States Army Corps of Engineers (USACE) at the request of the following non-federal sponsors (NFSs): City of Highland Park, the Lake County Stormwater Management Commission, the City of Lake Forest, the Village of Deerfield, and the East Skokie Drainage District. The purpose of this study was to aid NFSs in developing future plans for addressing flood damages. Recent flooding prompted communities in these watersheds to seek a better understanding of the current conditions. This report presents updated hydrology and hydraulic data, and an estimate of average annual economic damages to provide a better understanding of the problem and determine the potential for future flood risk management efforts.

To characterize existing flood conditions, this watershed evaluation made use of available hydrology and hydraulics models and updated precipitation frequencies. The hydrology and hydraulics were updated using data from the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC), the United States Geological Survey (USGS) and the Federal Emergency Management Agency (FEMA). USACE analyzed the sourced data and performed calibrations, as needed. Updated Illinois State Water Survey (ISWS) Bulletin 70 data was incorporated into the models. The models were used to produce outputs in the Hydrologic Engineering Center's River Analysis System (HEC-RAS) software for the economic analyses.

In addition, an evaluation was completed to test the performance of a reservoir on each river and demonstrate the possible effectiveness of structural features. The effectiveness of these structural features were estimated by reduced flood stages, and the resulting reductions in structure damages. The following reservoirs were selected based on the primary areas reported as flooded during the July 2017 flood event: a 130 acre-foot reservoir at the Highland Park Country Club and a 250 acre-foot reservoir at the Prairie Wolf Forest Preserve. It is assumed that reservoirs located upstream near the primary flood sites would be most efficient reservoir location for reducing flooding at the selected flood areas downstream.

USACE partitioned its economic analyses into two primary tasks. The first task involved developing an updated structure inventory and inputs for the Hydrologic Engineering Center's Flood Damage Analysis (HEC-FDA) software using source data from the Illinois Department of Natural Resources (IDNR). The second task involved performing an economic evaluation to understand the frequency, severity, and location of flood damages anticipated within the study area while also analyzing the effectiveness of the two reservoirs in reducing flood damages.

The economic evaluation compared the economic damages over a 50-year period of analysis, from 2019 to 2068, for two conditions. The future without-project (FWOP) condition assumed that there would be no measures taken to mitigate flood damages within the period of analysis. The future with-project (FWP) condition assumed the construction of the two reservoirs to reduce flood damages. The estimated flood damages for both conditions were compared to understand the efficacy of these structural alternatives and their economic viability.

The economic evaluation revealed that the reservoirs would not significantly reduce flood damages in the Skokie River or Middle Fork watersheds; less than 5% of the total average annual damages were reduced under the evaluated FWP conditions, for both rivers. Additionally, the scale of damages for the entire study area indicates that it is unlikely a structural measure would be a cost-effective (i.e., the average annual reduction in structural flood damages (benefits) would not exceed the average annual cost of implementing a structural measure). Furthermore, the ability to expand the capacity of the reservoirs or change the location is difficult because of the high level of urban development.

Given the evaluated reservoirs had little impact on reducing flood damages, USACE does not believe there is a federal interest in proceeding to a specifically authorized study. Based on the analysis, it is unlikely an economically viable structural alternative (i.e., one resulting in a benefit-to-cost ratio greater than 1.0) could be identified. Factors considered in this assessment are the locations of the evaluated structures which are geographically spread across a large area, as well as limited real estate available to implement structural measures, and the scale of damages for the entire study area indicates that it is unlikely a structural measure would be a cost-effective. USACE recommends nonstructural alternatives be considered by the local communities, including: structure elevation, structure relocation, buyouts, floodproofing, implementation of a flood warning system, and floodplain regulation.

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List of Acronyms

ACE	Annual Chance Exceedance
CFS	Cubic Feet Per Second
DEM	Digital Elevation Model
DRV	Depreciated Replacement Value
DWP	Detailed Watershed Plan
EGM	Economic Guidance Memorandum
ESRI	Environmental Systems Research Institute
FDA	Flood Damage Analysis
FEMA	Federal Emergency Management Agency
FIS	Flood Insurance Study
FWOP	Future Without-Project
FWP	Future With-Project
FY	Fiscal Year
GDM	General Design Memorandum
H&H	Hydrology & Hydraulics
HEC	Hydrologic Engineering Center
HMS	Hydrologic Modeling System
IDNR	Illinois Department of Natural Resources
ISWS	Illinois State Water Survey
IWR	Institute for Water Resources
MWRDGC	Metropolitan Water Reclamation District of Greater Chicago
NBCR	North Branch Chicago River
NEXRAD	Next-Generation Weather Radar
NFS	Non-Federal Sponsor
NOAA	National Oceanic and Atmospheric Administration
NSI	National Structure Inventory
OWR	Office of Water Resources
PAS	Planning Assistance to States
QA/QC	Quality Assurance/Quality Control
RAS	River Analysis System
SCS	Soil Conservation Service
SFHA	Special Flood Hazard Area
SI	Structure Inventory
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WSP	Water Surface Profile

Chapter 1 Introduction

1.1 Background

The United States Army Corps of Engineers (USACE) last studied the North Branch Chicago River watershed, extensively, in the early 1980's at the request of Lake and Cook Counties. At that time, both counties had recently completed a study of the Watershed Implementation Plan of the North Branch of the Chicago River. The study resulted in the construction of several reservoirs, but primarily focused on the West Branch. Since then, the North Branch of the Chicago River has not been evaluated, in-depth, by USACE.

State and local authorities have conducted more recent analyses. In 2009, the Lake County Stormwater Management District and the East Skokie Drainage District evaluated the Skokie River Watershed. In 2011, the Illinois Department of Natural Resources (IDNR) completed an investigation of two sites owned, partially, by the State of Illinois along the Middle Fork and Skokie River to determine the potential for future flood risk management efforts. The effort included more recent hydraulic modeling as well as an updated structure inventory. These efforts, as well as others, were incorporated into this study effort.

1.2 Study Purpose

The purpose of this study was to evaluate the watersheds of the Middle Fork and Skokie River (or East Fork) of the North Branch of the Chicago River. Recent flooding due to heavy rainfalls, most notably in July and October of 2017, prompted communities in these watersheds to seek a better understanding of the current conditions. This study updated the hydrologic and hydraulic data within the study area of the Skokie River and the Middle Fork in addition to evaluating estimated economic damages. The intent of updating the data and evaluations was to provide a better understanding of the flood conditions along both rivers and help to determine the potential for future flood risk management efforts. The purpose of this study was to aid non-Federal sponsors (NFS) in developing future plans for addressing flood damages. The NFSs of this study are: the City of Highland Park, the Lake County Stormwater Management Commission, the City of Lake Forest, the Village of Deerfield, and the East Skokie Drainage District.

1.3 Scope of Work

TAs described in the scope of work dated 16 January 2018, the study was partitioned into two categories, hydrology and hydraulics (H&H) and economics. The scope of work included updating the existing hydrology and hydraulic models with current data. Flood inundation maps were created using updated water surface profiles (WSPs) developed by the H&H models. The scope was later modified to test performance of previously evaluated structural measures. Given available funds, study team (USACE and NFSs) decided to evaluate two possible reservoirs, to demonstrate the possible effectiveness of structural features. The two possible reservoir projects, were evaluated for potential flood risk reduction benefits. The reservoirs evaluated were a 130 acre-foot storage basin along the Skokie River and a 250 acre-foot storage basin along the Middle Fork.

Furthermore, an economic evaluation was conducted using the Hydrologic Engineering Center's Flood Damage Analysis (HEC-FDA) software. The economic evaluation utilized an updated structure inventory that was developed using data collected by IDNR and local communities and, later, cross-referenced with the National Structure Inventory (NSI). The analysis evaluated estimated without-project economic damages which could be expected due to flooding over a 50-year period of analysis and also the potential economic benefits that would be associated with the implementation of the two proposed reservoirs represented in the hydraulic model. The effectiveness of the reservoirs would be estimated by reduced flood stages (as determined by the H&H analysis), and the resulting reductions in structure damages (as determined by the economic analysis).

Table 1-1 outlines the scope of work for the study.

Table 1-1: PAS-22 NBCR Study Tasks

PAS: NBCR Study Tasks	
Description	
Overall Task	**Sub-Task**
H&H: Utilize Existing Hydraulic Model and Create New Hydrology Model	Update Hydrology Model (HMS)
	Incorporate Updated ISWS Bulletin 70 Data into Models
	Geo-reference H&H Cross-Sections and Bridge Structures
	Produce HEC-FDA H&H Input Files
	Produce GIS Shapefiles (Inundation Maps, etc.)
	Provide Maximum Inundation Area for Inventory Development
	Perform Analysis and QA/QC Evaluation
Economics: Develop Structure Inventory	Collect Parcel Data for Structure Inventory (GIS & Assessor)
	Assign Damage Categories & Occupancy Types
	Identify Damage Reach Declinations
	Assign River Stationing
	Assign Ground Elevations
	Survey Structure Elevations (FFE & Low Entry)
	Compile HEC-FDA Input Files
Economics: Construct HEC-FDA Study & Perform Evaluation	Construct new study in current HEC-FDA version
	Perform analysis and QA/QC evaluation
	Produce output files and summary data
	Create damage maps
Economics/Planning: Document Analyses	Document analyses results, recommendations, assumptions, and uncertainties

1.3.1 H&H Scope Description

The updated hydrology and hydraulic analyses were used in existing models to create water surface profiles and inundation maps for various flood frequency events for evaluation in the economic model. A secondary objective was to evaluate whether the existing models provide a reasonable representation of real world conditions; this was necessary to determine if re-calibration of the hydrology model or development of a new, or updated, hydraulic model would be expected to provide a better representation of current flood damages. This was accomplished by comparing hydrologic model results from previous calibration against flow frequency analysis at available gage locations and any available high water marks or gage information relative to damage locations.

The existing hydraulic models for the Middle Fork and Skokie River were used for analysis. Existing hydrology models include the FIS HEC-1 model and the HEC-HMS model developed by the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) for the North Branch Chicago River – Detailed Watershed Plan (NBCR-DWP). An updated hydrologic model was developed using assumed values from the Illinois State Water Survey's (ISWS) Bulletin 70, released in March 2019. Routing reaches in the hydrology model were used to represent overbank flood storage and attenuation. The only known hydraulic models available were the FIS HEC-2 models, as updated for previous efforts. The steady-state HEC-2 model included detailed cross-sections and bridges, but did not include the geo-referenced model geometry necessary to develop inundation mapping. Key cross-section locations were used, along with the Special Flood Hazard Area (SFHA) delineations, to estimate inundation areas for the economic modeling.

1.3.2 Economic Analyses Scope Description

The primary objectives of the economic analyses were to evaluate the baseline condition in order to understand the frequency, severity, and location of flood damages anticipated within the study area and to evaluate the effectiveness of two reservoirs, in terms of reducing flood damages, within the study area. These analyses were performed using standard USACE methods and tools. The required work to perform the economic analyses was broken into two tasks. The first task focused on data development while the second consisted of an economic evaluation.

The data development task consisted of several required sub-tasks for collecting, transforming, and combining information into the appropriate input files for the economic evaluation software.

These sub-tasks included:

(1) Collecting parcel and assessor data
(2) Assigning damage categories and occupancy types
(3) Identifying damage reach delineations
(4) Assigning river stationing
(5) Assigning ground elevations
(6) Estimating structure elevations
(7) Compiling HEC-FDA input files

These sub-tasks required the use of ArcGIS Pro and Microsoft Excel to create the final text files. Based on the availability of digital structure information and generic depth-damage functions, the data development task can be performed on a wide range of inventory sizes without a significant change in overall effort. Utilizing Geographic Information Systems (GIS) software for the spatial data, the individual structure locations, in reference to the source of flooding, were developed efficiently. Microsoft Excel was used to combine the spatial data with tabular and survey data. For a given structure, it was important to identify the value, use, elevation (first floor and low entry), and location along the stream (river station). This information, along with a few other key descriptors, were provided in the final Hydrologic Engineering Center Flood Damage Analysis (HEC-FDA) software input file.

The economic evaluation task also consists of several sub-tasks required for estimating the annual expected damages, as well as event-based damages. These sub-tasks include:

(1) Constructing new study in the current version of HEC-FDA
(2) Performing analysis and QA/QC
(3) Producing output files and summary data
(4) Creating damage maps

The economic evaluation task required both H&H and economic input files and then used a Monte Carlo simulation to evaluate the estimated impacts while accounting for the associated uncertainty with the inputs. Once the output files from this evaluation were developed, they were combined with the GIS files used to develop the inputs to produce damage maps. These maps, combined with damage estimates, provided the basis for identifying potential flood risk management measures and alternatives.

1.4 Location and Description

The study area consisted of two forks of the NBCR, the Skokie River and the Middle Fork. The study focused on the portion of these waterways within Lake County, Illinois (Figure 1-1).

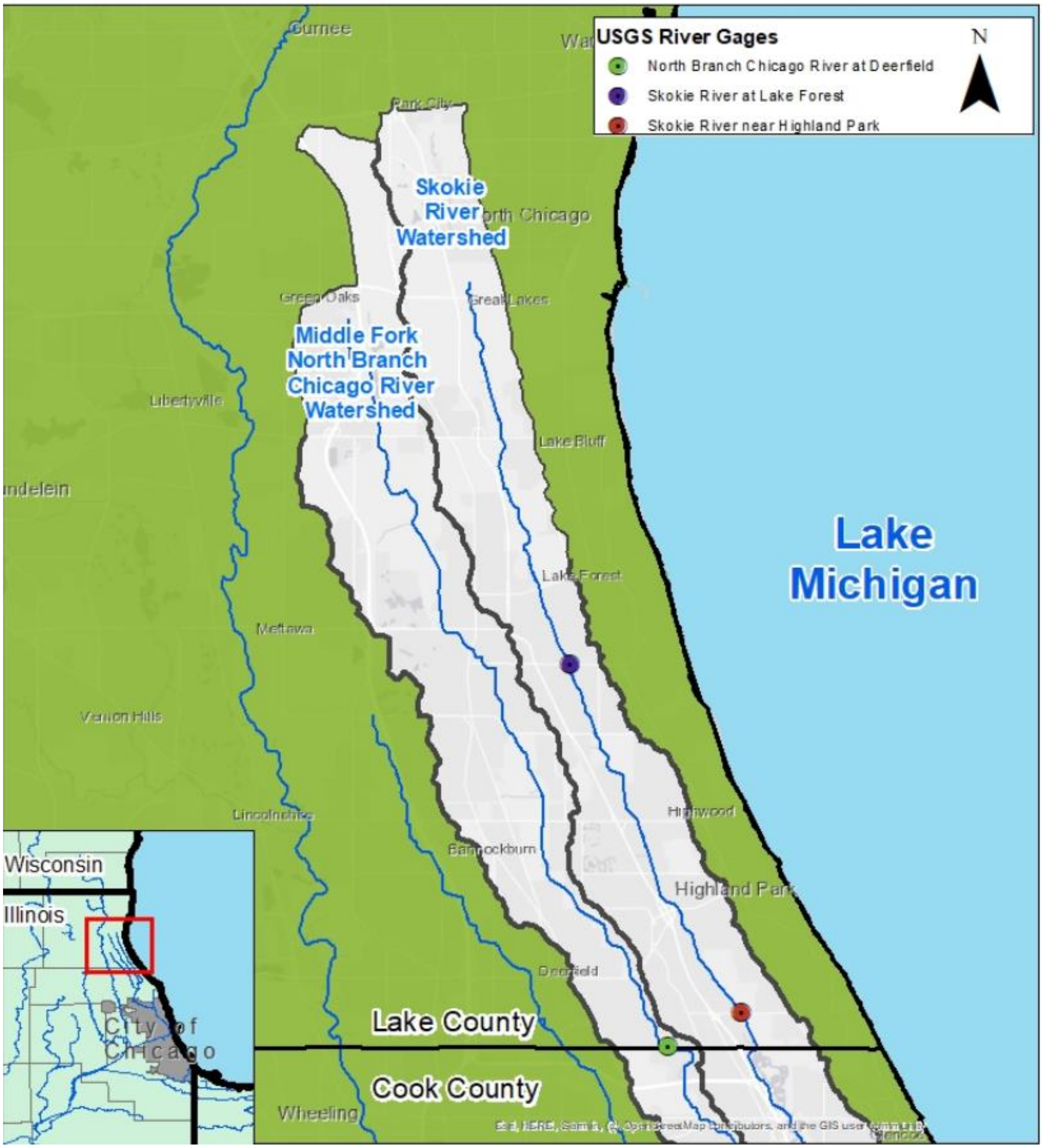


Figure 1-1: Project Study Area

The Skokie River and the Middle Fork run parallel and flow from north to south in the study area. The river centerlines, included in Figure 1-1, represent the extents of the study area for each river. The easternmost river that is outlined in Figure 1-1 was the portion of the Skokie River examined in this study. The westernmost river that is outlined in Figure 1-1 was the portion of the Middle Fork examined in this study. The study area for the Skokie River was between Park City, to the north, and Highland Park, to the south. The study area for the Middle Fork was between

Waukegan, to the north, and Deerfield and Highland Park, to the south. The study area's southern boundary was the county line between Lake County and Cook County.

Chapter 2 Hydrology & Hydraulic Analyses

2.1 Introduction

The hydrologic and hydraulic (H&H) analyses are instrumental in establishing a set of base data which was used to understand the frequency and location of flooding within the study area. The H&H data created in the Hydrologic Engineering Center River Analysis System (HEC-RAS) software provided the inputs necessary to evaluate the economic severity of flooding in HEC-FDA.

2.2 Hydrology Data and Model

The hydrology model used in this PAS study was developed from the Metropolitan Water Reclamation District of Greater Chicago's (MWRDGC) Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) model of the North Branch Chicago River drainage basin which was used in the Detailed Watershed Plan (DWP) study. The DWP included an HMS version of the Lake County watersheds.

2.3 Hydraulic Models

The hydraulic models were developed using the available 1997 FEMA Flood Insurance Study (FIS) HEC-2 models, which were converted to HEC-RAS data. Minor editing (completion of bridge data, etc.) was performed, as needed, to run the models in HEC-RAS (Version 5.0.3).

Since the HEC-2 model was not spatially geo-referenced, manual geo-referencing of the HEC-RAS model was required. A graphical stream centerline was imported to approximately geo-reference the cross-sections in the HEC-RAS study model. For the Middle Fork, the cross-sections were geo-referenced using cross-section locations provided by the Illinois Department of Natural Resources – Office of Water Resources (IDNR-OWR). For the Skokie River, the cross-sections were geo-referenced approximately with available information such as distance from bridges and cross-section locations in the FIS profiles and mapping. The graphical extents of the cross-sections, in both cases, were extended to include the 500-year flood extents. The placement and extension of the graphical cross-sections extents were for mapping purposes only. The cross-section station-elevation data for water surface computation was not updated from the HEC-2 models.

2.4 Calibration

To validate that the model reasonably predicts simulated storm events, calibration to three recent storm events was performed. The July 2017, April 2013, and September 2008 flood events were selected as calibration events because they represent three of the largest and most recent flood events experienced within the study area.

The July 2017 flood event in Lake County Illinois was driven by an intense cell of rainfall resulting in six to eight inches of rainfall over a 24-hour period. The April 2013 flood event was part of a widespread storm system stretching from Northeast Illinois to Quincy, Illinois. In Lake County, approximately three to five inches of rainfall fell within 24 hours, with some rain preceding which saturated the soil. The September 2008 flood event precipitation extended over most of the Chicago metropolitan area and caused extensive flooding. The rainfall in Lake County was less intense than in other areas, where around two to three inches fell in a 24 hour period.

Next-Generation Weather Radar (NEXRAD) gridded precipitation datasets were provided by the National Oceanic and Atmospheric Administration (NOAA). NEXRAD data for the three storms, used for calibration, were created and used as precipitation inputs for the HMS model. Figure 2-

1, below, shows the total precipitation grids for the July 2017 flood overlaid on the North Branch Chicago River watershed as an example of NEXRAD data inputted. Similar data was used for the other two calibration events.

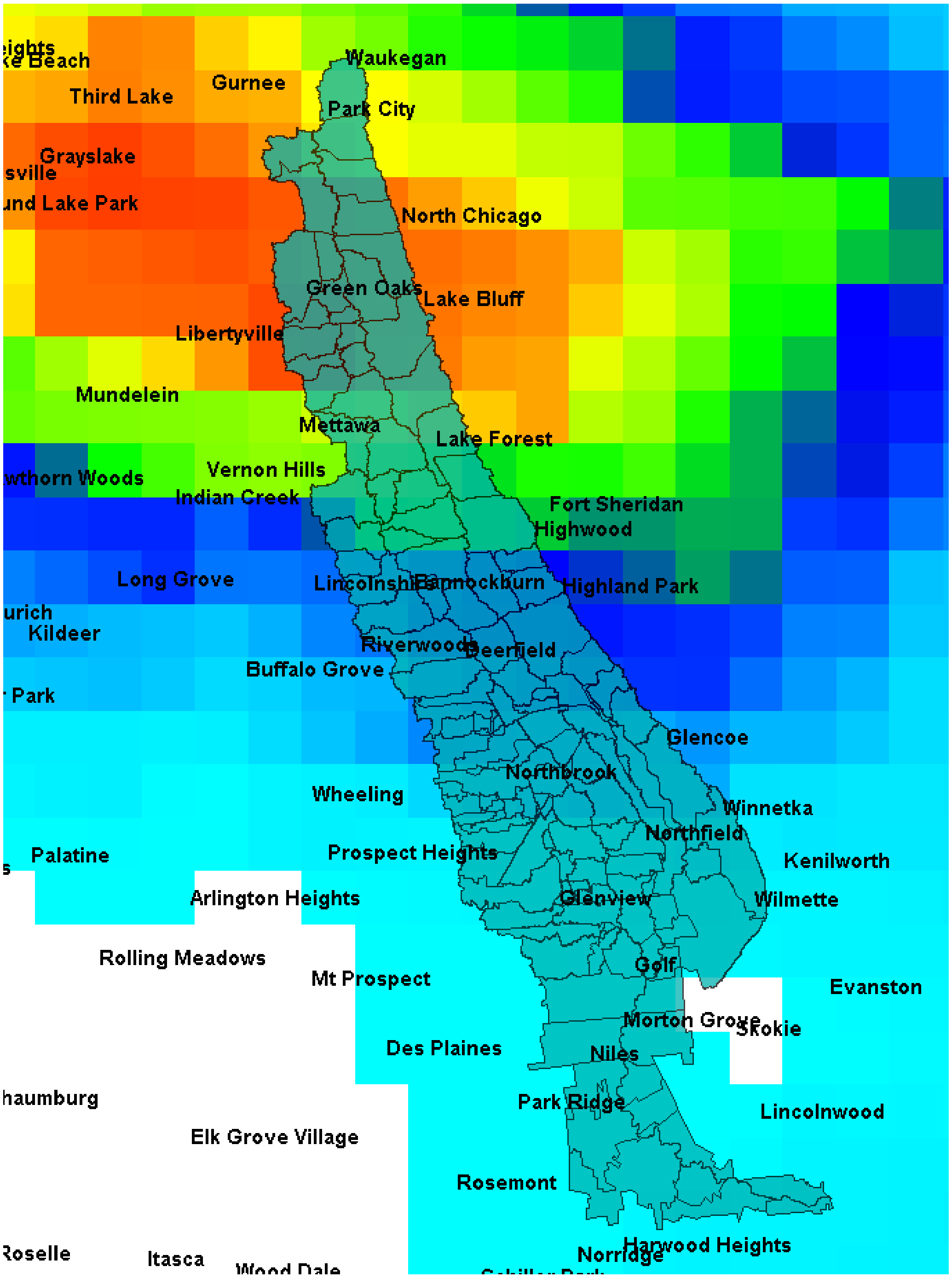


Figure 2-1: July 2017 NEXRAD Precipitation Grids overlaid on the North Branch Chicago River Watershed

The HMS flow hydrographs were compared to the observed flows at the United States Geological Survey (USGS) gages at Highland Park (Skokie River) and Lake Forest (Skokie River) and at Deerfield (Middle Fork) for the three historic flood events modeled. The location of these gages are included in Figure 2-1. Figures 2-2 through 2-10, below, present comparisons of the HMS computed flows versus the observed flows at these locations for the three historic flood events. The blue hydrograph curves contain the observed values and the red hydrograph curves contain the computed values. For the 2013 flood event, the Soil Conservation Service (SCS) Antecedent Runoff Condition III (green hydrograph) was adopted due to the fact that a smaller rainfall event preceded that event, so soil conditions were wet prior to the storm event used for calibration. Antecedent Runoff Condition II was used for the other two calibration events, as soil moisture was considered to be average prior to these events.

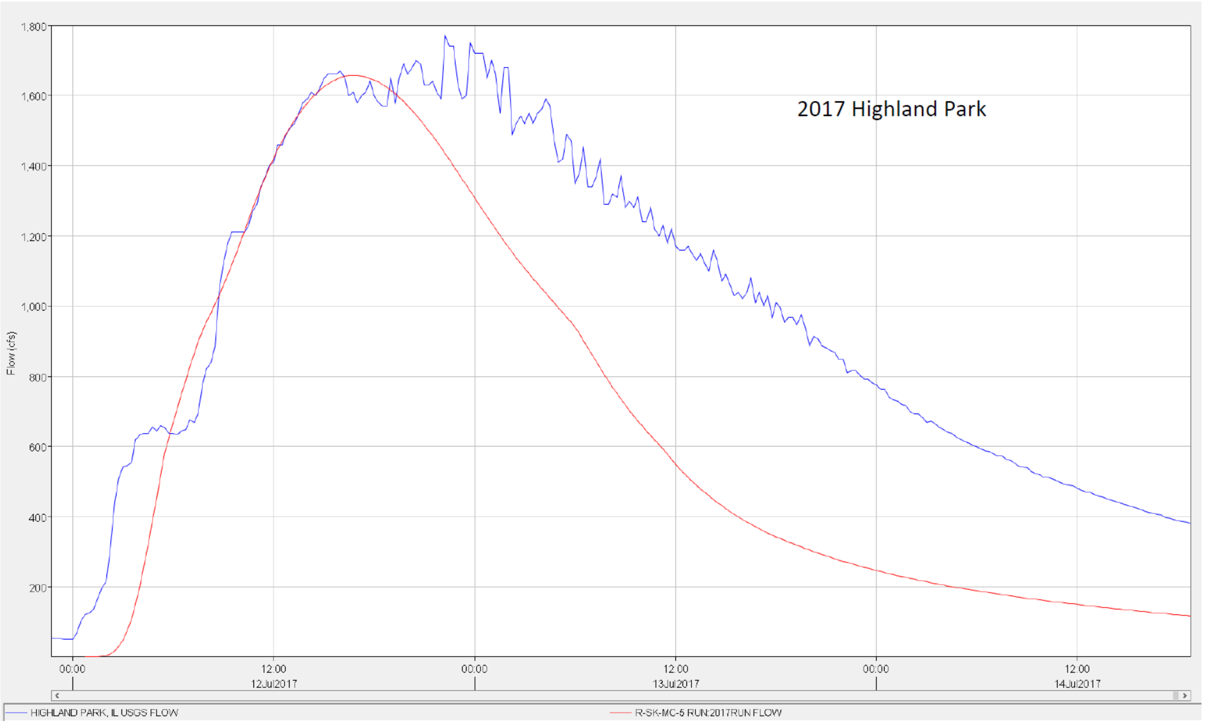


Figure 2-2: Calibration - July 2017 Flow Hydrographs at the USGS gage on the Skokie River in Highland Park, Illinois

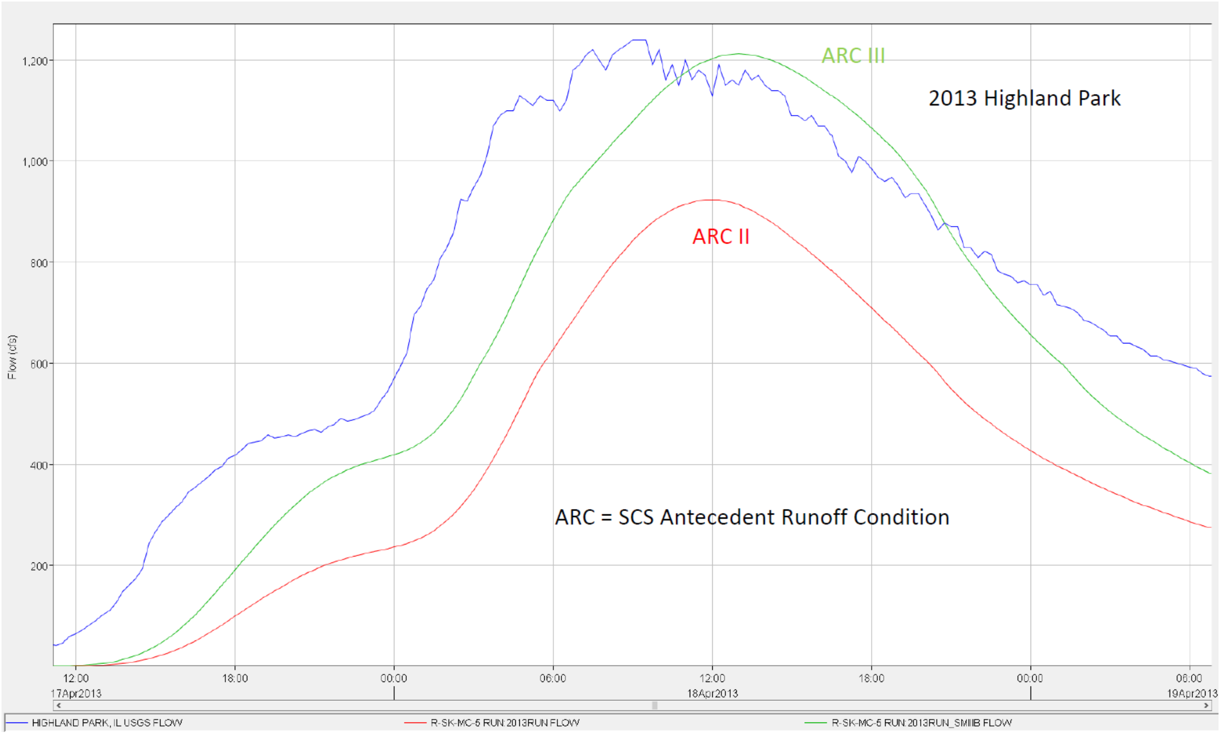


Figure 2-3: Calibration - April 2013 Flow Hydrographs at the USGS gage on the Skokie River in Highland Park, Illinois

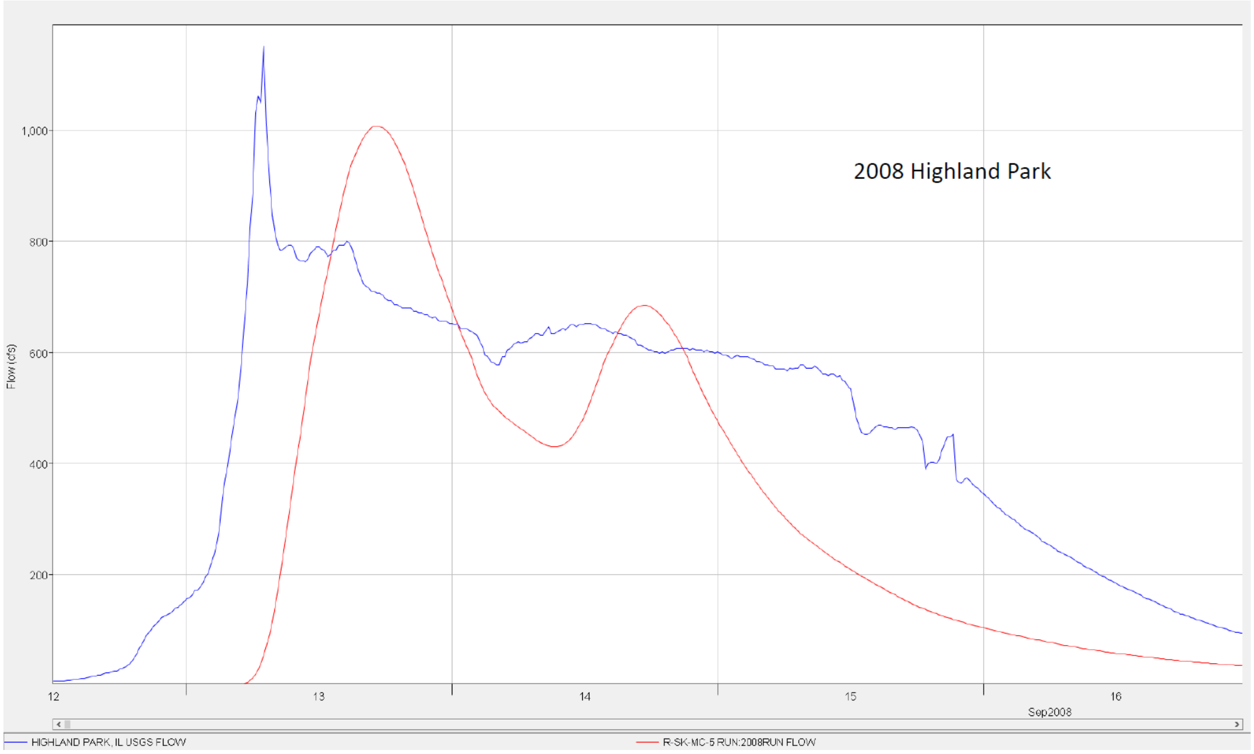


Figure 2-4: Calibration - September 2008 Flow Hydrographs at the USGS gage on the Skokie River in Highland Park, Illinois

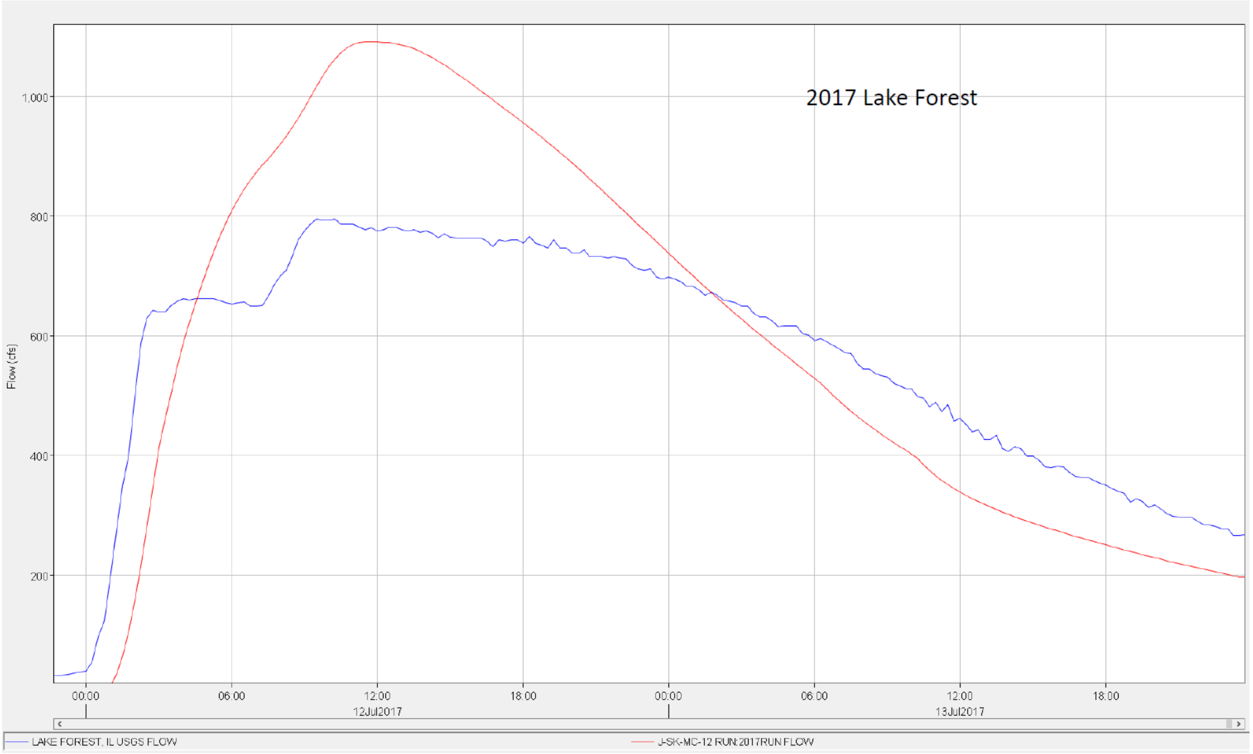


Figure 2-5: Calibration - July 2017 Flow Hydrographs at the USGS gage on the Skokie River in Lake Forest, Illinois

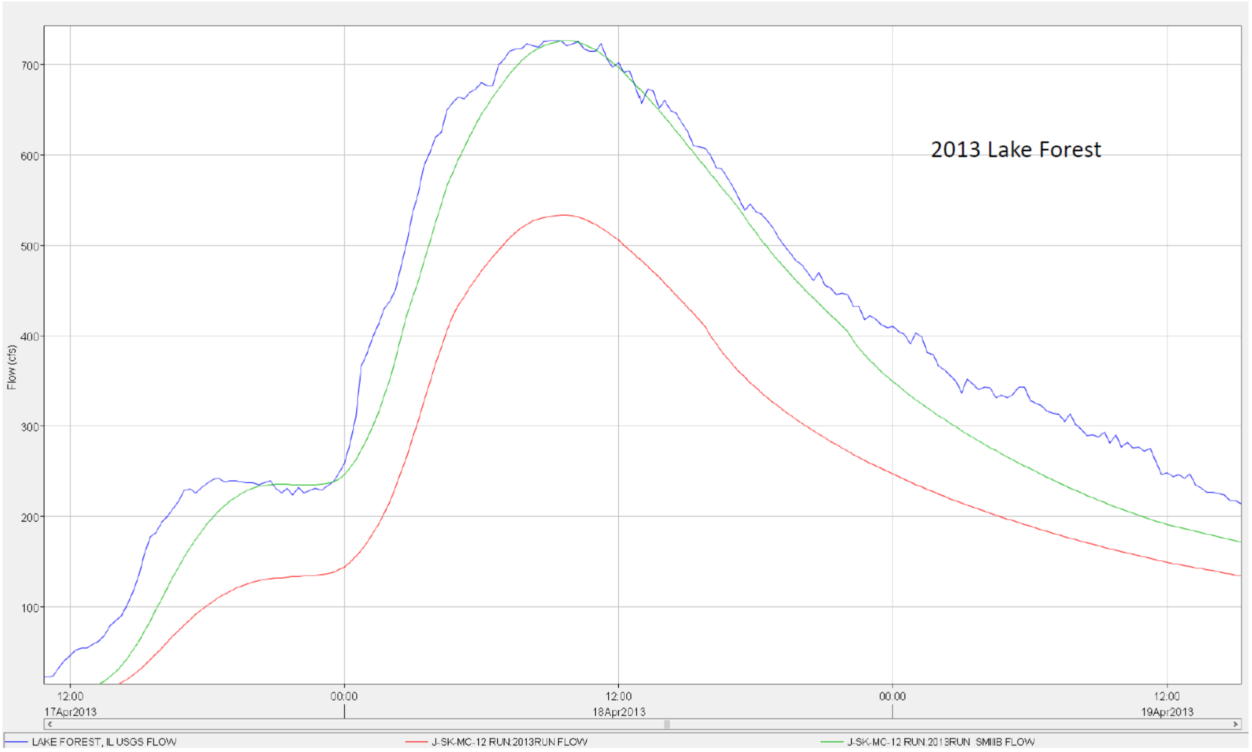


Figure 2-6: Calibration - April 2013 Flow Hydrographs at the USGS gage on the Skokie River in Lake Forest, Illinois

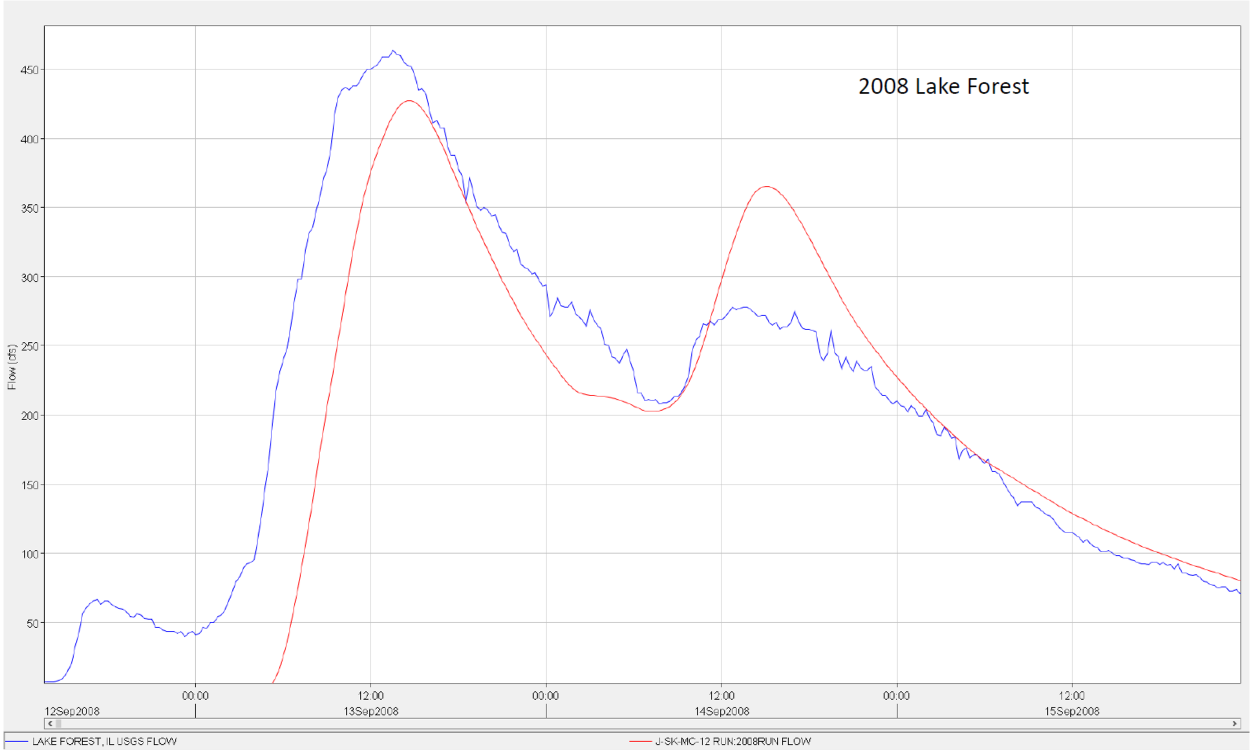


Figure 2-7: Calibration - September 2008 Flow Hydrographs at the USGS gage on the Skokie River in Lake Forest, Illinois

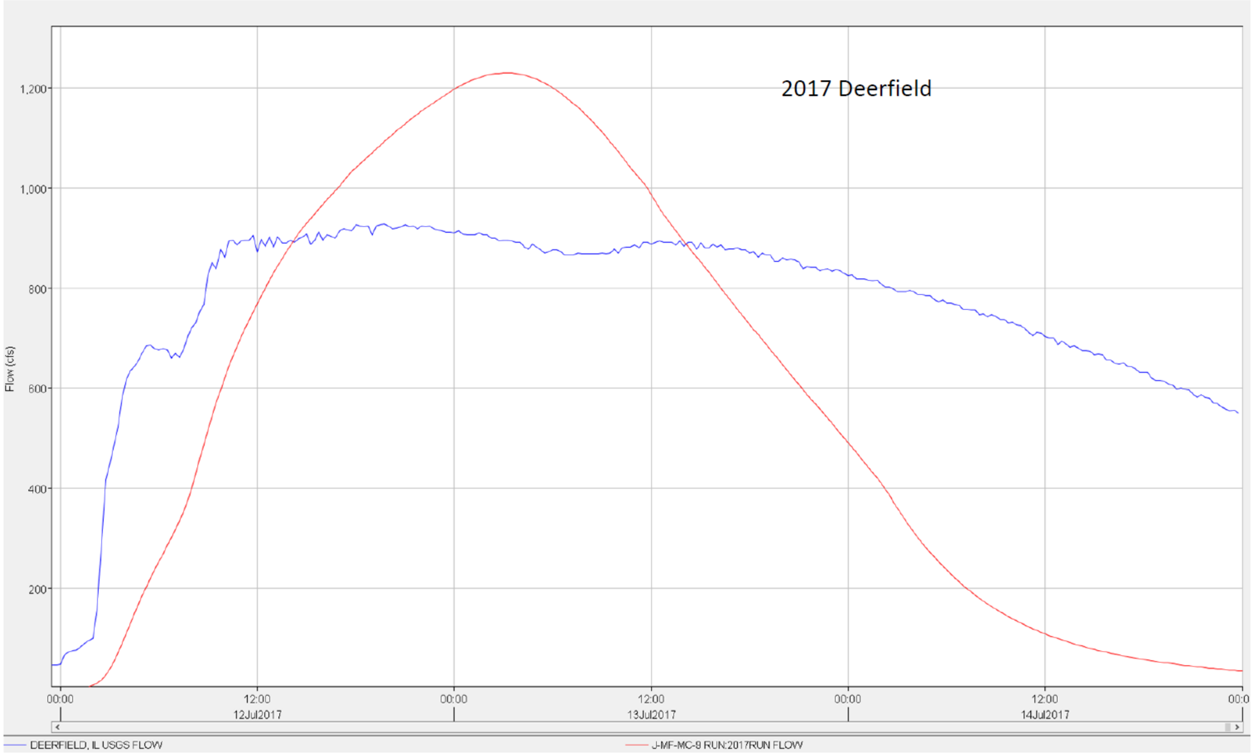


Figure 2-8: Calibration - July 2017 Flow Hydrographs at the USGS gage on the Middle Fork in Deerfield, Illinois

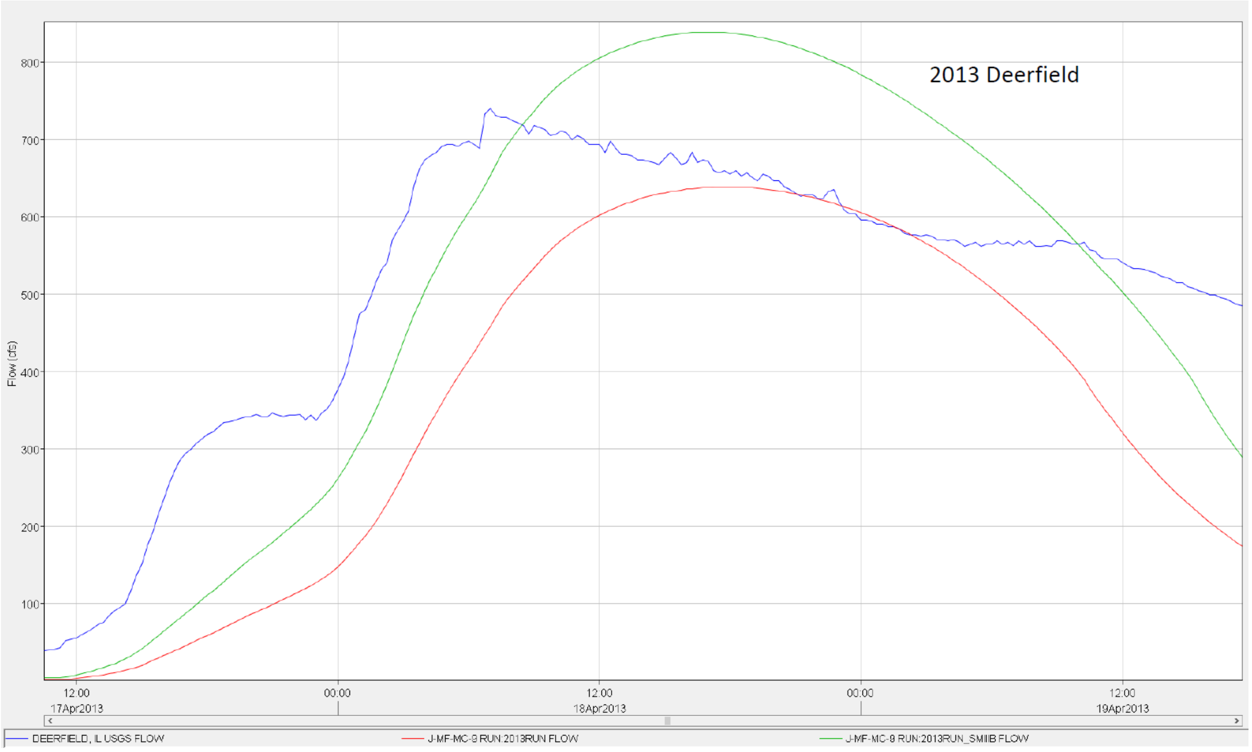


Figure 2-9: Calibration - April 2013 Flow Hydrographs at the USGS gage on the Middle Fork in Deerfield, Illinois

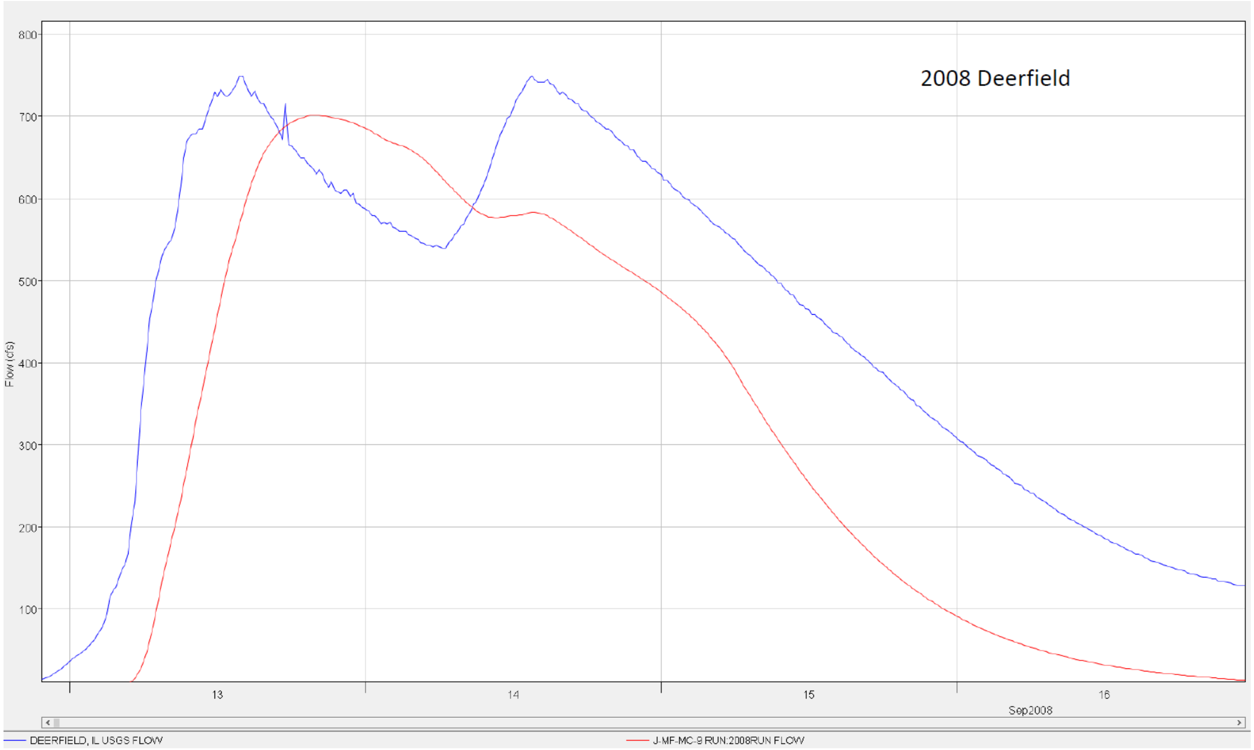


Figure 2-10: Calibration - September 2008 Flow Hydrographs at the USGS gage on the Middle Fork in Deerfield, Illinois

The HEC-HMS results demonstrate that the model reasonably represented the rainfall-runoff relationship for the three recent large events. Shape and peak flow were calibrated well for the 2013 and 2017 events in Highland Park and for the 2008 and 2013 events in Lake Forest. The event peak flows appeared to be overstated for the 2013 and 2017 events in Deerfield and for the 2017 event in Lake Forest.

The downstream boundary conditions, for the historic event models, used the peak stages for the historic events of the two downstream gages as targets.

The peak flows estimated from the HEC-HMS models were entered into the HEC-RAS model to estimate river stages (i.e. flood elevations), as a result of the three calibration events. Table 2-1 provides a comparison between modeled and recorded river stages at the USGS gage at Lake Forest for the three calibration events. The HEC-RAS results showed a very close maximum stage calibration on the Skokie River at the Lake Forest gage for the three historic flood events.

Table 2-1: Calibrated Stage Comparison at the Lake Forest Gage

	Skokie River Peak Stage Calibration at the USGS Gage at Lake Forest		
	2017	**2013**	**2008**
Gage	657.84	656.45	655.76
HEC-RAS	657.66	657.74	655.72
Difference	-0.18	1.29	-0.04

2.4.1 Validation

Preliminary results for the July 2017 flood mapping were presented to the local stakeholders. Their response indicated they believe that, overall, the flood mapping appeared as a reasonable representation of the observed flooded areas; this response is an additional validation of the modeling. Figure 2-11, below, is one example of the many areas reviewed with the local sponsors.

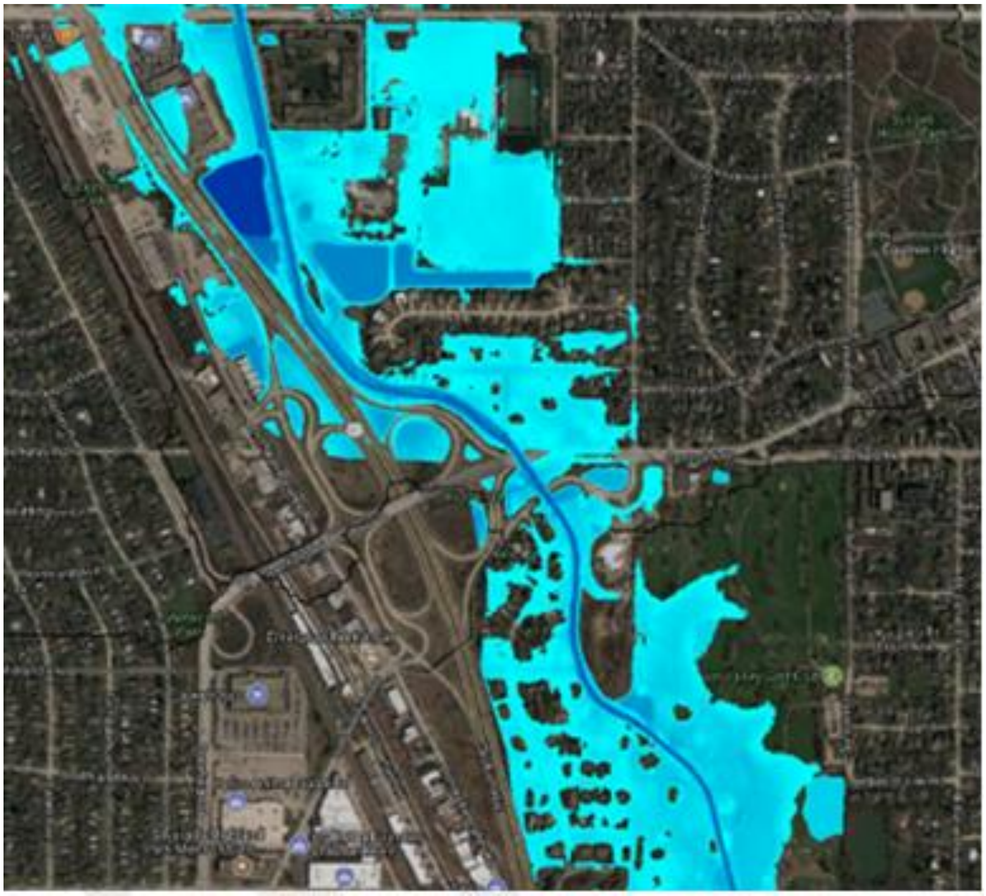


Figure 2-11: Example of Flood Mapping for the July 2017 Flood Event (Skokie River in Highland Park – Park Avenue West to South of Central Avenue)

A high water mark provided by the Village of Deerfield indicated that the modeling was high in relation to the observed data for the July 2017 event. The updated 100-year profile in the model is approximately 0.9 ft higher than the FEMA flood elevation along Woodvale Avenue, where the high water mark was taken. The differences were mostly due to the updated HMS hydrologic modeling and the updated ISWS Bulletin 70 precipitation.

2.5 Frequency Analysis

Peak annual flows for the three USGS gages located at Highland Park, Lake Forest and Deerfield, Illinois, are shown in Figures 2-12, 2-16, and 2-20, respectively. The USACE Non-Stationarity Tool was used to analyze the gage record. The heat maps from the tool indicated strong non-stationarities, for the three gages, beginning at water year 1992 for Highland Park and Lake Forest and water year 1981 for the Deerfield gage (Figures 2-13, 2-17 and 2-21). Peak annual flow frequency analyses were performed for the period of record and also from the point of non-stationarity to the present. Comparisons for the period of record versus the record from the point of non-stationarity are shown in Figures 2-14, 2-18 and 2-22. The shortened recent record was adopted for each gage with results compared to the DWP HMS peak flow values (24-hour duration) for both the 1989 Bulletin 70 and the updated 2019 Bulletin 70 values and the FEMA FIS values in Figures 2-15, 2-19 and 2-23. The updated Bulletin 70 precipitation was adopted for the synthetic event modeling for this analysis.

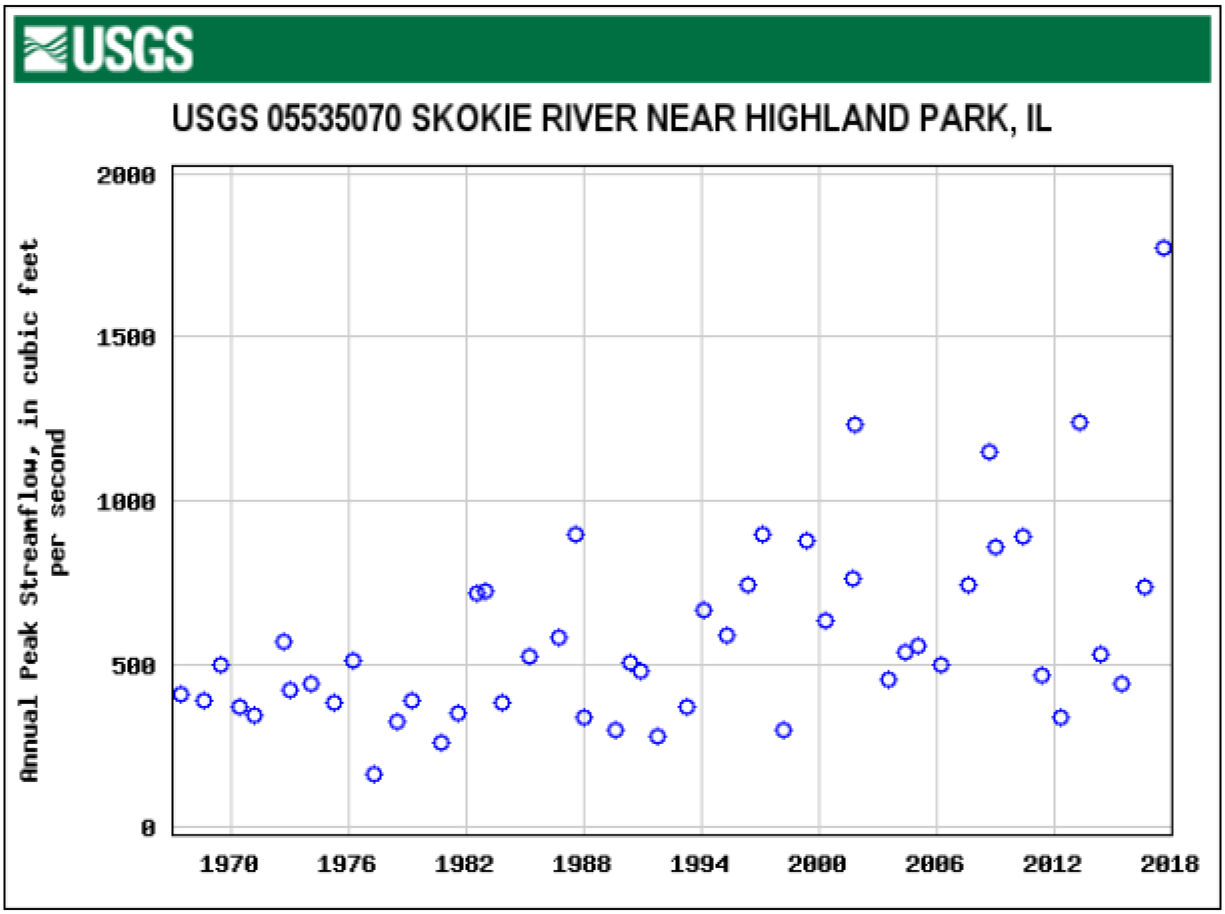


Figure 2-12: Peak Annual Flows for the Skokie River at Highland Park, Illinois

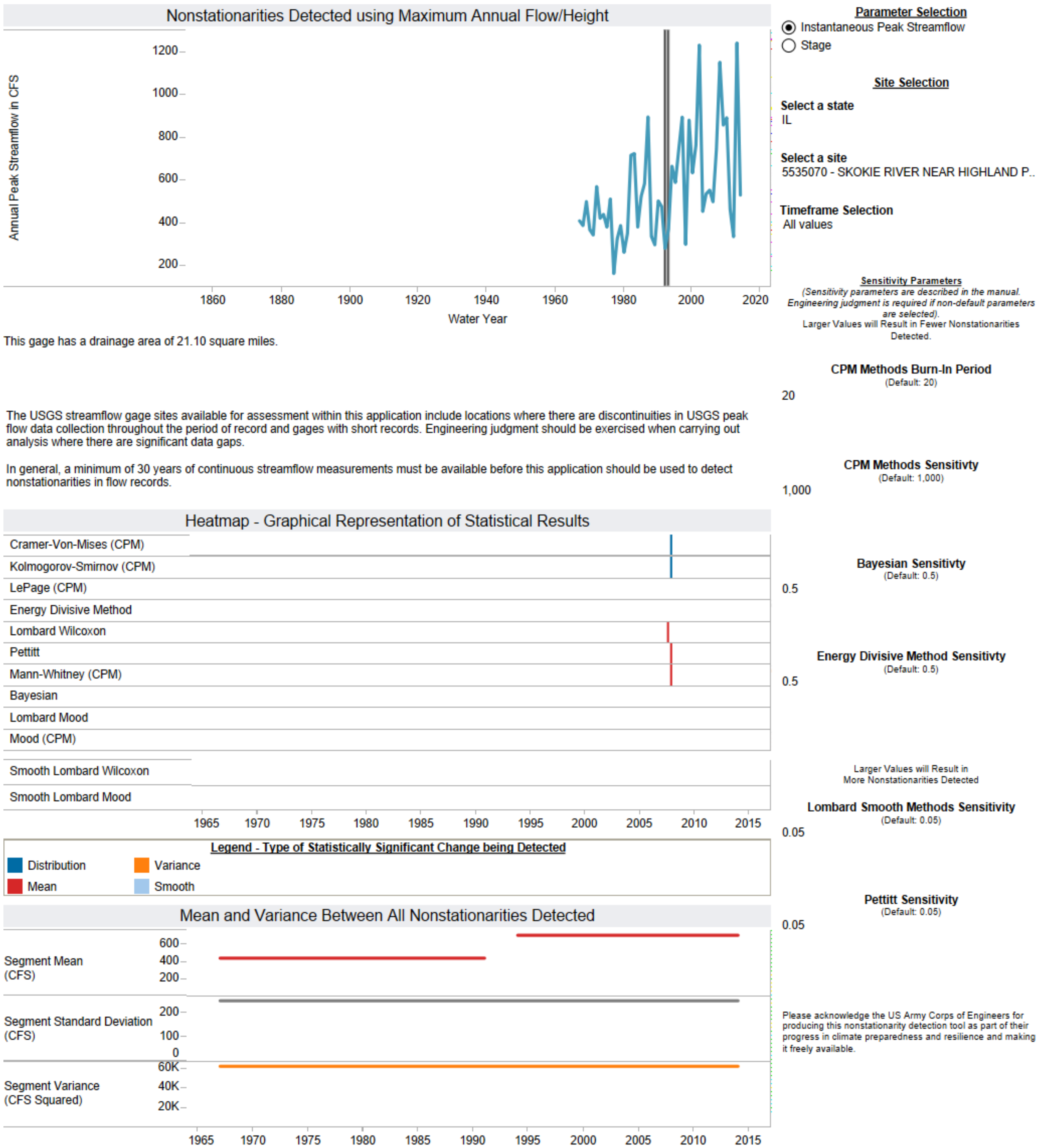


Figure 2-13: USACE Non-Stationarity Tool Heat Map for the Skokie River near Highland Park Gage

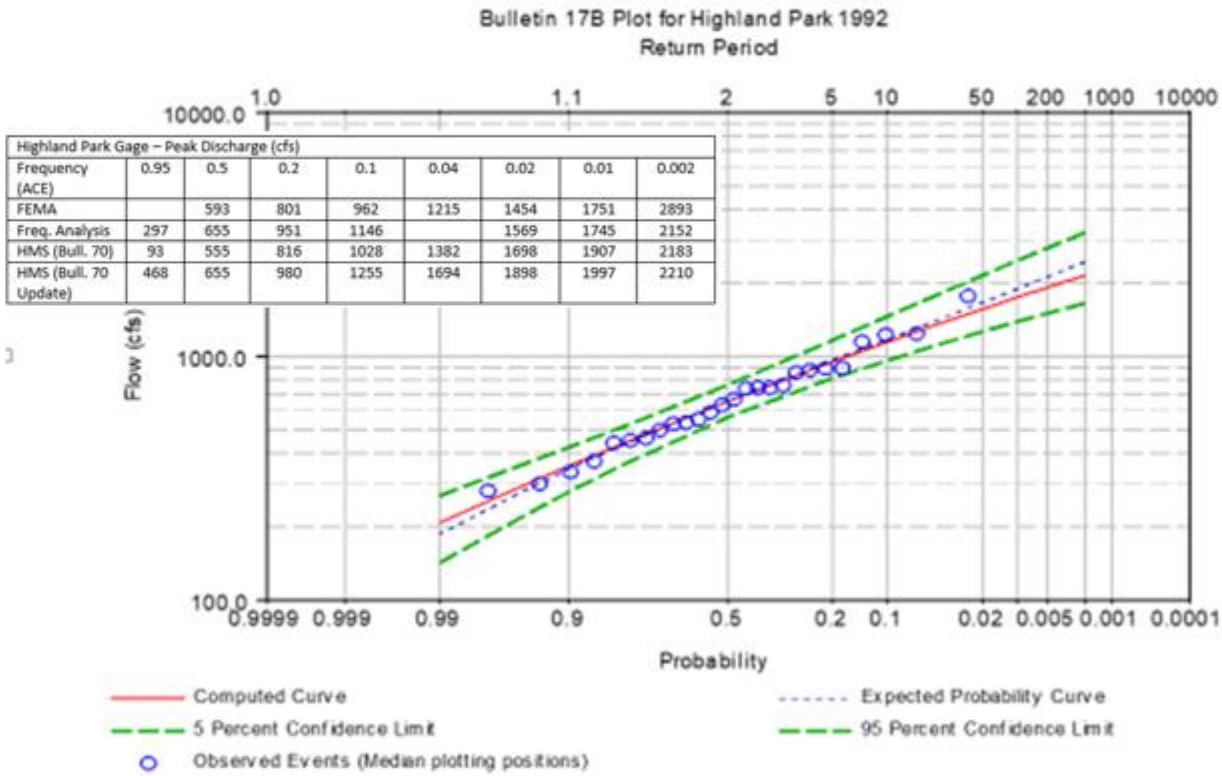
<< Frequency Curve >> 1967-2017
Highland Park-HIGHLAND PARK, IL-FLOW-ANNUAL PEAK

Computed Curve FLOW, CFS	Expected Probability FLOW, CFS	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, CFS	Confidence Limits 0.95 FLOW, CFS
1,751.2	1,863.6	0.2	2,278.2	1,439.3
1,563.3	1,640.3	0.5	1,993.5	1,302.5
1,420.7	1,476.4	1.0	1,782.1	1,197.0
1,277.2	1,315.4	2.0	1,573.6	1,089.1
1,084.3	1,105.3	5.0	1,301.2	940.6
933.6	945.1	10.0	1,095.7	821.3
774.9	780.0	20.0	887.7	691.2
533.8	533.8	50.0	594.1	480.1
360.0	357.2	80.0	403.3	314.6
290.4	286.1	90.0	330.7	246.8
242.1	236.3	95.0	280.5	200.1
170.2	161.3	99.0	205.2	132.6

<< Frequency Curve >> 1992-2017
Highland Park-HIGHLAND PARK, IL-FLOW-ANNUAL PEAK

Computed Curve FLOW, CFS	Expected Probability FLOW, CFS	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, CFS	Confidence Limits 0.95 FLOW, CFS
2,152.2	2,448.7	0.2	3,216.5	1,652.9
1,920.9	2,121.9	0.5	2,782.8	1,502.2
1,745.4	1,889.1	1.0	2,464.4	1,385.4
1,568.8	1,666.3	2.0	2,153.7	1,265.1
1,331.5	1,384.2	5.0	1,753.7	1,098.3
1,146.2	1,174.8	10.0	1,457.4	962.7
951.0	963.6	20.0	1,163.2	812.9
654.8	654.8	50.0	762.7	563.1
441.2	434.6	80.0	515.9	361.3
355.8	345.3	90.0	424.6	278.6
296.6	282.4	95.0	362.0	222.3
208.3	186.7	99.0	268.0	142.3

Figure 2-14: Peak Annual Flow Frequency Analyses for the Skokie River near Highland Park Gage



Highland Park Gage – Peak Discharge (cfs)

Frequency (ACE)	0.95	0.5	0.2	0.1	0.04	0.02	0.01	0.002
FEMA		593	801	962	1215	1454	1751	2893
Freq. Analysis	297	655	951	1146		1569	1745	2152
HMS (Bull. 70)	93	555	816	1028	1382	1698	1907	2183
HMS (Bull. 70 Update)	468	655	980	1255	1694	1898	1997	2210

Figure 2-15: Comparison of Peak Flow Frequency at the Skokie River at Highland Park Gage

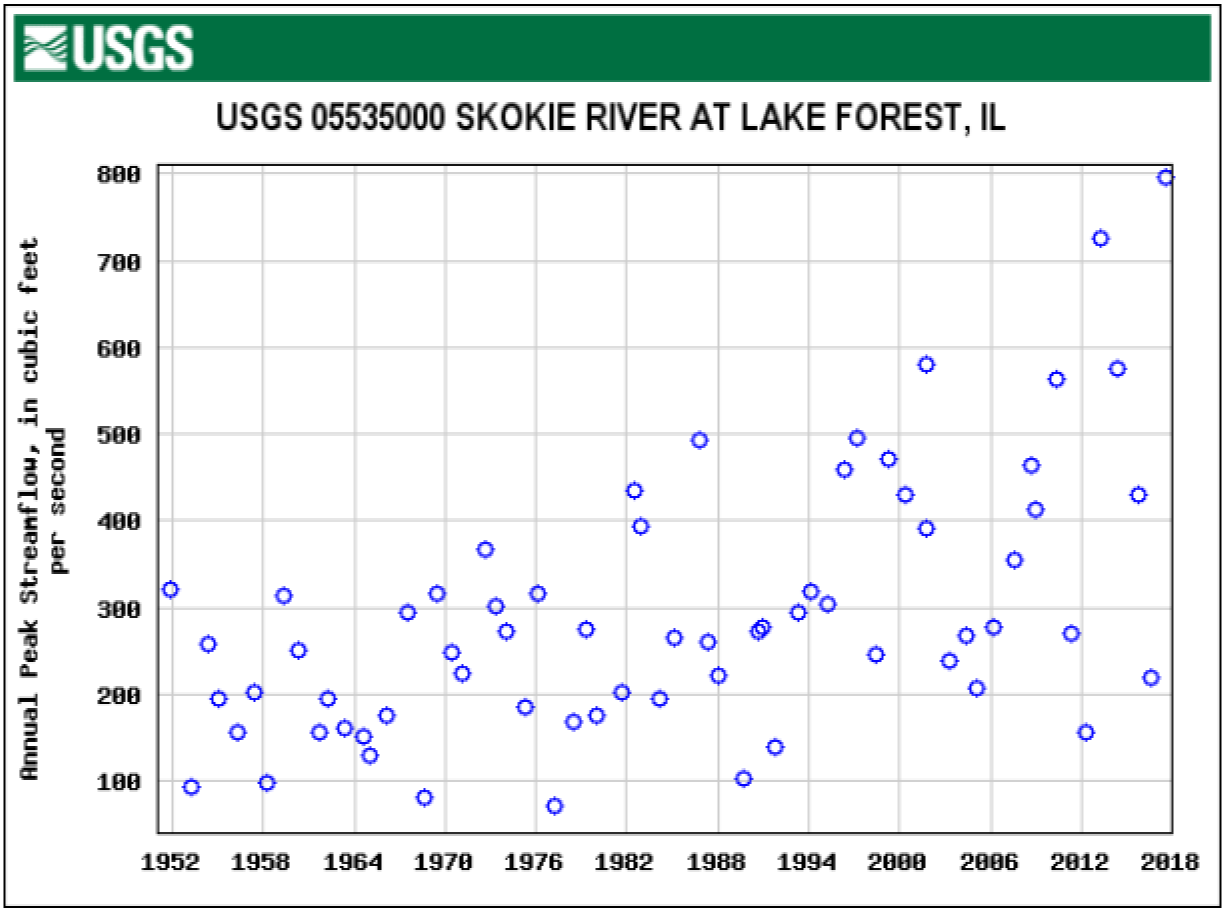


Figure 2-16: Peak Annual Flows for the Skokie River at Lake Forest, Illinois

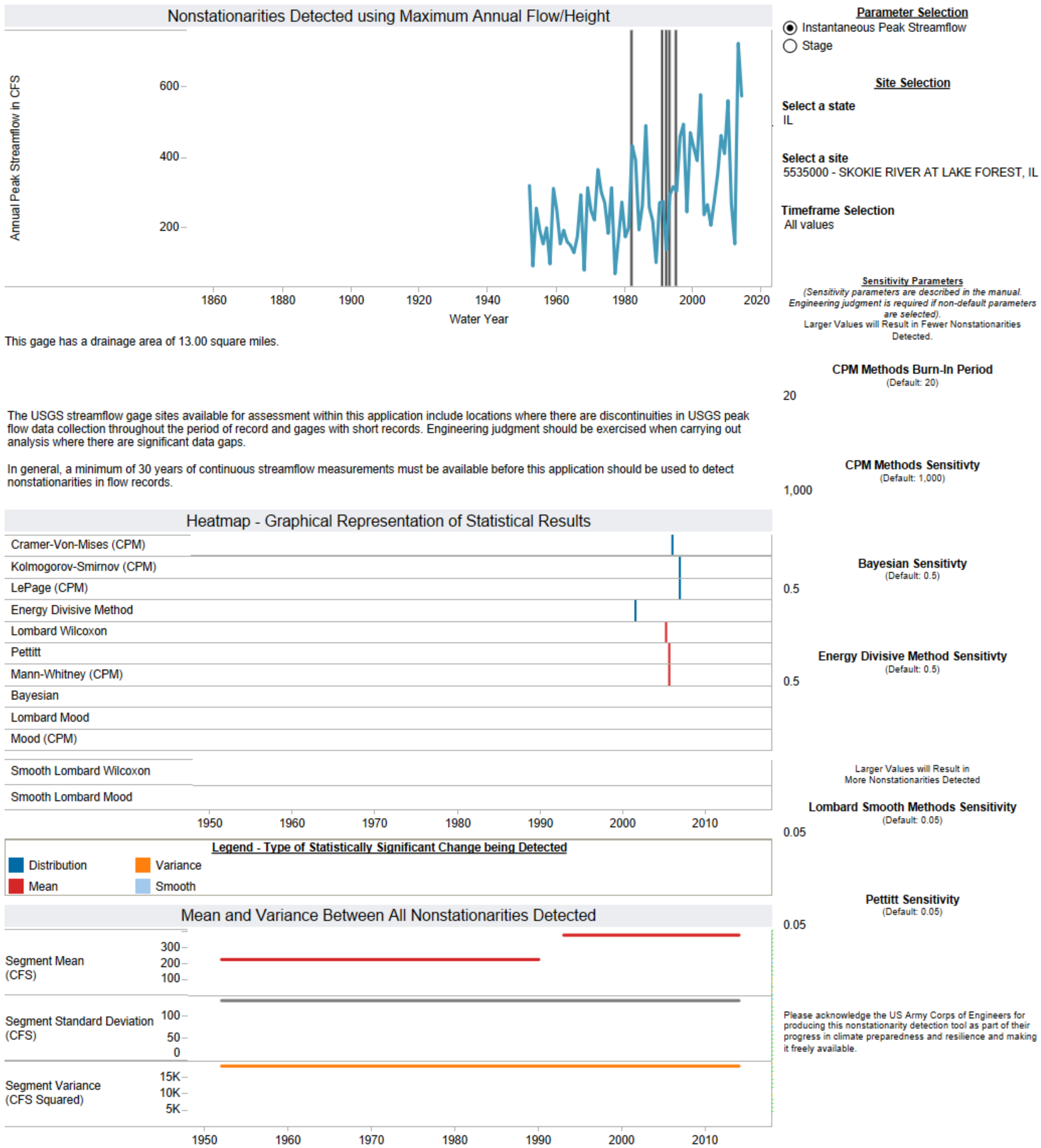


Figure 2-17: USACE Non-Stationarity Tool Heat Map for the Skokie River near Lake Forest Gage

1951-2017

<< Frequency Curve >>
Lake Forest-LAKE FOREST, IL-FLOW-ANNUAL PEAK

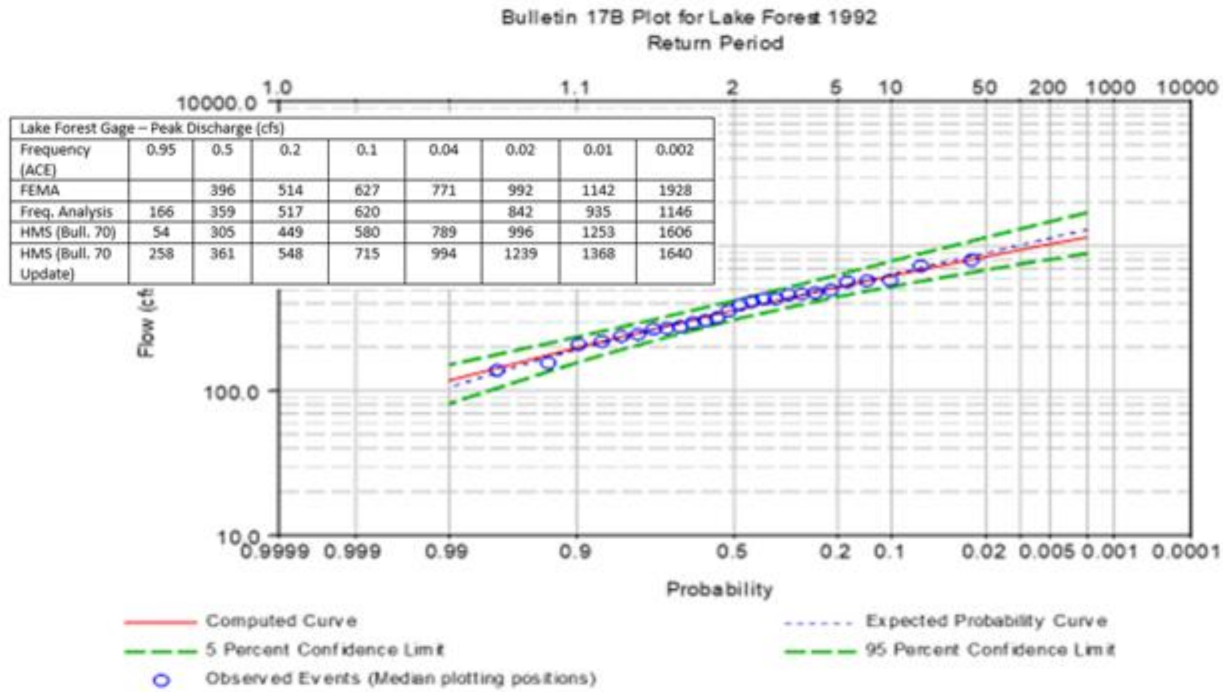
Computed Curve FLOW, CFS	Expected Probability FLOW, CFS	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, CFS	Confidence Limits 0.95 FLOW, CFS
1,004.4	1,059.6	0.2	1,295.8	824.7
883.7	921.1	0.5	1,118.4	735.7
793.4	820.2	1.0	988.3	668.0
703.6	721.8	2.0	861.5	599.6
585.0	594.7	5.0	698.3	507.3
494.2	499.4	10.0	577.5	434.6
400.5	402.8	20.0	457.3	357.3
263.1	263.1	50.0	292.4	236.9
168.7	167.6	80.0	189.0	147.9
132.4	130.7	90.0	150.8	113.0
107.9	105.6	95.0	125.0	89.6
72.5	69.2	99.0	87.5	56.9

1992-2017

<< Frequency Curve >>
Lake Forest-LAKE FOREST, IL-FLOW-ANNUAL PEAK

Computed Curve FLOW, CFS	Expected Probability FLOW, CFS	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, CFS	Confidence Limits 0.95 FLOW, CFS
1,146.4	1,300.2	0.2	1,696.5	886.2
1,026.0	1,130.7	0.5	1,473.0	807.3
934.5	1,009.5	1.0	1,308.3	746.0
842.2	893.2	2.0	1,147.2	682.7
717.6	745.4	5.0	938.9	594.7
620.0	635.2	10.0	783.8	523.0
516.8	523.5	20.0	629.0	443.5
359.1	359.1	50.0	416.7	310.0
244.3	240.8	80.0	284.6	201.1
198.1	192.4	90.0	235.3	156.0
165.8	158.1	95.0	201.5	125.2
117.5	105.6	99.0	150.3	81.0

Figure 2-18: Peak Annual Flow Frequency Analyses for the Skokie River near Lake Forest Gage



Lake Forest Gage – Peak Discharge (cfs)								
Frequency (ACE)	0.95	0.5	0.2	0.1	0.04	0.02	0.01	0.002
FEMA		396	514	627	771	992	1142	1928
Freq. Analysis	166	359	517	620		842	935	1146
HMS (Bull. 70)	54	305	449	580	789	996	1253	1606
HMS (Bull. 70 Update)	258	361	548	715	994	1239	1368	1640

Figure 2-19: Comparison of Peak Flow Frequency at the Skokie River at Lake Forest Gage

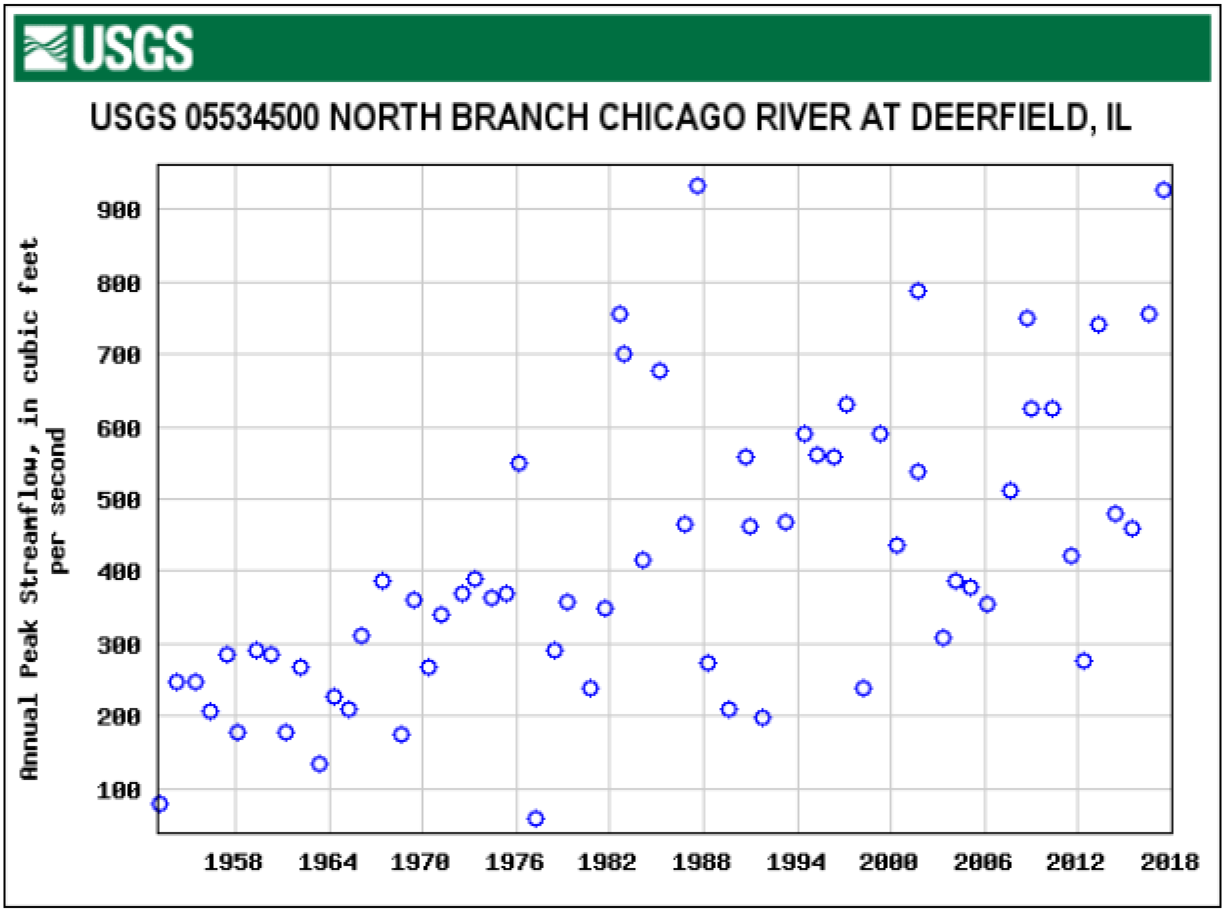


Figure 2-20: Peak Annual Flows for the Middle Fork at Deerfield, Illinois

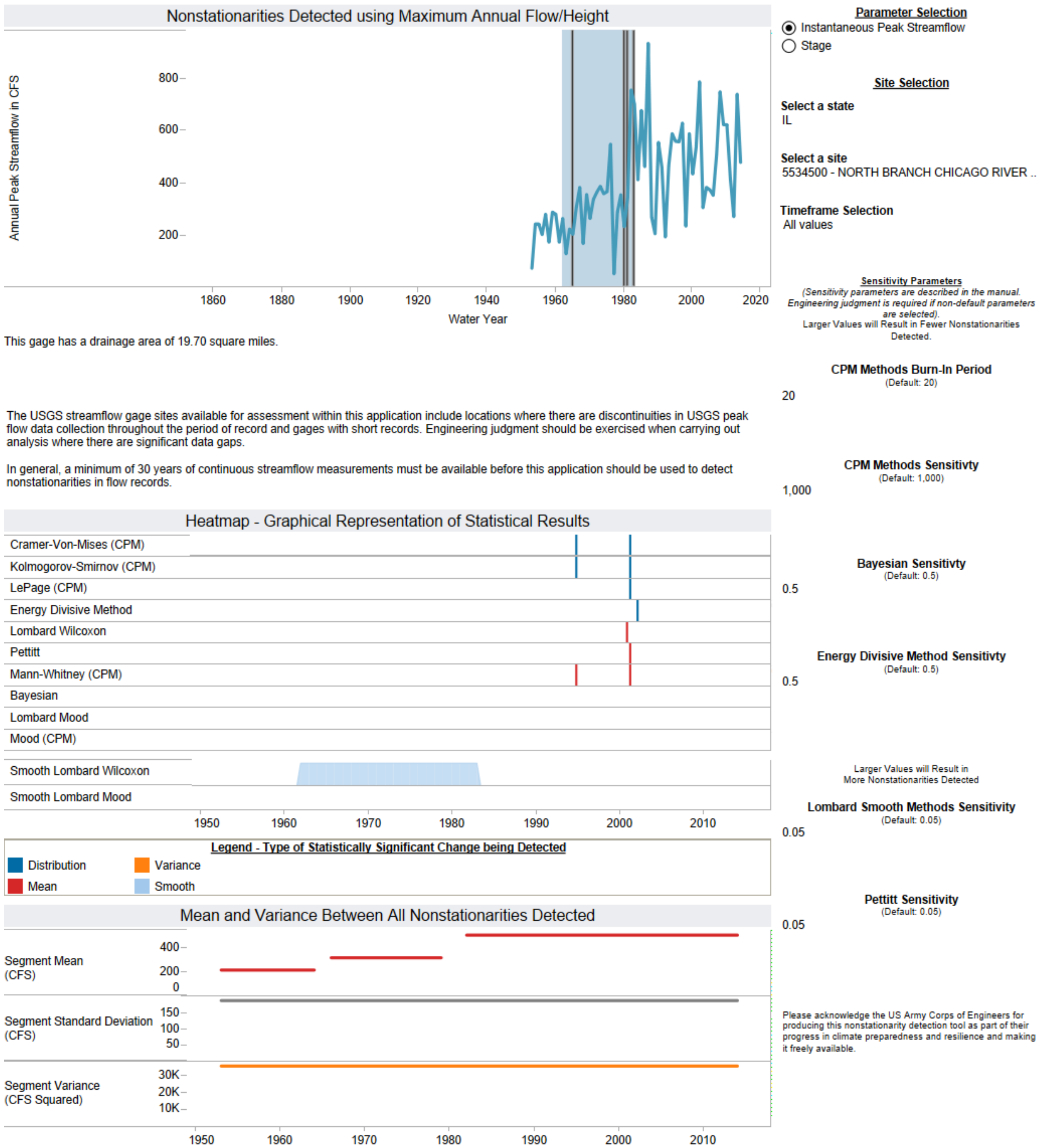


Figure 2-21: USACE Non-Stationarity Tool Heat Map for the Middle Fork near Deerfield Gage

1953-2017

<< Frequency Curve >>
NBCR_Lake-DEERFIELD, IL-FLOW-ANNUAL PEAK

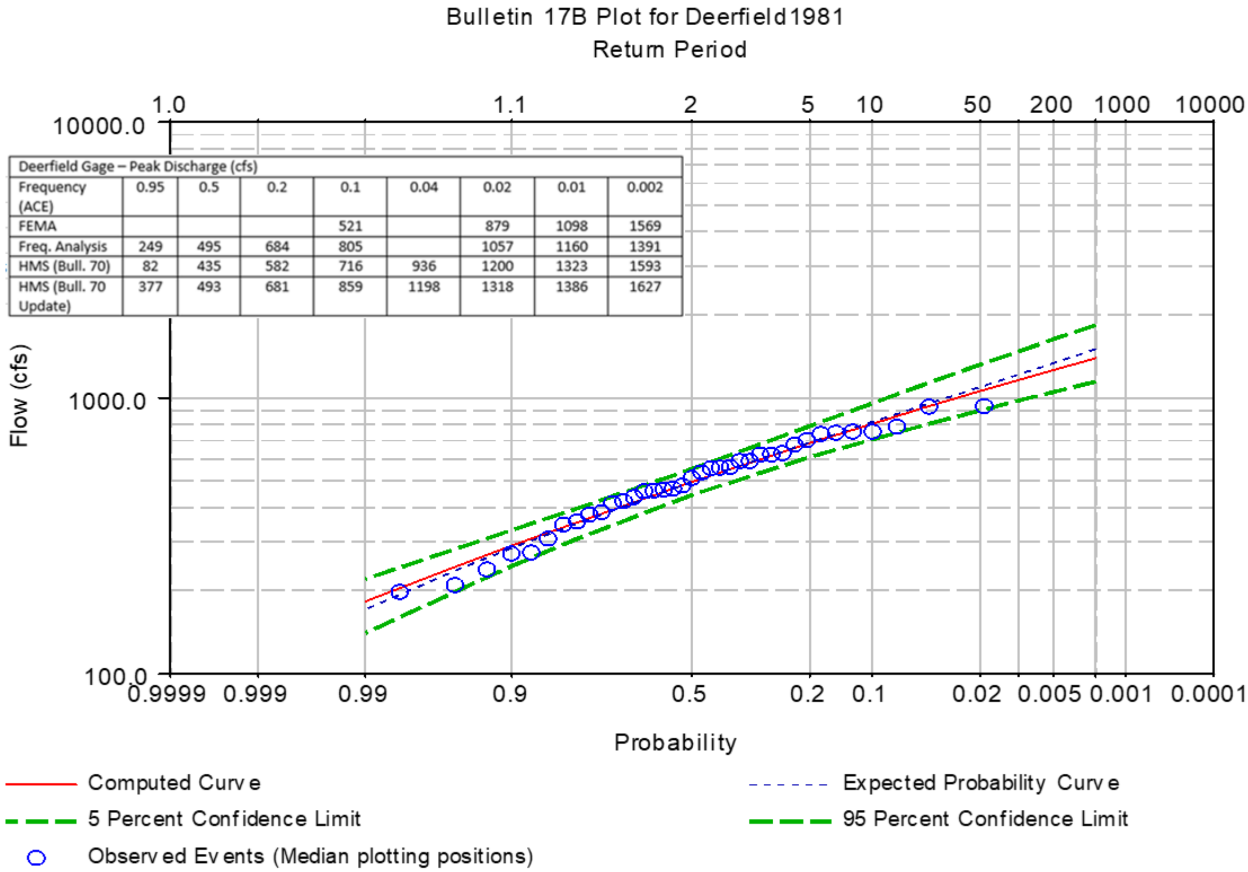
Computed Curve FLOW, CFS	Expected Probability FLOW, CFS	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, CFS	Confidence Limits 0.95 FLOW, CFS
1,383.6	1,458.1	0.2	1,773.2	1,142.3
1,222.7	1,273.4	0.5	1,538.0	1,023.2
1,101.8	1,138.3	1.0	1,364.7	932.2
981.2	1,006.0	2.0	1,195.1	839.9
821.0	834.5	5.0	975.6	714.8
697.6	704.9	10.0	811.9	615.8
569.5	572.7	20.0	648.1	509.7
379.6	379.6	50.0	420.7	342.7
247.2	245.6	80.0	276.0	217.4
195.6	193.2	90.0	222.0	167.7
160.5	157.2	95.0	185.3	134.0
109.3	104.5	99.0	131.3	86.4

1981-2017

<< Frequency Curve >>
NBCR_Lake-DEERFIELD, IL-FLOW-ANNUAL PEAK

Computed Curve FLOW, CFS	Expected Probability FLOW, CFS	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, CFS	Confidence Limits 0.95 FLOW, CFS
1,391.4	1,501.8	0.2	1,838.5	1,142.8
1,260.5	1,337.0	0.5	1,630.3	1,049.5
1,159.8	1,215.6	1.0	1,473.9	976.5
1,057.1	1,095.8	2.0	1,317.8	900.7
916.6	938.2	5.0	1,110.9	794.5
804.7	816.7	10.0	952.1	707.1
684.2	689.6	20.0	788.6	609.4
494.6	494.6	50.0	552.1	443.5
350.9	347.7	80.0	393.8	304.8
291.1	285.9	90.0	331.8	245.3
248.5	241.3	95.0	288.2	203.2
182.8	171.2	99.0	220.5	140.3

Figure 2-22: Peak Annual Flow Frequency Analyses for the Middle Fork near Deerfield Gage



Deerfield Gage – Peak Discharge (cfs)								
Frequency (ACE)	0.95	0.5	0.2	0.1	0.04	0.02	0.01	0.002
FEMA				521		879	1098	1569
Freq. Analysis	249	495	684	805		1057	1160	1391
HMS (Bull. 70)	82	435	582	716	936	1200	1323	1593
HMS (Bull. 70 Update)	377	493	681	859	1198	1318	1386	1627

Figure 2-23: Comparison of Peak Flow Frequency at the Middle Fork at Deerfield Gage

2.6 Stage Versus Flow Relationships

Rating curves were approximated at each gage for the three historic events by plotting stage versus flow. Measured stage versus flow data was also shown. These were compared to the synthetic event model results. Lake Forest showed three distinct rating curves; however, note that the model had very close stage calibration at this gage for all three events. For the other two gages, the modeled values seemed to most closely follow the 2017 flood curve.

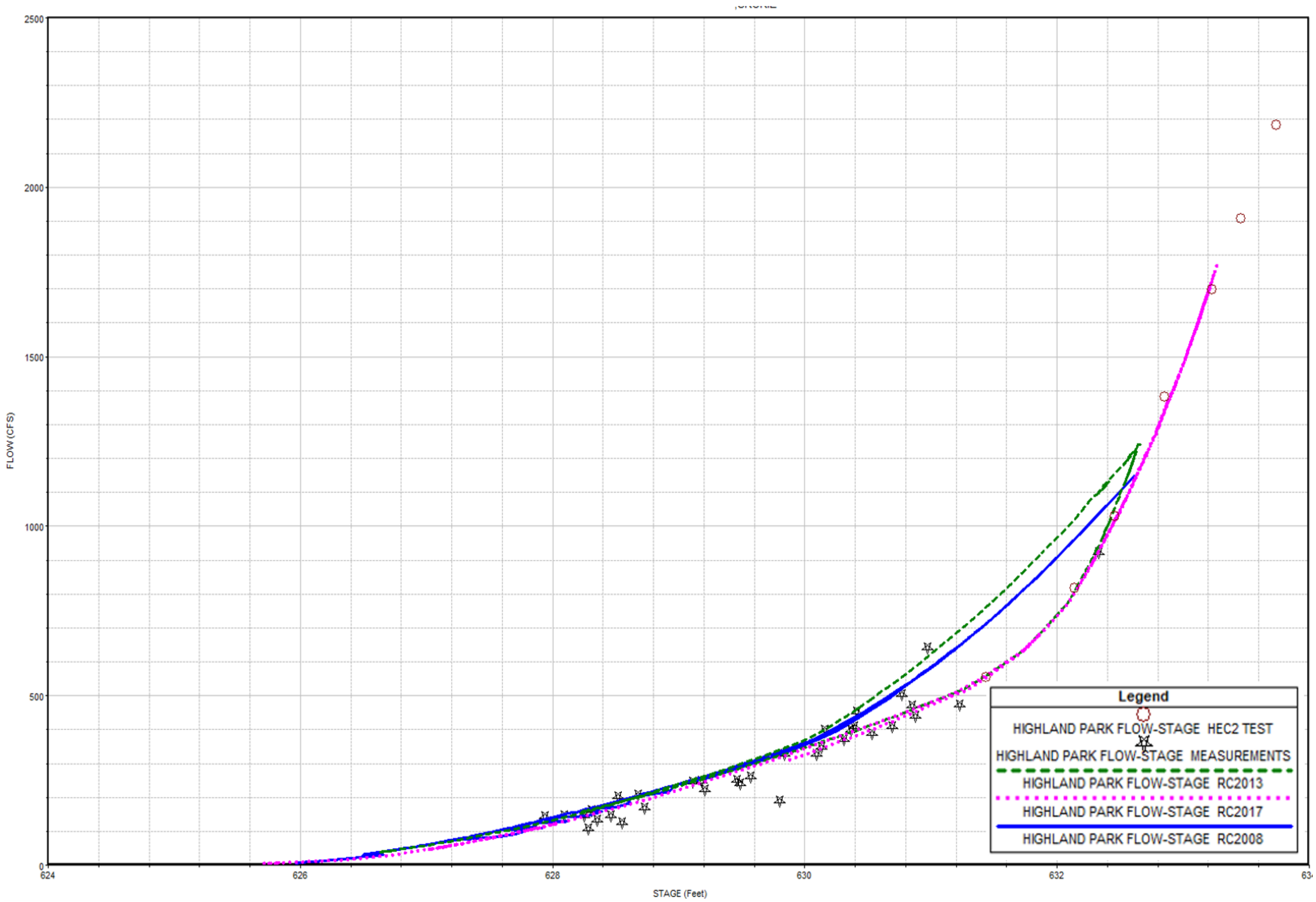


Figure 2-24: Comparison of Rating Curves at the Skokie River near Highland Park Gage Location

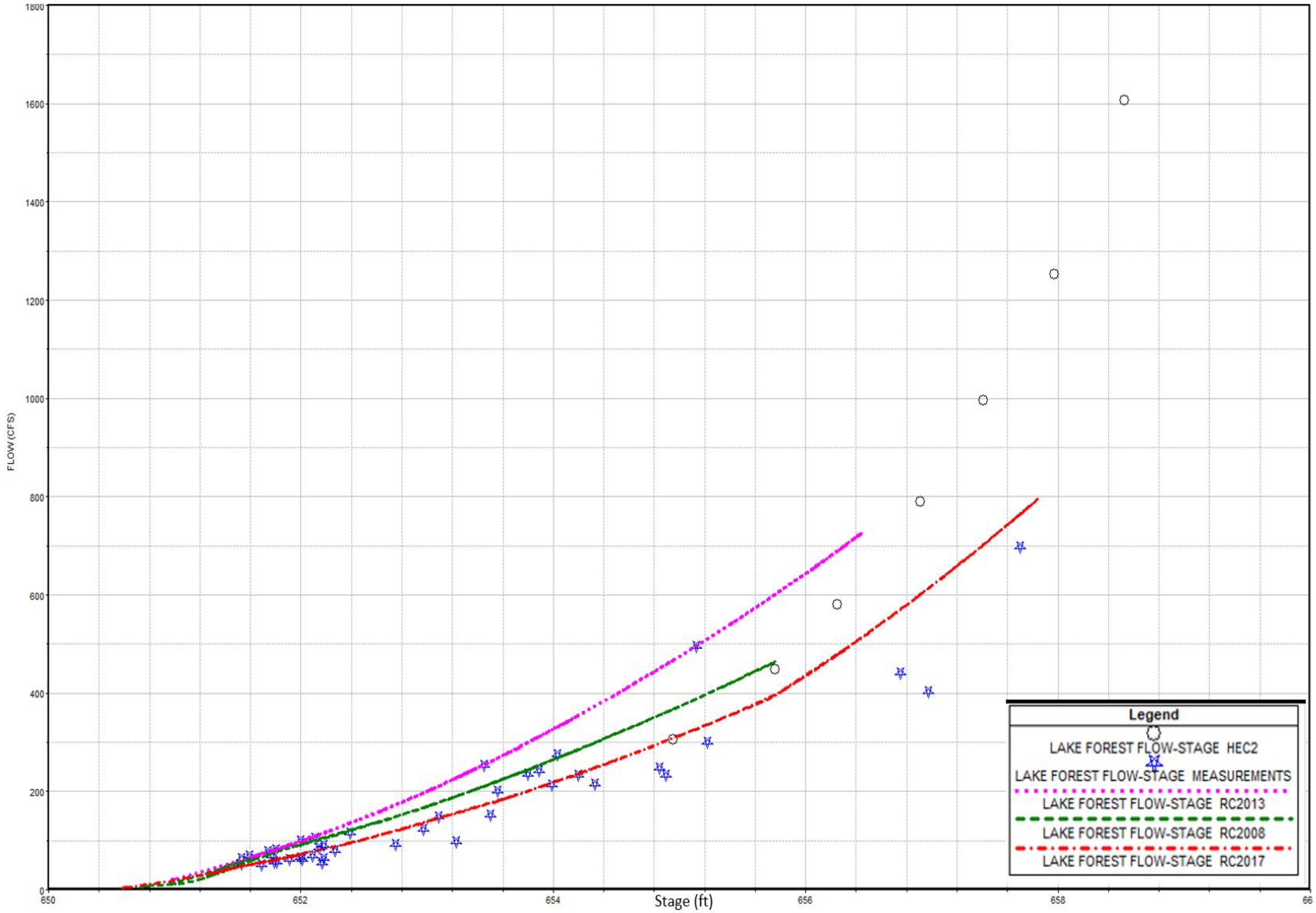


Figure 2-25: Comparison of Rating Curves at the Skokie River near Lake Forest Gage Location

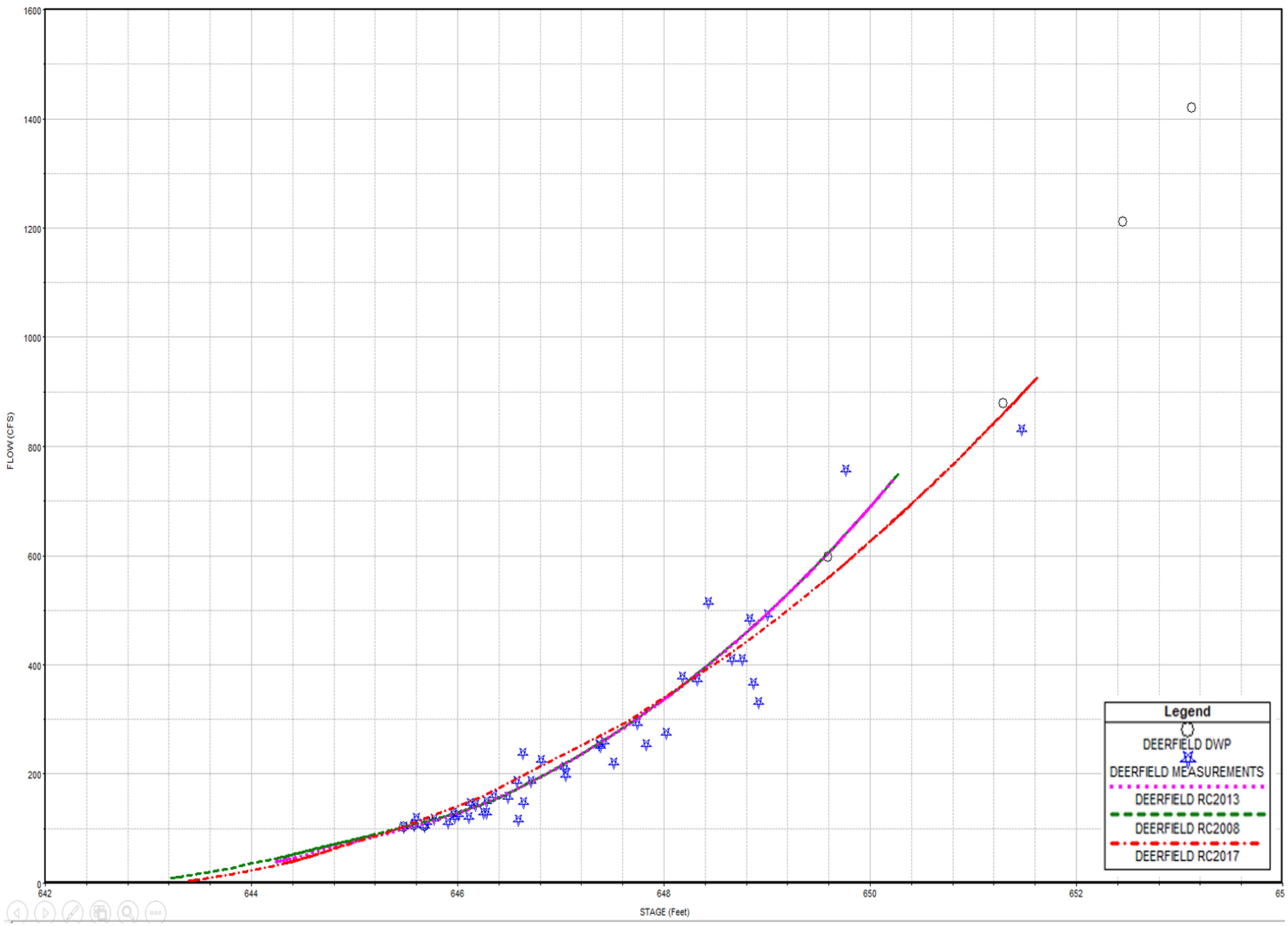


Figure 2-26: Comparison of Rating Curves at the Middle Fork at Deerfield Gage Location

2.7 Critical Duration

The critical storm is a design storm which provides the highest flood discharges and water surface elevations for the flooding source.

The tables below present 100-year peak flows for the applicable nodes in the HMS runs for the Skokie River and Middle Fork. The tables below present 100-year peak flows based on a 12-, 18-, 24-, and 48-hour storm duration for various nodes in the HMS runs for the Skokie River and Middle Fork. The maximum flows in the 48-hour duration for each node are highlighted in yellow in Table 2-2 and Table 2-3. The 24-hour duration was chosen as the critical duration for both streams because it had higher flows more frequently.

Table 2-2: Critical Precipitation Duration Analysis for the Skokie River (cfs)

Skokie River				
HMS node	**12 hr**	**18 hr**	**24 hr**	**48 hr**
R-SK-MC-4	1939.3	1977.3	2003.6	1974.8
R-SK-MC-5	1931.3	1971.8	1997.3	1967.4
J-SK-MC-7	2106.3	2144	2145.4	2127.4
J-SK-MC-8	1888.3	1915.8	1930.1	1901.1
R-SK-MC-8	1708.8	1749	1759	1723.7
J-SK-MC-10	1829.6	1918.7	1904.9	1858.7
J-SK-MC-11	1486.9	1541.3	1533.7	1515.4
J-SK-MC-12	1304.1	1355.2	1368.2	1352
J-SK-MC-13	1258.9	1345.1	1334.8	1348.5
J-SK-MC-14	973.9	1062.2	1126.3	1169.6
R-SK-MC-14	432.4	495.6	539.1	571.4
J-SK-MC-16	437.8	504.7	550.7	584.3
J-SK-MC-17	395	436.9	441.2	440
J-SK-MC-18	295.5	310.7	303.7	276.7
J-SK-MC-19	229.3	241.6	237.9	214.6
Highlighted cells indicate maximum for each node				

Table 2-3: Critical Precipitation Duration Analysis for the Middle Fork

Middle Fork				
HMS node	12 hr	18 hr	24 hr	48 hr
J-MF-MC-9	1302	1353.3	1386.1	1408.7
J-MF-MC-10	1333.5	1378.7	1410.4	1428.5
J-MF-MC-11	1326.8	1369.7	1410.9	1420.5
J-MF-MC-12	1339.9	1395.8	1445	1462.9
R-MF-MC-12	1273.3	1330.8	1370.3	1341.8
J-MF-MC-13	1417	1458.9	1487.7	1457.5
J-MF-MC-14	1362.8	1443	1487.9	1421.9
J-MF-MC-15	1529.1	1695.9	1702.5	1638.4
R-MF-MC-16	934.5	987.4	1001.8	933.4
R-MF-MC-17	821	858.3	856.3	791.7
R-MF-MC-18	752	785.1	777.8	724.7
R-MF-MC-20	531.7	554.9	558.6	528.6
R-MF-MC-22	401.7	420.2	428.2	411.7
R-MF-MC-23	350.1	358.8	360.3	348.7
J-MF-MC-24	163.7	174.5	469.4	398.5
Highlighted cells indicate maximum for each node				

2.8 Reservoir Development Methodology

During the first local sponsors progress meeting for the North Branch Chicago River PAS study on 2 October, 2018, which was attended by the City of Highland Park, East Skokie Drainage District, Lake Forest, Village of Deerfield, IDNR, LCSMC and the Corps of Engineers, preliminary flood mapping for the 2017 flood was reviewed. Primary flood areas noted at the meeting that included multiple structures reported as flooding by the local communities, were in Highland Park near Taylor Avenue, along Woodvale Avenue in Deerfield and the Park City area.

During the meeting, the Corps stated that the work that was included in the original scope was being completed faster than originally planned and there would likely be funds available to look at limited project conditions.

During the meeting it was pointed out that land was available just upstream of the Highland Park flood area at the Highland Park Country Club. After the meeting, available reports from other flood studies were provided to the Corps for review. After review of the reports and considering the locations of the primary flood areas that occurred during the historic 2017 flood event and due to the limited scope of the study, the Corps made a decision to concentrate first on the Highland Park and Deerfield areas of concern. The thorough analysis of Lake Bluff Reservoir study seemed to adequately cover the Park City area. The methods used in that study analysis were very complicated and would not be easily incorporated considering the limited scope of the PAS study.

It is assumed that reservoirs located upstream near the primary flood sites would be most efficient reservoir location for reducing flooding at the selected flood areas downstream.

During the second local sponsors progress meeting on 14 December 2018, results of preliminary modeling was presented by the Corps with Bulletin 70 precipitation (note: updated Bulletin 70 precipitation was not available until February 2019) for a 500 acre-foot reservoir on the Highland Park Country Club site. Meeting discussion revealed that the site has changed considerably since the Corps of Engineers Phase I GDM for the North Branch of the Chicago River (1983), where this was reservoir site number 7. Also, there are current plans to expand the pond on the site, which further limits the reservoir size that can be constructed. The footprint was further limited by keeping it outside the 100 year flood plain to avoid double accounting of storage. A gravity drain was assumed for draining the reservoir. The reservoir size based on these conditions resulted in a reservoir capacity of 130 acre feet.

For the Woodvale Avenue flood area location in Deerfield, the reservoir site was selected in a similar manner as the Highland Park Reservoir site. The Prairie Wolf Slough Forest Preserve (Site #18 from the 1983 Corps study) was the next site upstream with significant space available for a reservoir. This site has fewer restrictions on space than the Highland Park Country Club site. A preliminary reservoir size of 250 acre-feet was assumed. This is similar to the initial reservoir size used in the Lake Bluff Reservoir study.

Different weir elevations and lengths were modeled to maximize stage reductions for frequent flooding of structures, looking at water surface profiles, flood mapping and observing at what point the reservoir fills.

The results from these proposed reservoirs were presented at the third local sponsor progress meeting on 03 May 2019 after the hydraulic and economic analyses were completed.

2.9 Skokie River Economic Reaches 8 and 9

For the economic analysis in Skokie River reaches 8 and 9, which are primarily located in Park City and North Chicago, model results showed significant inundation for high frequency events (approximately two feet of flooding for the one year flood event in Park City near Washington Street). The FIS and Lake Bluff Flood Storage Feasibility Study show similarly high water surface elevations for relatively frequent events. Many of the cross-sections downstream of this area (between Belvidere Road and Buckley Road) do not show a well-defined channel, and the model does not include any stormwater or closed conduit conveyance structures. Based on a cursory review of aerial photography and digital topography, there appears to be missing channel information that is causing the hydraulic model to over predict water surface elevations, particularly for higher frequency events. While the hydraulic model shows a reasonable depiction of the channel in most locations, field reconnaissance, a review of as-built drawings for stormwater facilities, and possibly survey would likely be necessary to update the hydraulic model to provide reasonable flood inundation elevations and maps at higher frequency events.

Chapter 3 Economic Analyses

3.1 Introduction

The economic analyses estimated flood damages along the North Branch Chicago River in Lake County, Illinois; specifically, the Skokie River and the Middle Fork. As defined in the scope of work, the primary objectives of the economic analyses were to develop an updated structure inventory, compile HEC-FDA input files, construct a new study in HEC-FDA, perform an economic evaluation, and create damage maps, using standard USACE methods and tools. Completion of the economic analyses provided a better understanding of the expected economic flood damages, within the study area, in addition to being able to evaluate the effectiveness of the two reservoirs in reducing flood damages to structures.

The data development tasks provided the necessary inputs for a HEC-FDA study while HEC-FDA provided the outputs which were used to complete the economic evaluation. Primarily, the economic data was developed in the Environmental Systems Research Institute's (ESRI) ArcGIS Pro and Microsoft Excel using a structure inventory that was provided by the Illinois Department of Natural Resources (IDNR) as the original source data. The first part of the economic evaluation was conducted as a study in HEC-FDA. Subsequently, the HEC-FDA outputs were compiled in Microsoft Notepad and analyzed in Microsoft Excel. Summary tables of the HEC-FDA outputs were created to review the data, assist in producing the appropriate interpretations, and formulate conclusions.

3.2 Economic Data Development Methods

The economic data was developed using ESRI's ArcGIS Pro and Microsoft Excel. The base data was sourced from IDNR, local communities, and the NSI. A unique data set was created for the study area by filtering, transforming, and combining data from all three sources. The following subsections describe the methods which were used to develop the data used in the economic evaluation.

3.2.1 Structure Inventory

The structure inventory provided the economic basis for damage estimation and alternative evaluation. This inventory included estimated structure, content, and vehicle values. The development of each of these inputs are discussed in the following subsections.

<u>3.2.1.1 Collecting Parcel & Assessor Data</u>

IDNR and other local communities provided a structure inventory which contained the parcel and assessor data used in the study. This data served as the foundation for the data development process and the provided data set was compared with the NSI. Values in the IDNR data were modified when it was concluded that a different value would better reflect actual conditions in the project area; this was primarily accomplished by cross-referencing IDNR's data with the NSI and existing GIS data.

<u>3.2.1.2 Identifying Structures in the Study Area</u>

Both the IDNR SI and the NSI contained structures located outside of the study area and the 500-year floodplain. To develop a structure inventory which contained only structures that are estimated to be impacted by flooding in the study area, using the updated hydrology and hydraulic modeling, the structure inventory and the 500-year inundation boundary were imported into ArcGIS Pro and a spatial join was used to identify which structures are located within, or very close to, the 500-year floodplain along the Skokie River and the Middle Fork in Lake County, Illinois. The 500-year inundation boundary was chosen for the spatial join because it encompassed all relevant structures and inundation boundaries.

3.2.1.3 Assigning Damage Categories & Occupancy Types

Damage categories and occupancy types were assigned to each structure. Damage categories were assigned as either residential, commercial, industrial, or public. The occupancy types were assigned to the structure based on defining characteristics such as, if the structure has a basement, how many stories the structure has, and structure use. Table 3-1 displays the damage categories and occupancy types of structures located in the study area.

Table 3-1: Damage Categories and Occupancy Types

Damage Category	Occupancy Type	Description	Count
Residential	RES1-1SNB	Single-family, one story, no basement	184
Residential	RES1-1SWB	Single-family, one story, with basement	354
Residential	RES1-2SNB	Single-family, two stories, no basement	65
Residential	RES1-2SWB	Single-family, two stories, with basement	145
Residential	RES1-3SNB	Single-family, three stories, no basement	2
Residential	RES1-3SWB	Single-family, three stories, with basement	9
Residential	RES1-SLNB	Single-family, split-level, no basement	37
Residential	RES1-SLWB	Single-family, split-level, with basement	75
Residential	RES2	Manufactured house/mobile home	466
Residential	RES3A	Multi-family, duplex	1
Residential	RES3B	Multi-family, 3-4 units	17
Residential	RES3C	Multi-family, 5-9 units	29
Residential	RES6	Nursing home	2
Commercial	COM1	Retail Trade	52
Commercial	COM2	Wholesale Trade	2
Commercial	COM3	Personal and repair services	11
Commercial	COM4	Professional and technical services	17
Commercial	COM5	Depository institutions	6
Commercial	COM7	Medical office and clinic	1
Industrial	IND1	Heavy industrial	2
Industrial	IND2	Light industrial	1
Industrial	IND6	Construction facilities and offices	11
Public	GOV2	Emergency response	1
		Total	**1490**

3.2.1.4 Structure Depreciated Replacement Values (DRVs)

According to Engineer Regulation 1105-2-100 (D-15), building values should be evaluated as an estimate of depreciated replacement value (DRV) of the structure. DRVs estimate what it would cost to repair the damage to a structure. The NSI data was used to estimate the DRVs of structures contained in the structure inventory.

3.2.1.5 Structure Content Values

Structure contents are usually defined as everything within the structure that is not permanently installed such as, rugs, appliances, and store or warehouse inventories. The residential content-to-structure-value-ratio damages are provided within the generic curves documented by the USACE Institute for Water Resources (IWR) Economic Guidance Memorandum (EGM) 01-03. These content-damage functions are based on the structure value and vary by structure type. Each of these curves were developed to estimate content damages based on the structure value.

3.2.1.6 Inventory of Vehicles

Damages to vehicles were estimated in the economic evaluation. These damages were based on the number of commercial automobiles directly impacted per structure. Given that the majority of the study area contains residential structures, the majority of vehicles impacted were estimated to be personal vehicles which belonged to the local residents.

The automobile damages are calculated by correlating depth of flooding, depth-damage per automobile, and damage per inundated automobile. The total number of vehicles within the study area were estimated using the NSI.

3.2.1.7 Depth-Damage Functions

A depth-damage relationship defines how much damage occurs for an incremental depth of flooding. The deeper the flooding is, the higher the damage will be and each occupancy type has its own depth-damage function. These relationships are usually expressed as a percent of the total structure value; in the case of this study, the structure values were determined by DRVs. Figure 3-1 provides an illustrative example of a depth damage function for a single-family home with one floor and a basement (RES1-1SWB).

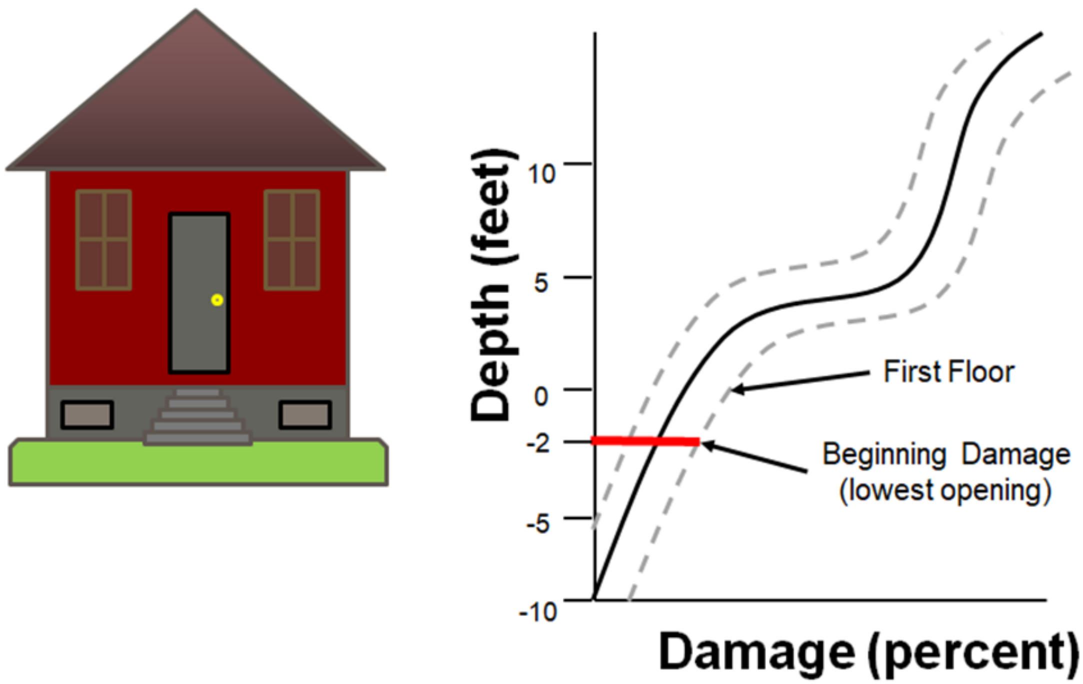


Figure 3-1: Conceptual Depth-Damage Function

<u>3.2.1.8 Assigning Ground Elevations</u>
Initial ground elevations were estimated using the NSI and added to the structure inventory. Ground elevations were corrected, when needed, using Lake County digital elevation model (DEM) data.

<u>3.2.1.9 Estimating Structure Elevations</u>
Structure elevations were estimated using the NSI and added to the structure inventory. Lake County DEM data was used to verify structure elevations, as needed.

3.2.3 Assigning River Stationing

River stationing for the Skokie River and the Middle Fork was identified by the hydraulic engineer. The Skokie River station range was between 45.625 and 29.495 river miles. A total of 16.13 river miles of the Skokie River were contained in the study area. The Middle Fork station range was between 343.58 and 329.11 river miles for the study area. A total of 14.47 river miles of the Middle Fork were contained in the study area.

3.2.4 Identifying Damage Reach Delineations

Defining damage reaches was essential for preparing the necessary inputs to perform an economic evaluation in HEC-FDA. According to the HEC-FDA user manual, damage reaches are, "specific geographical areas within a floodplain. They are used to define consistent data for plan evaluations and to aggregate structure and other potential flood inundation damage information by stage of flooding." In short, damage reaches are a method of partitioning the river and floodplain into sections which have similar hydraulic conditions.

In this study, the hydraulic engineer established suggested damage reach delineations based on the graphs shown in Figure 3-2 and Figure 3-3:

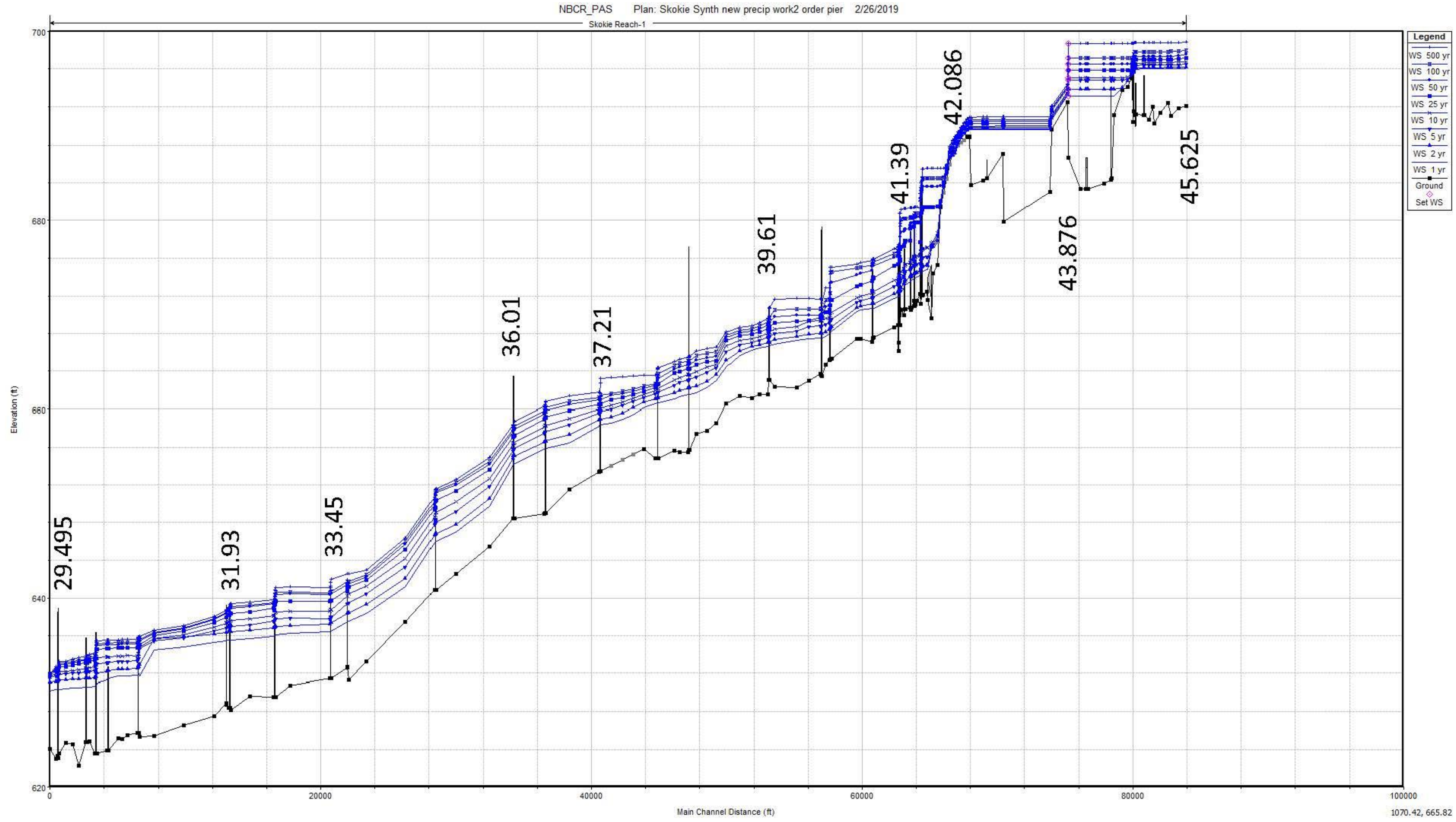


Figure 3-2: Damage Reach Delineations for the Skokie River

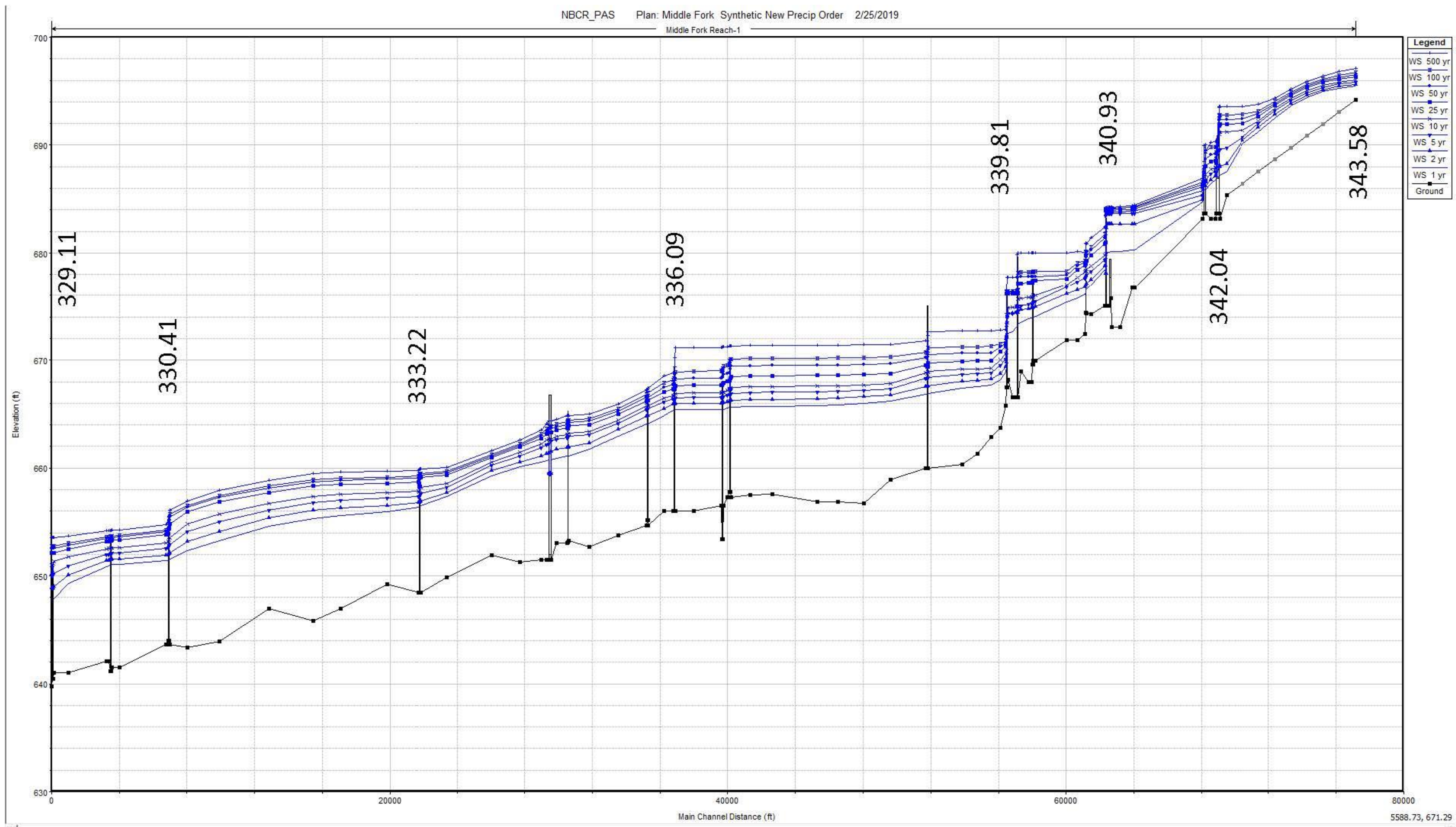


Figure 3-3: Damage Reach Delineations for the Middle Fork

The Skokie River was divided into nine damage reaches, defined in this study as Skokie01 through Skokie09. Skokie09 was the damage reach located furthest upstream and Skokie01 was located furthest downstream in the study area. Both river banks were included in all of the damage reaches. Table 3-2 provides a list of the defined damage reaches for the Skokie River with the recommended river stationing.

Table 3-2: Skokie River Damage Reach Delineations

Skokie River Damage Reach Delineations			
Name	Start (Downstream)	End (Upstream)	Bank
Skokie01	29.495	31.930	Both
Skokie02	31.931	33.450	Both
Skokie03	33.451	36.010	Both
Skokie04	36.011	37.710	Both
Skokie05	37.711	39.610	Both
Skokie06	39.611	41.390	Both
Skokie07	41.391	42.086	Both
Skokie08	42.087	43.876	Both
Skokie09	43.877	45.625	Both

The Middle Fork was divided into six damage reaches, defined in this study as MFork01 through MFork06. MFork06 was the damage reach located furthest upstream and MFork01 was the damage reach that is located furthest downstream in the study area. Both river banks were included in all of the damage reaches. Table 3-3 provides a list of the defined damage reaches for the Middle Fork with the recommended river stationing.

Table 3-3: Middle Fork Damage Reach Delineations

Middle Fork Damage Reach Delineations			
Name	Start (Downstream)	End (Upstream)	Bank
MFork01	329.110	330.410	Both
MFork02	330.411	333.220	Both
MFork03	333.221	336.090	Both
MFork04	336.091	339.810	Both
MFork05	339.811	342.040	Both
MFork06	342.041	343.580	Both

3.2.5 Compiling HEC-FDA Input Files

After all of the necessary hydrologic, hydraulic, and economic data was gathered, the inputs for the HEC-FDA study were compiled and sorted in Microsoft Excel and Microsoft Notepad. The input files included an updated structure inventory, depth-damage functions, water surface profiles, damage reaches, and river stationing.

3.3 Economic Evaluation

The economic evaluation was conducted in HEC-FDA and the outputs were analyzed in Microsoft Excel. The following subsections describe the assumptions of the economic evaluation, the project conditions, an overview of the quality assurance & quality control measures that were taken to ensure the accuracy of the results, and the development of output files and damage maps.

3.3.1 Economic Evaluation Assumptions

Important assumptions employed in the economic evaluation are:

(1) All inputs in this analysis were estimates and, therefore, subject to varying degrees of uncertainty;

(2) All monetary values are stated in 2019 price levels;

(3) The period of analysis was 50 years, 2019-2068, for both the future without-project (FWOP) and future with-project (FWP) conditions;

(4) The Fiscal Year 2019 (FY19) federal discount rate of 2.875 percent was used for the evaluation;

(5) All structural computations were based on industrial, commercial, public, and residential depreciated replacement values (DRVs) and do not include land values;

(6) All annualized benefits were calculated using an end-of-year discounting method;

(7) Land use and population data were held constant;

(8) All economic damages and benefits displayed reflect the best estimate, given available data.

3.3.2 Future Without-Project (FWOP) and Future With-Project (FWP) Conditions

To evaluate the efficacy for structural alternatives to mitigate flood damages, two proposed project conditions were modeled. A 130 acre-foot reservoir at the Highland Park Country Club for the Skokie River and a 250 acre-foot reservoir at the Prairie Wolf Forest Preserve for the Middle Fork were established to be the FWP conditions.

The two assumed locations of the reservoirs were Reservoir #7 on the Skokie River and Reservoir #18 on the Middle Fork; these reservoirs were outlined in the previous USACE study of this watershed, Phase 1 General Design Memorandum (GDM, 1983). The reservoir site selection was based on the primary areas that were reported as being flooded by the local communities in the July 2017 flood event and the location of the closest available upstream sites, relative to the reported flooding. These locations were anticipated to be the most effective for mitigating flood damages using a structural alternative, given the available data and current reservoir development constraints. Figure 3-4 provides a map of the general proximity of the assumed reservoir locations, circled in red, for each project condition.

To evaluate the efficacy for potential structural alternatives to mitigate flood damages, two project conditions were modeled, the FWOP and FWP conditions. The FWOP condition assumed that there would be no measures taken to mitigate flood damages within the 50-year period, from 2019 to 2068; no action was assumed as a baseline condition in order to evaluate the efficacy of the FWP condition while holding all other variables constant. The FWP condition assumed the construction of a 130 acre-foot reservoir at the Highland Park Country Club and a 250 acre-foot reservoir at the Prairie Wolf Forest Preserve to reduce flood damages. The estimated flood damages for both conditions were compared to understand the efficacy of flood mitigation using structural alternatives in the study area and determine whether structural measures would be economically viable (i.e., result in a benefit-to-cost ratio greater than 1.0).

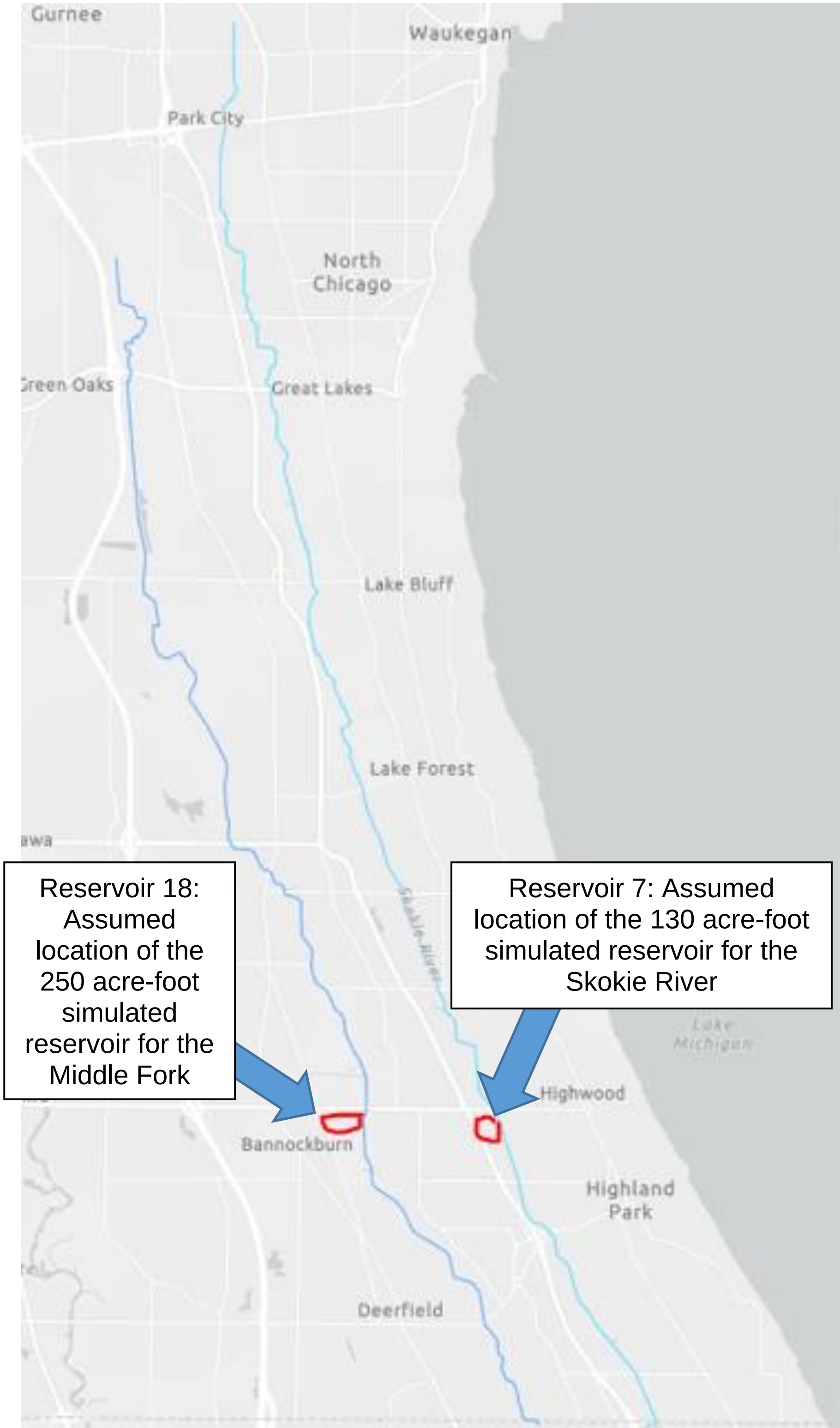


Figure 3-4: Assumed Project Storage Basin Locations

Below is the original plan of Reservoir Site #7 from the GDM study and an outline, in yellow, of the proposed reservoir overlaid onto the current flood map.

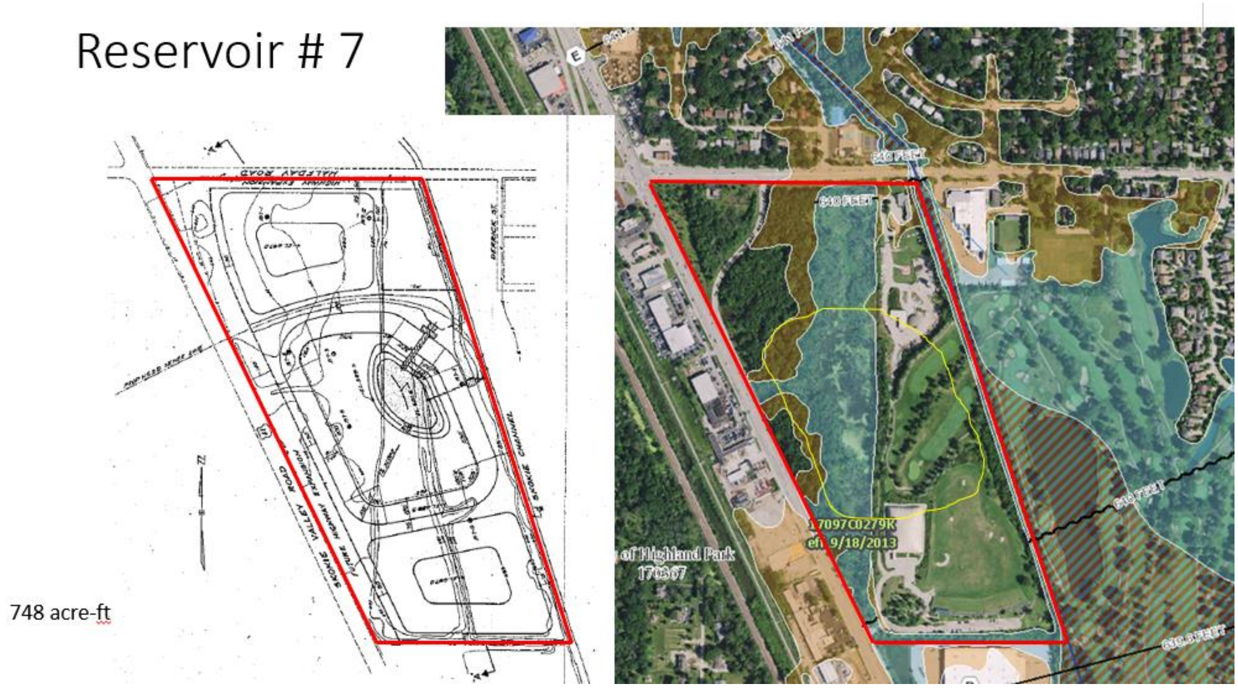


Figure 3-5: Reservoir 7 from the Phase 1 General Design Memorandum

The GDM study assumed this location would be available for construction of a reservoir; however, the site has since been developed and the reservoir capacity that was assumed, in the GDM, had to be reduced from 748 acre-feet to 130 acre-feet for this PAS study.

Figure 3-6: Proposed Development of the Highland Park Golf Course

For this study, the footprint of a reservoir, as shown on Figure 3-7, was assumed to be in place for the FWP condition. Using some broad assumptions, an approximate capacity of 130 acre-feet was assumed. The was located at the Highland Park Golf Course.

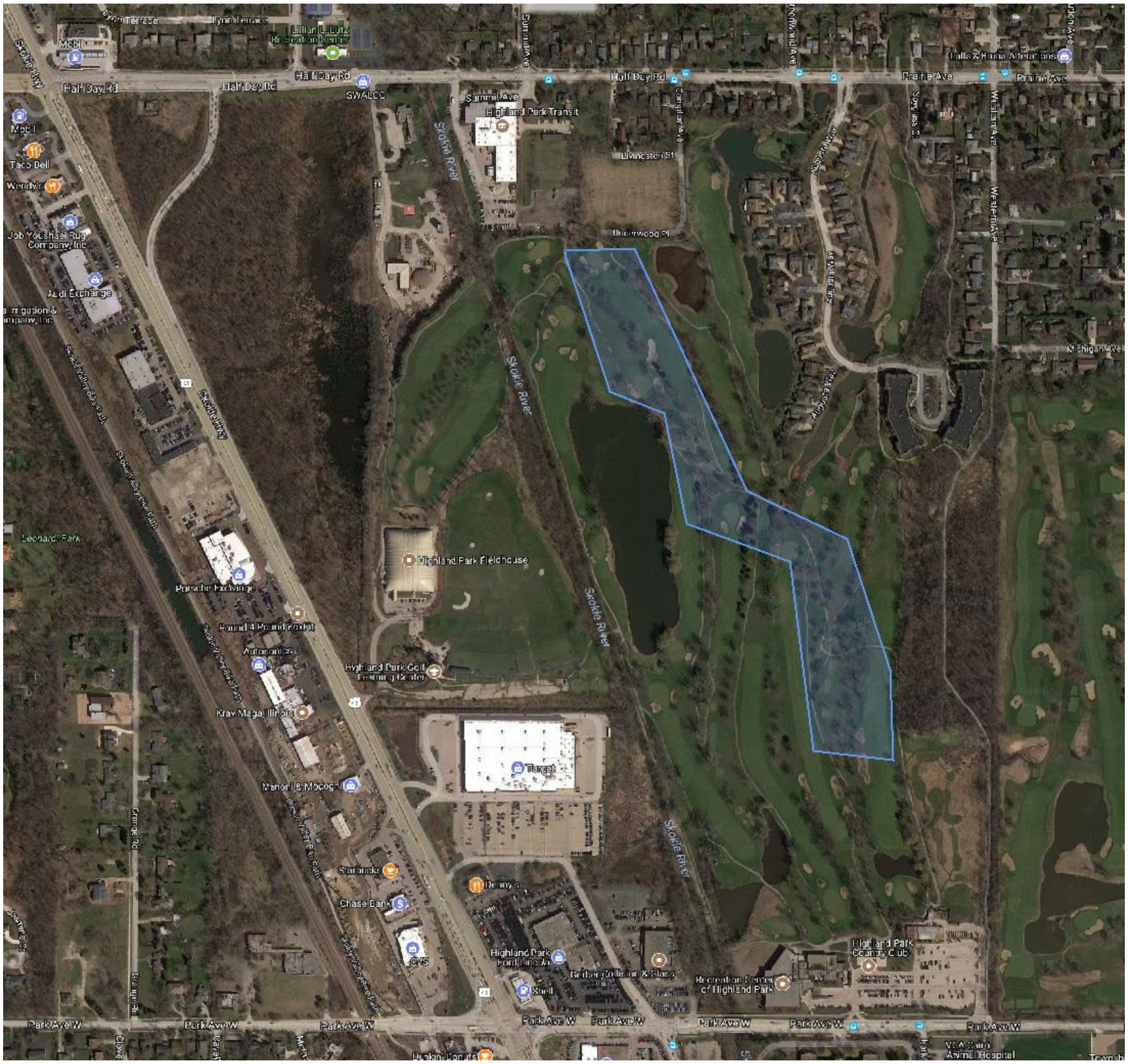


Figure 3-7: Highland Park Golf Course - Assumed Conceptual Reservoir Footprint – 130 Acre-Feet

For Reservoir Site #18, in Figure 3-8, the site currently has some development, but more area was estimated to be available for reservoir development than at the site location for Reservoir #7. A 250 acre-foot reservoir was assumed with no specific footprint. The reservoir was located in Highland Park, Illinois, at the Prairie Wolf Forest Preserve.

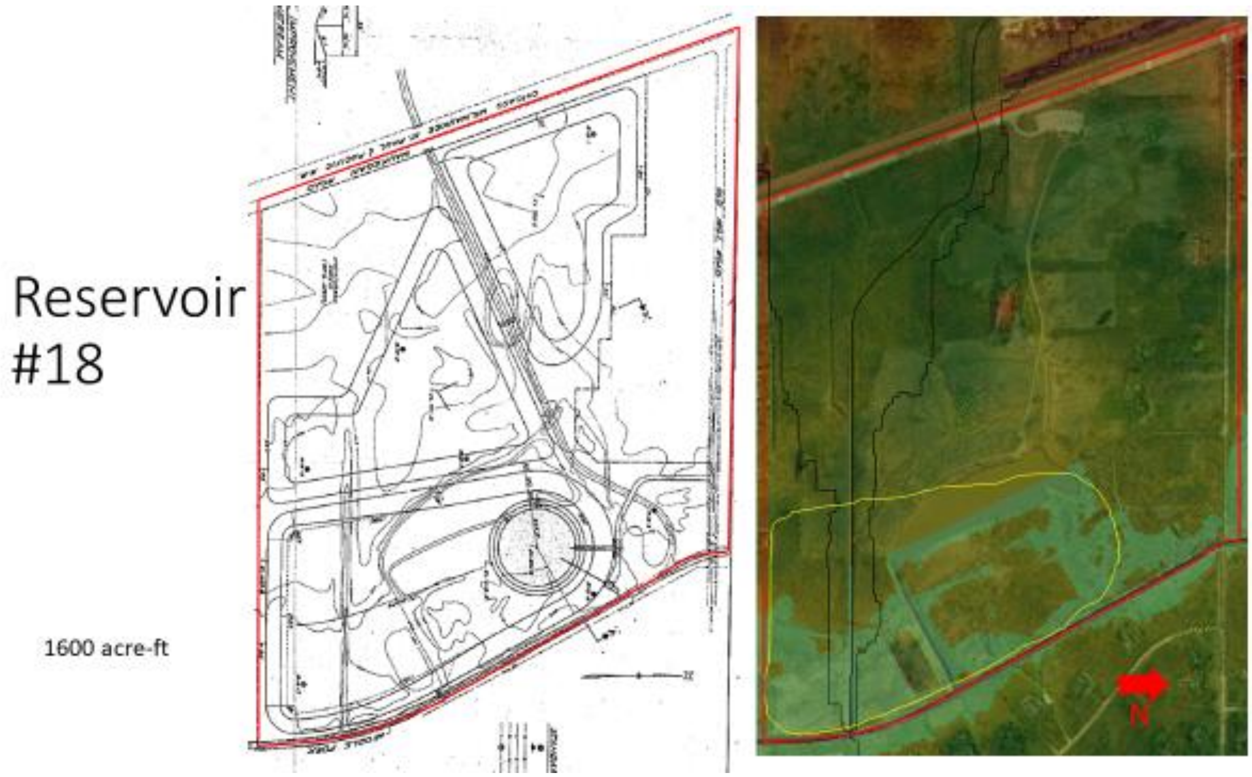


Figure 3-8: Reservoir 18 from the Phase 1 General Design Memorandum

3.3.3 HEC-FDA Study Development

The economic evaluation in the HEC-FDA study relied upon a mathematical relationship between four functions which were developed, for each damage reach, using the compiled input files. Figure 3-9 demonstrates the conceptual relationship between the four functions.

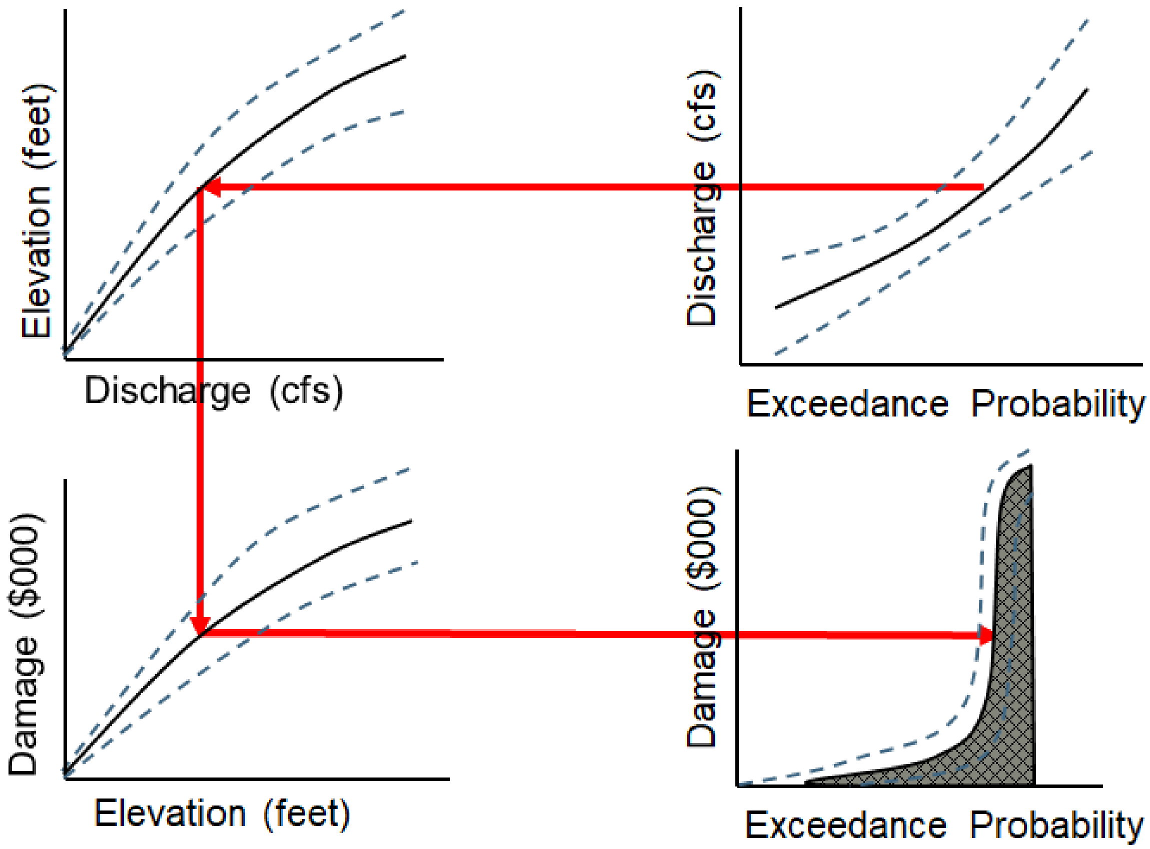


Figure 3-9: Conceptual HEC-FDA Damage Calculation Relationships

The Flow-Frequency and Stage-Flow Functions, depicted at the top of Figure 3-9, were developed in HEC-FDA using the HEC-RAS output. The Stage-Damage and Damage-Frequency functions were developed in HEC-FDA using the provided hydrologic and hydraulic data along with the structure inventory and depth-damage functions.

Four curves were developed for each damage reach; in total, 60 curves were developed. All curves were verified to be monotonically increasing functions to help ensure the accuracy of the estimated flood damages in HEC-FDA.

To compute estimated economic damages along the Skokie River and the Middle Fork, a Monte Carlo simulation was performed for the FWOP and FWP conditions.

3.3.3 Quality Assurance & Quality Control of HEC-FDA Outputs

The estimated annual damages, caused by flooding, were reviewed for appropriateness and consistency in a spreadsheet by the economist performing the HEC-FDA study. A second USACE economist was engaged to review the data and results. The study team met regularly to discuss the progress of the study and preliminary findings. The data was adjusted multiple times throughout the study to better reflect real world conditions.

3.3.4 Developing Output Files

The HEC-FDA study outputs were consolidated in various Microsoft Notepad files within the study folder. The most relevant data was extracted from the Microsoft Notepad files and placed into summary data tables in Microsoft Excel.

3.3.5 Damage Maps

Damage maps were created in ESRI’s ArcGIS Pro to reflect the structure inventory that was used in the study as well as the FWOP inundation boundary for the 500-year event. A river centerline was added for the Skokie River and the Middle Fork to show the position of the rivers on the map. The damage maps for the Skokie River and the Middle Fork are attached at the end of this report. The damage maps attached in this report are partitioned into three plates, or sections, which encompass the whole study area: the northern, middle, and southern sections.

3.4 Economic Evaluation Results and Conclusions

Based on the inputs discussed in the previous sections, a Monte Carlo simulation was performed in HEC-FDA to estimate the average annual damages for the FWOP and FWP conditions. The Skokie River and the Middle Fork were evaluated independently. Summary tables were constructed in Microsoft Excel using the HEC-FDA outputs. In the case of this economic evaluation, the economic benefits are defined as the reduction in average annual flood damages.

3.4.1 Skokie River

The estimated average annual damages for the Skokie River were evaluated, by reach, for both the FWOP and FWP conditions. Table 3-4 provides a summary of the estimated average annual damages, estimated average annual damages reduced, average annual flood damage reduction and the estimated number of structures impacted by the 500-year floodplain, by reach.

*Table 3-4: Average Annual Economic Flood Damage Estimation for the Skokie River**

Reach	Maximum Food Stage Reduction** (ft)	**FWOP Condition:** Average Annual Damages	**FWP Condition:** Average Annual Damages	Reduction in Average Annual Damages		Estimated Number of Structures (500-Year Floodplain)
				$	%	
Skokie01	0.29	$950,000	$926,000	$24,000	3%	206
Skokie02	0.45	$658,000	$615,000	$43,000	7%	95
Skokie03	0.40	$547,000	$516,000	$31,000	6%	248
Skokie04	0.27	$77,000	$77,000	-	-	23
Skokie05	0.00	-	-	-	-	12
Skokie06	0.00	$3,000	$3,000	-	-	20
Skokie07	0.00	$1,000	$1,000	-	-	2
Skokie08	0.00	***	***	***	***	13
Skokie09	0.00	***	***	***	***	570
Total	-	**$2,236,000**	**$2,138,000**	**$98,000**	**4%**	**1189**

*****The average annual damages reflect a 50-year period of analysis (FY19-68), the FY19 Federal discount rate (FDR) of 2.875 percent (per Economic Guidance Memorandum, 19-01, Federal Interest Rates for Corps of Engineers Projects for Fiscal Year 2019) and FY19 prices. Dollar values are rounded to the nearest thousand.

**Values represent the maximum reductions that occurred for the 25 year flood event.

*****All estimates were developed using best-available H&H and structure inventory data. After careful examination of the H&H data and the structure inventory, it was determined the hydraulic data needs to be updated further to better reflect actual hydraulic conditions; there have been changes in the alignment of the Skokie River, especially in in Reaches 08 and 09. Any future efforts to refine the estimates of average annual damages should include a survey to update the hydraulic model. The existing H&H data and is not adequate to provide meaningful results for Reaches 08 and 09. Further study and modeling of Skokie08 and Skokie09 would yield more accurate estimates for flood damages in both reaches; however, a reservoir would still need to be located upstream of these damage reaches for a reduction in economic flood damages.

The reaches that saw a reduction in flood damages were those located downstream of the reservoir; however, the estimated reduction in annual flood damages was fairly small. Consequently, the 130 acre-foot reservoir was concluded to provide little economic benefit or protection due to the low level of flood damage reduction in the study area. Additionally, as mentioned in the footnote of Table 3-4, the estimated economic flood damages for Skokie08 and Skokie09 are likely to be inaccurate because the hydraulic modeling for those reaches needs further examination and refinement.

Overall, in the reaches which experienced a reduction in flood damages in the FWP condition, the 130 acre-foot reservoir was the most effective for reducing damages in Skokie02 and least effective in Skokie01. Skokie01 encompassed the portion of the Skokie River that flows between Central Avenue and the county line between Lake County and Cook County in Highland Park, Illinois. Skokie 02 encompassed the portion of the Skokie River that flows between Half Day Road and Central Avenue in Highland Park, Illinois.

3.4.2 Middle Fork

The estimated average annual damages for the Middle Fork were evaluated by reach for both the FWOP and FWP conditions. Table 3-5 provides a summary of the estimated average annual damages, estimated average annual damages reduced, average annual flood damage reduction and the estimated number of structures impacted by the 500-year floodplain, by reach.

*Table 3-5: Average Annual Economic Flood Damage Estimation for the Middle Fork**

Reach	Maximum Food Stage Reduction** (ft)	**FWOP Condition:** Average Annual Damages	**FWP Condition:** Average Annual Damages	Reduction in Average Annual Damages		Estimated Number of Structures (500-Year Floodplain)
				$	%	
MFork01	0.14	$315,000	$310,000	$5,000	2%	78
MFork02	0.35	$1,961,000	$1,895,000	$66,000	3%	151
MFork03	0.36	$54,000	$54,000	-	-	33
MFork04	0.00	$216,000	$216,000	-	-	27
MFork05	0.00	$412,000	$412,000	-	-	12
MFork06***	0.00	-	-	-	-	0
Total	-	**$2,958,000**	**$2,887,000**	**$71,000**	**2%**	**301**

* The average annual damages reflect a 50-year period of analysis (FY19-68), the FY19 Federal discount rate (FDR) of 2.875 percent (per Economic Guidance Memorandum, 19-01, Federal Interest Rates for Corps of Engineers Projects for Fiscal Year 2019) and FY19 prices. Dollar values are rounded to the nearest thousand.

**Values represent the maximum reductions that occurred for the 25 year flood event.

***Although no structures were estimated to incur damages in MFork06, the reach was included in the table to reflect the full study area.

The 250 acre-foot reservoir was estimated to reduce flood damages in two reaches. Given the limited amount of flood damages that were reduced by the reservoir, it was concluded that this structural alternative provides little economic benefit or protection.

Overall, the 250 acre-foot reservoir was the most effective for reducing damages in MFork02 and least effective in MFork03. MFork02 encompassed the portion of the Middle Fork which flows from Half Day Road to Deerfield Road in Deerfield and Bannockburn, Illinois. MFork03 encompassed the portion of the Middle Fork which flows from IL-43 to Half Day Road in Bannockburn and Lake Forest, Illinois.

3.4.3 Summary of the Frequency, Severity, and Location of Flood Damages

The HEC-FDA outputs were examined to help analyze the frequency, severity, and location of flood damages on the Skokie River and the Middle Fork.

For the Skokie River, the most frequent flood events which cause damage were estimated to be north of East Westleigh Road and south of the Skokie Valley Bike Path in Lake Forest (Skokie04), Illinois. The least frequent flooding events which cause damage were estimated to be south of Buckley Road and north of Wyoming Avenue in North Chicago, IL (Skokie07). The majority of estimated flood damages occurred after the 100-year event (0.01 ACE). The most severe flooding was estimated to occur in Highland Park (Skokie01-03), Illinois, but the remaining reaches appeared to incur relatively low flood damages.

In terms of the Middle Fork, the most frequent flood events which cause damage were estimated to be in Deerfield and Lake Bluff, Illinois (MFork01). The least frequent flood events which cause damages were estimated to be in Lake Forest and Abbott Park, Illinois (MFork06). The majority of damages occurred after the 100-year event (0.01 ACE). The most severe flood damages were estimated to be located north of Deerfield Road and south of Half Day Road in Deerfield, Illinois (MFork02). Structures located south of Deerfield Road and north of the county line in Deerfield (MFork01) were estimated to have relatively moderate flood damages. Flood damages were estimated to be relatively low in Lake Forest and Highland Park, Illinois (MFork03-05).

Largely, flooding depths were minimal for both the Skokie River and the Middle Fork. The majority of structures located in the study area were estimated to experience less than a foot of flooding at the 100-year event. The greatest flooding depth which impacted a structure was estimated at approximately 2.9 feet and was located in Skokie09. Given that the H&H model for Skokie09 needed further refinement and tended to overstate the results, as discussed in Table 3-4, it is likely that 2.9 feet of flooding is an overstated value for the maximum flood depth at the 100-year event; this further validates the conclusion that flooding depths remain consistently low, at less than one foot, throughout the study area. Additional validation comes from the developed structure inventory which contained many structures located barely outside of the 500-year floodplain for both the Skokie River and the Middle Fork.

Study Conclusions and Recommendations

This Planning Assistance to States (PAS) Report documents the purpose, methods and findings of a watershed evaluation of the Middle Fork and Skokie River of the North Branch of the Chicago River in Lake County, Illinois. The study was completed by the United States Army Corps of Engineers (USACE) at the request of the following non-federal sponsors (NFSs): City of Highland Park, the Lake County Stormwater Management Commission, the City of Lake Forest, the Village of Deerfield, and the East Skokie Drainage District. The purpose of this study was to aid NFSs in developing future plans for addressing flood damages. Recent flooding prompted communities in these watersheds to seek a better understanding of the current conditions. This report presents updated hydrology and hydraulic data, and an estimate of average annual economic damages to provide a better understanding of the problem and determine the potential for future flood risk management efforts.

To characterize existing flood conditions, this watershed evaluation made use of available hydrology and hydraulics models and updated precipitation frequencies. The hydrology and hydraulics were updated using data from the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC), the United States Geological Survey (USGS) and the Federal Emergency Management Agency (FEMA). USACE analyzed the sourced data and performed calibrations, as needed. Updated Illinois State Water Survey (ISWS) Bulletin 70 data was incorporated into the models. The models were used to produce outputs in the Hydrologic Engineering Center's River Analysis System (HEC-RAS) software for the economic analyses.

In addition, an evaluation was completed to test the performance of a reservoir on each river, and demonstrate the possible effectiveness of structural features. The following reservoirs were selected based on the primary flooded areas during the July 2017 flood event: a 130 acre-foot reservoir at the Highland Park Country Club and a 250 acre-foot reservoir at the Prairie Wolf Forest Preserve. It is assumed that reservoirs located upstream near the primary flood sites would be most efficient reservoir location for reducing flooding at the selected flood areas downstream. The effectiveness of these structural features were estimated by reduced flood stages, and the resulting reductions in structure damages, as determined by the economic analysis.

USACE partitioned its economic analyses into two primary tasks. The first task involved developing an updated structure inventory and inputs for the Hydrologic Engineering Center's Flood Damage Analysis (HEC-FDA) software using source data from the Illinois Department of Natural Resources (IDNR). The second task involved performing an economic evaluation to understand the frequency, severity, and location of flood damages anticipated within the study area while also analyzing the effectiveness of the two reservoirs in reducing flood damages.

The economic evaluation compared the estimated economic damages over a 50-year period, from 2019 to 2068, for two conditions. The future without-project (FWOP) condition assumed that there would be no measures taken to mitigate flood damages within the period of analysis. The future with-project (FWP) condition assumed the construction of the two reservoirs to reduce flood damages. The estimated flood damages for both conditions were compared to understand the efficacy of these structural alternatives and their economic viability.

Conclusions

The hydrologic and hydraulic (H&H) analyses were instrumental in establishing a set of base data which was used to understand the frequency and location of flooding within the study area. Furthermore, the H&H data created in HEC-RAS provided the inputs necessary to evaluate the economic severity of flooding in HEC-FDA. Overall, the hydrologic and hydraulic analyses were successful in improving the understanding of the flood conditions due to overbank flooding, of the Skokie River and the Middle Fork in Lake County, Illinois.

In addition, the H&H evaluation presented an estimate of the effectiveness of possible structural measures at reducing flood stages, to include a 130 acre-foot reservoir at the Highland Park Country Club and a 250 acre-foot reservoir at the Prairie Wolf Forest Preserve. It is assumed reservoirs located upstream near the primary flood sites would be most efficient reservoir location for reducing flooding at the selected flood areas downstream. The maximum stage reductions along the Skokie River for the 25 year flood event ranged from 0.0 feet (Reaches 05 through 09) to 0.45 feet (Reach 02). The maximum stage reductions along the Middle Fork for the 25 year flood event ranged from 0.0 feet (Reaches 04 through 06) to 0.36 feet (Reach 03).

The economic evaluation resulted in three primary accomplishments. First, various datasets were constructed in preparation to conduct the economic evaluation including: an updated structure inventory, HEC-FDA inputs, and damage maps. Second, estimated flood damages along the Skokie River and the Middle Fork helped in developing an understanding of the severity, location, and frequency of economic flood damages in the study area. Finally, evaluating the effectiveness of the two reservoirs at mitigating flood damages provided insight into the general efficacy of these alternatives, within the study area.

The economic evaluation revealed that the reservoirs would not significantly reduce flood damages in the Skokie River or Middle Fork watersheds; for each river, less than 5% of the total average annual damages to structures were reduced by these structural measures.

Recommendations

Given the evaluated reservoirs had little impact on reducing flood damages, USACE does not believe there is a federal interest in proceeding to a specifically authorized study. Based on the analysis, it is unlikely an economically viable structural alternative (i.e., one resulting in a benefit-to-cost ratio greater than 1.0) could be identified. Factors considered in this assessment are the locations of the evaluated structures which are geographically spread across a large area, as well as limited real estate available to implement structural measures, and the scale of damages for the entire study area indicates that it is unlikely a structural measure would be a cost-effective. USACE recommends nonstructural alternatives be considered by the local communities, including: structure elevation, structure relocation, buyouts, floodproofing, implementation of a flood warning system, and floodplain regulation.

Damage Maps

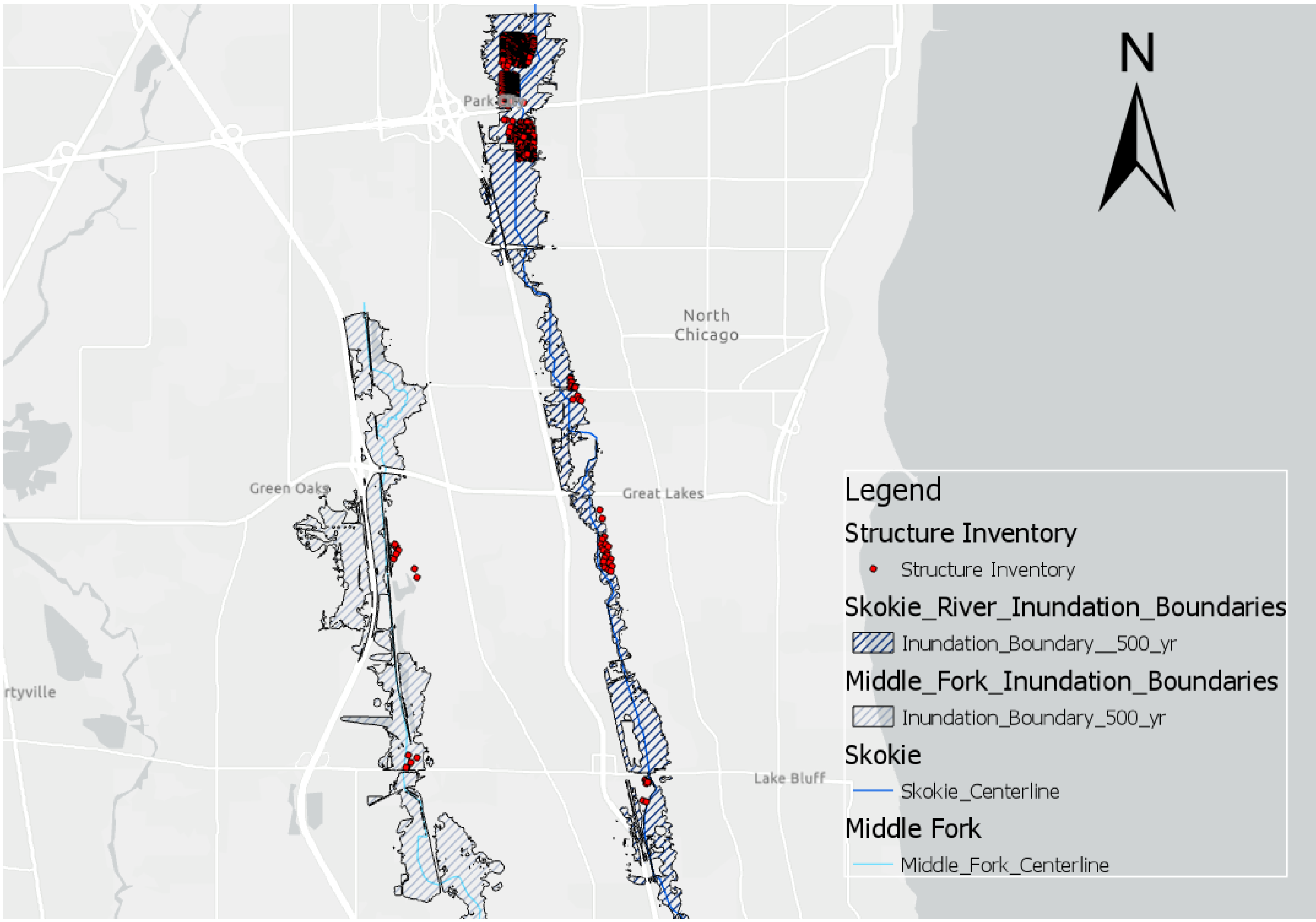


Plate 1: North Branch Chicago River – Skokie River and the Middle Fork (Northern Section)

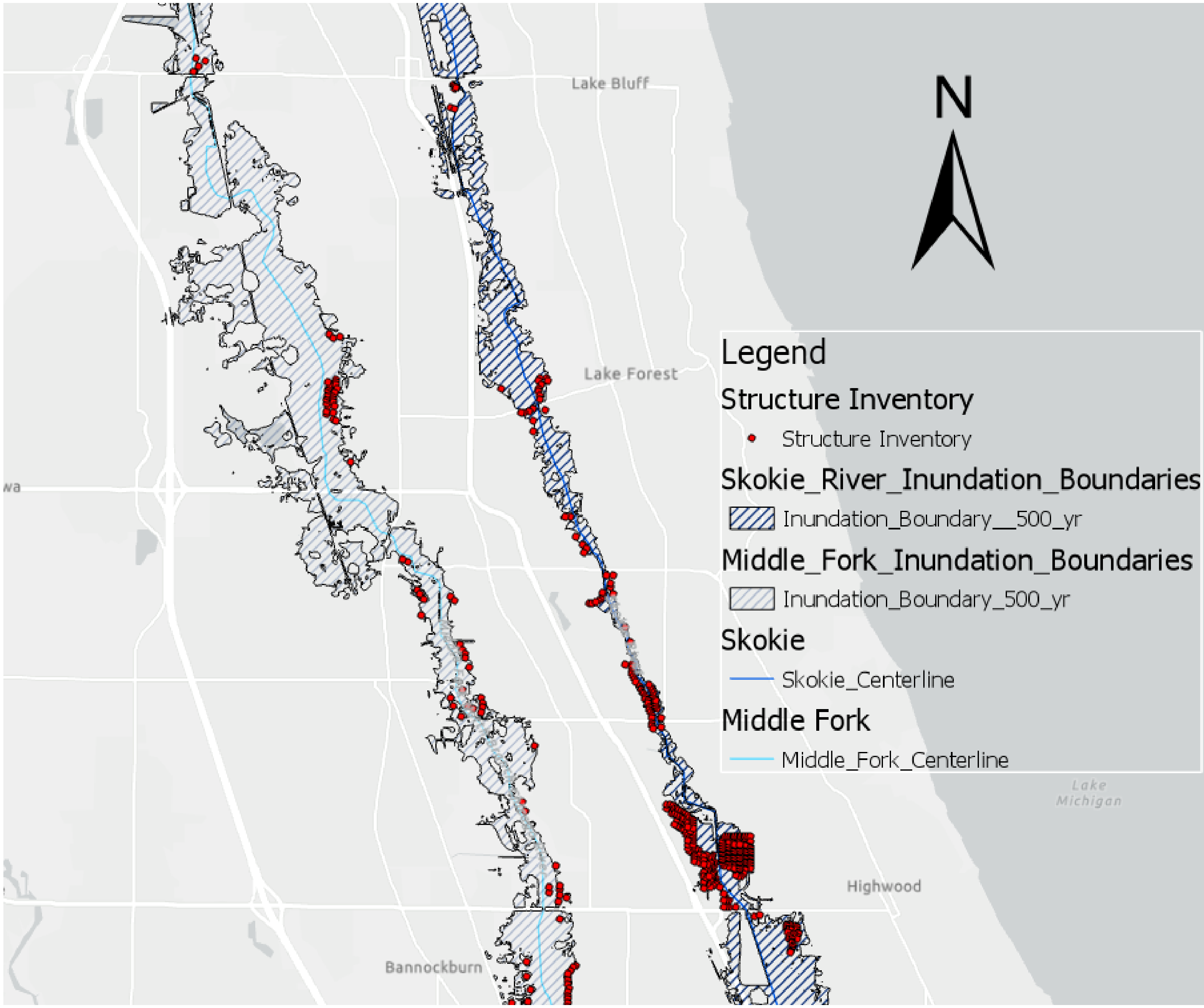


Plate 2: North Branch Chicago River – Skokie River and the Middle Fork (Middle Section)

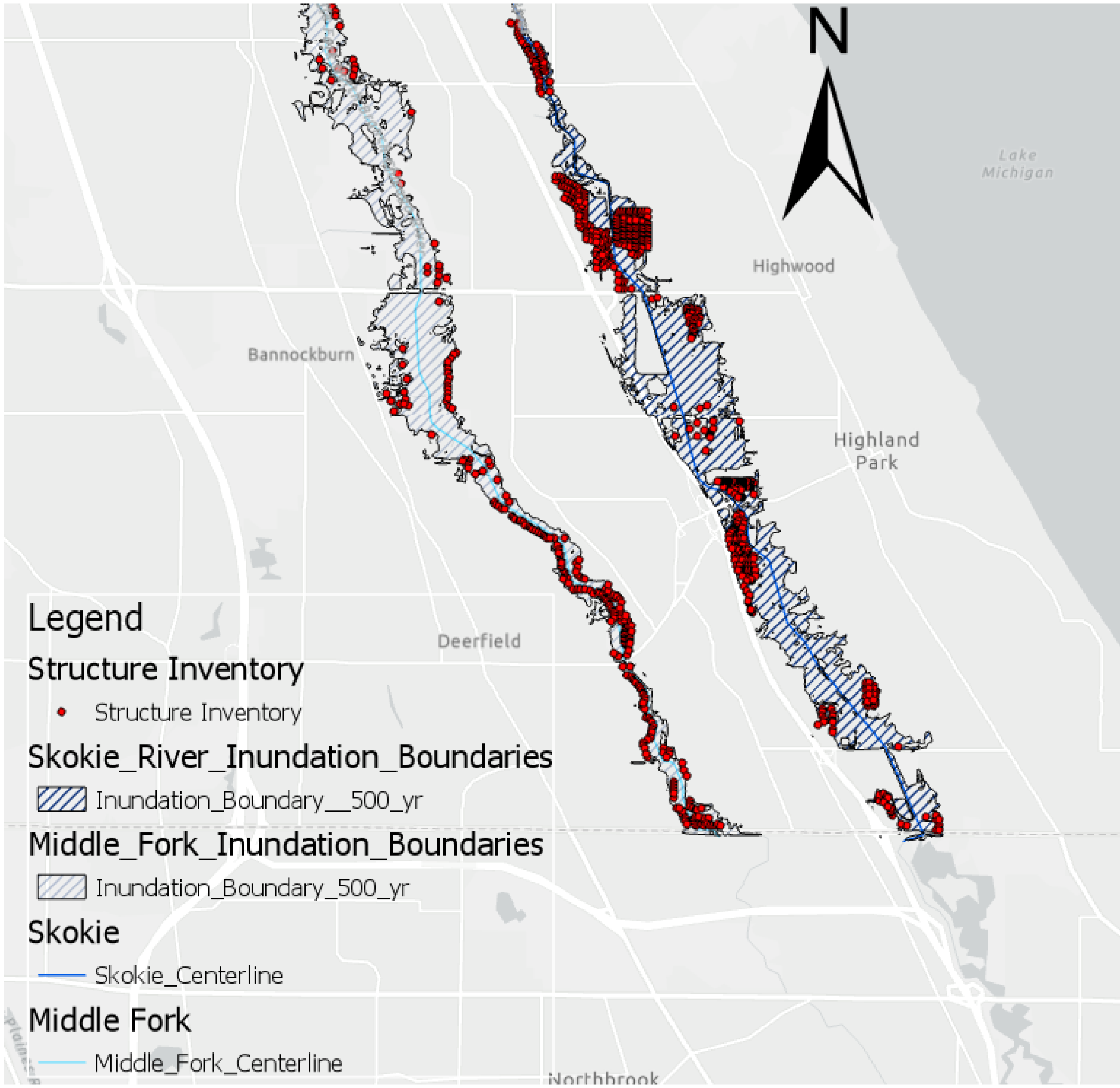


Plate 3: North Branch Chicago River – Skokie River and the Middle Fork (Southern Section)

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