Willow Brook
Flood Mitigation Study

East Hartford, Connecticut
August 2016

MILONE & MACBROOM®

Engineering | Planning | Landscape Architecture | Environmental Science

Willow Brook
Flood Mitigation Study

East Hartford, Connecticut
August 2016

MMI #2854-37-5

Willow Brook at Silver Lane

Prepared for:
Town of East Hartford
740 Main Street
East Hartford, CT 06455

Prepared by:
MILONE & MACBROOM, INC.
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State of Connecticut Funding Provided for Capital Improvements for Flood and Erosion Control, Administered by the Connecticut Department of Energy and Environmental Protection.

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ABBREVIATIONS/ACRONYMS AND DEFINITIONS

CFS	Cubic Feet per Second
DEEP	Connecticut Department of Energy & Environmental Protection
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
GIS	Geographic Information System
HEC-HMS	Hydrologic Engineering Center – Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center – River Analysis System
MDC	Metropolitan District Commission
MMI	Milone & MacBroom, Inc.
NFIP	National Flood Insurance Program
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
STA	River Station
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey

1.0 INTRODUCTION

1.1 Project Background

Willow Brook is a 3.5-mile long watercourse that drains the central portion of the Town of East Hartford Connecticut (the Town), including portions of the large complexes of Rentschler Field and Pratt & Whitney. The brook flows in a westerly orientation towards the Connecticut River. The contributing watershed area is highly developed, with a large percentage of impervious areas. Willow Brook's associated low-lying floodplain is broad and flat, with large expanses of pavement and developed areas. Figure 1-1 is a location plan of the brook and its contributing watershed.

The most recent detailed study of Willow Brook was completed in 1977 by the Federal Emergency Management Agency (FEMA). The brook is identified in FEMA's Flood Insurance Study (FIS) as the major flooding problem within the Town. The FEMA study further indicates that the watercourse has undersized culverts throughout its length. Figure 1- 2 depicts the FEMA-mapped floodplain of Willow Brook.

In order to better understand the flooding characteristics of Willow Brook, the Town retained Milone & MacBroom, Inc. (MMI) to undertake a detailed study of the hydrology and hydraulics of the brook and evaluate potential flood mitigation measures along its corridor. The subject study was funded through a grant from the Connecticut Department of Energy and Environmental Protection (DEEP).

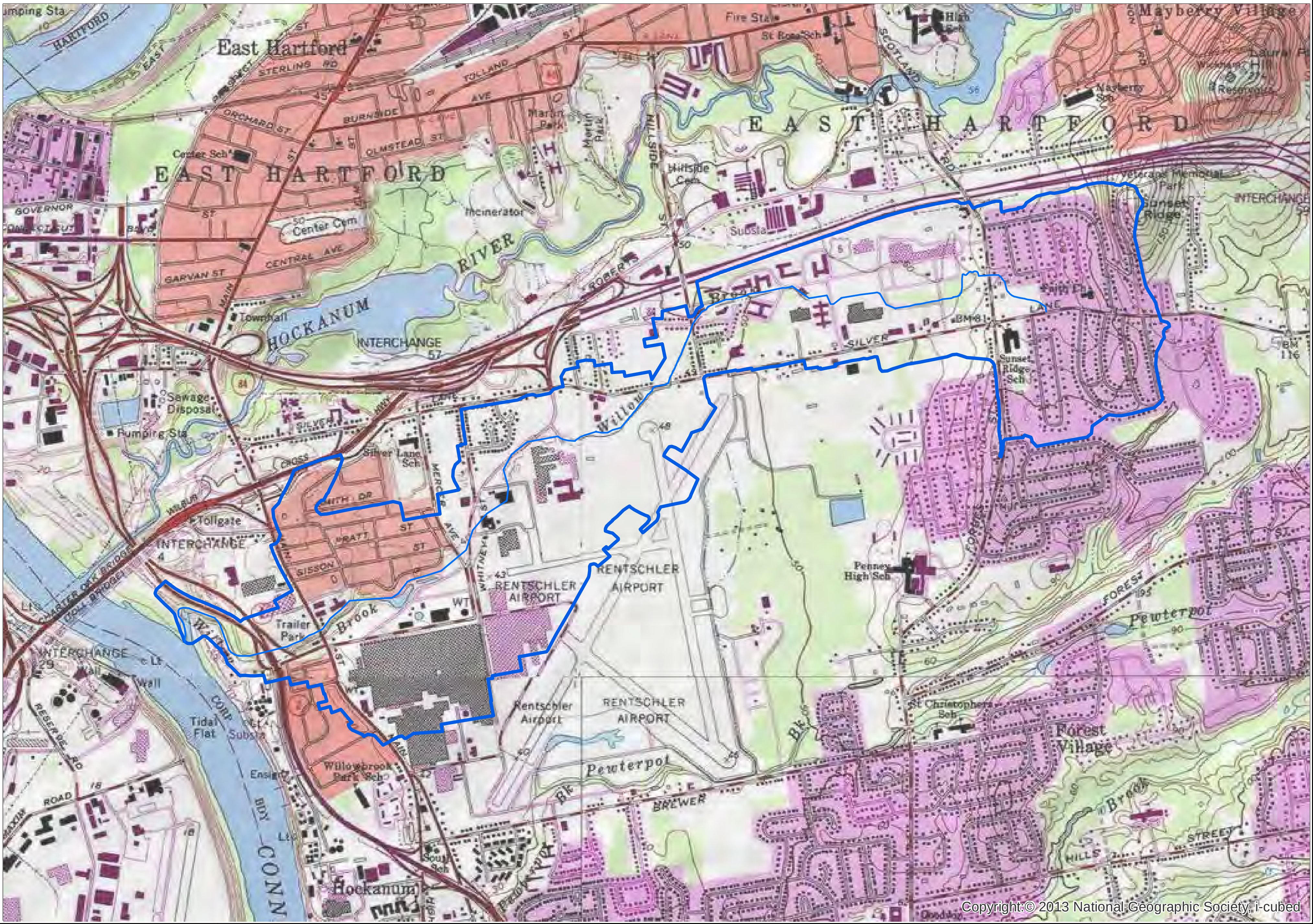
1.2 Study Goals and Objectives

The subject study assesses the present condition of Willow Brook to provide a more accurate portrayal of flooding characteristics, evaluate the floodplain extent and characteristics, and identify potential measures to reduce flooding. The specific objectives of this analysis include the following:

- Update the hydrology of the Willow Brook watershed to accurately portray current rainfall and runoff conditions in the watershed;
- Update the FEMA analysis of the 100-year (1% Annual Chance of Recurrence, ACR) floodplain using current data and mapping;
- Evaluate the existing flooding characteristics and identify problem areas;
- Engage the community to gather first-hand knowledge of local flooding characteristics ;
- Assess potential alternatives to alleviate channel flooding in problem areas;
- Determine the costs and benefits of potential mitigation projects;
- Identify possible funding sources for feasible mitigation alternatives; and
- Develop a list and Master Plan of recommended improvements.

The goals of this effort are as follows:

- Develop updated and accurate hydrology and hydraulics for Willow Brook;
- Define the Willow Brook floodplain to reflect changes that have occurred in the past 39 years since FEMA conducted its modeling;
- Identify means to reduce the areas subjected to flooding to provide relief to homeowners and businesses subject to flood insurance; and
- Promote economic development in areas consistent with land use plans and zoning.



SOURCE(S):
ESRI USA Topo Maps

N

Figure 1-1: Location Map

MXD: Y:\2854-37\GIS\Maps\Location Map.mxd

Willow Brook Flood Mitigation Study

LOCATION: East Hartford, Connecticut

Map By:	CMP
MMI#:	2854-37
Original:	7/20/2015
Revision:	7/20/2015
Scale:	1 in = 2,000 ft

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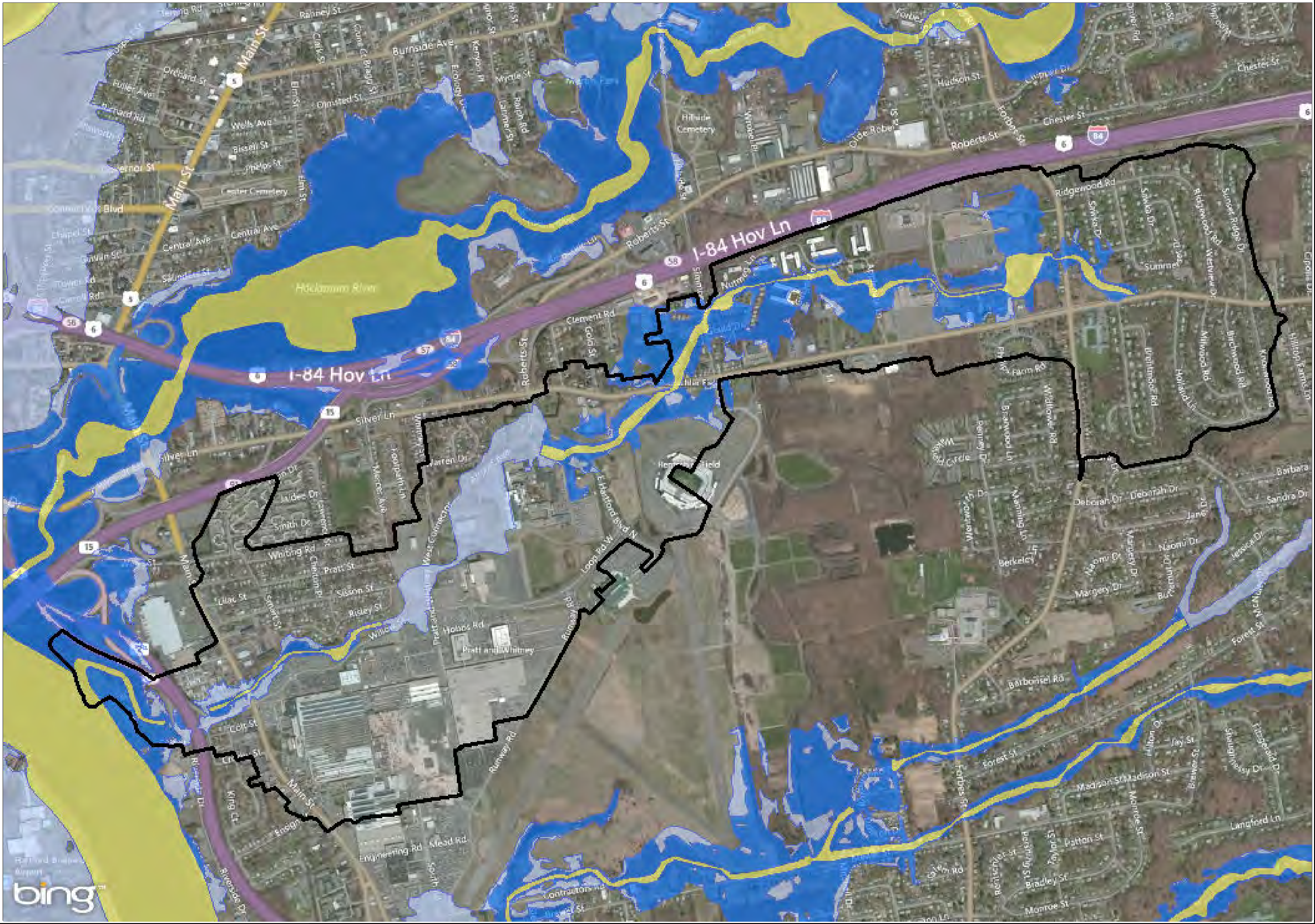


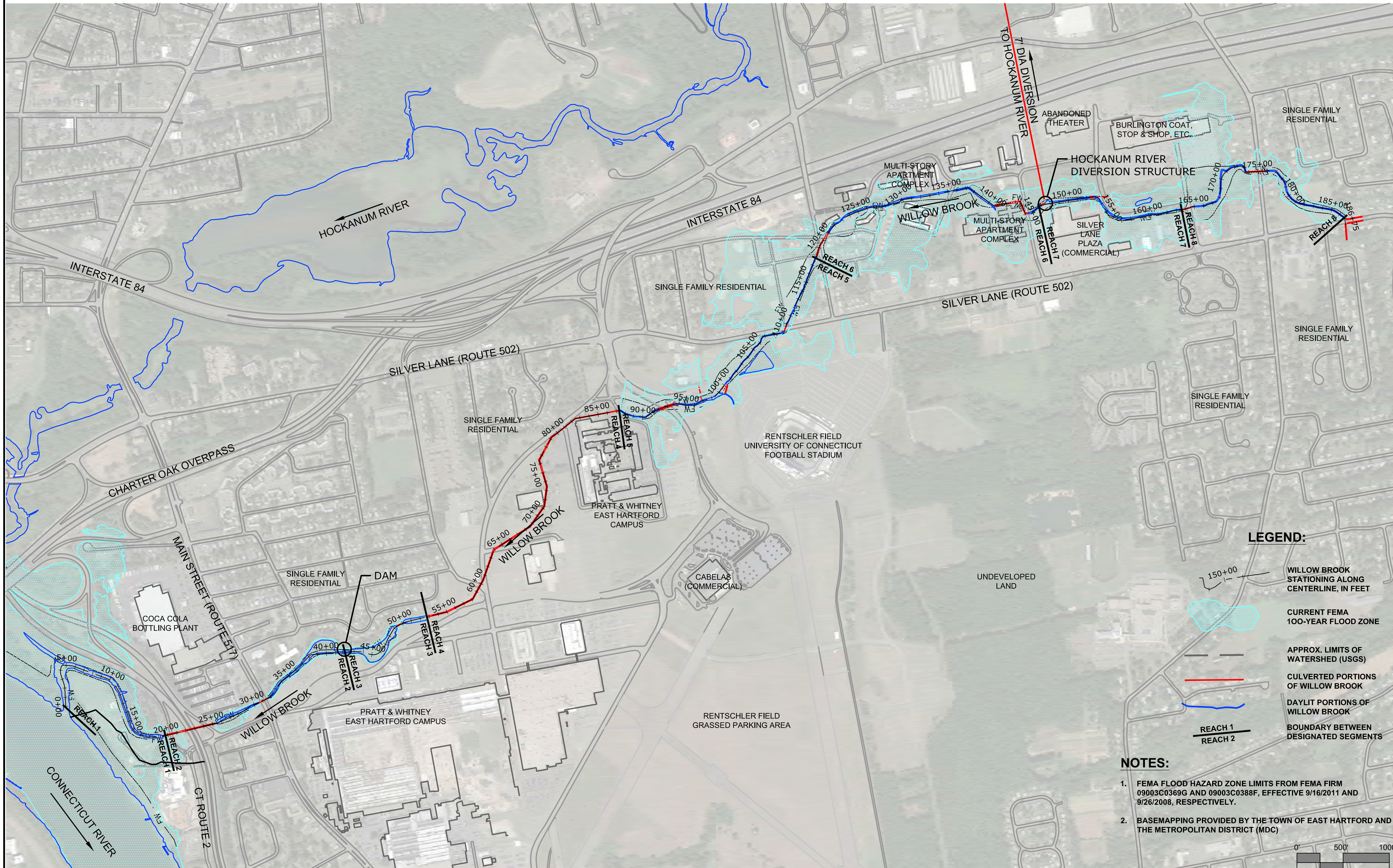
SOURCE(S): FEMA Flood Layer, Bing Aerial Hybrid	Figure 1-2: FEMA Inundation Map	Willow Brook Flood Mitigation Study	Map By: CMP; MMI#: 2854-37; Original: 7/20/2015; Revision: 7/20/2015; Scale: 1 in = 2,200 ft	MILONE & MACBROOM, 99 Realty Drive Cheshire, CT 06410, (203) 271-1773 Fax: (203) 272-9733, www.miloneandmacbroom.com
	MXD: Y:\2854-37\GIS\Maps\FEMA Map.mxd	LOCATION: East Hartford, Connecticut		

1.3 Nomenclature

In this report and associated mapping, stream stationing is used as a locator to identify specific points along the Willow Brook watercourse. Stationing is measured in feet, beginning at the mouth of Willow Brook where it discharges into the Connecticut River at River Station (RS) 0+00 and continuing upstream to RS 186+75. As an example, RS 73+00 indicates a point in the channel located 7,300 linear feet upstream of the mouth of Willow Brook at the Connecticut River. Figure 1-3 depicts stream stationing. All references to right bank and left bank in this report refer to "river right" and "river left," relative to the direction of flowing water; meaning the orientation assumes that the reader is standing in the river looking downstream.

1.4 Public Outreach

Public outreach meetings were held throughout the project. The first was held on February 10, 2015 during the data gathering phase; the second on July 15, during alternatives analysis, and the third on November 19, 2015 to present the master plan of improvements. These meetings provided more detailed, firsthand accounts of past flooding events; identified specific areas vulnerable to flooding and the extent and severity of flood damage; and provided opportunities to share the investigations and analysis with the community. This outreach effort has assisted in the identification of target areas for field investigations and analysis. Appendix A contains copies of the presentations as well as summaries of public comments from each of the meetings.



NOTES:

1. FEMA FLOOD HAZARD ZONE LIMITS FROM FEMA FIRM 09003C0369G AND 09003C0388F, EFFECTIVE 9/16/2011 AND 9/26/2008, RESPECTIVELY.
2. BASEMAPPING PROVIDED BY THE TOWN OF EAST HARTFORD AND THE METROPOLITAN DISTRICT (MDC)

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REVISIONS

WILLOW BROOK - INDEX PLAN

WILLOW BROOK
FLOOD MITIGATION STUDY
TOWN OF EAST HARTFORD
CONNECTICUT

DESIGNED	DRAWN	CHECKED
JCM	JCM	JAG

SCALE 1"=1000'
DATE FEB. 2015
PROJECT NO. 2854-37
SHEET NO.

FIG. 1-3

Drawing: W:\DESIGN\2854-37-DE\CAD\REPORT FIGURES\WB-INDEX-11X17.DWG Layout Tab:FIG 2-8
Plotted by: JAMESM On this date: Mon, 2016 August 1 - 10:47am

2.0 DATA COLLECTION

2.1 Initial Data Collection, Field Assessment & Survey

Public information pertaining to Willow Brook was collected from previously published documents and databases on file with the Town of East Hartford, the Metropolitan District Commission (MDC), the Connecticut Department of Energy & Environmental Protection (DEEP), Pratt & Whitney, and other local, state, and federal agencies and organizations. Data collected includes reports, photographs, newspaper articles, FEMA Flood Insurance Studies (FIS), aerial photographs, and geographic information system (GIS) mapping. Appendix B is a summary listing of data and reports collected.

Following initial data gathering, staff from MMI undertook field data collection efforts. Initial field assessment was conducted in December 2014 and January 2015. Selected locations identified in the initial phase were assessed more closely by multiple field teams throughout the spring of 2015. Information collected during field investigations included the following:

- Initial river corridor assessment, including characterization of the streambed and banks, riparian cover, and channel structure
- Visible infrastructure within the riparian corridor
- Photo documentation of inspected areas
- Geomorphic classification and assessment, including measurement of bankfull channel widths and depths at key cross sections
- Characterization of channel features
- Measurement and initial hydraulic assessment of bridges, culverts, and dams
- Inventory and of structures along the main stem of Willow Brook to characterize each bridge structure and culvert
- Inventory and characterization of storm drainage outfalls that discharge to Willow Brook
- Land use and development patterns
- Preliminary identification of potential flood hazard mitigation alternatives, including those requiring further analysis

After the initial field assessment was complete, more detailed field survey was conducted using survey-grade GPS to set benchmarks along the Willow Brook corridor, and streambed data and overbank elevations were surveyed using an Electronic Distance Meter (EDM) and data collector. This effort yielded cross sections of the stream and stream corridor. Additionally, invert and sizing data was surveyed for culverts and outfalls along Willow Brook.

All survey is referenced horizontally to the North American Datum of 1983 (NAD 1983) and vertically to the North American Vertical Datum of 1988 (NAVD 88). Topographic data was collected and processed in conformance with T2 accuracy standards, and was certified by a surveyor licensed in the State of Connecticut.

All surveyed topography was compiled into topographic and planimetric mapping provided by MDC. That mapping is based upon aerial survey completed in 2003 and was compiled at a scale of one inch equals eighty feet (1”=80’), with a contour interval of two feet.

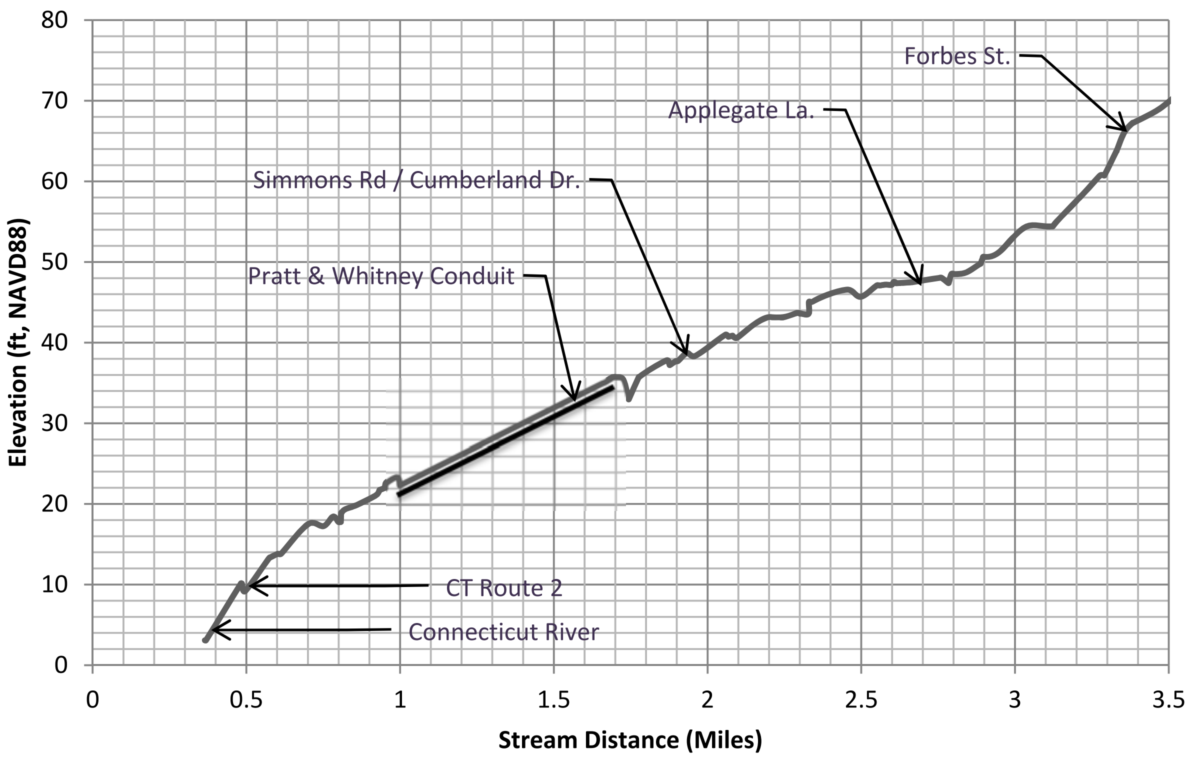
2.2 Brook Corridor Assessment

The Willow Brook Corridor is characteristic of a semi-urbanized stream that has been heavily impacted by development. The brook is located entirely within the Town of East Hartford, Connecticut. Although FEMA approximates the contributing watershed size as 2.4 square miles, a detailed assessment of the watershed including an assessment of stormwater drainage system mapping indicates that the drainage area is closer to 1.6 square miles.

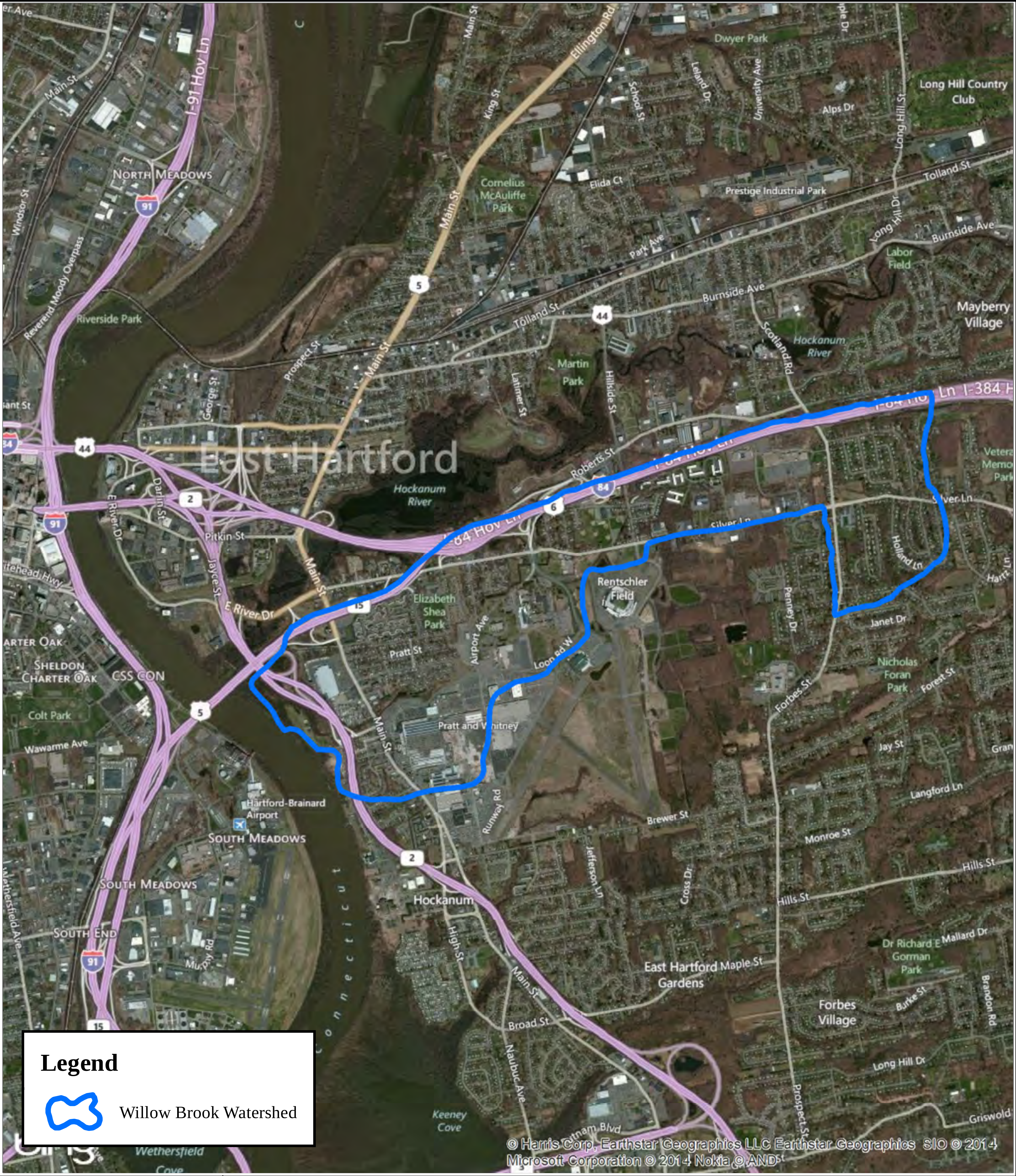
The length of Willow Brook is approximately 3.5 miles. It has an average slope of 0.36% percent from its headwaters to its outlet into the Connecticut River. The slope of the channel is relatively consistent over this length.

Figure 2-1 presents a profile of Willow Brook showing its elevation along its length. The brook drops a total of 67 vertical feet over its 3.5-mile length, from an elevation of 70 feet above sea level at its headwaters to an elevation of 3 feet at its outlet to the Connecticut River. This yields an average slope of 0.36 percent, indicating a very flat stream.

FIGURE 2-1
Longitudinal Profile of Willow Brook from Silver Lane to Connecticut River
(Source: MMI Survey)



Appendix C is an electronic photo log of select locations within the river corridor. Completed data sheets, field notes, photo documentation, and mapping developed for this project have been provided electronically to the Town of East Hartford. Figure 2-2 presents the Willow Brook watershed boundary.



SOURCE(S):
ESRI, CT DEEP

Figure 2-2: Willow Brook Watershed

LOCATION:
East Hartford, CT

N

Willow Brook Flood Study

MXD: Y:\2854-37\GIS\Maps\Watershed Map.mxd

Map By: JCS
MMI#: 2854-37
Original: 7/14/2014
Revision: 7/14/2014
Scale: 1 inch = 4,000 feet

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The Willow Brook stream corridor was divided into eight reaches, with Reach 1 being the furthest downstream. All references to right and left banks are noted relative to the flow of water, (i.e. looking downstream). Aerial photographs, topographic survey results, and field notes were used as the basis to delineate stream reaches with fairly uniform physical characteristics that can be collectively described. Stream reaches are described in Table 2-1 and are shown graphically in Figure 1-3.

TABLE 2-1
Summary of Study Reaches

Reach	Station Range	Downstream End	Upstream End	Length (ft)	Average Slope *
1	0+00 – 19+50	Connecticut River Confluence	D/S of State Route 2 Culvert	1,970	0.0%
2	19+50 – 42+00	D/S of State Route 2 Culvert	Pratt & Whitney Dam	2,250	0.7%
3	42+00 – 52+75	Pratt & Whitney Dam	D/S of Pratt & Whitney Conduit	1,075	0.3%
4	52+75 – 87+25	D/S of Pratt & Whitney Conduit	U/S of Pratt & Whitney Conduit	3,450	0.4%
5	87+25 – 118+00	U/S of Pratt & Whitney Conduit	D/S of Simmons Rd / Cumberland Dr Culvert	3,075	0.3%
6	118+00 – 146+75	U/S of Simmons Road / Cumberland Drive Culvert	D/S of Hockanum River Diversion Structure	2,875	0.1%
7	146+75 – 162+50	D/S of Hockanum River Diversion Structure	D/S of Charter Oak Mall Shopping Center Culvert	1,575	0.4%
8	163+50 – 186+75	D/S of Charter Oak Mall Shopping Center Culvert	U/S of Silver Lane Outfalls	2,325	0.7%

* Based on April 2015 survey

A description of each reach follows. These are based on field observations and measurements made by MMI staff.

Reach #1 Connecticut River to Route 2 Culvert (RS 0+00 to RS 19+50)

Reach #1 is a particularly flat stream segment that is heavily influenced by the Connecticut River. Tidal fluctuations from Long Island Sound extend upstream to the Hartford area, with typical tidal ranges between 0.5 and 1 foot. Higher river stages in the Connecticut River cause a backwater into Willow Brook as far as the downstream end of the Route 2 culvert, or about 2,000 feet upstream of the confluence of Willow Brook with the Connecticut River. This channel

Reach # 1 Connecticut River to Route 2 Culvert reach is flat and overly wide, with a fine-grained silty channel bottom and banks/floodplain lined with mature forest and vegetation. Recent beaver activity in the forested floodplain was visible during field investigations. Land ownership within the channel corridor is primarily public throughout this reach.

Reach #2 Route 2 Culvert to Pratt & Whitney Dam (RS 19+50 to RS 42+00)

Reach #2 Route 2 Culvert to Pratt & Whitney Dam

The channel upstream of Route 2 inclusive of the Main Street Bridge is highly entrenched, with steep (1:1), tall vegetated banks and no associated floodplain. These steep banks appear to have been created by placing fill in the floodplain, likely over many decades, to accommodate development in the surrounding areas. The channel slope in this reach averages 0.7%, making it one of the steeper reaches of the brook. Channel bed substrate in this area is characterized by a sandy gravel mix with cobbles and placed riprap, likely placed to protect against higher flood velocities.

The most upstream segment of this reach is a 300-foot long area that appears to have been dredged to create a small pond, although no dam or structure maintains the pond and it has silted in and vegetated over time. Invasive vegetative species, such as Japanese Knotweed, were noted to be prolific throughout this segment of the reach. Ownership of the downstream portion of this reach is public. Upstream of the Main Street crossing, the brook flows through private property within the Pratt & Whitney campus.

Reach #3 Pratt & Whitney Dam to Pratt & Whitney Conduit (RS 42+00 to RS 52+75)

Reach #3 Pratt & Whitney Dam to Pratt & Whitney Conduit

The Pratt & Whitney dam is located at the downstream end of Reach #3. The dam is a concrete structure that was originally constructed to impound water and create a small pond. Historically, the impounded water reportedly provided cooling and process water for the Pratt & Whitney production facility. Upstream of the dam, the small (550 feet long by 150 feet wide) pond has begun to fill with sediment, with invasive vegetation beginning to grow along the banks and atop sediment bars. The upstream end of this reach includes a small section of 108-inch RCP culvert that supports a small grassed path that does not appear to be in active use.

Reach #4 Pratt & Whitney Conduit (RS 52+75to 87+25)

Reach #4 Pratt & Whitney Conduit (Upstream Entrance)

Reach #4 is comprised of a 3,475 foot long conduit that contains Willow Brook beneath the Pratt & Whitney facility. The enclosed brook flows southwesterly from the Silver Lane entrance to Pratt & Whitney, to its discharge point above the impoundment (described in Reach #3). Based on historic aerial photographs, the conduit appears to have been constructed in stages as the Pratt & Whitney campus was expanded. Records of the varying pipe sizes and types are sparse, and direct observation of the culvert is difficult due to physical constraints. More detail about this conduit is provided in Section 2.12.3.

Reach #5 Pratt & Whitney Conduit to Simmons Road Culvert (RS 87+25 to 118+00)

Reach #5 Pratt & Whitney Conduit to Simmons Road Culvert

Upstream of the Pratt & Whitney conduit, the Willow Brook channel flows beneath the Rentschler Field access drive and through an overflow parking area that is located adjacent to athletic fields and residential homes. This reach of channel is more naturalized than many other segments of Willow Brook, and is bordered by a vegetative buffer on both banks. Substrate in this reach is characterized by a silty sand bed. The reach slope is 0.26%.

Reach #6 Simmons Road to Hockanum River Diversion Structure (RS 118+00 to 146+75)

Reach #6 Simmons Road to Hockanum River Diversion

Upstream of Simmons Road, Willow Brook is characterized by a flat reach, with an average slope of 0.14%. The brook in this reach flows through single family residential and multi-story apartment building complexes. The channel has a vegetated buffer throughout most of the reach. It also flows through a long, privately owned culvert beneath Applegate Lane.

Reach #6 has a silty bottom, and is subject to organic and manmade debris accumulation. Silt, leaves, and woody debris buildup has occurred over time as well, likely due to reduced flows in the channel caused by a diversion structure immediately upstream (described in Reach #7 narrative), combined with the shallow slope to create extremely low flow velocities.

Reach #7 Hockanum River Diversion Structure to Charter Oak Mall (RS 146+75 to 163+50)

Reach #7 Hockanum River Diversion Structure (upper photo) and upstream channel (lower photo)

The downstream end of Reach #7 is a diversion structure that is located upstream of Applegate Lane. The structure was built by the Town of East Hartford in 1979. The purpose of this diversion was to alleviate flooding in Willow Brook by diverting flow to the Hockanum River. A sluice gate was installed at the culvert to allow the manipulation of flows in Willow Brook. However, the sluice has been closed for decades.

Upstream of the Hockanum River Diversion structure is a flat stretch of channel with a good vegetative buffer. The banks are low, with a high silt content. This channel reach is subject to accumulation of leaves and woody debris, as well as some trash along the channel. The average channel slope is 0.4%. Manmade detention areas are located on both banks of this reach, both of which appear to have been constructed in support of the adjacent commercial properties and their associated large impervious parking areas.

Reach #8 Charter Oak Mall to Silver Lane Outfalls (RS 163+50 to 186+75)

The upstream-most reach of Willow Brook has an average channel slope of 0.7%. This segment is slightly steeper than most other reaches, and does not exhibit the same debris accumulation. Directly upstream of the Charter Oak Mall is in a large flat wetland system that provides detention.

Reach #8 Charter Oak Mall to Silver Lane Outfalls

Upstream of Forbes Street is a steeper, more well-defined channel. This reach has been prone to sediment accumulation from the multiple stormwater conveyance systems that discharge to it. Road sand has accumulated in the channel and is reportedly exacerbating drainage system-related flooding in the area. The Town has excavated the accumulated sediment in the past; however, additional sediment has since accumulated.

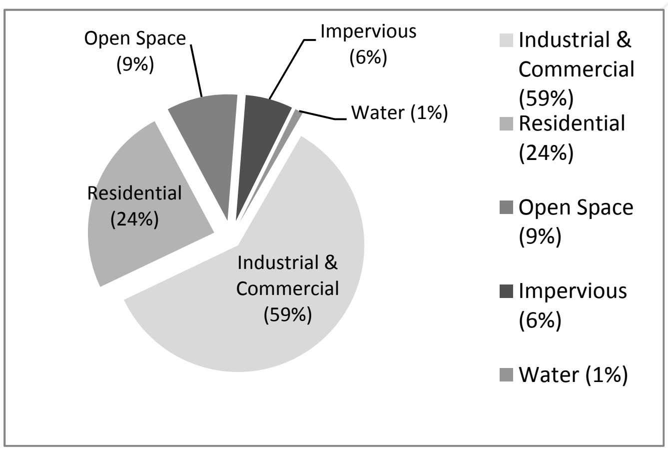
2.3 Land Uses in the Watershed

The primary land use found in the contributing watershed of Willow Brook is industrial and commercial development (59%), followed by residential development (24%). These include large expanses of rooftop and paved parking areas, which have the effect of increasing runoff.

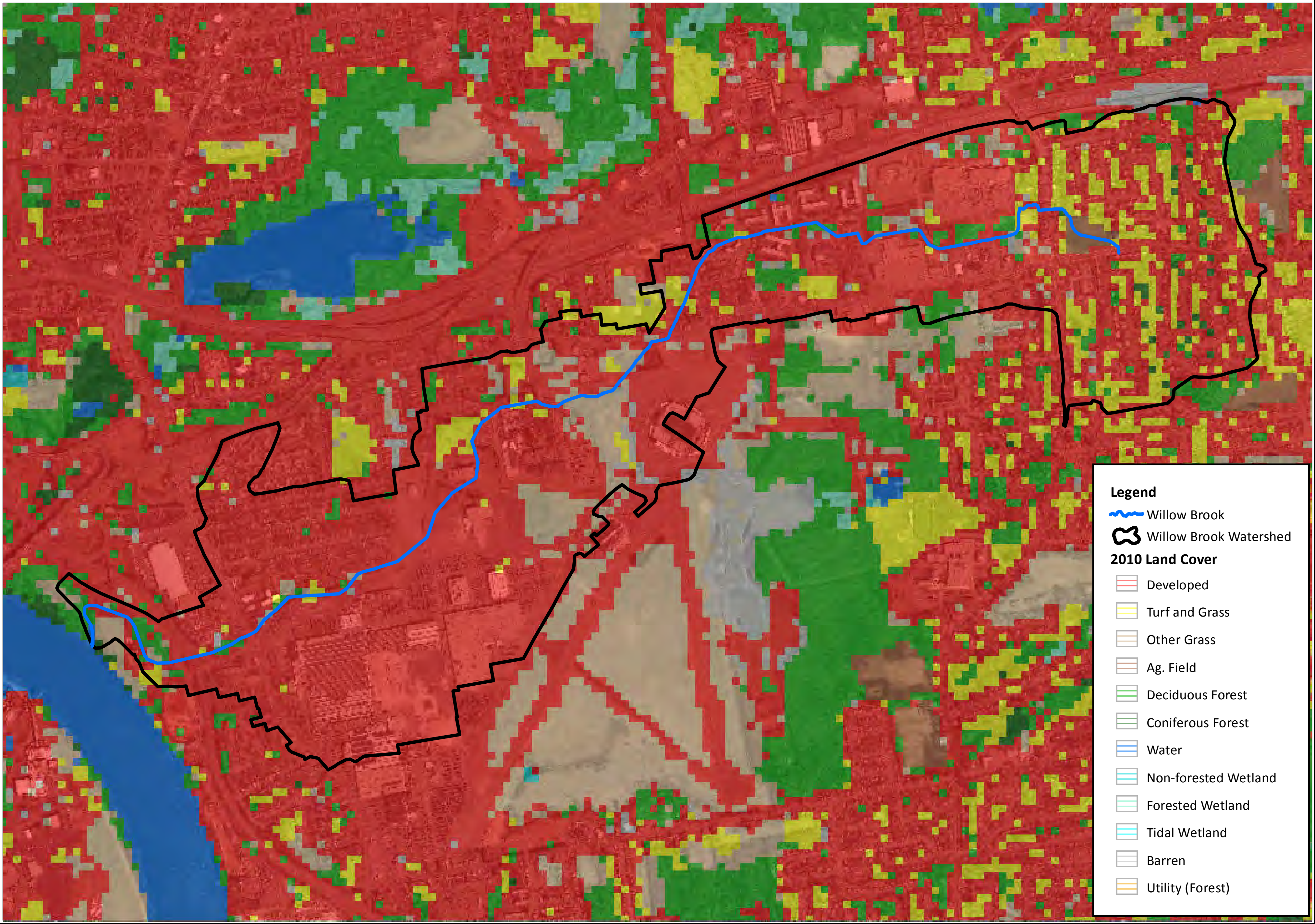
Residential and commercial development of the Willow Brook watershed has occurred over many decades. Development has had the effect of increasing impervious areas, which in turn increase stormwater runoff volume and peak flow rates during storm events. At the same time, development reduces the amount of natural storage in the watershed.

Table 2-2 presents the percentage of land-use types throughout the watershed. Figure 2-3 is a watershed map of Willow Brook showing land cover. Figure 2-4 presents a comparison of land use in the watershed between 1970 and 2012. Major areas of new development are highlighted with black boxes.

TABLE 2-2
Land Use Types in the Willow Brook Watershed (2015)



Land Use Type	Area (Ac)	Percentage
Industrial & Commercial	389.1	59%
Residential	153.6	24%
Open Space	61.4	9%
Other Impervious	41.0	6%
Water	10.2	1%
Total	655.3 ac	100%



SOURCE(S):
CT ECO 2010 Land Use Layer
CT ECO 2012 Orthoimagery

N

Figure 2-3: Land Cover

MXD: Y:\2854-37\GIS\Maps\Land Use.mxd

Willow Brook Flood Mitigation Study

LOCATION: East Hartford, Connecticut

Map By: CMP
MMI#: 2854-37
Original: 7/20/2015
Revision: 7/20/2015
Scale: 1 in = 2,250 ft

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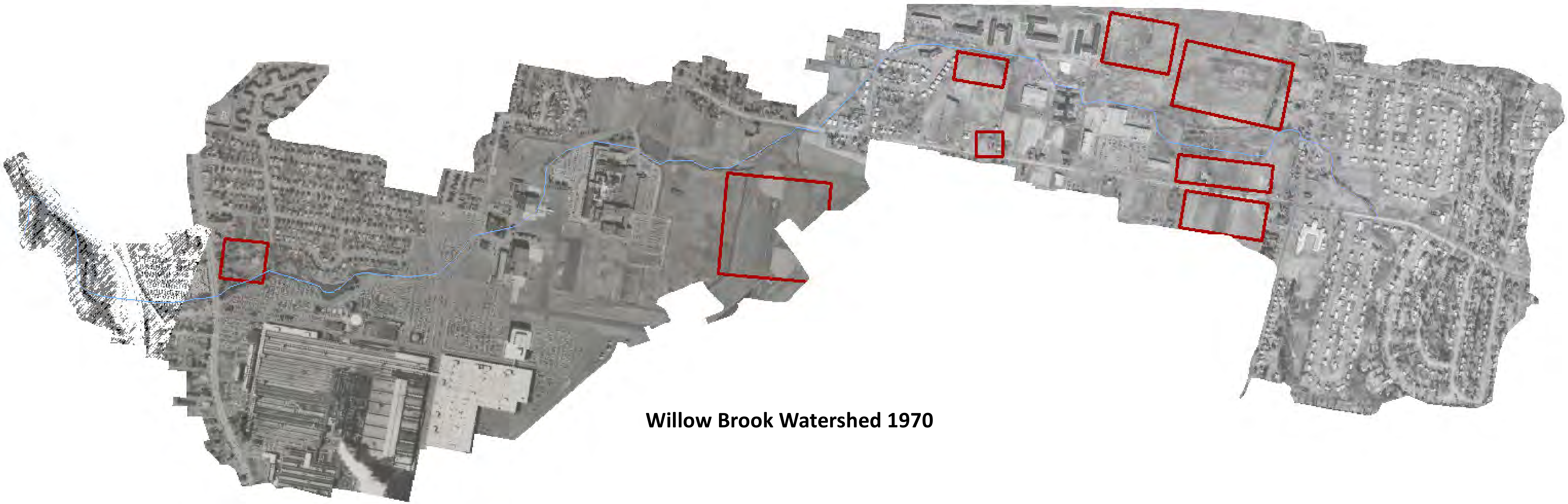

Willow Brook Watershed 1970

Willow Brook Watershed 2012

Historic Aerial Comparison of Willow Brook Watershed

WILLOW BROOK FLOOD MITIGATION STUDY
EAST HARTFORD, CONNECTICUT

SOURCE(S):
CT ECO 2012 Orthoimagery

Uconn MAGIC GIS Database
1970 Aerial Photography

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Map By: CMP
MMI#: 2854-37
MXD: Y:\2854-37\GIS\Maps\Historic-Aerials.mxd
1st Version: 5/22/2015
Revision: 6/8/2015
Scale: 1 in = 1,125 ft

Figure 2-4

2.4 Surficial Materials and Soil Types

Surficial materials in the Willow Brook watershed include alluvium overlying fines, fines, sand, sand and gravel, sand overlying fines, till, and thick till. Table 2-3 lists the surficial materials in order of their respective percentages. Figure 2-5 depicts the surficial materials in the watershed.

TABLE 2-3
Summary of Surficial Material Types

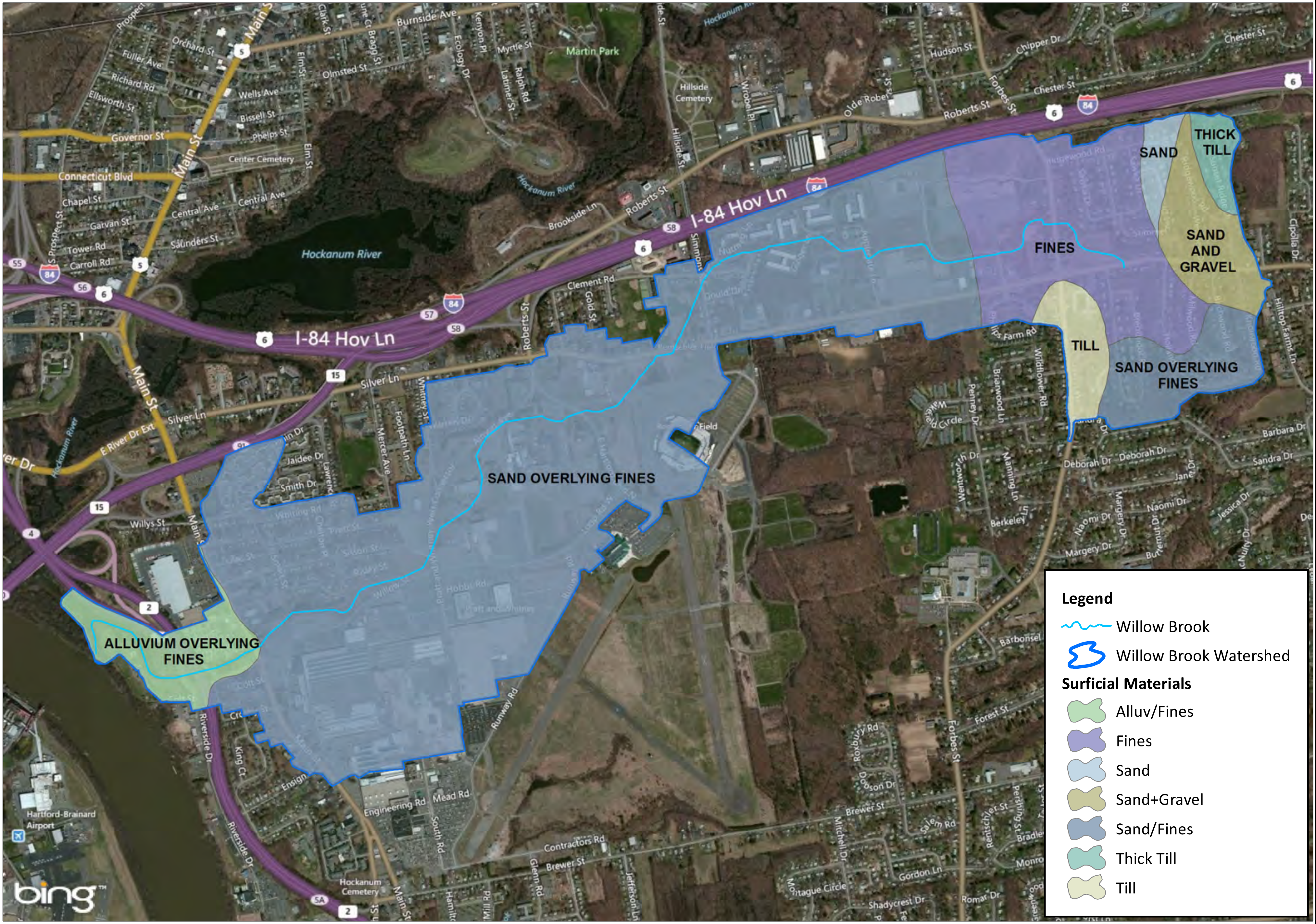
Surficial Material	Acres	Percent
Sand Overlying Fines	734.2	71.7%
Fines	150.5	14.7%
Alluvium Overlying Fines	46.1	4.5%
Sand and Gravel	43.4	4.2%
Till	24.8	2.4%
Thick Till	13.2	1.3%
Sand	11.7	1.1%
Water	0.1	0.1%

The types of surficial geology present within a watershed influence both the amount of infiltration that may occur during a storm event and the amount of base flow that can be provided to a stream. The types and percentages of surficial geology presented in Table 2-3 suggest that the majority of the Willow Brook watershed likely has a groundwater table that is perched above a finer layer. This perched condition could limit infiltration in areas where the groundwater table is close to the surface, but could also promote lateral downstream groundwater flow above the confining layer.

The Willow Brook watershed can be classified by a number of different soil types, with the primary being Urban land, Udorthents-Urban land complex, and Windsor-Urban land complex. Figure 2-6 depicts soil types in the Willow Brook watershed.

The vast majority (87.5%) of the soil types in the Willow Brook watershed are considered to be urbanized and are mapped as Urban land, Udorthents-Urban land complex, or Urban land complex combined with another soil type. Table 2-4 lists the soil types, descriptions, and their respective percentages in the watershed.

Soils are classified into hydrologic soil groups (HGS) to indicate the minimum rate of infiltration obtained for bare soil after prolonged wetting. The hydrologic soil groups (A, B, C, and D) are one element in determining runoff characteristics. The most excessively drained or permeable soils that promote the most infiltration are included as Group A, while at the other extreme Group D soils typically have impervious cover or other restrictions that restrict infiltration. The HGS is a means of characterizing the ability of the soil to infiltrate water during a rainfall event. A variety of hydrologic soil groups are present in the Willow Brook watershed, with Groups B and D being the most prevalent group due to the urbanization of the area.



SOURCE(S):
Bing Aerial Hybrid
CT DEEP Surficial Materials 1992

N

Figure 2-5: Surficial Materials

MXD: V:\2854-37\GIS\Maps\Surficial Materials.mxd

Willow Brook Flood Mitigation Study

LOCATION: East Hartford, Connecticut

Map By:	CMP
MMI#:	2854-37
Original:	7/20/2015
Revision:	8/3/2015
Scale:	1 in = 2,250 ft

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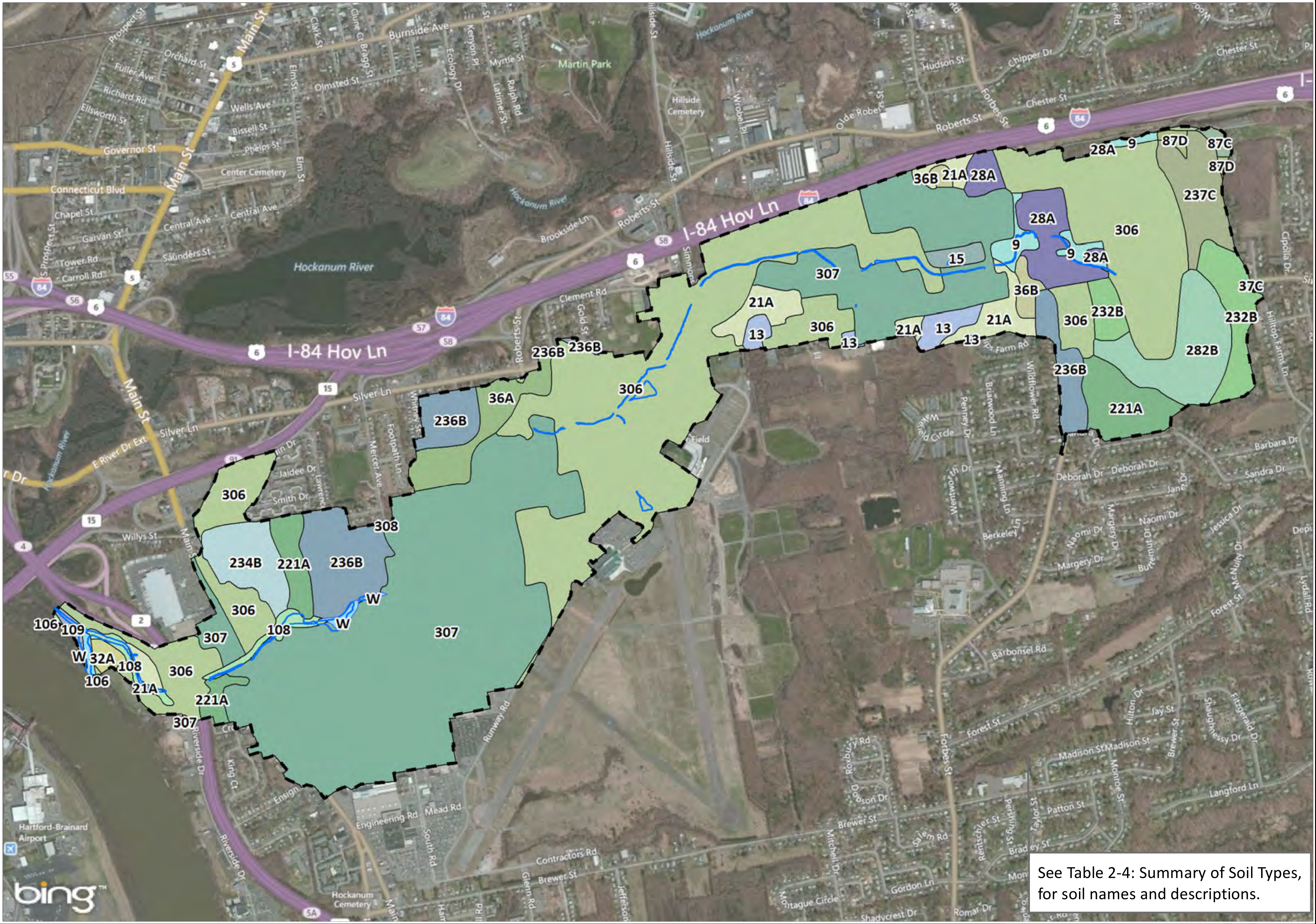


SOURCE(S): Bing Aerial Hybrid CT DEEP Soils 2009	N	**Figure 2-6: Soils Map**	**Willow Brook Flood Mitigation Study**	Map By: CMP MMI#: 2854-37 Original: 7/20/2015 Revision: 8/3/2015 Scale: 1 in = 2,250 ft	MILONE & MACBROOM 99 Realty Drive Cheshire, CT 06410 (203) 271-1773 Fax: (203) 272-9733 www.miloneandmacbroom.com
	MXD: V:\2854-37\GIS\Maps\Soils.mxd		LOCATION: East Hartford, Connecticut		

TABLE 2-4
Summary of Soil Types

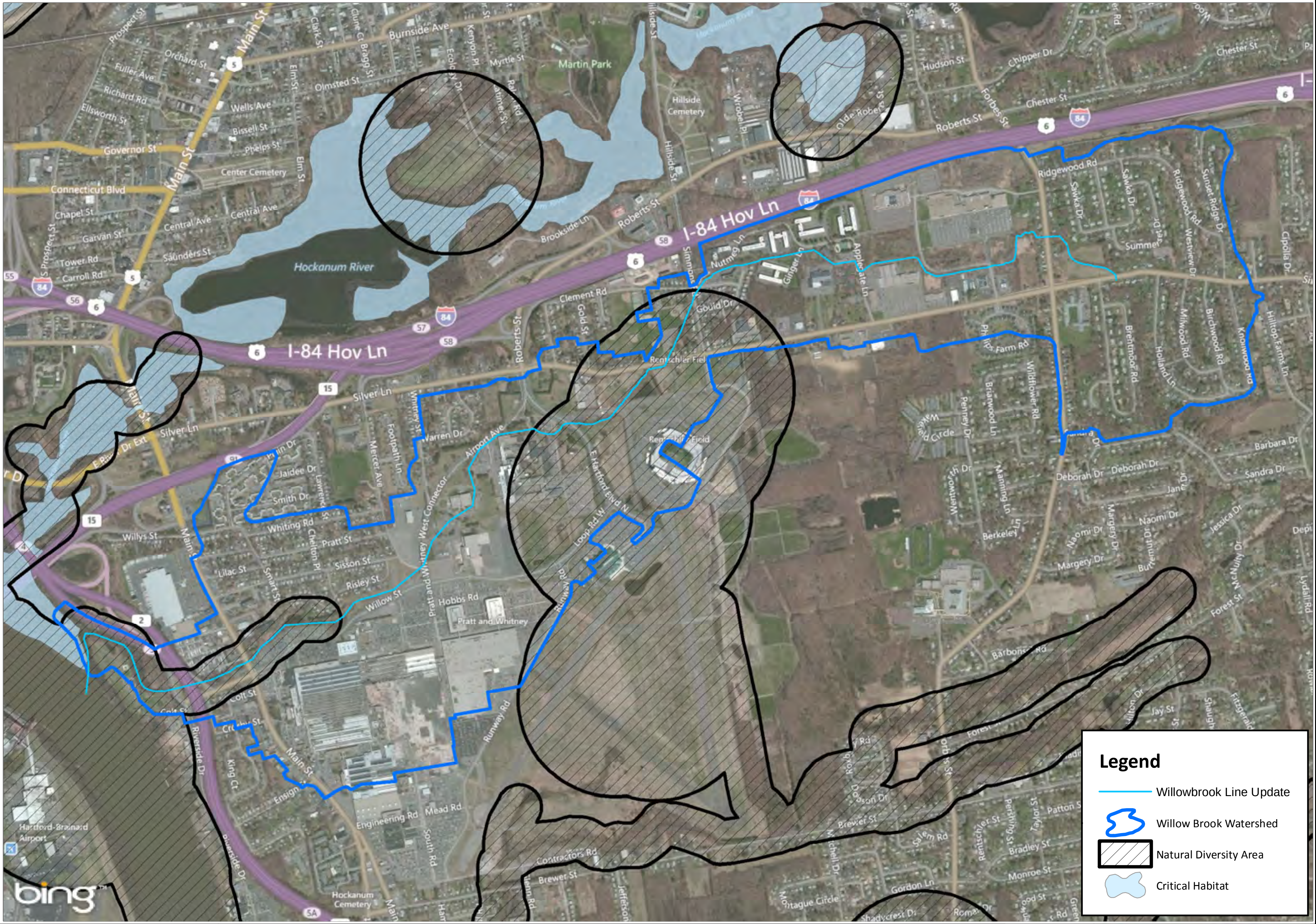
Soil Map Unit	Soil Name	Additional Soil Description	Hydrologic Soil Group	Acres	Percent
307	Urban land	---	B/D	352.6	34.4%
306	Udorthents-Urban land complex	---	B	342.4	33.4%
236B	Windsor-Urban land complex	0 to 8 percent slopes	A	57.5	5.6%
221A	Ninigret-Urban land complex	0 to 5 percent slopes	B	36.4	3.6%
282B	Broadbrook-Urban land complex	3 to 8 percent slopes	C	35.4	3.5%
21A	Ninigret and Tisbury soils	0 to 5 percent slopes	B	28.8	2.8%
232B	Haven-Urban land complex	0 to 8 percent slopes	B	27.0	2.6%
28A	Elmridge fine sandy loam	0 to 3 percent slopes	C	25.5	2.5%
237C	Manchester-Urban land complex	3 to 15 percent slopes	A	23.2	2.3%
36A	Windsor loamy sand	0 to 3 percent slopes	A	21.4	2.1%
234B	Merrimac-Urban land complex	0 to 8 percent slopes	B	21.2	2.1%
13	Walpole sandy loam	---	D	10.5	1.0%
9	Scitico, Shaker, and Maybid soils	---	D	9.5	0.9%
108	Saco silt loam	---	D	8.9	0.9%
36B	Windsor loamy sand	3 to 8 percent slopes	A	5.9	0.6%
15	Scarboro muck	---	D	4.3	0.4%
W	Water	---	D	3.2	0.3%
32A	Haven and Enfield soils	0 to 3 percent slopes	B	3.1	0.3%
87D	Wethersfield loam	15 to 25 percent slopes	C	2.4	0.2%
109	Fluvaquents-Udifluvents complex	Frequently flooded	D	2.2	0.2%
87C	Wethersfield loam	8 to 15 percent slopes	C	2.1	0.2%
106	Winooski silt loam	---	B	0.4	~0.0%
308	Udorthents	Smoothed	B	0.1	~0.0%

2.5 Bedrock Geology

According to the 1985 *Bedrock Geologic Map of Connecticut*, the entire Willow Brook watershed is underlain by Portland Arkose, a reddish-brown to maroon micaceous arkose and siltstone and red to black fissile silty shale from the Lower Jurassic geologic age. The Portland Arkose formation is a brown, fine-grained sandstone and is usually referred to as brownstone. According to various studies by the USGS, glacial sediment thickness is greater than 50 feet (and greater than 300 feet in some areas) downstream of Applegate Lane. It is unlikely that bedrock geology has a significant effect on streamflow conditions downstream of Applegate Lane. Upstream of Applegate Lane, the depth to bedrock is generally less than 50 feet, but is less than 10 feet in the vicinity of Forbes Street. The shallow bedrock geology could influence base flow conditions in this area.

2.6 Threatened and Endangered Species

Figure 2-7 presents the natural diversity database areas and critical habitat areas in and around the Willow Brook watershed. The natural diversity database (NDDB) areas represent the approximate location of state and federal listed species and significant natural communities. This information has been collected by CT DEEP staff, cooperating scientists, conservation groups and landowners.



SOURCE(S): Bing Maps Hybrid CT DEEP Bedrock Geology 1985	N MXD: V:\2854-37\GIS\Maps\NDDB.mxd	**Figure 2-7: NDDB Map**	**Willow Brook Flood Mitigation Study** LOCATION: East Hartford, Connecticut	Map By: CMP MMI#: 2854-37 Original: 8/3/2015 Revision: 5/19/2015 Scale: 1 in = 2,250 ft

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Figure 2-7 also depicts the location and distribution of selected critical habitats in the state of Connecticut. Connecticut critical habitats can serve to highlight ecologically significant areas and target areas of species diversity. The results of critical habitat search indicate that the Willow Brook watershed contains floodplain forest habitat along the Connecticut River. This area is unlikely to be affected by any flood mitigation efforts in the Willow Brook watershed.

Two areas of the Willow Brook watershed contain areas mapped in the NDDB. The first area is the lower reach of Willow Brook from the Connecticut River upstream to Lower Willow Brook Pond. The second area includes the Willow Brook corridor from the inlet of the Pratt & Whitney Conduit upstream to Cumberland Drive, and encompasses Rentschler Field and the northeastern portion of the Pratt & Whitney campus. The presence of such species can impact the ability to obtain state and federal permits for projects in these areas. Additional correspondence with state and/or federal agencies may be required for any contemplated work in these areas.

2.7 Bridge and Culvert Crossing Inventory

Bridge and culvert spans and heights were measured as part of field investigations and survey. Table 2-5 summarizes the bridge measurements collected. A specific identification number has been assigned to each structure. The first number refers to the reach within which the structure is located and the second number is chronological, beginning from the downstream direction and moving upstream.

The Connecticut Department of Transportation (CTDOT) maintains three state-owned roadways in the Willow Brook watershed. Interstate 84 is not included in the watershed, as its stormwater drainage systems are directed northerly towards the Hockanum River basin. The state-owned roadways within the watershed are CT Route 2, CT Route 517 (Main Street), and CT Route 502 (Silver Lane).

As part of the regular maintenance of state roadways, all bridges and culverts that convey Willow Brook beneath them are subject to State of Connecticut inspection at scheduled intervals based upon their size and importance. The most recent of these inspections records were obtained for these road crossings, as available, and have been appended to this report in Appendix D. Information from these reports was used to verify field measurements. Figure 2-8 provides an index map of the culverts found on Willow Brook.

2.8 Culvert Inspections

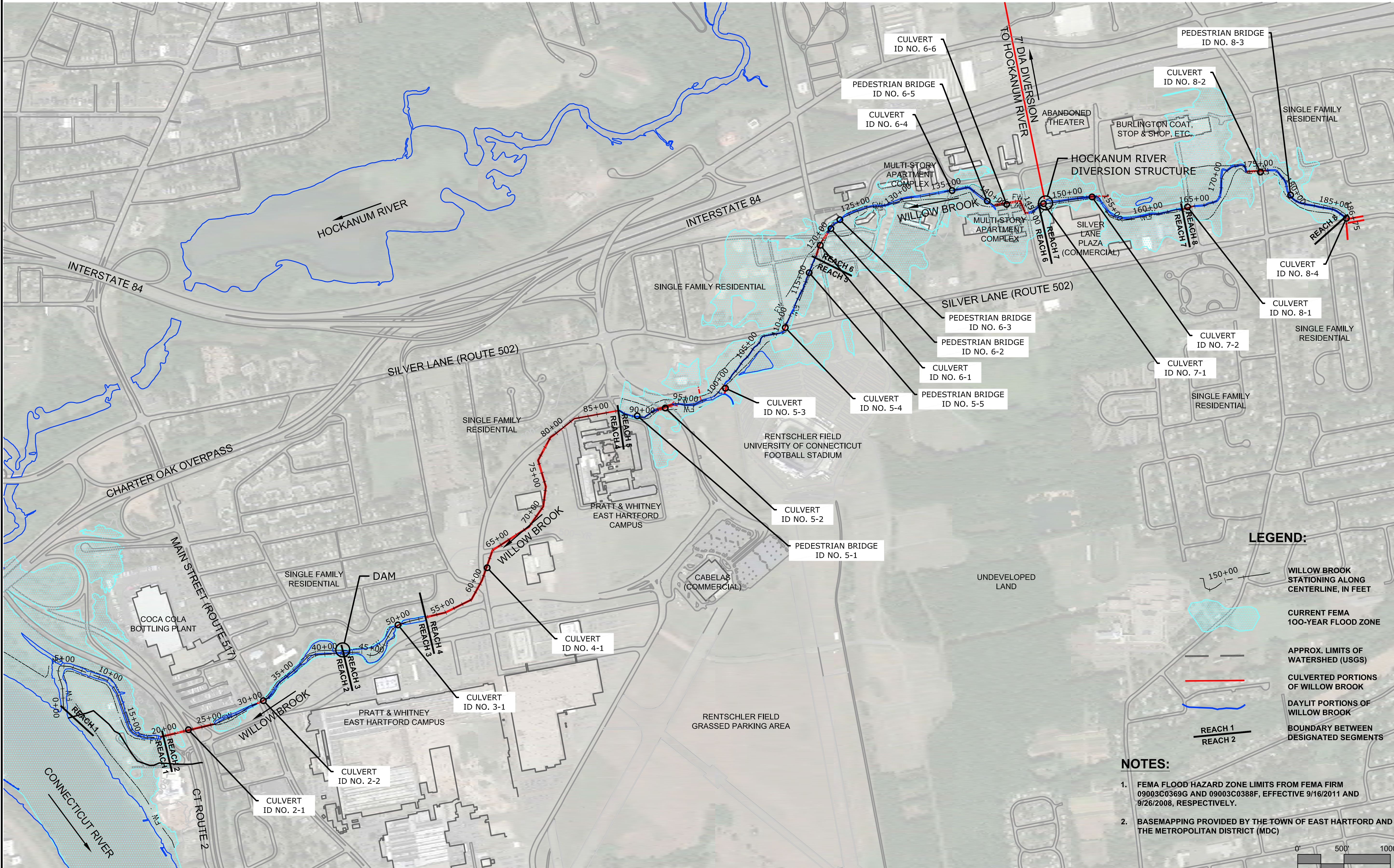
Closed Circuit Television (CCTV) inspection of certain underground portions of Willow Brook was performed. Culverts selected for CCTV inspection were based on age, length, ownership, accessibility, and ability to inspect visually (with higher priority given to those that could not be easily inspected visually). Seven culverts were ultimately selected. These are summarized in Table 2-6.

During field investigations, the camera was mounted on a remotely controlled tractor that was “driven” through each culvert. The video feed from the camera was recorded and the general condition of each pipe was assessed for debris, sedimentation, root penetration, structural issues, and general condition. The work was performed by National Water Main Cleaning Co. (NWMCC) in May of 2015. The ensuing narrative summarizes this effort. The full report provided by NWMCC is provided in Appendix E.

TABLE 2-5
Summary of Stream Crossing Data

ID	Crossing	D/S Sta	Length (ft)	Number, Size, Type	Owner
2-1	Route 2	19+75	610	10'H x 12'W Conc. Box	State of CT
2-2	CT Route 517 (Main St)	30+50	125	10'H x 10'W 3-Sided Conc. Box	State of CT
3-1	P&W Access Road	48+80	75	108" Dia CMP	Pratt & Whitney
4-1	P&W Campus	52+30	3,475	Varies, See Section 2.12.3	Pratt & Whitney
5-1	P&W Pedestrian Bridge	89+05	5	8'H x 50' Span Prefab. Steel Truss	Pratt & Whitney
5-2	East Hartford Blvd	91+40	180	7'H x 20'W 3-Sided Conc. Box	State of CT
5-3	Rentschler Field Access Drive	98+60	100	48" Dia RCP	State of CT
5-4	Silver Lane	108+60	70	U/S: 4'7"H x 6'1"W ACCMP Pipe-Arch D/S: 3'H x 6'W ACCMP Elliptical	State of CT
5-5	Pedestrian Bridge	116+75	5	5'H x 20'W Timber Frame	Private
6-1	Simmons Road / Cumberland Drive	117+45	280	U/S: 2'H x 10'W Conc. Box, 3-Sided D/S: (2x) 2'H x 5'W Conc. Box, 3-Sided	Town of East Hartford
6-2	Pedestrian Bridge	121+30	5	3.5'H x 16'W Timber Frame	Private
6-3	Pedestrian Bridge	122+95	5	2'H x 20'L Timber Frame	Private
6-4	Ginger Lane (Woodcliff Estates)	134+50	80	(4x) 46"H x 60"W ACCMP Pipe-Arch	Private
6-5	Pedestrian Bridge	137+80	5	3'H x 16'W Timber Frame	Private
6-6	Applegate Lane	140+05	475	(2x) 60" Dia CMP	Private
7-1	Hockanum River Diversion	146+40	45	48" Dia RCP	Town of East Hartford
7-2	Abandoned Bridge Behind Shopping Center	151+75	40	(2x) 4'H x 8'W Concrete Box	Private
8-1	Charter Oak Mall Shopping Center	163+20	100	(2x) 60" RCP, one blocked RCP	Private
8-2	Forbes Street	175+65	215	4'H x 10'W Concrete Box	Town of East Hartford
8-3	Farm Access	178+60	10	46"H x 96"W Concrete Box, 3 Sided	Town of East Hartford
8-4	Silver Lane Culvert	186+75	75	(2x) 24" Dia RCP	State of CT

Notes:
1. RCP = Reinforced Concrete Pipe
2. CMP = Corrugated Metal Pipe
3. ACCMP = Asphalt Coated Corrugated Metal Pipe



LEGEND:

- 150+00 — WILLOW BROOK STATIONING ALONG CENTERLINE, IN FEET
- CURRENT FEMA 100-YEAR FLOOD ZONE
- APPROX. LIMITS OF WATERSHED (USGS)
- CULVERTED PORTIONS OF WILLOW BROOK
- DAYLIT PORTIONS OF WILLOW BROOK
- REACH 1 / REACH 2 — BOUNDARY BETWEEN DESIGNATED SEGMENTS

NOTES:

1. FEMA FLOOD HAZARD ZONE LIMITS FROM FEMA FIRM 09003C0369G AND 09003C0388F, EFFECTIVE 9/16/2011 AND 9/26/2008, RESPECTIVELY.
2. BASEMAPPING PROVIDED BY THE TOWN OF EAST HARTFORD AND THE METROPOLITAN DISTRICT (MDC)

0' 500' 1000'
0 1/2" 1"
SCALE 1" = 1000'

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WILLOW BROOK - STRUCTURE INVENTORY MAP
WILLOW BROOK FLOOD MITIGATION STUDY
TOWN OF EAST HARTFORD CONNECTICUT

DESIGNED	DRAWN	CHECKED
JCM	JCM	JAG

SCALE: 1"=1000'
DATE: FEB. 2015
PROJECT NO.: 2854-37
SHEET NO.: FIG. 2-8

TABLE 2-6
List of Culvert Crossings for CCTV Inspection

ID	Crossing	D/S Sta	Length (ft)	Type	Size
5-3	Rentschler Field Access	98+60	100	RCP	48" Dia
5-4	Silver Lane	108+60	70	ACCMP Elliptical	3'H x 6'W
6-1	Simmons Rd / Cumberland Drive	117+45	280	Concrete Box,	2'H x 10'W
6-6	Applegate Lane	140+05	475	(Dual) CMP	60" Dia
7-1	Hockanum River Diversion	146+40	45	RCP	48" Dia
8-2	Forbes Street	175+65	215	Conc Box	4'H x 10'W
8-4	Silver Lane Culvert	186+75	75	(Dual) RCP	(2x) 24" Dia

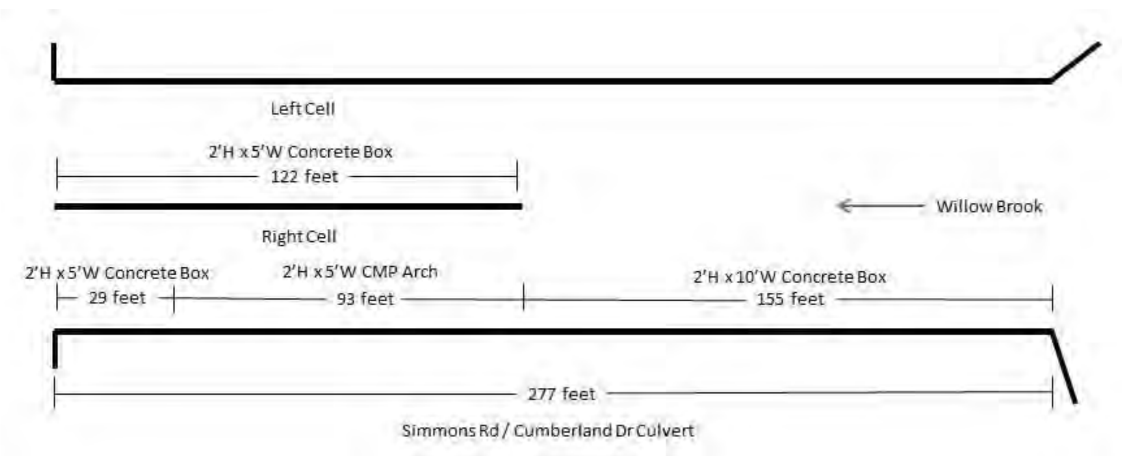
Notes:
1. RCP = Reinforced Concrete Pipe
2. CMP = Corrugated Metal Pipe
3. ACCMP = Asphalt Coated Corrugated Metal Pipe

ID 5-3 Rentschler Field Access; Structure Length – Survey started at upstream end of the culvert with the camera on wheels (crawler). After 50 feet, the crawler became lodged. The contractor attempted to pull the crawler through the culvert but this was not successful. The camera was next mounted to a PVC pipe float and pulled through the culvert. A total of 99 feet of culvert was surveyed, with a video time of six minutes. The culvert was in observed to be in good condition.

ID 5-4 Silver Lane – Survey began at the upstream end of the culvert using the crawler. Rust was visible along the bottom of the culvert and sand buildup was visible at the upstream end. A total of 65 feet was surveyed, with a video time of seven minutes.

ID 6-1 Simmons Road / Cumberland Road – This concrete box culvert changes to a CMP arch pipe after 29 feet. The pipe was observed to be in generally good condition with some rust. The concrete box culvert was observed to have some deterioration near the top corners and sand buildup was visible throughout the channel. At 122 feet, the culvert split into two separate cells. A total of 277 feet of the right cell was surveyed. The left cell was not surveyed, as the debris accumulation did not allow. Figure 2-9 provides a schematic of this structure.

FIGURE 2-9
Simmons Road / Cumberland Drive Culvert Schematic



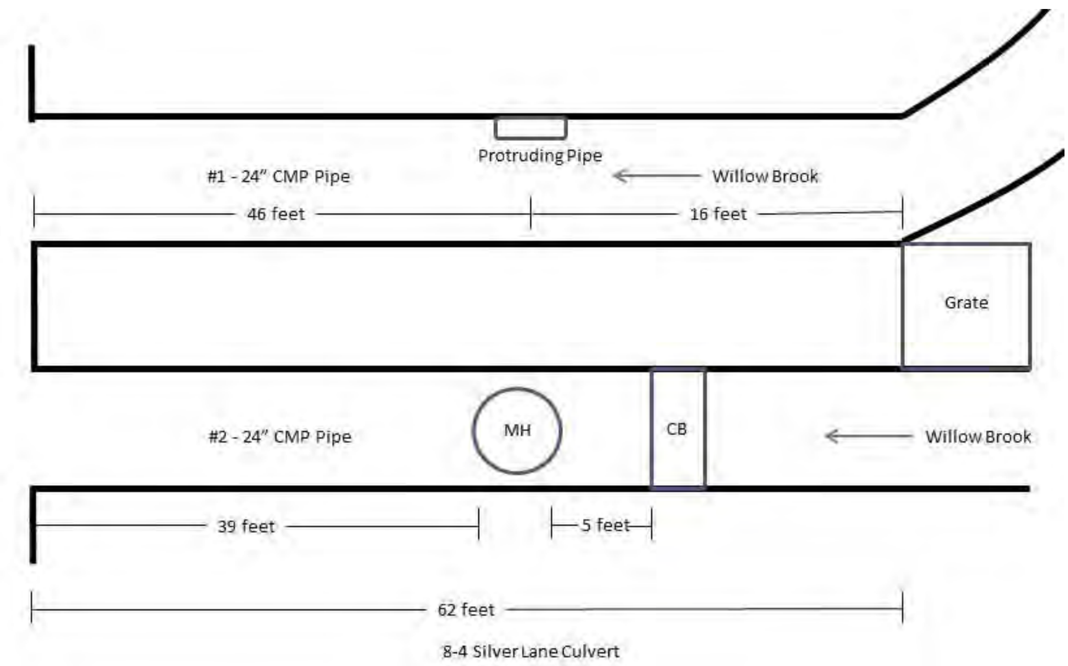
ID 6-6 Applegate Lane – This crossing was visually assessed; however, the accumulation of soft silt did not allow camera inspection. Over half of the culvert was filled with silt, organics, and debris, and inspection was not possible.

ID 7-1 Willow Brook at the Hockanum River Diversion – This culvert was found to be in good condition. A rust hole was observed at the top of the sluice gate. A total of 37 feet was inspected.

ID 8-2 Forbes Street – The camera was manually advanced through this culvert. Some groundwater bleedout through some joints was observed as well as weep holes and a few outfalls, all of which were documented. A total of 214 feet was surveyed.

ID 8-4 Silver Lane – This structure is comprised of two 24-inch diameter reinforced concrete pipes (RCP). The left and right cells (looking upstream) are referenced as #1 and #2, respectively. Survey began at the downstream end at cell #1. Broken pieces of concrete were observed next to the outfall. A total of 62 feet and 44 feet were surveyed for Cell #1 and #2, respectively. Figure 2-10 provides a schematic of this structure.

FIGURE 2-10
Silver Lane Culvert Schematic



2.9 Stormwater Outfall Inventory

Overland runoff within the Willow Brook watershed is almost entirely collected by stormwater systems and conveyed into the brook. Mapping of the stormwater collection and conveyance systems was provided by the Town of East Hartford. This data was previously collected in support of their National Pollutant Discharge Elimination System (NPDES) regulatory compliance efforts. The mapping was compiled by MMI along with mapping from Pratt & Whitney and the Metropolitan District Commission

(MDC) to create a composite map of the stormwater collection systems in the Willow Brook watershed. This information was field checked by MMI staff at discharge points, independently measured, and documented.

The final extents of drainage were used to refine the overall watershed delineation of Willow Brook. Table 2-7 presents a summarized list of the stormwater discharge points to Willow Brook. Figure 2-11 provides an index plan of the outfall locations.

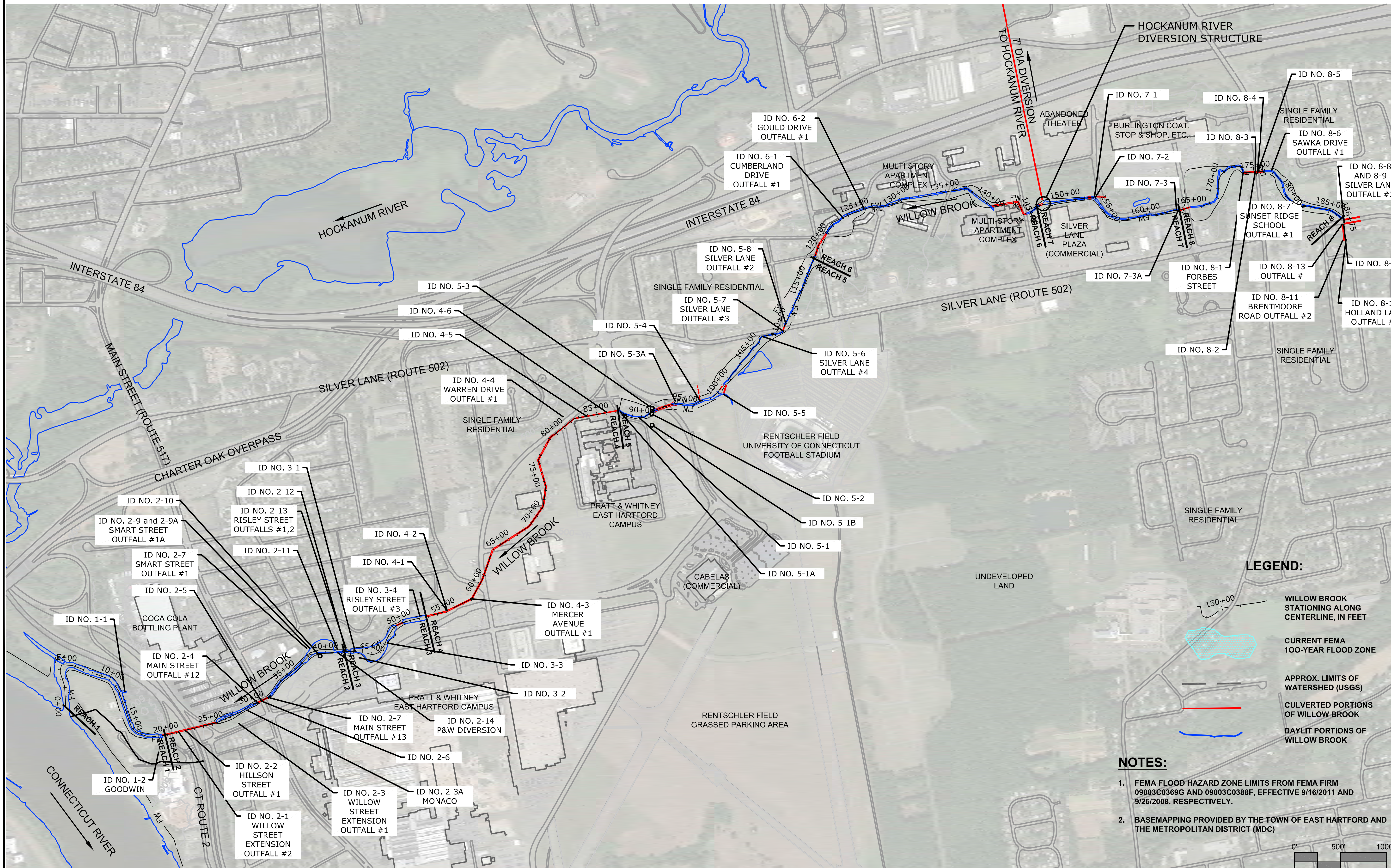
TABLE 2-7
List of Stormwater Discharge Points to Willow Brook

ID	Name	Station	Type	Size	Condition
1-1	Unnamed Outfall	15+55	RCP	18"	Fair
1-2	Goodwin Outfall	19+50	RCP	16"	New
2-1	Willow Street Extension Outfall #2	21+25	RCP	24"	Fair
2-2	Hillson Street Outfall #1	22+00	ACCMP	18"	Poor
2-3	Willow Street Extension Outfall #1	27+70	ACCMP	15"	Good
2-3A	Monroe Muffler Outfall #	28+30	RCP	18"	Poor
2-4	Main Street Outfall #12	30+75	RCP	42"	Good
2-5	Unnamed Outfall	30+90	RCP	24"	Good
2-6	Unnamed Outfall	30+95	RCP	24"	Good
2-7	Main Street Outfall #13	31+80	TILE	10"	N/A
2-8	Smart Street Outfall #1	38+25	CMP	54"	Good
2-9	Smart Street Outfall #1A	38+35	CMP	24"	Fair
2-9A	Smart Street Outfall	38+35	RCP	24"	Poor
2-10	Unnamed Outfall	39+35	---	----	---
2-11	Risley Street Outfalls #1,2	42+20	PVC	10"	Good
2-12	Unnamed Outfall	41+35	Metal	6"	N/A
2-13	Unnamed Outfall	42+20	CMP	12"	N/A
2-14	Unnamed Outfall	42+10	Concrete	(1) 93"Wx49"H (2) 46"Wx46"H	New
3-1	Unnamed Outfall	43+20	Metal	6"	Good
3-2	Unnamed Outfall	44+70	CPP	14"	New
3-3	Unnamed Outfall	47+15	CPP	24"	New
3-4	Risley Street Outfalls #3	52+05	PVC	12"	N/A
4-1	Unnamed Outfall	55+10	---	24"	N/A
4-2	Unnamed Outfall	55+15	RCP	72"	N/A
4-3	Mercer Avenue Outfall #1	58+10	RCP	15"	N/A
4-4	Warren Drive Outfall #1	81+60	RCP	18"	Fair
4-5	Unnamed Outfall	83+85	RCP	15"	Good
4-6	Unnamed Outfall	86+10	CMP	12"	N/A
5-1A	Unnamed Outfall	87+45	RCP	18"	Good
5-1	Unnamed Outfall	87+65	RCP	21"	Good
5-1B	Unnamed Outfall	90+25	CPP	12"	Good
5-2	Unnamed Outfall	91+15	RCP	30"	New

TABLE 2-7 (Continued)
List of Stormwater Discharge Point to Willow Brook

ID	Name	Station	Type	Size	Condition
5-3	Unnamed Outfall	91+50	RCP	24"	New
5-3A	Unnamed Outfall	94+00	RCP	14"	New
5-4	Unnamed Outfall	96+85	ACCMP	18"	Poor
5-5	Unnamed Outfall	99+10	RCP	(2x) 24"	New
5-6	Silver Lane Outfall #4	106+90	CMP	18"	N/A
5-7	Silver Lane Outfall #3	109+15	RCP	36"	Fair
5-8	Silver Lane Outfall #2	110+05	TILE	(2x) 16"	Poor
6-1	Cumberland Drive Outfall #1	123+45	RCP	15"	N/A
6-2A	Nutmeg Lane Outfall #1	126+25	RCP	24"	Fair
6-2	Gould Drive Outfall #1	127+70	RCP	15"	N/A
7-1	Unnamed Outfall	153+05	RCP	27"	N/A
7-2	Unnamed Outfall	153+20	ACCMP	(2x) 36"x60"	Poor
7-3	Unnamed Outfall	163+25	RCP	(2x) 60"	Fair
7-3A	Unnamed Outfall	163+40	RCP	32"	Good
8-1	Forbes Street Outfall #1	173+65	---	---	---
8-2	Unnamed Outfall	174+95	RCP	30"	N/A
8-3	Unnamed Outfall	175+00	CMP	24"	N/A
8-4	Unnamed Outfall	175+25	RCP	24"	N/A
8-5	Unnamed Outfall	175+25	TILE	15"	N/A
8-6	Sawka Drive Outfall #1	176+75	RCP	30"	Good
8-7	Sunset Ridge School Outfall #1	182+05	HDPE	12"	Good
8-8	Silver Lane Outfall #2	186+75	RCP	36"	Fair
8-9	Silver Lane Outfall #2	186+75	RCP	24"	Fair
8-10	Holland Lane Outfall #1	187+30	RCP	15"	N/A
8-11	Brentmoore Road Outfall #2	187+30	RCP	15"	N/A
8-12	Unnamed Outfall	186+80	RCP	24"	Good
8-13	Unnamed Outfall	186+80	RCP	24"	Good

Notes:
1. RCP = Reinforced Concrete Pipe
2. CMP = Corrugated Metal Pipe
3. ACCMP = Asphalt Coated Corrugated Metal Pipe
4. N/A = Outfall shown on mapping but not found



NOTES:

1. FEMA FLOOD HAZARD ZONE LIMITS FROM FEMA FIRM 09003C0369G AND 09003C0388F, EFFECTIVE 9/16/2011 AND 9/26/2008, RESPECTIVELY.
2. BASEMAPPING PROVIDED BY THE TOWN OF EAST HARTFORD AND THE METROPOLITAN DISTRICT (MDC)

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WILLOW BROOK - OUTFALL LOCATION PLAN

WILLOW BROOK FLOOD MITIGATION STUDY

TOWN OF EAST HARTFORD CONNECTICUT

DESIGNED	DRAWN	CHECKED
JCM	JCM	JAG

SCALE: 1"=1000'

DATE: JAN. 2015

PROJECT NO.: 2854-37

SHEET NO.: FIG. 2-11

Plotted by: JAMESM On this date: Mon, 2015 July 27 - 12:08pm

3.0 HYDROLOGIC ASSESSMENT

Determining the volume of water generated during a storm event is necessary to evaluate the extent of flooding. Peak discharges in a stream channel are a function of watershed size, land use characteristics, soil characteristics, vegetation, and rainfall patterns and can be estimated through a variety of hydrologic methods. This streamflow data can then, in turn, be used in conjunction with stream channel characteristics to hydraulically predict the depth and extent of water flow during various flood events.

The numerous hydrologic methods for estimating peak discharge within a watershed have varying degrees of accuracy, with the most accurate method being direct measurement. However, direct measurement of rainfall and streamflows must be performed over very long periods of time to be statistically meaningful. As there are no long-term streamflow gauging stations in the Willow Brook watershed, other hydrologic methods were used to estimate streamflow. The hydrologic methods used to evaluate flows in this study are listed below:

- The USGS maintains streamflow gauges that can be used to predict flows in nearby similar watersheds on a flow per drainage area basis. This method is relatively simiple but generally provides the most highly variable results because no two watersheds are exactly alike.

- The USGS has developed regression equations that use measured streamflows that are cross-referenced with other factors such as basin elevation, slope, watershed size, percentage of urbanization, and the area of the watershed served by storm drainage systems. As the regression equations are developed using field data collected from within Connecticut, the equations are considered to be moderately accurate predictors of streamflow. FEMA utilized such equations when estimating streamflow for the 1977 FIS. The USGS *National Streamflow Statistics* program contains regression equations for rural and urban areas in Connecticut based on data through 2004. The USGS *StreamStats* program provides these same regression equations within a web-based interface.

- The development of hydrologic models using computer programs can yield more accurate results as compared to the use of regression equations, since models take into account site-specific data in the watershed.

It is important to note that when using streamflow data and regression equations to estimate streamflow, that data from past storm events is inherently included. Therefore, factors such as changing rainfall patterns and watershed development over time may not be accurately reflected in the resulting flows unless care is taken to separate the flow data into specific periods.

3.1 Flood Events and Rainfall History

Climate change is predicted to increase the frequency of severe storms in the northeastern United States. Rainfall is expected to become more intense, and periods of heavy rainfall are expected to become more frequent. The Northeast Regional Climate Center (NRCC) reports that severe precipitation events that once occurred with a 100-year (1% ACR) frequency are now likely to occur twice as often.

Until recently, common engineering practice was to design storm drainage systems using the US Weather Service Technical Paper No. 40 (TP-40). The rainfall data presented in TP-40 is from 1961 and does not include the past 50 years of climatological data in which these trending increases in precipitation have been recorded.

Records of flooding in the Willow Brook watershed are sparse and difficult to quantify. A collection of records from various sources indicate that the watershed has experienced flood events, but finding events that align among the independent sources is difficult. The United States Geologic Survey (USGS) maintains stream gauges in the area, on the Hockanum River, Connecticut River, and Broad Brook. Below is a list of data sources investigated:

- Public Comment at Informational Meeting, February 19, 2015
- USGS Gage No. 01184490 – Broad Brook, South Windsor (1962 – current)
- USGS Gage No. 01192500 – Hockanum River, East Hartford (1929 – current)
- USGS Gage No. 01190070 – Connecticut River, Hartford CT (1838 – current)
- CTDOT Drainage Manual Page Appendix E “Major Flood Events in Connecticut Since 1927”
- Brainard Airport (KHFD) Weather Records

The strongest evidence for a significant rainfall event is for October 15, 2010, although no direct reports of flooding from property owners were found. Precipitation for this event was recorded by the Brainard Airport weather station as having 6.4 inches of rain fall in an 8-hour period. According to the CTDOT Drainage Manual intensity/duration/frequency (IDF) relationships, this equates to a 100-year (1% ACR) intensity storm. While this event did not cause the Connecticut River to peak in flood stage, due to the relatively small impact of this weather event relative to its large watershed, both Broad Brook and Hockanum River USGS gauges reported discharge levels higher than the 100-year (1% ACR) flood event.

Reports of flooding in the summer of 1984 seem to align with high flood stages of the Connecticut River reported in the Connecticut Department of Transportation Drainage Manual, but do not align with any significant flooding events as reported by nearby USGS gauges. Table 3-1 summarizes the dates on which various sources indicated flooding, and to what probable extent that flooding occurred.

Table 3-1
Flooding Records in Vicinity of Willow Brook Watershed

Date	USGS Gage #01184490 Broad Brook	USGS Gage #01192500 Hockanum River	USGS Gage #01190070 CT River	CTDOT Drainage Manual	Brainard Airport (KHFD) Weather Data
Oct. 15, 2005	100-Yr (Flood of Record)	50-Yr	-	-	> 100-yr
June 1, 1984	-	10-Yr	50-Yr – 100-Yr	100-yr	-
June 6, 1982	-	10-Yr – 50-Yr	N/A	-	-
Jan. 25, 1979	N/A	50-Yr	N/A	-	-
Jan. 27, 1976	10-Yr	-	N/A	-	-
Sept. 27, 1975	10-Yr – 50-Yr	-	-	-	-
Aug. 1955	N/A	10-Yr – 50-Yr	50-Yr – 100-Yr	> 100-Yr	10-Yr – 50-Yr
Sept. 1938	10-Yr	500-Yr (Flood of Record)	500-Yr	100-Yr	n

Notes: “N/A” indicates no data. “–“ indicates no appreciable flooding reported.

3.2 Peak Flow Estimation

3.2.1 FEMA FIS Discharges

The 2011 FIS published by FEMA provides effective peak discharges at several locations in the Willow Brook watershed. As described in the FIS on page 49 to 50, the peak flow rates were originally estimated by using a regression equation that weighted regionally predicted values with gauge data from 105 gauging stations in Connecticut through 1975 along with gauge data from four nearby gauging stations. The parameters used in the regression analyses were drainage area, rainfall, main channel length, main channel slope, and the extent of storm sewerage available. The peak flows were computed on the basis of selected gage data using the log-Pearson Type III method and transposed to individual locations via a weighting method.

The above method was used for locations at drainage areas greater than one square mile. At stations with less than one square mile of drainage area, the Rational Method was used to estimate peak discharges. A pass-through discharge was determined at the diversion structure and added to downstream flows. Table 3-2 presents the discharges estimated for Willow Brook as presented in the FIS.

Table 3-2
Summary of Peak Discharges for Willow Brook in 2011 FEMA FIS

Location	Drainage Area (square miles)[1]	Peak Discharges (cfs)			
		10-Year (10% ACR)	50-Year (2% ACR)	100-Year (1% ACR)	500-Year (0.2% ACR)
Cross section AA upstream of Hockanum River diversion	0.50	190	350	445	680
Approximately 165 feet upstream of Applegate Lane	0.20 (0.70)	190	320	395	570
Silver Lane	0.50 (1.00)	230	380	475	700
Cross section H (upstream of Pratt & Whitney Conduit)	1.20 (1.70)	275	480	590	1,010
Cross section G (downstream of Pratt & Whitney Conduit)	1.70 (2.20)	330	585	735	1,250
At confluence with Connecticut River	2.40 (2.90)	400	725	915	1,560

Note:
1. The FIS table suggests that FEMA truncated the drainage area at the diversion to the Hockanum River. As such, the total drainage basin area per FEMA was 2.90 square miles.
2. ACR = Annual Chance of Recurrence

FEMA reduced flows downstream of the diversion structure by assuming a pass-through discharge at the sluice gate with the remaining flow passing through the diversion structure to the Hockanum River. Based upon updated assessment, the 10% ACR chance discharge was assumed to flow downstream through the sluice gate, with only 8.6%, 11.2%, and 16.2% of the discharge diverted to the Hockanum River for the 50-year (2% ACR), 100-year (1% ACR), and the 500-year (0.2% ACR) peak discharges, respectively.

Given the changes in discharge rates that have been observed in Connecticut in recent years, and the additional development that has occurred in the Willow Brook watershed since 1977, it is logical that the discharges presented by FEMA are lower than those that are experienced today. However, the delineation of the Willow Brook watershed and the use of the sluice gate have also changed since the late 1970s, which results in lower flows in the lower part of the watershed than would otherwise be expected.

3.2.2 Estimated Flows Based on Recent USGS Regression Equations

The USGS program *StreamStats* version 2.0 was utilized to estimate peak flows within the Willow Brook watershed. This interactive web-based program utilizes regression equations developed by the USGS in 2004 to compute peak flows. The user specifies a point along a watercourse where discharges are to be calculated, and the program delineates a watershed to that point and estimates flows based on drainage area, 24-hour rainfall values, average basin elevation, percentage of wetlands, and other factors. Results of the *StreamStats* analysis are presented in Table 3-3.

Table 3-3
Summary of Peak Discharges Estimated by USGS *StreamStats* Program

Location in Willow Brook Watershed	Drainage Area (square miles)	Peak Discharges (cfs)					
		50% ACR (2-Year)	10% ACR (10-Year)	4% ACR (25-Year)	2% ACR (50-Year)	1% ACR (100-Year)	0.2% ACR (500-Year)
At diversion to Hockanum River	0.26	10.4	22.4	30.0	37.3	43.7	90.7
Upstream of Pratt & Whitney Conduit	0.92	26.1	56.8	80.3	96.7	115	237
At confluence with Connecticut River	2.00	48.9	103	144	179	215	416

The *StreamStats* algorithm conducted for the watershed to the Hockanum River diversion structure appears to be erroneous. The algorithm is not site-specific enough to account for the micro-topography and urban storm drainage systems in the Willow Brook watershed, such that the results should be considered approximate. The watershed delineation for the downstream areas appears to be substantially correct.

The USGS *National Streamflow Statistics* (NSS) software program (version 6.12) was also utilized to generate peak discharges. This program also utilizes the 2004 USGS regression equations for Connecticut, but in conjunction with a 1989 USGS report regarding the effects of urbanization on peak streamflows in Connecticut. Analysis can be performed on both rural and urbanized watersheds, and the user is able to provide urbanization factors to better reflect the watershed where peak discharges are being evaluated. Results of the NSS software program analysis are presented in Table 3-4.

It should be noted that the rainfall values utilized by *StreamStats* to generate peak discharges differ from those published in other sources.

TABLE 3-4
Summary of Peak Discharges Estimated by USGS NSS Software Program

Location in Willow Brook Watershed	Drainage Area (square miles)	Peak Discharges (cfs)					
		50% ACR (2-Year)	10% ACR (10-Year)	4% ACR (25-Year)	2% ACR (50-Year)	1% ACR (100-Year)	0.2% ACR (500-Year)
Rural Equations							
At diversion to Hockanum River	0.54	42.5	94.7	125	147	171	225
Upstream of Pratt & Whitney Conduit	0.90	62.4	139	185	218	254	339
At confluence with Connecticut River	1.61	96.9	217	288	343	400	541
Urban Equations							
At diversion to Hockanum River	0.54	91.4	177	214	252	287	347
Upstream of Pratt & Whitney Conduit	0.90	135	262	317	373	427	516
At confluence with Connecticut River	1.61	210	407	495	583	673	820
Urban Equations (Extreme Input Limits)							
At diversion to Hockanum River	0.54	177	326	386	445	506	604
Upstream of Pratt & Whitney Conduit	0.90	243	450	536	618	707	847
At confluence with Connecticut River	1.61	379	700	837	967	1,110	1,350

3.2.3 Estimated Flows Based on Nearby USGS Gauging Stations

The data from four long-term USGS gauging stations located near the Willow Brook watershed were evaluated to estimate peak discharges along Willow Brook. Peak flow data from each gauging station were downloaded from the USGS website and analyzed using the USGS computer program PKFQWin version 5.2. The four gauges analyzed include the Hockanum River at East Hartford, North Branch Park River at Hartford, Stony Brook near West Suffield, and Broad Brook at Broad Brook. Characteristics of each gauging station are summarized in Table 3-5.

TABLE 3-5
USGS Gauging Station Information

Gauging Station	USGS ID#	Drainage Area (square miles)	Period of Record for Peak Streamflows		
			Begin Date	End Date	Years of Data
Hockanum River at East Hartford, CT	01192500	73.4	Mar. 3, 1920	Jun. 14, 2013	87
North Branch Park River at Hartford, CT	01191000	26.8	Mar. 12, 1936	Apr. 16, 1996	53
Stony Brook near West Suffield, CT	01184100	10.4	Sep. 12, 1960	Jun. 14, 2013	54
Broad Brook at Broad Brook, CT	01184490	15.5	Sep. 21, 1938	Jun. 14, 2013	48

The ideal USGS gauging station for comparing streamflows would measure flow in a relatively small, urbanized watershed with a recent period of record. Out of the four gauging stations, the Hockanum River gauge is the nearest to the Willow Brook watershed but also has the largest drainage area. The Stony Brook and Broad Brook gauges drain smaller watershed areas than the Hockanum River, but also drain areas that are much more rural than the Willow Brook watershed. The North Branch Park River gauge also drains a significantly urbanized watershed, but the available peak flow data is not as recent. The data for the North Branch Park River gauging station also indicates that the data was under a known effect of regulation or urbanization beginning in 1963. As such, although the basin is urbanized the peak discharges may also be regulated by upstream storage. Therefore, the data from each station is considered to have pros and cons for this analysis. Peak discharge estimates obtained through this analysis are presented in Table 3-6.

TABLE 3-6
Summary of Peak Discharges for Nearby USGS Gauging Stations

Location in Willow Brook Watershed	Drainage Area (square miles)	Peak Discharges (cfs)					
		50% ACR (2-Year)	10% ACR (10-Year)	4% ACR (25-Year)	2% ACR (50-Year)	1% ACR (100-Year)	0.2% ACR (500-Year)
Hockanum River at East Hartford, CT	73.4	1,101	2,291	3,030	3,642	4,306	6,085
North Branch Park River at Hartford, CT	26.8	1,173	2,766	4,061	5,331	6,931	12,500
Stony Brook near West Suffield, CT	10.4	415	1,023	1,462	1,856	2,313	3,668
Broad Brook at Broad Brook, CT	15.5	402	898	1,239	1,538	1,877	2,856

In order to compare the peak discharge data in Table 3-6 to other estimated flows for Willow Brook, the discharge data can be normalized by drainage area. Unit peak discharges for the USGS gauging station data are presented in Table 3-7. This process also allows for discharges to be estimated at a variety of points within the Willow Brook watershed.

TABLE 3-7
Summary of Unit Peak Discharges for Nearby USGS Gauging Stations

Location in Willow Brook Watershed	Drainage Area (square miles)	Peak Discharges (cfs)					
		50% ACR (2-Year)	10% ACR (10-Year)	4% ACR (25-Year)	2% ACR (50-Year)	1% ACR (100-Year)	0.2% ACR (500-Year)
Hockanum River at East Hartford, CT	73.4	15.0	31.2	41.3	49.6	58.7	82.9
North Branch Park River at Hartford, CT	26.8	43.8	103	152	199	259	466
Stony Brook near West Suffield, CT	10.4	39.9	98.4	141	178	222	353
Broad Brook at Broad Brook, CT	15.5	25.9	58.0	79.9	99.2	121	184

3.2.3 Summary of Estimated Flows

The estimated flows in the preceding sections represent a variety of locations and incorporate a variety of drainage basin areas. In order to provide a direct comparison of flows between each method and the location in the watershed, flows from the FIS and the USGS *StreamStats* program were normalized by watershed area and converted to be consistent with the drainage area for the Hockanum River diversion, the entrance to the Pratt & Whitney Conduit, and the total watershed area to the Connecticut River. Table 3-8 presents the estimated flows presented in the preceding sections as applied to the Willow Brook watershed. A brief summary of the overall effectiveness and reliability of these estimation methods follows.

TABLE 3-8
Summary of Estimated Peak Discharges for Willow Brook

Location in Willow Brook Watershed	Drainage Area (square miles)	Peak Discharges (cfs)					
		50% ACR (2-Year)	10% ACR (10-Year)	4% ACR (25-Year)	2% ACR (50-Year)	1% ACR (100-Year)	0.2% ACR (500-Year)
FEMA FIS							
At diversion to Hockanum River	0.54	N/A	205	N/A	378	481	734
Upstream of Pratt & Whitney Conduit	0.90	N/A	206	N/A	360	443	758
At confluence with Connecticut River	1.61	N/A	268	N/A	486	614	1,047
USGS StreamStats							
At diversion to Hockanum River	0.54	21.6	46.5	62.3	77.5	90.8	188
Upstream of Pratt & Whitney Conduit	0.90	25.5	55.6	78.6	94.6	113	232
At confluence with Connecticut River	1.61	36.9	77.8	109	135	162	314
USGS NSS Rural Equations							
At diversion to Hockanum River	0.54	42.5	94.7	125	147	171	225
Upstream of Pratt & Whitney Conduit	0.90	62.4	139	185	218	254	339
At confluence with Connecticut River	1.61	96.9	217	288	343	400	541
USGS NSS Urban Equations							
At diversion to Hockanum River	0.54	91.4	177	214	252	287	347
Upstream of Pratt & Whitney Conduit	0.90	135	262	317	373	427	516
At confluence with Connecticut River	1.61	210	407	495	583	673	820
USGS NSS Urban Equations (Extreme Input Limits)							
At diversion to Hockanum River	0.54	177	326	386	445	506	604
Upstream of Pratt & Whitney Conduit	0.90	243	450	536	618	707	847
At confluence with Connecticut River	1.61	379	700	837	967	1,110	1,350

TABLE 3-8 (Cont.)
Summary of Estimated Peak Discharges for Willow Brook

Location in Willow Brook Watershed	Drainage Area (square miles)	Peak Discharges (cfs)					
		50% ACR (2-Year)	10% ACR (10-Year)	4% ACR (25-Year)	2% ACR (50-Year)	1% ACR (100-Year)	0.2% ACR (500-Year)
USGS Peak Flow Analysis Based on Hockanum River Gauging Station, East Hartford, CT							
At diversion to Hockanum River	0.54	8.1	16.9	22.3	26.8	31.7	45
Upstream of Pratt & Whitney Conduit	0.90	13.5	28.1	37.2	44.7	52.8	75
At confluence with Connecticut River	1.61	24.2	50.3	66.5	79.9	94.5	133
USGS Peak Flow Analysis Based on North Branch Park River Gauging Station, Hartford, CT							
At diversion to Hockanum River	0.54	23.6	55.7	81.8	107	140	252
Upstream of Pratt & Whitney Conduit	0.90	39.4	93	136	179	233	420
At confluence with Connecticut River	1.61	70.5	166	244	320	416	751
USGS Peak Flow Analysis Based on Stony Brook Gauging Station, Suffield, CT							
At diversion to Hockanum River	0.54	21.5	53.1	75.9	96.4	120	190
Upstream of Pratt & Whitney Conduit	0.90	35.9	88.5	127	161	200	317
At confluence with Connecticut River	1.61	64.2	158	226	287	358	568
USGS Peak Flow Analysis Based on Broad Brook Gauging Station, Broad Brook, CT							
At diversion to Hockanum River	0.54	14.0	31.3	43.2	53.6	65.4	99
Upstream of Pratt & Whitney Conduit	0.90	23.3	52.2	71.9	89.3	109	166
At confluence with Connecticut River	1.61	41.8	93.3	129	160	195	297

- Only the normalized FEMA FIS flows attempted to account for an operating condition at the Hockanum River diversion structure. These flows are considered to be reliable although the underlying rainfall values are believed to be out of date.

- The USGS *StreamStats* software, the USGS NSS Rural Equations, and the USGS Peak Flow Analysis transforms for the Hockanum River, Stony Brook, and Broad Brook gauging stations are believed to underestimate flow in the Willow Brook watershed. It is believed that these methods are underestimating the amount of impervious surfaces in the watershed. The underlying rainfall values are also less current than other data (see discussion in Section 3.2.7).

- The USGS Peak Flow Analysis Transform for the North Branch Park River gauging station provides a higher estimate of peak flows, but not as high as the FEMA FIS flows. Although this watershed is urbanized, the watershed is much larger than the Willow Brook watershed and areas of regulation by dams or upstream rural areas are possible.

- The USGS NSS Urban Equations also appear to provide a reasonable estimate of peak flows, as they take into account the urbanized nature of the watershed. Many of the flow estimates are similar to the normalized FEMA FIS flows. However, these flows do not account for the Hockanum River diversion.

These peak flow estimates will be compared to the modeled flows calculated using hydrologic modeling prepared for this study. A description of the hydrologic assessment and model is provided in the following section.

3.3 HEC-HMS Assessment

In order to assess the flow conditions in the Willow Brook watershed, a hydrologic model was developed using the computer modeling program known as the Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS) version 4.0. This hydrologic modeling program was developed by the United States Army Corps of Engineers to forecast the rate of surface water runoff and river flow rates based on several sub-watershed factors. The rate of river flow is necessary to prepare an updated hydraulic assessment (Section 4.0).

The HEC-HMS program was designed to model a wide variety of watersheds ranging from large and rural to small urban watersheds such as Willow Brook. The model input data includes information such as contributing watershed area, the runoff curve number (CN), the lag time of the watershed, the available storage volume within the watershed, the channel routing, and rainfall data for the area. Each of these elements is described in the ensuing text.

3.3.1 Subwatershed Delineations

Base mapping of the Willow Brook watershed was obtained from the Town of East Hartford and other sources. The mapping included MDC base maps, Town of East Hartford topographic maps, and plan sets related to various developments completed or ongoing in the Willow Brook watershed. The information included two-foot topographic contours and the location of roadways, catch basins, storm sewers, buildings, and parking lots. Additional topographic information was obtained from the statewide two-foot topographic contours developed in 2000 by the University of Connecticut's Center for Land Use Education and Research (CLEAR). These topographic contours are available through the Connecticut DEEP GIS website.

The overall Willow Brook watershed was delineated on the basis of contributing topographic areas with consideration given for localized drainage boundaries that occur due to the presence of storm sewers and catch basins. The overall Willow Brook watershed drains 1.61 square miles in the Town of East Hartford to its confluence with the Connecticut River.

Willow Brook does not appear to have any natural tributaries, although several storm drainage ditches are directed to the brook. Numerous stormwater outfalls also direct flow into the brook. In order to properly account for the numerous flow inputs into the main stem of Willow Brook, the watershed was divided into 57 sub-watersheds for analysis. Table 3-9 provides a general geographic description of the outlet point or point of analysis of each sub-watershed. Figures 3-1, 3-2, and 3-3 present the overall watershed boundary and the delineated sub-watershed boundaries. Nomenclature for the sub-watersheds is provided as follows:

Sub-Watershed Flow Direction

Willow Brook Flood Mitigation Study

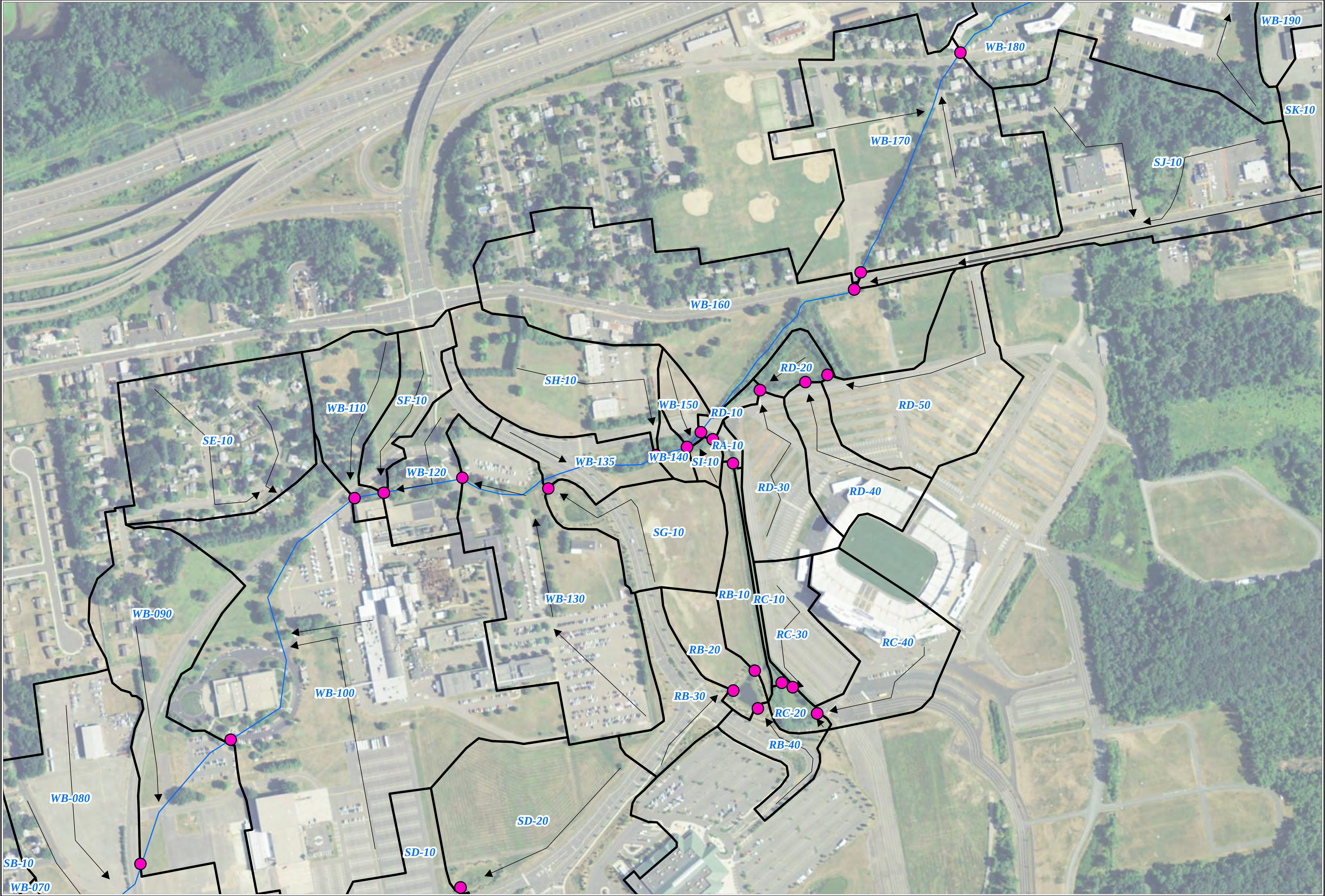
East Hartford, Connecticut

SOURCE(S):
Pratt and Whitney
Town of East Hartford
CT DEEP 2012 Aerial Imagery

MILONE & MACBROOM
99 Realty Drive
Cheshire, Connecticut 06410
(203) 271-1773 Fax (203) 272-9733
www.miloneandmacbroom.com

Map By: CMP
MMI#: 2854-37
MXD: V:\2854-37\GIS\Maps\Lower Sub-Watershed Tc.mxd
1st Version: 2/10/2015
Revision: 8/3/2015
Scale: 1 in = 500 ft

Figure 3-1



Sub-Watershed Flow Direction

Willow Brook Flood Mitigation Study

East Hartford, Connecticut

SOURCE(S):
Pratt and Whitney
Town of East Hartford
CT DEEP 2012 Aerial Imagery

MILONE & MACBROOM
99 Realty Drive
Cheshire, Connecticut 06410
(203) 271-1773 Fax (203) 272-9733
www.miloneandmacbroom.com

Map By: CMP
MMI#: 2854-37
MXD: V:\2854-37\GIS\Maps\Mid Sub-Watershed Tc.mxd
1st Version: 2/10/2015
Revision: 8/3/2015
Scale: 1 in = 383 ft

Figure 3-2

Milone & MacBroom
99 Realty Drive
Cheshire, Connecticut 06410
(203) 271-1773 Fax (203) 272-9733
www.miloneandmacbroom.com

SOURCE(S):
Pratt and Whitney
Town of East Hartford
CT DEEP 2012 Aerial Imagery

Sub-Watershed Flow Direction

Willow Brook Flood Mitigation Study

East Hartford, Connecticut

Map By: CMP
MMI#: 2854-37
MXD: V:\2854-37\GIS\Maps\Upper Sub-Watershed Tc.mxd
1st Version: 2/10/2015
Revision: 8/3/2015
Scale: 1 in = 500 ft

Figure 3-3

- Sub-watersheds are numbered in the upstream direction. Spacing is provided in the numbering system to allow for additional sub-watershed delineations as a project progresses.

- Sub-watersheds that represent direct input into Willow Brook are denoted with "WB" and range from "WB-010" to "WB-260".

- Sub-watersheds that represent local stormwater collection systems that outfall to Willow Brook are denoted with "S" followed by an identification letter. For example, these sub-watersheds range from "SA-10" to "SM-10". In some cases, these watersheds may have upstream tributaries which are denoted in the traditional manner of upstream numbering.

- Sub-watersheds that represent local stormwater collection systems at and around Rentschler Field were denoted with "R" followed by an identification letter. In all other respects, this category is the same as for "S" sub-watersheds

- Finally, one sub-watershed associated with collecting stormwater from Pratt & Whitney was denoted as "PR-10". This delineation was added later in the analysis process and received a new numbering scheme so as to not renumber the "S" sub-watersheds.

TABLE 3-9
Willow Brook Sub-Watershed Descriptions

Sub-watershed	Area (acres)	Downstream Analysis Point
		Main Stem of Willow Brook
WB-10	13.54	Confluence of Willow Brook with the Connecticut River
WB-20	7.50	Downstream of Sewage Treatment Plant / Confluence of SA-10
WB-30	15.38	Outlet of Route 2 box culvert
WB-40	73.68	Inlet to Route 2 box culvert
WB-50	19.75	Inlet to Main Street culvert / Confluence of SB-10, PR-10, and SB-10
WB-60	8.08	Pratt and Whitney Dam / Confluence of SC-10, PR-10 (overflow only)
WB-70	5.53	Inlet to culvert downstream of "Upper Willow Brook Pond" / Confluence of SD-10 (overflow only)
WB-80	16.20	Outlet of lower section of Pratt & Whitney Willow Brook Culvert
WB-90	17.37	Pratt & Whitney Conduit to Airport Avenue
WB-100	45.52	Pratt & Whitney Conduit to Corporate Training Center
		Drainage Networks
WB-110	5.14	Upper section of Willow Brook Culvert to end of twin 48-inch pipes at Airport Avenue and confluence with SE-10
WB-120	4.67	Initial upper section of Pratt & Whitney Willow Brook Culvert to confluence with SF-10
WB-130	16.58	Inlet to Pratt & Whitney Willow Brook Culvert
WB-135	3.37	Outlet of E. Hartford Blvd. North crossing / Confluence of SG-10
WB-140	0.73	Between E. Hartford Blvd. North and Rentschler Field access road / Confluence of SH-10
WB-150	1.29	Between E. Hartford Blvd. North and Rentschler access road / Confluence of SI-10
WB-160	22.64	Inlet to culvert at northwest corner of Rentschler Field parking area
WB-170	21.96	Outlet of downstream Silver Lane culvert crossing / Confluence of SJ-10
WB-180	27.91	Inlet to Cumberland Drive culvert
WB-190	20.03	Outlet to Ginger Lane culvert

TABLE 3-9 (Continued)
Willow Brook Sub-Watershed Descriptions

Sub-watershed	Area (acres)	Downstream Analysis Point
Drainage Networks		
WB-200	2.67	Outlet of Applegate Lane culvert / Confluence of SK-10
WB-210	8.90	Inlet of Applegate Lane culvert
WB-220	7.63	Hockanum River diversion structure / Willow Brook sluice gate
WB-230	37.83	Outlet of SL-10 and SM-10 downstream of Charter Oak Mall
WB-240	50.69	Inlet of culvert on access road to Charter Oak Mall
WB-250	7.86	Inlet of Forbes Street culvert
WB-260	123.53	Outlet of upstream Silver Lane culvert crossing
PR-10	37.95	“Lower Willow Brook Pond” (WB-50) / “Middle Willow Brook Pond” (WB-60) (overflow)
SA-10	4.03	Confluence with WB-20 near Sewage Treatment Plant
SB-10	63.84	“Lower Willow Brook Pond” (WB-50)
SC-10	5.13	Pratt and Whitney Dam (WB-60)
SD-10	84.72	“Lower Willow Brook Pond” (WB-50) / “Upper Willow Brook Pond” (WB-70) (overflow)
SD-20	17.19	Outlet of Detention Pond SD-20
SE-10	12.64	Pratt & Whitney Willow Brook culvert near Airport Avenue (WB-110)
SF-10	3.28	Upper section of Willow Brook culvert (WB-120)
SG-10	6.47	Outlet of Detention Pond SG-10 (WB-135)
SH-10	9.28	Between E. Hartford Blvd. North and Rentschler Field access road (WB-140)
SI-10	0.56	Between E. Hartford Blvd. North and Rentschler Field access road (WB-150)
SJ-10	27.07	Outlet of downstream Silver Lane culvert crossing (WB-170)
SK-10	11.71	Outlet of Applegate Lane culvert (WB-200)
SL-10	0.50	Outlet of culvert at downstream of Charter Oak Mall (WB-230)
SL-20	11.21	Inlet to storm drainage system from Detention Pond SL-20
SM-10	44.65	Outlet of culvert at downstream of Charter Oak Mall (WB-230)
RA-10	0.33	Confluence of western Rentschler Field drainage channel with northern Rentschler Field drainage outfall
RB-10	2.66	Confluence of Cabela’s drainage channel with western Rentschler Field drainage outfall
RB-20	2.79	Outlet of Detention Basin RB-20
RB-30	4.05	West inlet of Detention Basin RB-20
RB-40	2.18	Southeast inlet of Detention Basin RB-20
RC-10	0.46	Western Rentschler Field drainage channel and culvert at confluence with Cabela’s drainage channel
RC-20	0.95	Outlet of Detention Basin RC-20
RC-30	4.06	Northeast inlet of Detention Basin RC-20
RC-40	7.48	East inlet of Detention Basin RC-20
RD-10	0.53	Outlet of culvert at northwest corner of Rentschler Field parking area
RD-20	1.41	Outlet of Detention Pond RD-20
RD-30	5.25	Southwest inlet of Detention Basin RD-20
RD-40	4.48	South inlet of Detention Basin RD-20
RD-50	9.79	Southeast inlet of Detention Basin RB-20

3.3.2 Runoff Curve Number

The runoff Curve Number (CN) system was developed by the Natural Resources Conservation Service (NRCS). CNs range from 30 to 98 based on a combination of underlying soil types and existing land uses. Land cover was classified for the each sub-watershed based on 2009 to 2013 aerial imagery combined with field verification. Based on the cover type and conditions presented in Table 2-2 of the TR-55 user's manual (USDA, 1986), sub-watersheds were delineated into commercial and business, impervious (paved), industrial, newly graded, open space, residential (by lot size), right-of-way, water, and woods.

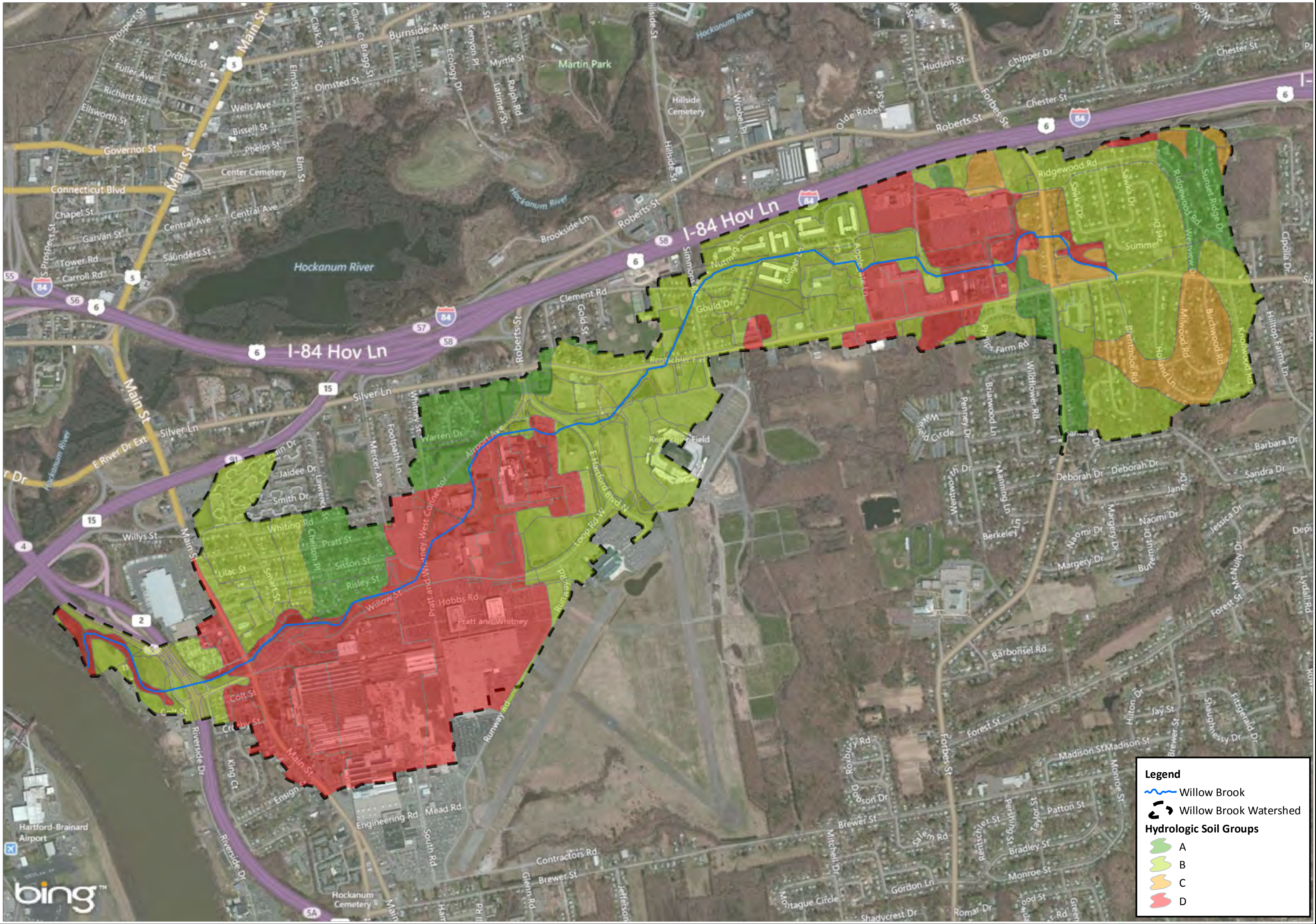
Soil types in the watershed were determined from the NRCS Web Soil Survey in conjunction with the Connecticut DEEP GIS database of the NRCS soil survey. The Hydrologic Soil Group (HSG) classifications were defined for each sub-watershed based on the values presented in Appendix A of the TR-55 manual as updated by NRCS. The NRCS divides soils into four HSGs (A, B, C, or D) depending on their infiltration capacity and ability to absorb water. HSG "A" soils have high infiltration capacity and consist of well drained soils. HSG "D" soils have the lowest infiltration capacity and, hence, generate the highest runoff rates. Sandy soils would generally be considered HSG "A" or "B" because of their high potential infiltration capacity. Table 3-10 summarizes the area of each HSG in the Willow Brook watershed. Figure 3-4 depicts the soil group classifications for the watershed.

Table 3-10
Land Area of Each Hydrologic Soil Group

Hydrologic Soil Group	Acres	Percent of Total
A	125.7	10.9%
B	737.6	63.7%
C	14.0	1.2%
D	280.2	24.2%
Total	**1157.6**	**100.0%**

Weighted CNs were developed for each sub-watershed based on the areal extent of HSG types and land cover type. Impervious areas such as paved parking lots and buildings were assigned a CN 98. The CNs used in the model were based on CNs for Connecticut developed by MMI to reflect conditions in Connecticut rather than the Midwestern conditions that were used to develop the NRCS's published CNs. These numbers have been accepted for use by the NRCS. A memo documenting these numbers and a letter from the NRCS authorizing their use are presented in Appendix F. CN calculations for each sub-watershed in the Willow Brook watershed are presented in Appendix G. A summary of the CNs used in the HEC-HMS model is presented in Table 3-11.

Estimating land cover using a categorical approach such as applying a land cover of "one-acre residential" over portions of the watershed rather than specifying individual areas of impervious, wooded, and grassed cover can potentially overestimate the CN value applied to that particular portion of the sub-watershed. The result can potentially lead to higher overall composite CN values, which have been developed that way by design to build conservatism into the modeling approach. The method of applying a categorical land cover is a common approach. For the Willow Brook watershed, delineating individual impervious, grassed, and wooded cover types was completed as reasonably possible with consideration for contiguous areas of similar land uses.



SOURCE(S): Bing Aerial Hybrid CT DEEP Soils 2009	N MXD: V:\2854-37\GIS\Maps\HSG.mxd	**Figure 3-4: Hydrologic Soil Groups**	**Willow Brook Flood Mitigation Study** LOCATION: East Hartford, Connecticut	Map By: CMP MMI#: 2854-37 Original: 7/20/2015 Revision: 7/31/2015 Scale: 1 in = 2,250 ft

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TABLE 3-11
CN Values for Existing Conditions HEC-HMS Model

Sub-watershed	Area (acres)	SCS Composite CN Value	Sub-watershed	Area (acres)	SCS Composite CN Value
Main Stem of Willow Brook			***Drainage Networks***		
WB-10	13.54	80	PR-10	37.95	93
WB-20	7.50	74	SA-10	4.03	91
WB-30	15.38	83	SB-10	63.84	51
WB-40	73.68	91	SC-10	5.13	49
WB-50	19.75	93	SD-10	84.72	98
WB-60	8.08	75	SD-20	17.19	85
WB-70	5.53	70	SE-10	12.64	49
WB-80	16.20	93	SF-10	3.28	72
WB-90	17.37	77	SG-10	6.47	76
WB-100	45.52	86	SH-10	9.28	67
WB-110	5.14	53	SI-10	0.56	74
WB-120	4.67	90	SJ-10	27.07	82
WB-130	16.58	90	SK-10	11.71	77
WB-135	3.37	89	SL-10	0.50	95
WB-140	0.73	80	SL-20	11.21	94
WB-150	1.29	83	SM-10	44.65	84
WB-160	22.64	73	RA-10	0.33	89
WB-170	21.96	69	RB-10	2.66	69
WB-180	27.91	79	RB-20	2.79	73
WB-190	20.03	83	RB-30	4.05	91
WB-200	2.67	92	RB-40	2.18	92
WB-210	8.90	90	RC-10	0.46	79
WB-220	7.63	75	RC-20	0.95	88
WB-230	37.83	78	RC-30	4.06	92
WB-240	50.69	62	RC-40	7.48	92
WB-250	7.86	69	RD-10	0.53	91
WB-260	123.53	68	RD-20	1.41	98
			RD-30	5.25	81
			RD-40	4.48	91
			RD-50	9.79	78

3.3.3 Time of Concentration

Time of concentration is defined as the time it takes a drop of water to travel from the most hydrologically distant point in the watershed (or sub-watershed) to the watershed (or sub-watershed) outlet. This value generally defines how quickly after the start of a rainfall event that peak flows will be observed in the stream channel or outlet point. For each sub-watershed, sheet flow, shallow concentrated flow, and channel flow values were determined based on the available topography and mapping data. Calculations of the time of concentration for each sub-watershed are presented in Appendix H. The minimum time of concentration for any sub-watershed is five minutes based on TR-55 standards.

The HEC-HMS model requires input of lag time rather than time of concentration. Although there are varying definitions of lag time, it is typically taken as the length of time from the start of runoff to the peak of flow through the watershed. NRCS has established an average relationship between lag time and the time of concentration as follows: T_l=0.6t_c (where: T_l = lag time and T_c = time of concentration).

The coefficient of 0.6 in the equation accounts for the fact that on average the time to peak flow in the watershed is 60% of the time it takes water from the outer limits of the watershed to reach the outlet. Table 3-12 presents the lag time for each sub-watershed that was used as input data to the HMS model. A minimum lag time of three minutes was utilized as a function of minimum time of concentration of five minutes discussed above.

TABLE 3-12
Lag Time Values Used in the Existing Conditions HEC-HMS Model

Sub-watershed	Area (acres)	Lag Time (min)	Sub-watershed	Area (acres)	Lag Time (min)
Main Stem of Willow Brook			***Drainage Networks***		
WB-10	13.54	17.4	PR-10	37.95	15
WB-20	7.50	26.4	SA-10	4.03	13.2
WB-30	15.38	24.6	SB-10	63.84	22.2
WB-40	73.68	10.8	SC-10	5.13	15.6
WB-50	19.75	12.6	SD-10	84.72	36.6
WB-60	8.08	3	SD-20	17.19	24.6
WB-70	5.53	15.6	SE-10	12.64	34.2
WB-80	16.20	30.6	SF-10	3.28	23.4
WB-90	17.37	9.6	SG-10	6.47	25.2
WB-100	45.52	29.4	SH-10	9.28	24.6
WB-110	5.14	26.4	SI-10	0.56	14.4
WB-120	4.67	18.6	SJ-10	27.07	27.6
WB-130	16.58	6.6	SK-10	11.71	12.6
WB-135	3.37	11.4	SL-10	0.50	5.4
WB-140	0.73	11.4	SL-20	11.21	9.6
WB-150	1.29	7.8	SM-10	44.65	12
WB-160	22.64	23.4	RA-10	0.33	6.6
WB-170	21.96	34.8	RB-10	2.66	19.2
WB-180	27.91	45.6	RB-20	2.79	25.2
WB-190	20.03	22.8	RB-30	4.05	25.2
WB-200	2.67	4.8	RB-40	2.18	5.4
WB-210	8.90	12.6	RC-10	0.46	3
WB-220	7.63	49.8	RC-20	0.95	5.4
WB-230	37.83	18	RC-30	4.06	3
WB-240	50.69	21	RC-40	7.48	4.2
WB-250	7.86	20.4	RD-10	0.53	3
WB-260	123.53	41.4	RD-20	1.41	3
			RD-30	5.25	3
			RD-40	4.48	3
			RD-50	9.79	18.6

3.2.4 Surface Water Storage and Reservoir Routing

Natural storage areas do not appear to exist within the Willow Brook watershed, but there are several man-made detention basins and impoundments constructed to provide storage of storm water runoff and main channel flows. Given the small size of the Willow Brook watershed, each storage area was considered in detail for this study.

The reservoir routing calculations are performed by the computer modeling software by balancing the amount of flow entering the pond with the available storage volume with the discharge capacity of the outlet. The stage versus storage relationship of each impoundment was calculated using available topographical mapping for the town of East Hartford along with surveyed elevation of outlets and weirs where appropriate. The outlet configuration of each impoundment was inserted into the model and was utilized by the model to calculate a storage versus discharge relationship. Each impoundment was modeled to have a combination of several outlets including the primary spillway or outlet pipe, and the top of berm or dam modeled as a broad-crested weir.

Table 3-13 presents the storage areas included in the model. A brief description of each storage area follows. All elevations are referenced to the North American Vertical Datum of 1988.

Table 3-13
Existing Storages in the Willow Brook Watershed

Storage Area Model ID	Description	Outlet Elevation (ft NAVD 88)	Overflow Elevation (ft NAVD 88)	Storage at Overflow Elevation (acre-feet)
ST-SL-20	Detention basin south of abandoned theater	56.2'	57.7	0.42
ST-WB-160	Slackwater Area East of RD-20	40.6'	46.2	1.70
ST-RD-20	Detention pond north of Rentschler Field	41.0'	45.0	4.03
ST-RD-10	Downstream of Weir at ST-RD-20	41.6'	45.7	0.05
ST-RC-20	Detention pond West of Rentschler Field	41.1'	45.0	1.53
ST-RC-10	Outlet of ST-RC-20 between weir and downstream culvert	41.2'	44.0	0.07
ST-RB-20	Northeast of Cabela's- "Detention Pond #2"	40.0'	44.1	1.19
ST-SG-10	E. Hartford Blvd at Willow Brook- "Detention Pond #1"	37.0'	44.2	0.79
ST-SD-20	West of Cabela's- "Detention Pond #4"	36.5'	40.4	1.05
ST-WB-70	Upper Willow Brook Pond	22.0'	37.7	5.36
ST-WB-60	Lower Willow Brook Pond	19.0'	30.4	4.87
ST-WB-50	Willow Brook upstream Route 5 culvert	14.8'	32.8	36.02

<u>*ST-SL-20*</u> – South of the abandoned theater is a detention basin that collects drainage from the theater property. This basin receives inflow from three storm water pipes. A single 24-inch diameter pipe outflows from the storage area with an invert elevation of 55.96 feet. When the water surface reaches the approximate overflow elevation of 57.7 feet, the associated storage volume is approximately 0.42 acre-feet.

ST-WB-160 – To the east of detention basin RD-20 is a slackwater area off of the main channel that fills when Willow Brook reaches an approximate water surface elevation of 40.6 feet. The top of the bank surrounding the slackwater area is at an approximately elevation of 45.5 feet, and the associated storage volume is approximately 1.70 acre-feet at this elevation.

ST-RD-20 – Detention basin RD-20 is located north of Rentschler Field and collects drainage from the northern Rentschler Field parking lots. The outlet structure is a 12-inch diameter pipe (invert elevation 41.0 feet) below a multi-tiered concrete weir (top elevation of 44.9 feet). The overflow elevation of the berm is at approximately 45.0 feet, and the associated storage volume is approximately 4.03 acre-feet at this elevation.

ST-RD-10 – This storage area is minor but acts to slightly detain and convey water from RD-20 downstream to a drainage channel tributary to Willow Brook. The invert elevation of the downstream 36-inch culvert is approximately 41.6 feet. The overflow elevation of the berm is approximately 45.7 feet, and the associated storage volume is approximately 0.05 acre-feet at this elevation.

ST-RC-20 – Detention basin RC-20 lies southwest of Rentschler Field and collects drainage from the southwest Rentschler Field parking lots. The outlet control is a 12-inch orifice (invert elevation approximately 41.1 feet) set below a multi-tiered concrete weir (top elevation of approximately 45.0 feet). The overflow elevation of the berm is at approximately 45.0 feet, and the associated storage volume is approximately 1.53 acre-feet at this elevation.

ST-RC-10 – This storage area is minor but acts to slightly detain and convey water from RC-20 downstream to a culvert leading to a drainage channel tributary to Willow Brook. The invert elevation of the downstream 36-inch culvert is approximately 40.5 feet. The overflow elevation of the berm is approximately 44.0 feet, and the associated storage volume is approximately 0.07 acre-feet at this elevation.

ST-RB-20 – Detention basin RB-20 is located to the southwest of Rentschler Field between the Rentschler parking lot and Cabela's parking lot. This basin collects drainage from East Harford Boulevard North and a section of field just north of the basin. Inflow to the basin is controlled by two sediment traps. Outflow from the basin is controlled by an outlet structure with an eight inch orifice at elevation 40.0 feet and a grate at 44.1 feet. Overflow from the basin also occurs at an approximate elevation of 44.1 feet, and the associated storage volume at this elevation is approximately 1.19 acre-feet.

ST-SG-10 –Detention basin SG-10 is located south of where Willow Brook is conveyed beneath East Hartford Boulevard North and collects drainage from the roadway and the open field located to the east of the roadway. The outlet control is an eight-inch diameter orifice (invert elevation approximately 41.0 feet) and a grate at 44.2 feet which is controlled by a 30-inch diameter outflow pipe. Overflow from the basin also occurs at an approximate elevation of 44.2 feet, and the associated storage volume at this elevation is approximately 0.79 acre-feet.

ST-SD-20 – Detention basin SD-20 collects water from the field surrounding the basin to the north along with a section of Cabela's parking area and the adjacent area of Loop Road West. The outlet control is a 12-inch diameter orifice (invert elevation approximately 36.5 feet) and a grate at 40.4 feet which is controlled by a 15-inch diameter outflow pipe. Overflow from the basin also occurs at an approximate elevation of 40.4 feet, and the associated storage volume at this elevation is approximately 1.05 acre-feet.

ST-WB-70 – This storage basin is locally known as Upper Willow Brook Pond and is located immediately downstream of the Pratt & Whitney Conduit. The outflow pipe for this basin is a 108-inch diameter pipe that flows into Lower Willow Brook pond where a dam controls the water surface elevation in both ponds. The invert of the outflow pipe is at elevation 22.0 feet, and the overflow elevation is approximately 37.7 feet. The associated storage volume at the overflow elevation is 5.36 acre-feet.

ST-WB-60 – This storage basin is locally known as Lower Willow Brook Pond and is impounded by the Pratt & Whitney dam. A combination of flashboards and a tainter gate can be used to control the water elevation. The low-level spillway is located at elevation 20.8 feet, while the tainter gate spillway is located at 24.4 feet. The normal pool elevation behind the dam was set at 27.2 feet based on plans prepared for Pratt & Whitney unrelated to this project. An upper spillway is located at elevation 27.9 feet, and this spillway was assumed to be open in the model. The top of the dam is located at 30.4 feet and the associated storage volume at this overflow elevation is 4.87 acre-feet.

ST-WB-50 – This storage basin evaluates channel storage downstream of the Pratt and Whitney dam as controlled by the conveyance of the culvert below Main Street. This area provides flood storage during floods when the volume of inflow exceeds the conveyance capacity of the culvert. The outflow structure has invert elevation of approximately 14.8 feet. The overflow elevation for the impoundment is 32.8 feet, and the associated storage volume at this overflow elevation is 36.02 acre-feet.

3.3.5 Channel Routing

Streams and floodplains with limited storage volume yet mild gradients, wide widths, or long lengths may delay the downstream movement of flow due to low water velocity. This limited flood attenuation is represented in the hydrology model as channel routing to describe the amount of time required for stormwater to flow from the upper reaches of a sub-basin to its outlet point. The amount of time water travels to the sub-basin outlet is a function of the size, shape, slope, and roughness of the open channel or enclosed conduit. Channel routing was applied to 32 reaches in the Willow Brook watershed (Table 3-14) using the Muskingum-Cunge method for both open channels and conduits. Eight-point cross-sections were utilized to model each reach based on surveyed cross sections developed for the hydraulic model described in Section 4.0.

3.3.6 Diversions

A structure diverts flows from the upper portion of Willow Brook to the Hockanum River. This structure was simulated in the hydrologic model as DIV-220. The normal operating condition based on field conditions is to allow all upstream flow to divert to the Hockanum River. An alternative operating condition was also programmed with the sluice gate opened to allow downstream flow.

An inflow versus diversion relationship was developed for each of the two operating conditions. Under the first condition, the downstream control was assumed to be the 84-inch pipe. The software program HY-8 version 7.2 was utilized to simulate the discharge capability of the entire diversion pipe and the backwater head behind the pipe at various discharges. An elevation-discharge relationship was created between the topography of the overflow berm using the broad-crested weir equation to simulate the effects of overflow. HY-8 was also used to calculate the potential discharge through the sluice gate for the alternative operating condition. The inflow-diversion function was modified based on this discharge to provide the alternative operating scenario.

A second diversion element (DIV-SD-10) used in the model simulates the effect of the recently installed diversion structure that diverts stormwater from the Pratt & Whitney campus to downstream of the dam impounding Lower Willow Brook Pond. Outflow from sub-watershed SD-10 is routed downstream instead of entering Upper Willow Brook Pond except when flows exceed the capacity of the pipe (56 cfs). At that point, water spills into Upper Willow Brook pond. A third diversion element in the model (DIV-PR-10) serves a similar function to divert stormwater from sub-watershed PR-10 to Lower Willow Brook Pond. The capacity of this pipe is 221 cfs, with overflow into Lower Willow Brook Pond.

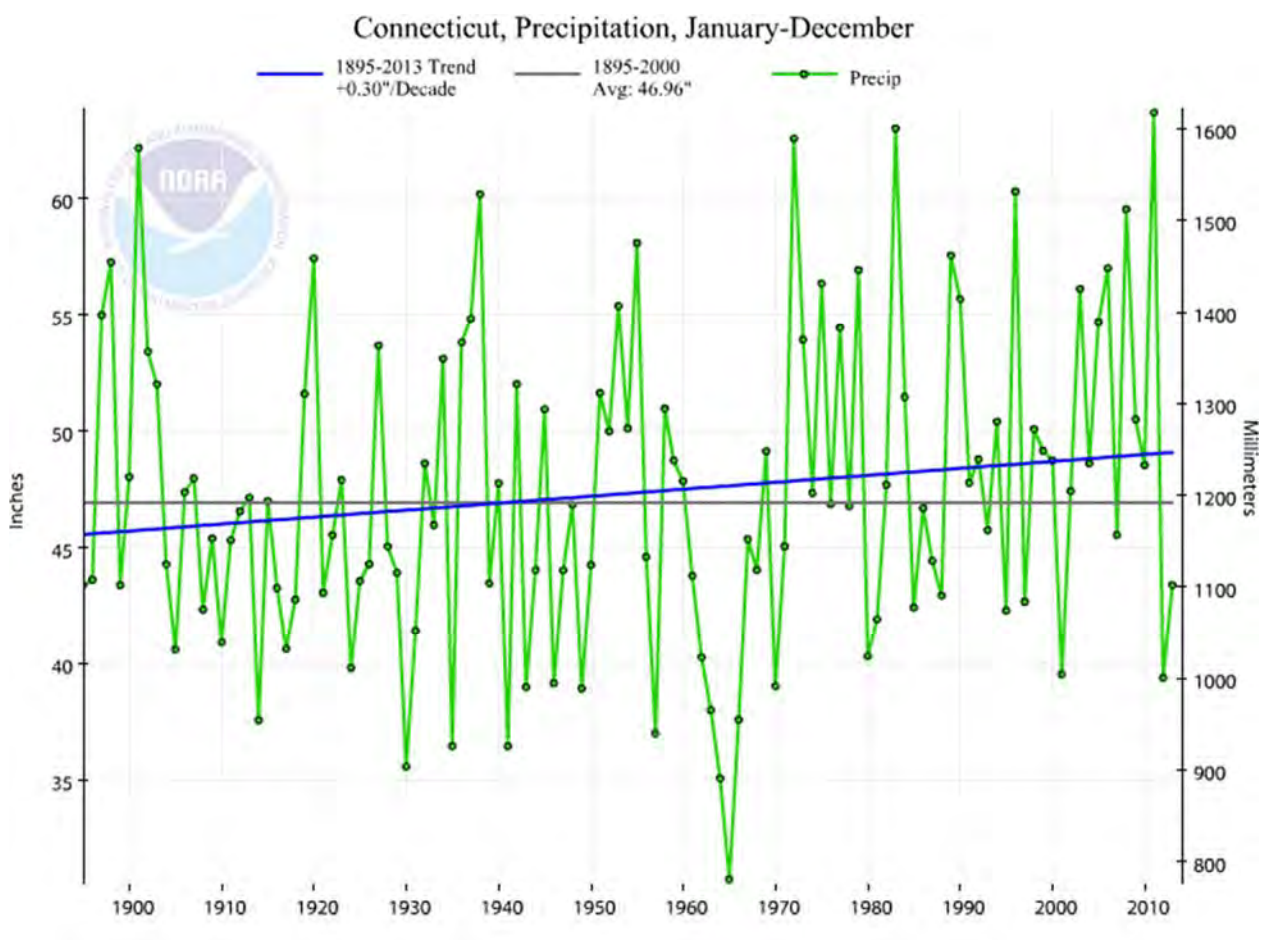
TABLE 3-14
Channel Routing Reaches

Reach ID	Reach Description
R-WB-250	Flow at outlet of WB-260 through watershed WB-250
R-WB-240	Flow at outlet of WB-250 through watershed WB-240
R-WB-230	Flow at outlet of WB-240 through watershed WB-230
R-SL-10	Flow at outlet of SL-20 through watershed SL-10
R-WB-220	Flow at outlet of WB-230, SL-10, and SM-10 through watershed WB-220
R-WB-210	Flow at outlet of WB-220 through watershed WB-210
R-WB-200	Flow at outlet of WB-210 through watershed WB-200
R-WB-190	Flow at outlet of WB-200 and SK-10 through watershed WB-190
R-WB-180	Flow at outlet of WB-190 through watershed WB-180
R-WB-170	Flow at outlet of WB-180 through watershed WB-170
R-WB-160	Flow at outlet of WB-170 and SJ-10 through watershed WB-160
R-RD-10	Flow at outlet of RD-20 through watershed RD-10
R-RC-10	Flow at outlet of RC-20 through watershed RC-10
R-RB-10	Flow at outlet of RB-20 through watershed RB-10
R-RA-10	Flow at outlet of RB-10 and RC-10 through watershed RA-10
R-SI-10	Flow at outlet of RA-10 and RD-10 through watershed SI-10
R-WB-150	Flow at outlet of WB-160 through watershed WB-150
R-WB-140	Flow at outlet of WB-150 and RA-10 through watershed WB-140
R-WB-135	Flow at outlet of WB-140 and SH-10 through watershed WB-135
R-WB-130	Flow at outlet of WB-135 and SG-10 through watershed WB-130
R-WB-120	Flow at outlet of WB-130 through watershed WB-120
R-WB-110	Flow at outlet of WB-120 and SF-10 through watershed WB-110
R-WB-100	Flow at outlet of WB-110 through watershed WB-100
R-WB-90	Flow at outlet of WB-100 through watershed WB-90
R-WB-80	Flow at outlet of WB-90 through watershed WB-80
R-SD-10	Flow at outlet of SD-20 through watershed SD-10
R-WB-70	Flow at outlet of WB-80 through watershed WB-70
R-WB-60	Flow at outlet of WB-70 and SD-10 through watershed WB-60
R-WB-40	Flow at outlet of WB-50 through watershed WB-40
R-WB-30	Flow at outlet of WB-40 through watershed WB-30
R-WB-20	Flow at outlet of watershed WB-30 through watershed WB-20
R-WB-10	Flow at outlet of watershed WB-20 and SA-10 through watershed WB-10

3.3.7 Precipitation

Precipitation is a critical element in hydrologic modeling. The total depth of rainfall during a storm event as well as the intensity of the rainfall play a strong role in dictating the overall runoff from a watershed. The effects of urbanization are exacerbated by the changes in rainfall patterns. Connecticut's annual mean precipitation has increased approximately 0.96 inches per decade through the last century. This trend is depicted graphically on Figure 3-5. The data are suggestive of a trend towards increased rainfall (and therefore runoff) in Connecticut.

FIGURE 3-5
Precipitation Trends in Connecticut 1895-2008
(Source: NOAA)



Historically, the standard of practice for design engineers in Connecticut has been to use rainfall data published in Technical Paper 40 (TP-40) by the United States Weather Bureau in 1961. TP-40 predicts rainfall depths over a 24-hour period equated to a storm frequency (e.g., 100-year storm or 1% ACR) based on storm data from the first half of the 20th century.

As stated in the FIS, FEMA commissioned Anderson-Nichols & Co., Inc. to develop the original hydrologic and hydraulic analyses for all significant flooding sources for the Town of East Hartford. That work was completed in August 1977. The rainfall data used to develop hydrologic estimates of flood flows for the

Willow Brook corridor were based upon the rainfall data provided in TP-40. Table 3-15 compares those data with more recent data provided by various sources.

TABLE 3-15
Rainfall Depth over 24-Hour Period

Rainfall Data Source	Total Rainfall (Inches) by Storm Recurrence Interval					
	2-YR (50% ACR)	10-YR (10% ACR)	25-YR (4% ACR)	50-YR (2% ACR)	100-YR (1% ACR)	500-YR (0.2% ACR)
TP-40 (1961)	3.2	4.7	5.5	6.2	6.9	8.9
USGS *StreamStats*	3.2	4.5	5.5	6.4	7.5	N/A
NRCC	3.21	4.75	5.95	7.05	8.36	12.43

The TR-55 analysis requires the use of TP-40 with the Soil Conservation Service (SCS) Type III storm curve to generate a hyetograph (an intensity versus duration curve) of the total rainfall over a 24-hour period. The Type III curve is assigned to coastal areas along the Atlantic coast which are susceptible to high intensity rainfall from tropical storms.

Rainfall data used by the USGS *StreamStats* program utilizes different rainfall values. According to the USGS, pre-2003 rainfall data were compiled by the Northeast Regional Climate Center (NRCC) across the State of Connecticut. The USGS (Ahearn, 2004) recompiled this data to develop 24-hour rainfall totals at 1,000-foot intervals across the state. The data is similar to the TP-40 data for the 2-year, 10-year, and 25-year recurrence intervals, but demonstrates that the magnitude of larger storms has increased over time.

The most current data published by NRCC (and presented in Table 3-15) accounts for both historical and recent rainfall occurrences through 2008. NRCC data takes into account that the magnitude of both small and large storms has increased in the Northeast over time. The NRCC provides a specified hyetograph for its storm data based on historical variability to replace the use of the Type III curve. A comparison of the Type III curve and the NRCC hyetograph is presented in Figure 3-6. As can be seen on the figure prepared by the NRCC, the NRCC hyetograph is “softer” than the hyetograph for the Type III curve (i.e., the intensity of the rainfall in the center of the storm is less than that for the Type III curve, with the modified rainfall being distributed towards the beginning and ends of the storm).

The more recent data from NRCC reflects a trend of increasing precipitation that has been observed in Connecticut. Figure 3-7 presents a comparison between the TP-40 rainfall depths and the more current NRCC rainfall depths. It is important to note that these depths are for a storm over a 24-hour period. Variations in the length of storm can impact the runoff rates from watersheds. For example, if 3.5 inches of rainfall were to occur over a six-hour period rather than over 24 hours, the result would be increased flooding of streams and streets.

It is important to note that the references to the 2-year, 10-year, etc. storm event are somewhat misleading. In fact, a 2-year storm is one that has a chance of occurring once every two years. Therefore, there is a 50% chance that it could occur in any given year, and a 100-year storm has a 1% chance of recurrence in any given year. Table 3-15 reflects both this annual occurrence potential as well as the traditional reference to the 2-, 10-, 50-, 100-, and 500-year events.

Although the NRCC data has been available for several years, it is only recently that the use of NRCC data has begun to be adopted for engineering design purposes. The Connecticut Department of Transportation began requiring the use of the NRCC dataset for bridge and culvert designs in December 2014.

The hydrologic model was run using both the TP-40 and NRCC data for the purposes of evaluating the effect of rainfall on runoff from the two datasets, as well as to help evaluate potential mitigation alternatives.

Figure 3-6
NRCC and SCS Type III Precipitation Distribution Curves

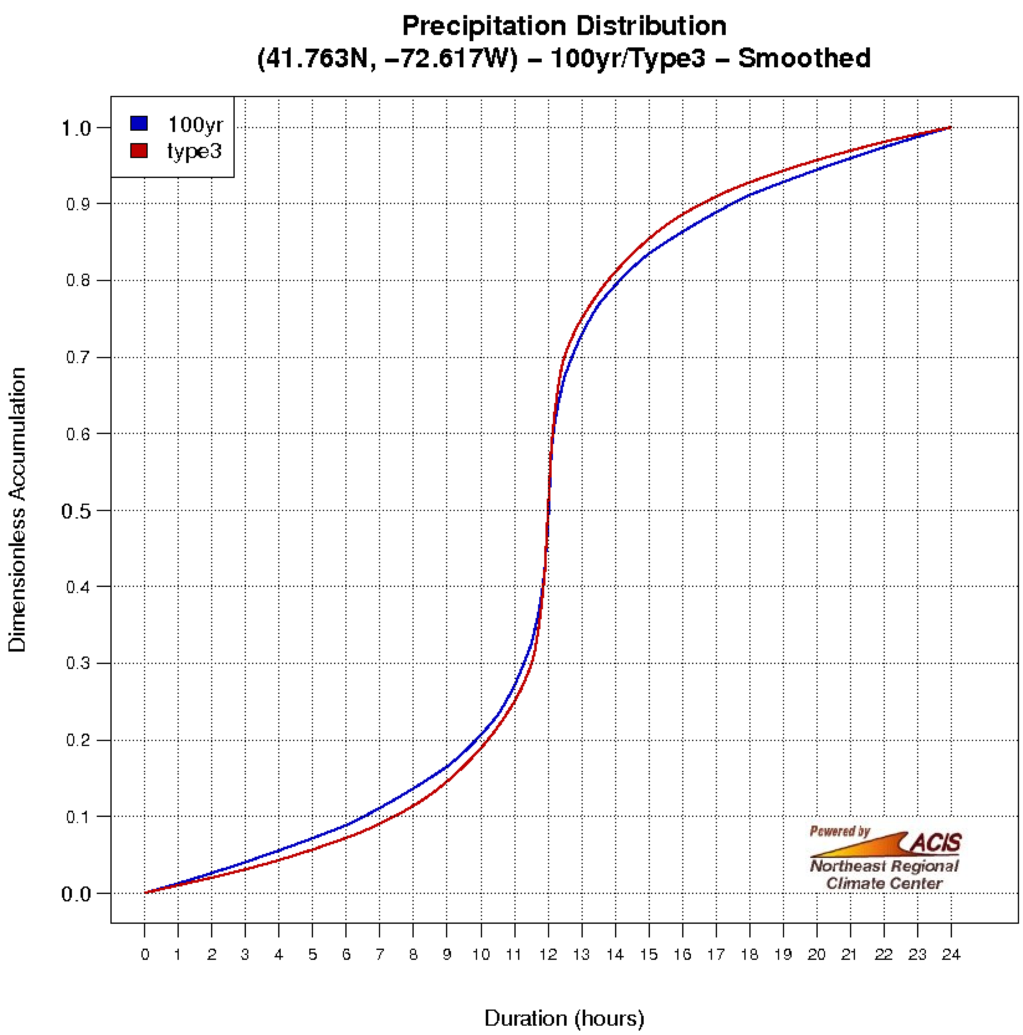
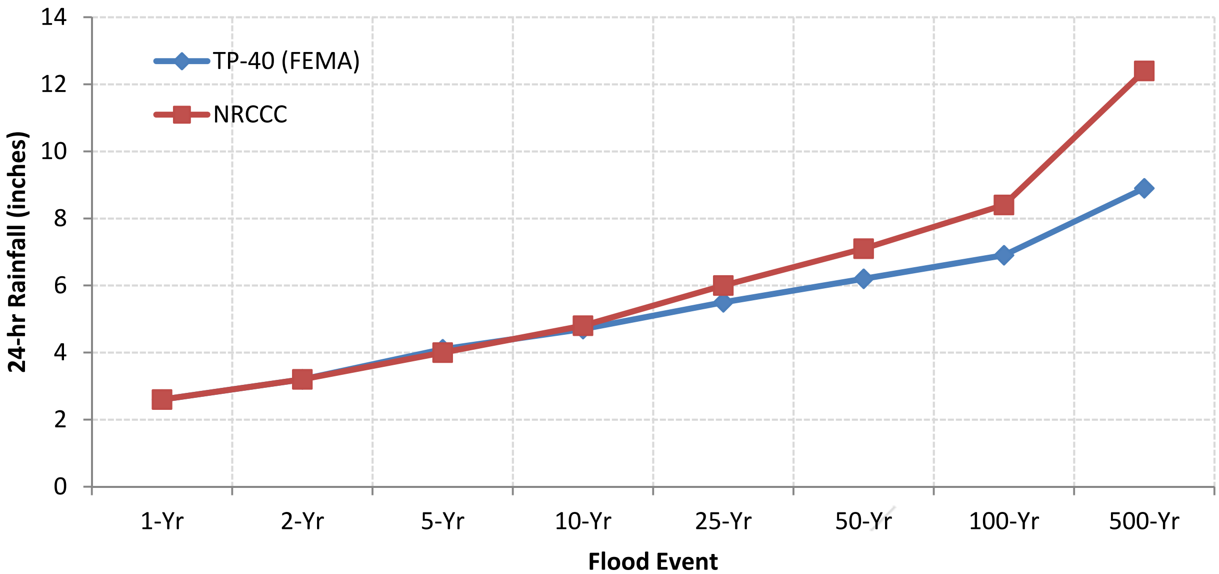


FIGURE 3-7
Rainfall Data Comparison (TP-40 vs. NRCC)



3.4 Results of Existing Conditions Analysis

Table 3-16 presents the predicted channel flow rates at selected areas within the watershed with values presented in both peak flow (cfs) and unit peak flow (cfs per square mile, or csm). HEC-HMS input and output files are presented in Appendix I. Results are presented for both sets of rainfall data as discussed above. The flows in Table 3-17 are based upon those methods believed to provide the more reliable estimates of peak flow.

Comparing the results from HEC-HMS output to the peak discharges presented in Table 3-8, the results of the HEC-HMS analysis appear to generate higher flows for both the TP-40 and NRCC data than those provided in the FEMA FIS and estimated through the NSS equations. This result is expected to some degree, as the model takes into account the greater amount of impervious surfaces that exist in the watershed today. For example, a total of 19 sub-watersheds in the model have CN values over 90, and sub-watershed SD-10 (8% of the entire watershed) has a CN value of 98 (the highest possible value). The skew between the estimated and predicted flows becomes greater as larger floods are considered in correlation with the increasing amount of rainfall available (particularly for the NRCC dataset).

The discharges generated in the HEC-HMS model were utilized to provide flows for the hydraulic model discussed in the Section 4.0.

TABLE 3-16
Predicted Peak Flows from HEC-HMS Hydrologic Model

Watershed Location	Hockanum River Diversion		Upstream of Pratt & Whitney Conduit		At Connecticut River	
Watershed Area (sq. mi.)	0.54		0.90		1.61	
Storm Event	**cfs**	**csm**	**cfs**	**csm**	**cfs**	**csm**
50% ACR (2-year)						
TP-40 Rainfall – Sluice Closed	99.3	184	103	114	297	184
TP-40 Rainfall – Sluice Open	99.3	184	135	150	310	192
NRCC Rainfall – Sluice Closed	103	191	95.3	106	292	181
NRCC Rainfall – Sluice Open	103	191	127	141	295	183
10% ACR (10-year)						
TP-40 Rainfall – Sluice Closed	232	429	204	227	536	333
TP-40 Rainfall – Sluice Open	232	429	237	263	563	350
NRCC Rainfall – Sluice Closed	217	402	192	213	496	308
NRCC Rainfall – Sluice Open	217	401	223	248	524	325
4% ACR (25-year)						
TP-40 Rainfall – Sluice Closed	322	596	266	296	687	427
TP-40 Rainfall – Sluice Open	322	596	308	342	719	447
NRCC Rainfall – Sluice Closed	332	616	272	302	697	433
NRCC Rainfall – Sluice Open	332	616	317	352	730	453
2% ACR (50-year)						
TP-40 Rainfall – Sluice Closed	405	750	322	357	821	510
TP-40 Rainfall – Sluice Open	405	750	374	415	847	526
NRCC Rainfall – Sluice Closed	451	812	352	391	885	550
NRCC Rainfall – Sluice Open	451	835	408	453	912	567
1% ACR (100-year)						
TP-40 Rainfall – Sluice Closed	494	914	381	423	959	595
TP-40 Rainfall – Sluice Open	494	914	438	487	998	620
NRCC Rainfall – Sluice Closed	603	1,116	475	528	1,146	712
NRCC Rainfall – Sluice Open	603	1,116	523	581	1,184	735
0.2% ACR (500-year)						
TP-40 Rainfall – Sluice Closed	752	1,392	653	726	1,368	849
TP-40 Rainfall – Sluice Open	752	1,392	683	759	1,394	866
NRCC Rainfall – Sluice Closed	1,027	1,901	1,057	1,174	1,916	1,190
NRCC Rainfall – Sluice Open	1,027	1,901	1,074	1,193	1,992	1,237

TABLE 3-17
Comparison of Model Predicted and Estimated Peak Flows

Watershed Location	Hockanum River Diversion	Upstream of Pratt & Whitney Conduit	At Connecticut River
Watershed Area (sq. mi.)	0.54	0.90	1.61
Annual Occurrence (Storm Event)	**Discharge, cfs**	**Discharge, cfs**	**Discharge, cfs**
10% ACR (10-year)			
FEMA FIS	205	206	268
NSS Urban Equations	177	262	407
NSS Urban Equations (Extreme Input Limits)	326	450	700
TP-40 Rainfall – Sluice Closed	232	204	536
TP-40 Rainfall – Sluice Open	232	237	563
NRCC Rainfall – Sluice Closed	217	192	496
NRCC Rainfall – Sluice Open	217	223	524
2% ACR (50-year)			
FEMA FIS	378	360	486
NSS Urban Equations	252	373	583
NSS Urban Equations (Extreme Input Limits)	445	618	967
TP-40 Rainfall – Sluice Closed	405	322	821
TP-40 Rainfall – Sluice Open	405	374	847
NRCC Rainfall – Sluice Closed	451	352	885
NRCC Rainfall – Sluice Open	451	408	912
1% ACR (100-year)			
FEMA FIS	481	443	614
NSS Urban Equations	287	427	673
NSS Urban Equations (Extreme Input Limits)	506	707	1,110
TP-40 Rainfall – Sluice Closed	494	381	959
TP-40 Rainfall – Sluice Open	494	438	998
NRCC Rainfall – Sluice Closed	603	475	1,146
NRCC Rainfall – Sluice Open	603	523	1,184
0.2% ACR (500-year)			
FEMA FIS	734	758	1,047
NSS Urban Equations	347	516	820
NSS Urban Equations (Extreme Input Limits)	604	847	1,350
TP-40 Rainfall – Sluice Closed	752	653	1,368
TP-40 Rainfall – Sluice Open	752	683	1,394
NRCC Rainfall – Sluice Closed	1,027	1,057	1,916
NRCC Rainfall – Sluice Open	1,027	1,074	1,992

4.0 HYDRAULIC ASSESSMENT OF EXISTING CONDITIONS

4.1 Introduction

Hydraulic analysis was conducted by FEMA as part of its 1977 Flood Insurance Study of Willow Brook. Conditions have significantly changed since the FEMA study and, for that reason, updated field survey and modeling was conducted as part of the subject study in order to better characterize and understand modern flooding risks and causes.

Hydraulic analysis of Willow Brook was conducted using the HEC-RAS program. The HEC-RAS computer program (*River Analysis System*) was written by the United States Army Corps of Engineers (USACE) Hydrologic Engineering Center (HEC) and is considered to be the industry standard for riverine flood analysis. The model is used to compute water surface profiles for one-dimensional, steady-state, or time-varied flow. 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.

4.2 Hydraulic Structures of Interest

Willow Brook has a number of man-made structures that influence the flooding characteristics of the stream, including a dam, a one-mile long underground conduit, and a diversion structure. Accurate assessment of the behavior of these structures is important to understanding the flooding behavior of the brook; therefore a significant amount of time was devoted to researching and understanding these structures, their design and history, and their current operational characteristics. The following summarizes the findings of that research.

4.2.1 Hockanum River Diversion Structure

The Hockanum River diversion structure is located upstream of Applegate Lane. The structure was built by the Town of East Hartford in the late 1970s for the purpose of reducing flooding along Willow Brook. Water flows over a concrete weir and then into 84-inch diameter reinforced concrete pipe (RCP) that conveys water north approximately 2,100 linear feet beneath Interstate 84 to its terminus north of Olde Roberts Street. An open channel then conveys the discharge to the Hockanum River. The diversion is registered with the Connecticut Department of Energy and Environmental Protection (CTDEEP, Registration No. 4000-54-STO-RI).

A sluice gate on the culvert on Willow Brook adjacent to the diversion structure allows the manipulation of flows in Willow Brook. When open, water is allowed to flow downstream in Willow Brook. When fully closed, the entire flow of the brook is diverted via the diversion structure beneath Interstate 84 and into the Hockanum River. Even with the sluice in the open position, a large percentage of floodwaters are diverted to the Hockanum River.

Photo: Hockanum River Diversion Structure, Looking Downstream

FEMA developed hydraulic modeling of the Hockanum River diversion structure based upon a rating curve, such that no flow is diverted into the Hockanum during the 10-year storm and only 11.2% of the upstream flow is diverted under the 100-year (1% ACR) storm. The assumptions of the FEMA model were made prior to the construction of the diversion channel, which was completed after the publication of the FEMA FIS.

For the past several decades, the Willow Brook sluice has been permanently closed for decades, thus diverting 100% of the normal upstream flows in Willow Brook to the Hockanum River. Flows modeled by MMI using HEC-HMS were evaluated with the sluice gate both open and closed, but all proposed alternatives to flood mitigation were evaluated with the sluice gate open. The sluice structure in Willow Brook is subject to overtopping in extreme events, with a portion bypassing the structure by flooding the adjacent shopping center parking area and reentering the Willow Brook stream just upstream of Applegate Lane.

Under present conditions, nearly 100% of the Willow Brook flow is diverted to the Hockanum River, inclusive of the upper 0.54 square miles of the watershed. The Town of East Hartford has a diversion registration on file with CTDEEP for the physical diversion structure from Willow Brook to the Hockanum River, with no "consumptive" use.

The following is an excerpt from FEMA: "*The discharges on Willow Brook were determined after separating the drainage basin into two sub-areas. One area is above the diversion structure and the other includes just the contributing area below the diversion. A pass-through discharge was then determined at the diversion structure and added to the downstream flow values.*" Table 4-1 presents a comparison of FEMA modeled condition at the Hockanum River Diversion compared to existing conditions based upon the constructed structure. Again, it is noted that FEMA's model pre-dates the completion of construction of this diversion.

TABLE 4-1
Flow Diverted Out of Willow Brook Watershed
At Hockanum River Diversion Structure

Flood Event	Diversion to Hockanum River	
	FEMA FIS	Existing Conditions
10-Yr	0%	100%
50-Yr	8.6%	97.3%
100-Yr	11.2%	76.3%
500-Yr	16.2%	47.9%

Maintaining the sluice gate in a permanently closed position reduces downstream water flows under all conditions, with modest reductions in flooding inundation for the extreme flows, including the statistical 100-year (1% ACR) flood event.

4.2.2 Pratt & Whitney Conduit

A major element of the Willow Brook stream corridor is a conduit that carries Willow Brook beneath the Pratt & Whitney campus. Significant portions of the campus drain to the conduit via underground stormwater conveyance systems, which were referenced in historic mapping but not verified in detail as part of this study. The conduit is a 3,475-foot composite structure with varying dimensions. It begins near East Hartford Boulevard North and Founders Road, and discharges to the Willow Brook Ponds near Willow Street. The conduit was constructed over time, with each segment added during a different phase of campus expansion. The best available information on file with the Town of East Hartford as well as limited field investigation were used to document the alignment and composition of the various culvert segments. The conduit also receives additional runoff from lateral storm drains that discharge to it.

Based on the information that has been gathered from the Town of East Hartford and Pratt & Whitney, the conduit consists of at least six different independent culverts that are joined together. Table 4-2 summarizes this information, starting at the upstream end and working downstream.

TABLE 4-2
Compiled Information for Pratt & Whitney Conduit

Type	Length (LF)
(2x) 48-inch RCP	85
60-inch RCP	750
84-inch Brick Culvert	+/- 1,200
Unknown	910
72-inch RCP	300
108-inch CMP	230
TOTAL	**3,475**

Other Data
Length =3,475 lf
Inv. U/S = 35.03
Inv. D/S = 22.41
Overall Calculated Slope = 0.36%

The Federal Emergency Management Agency (FEMA) Flood Insurance Rate Mapping (FIRM) for Willow Brook, published in August 1977, indicates that the 100-year (1% ACR) frequency Flood Hazard Zone is contained within the Pratt & Whitney conduit; however, the published flood water profile is not consistent with the floodplain mapping. The profile, as well as the hydraulic calculations provided by

FEMA, indicate that the conduit overtops at its upstream end and is under capacity, implying that the Pratt & Whitney property is subject to flooding during the 100-year (1% ACR) flood event. It does not appear that FEMA modeled the conduit in detail.

A document entitled "*Guidelines and Specifcations for Flood Hazard Mapping Partners, Appendix E: Guidance for Shallow Flooding Analyses and Mapping*," published by FEMA in April 2003 outlines a process by which shallow flooding (i.e. flooding less than one foot in depth) should be mapped under the FEMA protocol. Specifically, the guidance states that "sheet runoff" flooding zones shall be determined by assessing the 1-percent-annual-chance flood discharge at the upstream end of the area and then the discharge shall be routed uniformally across the entire area that is believed to be susceptible to sheet flow.

If the depths determined based on the hydraulic computations result in average depths of 1.00 feet or less, the guidelines indicate that the area shall be mapped as Zone X (or the 500-year floodplain), even if it is sucscpetible to flooding during the 100-year (1% ACR) event. The reasoning is that this type of flooding generally becomes impacted by curbs, debris, fences, yards, and changes in microtopography, and is typically routed or intercepted by stormwater drainage systems. These complicated and sometimes unpredictable flow patterns can be diffiuclt and costly to analyze, and are outside the scope and funding parameters of FEMA to provide such mapping. It is clear that FEMA delineated the area above the Pratt & Whitney conduit in this manner. This also explains the shape and limits of the Zone X designation in that area.

MMI has evaluated the Pratt & Whitney conduit flow capacity for both inlet and outlet control based on available conduit data and assumptions. A manual analysis confirms the conduit barely has adequate outlet capacity combined with inadequate inlet capacity. Consequently, the twin 48-inch reinforced concrete pipes at the upstream end of the conduit limit its capacity to approximately 272 cubic feet per second (cfs).

Based on MMI's assessment, the Pratt & Whitney conduit was confirmed to be undersized, with two primary causes. The upstream inlet to the conduit is bottle-necked by dual 48-inch culverts that do not have sufficient inlet capacity to convey the 100-year (1% ACR) flow into the conduit without overtopping the embankment and allowing water to flood the nearby parking areas and buildings. The secondary cause is a 108-inch corrugated metal pipe (CMP) culvert located downstream of the Pratt & Whitney conduit near Risley Street. This culvert is undersized and impounds flood water, thus increasing the tailwater condition and causing a backwater through the composite Pratt & Whitney conduit.

4. 2.3 Pratt & Whitney Dam

The Pratt & Whitney Dam is a concrete structure that was originally constructed to impound water and create a small pond/reservoir. This impoundment reportedly provided process water for use in the factory for various cooling, cleaning, and industrial processes. The dam was designed to provide easy manipulation of the upstream water surface elevations through multiple openings, weir boards, and a tainter gate. The dam is approximately 12 feet tall and 63 feet wide at its crest. It is constructed of concrete, with multiple openings and gates used to control flow. A three-foot high by eight-foot wide tainter gate provides the majority of flow control through the structure, with two other rectangular openings controlled by flashboards. The operators for these gates are located on the top of the dam, where railing and walkways have been constructed for pedestrian and maintenance access.

Historically, Pratt & Whitney withdrew process and/or cooling water from the lower pond on Willow Brook, though they reportedly have not done so in many years. The water diversion from this impoundment is registered with the Connecticut Department of Energy and Environmental Protection (CTDEEP, Registration No. 4000-017-IND-1M), authorizing the consumption of up to 21 million gallons per day (or approximately 32.5 cubic feet per second sustained over 24 hours) from the pond.

Photo: Pratt & Whitney Dam, Looking Upstream

When diversion registrations were first filed in the early 1980s, it was common practice to report a peak instantaneous withdrawal rate based on pump or pipe capacity, regardless of whether the stream ecology could sustain the withdrawal. Relative to Pratt & Whitney's total daily registered diversion of 21 mgd, the capacity of the lower pond is only 3.5 million gallons (based on 2015 survey by MMI), or about four hours of pumping at the diversion flow rate.

4.3 Federal Emergency Management Agency (FEMA) Analysis

A detailed study of Willow Brook was performed and published in the August 1977 FEMA Flood Insurance Study (FIS). In 2006, the Connecticut River was restudied in detail throughout Hartford County, which impacts the tailwater conditions of Willow Brook. These new flood elevations were used to delineate the floodplain boundary for the downstream-most 0.6 miles of Willow Brook.

In September 2008, FEMA consolidated its published studies and mapping for all municipalities within Hartford County into one countywide FIS. This FIS was revised again in September, 2011, which is now the current effective FIS at the time of this writing. These most recent updates generated revised mapping based upon updated topography of the watershed; however, the underlying computations and modeling performed to generate the flooding elevations were not updated as part of the most recent publications. No new hydrologic or hydraulic analysis was conducted in support of the remapping effort.

The published 100-year (1% ACR) floodplain of Willow Brook encompasses large commercial and residential areas along Applegate Lane, Ginger Lane, Simmons Road, Silver Lane and Clement Road, including several multi-family residential complexes. The FEMA FIS states that Willow Brook is the major source of flooding in the Town of East Hartford. Large impervious areas, undersized culverts, and a wide low-lying floodplain contribute to flooding problems.

In 1979, following the FEMA FIS publication, the diversion structure was constructed upstream of Applegate Lane for the purpose of reducing flooding problems along Willow Brook. A side weir diverts storm flow into a 4,000-foot long 84-inch diameter pipe, which then carries flow under Interstate Route 84 and into the Hockanum River to the north. The FEMA analysis account for the diversion structure by reducing flows within the Willow Brook corridor. Various elements of the FEMA Flood Insurance Rate Mapping (FIRM) and its supporting computational data were found to be out of date, or otherwise inconsistent with existing conditions. Table 4-3 presents a brief summary of noted inconsistencies. These are discussed in greater detail in the ensuing narrative.

TABLE 4-3
Summary of Inconsistencies Between FEMA Modeling and Existing Conditions

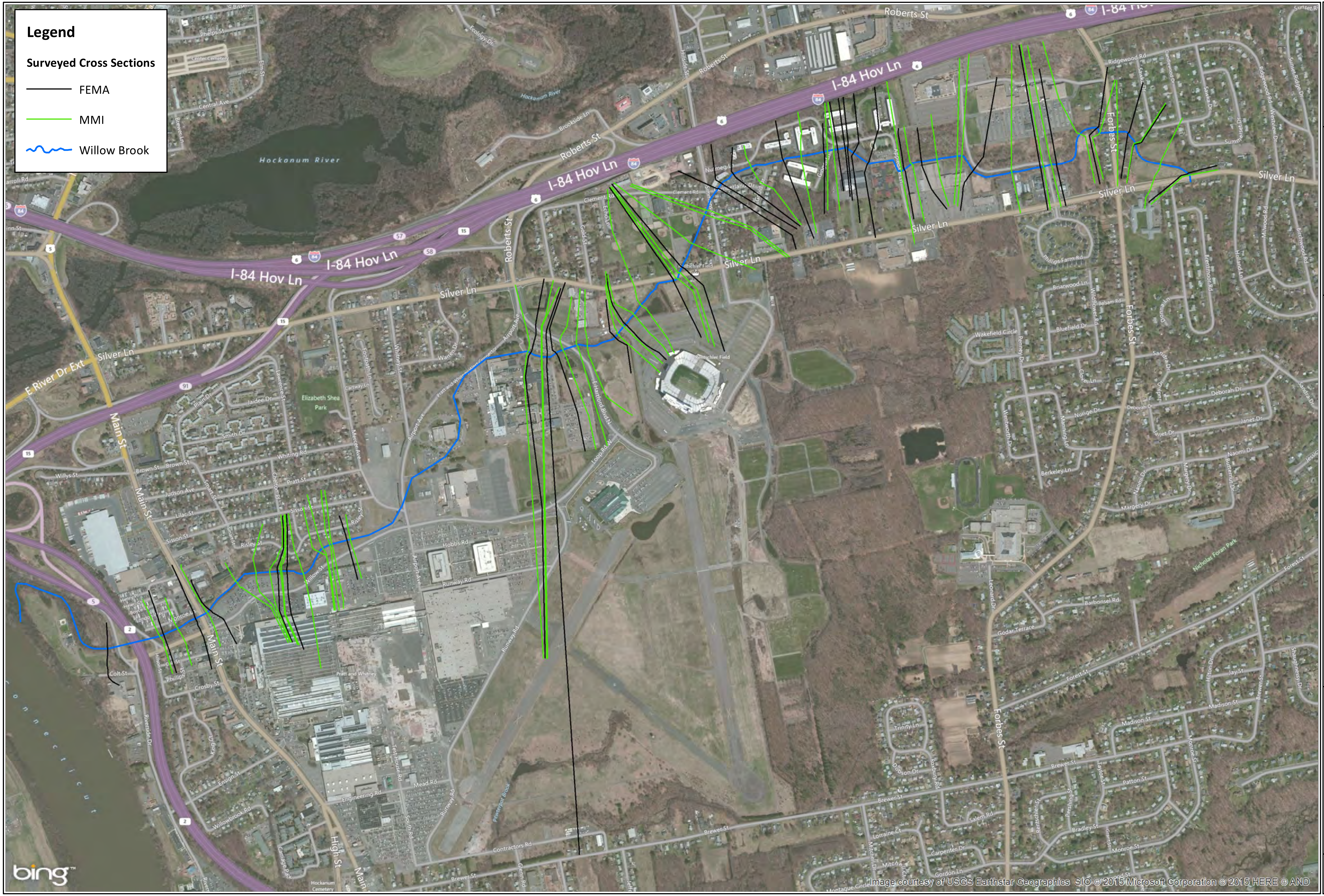
River Station	Location	Description
n/a	n/a	Rainfall and hydrology does not reflect current records
48+80 – 49+55	Pratt & Whitney Access Road (Between Upper/Lower Willow Ponds)	Not included in FEMA modeling
52+30 – 86+80	Pratt & Whitney Conduit	Not included in FEMA modeling
89+05	Pratt & Whitney Pedestrian Bridge to parking area	Not included in FEMA modeling
93+15 – 91+40	East Hartford Boulevard Culvert	FEMA model presents this crossing as dual 48-inch diameter circular pipes, which were replaced with a 7-foot high by 20-foot wide concrete box during the construction of Rentschler Field
116+75, 121+30, 122+95, 137+80	Pedestrian Bridges	Not included in FEMA modeling
134+50 – 135+10	Ginger Lane Culvert	FEMA model: two 3.7'h x 9.2'w concrete boxes. These were replaced with four 46"x60" ACCMP Pipe Arches.
146+40 – 146+90	Hockanum River Diversion Structure	FEMA Modeled with diversion curve that does not match existing conditions
151+75 – 152+15	Bridge Behind Silver Lane Plaza	Not included in FEMA modeling
175+65 – 175+90	Forbes Street Culvert	FEMA model: two circular pipes, a 24" and a 36" culvert. These were replaced by the Town of East Hartford with a 10' by 4' precast concrete box culvert sometime shortly after June 1978.

4.4 FEMA Duplicate Effective Model

A copy of the September 1976 HEC-2 input data was provided by FEMA in scanned pdf files. The input data from that model was used as the basis for the duplicate effective model. A total of 85 FEMA cross sections between the confluence with the Connecticut River and Silver Lane were used to create the HEC-RAS model, which included FEMA lettered cross sections A through AH and 51 unlettered cross sections. Figure 4-1 presents the cross section locations used to create the FEMA duplicate effective model.

The 1976 HEC-2 elevation data was referenced to the National Geodetic Vertical Datum of 1929 (NGVD29). All elevations in the current Flood Insurance Study (FIS) and Flood Insurance Rate Maps (FIRM) are referenced to North American Vertical Datum of 1988 (NAVD88). The conversion factor provided in the FIS from NAVD88 to NGVD29 is 0.81 feet. This conversion factor was applied to all vertical elevations in the model.

The Effective Duplicate Model was created by inputting the FEMA Effective Model into the ACOE HEC-RAS 4.0 program. Flow rates from the FIS were used for the duplicate effective model run as well. Boundary conditions were maintained from HEC-2, including a downstream starting water surface elevation. The model was run in the subcritical flow regime. An upstream boundary condition of normal depth was used.



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SOURCE(S):
Bing Maps Hybrid
FEMA 2014 Hartford County DFIRM

CROSS SECTION LOCATION MAP

WILLOW BROOK FLOOD MITIGATION STUDY

EAST HARTFORD, CONNECTICUT

Map By: JEP
MMI#: 2854-37
MXD: Y:\2854-37\GIS\Maps\Survey-XS.mxd
1st Version: 6/10/2015
Revision: 6/10/2015
Scale: 1 in = 1,000 ft

Figure 4-1

HEC-2 and HEC-RAS have differences in modeling approach, including conveyance calculations; bridge, culvert, and dam modeling approaches; and critical depth calculations. Each of these differences can, and are expected to, cause differences in results. One of the more significant differences occurs in the input and computations at structures, such as culverts and bridges. HEC-2 utilizes two bridge modeling approaches: the normal bridge and special bridge. Normal bridges utilize information on the bridge geometry and surrounding physical conditions. Special bridges do not provide bridge opening geometry, but rely on the user input cross sectional area. Special bridge openings are estimated in HEC-2 based on maximum low chord elevation, channel invert, and opening width. In some cases, if a bottom elevation is specified in HEC-2 that does not match the channel invert, a culvert was input to provide the correct bridge opening invert. HEC-2 does not have a specific inline structure feature, so the Willow Pond Dam was included as bridge structure.

The bridge modeling approach was specified by the HEC-2 modeler in choosing either normal or special bridge calculations. The normal bridge method uses only the energy equations. The special bridge method calculates losses for low flow, weir flow, and pressure flow. Even if the special bridge method is selected, if there are no piers in the cross section, the model will revert to the energy calculation. Bridge model approach was selected in the duplicate effective HEC-RAS model run to match the method used in the HEC-2 model.

Water surface elevations were calculated at each cross section using the one-dimensional energy equation, which considers losses due to friction and transitions between cross sections. Frictional losses were evaluated by Manning's roughness coefficients (n-values) at each cross section and solving the Manning's equation. Manning's n-values for the overbanks and channel ranged from 0.02 to 0.12 and 0.015 to 0.08, respectively.

Water surface elevations were computed using a subcritical (i.e., deep and tranquil) flow regime, which did not allow the model to compute supercritical (i.e., shallow and jetting) water surface elevations. All computed water surface elevations were limited to critical depth, therefore producing greater flood depths. The subcritical flow regime requires a downstream boundary condition, which was set at a known water surface elevation based on the FEMA FIS flood profiles.

The duplicate effective model is generally consistent with the FEMA effective model, although the predicted water surface elevations varied in multiple locations. Table 4-4 provides a summary of the 100-year (1% ACR) floodplain water surface elevations as compared between the FEMA published information and the duplicate effective model.

Only two FEMA lettered cross sections, D and E, did not match FEMA published water surface elevations within half of a foot. One explanation for this discrepancy could be that the FEMA FIS floodway data table and flood profile show different water surface elevations at these cross sections, 29.0 feet and 29.4 feet, respectively. If the flood profile is correct, then the duplicate effective model matches water surface elevations within half of a foot.

TABLE 4-4
Comparison of 100-year (1% ACR) Water Surface Elevations
Published vs. Duplicate Effective Model

FEMA Letter	River Station (feet)	Location	Published (feet)	Duplicate (feet)	Difference (feet)
AH	185+86	40’ D/S of Silver Lane	75.1	75.2	-0.1
AG	178+15	350’ U/S of Forbes Street	72.8	72.8	0.0
AF	176+67	175’ U/S of Forbes Street	71.1	71.0	0.1
AE	172+87	190’ D/S of Forbes Street	64.7	64.8	0.0
AD	165+58	75’ U/S of Charter Oak Mall Access Drive	61.7	61.7	0.0
AC	163+68	65’ D/S of Charter Oak Mall Access Drive	58.5	58.4	0.1
AB	155+55	U/S end of Silver Lane Plaza	55.0	55.2	-0.1
AA	148+58	U/S of the Hockanum River Diversion Structure	54.6	55.0	-0.4
Z	146+41	D/S of the Hockanum River Diversion Structure	54.8	55.0	-0.2
Y	140+55	D/S of Applegate Lane Culvert	53.4	53.5	-0.1
X	138+49	215’ D/S of Applegate Lane Culvert	53.3	53.5	-0.2
W	137+49	175’ U/S of Ginger Lane	53.3	53.5	-0.2
V	137+23	150’ U/S of Ginger Lane	53.2	53.4	-0.2
U	136+33	50’ U/S of Ginger Lane	53.0	53.3	-0.3
T	134+69	50’ D/S of Ginger Lane	52.4	52.4	0.0
S	129+62	550’ D/S of Ginger Lane, Woodcliff Apartments	50.8	50.7	0.1
R	123+55	290’ U/S of Cumberland Drive	49.6	49.7	-0.1
Q	121+97	110’ U/S of Cumberland Drive	49.4	49.7	-0.3
P	121+23	35’ U/S of Cumberland Drive	49.3	49.7	-0.4
O	117+64	65’ D/S of Simmons Road	47.7	47.8	-0.1
N	110+35	80’ U/S of Silver Lane	47.4	47.7	-0.3
M	108+66	80’ D/S of Silver Lane	45.7	45.9	-0.1
L	100+53	60’ U/S of Rentschler Field Access Road	45.6	45.9	-0.3
K	98+37	90’ D/S of Rentschler Field Access Road	44.2	44.2	0.0
J	91+19	125’ D/S of East Hartford Boulevard	43.5	43.7	-0.2
I	89+81	215’ D/S of East Hartford Boulevard	43.1	43.1	0.0
H	87+81	40’ U/S of Pratt & Whitney Conduit	43.0	43.0	0.0
G	52+38	40’ D/S of Pratt & Whitney Conduit	32.7	32.7	0.0
F	43+4	70’ U/S of Pratt & Whitney Dam	32.5	32.5	0.0
E	42+29	40’ D/S of Pratt & Whitney Dam	29.0	29.8	-0.8
D	32+52	90’ U/S of Main Street	29.0	29.7	-0.7
C	30+31	50’ D/S of Main Street	29.0	29.0	0.0
B	26+14	155’ U/S of Route 2 On-Ramp	29.0	29.0	0.0
A	19+11	100’ D/S of Route 2 Off-Ramp	29.0	29.0	0.0

NOTE:
1. All elevations are in North American Vertical Datum of 1988 (NAVD88).
2. Distances measured along stream channel, from closest edge of roadway (not culvert or bridge face).

4.4 Existing Conditions Model

An existing conditions model of Willow Brook was developed. In order to accurately reflect current site topography in the existing conditions model, all lettered FEMA cross section locations were re-surveyed in April 2015, and updated. Additionally, 46 cross sections were added based upon the updated survey data to provide a basis of comparison to proposed conditions. In all, the survey effort included the wetted area (within bankfull elevation) of 80 stream cross sections, plus the survey of 19 bridges/culverts. This data was combined with base mapping provided by MDC to develop sufficient model geometry such that existing conditions flooding up to and including the 500-year recurrence interval could be modeled.

HEC-GeoRAS 4.1.1, an extension for ArcGIS (ESRI 2006), was used to extract stream system geometry from terrain data for automated input to HEC-RAS. HEC-GeoRAS is an interactive platform for setting up all geometry components necessary for HEC-RAS modeling and viewing results. Topography from the town was processed using ArcGIS to create a triangulated irregular network (TIN) representing ground elevation for use in modeling.

FEMA Effective Model cross section locations were maintained, and the additional cross sections were added where necessary. Floodplain topography was extracted from the 2008 topographic mapping with HEC-GeoRAS for all model cross sections. Field survey of the wet channel cross sections completed by MMI was then substituted into the model for all new cross sections and to update FEMA Effective Model cross sections.

Manning's roughness coefficients were selected to reflect existing conditions. Manning's n-values for the overbanks ranged from 0.017 to 0.08 and 0.03 for the channel.

The stream centerline was delineated based upon 2012 aerial photogrammetry, and was found to align closely with the alignment and stationing used in the FEMA analysis.

Ineffective flow areas (i.e., locations where water ponds but does not move) and flow obstructions such as buildings were delineated in GIS and imported into HEC-RAS with HEC-GeoRAS.

Contraction and expansion coefficients of 0.1 and 0.3, respectively, were utilized for straight and uniform reaches of channel, where the floodplain generally flowed at a uniform width. The respective coefficients were increased at bridge and culvert locations, or other areas deemed appropriate based upon field investigation where floodplain development or site conditions caused sudden changes in floodplain width.

The reduction in capacity of certain culverts subject to excessive sedimentation and debris was reflected by applying a depth of blockage to each culvert based upon sediment measured in the field at the time of survey. Other crossings which were modeled as bridges utilize the inlet and outlet geometry as reflected by current survey to determine the hydraulic capacity of the crossing. Table 4-5 summarizes the crossings which were modified to reflect the reduced capacity due to sedimentation, either through the approximation of one average value for use in the culvert algorithms, or through detailed topography at the inlet and outlet for use in bridge algorithms.

TABLE 4-5
Structures Impacted by Debris and/or Sedimentation

D/S Sta	U/S Sta	Depth (ft)	Description	Bridge/Culvert
140+65	145+40	2.8	Applegate Lane	Culvert
135+05	135+85	0.7	Ginger Lane	Culvert
117+45	120+85	0.5 - 1	Simmons Rd / Cumberland Dr	Bridge
99+15	100+15	0.7	Rentschler Field Access Road	Culvert
91+95	93+75	2.0 – 4.0	East Hartford Boulevard	Bridge

Upstream and downstream boundary conditions were retained, where possible, from the original FEMA model. Downstream boundary conditions (tailwater) are controlled by the flood stages of the Connecticut River. The elevations used by FEMA were adopted for use in the revised hydraulic modeling, as presented on the published profile of Willow Brook. The upstream boundary condition was set to a normal depth computation based upon the slope of the first reach of open channel.

Water surface elevations were computed using a subcritical (i.e., deep and tranquil) flow regime, which did not allow the model to compute supercritical (i.e., shallow and jetting) water surface elevations. All computed water surface elevations were limited to critical depth, therefore producing greater flood depths. This was done in compliance with FEMA modeling requirements. The subcritical flow regime requires a downstream boundary condition, which was set at a known water surface elevation at the Connecticut River based on the FEMA FIS flood profiles.

Flow data developed by MMI and documented in Section 3.0 was used in this hydraulic model. Ten flow change locations were added in the HEC-RAS model at tributaries and significant changes in watershed area to describe the hydrology as accurately as possible. The Existing Conditions flows are higher than the FEMA Effective flows, but a change in the way that the Hockanum River Diversion Structure is reflected in the model has the net effect of lowering flows downstream of that location.

4.5 Existing Conditions Results

The results of the HEC-RAS hydraulic modeling provide an overall reduction in the extent of mapped 100-year (1% ACR) floodplain throughout the watershed as compared to the published FEMA mapping, with some minor areas reflecting increases. This is primarily due to the more detailed assessment of the Hockanum River diversion structure relative to its hydraulic performance and operation. Because the structure diverts more water out of the watershed than anticipated by FEMA, the FEMA FIRM floodplain is overstated when compared with existing conditions, especially for channel reaches directly downstream of the structure. It is noted that while the FEMA model accounted for the diversion structure, the actual construction was not completed until two years following the FEMA FIS publication.

Table 4-6 provides a summary of the 100-year (1% ACR) floodplain water surface elevations as compared between the FEMA published information and the MMI Existing Conditions modeling.

TABLE 4-6
Comparison of 100-year (1% ACR) Water Surface Elevations
Published vs. MMI Existing Conditions

FEMA Letter	River Station (feet)	Location	Published (feet)	MMI Existing Conditions (feet)
AH	185+86	40’ D/S of Silver Lane	75.1	73.4
AG	178+15	350’ U/S of Forbes Street	72.8	71.4
AF	176+67	175’ U/S of Forbes Street	71.1	68.3
AE	172+87	190’ D/S of Forbes Street	64.7	62.2
AD	165+58	75’ U/S of Charter Oak Mall Access Drive	61.7	60.6
AC	163+68	65’ D/S of Charter Oak Mall Access Drive	58.5	59.9
AB	155+55	U/S end of Silver Lane Plaza	55.0	56.2
AA	148+58	U/S of the Hockanum River Diversion Structure	54.6	55.1
Z	146+41	D/S of the Hockanum River Diversion Structure	54.8	53.4
Y	140+55	D/S of Applegate Lane Culvert	53.4	50.6
X	138+49	215’ D/S of Applegate Lane Culvert	53.3	50.6
W	137+49	175’ U/S of Ginger Lane	53.3	50.5
V	137+23	150’ U/S of Ginger Lane	53.2	50.4
U	136+33	50’ U/S of Ginger Lane	53.0	50.4
T	134+69	50’ D/S of Ginger Lane	52.4	50
S	129+62	550’ D/S of Ginger Lane, Woodcliff Apartments	50.8	49.5
R	123+55	290’ U/S of Cumberland Drive	49.6	47.8
Q	121+97	110’ U/S of Cumberland Drive	49.4	47.3
P	121+23	35’ U/S of Cumberland Drive	49.3	47.3
O	117+64	65’ D/S of Simmons Road	47.7	47.1
N	110+35	80’ U/S of Silver Lane	47.4	46.5
M	108+66	80’ D/S of Silver Lane	45.7	44.8
L	100+53	60’ U/S of Rentschler Field Access Road	45.6	44.7
K	98+37	90’ D/S of Rentschler Field Access Road	44.2	43.3
J	91+19	125’ D/S of East Hartford Boulevard	43.5	43
I	89+81	215’ D/S of East Hartford Boulevard	43.1	43
H	87+81	40’ U/S of Pratt & Whitney Conduit	43.0	43
G	52+38	40’ D/S of Pratt & Whitney Conduit	32.7	36.8
F	43+40	70’ U/S of Pratt & Whitney Dam	32.5	32.2
E	42+29	40’ D/S of Pratt & Whitney Dam	29.0	31.6
D	32+52	90’ U/S of Main Street	29.0	31.5
C	30+31	50’ D/S of Main Street	29.0	29
B	26+14	155’ U/S of Route 2 On-Ramp	29.0	29
A	19+11	100’ D/S of Route 2 Off-Ramp	29.0	29

NOTES:
1. All elevations are in North American Vertical Datum of 1988 (NAVD88).
2. Existing Conditions results based upon the Hockanum River Diversion Structure sluice gate remaining open through the analysis.

A major departure of MMI’s analysis as compared to FEMA’s modeling is the treatment of the Hockanum River Diversion Structure. As part of their study, FEMA allocated diversion from Willow Brook to the Hockanum River based on a rating curve wherein only 11.2% of Willow Brook flow would be diverted during the 100-year (1% ACR) event. This was presumably based on preliminary design of the structure, as the FEMA modeling was published two years prior to completion of construction of the diversion structure. Given the capacity of the sluice gate on Willow Brook and the capacity of the adjacent Hockanum River Diversion, a greater percentage of flow is diverted. As a result, even though MMI's hydrology predicts higher runoff as compared to FEMA, the current hydraulics at the diversion structure more than compensate for the increase. For instance, MMI predicted flows at the upstream end of the Pratt & Whitney conduit are lower than FEMA's, with the Willow Brook sluice opened or closed.

4.6 Model Validation

Calibration of the model was limited due to a lack of quantifiable flooding reports or records within the watershed. Records of probable flooding were collected where available. Public outreach efforts through letters and public informational meetings yielded very few reports of flooding along Willow Brook. No field measurements of peak discharges, or river gauging was undertaken to verify hydrology, as no substantial flooding took place during the period of study with which to calibrate the model.

Ideally during a large flood event, stage and discharge data would be recorded at multiple locations along the modeled reach. Additional flood information should be collected for comparison with the existing model as it may become available in the future.

5.0 EVALUATION OF FLOOD MITIGATION MEASURES

In order to better understand the flooding characteristics of Willow Brook, its hydraulic properties were evaluated using updated field data and state-of-the-art computer modeling methodologies as described in Section 4.0. The results of the modeling provide an understanding of the flooding that occurs under existing conditions. The following analysis builds upon those results to determine the feasibility and effectiveness of various flood mitigation methods that may be implemented to achieve reductions in flooding.

Flood mitigation measures can include a variety of actions, including bridge and culvert modification, channel widening or deepening, floodplain enhancement, upstream detention, individual structure flood proofing, and procedural or regulatory approaches to address long-term changes in land use, stormwater management, and peak flow attenuation. This section identifies potential mitigation methods and evaluates them for effectiveness.

The analysis herein has been conducted on a watershed-wide scale. The various alternatives and methods have been assessed on a conceptual level. Prior to implementation, mitigation alternatives will require further survey, analysis, regulatory review and approval, procurement of funding, and potentially land easements from property owners.

5.1 Effects of Development

Many reaches of the Willow Brook riparian corridor and floodplain have been manipulated by land use development, placement of fill in the natural floodplain, channelization or channel relocation, and enclosure of the brook in culverts and conduits. These changes interrupt the natural processes that occur in a stable, naturalized stream. Examples of how human manipulation of the Willow Brook corridor potentially affects flooding are presented in Table 5-1.

TABLE 5-1
Effects of Development and Manipulation of Willow Brook on Flooding

Causes	Effect
Influxes of road sand from storm drainage systems	Sand accumulates and settles, causing accumulation, rooting of invasive vegetation, and loss of hydraulic capacity in the channel.
Channel dredging	Without proper design, alteration to the slope/depth of a channel influences its ability to maintain continuity upstream and downstream, and can cause sediment aggradation, unstable/steep banks.
Fill and development in the floodplain	Increases flood velocities and depths inside the channel and on the overbank can cause erosion coupled with deposition of material downstream, and can reduce natural floodplain storage, potentially increasing flooding in other areas.
Channel straightening	Channel straightening reduces the effective length of the channel and thus increases the slope of the stream bed and velocity of floodwaters. Erosive velocities can "move the problem elsewhere in the system."
Enclosure of a watercourse in an underground culvert or conduit	Enclosure of a watercourse has detrimental effects on habitat; removes floodplain storage; causes structural and debris maintenance concerns; and can exacerbate upstream flooding.

In addition to the physical effects that channel manipulation and floodplain filling can have on a waterway, development within a watershed and increased reliance on storm sewer conveyance systems can have a dramatic effect on peak flow rates during rain events. As more impervious area is added to the watershed, less rainwater is able to infiltrate into the ground, and instead becomes overland runoff. When that runoff is collected within a stormwater system, it flows underground and discharges to the receiving waterway much more quickly than if that same runoff were to make its way overland via natural, vegetated soils. The net effect of watershed development is more runoff moving more quickly to the stream as compared to a natural system.

Modern land use regulations require on-site detention systems to mitigate peak stormwater discharge flows. Detention basins are used to collected stormwater runoff, and then detain and release it in a manner that is intended to either mimic natural runoff or dampen the impacts of peak flows in the stream. Engineering design of such systems is typically undertaken at the development stage; however, proper functionality of such systems relies on continued maintenance and inspection. Sediment build-up and/or structural damage can impede the ability of these systems to work as they were designed. The burden of enforcement of proper maintenance usually falls to the municipality. The often complex ownership, sheer number of systems, and lack of enforcement power (i.e. laws and penalties) results in systems that are not properly maintained or functioning. This is the case across local systems in Connecticut and elsewhere.

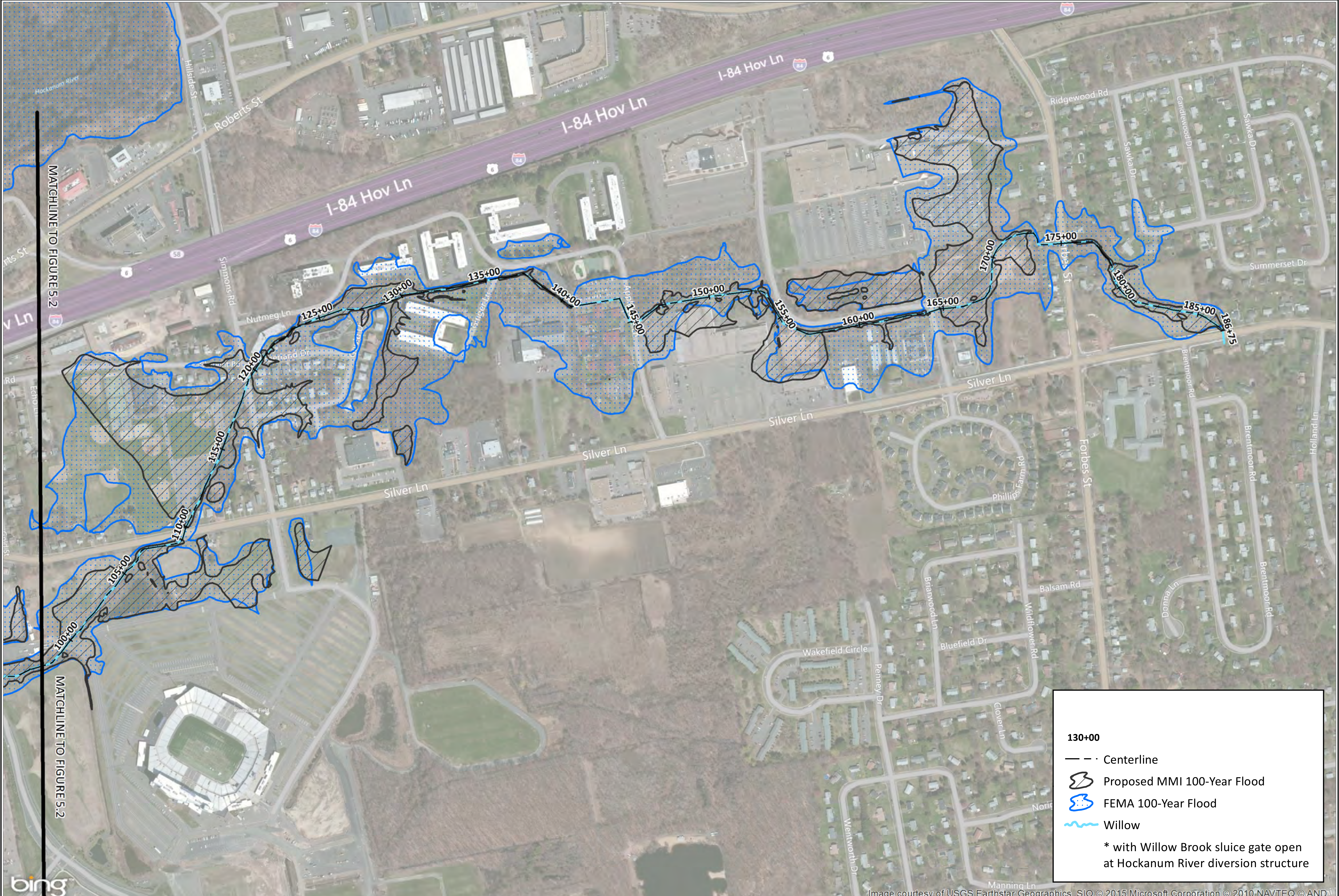
5.2 FEMA Map Revision

As described in Sections 3.0 and 4.0, updated assessment of the Willow Brook corridor and floodplain delineation was completed for the purpose of determining the effects of the changing land uses, current rainfall data, and updated topography as compared with the 1977 FEMA analysis and Flood Insurance Rate Mapping (FIRM). The changes are described in detail in the preceding sections of this report. The major changes that have taken place over nearly 40 years include:

- Increased in rainfall amounts and Intensity
- Increased development in the watershed
- Revised contributing watershed boundary due to construction of piped stormwater drainage systems
- Increased peak flows
- Changes in topography
- Replacement of culverts and bridges
- Construction of the Hockanum River diversion structure

The above changes are reflected in the current hydraulic modeling and were used to generate a revised existing conditions floodplain map. This mapping reflects an updated and more accurate portrayal of the flooding characteristics for the 100-year (1% ACR) flood in Willow Brook. Figures 5-1 and 5-2, present the changes as a result of this analysis.

As depicted in these figures, many areas located just downstream of the Hockanum River diversion structure (just upstream of Applegate Lane) are removed from the floodplain under MMI existing conditions hydrology and hydraulic analysis. This is due in large part to the structure diverting much of the flood flow from Willow Brook, northerly to the Hockanum River watershed.



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SOURCE(S):
FEMA, BASE LAYER: IMAGE COURTESY OF USGS
EARTHSTAR GEOGRAPHICS SIO (C) 2015
MICROSOFT CORPORATION (C) 2015

WILLOW BROOK EXISTING CONDITIONS

WILLOW BROOK FLOOD MITIGATION STUDY

EAST HARTFORD, CONNECTICUT

Map By: JCS
MMI#: 2854-37
MXD: Y:\2854-37\GIS\Maps\2bi_ExCond_1_11x17.mxd
1st Version: 7/22/2015
Revision: 11/17/2015
Scale: 1 in = 500 ft

Figure 5-1

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EARTHSTAR GEOGRAPHICS SIO (C) 2015
MICROSOFT CORPORATION (C) 2015

WILLOW BROOK EXISTING CONDITIONS

WILLOW BROOK FLOOD MITIGATION STUDY

EAST HARTFORD, CONNECTICUT

Map By: JCS
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MXD: Y:\2854-37\GIS\Maps\2bi_ExCond_2_11x17.mxd
1st Version: 7/22/2015
Revision: 11/17/2015
Scale: 1 in = 500 ft

Figure 5-2

The Hockanum River diversion structure, as discussed in Section 4.2.1 includes a sluice gate on Willow Brook that can be opened or closed. When open, water is allowed to flow downstream within Willow Brook; when closed all of the Willow Brook flow is directed to the Hockanum River, except for extreme flows that overtop the bank. The sluice gate has a small capacity compared to the total flow of Willow Brook during higher river stages. For the purpose of alternatives analysis modeling, the sluice gate was modeled as remaining open. This represents a conservative (worse case) flooding condition for the downstream areas along Willow Brook. Although the gate has remained closed since its installation, the gate open scenario provides a more realistic portrayal of an emergency situation or a mechanical failure during a flood event. The updated analysis revealed that flooding characteristics are likely more in line with actual flooding conditions reported by anecdotal reports from property owners in the area.

Mitigation Alternative WS-1 – FEMA LOMR Application

This flood mitigation alternative involves petitioning FEMA for a flood insurance map revision based upon the updated analysis. The National Flood Insurance Program (NFIP) has over 20,000 participating communities across the country. Residents in those communities are eligible for flood insurance, so long as the community complies with the program's stipulations, among which are management of floodplain development and ensuring that effective Flood Insurance Rate Maps are kept as up to date as possible. Robust processes are in place for a community to apply for a map revision when an existing map is found to be lacking in technical detail or better technical information is developed.

The map revision process is described in detail in Part 65 of the NFIP regulations. This process is referred to as a Letter of Map Revision (LOMR) application. The process involves submission of an application as well as supporting technical data, such as hydrologic assessment, hydraulic modeling, and revised floodplain mapping. The process includes a review period as well as public input. Adoption of the mapping requires a formal application to the Federal Emergency Management Agency (FEMA). The process can take 12 or more months for republication of the Flood Insurance Rate Maps (FIRMs).

Upon republication of the floodplain maps, property owners who have been removed from the floodplain may petition their mortgage lender to eliminate the requirement to carry flood insurance. Properties that have been remapped *into* the floodplain may be required to purchase flood insurance if they hold a mortgage on their property. A successful remapping of the Willow Brook floodplain would result in a significantly larger number of properties who are removed from the floodplain, than those that are added.

5.3 Localized Flood Mitigation Alternatives

Alternatives were assessed to determine the potential for floodplain reduction in a number of localized areas. These were chosen based upon a number of factors, including the severity of flooding, the number of impacted properties, and the ability to undertake improvement projects. All assume that remapping of the FEMA floodplain will take place. Each of the alternatives is listed in Table 5-2 and described in detail in the ensuing narrative. The following primary flood impact areas were identified.

- Area 1 –Willow Street and Founders Road Area
- Area 2 – Upstream of Simmons Road and Cumberland Drive
- Area 3 – Applegate Lane Area
- Area 4 – Upstream of Applegate Lane
- Area 5 – Downstream of Forbes Street
- Area 6 – Upstream of Forbes Street (DePietro Park)

TABLE 5-2
Summary of Flood Mitigation Alternatives Assessed

Area	No.	Description	Significant Flood Relief?	Recommend Further Consideration?	Property Ownership
Entire Corridor	WS-1	FEMA Map Revision	Yes	Yes	N/A
Willow Street Area	1-1	Full Upgrade of Pratt & Whitney Conduit	No	No	Private
Willow Street Area	1-2	Partial Upgrade of Pratt & Whitney Conduit	No	Maybe: Cost Dependent	Private
Simmons Road Area	2-1	Upgrade Simmons Road Culvert	No	No	Town and Private
Simmons Road Area	2-2	Remove Pedestrian Bridge and Widen Channel	Yes	Yes	Town and Private
Simmons Rd Area	2-3	Remove Sediment Upstream of Cumberland Drive and Gould Drive	Yes	Maybe (Few Properties Impacted)	Town and Private
Applegate Lane Area	3-1	Sediment Removal From Applegate Lane Culverts	No	No	Private
U/S of Applegate Lane	4-1	Deepen and Widen Channel, Remove Abandoned Pedestrian Bridge	No	No	Private
U/S of Applegate Lane	4-2	Reconstruct Plaza at Higher Elevation & Apply for FEMA CLOMR	Yes	Yes	Private
U/S of Applegate Lane	4-3	Raise Elevation of Plaza & Remove Abandoned Bridge	Yes	Yes	Private
U/S of Applegate Lane	4-4	Clear Northern Portion of Plaza Property and Lower Grade	Yes	Maybe (high cost)	Private
U/S of Applegate Lane	4-5	Enclose Willow Brook in Conduit through Length of Property	No	No	Private
D/S of Forbes Street	5-1	Unblock Culvert Beneath Access Drive	No	Yes (Low Cost)	Private
D/S of Forbes Street	5-2	Upgrade Access Road Culvert	Yes	Yes (High Cost)	Private
D/S of Forbes Street	5-3	Upgrade Access Road Culvert with Parking Lot Modifications	Yes	Yes	Private
U/S Forbes Street	6-1	Sediment Management	N/A	Yes	Private & Town

The existing conditions hydraulic model described in Section 4.0 was used as the basis for evaluation of improvements, using the 100-year (1% ACR) flood flow developed by MMI with the sluice gate located at the Hockanum River diversion structure open.

It should be noted that the various alternatives have been assessed with the HEC-RAS hydraulic model, which predicts peak stage during a flood, but does not account for timing differences caused by the impoundment of water. Severely under-sized culverts can impound water during a flood, acting similar to a dam. Replacement of those culverts with larger crossings may allow more water to flow downstream and in some instances can increase downstream flooding. While the detention capacity of existing culverts appears to be small in relation to downstream flows, these effects would need to be explored in greater detail before the final design for any culvert replacement is developed.

5.3.1 Area 1: Willow Street and Founders Road Area (Sta: 35+00 – 100+00)

Area 1 encompasses the underground section of Willow Brook through the Pratt & Whitney site. Although a full assessment of the Pratt & Whitney conduit could not be completed due to accessibility issues and incomplete data on the composition and condition, an approximate assessment of the inlet capacity of the conduit was conducted to determine its effects on the upstream flooding. A detailed memorandum documenting this assessment and the associated computations is included in Appendix J. Figure 5-3 is a location map of this area.

The Pratt & Whitney conduit was confirmed to be undersized, with two primary causes. The upstream inlet to the conduit is bottle-necked by dual 48-inch culverts that do not have sufficient inlet capacity to convey the 100-year (1% ACR) flow without overtopping the embankment and allowing water to flood the nearby parking areas and buildings. The secondary cause is a 108-inch corrugated metal pipe (CMP) culvert located downstream of the Pratt & Whitney conduit near Risley Street. The culvert, which is visible on aerial photographs, does not appear to serve a clear purpose. The culvert is undersized and impounds flood water, thus increasing the tailwater condition and causing a backwater through the composite Pratt & Whitney conduit. The assessment yielded the following findings:

1. The Pratt & Whitney conduit does not have the capacity to carry the 100-year (1% ACR) flow as computed by FEMA or MMI, and at a minimum the dual 48-inch pipes at its inlet are undersized.

2. FEMA has mapped the Pratt & Whitney site as being located within Zone X, or the equivalent of the 500-year flood, due to the shallow (less than one foot) flooding that is predicted to occur there.

3. The MMI hydrology with the Hockanum River diversion structure diverting at full capacity (i.e. the Willow Brook sluice gate completely closed) predicts river flows at Pratt & Whitney that are slightly lower than those predicted by FEMA with the sluice gate open or partially open.

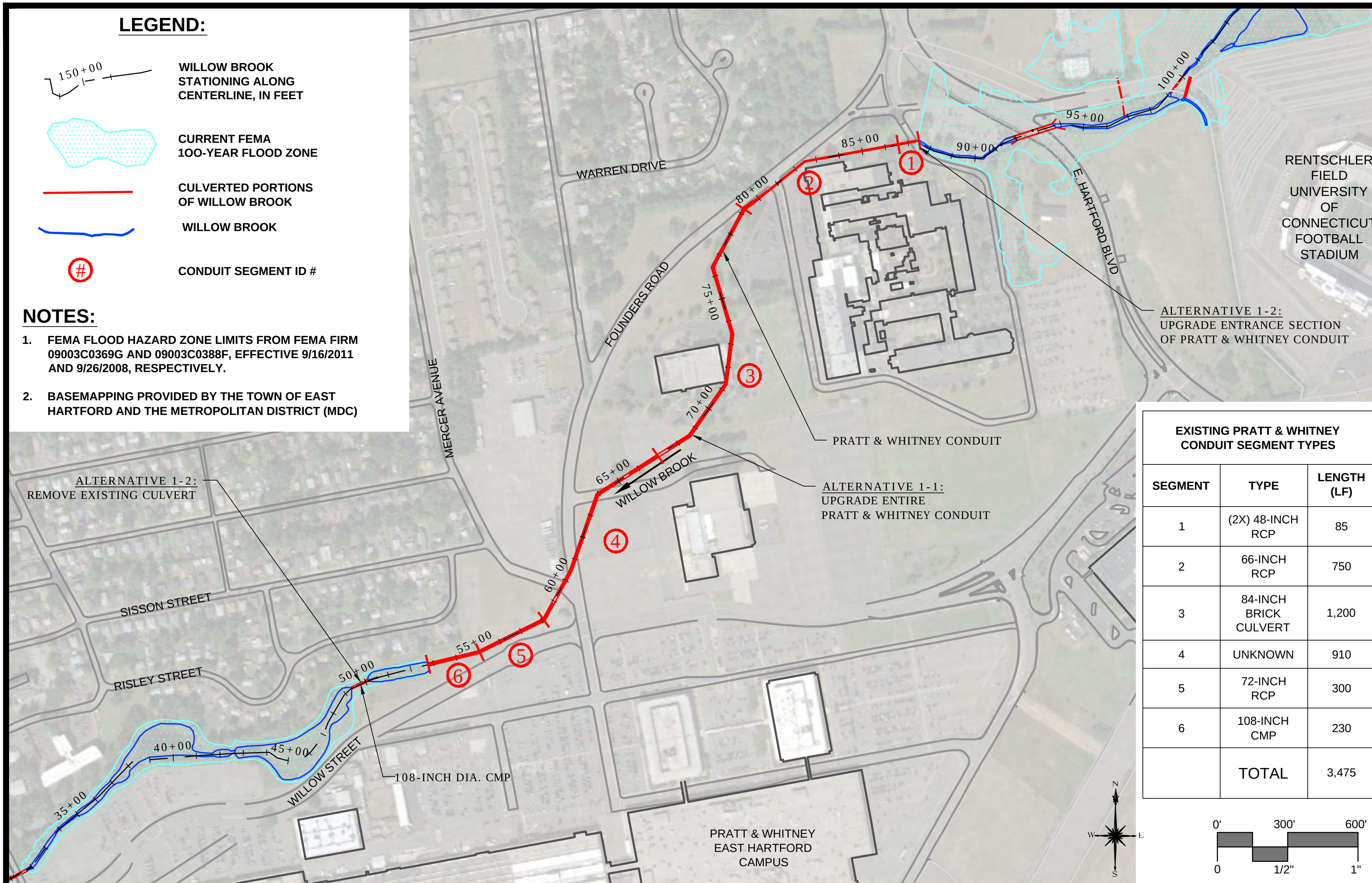
4. Assuming FEMA's guidance relative to shallow flooding is maintained, the Pratt & Whitney site will continue to be mapped within Zone X, or the 500-year floodplain, but outside of the 100-year (1% ACR) floodplain under a condition where new hydrology and a closed sluice at the Hockanum River diversion structure is modeled.

LEGEND:

- 150+00 — WILLOW BROOK STATIONING ALONG CENTERLINE, IN FEET
- CURRENT FEMA 100-YEAR FLOOD ZONE
- CULVERTED PORTIONS OF WILLOW BROOK
- WILLOW BROOK
- # — CONDUIT SEGMENT ID #

NOTES:

1. FEMA FLOOD HAZARD ZONE LIMITS FROM FEMA FIRM 09003C0369G AND 09003C0388F, EFFECTIVE 9/16/2011 AND 9/26/2008, RESPECTIVELY.
2. BASEMAPPING PROVIDED BY THE TOWN OF EAST HARTFORD AND THE METROPOLITAN DISTRICT (MDC)



EXISTING PRATT & WHITNEY CONDUIT SEGMENT TYPES		
SEGMENT	TYPE	LENGTH (LF)
1	(2X) 48-INCH RCP	85
2	66-INCH RCP	750
3	84-INCH BRICK CULVERT	1,200
4	UNKNOWN	910
5	72-INCH RCP	300
6	108-INCH CMP	230
	TOTAL	3,475

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DESIGNED	JCM
DRAWN	JCS
CHECKED	JCM

AREA 1: WILLOW ST AND FOUNDERS RD AREA

WILLOW BROOK
FLOOD MITIGATION STUDY

TOWN OF EAST HARTFORD
CONNECTICUT

DRAWING NAME:

FIG. 5-3

Mitigation Alternative 1-1 – Upgrade Entire Pratt & Whitney Conduit

Upgrading the Pratt & Whitney conduit would likely be a multi-million dollar endeavor and though it may improve the shallow surface flooding that is predicted to occur under extreme flows, no change in the mapped 100-year (1% ACR) floodplain would occur. No significant flood impacts have been reported in this area; therefore, an expensive conduit upgrade may not be warranted. The flooding occurs entirely on Pratt & Whitney property, and as such they may be interested in pursuing a benefit/cost analysis of any conduit repairs. When the conduit reaches the end of its useful life and needs replacement, detailed hydraulic analysis should be conducted to size a replacement structure that is suitable to carry stream flows under high flows.

Mitigation Alternative 1-2 – Partial Upgrade of Pratt & Whitney Conduit

MMI evaluated a series of upgrades to the dual 48-inch pipes. Replacement with twin 48-inch by 72-inch box culverts would allow for sufficient inlet capacity to convey the 100-year (1% ACR) flood event. This would only be a valid approach, however, if the conduit hydraulics are confirmed to be "bottle-necked" by the inlet control.

Other elements within the conduit may influence the hydraulics and cause the conduit to have other restrictions which have not been analyzed in full detail due to a lack of information about the conduit. However, one such restriction that has been identified as causing a backwater effect on the conduit during the 100-year (1% ACR) flow is the downstream 108-inch CMP. This culvert would have to be removed to overcome the high tailwater condition at the downstream end of the Pratt & Whitney conduit in order for upgrades at the inlet to have any effect.

While this alsternative was evaluated on a conceptual level, the logistics of constructing junction chambers at culvert transitions, repairing damaged sections of existing culvert, and assessing the hydraulic competence of the entire conduit, additional survey and analysis would be necessary to determine the feasibility of such an alternative.

5.3.2 Area 2: Simmons Road and Cumberland Drive Area

A number of residential homes and apartment complexes in the Simmons Road and Cumberland Drive area are mapped in the FEMA floodplain. Through public outreach, informational meetings, and discussions with Town representatives, no records or reports of flooding have been identified in the area. Removing non-flood prone homes from the Special Flood Hazard Area (SFHA) may remove the requirement to carry flood insurance (subject to individual lender requirements), which could save the property owners money on an annual basis.

The updated hydraulic analysis and mapping of existing conditions described in Section 5.2 would remove approximately 36 residential homes and 4 multi-story apartment buildings (Woodcliff Estates) in this area from the delineated floodplain, as well as generally reducing the extents of the floodplain in the area. Figure 5-4 presents the modified floodplain according to the updated analysis. Figure 5-5 is a location plan of the Simmons Road and Cumberland Drive residential area.

SOURCE(S):
FEMA, USGS, Microsoft

Area 2: Proposed LOMR Updated Floodplain Mapping for Simmons Road and Cumberland Drive Area

LOCATION:
East Hartford, Connecticut

Figure 5-4

N

Willow Brook Flood Mitigation Study

MXD: Y:\2854-37\GIS\Maps\Simmons Cumberland Area bi.mxd

Map By: JCS
MMI#: 2854-37
Original: 9/2/2015
Revision: 11/18/2015
Scale: 1 inch = 400 feet

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Drawing: W:\DESIGN\2854-37-DE\CAD\WB-REPORT FIGURES.DWG Layout Tab:5-5 A2 SIMMONS

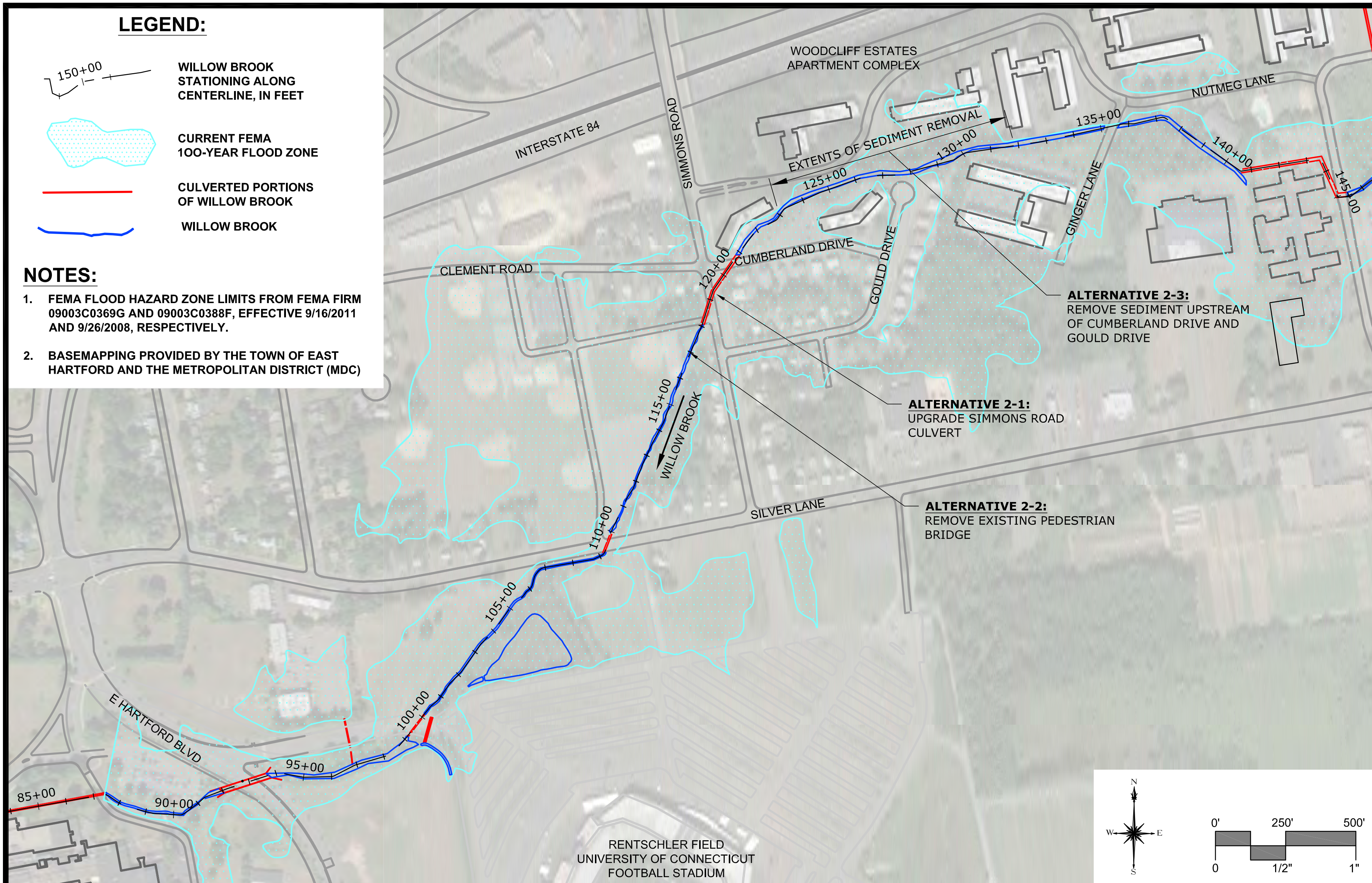
Plotted by: JAMESM On this date: Thu, 2015 November 19 – 12:09pm

LEGEND:

- 150+00 — WILLOW BROOK STATIONING ALONG CENTERLINE, IN FEET
- CURRENT FEMA 100-YEAR FLOOD ZONE
- CULVERTED PORTIONS OF WILLOW BROOK
- WILLOW BROOK

NOTES:

1. FEMA FLOOD HAZARD ZONE LIMITS FROM FEMA FIRM 09003C0369G AND 09003C0388F, EFFECTIVE 9/16/2011 AND 9/26/2008, RESPECTIVELY.
2. BASEMAPPING PROVIDED BY THE TOWN OF EAST HARTFORD AND THE METROPOLITAN DISTRICT (MDC)



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AREA 2: UPSTREAM OF SIMMONS RD & CUMBERLAND DR

WILLOW BROOK
FLOOD MITIGATION STUDY

TOWN OF EAST HARTFORD
CONNECTICUT

DRAWING NAME:

FIG. 5-5

Mitigation Alternative 2-1 – Upgrade Simmons Road Culvert

The culvert that conveys Willow Brook beneath Simmons Road and Cumberland Drive is a concrete box with six to twelve inches of silt and road sand accumulated inside. The culvert is in fair condition, with a failing headwall due to scour at the upstream end. The hydraulic analysis of the existing culvert indicates that it overtops during storm events greater than the 2-year event.

Replacement of the Simmons Road culvert with a larger structure was assessed to determine if the upstream floodplain could be reduced. The 100-year (1% ACR) flood flow at the crossing is approximately 289 cubic feet per second (cfs). Ignoring the effects of tailwater, an open area of approximately 50 square feet would be required to pass the flow with velocities less than six feet per second. Because of height restrictions due to the elevation of Simmons Road and the surrounding residential development, any proposed structure would be limited to approximately 2.5 feet in height. To achieve the desired 50 square feet, an overall span of 20 feet would be required. A larger, 30 foot span culvert was also assessed as an additional trial to determine the effectiveness of increasing the culvert size. Table 5-3 provides a comparison of the dimensions of the existing and alternative sized culverts.

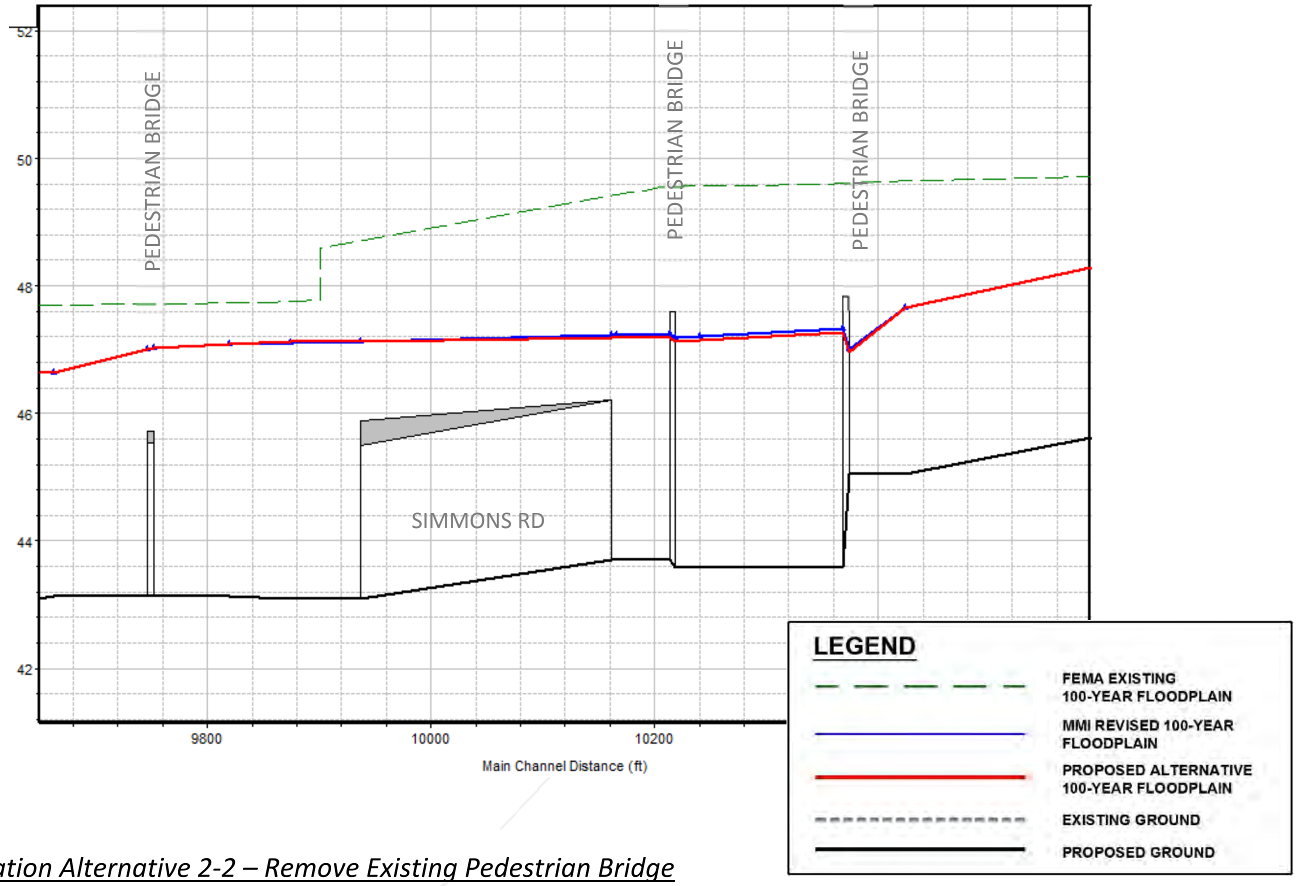
TABLE 5-3
Alt 2-1: Existing vs Proposed Culverts at Simmons Road and Cumberland Drive

Condition	Width (ft)	Height (ft)	Open Area (sf)
Existing Conditions	10	2	20
Proposed Conditions Trial 1	20	2.5	50
Proposed Conditions Trial 2	30	2.5	75

Hydraulic modeling predicts almost no benefit to flooding as a result of increased culvert sizes. The model output showed almost no decrease in the water surface elevation for the 20-foot span, and less than 0.1 foot upon increasing the culvert size to a 30-foot span for the 10-year, 50-year, or 100-year (1% ACR) flows. Figure 5-6 shows a profile of the results for the larger, 30-foot span trial.

The profile depicted in Figure 5-6 predicts shows that a timber-frame pedestrian bridge downstream of the Simmons Road culvert appears to be creating a backwater effect that causes the Simmons Road culverts to be subject to flooding regardless of its size. Therefore, iterating with larger culvert configurations was not pursued and instead, further evaluation was undertaken to address the issue of the backwater in Mitigation Alternative 2-2. In addition to the capacity of this culvert, the upstream headwall is failing and if it collapsed could obstruct flows from entering the culvert and cause flooding of the adjacent residential areas. As a preventive measure, this headwall should be repaired.

FIGURE 5-6
Alt 2-1: Simmons Road Culvert Replacement
PROFILE – Existing vs Proposed Condition, 100-year (1% ACR)



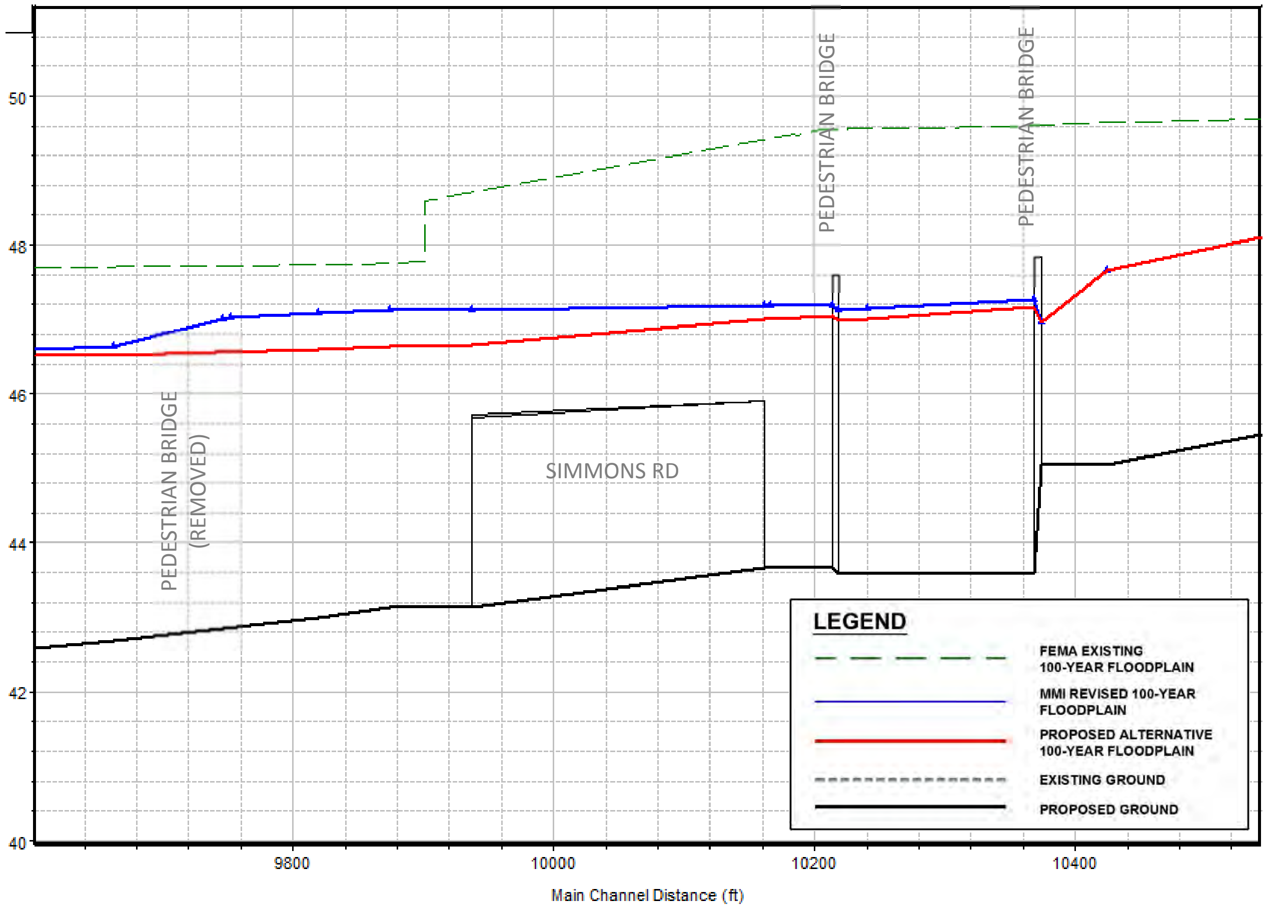
Mitigation Alternative 2-2 – Remove Existing Pedestrian Bridge

As described in Mitigation Alternative 2-1, the backwater effects from a timber pedestrian bridge cause the Simmons Road culvert to overtop, regardless of the size of any replacement that is proposed. The pedestrian bridge is located on private property approximately 200 feet downstream of the Simmons Road culvert, and was not modeled in the FEMA analysis, indicating that it may not have been present at the time the study was performed.

Alternative 2-2 explores the effects of leaving the existing 10-foot wide by 2-foot high culvert, and removing the pedestrian bridge. The removal of the bridge would require some minor channel regrading to widen the banks downstream of Simmons Road for approximately 500 linear feet of channel to be effective. Hydraulic modeling of this alternative had a much more significant impact to the flood elevations. The model output is graphically presented below in Figure 5-7.

According to the results, removal of the pedestrian bridge and minor channel regrading have a significant impact on the flooding characteristics of the Simmons Road culvert. Under this alternative, the existing culvert at Simmons Road would be capable of passing the 25-year flow without overtopping, and the 100-year flood elevation is reduced by approximately 0.5 feet.

FIGURE 5-7
Alt 2-2: Pedestrian Bridge Removal, and Channel Regrading
PROFILE – Existing vs Proposed Condition, 100-year (1% ACR)



Further exploration of the Simmons Road crossing was undertaken to assess whether increasing the size of the culvert in addition to the removal of the pedestrian bride could further improve flooding conditions in the area; however, increasing the size of the culvert in the hydraulic model did not provide any appreciable benefit. Future replacement of the Simmons Road culvert, when required, should attempt to achieve the minimum structural width and pass the 100-year flood flow.

Mitigation Alternative 2-3 – Remove Sediment Upstream of Cumberland Drive and Gould Drive

Hydraulic modeling predicts a uniform and flat 100-year water surface elevation upstream of the Simmons Road and Cumberland Drive culverts, and shows that a more significant increase in water surface elevation occurs upstream of a second pedestrian bridge that serves an apartment building parking lot near RS 123+00. Modeling further shows that the channel elevation increases approximately 1.5 feet just upstream of this bridge. It is possible that this is due to sediment that has deposited in the channel.

In order to assess the effects of removing sediment from this section of channel, the HEC-RAS model was revised to reflect removal of approximately 1.5 feet of material from the channel bed over a distance of approximately 900 feet. The estimated volume of sediment removal is approximately 1,600 cubic yards. Figure 5-8 presents the limits of sediment removal as well as the anticipated changes to the 100-year water surface elevation. The dashed gray line indicates existing conditions ground elevation, while the black line shows the proposed channel elevation after sediment removal is complete. The modeling predicts a lowering of flooding depths in the Woodcliff Estates area up to 1.5 feet.

FIGURE 5-8
Alt 2-3: Remove Sediment Upstream of Cumberland Drive
PROFILE – Existing vs Proposed Condition, 100-Year (1% ACR) Water Surface

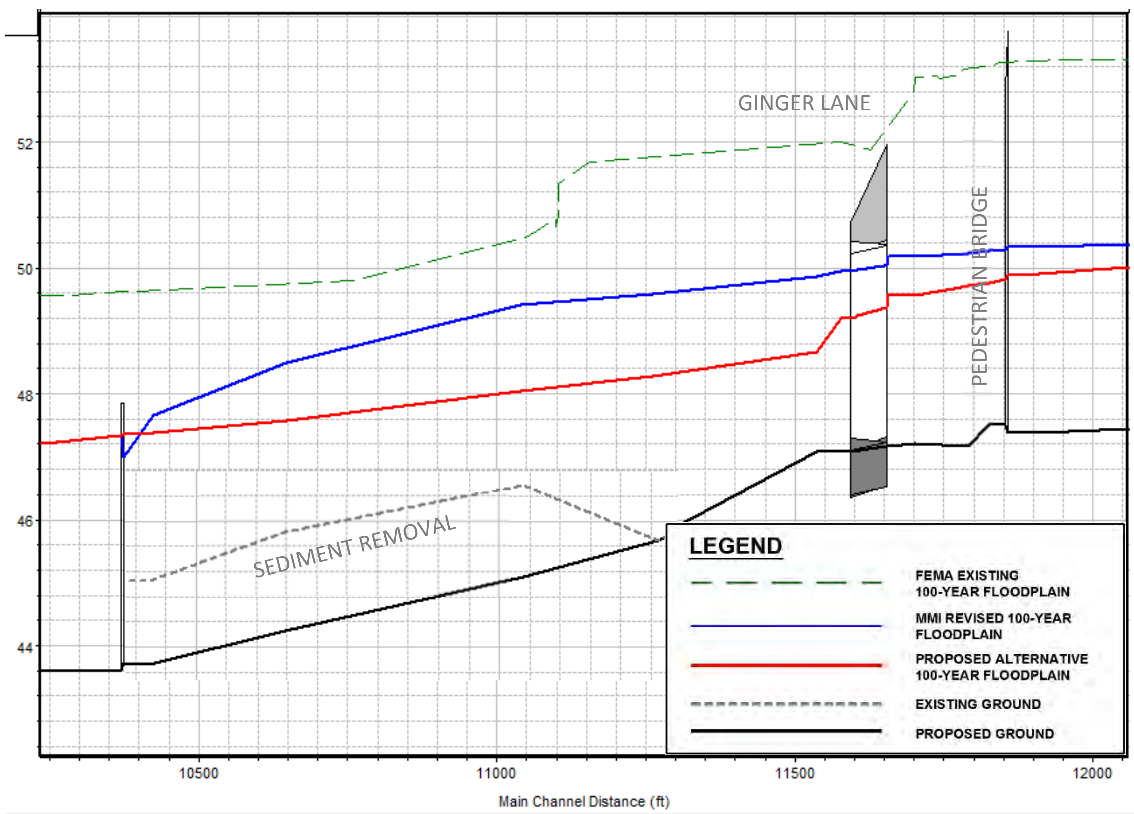


Figure 5-9 depicts a revised Simmons Road floodplain delineation with a combination of updated FEMA mapping and sediment removal in the Gould Drive area. The red line indicates the FEMA floodplain, and the yellow line indicates the revised floodplain as assessed in existing conditions. The blue hatched area indicates the revised floodplain that sediment removal could obtain.

While the sediment removal shows a minor reduction of floodwaters upstream, it does not remove any additional structures from the floodplain beyond what the revised floodplain mapping will remove. Additionally, while sediment removal can provide short-term benefits, it will not address the root causes of the aggradation. Sediment accumulation occurs in the segments of channel with low velocities, flat slopes, and shallow depths. Those root causes may be further exacerbated by the undersized pedestrian bridges located downstream, which slow flood velocities even further. Therefore the sediment removed may accumulate again over time. These challenges may outweigh the small benefits provided from this alternative.

SOURCE(S):
FEMA, USGS, Microsoft

Alt 2-3: Floodplain Mapping with Sediment Removal

LOCATION:
East Hartford, Connecticut

Figure 5-9

N

Willow Brook Flood Mitigation Study

MXD: Y:\2854-37\GIS\Maps\7bi_8x11.mxd

Map By: JCS
MMI#: 2854-37
Original: 9/2/2015
Revision: 11/17/2015
Scale: 1 inch = 400 feet

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The Natural Diversity Database (NDDB) mapping provided by the CTDEEP indicates critical habitat for listed species exists in or around this area, and as such would need to be explored in more detail before any project will be permitted. Challenges to sediment removal include potential environmental impacts, regulatory permitting, potential sediment disposal if the sediment is found to be contaminated, and the likelihood that the area will refill over time with sediment and require regular maintenance to keep the area free of aggradation.

5.3.3 Area 3: Applegate Lane Area

An assisted living/medical facility, as well as a bowling alley, and a building associated with a nearby apartment complex have been mapped in the FEMA floodplain in the Applegate Lane area. Figure 5-10 depicts the FEMA delineated floodplain in this area. Figure 5-11 is a detailed location plan. Through public outreach, informational meetings, and discussions with the Town, no records or reports of flooding in the area have been identified. Removing non-flood prone homes from the Special Flood Hazard Area (SFHA) would eliminate the need to carry flood insurance.

The updated hydraulic analysis and mapping of existing conditions described in Section 5.2 would remove approximately four large structures in this area from the delineated floodplain, including an assisted living facility (Aurora Senior Living), a bowling alley (Silver Lanes), a clubhouse (associated with Woodcliff Estates), and a multi-story apartment building (Saint Elizabeth Manor). This reach of channel is located directly downstream of the Hockanum River Diversion Structure, which removes most of the contributing flood flows from Willow Brook and conveys them north to the Hockanum River.

Mitigation Alternative 3-1 – Sediment Removal From Applegate Lane Culverts

Willow Brook is currently conveyed beneath Applegate Lane through dual 60-inch diameter corrugated metal pipes (CMPs). The exact path of the pipes is unknown, but the estimated location of the culverts yields a length of 475 linear feet. Approximately 34 inches of the 60-inch diameter pipe was observed to be filled with sediment and debris at its upstream end, effectively cutting the capacity of these culverts in half. The sedimentation exhibited here is indicative of low flows and low velocities, likely due to the reduction in contributing watershed caused by the upstream Hockanum River Diversion Structure.

Under most flow conditions, the hydraulic capacity of the Applegate Lane culverts is not the controlling factor for flooding, even with the effects of the sedimentation. With the Hockanum River diversion structure, just 200 feet upstream, flows to the culvert are minimal. Hydraulic modeling predicts that the Hockanum River diversion structure overtops during the 50-year and greater flood events, and bypassing water begins to flow around the structure, through the parking area to the south, and towards the Applegate Lane culvert. During the 100-year (1% ACR) flood event, significant flows may reach the Applegate Lane crossing; however, these flows are still not significant enough to cause flooding of any nearby structures. Cleaning of the pipes and restoring their hydraulic capacity is not predicted to significantly impact the flood elevations in this area.

The low flows and flat gradient at this structure imply that flows are not likely to create self-scouring velocities through this reach, and that siltation will continue to be a problem. It is also likely that the existing siltation and debris will further reduce water velocities, which may increase the rate at which additional accumulation ocurrs.

SOURCE(S):
FEMA, USGS, Microsoft

Area 3: Proposed LOMR Updated Floodplain Mapping for Applegate Lane Area

LOCATION:
East Hartford, Connecticut

Figure 5-10

N

Willow Brook Flood Mitigation Study

MXD: Y:\2854-37\GIS\Maps\Applegate Lane 8x11.mxd

Map By: JCS
MMI#: 2854-37
Original: 9/2/2015
Revision: 11/18/2015
Scale: 1 inch = 400 feet

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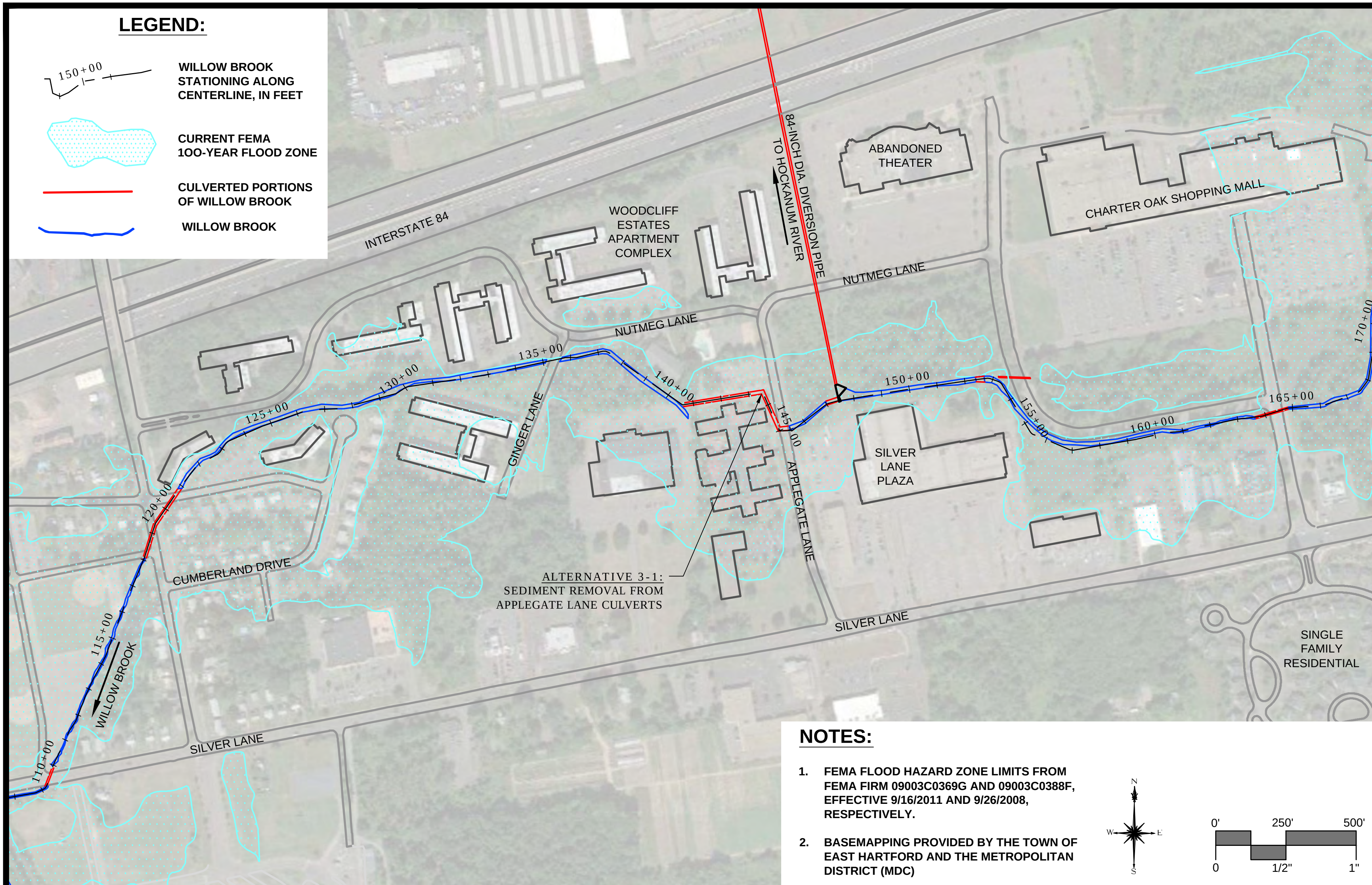

NOTES:

1. FEMA FLOOD HAZARD ZONE LIMITS FROM FEMA FIRM 09003C0369G AND 09003C0388F, EFFECTIVE 9/16/2011 AND 9/26/2008, RESPECTIVELY.
2. BASEMAPPING PROVIDED BY THE TOWN OF EAST HARTFORD AND THE METROPOLITAN DISTRICT (MDC)

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SCALE	1"=500'
PROJ. NO.	2854-37
DESIGNED	JCM
DRAWN	JCS
CHECKED	JCM

AREA 3: APPLEGATE LANE AREA

WILLOW BROOK
FLOOD MITIGATION STUDY

TOWN OF EAST HARTFORD
CONNECTICUT

DRAWING NAME:

FIG. 5-11

At its current level, due to the likely cost and difficulty of cleaning or replacing these pipes (including access issues, property ownership issues, bypass water and turbidity control, and material disposal costs), coupled with the lack of flooding implications, this alternative was not considered further, but may be considered by the private property owner if conditions worsen.

5.3.4 Area 4: Upstream of Applegate Lane

Area 4 is mapped in the FEMA floodplain. It includes an existing commercial development known as the Silver Lane Plaza. The commercial plaza structure and surrounding parking infrastructure are largely vacant. The Town of East Hartford has expressed interest in promoting redevelopment of this area; therefore, accurate mapping of the floodplain is critical to provide areas that are able to be developed.

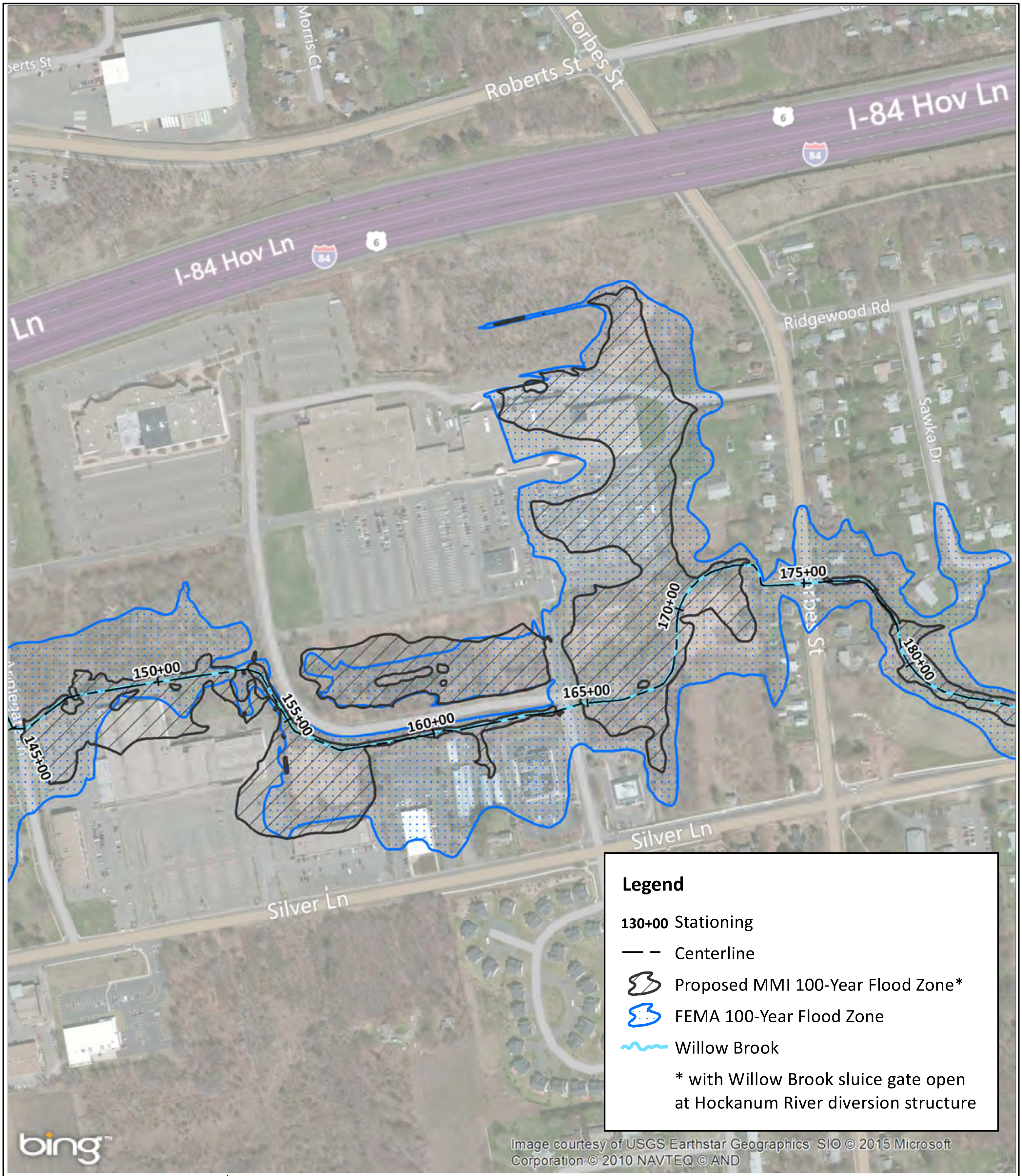
The updated hydraulic analysis and mapping of existing conditions described in Section 5.2 remove two commercial structures from the floodplain, and reduce the extents of the floodplain on the property of two other structures. The modeling shows a revised floodplain in the Silver Lane Plaza, with areas that are removed from the floodplain and small areas that are added due to updated topography. This reach of channel is located directly upstream of the Hockanum River diversion structure, which removes most of the contributing flood flows from Willow Brook and conveys them north to the Hockanum River. Figure 5-12 presents the modified floodplain according to the updated analysis. Figure 5-13 is a detailed location map of this area.

Mitigation Alternative 4-1 – Clear Debris, Widen Channel, Remove Abandoned Bridge

The Willow Brook channel located to the north of the Silver Lane Plaza is a relatively flat segment that has been subject to debris and sediment accumulation. This accumulation has had the effect of reducing the ability of this reach of channel to effectively convey flood flows, and exacerbates flooding in the area. Cleaning and widening of the channel for approximately 800 linear feet starting upstream of the Hockanum River diversion structure was assessed in the hydraulic modeling to explore the effects on flood elevations.

Also of concern is an abandoned bridge that is undersized for the 100-year (1% ACR) flood and causes a backwater effect during high flows. The bridge does not connect any current (or known future) land use elements, and therefore its removal should have no negative effects on the property use.

Photo: Debris in Willow Brook behind Silver Lane Plaza



SOURCE(S): FEMA, USGS, Microsoft	Area 4: Proposed LOMR Updated Floodplain Mapping for Upstream of Applegate Lane	LOCATION: East Hartford, Connecticut
Figure 5-12	Willow Brook Flood Mitigation Study MXD: Y:\2854-37\GIS\Maps\Upstream of Applegate.mxd	Map By: JCS MMI#: 2854-37 Original: 9/2/2015 Revision: 11/17/2015 Scale: 1 inch = 400 feet

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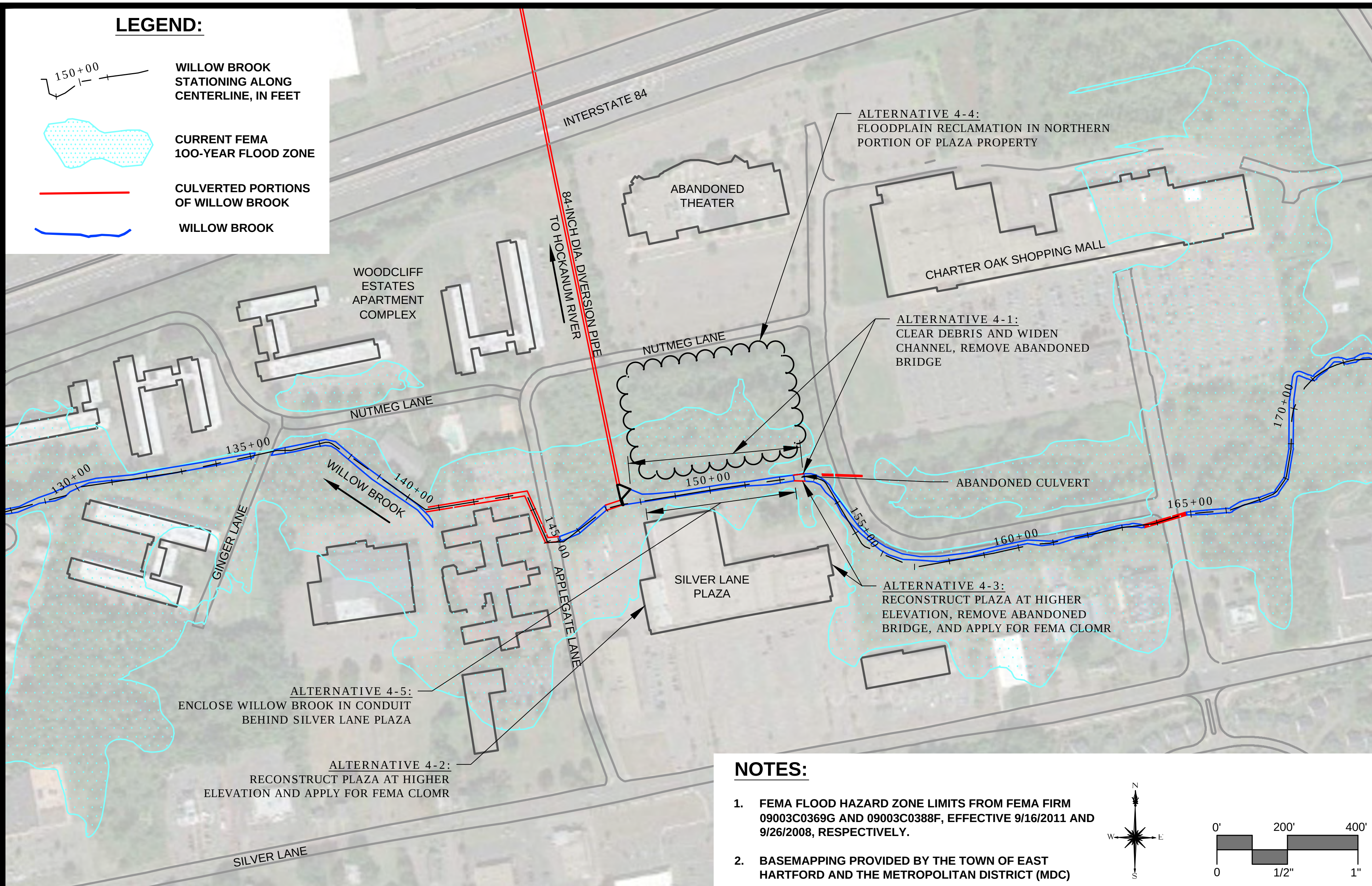

NOTES:

1. FEMA FLOOD HAZARD ZONE LIMITS FROM FEMA FIRM 09003C0369G AND 09003C0388F, EFFECTIVE 9/16/2011 AND 9/26/2008, RESPECTIVELY.
2. BASEMAPPING PROVIDED BY THE TOWN OF EAST HARTFORD AND THE METROPOLITAN DISTRICT (MDC)

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SCALE	1"=200'
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DRAWN	JCS
CHECKED	JCM

AREA 4: UPSTREAM OF APPLEGATE LANE

WILLOW BROOK FLOOD MITIGATION STUDY

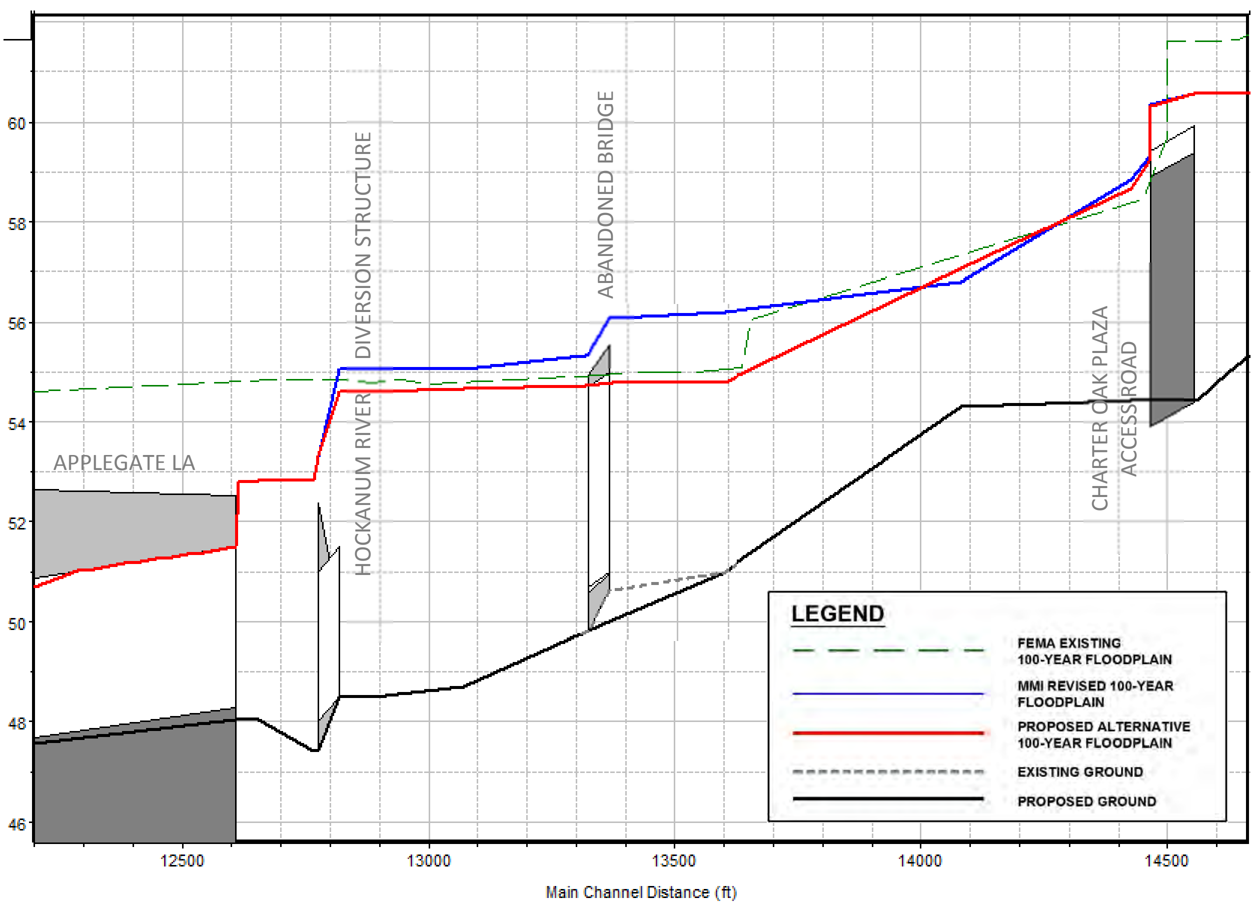
TOWN OF EAST HARTFORD
CONNECTICUT

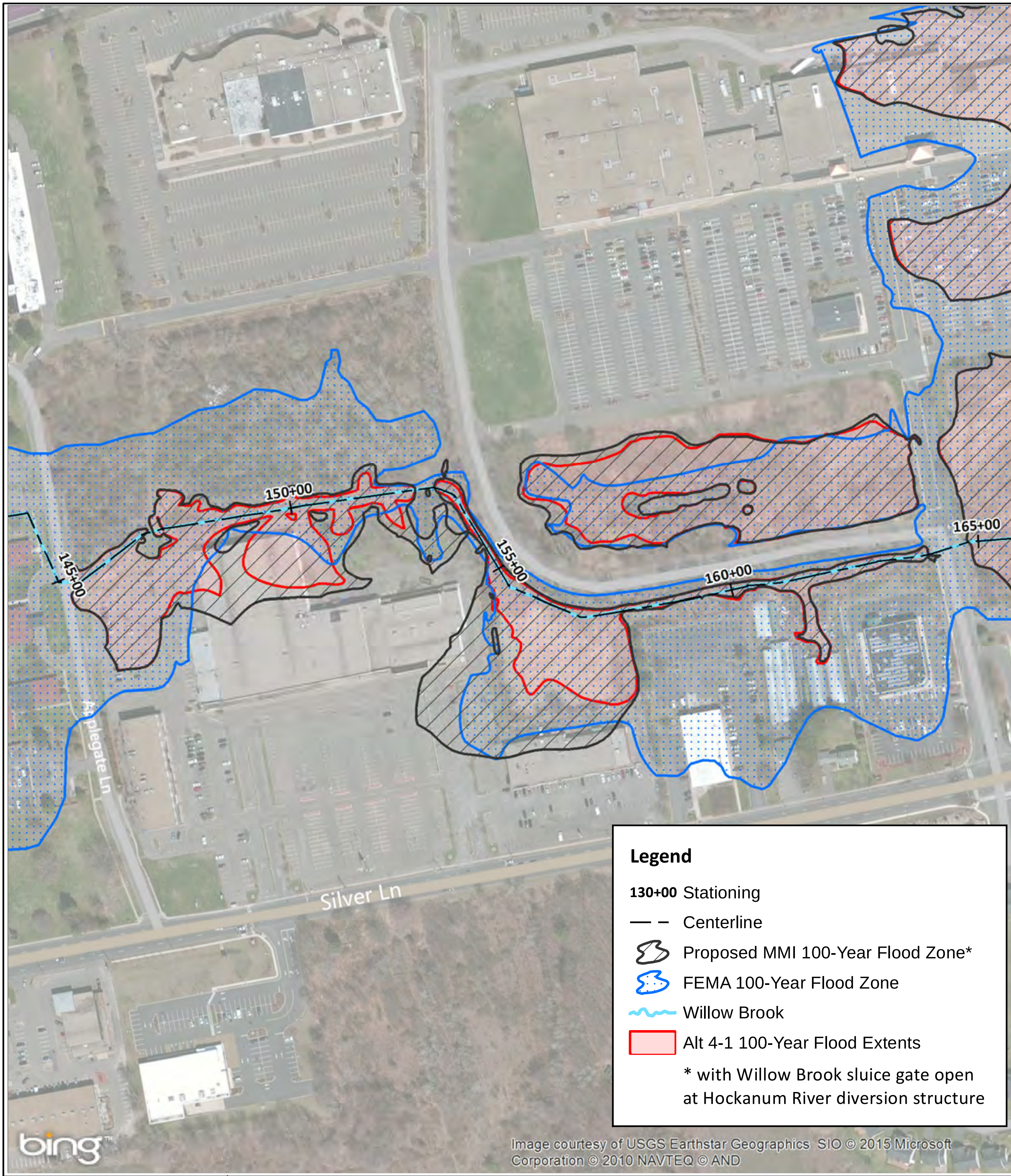
DRAWING NAME:

FIG. 5-13

Figure 5-14 presents the limits of channel deepening as well as the anticipated changes to the 100-year (1% ACR) water surface elevation in profile view. The modeling predicts a lowering of upstream flooding depths in the Silver Lane Plaza area up to 1.5 feet, but does not succeed in removing the plaza, or any upstream structures from the floodplain. Figure 5-15 shows the reduction in floodplain from a plan view. No additional structures are removed from the 100-year (1% ACR) floodplain under this alternative. Therefore, it is not recommended.

FIGURE 5-14
Alt 4-1: Widened Channel Behind Silver Lane Plaza
PROFILE – Existing vs Widened Condition, 100-year (1% ACR) Water Surface





SOURCE(S):
FEMA, USGS, Microsoft

Alt 4-1: Floodplain Mapping for Widened Channel Behind Silver Lane Plaza

LOCATION:
East Hartford, Connecticut

Figure 5-15

Willow Brook Flood Mitigation Study

MXD: Y:\2854-37\GIS\Maps\4bi_8x11.mxd

Map By: JCS
MMI#: 2854-37
Original: 9/2/2015
Revision: 11/17/2015
Scale: 1 inch = 250 feet

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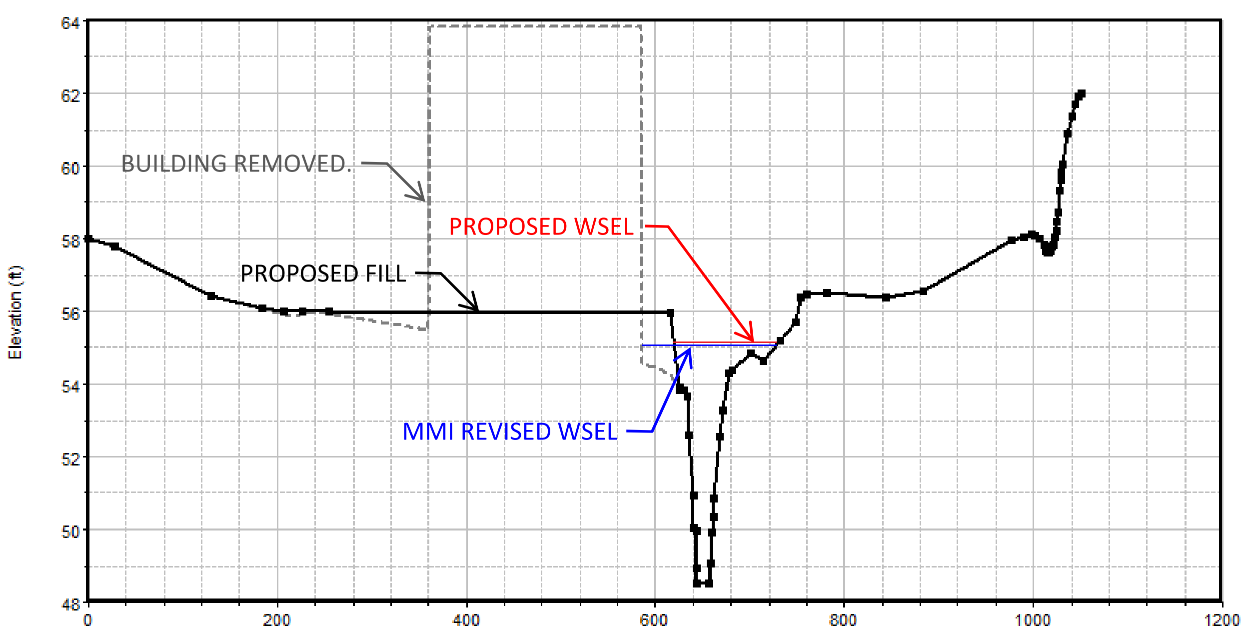
Mitigation Alternative 4-2 – Reconstruct Plaza at Higher Elevation and Apply for FEMA CLOMR

The potential for redevelopment of the Silver Lane Plaza depends in part upon the flooding characteristics of Willow Brook. While portions of the existing buildings are mapped within the 100-year (1% ACR) floodplain, these buildings could be demolished if the property were to be redeveloped. If a private developer were to propose redevelopment of the property, it would be possible to incorporate raising the elevation of the site such that the buildable area would be expanded.

Placement of any kind of fill in the existing floodplain would be require environmental and hydraulic review, due to the potentially damaging impacts such modification may have on the upstream and downstream areas of Willow Brook. Such action would be subject to local approval, and would need to comply with NFIP criteria (i.e. less than one foot of rise in flood water surface elevations).

The HEC-RAS hydraulic model was used to assess the feasibility of raising the grade of the Silver Lane Plaza out of the flood pone area. The alternative involves placing between one and two feet of fill in certain low areas on the property, and raising the elevation of the southern bank of Willow Brook between RS 148+50 and RS 160+00 to elevations between 56 and 57 feet NAVD. Figure 5-16 presents a typical section depicting the changes.

FIGURE 5-16
Alt 4-2: Raise Elevation of Silver Lane Plaza
CROSS SECTION, STA 13000 – Existing vs Dredged Condition, 100-year (1% ACR) Water Surface

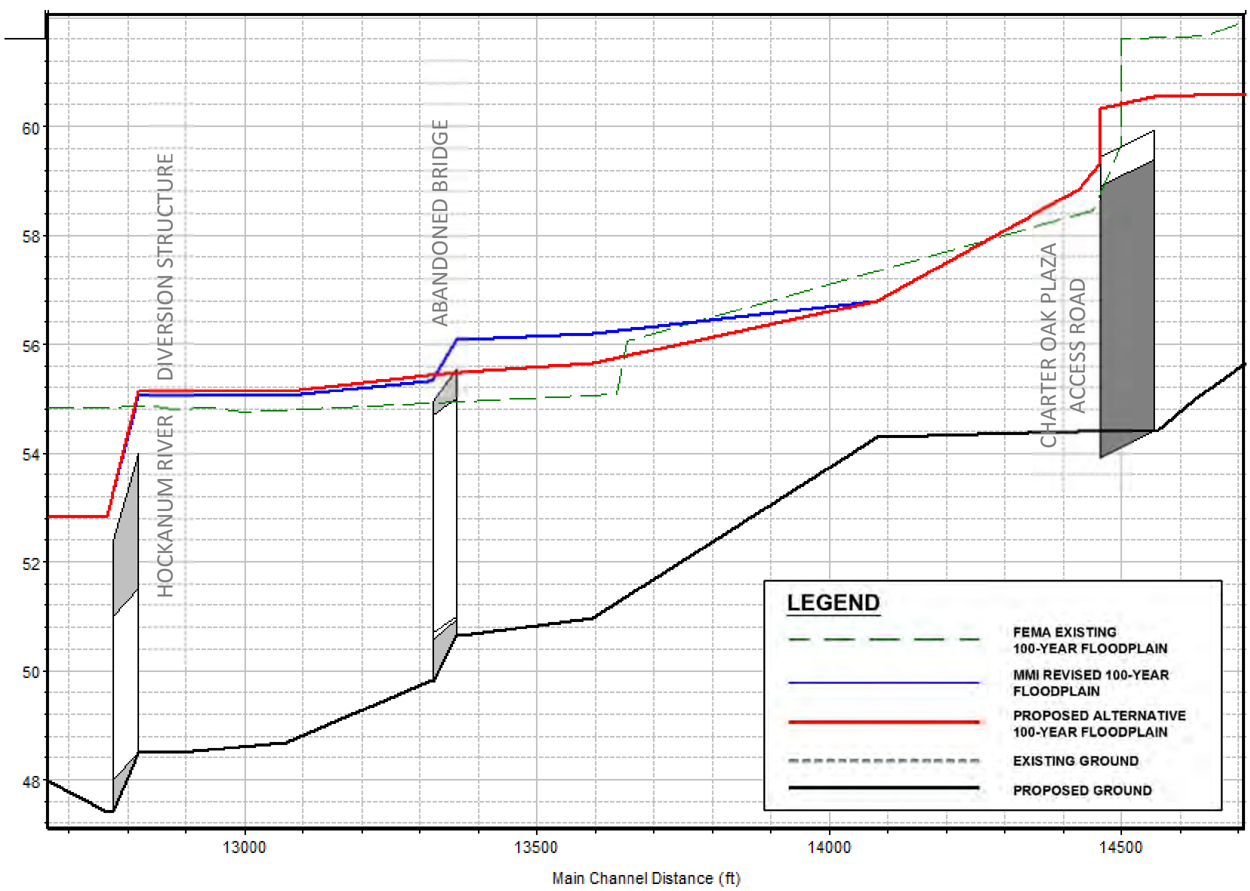


Raising the elevation of land in the floodplain would cause water surface elevations in the immediate surrounding area to increase; however, not dramatically. Modeling predicts that the 100-year (1% ACR) floodplain would increase by approximately 0.3 feet up to the Charter Oak Shopping Mall access road. This alternative would represent a major financial endeavor and would only be viable if a private development interest were to support it. The flood mitigation would be singularly for the benefit of the Plaza property.

Mitigation Alternative 4-3 – Raise Plaza Elevation and Remove Abandoned Bridge

In order to provide mitigation to the increase in floodwaters caused by raising the elevation of Silver Lane Plaza, Alternative 4-2 was further explored by assessing the removal of the abandoned bridge behind the plaza. Figure 5-17 presents a profile of the results of the modeling as compared with existing conditions. The slight rise in water surface is confined to the Silver Lane Plaza property, and the removal of the bridge provides a net lowering of water surface upstream as compared with existing conditions. This provides a benefit to upstream flood elevations and offsets the effects of raising the elevation of the plaza, and therefore would be a more prudent course of action if a private developer were to pursue redevelopment of the property.

FIGURE 5-17
Alt 4-3: Raise Elevation of Silver Lane Plaza and Remove Abandoned Bridge
PROFILE – Existing vs Dredged Condition, 100-year (1% ACR) Water Surface



Mitigation Alternative 4-4 – Floodplain Reclamation to the North of Silver Lane Plaza and Lower Grade

The lowering of an adjacent wooded floodplain to the north of the Silver Lane Plaza was explored as an alternative to raising the land. This would provide a greater area for floodwaters to spread out, potentially lowering flood elevations. Iterative trials were performed to determine by how much the floodplain would have to be lowered in order to remove the adjacent area from the 100-year (1% ACR) floodplain. A large swath of land would have to be clear-cut and a large volume of material would have to be removed from the site in order to achieve a significant flood benefit. The area of clearing is estimated as 500 linear feet by 350 feet wide of clearing trees and average cuts of 3 feet deep, as shown in the yellow hatched area in Figure 5-18. Figure 5-19 presents a cross sectional view. Figure 5-20 presents the model results.

FIGURE 5-18
Floodplain to be Cleared and Lowered - Aerial View of Extents

In order to remove the existing building from the floodplain, it is estimated that an approximate volume of material to be removed from the site would be 20,000 cubic yards, or 1,400 triaxle dump truck loads. It is unlikely that such an endeavor would be financially feasible, given the immense cost that would be required.

FIGURE 5-19
Alt 4-4: Floodplain to be Cleared and Lowered
CROSS SECTION – Floodplain Reclamation and Lowering of Grade, 100-year (1% ACR) Water Surface

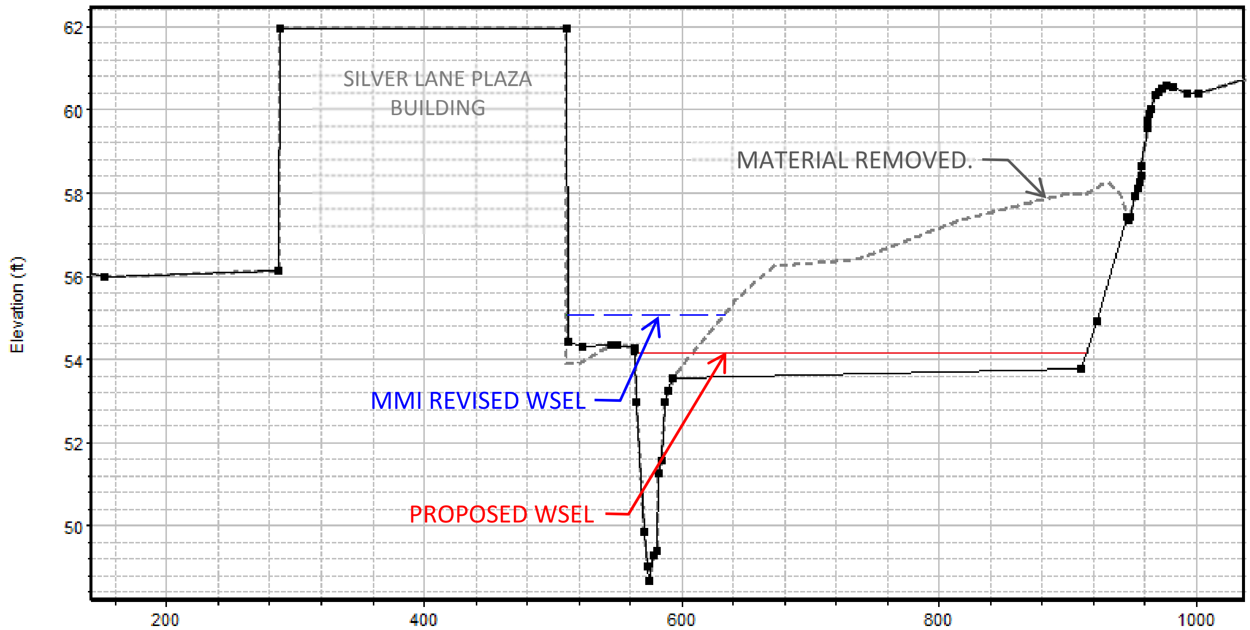
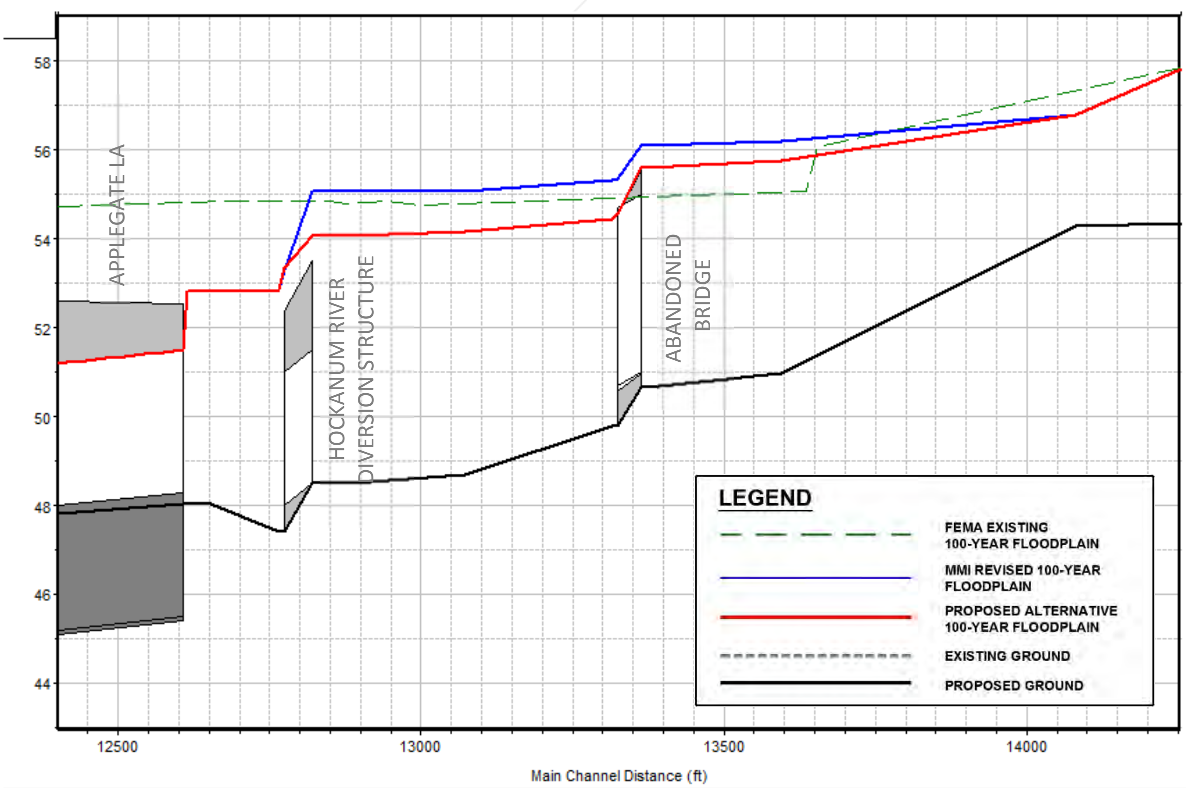


FIGURE 5-20
Alt 4-4: Floodplain to be Cleared and Lowered
PROFILE – Existing vs Proposed Condition, 100-year (1% ACR) Water Surface

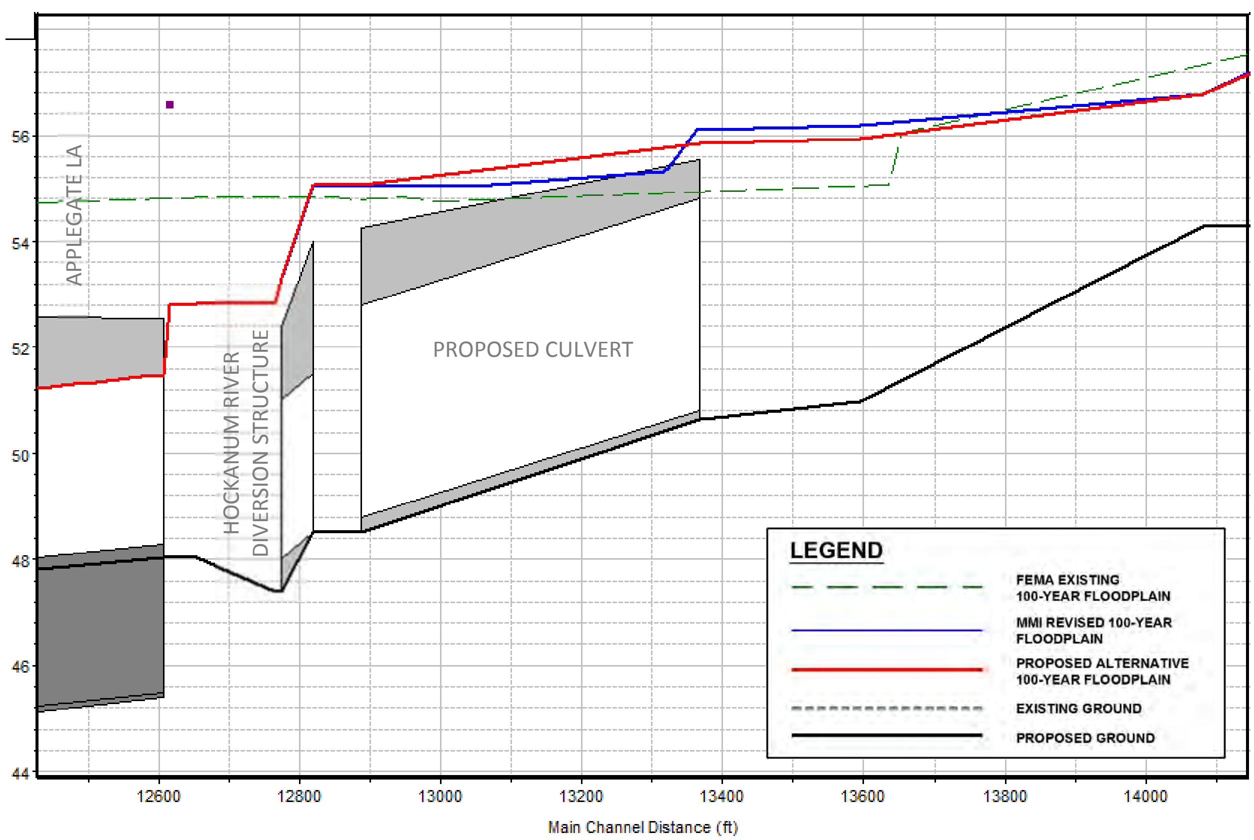


Mitigation Alternative 4-5 – Enclose Willow Brook in Conduit Behind Silver Lane Plaza

Comments from the public indicated the desire to enclose Willow Brook in a conduit for this reach of channel. Through iterative trials of different sizes and configurations, this approach would require the use of a conduit 480 feet long by 24-foot wide by 4-foot high box in order to convey flows. The proposed conduit was predicted to have sufficient capacity to pass the 100-year (1% ACR) flood; however, due to the backwater created by the Hockanum River diversion structure, it was not able to convey the flow of Willow Brook without overtopping. The culvert as modeled starts at the abandoned bridge on the upstream end, and ends 65 feet upstream of Hockanum river diversion structure. See Figure 5-21.

Not only is this alternative likely to be prohibitively expensive and ineffective relative to reduction of flooding, it is unlikely to be approved through the required local, state, and federal permitting requirements due to the environmental impacts that would likely ensue. For these reasons, this alternative is not recommended.

FIGURE 5-21
Alt 4-5: Conduit to Enclose Willow Brook
PROFILE – Existing vs Proposed Condition, 100-year (1% ACR) Water Surface



5.3.5 Area 5: Downstream of Forbes Street

An existing commercial development known as the Charter Oak Mall Shopping Center is mapped within the FEMA floodplain. The shopping center is heavily used. This area is very flat, with little elevation change between the Willow Brook channel and the adjacent floodplain. Through public outreach, informational meetings and discussions with Town representatives, no records or reports of flooding in the area have been identified. Figure 5-22 depicts the FEMA delineated floodplain. Figure 5-23 is a detailed location plan of the area.

The updated hydraulic analysis and mapping of existing conditions described in Section 5.2 would remove approximately six residential homes from the mapped floodplain in this area. This reach of channel is located directly upstream of the Hockanum River diversion structure, which removes most of the contributing flood flows from Willow Brook and conveys them north to the Hockanum River.

Mitigation Alternative 5-1 – Unblock Access Road Culvert

Vehicular access to the Charter Oak Mall commercial development is from two points, one along Silver Lane and a second from Forbes Street. The access drive from Silver Lane crosses over Willow Brook with dual 60-inch reinforced concrete pipe (RCP) culverts. However, one of these culverts was intentionally blocked with mortared concrete. The reason for this blockage is not known; however it has the effect of cutting the hydraulic capacity of the crossing in half.

In order to assess the effects this blockage has on flooding in the area, the HEC-RAS model was modified to remove the blockage and predict the water surface elevations. Figure 5-24 presents a profile view of the modeling results of this alternative as compared with existing conditions. The model predicts that opening up the second culvert reduces the upstream 100-year (1% ACR) water surface elevation by approximately 0.5 feet. However, the results indicate that even by removing the blockage and effectively doubling the opening area, the crossing is still undersized to convey the 100-year (1% ACR) flow. Due to the low cost, it is recommended that the second culvert be unblocked.

Mitigation Alternative 5-2 – Upgrade Access Road Culvert

In order to remove the hydraulic restriction of the RCP culverts beneath the Charter Oak Shopping Mall access road crossing, a second mitigation alternative that replaced the dual RCP culverts with a single 16-foot wide by 5-foot high box was assessed. Larger sizes were assessed as well, but modeling showed that the larger sizes provided very little benefit, as the capacity of the crossing became controlled by the downstream channel instead of the culvert size.

Replacing the RCP culverts would provide a modest reduction in water surface elevations during the 100-year (1% ACR) flood by 1.4 feet. Figure 5-25 presents a profile view of the modeling results for the alternative.

Figure 5-26 presents the final modified floodplain after replacement of the culvert according to the hydraulic modeling described above. The mapping as presented indicates that the shopping plaza would still be subject to flooding. However, the depth of flooding predicted in the plaza is approximately one foot lower than predicted by FEMA, which may have an impact on the flood insurance rates paid by the owners of the property.

SOURCE(S):
FEMA, USGS, Microsoft

Area 5: Proposed LOMR Updated Floodplain Mapping Downstream of Forbes Street

LOCATION:
East Hartford, Connecticut

Figure 5-22

N

Willow Brook Flood Mitigation Study

MXD: Y:\2854-37\GIS\Maps\Charter Oak Area.mxd

Map By: JCS
MMI#: 2854-37
Original: 9/2/2015
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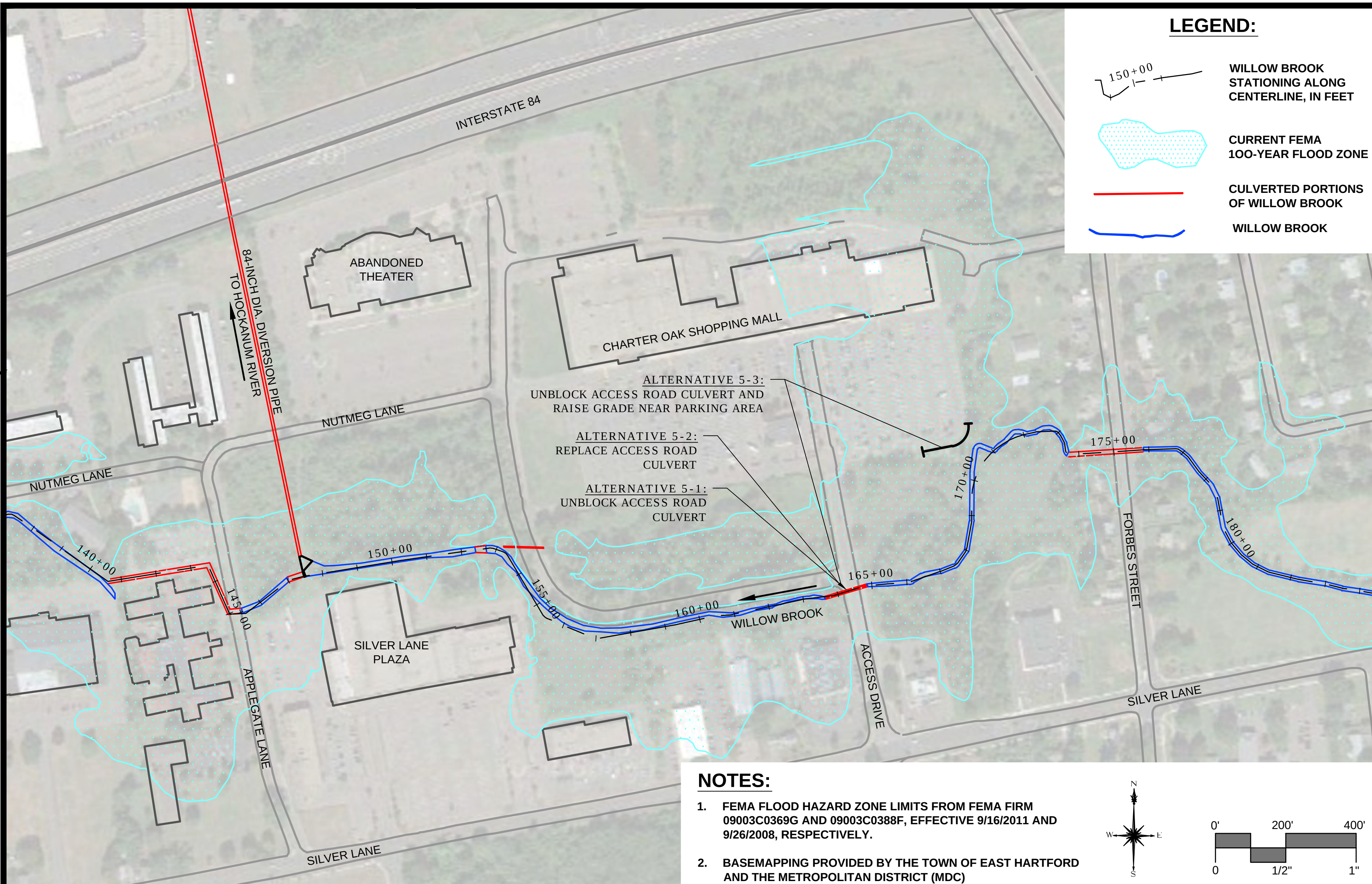

NOTES:

1. FEMA FLOOD HAZARD ZONE LIMITS FROM FEMA FIRM 09003C0369G AND 09003C0388F, EFFECTIVE 9/16/2011 AND 9/26/2008, RESPECTIVELY.
2. BASEMAPPING PROVIDED BY THE TOWN OF EAST HARTFORD AND THE METROPOLITAN DISTRICT (MDC)

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SCALE	1"=400'
PROJ. NO.	2854-37
DESIGNED	JCM
DRAWN	JCS
CHECKED	JCM

AREA 5: DOWNSTREAM OF FORBES STREET

WILLOW BROOK FLOOD MITIGATION STUDY

TOWN OF EAST HARTFORD
CONNECTICUT

DRAWING NAME:

FIG. 5-23

FIGURE 5-24
Alt 5-1: Unblock Culvert Beneath Charter Oak Shopping Center Access Drive
PROFILE – Existing vs Proposed Condition, 100-year (1% ACR) Water Surface

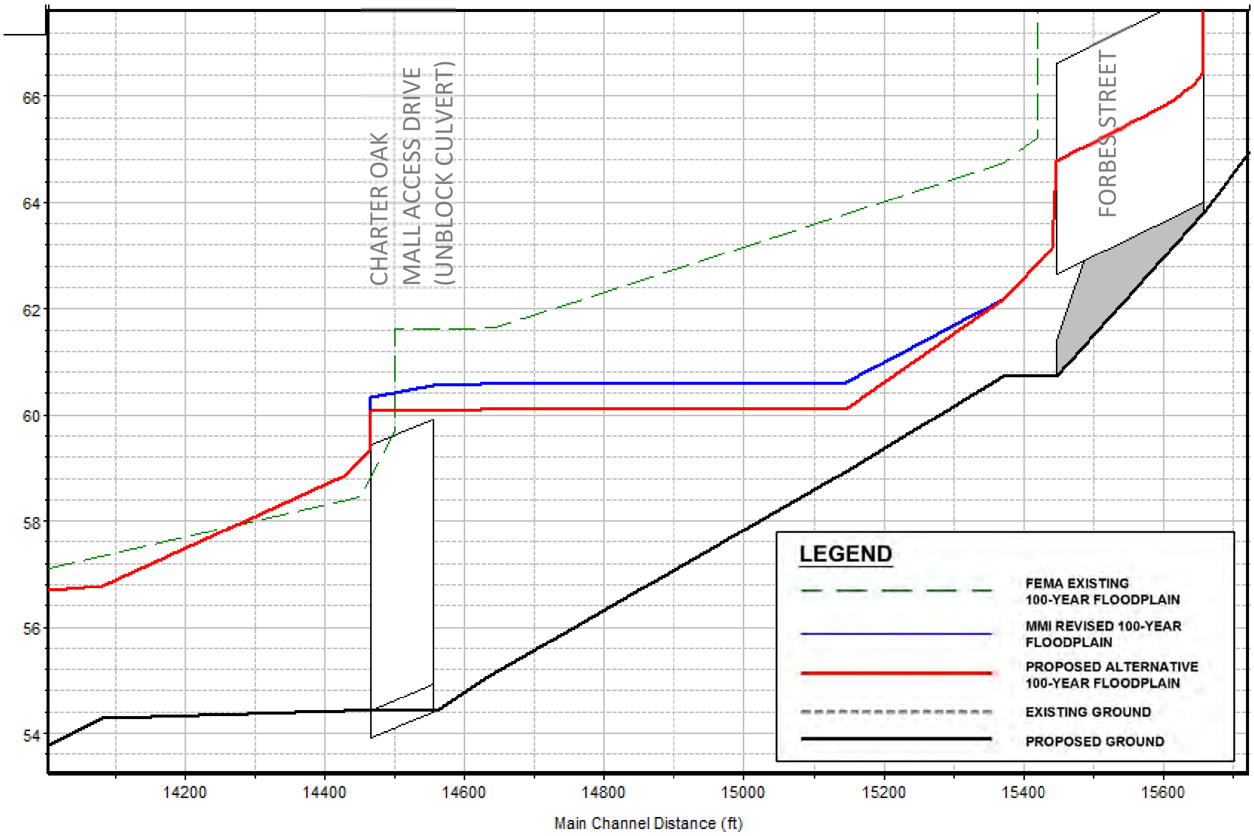
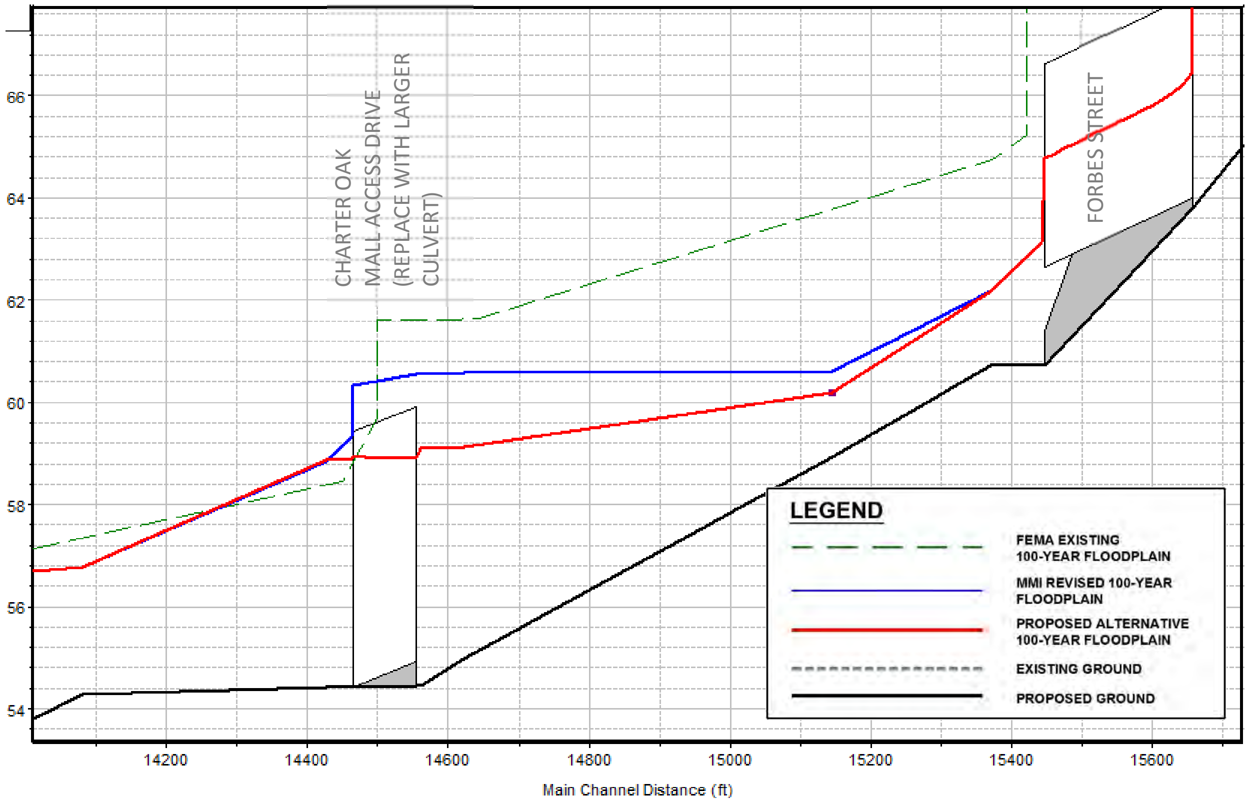
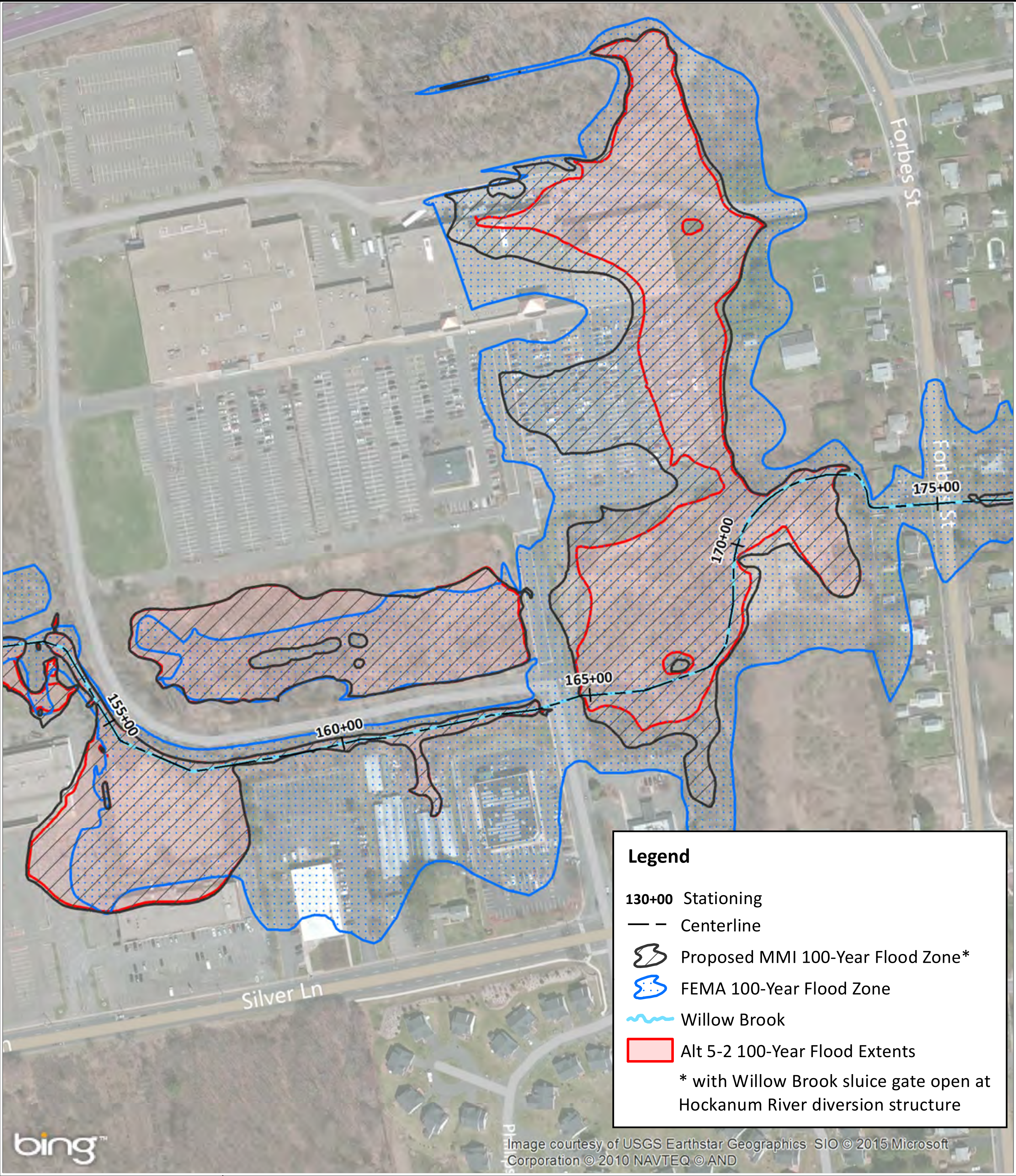


FIGURE 5-25
Alt 5-2: Upgrade Culvert Beneath Charter Oak Shopping Center Access Drive
PROFILE – Existing vs Proposed Condition, 100-year (1% ACR) Water Surface





SOURCE(S):
FEMA, USGS, Microsoft

Alt 5-2: Updated Floodplain Mapping for Culvert Replacement Charter Oak Shopping Mall Access Drive

LOCATION:
East Hartford, Connecticut

Figure 5-26

N

Willow Brook Flood Mitigation Study

MXD: Y:\2854-37\GIS\Maps\6bi_8x11.mxd

Map By: JCS
MMI#: 2854-37
Original: 9/2/2015
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Mitigation Alternative 5-3 – Unblock Access Road Culvert and Raise Grade near Parking Area

Due to the lowering of water surface elevations achieved through the unblocking of the access road culvert (presented in Alternative 5-1), the flood waters access to the structures in the Charter Oak Shopping Mall are limited to a narrow, approximately 40-foot wide segment of low-lying ground at the southwest corner of the existing parking lot. Modeling results indicate that this floodwater could be blocked from entering the parking lot and accessing the buildings by raising the elevation of the grassed shoulder near the parking area, which could remove the entire shopping plaza from the 100-year (1% ACR) floodplain. This would require additional permission from FEMA to perform the work, but could effectively remove the entire developed portion of the property from the FEMA designated floodplain. Additional assessment of the alternative would have to be performed to ensure that such a modification of the floodplain would not create adverse effects elsewhere in the stream corridor. Figure 5-27 presents the final modified floodplain after making the modifications described above.

5.3.6 Area 6: Upstream of Forbes Street (DePietro Park)

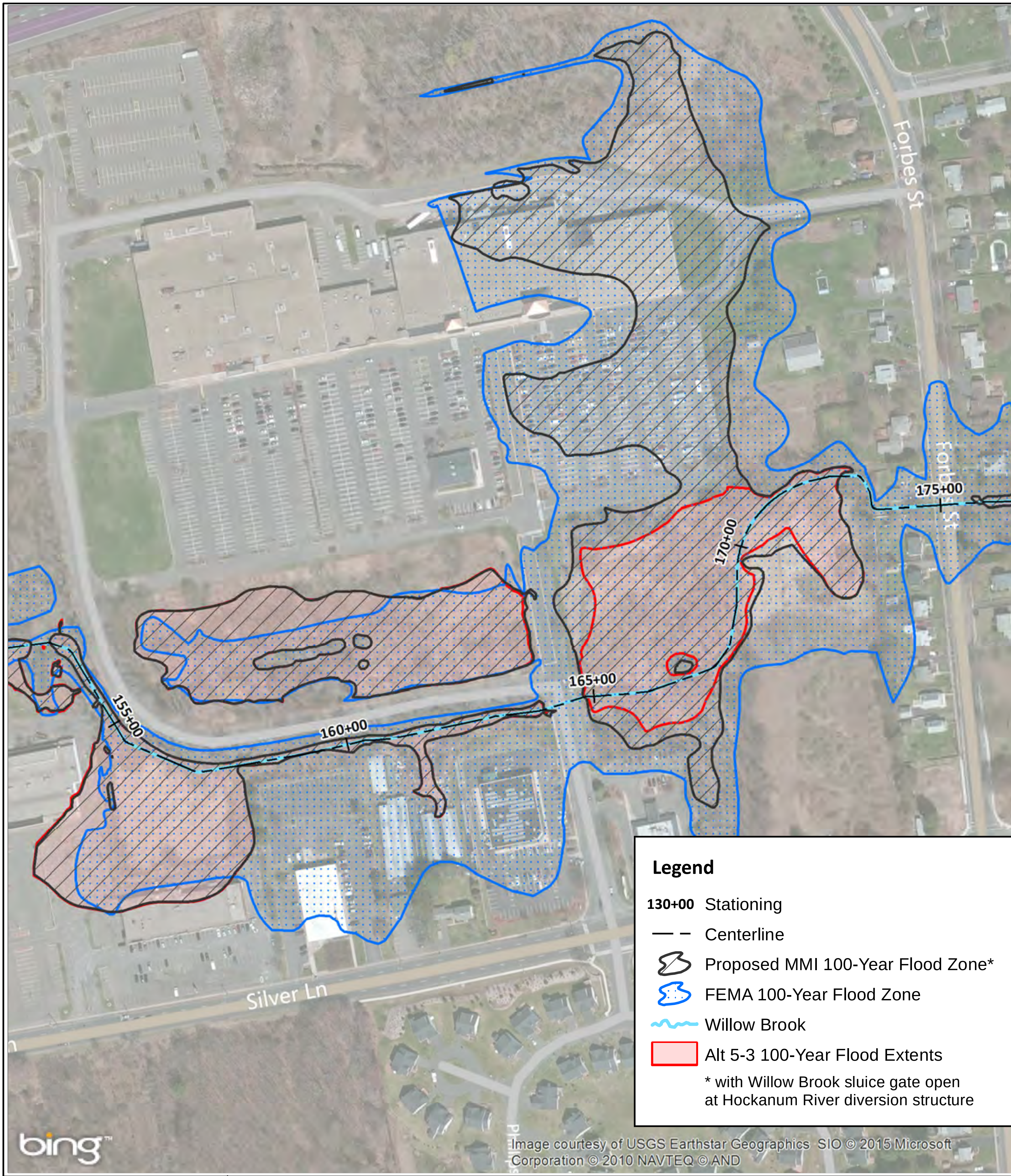
During the first public informational meeting, held on February 10, 2015, concern was raised over the accumulation of sediment, invasive vegetation, and debris in Willow Brook between Forbes Street and Silver Lane, where multiple stormwater systems discharge to form the upstream headwaters of the brook. Reports of flooding from property owners on Sawka Drive and Forbes Street were conveyed at the public meeting and through written correspondence to the Town. Some of the properties in question appear to be in the FEMA designated floodplain, highlighted in red in Figure 5-28. Figure 5-29 is a detailed location map of the area.

Upon evaluation of the hydraulic modeling and creation of an updated floodplain mapping as described in Section 5.2, two residential homes in this area were found not to be within the 100-year (1% ACR) floodplain. This eliminates the only two homes that were mapped within the floodplain upstream of Forbes Street. This is due in large part to the more recent installation of a concrete box culvert beneath Forbes Street, which is not reflected in the FEMA modeling. Inclusion of this culvert has the effect of reducing upstream water surface elevations. The concerns raised during the public informational meeting were believed to have been caused by stormwater runoff and overland flow, or high groundwater in the area and not related to flooding of the watercourse.

Mitigation Alternative 6-1 – Sediment Removal and Long-Term Sediment Management

While maintenance dredging was performed in this area in the late 1990s, nearby property owners expressed concern that work may need to be performed again to remove sediment and debris. The limits of work performed during this maintenance was contained within DePietro Park. According to public comment, invasive species, such as *Phragmites australis* (common reed) were noted in the park since the last maintenance has occurred.

It is recommended that the major contributors of sediment be retrofitted with a sediment forebay, as funding and property access allows, and a maintenance plan be put into place for the cleaning and removal of sediment from those forebays on a regular basis. Further analysis of the upstream stormwater drainage systems would have to be performed in order to properly size and design the forebays, and funding would have to be allocated to the design, permitting, and construction of said forebays, as well as the continued maintenance and sediment removal.



SOURCE(S):
FEMA, USGS, Microsoft

Alt 5-3: Updated Floodplain Mapping After Raising Grade at Charter Oak Shopping Mall

LOCATION:
East Hartford, Connecticut

Figure 5-27

N

Willow Brook Flood Mitigation Study

MXD: Y:\2854-37\GIS\Maps\Alt 5-3_8x11.mxd

Map By: JCS
MMI#: 2854-37
Original: 9/2/2015
Revision: 11/17/2015
Scale: 1 inch = 250 feet

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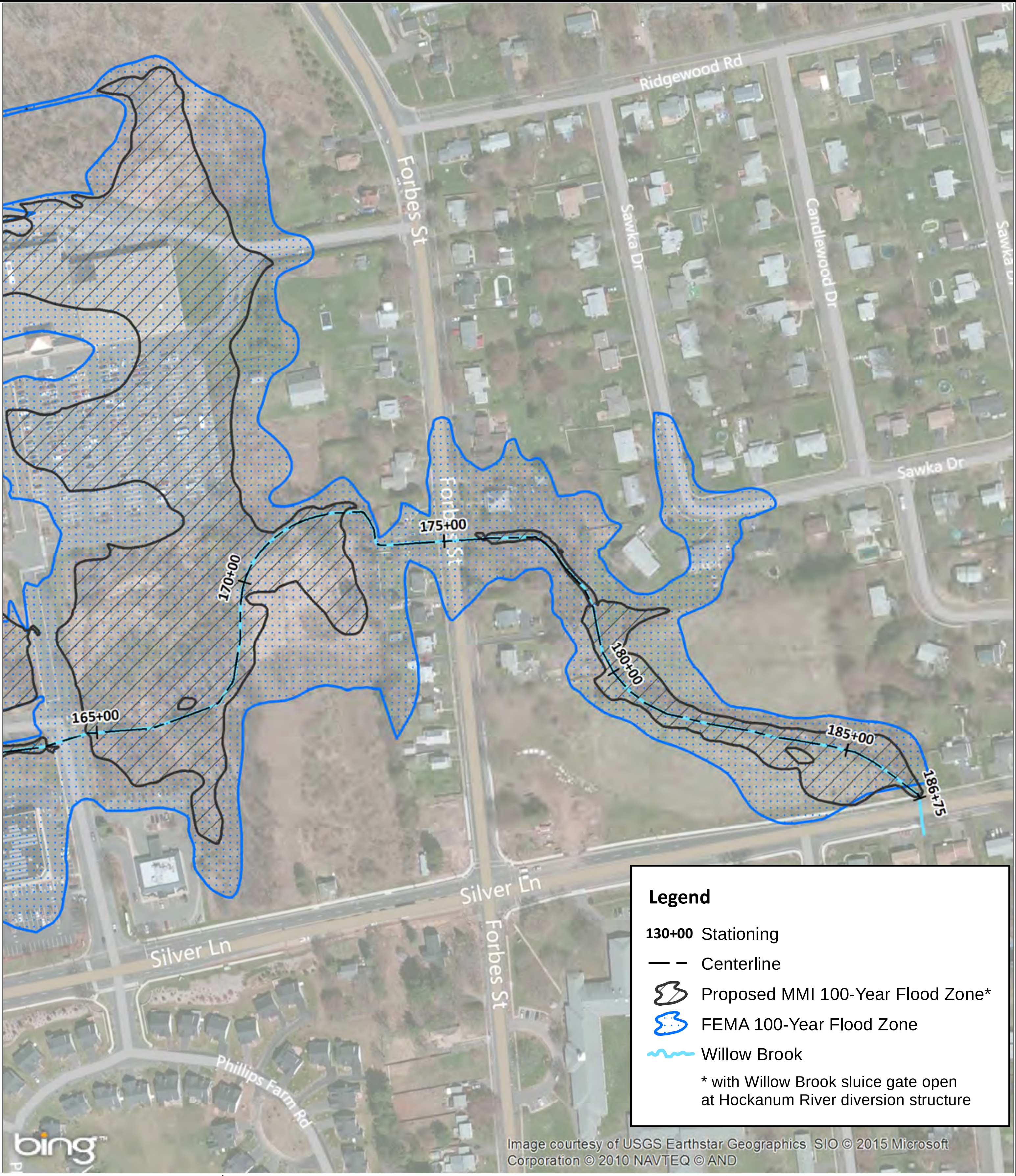

SOURCE(S): FEMA, USGS, Microsoft

Area 6: Proposed LOMR Updated Floodplain Mapping Upstream of Forbes Street

LOCATION: **East Hartford, Connecticut**

Figure 5-28

N

Willow Brook Flood Mitigation Study

MXD: Y:\2854-37\GIS\Maps\DePietro Park Area.mxd

Map By: JCS
MMI#: 2854-37
Original: 9/2/2015
Revision: 11/17/2015
Scale: 1 inch = 250 feet

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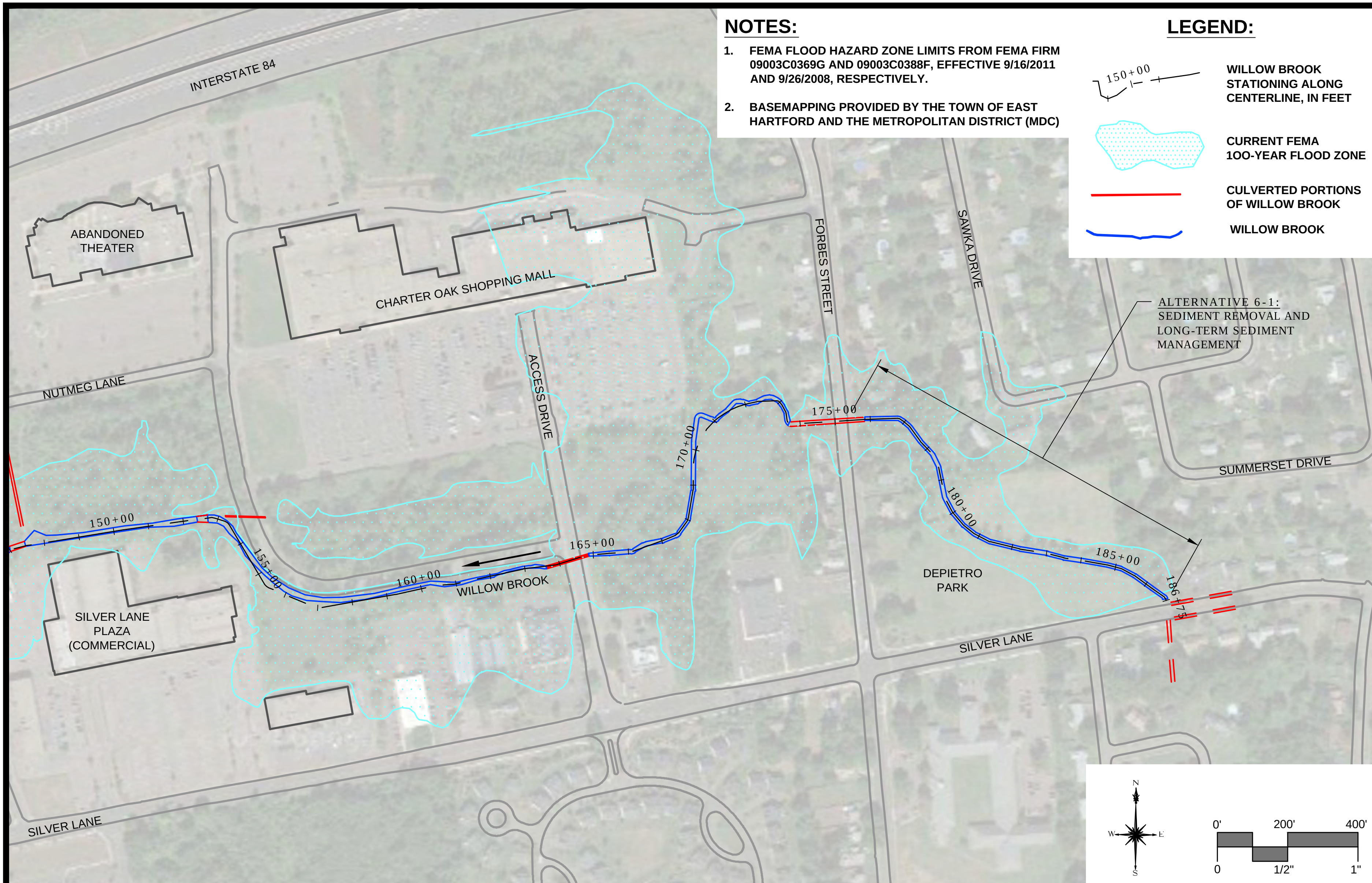

NOTES:

1. FEMA FLOOD HAZARD ZONE LIMITS FROM FEMA FIRM 09003C0369G AND 09003C0388F, EFFECTIVE 9/16/2011 AND 9/26/2008, RESPECTIVELY.
2. BASEMAPPING PROVIDED BY THE TOWN OF EAST HARTFORD AND THE METROPOLITAN DISTRICT (MDC)

LEGEND:

- 150+00 — WILLOW BROOK STATIONING ALONG CENTERLINE, IN FEET
- CURRENT FEMA 100-YEAR FLOOD ZONE
- CULVERTED PORTIONS OF WILLOW BROOK
- WILLOW BROOK

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DESIGNED	JCM
DRAWN	JCS
CHECKED	JCM

AREA 6: UPSTREAM OF FORBES STREET

WILLOW BROOK
FLOOD MITIGATION STUDY

TOWN OF EAST HARTFORD
CONNECTICUT

DRAWING NAME:

FIG. 5-29

5.4 Maintenance Concerns

Four primary maintenance concerns were identified along the Willow Brook corridor relative to the channel and structures: debris management, sedimentation/vegetation management, structural condition of crossings, and condition of stormwater outlets. Each is discussed in detail in the following sections.

5.4.1 Debris Management

Based upon field investigation by MMI staff, many reaches of the Willow Brook channel are impacted by debris and sediment accumulation. This is likely due to a combination of a low gradient (flat) watershed and stream slope, coupled with the highly developed watershed. Concern about debris and sedimentation was raised at the public informational meeting held on February 10, 2015. Comments relative to that meeting are found in Appendix A. Figure 5-30 presents a plan of possible sedimentation and debris management areas. Table 5-4 presents a summary of channel reaches where debris management may be considered.

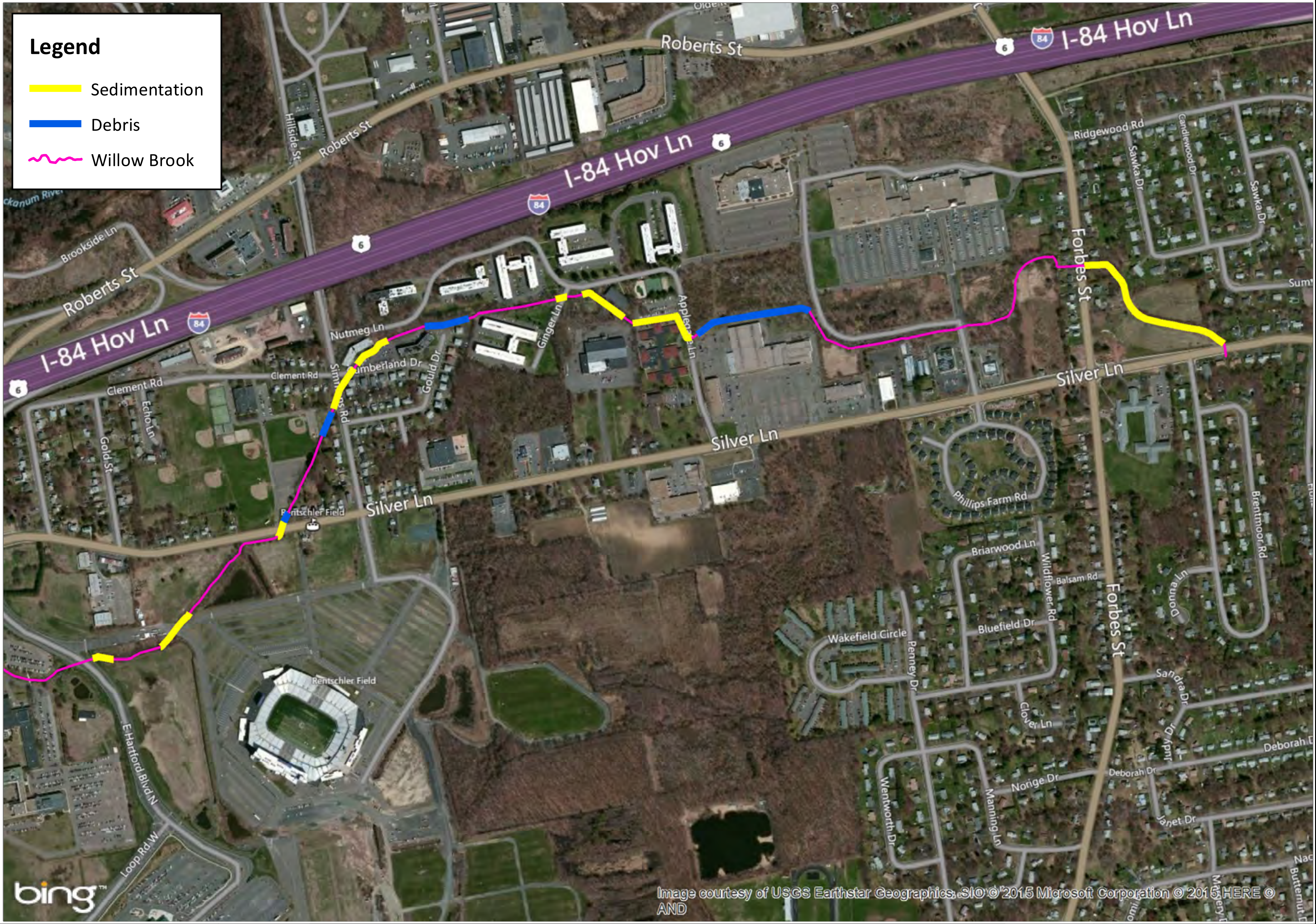
TABLE 5-4
Summary of Debris Management Areas

Sta (D/S)	Description
148+00	Channel behind Silver Lane Plaza
147+00	Hockanum River Diversion Structure
145+00	Channel upstream of Applegate Lane
128+00	Channel between Cumberland Drive and Ginger Lane
117+00	Downstream of Simmons Road
110+00	Channel/Fence upstream of Silver Lane Culvert

Accumulations within the channel at many of the areas noted consist of large woody debris and trash that has been discarded into the brook. As debris settles and accumulates, it has the tendency to capture further debris that is mobilized during a high stream flows, so this condition can be expected to worsen over time. Debris can sometimes accumulate to a point at which it impedes or completely blocks flow, called a debris jamb.

Photo: Debris Accumulation at the Hockanum River Diversion Structure

Debris accumulation can be influenced by a number of factors. A high source of debris such as unmanaged woods or a high rate of trash disposal in the system introduces debris to the channel. Areas of lower velocity tend to more readily accumulate debris. The adjacent photo shows debris accumulations at the Hockanum River diversion structure, which was constructed with chain link fencing and trash racks that have been damaged by debris during floods and have now failed. Woody debris has begun accumulating here and could impact the hydraulic performance, as well as further impact the structural stability of this structure.



SOURCE(S): Bing Maps Hybrid	N **Figure 5-30:** **Debris and Sedimentation Issues** MXD: Y:\2854-37\GIS\Maps\Debris-Sediment.mxd	**Willow Brook Flood Mitigation Study** LOCATION: East Hartford, CT	Map By: JEP MMI#: 2854-37 Original: 6/2/2015 Revision: 6/10/2015 Scale: 1 in = 800 ft	MILONE & MACBROOM 99 Realty Drive Cheshire, CT 06410 (203) 271-1773 Fax: (203) 272-9733 www.miloneandmacbroom.com

The photo on the left (below) presents an area near Silver Lane where a security fence constructed across the channel causes the accumulation of leaf litter and woody debris that has the effect of increasing backwater near homes along Simmons Road. The photo on the right shows an area near the end of the Gould Road cul-de-sac where litter, debris, wood, and trash has accumulated in the channel.

Photo: Debris accumulation near Gould Drive (left) and Silver Lane (right)

Management of debris may require the development of a long-term strategy and inspection schedule of those areas that are known to be debris-prone, as identified in Figure 5-26. While regulatory approval may be required at the local level, this type of work can be completed with hand tools and labor, such that disturbance to the channel should be minimal. If a debris management plan were developed and implemented, it may require Town of East Hartford resources to provide labor crews through Department of Public Works, or to contract labor for the removal and disposal of the debris on a semi-annual basis. Alternatively, volunteer interest could be coordinated via a "Brook Cleanup" initiative, which may be an effective and cost efficient way of removing debris in the channel.

5.4.2 Sediment and Vegetation Management

Due to the low gradient slope of Willow Brook, many reaches of the channel are subject to low velocities in normal flow conditions. As stormwater runoff containing silts and road sand enters the system through the multitude of stormwater outfalls that feed the channel, sediment can be deposited in these areas of low velocity and is prone to settling on the channel bed. This sediment can accumulate over time and begin to vegetate, which reduces the hydraulic capacity of the channel and has the effect of increasing flood elevations.

Table 5-5 presents a summary of channel reaches where sediment management may be considered.

TABLE 5-5
Summary of Potential Sediment Management Areas

Sta (D/S)	Description
176+00	Upstream of Forbes Street
141+00	Applegate Lane Culvert
118+00	Simmons/Cumberland Culvert
109+00	Silver Lane Culvert
100+00	Rentschler Field Access Culvert
92+00	East Hartford Boulevard Bridge
n/a	Detention Basin Inspection and Maintenance

5.4.3 Structural Conditions of Crossings

Some culverts within the Willow Brook watershed were assessed with a CCTV system to characterize their structural and hydraulic conditions. Some structural concerns were also noted during the visual assessment of the stream corridor. While these defects do not directly affect flooding, a structural failure of any of these structures could plug the channel and cause or exacerbate flooding. A failure of the Hockanum River diversion structure would be especially devastating given the amount of floodwater it removes from the Willow Brook corridor. Table 5-6 presents a summary of structural issues to culverts, bridges, or other hydraulic structures on Willow Brook.

TABLE 5-6
Summary of Structural Concerns

Sta (D/S)	Description	Structural Concern
164+00	Charter Oak Shopping Mall Access	Blocked second barrel
147+00	Hockanum River Diversion Structure	Weir, sluice gate, and fencing
118+00	Cumberland Drive / Simmons Road Culvert	Upstream headwall failure
112+00	Various Pedestrian Crossings near Athletic Fields	Timber, risk of blockage or mobilization during flood
110+00	Upstream of Silver Lane Crossing	Fence with debris accumulation
53+00	Pratt & Whitney Conduit	Age, unknown condition

5.4.4 Stormwater Outfall Condition

A majority of the water flowing in Willow Brook discharges from the storm drainage systems in the area. The road sand carried by these systems discharge directly to the brook and can lead to excess sedimentation in the brook corridor. Additionally, oils, chemicals, and deicing agents that discharge to the system can disrupt the natural ecology and vegetative growth in the corridor, as can nutrient-rich runoff from lawns, fertilizer, agricultural land use that can promote the growth of invasive vegetation. The water quality of Willow Brook is impacted by all of these sources. Maintenance of these outfalls can help address sedimentation issues, while design of all future or replacement stormwater outfall treatment systems using current design standards and Best Management Practices (BMPs) will help improve water quality through Willow Brook. Use of these standards can be required and enforced through local regulation and permit approval processes.

The State of Connecticut Stormwater Quality Manual (2004) provides a thorough and comprehensive description of the BMPs for stormwater outfalls from developed sites or roadways. These outfalls should typically include primary and secondary treatment of the discharge water to detain increases in peak discharge, as well as to provide sediment basins and nutrient treatment through constructed wetlands. These treatment areas can increase water quality and decrease flow peaking, and are more easily maintained without disturbing the entirety of the stream corridor.

Due to the age of the dense suburban development throughout the Willow Brook watershed, BMPs were largely not put in place or practiced at the time of development. Retrofitting existing systems by constructing treatment basins at each outfall would be extremely costly and is likely to be impossible due to unavailability of open space within the Willow Brook corridor. However, the need for these types of treatment should be considered as future development or redevelopment is proposed within the watershed. Portions of developable land may be utilized for treatment of stormwater runoff, which over time can incrementally drive the Willow Brook watershed towards a more balanced, healthy ecosystem stream corridor, and can slow the effects of sedimentation and nutrient loading in the Brook.

5.5 Flood Storage and Detention

During flood mitigation analyses it can be beneficial to assess open-space areas within the contributing watershed that may be well suited to provide floodwater detention. Construction of an appropriate detention area adjacent to the brook that can capture and “detain” floodwaters to allow the storm to pass before release can help to attenuate the peak flowrates during a precipitation event and provide flooding relief to downstream areas.

Two such areas were identified within the Willow Brook watershed as being open, flat, and potentially well suited for use as detention. The DePietro Park area upstream of Forbes Street is an open, relatively flat area, as well as a flat wetland area to the southeast of the Charter Oak Mall Shopping Center.

Typically the goal or "rule of thumb" for a feasible, cost effective flood detention area is to store at least ten percent of the runoff generated during the 100-year (1% ACR) event. This is based upon the idea that storage of less water will still cost a significant amount of financial investment, but may not provide an appreciable change to flows. The two areas identified above are too small to be able to accommodate a volume as large as ten percent of the 100-year (1% ACR) flood event without building a relatively high and costly flood control structure that would likely impact surrounding homes due to the small change in elevation between these areas and the surrounding development. Additionally, and perhaps more prohibitively, the two areas identified are located upstream of the Hockanum River diversion structure. While any proposed detention area would serve as a sink for some small percentage of water to be held during a 100-year (1% ACR) event, the Hockanum River diversion structure acts as a sink for virtually all flow to be removed from the upper watershed during flood events. Therefore, any additional attempt at mitigating flooding would not be necessarily as effective as the structure is on its own.

Downstream of the Hockanum River diversion structure, flood attenuation could be effective. However, no sufficiently open areas occur downstream of the structure until Rentschler Field. Providing peak flow attenuation this far down in the watershed would provide little to no benefit to the majority of residential structures currently mapped within the floodplain, as the majority are located upstream of this location. Therefore, flood storage and detention is not considered to be a viable alternative to flood mitigation in the Willow Brook watershed.

5.6 Localized Flood Protection Measures for Individual Structures

A number of the hydraulic improvements analyzed in the previous sections when implemented have the potential to provide flooding relief for some structures along Willow Brook. However, it is important to realize that the improvements will not protect all properties and some properties adjacent to the brook will continue to flood. Flood mitigation improvements are typically designed for the 1% chance storm. However, variations in rainfall depth and intensity will always have the potential to generate flooding in unanticipated ways. To that end, property owners along Willow Brook who have experienced recurring flooding may wish to consider flood proofing of structures.

There are three basic approaches to flood proofing individual structures: (1) elevate the building; (2) relocate the structure; or (3) undertake structural flood proofing. Each approach is described below. Additional information can be obtained through publications listed in the references section of this report.

Elevation of Buildings – Elevation is exactly as the name implies, raising the finished floor elevation of a structure above the predicted flood elevation. FEMA encourages setting finished floor elevations two feet above the predicted elevation of the 1% chance flood. Buildings can be elevated onto a foundation wall, piers, columns, or piles. The selected approach depends on the proximity of the structure to the channel as well as the structural qualities of the underlying soils. In areas very close to the channel, piers or piles may be a better solution so that floodwaters can flow under the structure rather than being blocked. This approach is feasible, and it creates a reliable protection. However, elevating a building can be costly. Consideration must be given to not only the structure but service utilities as well. Electric boxes and air conditioning units must be elevated to fully protect the building. The end result of elevation may not be aesthetically pleasing, particularly if the elevation must be in excess of two or three feet. Stairs may be required to access the building, and zoning regulations may have height restrictions to be considered. Depending on the height of elevation and site-specific conditions, basements may need to be eliminated as part of this process.

Relocation of Buildings – Relocation of structures is exactly what the name implies – moving an entire structure away from the channel. In many instances this is not feasible within the available land area of residential lots. Therefore, the structure may need to be relocated to an entirely different building lot, at which point this may not be an economically appropriate solution.

Structural Flood Proofing of Buildings – With structural flood proofing, the structure remains in place and attempts are made to minimize flood damage by protecting the structure from the rising floodwaters. A number of flood proofing approaches are available for residential homeowners including levees, floodwalls, closures, and sealants. The former two techniques are often considered together as barriers and the latter two techniques as dry flood proofing.

Barrier Flood Proofing – Barriers must be designed and constructed under the supervision of a qualified professional engineer. Barrier protection is only suitable when it is properly constructed and when routine maintenance is performed.

Levees – A levee is an embankment intended to contain floodwaters within the channel. These structures can be built at a localized scale, protecting a single home or a small development. If this approach is taken, the design phase is critical, as homeowners must be willing to live with the changed landscape. The other key decision during the design phase is determining the height of the levee, which in turn determines the level of protection for the homeowner. In many instances, a levee might be built to protect up to a 10% or 4% flood and will be overtopped by larger floods. Once overtopped, floodwaters can typically not drain by gravity, and a pump station is then needed to evacuate floodwater.

Increasing protection (i.e., up to the 1% storm) requires a larger land area because levees are typically six to eight times as wide as they are high in order to limit erosion. Any levee should be constructed under the supervision of a qualified professional engineer. The type of material used to construct the levee is critical since the use of material that is not impervious will result in seepage. Failure of the levee through improper construction can have disastrous effects for property owners if they assumed they were fully protected. Once the levee is constructed, ongoing maintenance is also important to ensure the levee functions as it was designed to.

Floodwalls – Floodwalls are vertical concrete structures intended to contain floodwater in a channel. In many instances, these are constructed after a flood or series of damaging floods have occurred. Like levees, floodwalls can be built on a local scale but do require as much space. Some floodwalls are built to protect an isolated structure such as a door or air conditioning unit. Similar to levees, design of these structures requires the supervision of a professional engineer.

Dry Flood Proofing – Dry flood proofing techniques are intended to protect structures by preventing floodwaters from entering. This is typically done by constructing watertight doors and windows, sometimes providing gasketed covers that must be installed prior to a pending flood. The difficulty is that these methods often rely on a homeowner to install the gasketed materials. Before either of these techniques is deployed, it is imperative that a homeowner have a professional engineer assess the home and its foundation. Because floodwater can exert significant hydrodynamic and hydrostatic pressure on a building, the building's structural integrity should be assessed to determine if dry flood proofing techniques are appropriate and verify that the structure can sustain the anticipated flooding. When structures flood, the hydrostatic pressures balance out on each side of the foundation, and structural integrity is not as much of an issue.

Closures – The material used to create an enclosure varies from plywood sheets to steel stop logs. It is difficult to construct these structures in such a way as to be completely watertight. As such, the installation of pumps often accompanies the construction of a closure.

Sealant – Many wall structures leak water unless specific construction techniques are implemented. Therefore, property owners who experience less than three feet of flooding may find sealants an appropriate form of flood protection. Sealants can be made of a variety of materials, but most commonly these are plastic. Installation must be completed carefully to prevent any holes from developing. Because the plastic is under pressure during a flood, a small hole will create a leak that can grow and eventually flood the structure. The effectiveness of sealants varies considerably depending on the exterior construction material of the structure. Sealants are typically recommended for buildings without a basement. If the structure does have a basement, the presence of an effective drain system is an important consideration before embarking on a sealant project as leaks from the sealant will inevitably occur. As an alternative to sealant materials for existing brick wall or concrete houses, a plastic liner can be set against the brick and then an additional brick layer constructed to hide the liner. Slab-on-grade structures tend to be somewhat easier to seal because there are fewer joints for the water to enter.

5.7 Strategic Acquisition of Flood Prone Properties

In areas along Willow Brook where dwellings have suffered repeated losses due to flooding, property acquisition is a potentially viable mitigation alternative either through a FEMA buyout program or governmental buyout. Such properties can be converted to passive, non-intensive land uses such as streamside parks, picnic areas, fishing access sites or wildlife observation areas, or simply left as unimproved open space.

In instances where properties may qualify, property acquisitions may be funded by FEMA under three grant programs: the Hazard Mitigation Grant Program (HMGP), Pre-Disaster Mitigation (PDM), and Flood Mitigation Assistance (FMA). The PDM Program was authorized by Part 203 of the Robert T. Stafford Disaster Assistance and Emergency Relief Act (Stafford Act) and provides funds for hazard mitigation planning and mitigation projects. The HMGP is authorized under Section 404 of the Stafford Act and provides grants to implement hazard mitigation measures after a major disaster declaration. A key purpose of the HMGP is to ensure that any opportunities to take critical mitigation measures to protect life and property from future disasters are not "lost" during the recovery and reconstruction process following a disaster.

The FMA program was created as part of the National Flood Insurance Reform Act (NFIRA) of 1994 with the goal of reducing or eliminating claims under the National Flood Insurance Program (NFIP). FEMA provides FMA funds to assist states and communities with implementing measures that reduce or eliminate the long-term risk of flood damage to buildings, homes, and other structures insurable under the NFIP. The long-term goal of FMA is to reduce or eliminate claims under the NFIP through mitigation activities.

The NFIP provides the funding for the FMA program. The PDM and FMA programs are subject to the availability of appropriation funding, as well as any program-specific directive or restriction made with respect to such funds. FEMA is the entity that dispenses funds for all three programs.

Historically, acquisitions and elevations of structures have been eligible for funding only when the project is found to be cost effective using FEMA's benefit-cost analysis (BCA) program. The BCA utilizes data from the FIS or previous flood damage claims to calculate the benefit-cost ratio (BCR) associated with the acquisition. The project cost (acquisition fees plus site restoration) must be known to determine the BCR. While this process has proved effective for funding many property acquisitions nationwide, there have been many instances where BCRs above 1.0 were not computed due to site-specific challenges or data gaps.

The Biggert-Waters Flood Insurance Reform Act of 2012 made several changes to the mitigation programs, and the new Hazard Mitigation Assistance (HMA) guidance was released in July 2013. One potentially important change to the PDM, HMGP, and FMA programs is that green open space and riparian area benefits can now be included in the project BCR once the project BCR reaches 0.75 or greater. This is one potential method of bridging the gap between a BCR of 0.75 and a BCR of 1.0.

On August 15, 2013, FEMA issued new guidance for acquisitions and elevations of structures within Special Flood Hazard Areas (SFHAs). According to the guidance, acquisitions with a project cost lower than $276,000 and elevations with a project cost lower than $175,000 may be considered automatically cost-effective for structures in SFHAs. Although this is a new interpretation of cost effectiveness, it could mean that acquisitions and elevations may be more easily funded without consideration of the BCA.

Once a structure has been acquired through use of a FEMA grant and demolished, the property must remain as open space; if the Town acquires a property with independent funding, there are no requirements on land use. The intent of the FEMA mitigation programs is that structures will not be built in the open space although passive recreation is permitted. To offset the loss of the structure and its occupant, the community should strive to facilitate relocation nearby in areas outside of the floodplain.

6.0 RECOMMENDED IMPROVEMENTS MASTER PLAN

6.1 Master Plan Description

The Willow Brook Flood Mitigation Study has assessed and identified the primary factors contributing to riverine flooding within the Willow Brook floodplain. The preceding sections describe the data collected, evaluation methods undertaken, and the alternatives that were assessed. This section summarizes the alternatives that were selected as being viable and effective, and provides a summary of considerations relative to their implementation. Issues such as funding, permitting, property ownership, impacts and other considerations were examined, such that projects could be prioritized and a master plan developed.

Stormwater and roadway drainage systems were not evaluated as part of the Willow Brook Flood Mitigation Study. As such, flooding that occurs as a result of undersized, under-maintained, or antiquated stormwater infrastructure was not considered in this study.

6.2 Summary of Findings

Based on the analysis of the the hydrology and hydraulics of Willow Brook, the most significant issue relating to flooding was found to be the outdated nature of the Federal Emergency Management Agency (FEMA) Flood Insurance Rate Mapping (FIRM). The mapping is used to characterize the flood risks associated with properties and structures located in floodprone areas. In the case of Willow Brook, a diversion structure located in the upper third of the watershed (described in Section 4.2.1) has the effect or significantly reducing flows in downstream areas of the brook. This diversion provides significant flood relief for densely developed residential areas not reflected in the FEMA mapping.

In addition to the FEMA mapping discrepancy, other recurring issues noted throughout the watershed include aging and undersized culvert crossings (many of which are privately owned), and the accumulation of sediment and debris throughout this very flat channel.

6.3 Summary of Recommended Actions

A comprehensive summary of potential alternatives aimed at reducing flooding associated with Willow Brook was discussed in Section 5. Figure 6-1 graphically presents a summary of recommended alternatives. Table 6-1 provides a summary of the alternatives recommended for further assessment, as well as a preliminary assessment of their relative cost.

TABLE 6-1
Summary of Alternatives Recommended for Further Assessment

Area	No.	Description	Report Reference	Property Ownership	*Relative Cost
Entire Corridor	WS-1	FEMA Map Revision	Section 5.2	Town	$
Entire Corridor	WS-2	Debris Removal	Section 5.4.1	Town and Private	$$
Entire Corridor	WS-3	Sediment Removal	Section 5.4.2	Town and Private	$$$
Simmons Road Area	WS-4	Replace Failed Simmons Road Headwall	Section 5.4.3	Town and Private	$$$
Simmons Road Area	2-2	Remove Pedestrian Bridge and Widen Channel	Section 5.3.2	Town and Private	$$
Simmons Road Area	2-3	Remove Sediment Upstream of Cumberland Drive and Gould Drive	Section 5.3.2	Town	$$
U/S of Applegate Lane	WS-4	Remove Sediment and Debris, and Perform Structural Repairs of Hockanum River Diversion	Section 5.4.3	Town	$$$
U/S of Applegate Lane	4-2	Reconstruct Plaza at Higher Elevation & Apply for FEMA CLOMR	Section 5.3.4	Private	$$$$
U/S of Applegate Lane	4-3	Raise Elevation of Plaza & Remove Abandoned Bridge	Section 5.3.4	Private or Future Developer	$$$$
D/S of Forbes Street	5-1	Unblock Culvert Beneath Access Drive	Section 5.3.5	Private	$
D/S of Forbes Street	5-2	Upgrade Access Road Culvert	Section 5.3.5	Private	$$
D/S of Forbes Street	5-3	Upgrade Access Road Culvert, Raise Grade Near Parking Area	Section 5.3.5	Private	$$

*NOTE: Relative Cost designated by $ symbols on a scale 1 - 5, with 5 being the highest.

Figure 6-1 presents a master plan indicating the location of all recommended improvements throughout the Willow Brook corridor.

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Plotted by: JAMESM On this date: Tue, 2016 August 2 - 10:06am

LEGEND:

150+00 — WILLOW BROOK STATIONING ALONG CENTERLINE, IN FEET

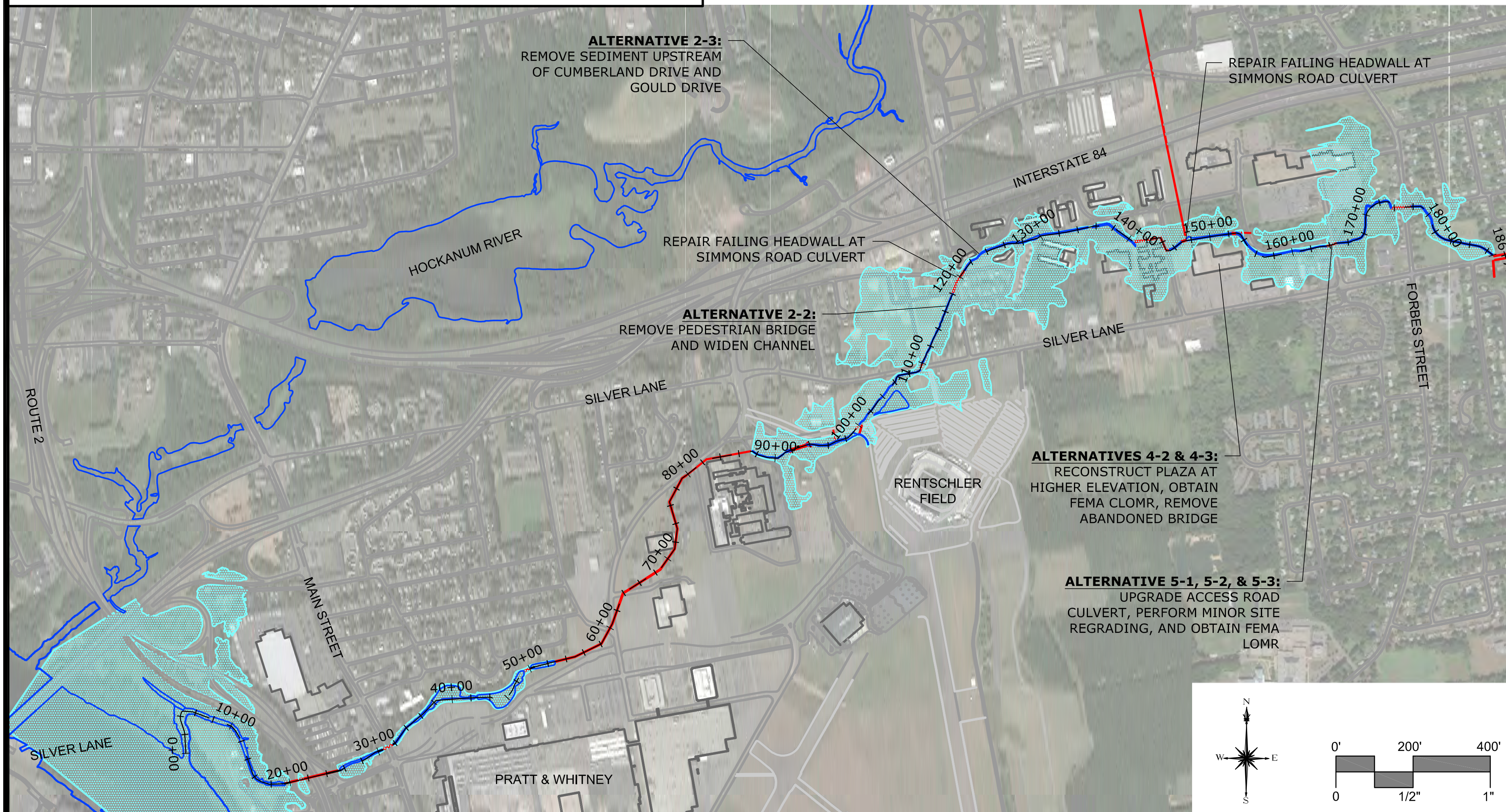
CURRENT FEMA 100-YEAR FLOOD ZONE

CULVERTED PORTIONS OF WILLOW BROOK

WILLOW BROOK

NOTES:

1. FEMA FLOOD HAZARD ZONE LIMITS FROM FEMA FIRM 09003C0369G AND 09003C0388F, EFFECTIVE 9/16/2011 AND 9/26/2008, RESPECTIVELY.
2. BASEMAPPING PROVIDED BY THE TOWN OF EAST HARTFORD AND THE METROPOLITAN DISTRICT (MDC)



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SUMMARY OF RECOMMENDED ALTERNATIVES

WILLOW BROOK FLOOD MITIGATION STUDY

TOWN OF EAST HARTFORD CONNECTICUT

DRAWING NAME:

FIG. 6-1

6.4 Potential Funding Opportunities

While funding sources are available for the implementation of different types of flood mitigation projects, the recommended improvements for the Willow Brook corridor may not be eligible for many of them. State and Federal granting programs exist for infrastructure improvements, flood mitigation, natural habitat restoration, and other project types. Many of the properties that would benefit from the implementation of recommended improvements are privately owned and do not meet the criteria for funding programs. Furthermore, many of these granting programs require a demonstration that implementation of the project would provide more benefit to the community than its construction cost would incur. A formal Benefit–Cost Analysis (BCA) would typically be performed on each project. In order to demonstrate a benefit, a project must mitigate a condition which, if not implemented, would have caused quantifiable losses. The lack of demonstrable losses throughout the Willow Brook watershed would not support a BCA greater than 1.0 and therefore formal BCA analysis was not undertaken.

Some of the major grant programs that are generally be applicable to flood control projects are described below.

FEMA Pre-Disaster Mitigation (PDM) Program

The Pre-Disaster Mitigation Program was authorized by Part 203 of the Robert T. Stafford Disaster Assistance and Emergency Relief Act (Stafford Act), 42 U.S.C. 5133. The PDM program provides funds to states, territories, tribal governments, communities, and universities for hazard mitigation planning and implementation of mitigation projects prior to disasters, providing an opportunity to reduce the nation's disaster losses through pre-disaster mitigation planning and the implementation of feasible, effective, and cost-efficient mitigation measures. Funding of pre-disaster plans and projects is meant to reduce overall risks to populations and facilities.

The PDM program is subject to the availability of appropriation funding, as well as any program-specific directive or restriction made with respect to such funds. In recent years, funds have been extremely limited and FEMA provided strict constraints to the states on how many projects could be submitted for consideration.

FEMA Hazard Mitigation Grant Program (HMGP)

The HMGP is authorized under Section 404 of the Robert T. Stafford Disaster Relief and Emergency Assistance Act. The HMGP provides grants to states and local governments to implement long-term hazard mitigation measures after a major disaster declaration. The purpose of the HMGP is to reduce the loss of life and property due to natural disasters and to enable mitigation measures to be implemented during the immediate recovery from a disaster. A key purpose of the HMGP is to ensure that any opportunities to take critical mitigation measures to protect life and property from future disasters are not "lost" during the recovery and reconstruction process following a disaster.

FEMA Flood Mitigation Assistance (FMA) Program

The FMA program was created as part of the National Flood Insurance Reform Act (NFIRA) of 1994 (42 U.S.C. 4101) with the goal of reducing or eliminating claims under the NFIP. FEMA provides FMA funds to assist states and communities with implementing measures that reduce or eliminate the long-term risk of flood damage to buildings, homes, and other structures insurable under the NFIP. The long-term goal of FMA is to reduce or eliminate claims under the NFIP through mitigation activities.

Like PDM, FMA programs are subject to the availability of appropriation funding, as well as any program-specific directive or restriction made with respect to such funds.

U.S. Army Corps of Engineers

The Corps provides 100% funding for floodplain management planning and technical assistance to states and local governments under several flood control acts and the Floodplain Management Services Program (FPMS). Specific programs used by the Corps for mitigation are listed below.

- Section 205 – Small Flood Damage Reduction Projects: This section of the 1948 Flood Control Act authorizes the Corps to study, design, and construct small flood control projects in partnership with non-Federal government agencies. Feasibility studies are 100% federally-funded up to $100,000, with additional costs shared equally. Costs for preparation of plans and construction are funded 65% with a 35% non-federal match. In certain cases, the non-Federal share for construction could be as high as 50%. The maximum federal expenditure for any project is $7 million.

- Section 14 – Emergency Streambank and Shoreline Protection: This section of the 1946 Flood Control Act authorizes the Corps to construct emergency shoreline and streambank protection works to protect public facilities such as bridges, roads, public buildings, sewage treatment plants, water wells, and non-profit public facilities such as churches, hospitals, and schools. The maximum federal expenditure for any project is $1.5 million.

- Section 208 – Clearing and Snagging Projects: This section of the 1954 Flood Control Act authorizes the Corps to perform channel clearing and excavation with limited embankment construction to reduce nuisance flood damages caused by debris and minor shoaling of rivers. Cost sharing is similar to Section 205 projects above. The maximum federal expenditure for any project is $500,000.

- Section 206 – Floodplain Management Services: This section of the 1960 Flood Control Act, as amended, authorizes the Corps to provide a full range of technical services and planning guidance necessary to support effective floodplain management. General technical assistance efforts include determining the following: site-specific data on obstructions to flood flows, flood formation, and timing; flood depths, stages, or floodwater velocities; the extent, duration, and frequency of flooding; information on natural and cultural floodplain resources; and flood loss potentials before and after the use of floodplain management measures. Types of studies conducted under FPMS include floodplain delineation, dam failure, hurricane evacuation, flood warning, floodway, flood damage reduction, stormwater management, floodproofing, and inventories of floodprone structures. When funding is available, this work is 100% federally funded.

In addition, the Corps provides emergency flood assistance (under Public Law 84-99) after local and state funding has been used. This assistance can be used for both flood response and post-flood response. Corps assistance is limited to the preservation of life and improved property; direct assistance to individual homeowners or businesses is not permitted. In addition, the Corps can loan or issue supplies and equipment once local sources are exhausted during emergencies.

Other Potential Sources of Funding

- Small Town Economic Assistance Program (STEAP) – The Office of Policy and Management Renewal administers the STEAP program for the State of Connecticut. The STEAP program provides financial assistance to eligible cities, towns, and villages in order to fund economic development, community conservation, and quality of life capital projects for localities that are ineligible to receive Urban Action (CGS Section 4-66c) bonds.

6.5 Descriptions of Recommended Actions

Considerations for implementation has been evaluated for each of the recommended actions in greater detail in this section.

6.5.1 WS-1 – FEMA Map Revision

The revised floodplain mapping (developed through the updated analysis described in the preceding sections) provides a more accurate portrayal of the flooding characteristics for the 100-year (1% ACR) flood in Willow Brook. In many cases, this includes a reduction in areas shown on the map as being floodprone. The results correlate better with anecdotal flooding reports from area residents, who in some cases do not report having been flooded during recent high-flow events.

Ensuring that FEMA mapping is as accurate as possible provides property owners with the means to obtain flood insurance when they are subject to flooding, and to avoid a potentially unnecessary financial burden when they are not subject to flooding. The Letter of Map Revision (LOMR) process involves submission of an application as well as supporting technical data, such as hydrologic assessment, hydraulic modeling, and revised floodplain mapping. Upon republication of the floodplain maps, property owners who have been removed from the floodplain may petition their mortgage lender to eliminate the requirement to carry flood insurance. A successful remapping of the Willow Brook floodplain would result in a significant number of properties which would be removed from the floodplain.

WS-1 – FEMA Map Revision			
Priority High	**Benefit** High: Eliminate non-floodprone properties from designated flood zone, reduce or eliminate need for flood insurance, and ensure flood risks are accurately represented in community	**Cost** $20k-$50k	**Timeframe** 1 year
Funding Eligibility High	**Property Ownership** N/A	**Impacts** N/A	**Permitting** FEMA

6.5.2 WS-2 – Debris Removal

Debris and trash at various locations along Willow Brook

Many reaches of Willow Brook are impacted by debris accumulation. This is likely due to a combination of its low gradient watershed, and longitudinal slope, coupled with the highly developed nature of the surrounding land. Debris accumulation reduces the hydraulic capacity of the channel, and has the effect of increasing flood elevations.

Cleanup work can be performed along the brook corridor to remove large woody debris and trash. This would require work crews to enter the brook, and manually remove the debris and trash. Maintenance work of this nature is often completed by municipal crews, but public outreach can be leveraged to garner volunteer support through local citizens and action groups. Depending on the scope and scale of work, the work may require local permitting through the Town of East Hartford Inland Wetlands Commission. It is recommended that long-term monitoring and ongoing maintenance is pursued, incurring costs in the future which should be budgeted for.

WS-2 – Debris Removal			
Priority High	**Benefit** High: increase the water-carrying capacity of the channel.	**Cost** $1k - $10k at each location	**Timeframe** 3 to 6 Months
Funding Eligibility Town of East Hartford, Private	**Property Ownership** Town and Private	**Impacts** Wetland and stream channel vegetation and habitat through construction disturbance	**Permitting** Town of East Hartford

6.5.3 WS-3 – Sediment Removal

Stormwater runoff containing silt and road sand enters Willow Brook through many outfalls that feed the channel. Much of the sediment from these outfalls is deposited in areas of low velocity. This sediment can accumulate over time and begin to vegetate, which reduces the hydraulic capacity of the channel and has the effect of increasing flood elevations.

Sediment accumulation upstream of East Hartford Boulevard North

Removal of sediment in the channel can be performed to help restore the hydraulic capacity of the channel. This would require work crews to enter the brook with small machinery or a less invasive vacuum-style truck to mechanically remove the vegetation and sediment. This work could be performed by municipal maintenance staff, or could be contracted to a private party. The work may require local permitting through the Town of East Hartford Inland Wetlands Commission. It is recommended that long-term monitoring and ongoing maintenance is pursued, incurring costs in the future which should be budgeted for. No chemical testing has been performed on sediment within the Willow Brook corridor, therefore it is unclear if any contaminants are present, and if sediment removed from the brook would be suitable for reuse in other areas.

WS-3 – Sediment Removal			
Priority Medium	**Benefit** High: increase the water-carrying capacity of the channel.	**Cost** $25k – 100k at each location	**Timeframe** 6 to 12 Months
Funding Eligibility Town of East Hartford, Private	**Property Ownership** Town and Private	**Impacts** Sediment may have chemical constituents or pollutants that require special disposal	**Permitting** Town of East Hartford, State of CT DEEP, USACE

6.5.4 WS-4A – Remove Existing Fence Across Channel

Existing fence across channel collecting debris, upstream of Silver Lane

During the visual assessment of the stream corridor, some concerns were noted regarding the structural condition of items built in or near the stream channel, and their impact on flooding of the area. An existing fence just upstream of the Silver Lane crossing has begun to collect debris, which limits the ability of water to pass. This condition is likely to be worsened under icing conditions, and may be having an adverse impacts on the upstream homes.

It is unclear if this fence falls within the Town of East Hartford right of way, or is on private property, without more detailed survey investigation. It is recommended that the property ownership of the fence be verified. If the fencing is Town owned, it can be disassembled and removed at a relatively low cost. If it is privately owned, the property owner could be approached, and a formal request for the removal of the fence could be issued.

WS-4 – Address Structural Issues with Existing Infrastructure			
Priority Medium	**Benefit** Medium: Would eliminate hydraulic restriction and improve flooding to upstream homes.	**Cost** $1k - $5k	**Timeframe** 2 months
Funding Eligibility Town	**Property Ownership** Town and Private	**Impacts** Wetland, stream channel, traffic and roadway, utilities	**Permitting** Town of East Hartford

6.5.5 WS-4B – Replace Failed Simmons Road Headwalls

Another location where structural concerns were noted during the visual assessment of the stream corridor was at the Simmons Road culvert crossing. Although the Simmons Road culvert wingwalls have separated from the culvert and one begun leaning towards the stream channel. Additional erosion around the wall could cause it to fall into the channel and obstruct the culvert crossing, which would cause unexpectedly high flooding in the area.

It is recommended that the headwalls and parapet of the Simmons Road culvert be removed and reconstructed. This would involve the design of cast-in-place concrete walls with footings sufficiently deep to prevent damage from frost or scour. The design and construction would likely be contracted out by the Town to a third party.

Failed concrete wingwall upstream of Simmons Road and Cumberland Drive culvert crossing

WS-4 – Address Structural Issues with Existing Infrastructure			
Priority Medium	**Benefit** Medium: No immediate flooding benefits, but will provide reduction in risk of failure	**Cost** $100 - $150k	**Timeframe** 6 to 12 months
Funding Eligibility Town	**Property Ownership** Town and Private	**Impacts** Wetland, stream channel, traffic and roadway, utilities	**Permitting** Town of East Hartford

6.5.6 WS-4C – Repair Hockanum River Diversion Structure

Some corrosion and debris related concerns were noted at the Hockanum River Diversion Structure during the visual assessment of the stream corridor. As shown in the adjacent photograph, corrosion and debris have caused damage to the sluicegate, the trash rack, and chainlink fencing.

The design repairs will consist of removal and replacement of the chain link fence, trash rack, and sluice gate. Additionally, repairs to the concrete are anticipated to consist of surficial patching and caulking of joints and cracks.

Debris and structural failure of Hockanum River Diversion Structure

WS-4 – Address Structural Issues with Existing Infrastructure			
Priority Medium	**Benefit** Medium: No immediate flooding benefits, but will provide reduction in risk of failure	**Cost** $150k - $250k	**Timeframe** 1 to 2 years
Funding Eligibility Town	**Property Ownership** Town	**Impacts** Wetland, stream channel, traffic and roadway, utilities	**Permitting** USACE State of CT DEEP Town of East Hartford

6.5.7 2-2 – Remove Pedestrian Bridge and Widen Channel

The backwater effects from an existing pedestrian bridge causes flooding upstream towards the Simmons Road area. The pedestrian bridge is located on private property approximately 200 feet downstream of the Simmons Road culvert. This structure was not modeled in the FEMA analysis, indicating that it may not have been present at the time the study was performed, but is located within the active floodway of the brook.

Private pedestrian bridge

The bridge is located on private property. This improvement would require the property owner to initiate and implement this improvement, but a formal request from the Town could be made for its removal.

2-2 – Remove Pedestrian Bridge and Widen Channel			
Priority High	**Benefit** High: Will remove flow restriction and increase hydraulic capacity of Willow Brook	**Cost** $2k-$5k	**Timeframe** 1 to 3 Months
Funding Eligibility Town of East Hartford, Private	**Property Ownership** Town and Private	**Impacts** Pedestrian accessibility	**Permitting** Town of East Hartford

6.5.8 2-3 – Remove Sediment and Channel Deepening Upstream of Gould Drive

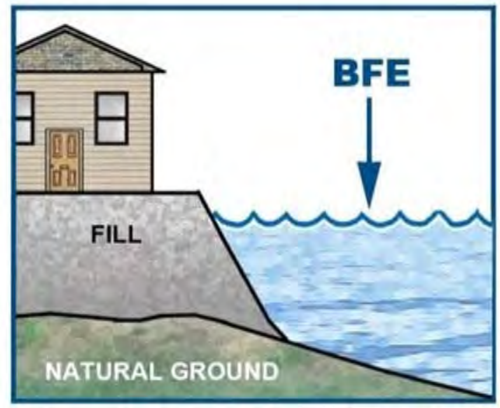
Sediment, debris, and trash accumulation near Gould Drive

Sediment and debris have accumulated in the channel upstream of Cumberland Drive and Gould Drive. This reach of channel is relatively flat with shallow, slow-moving water. The floodplain is also very relatively flat and broad, where a minor increases in water surface elevation of a foot or two can cause water to leave the Willow Brook banks and flood onto the surrounding roadways.

This alternative includes the removal of approximately 1.5 feet of material from the channel bed over a distance of approximately 900 feet. The estimated volume of sediment removal is approximately 1,600 cubic yards. The area in question crosses both public and private lands. This could be completed by Town crews with permission of the impacted private property owners.

WS-3 – Sediment Removal			
Priority Medium	**Benefit** High: increase the water-carrying capacity of the channel.	**Cost** $50k – 100k	**Timeframe** 6 to 12 Months
Funding Eligibility Town of East Hartford, Private	**Property Ownership** Town and Private	**Impacts** Sediment may have chemical constituents or pollutants that require special disposal	**Permitting** Town of East Hartford, State of CT DEEP, USACE

6.5.9 4-2 – Reconstruct Plaza at Higher Elevation & Apply for FEMA CLOMR



Schematic of fill-elevated structure

The potential for redevelopment of the commercial property currently named the Silver Lane Plaza depends in part upon the flooding characteristics of Willow Brook. The existing buildings are currently mapped within the floodplain, and it is likely that their first floor elevation is beneath the 100-year flood elevation. These could be demolished, and the fill could be imported to raise the site above the floodplain elevation. This alternative would require approximately one to two feet of fill, and would represent a major financial endeavor. This alternative would be viable only if a private development interest were to support it. The flood mitigation would only benefit the Plaza property. It would also might require compliance with flood mitigation permits at a local level, and could require USACE and CTDEEP permits, and may require approval from FEMA. Preliminary analysis indicates that placement of fill in this area without compensatory cut would cause a rise in upstream water surface elevations.

4-2 – Reconstruct Plaza at Higher Elevation & Apply for FEMA CLOMR			
Priority Low	**Benefit** Medium: Benefits to redevelopment potential of one commercial property only	**Cost** >$500k	**Timeframe** 1 to 2 Years
Funding Eligibility Private	**Property Ownership** Private	**Impacts** Impacts to wetland, floodplain, flooding on nearby properties.	**Permitting** FEMA, USACE State of CT DEEP, Town of East Hartford

6.5.10 4-3 – Remove Abandoned Bridge

Alternative 4-2 recommends placement of fill to elevate the first floor elevation of a commercial structure in the floodplain, which causes a rise in flood elevations upstream. In order to help provide mitigation for the increase in flood elevations , removal of an abandoned bridge behind the plaza is also recommended. This would provide a benefit to upstream flood elevations and would offset the effects of raising the elevation of the plaza. This alternative would have all the same challenges as 4-2, but would the relatively minor cost of removing the abandoned bridge could mitigate some of the effects of the placement of fill within the floodplain, and present an alternative approach to achieving the same goal.

Abandoned bridge

4-3 – Raise Elevation of Plaza & Remove Abandoned Bridge			
Priority Low	**Benefit** Medium: Benefits to redevelopment potential of one commercial property only	**Cost** >$500k (Alt 4-2) $5k-$10k (bridge removal)	**Timeframe** 1 to 2 Years
Funding Eligibility Private	**Property Ownership** Private	**Impacts** Impacts to wetland, floodplain, and flooding on nearby properties.	**Permitting** FEMA, USACE State of CT DEEP, Town of East Hartford

6.5.11 5-1 – Unblock Culvert Beneath Access Drive

One of two 60-inch reinforced concrete pipe (RCP) culverts beneath the access drive to Charter Oak Plaza from Silver Lane was intentionally blocked with concrete/mortar, which cuts the hydraulic capacity of the crossing in half. Removal of the blockage would reduce the 100-year floodplain elevation by 0.5 feet, but the crossing is still undersized to convey the 100-year (1% ACR) flow. Due to the low cost, it is recommended that the second culvert be unblocked. This would involve hand labor to chip away and remove the concrete from the culvert, and could be completed at a relatively low cost. The crossing is privately owned, but a formal request from the Town could be made for its removal.

5-1 – Unblock Culvert Beneath Access Drive			
Priority High	**Benefit** High: Double the capacity of the existing culvert crossing	**Cost** <$1k	**Timeframe** <1 Month
Funding Eligibility Private	**Property Ownership** Private	**Impacts** None	**Permitting** None

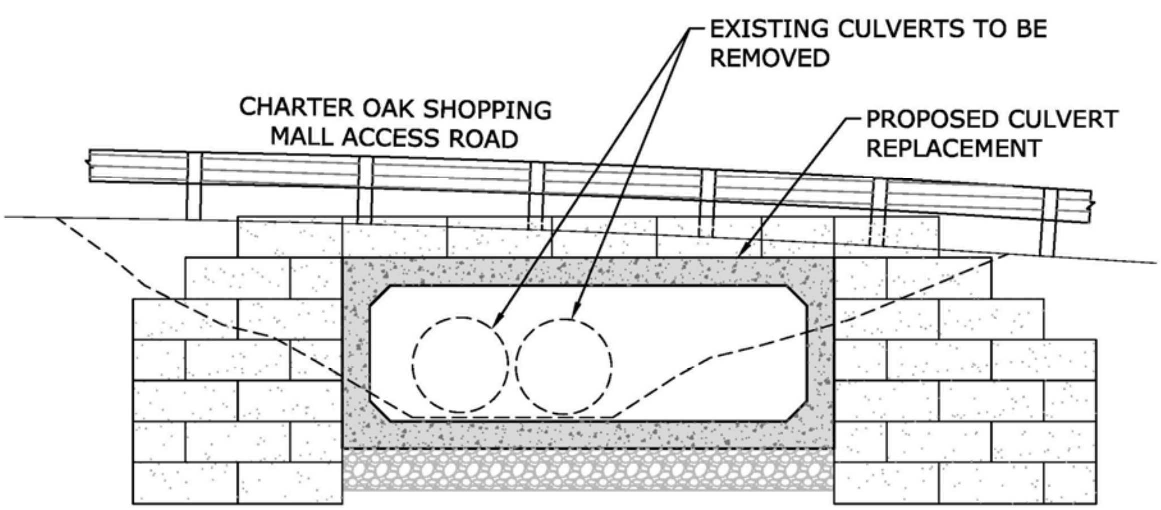
6.5.12 5-2 – Upgrade Access Road Culvert

Replacement of the culverts beneath the Charter Oak Shopping Mall access road with a 16-foot by 5-foot box culvert provides flood relief to the plaza, and upstream properties. While predicted flooding of the Charter Oak Plaza could not be completely eliminated by upgrading the culvert alone, the depth of flooding predicted in the plaza is approximately one foot lower than predicted by FEMA, which may have an impact on the flood insurance rates paid by the owners of the property.

Existing culverts beneath Charter Oak Shopping Mall Access Road

5-2 – Upgrade Access Road Culvert			
Priority Medium	**Benefit** Medium: Reduce water surface elevations but does not eliminate flooding of Charter Oak Shopping Plaza	**Cost** $250k – $500k	**Timeframe** 1 to 2 Years
Funding Eligibility Private	**Property Ownership** Private	**Impacts** Wetland, stream channel, traffic and roadway, utilities	**Permitting** State of CT DEEP Town of East Hartford

FIGURE 6-2



6.5.13 5-3 Upgrade Access Road Culvert, Raise Grade Near Parking Area

The Charter Oak Shopping Mall can be removed from the FEMA floodplain by combining culvert improvements with floodplain modification. According to the hydraulic modeling and aerial topography, floodwater from Willow Brook reaches the shopping mall through shallow, overland sheet flow which flows through a low point in the parking area, across the pavement, and accesses the buildings. Slight regrading and raising the elevation of the grassed shoulder near this low point in the parking area could potentially remove the entire shopping plaza from the 100-year (1% ACR) floodplain. This would require additional permission from FEMA to perform the work, but could effectively remove the entire developed portion of the property from the FEMA designated floodplain.

5-2 – Upgrade Access Road Culvert, Raise Grade Near Parking Area			
Priority Medium	**Benefit** High: Remove Charter Oak Shopping Plaza from 100-year floodplain	**Cost** $250k – $500k (culvert) $50k - $100k (parking)	**Timeframe** 2 – 3 Years
Funding Eligibility Private	**Property Ownership** Private	**Impacts** Wetland, stream channel, traffic and roadway, utilities, floodplain, and may increase flooding on nearby properties.	**Permitting** FEMA, USACE State of CT DEEP, Town of East Hartford

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