GZA GeoEnvironmental, Inc.

Downtown Resilience and Recovery Plan

Westport, Connecticut

Prepared by:
GZA GeoEnvironmental, Inc.

Prepared For:
The Town of Westport, Connecticut
Public Works Department

October 2018

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Cover Image Source: Larry Untermeyer for WestportNow.com. 2010.
http://cdn.westportnow.com/ee/images/uploads/westportautumnsaugnorth11151001pop.jpg

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Introduction and Acknowledgements

Section 1 Introduction & Acknowledgements

INTRODUCTION

Downtown Westport is highly vulnerable to flooding due to coastal storm surge and intense rainfall and the combined effects of each of these, which often occurs during tropical storms, hurricanes and nor'easters. Over the last few years, the downtown was flooded during coastal storms including Superstorm Sandy (October 2012) and Tropical Storm Irene (August 2011). The flood risk of the downtown area will increase in the future due to climate change, in particular sea level rise and increase in precipitation intensity.

The vulnerability of the downtown area is due, in part, to its low-lying coastal setting and proximity to the tidally-influenced Saugatuck River. It is also due to the existing capacity of the stormwater infrastructure to manage stormwater runoff, including piping, catch basins, manholes and outfall structures as well flow within Dead Man's Brook (which flows through the eastern portion of the downtown area).

Mitigating the risks associated with flooding is a goal of the Town, as detailed in the *2015 Downtown Master Plan* (2015 DMP) and *2016 Natural Hazard Mitigation Plan Update* (2016 NHMP).

The Town has prepared this plan, "The Downtown Westport Resilience and Recovery Plan" (the Plan), which was funded by the federal Community Development Block Grant Disaster Recovery Program (CDBG-DR) grant, to analyze the downtown area flood risk and to evaluate flood mitigation strategies and measures. This plan includes a characterization of the flood hazards (including flooding due to coastal storm surge and precipitation), a vulnerability assessment of buildings and roadways, and recommendations for flood mitigation strategies and actions.

Certain details of this study, including numerical modeling and survey details, have been provide to the Town previously and are only summarized in the Plan. Electronic ArcMAP GIS layers have been provided to the Town.

ACKNOWLEDGEMENTS

TOWN OF WESTPORT DEPARTMENT OF PUBLIC WORKS

Peter Ratkiewicz, P.E. Director, Stephen Edwards, P.E. Former Director. Amrik Matharu, EIT Engineer II

TOWN OF WESTPORT FLOOD & EROSION CONTROL BOARD

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Katherine Daniel, AICP, Deputy Director

WESTPORT DOWNTOWN MERCHANTS ASSOCIATION

Randy Herbetson, President, Colleen Wiedmann, Marketing & Membership Director

PLANNING AND ENGINEERING TEAM

GZA GeoEnvironmental, Inc. Also, the approximately ninety-five Downtown Westport businesses that participated in the Downtown Survey including but not limited to: Alegro; Allen Edmonds; Amenity Nail and Spa; Amis Trattoria; Ann Taylor; Anthropologie; Arezzo; AT&T; Athleta; Banana Republic; Bar Taco; Bedford Square; Bella Bridesmaid; Benefit Cosmetics; Bluemercury; BNY Mellon; Boca Restaurant and Bar; Brooks Brothers; Bungalow; Charter Realty and Development Corp.; Clinical Skin Care; Compass Commons; Crtical Mix; Dovecote; Finalment Trattoria; Francois DuPont Jewelers; Freshii; Green & Tonic; Greenfield Partners; Intermix; J. Crew; Jack Wills; Joie; Lucy's; Marine Layer; Moffly Media; Nike; Patagonia; Pink Sumo; Raveis; Roots Salon; Shoe-In; Soleil Toile; Talbots; Urban Outfitters; Vineyard Vines; William Pitt; and more.

The residents of Westport who provided input during the public meeting held on June 6, 2018.

PLANNING PROCESS

The planning process was designed to assist the Town with better understanding the flood risk within the Downtown Westport area, including flooding resulting from precipitation events, coastal storm surge and combined storm surge and rainfall. The Plan preparation included the following:

- Inventory and survey of the Downtown area stormwater infrastructure;
- Characterization of the flood hazards including rainfall, coastal flooding and the effects of sea level rise;
- Inventory and site walk-overs of Downtown area buildings located within FEMA Special Flood Hazard Areas (SFHA);
- Evaluation of flood vulnerability of buildings and roadways located within the Downtown area;
- Public outreach at a June, 2018 public meeting; and
- Development of flood mitigation strategies and alternatives.

TOWN PLANS, POLICIES AND REGULATIONS

The implementation of flood mitigation, resilience and climate adaptation strategies and actions should take place within the framework of existing Town plans, policies and regulations and align with the Town's planning goals and budget. These include the following:

- 2017 Plan of Conservation and Development
- 2016 Town Natural Hazard Mitigation Plan Update
- 2015 Downtown Westport Master Plan
- 2014 Westport Village District Study
- 2013 State Natural Hazard Mitigation Plan
- 2012 Westport Center Historic Resources Inventory
- 2007 Concept Plan to Improve Downtown Parking Facilities
- 2007 Master Plan for Jesup Green and Baron's South
- Downtown Plan of Westport (2001)
- Federal and State Flood Regulations
- Local floodplain ordinances
- Local zoning regulations
- State and federal regulations and permits related to flooding.

FLOOD HAZARD VULNERABILITY

GZA completed an evaluation of the flood hazards affecting the Downtown area, currently and in the future. The evaluation included an assessment of both coastal storm surge-related flooding, precipitation-related flooding and combined storm surge and rain flooding.

To evaluate flooding due to coastal storm surge, GZA utilized publicly available data that describes the flood risk near and within the Downtown area, including: 1) the FEMA Flood Insurance Rate Maps (FIRMs) and Flood Insurance Studies (FIS); NOAA tidal datums; 3) the results of the USACE North Atlantic Coast Comprehensive Study (NAACS); 4) the NOAA 2017 sea level rise projections at the NOAA Bridgeport tide station; 5) NOAA extreme value statistical evaluation of the monthly NOAA Bridgeport tide station water level data (80-year record); and 6)

To evaluate flooding due to precipitation, GZA surveyed and analyzed the existing stormwater management infrastructures within the Downtown area, including numerical modeling of the Downtown infrastructure system. Design precipitation intensities were developed using the NOAA Atlas 14 regional values.

The results of the flood hazard characterization are presented in the following attachments:

- **Attachment 1** presents the results of GZA's Stormwater Infrastructure Survey;
- **Attachment 2** presents an Overview of Coastal Flood Hazards;
- **Attachment 3** presents Precipitation, River and Combined Flood Analysis.

To evaluate the flood vulnerability of Downtown area properties and roadways, GZA completed:

- A site reconnaissance survey of properties located within the FEMA special flood hazard areas and an exposed value assessment of properties located within different flood recurrence interval inundation areas (see **Attachments 4 and 5**);
- A vulnerability assessment of roadways located within different flood recurrence interval inundation areas (see **Attachment 6**).

Section 2
Downtown Inundated Properties Audit

DOWNTOWN OVERVIEW

Aerial photograph of Downtown from 1949 before Parker Harding Plaza and Levitt Pavilion were built on reclaimed ground.

Aerial photograph of Downtown Westport after the land reclamation project in the 1950s that led to the development of Parker Harding Plaza and Levitt Pavilion

The 2015 Downtown Westport Master Plan (2015 DMP) illustrates how Downtown Westport has undergone a series of transformations over the last 150 years. During the 19th century, buildings along Main Street abutted the Saugatuck River allowing for the exchange of goods to ships bound for New York City and beyond. Downtown was smaller and several places today did not exist such as Parker Harding Plaza. The electrification of the New York-New Haven train line and the construction of the Merritt Parkway and Interstate I-95 during the 20th century made Westport much more accessible thus transforming the Downtown's economy from an industrial one to a service-oriented economy as Westport became more of a residential community. In the 1950s, the reclamation of the Saugatuck riverfront (as shown in the image above) created the Parker Harding Plaza adjacent to Main Street and provided parking for the shopping districts in Downtown. Today, the Downtown area serves as a regional destination for its small-town character, inviting waterfront, fine-dining, and high-end boutique stores.

Figures 2-1 and 2-2 shows the location of Downtown in relation to the Westport town limits. The Downtown Westport area is located along the Saugatuck River, north and south of Route 1.

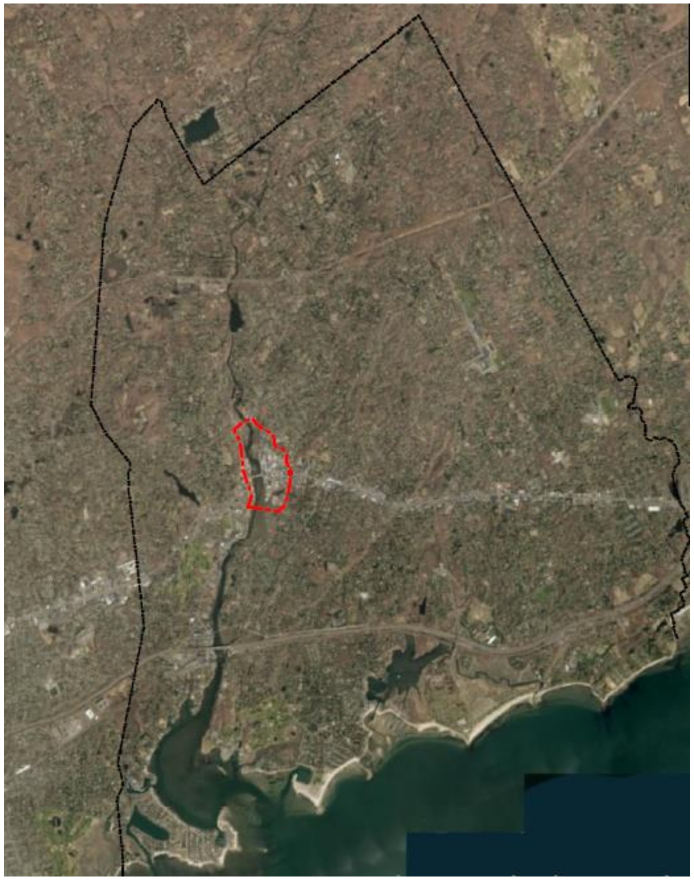


Figure 2-1: Location of Downtown Westport Study Area

Figure 2-2: Perspective of Downtown Westport Study Area

The 2015 DMP includes an inventory of 119 retail businesses that occupy close to 269,000 square feet of building space as of August 2014. These retail establishments generate $531 Million in annual sales. As of August 2014, the 119 retail stores include:

- 33 community serving goods and services
- 11 full-service restaurants
- 53 apparel stores
- 16 home furnishings and improvements stores
- 3 specialty goods stores
- 3 other retail stores

The number of retail businesses has likely increased since 2015 with the addition of new developments in Downtown such as Bedford Square on Church Lane.

Downtown is not just home to a bustling and robust retail core but is also home to a diverse group of cultural and community resources including the Westport Library and Police Department and professional services ranging from legal to medical services to real estate. **Figure 2.3** on the following page shows the distribution of parcel types located within the downtown study area. Based on the most recent 2018 Town Assessor's data there are a total of 155 parcels of land within the Downtown study area, including:

– 119 Commercial Parcels
– 19 Residential Parcels
– 7 Parking Parcels
– 8 Vacant Parcels (without structures)
– 2 Parcels with no data

Downtown Westport Properties located on Jessup just east of the Saugatuck River

GZA Survey Team conducting a survey interview on Main Street in Downtown Westport

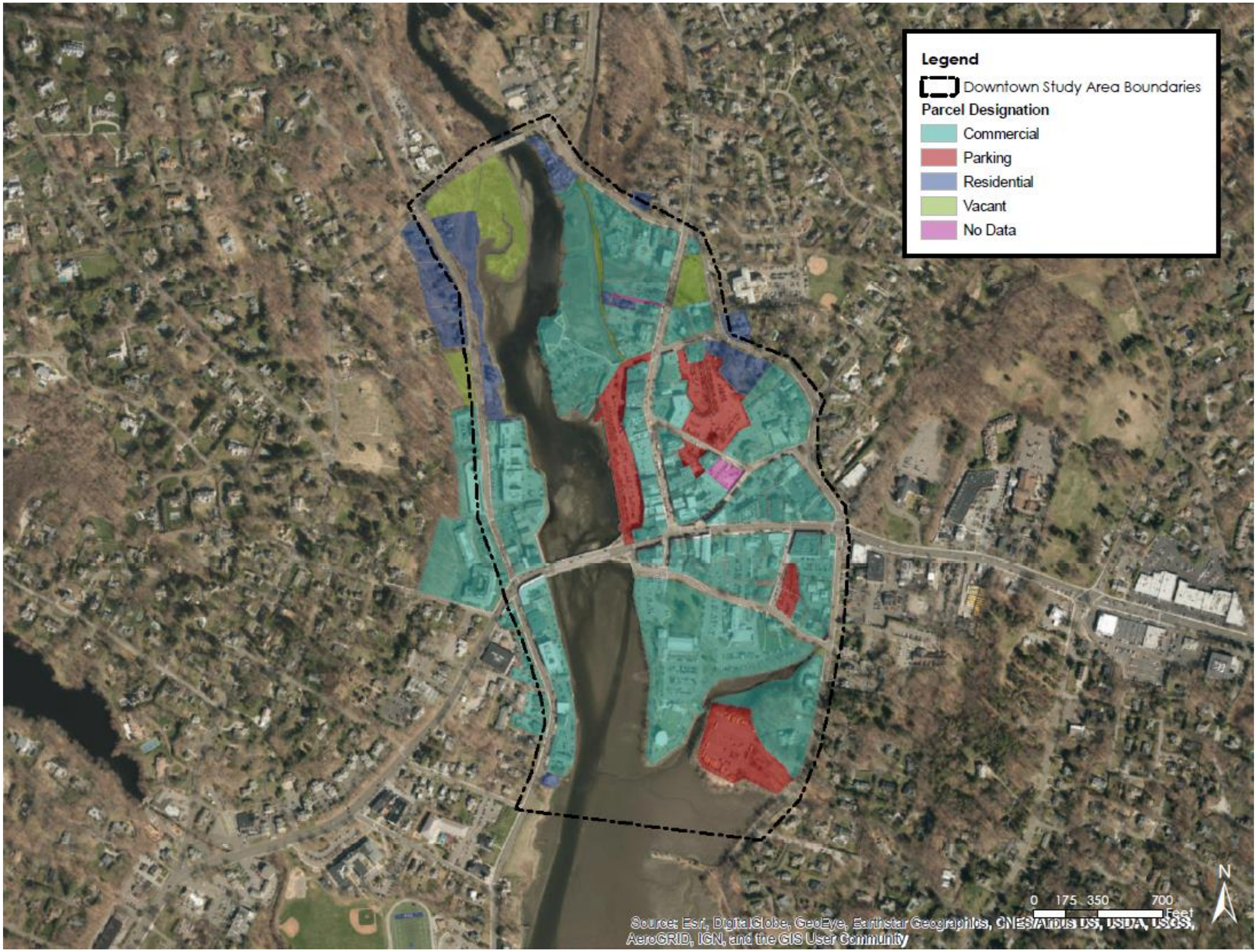


Figure 2.3 Downtown Parcel Types

Downtown Survey Overview

The purpose of the survey was to investigate building exteriors and interiors and lower floors, including basements and crawlspaces, of properties located on 154 parcels within the FEMA Special Flood Hazard Area (SFHA) as shown on **Figure 2.3** (facing). GZA prepared a Downtown survey (see **Attachment 4**) that included questions modeled on the "Checklist for Vulnerability of Flood-prone Sites and Buildings" included in FEMA's *P-936 Floodproofing Non-Residential Buildings*. Several weeks in advance of conducting the survey, the Town of Westport circulated a letter to inform property owners and business of the purpose of the survey and timeframe for when the surveys would be conducted by GZA. **Figure 2.4** served as the roadmap for GZA in conducting survey interviews of the Downtown properties located within the FEMA SFHA.

Survey Implementation

On July 5 and July 6, 2017, two GZA survey teams interviewed businesses and property owners, located in the Downtown study area. The teams examined building features and documented results for each property that included the identification of critical building details that are vulnerable to impacts from flooding outlined in the Downtown survey (see form on **Attachment 4**) including but not limited to the following:

- Type and number of openings (i.e. doors, windows, floor drains, etc.);
- Foundation Type (e.g. slab on grade);
- Location of mechanical systems (e.g. heating, ventilation, and air conditioning (HVAC);
- Location of electrical systems;
- Location of plumbing and gas systems;
- Is there a basement or crawlspace.

GZA created an Excel™ database of the collected property data.

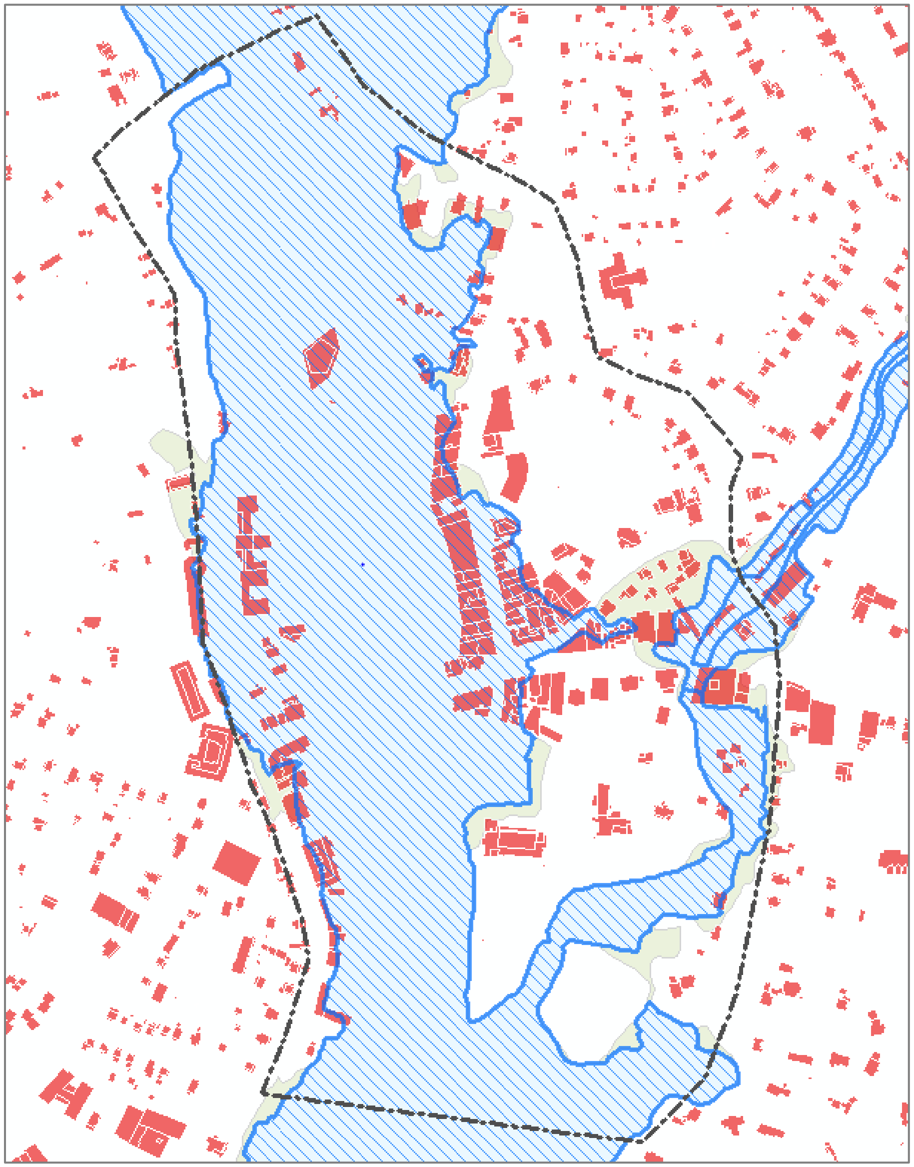


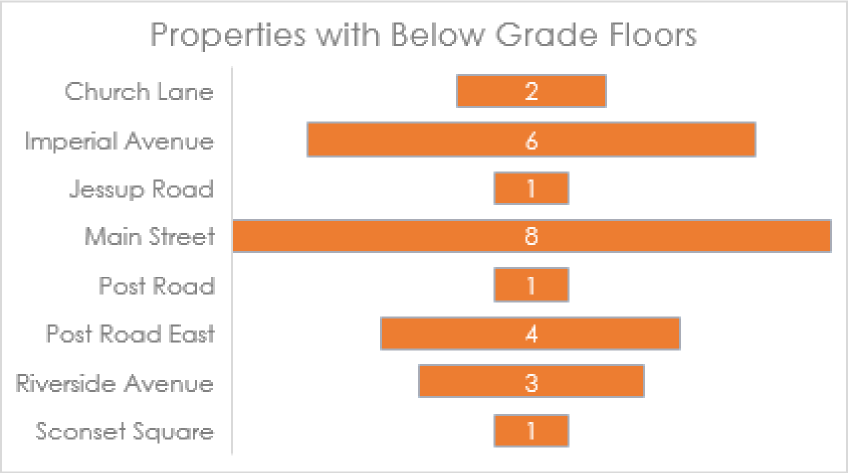
Figure 2.4 Downtown Westport Properties located in the FEMA Special Flood Hazard Area (SFHA)

Section 2 Downtown Inundated Properties Audit

GZA was able to access approximately 87 of 122 properties during the survey interview process. GZA documented and provided the Town with the detailed results of the downtown surveys in an Excel™ database that provides the comprehensive survey results for each of the properties evaluated during the two-day field survey. An overview of the key findings that were used to inform the identification of resilience and recovery opportunities and recommendations are presented below.

Properties with Finished Floors "Below-Grade"

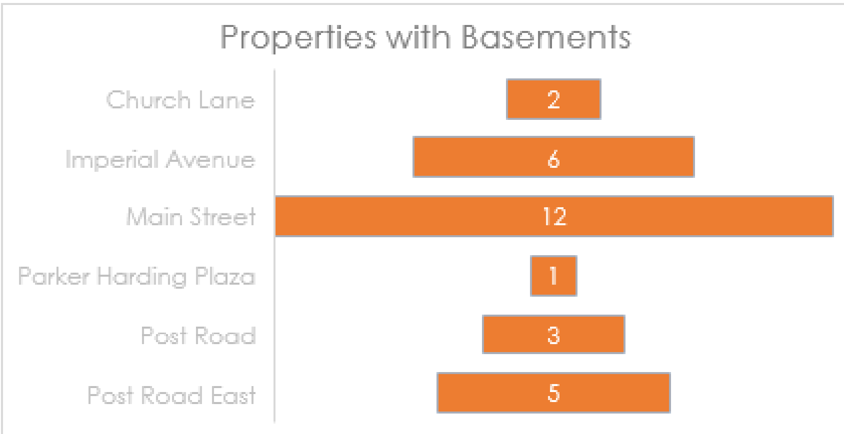
Twenty-six (26) properties in Downtown Westport have finished floors that are below street grade. The number of properties by street are presented below.

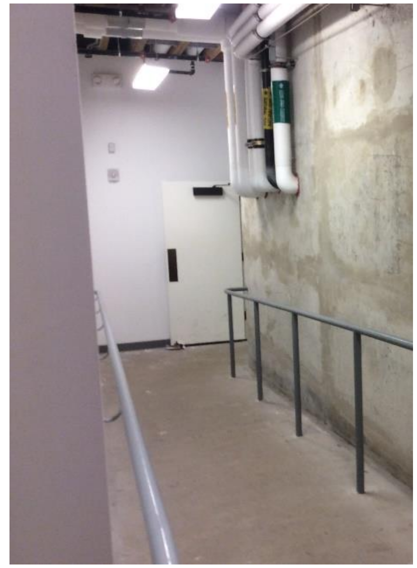


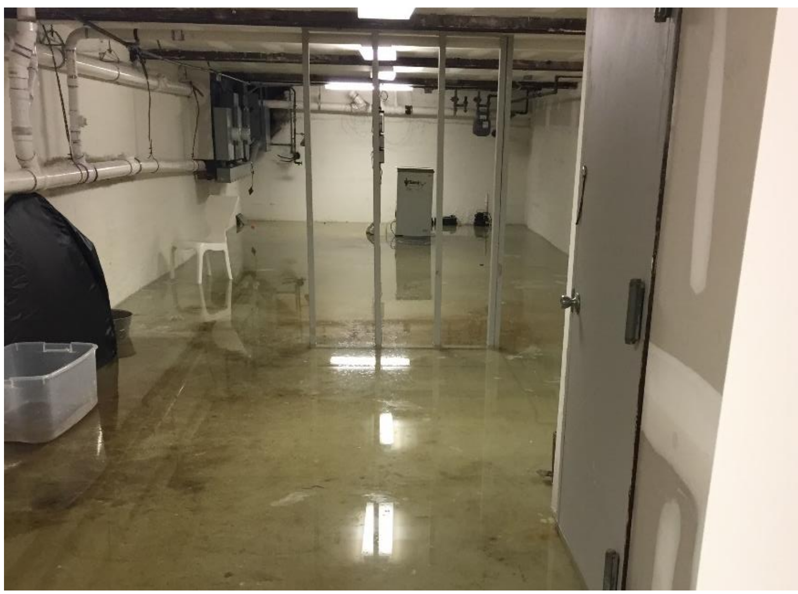
Images of a retail apparel businesses with finished floors below grade located on Post Road.

Properties with Basements

Twenty-nine (29) properties in Downtown Westport have subgrade basements. Below is an overview of the number of properties by street location.



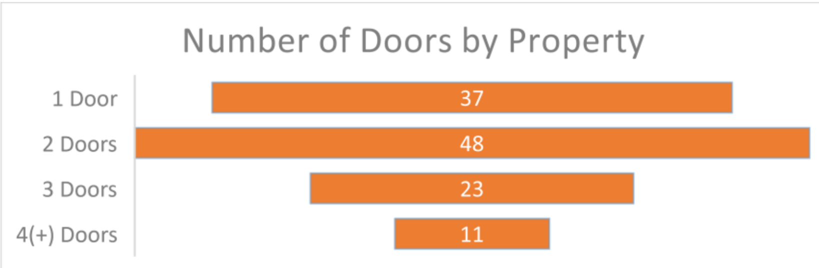




Images of properties in Downtown with subgrade basements

Number of Doors by Property

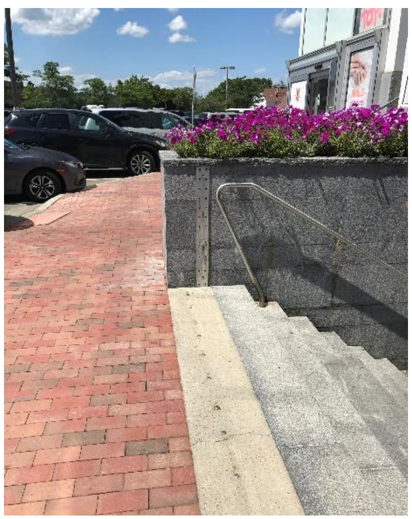
Most properties in Downtown Westport have between one to three flood vulnerable doors that provide access to the building as presented below.

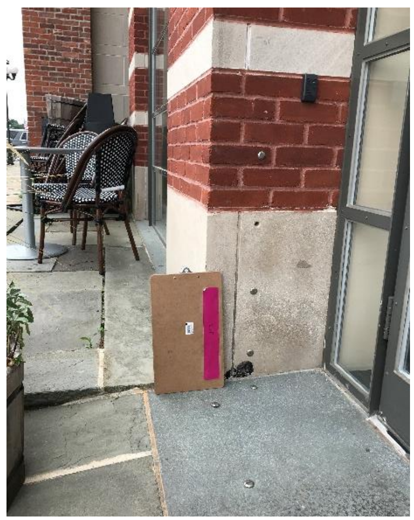


Properties with Flood Protection

Twenty (20) properties in Downtown Westport have taken a proactive approach to installing flood protection systems at entrances that are vulnerable to flooding. These deployable and permanent flood protection systems including: sandbags; aluminum stop logs; and elevated structures.

Image of a retail apparel business entrance located on Post Road





Images of flood protection at multiple buildings in Downtown

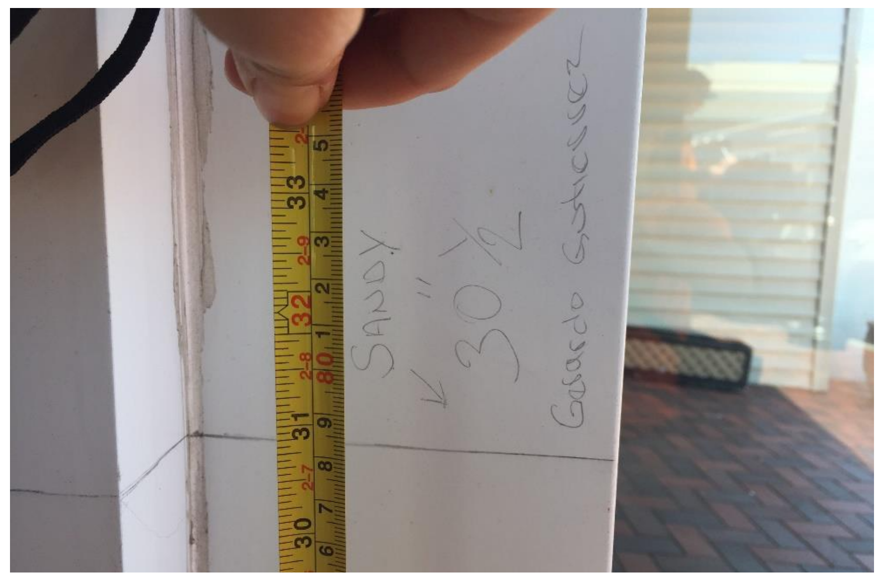


Image of the depth of flooding during Sandy at a business entrance

Critical Building Systems and Utilities

The survey teams identified flood vulnerable critical building systems and utilities at approximately 43 of the 122 properties surveyed. Seventy-nine properties were not accessible for viewing to a lack of access to the properties and/or critical system and utility locations. GZA provided the Town with a survey database that includes details of the types and location of the critical building systems and utilities including electrical, mechanical (i.e. HVAC), and plumbing and gas systems. Below is an overview of the type and number of critical systems identified.

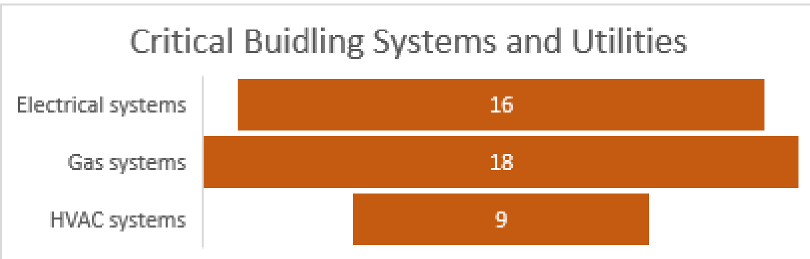


Image of HVAC system on the roof and propane tanks at grade behind Main St.

Image of elevated HVAC system on the first floor of building on Main St.

Image of Electrical Transformer near a catch basin in the back of 101 Post Road East

Section 3
Flood Vulnerability

Section 3 Flood Vulnerability

This section looks at the Downtown's vulnerability to both precipitation and coastal flood hazards. This information supports determination of the Town's flood risk. Coastal flood inundation is the principal flood hazard. This flood hazard is compounded by the limitations of the stormwater infrastructure capacity to drain low-lying areas, in particular during times of high tides and storm surge. The vulnerability to coastal and precipitation flooding are presented separately.

Coastal Flood Vulnerability

The vulnerability to coastal flooding is characterized in this study in terms similar to those used by FEMA. Structures, businesses, property-owners, tenants and residents located:

- Within the limits of the 100-year recurrence interval flood are considered to be in a high flood hazard zone;
- Within the limits between the 100 and 500-year recurrence interval floods are located in a low to moderate flood hazard zone; and
- Outside the limits of the 500-year recurrence interval flood are located in a low flood hazard zone.

Although not evaluated by FEMA for the National Flood Insurance program (NFIP), structures, businesses, property and residents located within flood inundation areas with recurrence intervals less than 100-years (i.e., more frequent flooding) are considered to be in areas with a very high flood vulnerability.

The evaluation of coastal flood risk also considered the type of structure and its importance to public safety and loss potential. ASCE/SEI 24-14 "Flood Resistant Design and Construction" categorizes buildings and structures into one of four Flood Design Classes based on use and occupancy. The Flood Design Class dictates the level of acceptable risk and appropriate level of flood protection. The Flood Design Class was used to assess vulnerability in this study.

The following pages summarize the coastal flood risk of the following key assets in Downtown Westport including:

- Parcels (including building valuations based on 2018 Assessor's data)
- Roadways

Downtown Area Buildings

The Downtown study area, approximately 140 acres, within the Town of Westport is comprised of a mix of both commercial and residential properties. There are a total of 154 parcels based on the 2018 Assessor's data. Buildings and structures within the study area are valued at approximately $450 Million. Commercial parcels account for just over $440 Million and residential properties account for just under $8.5 million in total valuation.

The buildings located within flood vulnerable areas of the Downtown are generally categorized as ASCE 24 Flood Design Class 2 – moderate risk to the public or moderate disruption to the community should they be damaged of fail to flooding. No High Occupancy or Essential Facilities (Flood Design Classes 3 and 4) are present within flood vulnerable areas of the Downtown.

GZA estimated the location and extent of building inundation under current coastal flood conditions for the following recurrence interval floods: 2-year; 5-year; 10-year; 20-year; 25-year; 50-year; and 100-year recurrence interval coastal floods based on FEMA FIRMs and GZA's coastal flood modeling (**Attachment 2**). Residential and commercial buildings valued at approximately $234 million and $295 million are vulnerable under the current coastal flood risk scenarios of the 100-year and 500-year recurrence interval floods, respectively. Appraised building values within flood inundation areas associated with multiple recurrence intervals are shown below.

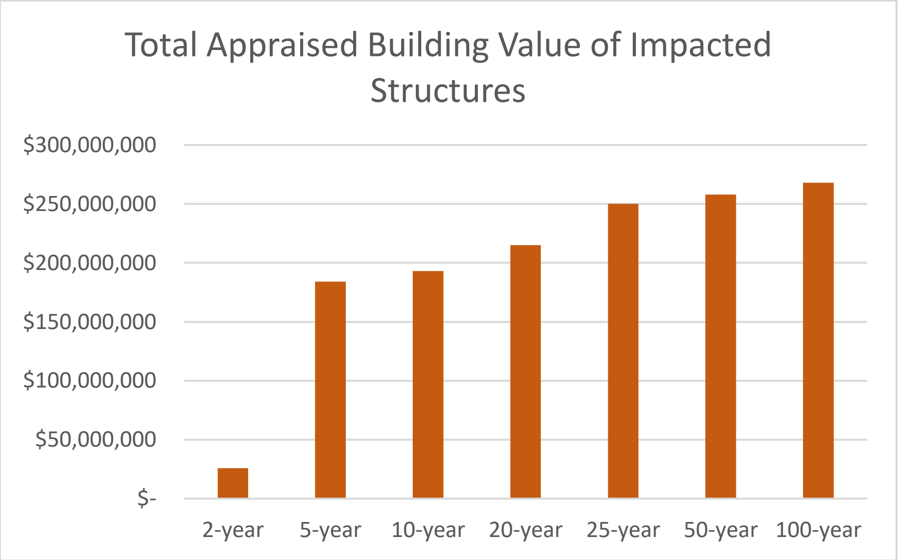


Figure 3-1: Total Downtown Building Valuation at risk to 2-year, 5-year, 10-year, 20-year, 25-year, 50-year, 100-year and 500-year recurrence interval coastal floods

The vulnerability of downtown parcels (including buildings) was evaluated relative to coastal flooding (USACE NACCS flood-frequency data), up to the 100-year recurrence interval flood.

As shown in **Figure 3-1,** the vulnerable asset value increases significantly between the 2-year and 5-year recurrence intervals. This indicates the vulnerability of Downtown assets to both frequent flooding (today) and the increased frequency of flooding in the future due to sea level rise. The total number of downtown parcels that are vulnerable to coastal flood risk more than triples from 13 to 55 from the 2-year to the 10-year recurrence interval floods. The rise corresponds to a total increase in vulnerable value at risk from $26 million to $193 million between these two coastal flood events.

As presented on **Figure 3.2** approximately 47% of the total parcels of land in Downtown Westport are vulnerable during the 100-year coastal flood recurrence interval. In addition, just over 30% and 35% of Downtown parcels will experience some degree of flooding during higher probability flood events under the 5-year and 10-year coastal flood recurrence intervals. Based on this analysis, within the Downtown area:

High Flood Hazard Zone: 67 properties; $233,700,200 vulnerable value

Low to Moderate Flood Hazard Zone: 24 properties; $61,241,500 vulnerable value

Low Hazard Area: 63 properties; $154, 908,300 low flood hazard

As shown on **Figure 3-3,** parcels located on the eastern side of the Saugatuck River along Main Street, Parker Harding Plaza, Post Road West, Taylor Place, Jessup Road (east of the intersection of Jessup Road) and Imperial Avenue are very vulnerable to coastal flooding. Parcels located on the western side of the Saugatuck River on Wilton Road and Riverside Avenue are also vulnerable to coastal flooding. **Attachment 5** presents additional detail.

The effect of sea level rise will result in an increase in frequency of coastal flood inundation to parcels located in these areas.

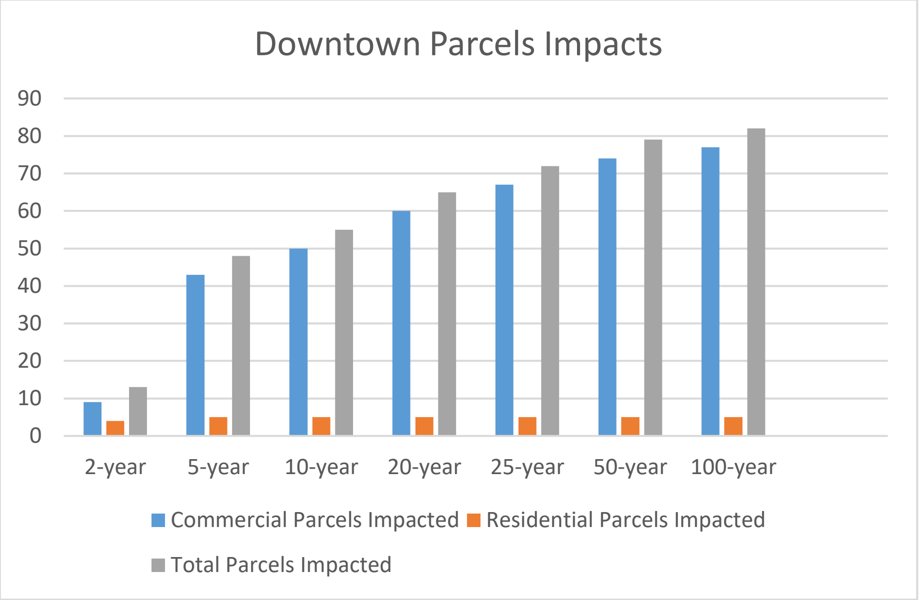


Figure 3-2: Total Downtown Building Parcels at risk to 2- year, 5-year, 10-year, 20-year, 25-year, 50-year, 100-year and 500-year coastal floods

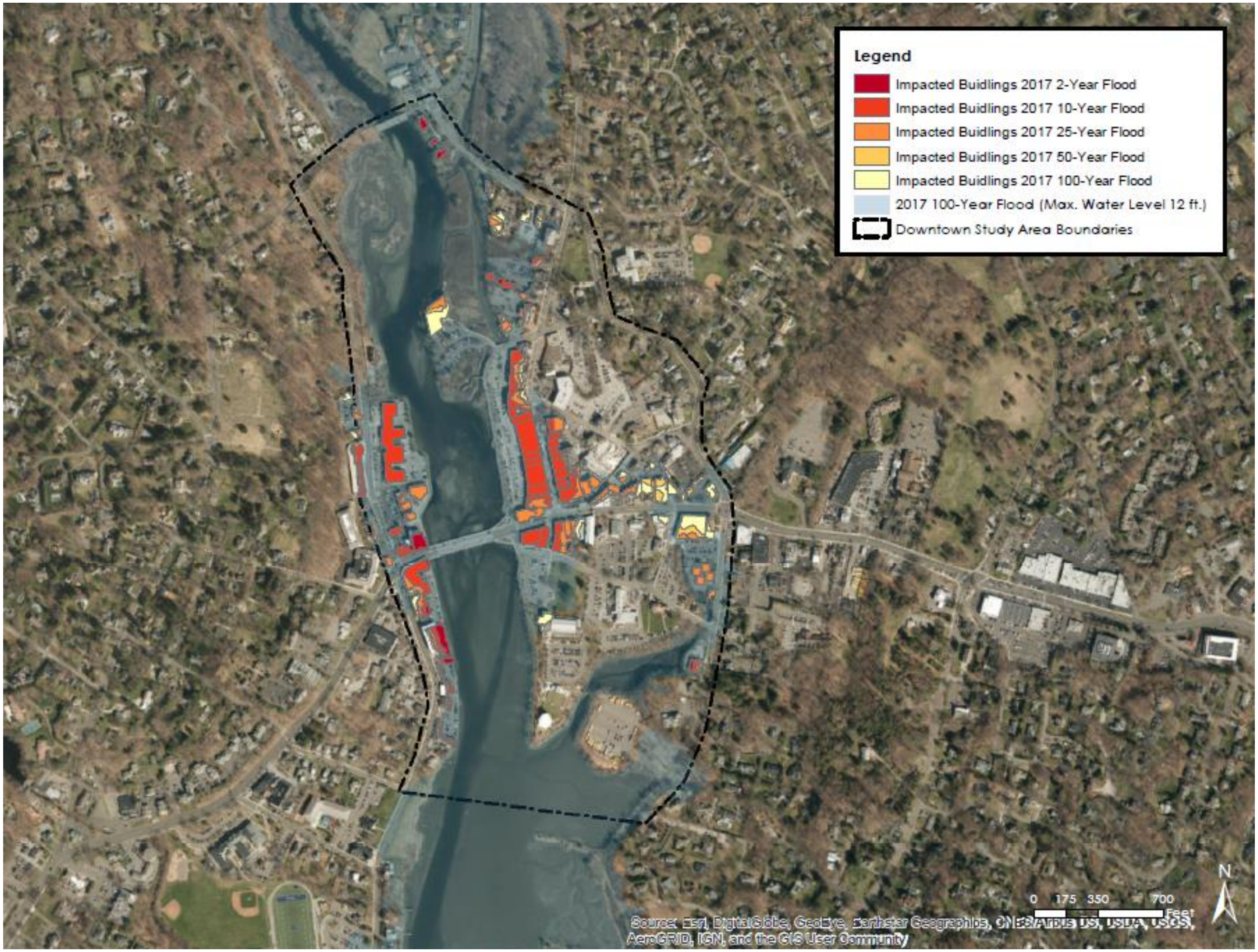


Figure 3.3 Inundated property parcels during the 2-yr, 10-yr, 25-yr, 50-yr and 100-year recurrence interval floods

ROADWAYS

Downtown Westport is served by major arterials (US Route 1 and State Route 33) and a network of smaller roads that provide access throughout the Town and serve as collectors for the major arterials. There is a total of approximately 3.8 miles of roadway in the Downtown Westport study area including 1-mile of State roads and 2.8 miles of Municipal roads.

The key state roads include:

- Wilton Road (State Route 33)
- Riverside Avenue (State Route 33)
- Post Road East (US Route 1)
- Post Road West (US Route 1)

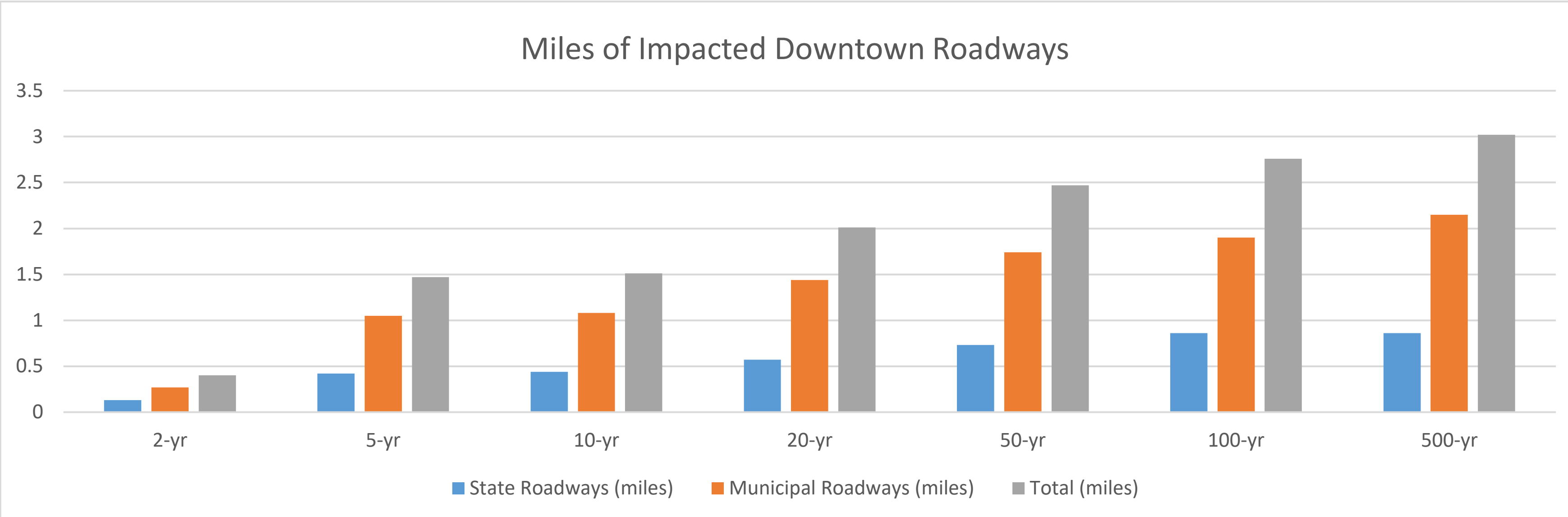
The key municipal roads are as follows:

- Imperial Avenue
- Kings Highway North
- River Knoll
- Thomas Road
- Myrtle Avenue
- Taylor Place
- Jesup Road
- Mani Street
- Cross Street
- Avery CT
- Elm Street
- Evergreen Avenue
- Edge Hill Lane
- Church Lane #1 and #2
- Foxfire Lane
- Violet Lane
- Avery Place
- Parker-Harding Plaza
- Bay Street
- Lincoln Street
- Belden Place
- Canal Street

	2-yr	5-yr	10-yr	20-yr	50-yr	100-yr	500-yr
State Roadways (miles)	0.13	0.42	0.44	0.57	0.73	0.86	0.86
State Roadways (%)	12.2%	41.1%	42.6%	55.4%	70.7%	83.0%	83.9%
Municipal Roadways (miles)	0.27	1.05	1.08	1.44	1.74	1.90	2.15
Municipal (%)	9.7%	37.8%	38.7%	51.7%	62.6%	68.4%	77.5%
Total (miles)	0.40	1.47	1.51	2.01	2.47	2.76	3.02

Table 3.1 Vulnerability Profile of Downtown Westport Roads

GZA estimated the location and extent of roadway inundation under current coastal flood conditions, including storm events corresponding to the following recurrence intervals: 2-year; 5-year; 10-year; 20-year; 50-year; 100-year; and 500-year recurrence interval floods as determined by GZA's coastal analysis. **Figure 3.4 and 3.5** show these impacts relative to the various flood recurrence intervals. Approximately 2.8 and 3 miles of roadway in Downtown are vulnerable under the current coastal flood risk scenarios of the 100-year and 500-year recurrence interval floods, respectively. These flood recurrence intervals represent the appropriate evaluation risk levels for transportation infrastructure investment planning and State and municipal levels. The total roadway under these coastal flood scenarios represent about 72% to 79%, respectively, of the roads within the Downtown Westport study area. More frequent flood events, such as the 2-year and 10-year recurrence intervals should be specifically considered as important due to their high frequency and "chronic flood inundation" potential. **Attachment 6** includes maps showing the length of roads for each flood recurrence interval. As discussed later in the Plan, certain low-lying roadways are also vulnerable to flooding during intense precipitation events. Note that the bridge deck elevation has not been confirmed. Although shown as vulnerable during the 2-year recurrence interval flood, the deck elevation is expected to be at 9 to 11 feet NAVD88.



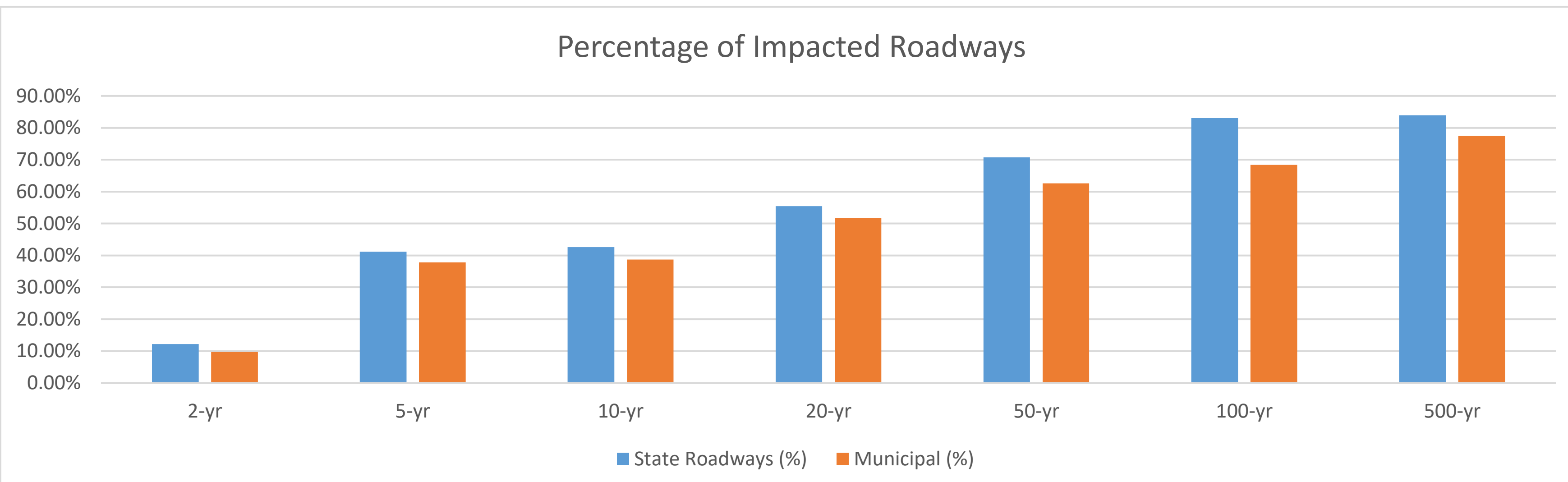


Figure 3.4 Inundated roads during the 2-yr, 10-yr, 25-yr, 50-yr and 100-year recurrence interval floods

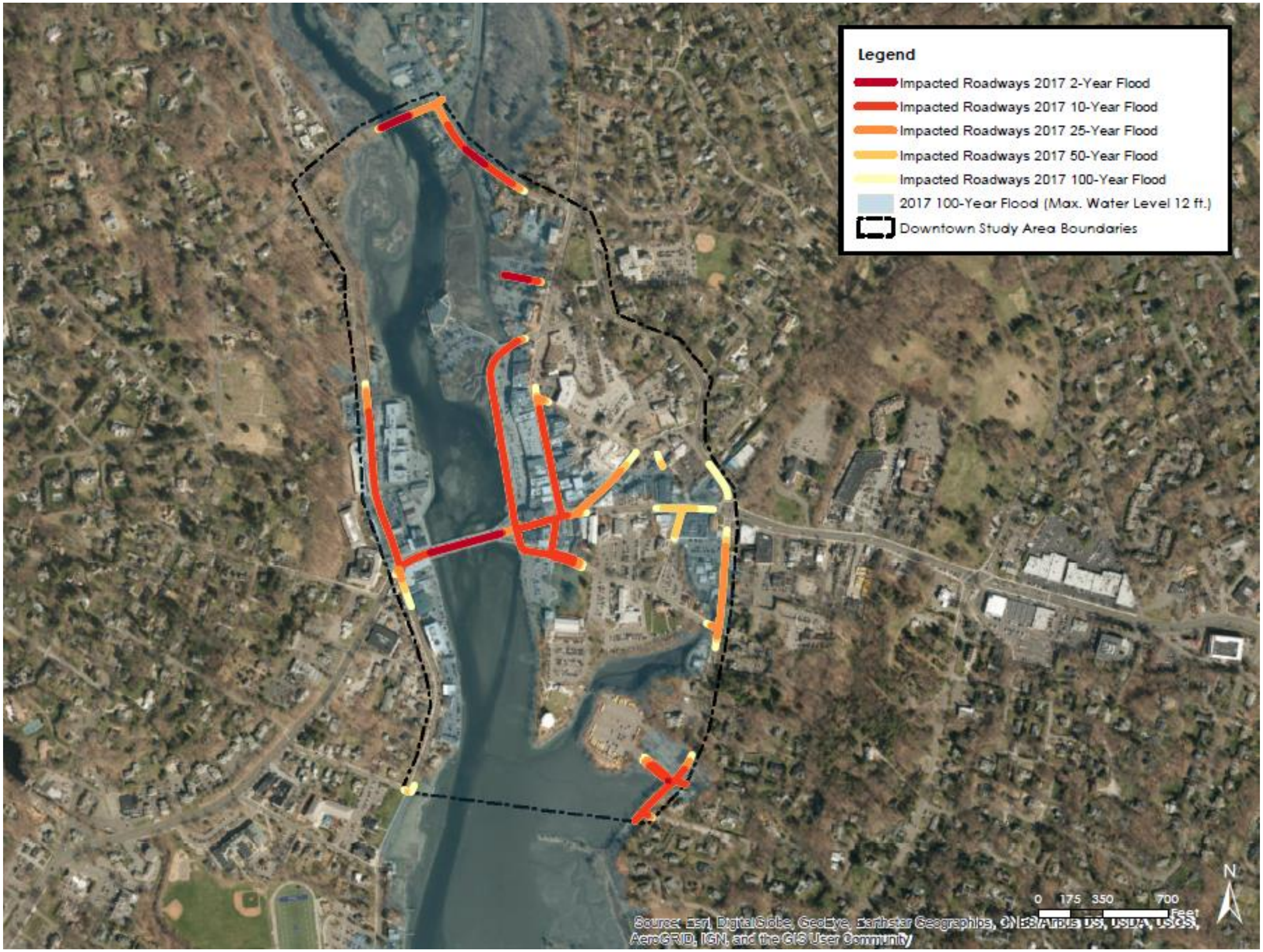


Figure 3.5 Inundated roads during the 2-yr, 10-yr, 25-yr, 50-yr and 100-year recurrence interval floods

Precipitation and Stormwater Flooding

GZA identified potential flood inundation areas and estimated flooding depths due to flooding during precipitation events with stormwater ponding. The stormwater surface runoff analysis was performed using FLO-2D, a 2-dimensional, numerical flow model, to identify areas most likely to flood during rain events and high-tides (MHHW), as well as the effects of combined rain and storm surge. The analysis assessed the stormwater infrastructure capacity to collect and discharge stormwater away from Downtown areas.

Based on the results of the 2-dimensional runoff analysis, GZA identified four Downtown areas likely to be impacted by flooding. The 4 high-risk areas include:

1. Wilton Road / Riverside Avenue
2. Main Street
3. Elm Street Parking Area
4. Colonial Green Shopping Area

Wilton Road/Riverside Ave

The model results indicate that flooding along Wilton Road and Riverside Avenue due to stormwater runoff is likely during relatively high probability precipitation events including and exceeding the 5-year, 24-hour storm. The model predictions are consistent with observations made by local business owners during precipitation events as conveyed during the property investigations and interviews conducted by GZA in July 2017. Model results predict that flooding depths may prevent travel along Wilton Road during the peak intensity of storm events equaling or exceeding the 10-year, 24-hour storm. Flood inundation impacts along Wilton Road and Riverside Avenue during recurrence interval events are shown in **Figure 3-6.**

Image of High Tide Alert for Residents on Riverside Avenue (Image Ref. WestportNow.com

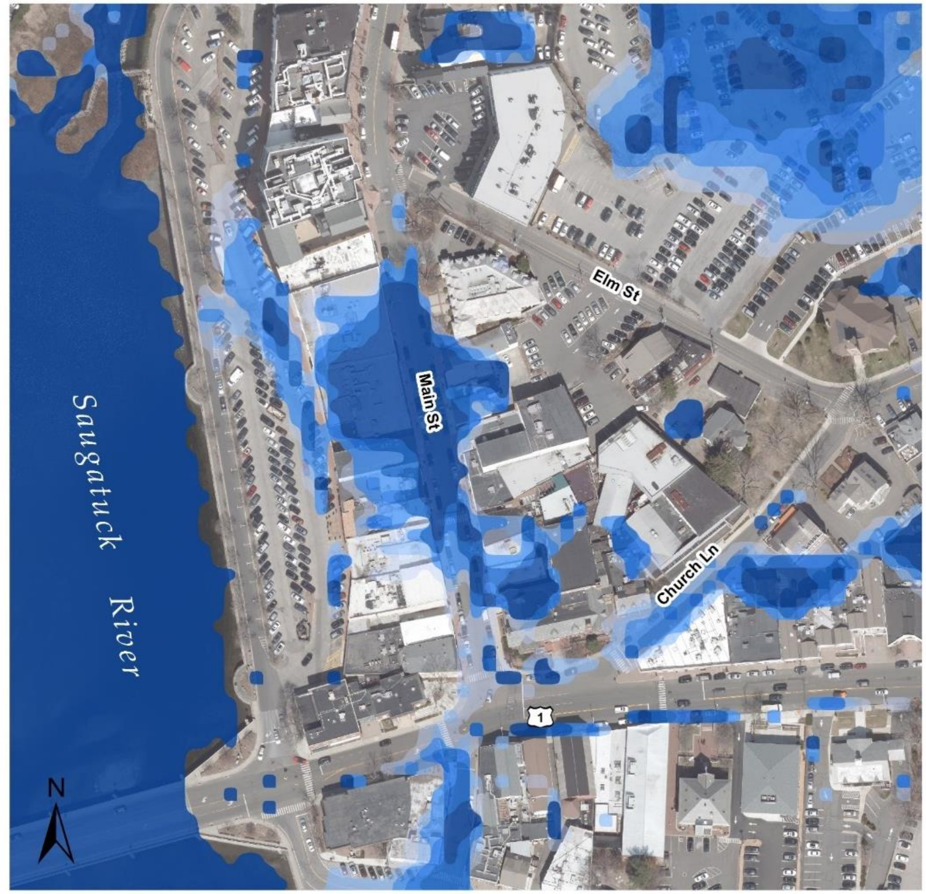
Inundation	Wilton Road Max Flood Depths
2-Year, 24-Hour	0.3 ft
5-Year, 24-Hour	0.5 ft
10-Year, 24-Hour	1.0 ft
25-Year, 24-Hour	1.8 ft
50-Year, 24-Hour	2.2 ft
100-Year, 24-Hour	2.4 ft

Figure 3.6: Maximum Flood Depths at Wilton Road/Riverside Ave. due to Precipitation (coincident with MHHW)

Main Street

Model results indicate that flooding along Main Street, particularly between Post Road E and Elm Street, due to stormwater runoff may occur as frequently as every year on average. Ground surface elevations are very low along Main Street and typically range between Elevation 7 and 8 feet NAVD88. Storm events such as the 2-year, 24-hour storm and greater may result in significant flooding depths exceeding 6 to 12 inches during the peak storm intensity and cause flooding and inundation of roadways and parking lots. Interviews conducted in July, 2017 confirmed that precipitation-based flooding along Main Street is a major problem, and model results indicate this problem will continue, and potentially increase, in the future. Flood inundation impacts along Main Street during recurrence interval events are shown in **Figure 3-7**.

Flooding along Main Street during Tropical Storm Irene in August 2011 (Image Ref. WestportNow.com)



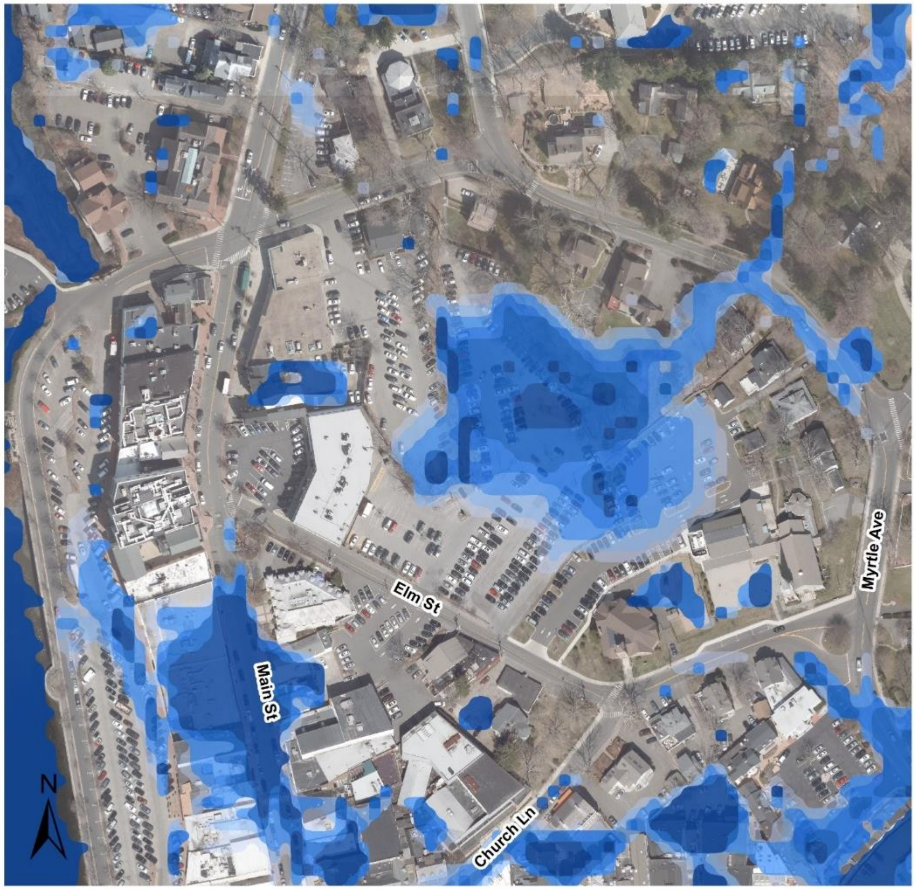
Inundation	Main Street Max Flood Depths
2-Year, 24-Hour	1.2 ft
5-Year, 24-Hour	1.4 ft
10-Year, 24-Hour	1.4 ft
25-Year, 24-Hour	1.5 ft
50-Year, 24-Hour	1.6 ft
100-Year, 24-Hour	1.6 ft

Figure 3.7: Maximum Flood Depths at Main Street due to Precipitation (coincident with MHHW)

Elm Street Parking Area

Model results predict that the Elm Street parking area may experience inundation and significant ponding depths during relatively high frequency events (such as the 2-year, 24-hour storm and greater) due to surface runoff. Elevations within the parking lot area are as low as elevation 7 feet NAVD88 and the area is located within a localized low-point in the surrounding drainage area. Stormwater in the parking lot is collected in catch basins and drains to Church Lane and eventually discharges to the Saugatuck River. This stormwater system includes a tide gate at the downstream end, but if the tide gate were non-functional this area would likely inundate due to storm surge and high tides based on future sea level rise scenarios. Flood inundation impacts in the Elm Street parking area during recurrence interval events are shown in **Figure 3-8.**

Flooding along Myrtle Avenue during flooding resulting from a 3-inch rainstorm in March 2007 (Image Ref. WestportNow.com)



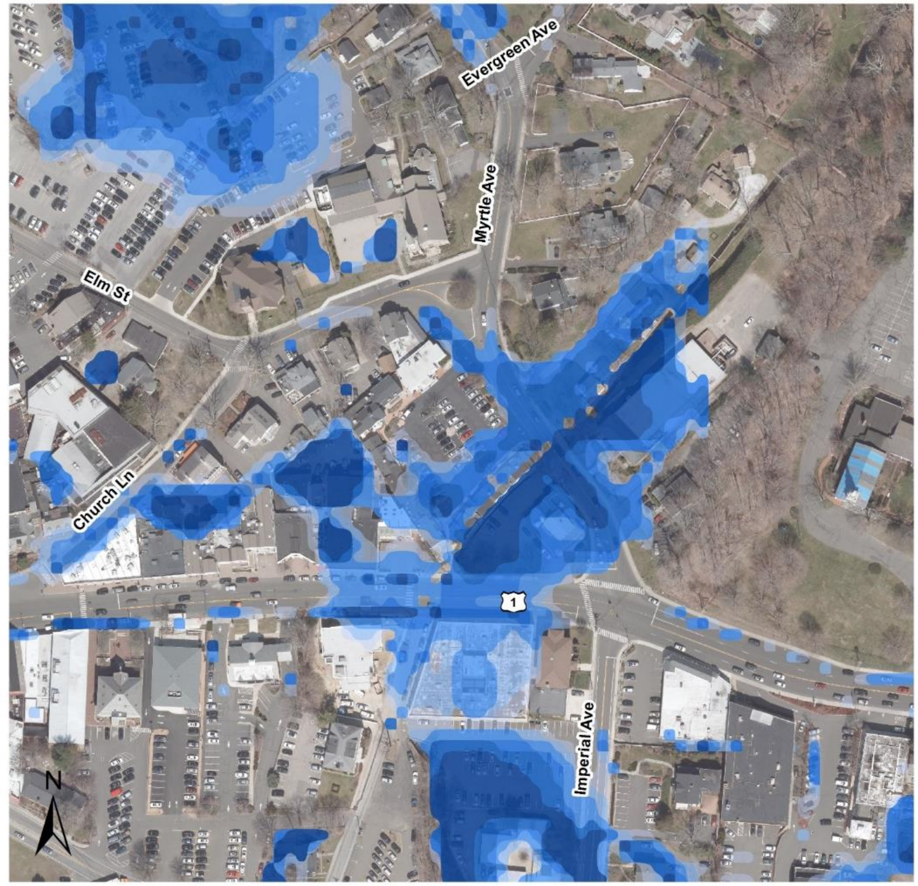
Inundation	Parking Area Max Flood Depths
2-Year, 24-Hour	1.2 ft
5-Year, 24-Hour	2.7 ft
10-Year, 24-Hour	3.2 ft
25-Year, 24-Hour	3.9 ft
50-Year, 24-Hour	4.5 ft
100-Year, 24-Hour	5.0 ft

Figure 3.8: Maximum Flood Depths at Elm Street Parking due to Precipitation (coincident with MHHW)

Colonial Green Shopping Center

The Colonial Green Shopping Center, and surrounding areas, are likely to be subject to some flooding due to surface runoff, but primarily, the main reason for flooding is overtopping of Dead Man's Brook's banks during high brook flows. Flooding is due to insufficient hydraulic capacity of the brook due to constriction and channelization within the downtown urban area. BL Companies is currently analyzing the hydraulic function of Dead Man's Brook and providing recommendations for improvements to increase the hydraulic capacity of the brook and to reduce flooding to adjacent property owners. This area is likely to inundate during relatively high frequency riverine flood events and will continue to inundate in the future without major modifications to the Dead Man's Brook channel geometry. Flood inundation impacts in the Colonial Green Shopping Center during recurrence interval events are shown in **Figure 3-9**.

Image of Dead Man's Brook adjacent to the Colonial Green Shopping Center



Inundation	Colonial Green Max Flood Depths
2-Year, 24-Hour	1.6 ft
5-Year, 24-Hour	2.5 ft
10-Year, 24-Hour	3.1 ft
25-Year, 24-Hour	3.7 ft
50-Year, 24-Hour	4.0 ft
100-Year, 24-Hour	4.2 ft

Figure 3.9: Maximum Flood Depths at Colonial Green Shopping Center due to Precipitation (coincident with MHHW)

Further analysis should be performed to identify specific system components (i.e., pipe diameters or catch basin inlet types) which are under-sized and should be replaced with infrastructure of greater capacity to alleviate flooding within the downtown areas. This analysis could be used to develop recommendations for system improvements to increase the Downtown area's ability to drain roadways and property during precipitation-based flooding events in the future. This recommendation identifies a specific area for further investigation to reduce flooding impacts caused by stormwater runoff that builds from recommendations included in the 2015 Downtown Westport Masterplan.

Effect of Coastal Flood Levels of Stormwater System Response

Higher coastal flood water levels (astronomical high tides, storm surge) can decrease the efficiency of stormwater systems to effectively drain water away from the Downtown area, thus increasing the severity of precipitation-based flooding. Based on GZA's modeling of coincident precipitation and coastal storm surge events, in general, the coincident precipitation-based and coastal storm surge simulations results in increased depths within flooded areas but do not appear to result in substantial increases in the extent of inundation area, when compared to simulations performed using MHHW as the downstream boundary condition.

In addition, review of the coincident scenario simulations concluded that flood inundation resulting from storm surge resulted in more substantial impacts in the Downtown area than flooding resulting from precipitation-based events. Accordingly, coincident events with increasing severity of coastal storms resulted in reduced increases in inundation when compared to the simulations performed within MHHW as the downstream boundary. Regardless, these results identify the effects of the response of the existing stormwater infrastructure even if flood protection barriers are used to prevent flood inundation from coastal storm surges.

As an example, **Figure 3-10** shows the potential increases in water surface depths during the 50-year, 24-hour precipitation-based during a coincident 5-year storm surge within the Saugatuck River as compared to MHWW within the Saugatuck during the same precipitation event.

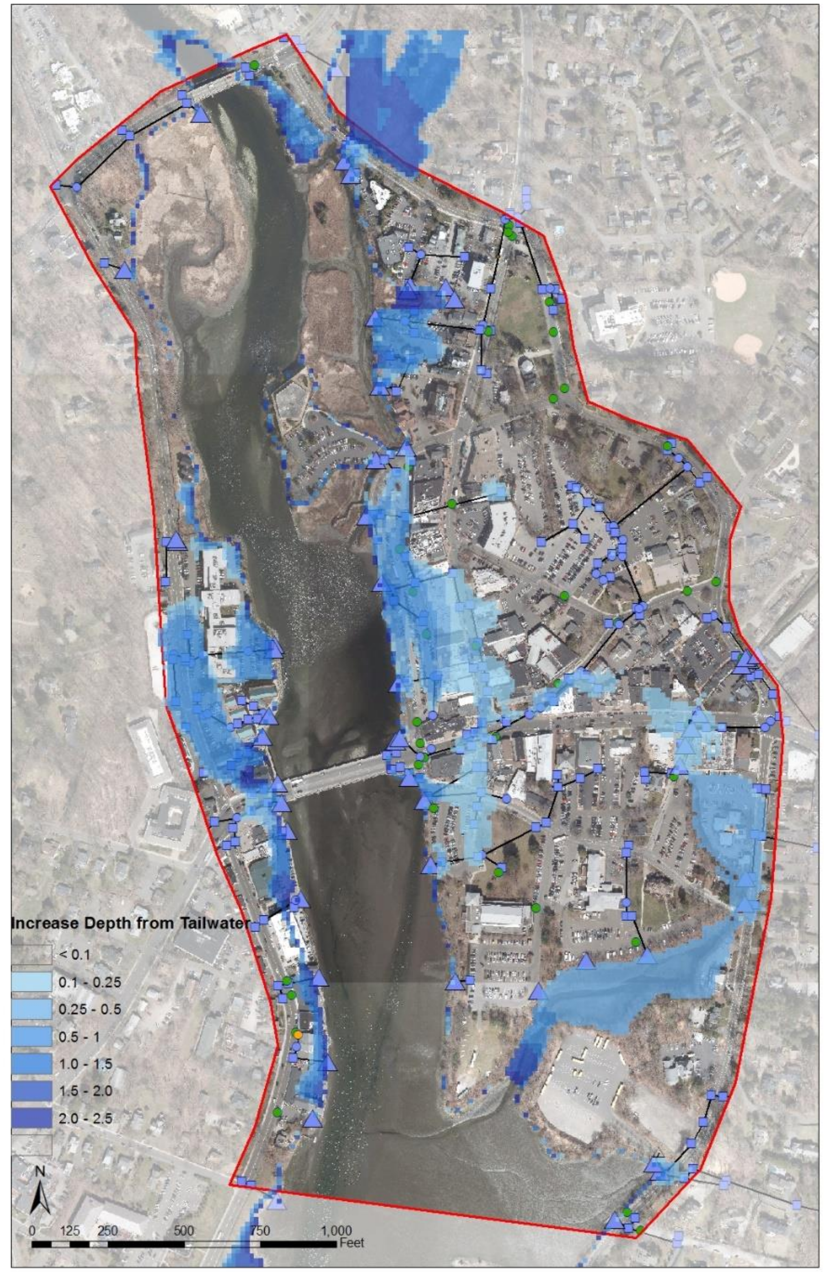


Figure 3.10: Potential Increase in Precipitation Flood Depths due to Backwater Effects

Climate Change Effects on Extreme Precipitation Events

A changing climate will likely increase the severity of precipitation-related flooding within the Downtown area in the future. The final draft report titled "U.S. Global Change Research Program Climate Science Special Report (CSSR)" dated June 28, 2017 and developed by 13 federal agencies, presents conclusions associated with climate change impacts on extreme precipitation and flooding (Wuebbles et al, 2017). The report states "Extreme precipitation events will *very likely* continue to increase in frequency and intensity throughout most of the world (*high confidence*)." This report concludes that extreme precipitation events have a 90% - 100% likelihood of increasing in frequency and intensity in the future. As extreme precipitation events increase in frequency and severity, the Downtown area will be subject to greater risk of flooding from precipitation-based, and resulting, riverine flooding.

In support of the development of updated regression equations to estimate peak streamflow for selected annual exceedance probabilities for streams in New England, the United States Geologic Society (USGS) performed analysis of historical precipitation and stream-gage records in Massachusetts, Connecticut, New Hampshire, New York, Rhode Island, and Vermont. The analysis identified some positive trends in increasing peak stream flows, and Connecticut had the highest percentage of stream gages used in the study with a significant positive trend. The report provided limited analysis for increases in future stream flow predictions with resulting 10-, 20-, and 30-year projected increases of 2-, 4-, and 7-percent in peak streamflow.

The predicted flooding impacts presented in this report are based on current precipitation and riverine estimates. Current scientific literature suggests that precipitation and riverine peak flows will likely increase in the future. As a result, it is reasonable to expect flooding estimates presented within this report may increase in severity in the future.

"Heavy precipitation events in most parts of the United States have increased in both intensity and frequency since 1901 (*high confidence*). There are important regional differences in trends, with the largest increases occurring in the northeastern United States (*high confidence*)." (US Global Research Program CSSR, 2017)

Combined Coastal and Precipitation Flooding

The Downtown Westport area is highly vulnerable to coastal flood inundation. As discussed in **Attachment 2** and presented in **Figures 3.11 and 3.12**, below, coastal flood inundation during the 100-year and 500-year recurrence interval flood inundates much of the Downtown area. These results are consistent with the current FEMA FIRMs. Coastal flood inundation occurs during flood events with a predicted probability as high as the 2-year recurrence interval flood.

Along the east and west sides of the Saugatuck River within the Downtown area, coastal flood inundation occurs due to:

- Overtopping of the shoreline structures and adjacent areas, including:
    - Adjacent to Parker Harding Plaza
    - Wetland (tidal marsh) areas to the north of Avery Pl and Parker Harding Plaza, including development at Gorham Island Road
    - Along Post Road at the bridge
    - Eastern shoreline, south of the bridge
    - Adjacent to Wilton Road
    - Adjacent to Riverside Avenue
- Tidal storm surge along Deadman's Brook
- Flood inundation due to both of the above-described conditions appear to hydraulically connect north of the Colonial Green Shopping Center and Post Road West.

Images presented on **Figures 3-13 through 3-20** highlight these areas.

Coastal storms can result in combined storm surge and precipitation, and the flood effects are a combination of both rain and storm surge. As shown on the FEMA FIRM, Deadman's Brook contributes a river flood component that (due to its small watershed) is effected by local, intense precipitation. The Brook is culverted to the south of Post Road West (beneath the Colonial Green Shopping Center), at which point it becomes an open channel discharging to the Saugatuck River. The Brook is tidally-influenced and subject to both precipitation and storm surge-related flooding.

As discussed previously, elevated water levels due to coastal flooding can also have a significant effect on the performance of the stormwater infrastructure system due to backwater (aka tailwater) effects. So, even if coastal flood protection is implemented, additional flood mitigation measures will be required to manage precipitation-related flooding.

The effects of climate change will increase both coastal flood elevations (principally due to sea level rise) and intensity of precipitation events.

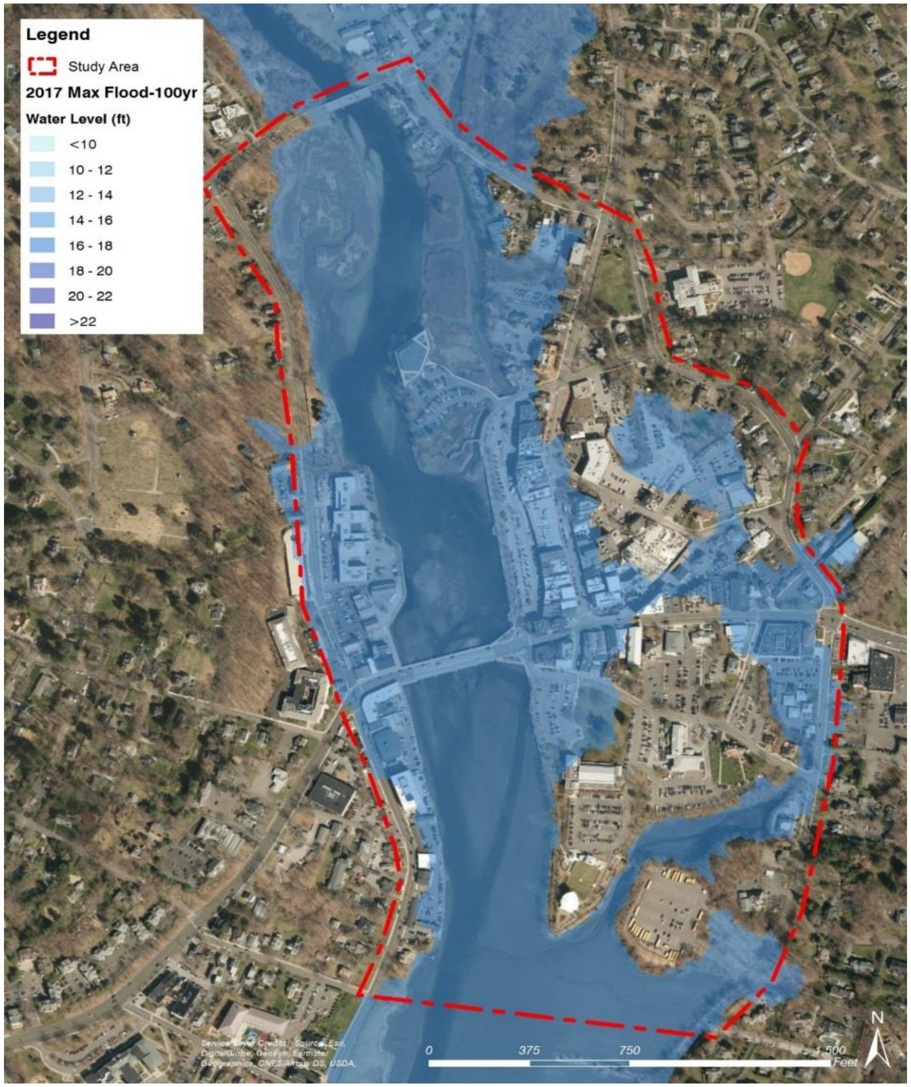


Figure 3.11: ADCIRC Model Simulation Results for the 2017 100-year return period (1% annual chance) peak flood inundation and elevations

Figure 3.12: Flood Extent in Downtown for the 2017 500-year return period (1% annual chance) peak flood inundation

Figure 3.13: Images within Coastal Flood Inundation Areas along Parker Harding Plaza and Main Street

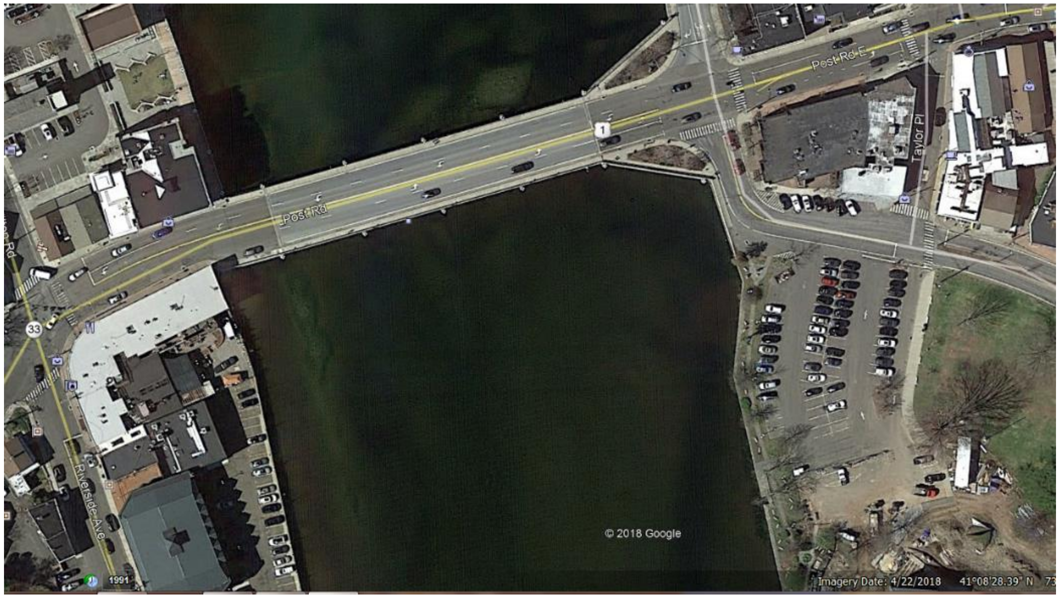


Figure 3.14: Images within Coastal Flood Inundation Areas along Post Road near the Post Road Bridge

Figure 3.15: Images within Coastal Flood Inundation Areas along Wilton Road

Figure 3.16: Images within Coastal Flood Inundation Areas along Wilton Road

Figure 3.17: Images within Coastal Flood Inundation Areas along Riverside Avenue

Figure 3.18: Images within Coastal Flood Inundation Areas along Riverside Avenue

Figure 3.19: Images within Coastal Flood Inundation Areas near Deadman's Brook

Figure 3.20: Images within Coastal Flood Inundation Areas near Gorhman Island Road

Shoreline Features

The shoreline features/structures include:

- A masonry seawall along Parker Harding Plaza. The seawall has a concrete cap and open wire fence. The top of the wall is approximately at street grade. The wall extends from the State Street East Bridge abutment (to the south) to the wetlands to the north (adjacent to the timber boardwalk).
- Wetlands surround the developed areas along Gorham Island. The Saugatuck River shoreline is river inlet sides armored with a granite rip-rap revetment.
- The shoreline adjacent to Wilton Road consists of a timber pier and granite rip-rap shoreline revetment.
- The shoreline adjacent to Riverside Avenue, south of the bridge, consist of a masonry sea wall with a concrete cap (wall extends to about midway between Cross Street and Lincoln Street).
- The bridge abutments consist of a masonry seawall topped with a concrete wall which extends about 3 feet above street grade. The bridge is a steel-framed deck spanning masonry bridge piers. The bridge deck elevation is relatively low, at about 9 to 10 feet NAVD88. The bridge has concrete sidewalls which extend about 3 feet above deck level.

Figure 3.21: Images showing shoreline structures within Coastal Flood Inundation Areas along Parker Harding Plaza

Figure 3.22: Images showing shoreline revetment at Gorham Island

Figure 3.23: Images of the Bridge, looking east from Wilton Road

Figure 3.24: Images showing shoreline seawalls in front of buildings along Riverside Avenue near the Bridge

Section 4
Flood Mitigation Strategies and Measures

FLOOD PROTECTION STRATEGIES AND MEASURES

Municipal climate adaption and flood mitigation generally utilize three strategies:

- **Retreat:** Relocate development and infrastructure to outside of current and future floodplains;
- **Protect:** Prevent flood inundation through the use of large-area flood protection barriers;
- **Accommodate:** Mitigate the effects of flooding using measures using localized measures, including:
    - Compliance with the flood regulations, through elevating structures, dry floodproofing and wet floodproofing;
    - Elevating and/or protecting transportation and other essential infrastructure.

Given the current level of development within the Downtown area, Retreat is not expected to be a practical alternative. A flood protection approach for the Downtown area should include a combination of Protect and Accommodate strategies. The flood protection strategy will also need to include improvement of the existing stormwater infrastructure within the Downtown area as well as within contributing watersheds.

Protect

The Protect flood protection strategy typically employs large-area perimeter coastal flood protection. Perimeter flood protection can consist of permanent flood barriers, such as permanent floodwalls, and temporary, deployable measures. Permanent measures can be very expensive to construct and often have negative consequences such as loss of water views, significant disturbance, high cost, etc. Conversely, deployable, temporary measures require adequate warning, material storage, the available manpower to deploy, regular require training and emergency response planning.

Permanent and/or deployable flood barriers should be constructed to a minimum flood elevation equal to or greater than the 100-year recurrence interval flood. The current 100-year recurrence interval flood stillwater elevation ranges from approximately 10.4 feet NAVD88 (FEMA coastal transect, Base Flood Elevation near Downtown area = 10 feet NAVD88) to 12.0 feet NAVD88 (mean NACCS, with an upper confidence interval of 15.8 feet NAVD88). A permanent barrier constructed as a FEMA-accredited levee (assumed for planning purposes), will need to be at least 2 to 3 feet higher than the FEMA BFE (currently, flood protection levels of Elevation 12 to 13 feet NAVD88).

Temporary, deployable flood barriers do not comply with the requirements for a FEMA-accredited levee.

To achieve this minimum level of flood protection (assumed Elevation 12 to 13 feet NAVD88), flood protection heights at perimeter flood locations will generally need to range from:

- Along Parker Harding Plaza:
    - Existing grades range from about 4 feet to 9 feet NAVD88
    - Barrier height: 3 to 8 feet
    - FEMA-accredited levee height: 4 to 9 feet
    - Approximate barrier length: 1,100 linear feet
    - Possible tie-in to bridge abutment wall
- Along eastern shoreline, south of the bridge:
    - Existing grades range from about 6 feet to 13 feet NAVD88
    - Barrier height: 1 to 6 feet
    - FEMA-accredited levee height: 1 to 7 feet
    - Approximate barrier length: 500 linear feet
    - Possible tie-in to bridge abutment wall
- Adjacent to Wilton Road
    - Existing grades approximately 9 to 12 feet NAVD88
    - Barrier height: 1 to 3 feet
    - FEMA-accredited levee: not feasible
    - Approximate barrier length: 1,200 linear feet
    - Possible tie-in to bridge abutment wall
- Adjacent to Riverside Avenue:
    - Existing grades approximately 6 to 14 feet NAVD88
    - Barrier height: 1 to 6 feet
    - FEMA-accredited levee: not feasible
    - Protect with perimeter flood barrier system to Cross Street
    - Enhance existing flood walls
    - Approximate barrier length: 400 linear feet
    - Possible tie-in to bridge abutment wall

Given the required flood barrier height, degree of disturbance and negative impacts and construction cost, a FEMA-accredited flood levee does not appear to be a practical or cost effective measure for the Downtown area.

Temporary, deployable measures, used as a large-area perimeter flood barrier, can be a practical alternative for the Downtown area, in particular along the east shoreline. These systems can be completely deployable or can be a combined low permanent wall with a deployable upper flood protection level. Some of these measures can be further divided into active and passive solutions. Active solutions require human intervention either before, during, or after the flood event. Active solutions are typically temporary, meaning they are put in place during the flood but removed when flooding is not present. Passive solutions do not require human intervention. Passive solutions are permanent, meaning they are in place at all times.

Examples of temporary and deployable perimeter flood barriers are presented below:

Inflatable Barriers: These systems (example Tiger Dams™) are a relatively simple rapid deployment system designed to act as a temporary emergency flood barrier. The systems typically consist of elongated stackable, flexible tubes, joined end to end and filled with water. The tubes are capable of being stacked up to a maximum of 32 feet high and linked together seamlessly for miles. They can be virtually any length and take any shape. Each tube (Tiger Dams™) weighs 65 lbs dry and 6,300 lbs when filled with water. These temporary engineered, interlocking, flexible tubes are then drained of water which can flow back into the river when the flooding subsides. When the floodwaters recede, the tubes can be drained within minutes, rolled up and reused again and again. They (Tiger Dams™) can roll up into a small package for storage (approximately 10 inches high x 19 inches wide). Deployment can be done from a pickup truck, the trunk of a car, emergency vehicles, etc.

Temporary Flood Walls (Panels): These systems (example AquaFence Floodwall™) are panelized, flexible flood barriers, generally made of laminate, stainless steel, aluminum and reinforced PVC canvas. In high-wind situations, an anchoring system is included to add stability and enhanced performance. A team of 12 people can install about 100 meters (328 feet) of FloodWall per hour. FloodWall is packaged and stored in custom-designed stackable wooden crates (2,1m x 1,2m, 7ft x 4ft). The crates can be stacked in columns of 4 high. For example, a typical parking spot can hold 2 crates deep and 4 high, to provide 500 linear feet of 4 foot fence. After a deployment, the panels should be cleaned and dried for storage and future use.

Temporary Flood Walls (Stop Logs): These systems (examples Invisible Flood Control Wall [IFCW™] and IBS Fontine) consist of gasketed aluminum planks and steel posts, which are quickly mountable and watertight. Steel base plates are cast into concrete foundations and are the only permanently installed feature of the flood barrier system. Applications for the system include perimeter walls, flood closures, and flood proofing. The anchors are permanently installed and the stop logs are erected before a flood event occurs. After the flood, the wall is easily demounted and stored. The estimated pre-storm installation time is calculated approximately by multiplying the height times the width and dividing by 200. The planks are available in any length, generally around 20 feet. The planks are stored with the planks vertically stacked for storage.

Figure 4.1: Images showing Inflatable barriers (top) and Panel Flood Walls (bottom)

Figure 4.2: Images showing Stop Log Flood Barriers

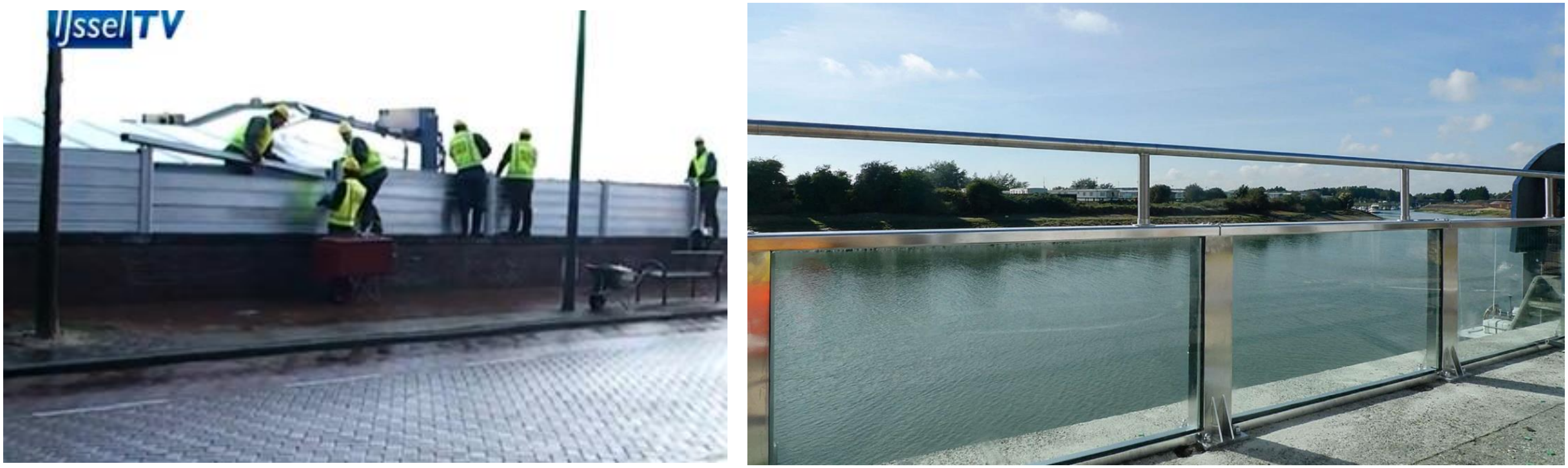


Figure 4.3: Images showing combined permanent/temporary flood barriers (left) and Glass Walls (right)

Stormwater Management

Based on GZA's modeling, insufficient stormwater capacity is causing flooding at Wilton Road/Riverside Avenue, Main Street, and the Elm Street Parking area. Further analysis of the stormwater system is recommended to identify the system's control points (i.e. locations that limit the system's capacity). The modeling also showed that at the Colonial Green Shopping Center, flooding is caused by insufficient capacity of Dead Man's Brook. It is GZA's understanding that another consultant, BL Companies, is currently developing recommendations for improving the capacity of the brook. The changes to the stormwater system and the brook would be considered long term as they would likely require more than a couple years to implement. The model also shows ponding of water at certain topographic low points.

GZA's modeling shows that storm surge contributes more to Downtown flooding than precipitation. Therefore, since drainage improvements typically alleviate flooding from precipitation-based events, these measures may be considered secondary compared to measures that address storm surge.

Overall Issues:

Overall, there are multiple considerations which result in flooding of the downtown area as a result of local precipitation, including:

- The downtown area consists of generally low topography at the downstream limit of the surrounding contributing watersheds.
- There is minimal elevation difference between the high tide elevation and the rim elevations of many structures in the downtown area.
- The highly urbanized downtown area has a significant percentage of impervious surface (68%, excluding waterbodies) which results in high volumes of runoff resulting from precipitation.
- Portions of the aging stormwater infrastructure within the Downtown area are insufficiently sized and in some locations in poor condition to properly convey peak rainfall intensities under current and future climate scenarios.

Drainage Improvements:

Drainage improvements can be implemented to reduce flooding caused by local precipitation.

- The stormwater system capacity can be increased by increasing the size and/or quantity of stormwater inlets, pipes, and outfalls, and clearing the system of debris through regular maintenance.
- The conveyance capacity of local streams can be increased by dredging/widening channels, straightening channels, and clearing debris from channels. At topographic low points where no stream or drain is located or can be constructed, pumps can be installed for improved drainage.
- Low points resulting in ponding of stormwater can be drained with the installation of stormwater pump stations. However, the overall effectiveness of pump stations may be reduced due to low head differential between the stormwater systems and the downstream high tide elevations, resulting in potentially significantly large and costly pump systems.
- Surface runoff can be stored above-ground in detention ponds or below ground in storage tanks, providing temporary retention of stormwater.
- Overall reduction in runoff volumes through the reduction in impervious surfaces or installation of Low Impact Development (LID) systems, such as rain gardens (green infrastructure), which may detain and promote infiltration and reduce overall runoff volumes. Reduction in imperviousness both in the downtown areas and upstream contributing watershed will be beneficial.
- Installation of tide gates and backflow preventers at outfalls exposed to tidal flooding. However, the effectiveness of backflow preventers may be limited during certain situations where the peak precipitation intensity and high tide are coincident. Due to the limited head within the stormwater systems the drainage capacity of the stormwater systems may be limited.

As described in **Section 3**, there are 4 major areas within the Downtown that are vulnerable to stormwater ponding and precipitation flooding. These areas are discussed in detail.

Figure 4-4: Underground stormwater detention; photo from Contech Figure Engineered Solutions

Location 1: Wilton Road/Riverside Ave.:

Causes of precipitation flooding:

- Low topography along Wilton Road (Elevation 5 to 7 feet NAVD88) causing localized ponding from offset runoff, as well as limited head difference within the stormwater systems.
- Limited stormwater capacity in the 18-inch diameter stormwater system draining the Wilton Road low point.
- Upstream contributing watershed along Old Hill Road that drains to a drainage ditch / intermittent stream which drains to / below Wilton Road.

Considerations for flood mitigation alternatives:

- Limited potential for subsurface detention and infiltration due to low topography on Wilton Road and likely high groundwater.
- Limited efficacy of tide gates and pump stations due to low head differential between stormwater systems and high tide elevations.
- Limited area for above ground detention/infiltration systems.

Flood Mitigation Measures:

- Increase stormwater capacity of systems draining to Saugatuck River.
- Increase conveyance capacity of ditch/intermittent stream west of Wilton Road to convey flows to Saugatuck River.

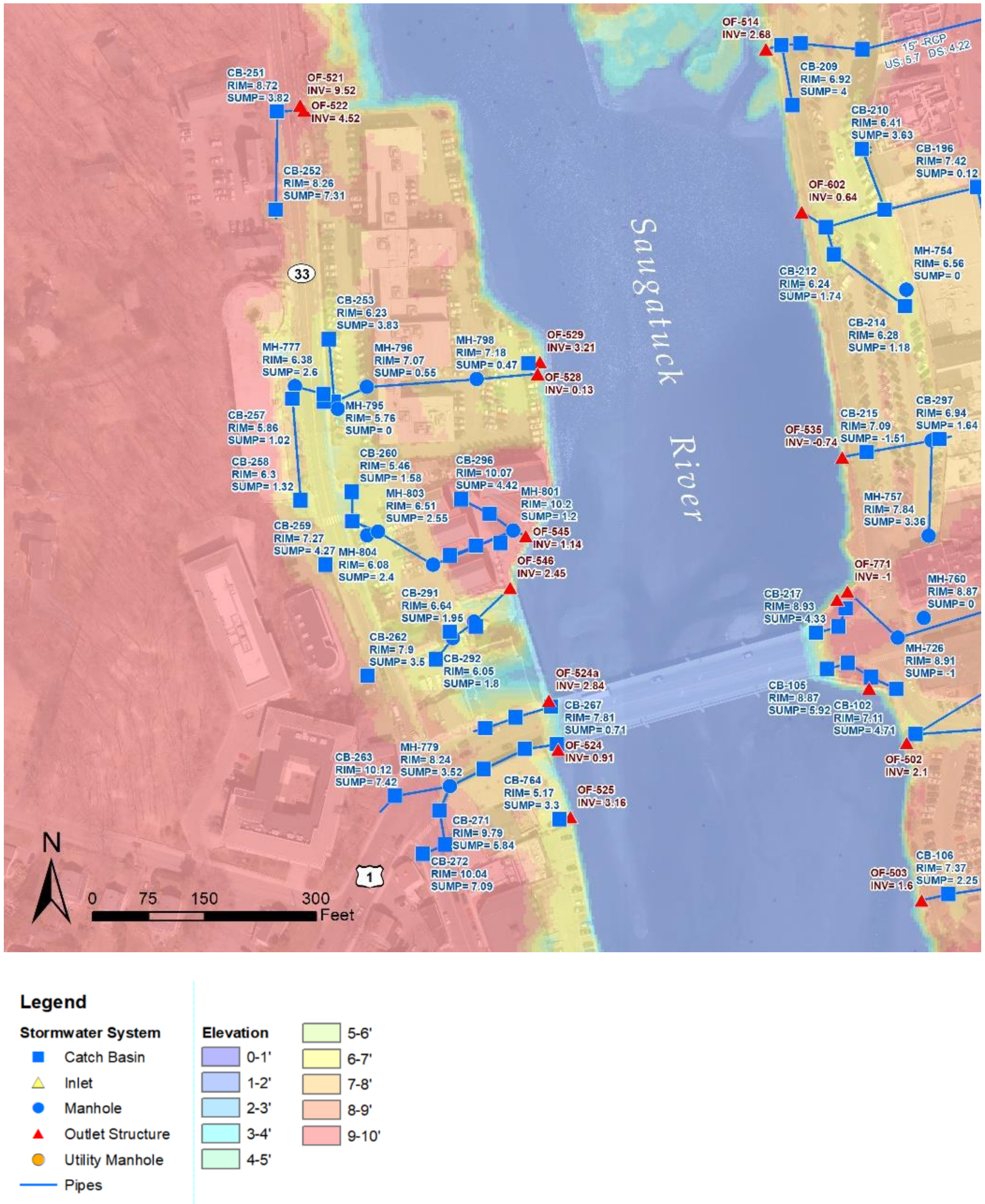


Figure 4.5: Ground surface elevation and stormwater infrastructure at Wilton Road and Riverside Avenue

Location 2: Main Street:

Causes of flooding:

- Substantial amounts of directly-connected impervious surfaces within the immediate downtown area.
- Low topography along Main Street (Elevations 6 to 7 feet NAVD88) causing localized ponding of offset runoff, as well as, limited head difference within the stormwater systems.
- Aging infrastructure that may not operate efficiently. The survey team was unable to identify all connections within the system due to debris and assumptions were made in the analysis.
- Limited stormwater capacity in the 15-inch diameter stormwater system draining through the Harding Plaza Parking Lot.

Considerations for mitigation alternatives:

- Limited potential for subsurface detention and infiltration due to low topography on Wilton Road / Harding Plaza and likely high groundwater.
- Limited efficacy of tide gates and pump stations due to low head differential between stormwater systems and high tide elevations.
- Limited area for above ground detention/infiltration systems.

Flood Mitigation Measures:

- Increase stormwater capacity of systems draining to Saugatuck River.
- Reduce the amount of imperviousness within the immediate downtown area through installation of low-impact development solutions.
- Increase the infiltration capacity in the Harding Plaza area using pervious pavement/pavers/rain gardens (Green Infrastructure).
- Raise roadways.

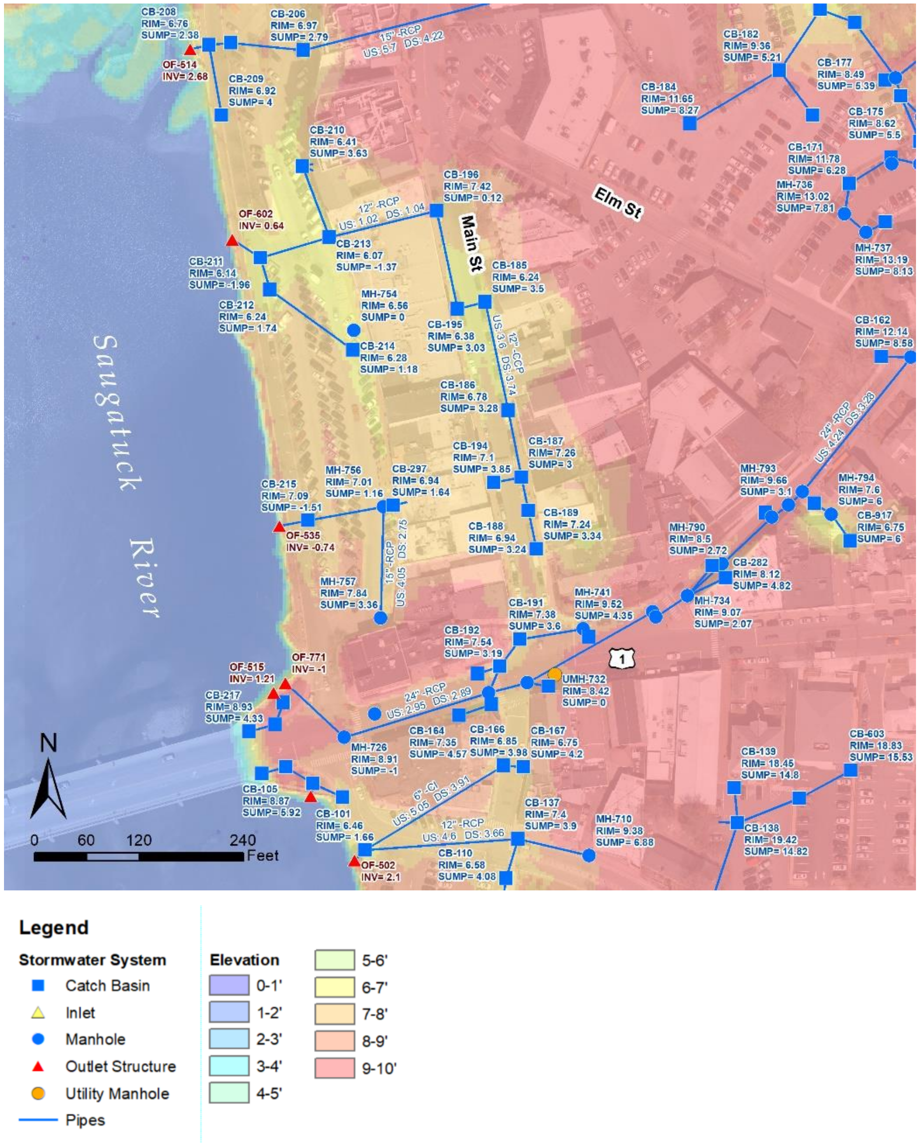


Figure 4.6: Ground surface elevation and stormwater infrastructure at Main Street

Location 3: Elm Street Parking Area:

Causes of flooding:

- Low topography in Elm Street Parking lot (Elevation 6 to 7 feet NAVD88) causing localized ponding of offset runoff, as well as, limited head within the stormwater systems.
- Large, highly impervious watershed draining to 30-inch diameter stormwater system draining through Post Road E.

Considerations for mitigation alternatives:

- Limited potential for subsurface detention and infiltration due to low topography on Wilton Road and likely high groundwater.
- Limited efficacy of tide gates and pump stations due to low head differential between stormwater systems and high tide elevations.
- Limited area for above ground detention / infiltration systems.

Flood Mitigation Measures:

- Increase stormwater capacity of system draining to Saugatuck River.
- Potentially incorporate subsurface detention systems for sub-systems of overall drainage system (at higher elevations).
- Increase the infiltration capacity in the Elm Street Parking Area using pervious pavement/pavers/rain gardens (Green Infrastructure).
- Raise parking area.

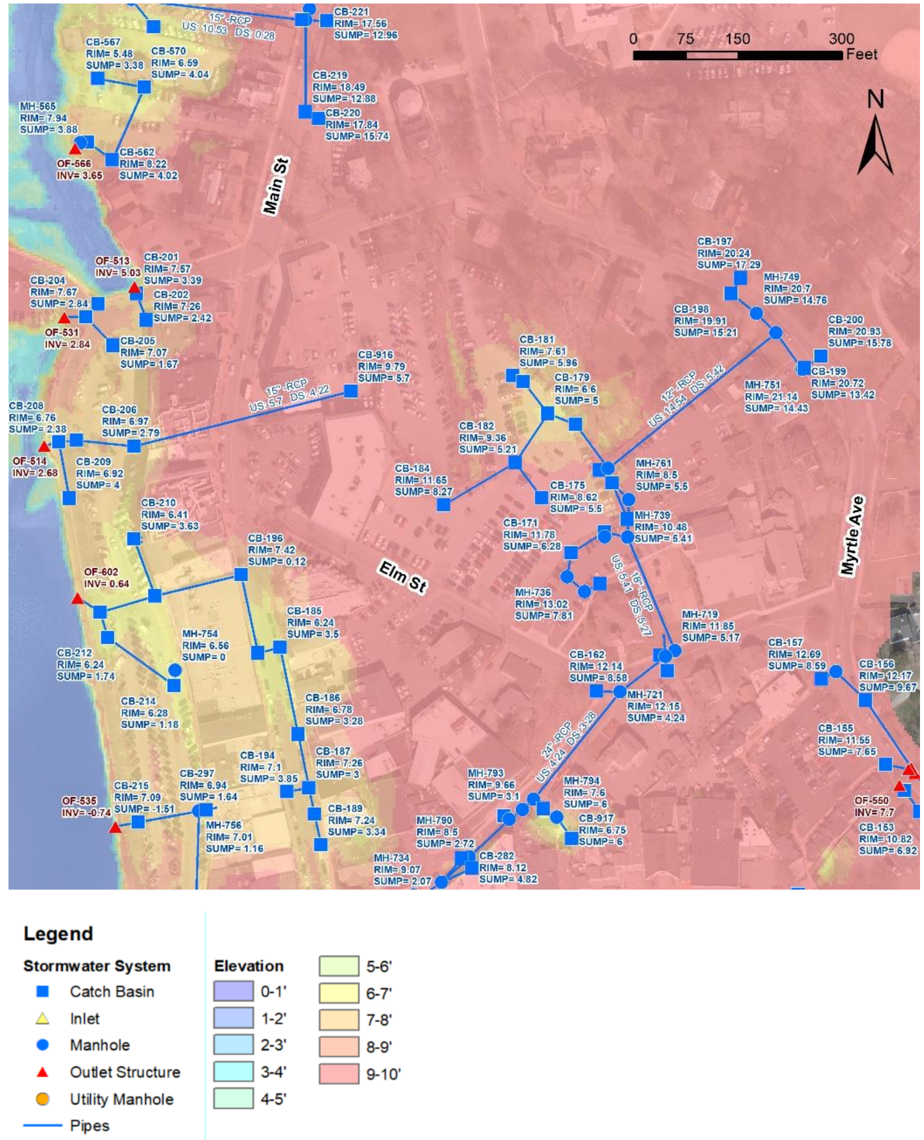


Figure 4.7: Ground surface elevation and stormwater infrastructure at Elm Street Parking Area

Location 4: Colonial Green Shopping Center:

Causes of flooding:

- Large contributing watershed to Dead Man Brook.
- Limited hydraulic capacity of channelized portion of Dead Man Brook.
- Low topography in Colonial Green Shopping Center (Elevations 6 to 8 feet NAVD88).
- Large upstream contributing watershed that drains to 15-inch diameter stormwater system along Post Road E and ultimately discharges to Dead Man Brook.

Concerns for mitigation alternatives:

- Limited potential for subsurface detention due to low topography on Wilton Road and likely high groundwater.
- Limited efficacy of tide gates and pump stations due to low head differential between stormwater systems and high tide elevations.
- Limited area for above ground detention / infiltration systems.

Flood Mitigation Measures:

- Implement recommendations from Dead Man Brook Study and increase capacity of channelized portion of Dead Man Brook.
- Increase stormwater capacity of systems draining to Dead Man Brook.
- Install low-impact development or green infrastructure systems in the upstream portion of the watershed to increase retention of runoff.

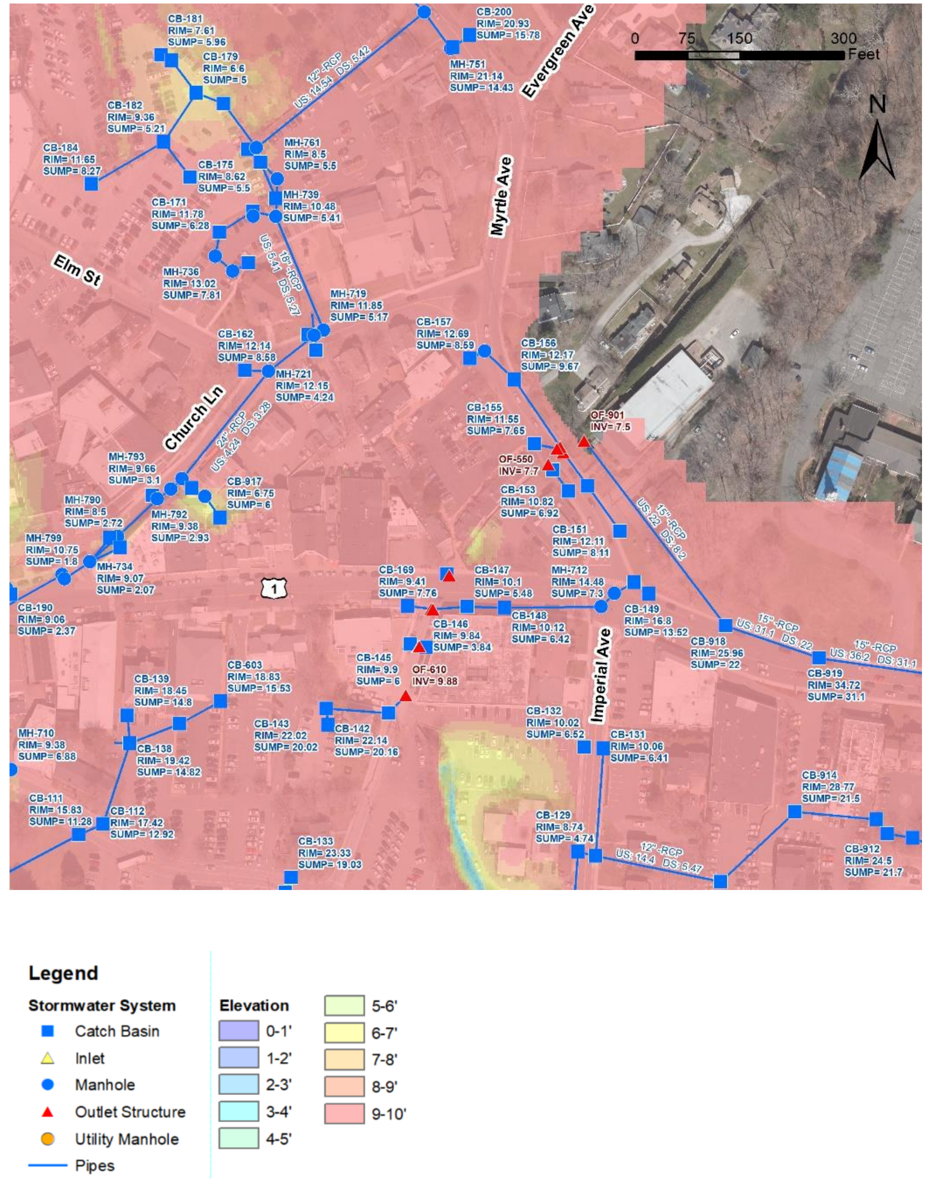


Figure 4.8: Ground surface elevation and stormwater infrastructure at Colonial Green Shopping Center

Accommodate

The Accommodate strategy relies primarily on flood protection that is implemented by:

- Private property owners, generally by compliance with building code flood regulations.
- The municipality, responsible for protection of transportation and stormwater infrastructure as well as Essential Facilities and Lifeline Systems.

A strategy of Accommodate typically includes:

- elevation of buildings, structures and infrastructure, including compliance with local, State and federal codes and regulations;
- dry flood-proofing of buildings and structures;
- wet floodproofing;
- use of temporary flood protection measures at the property or street scale;
- emergency/flood response plans;
- operation and maintenance of culverts and tide gates;
- operation and maintenance of pump stations;
- dredging of waterways;
- post-storm repair and clean-up.

The measures identified above can be implemented at lower incremental costs (relative to the strategies of Retreat and Protect) and are, therefore easier to implement. However, their net costs may be higher and their efficiency and long term benefits less.

The effective State Building Code (2018) includes the 2015 International Building Code and the State Building Code Connecticut Supplement and 2018 Amendments. The State Building Code also incorporates by reference ASCE 7 (Minimum Design Loads for Buildings and Other Structures) and ASCE 24 (Flood Resistant Design and Construction), which contain most of the requirements related to flood regulations. The Connecticut State Building Codes support and are consistent with the federal NFIP regulations (44CFR Parts 59 and 60).

Triggering events requiring compliance with the building code include:

- New Construction
- Substantial Damage
- Substantial Improvement

Substantial Damage as defined by FEMA "substantial damage" applies to a structure in a Special Flood Hazard Area – or floodplain – for which the total cost of repairs is 50 percent or more of the structure's market value before the disaster occurred, regardless of the cause of damage. This percentage rule can vary among jurisdiction. Substantial improvement as defined by FEMA is, any reconstruction, rehabilitation, addition, or other improvement of a structure, the cost of which equals or exceeds 50 percent of the market value of the structure before the "start of construction" of the improvement. This term includes structures which have incurred "substantial damage," regardless of the actual repair work performed.

Guidance for flood protection measures consistent with an Accommodate strategy include:

1. "Floodproofing Non-Residential Buildings", FEMA P-936, Flood Emergency Management Agency (FEMA), July 2013.
2. "Selecting Appropriate Mitigation Measures for Floodprone Structures", FEMA 551, Flood Emergency Management Agency (FEMA), March 2007.

Town planning measures are also a key part of an Accommodate strategy. Westport's 2015 Downtown Master Plan include:

1. Encouraging the elevation of buildings to higher levels through funding support from state grants.
2. Enacting tough regulations on renovation and construction in flood-prone areas. Homeowners or businesses that build additions or renovations in flood-prone areas must elevate the structure to one foot above the Base Flood Elevation (BFE) if their renovations or additions exceed 50 percent of the fair market value of the property in any five-year period (as per FEMA National Flood Insurance Requirements enacted in 2012). Experience in Westport demonstrates that structures elevated above the 100-year flood hazard levels had less damage than structures that were not elevated.
3. Widening of channels and enlarging of culverts in flood areas.
4. Encouraging low impact development (LID) techniques.
5. Adopting a policy that requires a "zero net increase in the rate of runoff" for new residential construction.

Examples of Accommodate measures are presented below.

Figure 4-9: Structure protected by a floodwall (FEMA, 2007)

Property floodwalls are encouraged by FEMA; however, these measures are not accounted for in determining: 1) compliance with local, State and federal flood building codes; or 2) national flood insurance premiums. Property floodwalls around commercial facilities may result in reduction of private flood insurance.

Figure 4-10: Aluminum door flood shield used for flooding less than 3 feet deep. (FEMA, 2013)

Property door barriers are encouraged by FEMA; however, these measures are not accounted for in determining: 1) compliance with local, State and federal flood building codes; or 2) national flood insurance premiums. The one exception is when they are used as part of a dry floodproofing design. Property door barriers commercial for facilities may result in reduction of private flood insurance.

Figure 4-11: Application of Waterproofing (FEMA, 2013)

Figure 4-12: Elevating Structures (FEMA, 2013)

Application of waterproofing sealants is a component of "dry floodproofing", in compliance with flood regulations or commercial and mixed-use structures.

Elevating structures is the one of the most common measures to comply with flood regulations. However, this approach is limited in developed urban areas and areas with historic structures.

Where the entire building or lower-level cannot be elevated, interior areas can be elevated as shown in **Figure 4-33**.

Figure 4-13: Hardware Store on Main Street in Darlington, WI showing ramp to elevated interior first floor (FEMA, 2013)

Section 5
Flood Mitigation Recommendations

The Downtown area is highly vulnerable to flooding and a long term flood strategy and implementation of flood mitigation measures are warranted. Based on the estimated valuation of flood vulnerable properties, it is expected that flood mitigation measures (presented herein) will result in a net positive Benefit/Cost Ratio. This is without consideration of other flood impacts such as diminished real estate value, disruption of operations and a net migration of business owners away from Westport.

The following presents a mitigation strategy for Downtown Westport:

1. Perimeter Flood Protection: Further evaluate the use of a wide-area, municipal perimeter flood protection including:
   - Along Parker Harding Plaza:
     - Existing grades range from about 4 feet to 9 feet NAVD88
     - Barrier height: 3 to 8 feet
     - Approximate barrier length: 1,100 linear feet
     - Possible tie-in to bridge abutment wall
   - Along eastern shoreline, south of the bridge:
     - Existing grades range from about 6 feet to 13 feet NAVD88
     - Barrier height: 1 to 6 feet
     - Approximate barrier length: 500 linear feet
     - Possible tie-in to bridge abutment wall

   Based on GZA's work completed to-date, it appears that temporary flood barriers (or a permanent low wall with a temporary upper barrier) appear to be the preferred approach at this location.

   The length of the perimeter protection would be about 1,600 linear feet and the height would range from about 3 to 8 feet. Permanent construction of anchors and base plates and concrete foundation platform is required.

   Deployment would require about 500 manhours, which would require significant staff (likely more than permanent Town staff, requiring a subcontractor). Assuming a 48-hour advance deployment time, about 10 to 12 people would be required.

   From the Westport Plan: The main recommendation of the study was to place a three-foot high, one-foot wide cap on top of the existing riverbank walls at Parker Harding Plaza and Jesup Road to raise the wall to one foot above the 100-year flood elevation.

Figure 5-1: Approximate Limits of Perimeter Flood Protection

2. Improvement of Existing Flood Walls: Improvement of existing flood walls, in conjunction with property-scale flood protection:
   - Adjacent to Riverside Avenue:
     - Existing grades approximately 6 to 14 feet NAVD88
     - Barrier height: 1 to 6 feet
     - FEMA-accredited levee: not feasible
     - Protect with perimeter flood barrier system to Cross Street
     - Enhance existing flood walls
     - Approximate barrier length: 400 linear feet
     - Possible tie-in to bridge abutment wall

   Based on GZA's work completed to-date, it appears that improvement of the existing flood walls located along the individual parcels along the west shoreline appears to be the preferred approach.

   The length of the wall improvements perimeter protection would be about 400 linear feet and the height would range from about 1 to 6 feet.

3. Localized Temporary, Deployable Flood Walls: Deployment of temporary flood barriers, on a property scale:
   - Adjacent to Wilton Road
     - Existing grades approximately 9 to 12 feet NAVD88
     - Barrier height: 1 to 3 feet
     - FEMA-accredited levee: not feasible
     - Approximate barrier length: 1,200 linear feet
     - Possible tie-in to bridge abutment wall

Figure 5-2: Approximate Limits of Perimeter Flood Protection along Riverside Avenue

Figure 5-3: Approximate Limits of Temporary, Deployable Flood Protection along Wilton Road

Figure 5-4: Approximate Limits of Temporary, Deployable Flood Protection at intersection of Jesup Road and Imperial Avenue

4. Localized Temporary, Deployable Flood Walls: Deployment of temporary flood barriers, on a property scale:
    - Along Jesup Road and Imperial Avenue
    - Existing grades approximately 9 to 15 feet NAVD88
    - Barrier height: 1 to 3 feet
    - Approximate barrier length: 400 linear feet

5. Stormwater Improvements: Stormwater improvements are recommended at four areas that have a high probability of stormwater flooding including:
    - Wilton Road / Riverside Avenue
    - Main Street
    - Elm Street Parking Area
    - Colonial Green Shopping Area

GZA's analysis, including numerical modeling, A more detailed engineering analysis is required to identify specific stormwater improvements at each of the areas of concern. In general, flood measures include the following:

- Complete a detailed stormwater system capacity analysis to identify the capacity and limitations of stormwater systems in the downtown area and make site-specific recommendations for system improvements.
- Develop a master watershed management plan to identify locations to reduce imperviousness or include detention/retention systems in the upstream contributing areas to reduce runoff to the downstream area.
- Install retention/detention storage systems (including subsurface storage systems).
- Install/promote Low Impact Development (LID) features including:
    - Reduce the impervious cover within the downtown area as well as the upstream contributing watershed to reduce runoff volumes.
    - Use LID features to detain water (rain gardens, curb depressions, etc.).
- Install functional tide gates and backflow preventers at all outfalls.
- Install stormwater pump stations.
- Raise roadways to minimize low points and increase the hydraulic head within the stormwater systems.

6. Planning and Policy: From Westport Planning Report Policy Actions: The Town encourages certain activities and passed new rules to mandate specific measures, which include:

- Encouraging the elevation of buildings to higher levels through funding support from state grants.
- Enacting tough regulations on renovation and construction in flood-prone areas. Homeowners or businesses that build additions or renovations in flood-prone areas must elevate the structure to one foot above the Base Flood Elevation (BFE) if their renovations or additions exceed 50 percent of the fair market value of the property in any five-year period (as per FEMA National Flood Insurance Requirements enacted in 2012). Experience in Westport demonstrates that structures elevated above the 100-year flood hazard levels had less damage than structures that were not elevated.
- Widening of channels and enlarging of culverts in flood areas.
- Encouraging low impact development (LID) techniques.
- Adopting a policy that requires a "zero net increase in the rate of runoff" for new residential construction.

In addition, we recommend that:

- The Town provide planning guidance and education to property owners which highlights the State standard for sea level rise:

  https://circa.uconn.edu/2018/03/27/sea-level-rise-projections-for-the-state-of-connecticut-webinar-recording-available/

- Encourage (and provide guidance to) owners of properties not currently in compliance with building code flood regulations to:
    - Develop and implement emergency flood response plans;
    - Utilize deployable measures to mitigate flood effects.
- Consider sea level rise for all future Town projects including transportation infrastructure.
- Consider increased precipitation rates for all future stormwater infrastructure projects.
- Consider increased flood inundation limits when locating future Essential Facilities and Lifeline Systems. These limits can be readily approximated using: existing FEMA or NACCS flood elevations, the NOAA 2017 sea level rise (or State standards) and the new State Lidar data. http://cteco.uconn.edu/data/flight2016/

Attachment 1

The stormwater infrastructure system within the Downtown Westport area consists of a combination of old and new infrastructure owned by the Town and drainage systems on private property. Most of the stormwater infrastructure consists of collection systems which drain relatively small watersheds (less than 5 acres). The existing stormwater infrastructure had been, generally, unmapped. To better document the existing infrastructure and support numerical modeling of precipitation events, GZA performed a survey and inventory of the stormwater infrastructure within the Downtown area and developed a comprehensive database and ArcGIS files of the catch basins, manholes, piping and outfalls stormwater infrastructure within the Downtown area.

GZA's study included: 1) review of available Town GIS data; and 2) a detailed field survey and inventory of outfalls, catch basins, manholes, and storm drain piping. In addition to providing necessary input data for modeling of the stormwater infrastructure, the stormwater system documentation performed as part of GZA's study advanced the Town's progress toward achieving compliance with requirements outlined in the General Permit for discharge of stormwater from Small Municipal Separate Storm Sewer Systems (MS4).

Preliminary Review of Existing Data

GZA reviewed available Town stormwater infrastructure information, including GIS layer data of digitized manhole, outfall, pipe, and storm inlet information. The GIS data included approximately 70 inlet, manhole or outfall structures, consisting of approximately 20 percent of the total stormwater infrastructure present within the Downtown area. The data included feature locations and basic structure information such as pipe size and material. G ZA verified the inlet and manhole information using Google Earth and Google Street View technologies and identified nearly 200 additional structures not included in the original dataset.

Stormwater Infrastructure Survey

The professional surveyor firm DiMarzo & Bereczky, under contract to GZA, performed an elevation, alignment and dimension survey of the storm sewer infrastructure system in Downtown area. The survey was performed between April and May, 2017. The survey documented the geospatial location of: manholes; catch basins; piping; outfalls; and open channel conveyances. The data collected during the field survey included: structure rim/grate elevations; sump elevations; pipe material shape and size; and outfall features, including headwalls or flap valves. The pipe alignment and connectivity of structures and pipes was inferred based on field inspection within manholes and catch basins and surveyor experience.

Attachment 1 Figure 1: Stormwater infrastructure Survey

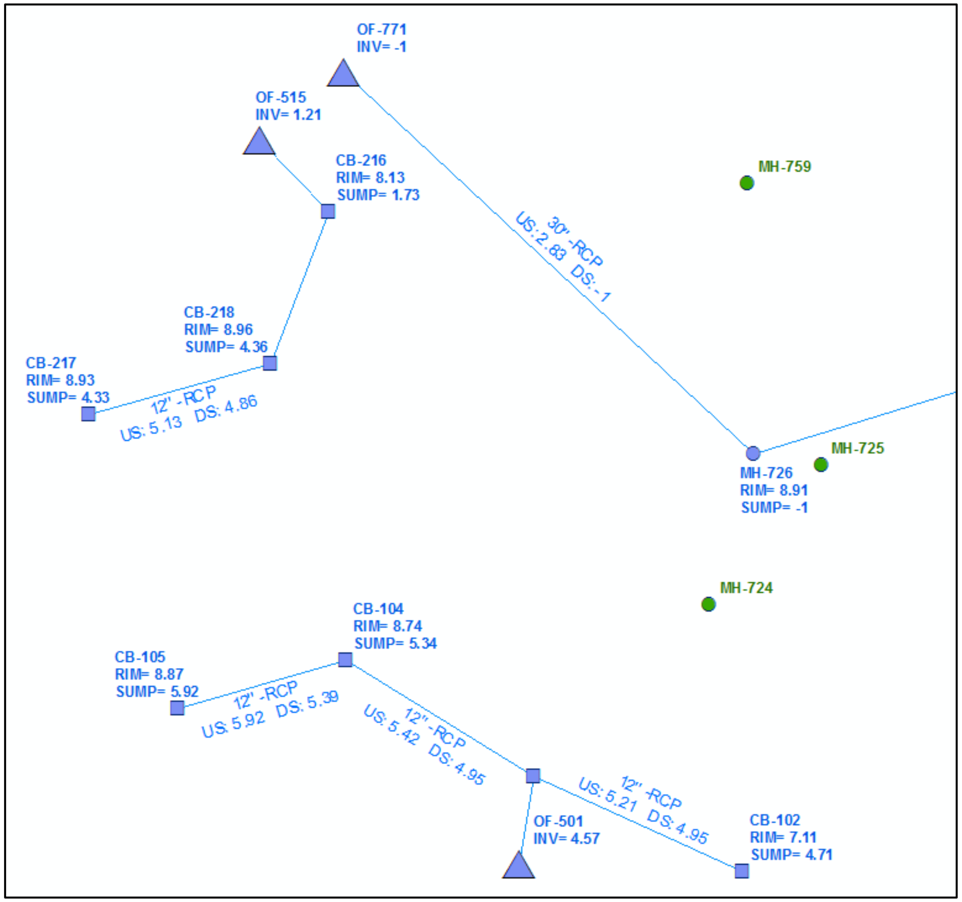
Stormwater Infrastructure Geospatial Database

GZA used the survey results to develop stormwater mapping and network connectivity geospatial database for the Downtown area. At locations where known structures could not be field-located (e.g., due to vegetation or inaccessibility) the structures were added to the geospatially located based on engineering judgement.

Additional stormwater drainage features, that are located outside of the Downtown area but contribute stormwater to the Downtown area infrastructure system, were added at locations determined based on review on aerial photography, for purposes of performing the numerical stormwater modeling.

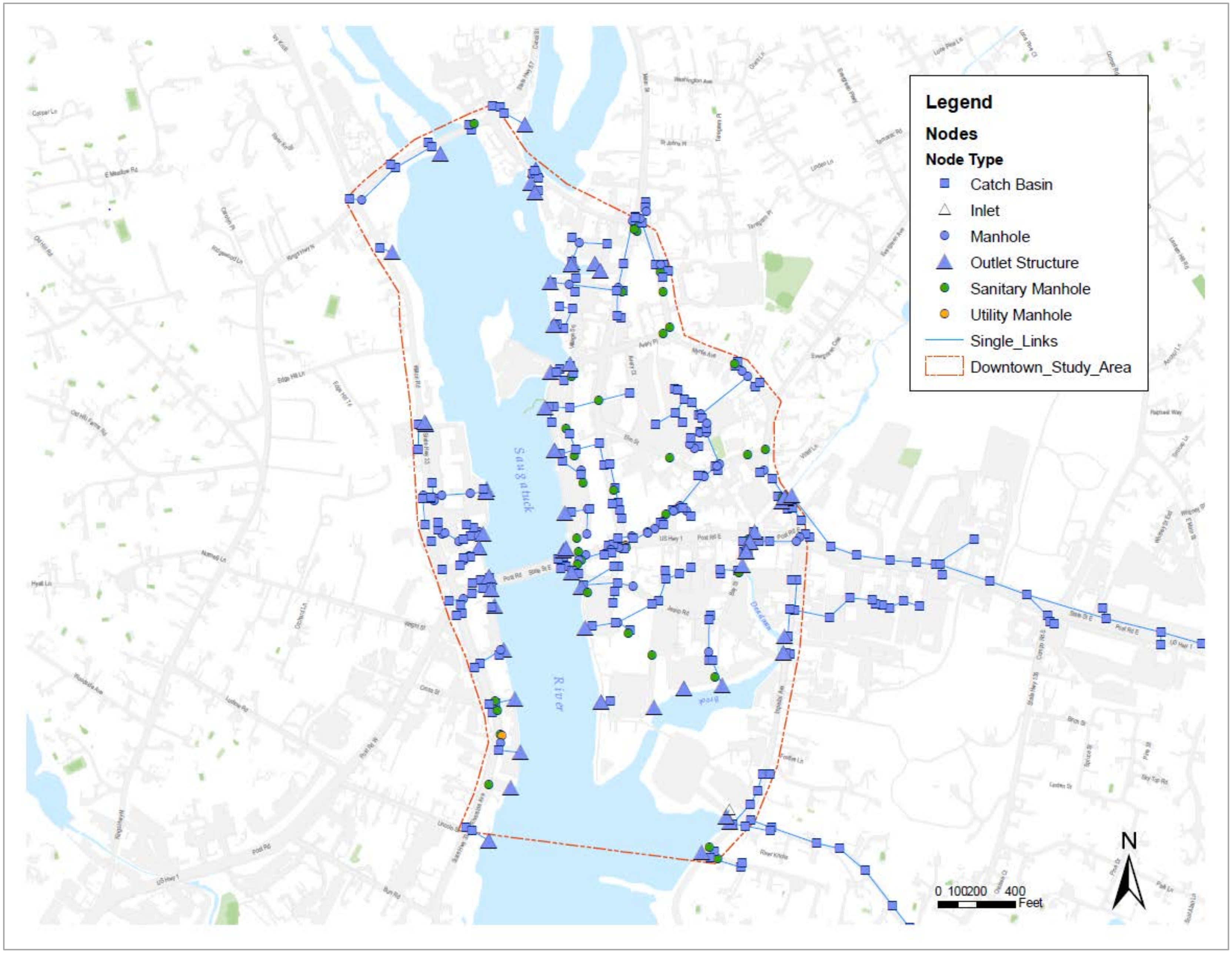
The geospatial database of the Downtown area stormwater infrastructure system includes over 350 drainage structures (manholes, catch basins and outfalls) and 300 pipes within the Downtown area. A typical example of the geospatial layer data is shown in **Attachment 1 Figure 2.** The electronic files of the geospatial database were provided to the Town for incorporation within their GIS data systems.

Attachment 1 Figure 3, on the following page presents the stormwater infrastructure within the Downtown area.



Attachment 1 Figure 2: Screenshot of Typical GIS stormwater infrastructure data layer

Attachment 1 Figure 3 (next page): Overview of the Downtown Westport area stormwater infrastructure.


Legend
Nodes
Node Type
Catch Basin
Inlet
Manhole
Outlet Structure
Sanitary Manhole
Utility Manhole
Single_Links
Downtown_Study_Area
Saugatuck River
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Attachment 2

OVERVIEW

GZA evaluated the vulnerability of flooding within the Downtown Westport area resulting from the combined effects of precipitation, river and coastal storm surge associated with multiple risk levels (annual probability of occurrence). GZA's evaluation of the coastal flood events included tide, sea level rise and extreme flood events (due to coastal storms).

The following provides an overview of the Westport coastal flood risk.

COASTAL FLOOD HAZARDS

The Westport downtown is vulnerable to coastal flooding due to its proximity to the Saugatuck River, which is hydraulically connected to Long Island Sound and tidal. The Westport Downtown area, located approximately 3 miles north of the mouth of Saugatuck River, is protected from the effects of waves during coastal storms; however, coastal storm surge propagates up the river and due to hydrologic effects can result in higher surge levels than experienced along the coast of Long Island Sound. The peninsulas and islands at Saugatuck River mouth and the flow path of the Saugatuck River serve to reduce Sound storm waves from entering Saugatuck River, and the local wave fetch during flooding around the Westport Downtown area is approximately 0.6 mile, which results in small storm waves at Westport downtown.

There are a number of sources of information that predict the probability of coastal flooding in the vicinity of Westport. These include: 1) FEMA Flood Insurance Studies; 2) statistical analyses of NOAA tide station water level data (+/- 50 year record); and 3) the USACE North Atlantic Coast Comprehensive Study (NACCS).

To evaluate the coastal flood hazard at Westport, GZA performed:

1. An evaluation of metocean and flood data including:
    a. the Federal Emergency Management Agency (FEMA) effective Flood Insurance Rate Map (FIRM) and the FEMA Flood Insurance Study (FIS);
    b. the National Oceanic and Atmospheric Agency (NOAA), tide gage data; and
    c. the U.S. Army Corps of Engineers (USACE) North Atlantic Coast Comprehensive Study (NACCS).
2. Review of the 2017 National Oceanic and Atmospheric Agency (NOAA) and Connecticut standardized sea level rise projections.
3. numerical hydrodynamic modeling of tides and storm surge using the Advanced Circulation Model (ADCIRC).

Flood Probability of Occurrence

Coastal flood hazards include:

- tides;
- extreme water levels due to storm surge;
- waves; and
- coincident high wind and precipitation

These coastal hazards are typically described (by FEMA and other flood planners and engineers) in terms of their likelihood of occurrence. Specifically, coastal floods, waves, precipitation and wind intensity are characterized by their "annual exceedance probability [AEP]" and, similarly, their "recurrence interval".

The AEP defines the probability that a certain condition (say, flood water level) will be encountered or exceeded at least once in any given year. The FEMA base flood elevation (shown on FEMA Flood Insurance Rate Maps [FIRMs]) represents the predicted 1% AEP (aka 100-year recurrence interval) flood. This flood water level has a 1 in 100 chance of being met or exceeded in any given year.

Since it is important (for Town planners as well as homeowners) to consider all coastal flood risks, conditions associated with other occurrence probabilities are also important. Due to their importance for public safety, Essential Facilities (police, emergency responders) conservatively consider lower probability floods (i.e., the 500-year recurrence interval flood). At the other end of the spectrum, although less intense, high probability floods (such as the 2-year and 10-year recurrence interval floods) are important because they are predicted to occur frequently.

The recurrence interval (for example the 100-year recurrence interval flood) does not mean that it will only occur every 100 years - rather it is a statistical probability that reflects the chance of that flood (or a greater flood) occurring at least once in any year. However, over a specific length of time (e.g., 30-year mortgage) the chance of experiencing that flood (or greater flood) at least once is greater than the annual probability. For example, the 100-year recurrence interval flood has about a 25% chance (1 in 4) of occurring at least once in a 30-year period.

Sea Level Rise

Sea level rise will increase the future coastal flood risk at Westport. For a given flood water level, it increases the probability of experiencing that same flood level in the future relative to today. On the other hand, for a given occurrence probability it increases the associated flood water level. In effect this will result in higher tides, and storms like Superstorm Sandy will be both more frequent and worse with respects to future damages to occurring in Downtown.

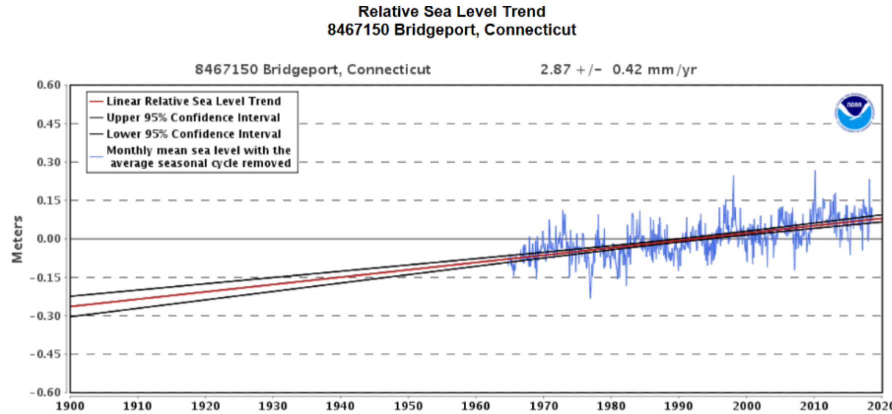
On average, over the last +/- 50 years the observed rate of sea level rise at Bridgeport has been about 2.87 millimeters per year (about 0.11 inch/year or about 11 inches in 100 years). **Attachment 2 Figure 1** shows the monthly mean sea level without regular seasonal fluctuations. However, the rate of sea level rise has been observed to be increasing and is predicted to substantially increase during the next 25 to 100 years. As of the date of this plan the most current industry-accepted sea level rise projections for Westport are those published by the National Oceanic and Atmospheric Administration (NOAA) in 2017. **Attachment 2 Figure 2** presents NOAA 2017 sea level rise projections (relative to 2000) for Bridgeport. Several projections are presented, representing different likelihood of occurrence (Kopp et al, 2014). The projections are fairly closely grouped in the near-term (+/- 2040) but become quite varied toward the end of the century, reflecting the significant uncertainty associated with predicting long-term sea level rise.

The NOAA Low projections are generally consistent with the observed historical rates of RSLC. The predicted relative sea level rise at Westport between the years 2017 and 2117 (based on projections at NOAA tide station 8467150 at Bridgeport, CT are summarized in **Attachment 2 Table 1** (in feet). These projections were developed using the USACE Sea Level Change Curve Calculator (version 2017.42) and are based on NOAA 2017 projection.

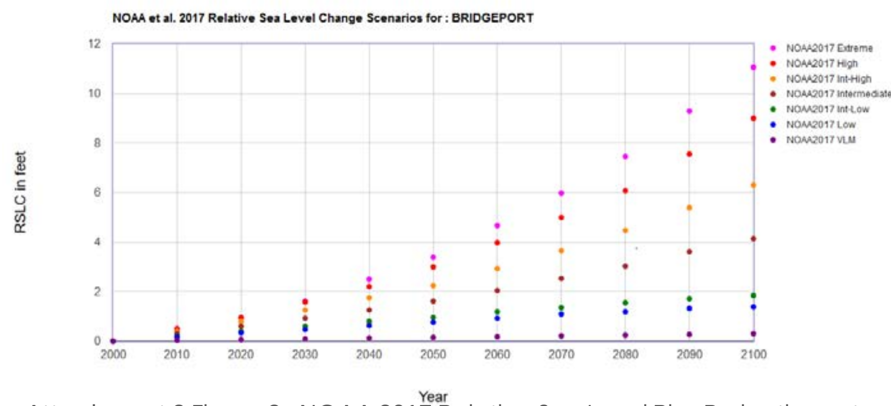
Year	NOAA (LOW)	NOAA (INT-LOW)	NOAA (INT)	NOAA (INT-HIGH)	NOAA (HIGH)
2042	0.65	0.82	1.32	1.84	2.36
2067	1.03	1.30	2.38	3.42	4.68
2117	1.50	2.06	5.01	7.86	11.44

Attachment 2 Table 1: NOAA 2017 Relative Sea Level Rise Projections at Bridgeport

For the purposes of this plan, it can be assumed that the NOAA 2017 Intermediate-Low projection shown below has a high likelihood of occurrence (50% to 100%) and the Intermediate projection (2% to 17%) is a reasonable upper bound. This means that (relative to the year 2000), sea levels are predicted to rise (with a reasonable probability) by 1 foot to 1.6 feet by 2050 and 1.8 feet to 4.1 feet by 2100. It could be higher or lower, but at this time these are reasonable projections for planning purposes. The Intermediate projections are in-line with projections currently recommended by the State. Extreme projections (currently predicted to have very low probability) have sea levels rising at Westport on the order of 4.7 feet and 11.1 feet (50 and 100 years from 2017, respectively). The Intermediate-High projection (0.4% to 1.3%) was conservatively used by GZA for numerical flood modeling.



Attachment 2 Figure 1: Observed Sea Level Rise at the NOAA Bridgeport Tide Gage



Attachment 2 Figure 2: NOAA 2017 Relative Sea Level Rise Projections at Bridgeport

Tides

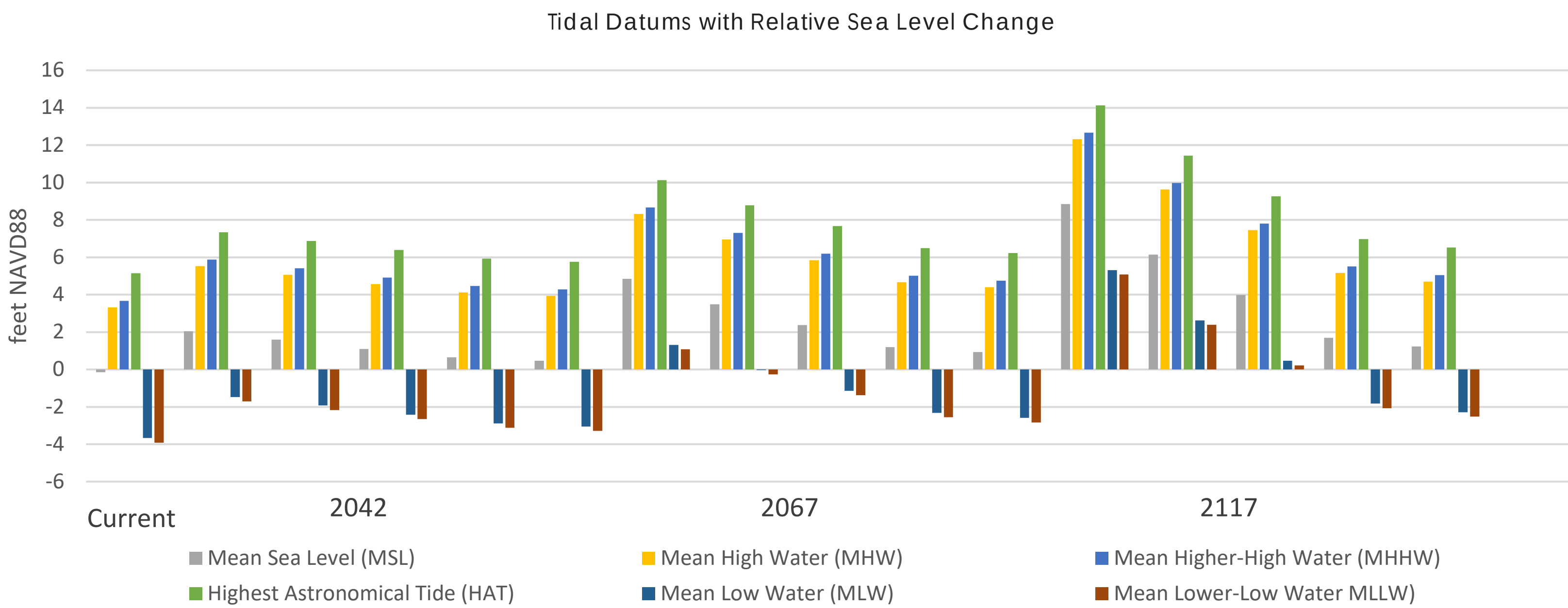
Tides are the daily rise and fall of the Earth's waters by long period waves that move through the oceans in response to astronomical gravitational forces, predominantly exerted by the moon and sun. The tides in Long Island Sound, including Saugatuck River, are diurnal, which means that during each lunar day (24 hours and 50 minutes) there are two high tides and two low tides. The high and low tides elevations vary during a daily tide cycle and over a lunar cycle but are generally characterized by statistical mean values. A reasonable estimate of the effects of relative sea level rise on tides can be developed by linear superposition of the predicted RSLC to the current epoch tidal datums. **Attachment 2 Table 2** presents the current and predicted changes to the tidal datums for the Westport area[1] due to RSLC for the years 2042, 2067 and 2117, in feet NAVD88. **Attachment 2 Figure 3** graphically presents the tidal datums with RSLC.

The current and future tide elevations, relative to the NAVD88 datum, at Saugatuck River are presented below.

Tidal Datum	Current 2017	2042					2067					2117				
		High SLR	Int-High	Int	Int-Low	Low SLR	High SLR	Int-High	Int	Int-Low	Low SLR	High SLR	Int-High	Int	Int-Low	Low SLR
Mean Sea Level (MSL)	-0.15	2.21	1.69	1.17	0.67	0.50	4.53	3.27	2.23	1.15	0.88	11.29	7.71	4.86	1.91	1.35
Mean High Water (MHW)	3.32	5.68	5.16	4.64	4.14	3.97	8.00	6.74	5.70	4.62	4.35	14.76	11.18	8.33	5.38	4.82
Mean Higher-High Water (MHHW)	3.67	6.03	5.51	4.99	4.49	4.32	8.35	7.09	6.05	4.97	4.70	15.11	11.53	8.68	5.73	5.17
Highest Astronomical Tide (HAT)	5.14	7.50	6.98	6.46	5.96	5.79	9.82	8.56	7.52	6.44	6.17	16.58	13.00	10.15	7.20	6.64
Mean Low Water (MLW)	-3.67	-1.31	-1.83	-2.35	-2.85	-3.02	1.01	-0.25	-1.29	-2.37	-2.64	7.77	4.19	1.34	-1.61	-2.17
Mean Lower-Low Water (MLLW)	-3.91	-1.55	-2.07	-2.59	-3.09	-3.26	0.77	-0.49	-1.53	-2.61	-2.88	7.53	3.95	1.10	-1.85	-2.41

Attachment 2 Table 2: Current and Future Tidal Datums at Westport

[1] NOAA Saugatuck River tide gage. Tidal datum analysis period of 1983 to 2001.



Attachment 2 Figure 3: Current and Future Tidal Datums at Westport

Extreme Coastal Flooding

Extreme coastal flooding at Westport is due to storm surges that result from two types of storms: Extra-tropical storms (Nor'easters) and tropical cyclones (Tropical Storms and Hurricanes).

Nor'easters are relatively common in New England during the spring, winter and fall. They are less intense than hurricanes but have a large wind field and are long in duration (sometimes lasting several days). These characteristics can result in significant storm surges. This is particularly true within Long Island Sound, where the long axis of the Sound trends northeast-southwest in line with the predominant wind direction during Nor'easters. Nor'easters often occur in conjunction with large snowfalls, which makes emergency response and recovery much more difficult.

Hurricanes occur relatively infrequently in New England. Hurricanes of high intensity with the tracks and landfalls necessary to cause large floods in Westport are even rarer. Hurricanes have historically resulted in the largest storm surge flooding effecting the Westport area. Tropical storms and hurricanes have also resulted in the most significant rainfalls.

Hurricane Sandy, although its landfall was over 200 nautical miles south of Westport, was one of the most significant flood events in Connecticut history. Sandy's storm surge when combined with tides, caused water levels to reach Elevation 9.3 feet NAVD88 in the vicinity of Bridgeport and Westport. As experienced during Hurricane Sandy, Downtown Westport is subject to coastal hazards and storm surge that propagates up the tidal portion of the Saugatuck River. However, although the Downtown is vulnerable to coastal flooding impacts from Hurricane events, the Downtown is more protected than the coastal areas fronting Long Island Sound. Extreme water levels may inundate portions of the Downtown Area, but these areas will not be impacted by significant wave action and increased velocities that portions of the town's southern coast might experience.

Attachment 2 Table 3 summarizes the top ten water levels at the Bridgeport tide station relative to MHHW. The highest observed water levels resulted from hurricanes, with the highest documented flood water level observed during the Hurricane of 1938. The Hurricane of 1938 would likely have a stillwater[2] flood elevation at Westport on the order of 11 feet to 12 feet NAVD88 were it to happen today.

Elevation (ft-NAVD88)	Date	Storm
9.20	10/30/2012	Hurricane Sandy
8.20	08/28/2011	
8.20	12/11/1992	
7.54	10/31/1991	Hurricane Bob
7.15	10/25/1980	
6.77	03/29/1984	
6.75	09/27/1985	
6.69	10/19/1996	
6.68	11/12/1968	
6.67	04/16/2007	

Attachment 2 Table 3: Top Ten Observed Water Levels at the NOAA Bridgeport Tide Gage

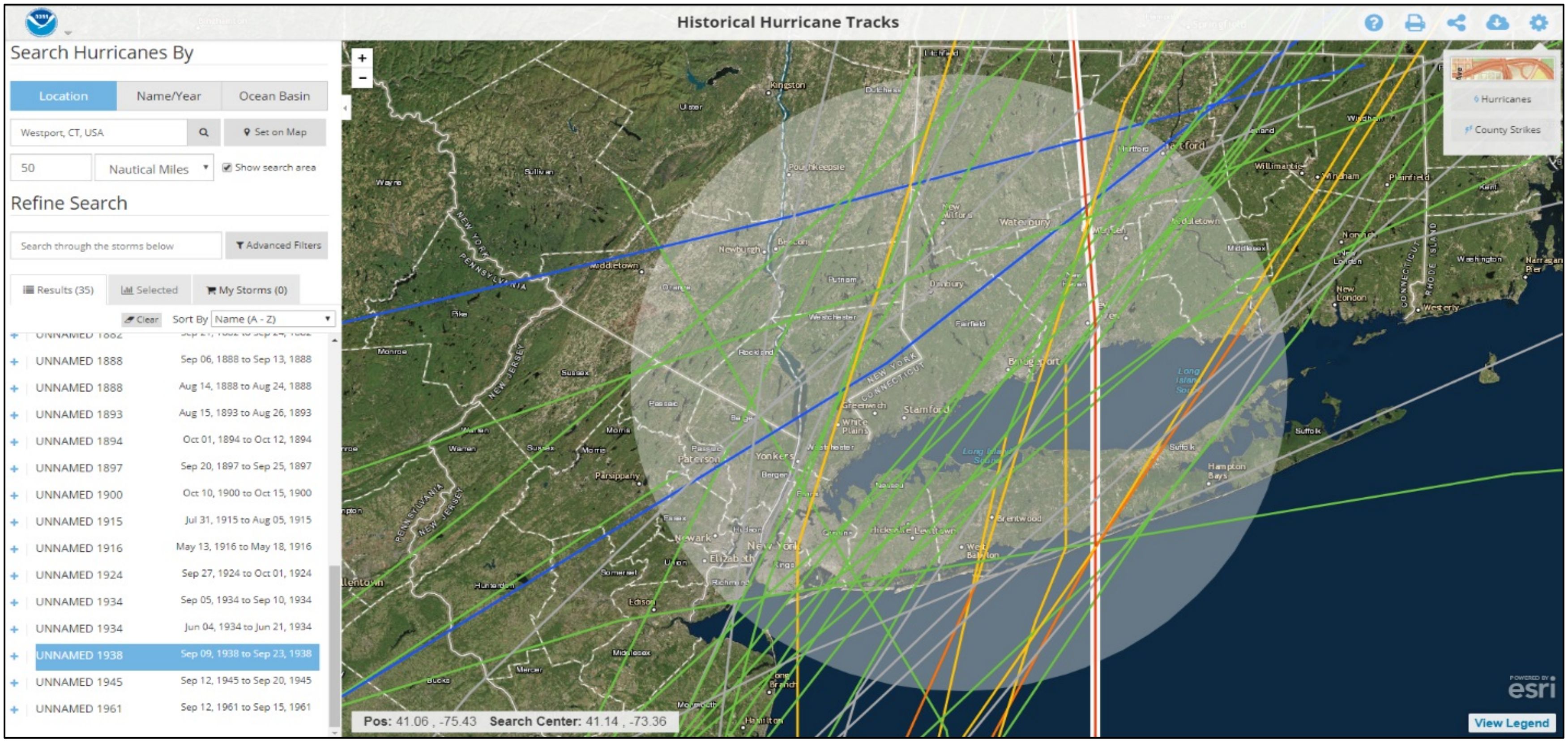
According to the NOAA Office for Coastal Management, 35 tropical cyclones (including hurricanes and tropical storms) have tracked within a 50-nautical mile radius of Westport since the mid-1800s (see Figure 2-8 for storm tracks). The most intense hurricane of record in the vicinity of Westport is the Hurricane of 1938 (track highlighted in red in Figure 2-8). According to NOAA, this hurricane was a Category 3 intensity at landfall along the Connecticut coast. There were also several high intensity hurricanes during the 1800s and early 1900s that made landfall along Long Island, although details about their intensity are limited.

[2] Stillwater refers to the water level, not including wave effects.

Of the 35 tropical cyclones, 5 hurricanes and tropical storms passed within a 50-nautical mile radius of Westport during the last 25 years. These storms are listed below (with maximum track intensities indicated):

- Beryl, Tropical Storm, 1994
- Bertha, Category 3 Hurricane, 1996
- Floyd, Category 4 Hurricane, 1999
- Hanna, Category 1 Hurricane, 2008
- Irene, Category 3 Hurricane, 2011

Although these hurricanes reached intensities as high as Category 4 at some point over their storm track, the storm intensities decreased significantly over the colder New England waters.



Attachment 2 Figure 4: NOAA Tropical Storm Tracks within 50-mile Radius of Westport since 1842

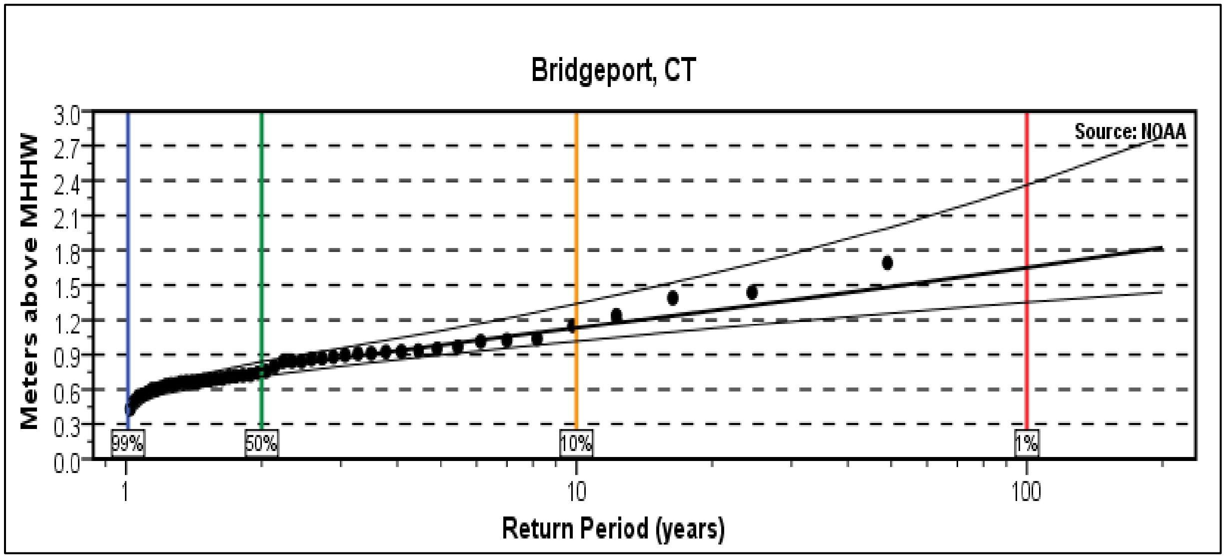
Predicting Coastal Flood Probabilities

Flood hazard mitigation planning requires characterizing flooding in terms of risk, by associating different flood levels with probabilities of occurrence. GZA evaluated the coastal flood probabilities based on:

1. Statistical analysis of the NOAA Bridgeport tide station water level data which provides an indication of the recurrence interval of flooding based on an approximately 80-year period of record.
2. FEMA Flood Insurance Study and Rate Maps: FEMA has characterized the current flood hazard within Westport for the purposes of the National Flood Insurance Program (NFIP). FEMA uses the 1% annual chance (100-year recurrence interval) flood event to characterize flood risk, presented on Flood Insurance Rate Maps (FIRMs). FEMA also presents the 0.2% annual chance flood inundation limits on these maps.
3. The USACE North Atlantic Coast Comprehensive Study (NACCS): The USACE performed extensive regional coastal flood hazard analyses after Hurricane Sandy (the North Atlantic Coast Comprehensive Study). These analyses utilized interpretation of meteorological parameters, numerical computer modeling of storm surge and waves, and statistical analysis (e.g., Joint Probability Method-Optimum Sampling, Empirical Simulation Technique) to characterize regional flood hazards. The USACE NACCS study provides project sea level rise flood elevations and save points located along the Atlantic Coast.

<u>Statistical Analysis of NOAA Bridgeport Tide Gage</u>:

NOAA statistically analyzed annual water level data at the NOAA Bridgeport tide gage using the Generalized Extreme Value (GEV) probability distribution to estimate water levels for various return period events. The results are shown below (relative to meters above MHHW). The 95% confidence intervals are also shown.



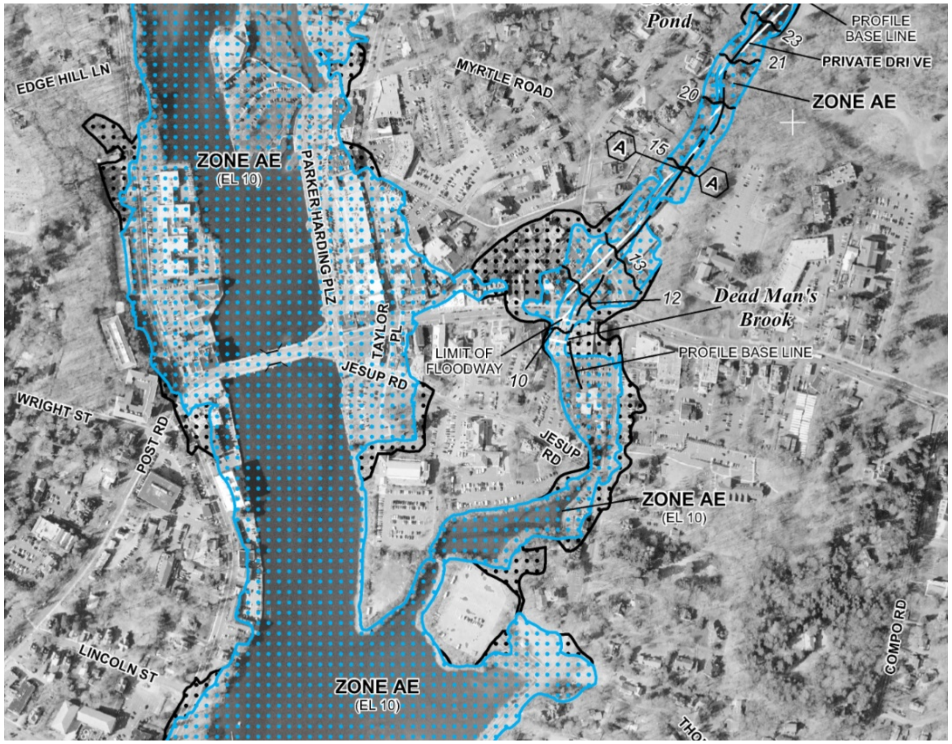
Attachment 2 Figure 5: Extreme Value Statistical Analysis of NOAA Bridgeport Tide Gage (in meters, relative to MHHW)

FEMA Flood Insurance Study and Insurance Rate Map:

The FEMA FIRM for Westport is Panel 09001C0413G, effective date of July 8, 2013. The effective FEMA flood hazard areas and Base Flood Elevations (BFE) (feet, NAVD88) are shown on **Attachment 2 Figure 9**. The FEMA BFE is the elevation to which floodwater are expected to rise during the 1% annual chance flood (100-year recurrence interval). BFEs within coastal zones includes multiple components which define the elevation, including the stillwater elevation plus wave set-up (where present) plus a portion of wave height. In conditions with waves, the BFE effectively represents the water level associated with the wave crest elevation. Under certain conditions, the BFE may also represent the elevation of wave overtopping or run-up.

FEMA used statistical analysis of tide gage data (Regional Frequency Analysis using L-Moments) to develop the coastal stillwater elevation flood-frequency relationship. As part of the Flood Insurance Study (FIS), FEMA performed coastal hydrologic and hydraulic analyses at transects located perpendicular to the shore and spaced at intervals to estimate flood heights along the coastline. Two transects (29 and 30) were developed to estimate flood heights along the coastline in the vicinity of Westport along the Long Island shoreline. Topographic data (ground surface elevation and bathymetry) used for the current Fairfield County FEMA FIS and FIRMs was developed using 2006 LiDAR and NOAA National Ocean Service (NOS) Hydrographic Data Base (NOSHDB) and Hydrographic Meta Data Base (HSMDB) (NOAA, May 2010; converted from MLLW to NAVD88).

As shown **Attachment 2 Figure 6**, FEMA special flood hazard areas in the vicinity of Downtown Westport are characterized by Zone AE areas, which are defined by the coastal stillwater elevation and are not significantly impacted by wave effects. The coastal BFE within the Downtown Area is elevation 10-feet NAVD88.



Attachment 2 Figure 6: FEMA Flood Insurance Rate Map

USACE North Atlantic Coast Comprehensive Study:

The results of the USACE NACCS are available at specific "save point" locations. **Attachment 2 Figure 7** shows the locations of "save points" within Saugatuck River, close to Westport downtown. USACE-predicted Total Water Level data, including the stillwater elevation plus wave setup, are available at these locations.

Attachment 2 Table 4 summarizes the predicted coastal flood stillwater elevations resulting from each of the information sources described above. The FEMA values shown are for a Long Island Sound coastal transect (values may differ near the Downton area. The USACE values are for "save point" 8044.

Attachment 2 Figure 7: USACE NACCS Save Point Locations near Westport

Attachment 2 Table 4: Summary of Current and Future Flood Stillwater Elevations Developed by Several Different Sources

RETURN PERIOD	1-YR	2-YR	5-YR	10-YR	20-YR	50-YR	100-YR	200-YR	500-YR	1,000-YR
2017:								-	-	-
NOAA MEAN	4.8	5.9	6.7	7.2	7.7	8.2	8.8	9.3		
NOAA UB	4.8	6.2	7.0	7.8	8.7	10.0	11.2	12.5		
NOAA LB	4.8	5.7	6.4	6.7	7.1	7.5	7.8	8.1		
FEMA				8.1		9.7	10.4		11.8	
USACE MEAN	5.9	7.0	8.3	9.1	10.0	11.0	12.0	13.4	15.4	17.0
USACE UB	9.0	9.9	11.1	12.0	12.9	14.4	15.8	17.3	19.4	20.9
USACE LB	2.9	4.1	5.5	6.3	7.0	7.6	8.1	9.4	11.5	13.1
2042:										
USACE MEAN (LOW SLR)	6.5	7.6	8.9	9.7	10.6	11.6	12.6	14.0	16.0	17.6
USACE MEAN (INT-LOW SLR)	6.7	7.8	9.1	9.9	10.8	11.8	12.8	14.2	16.2	17.8
USACE MEAN (INT SLR)	7.2	8.3	9.6	10.4	11.3	12.3	13.3	14.7	16.7	18.3
USACE MEAN (INT-HIGH SLR)	7.7	8.8	10.1	10.9	11.8	12.8	13.8	15.2	17.2	18.8
USACE MEAN (HIGH SLR)	8.3	9.4	10.7	11.5	12.4	13.4	14.4	15.8	17.8	19.4

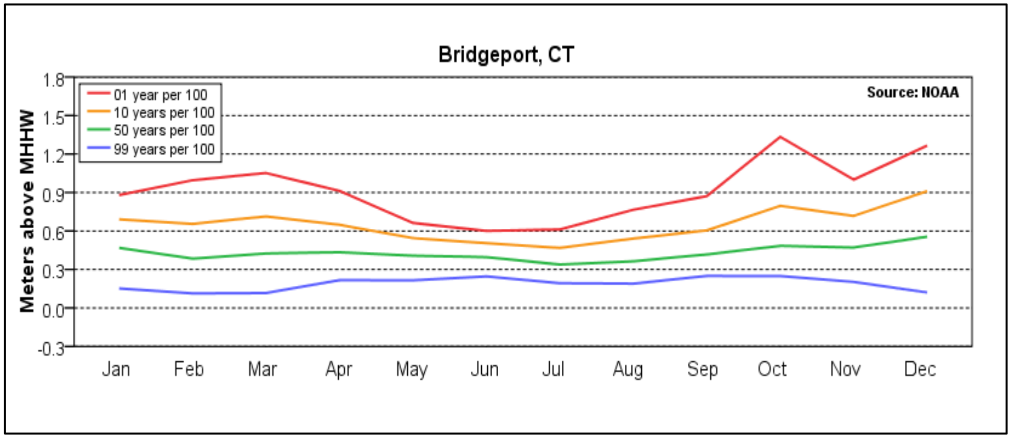
2067:	1-YR	2-YR	5-YR	10-YR	20-YR	50-YR	100-YR	200-YR	500-YR	1,000-YR
USACE MEAN (LOW SLR)	6.9	8.0	9.3	10.1	11.0	12.0	13.0	14.4	16.4	18.0
USACE MEAN (INT-LOW SLR)	7.2	8.3	9.6	10.4	11.3	12.3	13.3	14.7	16.7	18.3
USACE MEAN (INT SLR)	8.3	9.4	10.7	11.5	12.4	13.4	14.4	15.8	17.8	19.4
USACE MEAN (INT-HIGH SLR)	9.3	10.4	11.7	12.5	13.4	14.4	15.4	16.8	18.8	20.4
USACE MEAN (HIGH SLR)	10.6	11.7	13.0	13.8	14.7	15.7	16.7	18.1	20.1	21.7
2117:										
USACE MEAN (LOW SLR)	7.4	8.5	9.8	10.6	11.5	12.5	13.5	14.9	16.9	18.5
USACE MEAN (INT-LOW SLR)	8.0	9.1	10.4	11.2	12.1	13.1	14.1	15.5	17.5	19.1
USACE MEAN (INT SLR)	10.9	12.0	13.3	14.1	15.0	16.0	17.0	18.4	20.4	22.0
USACE MEAN (INT-HIGH SLR)	13.8	14.9	16.2	17.0	17.9	18.9	19.9	21.3	23.3	24.9
USACE MEAN (HIGH SLR)	17.3	18.4	19.7	20.5	21.4	22.4	23.4	24.8	26.8	28.4

Seasonality of Coastal Flooding

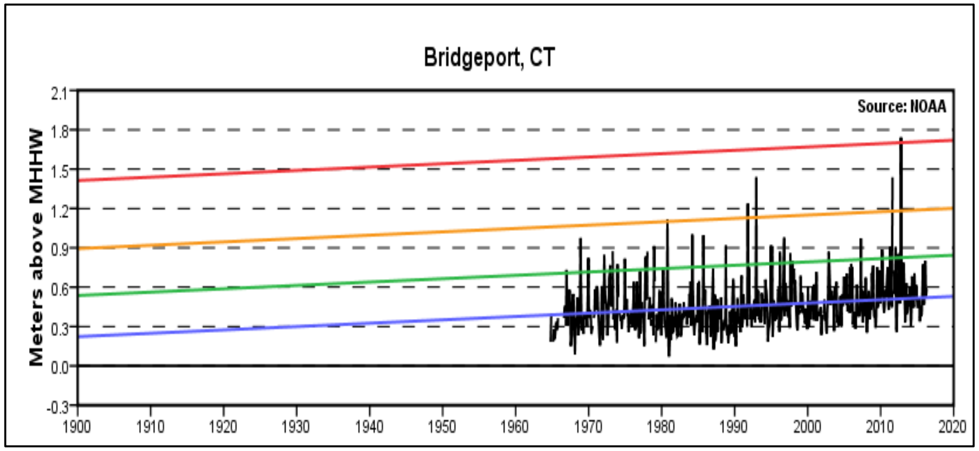
NOAA statistically analyzed water level data on monthly basis showing the seasonal variability of coastal flood risk. The results are presented in **Attachment 2 Figure 8** for the NOAA Bridgeport tide gage (relative to meters above MHHW). As shown on **Attachment 2 Figure 9,** the greatest flood risk is during the late Summer, Fall and Winter which includes tropical storms, hurricanes and Nor'Easters. The probability of extreme flooding during late Summer is low.

Uncertainty and Flood Probability

There is no "exact" prediction of flood probability; rather, there are a range of probabilities (and corresponding flood elevations) that reflect different prediction methods, error, and uncertainty. For example, statistical extrapolation of the NOAA Bridgeport tide gage data has significant uncertainty for predicting floods beyond the 20 to 50-year return period floods due to the limited period of record. The USACE NACCS utilized the "state-of-the-practice" methodology; however, there is still significant statistical uncertainty relative to meteorological parameter characterization, methodology and model error.



Attachment 2 Figure 8: NOAA Seasonal Variation of Exceedance Probability Curve at NOAA Bridgeport Tide Gage



Attachment 2 Figure 9: NOAA Water Levels with Exceedance Probability Curves at NOAA Bridgeport Tide Gage

GZA Numerical Coastal Flood Modeling

GZA performed flood simulations using numerical hydrodynamic models of tides and storm surge. The coastal floods corresponding to tidal flow, the 100-year recurrence interval flood (1% annual chance) and the 500-year recurrence interval (0.2% annual chance) were modeled. The model simulations were performed using the two-dimensional, hydrodynamic computer model ADvanced CIRCulation model (ADCIRC). The purposes of GZA's model simulations were to: 1) evaluate flooding hydro-dynamically and temporally; and 2) reflect the current topographic methodology.

The ADCIRC storm surge flood simulation process utilized a robust, but simplified approach that included: 1) creation of a local area, high resolution model mesh; 2) development of synthetic hydrographs representative of storm types associated with the 100-year return period flood (1% annual chance); 3) utilization of the USACE NACCS-predicted peak stillwater elevations at the model boundary to develop the peak hydrograph water level; and 5) stressing the model with the synthetic hydrograph and model domain wind field. This approach provides the benefits of numerical hydrodynamic models, approximating scenario-based simulations, but ties the overall flood hazard definition (model boundary water levels) to those developed by the USACE NACCS. GZA performed a model validation for tidal conditions and for Hurricane Sandy. Additional validation was performed by comparison of GZA model output to representative NACCS output for save points located within the model domain.

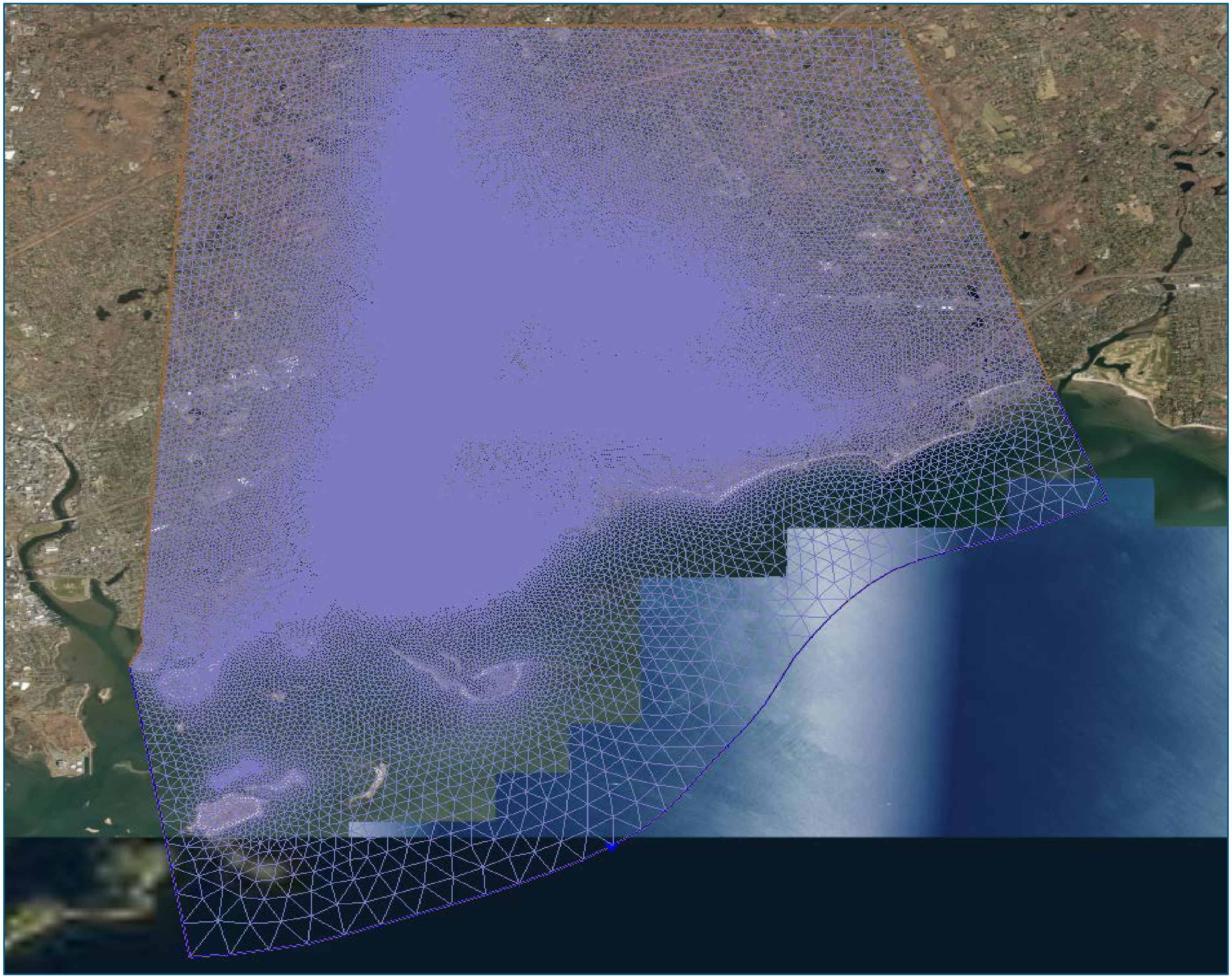
A high resolution ADCIRC mesh was developed to represent the detailed topographic features in Westport. The mesh covers Saugatuck River and Westport downtown, and extends approximately 3.5 miles off the coast (location of the open boundary) (**Attachment 2 Figure 10**). The mesh consists of 169,676 finite elements, and the grid resolution at the Westport downtown is approximately 7 to 10 meters (**Attachment 2 Figure 11**).

ADCIRC is a two-dimensional, depth integrated, barotropic time-dependent long wave, hydrodynamic circulation model, and can be applied to domains in deep oceans, the continental shelf, near-shore, and small-scale estuarine systems.

NOAA 2017 Intermediate-High sea level rise scenarios were simulated for the years 25, 50 and 100 years from 2017 for averaged 26th water surface elevation of astronomical tide. RSLC was added to antecedent water levels and the synthetic hydrograph. GZA performed the ADCIRC simulation for tides and the 100-year recurrence interval (1% annual chance), and simple, elevation-based flood mapping was performed for the 500-year recurrence interval flood (0.2% annual chances). **Attachment 2 Table 5** presents the flood modeling scenarios analyzed for the Study.

YEAR	SLR SCENARIO	MODELING SCENARIO	MAPPING APPROACH
2017	No SLR	Tides	ADCIRC
		100-year return period	ADCIRC
		500-year return period	Elevation-Based
2042	Int-High SLR	Tides	ADCIRC
2067	Int-High SLR	Tides	ADCIRC
2117	Int-High SLR	Tides	ADCIRC

Attachment 2 Table 5: GZA Numerical Model Coastal Flood Simulations



Attachment 2 Figure 10: GZA Model Mesh

Attachment 2 Figure 11: GZA Model Mesh of Downtown Area

Wind Intensity Analysis

Hourly, 1 and/or 2-minute average wind data at the Igor Sikorsky Airport, located 12 miles east of Bridgeport, was downloaded from the National Climatic Data Center (NCDC). The record covers 1948 to 1969, 1973 to 1999, 2004 to 2016, a total of 61 years, from two separate datasets provided by NCDC. GZA performed an extreme value statistical analysis. The predicted wind-frequency curve (Figure 2-17) was based on the best fit using a GEV distribution. Directional wind speeds were not evaluated, and the wind was conservatively modeled from a southerly direction to maximize fetch and wind set-up. The recommended design 1 and 2-minute sustained and 3-second (Gust) wind speeds for various annual recurrence intervals are listed in **Attachment 2 Tables 6 and 7**. In comparison, the Hurricane of 1938 had observed sustained wind speeds at landfall between Bridgeport and New Haven of about 115 mph. The modeled sustained wind speeds are summarized in **Attachment 2 – Table 6**.

RETURN PERIOD (YEAR)	ASCE 7-10 3-SECOND GUSTS	
	(mph)	(m/s)
10	76	33.5
25	86	38.4
50	92	41.1
100	98	43.8

Attachment 2 Table 6: Wind Gust Speeds at Westport per ASCE 7-10

RETURN PERIOD (YEAR)	WIND SPEED AT SIKOSKY AIRPORT	
	(mph)	(m/s)
10	58	25.0
25	68	30.4
50	77	34.9
100	87	39.3
500	114	53.2

Attachment 2 Table 7: Summary of Statistical Sustained (1 and 2-minute average) Wind Speeds at Sikorsky Airport near Bridgeport based on Recurrence Interval

Model Simulation Results

It is noted that the stillwater elevations presented on these figures are higher than those established by FEMA. The reason is that the USACE NACCS-predicted stillwater elevations (used for the model simulations) are higher than those predicted by FEMA.

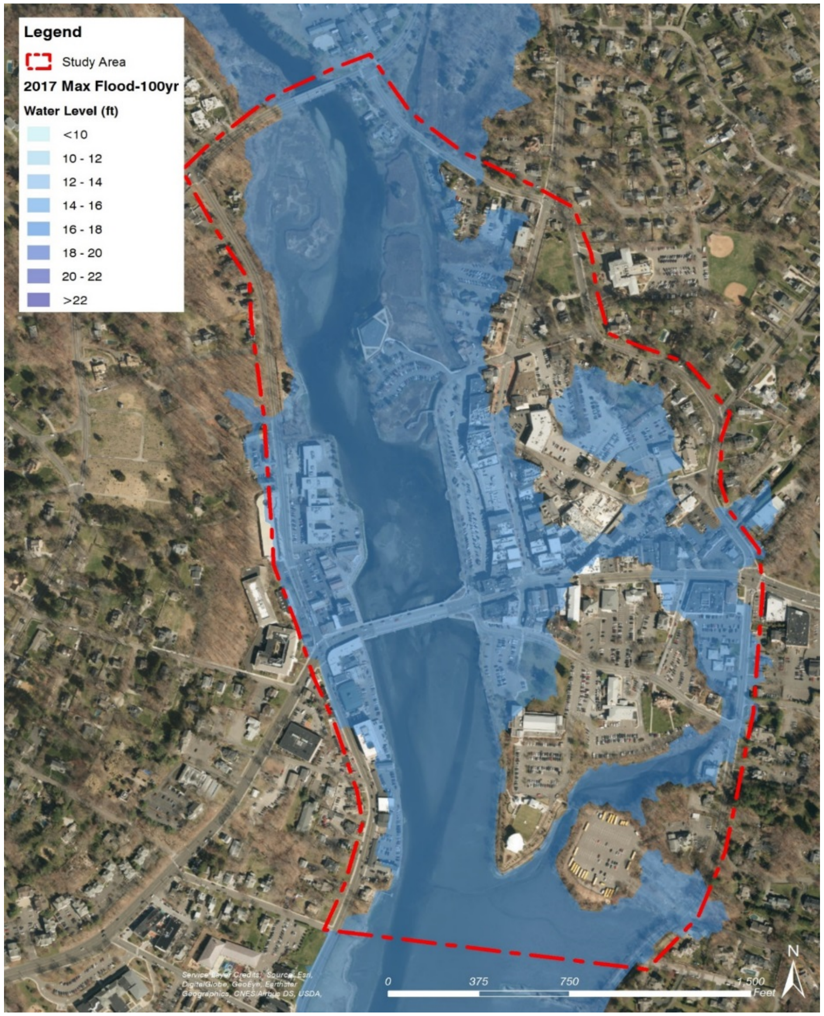
- **Figure 2-12** presents the simulation results for the 2017 100-year return period (1% annual chance) peak flood inundation and elevation using ADCIRC.
- **Figure 2-13** presents the flood extent for the 2017 500-year return period (0.2% annual chance) peak flood inundation based on simplified, elevation-based mapping.
- **Figures 2-14** present hourly time steps around the peak 2017 100-year return flood to demonstrate temporally how flood inundation propagates inland.

GZA's ADCIRC model storm surge simulations are coupled at the model domain boundary (in Long Island Sound) with peak flood elevations developed in the NACCS and with GZA-developed synthetic hydrographs and model domain wind field. GZA model output was validated by comparison to USACE NACCS output for representative NACCS "save points" located within GZA's model domain (see Figure 2-13):

As shown in Attachment 2 Table 8, there is relatively good comparison between GZA's simulated results and USACE NACCS. The USACE NACCS data presented in the comparison above represents mean values. In general, GZA results conservatively (but marginally) exceed the NACCS mean values for nearshore flood elevation, on the order of 0.1 foot to 0.4 foot, except for the save point 8044 where the GZA results exceed NACCS mean value by about 1.0 feet. This is probably because GZA used a conservative wind direction of due north, which pushes more water volume toward Saugatuck River upstream, and the water levels at Saugatuck River upstream were raised by wind setup and funneling effects of storm surge. This difference is considered by GZA to be acceptable for planning purposes and well within the uncertainties associated with predicting flood-frequency relationships and sea level rise.

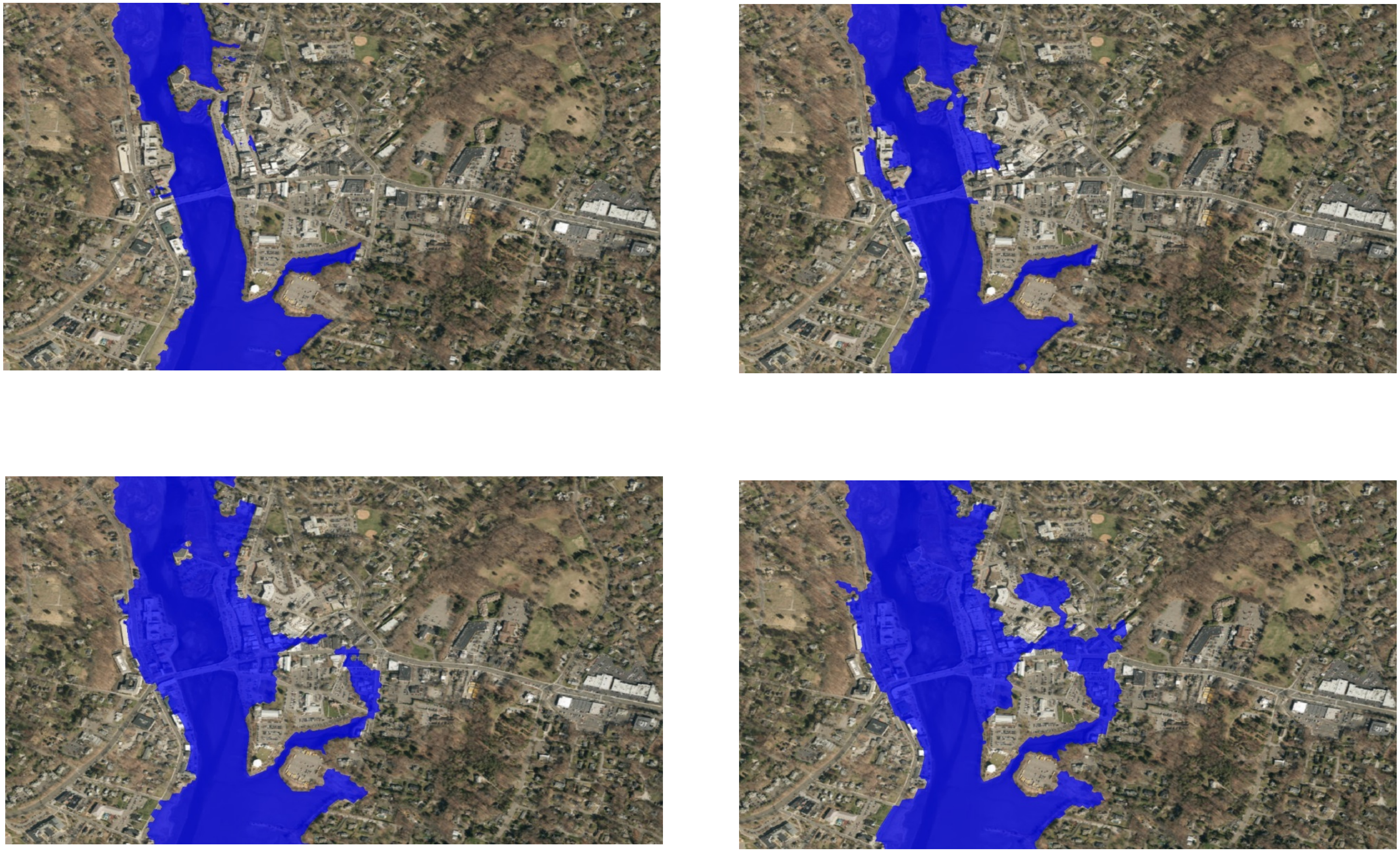
NACCS SAVE POINT	LONGITUDE	LATITUDE	100-YEAR FLOOD ELEVATION	
			NACCS	Simulated
8046	-73.36333	41.10435	12.0	12.0
8042	-73.37303	41.1117	12.1	12.3
8043	-73.36953	41.12362	12.2	12.6
8044	-73.3624	41.13518	12.0	13.0

Attachment 2 Table 8: Comparison of Modeled and NACCS Model Output



Attachment 2 Figure 12: ADCIRC Model Simulation Results for the 2017 100-year return period (1% annual chance) peak flood inundation and elevations

Attachment 2 Figure 13: Flood Extent in Downtown for the 2017 500-year return period (1% annual chance) peak flood inundation



Attachment 2 Figure 14: 2017 100-year Recurrence Interval Hourly Flood Time Steps during Typical Flood Event

Attachment 3

Precipitation-Based Flooding

For this study, local intense precipitation (LIP) is defined as a high-intensity precipitation event centered over the Downtown Westport area and the local watershed. Rainfall depths were based on the NOAA Atlas 14, Volume 10 for New England (2015) and estimated using the Point Frequency Estimate online tool. The online tool develops up-to-date rainfall depth estimates based on historic precipitation data for individual sites. Point precipitation frequency depths for Westport, CT are provided in **Table 1.**

The rainfall hyetographs were developed using the 24-hour, frequency event depths from NOAA Atlas 14 and assigning a SCS Type III rainfall distribution. Type III distributions represent Connecticut coastal areas where tropical storms bring large 24-hour rainfall amounts. The temporal distribution used for the analysis centers the peak rainfall intensity around hour 12:00 of the 24-hour storm event.

For precipitation-based scenarios, the Mean Higher High Water (MHHW) elevation was used as the downstream boundary condition within the Saugatuck River using Tide Gage information for NOAA Station ID 8468191 – Saugatuck River. The NOAA Tide Gage Station provides tidal elevation information for the location near All Seasons Marine Works at 609 Riverside Avenue, located approximately 1.5 miles downstream of the Downtown Area. The MHHW elevation was calculated to be 3.67 ft-NAVD88.

Rainfall hyetographs were used as inputs into the model for the LIP simulations. Rainfall is transformed into runoff within FLO-2D. The FLO-2D simulations were performed to establish maximum water surface elevations, flow depths and flow velocities resulting from the LIP in the Downtown Westport Area. Surface runoff generally discharges to Dead Man's Brook and/or Saugatuck River located within the center of the Downtown Area.

Riverine Flood Hazards

GZA evaluated two riverine watercourses for this analysis: Dead Man's Brook and Saugatuck River as these were the only two watercourses that are would influence flooding in the Downtown Westport. Riverine routing and resulting overtopping of stream banks of Dead Man's Brook was simulated for all of the precipitation-based scenarios. Most of the contributing drainage area of Dead Man's Brook is located outside of the model domain, and thus, the surface runoff simulated within the Downtown Area contributing watershed does not fully account for the peak discharges within the brook during rain storms. As part of a separate independent analysis, BL Companies analyzed the hydrologic and hydraulic function of Dead Man's Brook and the contributing watershed. As part of the analysis, BL Companies developed a watershed-based rainfall-runoff model to estimate the runoff hydrograph and peak flows within Dead Man's Brook at Myrtle Avenue (located at the upstream boundary of the FLO-2D model domain along Dead Man's Brook) during the 2-, 10-, 50-, 100-, and 500-year, 24-hour storm events, and provided the hydrographs to GZA for use in this analysis. GZA developed a logarithmic best-fit for the flow events to estimate the 5-year and 25-year, 24-hour peak flows for the brook for use in this analysis. Peak discharges within Dead Man's Brook at Myrtle Ave for recurrence interval storm events are provided in **Table 4**.

Due to the relatively small contributing drainage area of Dead Man's Brook and the likelihood that peak surface runoff from LIP events would coincide with peak discharges within Dead Man's Brook, the riverine flooding simulations were modeled within the LIP simulations.

Due to the coastal-tidal influence, a riverine analysis of peak flows within the Saugatuck River was not performed as part of this analysis. The MHHW elevation was used for the downstream boundary condition within the river for the precipitation-based simulations. This approach of treating the Saugatuck River as a coastal waterway is consistent with FEMA's analysis of the river as part of the National Flood Insurance Program (NFIP). The Flood Insurance Study (FIS) estimates peak water surface elevations within the Saugatuck River in the downtown area using coastal analysis methodology. The FIS does not provide peak discharge or water surface elevations for the river downstream of the dam located at Guilder Lane in Westport, CT, indicating a riverine analysis to estimate flood risk is not appropriate to adequately define flooding risk within the floodplain, and a coastal analysis is more applicable.

Compound Flooding Events

Increasingly, coastal communities are considering the impacts of coincident precipitation and storm surge events, as well as designing to account for potential sea level rise conditions. The 2015 research report published in *Nature* by Wahl et. al. entitled, "Increasing risk of compound flooding from storm surge and rainfall for major US cities" presents an analysis demonstrating the likelihood of joint occurrences of storm surge and heavy precipitation. The 2015 report also, presents evidence that the number of compound events has increased significantly over the past 100 years at many coastal cities. The report specifically sites nearby New York City as an example location where observed increases in compound events results from an increase in storm surge weather patterns that also include high precipitation (Wahl et. al., 2015).

GZA performed a limited correlation analysis of dependent peak riverine discharge (precipitation-based events) and peak water levels resulting from coastal storm surge. The goal of the analysis was to evaluate potential correlation of precipitation and storm surge events at Westport and develop rational combinations of inputs for the precipitation-based and coastal storm surge model simulations. GZA analyzed monthly maximum daily rainfall from the Sikorsky Memorial Airport Rain Gage (located approximately 12.5 miles from Downtown Westport) and monthly maximum water levels from the Bridgeport, CT Tide Gage (located approximately 9.5 miles from Downtown Westport). GZA plotted both the maximum precipitation total and maximum water level elevation for historic storm events (either precipitation-based or coastal storm-based) on a logarithmic scale to identify the resulting return period for each event. GZA then reviewed the return interval combinations for the precipitation and coastal storm surge events. GZA identified a correlation, albeit weak, of maximum rainfall and peak water levels for most monthly maximum events. For the more extreme rainfall and storm surge events, GZA developed the following recommended parameter combinations (**Table 3** below) based on GZA's statistical review of historic records and engineering judgment. These parameter combinations approximately serve as an upper bound envelope for the two correlated data categories, to be evaluated as part of the Downtown Area combined effects inundation analysis.

Effects of Sea Level Rise

GZA evaluated the potential for future high-tides to inundate areas of Downtown Westport as the result of increased water levels due to sea level rise and potential backflow within existing storm drain systems. Evaluation of the Intermediate High-scenario was performed.

Precipitation and Stormwater Modeling

Flooding occurs within Downtown Westport during precipitation events when the existing stormwater infrastructure is unable to manage intense precipitation events, resulting in localized areas of "ponding" and "flash" flooding. Precipitation-related flooding can also occur coincidently with coastal storm surge and/or riverine flooding. These combined flooding events may result in greater areas subject to flooding and flooding occurring to greater depths.

The purpose of this plan is to provide a detailed analysis of the Downtown area drainage systems, and to recommend improvements that will enhance their function along with improving resiliency and recovery after major storms. GZA evaluated extreme precipitation-based, and resulting, riverine flooding events including the 2-, 5-, 10-, 25-, 50-, and 100-year, 24-hour precipitation events. The 24-hour storm events modeled as part of this analysis are theoretical rain events with precipitation totals based on site-specific predictions developed by National Oceanic and Atmospheric Administration (NOAA) from historical precipitation data. These events include peak rainfall intensity centered around the 12-hour mark and are commonly used for engineering design and analysis to predict potential flooding and evaluate stormwater system capacity.

The Downtown Area analysis also included evaluation of coastal storm surge under current and predicted sea level rise conditions, over the next 100 years. The Downtown Area is vulnerable to flooding due to its generally low-lying topography within the surrounding watershed, proximity to the tidally influenced Saugatuck River, and proximity to Dead Man's Brook which flows through the eastern portion of the Downtown Area.

GZA performed 2-dimensional surface modeling to simulate runoff patterns and estimate flood depths for multiple scenarios. GZA performed a storm drain analysis to evaluate the capacity of existing storm drain systems to drain stormwater away from surface areas to Dead Man's Brook and the Saugatuck River. Additionally, GZA used results from the USACE North Atlantic Coast Comprehensive Study (NACCS) to 1) establish the coastal flood stillwater elevations for the above-noted recurrence intervals; and 2) route the coastal, riverine, and precipitation-based flooding through the downtown area.

24-Hour Storm Return Frequency (Years)	Precipitation Depth (inches)
2	3.5
5	4.5
10	5.4
25	6.5
50	7.4
100	8.3

Attachment 3 Table 1: Precipitation Depths in Westport, CT per NOAA Atlas 14

	Peak Discharge (cfs)
2	280
5	470
10	620
25	920
50	1040
100	1250

Attachment 3 Table 2: Peak Discharges at Dead Man's Brook at Myrtle Avenue

Return Period for Rain (year)	Return Period for Stillwater (year)
2	100
5	50
10	25
25	10
50	5
100	2

Attachment 3 Table 3: Precipitation and Stillwater Joint Probabilities

Outlook (Year)	Rise in Local Relative Sea Level Change (feet)
25-Year (2042)	1.8
50-Year (2067)	3.5
100-Year (2117)	6.5

Attachment 3 Table 4: Modeled Sea Level Rise

To evaluate the precipitation, riverine, and coastal-related flood hazards within the Downtown Area, GZA performed:

1. Preliminary mapping of existing drainage systems and field inventory of the stormwater infrastructure in the Downtown Area;
2. Numerical hydrodynamic modeling and inundation mapping of riverine and precipitation-based flooding; and
3. Inundated private properties investigation and field examination in the inundated areas.

The results of GZA's flood hazard evaluation of the Downtown Area were used to evaluate the vulnerability of structures, infrastructure and essential lifeline facilities within the special flood hazard area in Downtown Westport. In particular, flooding due to local intense precipitation (LIP) and stormwater runoff are a source of flooding in four distinct areas.

LIP events often occur during storms that also include storm surge and waves, and during these events, the flooding due to storm surge dictates the flood inundation areas. Additionally, sea level rise will likely increase the severity of precipitation-based flooding due to increased tailwater elevations and may result in backwater and surcharging of stormwater systems during high tide events. While flash flooding occurs throughout Westport during these single events, urban flooding is a persistent condition in the Downtown Area characterized by disruption of the community and costly impacts to property owners.

The following summarizes the results of GZA's stormwater and riverine flood hazard evaluation.

Numerical Stormwater Models

GZA performed flood simulations using numerical hydrodynamic models to analyze precipitation-based surface runoff, riverine flows, and coastal tides and storm surge. The model simulations were performed using ADvanced CIRCulation model (ADCIRC) to model coastal storm surge; FLO-2D to model unconfined 2-dimensional surface runoff; and Environmental Protection Agency (EPA) EPA SWMM to perform storm drain pipe routing. The purposes of GZA's model simulations were to: 1) evaluate flooding hydrodynamically and temporally; and 2) reflect the current topographic methodology. ADCIRC, FLO-2D and EPA SWMM are all modeling software approved by FEMA for use in Flood Insurance Studies and are appropriate models for simulating the flooding conditions associated with coastal, riverine, and surface water flooding.

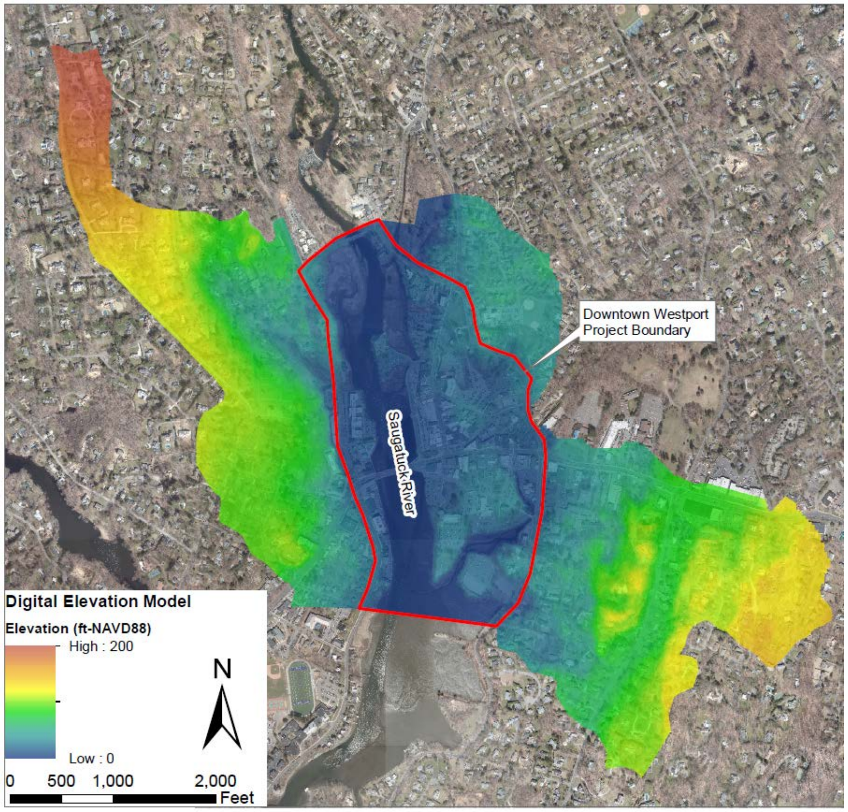
Surface Runoff Simulations

Due to anticipated unconfined flow characteristics of the Site, a two-dimensional hydrodynamic computer model, FLO-2D, was used to model surface runoff. The purpose of the modeling analysis was to identify high-risk areas prone to surface flooding and help evaluate the incremental flooding depth within the Downtown Area during potential flooding scenarios. FLO-2D is a physical process model that routes flood hydrographs over unconfined flow surfaces using the dynamic wave approximation to the momentum equation. FLO-2D moves flood volume on a series of tiles (grid) for overland flow or through stream segments for channel routing.

GZA performed a topographic assessment of the downtown area to determine the primary route that floodwaters follow in inundating low-lying areas, including overland flow, and backflow through the drainage systems. The method of analysis for developing the exterior two-dimensional FLO-2D model used to estimate water depths included the following general process:

1. Define the FLO-2D model limits for the flood analysis.
2. Develop the FLO-2D computer model with site features.
3. Develop LIP inputs.
4. Perform flood simulations in FLO-2D and estimate maximum water surface elevations throughout the study area.

GZA developed a topographic model (digital elevation model - DEM) of the greater Downtown Westport Area using available GIS data and the South Western Regional Planning Agency (SWRPA) LiDAR digital mapping developed in April 2013. The vertical accuracy of the topographic model is defined as sufficient to support 1-foot contours or 6-inch accuracy of well-defined points, which is typically sufficient to capture localized depressions and flood pathways. The Downtown Study Area consists of the section of Westport spanning from Imperial Ave and Myrtle Ave on the East, Wilton Road and Riverside Ave on the West, Kings Highway on the North, and the Levitt Pavilion on the South. The project computational boundary extends upgradient of the study area to incorporate the entire contributing drainage watershed to the Downtown Area and to include areas anticipated to influence flooding within Downtown. The Downtown Study Area and the topographic information within the model domain are shown in **Figure 1.**



Attachment 3 Figure 1: Digital Elevation Model

The project grid element size was selected based on the level of detail appropriate for the project (i.e., to evaluate site-specific structures, entrances, etc.). A grid size of 15-feet by 15-feet was used to provide sufficient resolution to simulate localized runoff patterns. The model grid was created, and the terrain elevation data was interpolated and assigned as grid element elevations from the DEM. The model includes 90,906 individual grid elements. Manual modifications were made to some of the interpolated elevations within FLO-2D based on site survey of rim/grate elevations of drainage structures.

Outflow grid elements are assigned at the model domain boundary to allow discharge off the grid system without affecting the water surface elevation at grid elements of interest. Additionally, the topographic model included bathymetric information for the Saugatuck River and Dead Man's Brook allowing for these waterways to convey water away from the downtown area. Dead Man's Brook was specifically modeled as a channel feature within FLO-2D to more accurately route riverine flows through the waterway. Channel geometry and input hydrographs for recurrence interval floods were assigned to the upstream boundary of the Dead Man's Brook channel based on peak flow information provided to GZA by BL Companies.

Storm Drain Simulations

EPA SWMM, a dynamic hydrologic-hydraulic model, was used to simulate hydraulic routing and assess the capacity of existing storm drainage systems within the Downtown Area. SWMM is dynamic hydrology-hydraulic model with the capability to simulate hydraulic routing of closed-conduit drainage systems. The FLO-2D model simulates the exchange of surface water flow with the storm drain system information described in Section 3.1. The model system is coupled such that the FLO-2D model calculates all hydrologic and hydraulic flood routing while the closed conduit component of EPA SWMM computes the pipe hydraulics and flow routing in a storm drain network.

The hydraulic element of EPA SWMM uses a link-node concept to simulate real-world systems. A node is a distinct location in the drainage system where conservation of mass or continuity is maintained. Links are the connections between nodes and are used to transfer or convey water through the drainage system. The node-link systems within EPA SWMM are direct representations of the geospatial database developed from the field survey information. Structure rim/grate elevations, grate types, pipe inverts, and material and size included in the storm drain model match existing information for the structures.

Inlet capacity of each catch basin was modeled based on the unique catch basin grate type information of each structure collected during the field survey. The analysis evaluated the ability of the existing storm drain systems to reduce flooding and ponding of water and identify potential system deficiencies. Additionally, the storm drain model simulated backflow conditions within systems without tide gates during storm surge events. Structures without tide gates and backflow preventers will allow flooding and inundation at inland locations where water flows through the stormwater system and out of the catch basin grate inlets.

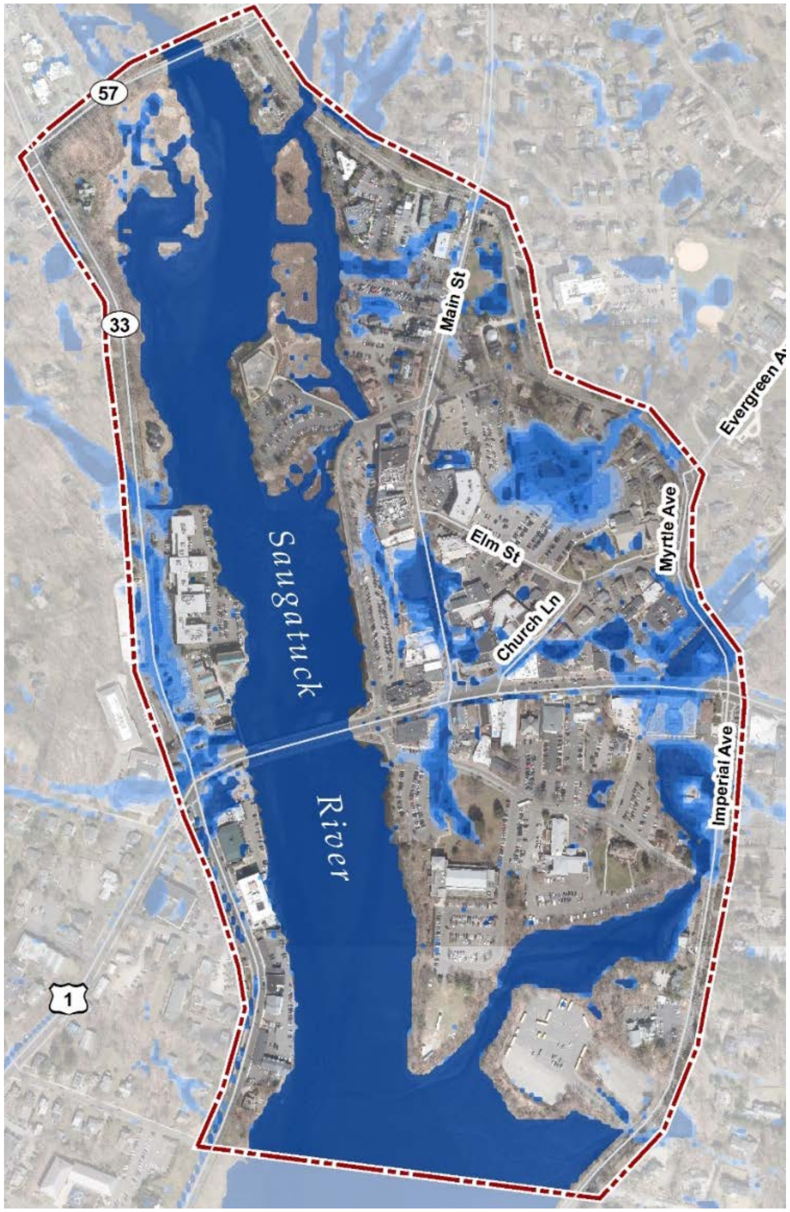
Coastal Simulations

GZA modeled potential coastal storm surge scenarios in the Downtown Area using FLO-2D and integrating storm surge hydrograph output data from the ADCIRC model analysis. Storm surge hydrograph information was input to FLO-2D at the southern boundary, within the Saugatuck River banks, to simulate surface inundation along the Saugatuck and Dead Man's Brook banks, as well as, model the exchange of tidal flow into the stormwater systems at locations that did not include tide gates or backflow preventers.

GZA evaluated potential flooding scenarios for precipitation-based flooding, riverine flooding, and coastal storm surge for multiple design frequency events.

Results of Precipitation Modeling

A surface runoff analysis performed using FLO-2D to identify areas most likely to flood during rain events, as well as, low-lying areas that may be affected by storm surge and future sea level rise during high-tides. The analysis assessed the storm drain systems' ability to collect and discharge stormwater away from downtown areas. Model results of predicted maximum water depths during precipitation-based flooding events is shown in **Figure 2**. Estimated flood depths increased within inundation areas during storms of increasing severity.



Attachment 3 Figure 2: Modeled Precipitation Flood Inundation Areas (note: coastal flood inundation not shown)

Attachment 4

DIRECTIONS: FILL OUT FORM AND CIRCLE ALL ANSWERS THAT APPLY.

Building Address:

Business Name:

Number of Stories: 1 2 3 ____

Are any of the building floors below grade?

Yes Please describe:

No

What type of openings penetrate the building envelope?

Doors	How many? ______
Windows	How many? ______
Cracks	How many? ______
Vent Openings	How many? ______
Plumbing Fixtures	How many? ______
Floor Drains	How many? ______

What is the foundation type?

Slab on grade

Pile Foundation

Reinforced Pier System

Unreinforced Pier System

Perimeter Walls

Other:

What is the construction type?

Wood Frame

Masonry, Reinforced

Masonry, Unreinforced

Concrete, Reinforced

Steel Frame

Other:

Is there a basement? Yes No

Do storage hazards exist in the basement or on site?

Yes No

If storage hazards exit then:

Described if there are any utilities of value (boiler, HVAC, water heater, oil/gas, electrical, computers, lab materials, merchandise, etc.)

Is the basement flood-proofed? Yes No

If Yes, how:

Are any critical contents (files, computers, servers, equipment, or data) on levels of the facility below flood elevations?

Yes Please describe:

No

If the building is elevated on a crawlspace or on an open foundation, are there any enclosed areas?

Yes No

Describe building portions below DFE:

Are flood resident materials used for structural and non-structural finishes below the DFE?

Yes No

Describe flood resistant material:

What fire protection is provided?

Sprinklers

Other:

Is it in service? Yes No

Identify locations of facility utility and process supply shutoff valves:

UTILITY SYSTEMS

Are the following protected from flooding?

Potable water supply: Yes No

Wastewater service: Yes No

Are any manholes below the DFE?

Yes How many:

No

If the site is served by an onsite system, is it located in a flood-prone area?

Yes Have backflow valves been installed?

No

ELECTRICAL SYSTEMS

Are electrical systems, including back-up power generators, panels, and primary service equipment, located above the DFE?

Yes No

Are the switches and wiring required for safety (minimal lighting, door openers) below flood level designed for use in damp locations?

Yes No

MECHANICAL SYSTEMS

Are air handlers, HVAC systems, and other mechanical equipment and systems located above the DFE?

Yes No

Are the vents and inlets located above the flood level or sealed to prevent entry of floodwater?

Yes Above flood level? Sealed to prevent floodwater entry?

No

PLUMBING AND GAS SYTEMS

Are plumbing fixtures and gas fired equipment (e.g. meters, pilot-light devices/burners) located above the DFE?

Yes No

Is the plumbing and gas piping that extends below flood levels installed to minimize damage?

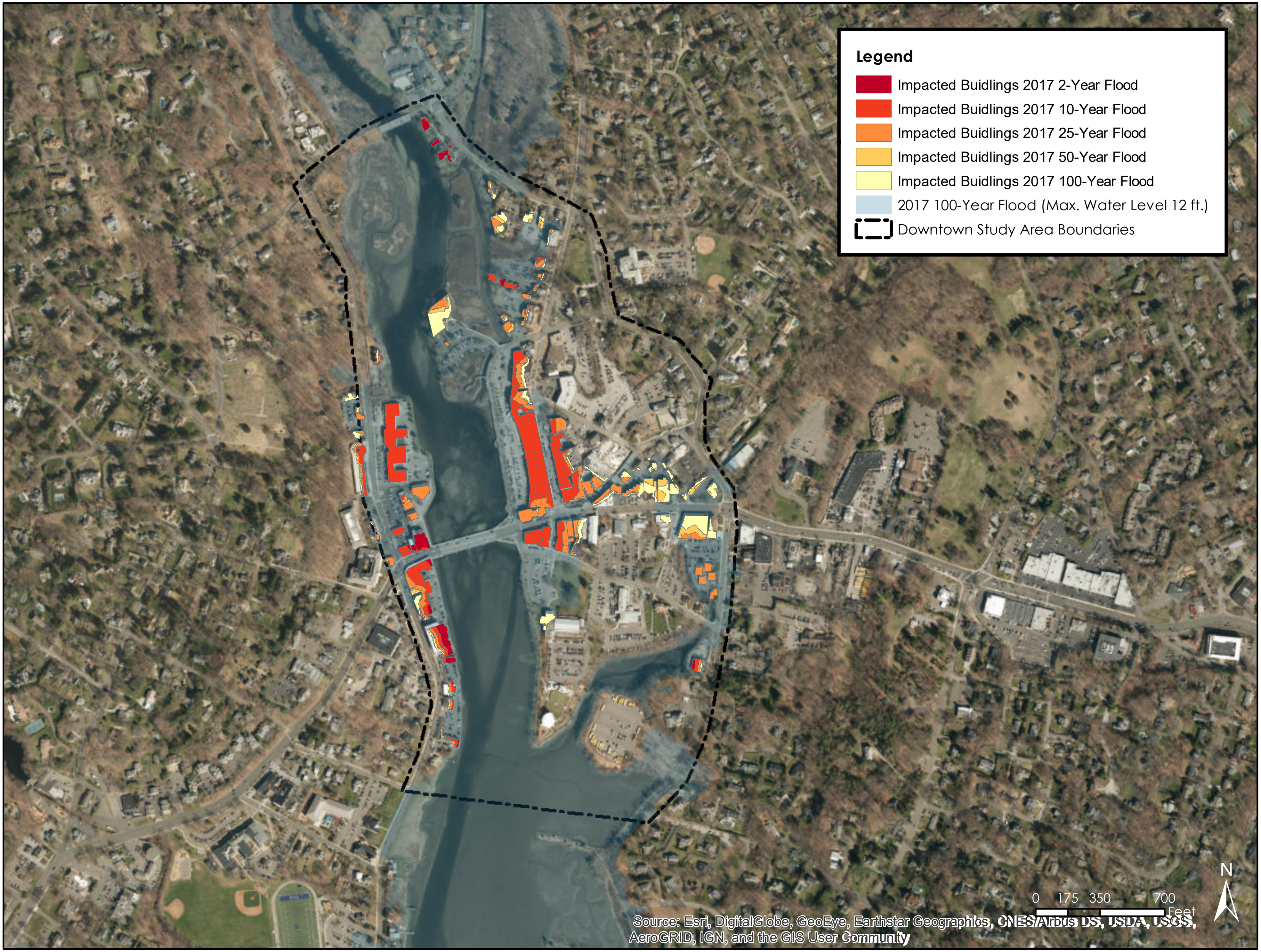
Yes No

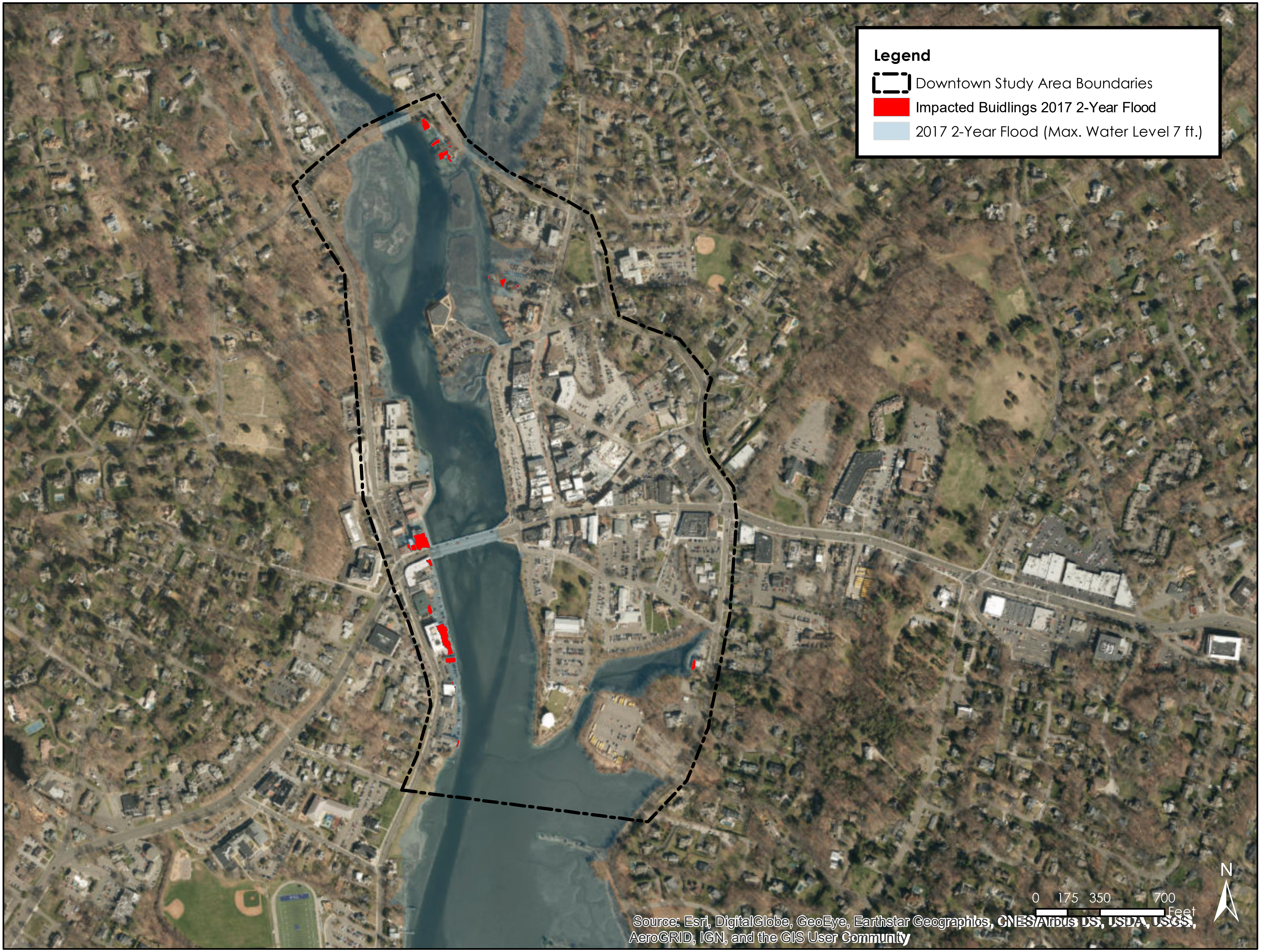
GZA Staff:

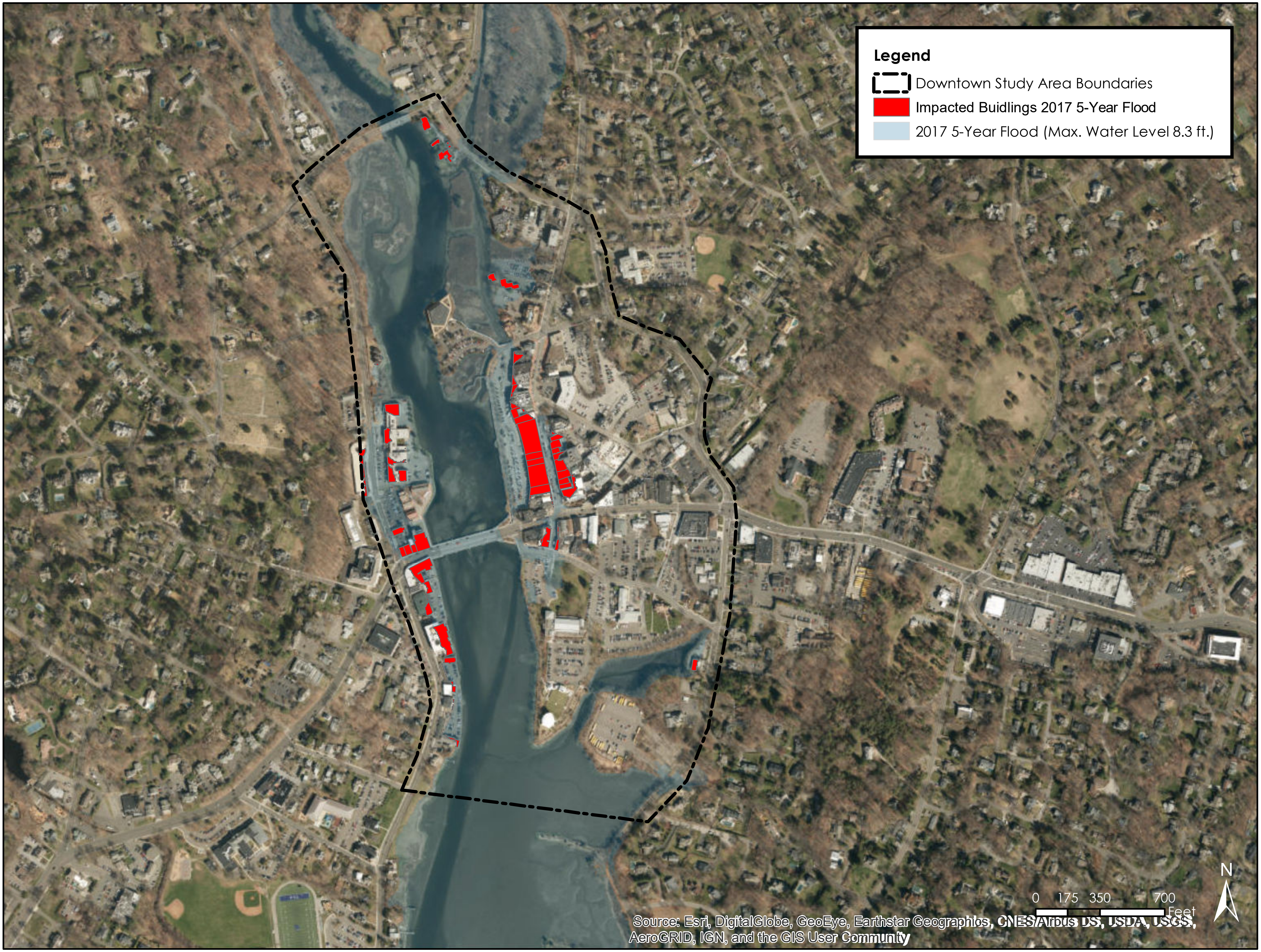
Time and Date:

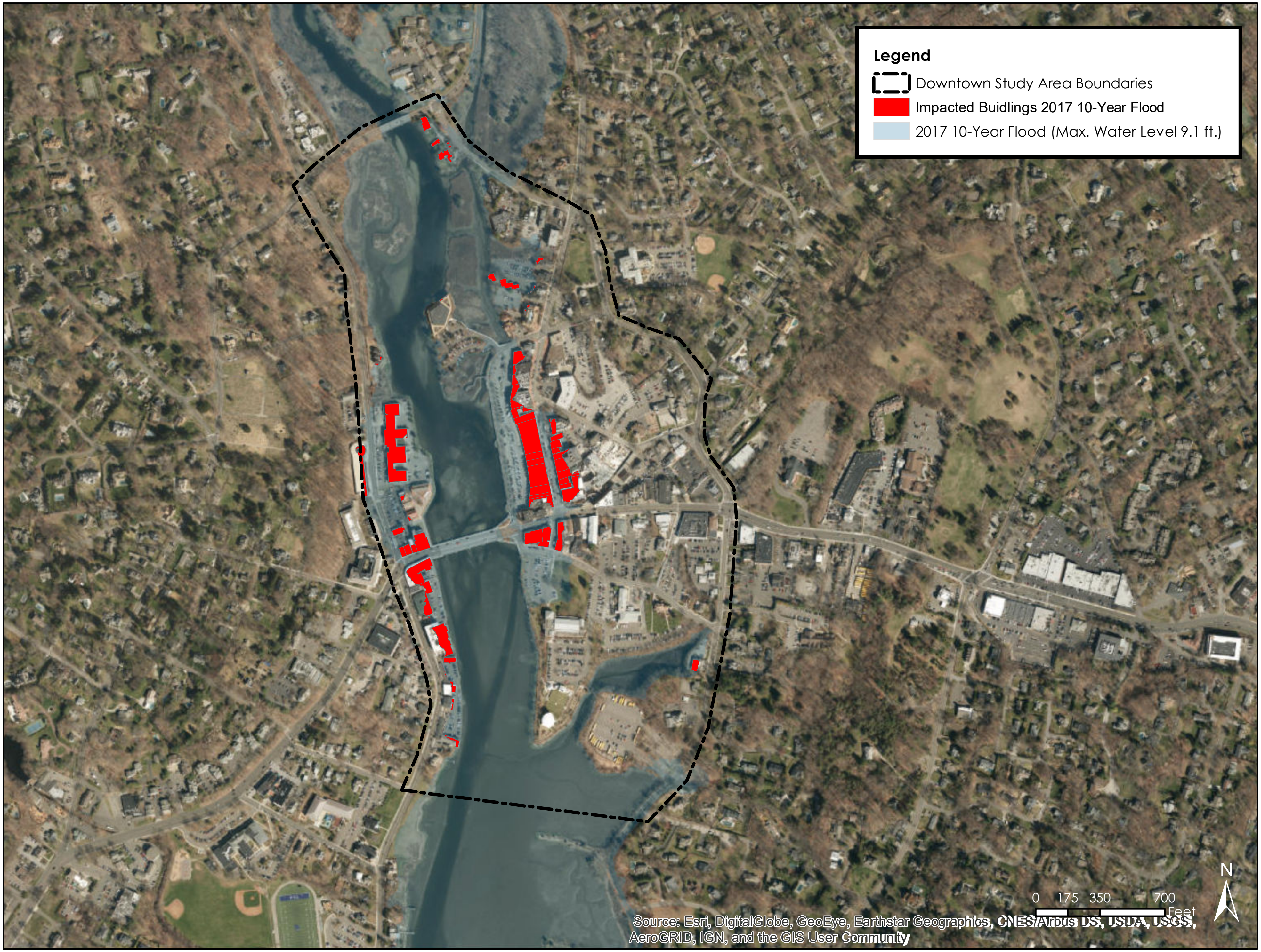
Additional Notes:

Attachment 5

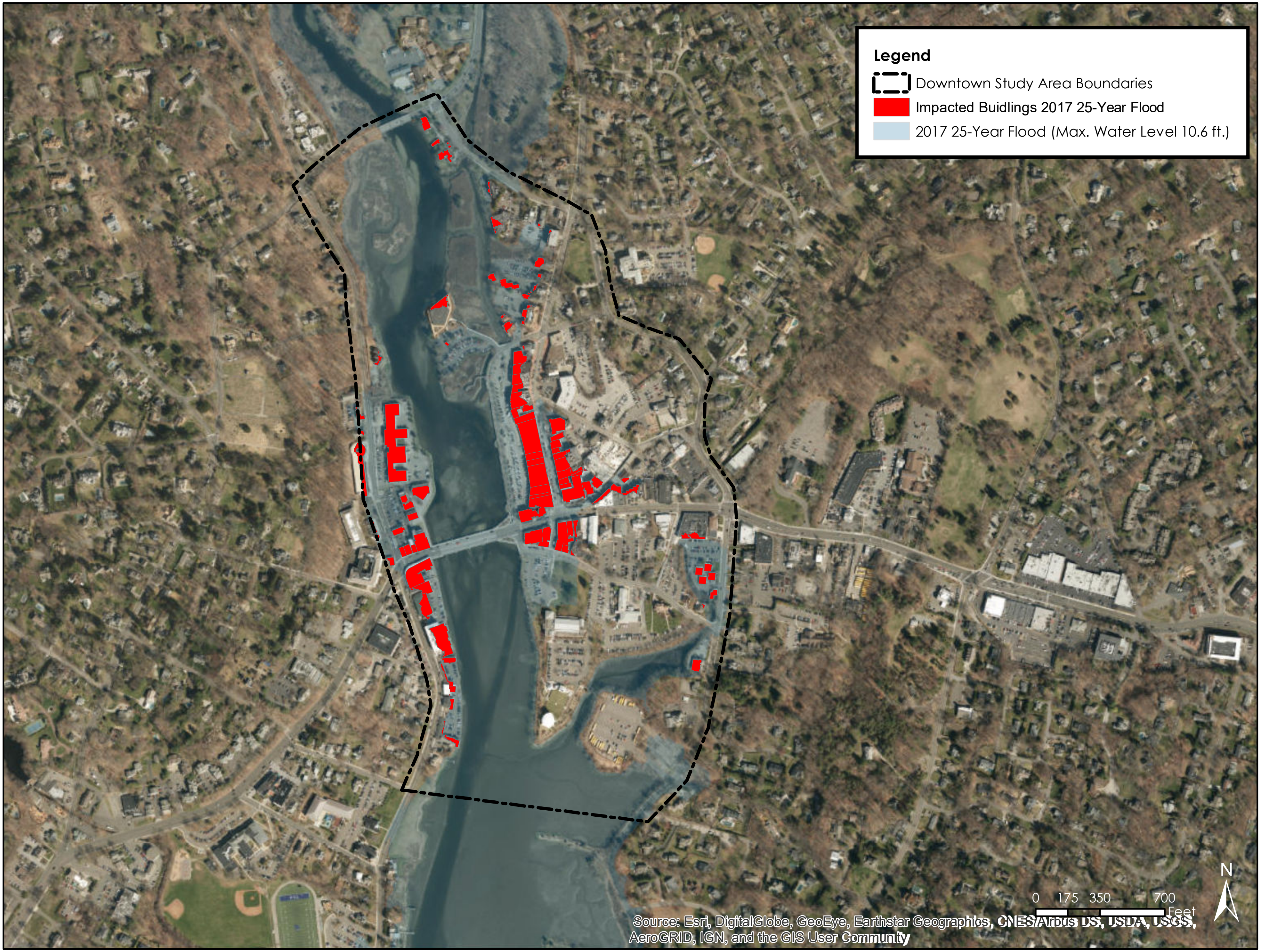

Legend
Impacted Buidlings 2017 2-Year Flood
Impacted Buidlings 2017 10-Year Flood
Impacted Buidlings 2017 25-Year Flood
Impacted Buidlings 2017 50-Year Flood
Impacted Buidlings 2017 100-Year Flood
2017 100-Year Flood (Max. Water Level 12 ft.)
Downtown Study Area Boundaries
0 175 350 700
Feet
N
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

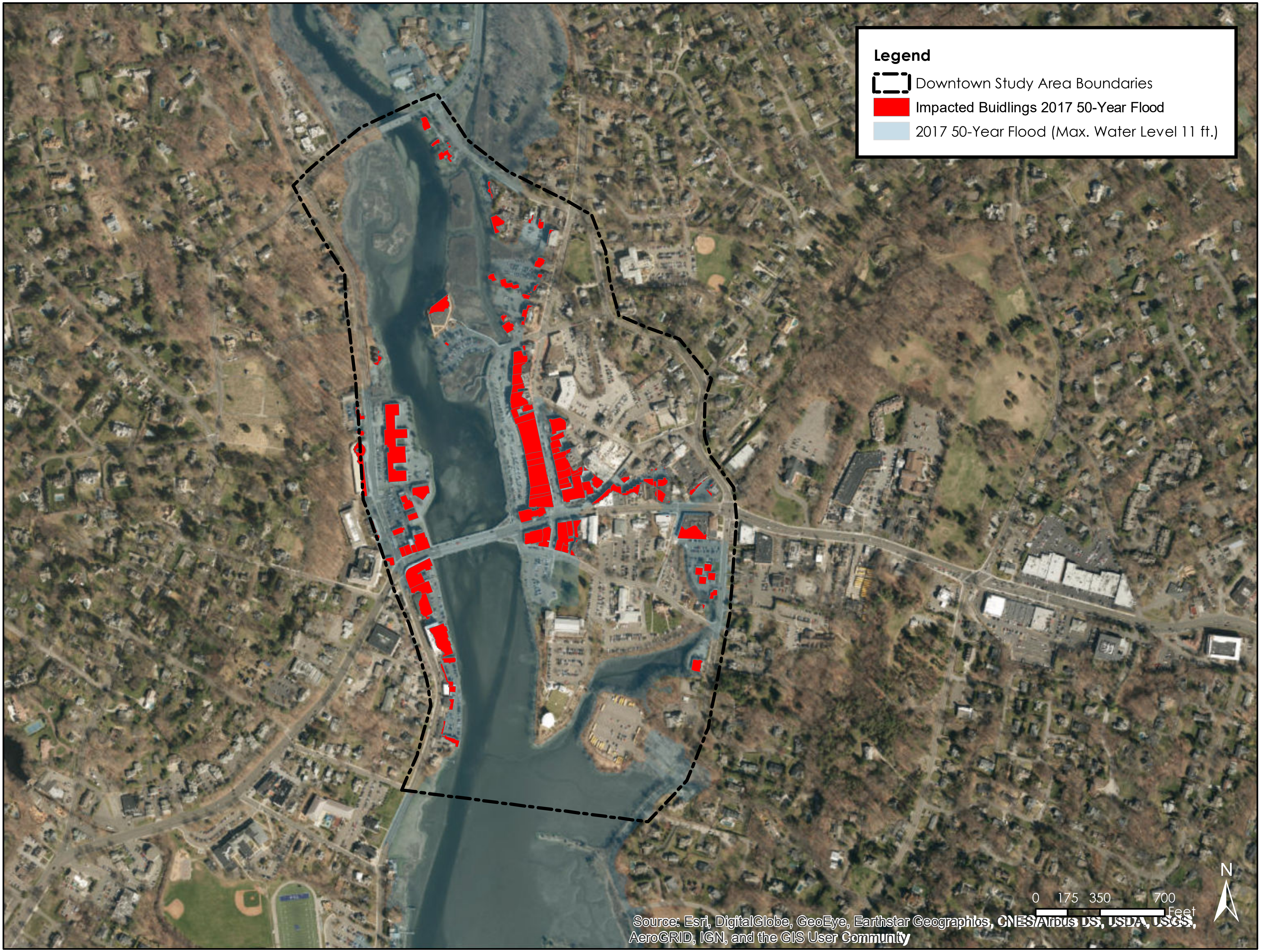

Legend
Downtown Study Area Boundaries
Impacted Buidlings 2017 2-Year Flood
2017 2-Year Flood (Max. Water Level 7 ft.)
0 175 350 700
Feet
N
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

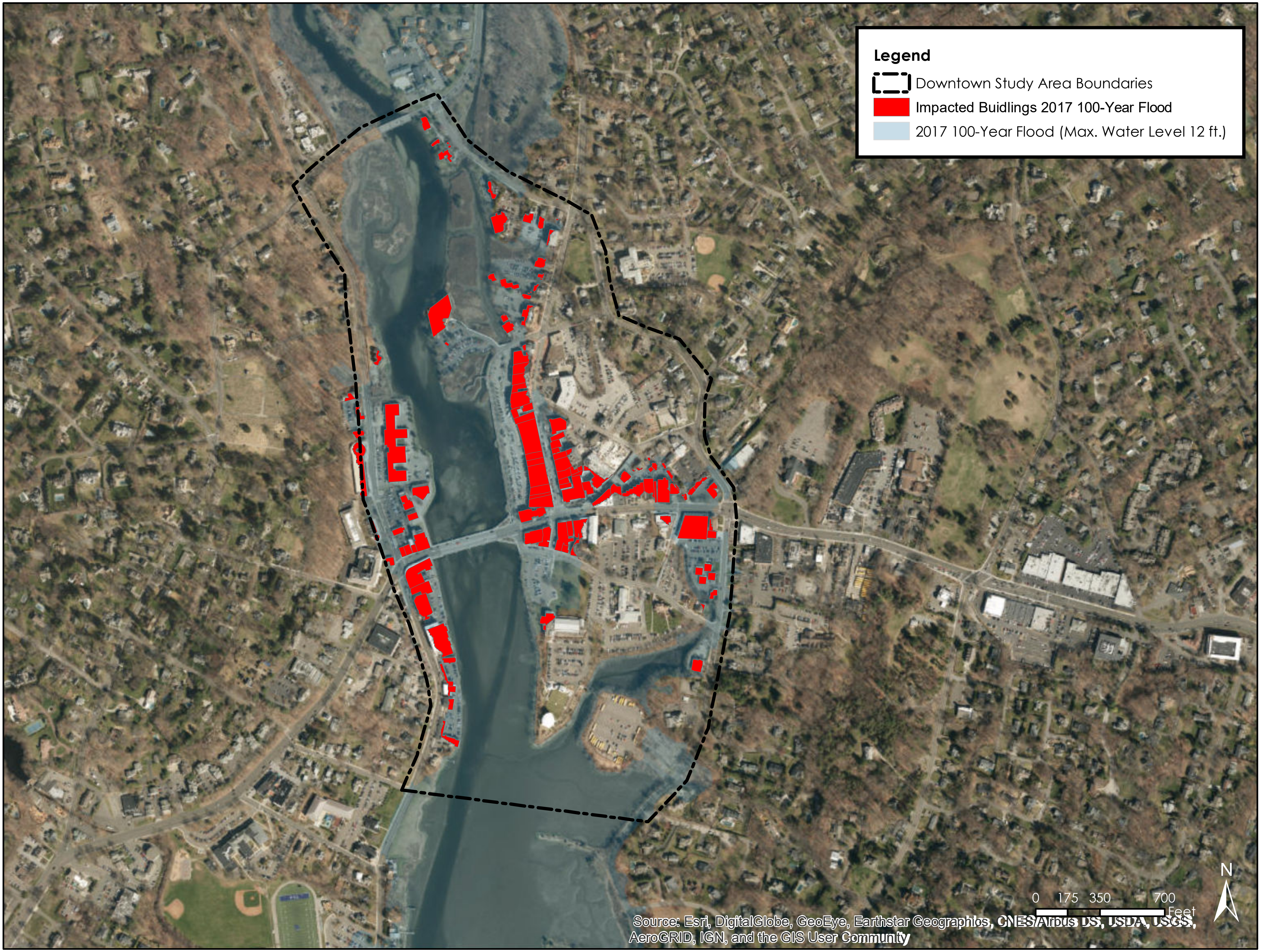

Legend
Downtown Study Area Boundaries
Impacted Buidlings 2017 5-Year Flood
2017 5-Year Flood (Max. Water Level 8.3 ft.)
0 175 350 700
Feet
N
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community



Legend
Downtown Study Area Boundaries
Impacted Buidlings 2017 10-Year Flood
2017 10-Year Flood (Max. Water Level 9.1 ft.)
0 175 350 700
Feet
N
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community


Legend
Downtown Study Area Boundaries
Impacted Buidlings 2017 25-Year Flood
2017 25-Year Flood (Max. Water Level 10.6 ft.)
0 175 350 700
Feet
N
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community


Legend
Downtown Study Area Boundaries
Impacted Buidlings 2017 50-Year Flood
2017 50-Year Flood (Max. Water Level 11 ft.)
0 175 350 700
Feet
N
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community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2017 100-Year Flood (Max. Water Level 12 ft.)
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Feet
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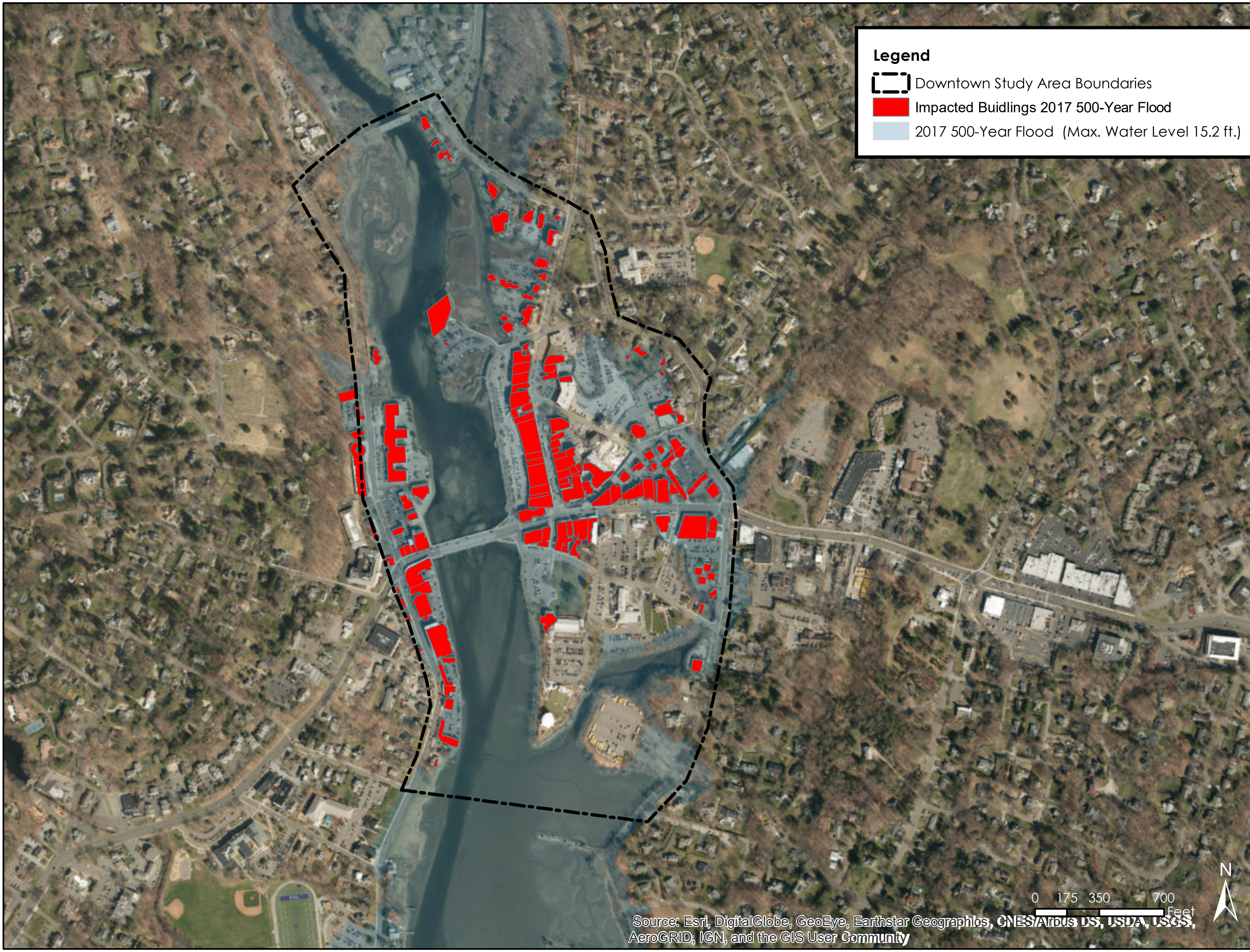
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Downtown Study Area Boundaries
Impacted Buidlings 2017 500-Year Flood
2017 500-Year Flood (Max. Water Level 15.2 ft.)
0 175 350 700
Feet
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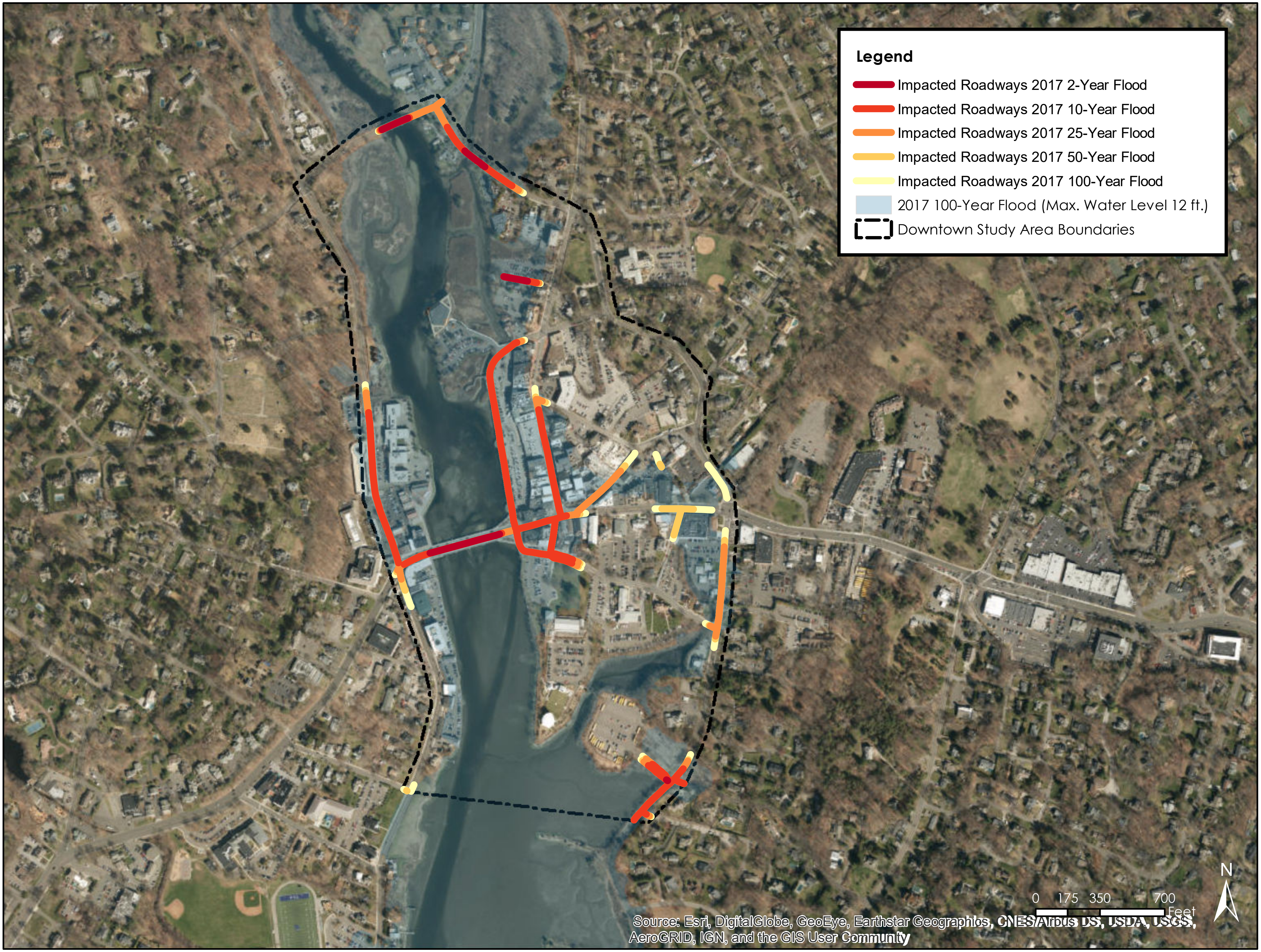
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Attachment 6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Impacted Roadways 2017 2-Year Flood
Impacted Roadways 2017 10-Year Flood
Impacted Roadways 2017 25-Year Flood
Impacted Roadways 2017 50-Year Flood
Impacted Roadways 2017 100-Year Flood
2017 100-Year Flood (Max. Water Level 12 ft.)
Downtown Study Area Boundaries
0 175 350 700
Feet
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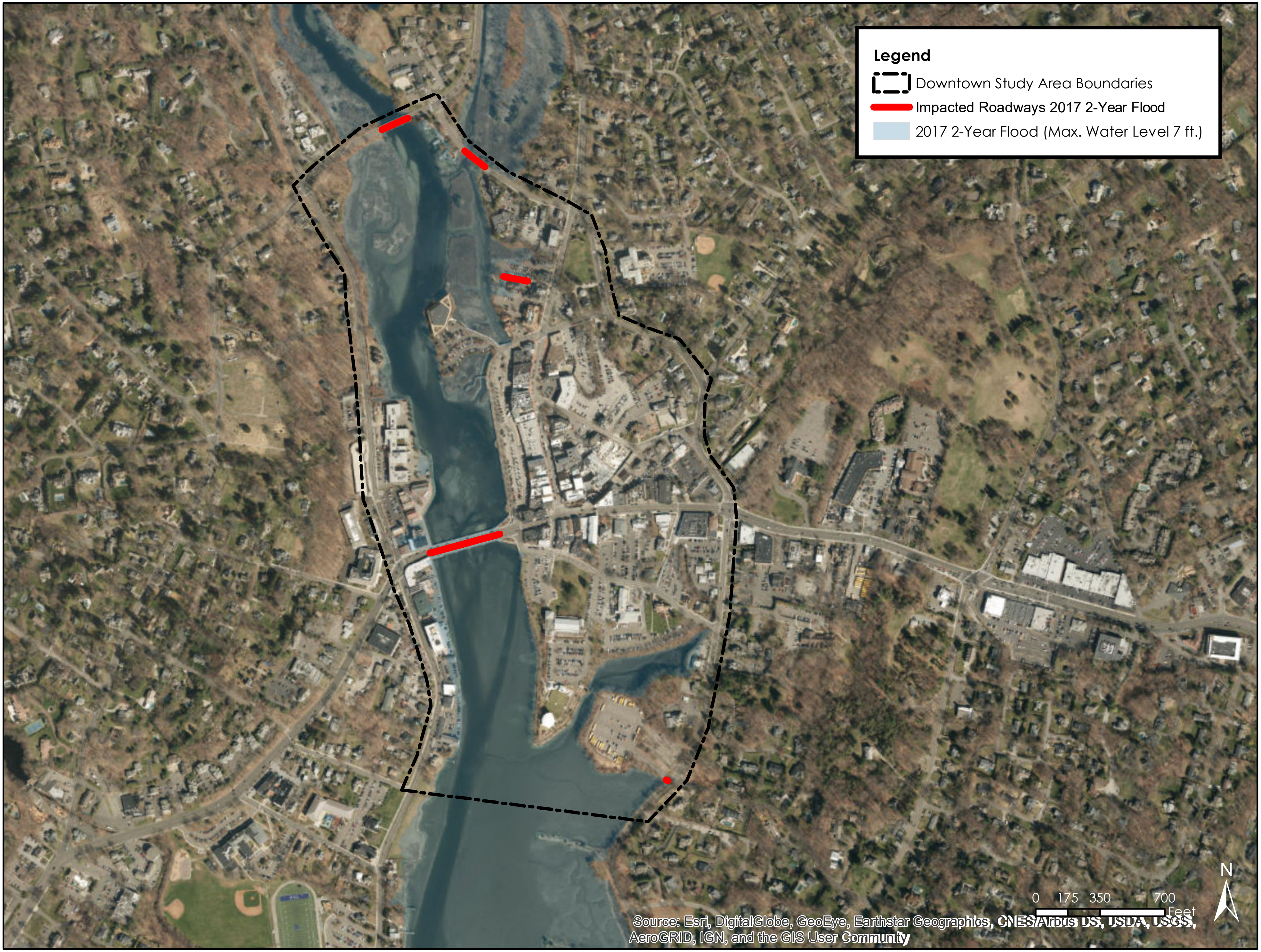
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Downtown Study Area Boundaries
Impacted Roadways 2017 2-Year Flood
2017 2-Year Flood (Max. Water Level 7 ft.)
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Feet
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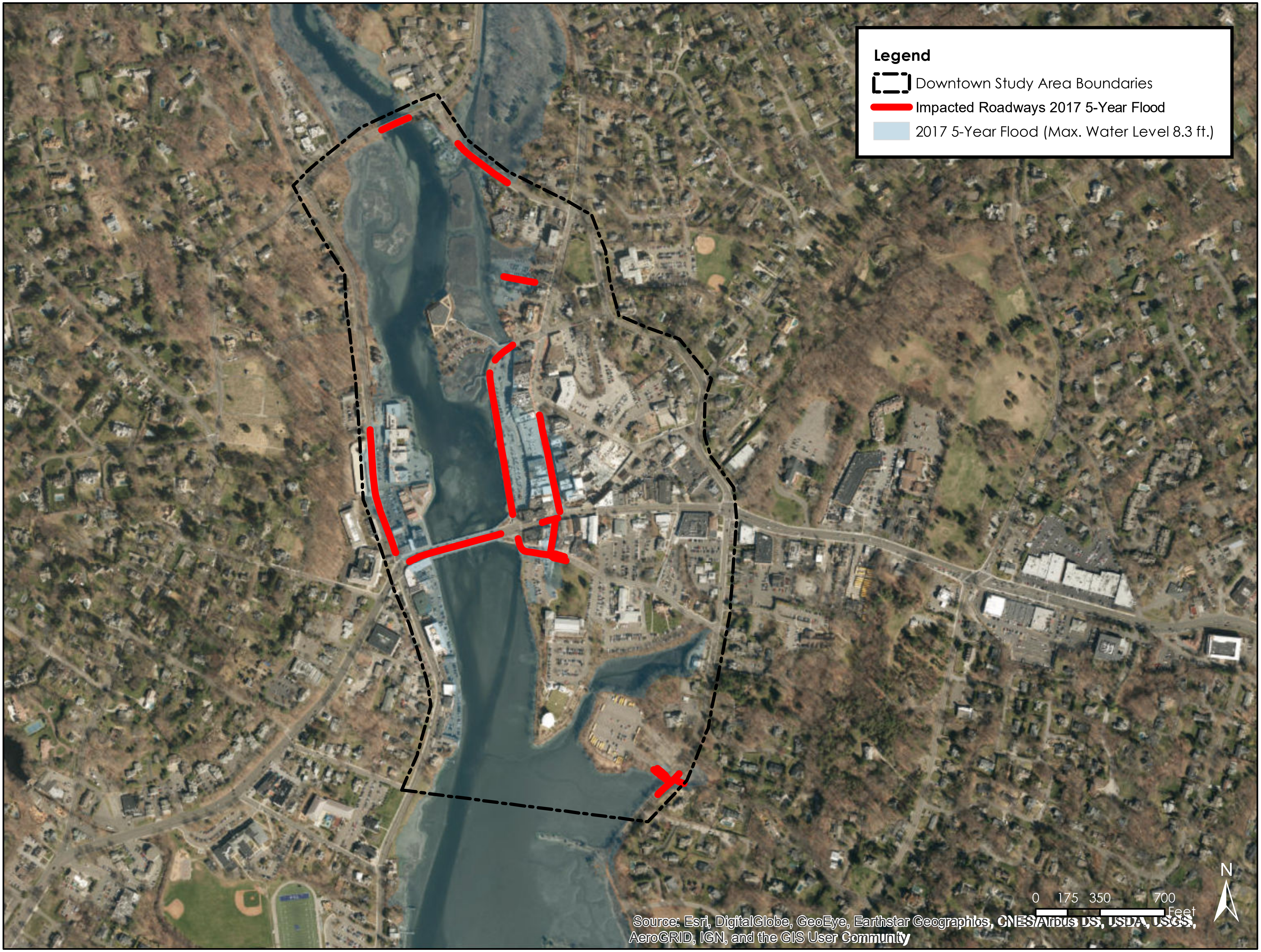
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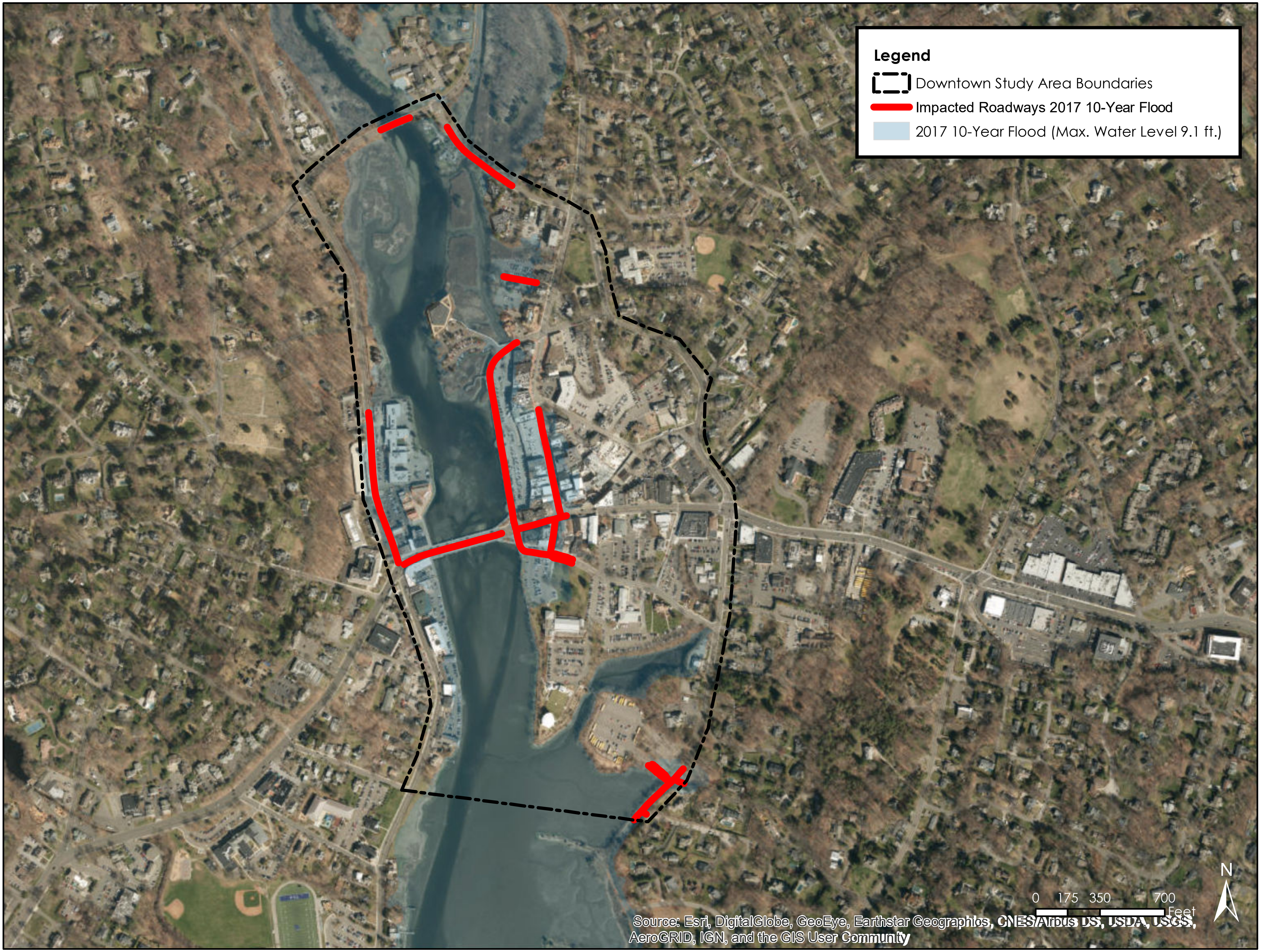
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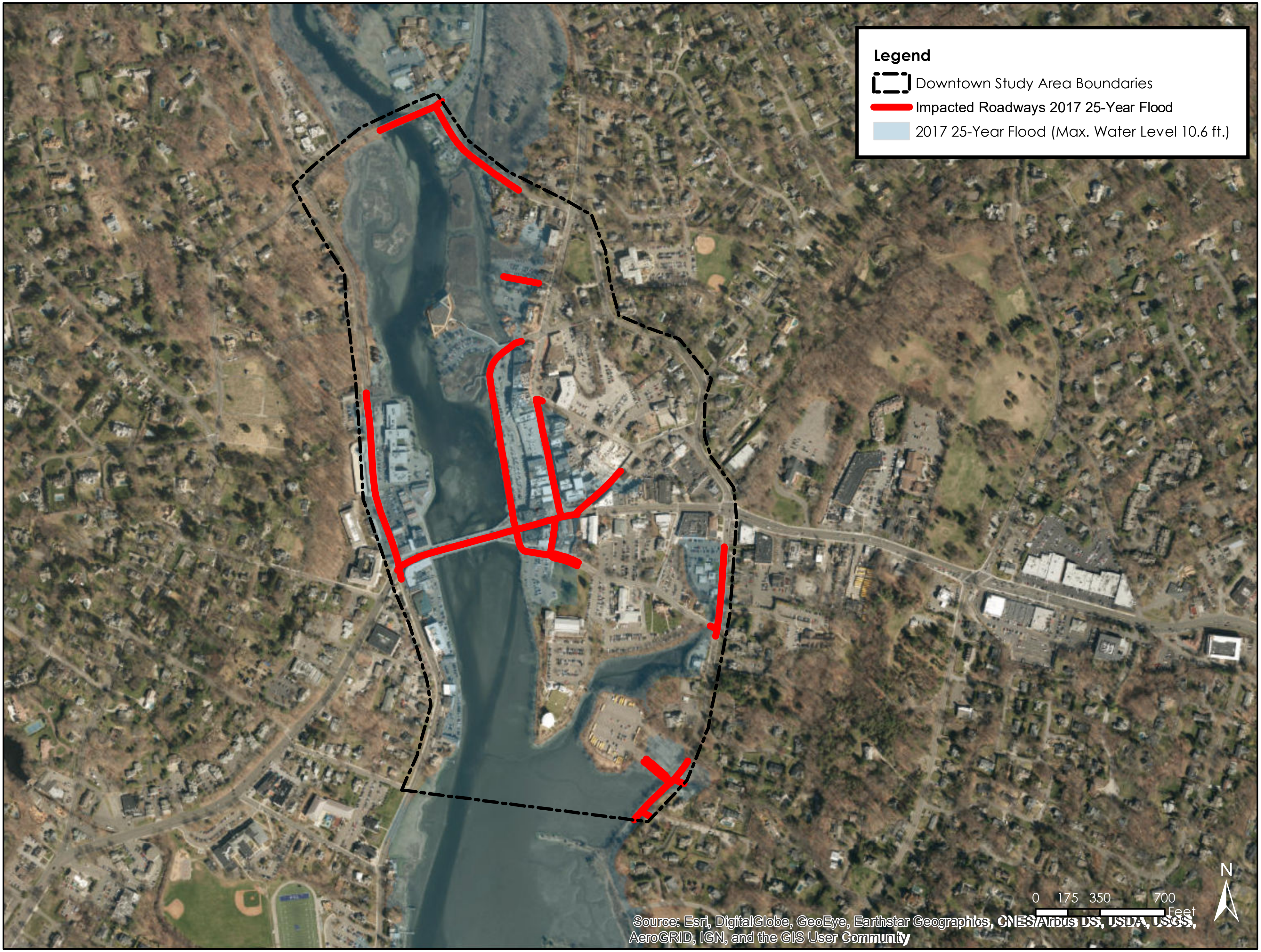
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Downtown Study Area Boundaries
Impacted Roadways 2017 25-Year Flood
2017 25-Year Flood (Max. Water Level 10.6 ft.)
N
0 175 350 700
Feet
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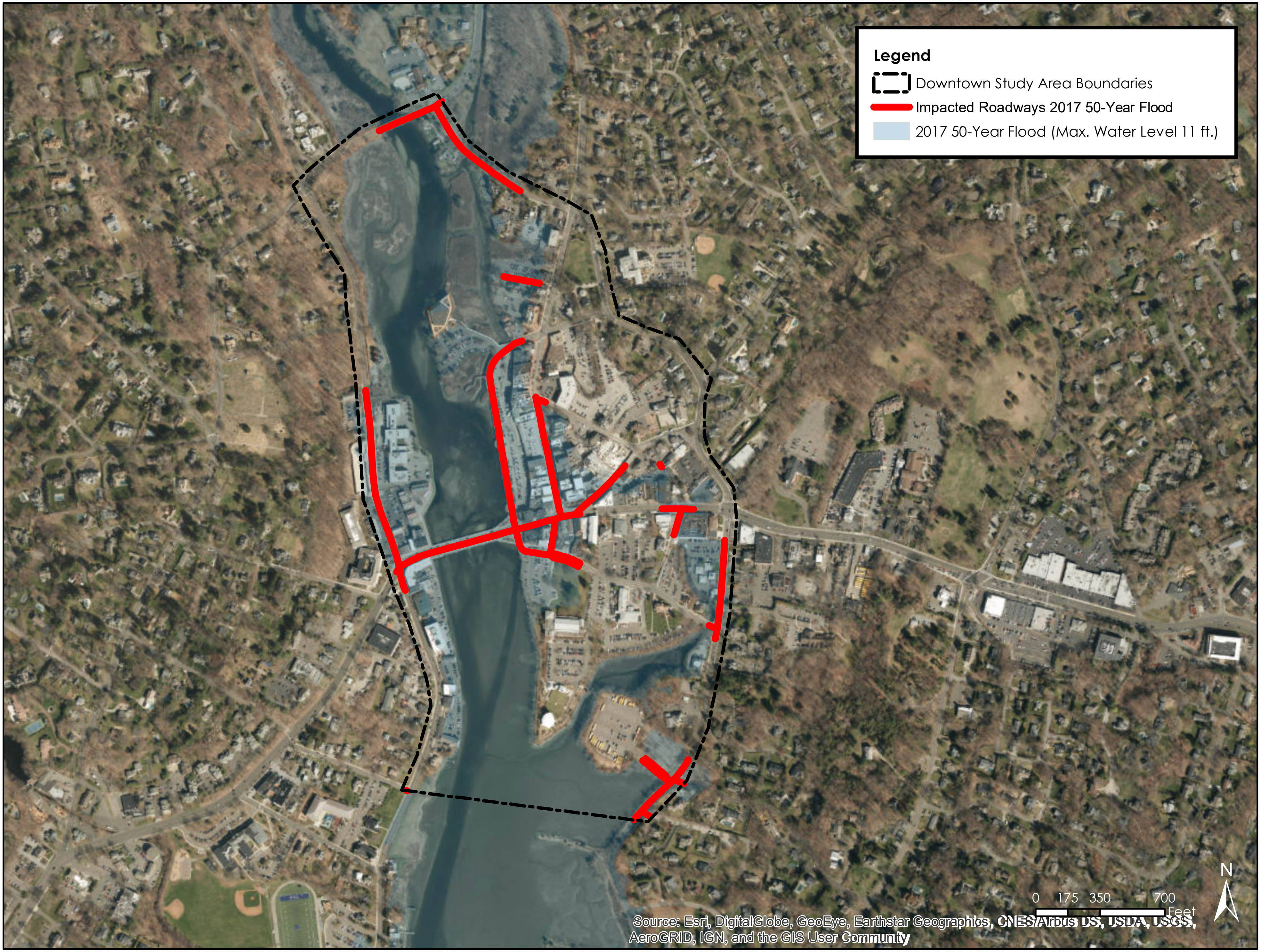
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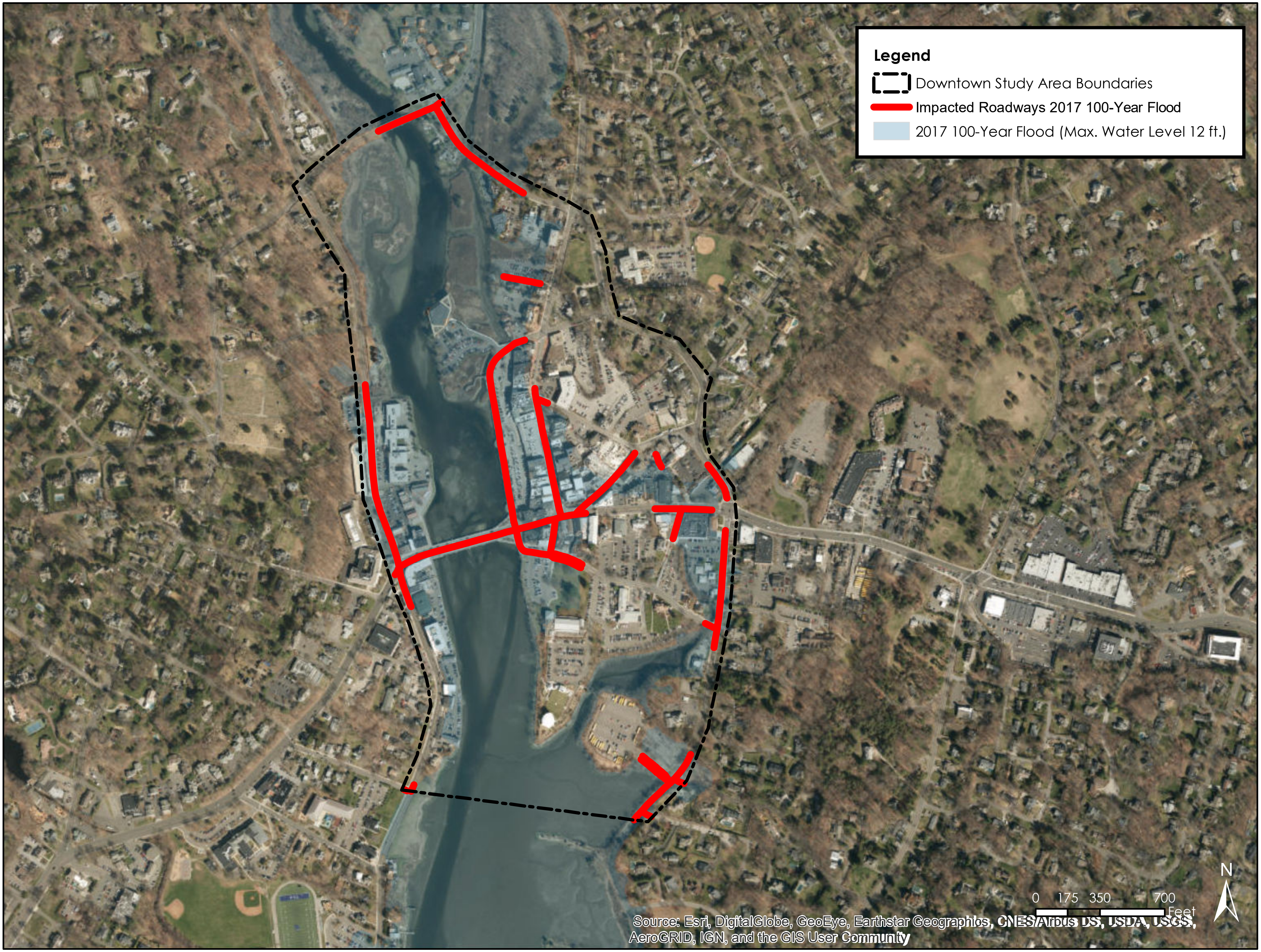
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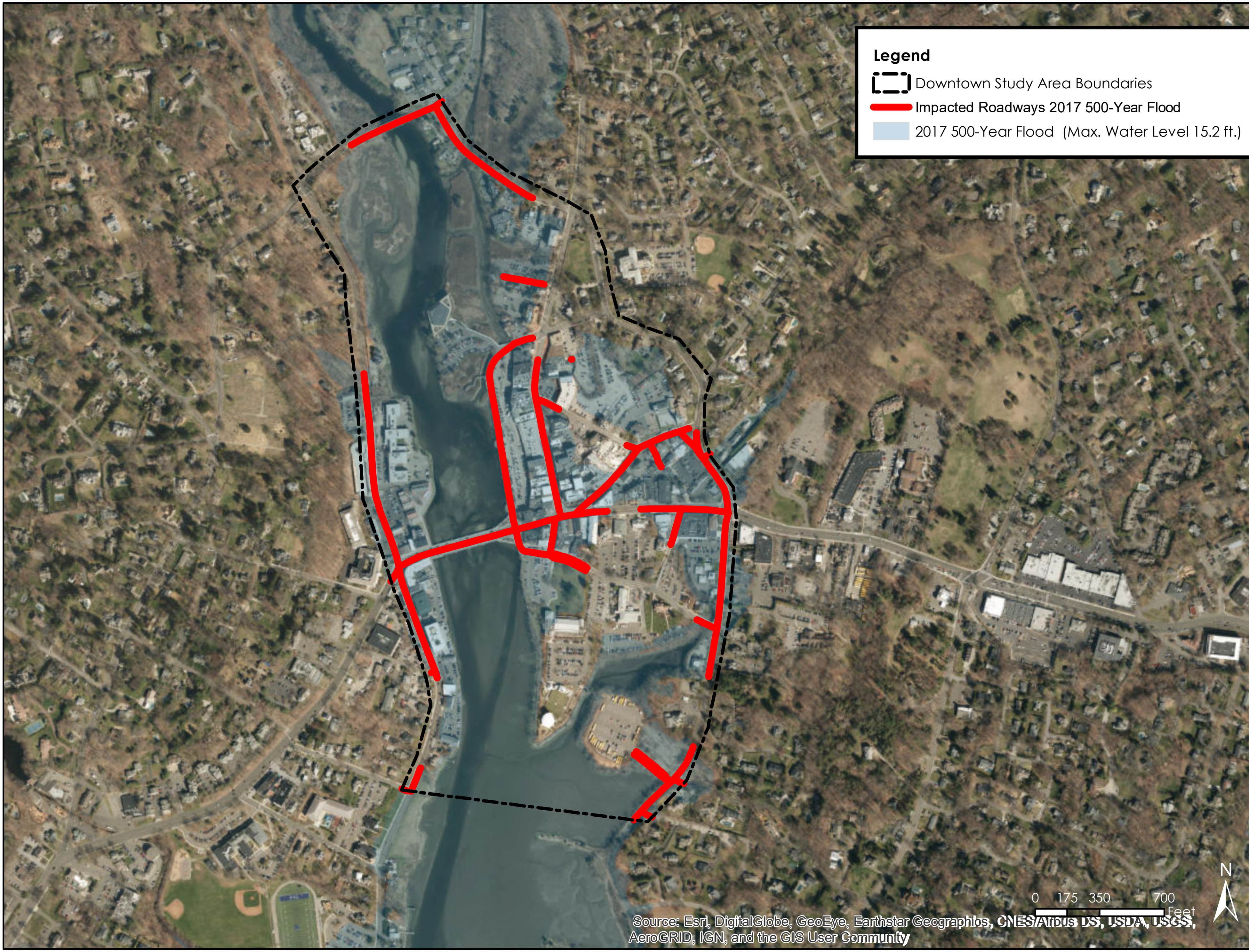
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