Intended for

New York State Department of Environmental Conservation

625 Broadway

Albany, New York 12233

Document type

Final Report

Date

July 2021

RESILIENT NEW YORK FLOOD MITIGATION INITIATIVE

CROOKED BROOK, CHAUTAUQUA COUNTY, NEW YORK

Prepared for:

New York State Office of General Services

New York State Department of Environmental Conservation

Project Team:

Ramboll

Highland Planning

Gomez and Sullivan Engineers

RESILIENT NEW YORK FLOOD MITIGATION INITIATIVE
CROOKED BROOK, CHAUTAUQUA COUNTY, NEW YORK

Project name	**Resilient New York Flood Mitigation Initiative – Crooked Brook, Chautauqua County, New York**
Project no.	**SD120**
Recipient	**New York State Office of General Services**
Document type	**Final Report**
Version	**1**
Date	**July 20, 2021**
Prepared by	**Kadir Goz**
Checked by	**Ahintha Kandamby, Ph.D., P.E.**
Approved by	**Shaun B. Gannon, P.E., D.WRE, P.H., CFM**

Ramboll

101 First Street
4th Floor
Utica, NY 13501
USA

T 315-956-6950

F 315-790-5434

https://ramboll.com

IN NOVEMBER 2018, NEW YORK STATE GOVERNOR ANDREW CUOMO COMMITTED FUNDING TO UNDERTAKE ADVANCED MODELING TECHNIQUES AND FIELD ASSESSMENTS OF 48 FLOOD PRONE STREAMS TO IDENTIFY PRIORITY PROJECTS AND ACTIONS TO REDUCE COMMUNITY FLOOD AND ICE JAM RISKS, WHILE IMPROVING HABITAT. THE OVERALL GOAL OF THE PROGRAM IS TO MAKE NEW YORK STATE MORE RESILIENT TO FUTURE FLOODING.

Ramboll

101 First Street
4th Floor
Utica, NY 13501
USA

T 315-956-6950

F 315-790-5434

https://ramboll.com

TABLE OF CONTENTS

TABLE OF TABLES

TABLE OF FIGURES

APPENDICES

ACRONYMS/ABBREVIATIONS

1-, 2-, 3-D	1-, 2-, and 3-Dimensional
AC	Acres
ACE	Annual Chance Flood Event
BCA	Benefit Cost Analysis
BCR	Benefit Cost Ratio
BFE	Base Flood Elevation
BRIC	Building Resilient Infrastructure and Communities
CCSWCD	Chautauqua County Soil and Water Conservation District
CDBG	Community Development Block Grants
CEHA	Coastal Erosion Hazard Area
CFA	Consolidated Funding Applications
CFR	Code of Federal Regulations
CFS	Cubic Feet per Second (ft^3/s)
CRRA	Community Risk and Resiliency Act
CRREL	Cold Regions Research and Engineering Laboratory
CSC	Climate Smart Communities
DEM	Digital Elevation Model
DHS	United States Department of Homeland Security
DRRA	Disaster Recovery Reform Act of 2018
EPF	Environmental Protection Fund
EWP	Emergency Watershed Protection
FCA	Flood Control Act
FEMA	Federal Emergency Management Agency
FHA	Federal Highway Administration
FHF	Flood Hazard Factor
FIA	Federal Insurance Administration
FIRM	Flood Insurance Rate Maps
FIS	Flood Insurance Study
FMA	Flood Mitigation Assistance
FT	Feet
GIS	Geographic Information System
GLERL	Great Lakes Environmental Research Laboratory
HEC	Hydrologic Engineering Center
HEC-RAS	Hydrologic Engineering Center's River Analysis System
HMGP	Hazard Mitigation Grant Program
HSGP	Homeland Security Grant Program
H&H	Hydrologic and Hydraulic
IGLD85	International Great Lakes Datum of 1985
IPaC	Information for Planning and Consultation
IPCC	Intergovernmental Panel on Climate Change
LF	Linear Feet
LiDAR	Light Detection and Ranging
LOMR	Letter of Map Revision
LP3	Log-Pearson III
MSC	Map Service Center
NAVD88	North American Vertical Datum of 1988
NCEI	National Centers for Environmental Information
NFIP	National Flood Insurance Program
NHD	National Hydrography Dataset

NPFA	Natural Protective Feature Area
NRCS	Natural Resources Conservation Services
NWI	National Wetlands Inventory
NYS	New York State
NYSDEC	New York State Department of Environmental Conservations
NYSDHSES	New York State Division of Homeland Security and Emergency Services
NYSDOS	New York State Department of State
NYSDOT	New York State Department of Transportation
NYSOEM	New York State Office of Emergency Management
NYSOGS	New York State Office of General Services
NYSOPRHP	New York State Office of Parks, Recreation, and Historic Places
PDM	Pre-Disaster Mitigation
RAMBOLL	Ramboll Americas Engineering Solutions, Inc.
RC	Circularity Ratio
RE	Elongation Ratio
RF	Form Factor
RL	Repetitive Loss
ROM	Rough Order of Magnitude
SFHA	Special Flood Hazard Areas
SHA	Structural Hazard Area
SQ MI	Square Miles (mi^2)
SRL	Severe Repetitive Loss
STORM	Safeguarding Tomorrow through Ongoing Risk Mitigation Act
USACE	United States Army Corps of Engineers
USHUD	United States Department of Housing and Urban Development
USSCS	United States Soil Conservation Service
USGS	United States Geologic Service
WQIP	Water Quality Improvement Project

1. INTRODUCTION

1.1 HISTORICAL INITIATIVES

Flood mitigation has historically been an initiative in western New York and in the Crooked Brook watershed. The Crooked Brook watershed has historically been a source of flooding events in Chautauqua County, New York. In response to periodic and repetitive flood losses in the City of Dunkirk, zoning ordinances with restrictions on construction in flood-prone areas as delineated on the Federal Insurance Administration (FIA) Flood Hazard Boundary Maps for the City have been implemented. In addition, the sea wall along the Lake Erie shore between Main Street and Servale Street on the east side of the City was raised 10 inches for additional protection against wave run-up and wave action (FIA 1980).

1.2 FLOODPLAIN DEVELOPMENT

General recommendations for high-risk floodplain development follow three basic strategies:

1. Remove the flood prone-facilities from the floodplain
2. Adapt the facilities to be flood resilient under repetitive inundation scenarios
3. Develop nature-based mitigation measures (e.g., floodplain benches, constructed wetlands, etc.) to lower flood stages in effected areas
4. Up-size bridges and culverts to be more resilient to ice jams, high flow events, and projected future flood flows due to climate change in effected areas

In order to effectively mitigate flooding along substantial lengths of a watercourse corridor, floodplain management should restrict the encroachment on natural floodplain areas. Floodplains act to convey floodwaters downstream, mitigate damaging velocities, and provide areas for sediment to accumulate safely. The reduction in floodplain width of one reach of a stream, often leads to the increase in flooding upstream or downstream. During a flood event, a finite amount of water with an unchanging volume must be conveyed and, as certain conveyance areas are encroached upon, floodwaters will often expand into other sensitive areas.

A critical evaluation of existing floodplain law and policies should be undertaken to evaluate the effectiveness of current practices and requirements within this watershed. Local floodplain regulations should be consistent with the National Flood Insurance Program (NFIP) and Federal Emergency Management Agency (FEMA) regulations since the City and Town of Dunkirk are participating communities in the NFIP and should involve a floodplain coordinator and a site plan review process for all proposed developments. This review should be in accordance with local regulations and the NFIP requirements, which require the community to determine if any future proposed development could adversely impact the floodplain or floodway resulting in higher flood stages and sequentially greater economic losses to the community.

1.3 RESILIENT NY INITIATIVE

In November of 2018, New York State (NYS) Governor Andrew Cuomo announced the Resilient NY program in response to devastating flooding in communities across the State in the preceding years. A total of 48 high-priority flood prone watersheds across New York State are being addressed through the Resilient NY program. Flood mitigation studies were commissioned using advanced modeling techniques and field assessments to identify priority projects in these 48 flood-prone watersheds, develop state-of-the-art studies to reduce flooding and ice jams, and to improve ecological habitats in the watersheds (NYSGPO 2018). The Crooked Brook watershed was chosen as a study site for this initiative.

The New York State Department of Environmental Conservation (NYSDEC) is responsible for implementing the Resilient NY program with contractual assistance from the New York State Office of General Services (NYSOGS). High-priority watersheds were selected based on several factors, such as frequency and severity of flooding and ice jams, extent of previous flood damage, and susceptibility to future flooding and ice-jam formations (NYSGPO 2018).

The Resilient NY flood studies will identify the causes of flooding within each watershed and develop effective and ecologically sustainable flood and ice-jam hazard mitigation projects. Proposed flood mitigation measures will be evaluated using hydrologic and hydraulic modeling to quantitatively determine flood mitigation strategies that would result in the greatest flood reductions benefits. In addition, the flood mitigation studies incorporate the latest climate change forecasts and assess open water and ice-jam hazards where future flood risks has been identified.

This report is not intended to address detailed design considerations for individual flood mitigation alternatives. The mitigation alternatives discussed are conceptual projects that have been initially developed and evaluated to determine their flood mitigation benefits. A more in-depth engineering design study would still be required for any mitigation alternative chosen to further define the engineering project details. However, the information contained within this study can inform such in-depth engineering design studies and be used in the application of state and federal funding and / or grant programs.

The goals of the Resilient NY Program are to:

1. Perform comprehensive flood and ice jam studies to identify known and potential flood risks in flood-prone watersheds
2. Incorporate climate change predictions into future flood models
3. Develop and evaluate flood hazard mitigation alternatives for each flood-prone stream area, with a focus on ice-jam hazards

The overarching purpose of the initiative is to evaluate a suite of flood and ice-jam mitigation projects that local municipalities can undertake to make their community more resilient to future floods. The projects should be affordable, attainable through grant funding programs, able to be implemented either individually or in combination in phases over the course of several years, achieve measurable improvement at the completion of each phase, and fit with the community way of life. The information developed under this initiative is intended to provide the community with a basis for assessing and selecting flood mitigation strategies to pursue; no recommendations are made as to which strategies the community should pursue.

The flood mitigation and resiliency study for Crooked Brook began in May of 2020 and a final flood study report was issued in May of 2021.

2. DATA COLLECTION

2.1 INITIAL DATA COLLECTION

Hydrological and meteorological data were obtained from readily available state and federal government databases, including ortho-imagery, flood zone maps, streamflow, precipitation, flooding, and ice-jam reports. Historical flood reports, newspaper articles, social media posts, community engagement meeting notes, and geographic information system (GIS) mapping were used to identify stakeholder concerns, produce watershed maps, and identify current high-risk areas. New York State Community Risk and Resiliency Act (NYSDEC 2020) guidelines, New York State Department of Transportation (NYSDOT) bridge and culvert standards, and United States Geologic Service (USGS) *FutureFlow Explorer* v1.5 (USGS 2016) and *StreamStats* v4.3.11 (USGS 2017) software were used to develop current and future potential discharges and bankfull widths and depths at various points along the stream channel. Hydrologic and hydraulic (H&H) modeling was performed previously, as part of the 1980 FEMA Flood Insurance Study (FIS) for the City of Dunkirk (FIA 1980).

Updated H&H modeling was performed in this study using the United States Army Corps of Engineers (USACE) Hydrologic Engineering Center's River Analysis System (HEC-RAS) v5.0.7 (USACE 2019b) software to determine water stage at current and potential future levels for high-risk areas and to evaluate the effectiveness of proposed flood mitigation strategies. These studies and data were obtained and used, all or in part, as part of this effort. Appendix A is a summary listing of data and reports collected.

2.2 PUBLIC OUTREACH

Initial project kickoff meetings were held virtually between June 22nd and 29th, 2020, with representatives of the NYSDEC, NYSOGS, Ramboll Americas Engineering Solutions, Inc. (Ramboll), Highland Planning, NYSDOT, Town of Pomfret, Village of Fredonia, Chautauqua County, and Chautauqua County Soil and Water Conservation District (CCSWCD) (Appendix D). During these meetings, project specifics including background, purpose, funding, roles, and timelines were discussed. Discussions included a variety of topics, including:

- Firsthand accounts of past flooding events
- Identification of specific areas that flooded in each community, and the extent and severity of flood damage
- Information on post-flood efforts, such as temporary floodwalls

This outreach effort assisted in the identification of current high-risk areas to focus on during the future flood risk assessments.

2.3 FIELD ASSESSMENT

Following the initial data gathering and agency meetings, field staff from Ramboll undertook field data collection efforts with special attention given to high-risk areas in the City of Dunkirk as identified in the initial data collection process. Initial field assessments of Crooked Brook were conducted in March of 2021. Information collected during field investigations included the following:

- Rapid "windshield" river corridor inspection
- Photo documentation of inspected areas
- Measurement and rapid hydraulic assessment of bridges, culverts, and dams
- Geomorphic classification and assessment, including measurement of bankfull channel widths and depths at key cross sections
- Field identification of potential flood storage areas
- Characterization of key stream bank failures, head cuts, bed erosion, aggradation areas, and other unstable stream channel features
- Preliminary identification of potential flood hazard mitigation alternatives, including those requiring further analysis

Included in Appendix B is a copy of the Stream Channel Classification Form, Field Observation Form for the inspection of bridges and culverts, and Wolman Pebble Count Form, as well as a location map of where field work was completed. Appendix C is a Photo Log of select locations within the river corridor. The collected field data was categorized, summarized, indexed, and geographically located within a GIS database. This GIS database will be made available to the NYSDEC and NYSOGS upon completion of the project.

All references to “right bank” and “left bank” in this report refer to "river right" and "river left," meaning the orientation assumes that the reader is standing in the river looking downstream.

3. WATERSHED CHARACTERISTICS

3.1 STUDY AREA

The Crooked Brook watershed lies entirely within Chautauqua County, New York, encompassing areas between the City of Dunkirk and the Town of Sheridan. The brook flows in a general northwest direction with its headwaters in the Town of Sheridan, and passes through the Towns of Pomfret and Dunkirk, Village of Fredonia, and City of Dunkirk before emptying into Lake Erie (Figure 3-1). Within the Crooked Brook watershed, the area between the City of Dunkirk was chosen as the target area due to their historical and recent flooding issues and the hydrologic conditions of the brook. Figures 3-2 and 3-3 depict the stream stationing along Crooked Brook in Chautauqua County, NY, in the City and Town of Dunkirk and Towns of Pomfret and Sheridan and in the study area of the City of Dunkirk, respectively.

The City of Dunkirk is located in western New York State in the northern section of Chautauqua County and was incorporated in 1880. The city is approximately 40 miles southwest of the City of Buffalo along the shore of Lake Erie. The City is bordered by the Town of Dunkirk to the east and west, the Village of Fredonia to the south, and Lake Erie to the north. The City of Dunkirk lies entirely in the Lake Erie Plain, which has an undulating or flat surface, and which in the city slopes gradually from the southern boundaries to the lake (FIA 1980).

The Town of Pomfret is located in the northern portion of Chautauqua County in western New York. It is bordered by Lake Erie, the Village of Fredonia, and the Town of Dunkirk to the north, the Towns of Sheridan and Arkwright to the east, the Town of Stockton to the south, and the Town of Portland to the west (FEMA 1984).

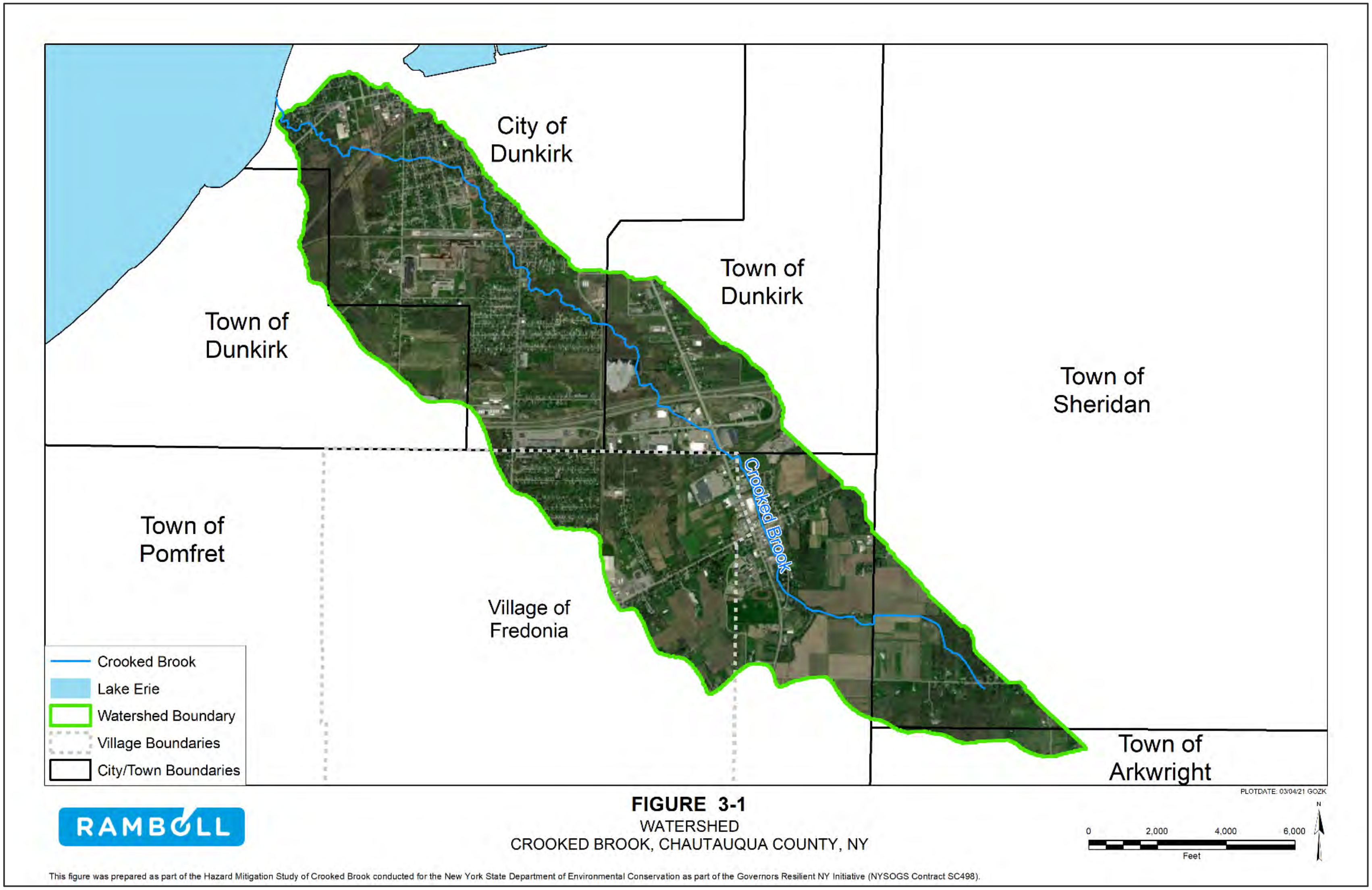

Figure 3-1. Crooked Brook Watershed, Chautauqua County, NY.

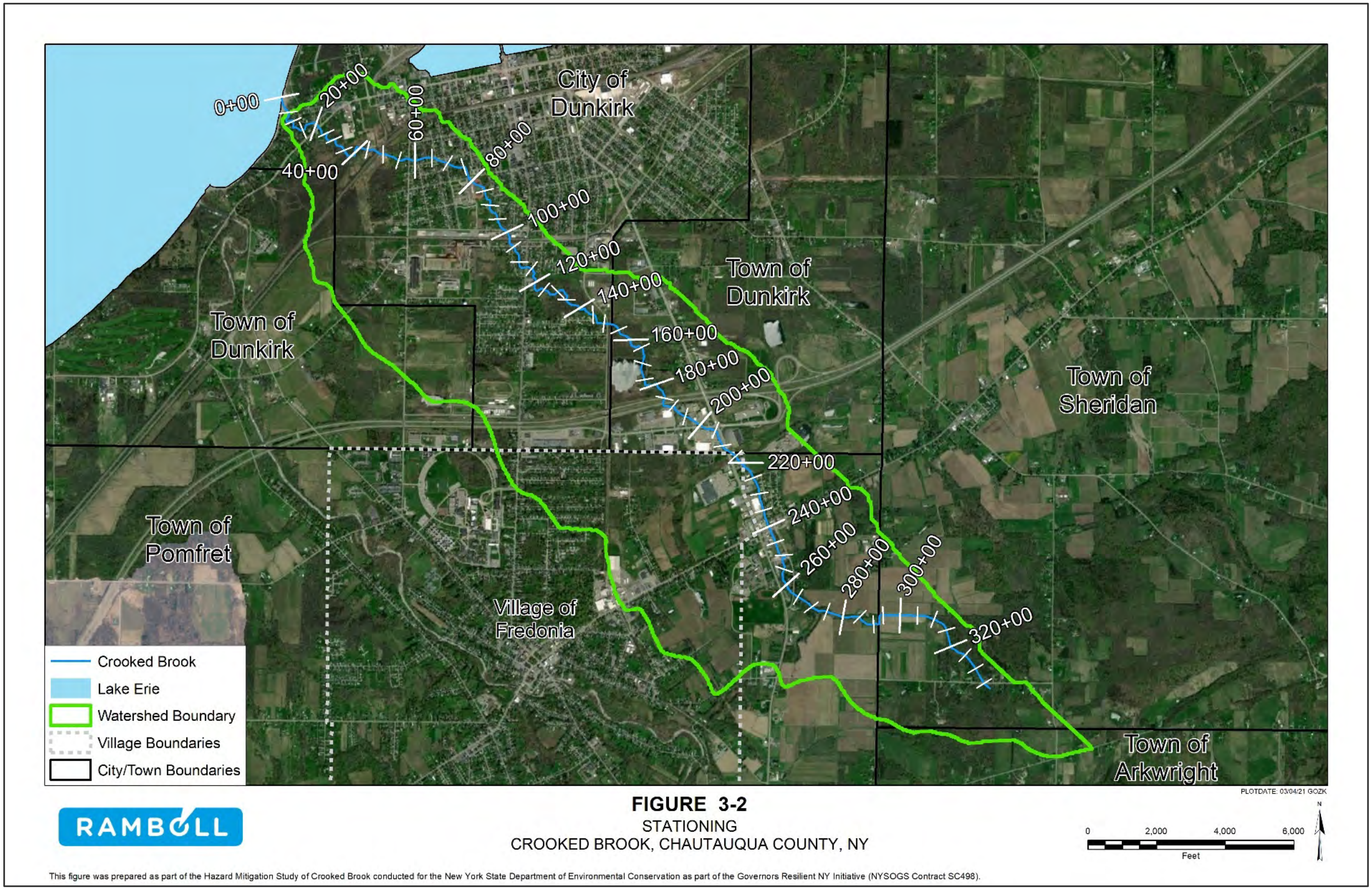

Figure 3-2. Crooked Brook Stationing, Chautauqua County, NY.

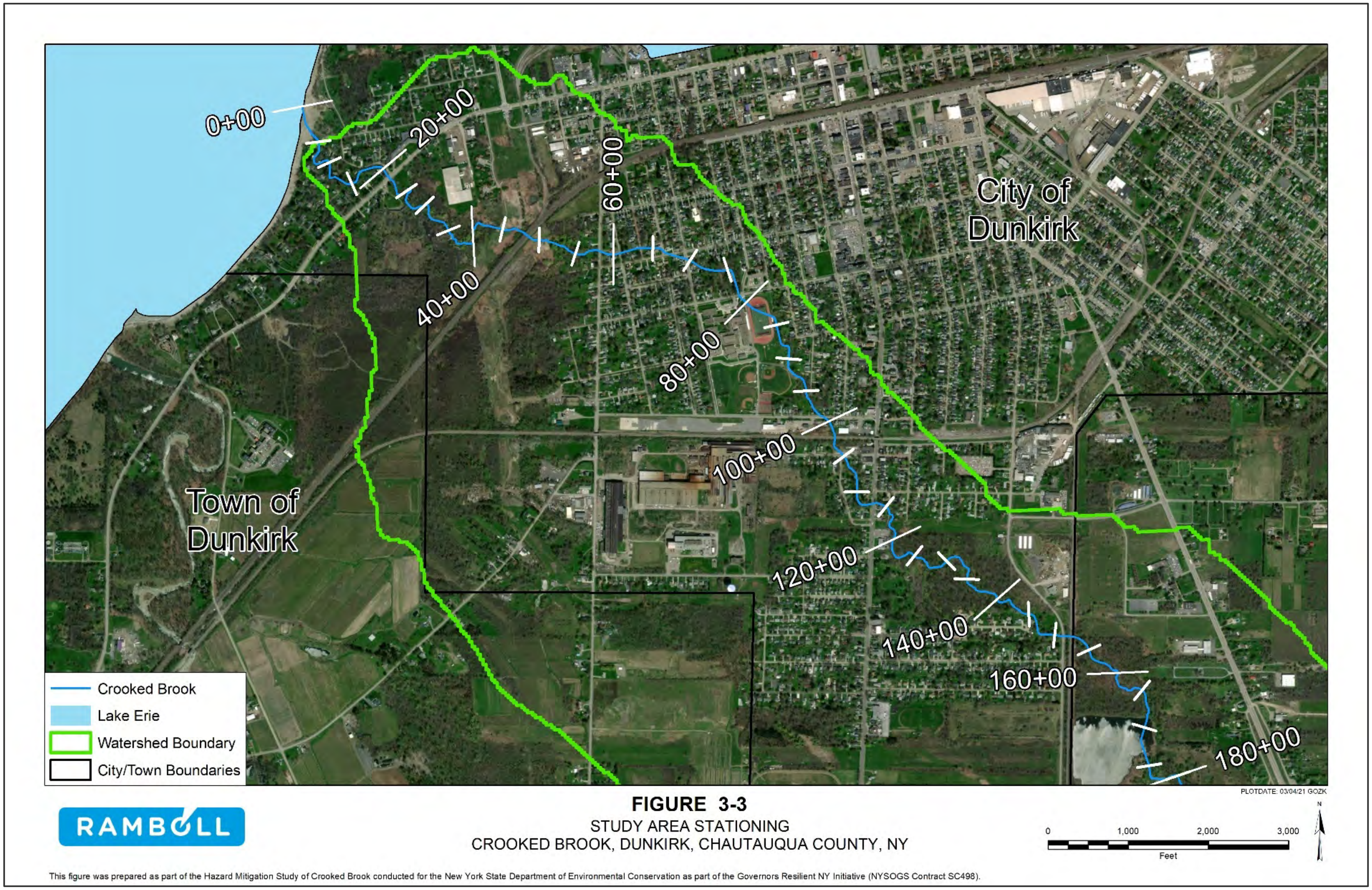

Figure 3-3. Crooked Brook Study Area Stationing, City of Dunkirk, Chautauqua County, NY.

3.2 ENVIRONMENTAL CONDITIONS

An overview of the environmental and cultural resources within the Crooked Brook watershed was compiled using the following online tools:

- **Environmental Resource Mapper** – The Environmental Resource Mapper is a tool used to identify mapped federal and state wetlands, state designated significant natural communities, and plants and animals identified as endangered or threatened by the NYSDEC (NYSDEC 2021) (https://gisservices.dec.ny.gov/gis/erm/)
- **National Wetlands Inventory (NWI)** – The NWI is a digital map database available on the Environmental Resource Mapper that provides information on the "status, extent, characteristics and functions of wetlands, riparian, and deep-water habitats" (NYSDEC 2021)
- **Information for Planning and Consultation (IPaC)** – The IPaC database provides information about endangered / threatened species and migratory birds regulated by the U.S. Fish and Wildlife Service (USFWS 2021) (https://ecos.fws.gov/ipac/)
- **National Register of Historic Places** – The National Register of Historic Places lists historic places worthy of preservation, as authorized by the National Historic Preservation Act of 1966 (NPS 2014) (https://www.nps.gov/maps/full.html?mapId=7ad17cc9-b808-4ff8-a2f9-a99909164466)

3.2.1 Wetlands

The State Regulated Freshwater Wetlands database shows the approximate location of wetlands regulated by New York state. The check zone is a 100-ft buffer zone around the wetland in which the actual wetland may occur. The National Wetlands Inventory was reviewed to identify national wetlands and surface waters (Figure 3-4). The Crooked Brook watershed includes riverine habitat, freshwater forested / shrub wetlands, freshwater ponds, and freshwater emergent wetlands (NYSDEC 2021).

3.2.2 Sensitive Natural Resources

The Crooked Brook watershed contains areas designated as significant natural communities as mapped by the Environmental Resource Mapper. The significant natural communities identified were sand beaches in the Uplands ecological system located at Point Gratiot (NYSDEC 2021) (Figure 3-5).

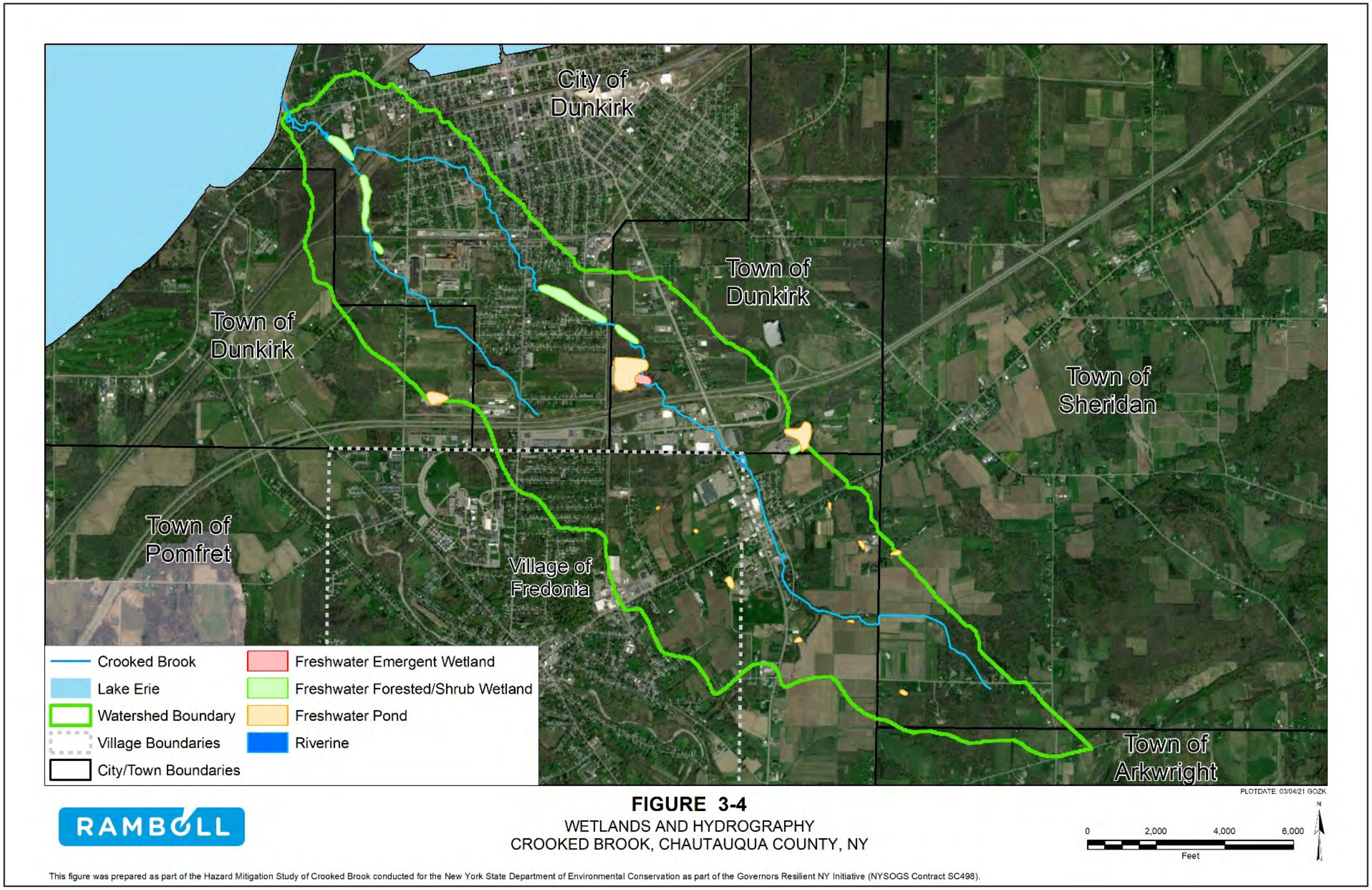

Figure 3-4. Crooked Brook Wetlands and Hydrography, Chautauqua County, NY.

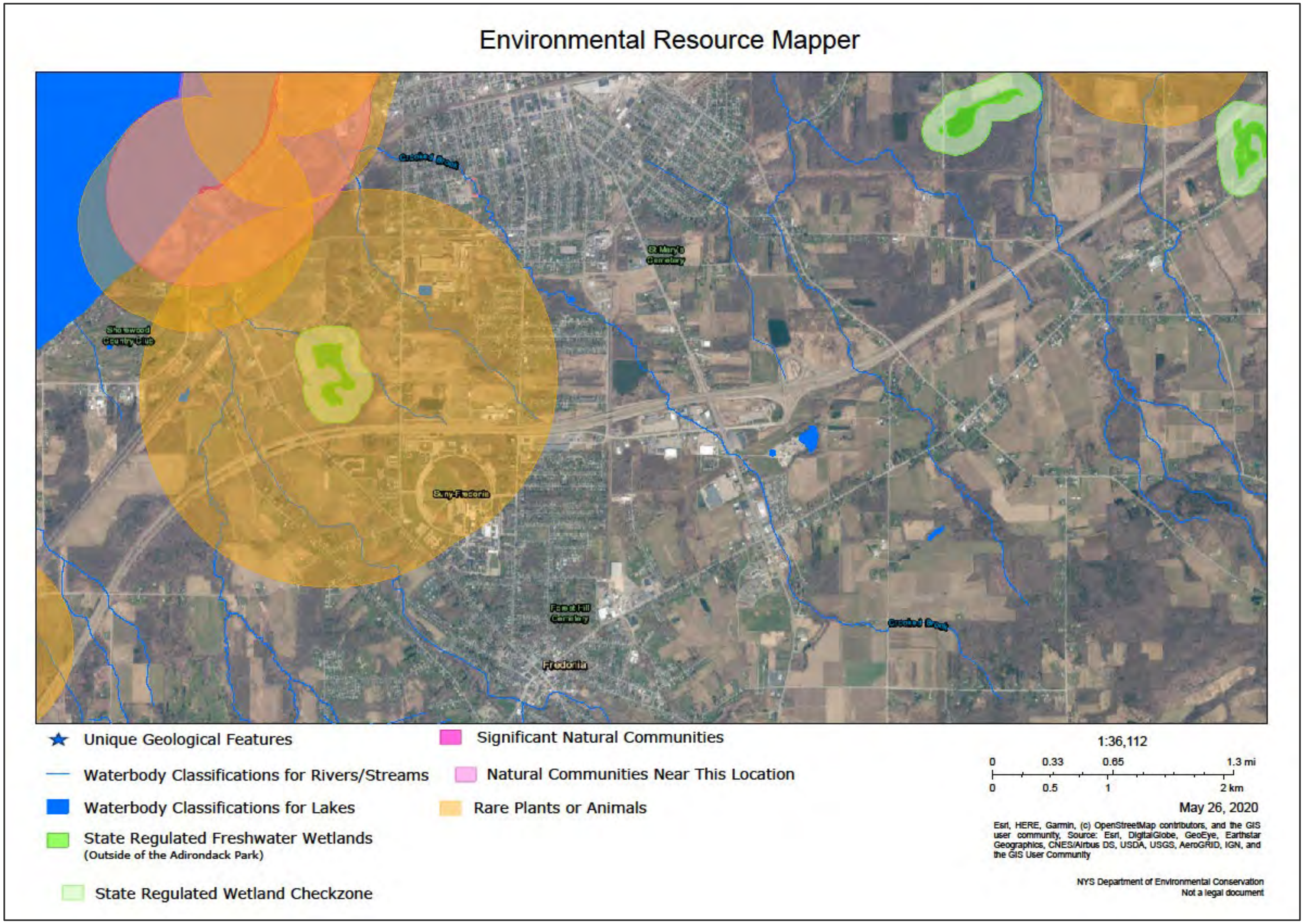

Figure 3-5. Significant Natural Communities and Rare Plants or Animals, Crooked Brook, Chautauqua County, NY.

3.2.3 Endangered or Threatened Species

The Environmental Resource Mapper shows that the watershed basin is within the vicinity of the Red-headed Woodpecker, which is listed as a Special Concern species by New York State. The NYSDEC Regional Office should be contacted to determine the potential presence of the species identified, if any permits are required, or if an environmental impact assessment needs to be performed prior to any project or action (NYSDEC 2021).

The USFWS Information for Planning and Consultation (IPaC) results for the project area list one threatened species, the Northern Long-eared Bat (Myotis septentrionalis). No critical habitat has been designated for the species at this location (USFWS 2021) (https://ecos.fws.gov/ipac/). The migratory bird species listed in Table 1 are transient species that may pass over, but are not known to nest within the project area.

Table 1. UFWS IPaC Listed Migratory Bird Species

(Source: USFWS 2021)

Common Name	Scientific Name	Level of Concern	Breeding Season
American Golden-plover	*Pluvialis dominica*	BCC Rangewide (CON)[2]	Breeds elsewhere
Bald Eagle	*Haliaeetus leucocephalus*	Non-BCC Vulnerable[1]	Breeds Sep 1 to Aug 31
Black-billed Cuckoo	*Coccyzus erythropthalmus*	BCC Rangewide (CON)[2]	Breeds May 15 to Oct 10
Bobolink	*Dolichonyx oryzivorus*	BCC Rangewide (CON)[2]	Breeds May 20 to Jul 31
Canada Warbler	*Cardellina canadensis*	BCC Rangewide (CON)[2]	Breeds May 20 to Aug 10
Dunlin	*Calidris alpina arcticola*	BCC-BCR[3]	Breeds elsewhere
Lesser Yellowlegs	*Tringa flavipes*	BCC Rangewide (CON)[2]	Breeds elsewhere
Prairie Warbler	*Dendroica discolor*	BCC Rangewide (CON)[2]	Breeds May 1 to Jul 31
Red-headed Woodpecker	*Melanerpes erythrocephalus*	BCC Rangewide (CON)[2]	Breeds May 10 to Sep 10
Ruddy Turnstone	*Arenaria interpres morinella*	BCC-BCR[3]	Breeds elsewhere
Semipalmated Sandpiper	*Calidris pusilla*	BCC Rangewide (CON)[2]	Breeds elsewhere
Snowy Owl	*Bubo scandiacus*	BCC Rangewide (CON)[2]	Breeds elsewhere
Wood Thrush	*Hylocichla mustelina*	BCC Rangewide (CON)[2]	Breeds May 10 to Aug 31

1. This is not a Bird of Conservation Concern (BCC) in this area but warrants attention because of the Eagle Act or for potential susceptibilities in offshore areas from certain types of development or activities.
2. This is a Bird of Conservation Concern (BCC) throughout its range in the continental USA and Alaska (CON).
3. This is a Bird of Conservation Concern (BCC) only in particular Bird Conservation Regions (BCRs) in the continental USA.

3.2.4 Cultural Resources

No facilities listed on the National Register of Historic Places were found within the project area. Consultation with New York State Office of Parks, Recreation, and Historic Places (NYSOPRHP) should be performed to identify the potential presence of archeological resources and the subsequent need to perform a cultural resource investigation (NPS 2014).

3.2.5 FEMA Mapping and Flood Zones

The Federal Insurance Administration was created by the National Flood Insurance Act of 1968 and administered by the United States Department of Housing and Urban Development (USHUD). The FIA was absorbed into FEMA through an executive order by President Jimmy Carter on April 1, 1979.

The FEMA Flood Map Service Center (MSC) (https://msc.fema.gov/portal/home) is a database that contains FEMA Flood Insurance Rate Maps (FIRMs) for areas that have had FEMA flood insurance studies completed throughout the United States (FEMA 2021b). The generated FIRMs for the Crooked Brook watershed indicate Special Flood Hazard Areas (SFHAs), which are land areas covered by the floodwaters of the 1 % annual chance flood event (ACE), along the banks of the creek, for almost the entire length of the creek. In the City of Dunkirk FIS, Flood Hazard Factors (FHFs) were used by the FIA to correlate flood information with insurance rate tables. The FHF for a reach is the average weighted difference between the 10 and 1% annual chance flood hazard (10- and 100-year flood) water-surface elevations expressed to the nearest 0.5-ft, and shown as a three-digit code on the FIRM. According to the FIS, the hydrologic and hydraulic analyses completed were a detailed study and included Crooked Brook in the detailed study (FIA 1980).

For Crooked Brook in the 1980 City of Dunkirk FIS, hydrologic analyses were performed to establish the peak discharge-frequency and elevation-frequency relationships for floods of the selected recurrence intervals. Detailed analyses of the hydraulic characteristics were carried out to provide estimates of the elevations of floods of the selected recurrence intervals. Cross-section data for Crooked Brook were obtained from interpretation of oblique aerial photographs and the below-water sections were obtained by field measurement. All bridges and culverts were surveyed to obtain elevation data and structural geometry. These sections were located at close intervals upstream and downstream of bridges and culverts in order to compute significant backwater effects of these structures. In addition, cross sections were taken between hydraulic controls wherever warranted by topographic changes. Water-surface profiles were developed using the USACE HEC-2 step-backwater computer model (USACE 1973; FIA 1980).

In addition, Crooked Brook is a Regulatory Floodway, which is defined as the watercourse channel and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than 1-ft over the BFE. In the regulatory floodway, communities must regulate encroachments, including fill, new construction, substantial improvements, and other development within the adopted regulatory floodway and demonstrate through hydrologic and hydraulic analyses performed in accordance with standard engineering practice that the proposed encroachment would not increase flood levels within the community during the occurrence of the base flood. Development in the portions of the floodplain beyond the floodway, referred to as the floodway fringe, is allowed as long as it does not increase the BFE more than 1.0-ft. Figure 3-6 displays the floodway data from the FIS for the City of Dunkirk, NY (FIA 1980; FEMA 2000).

FLOODING SOURCE		FLOODWAY			BASE FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	DISTANCE[1]	WIDTH (FT.)	SECTION AREA (SQ. FT.)	MEAN VELOCITY (F.P.S.)	REGULATORY (NGVD)	WITHOUT FLOODWAY (NGVD)	WITH FLOODWAY (NGVD)	INCREASE (FEET)
Crooked Brook								
A	150	64	244	5.0	579.5	579.5	579.6	0.1
B	350	70	284	4.3	580.6	580.6	580.6	0.0
C	700	60	236	5.1	581.3	581.3	581.4	0.1
D	1,730	60	312	3.9	583.2	583.2	583.9	0.7
E	1,900	100	387	3.1	585.5	585.5	585.5	0.0
F	2,800	100	481	2.5	586.2	586.2	586.7	0.5
G	3,550	115	507	2.4	586.8	586.8	587.8	1.0
H	3,900	100	377	2.1	587.4	587.4	588.3	0.9
I	4,110	65	208	3.8	588.1	588.1	588.9	0.8
J	4,510	48	186	4.2	589.6	589.6	589.8	0.2
K	4,680	50	333	2.4	592.9	592.9	593.2	0.3
L	5,480	38	104	7.6	593.4	593.4	593.6	0.2
M	6,740	44	304	2.6	606.6	606.6	606.7	0.1
N	7,540	33	151	5.2	606.9	606.9	607.3	0.4
O	8,230	55	284	2.8	615.4	615.4	615.6	0.2
P	8,830	43	192	4.1	616.2	616.2	616.3	0.1
Q	9,020	60	307	2.6	619.1	619.1	619.1	0.0
R	9,720	81	183	4.3	620.2	620.2	620.2	0.0
S	9,930	35	306	2.6	626.5	626.5	627.4	0.9

[1]Feet above Lake Erie

TABLE 3

FEDERAL EMERGENCY MANAGEMENT AGENCY
Federal Insurance Administration

CITY OF DUNKIRK, NY
(CHAUTAUQUA CO.)

FLOODWAY DATA

CROOKED BROOK

Figure 3-6. Regulatory Floodway Data, City of Dunkirk, Chautauqua County, NY.

FLOODING SOURCE		FLOODWAY			BASE FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	DISTANCE	WIDTH (FT.)	SECTION AREA (SQ. FT.)	MEAN VELOCITY (F.P.S.)	REGULATORY (NGVD)	WITHOUT FLOODWAY (NGVD)	WITH FLOODWAY (NGVD)	INCREASE (FEET)
Crooked Brook (continued)								
T	10,030[1]	67	427	1.8	626.5	626.5	627.5	1.0
U	10,240[1]	52	408	1.9	629.0	629.0	630.0	1.0
V	10,290[1]	52	408	1.9	629.0	629.0	630.0	1.0
W	10,480[1]	60	342	2.3	631.1	631.1	631.4	0.3
X	10,600[1]	68	362	2.2	631.2	631.2	631.5	0.3
Y	11,000[1]	51	213	3.7	631.2	631.2	631.7	0.5
Z	11,190[1]	41	258	3.1	633.4	633.4	633.5	0.1
AA	12,690[1]	60	96	7.3	637.5	637.5	637.9	0.4
AB	14,490[1]	45	154	4.6	650.3	650.3	650.7	0.4

[1]Feet above Lake Erie
[2]Feet above confluence with Crooked Brook

TABLE 3

FEDERAL EMERGENCY MANAGEMENT AGENCY
Federal Insurance Administration

CITY OF DUNKIRK, NY
(CHAUTAUQUA CO.)

FLOODWAY DATA

CROOKED BROOK AND TRIBUTARY OF CROOKED BROOK

Figure 3-6 (continued). Regulatory Floodway Data, City of Dunkirk, Chautauqua County, NY.

The flood zones indicated in the Crooked Brook study area are Zones A0, A1-7, B and C. A0 Zones are SFHAs subject to inundation by the 1% annual chance flood event as a result of shallow flooding where depths are between 1.0 to 3.0-ft where depths are shown on the map, but no FHFs are determined. Zones A1-7 are SFHAs subject to inundation by the 1% annual chance flood event determined by detailed methods with BFEs shown and zones subdivided according to FHF. B Zones are areas between the SFHAs and the limits of the 0.2% annual chance event (500-year) flood, including areas of the 0.2% flood plain that are protected from the 1% flood by dike, levee, or other water control structure. B Zones also include areas subject to certain types of 1% annual chance event shallow flooding where depths are less than 1.0-ft; and areas subject to 1% annual chance event flooding from sources with drainage areas less than 1 square mile (sq. miles). Zone B have no BFEs and are not subdivided by FHF. C Zones are areas of minimal flooding. For watercourses where FEMA has provided BFEs, but no floodway has been designated, or where FEMA has not provided BFEs, the community must review floodplain development on a case-by-case basis to ensure that increases in water surface elevations do not occur or identify the need to adopt a floodway if adequate information is available (FIA 1980). Figure 3-7 is a FIRM that includes a portion of Crooked Brook in the City of Dunkirk, NY (FIA 1981).

Digitized Q3 flood zone data derived from FEMA FIRMs was used to produce flood zone maps in this study. Digital Q3 flood data files contain only certain features from the FIRM hardcopy in effect at the time of scanning and do not replace the existing FIRM hardcopy maps. In addition, the process of georeferencing paper maps to digital images can distort certain features over large areas between known points. This process is not recommended to use for detailed flood zone delineation or analysis (FEMA 1996).

With regards to ice-jam flooding, the effective FEMA FIRMs only reflect flooding related to open-water or free-flow conditions. For this study, ice-jam flooding extents were determined using a wide variety of sources, including stakeholder input, news reports, computer models, etc. References to ice-jam flood extents are based solely on these sources and do not reflect the flood zone areas from the effective FEMA FIRMs.

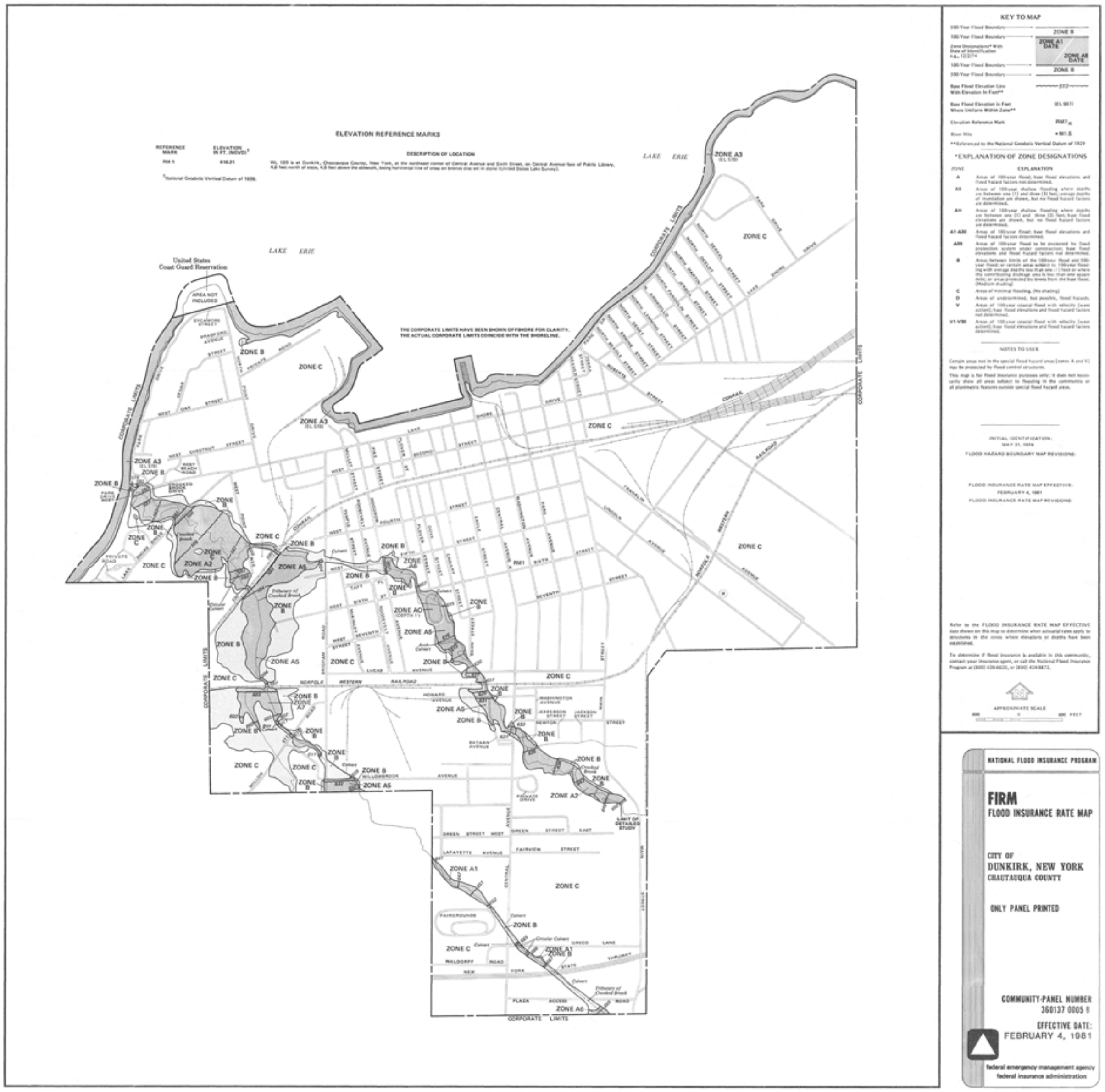

Figure 3-7. FEMA FIRM, City of Dunkirk, Chautauqua County, NY.

3.3 WATERSHED LAND USE

The Crooked Brook stream corridor is largely comprised of developed (42%) and forested (24%) lands within the basin. Of the developed lands, low intensity (17%) and open space (14%) comprise the largest proportion of the developed lands, while deciduous forests (24%) and grapes (15%) encompass the largest percentages of forested and cultivated lands, respectively (NASS 2019).

The distribution of different land use and cover types varies throughout the Crooked Brook basin. The upper portion of the basin, in the Towns of Pomfret and Sheridan, is primarily comprised of cultivated lands and grape fields, while the middle and lower portions, in the Town and City of Dunkirk, are primarily developed lands of varying intensities (high, medium, low, or open space) (NASS 2019).

According to the City of Dunkirk FIS, the city is a predominantly residential community. The commercial area is confined to downtown, a portion along State Route 5, and a shopping plaza at the extreme southern boundary of the city. Approximately 20% of the entire city area is designated for industrial use (FIA 1980).

3.4 GEOMORPHOLOGY

Chautauqua County is in two physiographic provinces: the Erie-Ontario Plain province and the Allegheny Plateau province. The Erie-Ontario Plain province is a lowland belt along the shores of Lake Erie. This belt is two to six miles wide and has topography typical of that of an abandoned lakebed. It has little relief except for a series of very narrow ravines cut across it by a number of streams. It ranges in elevation from 572-ft at Lake Erie to about 850-ft at the base of the bordering escarpment. The alignment of the escarpment parallels Lake Erie and ranges in elevation from 1,400-ft in the eastern part of the county to 1,600-ft in the western part (USSCS 1994).

The base of the escarpment constitutes the northern boundary of the Allegheny Plateau province, which occupies about 80% of the county. The plateau is characterized by steep valley walls, wide ridgetops, and flat-topped hills between drainageways. The part of the Allegheny Plateau in Chautauqua County is intersected by a number of broad, flat-bottomed valleys, presently occupied by sluggish, meandering streams. The topography is strongly influenced by the underlying bedrock, which is nearly level bedded (USSCS 1994).

On the Allegheny Plateau, the elevation rises from about 1,300-ft in the major valleys to 2,100-ft. The greater part of the upland portion of the plateau lies between elevations of 1,600 and 1,800-ft. The maximum elevation, 2,190-ft, occurs on Gurnsey Hill in the southeast corner of the county. Because it was never glaciated, this area has more rugged topography, longer and steeper slopes, deeply incised and V-shaped valleys, and does not have the irregular, hilly characteristics typical of much of the glaciated areas (USSCS 1994).

The bedrock geology in the area consists mostly of the Canadaway Group, which is composed primarily of shales, sandstones, and siltstones. The Canadaway Group is a succession of black and gray shales that include some thin siltstone layers and occurs above the Java Group. In Chautauqua County, the Canadaway Group averages about 1,050-ft in thickness and is subdivided into seven members. The oldest of these is the black Dunkirk Shale, which is about 85-ft thick and is exposed in the lake cliffs at Dunkirk (USSCS 1994; NYSGS 1999).

Prehistoric advances and retreats of glacial ice during the last ice age beginning approximately 300,000 years ago and ending 14,000 years ago affected the bedrock and soil composition of Chautauqua County, New York. Soil material and pieces of bedrock would be carried and redeposited by moving glacial sheets creating unconsolidated materials of various sizes, shapes, and mineral content. Because the deposited materials were variable, different soils formed in them. Erosion and sedimentation have been at work since the ice retreated and, as a result, steep, fan-shaped alluvial deposits accumulated at the mouths of streams where the velocity of the water slowed, and the sand and gravel dropped out of suspension. A striking topographic feature called the Beach Ridge runs parallel to Lake Erie and across the county. This feature represents the shore line of the former glacial lake, which developed during many years of wave action and erosion (USSCS 1994).

The drainage of Chautauqua County is separated into two systems: the Allegheny-Ohio-Mississippi River system and the Lake Erie-St. Lawrence River system. Along the northwestern part of the county, the drainage of the northern slope of the escarpment and lake plain flows north into Lake Erie through numerous small waterways and several major creeks, which includes Crooked Brook, and comprises the Lake Erie-St. Lawrence River system (USSCS 1994).

Within the Crooked Brook watershed basin, the most predominant soil types are Niagara silt loam (NgA) and Chenango gravelly loam (CnA) (NRCS 2019). Niagara silt loam makes up the largest proportion of soil type by total acreage within the Crooked brook basin. This soil is nearly level, very deep, and somewhat poorly drained. It is mainly in low areas on lake plains and to a lesser extent on broad flats in the larger valleys. Chenango gravelly loam makes up the second largest proportion of soil type with the basin and is nearly level, very deep, and well drained to excessively drained. It is on outwash plains, beach ridges, and stream terraces (USSCS 1994).

Figure 3-8 is a stream bed elevation and channel distance from the confluence with Lake Erie profile using 1-meter light detection and ranging (LiDAR) data from the NYSDEC for Crooked Brook. Crooked Brook has an average slope of 1.2% over the profile stream length. The creek’s streambed lowers approximately 408-vertical feet over this reach from an elevation of 980-ft above sea level (NAVD 88) at the headwaters in the Town of Sheridan to 572-ft above sea level at the confluence of Lake Erie in the City of Dunkirk, NY (NYSOITS 2017b).

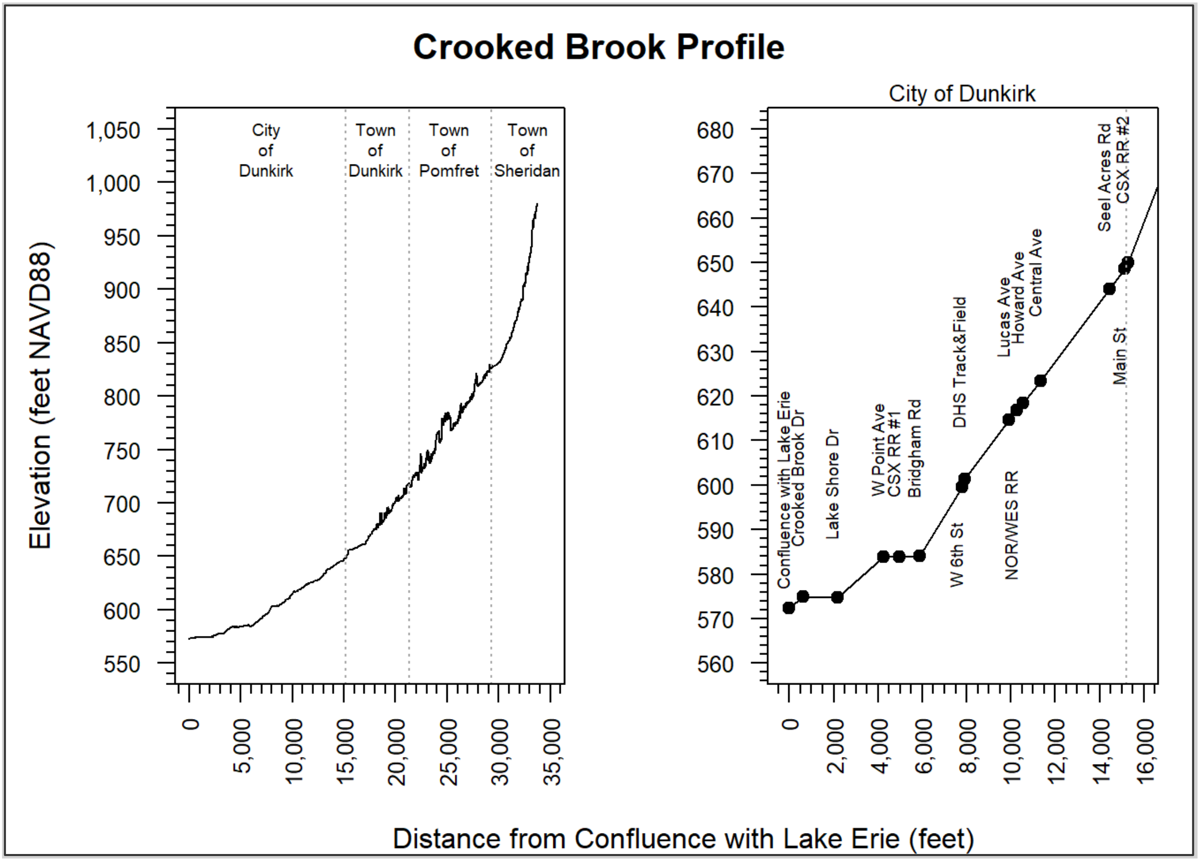

Figure 3-8. Crooked Brook profile of stream bed elevation and channel distance from the confluence with Lake Erie.

In addition, there are numerous locations where sediment depositional aggradation is occurring within the channel of Crooked Brook. Aggradation is a natural fluvial process where sediment and other materials are deposited in a stream channel when the supply of sediment is greater than the amount of material that the system is able to transport. Over time, aggradation can lead to the development of sand and sediment bars within the stream channel. These sand and sediment bars may restrict flow by reducing the in-channel flow area and may act as catchpoints for ice pieces during ice breakup events, potentially increasing open water flood risks and ice-jam formations (Mugade and Sapkale 2015).

3.5 HYDROLOGY

Crooked Brook drains an area of 5.5 square miles, is approximately 6.4 miles in length, and is located in the southwestern portion of New York State and in the northern portion of Chautauqua County. Crooked Brook rises in the vicinity of Stone Quarry Road in the Town of Sheridan and flows north / northwest crossing US Route 20 in the Town of Pomfret and the New York State Thruway in the Town of Dunkirk before entering the City of Dunkirk from the east side, near St. Hedwig’s Cemetery. It then flows through woodlands and Willow Brook Park, enters multiple residential areas within the City and crosses the Dunkirk High School football field and track, until flowing under the CSX

Transportation rail line southeast of Lake Shore Drive before emptying into Lake Erie (FIA 1980; USGS 2020).

The unnamed tributary of Crooked Brook originates in the vicinity of the New York State Thruway and Greco Lane-Central Avenue residential area in the City of Dunkirk. It heads northwest through the Chautauqua County Fairgrounds briefly crossing into the Town of Dunkirk near Dove Street and re-entering the City near Willowbrook Avenue. The tributary continues to flow northwest under Willow Road and the Norfolk Southern Railway Company rail line until merging with Crooked Brook about 600-ft downstream of the CSX Transportation rail line crossing (FIA 1980).

Table 2 is a summary of the basin characteristic formulas and calculated values for the Crooked Brook watershed, where A is the drainage area of the basin in square miles (mi^2), BL is the basin length in miles, and BP is the basin parameter in miles (Waikar and Nilawar 2014).

Table 2. Crooked Brook Basin Characteristics Factors

(Source: USGS 1978)		
Factor	**Formula**	**Value**
Form Factor (R_F)	A / B_L^2	0.18
Circularity Ratio (R_C)	$4*pi*A / B_P^2$	0.23
Elongation Ratio (R_E)	$2 * (A/pi)^{0.5} / B_L$	0.47

Form Factor (RF) describes the shape of the basin (e.g., circular or elongated) and the intensity of peak discharges over a given duration of time. Circularity Ratio (RC) gives an indication of topography where the higher the circularity ratio, the lower the relief and less disturbance to drainage systems by structures within the channel. Elongation Ratio (RE) gives an indication of ground slope where values less than 0.7 correlate to steeper ground slopes and elongated basin shapes. Based on the basin characteristics factors, the Crooked Brook watershed can be characterized as an elongated basin with lower peak discharges of longer durations, high-relief topography with structural controls on drainage, and steep ground slopes (Waikar and Nilawar 2014).

There is one USGS stream gage station on Crooked Brook in Chautauqua County, NY, which is located at the mouth of Crooked Brook with Lake Erie (USGS 0421338405). This gage is primarily used for water quality measurements of tributaries to Lake Erie and has no peak discharge measurements. This gage was determined to be insufficient for hydrologic analysis.

An effective FEMA FIS for the City of Dunkirk was issued on August 4, 1980 and included drainage area and discharge information from a detailed study for Crooked Brook. Table 3 lists the FEMA FIS drainage area and peak discharges, in cubic feet per second (cfs), for Crooked Brook (FIA 1980).

Table 3. Crooked Brook FEMA FIS Peak Discharges

(Source: FIA 1980)						
			Peak Discharges (cfs)			
Flooding Source and Location	**Drainage Area (mi^2)**	**River Station (ft)**	**10-Percent**	**2-Percent**	**1-Percent**	**0.2-Percent**
At mouth	5.75	0+00	750	1,100	1,200	1,700
At corporate limits	2.65	145+00	400	600	650	930

According to the effective FEMA FIS for Crooked Brook in the City of Dunkirk, in this study, the peak discharge-frequency relationships of nine USGS gaging stations on Cattaraugus Creek, Eighteenmile Creek, Smokes Creek, Buffalo Creek, Little Buffalo Creek, Cayuga Creek, Cazenovia Creek, and Scajaquada Creek (USGS 1965; USGS 1973) were first established using the standard log-Pearson Type III (LP3) method, as recommended by the Water Resources Council (WRC 1967). The length of record of these stations ranges from 11 to 35 years at the time of the study (FIA 1980).

A set of regional flood frequency curves was then established by correlating the peak discharge and drainage area information of the aforementioned nine gaging stations. The regional curves were also extended to cover watersheds with drainage areas of less than 15 sq. miles. Since the Federal Highway Administration (FHA - formerly Bureau of Public Roads) method was commonly used for estimating flood peaks of ungaged small watersheds in this region, this method was used to verify the validity of the extended curves. The peak discharges estimated from the extended regional curves check closely with the peak discharges estimated by the FHA method. The regional flood frequency curves were then used to establish the discharge-frequency relationships for Crooked Brook (BPR 1963; FIA 1980).

General limitations of the FEMA FIS methodology include: the limited regional flood frequency curves used to calculate discharge-frequency relationships; using the LP3 method with sample sizes of less than 30 years; and the extrapolation of regional curves to ungaged streams with drainage areas of less than 15 square miles. These limitations represent outdated methodologies for determining discharge-frequency relationships and introduce error at multiple stages in the calculations, which can lead to over or under estimations of peak discharges.

USGS *StreamStats* v4.3.11 software (https://streamstats.usgs.gov/ss/) is a map-based web application that provides an assortment of analytical tools that are useful for water-resources planning and management, and engineering purposes. Developed by the USGS, the primary purpose of *StreamStats* is to provide estimates of streamflow statistics for user selected ungaged sites on streams and for USGS stream gages, which are locations where streamflow data are collected (Ries et al. 2017; USGS 2017).

Methods for computing a peak discharge estimate for a selected recurrence interval at a specific site depend on whether the site is gaged or ungaged, and whether the drainage area lies within a single hydrologic region or crosses into an adjacent hydrologic region or State. Hydrologic regions refer to areas in which streamflow-gaging stations indicate a similarity of peak-discharge response that differs from the peak-discharge response in adjacent regions. These similarities and differences are defined by the regression residuals, which are the differences between the peak discharges calculated from station records and the values computed through the regression equation. There are currently six hydrologic regions in New York State (Lumia 1991; Lumia et al. 2006).

For ungaged sites, such as Crooked Brook in hydrologic Region 5 of New York State, *StreamStats* relies on regional regression equations that were developed by statistically relating the streamflow statistics to the basin characteristics for a group of stream gages within a region. Estimates of streamflow statistics for an ungaged site can then be obtained by measuring its basin characteristics and inserting them into the regression equations (Ries et al. 2017).

For example, the equation for estimating the 100-year flood for ungaged sites within one hydrologic region in New York is:

$$Q_{100} = 1.91 * (A)^{0.980} * (SL)^{0.636} * (P)^{0.590}$$

Where

A is the drainage area in square miles;

SL is the main channel slope in feet per mile; and

P is the mean annual precipitation, in inches (Lumia et al. 2006).

StreamStats delineates the drainage basin boundary for a selected site by use of an evenly spaced grid of land-surface elevations, also referred to as a digital elevation model (DEM), and a digital representation of the stream network. Using this data, the application calculates multiple basin characteristics, including drainage area, main channel slope, and mean annual precipitation. By using these characteristics in the calculation, the peak discharge values have increased accuracy and decreased standard errors by approximately 10% for a 1% annual chance interval discharge when compared to the drainage-area only regression equation (Ries et al. 2017).

However, when one or more of the basin characteristics for an ungaged site are outside the given ranges, then the estimates are extrapolated. *StreamStats* provides warnings when extrapolation occurs. Although *StreamStats* does provide estimates of streamflow statistics in these circumstances, no error indicators are provided with them, as the errors associated with these estimates are unknown and may be very large (Ries et al. 2017).

In addition, estimates of streamflow statistics that are obtained from regression equations are based on the assumption of natural flow conditions at the ungaged site unless the reports that document the equations state otherwise. If human activities such as dam regulation and water withdrawals substantially affect the timing, magnitude, or duration of flows at a selected site, the regression-equation estimates provided by StreamStats should be adjusted by the user to account for those activities (Ries et al. 2017). Table 4 is the summary output of peak discharges calculated by the USGS *StreamStats* software for Crooked Brook at selected profile locations.

Table 4. USGS *StreamStats* Peak Discharge for Crooked Brook at the FEMA FIS and Select Locations

(Source: USGS 2017)						
			Peak Discharges (cfs)			
Flooding Source and Location	**Drainage Area (mi^2)**	**River Station (ft)**	**10-Percent**	**2-Percent**	**1-Percent**	**0.2-Percent**
At mouth	5.52	0+00	587	937	1,100	1,520
Confluence with unnamed tributary	5.21	36+00	573	918	1,080	1,490
City and Town of Dunkirk corporate limits	2.56	152+50	375	616	730	1,030
Town of Dunkirk / Village of Fredonia corporate limits	1.06	214+00	178	294	348	491
Towns of Pomfret / Sheridan corporate limits	0.26	292+50	65	110	132	190

Using the standard error calculations from the regression equation analysis in *StreamStats*, an acceptable range at the 95% confidence interval for peak discharge values at the 10, 2, 1, and 0.2% annual chance flood hazards were determined. Standard error gives an indication of how accurate the calculated peak discharges are when compared to the actual peak discharges since approximately two-thirds (68.3%) of the calculated peak discharges would be within one standard error of the actual peak discharge, 95.4% would be within two standard errors, and almost all (99.7%) would be within three standard errors (McDonald 2014). Table 5 is a summary table of the USGS *StreamStats* standard errors at each percent annual chance flood hazard for Region 5 in New York State.

Table 5. USGS *StreamStats* Standard Errors for Full Regression Equations

Source: (Lumia et al. 2006)				
	Peak Discharges (cfs)			
	10-Percent	**2-Percent**	**1-Percent**	**0.2-Percent**
Standard Error	36.1	37.5	38.7	42.6

Based on the *StreamStats* standard error calculations, the majority of FEMA FIS peak discharges were determined to be outside of the acceptable range (95% confidence interval). For this study, to maintain consistency in the modeling outputs with the FEMA models and to develop a conservative analysis of flood risk in the Crooked Brook watershed, the effective FIS peak discharges were used in the HEC-RAS modeling software simulations.

In addition to peak discharges, the *StreamStats* software also calculates bankfull statistics by using stream survey data and discharge records from 281 cross-sections at 82 streamflow-gaging stations in a linear regression analyses to relate drainage area to bankfull discharge and bankfull-channel width, depth, and cross-sectional area for streams across New York state. These equations are intended to serve as a guide for streams in areas of the same hydrologic region, which contain similar hydrologic, climatic, and physiographic conditions (Mulvihill et al. 2009).

Bankfull discharge is defined as the flow that reaches the transition between the channel and its flood plain. Bankfull discharge is considered to be the most effective flow for moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphological characteristics of channels (Mulvihill et al. 2009). The bankfull width and depth of Crooked Brook is important in understanding the distribution of available energy within the stream channel and the ability of various discharges occurring within the channel to erode, deposit, and move sediment (Rosgen and Silvey 1996). Table 6 lists the estimated bankfull discharge, width, and depth at select locations along Crooked Brook as derived from the USGS *StreamStats* program.

Table 6. USGS *StreamStats* Estimated Drainage Area, Bankfull Discharge, Width, and Depth

(Source: USGS 2017)

Flooding Source and Location	River Station (ft)	Drainage Area (mi^2)	Bankfull Depth (ft)	Bankfull Width (ft)	Bankfull Streamflow (cfs)
At mouth	5.52	0+00	202	34.6	1.58
Confluence with unnamed tributary	5.21	36+00	193	33.7	1.56
City and Town of Dunkirk corporate limits	2.56	152+50	106	25.1	1.31
Town of Dunkirk / Village of Fredonia corporate limits	1.06	214+00	50.4	17.3	1.05
Towns of Pomfret / Sheridan corporate limits	0.26	292+50	15.4	9.61	0.75

3.6 INFRASTRUCTURE

According to the NYSDEC Inventory of Dams dataset (2009), there are no dams within the Crooked Brook watershed as identified by the NYSDEC. In addition, according to the NYSDOT Bridge Point Locations & Select Attributes dataset (2016), there are no bridges that cross Crooked Brook as identified by the NYSDOT (NYSDEC 2009; NYSDOT 2016).

There are three large culverts identified by the NYSDOT along Crook Brook. Of the three culverts, one is located in the City of Dunkirk, another near the boundary of the Town of Dunkirk and Village of Fredonia, and the last culvert is located in the Town of

Pomfret. Table 7 lists the culverts that are along Crooked Brook, including identification numbers, owners, and structural characteristics (NYSDOT 2014).

Table 7. Inventory of Culverts Crossing Crooked Brook

(Source: NYSDOT 2014)

Roadway Carried	Culvert ID (CIN)	Owner	Municipality	River Station (ft)	Span Length (ft)	Structure Length (ft)
Lake Shore Drive West (NY-5)	C520030	NYSDOT	City of Dunkirk	21+50	18	20
Bennett Road (NY-60)	C520147	NYSDOT	Town of Dunkirk	212+00	7	18
East Main Street (US-20)	C520122	NYSDOT	Town of Pomfret	240+00	6	7

According to the FEMA FIS for the City of Dunkirk, there are multiple structures along Crooked Brook that are unaccounted for in the NYSDOT datasets for culverts and bridges. Table 8 summarizes the FEMA FIS structures, including field measured structure characteristics and hydraulic capacity analyses.

Table 8. FEMA FIS Infrastructure Along Crooked Brook

(Source: FIA 1980; Ramboll 2021)

Roadway Carried	River Station (ft)	Owner	Structure Length[1] (ft)	Surface Width[2] (ft)	Hydraulic Capacity (% Annual Chance)
Park Drive West (Crooked Brook Drive)	2+25	City of Dunkirk	38.5	18	Unable to pass 10
Lakeshore Drive (NY-5)	18+25	City of Dunkirk	17.7	67.8	Unable to pass 10
West Point Avenue	40+25	City of Dunkirk	N/A	N/A	Unable to pass 10
Conrail (CSX Railroad)	46+25	CSX Transportation, Inc.	N/A	N/A	10
Culvert #1	55+50 to 67+00	Chautauqua County / City of Dunkirk	11.5	N/A	No Data
Culvert #2	75+50 to 82+00	City of Dunkirk	9.3	N/A	No Data
Arch-culvert	89+25	City of Dunkirk	Removed	Removed	10
Lucas Avenue	98+25	City of Dunkirk	14.3	N/A	10
Norfolk and Western Railroad	101+25	Norfolk Southern Railway Co.	N/A	N/A	Unable to pass 10
Howard Avenue	103+50	City of Dunkirk	15.3	87.7	10
Central Avenue	111+25	Chautauqua County	8	86	Unable to pass 10

* Note: Field measurements were taken in early March of 2021. Field conditions limited the ability to measure some structures. In addition, multiple structures passed through or were within private premises where field staff could not enter.

[1] Structure length is measured perpendicular to stream flow and represents the opening width of the structure for water to flow through.

[2] Surface width is measured parallel to creek flow and refers to the curb-to-curb width, which is the minimum distance between the curbs or the bridge railings (if there are no curbs), to the nearest 30mm or tenth of a foot (NYSDOT 2006).

Based on orthographic imagery and field observations of the Crooked Brook watershed, additional structures crossing Crooked Brook were identified. Along with the three NYSDOT large culverts and FEMA FIS profile structures, nine additional waterway crossing structures were identified, including two long culverts (culverts with structure lengths that exceed 250-linear feet), two pedestrian bridges, and one railroad bridge crossing (NYSOITS 2017a; Ramboll 2021).

Table 9 provides an infrastructure inventory summary. Figure 3-9 displays the locations of infrastructure that cross Crooked Brook in Chautauqua County, New York.

Table 9. Infrastructure Inventory Summary Table

(Source: FIA 1980; NYSOITS 2017a; NYSDOT 2014; Ramboll 2021)			
Infrastructure Type	**Roadway Carried**	**River Station (ft)**	**Owner**
Pedestrian Bridge	N/A	115+50	City of Dunkirk
Culvert	Seel Acres	147+00	City of Dunkirk
Culvert	Main Street	151+25	City of Dunkirk
Railroad Bridge	CSX Transportation Rail Line	152+00	CSX Transportation
Culvert	Interstate 90 (SB)	185+00	NYS Thruway Authority
Culvert	Interstate 90 (NB)	186+75	NYS Thruway Authority
Culvert	Vineyard Drive	192+50	Town of Dunkirk
Pedestrian Bridge	Vineyard Drive	196+50	Town of Dunkirk
Long Culvert - Outlet	Vineyard Drive	197+00	Town of Dunkirk
Long Culvert - Inlet	Vineyard Drive	201+75	Town of Dunkirk
Culvert	Vineyard Drive	203+00	Town of Dunkirk
Culvert	Bennett Road (NY-60)	208+75	Town of Dunkirk
Long Culvert - Outlet	Bennett Road (NY-60)	216+00	Village of Fredonia
Long Culvert - Inlet	Bennett Road (NY-60)	219+00	Town of Pomfret
Culvert	Bennett Road (NY-60)	223+00	Town of Pomfret
Culvert	Bennett Road (NY-60)	245+00	Town of Pomfret
Culvert	McAllister Road	263+50	Town of Pomfret
Culvert	Christy Road	291+50	Town of Pomfret
Culvert	Christy Road	293+50	Town of Sheridan
Culvert	Stone Quarry Road	335+00	Town of Sheridan

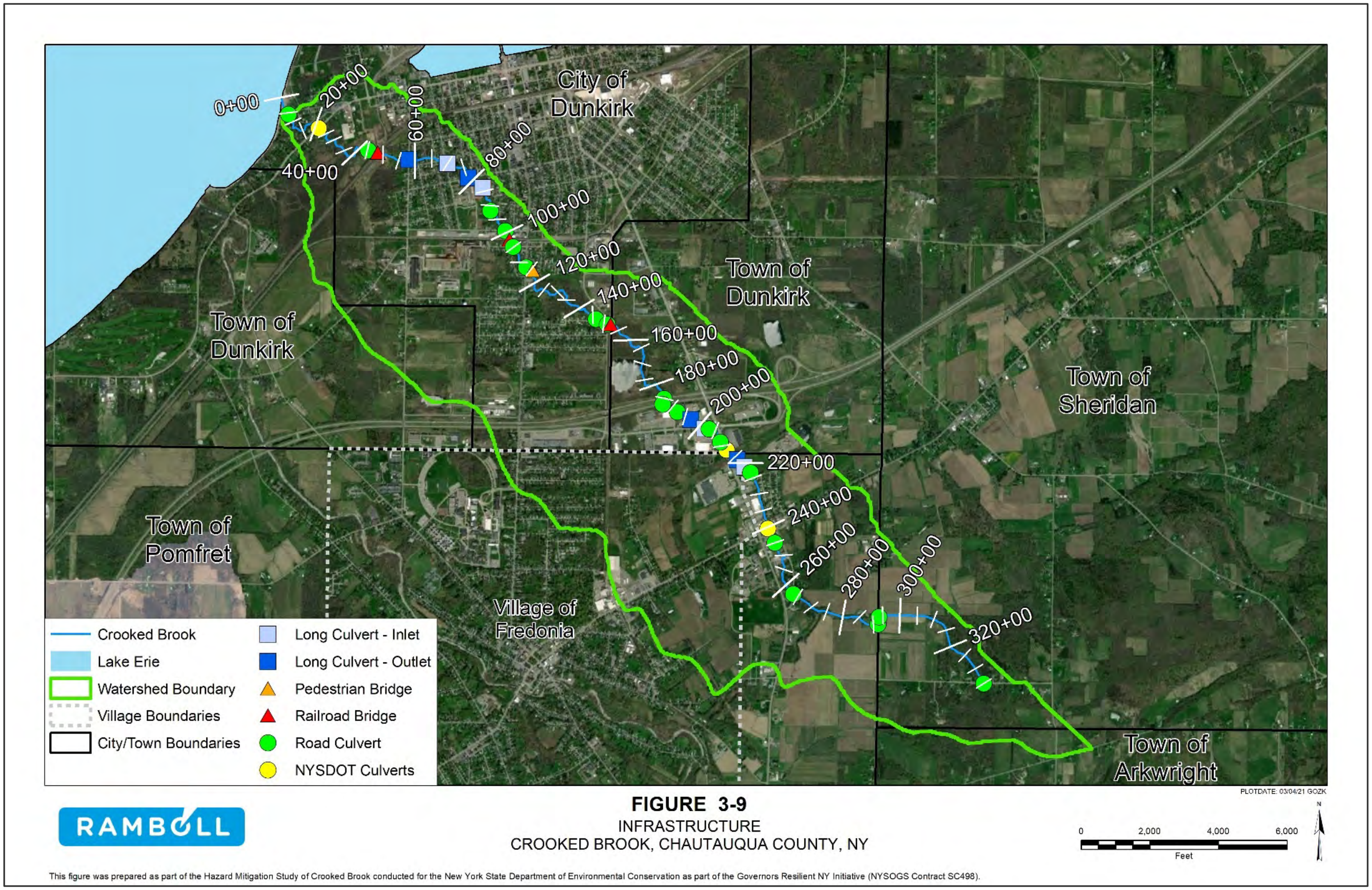

Figure 3-9. Crooked Brook Infrastructure, Chautauqua County, NY.

3.7 HYDRAULIC CAPACITY

Hydraulic capacity is the measure of the amount of water that can pass through a structure or watercourse. Hydraulic design is an essential function of structures in watersheds. Exceeding the capacity can result in damages or flooding to surrounding areas and infrastructure (Zevenbergen et al. 2012). In assessing hydraulic capacity of the culverts and bridges along Crooked Brook, the FEMA FIS profile in the City of Dunkirk was used to determine the lowest annual chance flood elevation to flow under the low chord of a bridge or culvert, without causing an appreciable backwater condition upstream (Table 8).

In New York State, hydraulic and hydrologic regulations for culverts were developed by the NYSDOT. The NYSDOT guidelines require culverts to be designed based upon an assessment of the likely damage to the highway and adjacent landowners from a given flow, and the costs of the drainage facility. The design flood frequency for drainage structures and channels is typically the 2% (50-year) annual chance flood hazard for interstates and other freeways, principal arterials, and minor arterials, collectors, local roads, and streets. If the proposed highway is in an established regulatory floodway or floodplain, then the 1% (100-year) annual chance flood hazard requirement must be checked (NYSDOT 2018).

The term “culvert” is defined as any structure, whether of single or multiple-span construction, with an interior width of 20 feet or less when the measurement is made horizontally along the center line of the roadway from face-to-face of abutments or sidewalls (NYSDOT 2020).

In assessing the hydraulic capacity of culverts, NYSDOT highway drainage standards require the determination of a design discharge (e.g. 50-year flood) through the use of flood frequencies. The design flood frequency is the recurrence interval that is expected to be accommodated without exceeding the design criteria for the culvert. There are four recommended methodologies: The Rational Method, the Modified Soil Cover Complex Method, historical data, and the regression equations. Each method should be assessed and the most appropriate method for the specific site should be used to calculate the design flood frequency and discharge (NYSDOT 2018).

In addition, current peak flows shall be increased to account for future projected peak flows based on the USGS *StreamStats* tool where current 2% peak flows shall be increased by 10% in Region 5. For critical culverts, the minimum hydraulic design criteria is three feet of freeboard over the 2% annual chance flood elevation. A critical culvert is considered to be vital infrastructure that the incapacity or destruction of such would have a debilitating impact on security, national economic security, national public health or safety, or any combination of those matters (NYSDOT 2018; USDHS 2010).

In an effort to improve flood resiliency of infrastructure in light of future climate change, New York state passed the Community Risk and Resiliency Act (CRRA) in 2014. In accordance with the guidelines of the CRRA, the NYSDEC released the *New York State Flood Risk Management Guidance for Implementation of the Community Risk and Resiliency Act* (2020) report. In the report, the NYSDEC outlined infrastructure guidelines, most notably the recommendation that culverts be able to fully pass the design flood without increasing headwater, and that they provide at least two feet of roadway freeboard above the projected 1% (100-year) annual chance flood hazard. An additional one foot of roadway freeboard should be considered for culverts on critical roadways (NYSDEC 2020a). When compared to current guidelines, the new CRRA climate change recommendation of freeboard for culverts encourages building more flood resilient infrastructure. Table 10 displays the 2% and 1% annual chance flood levels and their calculated difference at FEMA FIS infrastructure locations using the FIS profile for Crooked Brook.

Table 10. FEMA FIS profile 2 and 1% Annual Chance Flood Hazard Levels with Differences at Infrastructure Locations

(Source: FIA 1980)				
Roadway Carried	**River Station (ft)**	**2-Percent Water Surface Elevation (ft NAVD88)**	**1-Percent Water Surface Elevation (ft NAVD88)**	**Difference in Water Surface Elevations (ft NAVD88)**
Park Drive West (Crooked Brook Drive)	2+25	579.25	579.5	0.25
Lakeshore Drive (NY-5)	18+25	585.25	585.5	0.25
West Point Avenue	40+25	587.25	587.5	0.25
Conrail (CSX Railroad)	46+25	592.0	593.0	1.0
Culvert #1	55+50 to 67+00	606.0	606.5	0.5
Culvert #2	75+50 to 82+00	615.0	615.25	0.25
Arch-culvert	89+25	618.5	619.0	0.5
Lucas Avenue	98+25	625.5	626.5	1.0
Norfolk and Western Railroad	101+25	627.5	628.5	1.0
Howard Avenue	103+50	630.5	631.0	0.5
Central Avenue	111+25	633.25	633.5	0.25

According to the FEMA FIS profiles, no structure in the FIS profiles was determined to be able to pass a flood event exceeding the 10% annual chance (10-year flood). Of the nine structures that were modeled in the FIS, five were insufficient to pass all modeled flood events, including Park Drive West, Lakeshore Drive, West Point Avenue, the Norfolk and Western Railroad, and Central Avenue crossings (FIA 1980). Every structure that was modeled in the FIS profiles would be considered a high-risk constriction point along Crooked Brook based on the hydraulic capacity analysis due to the fact that none of the structures meet the NYSDOT guidelines for accommodating flow without exceeding the culverts drainage capability. Moreover, these structures do not meet the new draft CRRA climate change infrastructure guidelines as described above.

Even though these structures may have hydraulic capacity restraints, the NYSDOT has to balance both physical constraints along with cost versus benefit of replacing existing bridges to meet the new draft CRRA guidelines.

In addition, the USGS *StreamStats* tool was used to calculate the bankfull widths and discharge for each structure along Crooked Brook in the City of Dunkirk, New York (Table 11). Bankfull widths were derived from the USGS *StreamStats* software for all structures crossing Crooked Brook within the study area. Table 11 indicates that in the City of Dunkirk, there are eight structures that cross Crooked Brook that have structure openings that are smaller than the bankfull widths: Lake Shore Drive West (Hwy-5), Brigham Road, Woodrow Avenue, West 6th Street, the Dunkirk High School (DHS) Track & Field, West Lucas Avenue, West Howard Avenue, and Central Avenue. There is one structure with an opening that is very close (within five feet) of bankfull width: Crooked Brook Drive.

The structures with openings within five feet of bankfull are an area of concern since this indicates that water velocities have to slow and contract in order to pass through the structures, which causes upstream water surfaces to rise, increasing the potential for overtopping banks or backwater flooding. This issue is compounded by two factors: bankfull discharges occurring at the 80% annual chance flood hazard level, which indicates that relatively low-flow discharges can cause the water surface to rise as a result of the narrow structures within the watershed; and, surface runoff from both vegetated and impervious surfaces adjacent to the channel accumulating sediments and debris and depositing this material in the channel after heavy rain events. Both of these factors can lead to backwater upstream of the structure and potential flooding.

Table 11. Hydraulic Capacity of Potential Constriction Point Infrastructure Crossing Crooked Brook

Source: (Ramboll 2021; USGS 2017)

Roadway Carried	Structure Type	River Station (ft)	Structure Width (ft)	Bankfull Width (ft)	Bankfull Discharge (cfs)	Annual Chance Flood Event Equivalent[1]
Crooked Brook Drive	Culvert	5+50	38.5	34.5	202	80-percent
Lake Shore Drive West (Hwy 5)	Culvert	21+50	17.7	34.2	198	80-percent
West Point Avenue	Culvert	42+25	N/A	28.6	138	80-percent
CSX Transportation Rail Line	Railroad Bridge	48+25	N/A	28.5	137	80-percent
Brigham Road	Culvert	58+25	11.5	28.3	135	80-percent
Woodrow Avenue	Culvert	69+50	12	28.0	133	80-percent
West 6th Street	Culvert	78+50	9	27.9	132	80-percent
Dunkirk High School Football Field & Track	Culvert	84+00	9.3	27.3	126	80-percent
West Lucas Avenue	Culvert	99+25	14.3	27	123	80-percent
Norfolk Southern Railway Co. Rail Line	Railroad Bridge	102+50	N/A	26.9	122	80-percent
West Howard Avenue	Culvert	105+00	15.3	26.8	121	80-percent
Central Avenue	Culvert	113+75	8	26.7	120	80-percent
N/A	Pedestrian Bridge	115+50	N/A	26.6	119	80-percent
Seel Acres	Culvert	147+00	N/A	25.2	107	80-percent
Main Street	Culvert	151+25	31	25.1	106	80-percent
CSX Transportation Rail Line	Railroad Bridge	152+00	N/A	24.8	104	80-percent

[1] Annual Chance Flood Event Equivalent describes the equivalent annual chance flood event for the given bankfull discharge as calculated by the USGS *StreamStats* application. The 80% annual chance flood event is equal to a 1.25-year recurrence interval.

4. CLIMATE CHANGE IMPLICATIONS

4.1 FUTURE PROJECTED STREAM FLOW IN CROOKED BROOK

In New York State, climate change is expected to exacerbate flooding due to projected increases of 1-8% in total annual precipitation coupled with increases in the frequency, intensity, and duration of extreme precipitation events (events with more than 1, 2, or 4-inches of rainfall) (Rosenzweig, et al., 2011). In the NYSDEC CRRA report, two methods for estimating projected future discharges were discussed: an “end of design life multiplier” and the USGS *FutureFlow Explorer* map-based web application (NYSDEC 2020a).

USGS *FutureFlow Explorer* v1.5 (https://ny.water.usgs.gov/maps/floodfreq-climate/) is discussed as a potential tool to project peak flows under various climate scenarios into the future. *FutureFlow* was developed by the USGS in partnership with the New York State Department of Transportation. This application is an extension for the USGS *StreamStats* map-based web application and projects future stream flows in New York State. The USGS team examined 33 global climate models and selected five that best predicted past precipitation trends in the region. The results were then downscaled to apply to all six hydrologic regions of New York State. Three time periods can be examined: 2024-2049, 2050-2074 and 2075-2099, as well as two Intergovernmental Panel on Climate Change (IPCC) greenhouse gas emission scenarios: RCP 4.5 and RCP 8.5. RCP 4.5 is considered a midrange-emissions scenario, and RCP 8.5 is a high-emissions scenario (Taylor et al. 2011; NYSDEC 2020a).

In general, climate models are better at forecasting temperature than precipitation, and contain some level of uncertainty with their calculations and results. The USGS recommends using *FutureFlow* projections as qualitative guidance to see likely trends within any watershed and as an exploratory tool to inform selection of appropriate design flow. Current future flood projection models will not provide accurate results for basins that extend across more than one hydrologic region in New York state (NYSDEC 2020a).

Based on the current future flood projection models, flood magnitudes are expected to increase in nearly all cases in New York state, but the magnitudes vary among regions. While the *FutureFlow* application is still being upgraded, it can be used with appropriate caution. Climate model forecasts are expected to improve and as they do, the existing regression approach will be tested and refined further (NYSDEC 2020a).

The NYSDEC recommends that future peak-flow conditions should be adjusted by multiplying relevant peak-flow parameters by a factor specific to the expected service life of the structure and geographic location of the project. For western New York, the recommended design-flow multiplier is 10% increased flow for an end of design life of 2025-2100 (NYSDEC 2020a). Table 12 is a summary of the USGS *FutureFlow* projected peak discharges at the FEMA FIS locations for Crooked Brook.

Table 12. Crooked Brook Projected Peak Discharges

(Source: USGS 2016)						
			Peak Discharges (cfs)			
Flooding Source and Location	**Drainage Area (mi^2)**	**River Station (ft)**	**10-Percent**	**2-Percent**	**1-Percent**	**0.2-Percent**
At mouth	5.52	0+00	677	1,046	1,216	1,644
Confluence with unnamed tributary	5.21	36+00	660	1,024	1,186	1,614
City and Town of Dunkirk corporate limits	2.56	152+50	433	687	806	1,110
Town of Dunkirk / Village of Fredonia corporate limits	1.06	214+00	207	329	385	531
Towns of Pomfret / Sheridan corporate limits	0.26	292+50	85	138	164	229

Appendix F contains the HEC-RAS simulation summary sheets for the proposed and future condition simulations. The HEC-RAS model simulation results for the future condition model parameters using the future projected discharge values are similar to the base-condition model output with the only difference being future projected water surface elevations are up to 1.7-ft higher at specific locations, generally upstream of bridges or at the outlet with Lake Erie, due to backwater as a result of the increased discharges. Table 13 provides a comparison of HEC-RAS base condition, using the FEMA FIS peak discharges, and future condition, using the CRRA 10% multiplier, of water surface elevations at the FEMA FIS discharge locations.

Table 13. HEC-RAS Base and Future Conditions Water Surface Elevation Comparison

(Source: USGS 2016; USACE 2016a; USGS 2017)						
			Water Surface Elevations (ft NAVD88)[1]			
Flooding Source and Location	**Drainage Area (mi^2)**	**River Station (ft)**	**10-Percent**	**2-Percent**	**1-Percent**	**0.2-Percent**
At mouth	5.75	0+00	+ 2.3	+ 2.0	+ 2.0	+ 1.7
At corporate limits	2.65	145+00	+ 0.1	+ 0.1	+ 0.1	+ 0.2

[1] Positive changes in water surface elevation indicate the future conditions water surface elevation is higher than the base condition, while negative changes in water surface elevation indicate the future conditions water surface elevation is lower than the base condition.

5. FLOODING CHARACTERISTICS

5.1 FLOODING HISTORY

Flooding along Crooked Brook generally occurs in the summer and early winter months due to heavy rain, or rain on saturated soil events. The situation is compounded by restrictive and undersized waterway crossings, which can become overwhelmed or accumulate debris and clog openings potentially causing backwater flooding as a result. The heavily developed lower reaches of Crooked Brook, primarily in the City of Dunkirk, are at considerable risk of flood damages due to the close proximity of residential and commercial properties to the creek banks and topography of the floodplain in the City. In addition, high winds and elevated lake water levels from Lake Erie can cause localized flooding along the shoreline, which has intensified in recent years (NYSDEC 2020b).

Flooding in the City of Dunkirk occurs mostly along that portion of Crooked Brook which is downstream of the confluence of the tributary of Crooked Brook. Also, flooding problems exist along the Lake Erie shoreline and along the tributary of Crooked Brook in the vicinity of Greco Lane and Central Avenue (FIA 1980).

There have been reported floods in the City of Dunkirk in September and December 1972, 1973, September 1975, July 2010, July 2018, and April 2020. The 1972 floods, in September and December, were reported to have caused flooding of streets, stores, and home basements along Lake Erie in the vicinity of Crooked Brook (USGS 1976). The floods in 1973 and September 1975 had flood heights that varied from a few inches deep to about five feet deep, depending upon the terrain of the area flooded. However, no records were kept for these floods in the community. Most damage from these floods was to gardens, basements, stream banks, and to the Lake Erie shoreline, because of erosion (FIA 1980). The July 2010 and 2018 floods were a result of thunderstorms and heavy rains. The July 2010 event caused flooding along Crooked Brook at Routes 60 and 20 in the Town of Pomfret and Waldorf Road along the Tributary to Crooked Brook in the City of Dunkirk. The July 2018 event caused flooding between Central Avenue and Main Street in the City of Dunkirk (NCEI 2021). The April 2020 flooding event was caused by heavy rains and high winds off of Lake Erie, which caused localized flooding to homes and roadways near the lake along Crooked Brook in the City of Dunkirk (Observer Today 2020).

The main cause of flooding near the mouth of Crooked Brook is the buildup of sand and debris and the narrowness of the mouth, which restrict the free exit of water from the brook into the lake. This problem is further aggravated by occasional high water levels on Lake Erie and high wind velocities resulting in the backup of stream flow (FIA 1980).

In the past, flooding in the Greco Lane and Central Avenue areas in southern Dunkirk has been caused by heavy rains, spring thaws, and construction of the New York State Thruway and the plaza south of it, which sent increased runoff into inadequate storm drains (FIA 1980).

Flooding and erosion of the Lake Erie shoreline has been caused by high wind and wave action coupled with high water levels on the lake, a frequent occurrence in recent years. The roadbed along the lakefront in Point Gratiot Park has become so undermined by wave action on the lake that relocation of residents there may become necessary.

Also, whenever there is wave action and high water on the lake, extensive damage usually occurs to Lake Front Boulevard, which extends from Main Street to the area of Wright Park in the eastern section of the city along the shore of Lake Erie. The damage makes vehicular travel on this roadway impossible until repairs have been made, and this problem has occurred several times in recent years. No highwater marks or other pertinent flood data are available (FIA 1980).

According to FEMA flood loss data, there has been a total of 32 NFIP claims totaling approximately $411,000 in building and contents payments within the City of Dunkirk, New York since 1979. In addition, there are three properties identified as repetitive loss and no severe repetitive loss properties within the Crooked Brook watershed. A Repetitive Loss (RL) property is any insurable building for which two or more claims of more than $1,000 were paid by the NFIP within any rolling ten-year period, since 1978. A Severe Repetitive Loss (SRL) property is any insurable building for which four or more claims of more than $5,000 (or cumulative amount exceeding $20,000) were paid by the NFIP, or at least two separate claims payments have been made with the cumulative amount of exceeding the fair market value of the insured building on the day before each loss within any rolling ten-year period, since 1978 (FEMA 2019; FEMA 2020a; FEMA 2020b). It is important to note that the FEMA flood loss data only represents losses for property owners who participate in the NFIP and have flood insurance.

FEMA FIRMs are available for Crooked Brook from FEMA. Figures 5-1 and 5-2 display the floodway and 1 and 0.2% annual-chance flood event boundaries for Crooked Brook as determined by FEMA for the City and Town of Dunkirk, and the Towns of Pomfret and Sheridan, respectively. The maps indicate that in the City of Dunkirk, flooding generally occurs upstream of the CSX Transportation Railroad crossing and extends downstream to the confluence of Crooked Brook with the unnamed tributary and Lake Erie (FIA 1981).

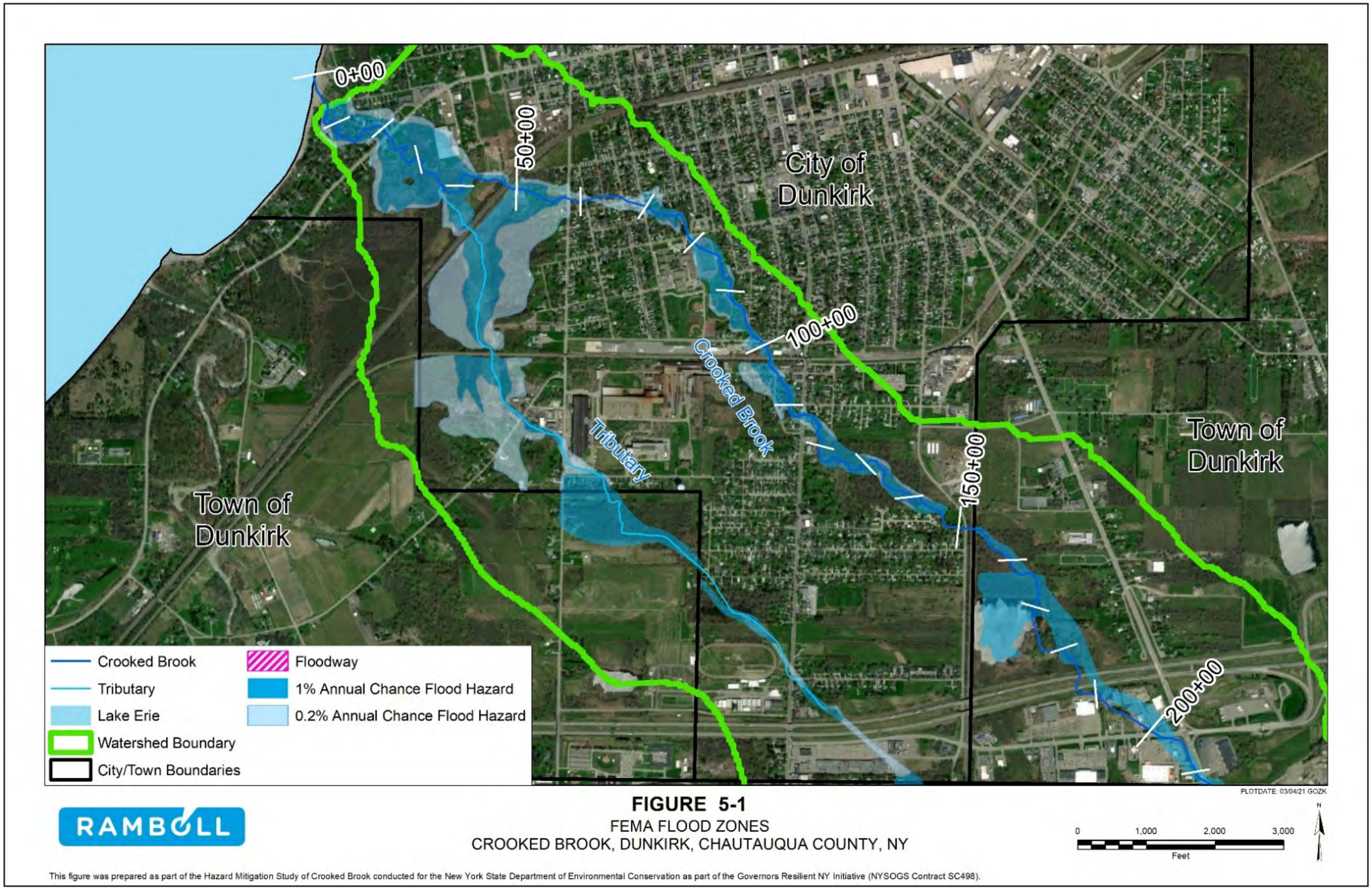

Figure 5-1. Crooked Brook FEMA flood zones, City and Town of Dunkirk, Chautauqua County, NY.

*Note: This map was created using FIRMs georeferenced to the earth's surface. This figure is not official and may not be used for regulatory purposes.

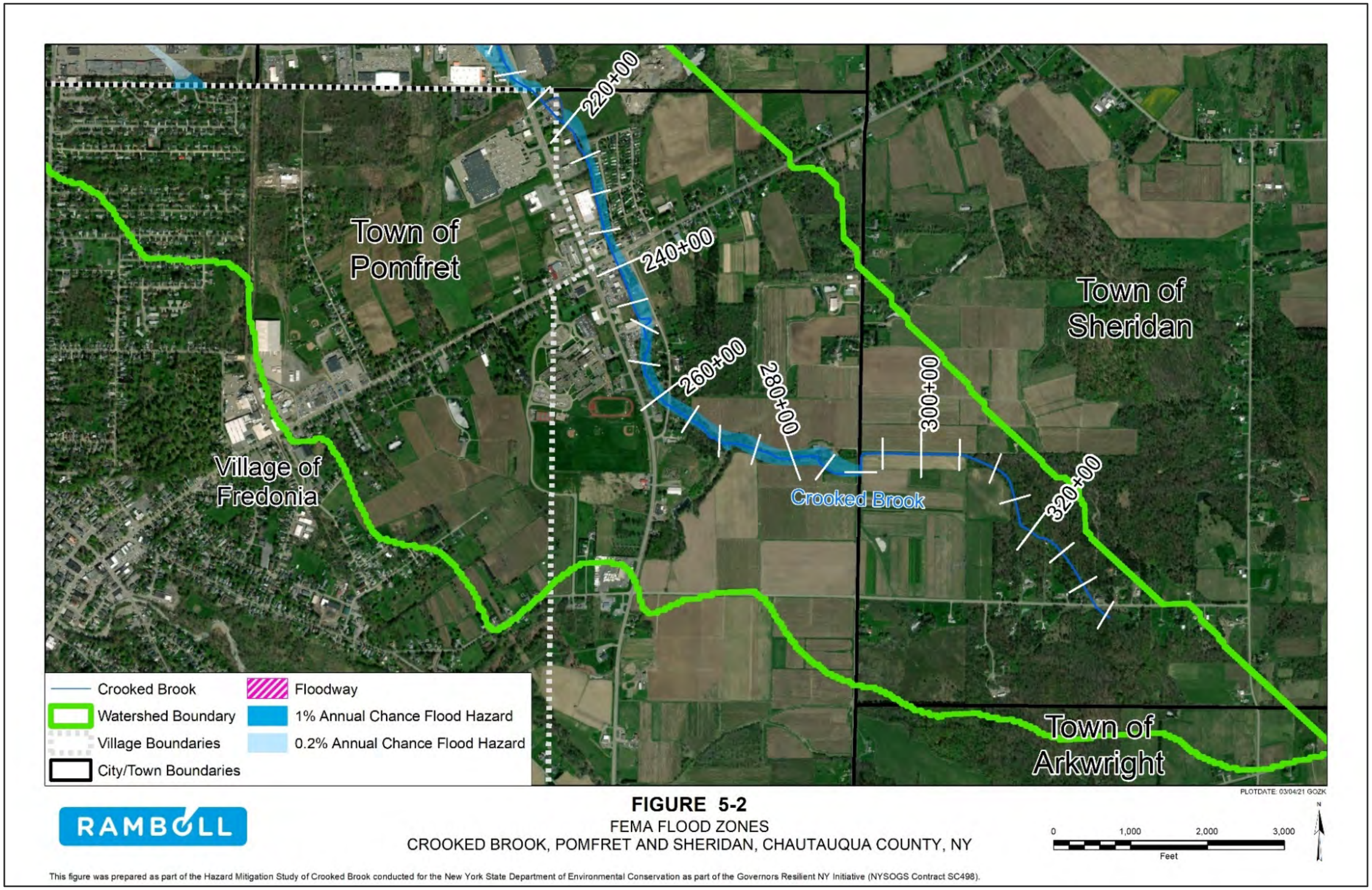

Figure 5-2. Crooked Brook FEMA flood zones, Towns of Pomfret and Sheridan, Chautauqua County, NY.

*Note: This map was created using FIRMs georeferenced to the earth's surface. This figure is not official and may not be used for regulatory purposes.

6. FLOOD RISK ASSESSMENT

6.1 FLOOD MITIGATION ANALYSIS

Flood events of a magnitude which are expected to be equaled or exceeded on the average during any 10, 50, 100, or 500-year period (recurrence interval) have been selected as having special significance for floodplain management and for flood insurance premium rates. These events, commonly termed the 10, 50, 100, and 500-year floods, have a 10, 2, 1, and 0.2% chance, respectively, of being equaled or exceeded during any year. Although the recurrence interval represents the long-term average period between floods of a specific magnitude, rare floods could occur at short intervals or even within the same year. The risk of experiencing a rare flood increases when periods greater than one year are considered (FIA 1980). The analyses reported here reflect flooding potentials based on conditions existing in the community at the time of completion of this study.

Hydraulic analysis of Crooked Brook was conducted using the HEC-RAS v5.0.7 program. The HEC-RAS computer program was written by the USACE Hydrologic Engineering Center (HEC) and is considered to be the industry standard for riverine flood analysis. The model is used to compute water surface profiles for 1 and 2-Dimensional (2-D), steady-state, or time-varied (unsteady) flow. In 1-Dimensional (1-D) solutions, the water surface profiles are computed from one cross section to the next by solving the one-dimensional St. Venant equation with an iterative procedure (i.e. standard step backwater method). Energy losses are evaluated by friction (Manning's Equation) and the contraction / expansion of flow through the channel. The momentum equation is used in situations where the water surface profile is rapidly varied, such as hydraulic jumps, mixed-flow regime calculations, hydraulics of dams and bridges, and evaluating profiles at a river confluence (USACE 2016a).

Hydraulic and Hydrologic modeling of Crooked Brook in the City of Dunkirk was completed by FEMA in 1979. Due to the age and format of the 1979 studies, an updated 1-D HEC-RAS model was developed using the following data and software:

- New York State Digital Ortho-imagery Program imagery for Chautauqua County (NYSOITS 2017a)
- Chautauqua County, NY 1-meter LiDAR DEM data with a vertical accuracy of 0.7-ft (NYSOITS 2017b)
- National Land Cover Database (NLCD) data (USGS 2019)
- RAS Mapper extension in HEC-RAS software
- ESRI ArcMap 10.7 with the HEC-GeoRAS extension GIS software (ESRI 2019)

The hydraulics model was developed for Crooked Brook beginning at the confluence with Lake Erie (river station 0+00) and extending upstream to the City and Town of Dunkirk corporate limits (river station 174+00).

6.1.1 Methodology of HEC-RAS Model Development

Using the LiDAR DEM data, orthoimagery, land cover data, and the RAS Mapper extension in the HEC-RAS software, a base condition model was developed using the following methodology:

- Main channel, bank lines, flow paths, and cross-sections, which were drawn along the main channel at stream meanders, contraction / expansion points, and at structures, were digitized in RAS Mapper
- These features were then exported to the ESRI ArcMap 10.7 GIS software
- Using the HEC-GeoRAS extension in ArcMap, LiDAR DEM and NLCD land cover data were obtained and used to develop updated terrain profiles for overbank areas, stream centerline and cross-section downstream reach lengths for the channel and left and right overbanks, flow paths and Manning's n values for land use were assigned
- The stream centerline, cross-sections, bank lines, flow paths, and land use data were then imported back into HEC-RAS where a 1-D steady flow simulation was performed using the effective FEMA FIS peak discharges

Downstream boundary conditions for the base and future conditions models were based on the FEMA FIS Lake Erie stillwater elevations. For the base condition model, the Lake Erie stillwater elevations from the City of Dunkirk effective FEMA FIS (1980) were obtained and converted to NAVD88 for use in the model.

For the future conditions model, Lake Erie stillwater elevations were obtained from the preliminary 2021 Erie County, New York FEMA FIS. In the preliminary FIS, FEMA completed an Updated Coastal Analysis for the entire shoreline of Erie County. The southernmost transect studied for the coastal analysis was at the Erie and Chautauqua County boundary. Since the City of Dunkirk is approximately 15 miles from the county boundary, the stillwater elevations at the southernmost transect were reasonably assumed to be coincidental and acceptable to use (FEMA 2021a). Table 14 displays the Lake Erie stillwater elevations for the City of Dunkirk, NY effective and Erie County, NY preliminary FEMA FIS reports.

Table 14. City of Dunkirk, NY (effective 1980) and Erie County, NY (Preliminary 2021) FEMA FIS Lake Erie Stillwater Elevations Comparison

(Source: FIA 1980; FEMA 2021a)

	Water Surface Elevations (ft NAVD88)			
Flooding Source and Location	**10-Percent**	**2-Percent**	**1-Percent**	**0.2-Percent**
City of Dunkirk, NY FEMA FIS (effective 1980)	575.9	577.1	577.5	578.3
Erie County, NY FEMA FIS (preliminary 2021)	578.6	579.1*	579.5*	580.0

* Note: These values differ from the 2 and 1% ACE WSELs in the Erie County, NY FEMA FIS (preliminary 2021). These values were adjusted based on reasonable scientific understanding that lower ACEs contain higher discharges, which would increase WSELs, and in an effort to produce a hydraulically correct model.

The stillwater values in the preliminary 2021 FIS were used for the future conditions downstream boundary condition for the following reasons:.

- These values are significantly higher (up to 2.7-ft) than the effective 1980 FIS for the City of Dunkirk
- According to the Great Lakes Environmental Research laboratory (GLERL), the lake-wide period of record (1918 to 2020) average water level for Lake Erie is EL 571.4-ft IGLD85 (EL 571.5-ft NAVD88), which is significantly lower than the 10% annual chance event of both the 1980 and 2021 FEMA FIS reports (GLERL 2020)
- Based on current research, there is disagreement over the projected water levels for the Great Lakes with different models projecting both modest decreases or increases in Lake Erie water levels (Angel and Kunkel 2010; Hayhoe et al. 2010; MacKay and Seglenieks 2012; Lofgren et al. 2011)

The base condition model water surface elevation results were then compared to past flood events with known water surface elevations and the effective FEMA FIS water surface elevation profiles to validate the model. After the base condition model was verified, it was then used to develop proposed condition models to simulate potential flood mitigation strategies.

As the potential flood mitigation strategies in this study are only preliminary, inundation mapping was not developed from the computed water surface profiles for each potential mitigation alternative. Inundation shown on figures within this report reflects that of the effective FEMA FIS for the City of Dunkirk and Towns of Dunkirk and Pomfret.

The effectiveness of each potential mitigation strategy was evaluated based on reduction in water surface elevations within the H&H model. The flood mitigation strategies that were modeled were:

- 1-1: Jetty at Confluence with Lake Erie
- 1-4: Increase Size of Crooked Brook Drive Culvert
- 2-1: Flood Bench Near Confluence with Unnamed Tributary
- 2-3: Remove West Point Avenue Culvert
- 2-4: Increase size of CSX Railroad Bridge Crossing
- 2-5: Install Crossing Pipes into CSX Railroad Bridge Embankment
- 2-6: Flood Bench Upstream Railroad Bridge Crossing
- 3-1: Install Flood Bench Downstream West 6th Street
- 3-2: Install Flood Bench Adjacent to DHS Baseball Field
- 3-3: Increase Size of West Lucas Avenue Culvert
- 3-4: Replace Pipe Culverts with Box Culvert Under Norfolk and Western Railroad Bridge Crossing

- 3-5: Install Additional Crossing Pipes into Norfolk and Western Railroad Bridge Embankment
- 3-6: Increase Size of West Howard Avenue Culvert
- 3-7: Replace Arch-culvert with Box Culvert Under Central Avenue
- 3-8: Increase Size of Central Avenue Culvert

The remaining alternatives were either qualitative in nature or required additional advanced 3-D modeling outside of the scope of this study.

Stationing references for the flood mitigation measures are based on the USGS National Hydrography Dataset (NHD) for Crooked Brook, which differs from the FEMA FIS stationing values (USGS 2020).

6.2 COST ESTIMATE ANALYSIS

Rough order of magnitude (ROM) cost estimates were prepared for each mitigation alternative. In order to reflect current construction market conditions, a semi-analogous cost estimating procedure was used by considering costs of a recently completed, similar scope construction project performed in Upstate New York. Phase I of the Sauquoit Creek Channel and Floodplain Restoration Project in Whitestown, New York contained many elements similar to those found in the proposed mitigation alternatives.

Where recent construction cost data was not readily available, RSMeans CostWorks 2019 was used to determine accurate and timely information (RSMeans Data Online 2019). Costs were adjusted for inflation and verified against current market conditions and trends.

For mitigation alternatives where increases in culvert sizes were evaluated, culvert size increases were initially analyzed based on 2-feet freeboard over the base flood elevation for a 1% annual chance flood event. Once these optimal sizes were determined, further analysis was completed including site constraints and constructability. Due to these additional constraints, often the size necessary to meet the freeboard requirement was not feasible. Cost estimates were performed based on projects determined to be constructible and practical.

Infrastructure and hydrologic modifications will require permits and applications to the NYS and / or FEMA, including construction and environmental permits from the State and accreditation, Letter of Map Revision (LOMR), applications to FEMA, etc. Application and permit costs were not incorporated in the ROM costs estimates.

6.3 ICE JAM ANALYSIS

According to the USACE Cold Regions Research and Engineering Laboratory (CRREL) ice jam database, National Centers for Environmental Information (NCEI) storm events database, the FEMA FIS, and the stakeholder engagement meeting, there have been no reported or observed ice-jam events on Crooked Brook (FIA 1980; NYSDEC 2020b; CRREL 2021; NCEI 2021). Therefore, ice-jam flooding was determined not to be a driving factor of flood risk in the City of Dunkirk. Instead, undersized culverts, debris accumulation, and lake enhanced flooding were determined to be the primary drivers of flooding within the City.

6.4 HIGH-RISK AREAS

Based on the FEMA FIS, NCEI storm events database, historical flood reports, and stakeholder input from engagement meetings, three areas along Crooked Brook were identified as high-risk flood areas in the City of Dunkirk, New York.

6.4.1 High-risk Area #1: Upstream Confluence with Lake Erie

High-risk Area #1 is at the mouth of Crooked Brook with Lake Erie and areas immediately upstream in the City of Dunkirk. Flooding in this area poses a threat to: multiple residential and commercial structures along Crooked Brook and West Point Drives; the culvert (C520030) at Lake Shore Drive (NY-5), which is NYSDOT owned; and vital shoreline protection and recreational areas at Point Gratiot Park (Figure 6-1).

According to the FEMA FIS, the Park Drive West (now known as Crooked Brook Drive) and Lake Shore Drive culverts are unable to pass the 10% annual chance flood hazard (Figure 6-2). However, the Lake Shore Drive culvert was replaced in 1994 by the NYSDOT and no FEMA H&H analysis has been performed or released incorporating the new structure data (FIA 1980; NYSDEC 2020b).

In addition, backwater at the confluence with Lake Erie can occur as a result of wind and wave action off Lake Erie forcing water upstream Crooked Brook, and sediment depositional aggradation that reduces the cross-sectional flow area of the channel and volume of water that can flow out to Lake Erie (NYSDEC 2020b).

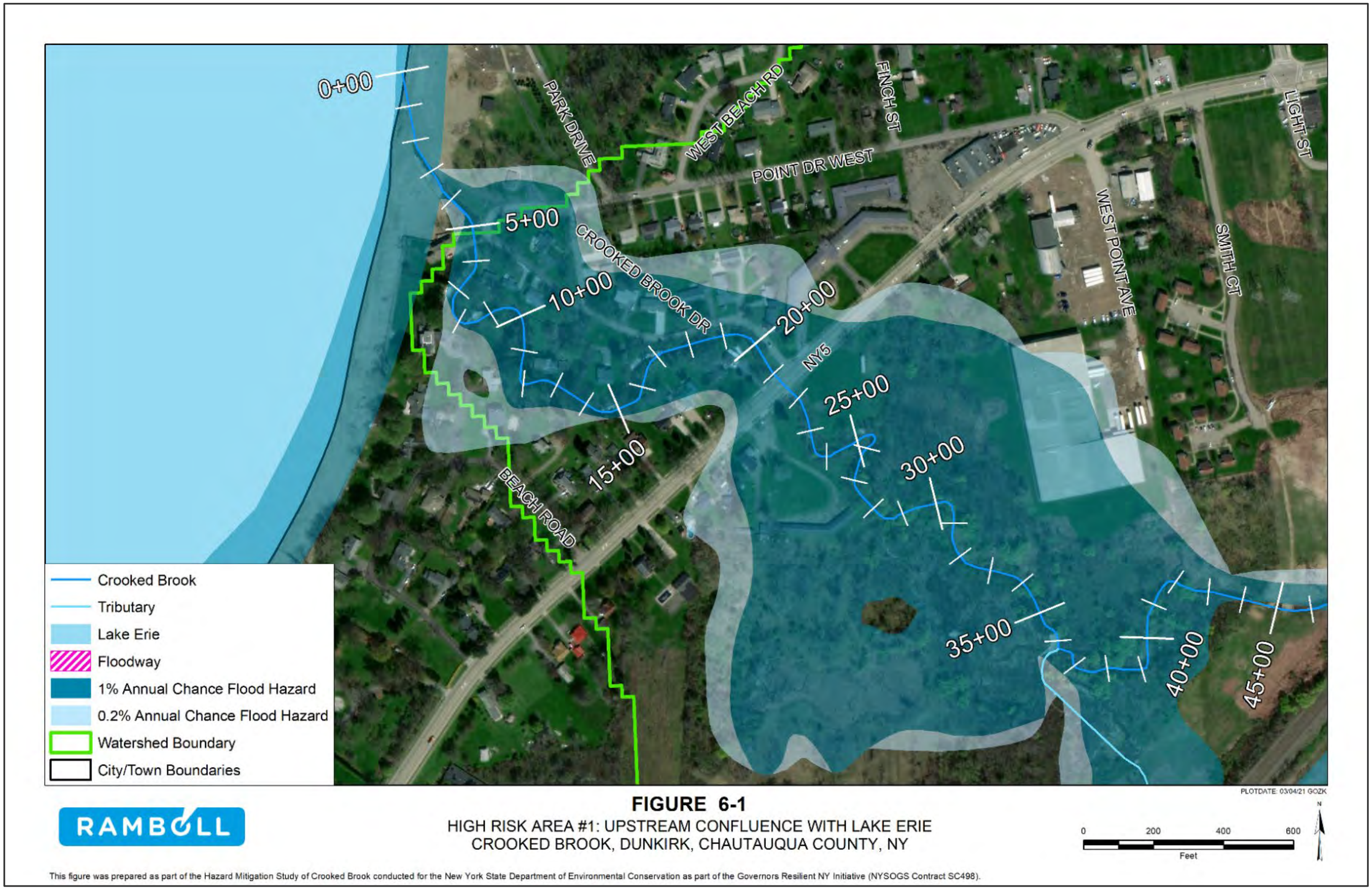

Figure 6-1. High-risk Area #1: Upstream Confluence with Lake Erie, Dunkirk, Chautauqua County, NY.

*Note: This map was created using FIRMs georeferenced to the earth's surface. This figure is not official and may not be used for regulatory purposes.

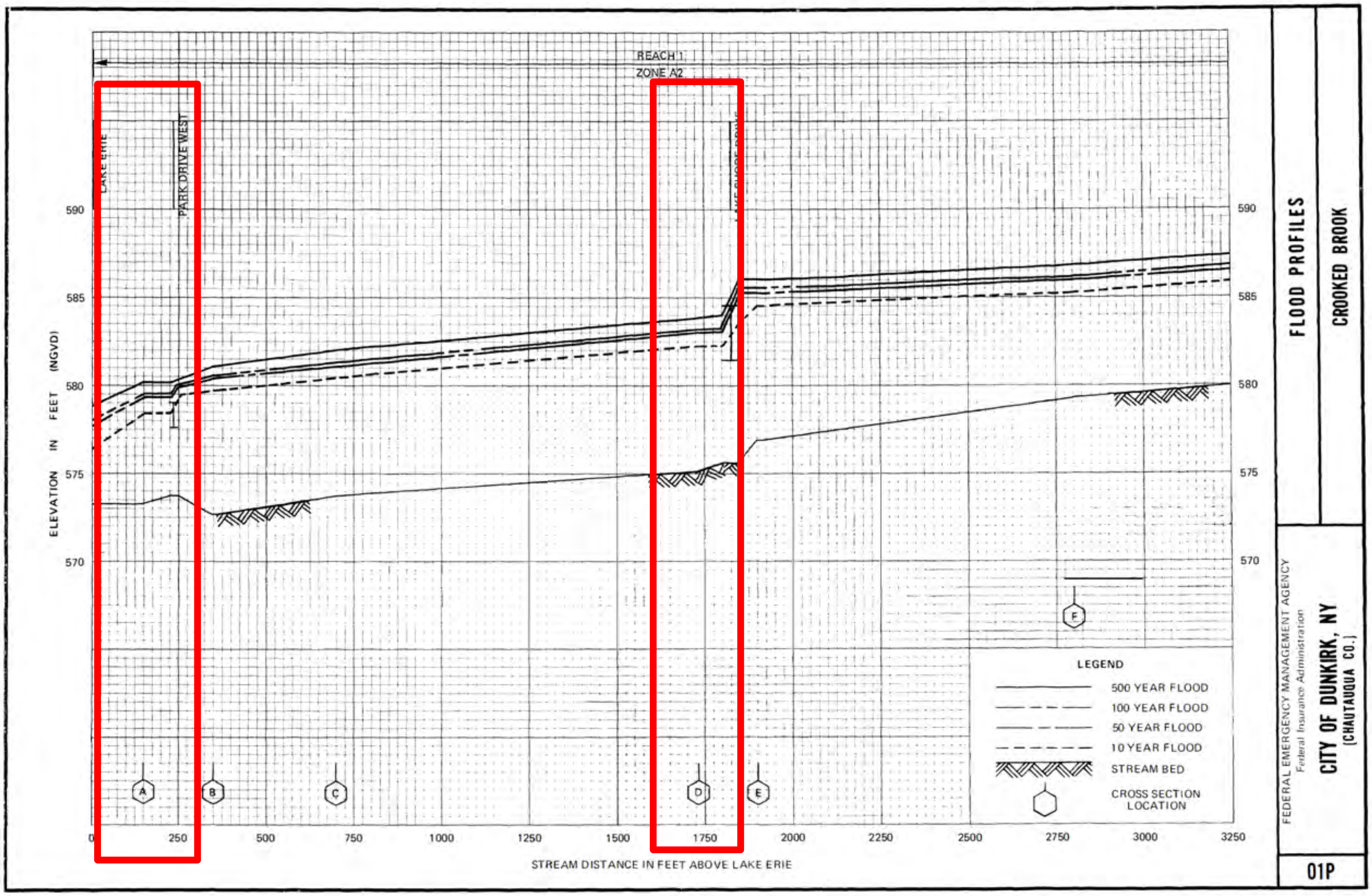

Figure 6-2. FEMA FIS profile for Crooked Brook upstream of the confluence with Lake Erie.

*Note: Park Drive West (Crooked Brook Drive) is located at river station 2+25 and Lake Shore Drive is located at river station 18+25 on the FEMA FIS profile.

6.4.2 High-risk Area #2: Upstream Confluence with Unnamed Tributary

High-risk Area #2 is the area in the vicinity of the confluence of Crooked Brook and the unnamed tributary in the City of Dunkirk starting at river station 36+00 and extending upstream to river station 55+00 (Figure 6-3). The flooding in this area occurs primarily over undeveloped land; however, a large commercial warehouse is within the FEMA 1 and 0.2% annual chance flood hazard zones, while multiple residential properties along Smith Court are within 150-ft of the FEMA flood zones. In addition, the CSX Transportation, Inc. company owns two railroad bridge crossings in this area: one over Crooked Brook and another over the unnamed tributary. According to the FEMA FIRM for the City of Dunkirk, both railroad bridge crossings act as constriction points and cause backwater flooding upstream creating flood risks for residential properties along Brigham Road and West 5th Street (FIA 1981).

This area is susceptible to open-water flooding due to multiple factors, including low lying topography, additional discharge from the unnamed tributary, sediment depositional aggradation restricting the in-channel flow area, and multiple structures in this reach that constrict flow within the channel. Figure 6-4 is the FEMA FIS profile for this reach and depicts the low chord elevation for the West Point Avenue culvert being unable to pass the 10% annual chance flood hazard, and the Conrail Railroad Bridge unable to pass the 2% annual chance flood hazard (FIA 1980). The inability to pass high-flow events increases the chance for backwater flooding and potential flood damages to areas and properties upstream of the bridge.

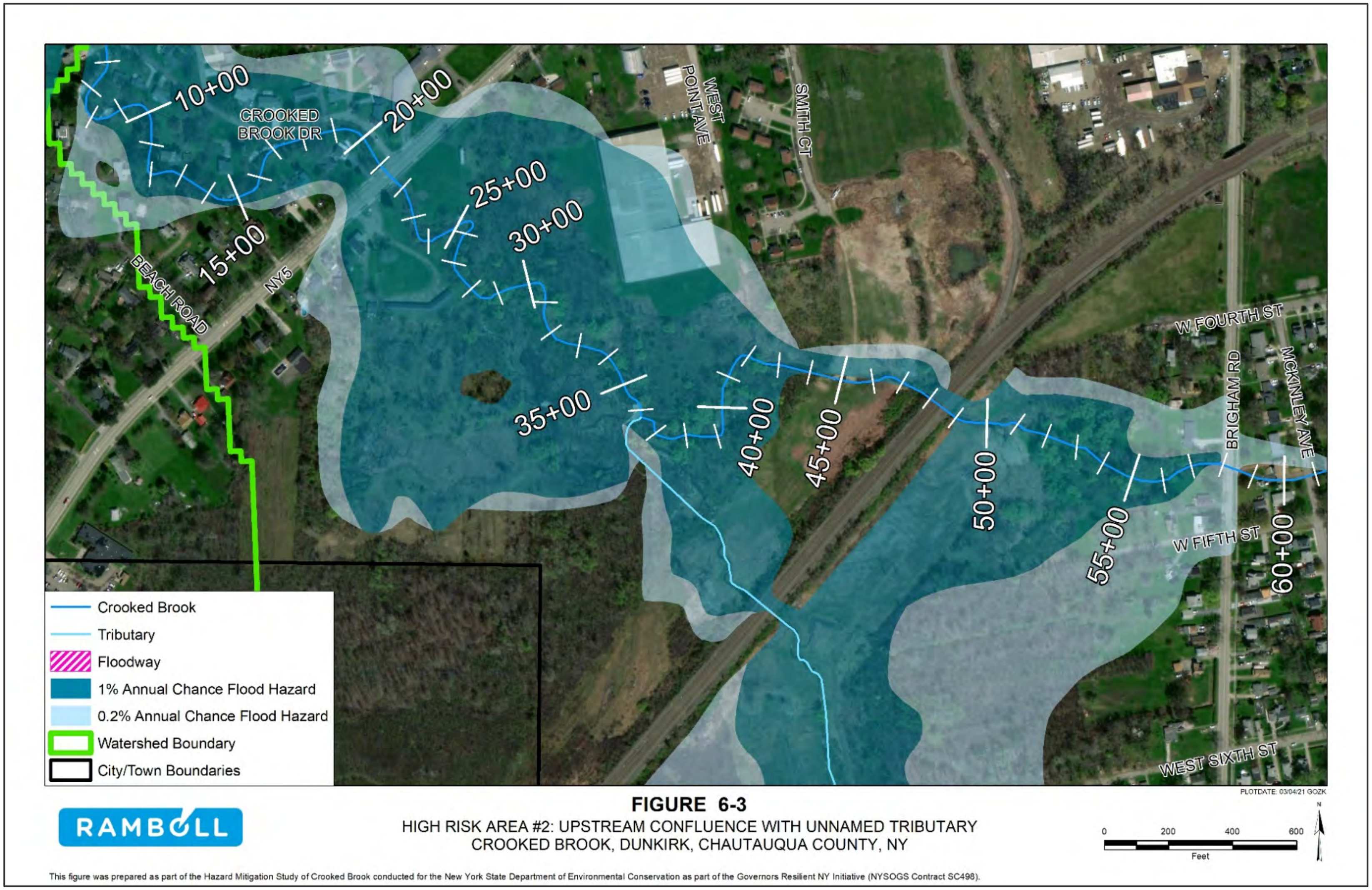

Figure 6-3. High-risk Area #2: Upstream Confluence with Unnamed Tributary, Dunkirk, Chautauqua County, NY.

*Note: This map was created using FIRMs georeferenced to the earth's surface. This figure is not official and may not be used for regulatory purposes.

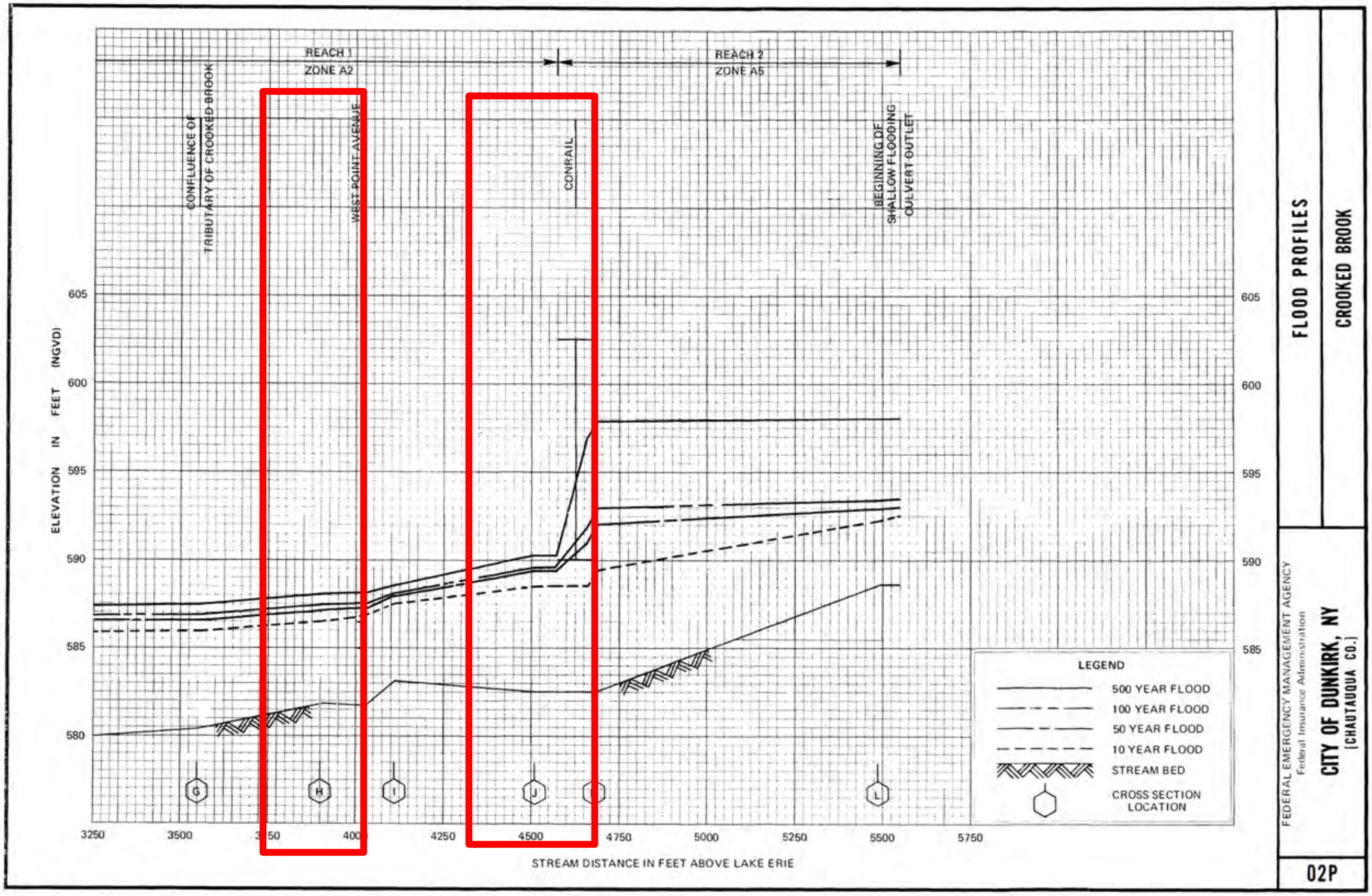

Figure 6-4. FEMA FIS profile for Crooked Brook in the vicinity of the Confluence with the Unnamed Tributary.

*Note: West Point Drive is located at river station 40+25 and the CSX Transportation, Inc. railroad bridge is located at river station 46+25 on the FEMA FIS profile.

6.4.3 High-risk Area #3: Brigham Road to Central Avenue Area

High-risk Area #3 is the reach of Crooked Brook that flows under multiple residential and commercial districts in the City of Dunkirk starting near Brigham Road at river station 58+25 and extending upstream to Central Avenue at river station 113+75 (Figure 6-5). The flooding in this reach occurs primarily upstream of infrastructure crossings over Crooked Brook and poses a risk to numerous residential and commercial properties, the Dunkirk High School, and multiple City of Dunkirk Division of Public Works facilities. In addition, the Norfolk Southern Railway Company owns a railroad bridge crossing in this area at river station 102+50. According to the FEMA FIRM for the City of Dunkirk, multiple infrastructure crossings act as constriction points and cause backwater flooding, including West Lucas, West Howard, and Central Avenues and the Norfolk Southern Railway bridge crossing (FIA 1981).

This area is susceptible to open-water flooding due to multiple factors, including a highly developed floodplain with large areas of impervious surfaces that concentrate flow into local waterways, separation of the water channel from its natural banks and floodplain, and multiple structures in this reach that constrict flow within the channel. Figure 6-6 is the FEMA FIS profile for the area in the vicinity of Central Avenue and depicts the low chord elevation for the West Lucas, West Howard, and Central Avenues and Norfolk Southern Railway bridge crossing. According to the FIS profiles, the West Lucas and West Howard Avenue culverts are unable to pass the 2% annual chance flood hazard, while the Norfolk Railway bridge and Central Avenue crossings are unable to pass the 10% annual chance flood hazard (FIA 1980). The inability to pass high-flow events increases the chance for backwater flooding and potential flood damages to areas and properties upstream of the bridge.

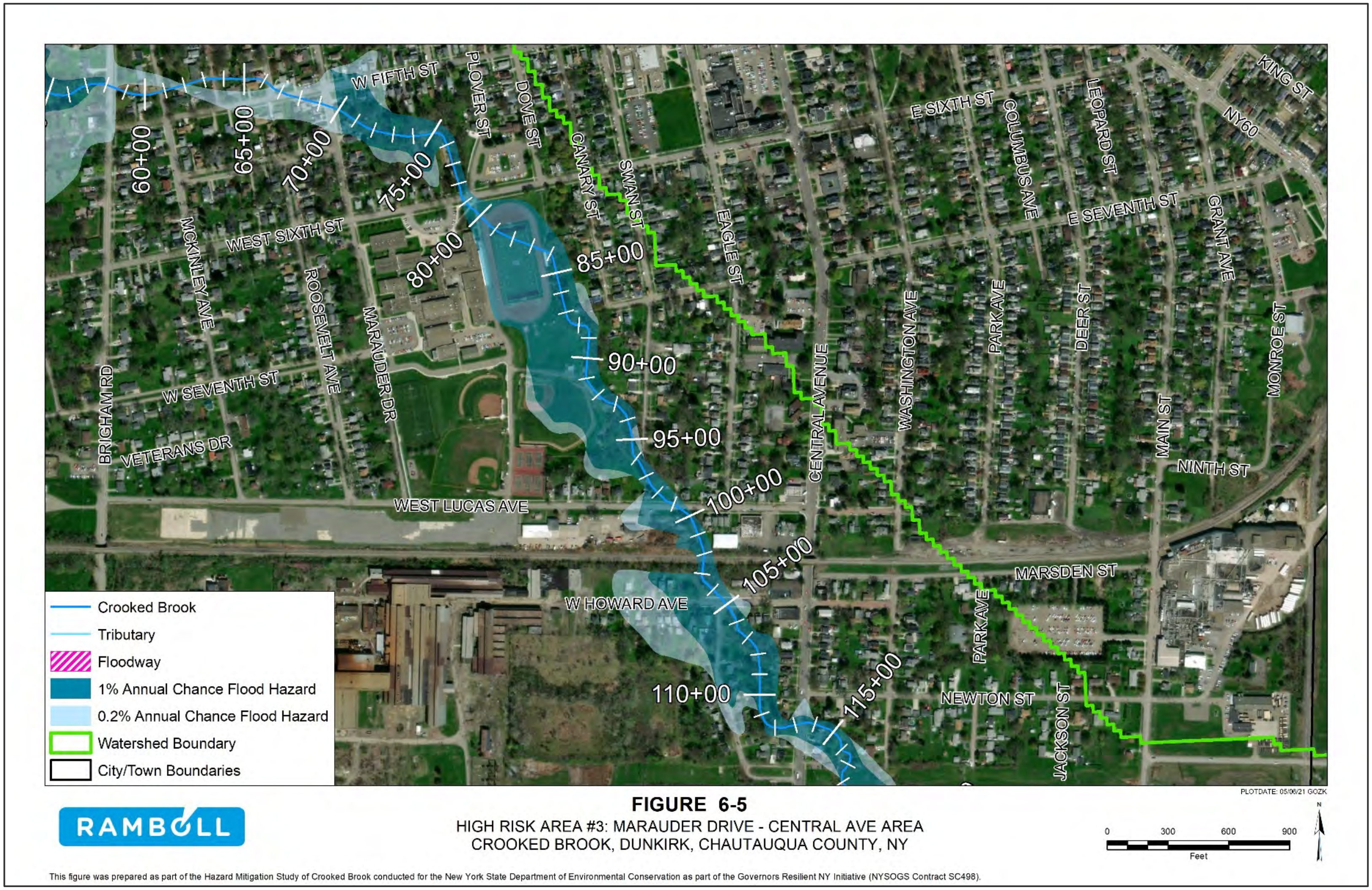

Figure 6-5. High-risk Area #3: Brigham Road to Central Avenue Area, Dunkirk, Chautauqua County, NY.

*Note: This map was created using FIRMs georeferenced to the earth's surface. This figure is not official and may not be used for regulatory purposes.

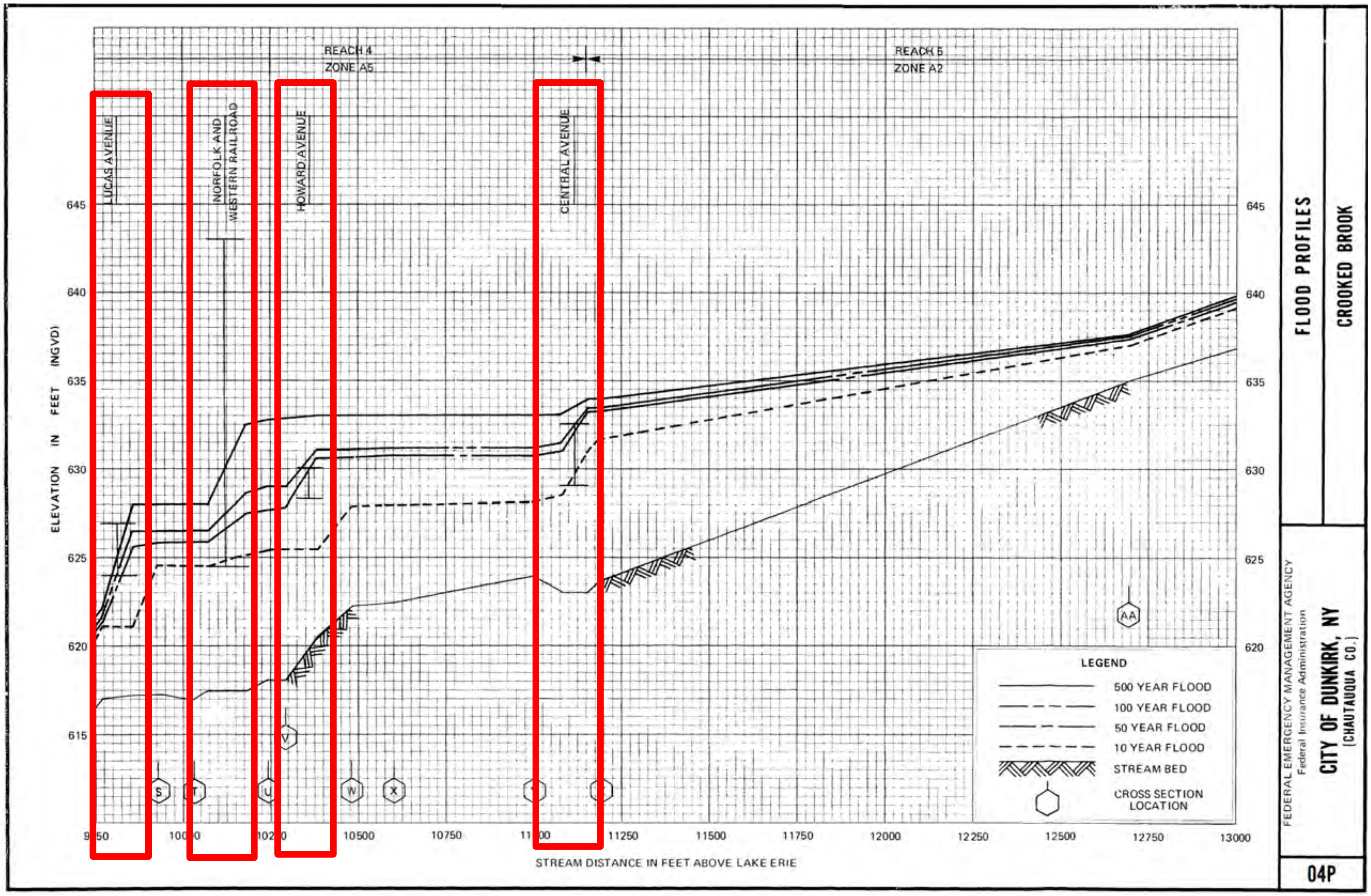

Figure 6-6. FEMA FIS profile for Crooked Brook in the vicinity of Central Avenue.

*Note: Central Avenue is located at river station 111+25 on the FEMA FIS profile.

7. MITIGATION ALTERNATIVES

The following are flood mitigation alternatives that have the potential to reduce water surface elevations along high-risk areas of Crooked Brook. These alternatives could potentially reduce flood related damages in areas adjacent to the creek. Local and State officials and stakeholders should evaluate each alternative before pursuing them further.

7.1 HIGH-RISK AREA #1

7.1.1 Alternative #1-1: Jetty at Confluence with Lake Erie

This measure is intended to address sediment buildup at the confluence of Crooked Brook with Lake Erie (river station 0+00), which would increase flow conveyance and potentially decrease flow depths in this area downstream of the Crooked Brook Drive bridge. A jetty is a structure, often made of large riprap, which projects into a waterbody, helping to limit sediment buildup. In this case, the jetty would project into Lake Erie on each side of Crooked Brook, helping to limit sediment buildup due to flows in Lake Erie, and to encourage free discharge of flows in Crooked Brook. Feedback from public outreach conducted for this report indicates that silt buildup can vary seasonally, with buildup reducing the channel outlet to only a few feet wide (Figure 7-1).

Crooked Brook at the confluence with Lake Erie is within a mapped Coastal Erosion Hazard Area (CEHA), specifically a Natural Protective Feature Area (NPFA) and Structural Hazard Area (SHA) as indicated by the Coastal Erosion Hazard Area Map for the City of Dunkirk. For a Coastal Erosion Management permit to be issued, the NYSDEC would need significant justification for the project and it would require an alternative analysis be completed. Before a jetty can be permitted, the community would need to demonstrate that it is the least impactful alternative that will mitigate their flooding issue, which is typically done through additional modeling. In addition, USACE permits and a New York State Department of State (NYSDOS) Coastal Consistency review would be required if the jetty required fill below the ordinary high water, which would be likely.

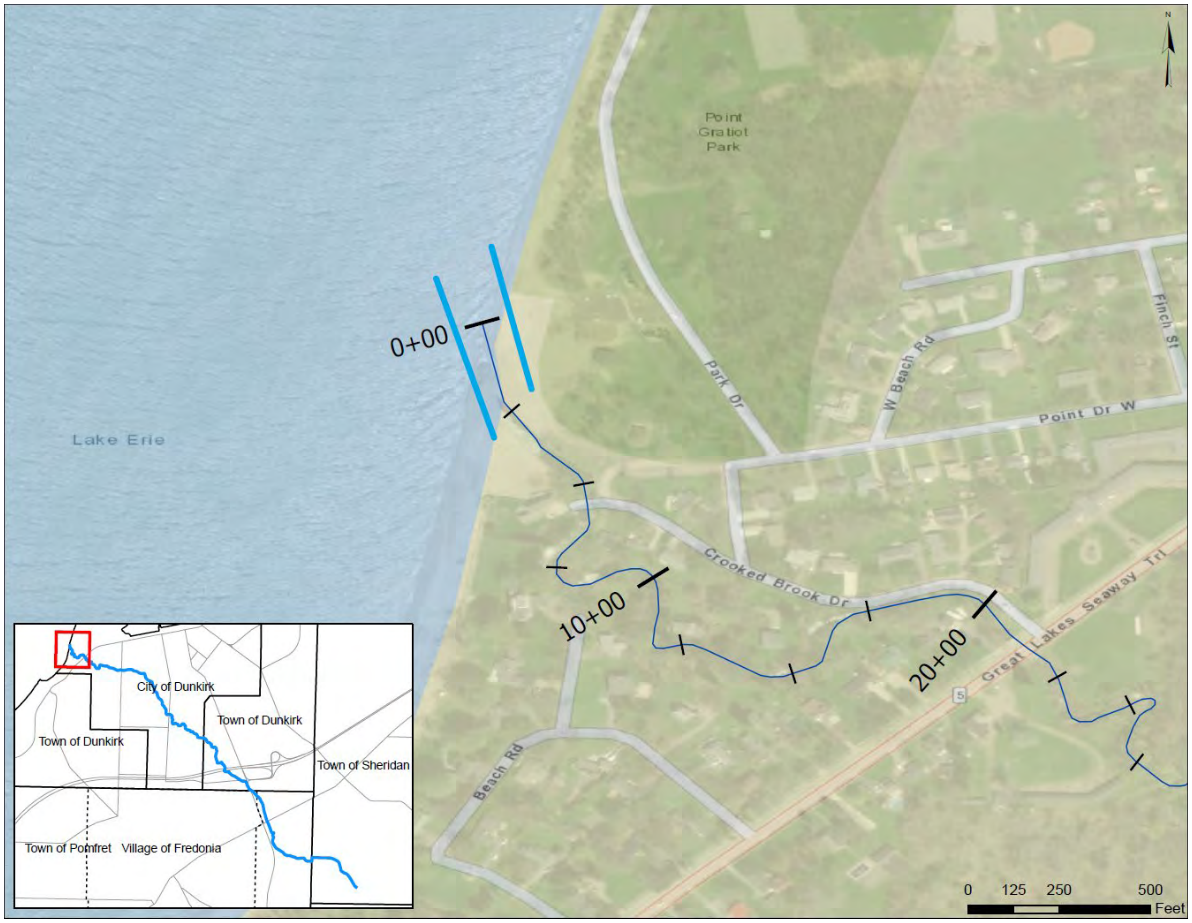

Figure 7-1. Location map for Alternative #1-1.

Prior to pursuing this alternative, for a coastal management project to be considered a feasible alternative, additional extensive hydrologic and hydraulic modeling, NYSDEC and USACE permitting, and a significant proposal justification, including only viable alternative and greatest benefit with least amount of impact, would be required. In addition, it is NYSDEC policy that non-structural (i.e. natural) solutions be considered before structural mitigation strategies are considered reasonable and necessary. For a structural mitigation strategy, the NYSDEC would require the following information:

- How the alternative will alleviate flooding and the effectiveness at various flood levels?
- What, if any, impacts there will be to sediment transport? How will any impacts be mitigated?
- What, if any, impacts will there be to adjacent areas (private properties, wetlands, nearshore)?
- Will the alternative cause increased erosion or flooding impacts to adjacent areas?
- What, if any, are the long-term maintenance requirements?

Hydraulic modeling of this measure estimates a decrease in water surface elevation at the outlet of up to approximately 0.5-ft during the 10% annual chance flood event. The water surface elevation decrease would continue upstream approximately to the Crooked Brook Drive bridge (Figure 7-2). The jetty would also help prevent sediment build-up due to littoral currents at the outlet and encourage higher velocities which inhibit new sediment build-up due to bed load sediment carried in Crooked Brook from upstream areas. The modeling output for future conditions displayed no significant changes in water surface elevations due to the increased discharges associated with predicted future flows in Crooked Brook.

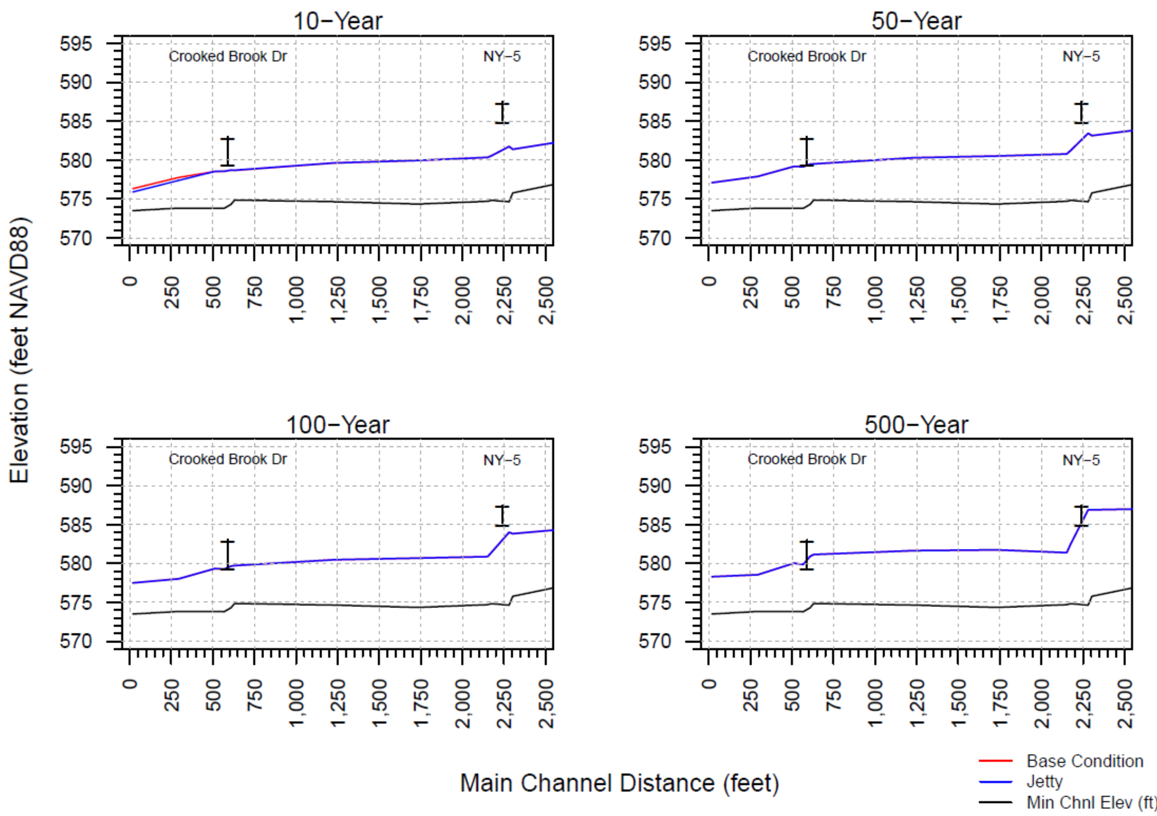

Figure 7-2. HEC-RAS model simulation output results for Alternative #1-1.

Removal of sediments at the confluence, by dredging or excavation, would likely produce similar results to those shown in modeling, but would provide only temporary relief until sediments inevitably build up again. The sediment movement is seasonally cyclical, due to the lake's tidal effects. A jetty would encourage hydraulic conditions which would provide a more sustainable method to preventing sediment buildup. Additional hydraulic modeling including 2-Dimensional coastal analyses would be required to further determine potential impacts and design for the jetty.

The disadvantages of a jetty is that the structure is designed to interrupt long-shore sediment transport, preventing sediment accumulation in an inlet or river mouth. Consequently, sediment accumulation typically occurs on their updrift side, and sediment starvation on their down-drift side. Furthermore, the formation of rip currents in the adjacent area should be expected. Due to the typical length of a jetty, it can be expected that there would be greater sediment loss to deep water during storm events when compared to similar areas without a jetty (Masselink and Hughes 2003; Appelquist et al. 2016).

When implementing jetties, long-shore sediment transport is therefore a critical design parameter. Considering this, it may be necessary to combine jetty construction with a sediment bypassing scheme, where sediment trapped by the jetty is dredged from its updrift side and deposited on the downdrift side of the tidal inlet / river mouth. This would maintain a degree of longshore sediment supply and could be implemented alongside channel dredging which is likely to be required for the maintenance (Appelquist et al. 2016).

USACE has the authority to construct small flood risk reduction projects that are engineeringly feasibly, structurally sound and cost efficient through the authority provided under Section 205 of the 1948 Flood Control Act (FCA), as amended. Coordination should also occur with NYSDEC as they need to be the non-Federal sponsor on these types of projects.

In addition, a FEMA Benefit-Cost Analysis (BCA) would need to be performed to determine the cost-effectiveness of the alternative prior to applying for FEMA mitigation grant programs funding. The BCA is the method by which the future benefits of a mitigation project are determined and compared to its cost. The end result is a Benefit-Cost Ratio (BCR), which is derived from a project's total net benefits divided by its total project cost. The BCR is a numerical expression of the cost effectiveness of a project. A project is considered to be cost effective when the BCR is 1.0 or greater.

The Rough Order Magnitude cost for this measure is $870,000. This estimate only addresses construction of the jetty and does not include the additional engineering, modeling, permitting requirements and / or maintenance costs.

7.1.2 Alternative #1-2: Sediment / Debris Management at Mouth

This measure is intended to the remove deposited sediment at the outlet of Crooked Brook with Lake Erie that has aggraded the creek channel (Figure 7-3). Sediment sources at the outlet are driven by both costal and riverine processes, including littoral drift along the shoreline of Lake Erie and the natural sediment transport and streambank erosion that occurs along Crooked Brook. As the sediment aggrades at the outlet, the channel geometry is altered, and the in-channel flow area is reduced. This, in turn, reduces the volume of water that can be transported safely within the channel without overtopping the banks. In addition, if large portions of sediment are transported downstream to the outlet from upstream sources, then sediment management and reduction measures should be considered and employed first to reduce sediment loads at the outlet.

A sediment management strategy that involves removing sediment from the channel, such as dredging, requires extensive environmental and modeling studies, application, sampling, testing, certification, permitting, operational and maintenance plans with proof of financial viability, and a significant proposal justification, including only viable alternative and greatest benefit with least amount of impact. The NYSDEC *Technical &*

Operations Guidance Series (TOGS) 5.1.9 In-Water and Riparian Management of Sediment and Dredged Material (2004) should be used to determine the procedure and necessary steps in order to develop a sediment removal strategy.

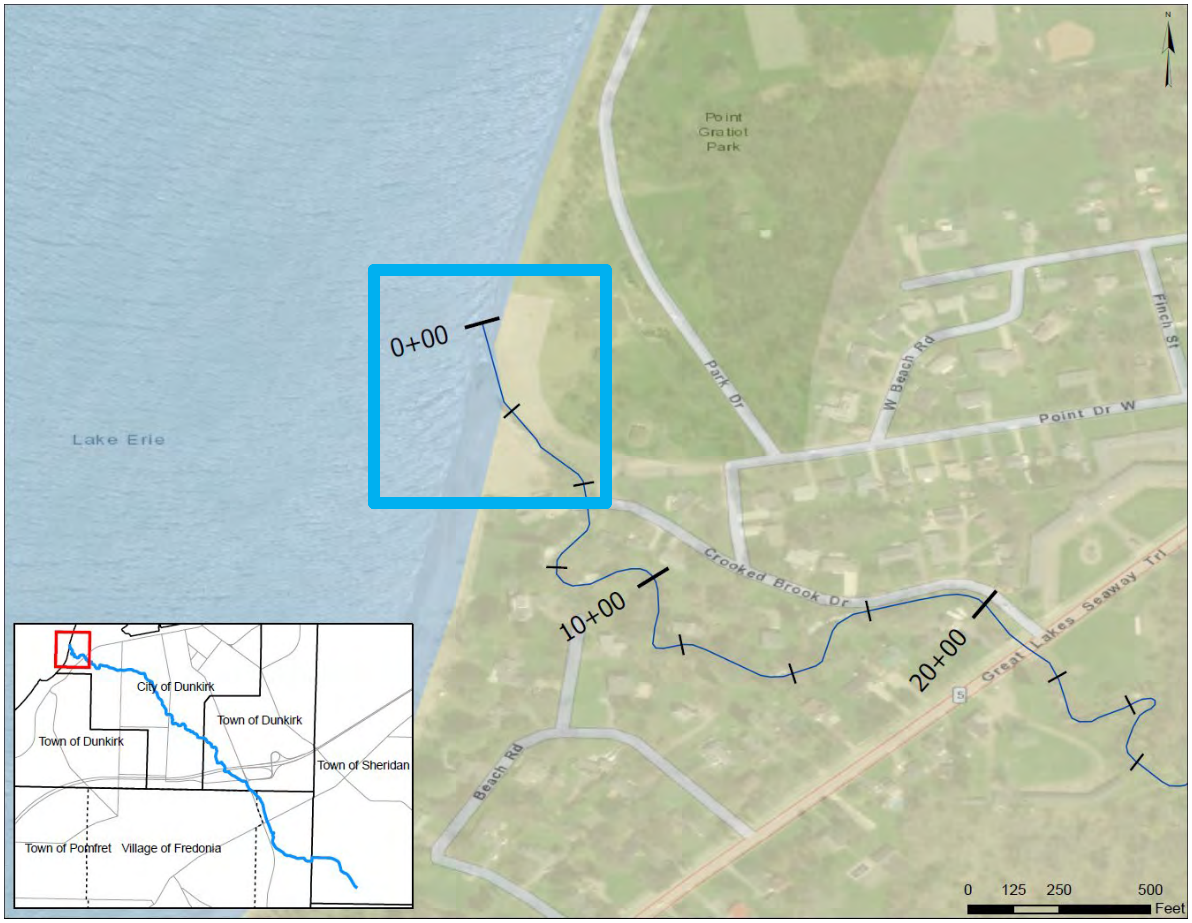

Figure 7-3. Location map for Alternative #1-2.

There are a number of federal, state, and local regulatory controls in place which apply to in-water and riparian sediment management projects. The applicability of these controls to each project depends on the particular circumstances of each case, such as the sediment classification and the intended use or management of the removed material (NYSDEC 2004).

Some or all of the following New York State and Federal Permits may be required: Use and Protection of Waters Permit; Freshwater Wetlands Permit; Tidal Wetlands Permit; State Pollutant Discharge Elimination System Permit; Clean Water Act § 401 Water Quality Certification and § 404 Permit and Rivers and Harbors Act § 10 Permits, issued by the USACE. An antidegradation review and Wild, Scenic and Recreational Rivers Program permits may also be required (NYSDEC 2004).

The basic steps involved in the application process and technical review of a sediment assessment and management plan involves the following:

1. A pre-application meeting with the NYSDEC to discuss all application, permitting, and information needs
2. A sampling plan to determine sampling requirements for proper characterization of proposed sediments and material to be removed
3. Laboratory analysis of sampled material
4. Evaluation of laboratory results
5. Determination of appropriate management options based on sediment class
6. Development of permit conditions for the process of removing sediments and materials and the management of the removed materials
7. Maintenance and monitoring of operations for the management plan (NYSDEC 2004)

Due to the complex nature of sediment transport during both coastal and riverine processes, no modeling simulations were performed for this alternative.

Sediment management at the outlet can improve water quality of both Lake Erie and Crooked Brook, and in-channel flow area and, thereby, reduce flood risk for areas in the vicinity of the outlet. However, the process of removing sediment can also fundamentally change the composition of aquatic habitats and potentially release pollutants into the water column that were previously secured in the channel sediments.

USACE has the authority to construct small flood risk reduction projects that are engineeringly feasibly, structurally sound and cost efficient through the authority provided under Section 205 of the 1948 FCA, as amended. Coordination should also occur with NYSDEC as they need to be the non-Federal sponsor on these types of projects. In addition, a FEMA BCA would need to be performed to determine the cost-effectiveness of the alternative prior to applying for FEMA mitigation grant programs funding.

The Rough Order Magnitude cost for this measure is $160,000, which does not include land acquisition costs for survey, appraisal, and engineering coordination.

7.1.3 Alternative #1-3: Revetments

This measure is intended to address sediment buildup at the confluence of Crooked Brook with Lake Erie (river station 0+00), which would increase flow conveyance and potentially decrease flow depths in this area downstream of the Crooked Brook Drive bridge (Figure 7-4). Revetments are shore-parallel, sloping structures, constructed landwards of the beach to dissipate and reduce wave action at the boundary between the sea and land. These structures typically protect a soft landform such as a dune area or coastal slope or provide supplementary protection to existing defenses such as a jetty. They are generally very solid, durable structures and are considered a hard engineering protection measure to address mainly erosion hazards (Appelquist et al. 2016).

Revetments are mainly built on exposed and moderately exposed sedimentary coastlines to address erosion hazards, but can also have secondary effects on flooding and gradual inundation hazards, depending on what they are designed to protect (Appelquist and Halsnaes 2015). These structures fix the location of the shoreline, helping to limit damage to vulnerable back-beach environments. Revetments are often constructed in combination with other protection measures including jetties, breakwaters, groins, beach nourishment, dikes, etc. (Appelquist et al. 2016).

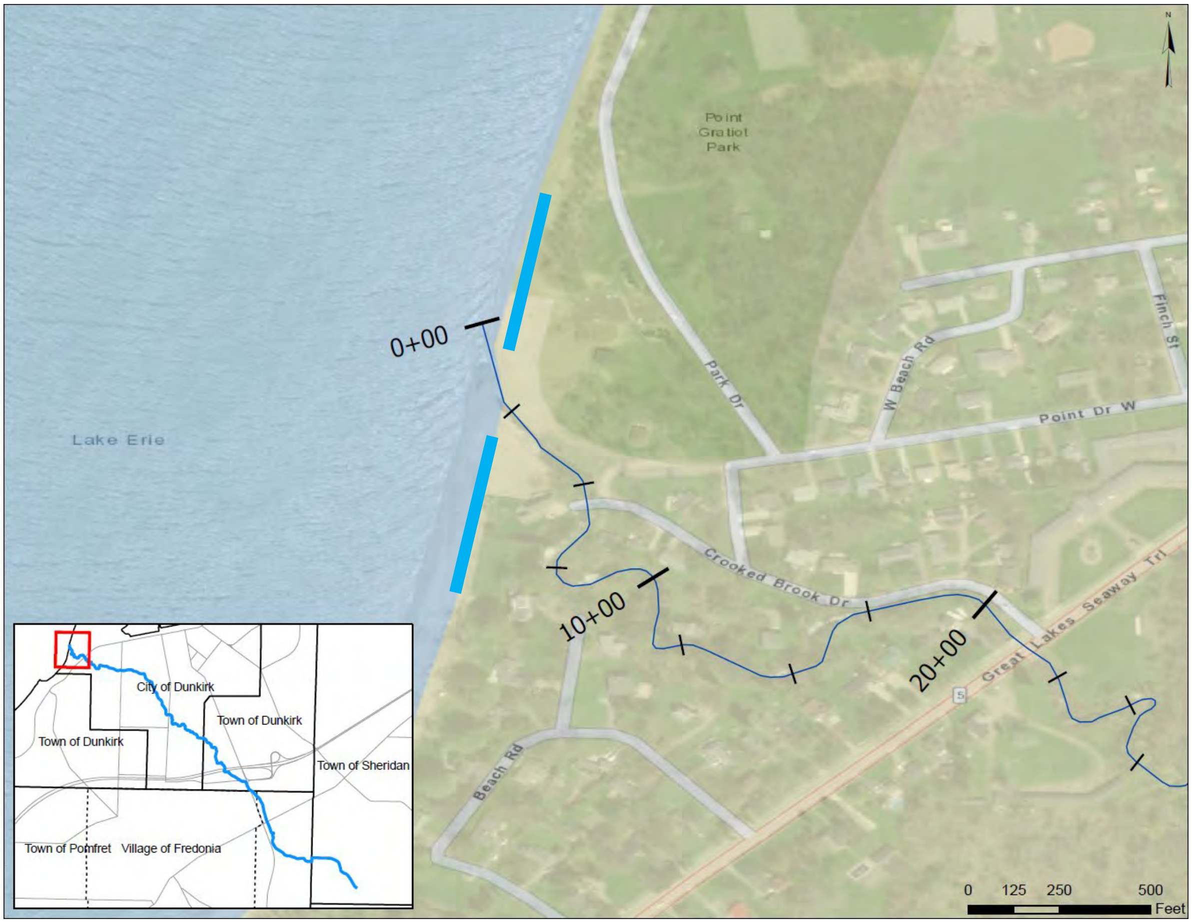

Figure 7-4. Location map for Alternative #1-3.

The structures are relatively simple to construct and do not cause major interference with the longshore sediment transport. Furthermore, by encouraging wave energy dissipation revetments are associated with fewer negative impacts such as scour and toe erosion, and are therefore also less susceptible to catastrophic instability (Appelquist et al. 2016).

While revetments are effective at dissipating wave energy and therefore reducing erosion at the coast, these structures do not address the root cause of coastal erosion. Since revetments are static structures, they tend to conflict with the natural coastal dynamics and may cause accelerated erosion of adjacent unprotected coastlines due to their effect on the dynamic processes. In addition, the presence of large voids between these units can create a public health hazard if the public are permitted access to the structure. The hazard can be addressed by either restricting access to the structure and beach, which is often seen as negative, or through the construction of a promenade and access points along the structure (Appelquist et al. 2016).

Prior to pursuing this alternative, for a coastal management project to be considered a feasible alternative, additional extensive hydrologic and hydraulic modeling, NYSDEC and USACE permitting, and a significant proposal justification, including only viable alternative and greatest benefit with least amount of impact, would be required. In addition, it is NYSDEC policy that non-structural (i.e. natural) solutions be considered before structural mitigation strategies are considered reasonable and necessary. For a structural mitigation strategy, the NYSDEC would require the following information:

- How the alternative will alleviate flooding and the effectiveness at various flood levels?
- What, if any, impacts there will be to sediment transport? How will any impacts be mitigated?
- What, if any, impacts will there be to adjacent areas (private properties, wetlands, nearshore)?
- Will the alternative cause increased erosion or flooding impacts to adjacent areas?
- What, if any, are the long-term maintenance requirements?

USACE has the authority to construct small flood risk reduction projects that are engineeringly feasibly, structurally sound and cost efficient through the authority provided under Section 205 of the 1948 FCA, as amended (Sections 14 and/or 103 could also apply depending on risk to nearby infrastructure and would require a benefit-cost analysis). Coordination should also occur with NYSDEC as they need to be the non-Federal sponsor on these types of projects.

In addition, a FEMA BCA would need to be performed to determine the cost-effectiveness of the alternative prior to applying for FEMA mitigation grant programs funding. The BCA is used to determine the BCR for the project, where a project is considered to be cost effective when the BCR is 1.0 or greater.

The Rough Order Magnitude cost for this measure is $750,000. This estimate only addresses construction of the revetment structure and does not include the additional engineering, modeling, permitting requirements and / or maintenance costs.

7.1.4 Alternative #1-4: Increase Size of Crooked Brook Drive Culvert

This measure is intended to address issues within High-risk Area #1 by increasing the width of the Crooked Brook Drive bridge opening, which would increase the cross-sectional flow area of the channel located at river station 5+50 (Figure 7-5).

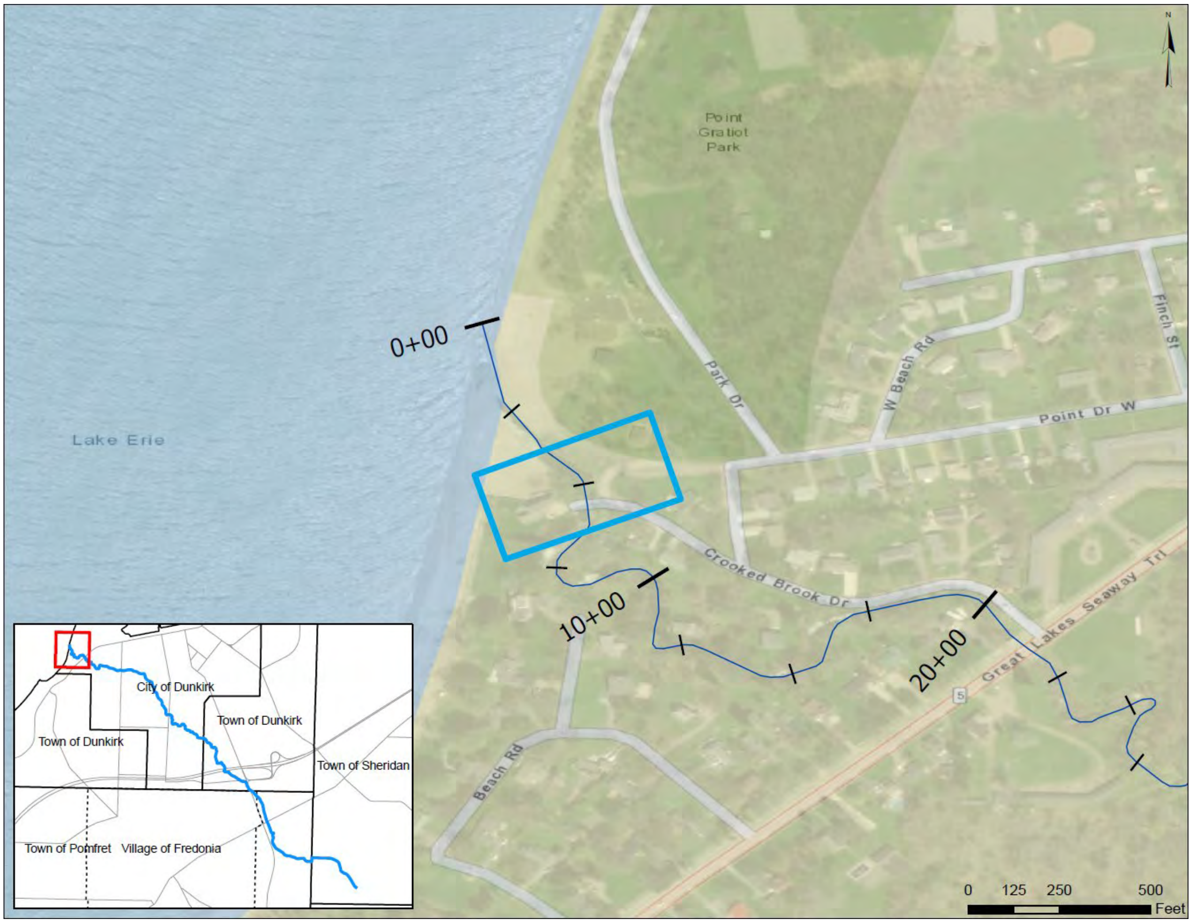

Figure 7-5. Location map for Alternative #1-4.

The bridge is owned by the City of Dunkirk, New York and has one central pier in the channel. The existing bridge structure has a bridge span of 38.5 feet, and a maximum low chord to channel bottom height of 8.7 feet (Ramboll 2021) (Figure 7-6). The flooding in the vicinity of the Crooked Brook Drive bridge poses a flood risk threat to nearby residential properties and City and County owned infrastructure.

Figure 7-6. Crooked Brook Drive bridge, Dunkirk, NY.

According to the FEMA FIS, there is backwater upstream of the Crooked Brook Drive bridge at annual chance flood levels less than or equal to 10%, and the bridge does not provide the NYSDOT recommended 2-feet of freeboard over the 2% annual chance flood water surface elevation (FIA 1980). This measure would potentially reduce the flood risk for, and benefit the properties adjacent to and immediately upstream of Crooked Brook Drive.

The proposed condition modeling confirmed that the Crooked Brook Drive bridge is a constriction point along Crooked Brook. The bridge widening scenario increased the cross-sectional flow area of the bridge on the right channel bank by 15 feet for a total opening width of 53.5 feet. The proposed condition modeling simulation results indicated water surface reductions of up to 1.2-ft in areas immediately upstream of the bridge extending up to NY-5 (Figure 7-7). The modeling output for future conditions displayed similar results with water surface reductions of up to 1.4-ft (Appendix F).

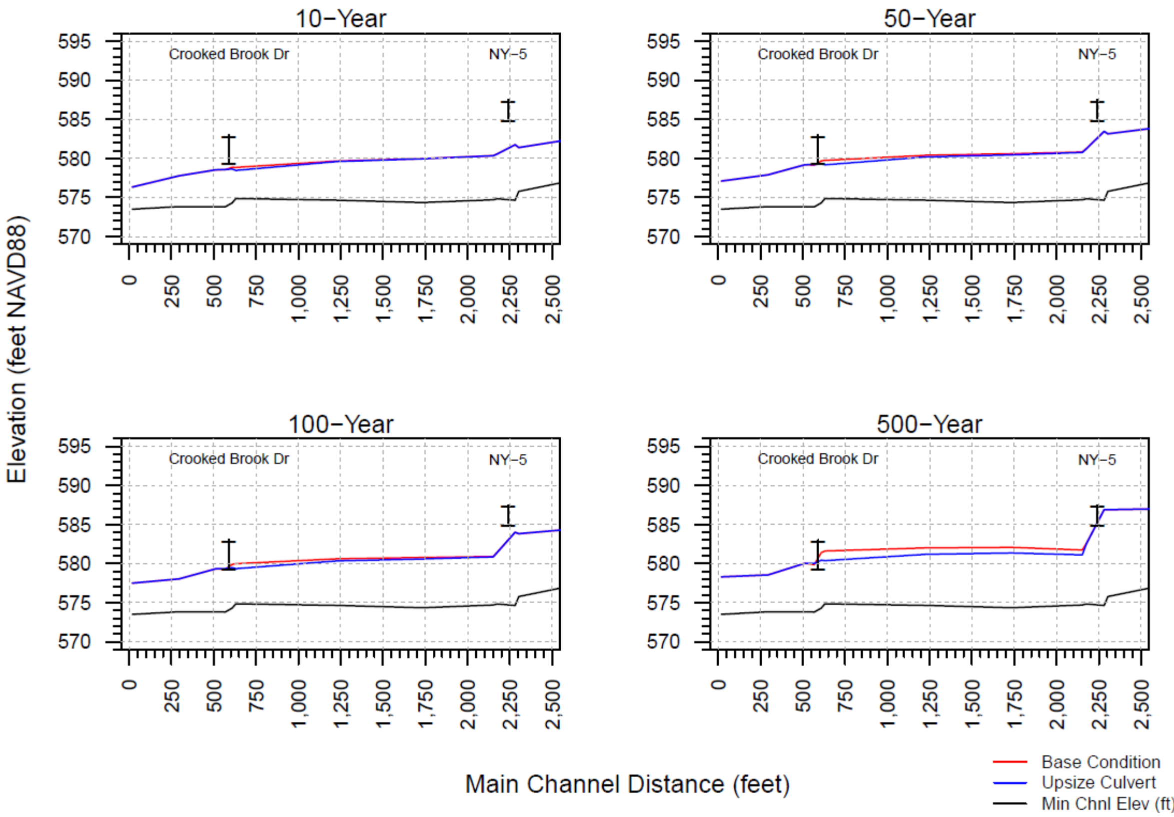

Figure 7-7. HEC-RAS model simulation output results for Alternative #1-4.

Crooked Brook Drive is located approximately 550-ft upstream of the outlet of Crooked Brook with Lake Erie and 1,700-ft downstream of the NY-5 bridge crossing. This reach of Crooked Brook is significantly impacted by backwater from Lake Erie. Backwater typically occurs during high water levels and high wind velocities from westerly winds on Lake Erie. As a result, Crooked Brook Drive and surrounding areas regularly experience flooding from multiple sources.

The potential benefits of this strategy are limited to the areas in the vicinity of and approximately 1,600-ft upstream of the Crooked Brook Drive bridge crossing, specifically between river stations 5+50 to 21+50.

The Rough Order Magnitude cost for this measure is $730,000, which does not include land acquisition costs for survey, appraisal, and engineering coordination.

7.2 HIGH-RISK AREA #2

7.2.1 Alternative #2-1: Flood Bench Near Confluence with Unnamed Tributary

Flood benches are flat areas adjacent to a stream set to some elevation (typically bankfull elevation), constructed to both create an area for flows above the set elevation to spread out and dissipate energy and to provide an area to catch erosion from the adjacent bank or upstream areas. Installing a flood bench would provide additional storage and floodplain width, which could potentially reduce damages in the event of flooding and address issues within High-risk Area #2. The flood bench would be located adjacent to the West Point Warehouse along West Point Avenue in the City of Dunkirk, New York between river stations 27+50 and 36+00 and is approximately 3.2 acres (Figure 7-8).

The flood bench is within the FEMA designated Special Flood Hazard Area or Zone A, which are areas subject to inundation by the 1% annual chance flood event determined by detailed methods where BFEs are shown, and mandatory flood insurance purchase requirements and floodplain management standards apply (FIA 1980). Appendix E depicts a flood mitigation rendering of a flood bench illustrating before and after landscape features.

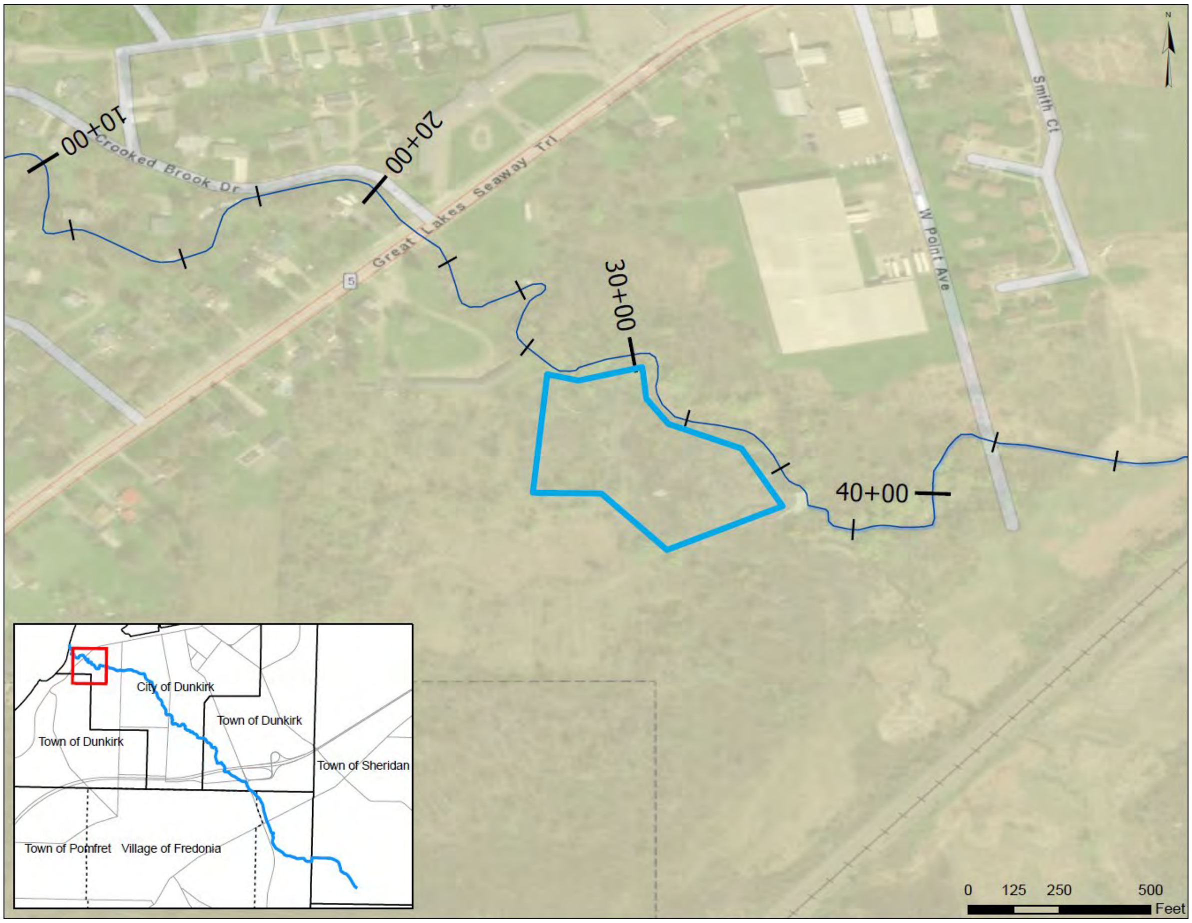

Figure 7-8. Location map for Alternative #2-1.

The flood bench design used for the proposed condition model simulation set the bench elevation approximately equal to the bankfull elevation with an average depth of 2.5-ft. The proposed condition model results indicated that a flood bench in this area would not provide a significant reduction in water surface elevations. Model results indicated a reduction of up to 0.3-ft in water surface elevations (Figure 7-9). The modeling output for future conditions displayed similar results with water surface reductions of up to 0.1-ft (Appendix F).

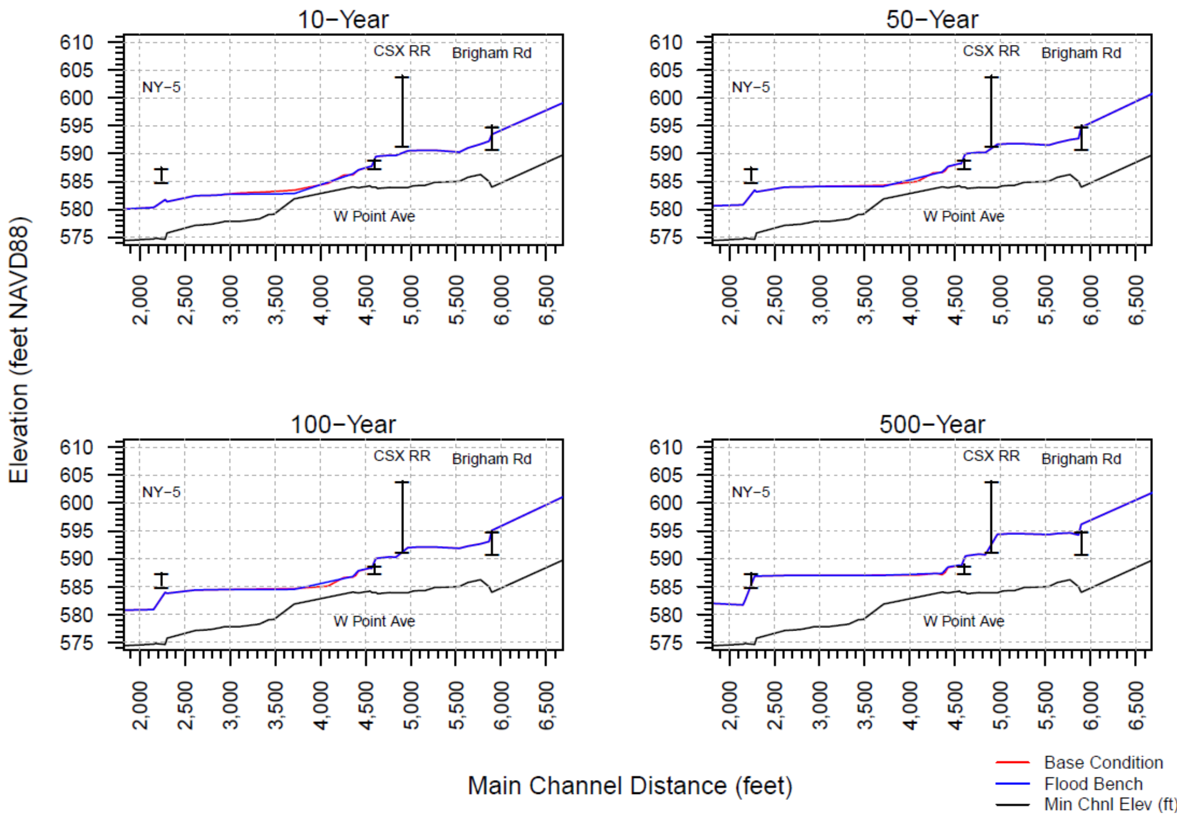

Figure 7-9. HEC-RAS model simulation output results for Alternative #2-1.

Flood benches generally provide flood protection for localized areas in the vicinity of and immediately upstream and / or downstream of the bench. Based on the analysis of high-risk areas, a flood bench located adjacent to West Point Avenue would not provide significant flood protection in this reach from open-water flooding. This is most likely a result of the topography and geomorphic features in this area, which are predominately low-lying wetlands and forested areas.

Based on the analysis of the flood bench simulation, this measure is not recommended due to the ineffectiveness of the measure to provide adequate flood protection to areas adjacent to West Point Avenue and the additional costs associated with constructing a flood bench.

The Rough Order Magnitude cost for this measure is $1,110,000, which does not include land acquisition costs for survey, appraisal, and engineering coordination.

7.2.2 Alternative #2-2: Flood Control Detention Structure Near Confluence with Unnamed Tributary

The construction of small flood-control detention structures in the headwaters and tributaries of flood-prone streams has proven successful at preventing flood damage in small towns throughout the United States (Helms 1986). These structures are traditionally located in rural areas in agricultural fields and undeveloped land. They maintain little to no permanent pool and are designed to detain water during larger flow events, decreasing peak-flow water surface elevations and minimizing flooding further downstream in developed areas. The area between NY-5 and the CSX Railroad bridge along Crooked Brook would be the best location for a flood-control structure in the downstream reach (Figure 7-10).

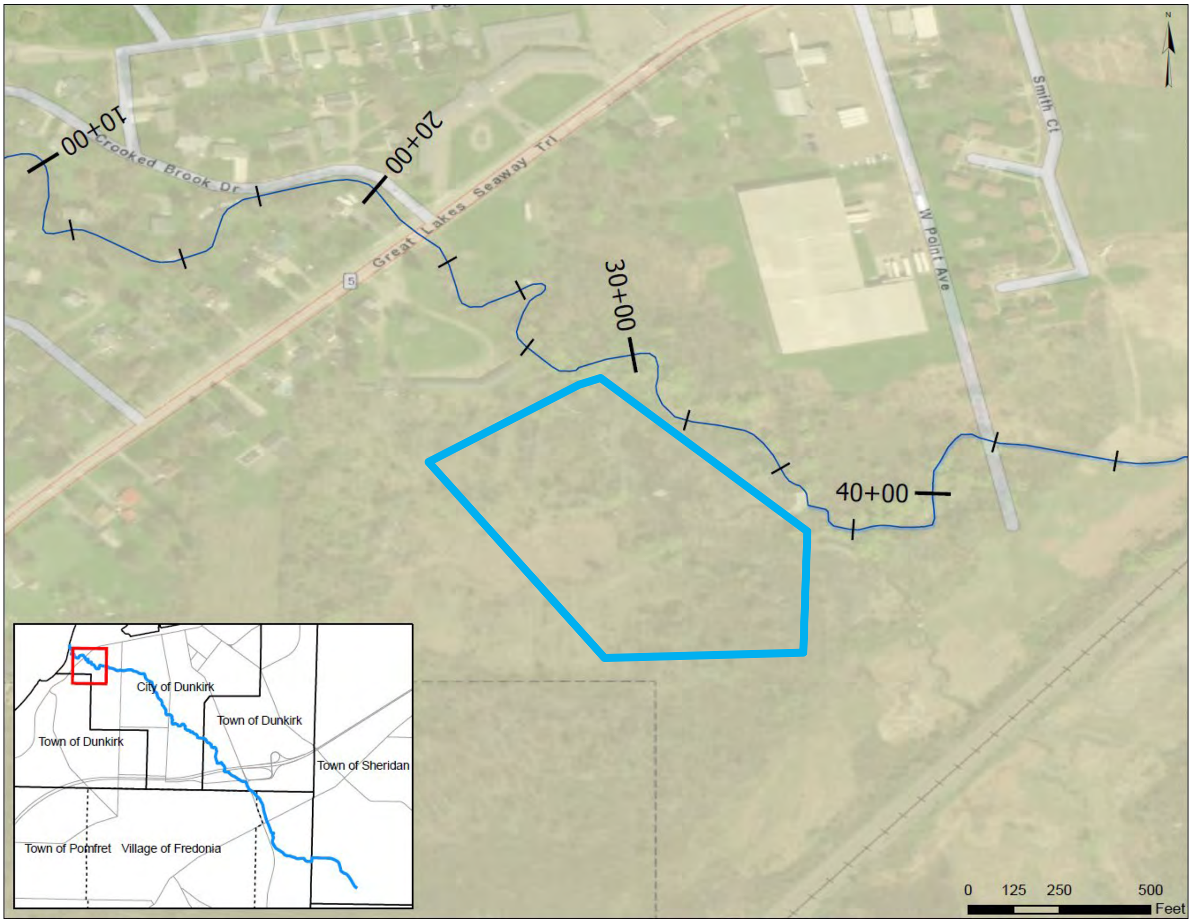

Figure 7-10. Location map for Alternative #2-2.

In New York State, a joint permit application from the NYSDEC and USACE may be required in order to construct, reconstruct, or repair a dam or other impoundment. The NYSDEC is entrusted with the regulatory power to oversee dam safety, which encompasses flood detention structures. To protect people from the loss of life and property due to flooding and / or dam failure, the NYSDEC Dam Safety Section, in cooperation with the USACE, reviews proposed dam construction and / or modifications, conducts dam safety inspections, and monitors projects for compliance with dam safety criteria.

To acquire a permit for the construction, reconstruction, or repair of a dam or other impoundment, a developer must submit an application to the NYSDEC for an Article 15 Dam Construction Permit, along with the USACE Joint Application Form that, if approved, would allow activities affecting waters within the state.

The USACE has the authority to construct small flood risk reduction projects that are engineeringly feasibly, structurally sound and cost efficient through the authority provided under Section 205 of the 1948 FCA, as amended. Coordination should also occur with the NYSDEC as they need to be the non-Federal sponsor on these types of projects. In addition, a FEMA BCA would need to be performed to determine the cost-effectiveness of the alternative prior to applying for FEMA mitigation grant programs funding. The BCA is used to determine the BCR for the project, where a project is considered to be cost effective when the BCR is 1.0 or greater.

Due to the conceptual nature of this measure, and significant amount of data required to produce a reasonable rough-order-of-magnitude cost, it is not feasible to quantify the costs of this measure without further engineering analysis and modeling. However, the cost of designing, permitting, constructing, and maintaining one or more flood-control dams in the headwaters of the Crooked Brook watershed are expected to be significant.

7.2.3 Alternative #2-3: Remove West Point Avenue Culvert

This measure is intended to address issues within High-risk Area #2 by removing the West Point Avenue culvert, which would increase the cross-sectional area and in-channel flow of Crooked Brook located at river station 45+00 (Figure 7-11). According to the FEMA FIS and the base condition HEC-RAS model, the West Point Avenue culvert causes backwater at annual chance flood levels less than and equal to 10%, and does not allow the required 2-feet of freeboard over the 1% annual chance flood water surface elevation (FIA 1980). In addition, the West Point Avenue culvert is an unpaved access road not classified as a major or minor roadway by the NYSDOT and no ownership information can be found within the NYSDOT roadway database (NYSDOT 2020).

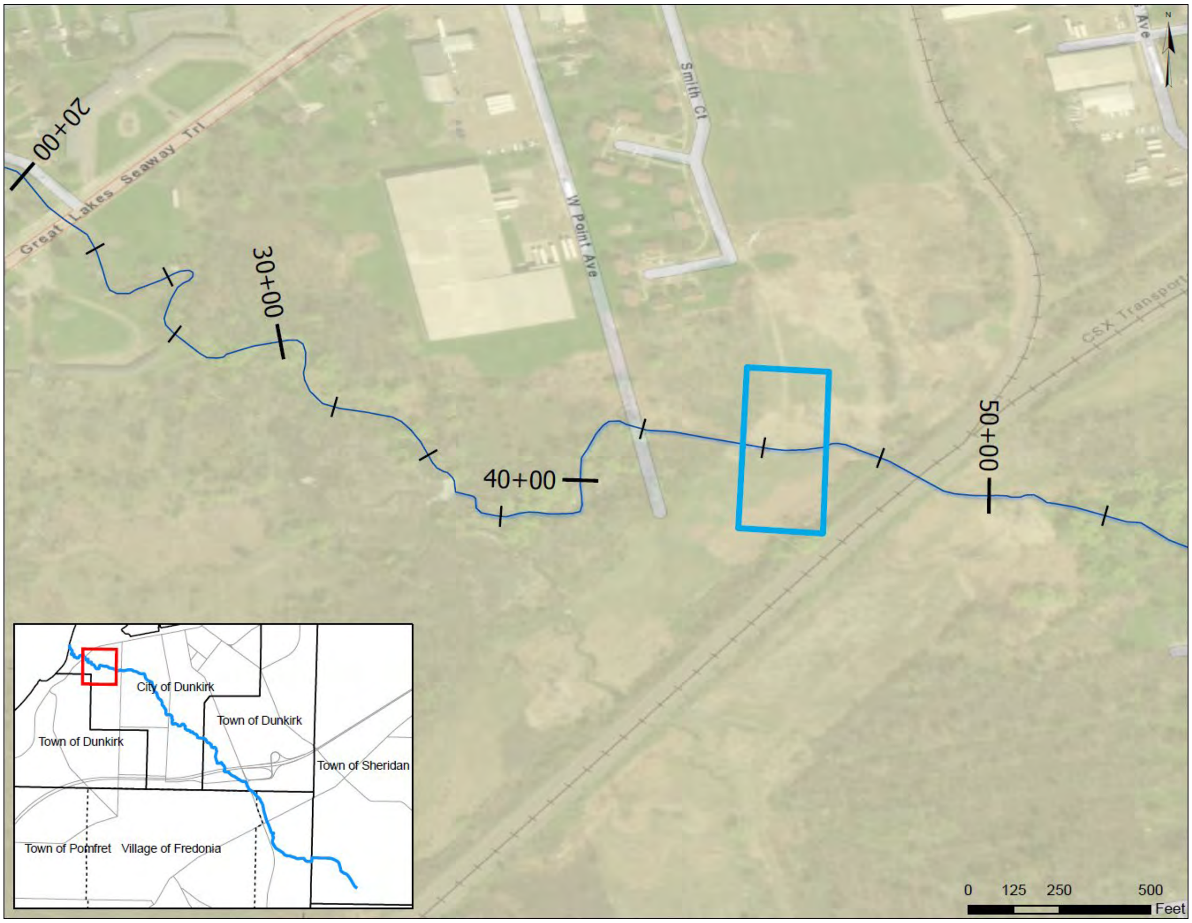

Figure 7-11. Location map for Alternative #2-3.

The removal of the West Point Avenue culvert would include all related structures, such as the abutments, top deck, rails, etc. The proposed condition model results indicated that removal of the culvert would provide a significant reduction in water surface elevations. Model results indicated a reduction of up to 0.9-ft in water surface elevations (Figure 7-12). The modeling output for future conditions displayed similar results with water surface reductions of up to 0.8-ft (Appendix F).

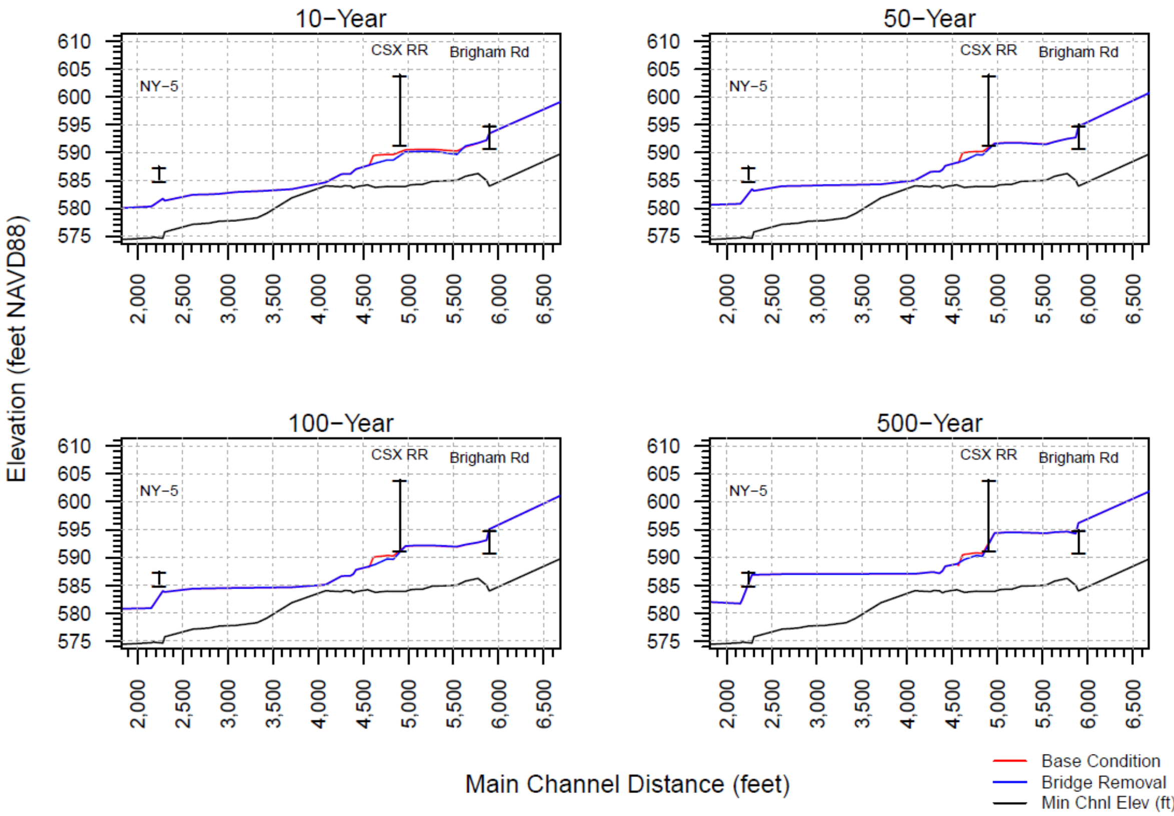

Figure 7-12. HEC-RAS model simulation output results for Alternative #2-3.

The potential water surface elevation reduction benefits of this alternative would extend approximately 1,300-ft upstream to the Brigham Road culvert, specifically along river stations 45+00 to 58+00.

The Rough Order Magnitude cost for this measure is $40,000, not including land acquisition costs for survey, appraisal, and engineering coordination.

7.2.4 Alternative #2-4: Increase Size of CSX Railroad Bridge Crossing

This measure is intended to increase the cross-sectional flow area of the channel by increasing the opening of the railroad bridge crossing located at river station 48+25. The bridge is owned by the CSX Transportation, Inc. company in the City of Dunkirk, New York (Figure 7-13). The existing bridge structure has a bridge span of 25 feet and a maximum low chord to channel bottom height of 8 feet (Ramboll 2021). The flooding in the vicinity of the railroad bridge poses a flood risk threat to nearby residential properties and City and County owned infrastructure upstream of the railroad crossing.

According to the HEC-RAS base condition model and FEMA FIS, the railroad bridge allows discharges at the 10% annual chance flood water surface elevation to pass, while all other Annual Chance Event WSELs exceed the low chord elevation and cause backwater upstream the of bridge (FIA 1980). In addition, the bridge crossing does not provide the NYSDOT recommended 2-feet of freeboard over the 2% annual chance flood water surface elevation.

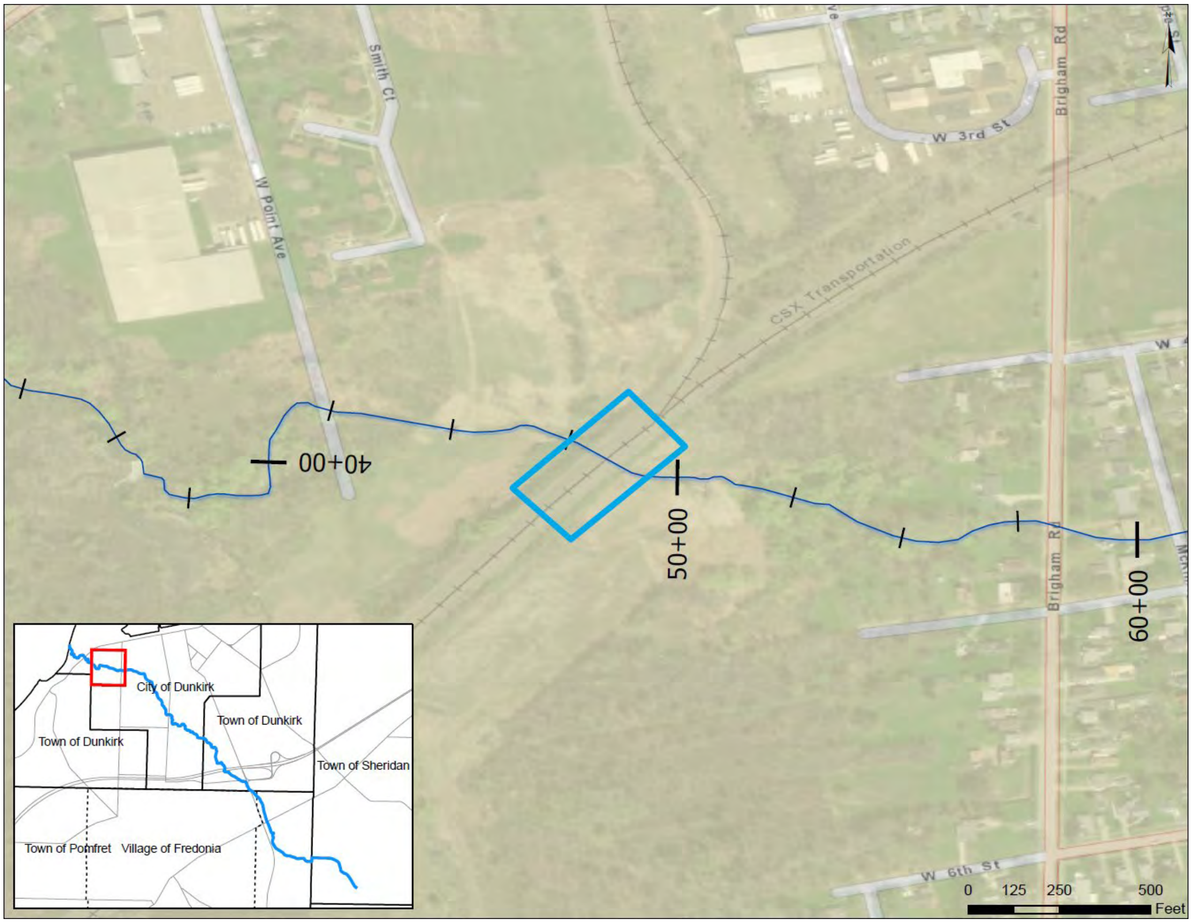

Figure 7-13. Location map for Alternative #2-4.

This measure would potentially reduce the flood risk for and benefit the properties adjacent to and immediately upstream of the railroad bridge. The proposed condition modeling confirmed that the CSX railroad bridge is a constriction point along Crooked Brook. The bridge widening scenario increased the cross-sectional flow area of the bridge on the right channel bank by 20 feet for a total opening width of 45 feet. The proposed condition modeling simulation results indicated water surface reductions of up to 2.8 feet in areas immediately upstream of the bridge extending up to the Brigham

Road culvert (Figure 7-14). The modeling output for future conditions displayed similar results with water surface reductions of up to 3 feet (Appendix F).

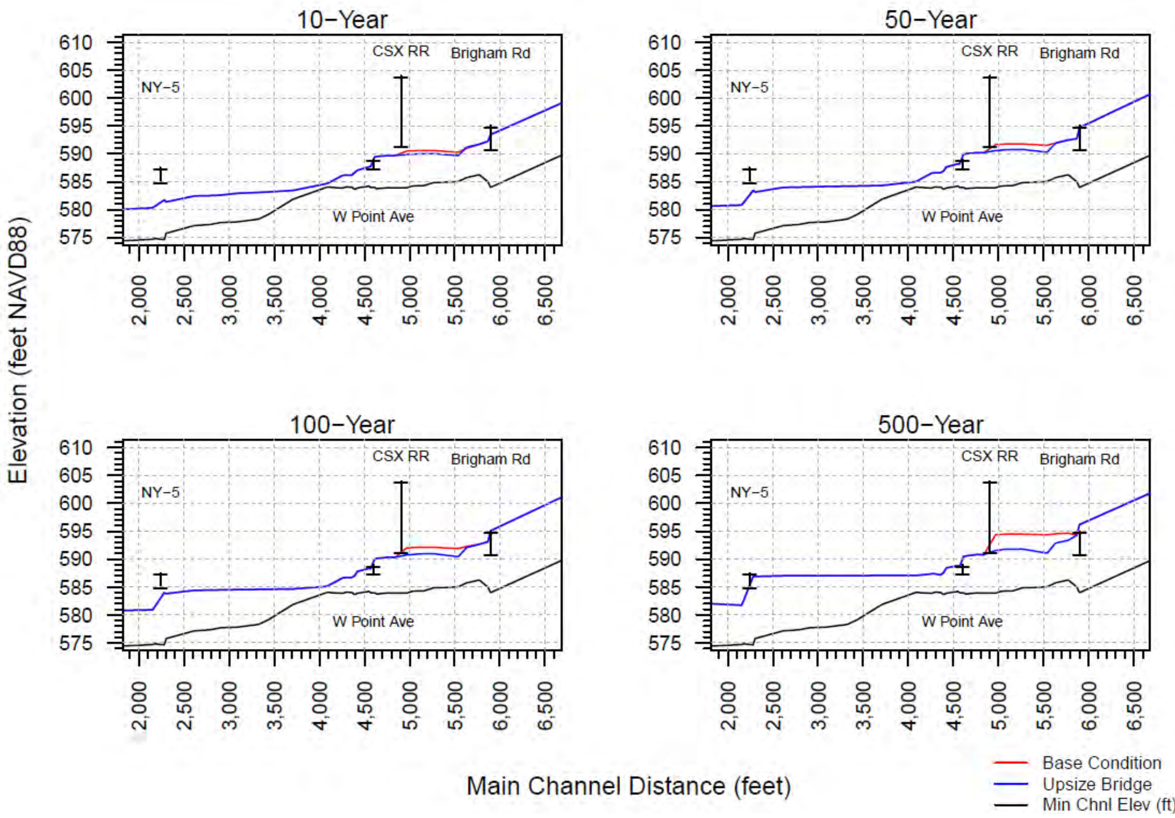

Figure 7-14. HEC-RAS model simulation output results for Alternative #2-4.

The potential water surface elevation reduction benefits of this alternative would extend approximately 1,100-ft upstream to the Brigham Road culvert, specifically between river stations 48+00 to 59+00.

The Rough Order Magnitude cost for this measure is $1,460,000, which does not include land acquisition costs for survey and appraisal, permitting, additional engineering and coordination, and / or special inspection requirements.

7.2.5 Alternative #2-5: Install Crossing Pipes into CSX Railroad Bridge Embankment

This measure is intended to increase the cross-sectional flow area of the channel by installing two additional pipe culverts on the left bank of the bridge opening of the railroad crossing located at river station 48+25. The bridge is owned by the CSX Transportation, Inc. company in the City of Dunkirk, New York (Figure 7-15). The existing bridge structure has a bridge span of 25 feet and a maximum low chord to channel bottom height of 8 feet (Ramboll 2021). The flooding in the vicinity of the railroad bridge poses a flood risk threat to nearby residential properties and City and County owned infrastructure upstream of the railroad crossing.

According to the HEC-RAS base condition model and FEMA FIS, the CSX bridge only allows discharges at the 10% annual chance flood water surface elevation to pass, while the 2, 1, and 0.2% Annual Chance Event WSELs exceed the low chord elevation and cause backwater upstream the of railroad bridge (FIA 1980). In addition, the bridge does not provide the NYSDOT recommended 2-feet of freeboard over the 2% annual chance flood hazard.

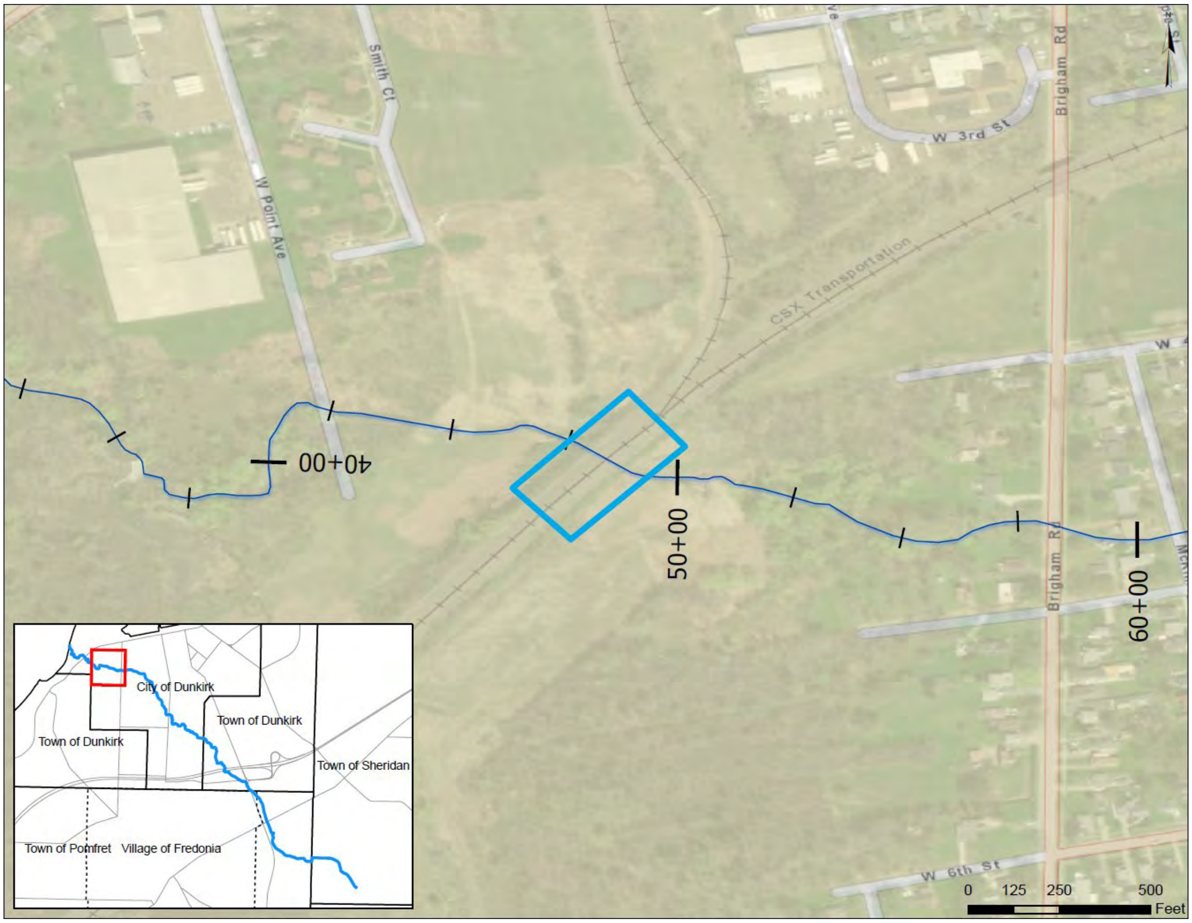

Figure 7-15. Location map for Alternative #2-5.

This measure would potentially reduce the flood risk for and benefit the properties adjacent to and immediately upstream of the railroad bridge. The crossing pipes scenario increased the cross-sectional flow area of the bridge on the left channel bank by including two 5-ft diameter pipe culverts placed above the bankfull elevation. The proposed condition modeling simulation results indicated water surface reductions of up to 2.1-ft in areas immediately upstream of the bridge extending up to the Brigham Road culvert (Figure 7-6). The modeling output for future conditions displayed similar results with water surface reductions of up to 2.4-ft (Appendix F).

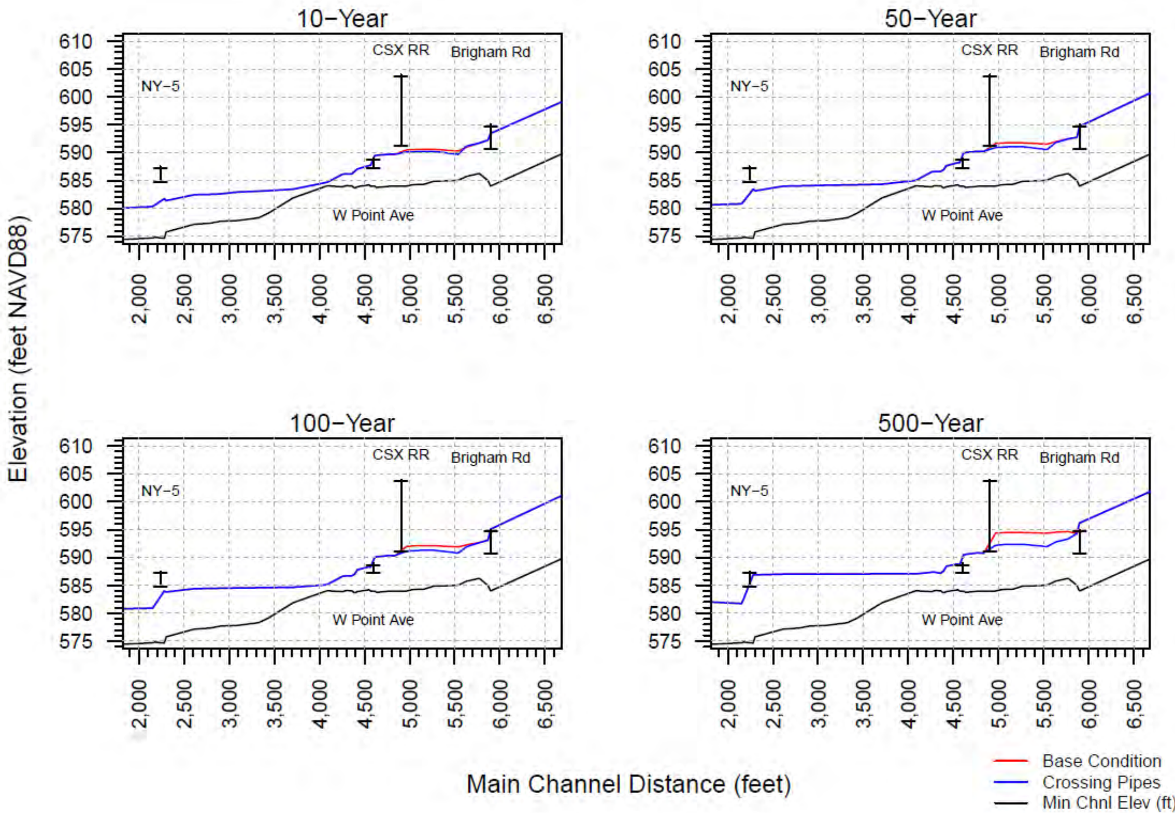

Figure 7-16. HEC-RAS model simulation output results for Alternative #2-5.

The potential water surface elevation reduction benefits of this alternative would extend approximately 1,100-ft upstream to the Brigham Road culvert, specifically between river stations 48+00 to 59+00.

The Rough Order Magnitude cost for this measure is $590,000, which does not include land acquisition costs for survey and appraisal, permitting, additional engineering and coordination, and / or special inspection requirements.

7.2.6 Alternative #2-6: Flood Bench Upstream of CSX Railroad Bridge Crossing

Installing a flood bench would provide additional storage and floodplain width, which could potentially reduce damages in the event of flooding and address issues within High-risk Area #2. The flood bench would be located upstream of the CSX railroad crossing in the City of Dunkirk, NY between river stations 48+00 and 52+50 and covers approximate 1.5 ac (Figure 7-17).

The flood bench is within the FEMA designated SFHA or Zone A, which are areas subject to inundation by the 1% annual chance flood event determined by detailed methods where BFEs are shown, and mandatory flood insurance purchase requirements and floodplain management standards apply (FIA 1980). Appendix E depicts a flood mitigation rendering of a flood bench illustrating before and after landscape features.

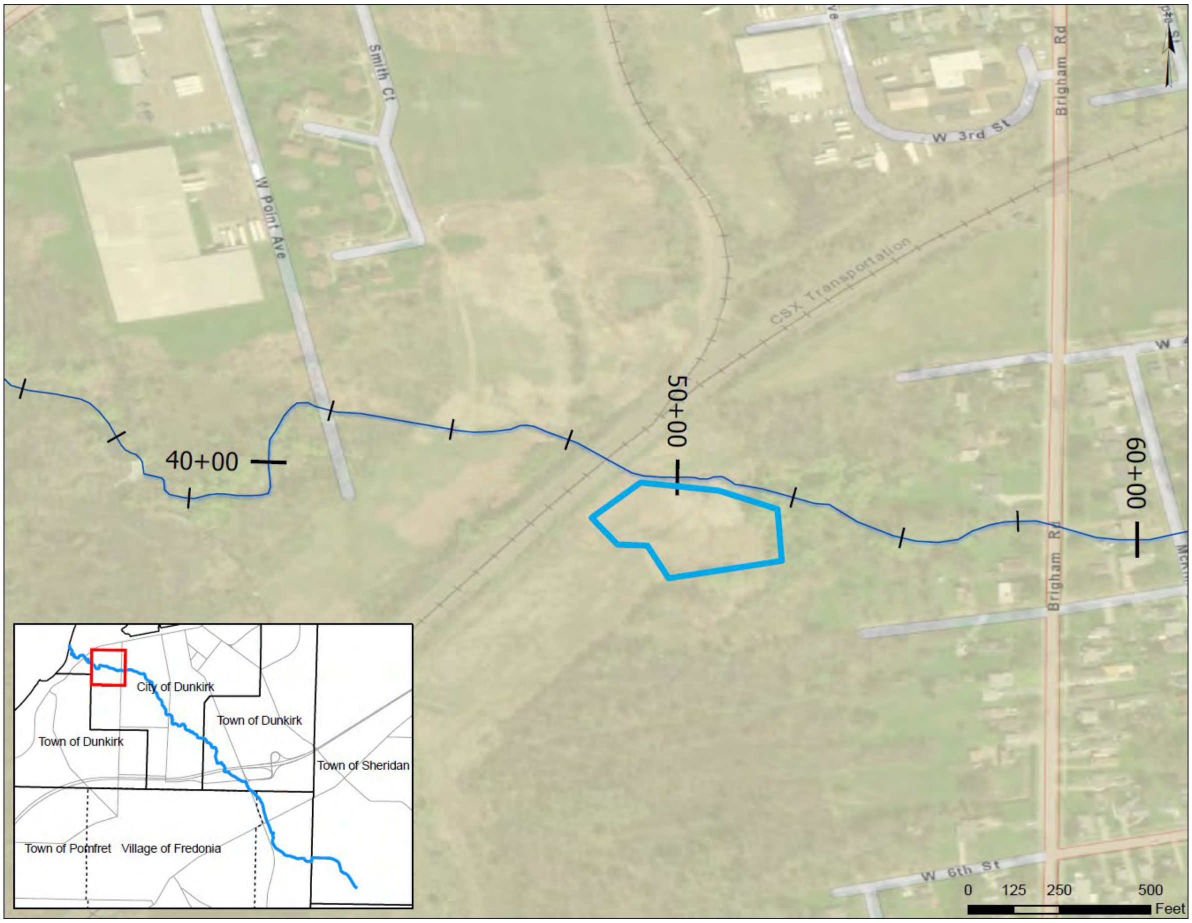

Figure 7-17. Location map for Alternative #2-6.

The flood bench design used for the proposed condition model simulation set the bench elevation approximately equal to the bankfull elevation with an average depth of 2.5-ft. The proposed condition model results indicated that a flood bench in this area would not provide a significant reduction in water surface elevations. Model results indicated a reduction of up to 0.1-ft in water surface elevations (Figure 7-18). The modeling output for future conditions displayed no significant changes in water surface reductions (Appendix F).

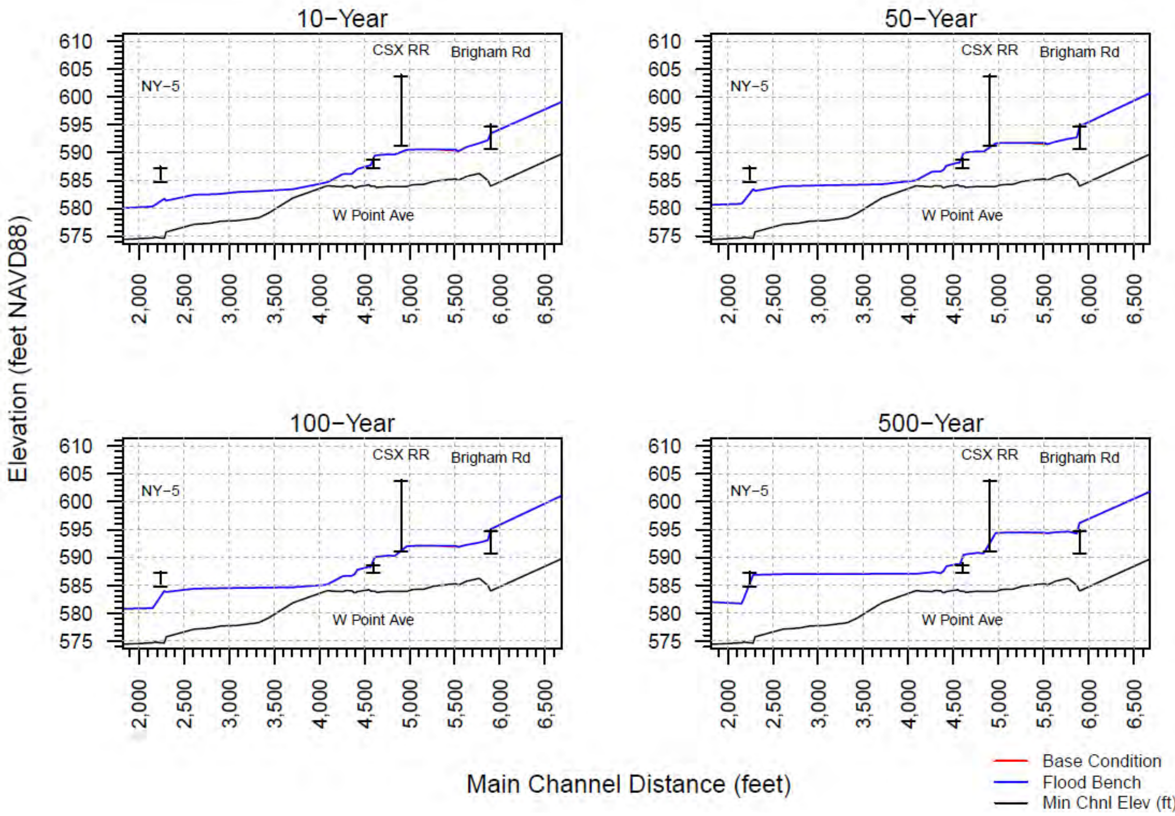

Figure 7-18. HEC-RAS model simulation output results for Alternative #2-6.

Flood benches generally provide flood protection for localized areas in the vicinity of and immediately upstream and / or downstream of the bench. Based on the analysis of high-risk areas, a flood bench located upstream of the CSX railroad crossing would not provide significant flood protection in this reach from open-water flooding. This is most likely a result of the topography and geomorphic features in this area, which are predominately low-lying wetlands and forested areas.

Based on the analysis of the flood bench simulation, this measure is not recommended due to the ineffectiveness of the measure to provide adequate flood protection to upstream of the CSX railroad crossing and the additional costs associated with constructing a flood bench.

The Rough Order Magnitude cost for this measure is $530,000, which does not include land acquisition costs for survey, appraisal, and engineering coordination.

7.3 HIGH-RISK AREA #3

7.3.1 Alternative #3-1: Install Flood Bench Downstream West 6th Street

Installing a flood bench would provide additional storage and floodplain width, which could potentially reduce damages in the event of flooding and address issues within High-risk Area #3. The flood bench would be located upstream of Woodrow Avenue and downstream of West 6th Street in the City of Dunkirk, New York between river stations 72+50 and 77+50 and covers approximately 1.5 ac (Figure 7-19).

The flood bench is within the FEMA designated SFHA or Zone A, which are areas subject to inundation by the 1% annual chance flood event determined by detailed methods where BFEs are shown, and mandatory flood insurance purchase requirements and floodplain management standards apply (FIA 1980). Appendix E depicts a flood mitigation rendering of a flood bench illustrating before and after landscape features.

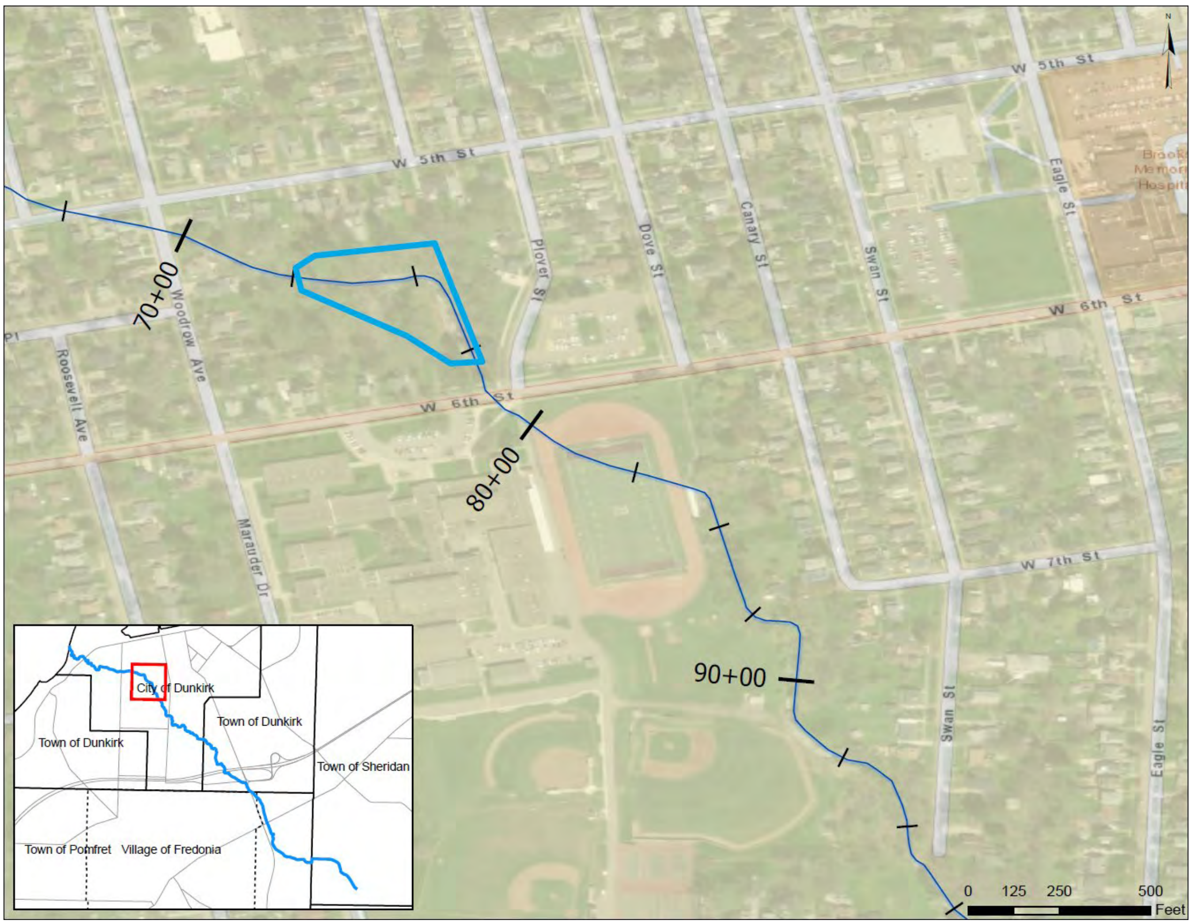

Figure 7-19. Location map for Alternative #3-1.

The flood bench design used for the proposed condition model simulation set the bench elevation approximately equal to the bankfull elevation with an average depth of 2.5-ft. The proposed condition model results indicated that a flood bench in this area would provide a significant reduction in water surface elevations. Model results indicated a reduction of up to 0.6-ft in water surface elevations (Figure 7-20). The modeling output for future conditions displayed water surface reductions of up to 0.9-ft (Appendix F).

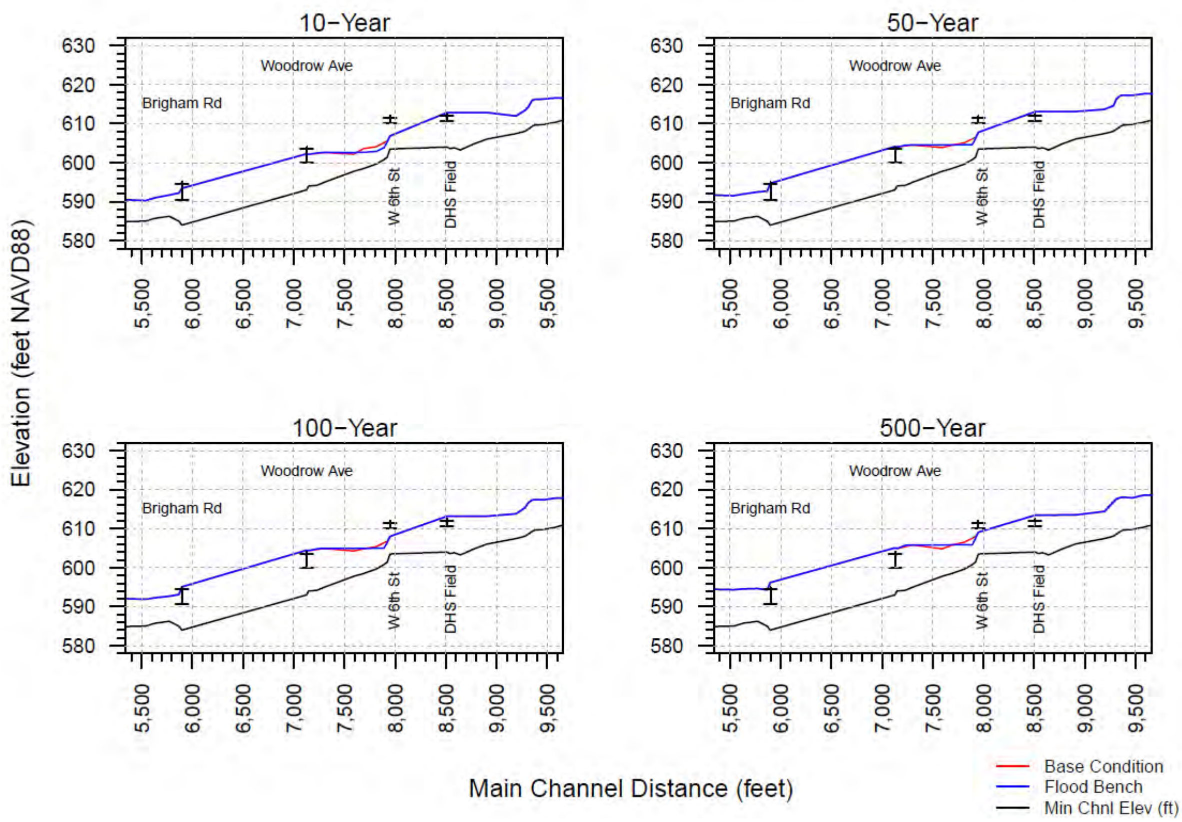

Figure 7-20. HEC-RAS model simulation output results for Alternative #3-1.

Flood benches generally provide flood protection for localized areas in the vicinity of and immediately upstream and / or downstream of the bench. Based on the analysis of high-risk areas, a flood bench located downstream of West 6th Street would provide significant flood protection in this reach from open water flooding.

The Rough Order Magnitude cost for this measure is $540,000, which does not include land acquisition costs for survey, appraisal, and engineering coordination.

7.3.2 Alternative #3-2: Install Flood Bench Adjacent to DHS Baseball Field

Installing a flood bench would provide additional storage and floodplain width, which could potentially reduce damages in the event of flooding and address issues within High-risk Area #3. The flood bench would be located adjacent to the Dunkirk high School (DHS) Baseball Field in the City of Dunkirk, New York between river stations 92+50 and 96+50 and covers approximately 0.8 ac (Figure 7-21).

The flood bench is within the FEMA designated SFHA or Zone A, which are areas subject to inundation by the 1% annual chance flood event determined by detailed methods where BFEs are shown, and mandatory flood insurance purchase requirements and floodplain management standards apply (FIA 1980). Appendix E depicts a flood mitigation rendering of a flood bench illustrating before and after landscape features.

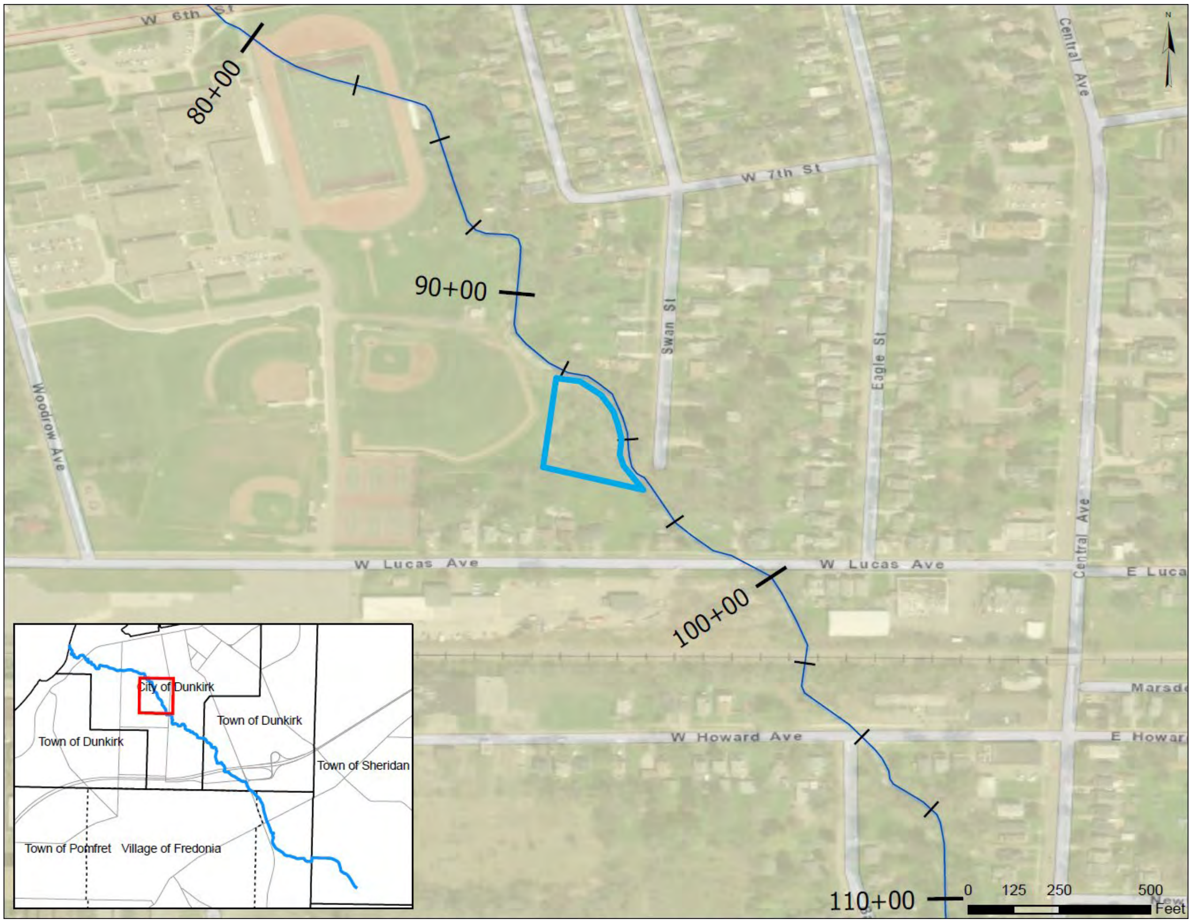

Figure 7-21. Location map for Alternative #3-2.

The flood bench design used for the proposed condition model simulation set the bench elevation approximately equal to the bankfull elevation with an average depth of 2.5-ft. The proposed condition model results indicated that a flood bench in this area would provide a moderate reduction in water surface elevations. Model results indicated a reduction of up to 0.4-ft in water surface elevations (Figure 7-22). The modeling output for future conditions displayed water surface reductions of up to 0.5-ft (Appendix F).

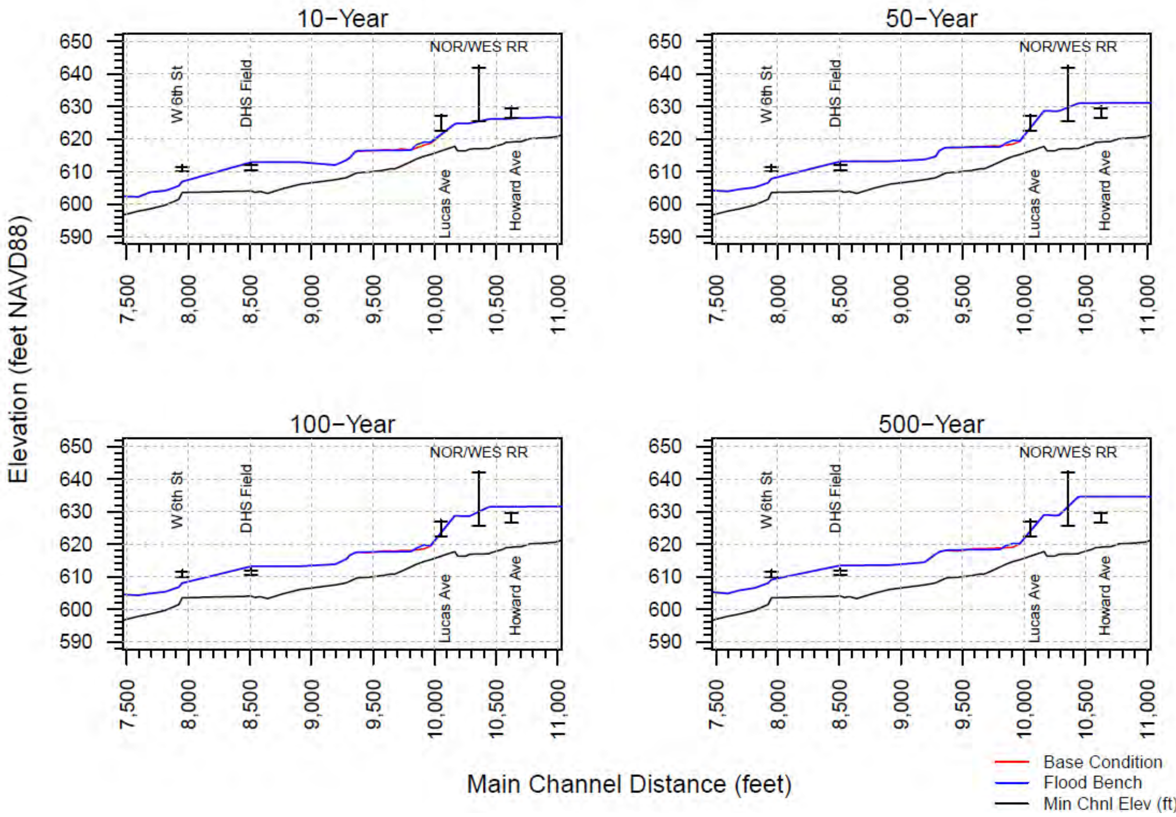

Figure 7-22. HEC-RAS model simulation output results for Alternative #3-2.

Flood benches generally provide flood protection for localized areas in the vicinity of and immediately upstream and / or downstream of the bench. Based on the analysis of high-risk areas, a flood bench located adjacent to the DHS baseball field would provide moderate flood protection in this reach from open-water flooding.

The Rough Order Magnitude cost for this measure is $310,000, which does not include land acquisition costs for survey, appraisal, and engineering coordination.

7.3.3 Alternative #3-3: Increase Size of West Lucas Avenue Culvert

This measure is intended to increase the cross-sectional flow area of the channel by increasing the opening of the West Lucas Avenue culvert located at river station 99+25. The culvert is owned by the City of Dunkirk (Figure 7-23).

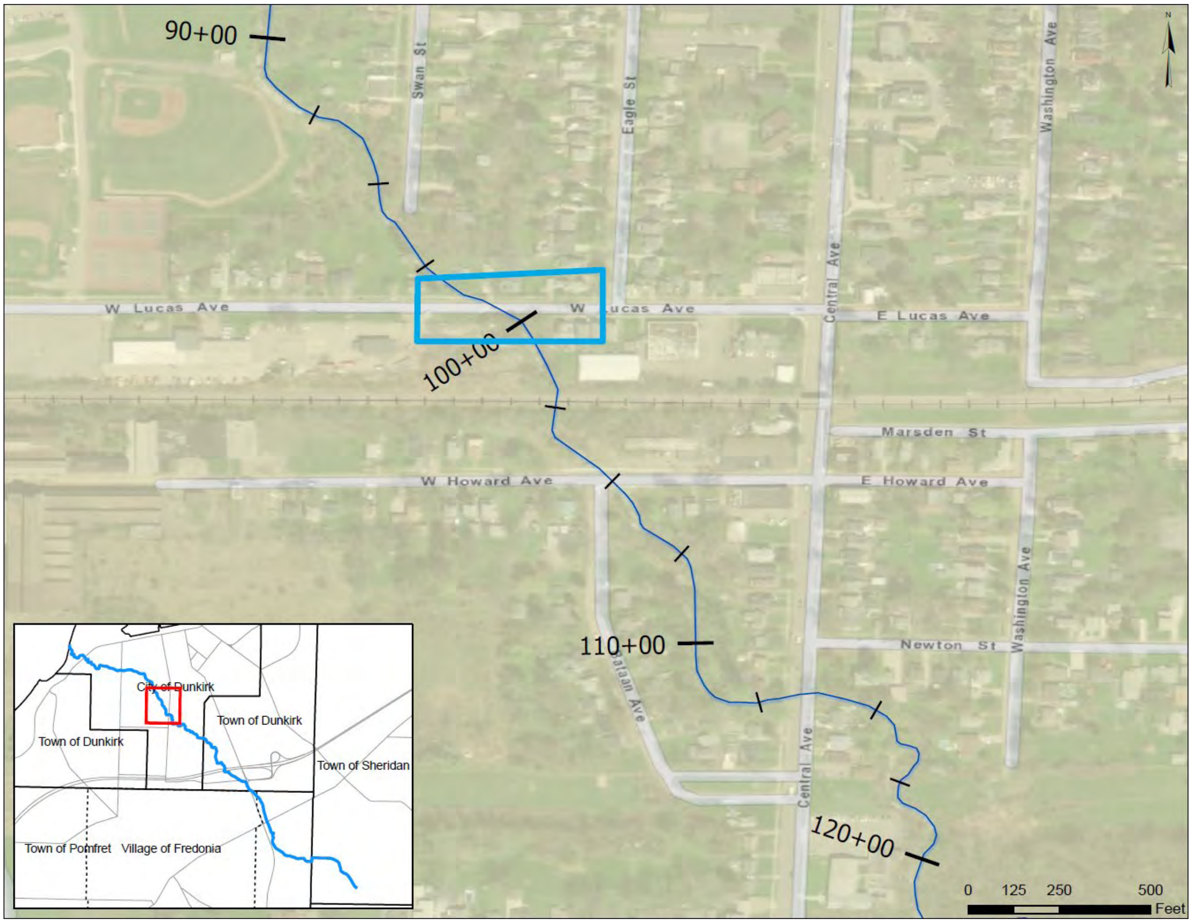

Figure 7-23. Location map for Alternative #3-3.

The existing culvert structure has an opening span of 15-ft and a maximum low chord to channel bottom height of 6.3-ft (Ramboll 2021) (Figure 7-24). The flooding in the vicinity of West Lucas Avenue poses a flood risk threat to nearby residential properties and City and County owned infrastructure upstream of the railroad crossing.

Figure 7-24. West Lucas Avenue culvert, Dunkirk, NY.

According to the HEC-RAS base condition model and FEMA FIS, the West Lucas Avenue culvert allows discharges at the 10-and 2% annual chance flood water surface elevation to pass, while the 1 and 0.2% Annual Chance Event WSELs exceed the low chord elevation and cause backwater upstream the of bridge (FIA 1980). In addition, the culvert does not provide the NYSDOT recommended drainage for a culvert in a regulatory floodway, which is the 1% annual chance flood hazard.

This measure would potentially reduce the flood risk for and benefit the properties adjacent to and immediately upstream of West Lucas Avenue. The proposed condition modeling confirmed that the West Lucas Avenue culvert is a constriction point along Crooked Brook. The culvert widening scenario increased the cross-sectional flow area of the bridge on the left channel bank by 15-ft for a total opening width of 30-ft. The proposed condition modeling simulation results indicated water surface reductions of up to 5.3-ft in areas immediately upstream of the bridge extending up to the Norfolk and Western Railroad crossing (Figure 7-25). The modeling output for future conditions displayed similar results with water surface reductions of up to 5.3-ft (Appendix F).

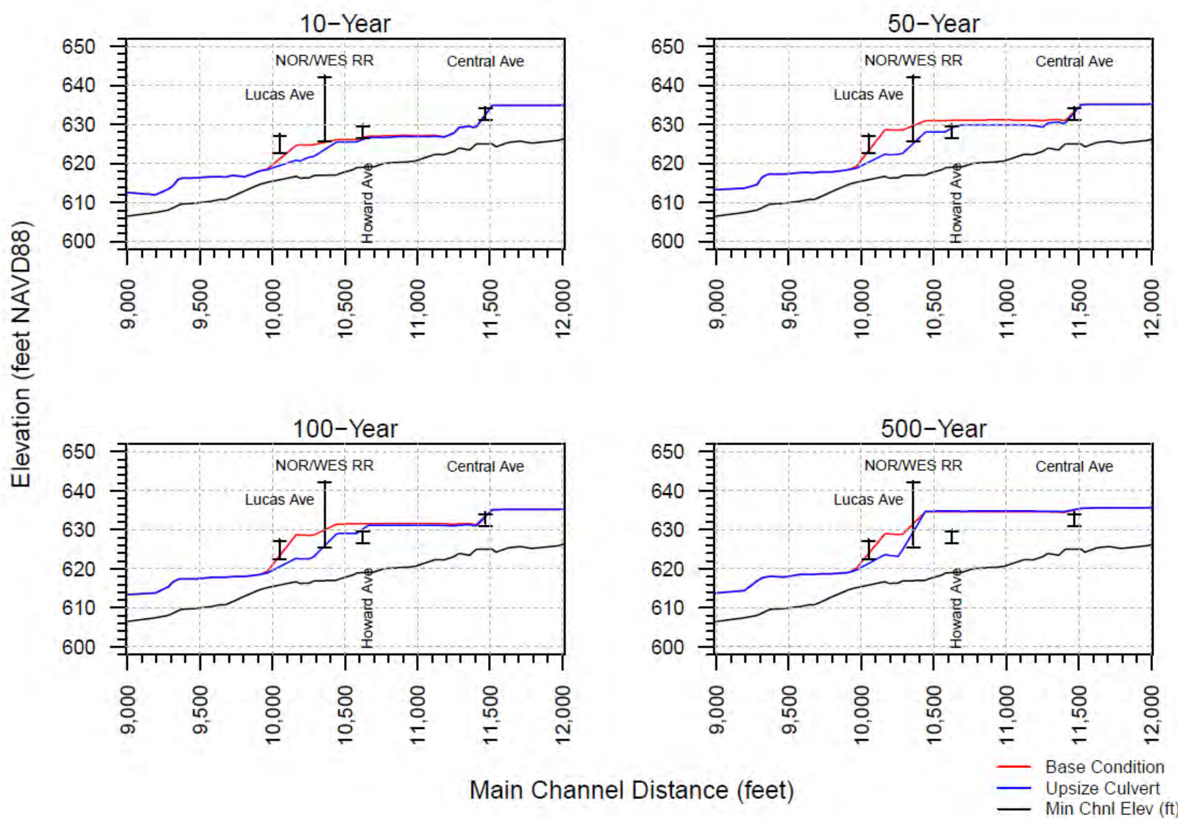

Figure 7-25. HEC-RAS model simulation output results for Alternative #3-3.

The potential water surface elevation reduction benefits of this alternative would extend approximately 1,500-ft upstream to the Central Avenue culvert, specifically between river stations 99+00 to 114+00.

The Rough Order Magnitude cost for this measure is $840,000, which does not include land acquisition costs for survey, appraisal, and engineering coordination.

7.3.4 Alternative #3-4: Replace Pipe Culverts with Box Culvert Under Norfolk and Western Railroad Crossing

This measure is intended to increase the cross-sectional flow area of the channel by replacing the existing pipe culverts with a single box culvert of equal size under the railroad crossing located at river station 101+25. The railroad crossing is owned by the Norfolk and Western Railroad company in the City of Dunkirk, New York (Figure 7-26).

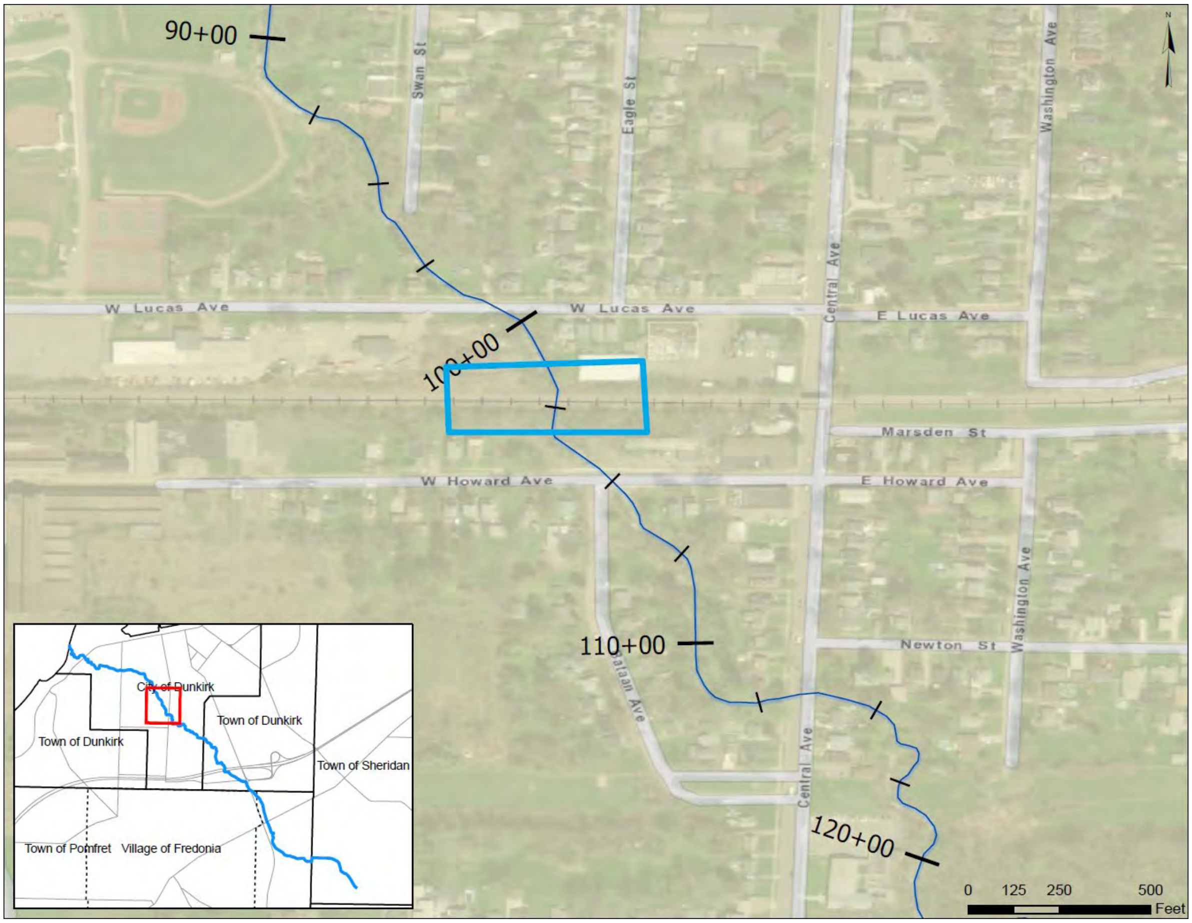

Figure 7-26. Location map for Alternative #3-4.

The existing culvert structure has a two pipe culverts with 8-ft diameters (Ramboll 2021) (Figure 7-27). The flooding in the vicinity of the railroad bridge poses a flood risk threat to nearby residential properties and City and County owned infrastructure both downstream and upstream of the railroad crossing.

Figure 7-27. Norfolk And Western Railroad pipe culverts, Dunkirk, NY.

According to the HEC-RAS base condition model and FEMA FIS, the Norfolk and Western Railroad crossing does not allow discharges at the 10, 2, 1 and 0.2% annual chance flood water surface elevation to pass, which causes WSELs to exceed the low chord elevation and cause backwater upstream of the culvert (FIA 1980). In addition, the culverts do not provide the NYSDOT recommended drainage for a culvert in a regulatory floodway, which is the 1% annual chance flood hazard.

This measure would potentially reduce the flood risk for and benefit the properties adjacent to and immediately upstream of the railroad bridge. The box culvert replacement scenario increased the cross-sectional flow area of the bridge by replacing the existing two 8-ft diameter pipe culverts with a single box culvert of 20-ft width and 8-ft height. The proposed condition modeling simulation results indicated water surface reductions of up to 3.4-ft in areas immediately upstream of the bridge extending up to the Brigham Road culvert (Figure 7-28). The modeling output for future conditions displayed similar results with water surface reductions of up to 4.1-ft (Appendix F).

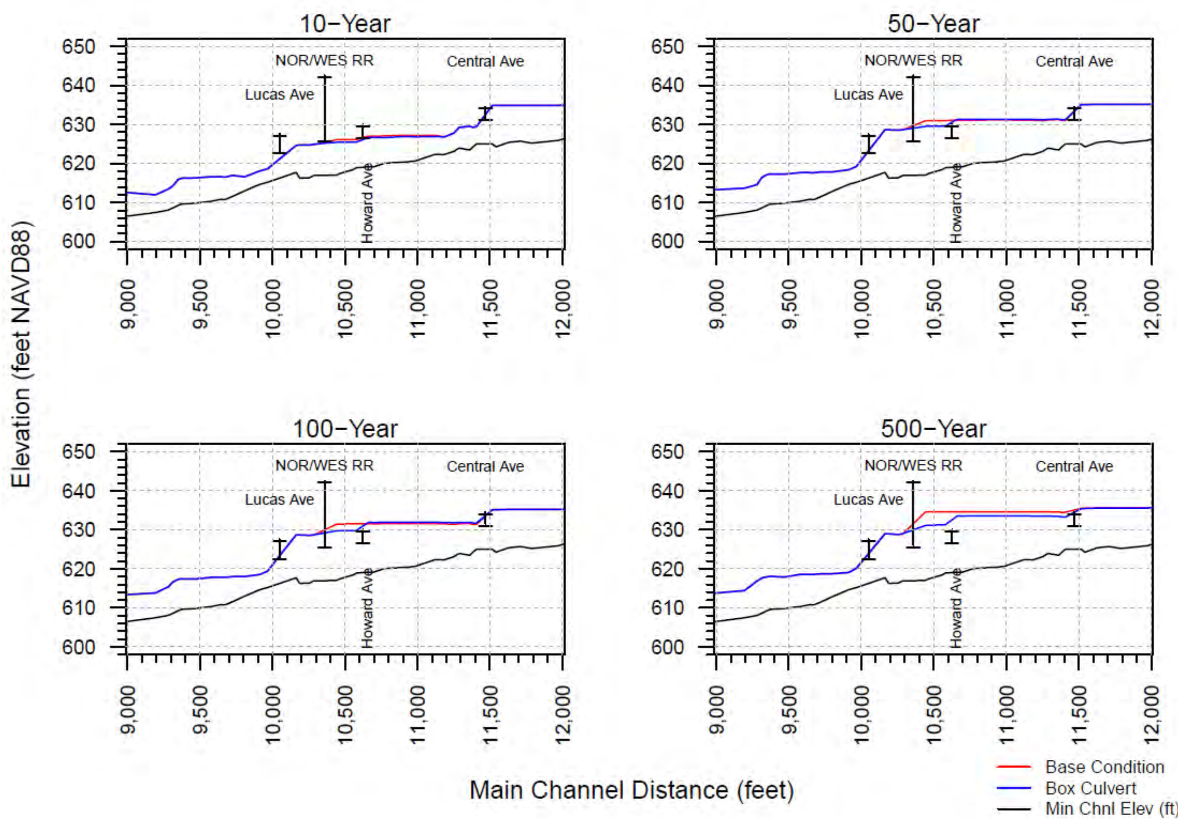

Figure 7-28. HEC-RAS model simulation output results for Alternative #3-4.

The potential water surface elevation reduction benefits of this alternative would extend approximately 1,250-ft upstream to the Central Avenue culvert, specifically between river stations 101+50 to 114+00.

The Rough Order Magnitude cost for this measure is $660,000, which does not include land acquisition costs for survey and appraisal, permitting, additional engineering and coordination, and / or special inspection requirements.

7.3.5 Alternative #3-5: Install Additional Crossing Pipes into Norfolk and Western Railroad Bridge Embankment

This measure is intended to increase the cross-sectional flow area of the channel by installing two additional pipe culverts on either side of the existing pipe culverts under the railroad crossing located at river station 101+25. The railroad crossing is owned by the Norfolk and Western Railroad company in the City of Dunkirk, New York (Figure 7-29). The existing culvert structure has two pipe culverts with 8-ft diameters (Ramboll 2021). The flooding in the vicinity of the railroad bridge poses a flood risk threat to nearby residential properties and City and County owned infrastructure both downstream and upstream of the railroad crossing.

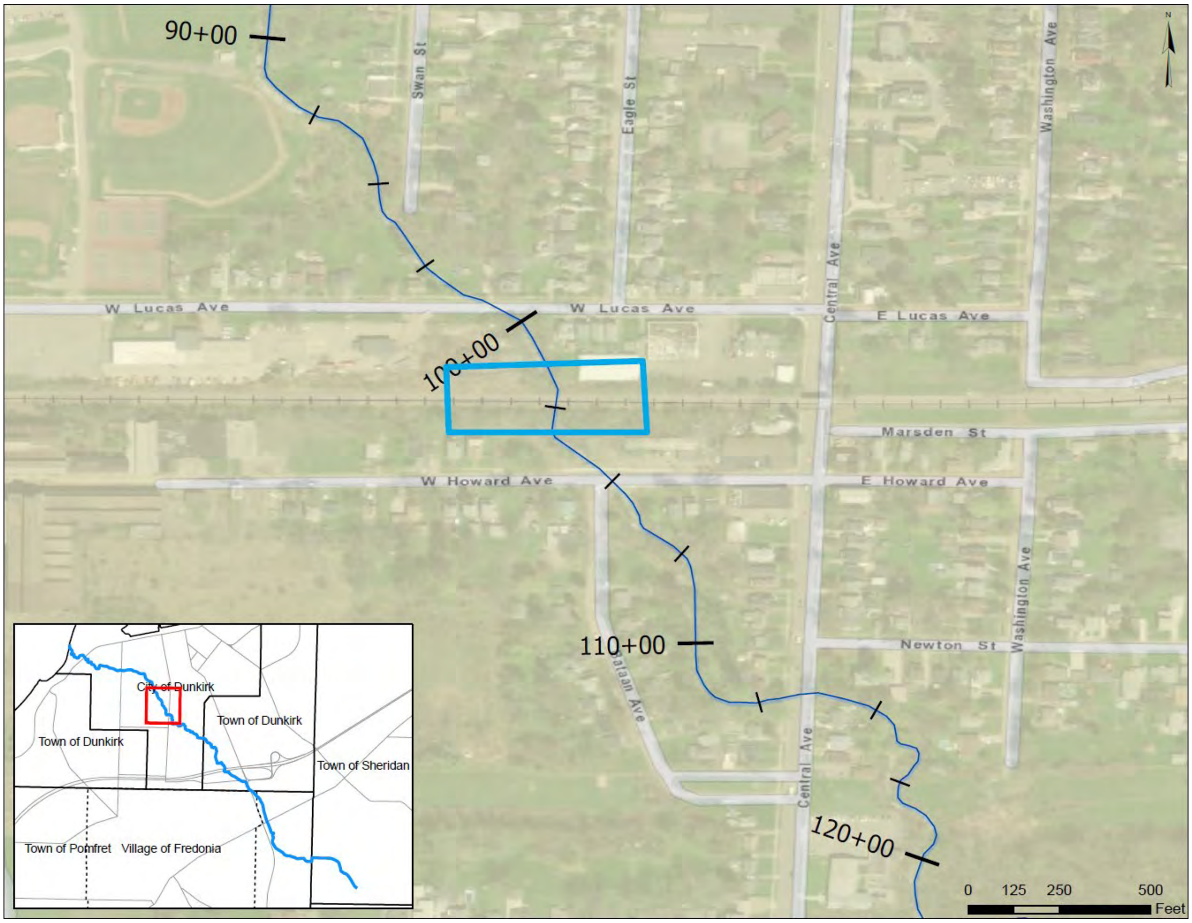

Figure 7-29. Location map for Alternative #3-5.

This measure would potentially reduce the flood risk for and benefit the properties adjacent to and immediately upstream of the railroad bridge. The crossing pipes scenario increased the cross-sectional flow area of the bridge on the left channel bank by including two 8-ft diameter pipe culverts placed in line with the existing pipe culverts. The proposed condition modeling simulation results indicated water surface reductions of up to 4.1-ft in areas immediately upstream of the bridge extending up to the Brigham Road culvert (Figure 7-30). The modeling output for future conditions displayed similar results with water surface reductions of up to 5.1-ft (Appendix F).

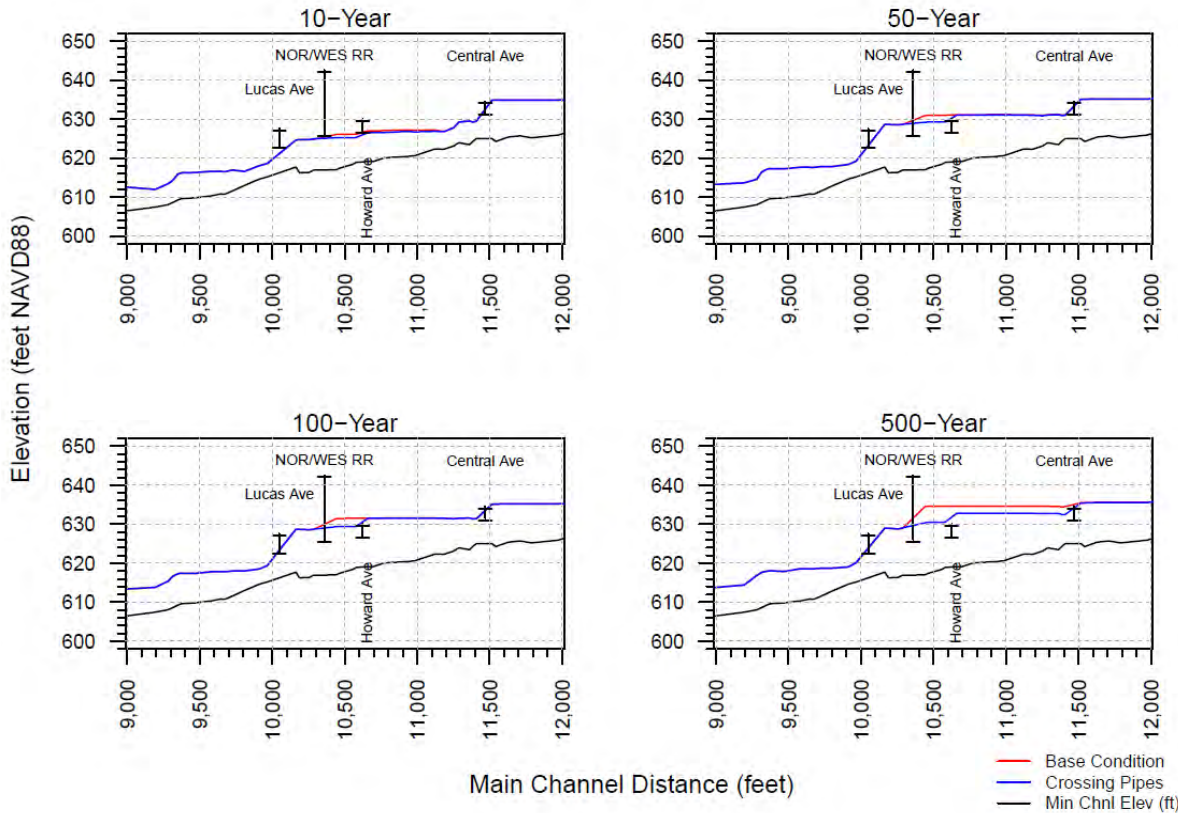

Figure 7-30. HEC-RAS model simulation output results for Alternative #3-5.

The potential water surface elevation reduction benefits of this alternative would extend approximately 1,250-ft upstream to the Central Avenue culvert, specifically between river stations 101+50 to 114+00.

The Rough Order Magnitude cost for this measure is $530,000, which does not include land acquisition costs for survey and appraisal, permitting, additional engineering and coordination, and / or special inspection requirements.

7.3.6 Alternative #3-6: Increase Size of West Howard Avenue Culvert

This measure is intended to increase the cross-sectional flow area of the channel by increasing the opening of the West Howard Avenue culvert located at river station 105+00. The culvert is owned by the City of Dunkirk (Figure 7-31).

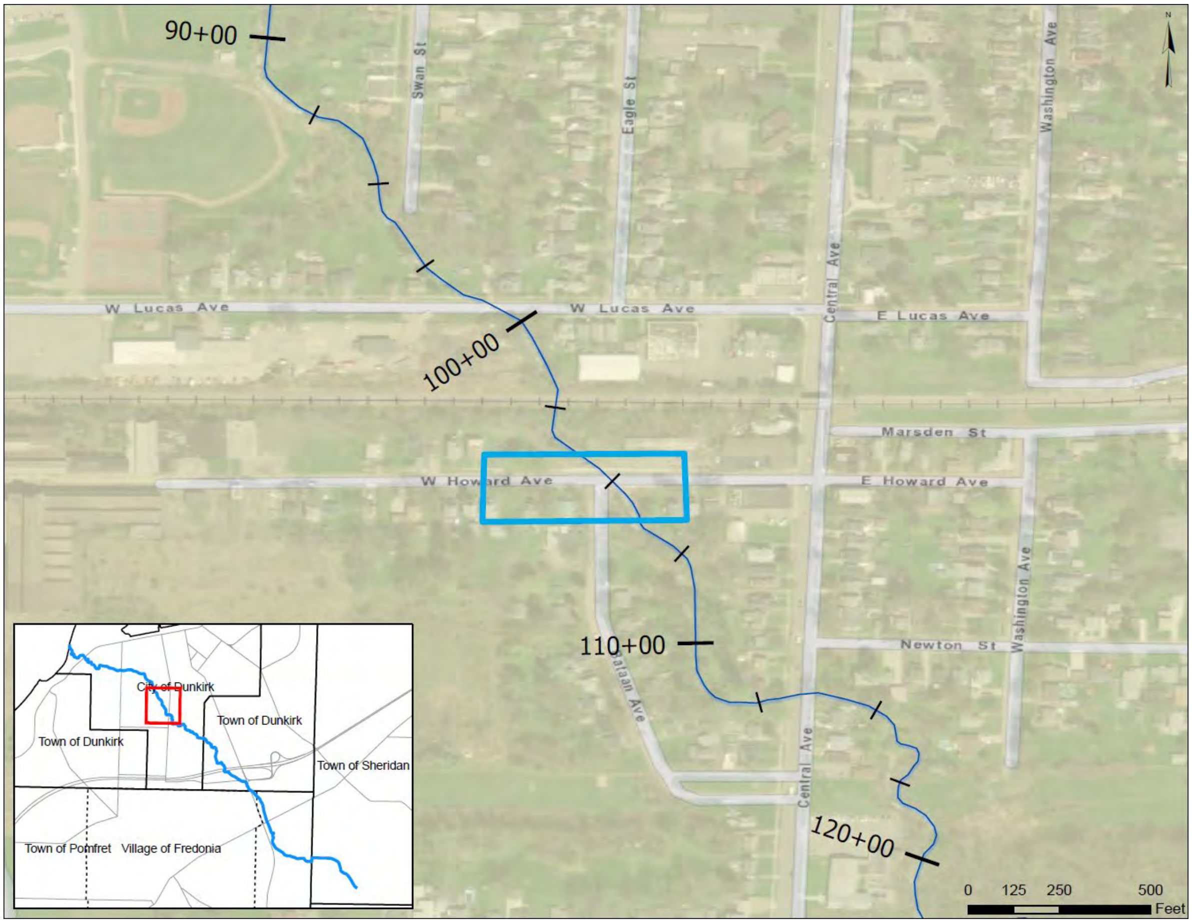

Figure 7-31. Location map for Alternative #3-6.

The existing culvert structure has an opening span of 15-ft and a maximum low chord to channel bottom height of 6.3-ft (Ramboll 2021) (Figure 7-32). The flooding in the vicinity of West Lucas Avenue poses a flood risk threat to nearby residential properties and City and County owned infrastructure upstream of the railroad crossing.

Figure 7-32. West Howard Avenue culvert, Dunkirk, NY.

According to the HEC-RAS base condition model and FEMA FIS, the West Howard Avenue culvert allows discharges at the 10% annual chance flood water surface elevation to pass, while the 2, 1 and 0.2% Annual Chance Event WSELs exceed the low chord elevation and cause backwater upstream of the culvert (FIA 1980). In addition, the culvert does not provide the NYSDOT recommended drainage for a culvert in a regulatory floodway, which is the 1% annual chance flood hazard.

This measure would potentially reduce the flood risk for and benefit the properties adjacent to and immediately upstream of West Howard Avenue. The proposed condition modeling confirmed that the West Lucas Avenue culvert is a constriction point along Crooked Brook. The culvert widening scenario increased the cross-sectional flow area of the bridge on the left channel bank by 15.5-ft for a total opening width of 31-ft. The proposed condition modeling simulation results indicated water surface reductions of up to 0.8-ft for low flow events only (i.e. 10% annual chance event) in areas immediately upstream of the bridge extending up to the Central Avenue culvert (Figure 7-33). The modeling output for future conditions displayed similar results with water surface reductions of up to 0.8-ft (Appendix F).

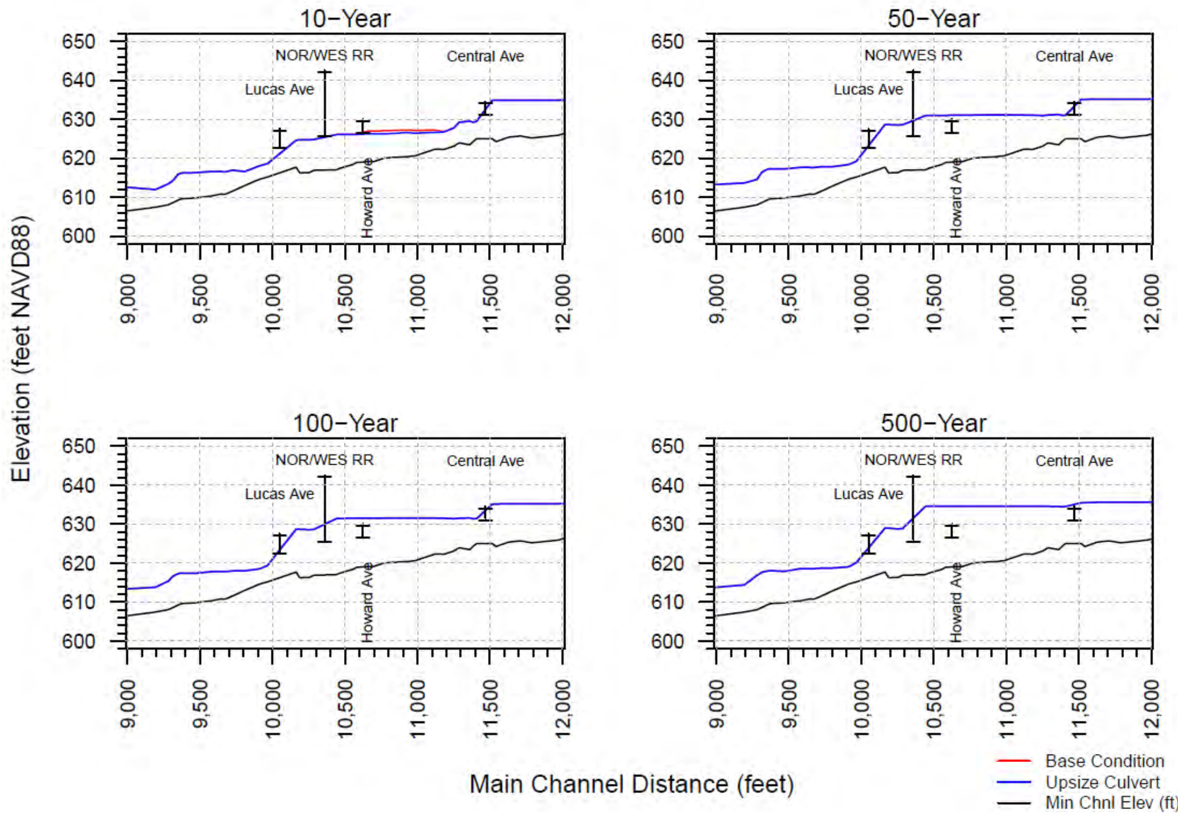

Figure 7-33. HEC-RAS model simulation output results for Alternative #3-6.

Backwater from West Lucas Avenue and the Norfolk and Western Railroad crossing during higher flow events (i.e. 2, 1, and 0.2% annual chance event) cause WSELs to overtop the West Howard Avenue culvert, reducing the flood mitigation potential of increasing the opening of the culvert. The potential water surface elevation reduction benefits of this alternative would extend approximately 600-ft upstream to the Central Avenue culvert, specifically between river stations 106+00 to 112+00.

The Rough Order Magnitude cost for this measure is $470,000, which does not include land acquisition costs for survey, appraisal, and engineering coordination.

7.3.7 Alternative #3-7: Replace Arch-culvert with Box Culvert Under Central Avenue

This measure is intended to increase the cross-sectional flow area of the channel by replacing the existing arch-culvert with a single box culvert of equal size under the Central Avenue crossing located at river station 113+75. The Central Avenue culvert is owned by the City of Dunkirk, New York (Figure 7-34).

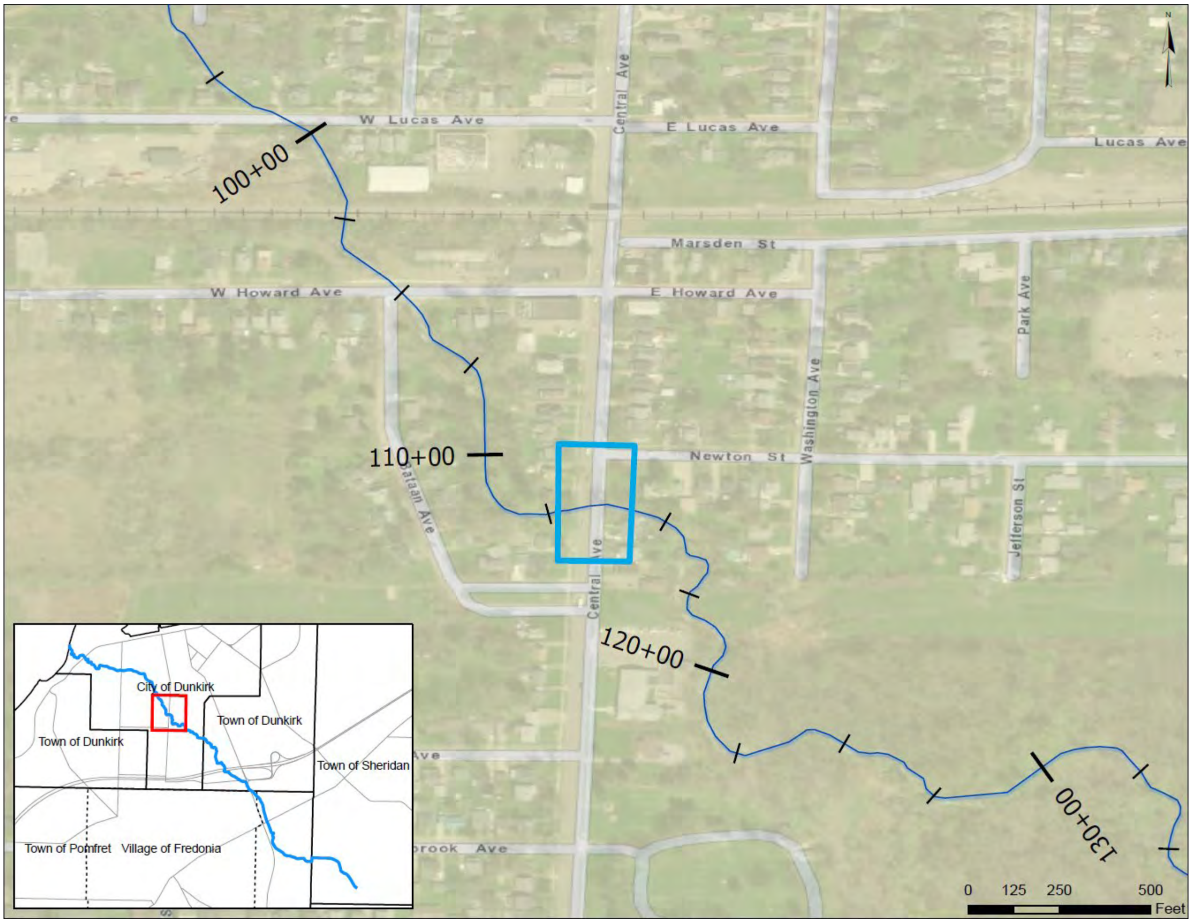

Figure 7-34. Location map for Alternative #3-7.

The existing arch-culvert structure has a 8-ft diameter (Ramboll 2021) (Figure 7-35). The flooding in the vicinity of Central Avenue poses a risk to nearby residential properties and City and County owned infrastructure, both downstream and upstream of the roadway crossing.

Figure 7-35. Central Avenue arch-culvert, Dunkirk, NY.

According to the HEC-RAS base condition model and FEMA FIS, the Central Avenue culvert does not allow discharges at the 10, 2, 1 and 0.2% annual chance flood water surface elevation to pass, which causes WSELs to exceed the low chord elevation and cause backwater upstream of the culvert (FIA 1980). In addition, the culvert does not provide the NYSDOT recommended drainage for a culvert in a regulatory floodway, which is the 1% annual chance flood hazard.

The box culvert replacement scenario increased the cross-sectional flow area of the culvert by replacing the existing 8-ft diameter arch-culvert with a single box culvert of 8-ft width and 6.5-ft height. The proposed condition modeling simulation results indicated no significant change in water surface elevations (Figure 7-36). The modeling output for future conditions displayed similar results with no significant change in water surface elevations (Appendix F).

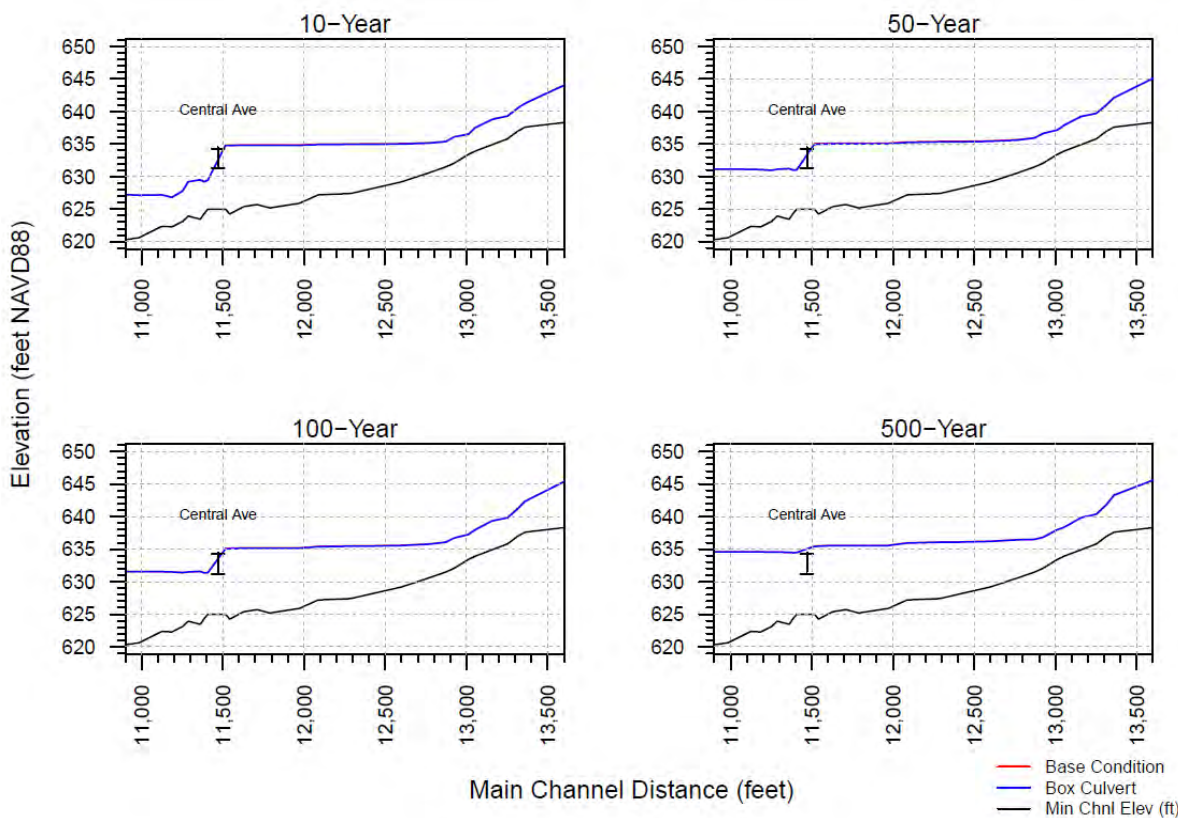

Figure 7-36. HEC-RAS model simulation output results for Alternative #3-7.

Based on the analysis of the H&H model simulation results, replacing the arch-culvert under Central Avenue with a box culvert of equal size would not provide significant flood protection in this reach from open-water flooding. This is most likely a result of the topography and geomorphic features in this area, which are predominately steep channel gradients and significant narrowing of the floodplain as Crooked Brook approaches Central Avenue.

This measure is not recommended due to the ineffectiveness of the measure to provide adequate flood protection to the areas immediately upstream and downstream of Central Avenue, and the additional costs associated with replacing the arch-culvert.

The Rough Order Magnitude cost for this measure is $230,000, which does not include land acquisition costs for survey, appraisal, and engineering coordination.

7.3.8 Alternative #3-8: Increase Size of Central Avenue Culvert

This measure is intended to increase the cross-sectional flow area of the channel by increasing the opening of the Central Avenue culvert located at river station 113+75. The culvert is owned by Chautauqua County in the City of Dunkirk, New York (Figure 7-37). The existing arch-culvert structure has a 8-ft diameter (Ramboll 2021). The flooding in the vicinity of Central Avenue poses a risk to nearby residential properties and City and County owned infrastructure both downstream and upstream of the roadway crossing.

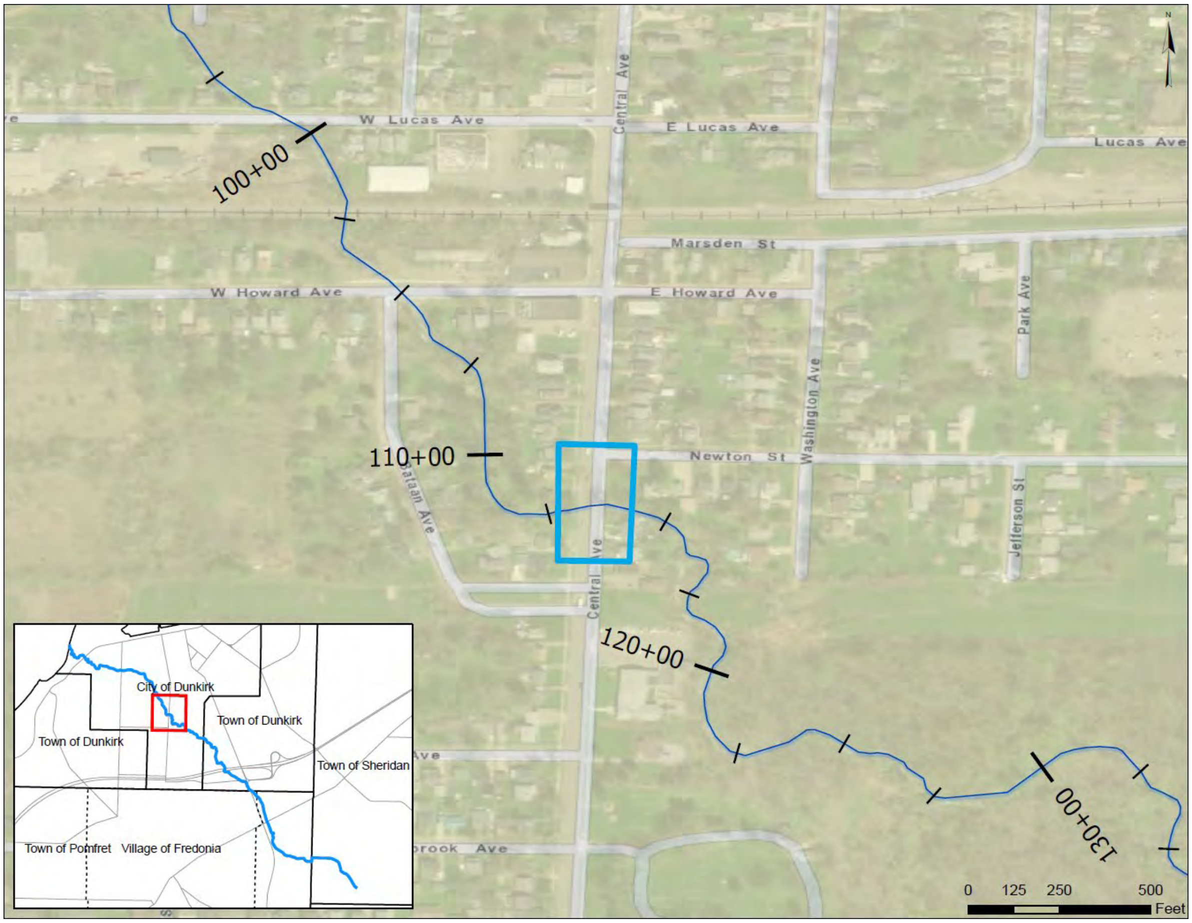

Figure 7-37. Location map for Alternative #3-8.

This measure would potentially reduce the flood risk for and benefit the properties adjacent to and immediately upstream of Central Avenue. The proposed condition modeling confirmed that the Central Avenue culvert is a constriction point along Crooked Brook. The culvert replacement and widening scenario increased the cross-sectional flow area of the culvert by replacing the existing arch-culvert with a box culvert and widening the left channel bank by 10-ft for a total opening width of 18-ft. The proposed condition modeling simulation results indicated water surface reductions of up to 3.5-ft, primarily for lower flow events (i.e. 10 and 2% annual chance event) (Figure 7-38). The modeling output for future conditions displayed similar results with water surface reductions of up to 3.7-ft (Appendix F).

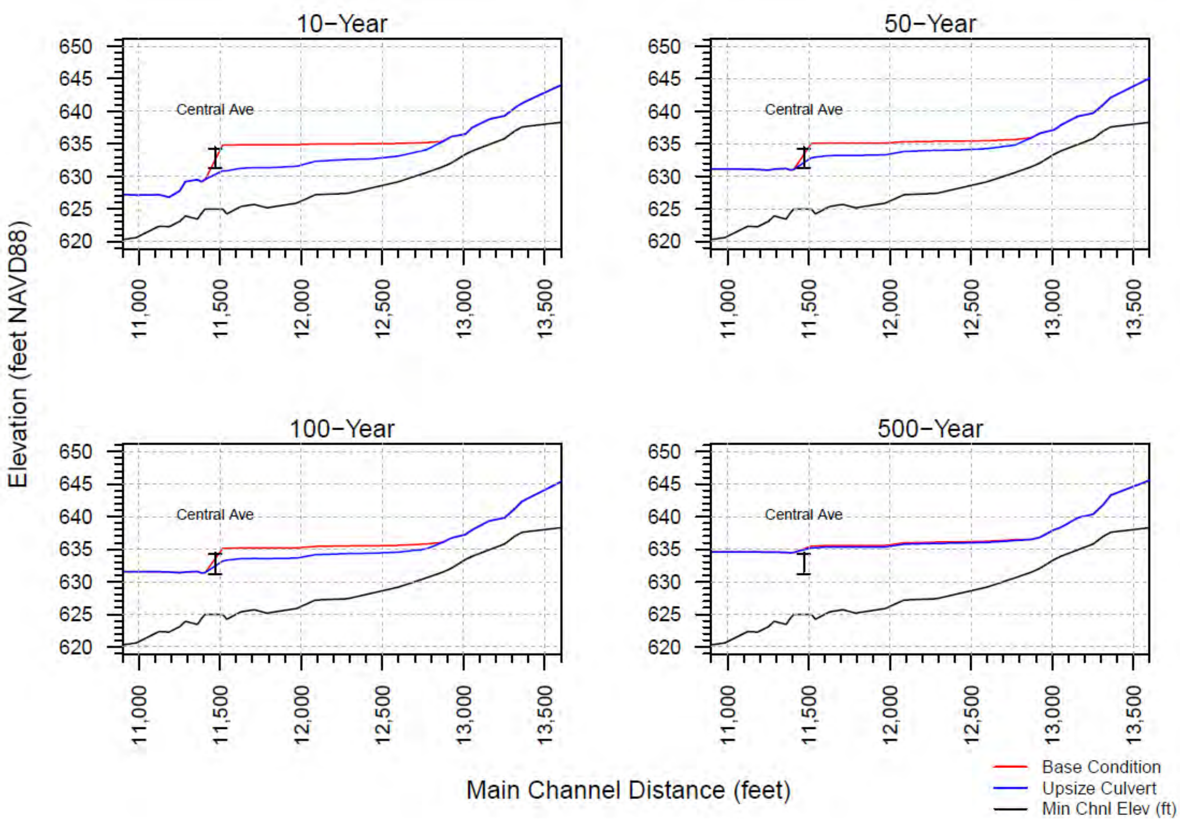

Figure 7-38. HEC-RAS model simulation output results for Alternative #3-8.

The potential water surface elevation reduction benefits of this alternative would extend approximately 1,450-ft upstream of Central Avenue, specifically between river stations 114+00 to 128+50.

The Rough Order Magnitude cost for this measure is $760,000, which does not include land acquisition costs for survey, appraisal, and engineering coordination.

7.3.9 Alternative #3-9: Flood Control Structure / Reservoir Upstream of Central Avenue

The construction of small flood-control structures in the headwaters and tributaries of flood-prone streams has proven successful at preventing flood damage in small towns throughout the United States (Helms 1986). These structures are traditionally located in rural areas in agricultural fields and undeveloped land. Many maintain little to no permanent pool and are designed to detain water during larger flow events, decreasing peak-flow water surface elevations and minimizing flooding further downstream in developed areas. The area between Central Avenue and the Main Street / CSX Railroad bridge along Crooked Brook would be the best location for a flood-control structure in the upstream reach (Figure 7-39).

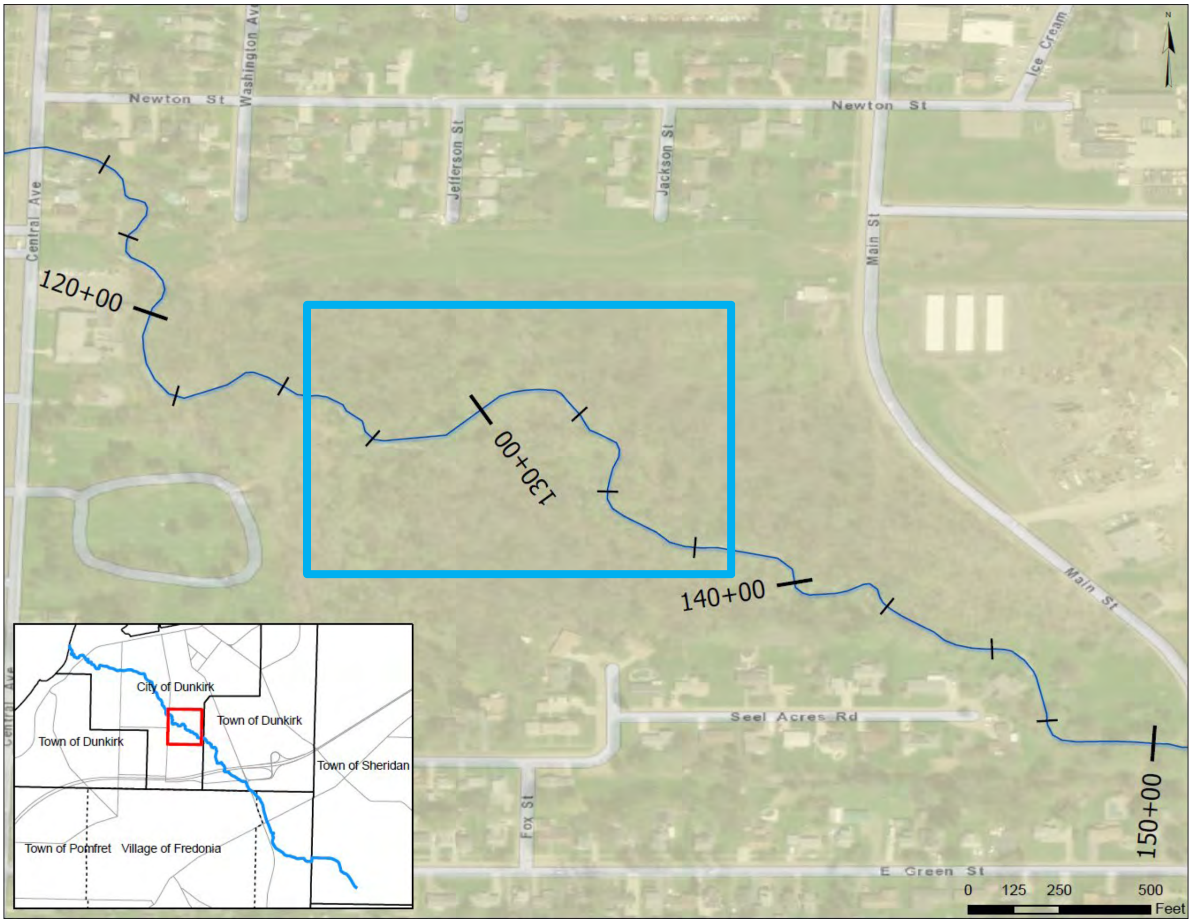

Figure 7-39. Location map for Alternative #3-9.

In New York State, a joint permit application from the NYSDEC and USACE may be required in order to construct, reconstruct, or repair a dam or other impoundment. The NYSDEC is entrusted with the regulatory power to oversee dam safety, which encompasses flood detention structures. To protect people from the loss of life and property due to flooding and / or dam failure, the NYSDEC Dam Safety Section, in cooperation with the USACE, reviews proposed dam construction and / or modifications, conducts dam safety inspections, and monitors projects for compliance with dam safety criteria.

To acquire a permit for the construction, reconstruction, or repair of a dam or other impoundment, a developer must submit an application to the NYSDEC for an Article 15 Dam Construction Permit, along with the USACE Joint Application Form that, if approved, would allow activities affecting waters within the state.

USACE has the authority to construct small flood risk reduction projects that are engineeringly feasibly, structurally sound and cost efficient through the authority provided under Section 205 of the 1948 FCA, as amended. Coordination should also occur with the NYSDEC as they need to be the non-Federal sponsor on these types of projects. In addition, a FEMA BCA would need to be performed to determine the cost-effectiveness of the alternative prior to applying for FEMA mitigation grant programs funding. The BCA is used to determine the BCR for the project, where a project is considered to be cost effective when the BCR is 1.0 or greater.

Due to the conceptual nature of this measure, and significant amount of data required to produce a reasonable rough-order-of-magnitude cost, it is not feasible to quantify the costs of this measure without further engineering analysis and modeling. However, the cost of designing, permitting, constructing, and maintaining one or more flood-control structures in the headwaters of the Crooked Brook watershed are expected to be significant.

8. BASIN-WIDE MITIGATION ALTERNATIVES

Non-structural measures attempt to avoid flood damages by modifying or removing properties currently located within flood-prone areas. These measures do not affect the frequency or level of flooding within the floodplain; rather, they affect floodplain activities. In considering the range of non-structural measures, the community needs to assess the type of flooding which occurs (depth of water, velocity, duration) prior to determining which measure best suits its needs (USACE 2016b).

8.1 Alternative #4-1: Early-warning Flood Detection System

Early-warning flood detection systems can be implemented, which can provide communities with more advanced warning of potential flood conditions. Early forecast and warning involve the identification of imminent flooding, implementation of a plan to warn the public, and assistance in evacuating persons and some personal property. A typical low cost early-warning flood detection system consists of commercially available off-the-shelf-components. The major components of an early-warning flood detection system are a sensor connected to a data acquisition device with built-in power supply or backup, some type of notification or warning equipment, and a means of communication.

The pressure transducer system can be powered from an alternating current source via landline or by batteries that are recharged by solar panels. The notification process can incorporate standard telephone or cellular telephone. Transfer of data from the system can be achieved using standard or cellular telephone, radio frequency (RF) telemetry, wireless internet, or satellite transceivers. Emergency management notification techniques can be implemented through the use of radio, siren, individual notification, or a reverse 911 system. More elaborate means include remote sensors that detect water levels and automatically warn residents. These measures normally serve to reduce flood hazards to life, and damage to portable personal property (USACE 2016b).

The Rough Order Magnitude cost for this strategy is approximately $120,000, not including annual maintenance and operational costs.

8.2 Alternative #4-2: Riparian Restoration

Riparian ecosystems support many critically important ecological functions, but most riparian areas have been severely degraded by a variety of human disturbances within the Crooked Brook watershed. Restoration, which is defined as the process of re-establishing historical ecosystem structures and processes, is being used more often to mitigate some of the past degradation of these ecosystems (Goodwin et al. 1997).

Adoption of a process-based approach for riparian restoration is key to a successful restoration plan, and in riparian systems flooding disturbance is a key process to consider. Successful restoration depends on understanding the physical and biological processes that influence natural riparian ecosystems, and the types of disturbances to anthropogenic modifications that cause damage to riparian areas. In this case, alteration of historical flooding processes has caused degradation of the riparian system.

Riparian ecosystems generally consist of two flooding zones: Zone I occupies the active floodplain and is frequently inundated, and Zone II extends from the active floodplain to the valley wall. Successful restoration depends on understanding the physical and biological processes that influence natural riparian ecosystems and the types of disturbance that have degraded riparian areas. Adoption of a process-based approach for riparian restoration is key to a successful restoration plan. Disturbances to riparian ecosystems in the Crooked Brook watershed have resulted from streamflow modifications by dams, reservoirs, and diversions; stream channelization; direct modification of the riparian ecosystem; and watershed disturbances (Goodwin et al. 1997).

With ecological processes in mind, a successful riparian restoration plan should focus on four key areas: (1) interdisciplinary approaches, (2) a unified framework, (3) a better understanding of fundamental riparian ecosystem processes, and (4) restoration potential more closely related to disturbance type (Goodwin et al. 1997).

Three issues should be considered regarding the cause of the degraded environment: (1) the location of the anthropogenic modification with respect to the degraded riparian area, (2) whether the anthropogenic modification is ongoing or can be eliminated, and (3) whether or not recovery will occur naturally if the anthropogenic modification is removed (Goodwin et al. 1997).

Riparian restoration requires a deep understanding of physical and ecological conditions that exist and that are desired at a restoration site. These conditions must be naturally sustainable given a set of water, sediment, and energy fluxes. If the conditions cannot be naturally sustained, the restoration will fail to meet the original goals (Goodwin et al. 1997).

8.3 Alternative #4-3: Debris Maintenance Around Infrastructure

Debris, such as trees, branches, and stumps, are an important feature of natural and healthy stream systems. In a healthy stream network, woody debris helps to stabilize the stream and its banks, reduce sediment erosion, and slow storm-induced high streamflow events. Fallen trees and brush also form the basis for the entire aquatic ecosystem by providing food, shelter, and other benefits to fish and wildlife. In the headwaters of many streams, woody debris influences flooding events by increasing channel roughness, dissipating energy, and slowing floodwaters, which can potentially reduce flood damages in the downstream reaches. Any woody debris that does not pose a hazard to infrastructure or property should be left in place and undisturbed, thereby saving time and money for more critical work at other locations (NYSDEC 2013).

However, in some instances, significant sediment and debris can impact flows by blocking bridge and culvert openings and accumulating along the stream path at meanders, contraction / expansion points, etc., which can divert stream flow and cause backwater and bank erosion. When debris poses a risk to infrastructure, such as bridges or homes, it should be removed. Provided fallen trees, limbs, debris, and trash can be pulled, cabled, or otherwise removed from a stream or stream bank without significant disruption of the stream bed and banks, a permit from the NYSDEC is not required. Woody debris and trash can be removed from a stream without the need for a permit under the following guidelines:

- Fallen trees and debris may be pulled from the stream by vehicles and motorized equipment operating from the top of the streambanks using winches, chains and or cables.
- Hand-held tools, such as chainsaws, axes, handsaws, etc., may be used to cut up the debris into manageable sized pieces.
- Downed trees that are still attached to the banks should be cut off near the stump. Do not grub (pull out) tree stumps from the bank; stumps hold the bank from eroding.
- All trees, brush, and trash that is removed from the channel should not be left on the floodplain. Trash should be properly disposed of at a waste management facility. Trees and brush can be utilized as firewood. To prevent the spread of invasive species, such as Emerald Ash Borer, firewood cannot be moved more than 50 miles from its point of origin.
- Equipment may not be operated in the water, and any increase in stream turbidity from the removal must be avoided (NYSDEC 2013).

Any work that will disturb the bed or banks of a protected stream (gravel removal, stream restoration, bank stabilization, installation, repair, replacements of culverts or bridges, objects embedded in the stream that require digging out, etc.) will require an Article 15 permit from the NYSDEC. Projects that will require disturbance of the stream bed or banks, such as excavating sand and gravel, digging embedded debris from the streambed or the use of motorized, vehicular equipment, such as a tractor, backhoe, bulldozer, log skidder, four-wheel drive truck, etc. (any heavy equipment), in the stream channel, or anywhere below the top of banks, will require either a Protection of Waters or Excavation or Fill in Navigable Waters Permit (NYSDEC 2013).

In addition, sediment control basins along Crooked Brook could be established to reduce watercourse and gully erosion, trap sediment, reduce and manage runoff near and downstream of the basin, and to improve downstream water quality. A sediment control basin is an earth embankment, or a combination ridge and channel, generally constructed across the slope and minor watercourses to form a sediment trap and water detention basin. The basin should be configured to enhance sediment deposition by using flow deflectors, inlet and outlet selection, or by adjusting the length-to-width ratio of the creek channel. Additional hydrologic and hydraulic studies should be performed to identify the optimal locations for the sediment control basins. Operation and maintenance costs to maintain the embankment, design capacity, vegetative cover, and outlet of the basin should be considered (NRCS 2002).

Consultation with the NYSDEC can help determine if, when and how sediment and debris should be managed and whether a permit will be required.

The Rough Order Magnitude cost for this strategy is up to $20,000, not including annual maintenance and operational costs.

8.4 Alternative #4-4: Retention Basin and Wetland Management

Stormwater ponds and wetlands are designed and constructed to contain and / or filter pollutants that flush off of the landscape. Without proper maintenance, nutrients such as nitrogen and phosphorus that are typically found in stormwater runoff can accumulate in stormwater ponds and wetlands leading to degraded conditions such as low dissolved oxygen, algae blooms, unsightly conditions, and odors. Excess sediment from the watershed upstream can also accumulate in wet ponds and wetlands. This sediment can smother the vegetation and clog any filtering structures or outlets. In addition, standing water in ponds can heat up during the summer months. This warmer water is later released into neighboring waters, which can have negative impacts on aquatic life (USEPA 2009).

Without proper maintenance, excess pollutants in ponds and wetlands may actually become sources of water quality issues such as poor water color / clarity / odor, low dissolved oxygen leading to plant die-off, and prevalence of algal blooms. When these ponds and wetlands are “flushed” during a large rain event, the excess nutrients causing these problems may be transferred to the receiving waterbody (USEPA 2009).

Maintenance is necessary for a stormwater pond or wetland to operate as designed on a long-term basis. The pollutant removal, channel protection, and flood control capabilities of ponds and wetlands will decrease if (USEPA 2009):

- Sediment accumulates reducing the storage volume
- Debris blocks the outlet structure
- Pipes or the riser are damaged
- Invasive plants take over the planted vegetation
- Slope stabilizing vegetation is lost
- The structural integrity of the embankment, weir, or riser is compromised

Pond and wetland maintenance activities range in terms of the level of effort and expertise required to perform them. Routine pond and wetland maintenance, such as mowing and removing debris or trash, is needed multiple times each year, but can be performed by citizen volunteers. More significant maintenance such as removing accumulated sediment is needed less frequently, but requires more skilled labor and special equipment. Inspection and repair of critical structural features such as embankments and risers, needs to be performed by a qualified professional (e.g., structural engineer) who has experience in the construction, inspection, and repair of these features (USEPA 2009). Water level management, if control structures are available, can be an effective tool to meet a range of pond and wetland habitat and process management objectives.

Program managers and responsible parties need to recognize and understand that neglecting routine maintenance and inspection can lead to more serious problems that threaten public safety, impact water quality, and require more expensive corrective actions (USEPA 2009).

8.5 Alternative #4-5: Flood Buyout Programs

Buyouts allow state and municipal agencies the ability to purchase developed properties within areas vulnerable to flooding from willing owners. Buyouts are effective management tools in response to natural disasters to reduce or eliminate future losses of vulnerable or repetitive loss properties. Buyout programs include the acquisition of private property, demolition of existing structures, and conversion of land into public space or natural buffers. The land is maintained in an undeveloped state for public use in perpetuity. Buyout programs not only assist individual homeowners, but are also intended to improve the resiliency of the entire community in the following ways (Siders 2013):

- Reduce exposure by limiting the people and infrastructure located in vulnerable areas
- Reduce future disaster response costs and flood insurance payments
- Restore natural buffers such as wetlands in order to reduce future flooding levels
- Reduce or eliminate the need to maintain and repair flood control structures
- Reduce or eliminate the need for public expenditures on emergency response, garbage collection and other municipal services in the area
- Provide open space for the community

Resilience achieved through buyouts can have real economic consequences in addition to improved social resilience. According to FEMA, voluntary buyouts cost $1 for every $2 saved in future insurance claims, an estimate which does not include money saved on flood recovery and response actions, such as local flood fighting, evacuation, and rescue, and recovery expenses that will not be incurred in the future. In order to achieve these goals, buyouts need to acquire a continuous swatch of land, rather than individual homes in isolated areas, or only some of the homes within flood-prone areas (Siders 2013).

Buyout programs can be funded through a combination of federal, state, or local funds, and are generally made available following a nationally recognized disaster. FEMA administers programs to help with buyouts under the Stafford Disaster Act, and the Department of Housing and Urban Development administers another program through Community Development Block Grants (CDBG). These funding sources can reduce the economic burden on the local community. However, these funds also come with guidelines and regulations that may constrain policy makers' options on whether to pursue a buyout strategy, and how to shape their programs. FEMA funds may be used to cover 75% of the expenses, but the remaining 25% must come from another non-federal source. In most cases, the buyout must be a cost-effective measure that will substantially reduce the risk of future flooding damage (Siders 2013).

For homes in the SFHA, FEMA has developed precalculated benefits for property acquisition and structure elevation of buildings. Based on a national analysis that derived the average benefits for acquisition and elevation projects, FEMA has determined that acquisition projects that cost $276,000 or less, or elevation projects that costs $175,000 or less, and which are located in the 1% annual chance event (i.e.

100 year recurrence interval) floodplain are considered cost-effective and do not require a separate benefit-cost analysis. For projects that contain multiple structures, the average cost of all structures in the project must meet the stated criteria. If the cost to acquire or elevate a structure exceeds the amount of benefits listed above, then a traditional FEMA approved benefits-cost analysis must be completed (FEMA 2015).

In the Crooked Brook watershed, there are approximately 400 residences within the FEMA 1 and 0.2% annual chance flood hazard zones. In addition, there are three FEMA Repetitive Loss (RL) and no Severe Repetitive Loss (SRL) properties located within the Crooked Brook watershed (Figure 8-1) (FEMA 2019; NYSGPO 2020).

Due to the variable nature of buyout programs, no ROM cost estimate was produced for this study. It is recommended that any buyout program begin with a cost-benefit analysis for each property. After a substantial benefit has been established, a buyout strategy study should be developed that focuses on properties closest to Crooked Brook in the highest-risk flood areas and progresses outwards from there to maximize flood damage reductions. In addition, structures located adjacent to flood prone infrastructure (i.e. bridges, culverts, etc.) should also be considered high-risk and prioritized in any buyout program strategy. A potential negative consequence of buyout programs is the permanent removal of properties from the floodplain, and resulting tax revenue, which would have long-term implications for local governments, and should be considered prior to implementing a buyout program.

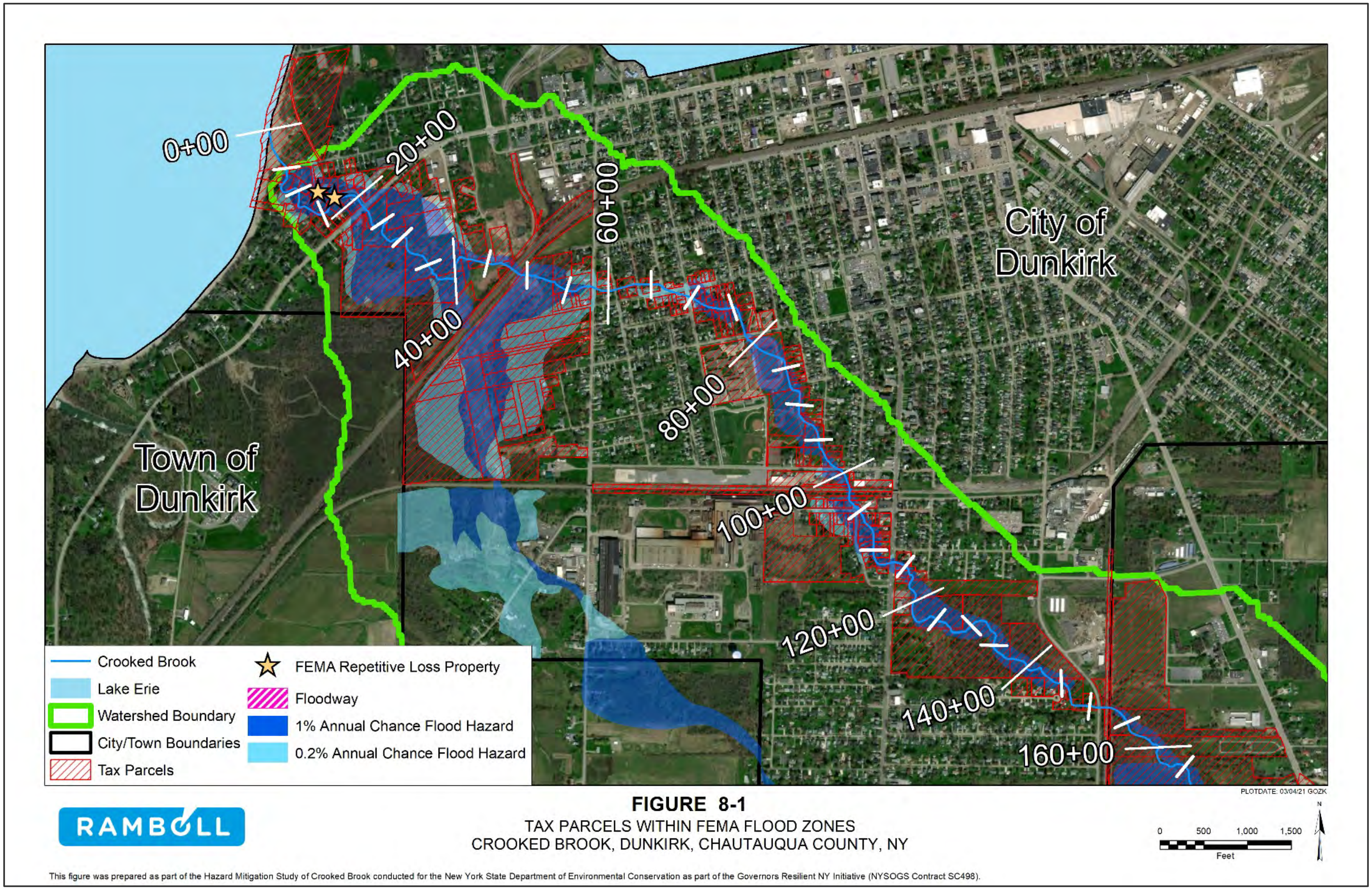

Figure 8-1. Tax Parcels within FEMA Flood Zones, Crooked Brook, City of Dunkirk, Chautauqua County, NY.

8.6 Alternative #4-6: Floodproofing

Floodproofing is defined as any combination of structural or nonstructural adjustments, changes, or actions that reduce or eliminate flood damage to a building, contents, and attendant utilities and equipment (FEMA 2000). Floodproofing can prevent damage to existing buildings and can be used to meet compliance requirements for new construction of residential and non-residential buildings.

The most effective flood mitigation methods are relocation (i.e. moving a home to higher ground outside of a high-risk flood area) and elevation (i.e. raising the entire structure above BFE). The relationship between the BFE and a structure's elevation determines the flood insurance premium. Buildings that are situated at or above the level of the BFE have lower flood risk than buildings below BFE and tend to have lower insurance premiums than buildings situated below the BFE (FEMA 2015b).

In some communities, where non-structural flood mitigation alternatives are not feasible, structural alternatives such as flood proofing may be a viable alternative. The National Flood Insurance Program has specific rules related to flood proofing for residential and non-residential structures. These can be found in the Code of Federal Regulations (CFR) 44 CFR 60.3 (FEMA 2000).

For communities that have been provided an exception by FEMA, the CFR allows for the floodproofing of residential basements as outlined in 44 CFR 60.6 (c) “a permit can be obtained to floodproof a residential building basement, if it can demonstrate an adequate warning time under a flood depth less than 5 feet and a velocity less than 5 fps.” Floodproofing residential basements should be considered during the design phase of a structure prior to construction. For existing structures, floodproofing residential basements can be a difficult, complex, and expensive measure to achieve. Instead, residential structures should be raised above the BFE in accordance with local regulations. Floodproofing is allowed for non-residential structures, with design guidelines outlined in FEMA P-936 – Floodproofing Non-Residential Structures (FEMA 2000; FEMA 2013). The local floodplain administrator should carefully review local ordinances, the CFR and available design guidelines perform issuing a permit for structural flood proofing. Floodproofing strategies include:

Interior Modification / Retrofit Measures

Interior modification and retrofitting involve making changes to an existing building to protect it from flood damage. When the mitigation is properly completed in accordance with NFIP floodplain management requirements, interior modification / retrofit measures could achieve the somewhat similar results as elevating a home above the BFE. Keep in mind, in areas where expected base flood depths are high, the flood protection techniques below may not provide protection on their own to the BFE or, where applicable, the locally required freeboard elevation (FEMA 2015b).

Examples include:

- *Basement Infill:* This measure involves filling a basement located below the BFE to grade (ground level)
- *Abandon Lowest Floor:* This measure involves abandoning the lowest floor of a two or more story slab-on-grade residential building
- *Elevate Lowest Interior Floor:* This measure involves elevating the lowest interior floor within a residential building with high ceilings

Dry floodproofing

A combination of measures that results in a structure, including the attendant utilities and equipment, being watertight with all elements substantially impermeable to the entrance of floodwater and with structural components having the capacity to resist flood loads (FEMA 2015b).

Although NFIP regulations require non-residential buildings to be watertight and protected only to the BFE for floodplain management purposes (to meet NFIP regulations), protection to a higher level is necessary for dry floodproofing measures to be considered for NFIP flood insurance rating purposes. Because of the additional risk associated with dry floodproofed buildings, to receive an insurance rating based on 1% annual chance (100-year) flood protection, a building must be dry floodproofed to an elevation at least 1-ft above the BFE (FEMA 2013).

Examples include:

- *Passive Dry Floodproofing System*: This measure involves installing a passive (works automatically without human assistance) dry floodproofing system around a home to protect the building from flood damage.
- *Elevation*: This measure involves raising an entire residential or non-residential building structure above BFE.

Wet floodproofing

The use of flood-damage-resistant materials and construction techniques to minimize flood damage to areas below the flood protection level of a structure, which is intentionally allowed to flood (FEMA 2015b).

Examples include:

- *Flood Openings*: This measure involves installing openings in foundation and enclosure walls located below the BFE that allow automatic entry and exit of floodwaters to prevent collapse from the pressures of standing water.
- *Elevate Building Utilities*: This measure involves elevating all building utility systems and associated equipment (e.g., furnaces, septic tanks, and electric and gas meters) to protect utilities from damage or loss of function from flooding.
- *Floodproof Building Utilities*: This measure involves floodproofing all building utility systems and associated equipment to protect it from damage or loss of function from flooding.

- *Flood Damage-Resistant Materials*: This measure involves the use of flood damage-resistant materials such as non-paper-faced gypsum board and terrazzo tile flooring for building materials and furnishings located below the BFE to reduce structural and nonstructural damage and post-flood event cleanup.

Barrier Measures

Barriers, such as floodwalls and levees, can be built around single or multiple residential and non-residential buildings to contain or control floodwaters (FEMA 2015b). Although floodwalls or levees can be used to keep floodwaters away from buildings, implementing these measures will not affect a building's flood insurance rating unless the flood control structure is accredited in accordance with NFIP requirements (44 CFR §65.10) and provides protection from at least the 1% annual chance (100-year) flood. Furthermore, floodwalls or levees as a retrofit measure will not bring the building into compliance with NFIP requirements for Substantial Improvement / Damage (FEMA 2013). Barrier measures require ongoing maintenance (i.e. mowing, etc.) which should be factored into any cost analysis. In addition, barrier measures tend to create a false sense of security for the property owners and residents that are protected by them. If a barrier structure is not properly constructed or maintained and fails, catastrophic damages to surrounding areas can occur.

- *Floodwall with Gates and Floodwall without Gates*: These two measures involve installing a reinforced concrete floodwall, which works automatically without human assistance, constructed to a maximum of four feet above grade (ground level). The floodwall with gates is built with passive flood gates that are designed to open or close automatically due to the hydrostatic pressure caused by the floodwater. The floodwall without gates is built using vehicle ramps or pedestrian stairs to avoid the need for passive flood gates.
- *Levee with Gates and Levee without Gates*: These two measures involve installing an earthen levee around a home, which works automatically without human assistance, with a clay or concrete core constructed to a maximum of six feet above grade (ground level). The levee with gates is built with passive flood gates that are designed to open or close automatically due to hydrostatic pressure caused by the floodwater. The levee without gates is built using vehicle access ramps to avoid the need for passive flood gates.

Modifying a residential or non-residential building to protect it from flood damage requires extreme care, will require permits, and may also require complex, engineered designs. Therefore, the following process is recommended to ensure proper and timely completing of any floodproofing project (FEMA 2015b):

- Consult a registered design professional (i.e. architect or engineer) who is qualified to deal with the specifics of a flood mitigation project
- Check your community's floodplain management ordinances
- Contact your insurance agent to find out how your flood insurance premium may be affected
- Check what financial assistance might be available

- Hire a qualified contractor
- Contact the local building department to learn about development and permit requirements and to obtain a building permit
- Determine whether the mitigation project will trigger a Substantial Improvement declaration
- See the project through to completion
- Obtain an elevation certificate and an engineering certificate (if necessary)

No cost estimates were prepared for this alternative due to the variable and case-by-case nature of the flood mitigation strategy. Local municipal leaders should contact residential and non-residential building owners that are currently at a high flood risk to inform them about floodproofing measures, the recommended process to complete a floodproofing project, and the associated costs and benefits.

8.7 Alternative #4-7: Area Preservation / Floodplain Ordinances

This alternative proposes municipalities within the Crooked Brook watershed consider watershed and floodplain management practices such as preservation and / or conservation of areas along with land use ordinances that could minimize future development of sensitive areas such as wetlands, forests, riparian areas, and other open spaces. It could also include areas in the floodplain that are currently free from development and providing floodplain storage.

A watershed approach to planning and management is an important part of water protection and restoration efforts. New York State's watersheds are the basis for management, monitoring, and assessment activities. The NYS Open Space Conservation Plan, NYSDEC's Smart Growth initiative and the Climate Smart Communities Program address land use within a watershed (NYSDEC [date unknown]). Land use planning should be incorporated into a municipalities comprehensive plan or, if a comprehensive plan does not exist, passed as a series of ordinances that consider more restrictive floodplain development regulations besides the New York State minimum requirements.

Natural floodplains provide flood risk reduction benefits by slowing runoff and storing flood water. They also provide other benefits of considerable economic, social, and environmental value that should be considered in local land-use decisions. Floodplains frequently contain wetlands and other important ecological areas which directly affect the quality of the local environment. Floodplain management is the operation of a community program of preventive and corrective measures to reduce the risk of current and future flooding, resulting in a more resilient community. These measures take a variety of forms, are carried out by multiple stakeholders with a vested interest in responsible floodplain management, and generally include requirements for zoning, subdivision, or building, building codes and special-purpose floodplain ordinances. While FEMA has minimum floodplain management standards for communities participating in the NFIP, best practices demonstrate the adoption of higher standards which will lead to safer, stronger, and more resilient communities (FEMA 2006).

Further hydrology and hydraulic model scenarios could be performed to illustrate how future watershed and floodplain management techniques could benefit the communities within the Crooked Brook watershed.

8.8 Alternative #4-8: Community Flood Awareness and Preparedness Programs / Education

Disaster resilience encompasses both the principles of preparedness and reaction within the dynamic systems and focuses responses on bridging the gap between pre-disaster activities and post-disaster intervention and among structural / non-structural mitigation. Integral to these concepts is the role of the community itself, and how the community adapts to being prepared for disasters and, ultimately, how the community takes on the effort of disaster risk reduction. By consulting the community at risk, the local stakeholder concerns can be taken into consideration, and thus be addressed accordingly in the post-disaster recovery stage (Nifa et al. 2017).

Community flood awareness programs should focus on a multi-scale, holistic strategy of preparedness and resilience and in this way attempt to achieve a substantial reduction of disaster losses, in lives, and in the social, economic, and environmental assets of the community. This approach should incorporate four functions of flood education (Dufty 2008):

1. Preparedness conversion: learning related to commencing and maintaining preparations for flooding.
2. Mitigation behaviors: learning and putting into practice the appropriate actions for before, during and after a flood.
3. Adaptive capability: learning how to change and maintain adaptive systems (e.g. warning systems) and build community competencies to help minimize the impacts of flooding.
4. Post-flood learnings: learning how to improve preparedness levels, mitigation behaviors and adaptive capability after a flood.

In developing a program, community leaders should consider a commitment to community participation in the design, implementation, and evaluation of flood education programs. A more participatory approach to community flood and other hazards can enhance community resilience to adversity by stimulating participation and collaboration of stakeholders and decision makers in building its capability for preparedness, response, and recovery. In addition, community flood education programs should be ongoing as it is unsure when a flood event will occur (Dufty 2008).

8.9 Alternative #4-9: Development of a Comprehensive Plan

Local governments are responsible for planning in a number of areas, including housing, transportation, water, open space, waste management, energy, and disaster preparedness. In New York State, these planning efforts can be combined into a comprehensive plan that steers investments by local governments and guides future development through zoning regulations. A comprehensive plan will guide the development of government structure as well as natural and built environment.

Significant features of comprehensive planning in most communities include its foundations for land use controls for the purpose of protecting the health, safety, and general welfare of the community's citizens. The plan will focus on immediate and long-range protection, enhancement, growth, and development of a community's assets. Materials included in the comprehensive plan will include text and graphics, including but not limited to maps, charts, studies, resolutions, reports, and other descriptive materials. Once the comprehensive plan is completed, the governing board motions to adopt it, i.e. town or village board (EFC 2015).

Development of a comprehensive plan in general is optional, as is the development of a plan in accordance with state comprehensive plan statutes. However, statutes can guide plan developers through the process. Comprehensive plans provide the following benefits to municipal leaders and community members (EFC 2015):

- Provides a legal defense for regulations
- Provides a basis for other actions affecting the development of the community (i.e. land use planning and zoning)
- Helps establish policies relating to the creation and enhancement of community assets

All communities within the watershed should develop or update their respective comprehensive plans in an effort to coordinate and manage any and all land use changes and development within the Crooked Brook floodplain.

In addition, any comprehensive plan developed for communities within the watershed should include future climate change and NYS Smart Growth practices. Local governments should incorporate sustainability elements throughout the comprehensive plan. "Future-proofing" management and mitigation strategies by taking climate change into consideration would ensure that any strategy pursued would have the greatest possible chance for success. NYS Smart Growth practices would maximize the social, economic, and environmental benefits from public infrastructure development, while minimizing unnecessary environmental degradation, and disinvestment in urban and suburban communities caused by the development of new or expanded infrastructure.

9. NEXT STEPS

Before selecting a flood mitigation strategy, securing funding, or commencing an engineering design phase, Ramboll recommends that additional modeling simulations and wetland investigations be performed.

9.1 ADDITIONAL DATA MODELING

Additional data collection and modeling would be necessary to more precisely model water surface elevations and the extent of potential flooding in overbank areas and the floodplain. 2-D unsteady flow modeling using the HEC-RAS program would incorporate additional spatial information in model simulations producing more robust results with a higher degree of confidence than the currently modeled 1-D steady flow simulations. 2-D ice simulations are highly recommended to access the wintery condition with the suggested alternatives to evaluate the water level rises due to presence of ice, ice-jam, or break-up ice jam conditions.

9.2 STATE / FEDERAL WETLANDS INVESTIGATION

Any flood mitigation strategy that proposes using wetlands in any capacity, needs to be evaluated based on federal and state wetland criteria before that mitigation strategy can be pursued for final consideration.

9.3 EXAMPLE FUNDING SOURCES

There are numerous potential funding programs and grants for flood mitigation projects that may be used to offset municipal financing, including:

- New York State Office of Emergency Management (NYSOEM)
- New York State Department of Transportation Bridge NY Program
- Regional Economic Development Councils / Consolidated Funding Applications (CFA)
- Natural Resources Conservation Services (NRCS) Emergency Watershed Protection (EWP) Program
- FEMA's Unified Hazard Mitigation Assistance (HMA) Program
- FEMA's Safeguarding Tomorrow through Ongoing Risk Mitigation (STORM) Act
- USACE Continuing Authorities Program (CAP)
- Chautauqua County 2% Occupancy Tax Grant Program for Lakes and Waterways

9.3.1 NYS Office of Emergency Management (NYSOEM)

The NYSOEM, through the U.S. Department of Homeland Security (DHS), offers several funding opportunities under the Homeland Security Grant Program (HSGP). The priority for these programs is to provide resources to strengthen national preparedness for catastrophic events. These include improvements to cybersecurity, economic recovery, housing, infrastructure systems, natural and cultural resources, and supply chain integrity and security. In 2018, there was no cost share or match requirement.

9.3.2 NYSDOT Bridge NY Program

The NYSDOT, in accordance with Governor Andrew Cuomo's infrastructure initiatives, announced the creation of the Bridge NY program. The Bridge NY program provides enhanced assistance for local governments to rehabilitate and replace bridges and culverts. Particular emphasis will be provided for projects that address poor structural conditions; mitigate weight restrictions or detours; facilitate economic development or increase competitiveness; improve resiliency and / or reduce the risk of flooding.

The program is currently open and accepting applications from local municipalities through the State Fiscal Years 2020-21 and 2021-22. A minimum of $200 million was made available for awards in enhanced funding under the Bridge NY program for local system projects during the two-year period. More funding may be added to either the bridge or culvert program if it becomes available after the announcement of the solicitation

Current program draft application submittals for pre-review must be received by April 14, 2021 for culvert applications and May 5, 2021 for bridge applications.

9.3.3 Regional Economic Development Councils / Consolidated Funding Applications (CFA)

The Consolidated Funding Application is a single application for state economic development resources from numerous state agencies. The ninth round of the CFA was offered in 2019.

9.3.3.1 Water Quality Improvement Project (WQIP) Program

The Water Quality Improvement Project Program, administered through the Department of Environmental Conservation, is a statewide reimbursement grant program to address documented water quality impairments. Eligible parties include local governments and not-for-profit corporations. Funding is available for construction / implementation projects; projects exclusively for planning are not eligible. Match for WQIP is a percentage of the award amount, not the total project cost. Deadlines are in accordance with the CFA application cycle.

9.3.3.2 Climate Smart Communities (CSC) Grant Program

The Climate Smart Communities (CSC) Grant Program is a 50/50 matching grant program for municipalities under the New York State Environmental Protection Fund, offered through the CFA by the NYS Office of Climate Change. The purpose of the program is to fund climate change adaptation and mitigation projects, and includes support for projects that are part of a strategy to become a Certified Climate Smart Community. The eligible project types that may be relevant include the following:

- The construction of natural resiliency measures, conservation or restoration of riparian areas and tidal marsh migration areas

- Nature-based solutions such as wetland protections to address physical climate risk due to water level rise, and / or storm surges and / or flooding
- Relocation or retrofit of facilities to address physical climate risk due to water level rise, and / or storm surges and / or flooding
- Flood risk reduction
- Climate change adaptation planning and supporting studies

Eligible projects include implementation and certification projects. Deadlines are in accordance with the CFA cycle.

9.3.4 NRCS Emergency Watershed Protection (EWP) Program

Through the Emergency Watershed Protection (EWP) Program, the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) can assist communities in addressing watershed impairments that pose imminent threats to lives and property. Most EWP projects involve the protection of threatened infrastructure from continued stream erosion. Projects must have a project sponsor, defined as a legal subdivision of the state, such as a city, county, general improvement district, or conservation district, or an Indian Tribe or Tribal organization. Sponsors are responsible for providing land rights to do repair work, securing the necessary permits, furnishing the local cost share (25 percent), and performing any necessary operation and maintenance for a ten-year period. Through EWP, the NRCS may pay up to 75 percent of the construction costs of emergency measures, with up to 90 percent paid for projects in limited-resource areas. The remaining costs must come from local services. Eligible projects include, but are not limited to, debris-clogged stream channels, undermined and unstable streambanks, and jeopardized water control structures and public infrastructures.

9.3.5 FEMA Hazard Mitigation Grant Program (HMGP)

The Federal Emergency Management Agency's Hazard Mitigation Grant Program (HMGP), offered by the New York State Division of Homeland Security and Emergency Services (NYSDHSES), provides funding for creating / updating hazard mitigation plans and implementing hazard mitigation projects. The HMA program consolidates the application process for FEMA's annual mitigation grant programs not tied to a State's Presidential disaster declaration. Funds are available under the Building Resilient Infrastructure and Communities (BRIC) and the Flood Mitigation Assistance (FMA) Programs.

For flood mitigation measures that are being considered for funding through FEMA grant programs, a benefit-to-cost analysis will be required. In order to qualify for FEMA grants and / or funding, the benefit to cost ratio must be greater than one.

9.3.5.1 Building Resilient Infrastructure and Communities (BRIC)

Beginning in 2020, the Building Resilient Infrastructure and Communities (BRIC) grant program, which was created as part of Disaster Recovery Reform Act of 2018 (DRRA), replaced the existing Pre-Disaster Mitigation (PDM) program and is funded by a six percent set-aside from federal post-disaster grant expenditures. BRIC will support states, local communities, tribes and territories as they undertake hazard mitigation projects, reducing the risks they face from disasters and natural hazards. BRIC aims to categorically shift the federal focus away from reactive disaster spending and toward research-supported, proactive investment in community resilience. Through BRIC, FEMA will invest in a wide variety of mitigation activities, including community-wide public infrastructure projects. Moreover, FEMA anticipates BRIC will fund projects that demonstrate innovative approaches to partnerships, such as shared funding mechanisms and/or project design.

9.3.5.2 Flood Mitigation Assistance (FMA) Program

The Flood Mitigation Assistance Program provides resources to reduce or eliminate long-term risk of flood damage to structures insured under the National Flood Insurance Program. The FMA project funding categories include Community Flood Mitigation – Advance Assistance (up to $200,000 total federal share funding) and Community Flood Mitigation Projects (up to $10 million total). Federal funding is available for up to 75% of the eligible activity costs. FEMA may contribute up to 100% federal cost share for severe repetitive loss properties, and up to 90% cost share for repetitive loss properties. Eligible project activities include the following:

- Infrastructure protective measures
- Floodwater storage and diversion
- Utility protective measures
- Stormwater management
- Wetland restoration / creation
- Aquifer storage and recovery
- Localized flood control to protect critical facility
- Floodplain and stream restoration
- Water and sanitary sewer system protective measures

9.3.6 FEMA's Safeguarding Tomorrow through Ongoing Risk Mitigation (STORM) Act

The STORM Act provides capitalization grants to participating states and tribes in order to loan money to local governments for hazard mitigation projects to reduce risks from disasters and natural hazards. The act states that $100 million would be authorized for fiscal years 2022 and 2023. As loans are repaid, the funds are available for other mitigation project loans.

This “resilience revolving loan fund” will be eligible for projects intended to protect against wildfires, earthquakes, flooding, storm surges, chemical spills, seepage resulting from chemical spills and floods, and any other event deemed catastrophic by FEMA. These low-interest funds will allow for cities and states to repay the loan with savings from mitigation projects. It also gives states and localities the flexibility to respond to oncoming disasters without paying high-interest rates so they can invest in their communities.

9.3.7 USACE Continuing Authorities Program (CAP)

The Corps' Continuing Authorities Program (CAP) is a group of nine legislative authorities under which the Corps of Engineers can plan, design, and implement certain types of water resources projects without additional project specific congressional authorization. The purpose of the CAP is to plan and implement projects of limited size, cost, scope and complexity. Table 15 lists the CAP authorities and their project purposes (USACE 2019a).

Table 15. USACE Continuing Authorities Program (CAP) authorities and project purposes

(Source: USACE 2019a)

Authority	**Project Purpose**
Section 14, Flood Control Act of 1946, as amended	Streambank and shoreline erosion protection of public works and non-profit public services
Section 103, River and Harbor Act of 1962, as amended (amends Public Law 79-727)	Beach erosion and hurricane and storm damage reduction
Section 107, River and Harbor Act of 1960, as amended	Navigation improvements
Section 111, River and Harbor Act of 1968, as amended	Shore damage prevention or mitigation caused by Federal navigation projects
Section 204, Water Resources Development Act of 1992, as amended	Beneficial uses of dredged material
Section 205, Flood Control Act of 1948, as amended	Flood control
Section 206, Water Resources Development Act of 1996, as amended	Aquatic ecosystem restoration
Section 208, Flood Control Act of 1954, as amended (amends Section 2, Flood Control Act of August 28, 1937)	Removal of obstructions, clearing channels for flood control
Section 1135, Water Resources Development Act of 1986, as amended	Project modifications for improvement of the environment

All projects in this program include a feasibility phase and an implementation phase. Planning activities, such as development of alternative plans to achieve the project goals, initial design and cost estimating, environmental analyses, and real estate evaluations, are performed during the feasibility phase, to develop enough information to decide whether to implement the project. The feasibility phase is initially Federally funded up to $100,000. Any remaining feasibility phase costs are shared 50/50 with the non-Federal sponsor after executing a feasibility cost sharing agreement (FCSA). The final design, preparation of contract plans and specifications, permitting, real estate acquisition, project contracting and construction, and any other activities required to construct or implement the approved project are completed during the implementation phase. The Corps and the non-federal sponsor sign a project partnership agreement (PPA) near the beginning of the implementation phase. Costs beyond the feasibility phase are shared as specified in the authorizing legislation for that section (USACE 2019a).

9.3.8 Chautauqua County 2% Occupancy Tax Grant Program for Lakes and Waterways

Chautauqua County collects a 2% occupancy tax to collect revenue to fund projects in the county which provide water quality benefits. Grants are available in amounts ranging from $500 to $40,000. Grant funding has been used for roadway drainage, agriculture, stormwater, streambank, and lakeshore projects. An application for an erosion control project along Village Park in the village of Silver Creek is currently under review, with construction scheduled to begin in 2021 (Chautauqua County 2019).

10. SUMMARY

The City of Dunkirk has had a history of flooding events along Crooked Brook. Flooding along Crooked Brook generally occurs in the summer and early winter months due to heavy rain or rain on saturated soil events. The situation is compounded by restrictive and undersized waterway crossings, which can become overwhelmed or accumulate debris and clog openings potentially causing backwater flooding as a result. The heavily developed lower reaches of Crooked Brook, primarily in the City of Dunkirk, are at considerable risk of flood damages due to the close proximity of residential and commercial properties to the creek banks and topography of the floodplain in the City. In addition, high winds and elevated lake water levels from Lake Erie can cause localized flooding along the shoreline, which has intensified in recent years (NYSDEC 2020b). In response to repetitive flooding events in recent years, the State of New York in conjunction with the City of Dunkirk and Chautauqua County are studying, addressing, and recommending potential flood mitigation projects for Crooked Brook as part of the Resilient NY Initiative.

This report analyzed the historical and present day causes of flooding in the Crooked Brook watershed. Hydraulic and hydrologic data was used to model potential flood mitigation measures. The model simulation results indicated that there are flood mitigation measures that have the potential to reduce water surface elevations along high-risk areas of Crooked Brook, which could potentially reduce flood related damages in areas adjacent to the creek. Constructing multiple flood mitigation measures would increase the overall flood reduction potential along Crooked Brook by combining the reduction potential of the mitigation measures being constructed.

Based on the flood mitigation analyses performed in this report, the mitigation measures that provided the greatest reductions in water surface elevations were the bridge and culvert upsizing measures. The upsizing measures associated with the West Lucas Avenue, Norfolk and Western Railroad, and Central Avenue culverts provided the most significant reductions in water surface elevations according to the H&H model simulation results. A flood mitigation measure in this reach would benefit numerous residential, commercial, and City owner properties and infrastructure.

There would be an overall greater effect in water surface elevations if multiple alternatives were built along Crooked Brook in different phases, rather than a single mitigation project. For example, upsizing multiple bridges / culverts along a single reach would compound the flood mitigation benefits of each measure.

However, structural upsizing measures generally are costly flood mitigation measures. The benefits of these measures in their respective reaches should be balanced with the associated costs of each upsizing measure to determine if it would be feasible to move an upsizing measure forward. In addition, other complications, such as traffic re-routing, should be taken into account when considering any of the structural upsizing measures.

The flood bench measures discussed for Crooked Brook would provide moderate flood mitigation benefits in their respective reaches. Flood benches, however, generally only benefit the areas immediately adjacent to and upstream of the constructed bench. Due to the heavily developed nature of the Crooked Brook floodplain, very few areas were found to be adequate for large scale flood benches that could potentially provide greater flood mitigation protections to historically vulnerable areas along Crooked Brook. In addition, flood bench measures generally tend to be the costliest of flood mitigation projects when compared to other measures discussed in this report. The benefits of these measures in their respective reaches should be balanced with the associated costs of each flood bench measure to determine if it would be feasible to move a flood bench project forward.

The outlet of Crooked Brook into Lake Erie has historically been a source of flooding caused primarily by large flows from heavy precipitation events or backwater from Lake Erie, and is often exacerbated by sediment buildup at the outlet. Flood mitigation and sediment management measures at the outlet of Crooked Brook can potentially reduce flood risk by reducing sediment buildup and increasing the channel flow area of Crooked Brook. However, any construction, dredging, excavating, etc. in the channel or at the outlet would need to meet strict local, state, and national construction and permitting requirements and restrictions.

The debris maintenance around waterway crossing infrastructure, riparian restoration, and retention basin and wetland management measures would maintain the flow channel area in Crooked Brook, help to reduce and / or manage runoff into the waterway during precipitation events, trap and / or reduce sediment entering the waterway, and improve overall water quality. Sediment and debris that enters the waterway reduces the channel flow area, which over time can reduce the flow capacity of the channel and potentially lead to greater occurrences of and more damaging flooding.

Floodproofing and flood buyout programs are effective mitigation measures but require large financial investments in individual residential and non-residential buildings. Floodproofing can reduce the future risk and flood damage potential but leaves buildings in flood risk areas so that potential for future flood damages remains. Flood buyout programs eventually lead to the removal of buildings from the floodplain. A benefit to floodproofing versus buyouts is that properties remain in the Village and the tax base for the local municipality remains intact. Floodproofing versus flood buyouts should be considered on a case-by-case basis with all associated benefits and drawbacks.

For flood mitigation measures that are being considered for funding through FEMA grant programs, a benefit-to-cost analysis will be required. In order to qualify for FEMA grants and / or funding, the benefit to cost ratio must be greater than one. Flood buyout programs can qualify for FEMA grant programs with a 75% match of funds. The remaining 25% of funds is the responsibility of state, county, and local governments. The case-by-case nature of buyouts requires widespread property owner participation to maximize flood risk reductions. An unintended consequence of buyout programs is the permanent removal of properties from the floodplain, including tax revenue, which would have long-term implications for local governments and should be considered prior to implementing a buyout program. Table 16 is a summary of the proposed flood mitigation measures, including modeled water surface elevation reductions and estimated ROM costs.

Table 16. Summary of Flood Mitigation Measures

Alternative No.	Description	Benefits Related to Alternative	ROM cost ($U.S. dollars)
1-1	Jetty at Confluence with Lake Erie	Model simulated WSEL reduction of up to 0.5-ft	$870,000 *
1-2	Sediment / Debris Management at Mouth	Improves water quality and increases channel flow area	$160,000 **
1-3	Revetments	Protects coastal structures and shorelines and helps to reduce / manage longshore sediment transport	$750,000 *
1-4	Increase Size of Crooked Brook Drive Culvert	Model simulated WSEL reduction of up to 0.8-ft	$730,000 **
2-1	Flood Bench Near Confluence with Unnamed Tributary	Model simulated WSEL reduction of up to 0.3-ft	$1,110,000 **
2-2	Flood Control Structure / Reservoir Near Confluence with Unnamed Tributary	Limits flood extents and depths downstream and helps with sediment transport	N/A
2-3	Remove West Point Avenue Culvert	Model simulated WSEL reduction of up to 0.9-ft	$40,000 **
2-4	Increase Size of CSX Railroad Bridge Crossing	Model simulated WSEL reduction of up to 2.8-ft	$1,460,000 ***
2-5	Install Crossing Pipes into CSX Railroad Bridge Embankment	Model simulated WSEL reduction of up to 2.1-ft	$590,000 ***
2-6	Flood Bench Upstream of Railroad Bridge Crossing	No significant reduction in model simulated WSELs	$530,000 **
3-1	Install Flood Bench Downstream of West 6th Street	Model simulated WSEL reduction of up to 0.6-ft	$540,000 **

Alternative No.	Description	Benefits Related to Alternative	ROM cost ($U.S. dollars)
3-2	Install Flood Bench Upstream Adjacent to DHS Baseball Field	Model simulated WSEL reduction of up to 0.4-ft	$310,000 **
3-3	Increase Size of Lucas Avenue Culvert	Model simulated WSEL reduction of up to 5.3-ft	$840,000 **
3-4	Replace Pipe Culverts with Box Culvert Under Norfolk and Western Railroad Bridge Crossing	Model simulated WSEL reduction of up to 3.5-ft	$660,000 ***
3-5	Install Additional Crossing Pipes into Norfolk and Western Railroad Bridge Embankment	Model simulated WSEL reduction of up to 4.2-ft	$530,000 ***
3-6	Increase Size of West Howard Avenue Culvert	Model simulated WSEL reduction of up to 0.8-ft	$470,000 **
3-7	Replace Arch-culvert with Box Culvert Under Central Avenue	No significant reduction in model simulated WSELs	$230,000 **
3-8	Increase Size of Central Avenue Culvert	Model simulated WSEL reduction of up to 3.5-ft	$760,000 **
3-9	Flood Control Structure / Reservoir Upstream of Central Avenue	Limits flood extents and depths downstream and helps with sediment transport	N/A
4-1	Early-warning Flood Detection System	Early flood warning for open water and ice-jam events	$120,000 ****
4-2	Riparian Restoration	Restores natural habitats, reduces / manages runoff, and improves water quality	Variable (case-by-case)
4-3	Debris Maintenance Around Culverts / Bridges	Maintains channel flow area and reduces flood risk	$20,000 ****
4-4	Retention Basin and Wetland Management	Reduces erosion, traps sediments, reduces / manages runoff, and improves water quality	Variable (case-by-case)

Alternative No.	Description	Benefits Related to Alternative	ROM cost ($U.S. dollars)
4-5	Flood Buyouts Program	Reduces and / or eliminates future losses	Variable (case-by-case)
4-6	Floodproofing	Reduces and / or eliminates future damages	Variable (case-by-case)
4-7	Area Preservation / Floodplain Ordinances	Reduces and / or eliminates future losses	Variable (case-by-case)
4-8	Community Flood Awareness and Preparedness Programs / Education	Engages the community to actively participate in flood mitigation and better understand flood risks	Variable (case-by-case)
4-9	Development of a Comprehensive Plan	Guides future development, provides legal defense for regulations, and helps establish policies related to community assets	Variable (case-by-case)

* Note: This estimate does not include the additional engineering, modeling, permitting requirements and / or maintenance costs.

** Note: This estimate does not include land acquisition costs for survey, appraisal, and engineering coordination.

*** Note: This estimate does not include land acquisition costs for survey and appraisal, permitting, additional engineering and coordination, and special inspection requirements.

**** Note: This estimate does not include annual operational costs.

11. CONCLUSION

Municipalities affected by flooding along Crooked Brook can use this report to support flood mitigation initiatives within their communities. This report is intended to be a high-level overview of proposed flood mitigation strategies and their potential impacts on water surface elevations in Crooked Brook. The research and analysis that went into each proposed strategy should be considered preliminary, and additional research, field observations, and modeling are recommended before final mitigation strategies are chosen.

In order to implement the flood mitigation strategies proposed in this report, communities should engage in a process that follows the following steps:

1. Obtain stakeholder and public input to assess the feasibility and public support of each mitigation strategy presented in this report.
2. Complete additional data collection and modeling efforts to assess the effectiveness of the proposed flood mitigation strategies.
3. Develop a list of final flood mitigation strategies based on the additional data collection and modeling results.
4. Select a final flood mitigation strategy or series of strategies to be completed for Crooked Brook based on feasibility, permitting, effectiveness, and available funding.
5. Develop a preliminary engineering design report and cost estimate for each selected mitigation strategy.
6. Assess funding sources for the selected flood mitigation strategy.

Once funding has been secured and the engineering design has been completed for the final mitigation strategy, construction and / or implementation of the measure should begin.

12. REFERENCES

Angel JR, Kunkel KE. 2010. The response of Great Lakes water levels to future climate scenarios with an emphasis on Lake Michigan-Huron. Ann Arbor (MI): Journal of Great Lakes Research 36(2): pp 51–58.

Appelquist LR, Halsnaes K. 2015. The Coastal Hazard Wheel System for Coastal Multi-Hazard Assessment & Management in a Changing Climate. Journal of Coastal Conservation 19(2): pp 157-179.

Appelquist LR, Balstrom T, Halsnaes K. 2016. Managing Climate Change Hazards in Coastal Areas: The Coastal Hazard Wheel Decision-Support System, Catalogue of Hazard Management Options. Nairobi (KE): United Nations Environment Programme. Available from: https://www.coastalhazardwheel.org/media/1217/main-manual-coastal-hazard-wheel.pdf.

Bureau of Public Roads (BPR). 1963. Hydraulic Engineering Circular No. 4, Estimating Peak Rates of Runoff from Small Watersheds in Portions of New York. Washington D.C. (US): United States Department of Commerce (USDOC). Available from: USDOC.

Chautauqua County. 2019. Applications Available in January for Chautauqua County Occupancy Tax Grant Program for Lakes and Waterways. Mayville (NY): Chautauqua County. Available from: https://chqgov.com/county-executive/news/applications-available-january-chautauqua-county-occupancy-tax-grant-program.

[CRREL] Cold Regions Research and Engineering Laboratory. [Internet]. 2021. Ice Jam Database. Hanover (NH): U.S. Geologic Survey (USGS). [updated 2021 Jan 31; cited 2021 Mar 5]. Available from: https://icejam.sec.usace.army.mil/.

Dufty N. 2008. A new approach to community flood education. East Melbourne (AU): The Australian Journal of Emergency Management. 23(2): pp 3-7.

Environmental Finance Center (EFC). 2015. New York State Comprehensive Plan Development: A Guidebook for Local Officials. Syracuse (NY): Syracuse University, Environmental Finance Center (EFC). Available from: https://efc.syr.edu/wp-content/uploads/2015/03/ComprehensivePlanning.pdf.

[ESRI] Environmental Systems Research Institute. [software]. 2019. ArcGIS for Desktop 10.7.1. Redlands (CA): Environmental Systems Research Institute (ESRI); [updated 2019 June 27; cited 2021 Mar 5]. Available from: https://support.esri.com/en/Products/Desktop/arcgis-desktop/arcmap/10-7-1#overview.

Federal Emergency Management Agency (FEMA). 1984. Flood Insurance Study, Town of Pomfret, Chautauqua County, New York. Washington DC (US): United States Department of Homeland Security (USDHS). Available from: FEMA.

[FEMA] Federal Emergency Management Agency. [Internet]. 1996. Q3 Flood Data, Chautauqua County, New York. Washington DC (US): United States Department of Homeland Security (USDHS); [updated 1996 June 24; cited 2021 Mar 5]. Available from: http://gis.ny.gov/gisdata/inventories/details.cfm?DSID=246.

Federal Emergency Management Agency (FEMA). 2000. Title 44. Emergency Management and Assistance Chapter I. Federal Emergency Management Agency, Department of Homeland Security Subchapter B. Insurance and Hazard Mitigation. Washington, D.C. (US): United States Department of Homeland Security (USDHS). Available from: FEMA.

Federal Emergency Management Agency (FEMA). 2006. Floodplain Management Requirements: A Study Guide and Desk Reference for Local Officials. Washington DC (US): United States Department of Homeland Security (USDHS). Available from: https://www.fema.gov/media-library-data/20130726-1539-20490-9157/nfip_sg_full.pdf.

Federal Emergency Management Agency (FEMA). 2013. Floodproofing Non-Residential Buildings. Washington, D.C. (US): United States Department of Homeland Security (USDHS). Report No.: FEMA P-936. Available from: https://www.fema.gov/media-library/assets/documents/34270.

Federal Emergency Management Agency (FEMA). 2015. Reducing Flood Risk to Residential Buildings That Cannot Be Elevated. Washington, D.C. (US): United States Department of Homeland Security (USDHS). Report No.: FEMA P-1037. Available from: https://www.fema.gov/media-library/assets/documents/109669.

Federal Emergency Management Agency (FEMA). [Internet]. 2019. Repetitive Loss and Severe Repetitive Loss dataset. Washington, D.C. (US): United States Department of Homeland Security; [updated 2019 May 3; cited 2021 Mar 5]. Available from: FEMA.

[FEMA] Federal Emergency Management Agency. [Internet]. 2020a. National Flood Insurance Program Terminology Index. Washington DC (US): United States Department of Homeland Security (USDHS); [updated 2020 Jul 18; cited 2021 Mar 30]. Available from: https://www.fema.gov/flood-insurance/terminology-index.

[FEMA] Federal Emergency Management Agency. [Internet]. 2020b. OpenFEMA Dataset: FIMA NFIP Redacted Claims. Washington DC (US): United States Department of Homeland Security (USDHS); [updated 2020 Jul 22; cited 2021 May 6]. Available from: https://www.fema.gov/openfema-data-page/fima-nfip-redacted-claims.

Federal Emergency Management Agency (FEMA). 2021a. Erie County, New York (All Jurisdictions) - Preliminary. Washington, D.C. (US): United States Department of Homeland Security; [cited 2021 Mar 25]. Available from: FEMA.

Federal Emergency Management Agency (FEMA). 2021b. FEMA Flood Map Service Center (MSC) - National Flood Hazard Layer (NFHL). Washington, D.C. (US): United States Department of Homeland Security; [updated 2021 Mar 26; cited 2021 Mar 31]. Available from: https://msc.fema.gov/portal/home.

Federal Insurance Administration (FIA). 1980. Flood Insurance Study, City of Dunkirk, New York, Chautauqua County. Washington, D.C. (US): Federal Emergency Management Agency (FEMA). Available from: FEMA.

Federal Insurance Administration (FIA). 1981. FIRM Flood Insurance Rate Map, City of Dunkirk, New York, Chautauqua County. Washington, D.C. (US): Federal Emergency Management Agency (FEMA). Available from: FEMA.

Goodwin CN, Hawkins CP, Kershner JL. 1997. Riparian Restoration in the Western United States. Washington DC (US): Society for Ecological Restoration. 5(4S): pp 4-14.

[GLERL] Great Lakes Environmental Research Laboratory. [Internet]. 2020. The Great Lakes Dashboard – Water Levels – Lake Erie. Ann Arbor (MI): National Oceanic and Atmospheric Administration (NOAA). [updated 2020 December 31; cited 2021 Mar 25]. Available from: https://www.glerl.noaa.gov/.

Hayhoe K, VanDorn J, Croley II T, Schlegal N, Wuebbles D. 2010. Regional climate change projections for Chicago and the US Great Lakes. Ann Arbor (MI): Journal of Great Lakes Research 36(2): pp 7-21.

Helms, D. 1986. Legacy of the Flood Control Act of 1936. In: Rosen H, Reuss M, editors. The Flood Control Challenge: Past, Present, and Future: Proceedings of a National Symposium, 1988. Chicago (IL): Public Works Historical Society, pp. 67-88. Available from: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/about/history/?&cid=nrcs143_010953.

Lofgren BM, Hunter TS, Wilbarger J. 2011. Effects of using air temperature as a proxy for potential evapotranspiration in climate change scenarios of Great Lakes basin hydrology. Ann Arbor (MI): Journal of Great Lakes Research 37(4): pp 744-752.

Lumia, R. 1991. Regionalization of flood discharges for rural, unregulated streams in New York, excluding Long Island. Albany (NY): United States Geologic Survey (USGS). Report No.: WRI 90-4197. Available from: https://pubs.usgs.gov/wri/1990/4197/report.pdf.

Lumia R, Freehafer DA, Smith MJ. 2006. Magnitude and Frequency of Floods in New York. Troy (NY): United States Geologic Survey (USGS). Report No.: SIR2006-5112. Available from: https://pubs.usgs.gov/sir/2006/5112/.

MacKay M, Seglenieks F. 2012. On the simulation of Laurentian Great Lakes water levels under projections of global climate change. Toronto (CA): Climatic Change 117(1-2): pp 1-13.

Masselink G, Hughes MG. 2003. Introduction to Coastal Processes and Geomorphology. Oxford (UK): Oxford University Press. pp. 354.

McDonald, JH. 2014. Handbook of Biological Statistics. 3rd ed. Baltimore (MD): Sparky House Publishing. 299 p.

Mugade UR and Sapkale JB. 2015. Influence of Aggradation and Degradation on River Channels: A Review. International Journal of Engineering and Technical Research (IJETR). 3(6): 209-212. ISSN: 2321-0869.

Mulvihill CI, Baldigo BP, Miller SJ, DeKoskie D, DuBois J. 2009. Bankfull discharge and channel characteristics of streams in New York State. Troy (NY): United States Geological Survey (USGS). Report No.: SIR 2009–5144. Available from: http://pubs.usgs.gov/sir/2009/5144/.

[NASS] National Agricultural Statistics Service. [Internet]. 2019. 2018 New York Cropland Data Layer. Washington D.C. (US): United States Department of Agriculture

(USDA). [updated 2019 Feb 15; cited 2021 Mar 5]. Available from: https://nassgeodata.gmu.edu/CropScape/.

[NCEI] National Centers for Environmental Information. [Internet]. 2021. Storm Events Database: Erie County, NY. Asheville (NC): National Oceanic and Atmospheric Administration (NOAA); [updated 2021 Jan 31; cited 2021 Mar 5]. Available from: https://www.ncdc.noaa.gov/.

National Park Service [software]. 2014. National Register of Historic Places. Washington, D.C. (US): United States Department of the Interior [updated 2014 April; cited 2021 Mar 5]. Available from https://www.nps.gov/maps/full.html?mapId=7ad17cc9-b808-4ff8-a2f9-a99909164466.

National Research Council (NRC). 2007. Elevation Data for Floodplain Mapping. Washington, DC (US): The National Academies Press, Committee on Floodplain Mapping Technologies. Available from: https://www.nap.edu/catalog/11829/elevation-data-for-floodplain-mapping. ISBN: 0-309-66807-7.

Natural Resources Conservation Service (NRCS). 2002b. Water and Sediment Control Basin (No.) CODE 638. Lincoln (NE): United States Department of Agriculture (USDA). Report No.: 638-1. Available from: NRCS.

[NRCS] Natural Resources Conservation Service. [Internet]. 2019. Web Soil Survey 3.3. Lincoln (NE): United States Department of Agriculture (USDA). Available from: https://gdg.sc.egov.usda.gov/GDGOrder.aspx.

New York State Department of Environmental Conservation (NYSDEC). [date unknown]. Watershed Management. New York State Department of Environmental Conservation (NYSDEC) web site. [accessed 2020 Oct 12]. Available from: https://www.dec.ny.gov/lands/25563.html.

New York State Department of Environmental Conservation (NYSDEC). 2004. Technical & Operational Guidance Series (TOGS) 5.1.9 In-Water and Riparian Management of Sediment and Dredged Material. Albany (NY): New York State Department of Environmental Conservation. Available from: https://www.dec.ny.gov/docs/water_pdf/togs519.pdf.

[NYSDEC] New York State Department of Environmental Conservation. [Internet]. 2009. Inventory of Dams - New York State (NYSDEC). Albany (NY): New York State Department of Environmental Conservation, Division of Water, Dam Safety Section; [updated 2020 Mar 6; cited 2021 Mar 5]. Available from http://gis.ny.gov/.

New York State Department of Environmental Conservation (NYSDEC). 2013. Removal of Woody Debris and Trash from Rivers and Streams. Albany (NY): New York State Department of Environmental Conservation. Available from: https://www.dec.ny.gov/docs/permits_ej_operations_pdf/woodydebrisfact.pdf.

New York State Department of Environmental Conservation (NYSDEC). 2020a. New York State Flood Risk Management Guidance for Implementation of the Community Risk and Resiliency Act. Albany (NY): New York State Department of Environmental Conservation. Available from: https://www.dec.ny.gov/docs/administration_pdf/frmgpublic.pdf.

New York State Department of Environmental Conservation (NYSDEC). 2020b. Resilient New York – Crooked and Canadaway Creeks – Meeting 1 – Stakeholder Working Group Interviews. Albany (NY): Highland Planning LLC.

[NYSDEC] New York State Department of Environmental Conservation. [software]. 2021. Environmental Resource Mapper. Albany, NY: New York State Department of Environmental Conservation (NYSDEC); [cited 2021 Mar 5]. Available from https://gisservices.dec.ny.gov/gis/erm/.

New York State Department of Transportation (NYSDOT). 2006. Bridge Inventory Manual (2006 Edition). Albany (NY): New York State Department of Transportation (NYSDOT), Bridge Data Systems Unit. Available from: https://www.dot.ny.gov/divisions/engineering/structures/manuals/bridge-inventory-manual.

New York State Department of Transportation (NYSDOT). [Internet]. 2014. Culvert Point Locations & Select Attributes - New York State Department of Transportation. Albany (NY): New York State Department of Transportation, GIS Coordinator; [updated 2019 February 1; cited 2021 Mar 12]. Available from: https://gis.ny.gov/gisdata/inventories/details.cfm?DSID=1255.

[NYSDOT] New York State Department of Transportation. [Internet]. 2016. Bridge Point Locations & Select Attributes - New York State Department of Transportation. Albany (NY): New York State Department of Transportation, Structures Division; [updated 2019 Feb; cited 2021 Mar 8]. Available from http://gis.ny.gov/.

New York State Department of Transportation (NYSDOT). 2018. Highway Design Manual: Chapter 8 – Highway Drainage. New York State Department of Transportation (NYSDOT). Available from: https://www.dot.ny.gov/divisions/engineering/design/dqab/hdm.

[NYSDOT] New York State Department of Transportation. [Internet]. 2020. NYS Roadway Inventory System Geodatabase. Albany (NY): New York State Department of Transportation (NYSDOT), GIS Coordinator. Available from: https://gis.ny.gov/.

[NYSGS] New York State Geological Survey. [Internet]. 1999. Statewide Bedrock Geology. Albany (NY): New York State Museum (NYSM), Technology Center. Available from: http://www.nysm.nysed.gov/gis.html.

[NYSGPO] New York State Governor's Press Office. [Internet]. 2018 Nov 5. Governor Cuomo Announces $3 Million for Studies to Reduce Community Flood Risk. New York State Governor's Press Office. Available from: https://www.governor.ny.gov/news/governor-cuomo-announces-3-million-studies-reduce-community-flood-risk.

[NYSGPO] New York State Office of Information Technology Services GIS Program Office, New York State Department of Taxation and Finance's Office of Real Property Tax Services (ORPTS), Chautauqua County Real Property Tax Services (ECRPTS). [Internet]. 2020. NYS Statewide 2019 Parcels for Public Use. Albany (NY): New York State Office of Information Technology Services (NYSOITS). Available from: https://gis.ny.gov/.

[NYSOITS] New York State Office of Information Technology Services. [Internet]. 2017a. 2016 12-inch Resolution 4-Band Orthoimagery West Zone. Albany (NY): New York State Office of Information Technology Services (NYSOITS), GIS Program Office. Available from: http://gis.ny.gov/gateway/mg/.

[NYSOITS] New York State Office of Information Technology Services. [Internet]. 2017b. Southwest 17 - Spring, New York Lidar; Hydro Flattened Bare Earth DEM. Albany (NY): New York State Office of Information Technology Services (NYSOITS), GIS Program Office. Available from: http://gis.ny.gov/elevation/NYS-High-Res-DEM.htm.

Nifa FA, Abbas SR, Lin CK, Othman SN. 2017. Developing A Disaster Education Program for Community Safety and Resilience: The Preliminary Phase. Langkawi (MA): The 2nd International Conference on Applied Science and Technology: AIP Conference Proceedings. 1891(020005): pp 1-6.

Observer Today. [Internet]. 2020 Apr 14. Crooked Brook Flood. Dunkirk (NY): The Nutting Company, Ogden Newspapers. Available from: https://www.observertoday.com/news/local-region/2020/04/crooked-brook-flood/.

Ramboll Americas Engineering Solutions, Inc. (Ramboll). 2021. Field Measurements – Crooked Brook. Utica (NY): Ramboll Americas Engineering Solutions, Inc..

Ries KG III, Newson JK, Smith MJ, Guthrie JD, Steeves PA, Haluska TL, Kolb KR, Thompson RF, Santoro RD, Vraga HW. 2017. StreamStats, version 4.3.8: U.S. Geological Survey Fact Sheet 2017–3046. Reston (VA): United States Department of the Interior (USDOI); [updated 2019 Mar 4; cited 2021 Mar 5]. Available from: https://streamstats.usgs.gov/ss/.

Rosenzweig C, Solecki W, DeGaetano A, O'Grady M, Hassol S, Grabhorn P, editors. 2011. Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation. Albany (NY): New York State Energy Research and Development Authority (NYSERDA). Available from: www.nyserda.ny.gov.

Rosgen DL, Silvey HL. 1996. Applied River Morphology. 2nd edition. Fort Collins (CO): Wildland Hydrology Books. 378 p.

RSMeans Data Online [Software]. 2019. RS Means CostWorks 2019 Version 16.03. Rockland (MA): Gordian, Inc.; [updated 2019; cited 2021 Mar 5]. Available from: https://www.rsmeans.com/products/online.aspx.

Siders, AR. 2013. Anatomy of a Buyout – New York Post-Superstorm Sandy. In: The 16th Annual Conference Litigating Takings Challenges to Land Use and Environmental Regulations. New York (NY): New York University School of Law. Available from: https://www.researchgate.net/publication/308518538_Anatomy_of_a_Buyout_Program_--_New_York_Post-Superstorm_Sandy.

Taylor KE, Stouffer RJ, and Meehl GA 2011. An Overview of CMIP5 and the Experiment Design. Bulletin of the American Meteorological Society (BAMS) [Internet]. [cited 2021 Mar 29]; 93(4): 485-498. Available from: https://journals.ametsoc.org/doi/pdf/10.1175/BAMS-D-11-00094.1.

United States Army Corps of Engineers (USACE). 1973. Hydrologic Engineering Center, HEC-2 Water Surface Profiles, Generalized Computer Program. Davis (CA): United States Army Corps of Engineers (USACE) Hydrologic Engineering Center (HEC).

United States Army Corps of Engineers (USACE). 2016a. HEC-RAS River Analysis System User's Manual Version 5.0. Davis (CA): United States Army Corps of Engineers (USACE) Hydrologic Engineering Center (HEC). Report No.: CPD-68. Available from: USACE.

United States Army Corps of Engineers (USACE). 2016b. Lexington Green – Section 205 of the 1948 Flood Control Act – Flood Risk Management. Buffalo (NY): United States Army Corps of Engineers (USACE), Buffalo District. Report No.: P2#443918. Available from: USACE.

United States Army Corps of Engineers (USACE). 2019a. Continuing Authorities Program. Concord (MA): United States Army Corps of Engineers (USACE), New England District. Available from: https://www.nae.usace.army.mil/missions/public-services/continuing-authorities-program/.

United States Army Corps of Engineers (USACE). [software]. 2019b. HEC-RAS Version 5.0.7. Davis (CA): United States Army Corps of Engineers (USACE), Hydrologic Engineering Center (HEC). Available from: USACE.

United States Department of Homeland Security (USDHS). 2010. DHS Risk Lexicon – 2010 Edition. Washington, D.C. (US): United States Department of Homeland Security (USDHS). Available from: http://www.dhs.gov/xlibrary/assets/dhs-risk-lexicon-2010.pdf.

United States Environmental Protection Agency (USEPA). 2009. Stormwater Wet Pond and Wetland Management Guidebook. Washington DC (US): United States Environmental Protection Agency (USEPA). Report No.: EPA 833-B-09-001. Available from: https://www.epa.gov/sites/production/files/2015-11/documents/pondmgmtguide.pdf.

United States Fish and Wildlife Service (USFWS) [software]. 2021. Information for Planning and Consultation (IPaC). Washington, D.C. (US): Environmental Conservation Online System (ECOS); [cited 2020 August 6]. Available from https://ecos.fws.gov/ipac/.

United States Geological Survey (USGS). 1965. Water-Supply Paper 1677, Magnitude and Frequency of Floods in the United States, Part 4. St. Lawrence River Basin. Washington D.C. (US): United States Geological Survey (USGS), Water Resources Division. Report No.: WRI 34-75. Available from: USGS.

United States Geological Survey (USGS). 1973. Water Resources Data for New York, Part 1, Surface Water Records, Albany, New York, Published Annually 1963-1973. Albany (NY): United States Geological Survey (USGS), Water Resources Division. Available from: USGS.

United States Geological Survey (USGS). 1976. Flood in New York, 1972, With Special Reference to Tropical Storm Agnes. Albany (NY): United States Geological Survey

(USGS), Water Resources Division. Report No.: WRI 34-75. Available from: https://pubs.usgs.gov/wri/1975/0034/report.pdf.

United States Geologic Survey (USGS). 1978. Chapter 7: Physical basin characteristics from hydrologic analysis. In: National Handbook of Recommended Methods for Water-Data Acquisition. Reston (VA): United States Geologic Survey, Office of Water Data Coordination. Available from: USGS.

[USGS] United States Geologic Survey. [Internet]. 2013. USGS National Climate Change Viewer. Reston (VA): United States Department of the Interior, United States Geological Survey; [updated 2019 April 26; cited 2020 August 7]. Available from: https://www2.usgs.gov/landresources/lcs/nccv/viewer.asp.

[USGS] United States Geologic Survey. [Internet]. 2016. Application of Flood Regressions and Climate Change Scenarios to Explore Estimates of Future Peak Flows, version 1.5. Reston (VA): United States Geologic Survey (USGS); [updated 2016 May 19; cited 2020 July 8]. Available from: https://streamstats.usgs.gov/ss/.

[USGS] United States Geologic Survey. [Internet]. 2017. StreamStats, version 4.3.8. Reston (VA): United States Geologic Survey (USGS); [updated 2020 February 6; cited 2020 June 24]. Available from: https://streamstats.usgs.gov/ss/.

[USGS] United States Geologic Survey. [Internet]. 2019. Multi-Resolution Land Characteristics Consortium (MRLC) - National Land Cover Database (NLCD) 2016 Land Cover Conterminous United States. Sioux Falls (SD): United States Geologic Survey (USGS). Available from: https://www.mrlc.gov/data.

[USGS] United States Geologic Survey. [Internet]. 2020. NHD 20200622 for New York State or Territory Shapefile Model Version 2.2.1. Sioux Falls (SD): United States Geologic Survey (USGS), National Geospatial Program. Available from: https://www.sciencebase.gov/catalog/item/5a96cdc5e4b06990606c4d74.

United States Soil Conservation Service (USSCS). 1994. Soil Survey of Chautauqua County, New York. Mayville (NY): United States Department of Agriculture (USDOA). Available from https://www.nrcs.usda.gov/Internet/FSE_MANUSCRIPTS/new_york/NY013/0/chautauqua.pdf.

Waikar ML, Nilawar AP. 2014. Morphometric Analysis of a Drainage Basin using Geographic Information System: A Case Study. International Journal of Multidisciplinary and Current Research. 2 (Jan/Feb): 179-184. ISSN: 2321-3124.

Water Resources Council (WRC). 1967. A Uniform Technique for Determining Flood Flow Frequency. Washington D.C. (US): Water Resources Council (WRC), Hydrology Committee. Report No.: Bulletin No. 15. Available from: https://water.usgs.gov/osw/bulletin17b/Bulletin_15_1967.pdf.

Zevenbergen LW, Ameson LA, Hunt JH, Miller AC. 2012. Hydraulic Design of Safe Bridges. Washington D.C. (US): United States Department of Transportation, Federal Highway Administration. Report No.: FHWA-HIF-12-018, HDS-7. Available from: https://www.fhwa.dot.gov/engineering/hydraulics/pubs/hif12018.pdf.