FLOOD MITIGATION & RESILIENCE REPORT

Hackensack River - SD109

Prepared for:

New York State Department of Environmental Conservation,
in cooperation with the New York State Office of General Services

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February 2022

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ACRONYMS

BFE	Base Flood Elevation
BIN	Bridge Identification Number
CFS	Cubic Feet per Second
CRRA	Community Risk and Resiliency Act
DEC	Department of Environmental Conservation
EWP	Emergency Watershed Protection
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
FMA	Flood Mitigation Assistance
FPMS	Floodplain Management Services (program)
GIS	Geographic Information System
HEC-RAS	*Hydrologic Engineering Center – River Analysis System*
HMGP	Hazard Mitigation Grant Program
HMP	Hazard Mitigation Plan
HRA	High Risk Area
LiDAR	Light Detection and Ranging
LWRP	Local Waterfront Revitalization Program
MWRR	Municipal Waste Reduction and Recycling
NAACC	North Atlantic Aquatic Connectivity Collaborative
NBI	National Bridge Inventory
NFIP	National Flood Insurance Program
NFIRA	National Flood Insurance Reform Act
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NWI	National Wetlands Inventory
NYS	New York State
NYSDEC	New York State Department of Environmental Conservation
NYSDOS	New York State Department of State
NYSDOT	New York State Department of Transportation
NYSOGS	New York State Office of General Services
PAS	Planning Advisory Service
PDM	Pre-Disaster Mitigation Program
RCP	Representative Concentration Pathway
RFC	Repetitive Flood Claims
SFHA	Special Flood Hazard Area
SIR	Scientific Investigations Report
SLR	SLR Engineering, Landscape Architecture, and Land Surveying, P.C.
SRL	Severe Repetitive Loss
STA	Station (river)
SWPPP	Stormwater Pollution Prevention Plan

USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WRD	Waterfront Redevelopment District
WSP	Water Supply Paper

SUMMARY

This analysis of the Hackensack River watershed is being conducted as part of the Resilient New York Program, an initiative of the New York State Department of Environmental Conservation. The Hackensack River originates in central Rockland County and drains southward into New Jersey. Analysis was conducted along flood-prone reaches of the Hackensack River, Pascack Brook, the Demarest Kill, and Nauraushaun Brook, all of which are part of the Hackensack River watershed. When measured at its outlet, the watershed is 201 square miles in size. An area of 61.6 square miles, or just over 30 percent of the watershed, is located within New York State. There are 3,172 acres of wetlands in the New York State portion of the Hackensack River watershed, or approximately 8 percent of the watershed. Wetlands play an important role in flood mitigation by storing water and attenuating peak flows.

Rockland County, including the Hackensack River watershed, has an active history of flooding. According to National Oceanic and Atmospheric Administration (NOAA) historical records, 25 hurricane or tropical storm tracks have passed within 65 miles of Rockland County since 1861, with five passing directly through Rockland County. Annual peak flow on the Hackensack River at Rivervale, New Jersey, has been recorded since 1942. The floods that resulted in the largest magnitude flows on the Hackensack River include the April 2007 Nor'easter and the August 2011 Tropical Storm Irene, both of which exceeded the 100-year flood event, and the September 2021 Tropical Storm Ida, which exceeded the 50-year flood event.

The New York State portion of the Hackensack River watershed is located north-northwest of New York City and is part of the New York Metropolitan Area. Developed land is the most common land cover, representing 69 percent of the watershed. Forested land consists of deciduous, coniferous, and mixed forest types and makes up another 20 percent of the land cover. An analysis of watershed land use is conducted as part of this analysis, and a Flood Resiliency Best Practices Audit is conducted for each community within the watershed.

Flood-prone High Risk Areas, or HRAs, within the watershed were identified, and an analysis of flood mitigation considerations within each HRA was undertaken. Factors with the potential to influence more than one HRA were also evaluated and discussed.

Much of this analysis focuses on stream crossings, where roads and railroads cross over the Hackensack River and its tributaries, and the watercourse is conveyed under the roadway through a bridge or culvert. A number of stream crossings are identified as being hydraulically undersized and are recommended for replacement. At various points in the watershed, homes and businesses are located within the Federal Emergency Management Agency's Special Flood Hazard Area, indicating that they are prone to flooding. Flood mitigation scenarios such as floodplain enhancement and channel restoration, road closures, and other flood protection measures are investigated and are recommended where appropriate.

1. INTRODUCTION

1.1 PROJECT BACKGROUND AND OVERVIEW

This work is a component of the Resilient New York Program, an initiative of the New York State Department of Environmental Conservation (NYSDEC), contracted through the New York State Office of General Services (NYSOGS). The goal of the Resilient New York Program is to make New York State more resilient to flooding and climate change. Through the program, flood studies are being conducted across the state, resulting in the development of flood and ice jam hazard mitigation alternatives to help guide implementation of mitigation projects.

The Hackensack River originates in central Rockland County and drains southward into New Jersey. This report will focus on the portion of the watercourses and watershed located within New York State, including the Hackensack River, Pascack Brook, the Demarest Kill, and Nauraushaun Brook. The report begins with an overview of the watercourses and watershed, summarizes the history of flooding, and identifies HRAs within the watershed. An analysis of flood mitigation considerations within each HRA is undertaken. Flood mitigation recommendations are provided either as HRA-specific recommendations or as overarching recommendations that apply to the entire watershed or stream corridor. Flood mitigation scenarios such as floodplain enhancement and channel restoration, road closures, and replacement of undersized bridges and culverts are investigated and are recommended where appropriate.

1.2 TERMINOLOGY

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

Stream stationing is used in the narrative and on maps as an address to identify specific points along the subject watercourses. Stationing on each watercourse is measured in feet, beginning at station 0+00 and continuing upstream. Stationing on the Hackensack River and Pascack Brook begins at station 0+00 at the New York/New Jersey state line. Stationing on the Demarest Kill and Nauraushaun Brook begins at station 0+00 at the confluences of these watercourses with the Hackensack River.

The Hackensack River watershed measured at its outlet to Newark Bay in New Jersey is 201 square miles in size. An area of 61.6 square miles, or just over 30 percent of the watershed, is located within New York State. This study focuses on the portion of the watershed located in New York State. Throughout this report, references to the Hackensack River, its tributaries, and the Hackensack River watershed pertain to the portions located in New York State.

The Federal Emergency Management Agency (FEMA) is an agency of the United States Department of Homeland Security. In order to provide a common standard, FEMA's National Flood Insurance Program (NFIP) has adopted a baseline probability called the base flood. The base flood has a 1 percent (one in 100) chance of occurring in any given year, and the base flood elevation (BFE) is the level floodwaters are expected to reach in this event. For the purpose of this report, the 1 percent annual chance flood is also referred to as the 100-year flood. Other recurrence probabilities used in this report include the 2-year flood event (50 percent annual chance flood), the 10-year flood event (10 percent annual chance flood), the 25-year flood event (4 percent annual chance flood), the 50-year flood event (2 percent annual chance flood), and the 500-year flood event (0.2 percent annual chance flood).

The Special Flood Hazard Area (SFHA) is the area inundated by flooding during the 100-year flood event. Within the project area, FEMA has developed Flood Insurance Rate Mapping (FIRM), which indicates the location of the SFHA along the Hackensack River and its tributaries.

2. DATA COLLECTION

Data were gathered from various sources related to the hydrology and hydraulics of the Hackensack River and its tributaries, Hackensack River watershed characteristics, recent and historical flooding in the affected communities, and factors that may contribute to flood hazards.

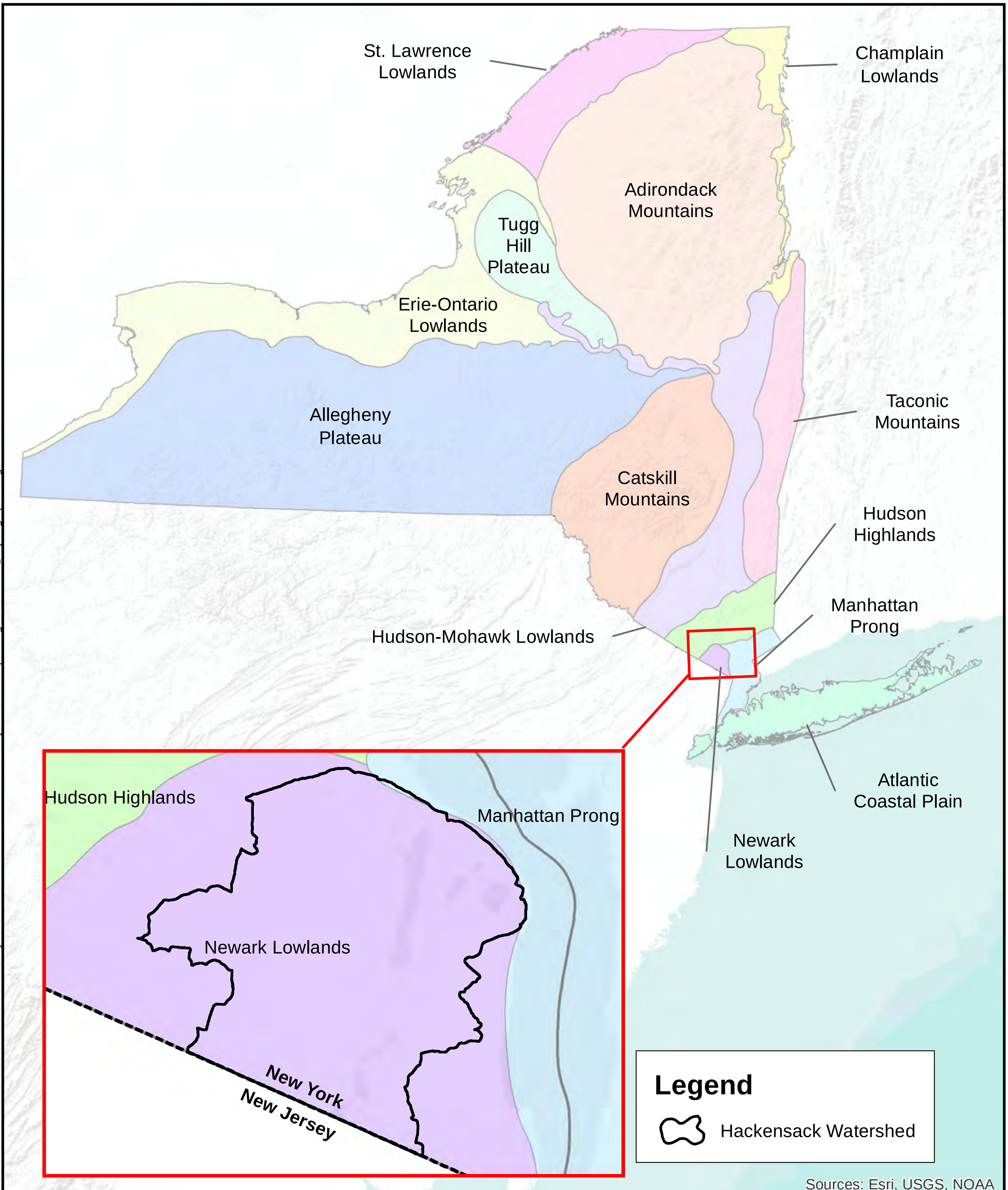
2.1 HACKENSACK RIVER WATERSHED CHARACTERISTICS

The Hackensack River watershed is located in Rockland County, in southeastern New York State, and falls within the physiographic region known as the Newark Basin or Newark Lowlands (Figure 2-1). The watershed flows in a generally southerly direction, draining the central and southeastern portions of Rockland County before flowing into New Jersey. Nearly the entire town of Clarkstown; the western portion of the town of Orangetown; and smaller portions of the towns of Ramapo and the villages of Chestnut Ridge, New Hempstead, Spring Valley, and New Square drain to the Hackensack River.

The Hackensack River watershed is oblong in shape, narrowing toward its outlet to Newark Bay in New Jersey. When measured at its outlet, the watershed is 201 square miles in size. An area of 61.6 square miles, or just over 30 percent of the watershed, is located within New York State and is the focus of this study. Figure 2-2 is a watershed map of the portion of the Hackensack River watershed located within New York State. Watershed relief is depicted in Figure 2-3.

The portion of the Hackensack River watershed that falls within New York State is underlain by bedrock that is classified as part of the Newark Group. Bedrock within this group dates from the Upper Triassic and has been mapped as distinct formations. Most of the watershed is underlain by bedrock of the Brunswick Formation, which consists of sedimentary conglomerate, sandstone, siltstone, mudstone, and arkose. Along the western border of the watershed is bedrock mapped as Hammer Creek Formation, a conglomerate. Forming the northern and eastern boundaries of the watershed and forming the Palisades cliffs that line the western side of the Hudson River is Palisades Diabase, an igneous rock type containing light feldspar and dark augite, which give the rock a distinctive "salt-and-pepper" appearance.

Surficial materials underlying the Hackensack River watershed consist primarily of glacial till, with areas mapped as exposed bedrock occurring along the northern and eastern margins of the watershed. Areas mapped as lacustrine silt and clay and outwash sand and gravel underlie the Hackensack River valley bottom in the central watershed, between Deforest Lake and the New York/New Jersey state line.



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SLR
231 MAIN STREET
SUITE 102
NEW PALTZ, NY 12561
845.633.8153

NYS PHYSIOGRAPHIC REGIONS
HACKENSACK RIVER FLOOD & RESILIENCY STUDY
SD109
ROCKLAND COUNTY
NEW YORK

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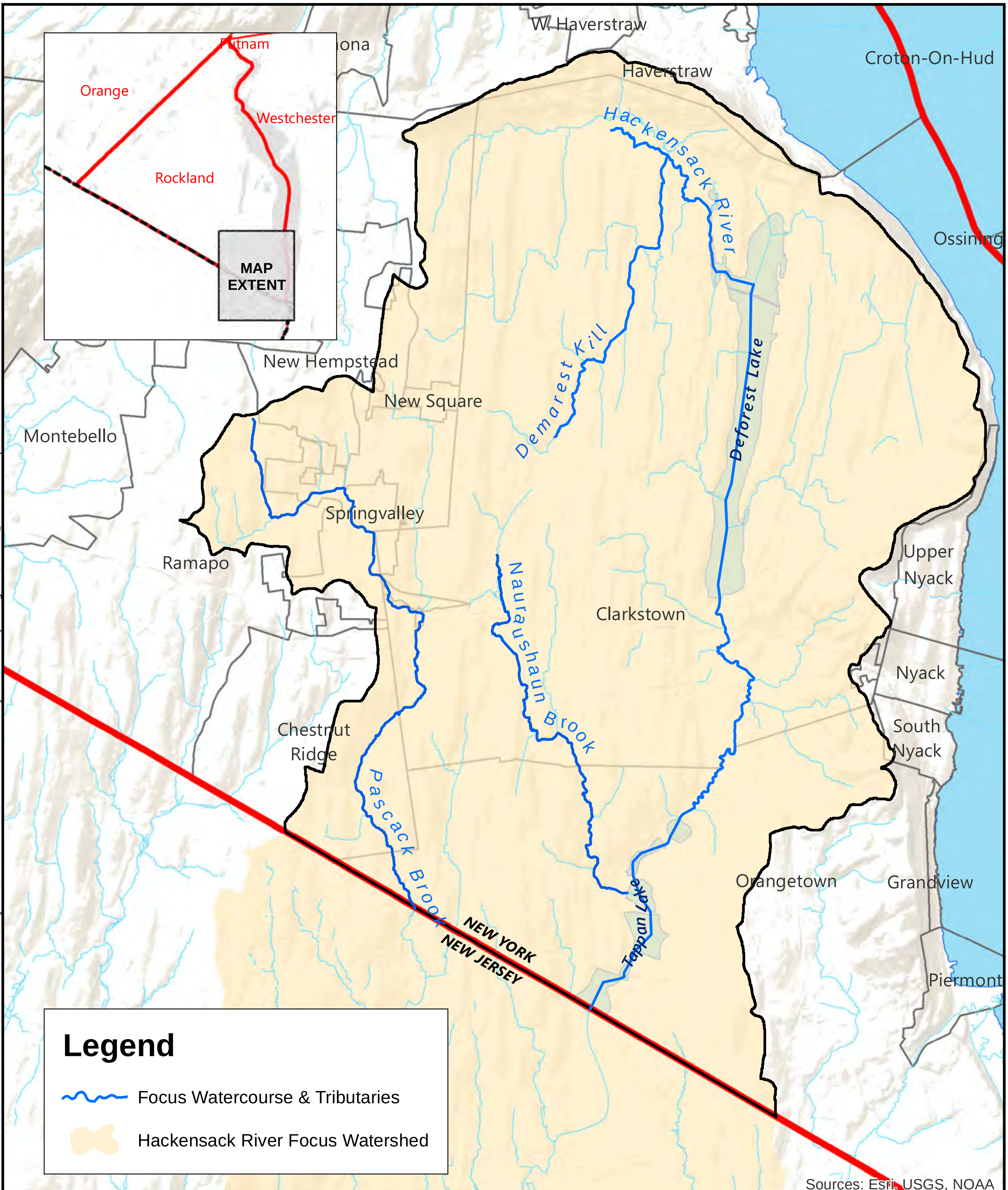
FIG. 2-1



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HACKENSACK RIVER WATERSHED MAP
HACKENSACK RIVER FLOOD & RESILIENCY STUDY
SD109
ROCKLAND COUNTY
NEW YORK

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FIG. 2-2

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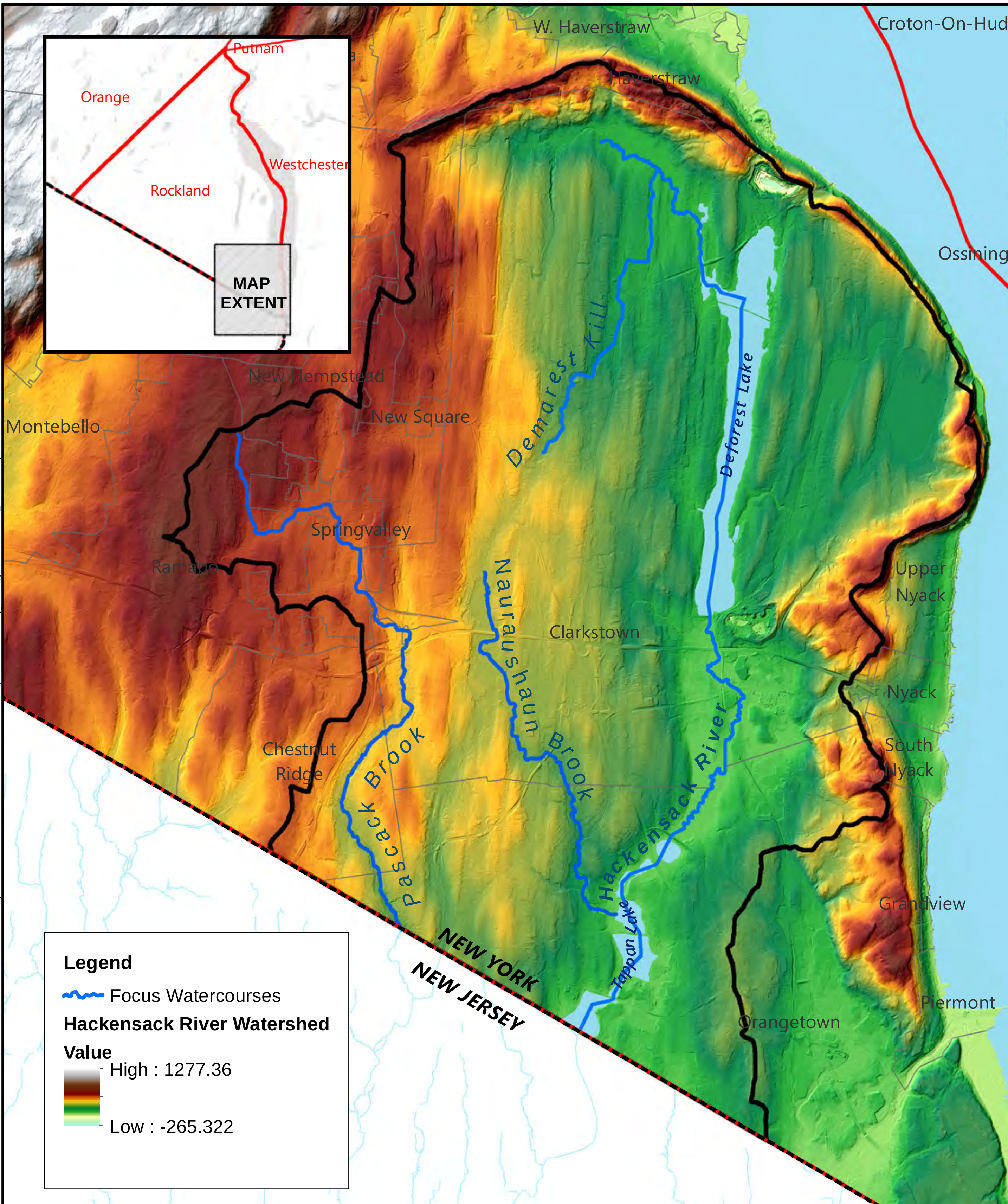

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RELIEF MAP

HACKENSACK RIVER FLOOD & RESILIENCY STUDY
SD109
ROCKLAND COUNTY
NEW YORK

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FIG. 2-3

During a rainfall event, the proportion of rainfall that runs off directly into rivers and streams or that infiltrates into the ground is greatly influenced by the composition of soils within a watershed. Soils are assigned a hydrologic soil group identifier, which is a measure of the infiltration capacity of the soil. These are ranked A through D. A hydrologic soil group A soil is often very sandy, with a high infiltration capacity and a low tendency for runoff except in the most intense rainfall events; a D-ranked soil often has a high silt or clay content or is very shallow to bedrock and does not absorb much stormwater, which instead is prone to run off even in small storms. A classification of B/D indicates that when dry the soil exhibits the properties of a B soil, but when saturated, it has the qualities of a D soil. Approximately 71 percent of the mapped soils in the Hackensack River watershed are classified as hydrologic soil group C, C/D, or D, indicating a low capacity for infiltration and a high tendency for runoff (Figure 2-4). This contributes to flash flooding in the watershed as rainfall runoff moves swiftly into streams rather than gradually seeping through the soils.

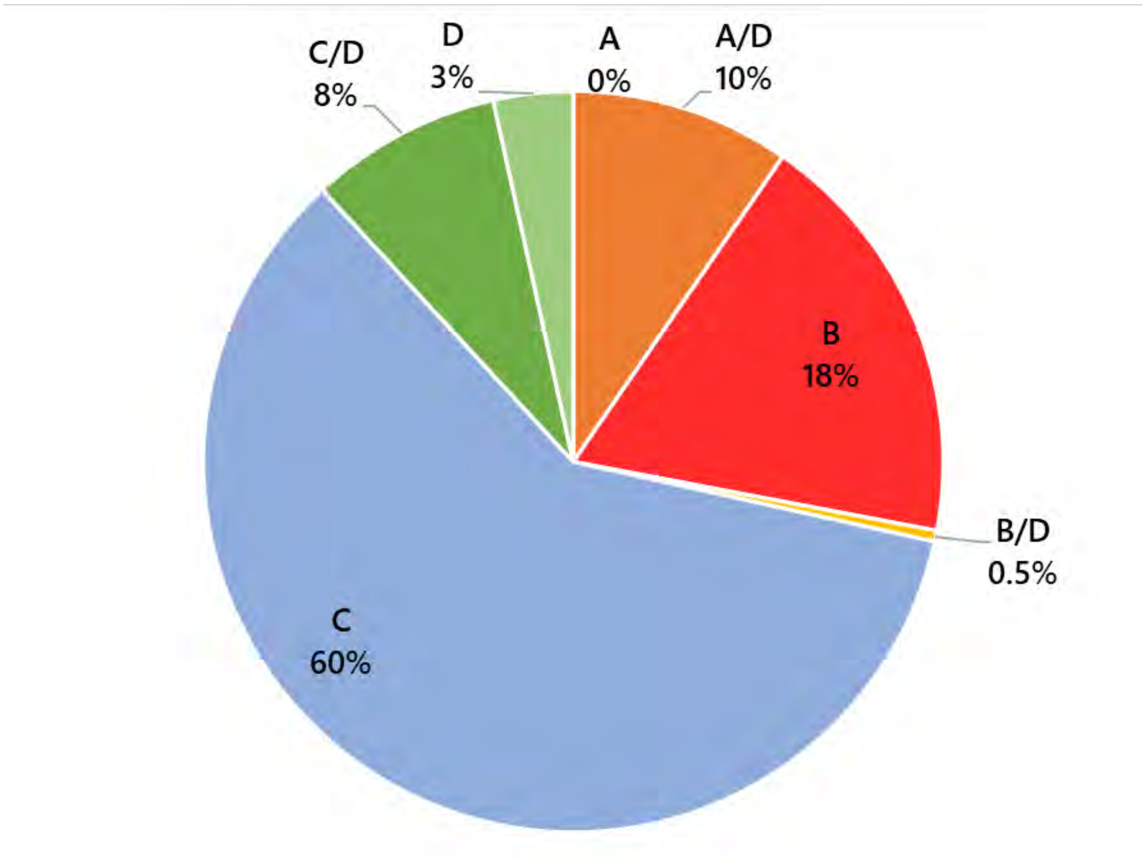


Figure 2-4: Hydrologic Grouping of Soils within the Hackensack River Watershed

and is shown graphically in Figure 2-5. Developed land is the most common land cover, representing 69 percent of the watershed. Forested land consists of deciduous, coniferous, and mixed forest types and makes up 20 percent of the land cover in the watershed. Open water and wetlands combined make up 8 percent of the land cover. The remaining 3 percent of the land cover consists of agricultural land, grassland and shrubland, and barren land.

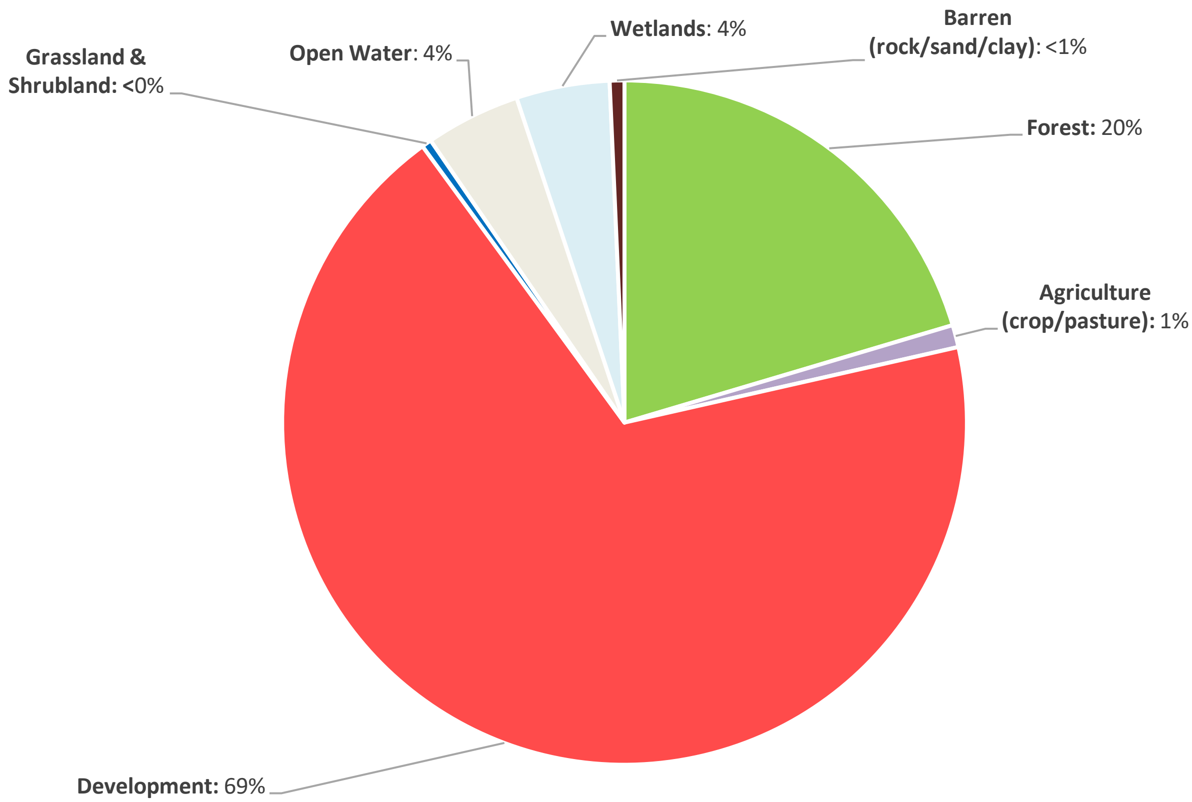


Figure 2-5: Land Cover within the Hackensack River Watershed

> It is estimated that since colonial times approximately 50 to 60 percent of the wetlands in the state of New York have been lost through draining, filling, and other types of alteration.

Wetland cover was also examined using information available from the U.S. Fish & Wildlife Service's National Wetlands Inventory (NWI). The NWI indicates that there are 3,172 acres of wetlands in the Hackensack River watershed, or approximately 8 percent of the watershed. This amount is consistent with the estimate above based on land cover and includes the following types of wetland habitats: freshwater forest/shrub wetland, freshwater emergent wetland, freshwater pond, lake (reservoirs), and riverine wetland. Much of this acreage can be attributed to large waterbodies in the watershed, which include Deforest Lake, Lake Tappan, Rockland Lake, Lake Lucille, Congers Lake, and Swartwout Lake.

NYSDEC-mapped wetlands are dispersed throughout the Hackensack River watershed and include approximately 210 acres along the Hackensack River above Deforest Lake, a 44.1-acre wetland along Tom's Brook, 48.4 acres of wetland located along tributaries to Rockland Lake, approximately 93 acres of wetlands along Nauraushaun Brook and its tributaries, and approximately 440 acres of wetlands along the Hackensack River between Deforest Lake and the New Jersey state line. Wetlands play an important role in flood mitigation by storing water and attenuating peak flows. It is estimated that since colonial times approximately 50 to 60 percent of the wetlands in the state of New York have been lost through draining, filling, and other types of alteration.

2.2 HACKENSACK RIVER WATERCOURSE

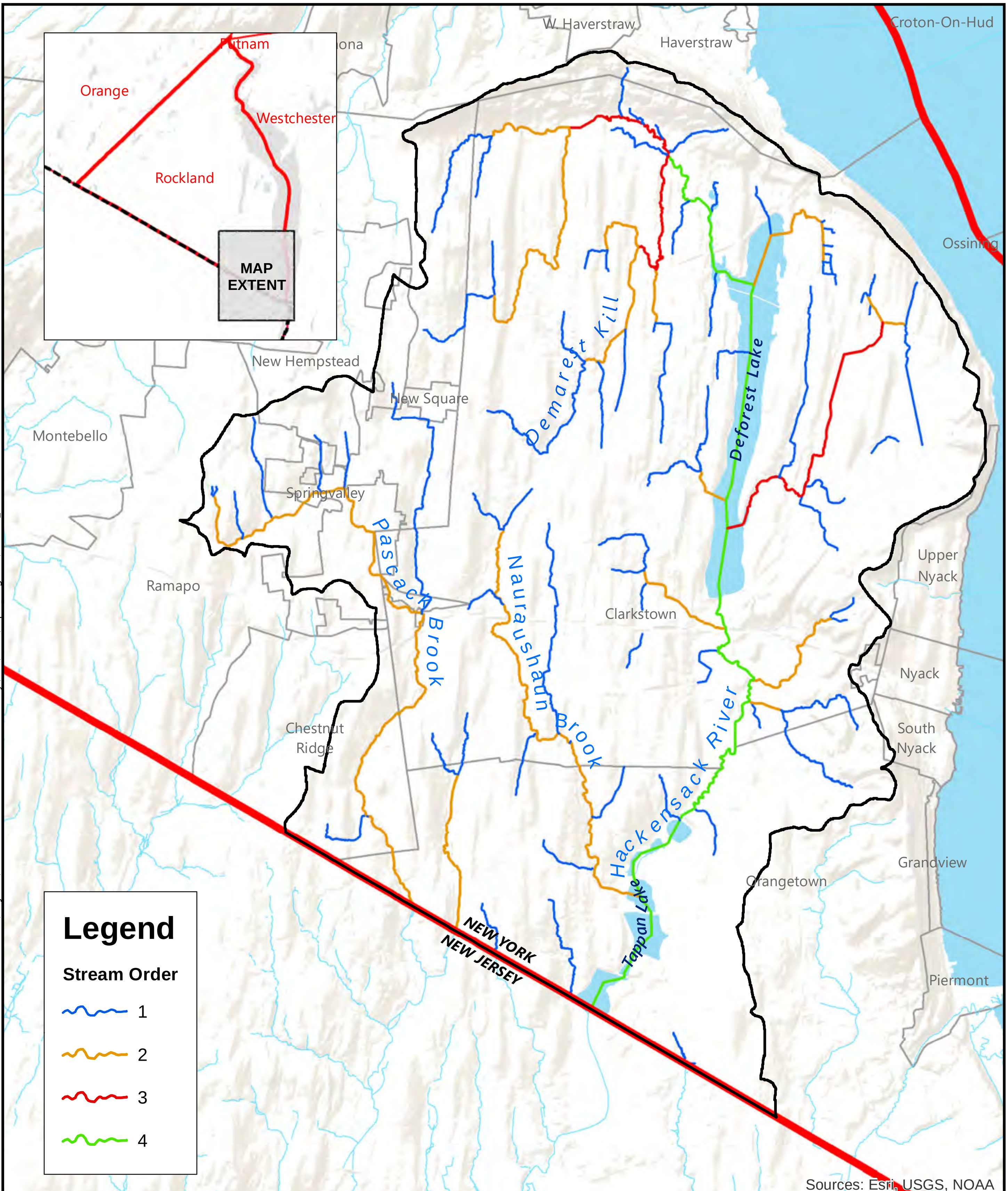
The main stem of the Hackensack River originates in the northern portion of the town of Clarkstown and flows southward for approximately 12.6 miles through Clarkstown and Orangetown before crossing into New Jersey. The Palisades cliffs that line the western side of the Hudson River form an area of high ground that separate the Hackensack and Hudson Rivers. Named tributaries to the main stem of the Hackensack River include the north-flowing Demarest Kill; Nauraushaun (on some maps Nauraushaunk) Brook, which flows generally southeastward to join the Hackensack River at Tappan Lake; New City Brook; Muddy Creek; and Pascack Brook. Pascack Brook flows southward in New York State and crosses the state line to join the Hackensack River in New Jersey.

Stream order provides a measure of the relative size of streams by assigning a numeric order to each stream in a stream network. The smallest tributaries are designated as first-order streams, and the designation increases as tributaries join. The main stem of the Hackensack River can be characterized as a sixth-order stream at its outlet where it discharges to Newark Bay and as a fourth-order stream for most of its length within New York State. Larger tributaries such the lower section of the Demarest Kill and the East Branch of the Hackensack River are third order. Second-order stream examples include Nauraushaun Brook, Pascack Brook, and the upper section of the Demarest Kill. Many of the first-order streams are unnamed. Figure 2-6 is a map depicting stream order in the Hackensack River watershed.

Characteristics of each order of stream (total length, average slope, and percentage of overall stream network) are summarized in Table 2-1. First- and second-order streams account for most of the overall stream length within the Hackensack River watershed (81 percent). First-order streams are steeper in slope than second- and third-order streams, which are steeper than the fourth-order main stem of the Hackensack River.

Table 2-1: Stream Order Characteristics in the NYS Portion of the Hackensack River Watershed

Stream Order	Total Length (miles)	Percentage of Overall Network Length (%)	Average Slope (%)
1^{st}	54.9	52	2.1
2^{nd}	31.3	29	1.2
3^{rd}	7.5	7	1.2
4^{th}	12.6	12	0.2
Total	**106.2**	**100**	



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NEW PALTZ, NY 12561
845.633.8153

STREAM ORDER

HACKENSACK RIVER FLOOD & RESILIENCY STUDY
SD109
ROCKLAND COUNTY
NEW YORK

N

0 4,000 8,000 Feet

SCALE 1 " = 8,000 '

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FIG. 2-6

2.3 HYDROLOGY

Hydrologic studies are conducted to understand historical, current, and potential future river flow rates, which are a critical input for hydraulic modeling software such as *Hydrologic Engineering Center – River Analysis System* (HEC-RAS). These often include statistical techniques to estimate the probability of a certain flow rate occurring within a certain period of time based on data from the past; these data are collected and maintained by the United States Geological Survey (USGS) at thousands of stream gauging stations around the country. For the streams without gauges, the USGS has developed region-specific regression equations that estimate flows based on watershed characteristics, such as drainage area and annual precipitation, as well as various techniques to account for the presence of nearby stream gauges or to improve analyses of gauges with limited records. These are based on the same watershed characteristics as gauged streams in that region so are certainly informative although not as accurate or reliable as a gauge due to the intricacies of each unique basin.

For the purposes of this study, we are primarily concerned with the more severe flood flows although hydrologic analyses may be conducted for the purposes of estimating low flows, high flows, or anywhere in between. The commonly termed "100-Year Flood" refers to the flow rate that is predicted to have a 1 percent, or 1 in 100, chance of occurring in any year. A "25-Year Flood" has a 1 in 25 chance of occurring (4 percent) every year. It is important to note that referring to a specific discharge as an "X-Year Flood" is a common and convenient way to express a statistical probability but can be misleading because it has no bearing whatsoever on when or how often such a flow actually occurs.

A simplified diagram of the hydrologic cycle is presented in Figure 2-7.

Along with the location, duration, and intensity of a storm, the flooding that may result from a rainfall event can vary widely depending on the unique hydrology of each basin. Characteristics of local topography, soils, vegetation cover and type, bedrock geology, land use and cover, river hydraulics and floodplain storage, ponding, wetland, and reservoir storage, combined with antecedent conditions in the watershed such as snow pack or soil saturation, can impact the timing, duration, and severity of flooding.

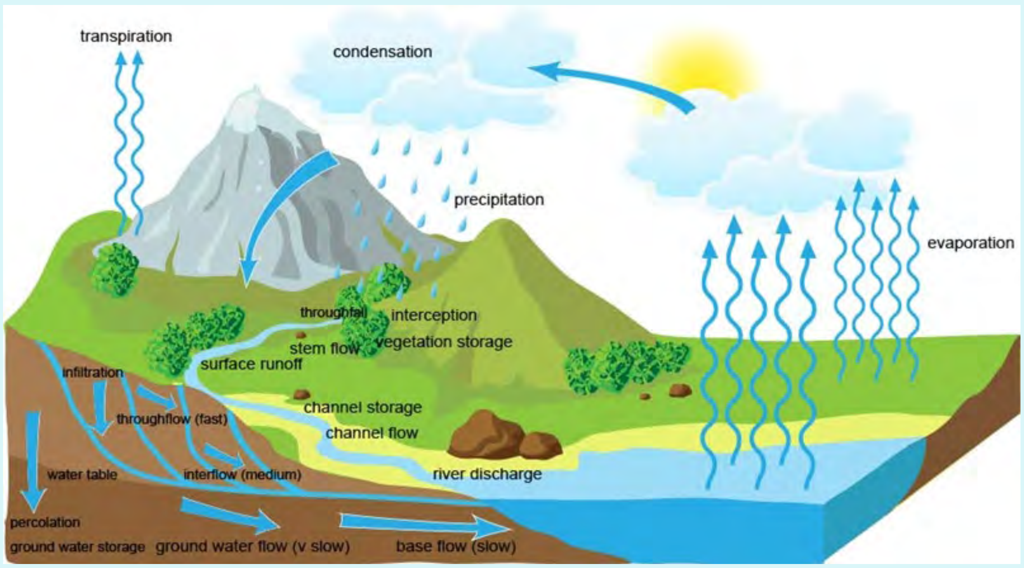

Figure 2-7: Diagram of Simplified Hydrologic Cycle

Flood hydrology for the Hackensack River and its tributaries was taken from the FEMA effective Flood Insurance Study (FIS) for Rockland County (36087CV001A, Effective March 4, 2014). The FEMA analysis is the most recently completed hydrologic analysis for Rockland County; therefore, those computed peak flows were used for hydraulic analysis. Discharge estimates at various locations along the Hackensack River, Demarest Kill, Nauraushaun Brook, and Pascack Brook are reported in the FEMA FIS for the 10-, 50-, 100-, and 500-year floods. These estimates are based on regional regression equations developed for New York State detailed in USGS Scientific Investigations Report (SIR) 2006-5112, as well as the urban runoff regressions defined in USGS Water Supply Paper (WSP) 2207. Analysis of stream gauge data is included for adequately gauged sections of watercourses. Flood flows in the Hackensack River watershed are presented in Table 2-2.

Table 2-2: Flood Hydrology for Hackensack River Watershed Developed for Rockland County FIS

Watercourse	Location	Drainage Area (square miles)	Peak Flood Discharge (cubic feet per second)			
			10-Year	50-Year	100-Year	500-Year
Demarest Kill	At confluence with Hackensack River	6.13	1,338	2,139	2,612	3,764
	At Heritage Drive	3.58	1,018	1,631	1,974	2,825
	At Main Street	2.91	857	1,375	1,659	2,374
	At Middletown Road	0.91	402	524	594	716
	At White Birch Court	0.56	333	441	484	591
Hackensack River	At the Town of Clarkstown-Town of Orangetown corporate limits	34.73	1,619	2,436	2,824	3,765
	At USGS 01376800 West Nyack	30.90	1,254	1,850	2,106	2,702
	Approximately 200 feet upstream of I-87	29.65	1,219	1,800	2,050	2,632
	At Old Mill Road	27.51	1,157	1,712	1,951	2,509
Nauraushaun Brook	At confluence with Hackensack River	5.92	1,157	1,863	2,264	3,274
	At abandoned Erie-Lackawanna Railroad	5.10	1,054	1,682	2,044	2,966
	At Town Line Road	4.45	915	1,467	1,781	2,576
	At Lake Nanjet	4.27	790	1,280	1,557	2,261
	Approximately 750 feet upstream of abandoned railroad	2.78	559	906	1,097	1,590
	At North Middletown Road	2.21	454	734	888	1,290
	At Smith Road	1.12	354	571	685	976
Pascack Brook	At the New York – New Jersey border	10.42	2,282	3,653	4,451	6,412
	At Town of Orangetown-Village of Chestnut Ridge Corp Limits	9.73	2,030	3,263	3,979	5,752
	Approximately 85 feet downstream of Grotke Road	8.95	2,006	3,221	3,938	5,684
	Approximately 1,060 feet downstream of Lillian Drive	8.35	1,885	3,035	3,696	5,350
	Approximately 180 feet downstream of S. Pascack Road	4.61	983	1,600	1,940	2,831
	Approximately 300 feet downstream of Dutch Lane	4.45	957	1,557	1,895	2,749
	Downstream of Maple Avenue Extension	4.16	857	1,400	1,698	2,487
	Approximately 175 feet upstream from Linden Avenue	3.09	730	1,110	1,320	1,880
	Approximately 100 feet downstream of Union Road	2.07	580	910	1,100	1,590
	Approximately 630 feet downstream of Lake Suzanne spillway	1.53	440	690	840	1,210
	Approximately 600 feet upstream of Francis Place	0.60	390	530	620	770
	Approximately 500 feet downstream of Rita Avenue	0.56	290	380	440	560
	Approximately 620 feet downstream of Grosser Lane	0.22	200	270	300	350

The web-based tool, "Application of Flood Regressions and Climate Change Scenarios to Explore Estimates of Future Peak Flows," developed by the USGS (Burns et al., 2015a,b) was used to obtain estimates for changes in peak-flood flows under a range of projected climate change scenarios at different periods in the future. This tool is currently only available for New York State and was used to assess flooding conditions that may occur in future decades, enabling proactive flood mitigation measures. These may include restricting development in areas that are not currently regulated floodplains but are reasonably expected to be in the future based on climate change projections or identifying bridges and culverts that currently perform well but may become hydraulically inadequate in the future.

Precipitation data were evaluated for two future scenarios, termed "Representative Concentration Pathways" (RCP), that provide estimates of the extent to which greenhouse gas concentrations in the atmosphere are likely to change through the 21st century. RCP refers to potential future emissions trajectories of greenhouse gases such as carbon dioxide. RCP 4.5 is considered a midrange-emissions scenario, and RCP 8.5 is a high-emissions scenario. Resulting precipitation and runoff estimates are based on five different climate models and are input into the USGS *StreamStats* program, a web-based implementation of regional hydrologic regression equations. Percent increases over *StreamStats* regression estimates based on current climatic data, as computed for the Hackensack River watershed, were applied to corresponding flood flows used in this analysis. The flows based on the more moderate greenhouse gas scenario were used in hydraulic models. Proposed replacement stream crossings were assessed based on the flood flows the structure would be expected to encounter over its design lifetime. When modeling culverts, the 2050-2074 projections were employed, as a 50-year design life is typical for such structures; the 2075-2099 projections were used for bridges, which are often in service for 75 to 100 years or more. Mean estimated increases on the Hackensack River at the New York-New Jersey state line based on the five climate models are presented in Table 2-3. These are based on regressions for Flood Frequency Region 2 in New York. Current and predicted future flows for the Hackensack River and its tributaries at various locations along the watercourses are compared in Table 2-4.

Table 2-3: Projected Increases in Flood Flows on the Hackensack River

Mean Change in Discharge (%)	2025-2049		2050-2074		2075-2099	
Greenhouse Gas Scenario	50-Year Flood	100-Year Flood	50-Year Flood	100-Year Flood	50-Year Flood	100-Year Flood
RCP 4.5	10	10	13	13	11	11
RCP 8.5	10	10	11	11	16	17

Table 2-4: Current and Projected Future Flood Flows Used in Hydraulic Analyses in the Hackensack River Watershed

Watercourse	Location	Peak Flood Discharge (cubic feet per second) Increase (%)					
		CURRENT		PROJECTED FUTURE (RCP 4.5, 2050-2074)		PROJECTED FUTURE (RCP 4.5, 2075-2099)	
		50-YEAR	100-YEAR	50-YEAR	100-YEAR	50-YEAR	100-YEAR
Demarest Kill	At confluence with Hackensack River	2,139	2,612	2,396 (12%)	2,925 (12%)	2,353 (12%)	2,873 (10%)
	At Heritage Drive	1,631	1,974	1,810 (11%)	2,211 (12%)	1,794 (12%)	2,171 (10%)
	At Main Street	1,375	1,659	1,526 (11%)	1,858 (12%)	1,513 (12%)	1,825 (9%)
	At Middletown Road	524	594	582 (11%)	659 (11%)	571 (11%)	653 (9%)
	At White Birch Court	441	484	490 (11%)	537 (11%)	481 (11%)	532 (9%)
Hackensack River	At the Town of Clarkstown-Town of Orangetown corporate limits	2,436	2,824	2,728 (12%)	3,163 (12%)	2,680 (10%)	3,135 (11%)
	At USGS 01376800 West Nyack	1,850	2,106	2,072 (12%)	2,359 (12%)	2,035 (10%)	2,338 (11%)
	Approximately 200 feet upstream of I-87	1,800	2,050	2,016 (12%)	2,317 (13%)	1,980 (10%)	2,276 (11%)
	At Old Mill Road	1,712	1,951	1,917 (12%)	2,205 (13%)	1,883 (10%)	2,166 (11%)
Nauraushaun Brook	At confluence with Hackensack River	1,863	2,264	2,124 (14%)	2,581 (14%)	2,105 (13%)	2,536 (12%)
	At abandoned Erie-Lackawanna Railroad	1,682	2,044	1,917 (14%)	2,330 (14%)	1,901 (13%)	2,289 (12%)
	At Town Line Road	1,467	1,781	1,658 (13%)	2,030 (14%)	1,643 (12%)	1,995 (12%)
	At Lake Nanjet	1,280	1,557	1,446 (13%)	1,759 (13%)	1,434 (12%)	1,744 (12%)
	Approximately 750 feet upstream of abandoned railroad	906	1,097	1,024 (13%)	1,240 (13%)	1,015 (12%)	1,229 (12%)
	At North Middletown Road	734	888	822 (12%)	1,003 (13%)	815 (11%)	986 (11%)

Watercourse	Location	Peak Flood Discharge (cubic feet per second) Increase (%)					
		CURRENT		PROJECTED FUTURE (RCP 4.5, 2050-2074)		PROJECTED FUTURE (RCP 4.5, 2075-2099)	
		50-YEAR	100-YEAR	50-YEAR	100-YEAR	50-YEAR	100-YEAR
	At Smith Road	571	685	640 (12%)	767 (12%)	634 (11%)	760 (11%)
Pascack Brook	At the New York – New Jersey border	3,653	4,451	4,055 (11%)	4,941 (11%)	3,982 (9%)	4,896 (10%)
Pascack Brook	At Town of Orangetown-Village of Chestnut Ridge Corporate Limits	3,263	3,979	3,622 (11%)	4,417 (11%)	3,557 (9%)	4,377 (10%)
Pascack Brook	Approximately 85 feet downstream of Grotke Road	3,221	3,938	3,575 (11%)	4,371 (11%)	3,511 (9%)	4,332 (10%)
Pascack Brook	Approximately 1,060 feet downstream of Lillian Drive	3,035	3,696	3,369 (11%)	4,103 (11%)	3,308 (9%)	4,066 (10%)
Pascack Brook	Approximately 180 feet downstream of S. Pascack Road	1,600	1,940	1,776 (11%)	2,153 (11%)	1,744 (9%)	2,134 (10%)
Pascack Brook	Approximately 300 feet downstream of Dutch Lane	1,557	1,895	1,728 (11%)	2,103 (11%)	1,697 (9%)	2,085 (10%)
Pascack Brook	Downstream of Maple Avenue Extension	1,400	1,698	1,554 (11%)	1,885 (11%)	1,526 (9%)	1,868 (10%)
Pascack Brook	Approximately 175 feet upstream from Linden Avenue	1,110	1,320	1,232 (11%)	1,465 (11%)	1,210 (9%)	1,439 (9%)
Pascack Brook	Approximately 100 feet downstream of Union Road	910	1,100	1,001 (10%)	1,221 (11%)	992 (9%)	1,199 (9%)
Pascack Brook	Approximately 630 feet downstream of Lake Suzanne spillway	690	840	759 (10%)	932 (11%)	752 (9%)	916 (9%)
Pascack Brook	Approximately 600 feet upstream of Francis Place	530	620	583 (10%)	688 (11%)	578 (9%)	676 (9%)
Pascack Brook	Approximately 500 feet downstream of Rita Avenue	380	440	418 (10%)	488 (11%)	414 (9%)	480 (9%)
Pascack Brook	Approximately 620 feet downstream of Grosser Lane	270	300	297 (10%)	333 (11%)	294 (9%)	327 (9%)

2.4 HYDRAULICS

To develop hydraulic modeling to assess flood mitigation alternatives, effective FEMA HEC-RAS hydraulic models were sought for areas of the Hackensack River watershed where they were available, which include the Hackensack River, Demarest Kill, Nauraushaun Brook, and Pascack Brook. These models were obtained from the NYSDEC, Floodplain Management Section, Bureau of Flood Protection and Dam Safety, which is gratefully acknowledged.

Hydraulic analyses for the above-listed watercourses were conducted using the HEC-RAS computer software. This program was developed by the United States Army Corps of Engineers (USACE) Hydrologic Engineering Center and is the industry standard for riverine flood analysis. The model is used to compute water surface profiles for one- and two-dimensional, steady- and unsteady-state flow conditions. The system can accommodate a full network of channels, a dendritic system, or a single river reach. HEC-RAS is capable of modeling water surface profiles under subcritical, supercritical, and mixed-flow conditions. Water surface profiles are computed from one cross section to the next by solving the one-dimensional energy equation with an iterative procedure called the standard step method. Energy losses are evaluated by friction (Manning's Equation) and the contraction/expansion of flow through the channel. The momentum equation is used in situations where the water surface profile is rapidly varied such as hydraulic jumps, mixed-flow regime calculations, hydraulics of dams and bridges, and evaluating profiles at a river confluence.

Model geometry was based on a combination of surveyed channel cross sections included in effective FEMA modeling, field measurements by SLR Engineering, Landscape Architecture, and Land Surveying, P.C. (SLR), and Light Detection and Ranging (LiDAR)-derived topographic mapping from the New York State (NYS) Geographic Information System (GIS) Clearinghouse. Roughness coefficients were applied to the model domain based on field observations and aerial orthophotography.

2.5 STAKEHOLDER MEETINGS

An important component of the data gathering for this study took place through stakeholder engagement. Two formal stakeholder meetings were convened by video conference call. The first meeting was held on December 15, 2020. This meeting was geared toward participation by government agencies and county and municipal staff and included participation from NYSDEC, NYSOGS, Rockland County, and watershed towns and villages. The second meeting was held on the evening of February 4, 2021, with participation from members of watershed groups. In addition to the formal video conferences, one-on-one conversations took place with representatives from the watershed municipalities and groups.

2.6 INFRASTRUCTURE

Several bridge and culvert crossings of the Hackensack River and its tributaries are contained within identified HRAs and in certain cases may contribute to flooding in these locations. These structures and summary details are listed below in Table 2-5.

Table 2-5: Summary Data for Assessed Bridge and Culvert Crossings of Hackensack River and Tributaries

River	Roadway	River Station (feet)	Structure	NBI BIN* (Owner)	Number of Spans/ Barrels	Span (feet)	Bankfull Width (feet) (Regional Regressions)
Hackensack River	Veterans Memorial Drive	30+05	Steel Stringer/Multi-Beam or Girder Bridge	3345990 (County)	1	120	73
	Convent Road	74+50	Steel Stringer/Multi-Beam or Girder Bridge	3346000 (County)	1	56	73
	Blauvelt Road	97+00	Steel Stringer/Multi-Beam or Girder Bridge	3345950 (County)	1	50	72
	987CX-PIP	129+00	Concrete Frame Bridge	1068652 (State)	1	68	69
	987C978C8501105 3	131+00	Concrete Frame Bridge	1068651 (State)	1	68	69
	Fifth Avenue	148+00	Prestressed Concrete Box Beam or Box Girders – Multiple Bridge	3345960 (County)	1	84	68
	Western Highway	241+50	Unknown (Currently being replaced)	3345790 (County)	Unknown	Unknown	Unknown
	CSX Transportation Bridge #1	244+00	Open Bottom Bridge	Not Listed (CSX Transportation Company)	1	59	59
	Route 59	281+00	Steel Stringer/Multi-Beam or Girder Bridge	1027732 (State)	2	120	66
	Route 59	282+00	Steel Stringer/Multi-Beam or Girder Bridge	1027731 (State)	2	120	66
	CSX Transportation Bridge #2	294+50	Open Bottom Bridge	Not Listed (CSX Transportation Company)	1	54.6	41
	I-287	325+00	Steel Stringer/Multi-Beam or Girder Bridge	5513999 (State)	1	67	65
	Old Mill Road	344+00	Steel Girder and Floorbeam System Bridge	3345770 (County)	1	54	63

River	Roadway	River Station (feet)	Structure	NBI BIN* (Owner)	Number of Spans/ Barrels	Span (feet)	Bankfull Width (feet) (Regional Regressions)
	Congers Road	532+00	Concrete Culvert	3345820 (County)	1	34	54
	County Road 23	558+00	Concrete Culvert	3345810 (County)	1	30	53
	Route 304	575+00	Steel Stringer/Multi-Beam or Girder Bridge	1045420 (State)	1	103	52
	County Road 29	607+50	Concrete Arch Bridge	3345750 (County)	1	39	51
Demarest Kill	County Road 29 (Haverstraw Road/Old Route 304)	37+00	Concrete Culvert	3367950 (County)	1	55	40
Demarest Kill	Cranford Drive	59+00	Concrete Culvert	2268200 (Town)	1	38	38
Demarest Kill	Squadron Boulevard	96+00	Concrete Culvert	2269000 (Town)	2	24 (total span)	35
Demarest Kill	Cavalry Drive	111+00	Open-Bottom Arch Culvert	Not Listed	1		34
Demarest Kill	North Main Street	132+50	Inlet: Twin Concrete Box Culvert	3369370 (County)	2	22 (total span)	33
Demarest Kill	North Main Street	132+50	Outlet: Concrete Box Culvert	3369370 (County)	1	8	33
Demarest Kill	New Hempstead Road	136+00	Concrete Open-Bottom Arch Culvert	3370840 (County)	1	41	32
Demarest Kill	Twin Elms Lane	171+00	Concrete Culvert	2269890 (Town)	1	26.7	20
Demarest Kill	Hall Road	210+00	Open-Bottom Arch Bridge	Not Listed (Private)	1	14	23
Nauraushaun Brook	Sickletown Road	15+50	Concrete Frame	3345970 (County)	1	30	41
Nauraushaun Brook	Blauvelt Road	26+50	Concrete Culvert	3364740 (County)	1	45	40
Nauraushaun Brook	Townline Road	107+50	Concrete Culvert	3364750 (County)	1	29	38
Nauraushaun Brook	Route 304	132+00	Reinforced Concrete Box Culvert	(State)	1	15	36

River	Roadway	River Station (feet)	Structure	NBI BIN* (Owner)	Number of Spans/ Barrels	Span (feet)	Bankfull Width (feet) (Regional Regressions)
	Blauvelt Road	137+50	Reinforced Concrete Box Culvert	Not Listed (State)	1	12	33
	Church Street	177+25	Concrete Culvert	2268890 (Town)	1	26	32
	Normandy Village Road	182+00	Twin Box Culverts	Not Listed (Private)	2	15	32
	East Charles Street	185+00	Open Bottom Arch Bridge	Not Listed (Private)	1	26	32
	Normandy Village – D/S Bridge	191+50	Triple Pipe Arch Culverts	Not Listed (Private)	3	6	32
	Normandy Village – U/S Bridge	193+00	Triple Pipe Arch Culverts	Not Listed (Private)	3	7.5	32
	First Street	197+00	Box Culvert	Not Listed (Private)	1	6	32
	Route 59	209+00	Reinforced Concrete Box Culvert	(State)	1	16.5	32
	Rockland Plaza Parking Lot	224+00	Concrete Box Culvert	Not Listed	1	18	29
	Alice Drive / I-87	254+00	Box Culvert	Not Listed	1	10.5	28
	Smith Road	288+00	Concrete Culvert	3369390 (County)	1	27	25
Pascack Brook	Washington Avenue	17+00	Steel Stringer/Multi-Beam or Girder Bridge	3346020 (County)	1	34	47
Pascack Brook	Pascack Road	50+50	Steel Stringer/Multi-Beam or Girder Bridge	3346190 (County)	1	42	46
Pascack Brook	Inline Structure	66+00	Concrete Dam	Not Listed			46
Pascack Brook	Grotke Road	74+00	Continuous Concrete Culvert Bridge	3346200 (County)	1	40	45
Pascack Brook	Lillian Drive	123+00	Concrete Tee Beam Bridge	3224160 (Town)	1	28	44
Pascack Brook	Convent Road	153+50	Prestressed Concrete Box Beam or Box Girders – Multiple Bridge	3364760 (County)	1	74	44

River	Roadway	River Station (feet)	Structure	NBI BIN* (Owner)	Number of Spans/ Barrels	Span (feet)	Bankfull Width (feet) (Regional Regressions)
	Blue Heron Road	185+75	Open-Bottom Bridge	2269410 (Town)	1	52	43
	Old Nyack Turnpike	205+25	Continuous Concrete Open Bottom Bridge	2224120 (Town)	2	27.85	42
	I-287	207+75	Steel Stringer/Multi-Beam or Girder Bridge	5514039 (State)	1	211	42
	Forman Drive	215+50	Concrete Frame Bridge	2268830 (County)	1	41	42
	South Pascack Road	226+00	Concrete Frame Bridge	2268820 (County)	1	36	41
	Route 59	254+95	Steel Truss Deck Bridge	1027660 (State)	1	332	37
	Railroad Bridge	274+00	Open-Bottom Bridge	Metro-North Railroad	1	21	36
	Lawrence Street	276+00	Steel Stringer/Multi-Beam or Girder Bridge	3364770 (County)	1	59	36
	Maple Avenue Extension	296+00	Open-Bottom Bridge	Not Listed	1	33	35
	Route 45 (North Main Street)	303+70	Unpainted Steel Stringer/Multi-Beam Grinder Open-Bottom Bridge	1091600 (State)	1	29	35
	Union Road	342+50	Open-Bottom Bridge	Not Listed	1	11.6	29

*NBI BIN = National Bridge Inventory Bridge Identification Number

In 2014, the Community Risk and Resiliency Act (CRRA) was signed into law to build New York's resilience to rising sea levels and extreme flooding. The Climate Leadership and Community Protection Act made modifications to the CRRA, expanding the scope of climate hazards and projects for consideration. These modifications became effective January 1, 2020. NYSDEC has provided guidelines for requirements under CRRA, which are summarized in a publication entitled *New York State Flood Risk Management Guidance for Implementation of the Community Risk and Resiliency Act.*

Based on guidance provided in the New York State Department of Transportation (NYSDOT) *Highway Design Manual* (NYSDOT 2021) and *Bridge Design Manual* (NYSDOT 2019), the design criteria for bridges and culverts are listed below. Culverts are classified as any stream crossings with a span of less than 20 feet (measured parallel to the roadway) while bridges have a span of 20 feet or greater.

- Culverts will be designed to pass the predicted 50-year storm event.
- Bridges will be designed to pass the 50-year storm event with 2 feet of freeboard below the bridge low chord and the 100-year storm event without touching the low chord.
- The structure will not raise the water surface elevations anywhere when compared to existing conditions for both the 50-year and 100-year flood events.
- The proposed bridge's low chord will not be lower than the existing low chord.
- Hydrologic analysis will include an evaluation of future predicted flows. The recommended design-flow multiplier for eastern New York State, which includes the Hackensack River watershed, is 110%.
- The maximum skew of the bridge pier(s) to the flow shall not exceed 10 degrees.
- Headwater at culverts will be limited to an elevation that:
    - Would not result in damage to upland property,
    - Would not increase the water surface elevation allowed by floodplain regulations, and
    - Would result in a headwater depth-to-culvert height ratio of not greater than 1.0 for culverts with a height greater than 5 feet and not greater than 1.5 for culverts with a height of 5 feet or less.

NYSDEC stream crossing guidelines require, where possible, that the following best management guidelines be incorporated:

- Provide a minimum opening width of 1.25 times the bankfull width of the waterway in the vicinity of the crossing.
- Use open-bottom or embedded, closed-bottom structures, which allows for installation of natural streambed material through the length of the structure.
- Match the channel slope through the bridge or culvert to the natural channel slope.
- Install bridges or culverts perpendicularly to the direction of flow of the stream.
- Install new or replacement structures so that no inlet or outlet drop would restrict aquatic organism passage.

3. IDENTIFICATION OF FLOOD HAZARDS

3.1 FLOODING HISTORY

Rockland County has an active history of hurricanes and tropical storms. According to NOAA historical records summarized in the FEMA FIS for Rockland County, 25 hurricane or tropical storm tracks have passed within 65 miles of Rockland County since 1861, including four Category 1 hurricanes, two Category 2 hurricanes, and 19 tropical storms. Of the 25 recorded storm events, five passed directly through Rockland County. Table 3-1 is a summary of flood events that impacted Rockland County and the Hackensack River watershed. The flood history is summarized from the FEMA FIS for Rockland County and the Rockland County Multi-Jurisdictional Hazard Mitigation Plan.

Table 3-1: Hackensack River Flood History

Date	Flood Event	Notes
1863 to 1915	Four unnamed tropical storms	
1972	Tropical Storm Agnes	
September 1975	Hurricane Eloise	Rockland County was included in areas eligible for both Individual and Public Assistance under Disaster Declaration DR-0487 following the impacts of the remnants of Hurricane Eloise. Heavy rainfall caused riverine flooding and an estimated $300 million in damage across the northeastern United States.
1988	Tropical Depression	
December 21, 1992	Nor'easter	This nor'easter, which caused widespread flooding and damage to commercial and residential properties, utilities, roads, and other infrastructure, resulted in Disaster Declaration 0974, under which Rockland County became eligible for both Public and Individual Assistance.
July 13, 1996	Hurricane Bertha	Hurricane Bertha originally made landfall in North Carolina but had weakened to a Tropical Storm by the time it reached the New York City area. It passed Long Island, producing torrential rain and strong gusty winds. Torrential rain caused flooding of low-lying and poor-drainage areas, streams, and rivers across the area. The heaviest rain fell in a band to the northwest of Bertha's track over the Lower Hudson Valley. The Mahwah River at Suffern in Rockland County rose above its 4-foot flood stage from 11:30 a.m. EST on July 13 through 10:15 a.m. on July 14. The crest stage was 5.75 feet at 1:15 p.m. on July 13. The Saw Mill River in Westchester County also flooded. Rainfall amounts recorded in Rockland County ranged from 3.25 inches at West Nyack to 4.65 inches at Pomona.

Date	Flood Event	Notes
September 16, 1999	Remnants of Hurricane Floyd	Tropical Depressions by the time it reached Rockland County. Widespread flooding in Rockland, Orange, Putnam, and Westchester Counties; total damage costs estimated at $14.6 million. Rainfall amounts from 3.16 inches at Nanuet to 3.31 inches at New City. The Mahwah River at Suffern was above its flood stage of 4 feet from 1:30 p.m. on September 16 until 3 a.m. on September 18. The crest stage was about 9.7 feet.
September 2004	Hurricane Ivan	Tropical Depressions by the time it reached Rockland County
April 15-16, 2007	Nor'easter	A nor'easter occurred during Sunday and Monday, April 15 and 16, which brought heavy rain and high winds that caused widespread and significant river, stream, and urban flooding of low-lying and poor-drainage areas. Rockland County was among the counties eligible for Individual and Public Assistance under the resulting Federal Disaster Declaration DR-1692. Costs to repair disaster damages to roads and drainage structures in Rockland County were estimated at $5,000,000.
September 2008	Tropical Storm Hanna	Tropical Depressions by the time it reached Rockland County

Date	Flood Event	Notes
August and September, 2011	Tropical Storm Irene and Tropical Storm Lee	Hurricane Irene formed from a tropical wave on August 21, 2011, in the tropical Atlantic Ocean. It moved west-northwestward before becoming a hurricane. Irene struck Puerto Rico as a tropical storm. Hurricane Irene steadily strengthened to reach peak winds of 120 mph on August 24. Irene then gradually weakened and made landfall on the Outer Banks of North Carolina with winds of 85 mph on August 27. It slowly weakened over land and re-emerged into the Atlantic on the following day. Later on August 28, Irene was downgraded to a tropical storm and made two additional landfalls, one in New Jersey and another in New York. Irene produced heavy damage over much of New York, totaling $296 million. The storm is ranked as one of the costliest in the history of New York, after Hurricane Agnes in 1972. Much of the damage occurred due to flooding, both from heavy rainfall in inland areas and storm surge in New York City and on Long Island. Tropical storm force winds left at least 3 million residents without electricity in New York and Connecticut. Ten fatalities are directly attributed to the hurricane. $296 million in damages across New York State, 7.52 inches of rainfall recorded at Tappan, New York Over 30,000 people were affected by boil water notices in Rockland County from both Hurricane Irene and Tropical Storm Lee. A total of five wastewater and sewage treatment facilities experienced overflow, bypass, or inundation during Hurricane Irene. Over 30 facilities in New York State released untreated wastewater into tributaries or the Hudson itself. Rockland County had three municipalities with 67 percent to 90 percent of its residents without power as of 8:30 a.m. on August 29, 2011. Twenty-three municipalities had 34 percent to 66 percent of their residents without power. The rest of the municipalities in the county either had 11 percent to 33 percent or 1 percent to 10 percent of their people without power. According to direct measures compiled by the Hudson River Estuary Program and NYSDEC, the costs from Hurricane Irene and Tropical Storm Lee amounted to $27,909,828.44 in Rockland County. That includes estimated storm recovery costs, expenditures from Project Hope (crisis counseling for residents impacted by Hurricane Irene), FEMA individual assistance aid, and costs of spill response and cleanup.

Date	Flood Event	Notes
October 29, 2012	Hurricane Sandy	Hurricane Sandy was the deadliest and most destructive hurricane of the 2012 Atlantic hurricane season, as well as the second-costliest hurricane in United States history. It was classified as the eighteenth named storm, tenth hurricane, and second major hurricane of the year. Hurricane Sandy made landfall in the United States about 8 p.m. EDT October 29, striking near Atlantic City, New Jersey, with winds of 80 mph. A full moon made high tides 20 percent higher than normal and amplified Sandy's storm surge. Hurricane Sandy affected 24 states, including the entire eastern seaboard from Florida to Maine and west across the Appalachian Mountains to Michigan and Wisconsin, with particularly severe damage in New Jersey and New York. Its storm surge hit New York City on October 29, flooding streets, tunnels, and subway lines and cutting power in and around the city. Damage in the United States is estimated at over $100 billion (2013 USD). Record coastal flooding in Lower New York. Towns of Stony Point and Piermont sustained major damage. In the village of Piermont, approximately 300 individuals were evacuated from homes and businesses.
August through October, 2021	Tropical Storm Henri, Tropical Storm Ida, and October Nor'easter	Tropical Storm Henri was the first tropical cyclone to make landfall in Rhode Island since Hurricane Bob in 1991. It proceeded to move west-northwestward, weakening down to a tropical depression while greatly slowing down. On August 23, Henri degenerated into a remnant low over New England, before dissipating on the next day over the Atlantic. Despite its relatively weak intensity, the storm brought very heavy rainfall over the Northeastern United States and New England, causing widespread flooding in many areas, including Rockland County. Record-breaking rainfall of 1.94 inches fell in just 1 hour in Central Park, the wettest hour on record for New York City. Hurricane Ida made landfall near Port Fourchon, Louisiana, and moved through the Northeastern United States as a Tropical Storm on September 1–2, 2021, dropping large amounts of rainfall across the region before moving out into the Atlantic. Widespread flooding shut down much of the New York City Subway system as well as large portions of the New Jersey Transit, Long Island Railroad, and Metro-North Railroad commuter rail systems and Amtrak intercity services. An October 2021 Nor'easter, which eventually became Tropical Storm Wanda, was an erratic nor'easter and tropical cyclone that struck the East Coast of the United States, causing widespread flooding in parts of New York and New Jersey.

The USGS gauge (01376800) at West Nyack has been recording peak flow data since 1960. Flow at this location is regulated by Deforest Lake, and there is a diversion from the gauging station pool for municipal supply for the village of Nyack. Discharge given for this station represents the flow of the Hackensack River downstream from this diversion. At flows greater than about 1,500 cubic feet per second (cfs), undetermined amounts of flow bypass the gauge as a result of overtopping of the Klein Avenue levee just upstream of the gauge. Therefore, the gauge is not considered reliable for peak flow analysis.

Annual peak flow on the Hackensack River at Rivervale, New Jersey, recorded since 1942 at the USGS gauge (01377000) located downstream of the project area provides a useful view of flood events. Flood recurrence information from the FEMA FIS showing the magnitude of the 10-, 50-, and 100-year flood events has been superimposed on the hydrograph. Figure 3-1 is a hydrograph showing annual peak flows recorded through 2019, updated to include 2021 flood events. The events that resulted in the largest magnitude flows on the Hackensack River at Rivervale, New Jersey, include the April 2007 Nor'easter and the August 2011 Tropical Storm Irene, both of which exceeded the 100-year flood event, and the September 2021 Tropical Storm Ida, which exceeded the 50-year flood event.

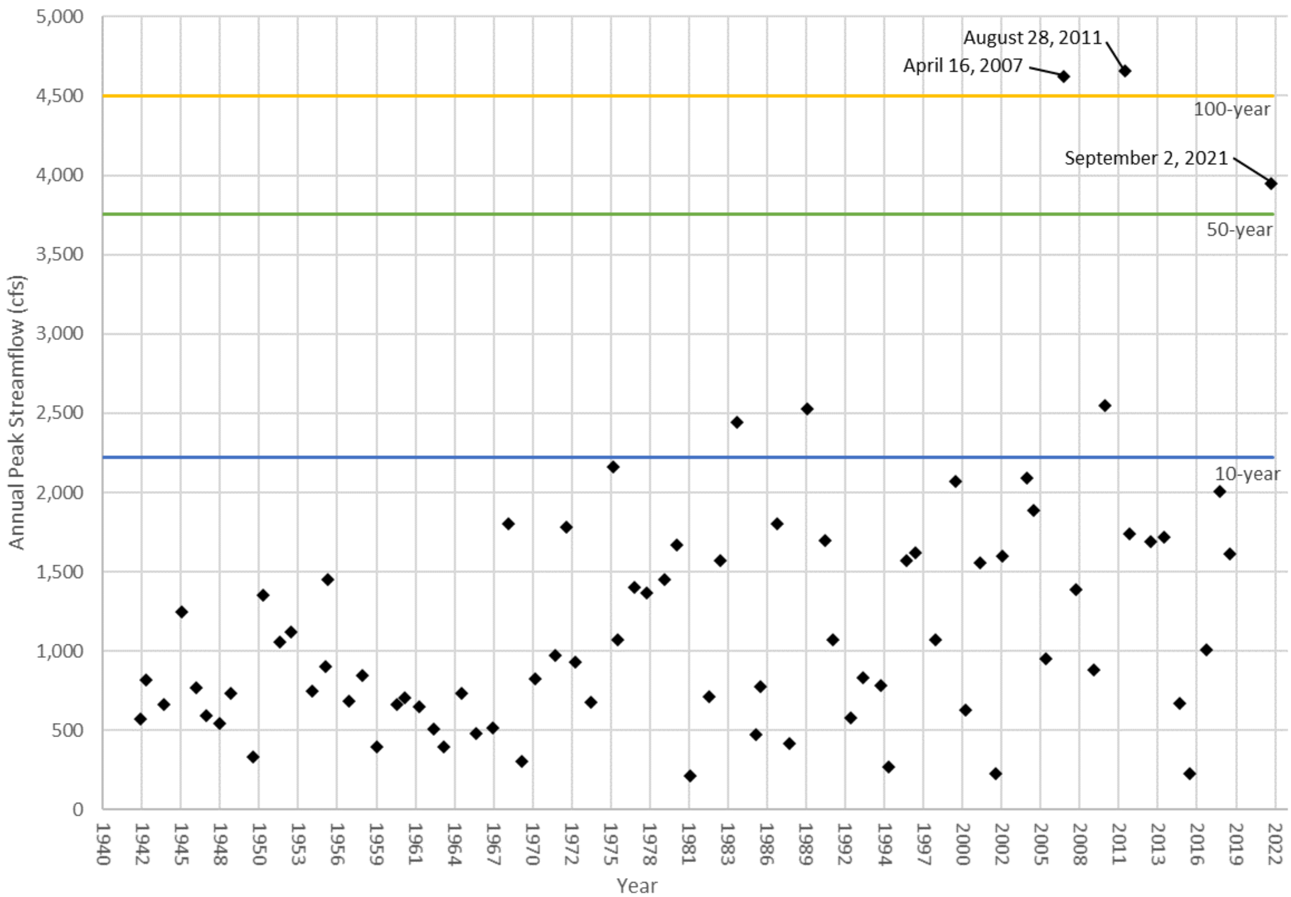

Figure 3-1:
Hydrograph of Annual Peak Flow on the Hackensack River at Rivervale, New Jersey
1942 – 2021

Annual peak flow on Pascack Brook at Westwood, New Jersey, recorded since 1934 at the USGS gauge (01377500) located downstream of the project area provides a view of flood history on Pascack Brook. Figure 3-2 is a hydrograph showing annual peak flows recorded through 2019, updated to include 2021 flood events. The events that resulted in the largest magnitude flows on Pascack Brook include the September 1999 remnants of Hurricane Floyd, which exceeded the 500-year flood event, the August 2011 Tropical Storm Irene, which exceeded the 50-year flood event, and the April 2007 Nor'easter and the September 2021 Tropical Storm Ida, both of which exceeded the 10-year flood event.

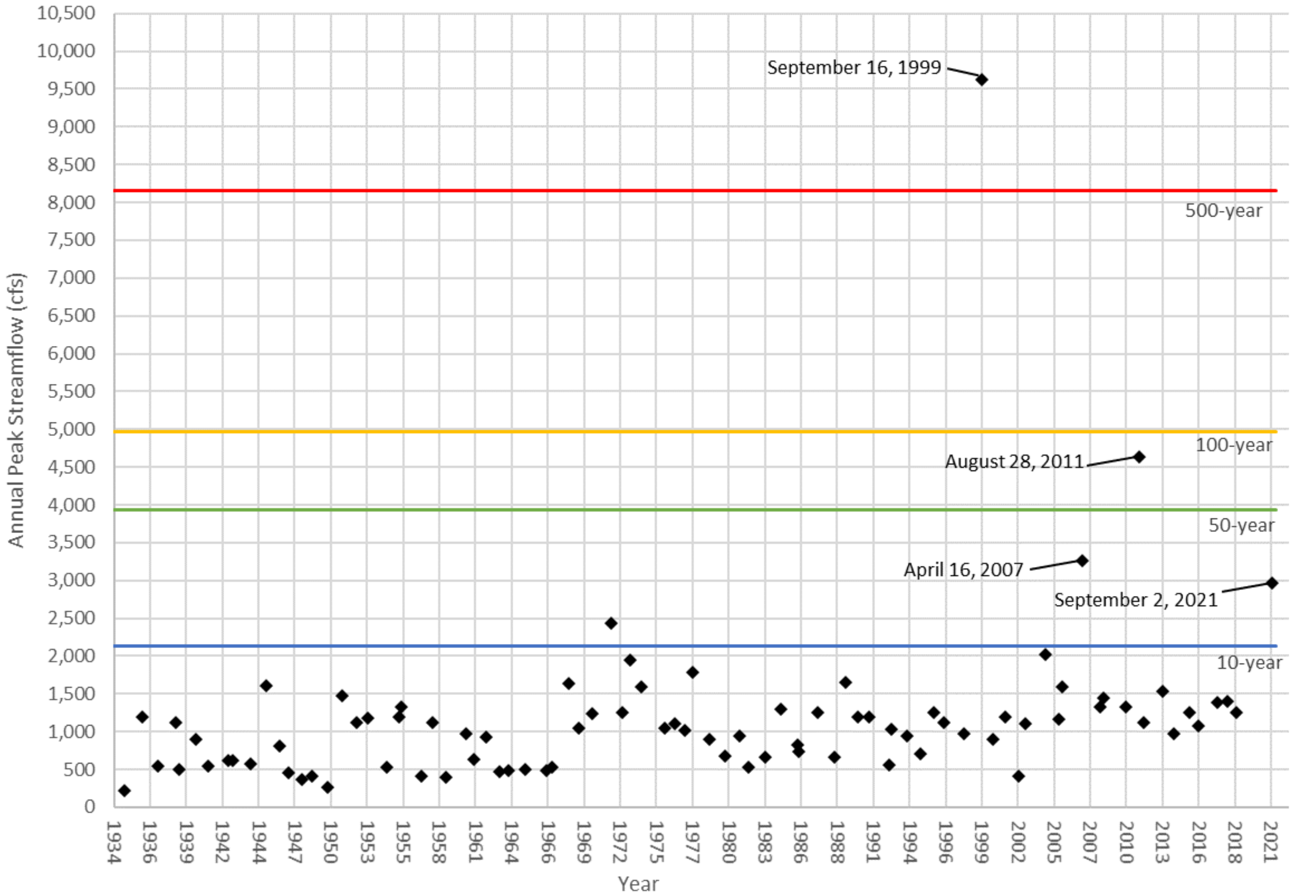

Figure 3-2:
Hydrograph of Annual Peak Flow on Pascack Brook at Westwood, New Jersey
1934 – 2021

3.2 FEMA MAPPING

As part of the NFIP, FEMA produces FIRMs that demarcate the regulatory floodplain boundaries. As part of a FIS, the extents of the 100-year and 500-year floods are computed or estimated, as well as the regulatory floodway, if one is established. The area inundated during the 100-year flood event is also known as the SFHA. In addition to establishing flood insurance rates for the NFIP, the SFHA and other regulatory flood zones are used to enforce local flood damage prevention codes related to development in floodplains.

> Over the period of a standard 30-year mortgage, a property located within the SFHA will have a 26 percent chance of experiencing a 100-year flood event. Structures falling within the SFHA may be at an even greater risk of flooding because if a house is low enough it may be subject to flooding during the 25-year or 10-year flood events. During the period of a 30-year mortgage, the chance of being hit by a 25-year flood event is 71 percent, and the chance of being hit by a 10-year flood event is 96 percent, which is a near certainty.

The FIS for Rockland County (36087CV001A) has been effective since March 2014. The flood hazard areas delineated by FEMA are mapped for each focus watercourse. Figures 3-3 and 3-4 depict flood hazard mapping along the Demarest Kill. Figures 3-5 through 3-11 depict mapping along the Hackensack River. Figures 3-12 and 3-13 depict mapping along Nauraushaun Brook. Figures 3-14 through 3-17 depict mapping along Pascack Brook. Each map displays the Special Flood Hazard Layers delineated by FEMA for each focus watercourse in this report, including the 1.0 percent annual chance flood hazard layer (100-year flood), 0.2 percent annual chance flood hazard layer (500-year flood), and the floodway hazard layer.

In addition to the Special Flood Hazard Layers delineated by FEMA, superimposed on each map are areas that are anticipated to be inundated during a future 100-year flood event. The 2050-2074 projections of future flows were employed.

The figures provide an overview of what FEMA data is available on each focus watercourse. Residents are encouraged to consult the most recent products available from the FEMA Flood Map Service Center (https://msc.fema.gov/portal/home) for a more complete understanding of the flood hazards that currently exist.

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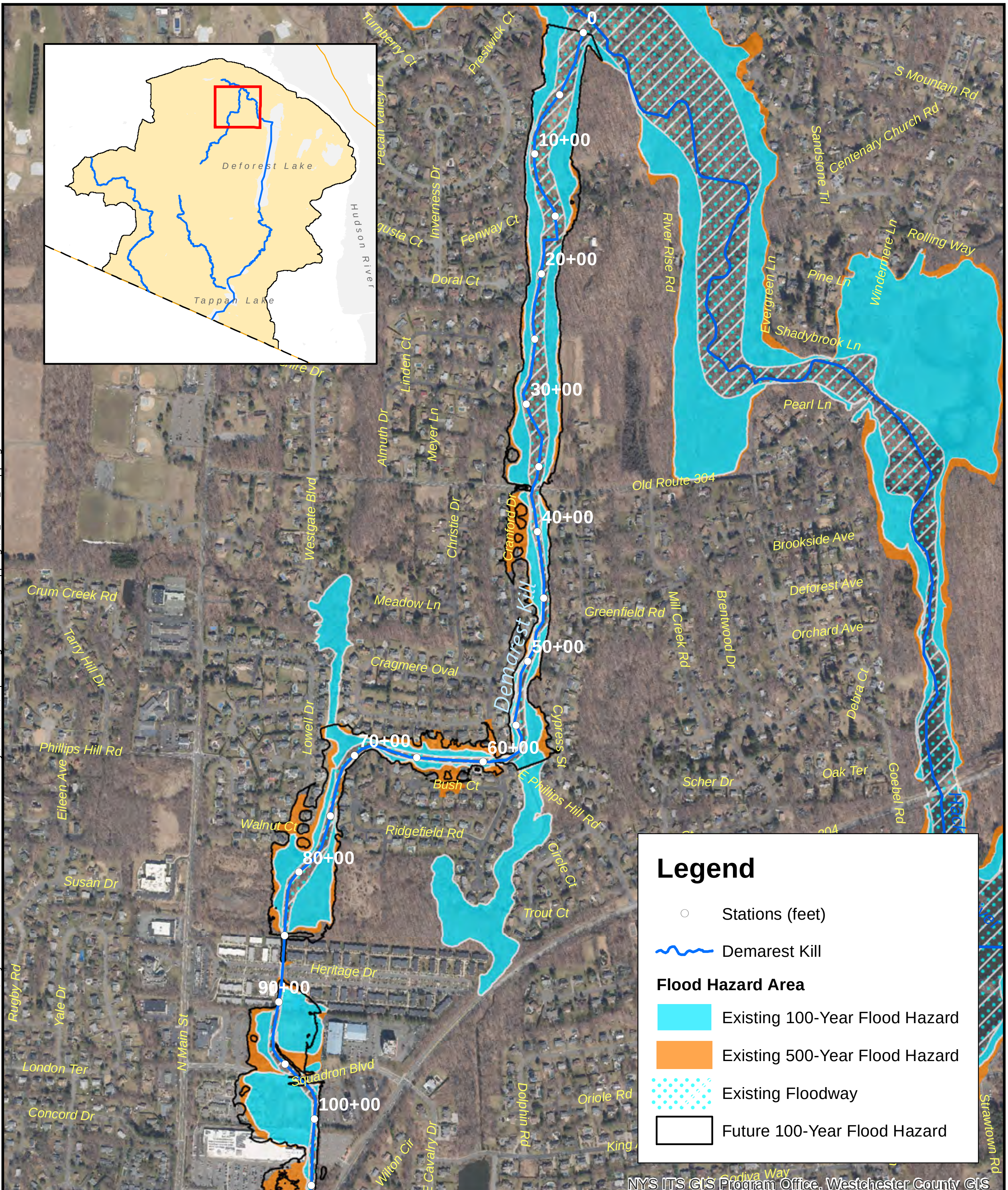

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231 MAIN STREET
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845.633.8153

DEMAREST KILL - FEMA MAPPING

HACKENSACK RIVER FLOOD & RESILIENCE STUDY
SD109
ROCKLAND COUNTY
NEW YORK

N

0 500 1,000
Feet

SCALE 1 " = 1,000 '

DATE 12/22/2021

16511.00005
PROJ. NO.

FIG. 3-3

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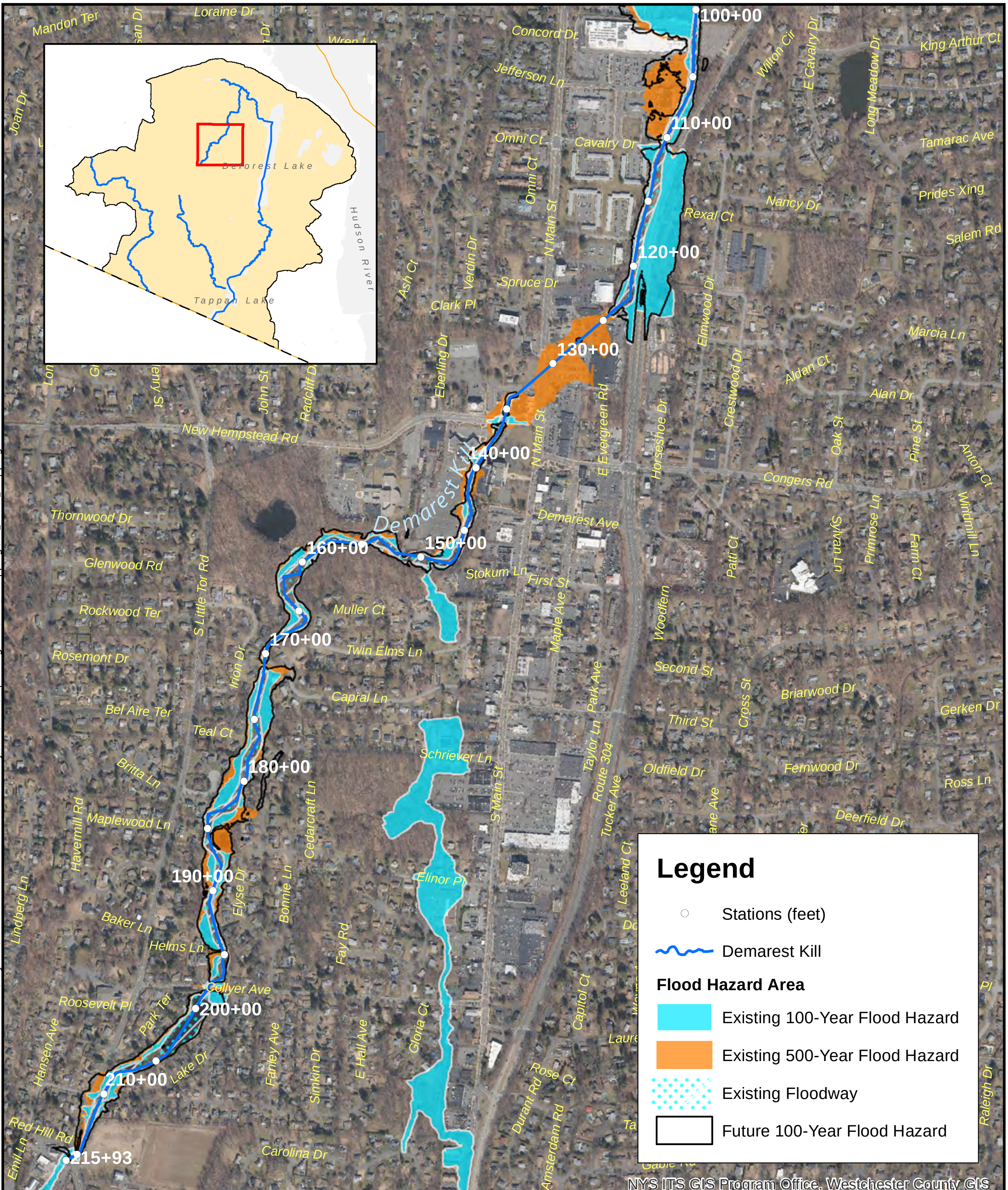

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DEMAREST KILL - FEMA MAPPING

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NEW YORK

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Feet

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FIG. 3-4

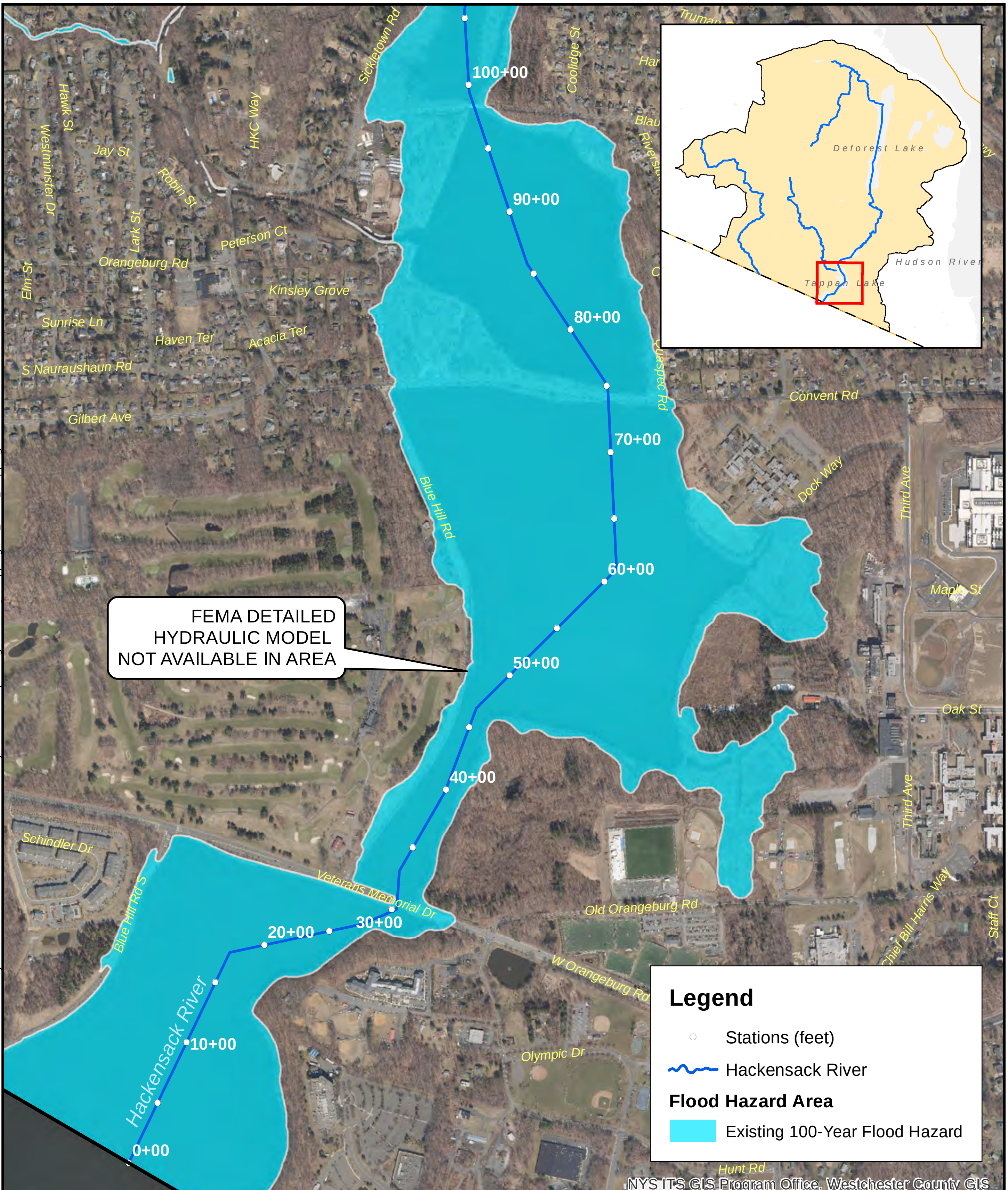

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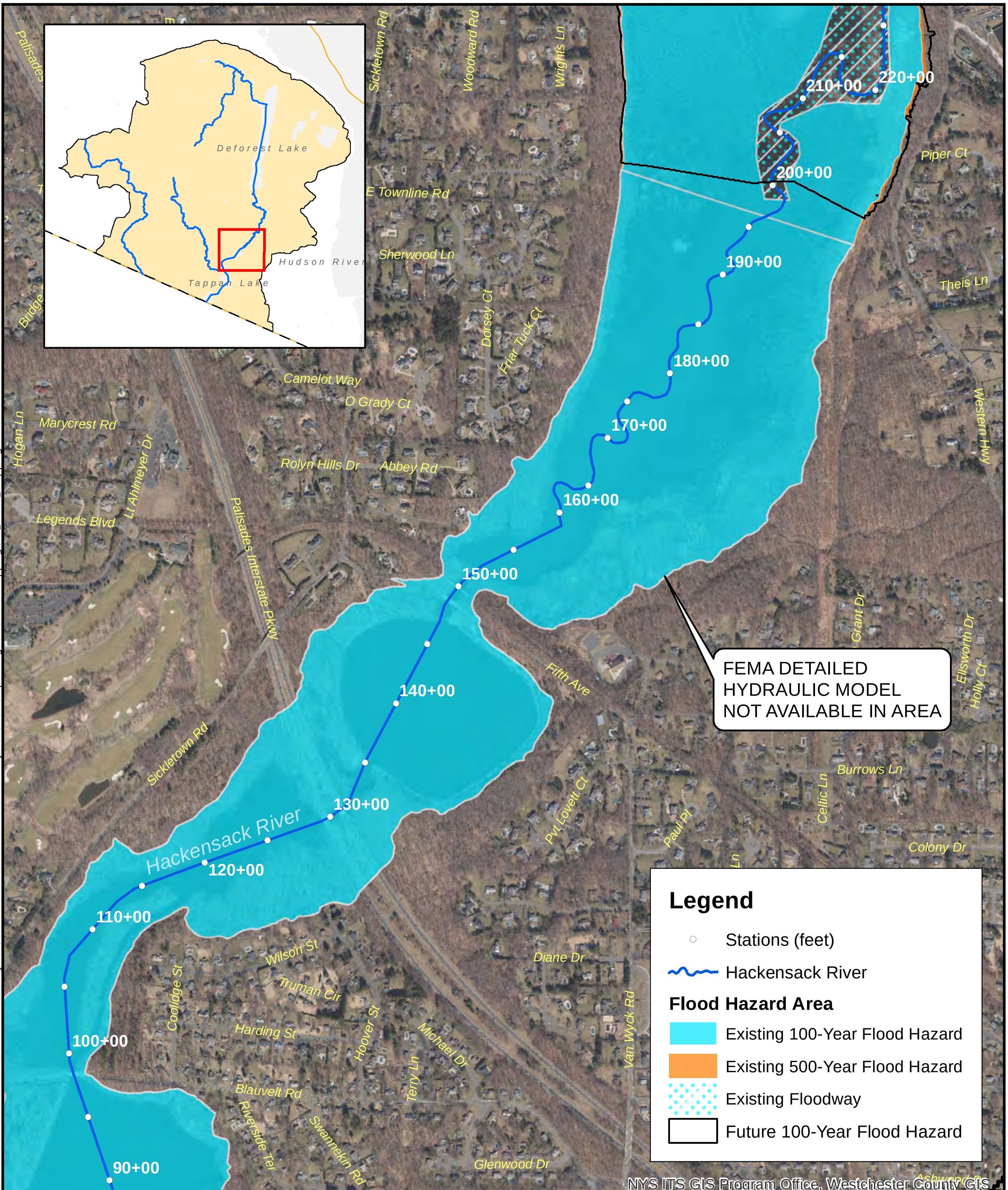
FIG. 3-5



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SCALE 1 " = 1,000 '

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FIG. 3-6

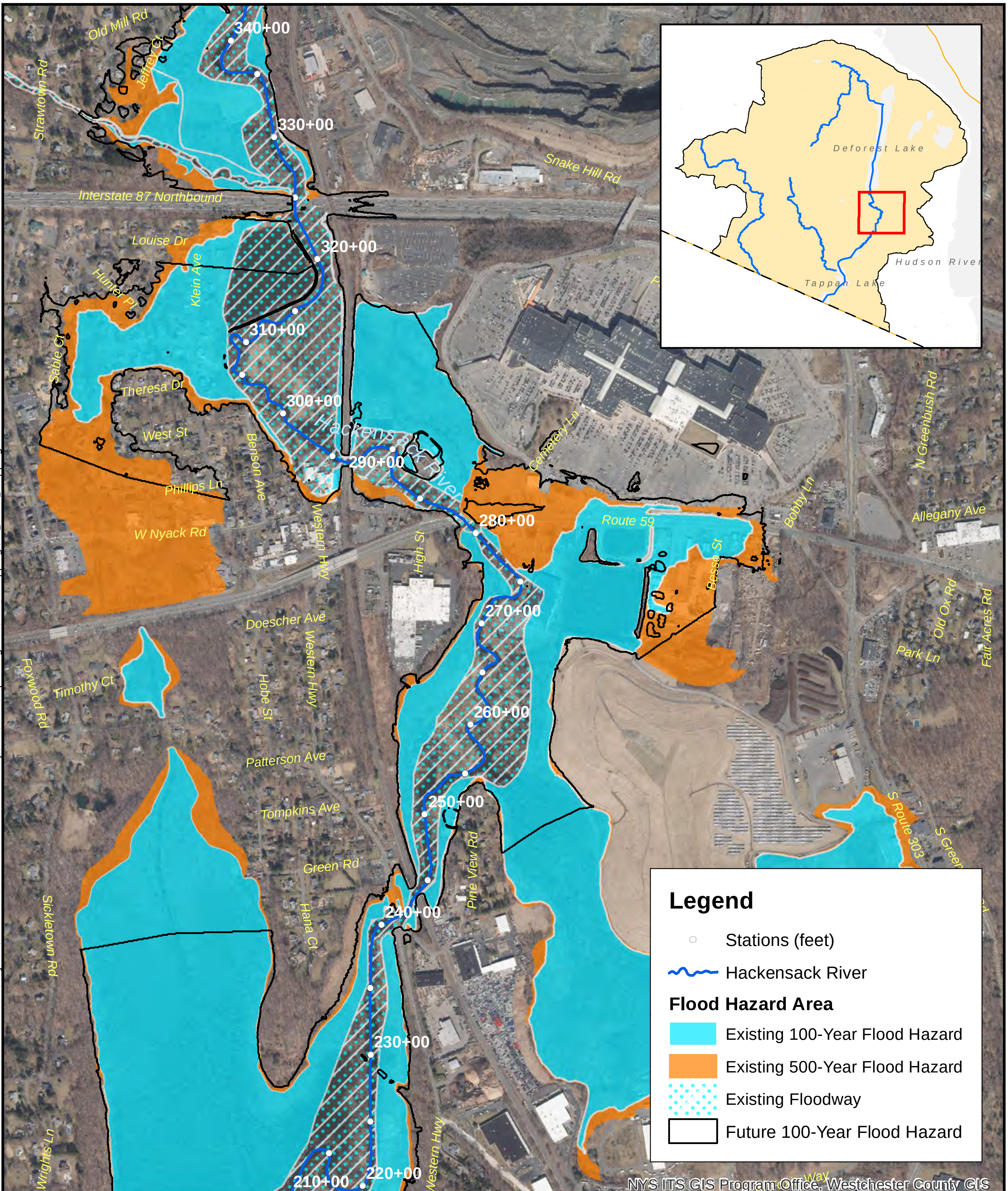

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FIG. 3-7

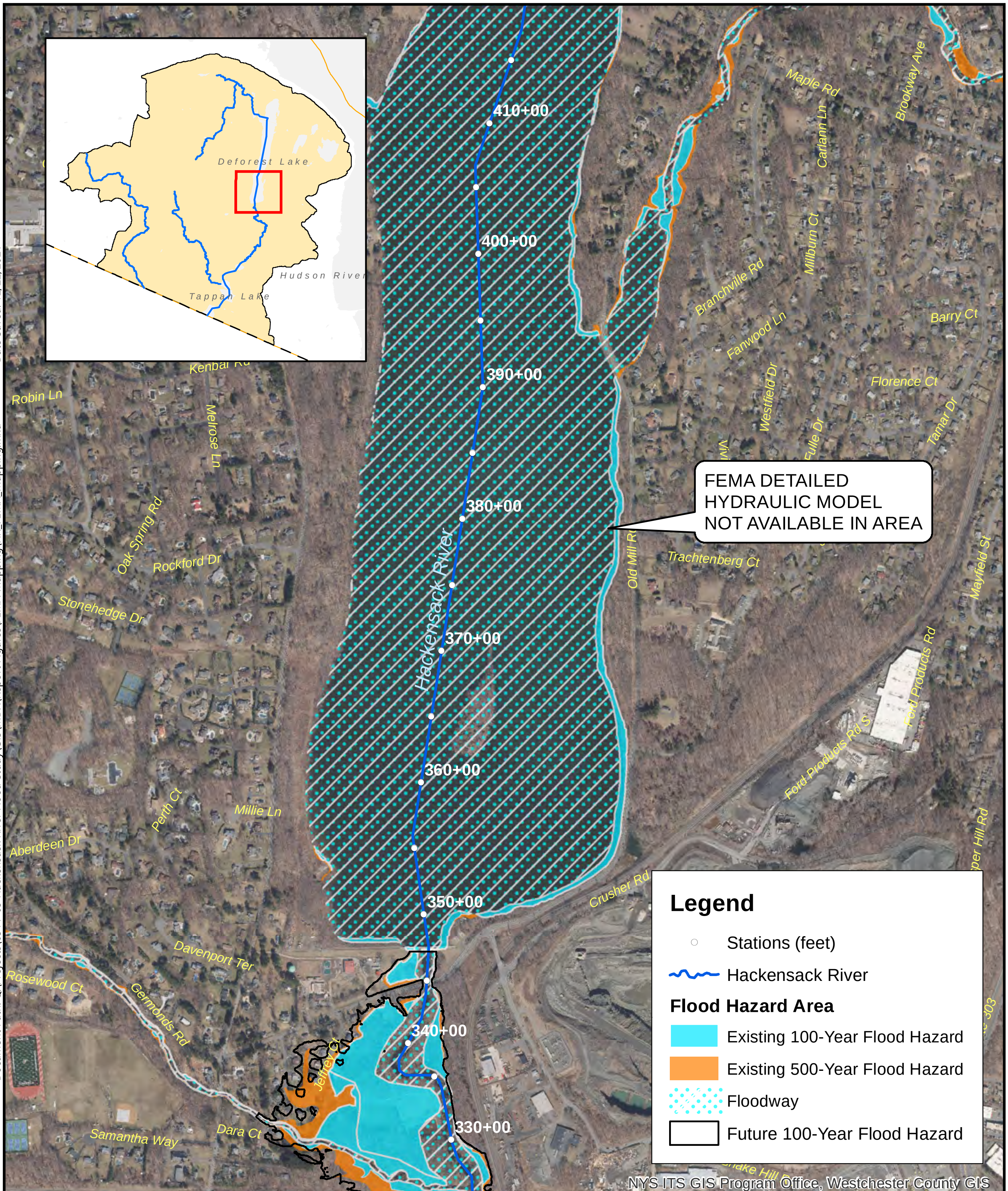

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FIG. 3-8

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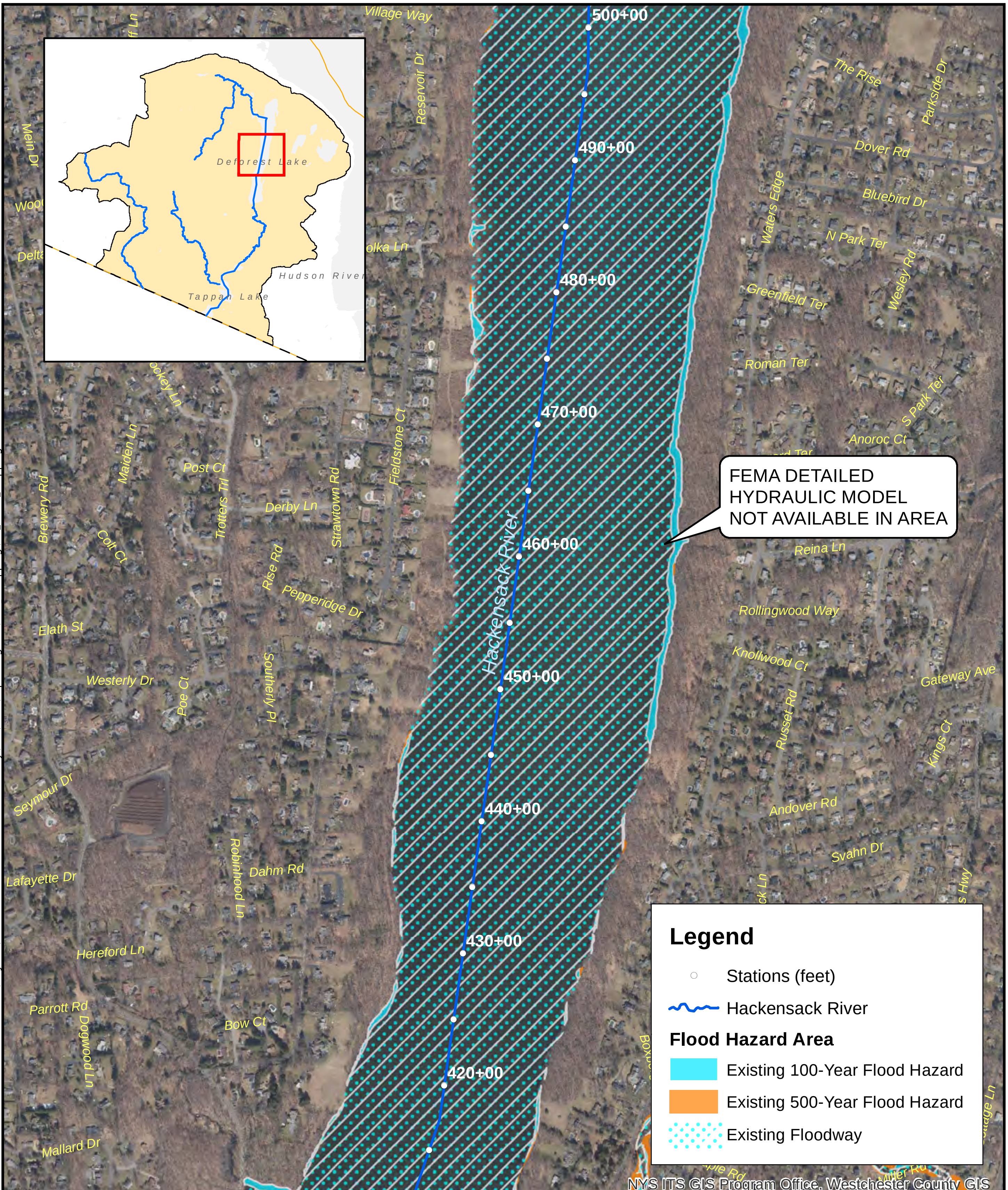

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N

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Feet

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FIG. 3-9

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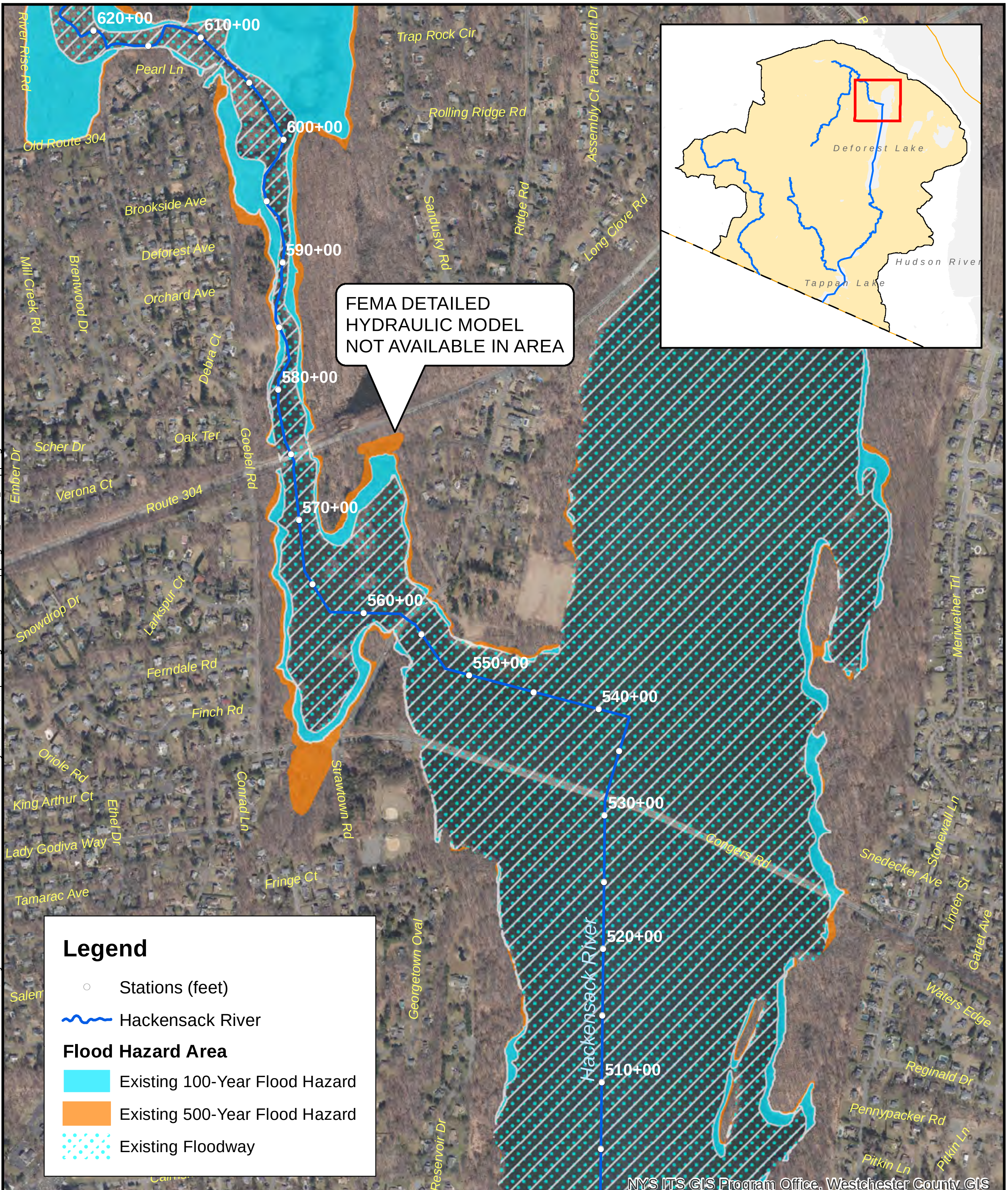

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FIG. 3-10

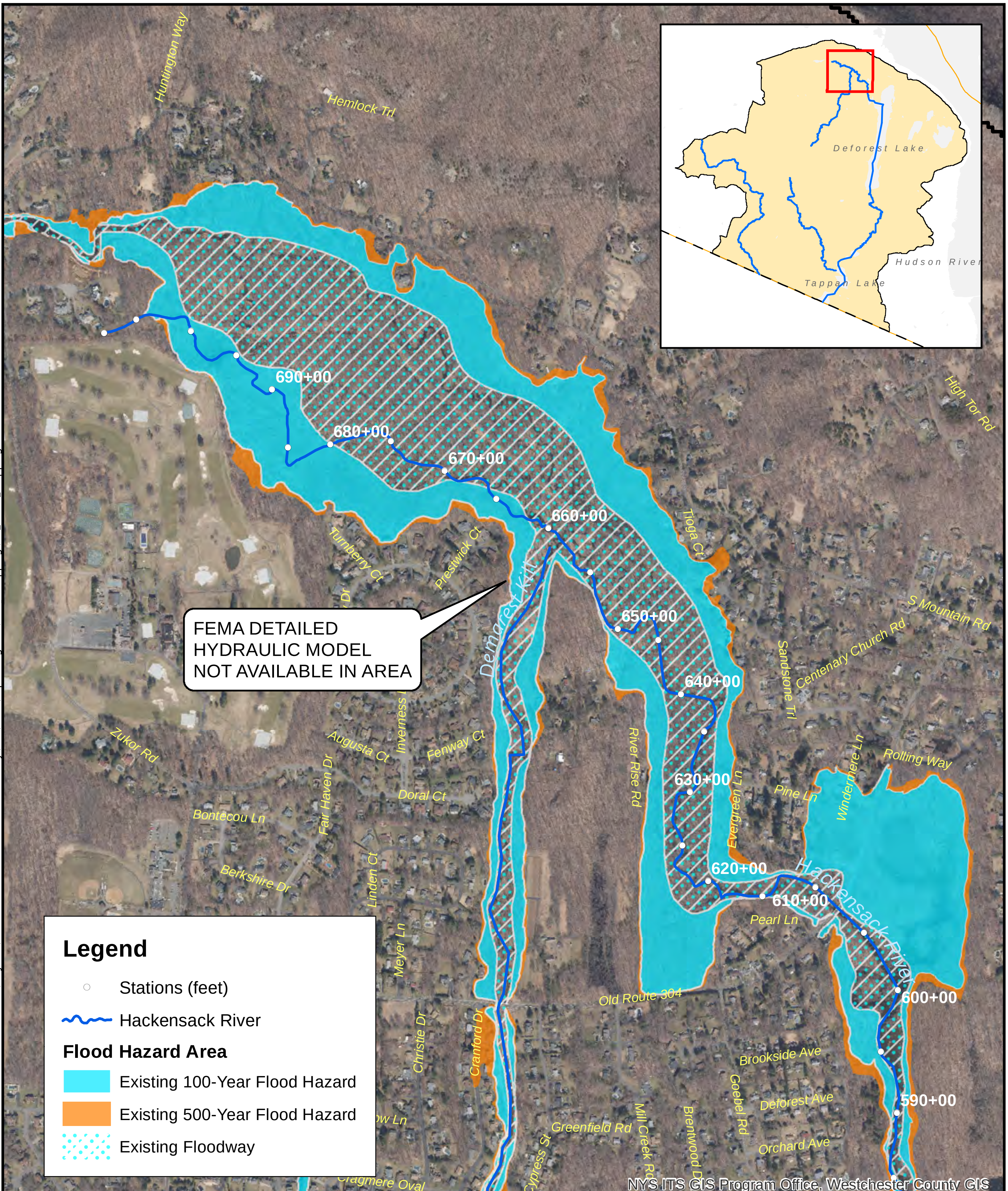

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FIG. 3-11

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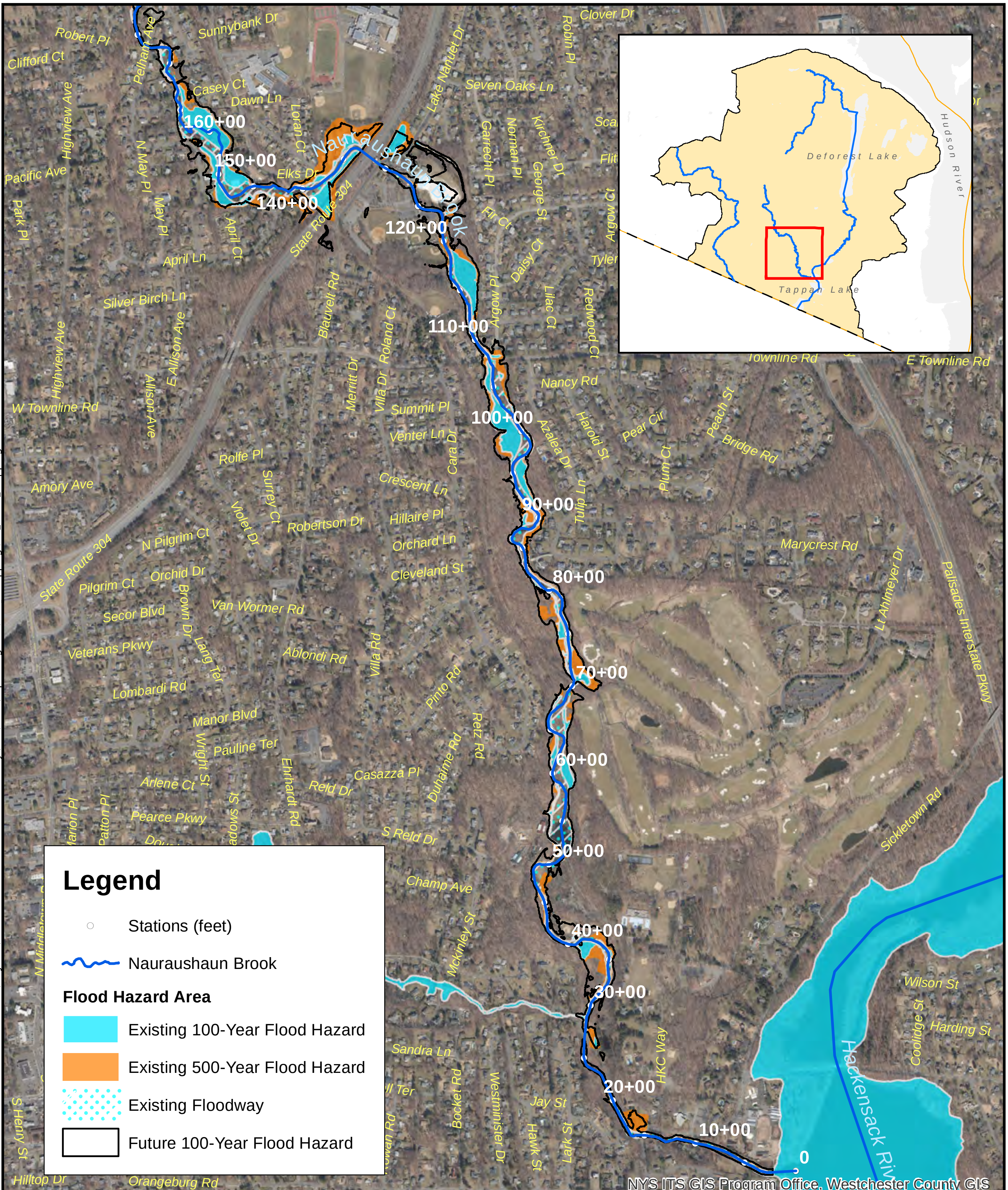

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SD109
ROCKLAND COUNTY
NEW YORK

N

0 500 1,000
Feet

SCALE 1 " = 1,250 '

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FIG. 3-12

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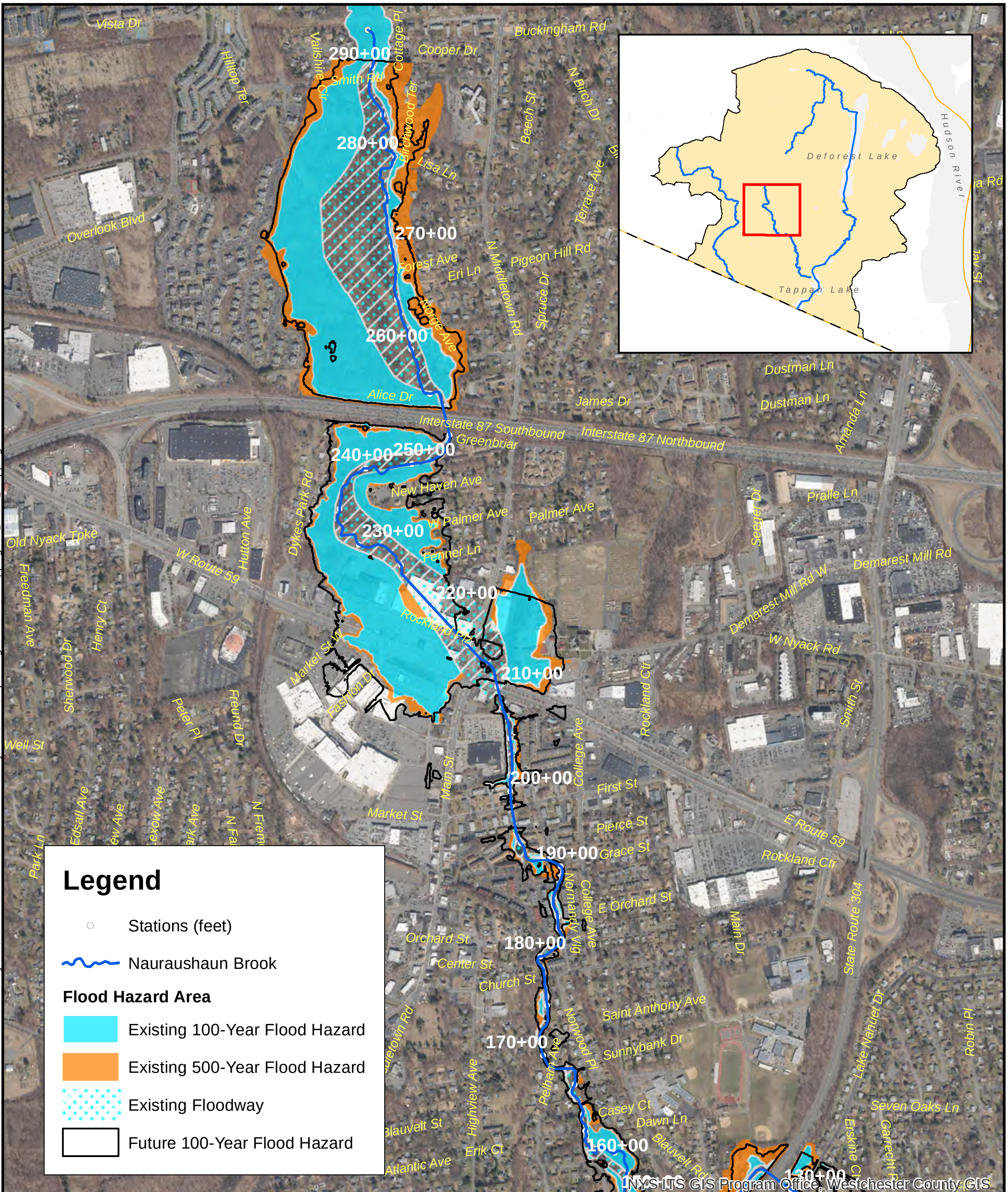

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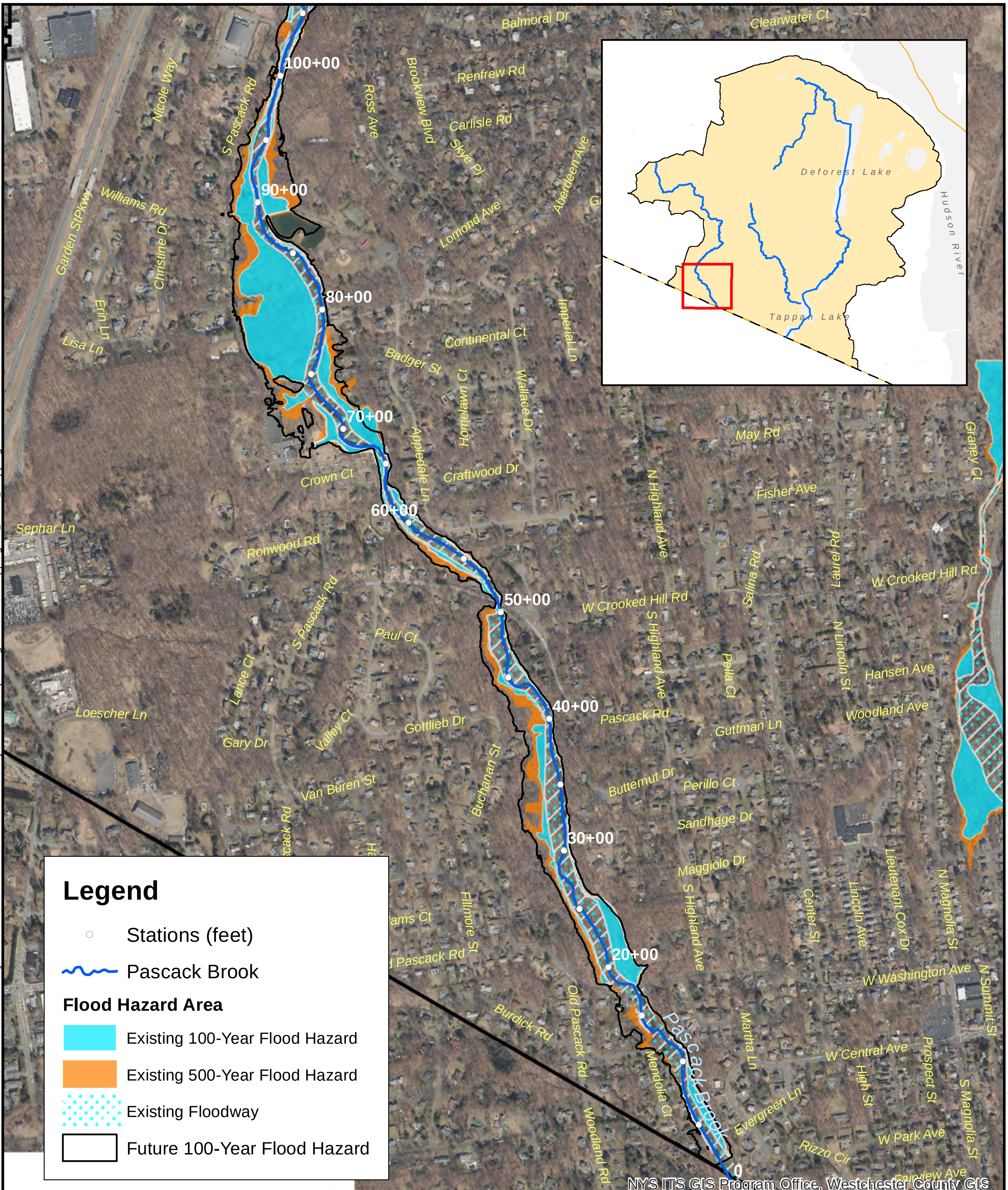
FIG. 3-13



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ROCKLAND COUNTY
NEW YORK

N

0 500 1,000
Feet

SCALE 1 " = 1,000 '

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FIG. 3-14

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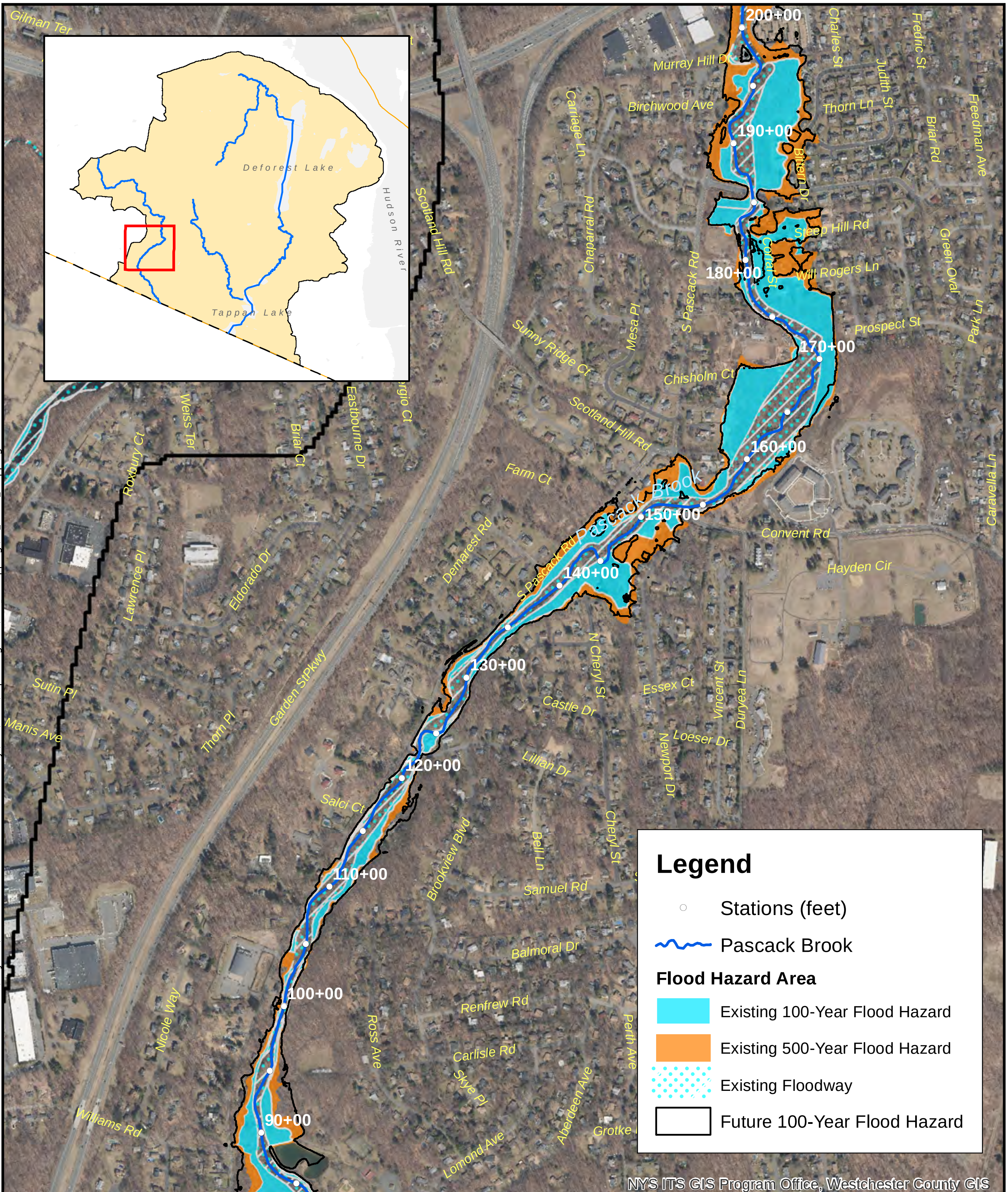

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Feet

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FIG. 3-15

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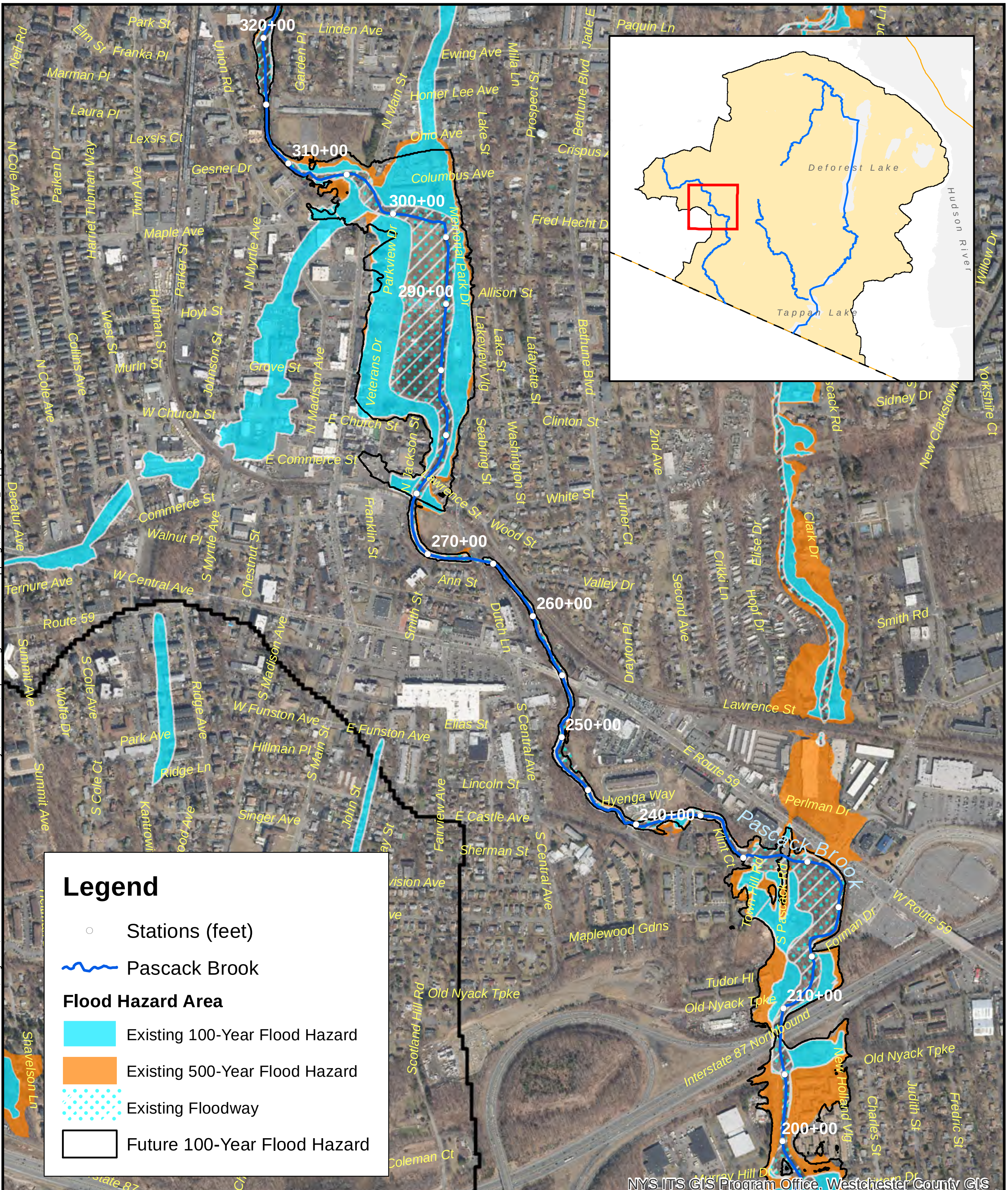

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N

0 500 1,000 Feet

SCALE 1 " = 1,000 '

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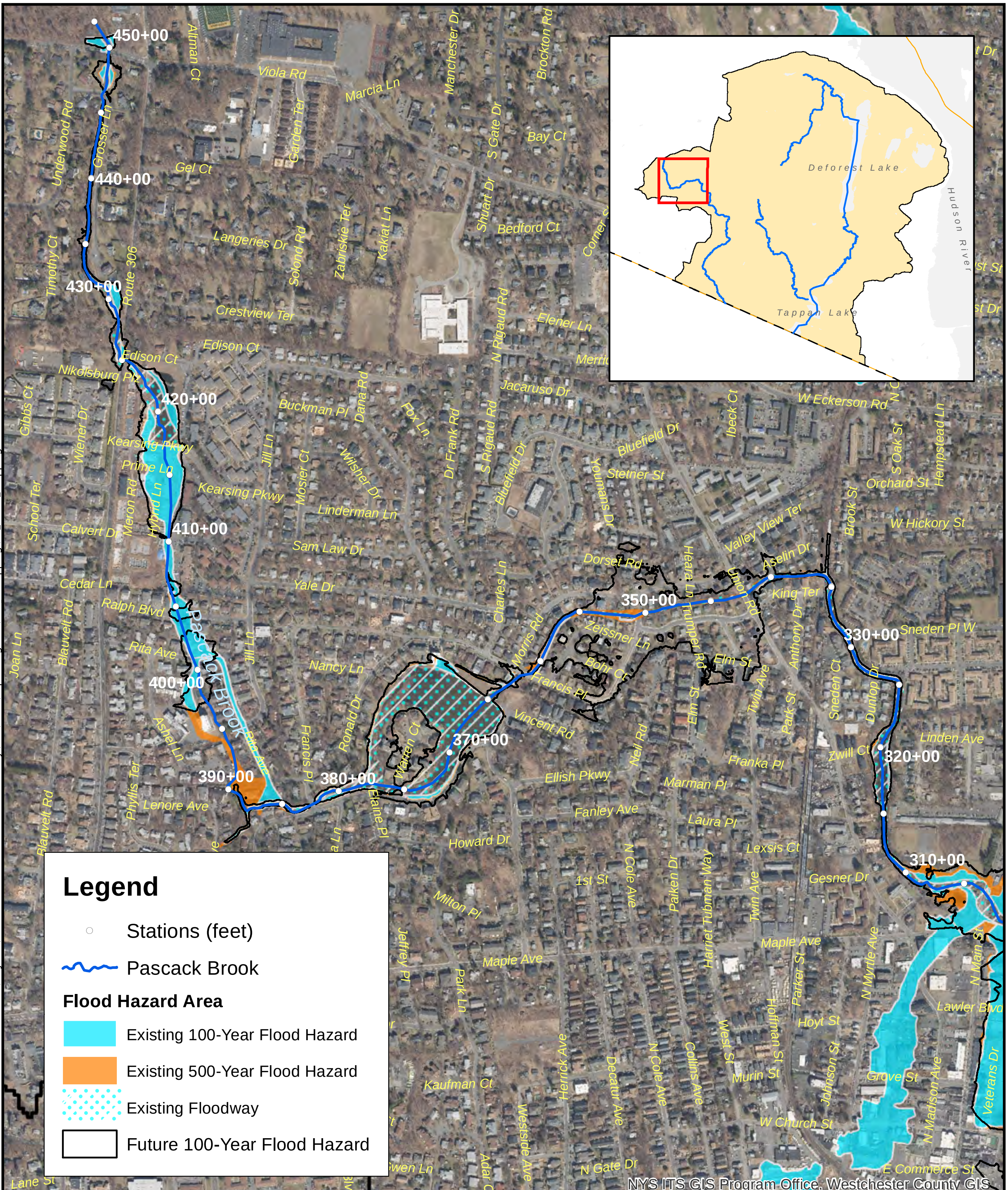
FIG. 3-16



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Feet

SCALE 1 " = 1,000 '

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FIG. 3-17

4. FLOOD MITIGATION ANALYSIS

In this section, flood-prone areas within the Hackensack River watershed are identified, and an analysis of flood mitigation considerations within each HRA is undertaken. HRAs were identified based on a variety of sources including comments received during stakeholder meetings; conversations with municipal officials, emergency responders, landowners, and business owners; and through review of FEMA FISs and FIRMs, County Hazard Mitigation Plans, on-line sources, and other documents. Factors with the potential to influence more than one HRA are also evaluated and discussed. Figure 4-1 shows the locations of all HRAs within the Hackensack River watershed in New York.

4.1 HIGH RISK AREA #1 – HACKENSACK RIVER IN WEST NYACK

HRA 1 includes the stretch of the Hackensack River from STA 240+00 to STA 345+00, in the hamlet of West Nyack between Western Highway and Old Mill Road (Figure 4-2). This section of the river is densely developed, passing alongside a flood control levee; under two CSX Railroad bridges, State Route 59, and Western Highway; and winding past neighborhoods, industries, and commercial development.

Flooding within HRA 1 is a chronic issue due to settlement and development within the Hackensack River's low-lying areas and floodplains. Undersized bridges over the river, and roadway and railroad embankments that transect the floodplain, significantly restrict flood conveyance and impound floodwaters. Consequently, neighborhood homes, roads, and commercial districts become flooded with deep but slow-moving water as frequently as the 10-year flood event (Figures 4-3 and 4-4). As of 2019, there were 48 repetitive loss properties reported within West Nyack, many of which fall within HRA 1.

At the time that this flood study was being conducted, the Klein Avenue Levee Improvement Project was under construction. This levee is located in HRA 1 along the right bank of the Hackensack River between STA 310+00 and STA 325+00. The levee improvements were not evaluated as part of this study, nor were the levee enhancements incorporated into the hydraulic modeling conducted for this analysis. Flood mapping presented in the analysis of HRA 1 represents conditions prior to the Klein Avenue Levee Improvement Project.

Several bridges span the Hackensack River within HRA 1. Old Mill Road (STA 344+00) and I-287 (STA 325+00) span the river near the upstream end of HRA 1. A CSX Railroad bridge at STA 294+50 (for the purpose of this report it is labeled CSX Railroad Bridge #2) has a 59-foot span and 8-foot rise. The bridge has a substantial railroad embankment associated with it, which encroaches on the floodplain of the Hackensack River. Moving downstream to STA 282+00 is a state-owned, open-bottom bridge with a 120-foot span, a 14-foot rise, and a single pier, that conveys State Route 59 over the river. A second CSX Railroad bridge (for the purpose of this report, CSX Railroad Bridge #1) at STA 244+00 consists of an open-bottom bridge with a 54.5-foot span and a 20-foot rise. Similar to the other CSX crossing in HRA 1, this bridge has a substantial railroad embankment associated with it that transects the floodplain. The Rockland County-owned Western Highway bridge at STA 241+50 was in the process of being replaced at the time of this flood study. The size of the planned replacement bridge is not known.

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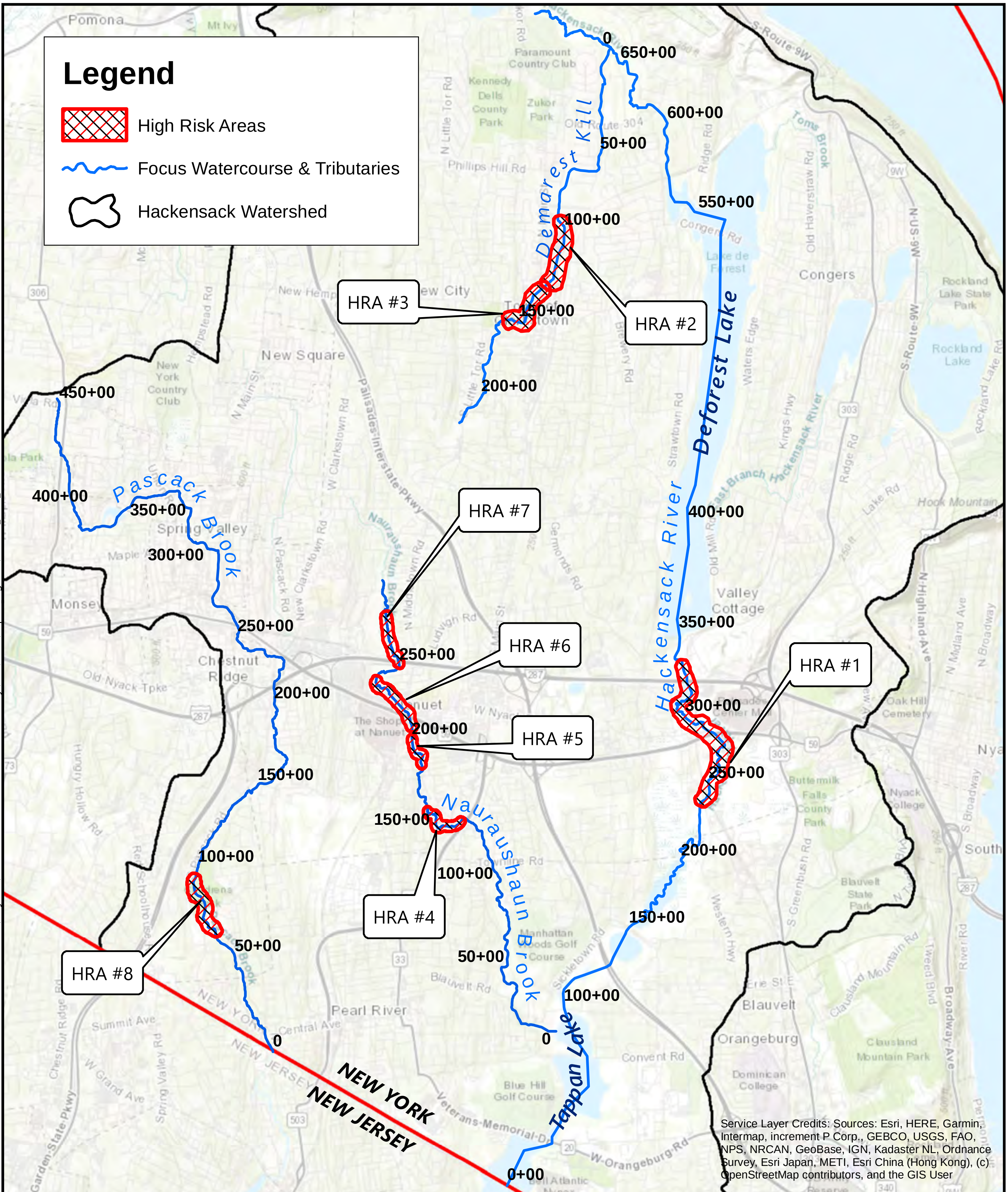

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HACKENSACK WATERSHED- HIGH RISK AREAS

HACKENSACK RIVER FLOOD & RESILIENCY STUDY

SD109

ROCKLAND COUNTY

NEW YORK

N

0 29,000 58,000
Feet

SCALE 1 " = 60,000 '

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FIG. 4-1

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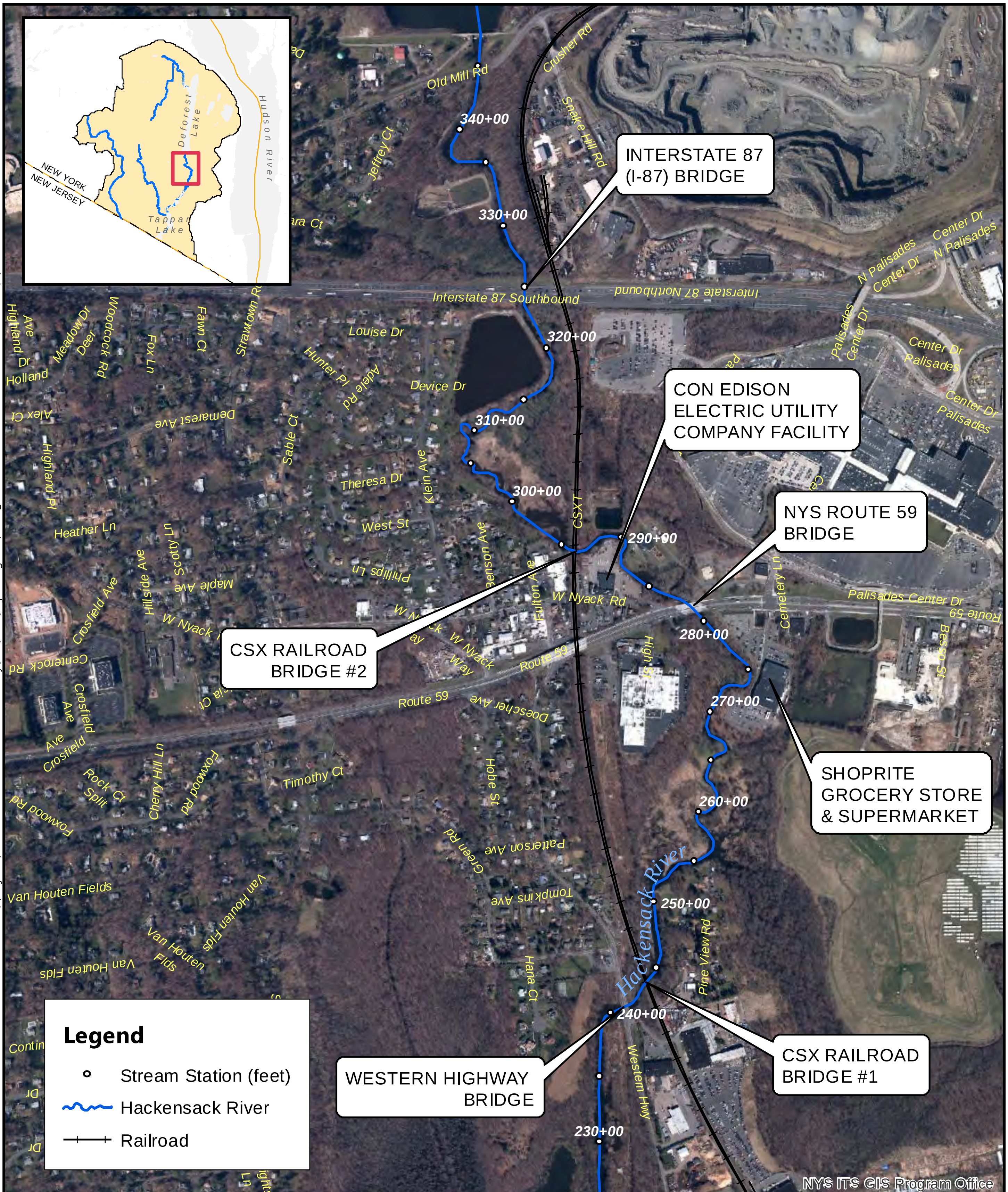

HIGH RISK AREA #1 - HAMLET OF WEST NYACK

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NEW YORK

N

0 500 1,000
Feet

SCALE 1 " = 1,000 '
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FIG. 4-2

SOURCE: 2016 AERIAL PHOTO, NYS ITS GIS Program Office

Figure 4-3: Flooding behind the Con Edison West Nyack Electric Utility Company Facility during September 2021 flood. CSX Bridge #2 at STA 294+50 is at bottom-right.

Figure 4-4: Portion of NYS Route 59 near Palisades Center Drive Under Water during Tropical Storm Irene in 2011

The county-owned Western Highway bridge and the CSX Railroad Bridge #1 are the downstreammost crossings in HRA 1. Both structures are hydraulically undersized, and together they create a significant backwater that extends upstream and contributes substantially to flooding. CSX Railroad Bridge #2 also acts as a major hydraulic constriction. Because these bridges are located in close proximity to one another, each affects the hydraulic performance of the next bridge or bridges upstream.

Replacing the Western Highway bridge and the CSX Railroad Bridge #1 with larger spans would reduce upstream water surface elevations during large-magnitude flood events. These reductions in backwater extend as far as 2 miles upstream of the crossings in the 100-year flood event, which would reduce the tailwater influence at all other bridges situated upstream in HRA 1. The Western Highway bridge is already in the process of being replaced. CSX Railroad Bridge #1, in order to pass flood flows and not act as a hydraulic constriction, should have a span of at least 85 feet (the current span is 59 feet). Floodplain relief culverts do not appear to be feasible at the location of CSX Railroad Bridge #1 due to the topography of the surrounding land and the proximity of Western Highway, which runs just downstream of and parallel to the CSX railroad line.

At CSX Railroad Bridge #2, increasing the span of this crossing to at least 82 feet (the current span is 54.6 feet), in combination with the improvements at the Western Highway bridge and CSX Railroad Bridge #1 described above, would reduce upstream flood depths by an additional 0.6 feet during the 100-year flood event. These reductions would extend upstream a distance of over 5,000 linear feet and would reduce headwater elevations at the I-87 bridge and the Mill Road bridge. Benefits resulting from the replacement of both CSX railroad bridges would extend from STA 244+00 upstream to above STA 350+00, up to the Deforest Lake dam, a distance of over 2 miles. The proposed improvements at the railroad bridges would lower water surface elevation at the Klein Avenue levee during flood events.

The introduction of relief culverts was evaluated at CSX Railroad Bridge #2. Seven 18-foot by 6-foot elliptical culverts were modeled through the railroad embankment to the left of the bridge. The relief culverts would lower water surface elevations by 0.2 feet during the 100-year flood event if implemented in combination with the recommended improvements at the Western Highway bridge and CSX Railroad Bridge #1. Replacement of the CSX Railroad Bridge #2 with a larger span would be more effective at reducing flooding in HRA 1 when compared to the installation of relief culverts.

A concept map showing recommended improvements in HRA 1 is depicted on Figure 4-5. These recommended improvements include replacing CSX Railroad Bridge #1 with a larger bridge with a minimum span of 85 feet and replacing CSX Railroad Bridge #2 with a larger bridge with a minimum span of 82 feet. It is recommended that the replacement of the more downstream bridge, CSX Railroad Bridge #1, be prioritized over the replacement of the upstream bridge, CSX Railroad Bridge #2.

Longitudinal profiles showing existing and proposed conditions under the 50-year, current and future flood events are depicted in Figure 4-6 and under the 100-year, current and future flood events in Figure 4-7. Existing and proposed conditions flood depth mapping for the 10-, 50-, and 100-year flood events are included in Figures 4-8 through Figure 4-13.

While the recommended replacements of CSX Railroad Bridge #1 and CSX Railroad Bridge #2 with larger bridges would greatly reduce flood depths in HRA 1, these improvements would not eliminate flooding. Therefore, floodproofing and voluntary buyouts of flood-prone structures are recommended in HRA 1.