SWM Consulting

Township of West Windsor
Mercer County, New Jersey

Little Bear Brook Flood Hazard Assessment
Phase I – Little Bear Brook and Millstone River

May 15, 2015

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1. Introduction

At the request of West Windsor Township, Mercer County, New Jersey, an assessment of the existing flood hazard risk to roadways, properties, and structures along Little Bear Brook, a tributary of the Millstone River, has been conducted. As detailed in the Township's February 2, 2012 *Request for Engineering Services*, this assessment was conducted in response to the following flood problem areas in the Township:

1. Frequent, chronic flooding of Washington and Alexander Roads that cross Little Bear Brook between U.S. Route 1 and the NJ Transit Northeast Corridor railroad tracks and Princeton Junction Station. During certain past years, including 2014, this flooding has occurred multiple times and forces road closures that prevent traffic movement, including by police, fire, and emergency vehicles.

2. Less frequent but more damaging flooding of residential, commercial, and other structures as well as Washington, Alexander, and other roadways located within the Brook's floodplain. Examples of this flooding occurred during Tropical Storm Floyd in 1999, Tropical Storm Irene in 2011, and, to a lesser extent, May 1, 2014.

The Little Bear Brook Flood Hazard Assessment was conducted concurrently with the development of a Regional Stormwater Management Plan for the Township's Redevelopment Area, an approximately 350-acre area surrounding the New Jersey Transit Princeton Junction Train Station. Since a large portion of the Redevelopment Area is located within the Little Bear Brook watershed, the Little Bear Brook Flood Hazard Assessment and the Redevelopment Area Regional Stormwater Management Plan were conducted concurrently in order to determine, in part, whether regional stormwater management facilities constructed in the Redevelopment Area could also help reduce the existing flooding along Little Bear Brook.

This Report presents the data, analyses, and results of Phase I of the Little Bear Brook Flood Hazard Assessment. It focuses on the current flood risk to roadways, properties, and structures along Little Bear Brook posed by excessive flows both in the Brook and the Millstone River. During the performance of the Flood Hazard Assessment, it was determined that the primary source of the frequent, chronic flooding of both Washington and Alexander Roads was neither Little Bear Brook nor the Millstone River but, instead, inadequate capacity of the storm sewer systems draining the roadways.

Therefore, the original scope of the Little Bear Brook Flood Hazard Assessment and the Regional Stormwater Management Plan was revised to also include both an analysis of these existing storm sewer systems and the development of preliminary system improvements to reduce the frequency and severity of this chronic roadway flooding. The data, analyses, and results of this storm sewer system analysis, including the potential use of stormwater management facilities both within and outside the Redevelopment Area will be presented in the separate Phase II Report on the Little Bear Brook Flood Hazard Assessment.

A summary of the scope of work of Phase I of the Little Bear Brook Flood Hazard Assessment (identified as Goal 1 in the Township's combined Flood Hazard Assessment and Regional Stormwater Management Plan) is presented in Figure 1 below. This information has been taken from a PowerPoint presentation on the progress of both Phase I of the Little Bear Brook Flood Hazard Assessment and the Regional Stormwater Management Plan given to the West Windsor Township Council and public on June 30, 2014. A copy of the Township's entire February 2, 2012 Request for Engineering Services that details the original scopes of work for the Flood Hazard Assessment and Regional Stormwater Management Plan is contained in **Appendix A – West Windsor Request for Engineering Services**.

Figure 1
Phase I Scope of Work
Little Bear Brook Flood Hazard Assessment

2. <u>Waterway and Watershed Characteristics</u>

2.1 <u>Little Bear Brook</u>:

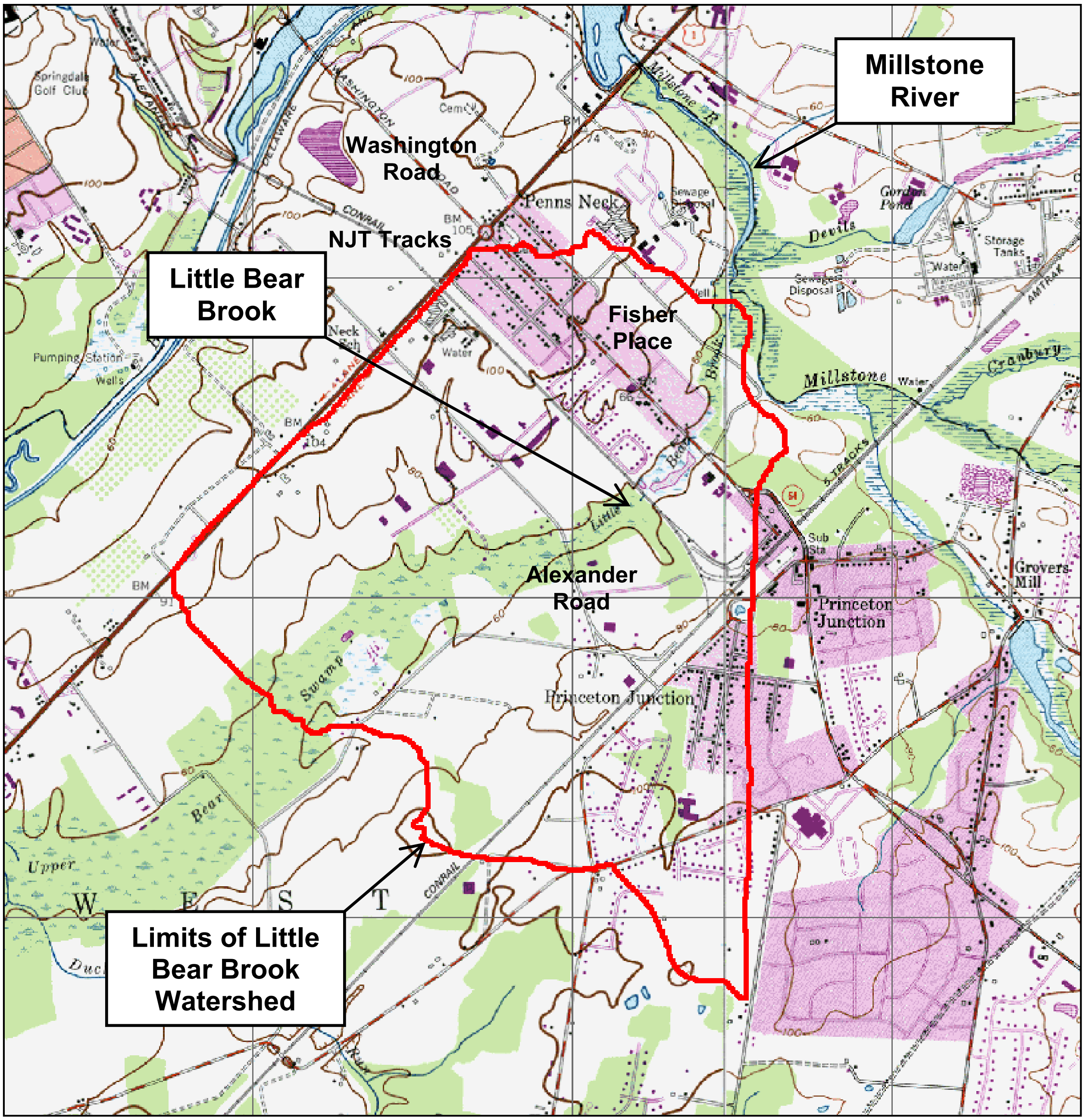
The limits of the 2.39-square mile Little Bear Brook watershed and the location of the Brook between Alexander Road and its confluence with the Millstone River are shown in Figure 2. As shown in the Figure, Little Bear Brook originates in the Upper Bear Swamp and flows in a northeasterly direction under Alexander Road, the New Jersey Transit (NJT) tracks between NJT's Princeton Junction and Princeton Train Stations, and Washington Road before discharging into the Millstone River approximately 0.8 miles (4,300 feet) upstream of the U.S. Route One Bridge over the River.

As shown in more detail in Figure 3 between Alexander Road and its confluence with the Millstone River, Little Bear Brook flows through both single and multi-family residential neighborhoods as well as a large office complex between Alexander Road and the NJT tracks and commercial and industrial buildings on Washington Road. Figure 4 depicts the approximate limits of the 500-Year floodplain along Little Bear Brook as published by the Federal Emergency Management Agency (FEMA) in both the May 1, 1984 West Windsor Township Flood Insurance Study (FIS) and the May 30, 2013 Draft Mercer County, New Jersey FIS. The 500-Year floodplain limits shown in Figure 4 illustrates the current flood hazard risk to roadways, residences, offices, and commercial buildings along the Brook from extreme flood events.

Additional details of the Little Bear Brook watershed are shown in Figures 5 and 6. Figure 5 depicts the various Land Uses in the watershed according to the 2012 Land Use/Land Cover data obtained from the New Jersey Office of GIS. Figure 6 depicts the various Hydrologic Soil Groups (HSGs) in the watershed according to the current SSURGO Soil Survey Geographic Database Soil Layer data for Mercer County compiled by the USDA Natural Resources Conservation Service (NRCS). It should be noted that all soils shown in Figure 6 that did not have an assigned HSG in the SSURGO Soil Data Layer were assumed to belong to HSG D.

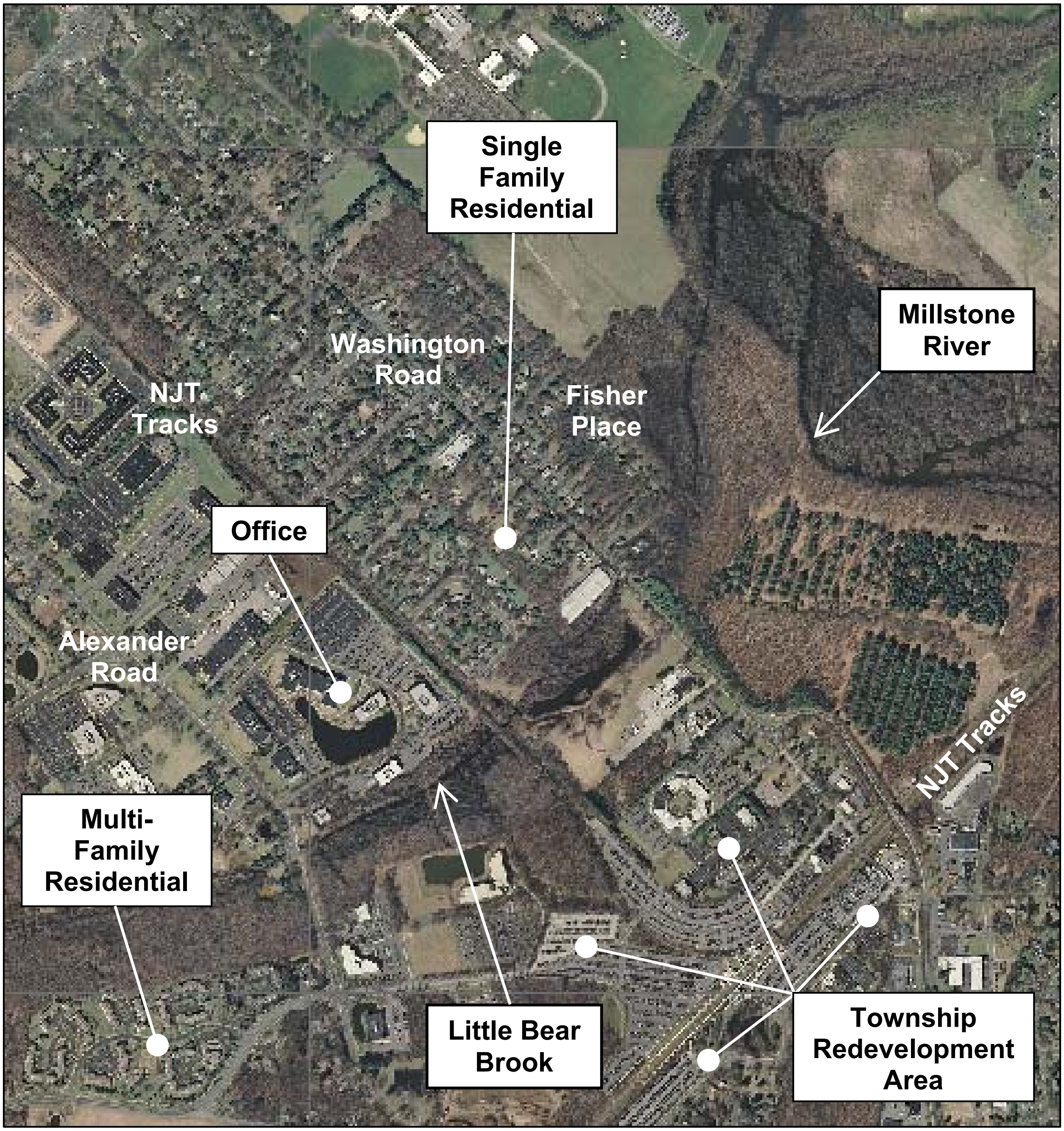
Also shown in both Figures are drainage subareas of the overall Little Bear Brook watershed to Alexander and Washington Road crossings of the Brook. These subarea delineations and associated Land Use and HSG data were used to compute estimated peak discharge to the mouth of Little Bear Brook and at these two road crossings. Further details about these peak discharges and their use in analyzing the existing flood hazard risk posed by the Brook are presented in below in **4. <u>Results of Flood Hazard Analysis</u>**.

Figure 2
Overall Little Bear Brook Watershed Limits
Little Bear Brook Flood Hazard Assessment



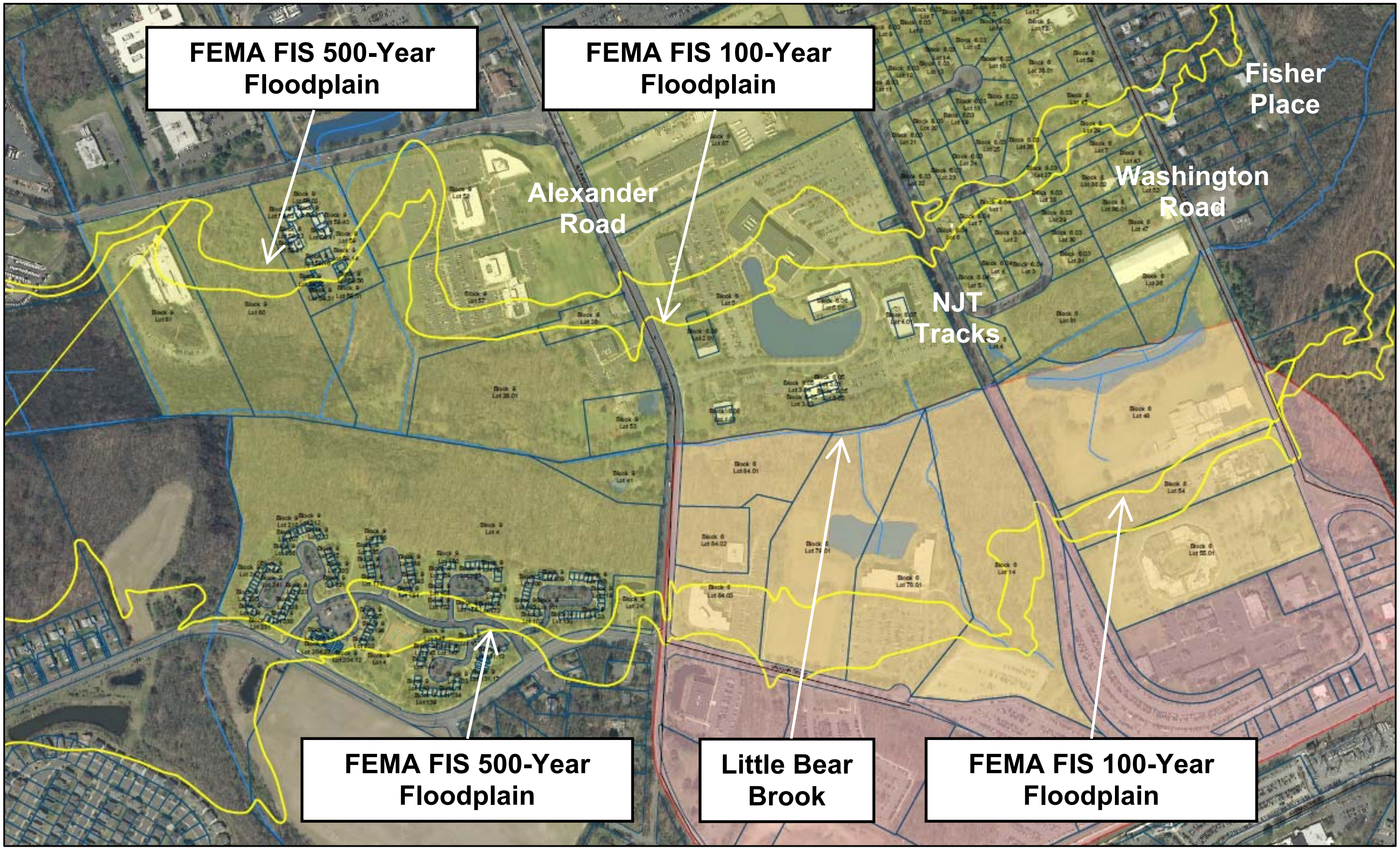
Base Map: USGS 7.5-Minute Series Topographic Mapping

Figure 3
Existing Development Along Little Bear Brook
Little Bear Brook Flood Hazard Assessment



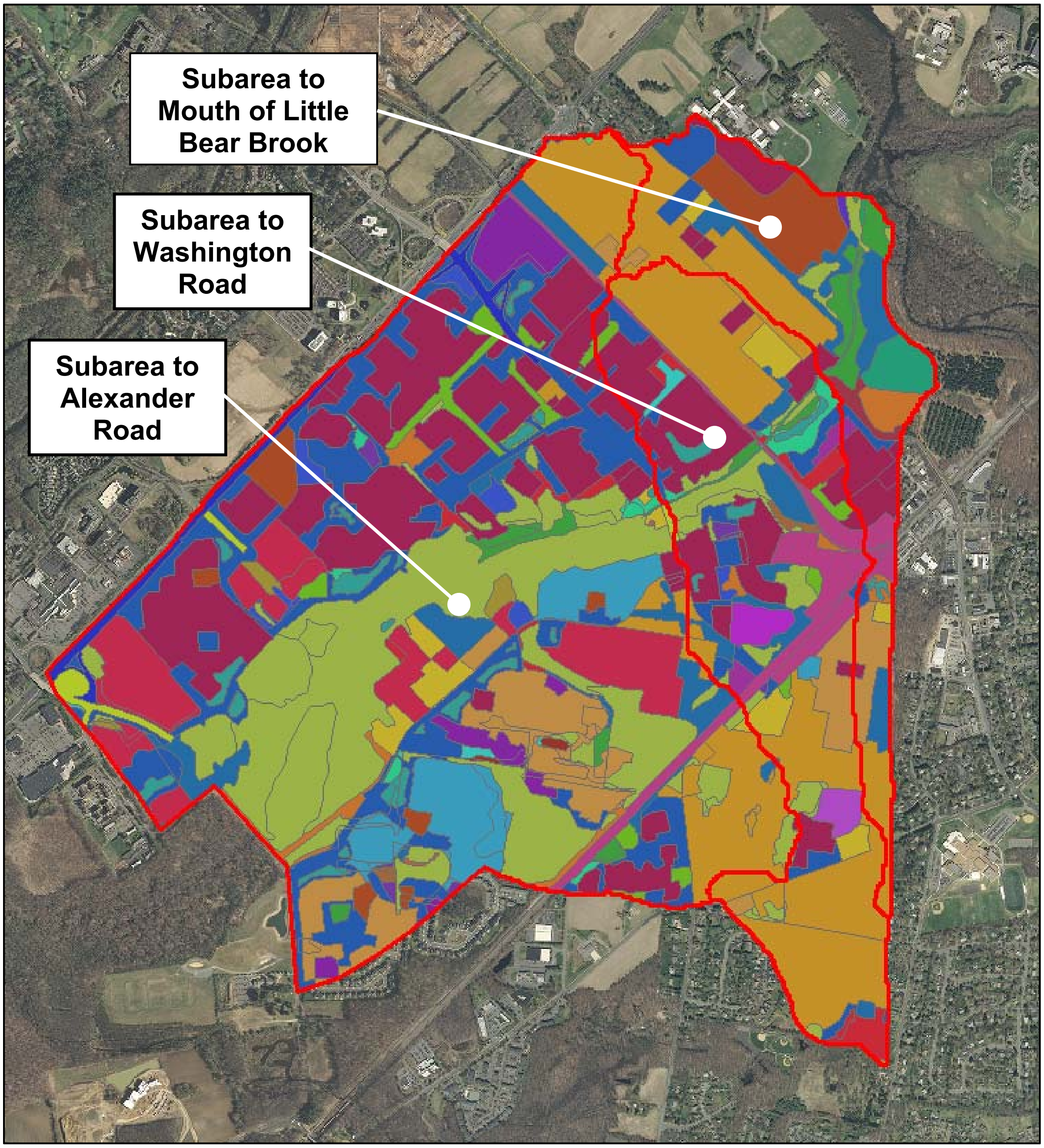
Base Map: New Jersey Office of GIS 2012 Orthophotography

Figure 4
Approximate Limits of FEMA 100 and 500-Year Floodplains Along Little Bear Brook
Little Bear Brook Flood Hazard Assessment



Map Source: Finished Floor Map - Princeton Hydro, LLC

Figure 5
Little Bear Brook Watershed Subareas and 2007 Land Use/Land Cover
Little Bear Brook Flood Hazard Assessment



Base Map: New Jersey Office of GIS 2012 Orthophotography

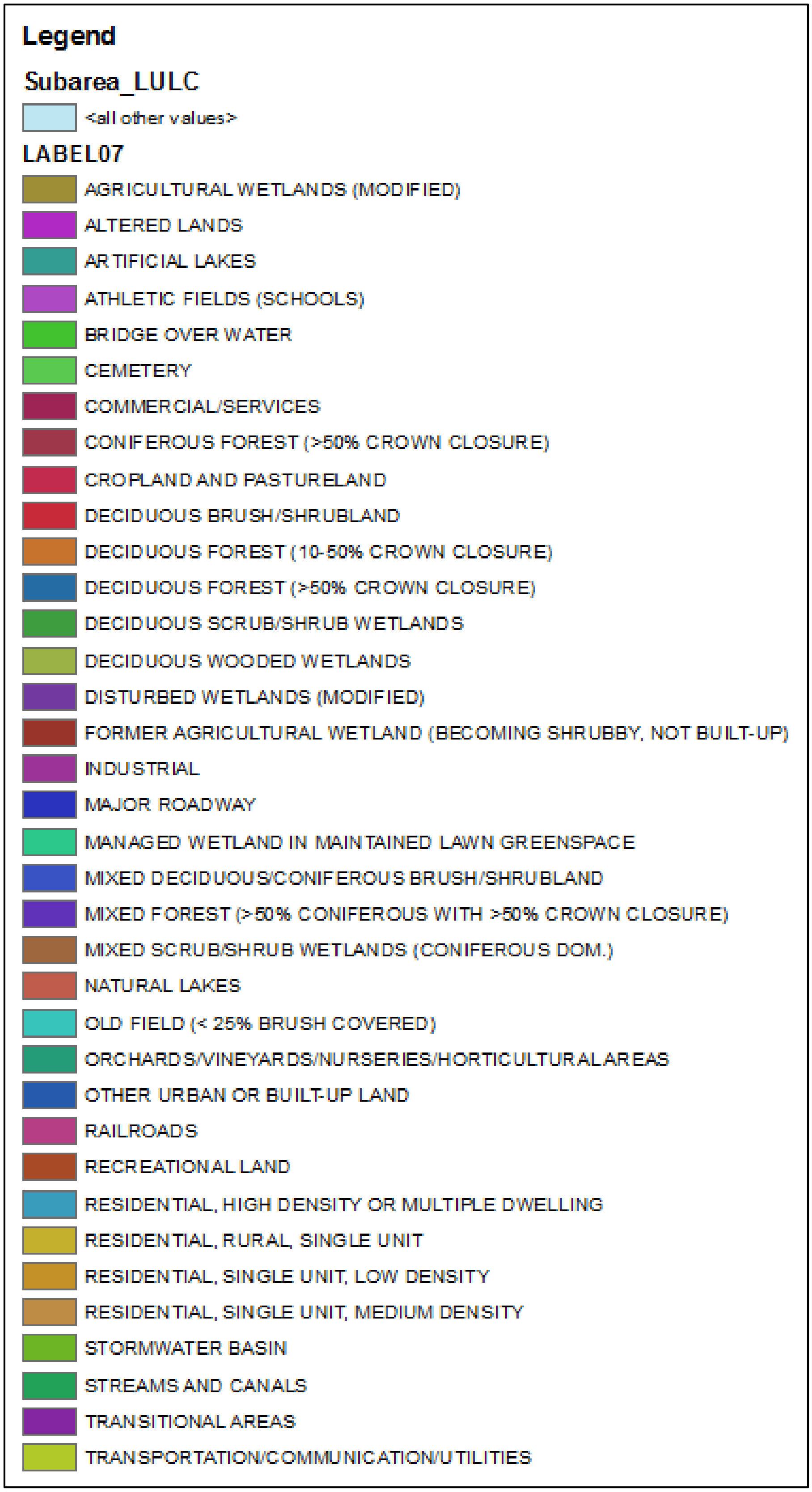
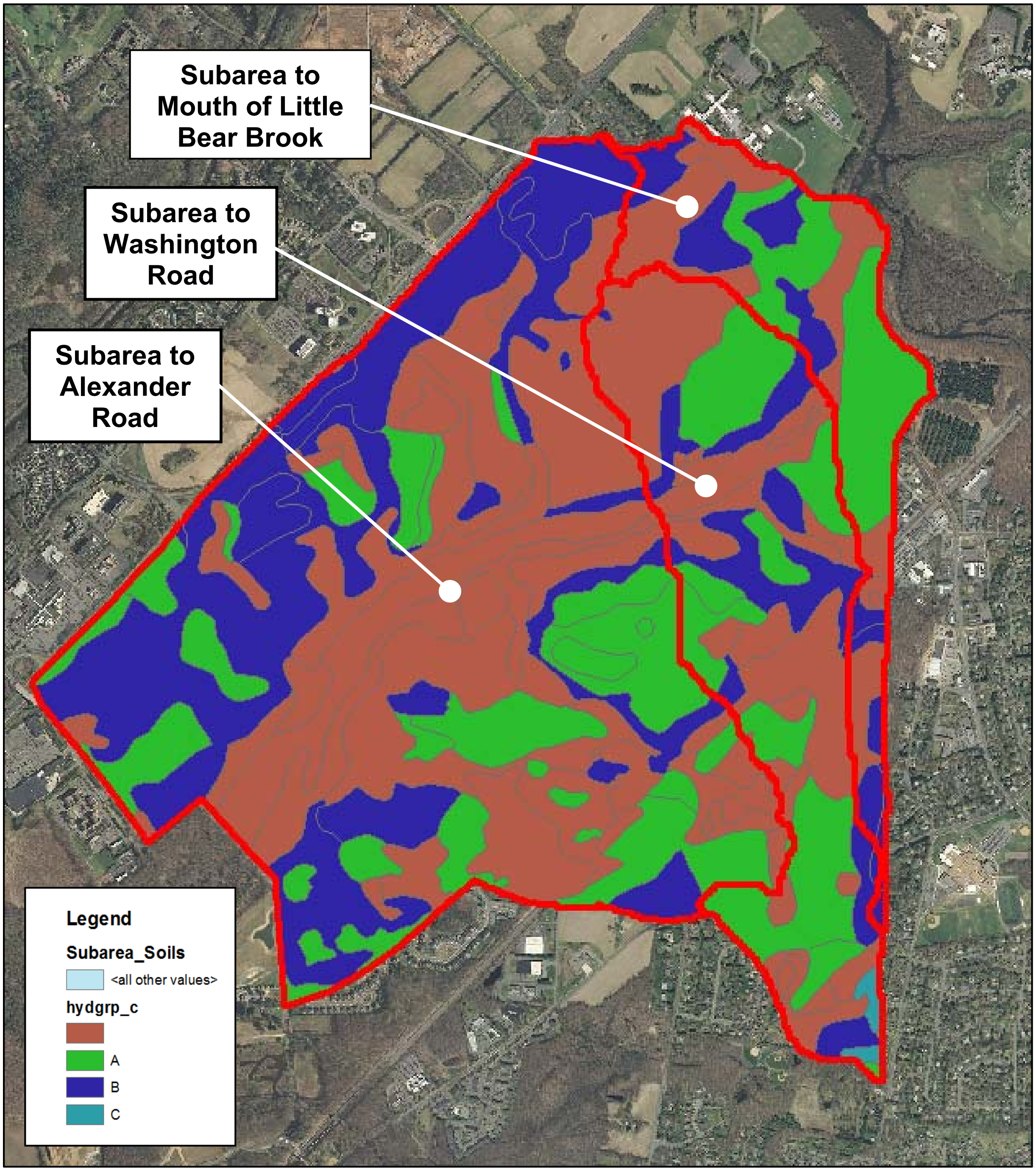

Legend
Subarea_LULC
<all other values>
LABEL07
AGRICULTURAL WETLANDS (MODIFIED)
ALTERED LANDS
ARTIFICIAL LAKES
ATHLETIC FIELDS (SCHOOLS)
BRIDGE OVER WATER
CEMETERY
COMMERCIAL/SERVICES
CONIFEROUS FOREST (>50% CROWN CLOSURE)
CROPLAND AND PASTURELAND
DECIDUOUS BRUSH/SHRUBLAND
DECIDUOUS FOREST (10-50% CROWN CLOSURE)
DECIDUOUS FOREST (>50% CROWN CLOSURE)
DECIDUOUS SCRUB/SHRUB WETLANDS
DECIDUOUS WOODED WETLANDS
DISTURBED WETLANDS (MODIFIED)
FORMER AGRICULTURAL WETLAND (BECOMING SHRUBBY, NOT BUILT-UP)
INDUSTRIAL
MAJOR ROADWAY
MANAGED WETLAND IN MAINTAINED LAWN GREENSPACE
MIXED DECIDUOUS/CONIFEROUS BRUSH/SHRUBLAND
MIXED FOREST (>50% CONIFEROUS WITH >50% CROWN CLOSURE)
MIXED SCRUB/SHRUB WETLANDS (CONIFEROUS DOM.)
NATURAL LAKES
OLD FIELD (< 25% BRUSH COVERED)
ORCHARDS/VINEYARDS/NURSERIES/HORTICULTURAL AREAS
OTHER URBAN OR BUILT-UP LAND
RAILROADS
RECREATIONAL LAND
RESIDENTIAL, HIGH DENSITY OR MULTIPLE DWELLING
RESIDENTIAL, RURAL, SINGLE UNIT
RESIDENTIAL, SINGLE UNIT, LOW DENSITY
RESIDENTIAL, SINGLE UNIT, MEDIUM DENSITY
STORMWATER BASIN
STREAMS AND CANALS
TRANSITIONAL AREAS
TRANSPORTATION/COMMUNICATION/UTILITIES

Figure 6
Little Bear Brook Watershed Subareas and NRCS Hydrologic Soil Groups
Little Bear Brook Flood Hazard Assessment



Base Map: New Jersey Office of GIS 2012 Orthophotography

Note: Unclassified Soils in SSURGO Database were assumed to be HSG D

Figure 7 depicts the Little Bear Brook watershed and waterway characteristics at its confluence with the Millstone River as computed by StreamStats software developed by the U.S. Geological Survey (USGS). As can be seen in the Figure, approximately 62 percent of the 2.39-square mile watershed is comprised of urban land use with only approximately 9 percent wooded and approximately 19 percent covered by open water or wetlands. These percentages are based upon the 2002 National Land Cover Dataset (NLCD) land-use data. In addition, the Brook has a relatively flat average slope at 17.4 feet per mile or approximately 0.3 percent. The high percentage of urban land use results in relatively high runoff volumes and peak runoff rates and relatively rapid initial runoff velocities to Little Bear Brook.

However, once watershed's runoff has reached Little Bear Brook, the Brook's flat bottom slope and the relatively high percentage of open water and wetlands combine to both slow the initial velocities and store the runoff volumes, resulting in attenuated peak discharges along the Brook. As will be discussed in detail in **4. Results of Flood Hazard Analysis** below, these characteristics of both the Little Bear Brook watershed and waterway are important factors in the assessment of the existing flood hazard risk along the Brook.

Figure 7
USGS StreamStats - Little Bear Brook Watershed and Waterway Characteristics
Little Bear Brook Flood Hazard Assessment

USGS
New Jersey StreamStats

Basin Characteristics Report

Date: Wed Jun 25 2014 09:16:46 Mountain Daylight Time
NAD27 Latitude: 40.3285 (40 19 42)
NAD27 Longitude: -74.6247 (-74 37 29)
NAD83 Latitude: 40.3286 (40 19 43)
NAD83 Longitude: -74.6243 (-74 37 27)

Parameter	Value
Drainage area in square miles	2.39
Percent of area covered by water and wetland.	19.1
Mean population density, people per square mile, 2000 census block data.	819
10-85 slope in feet per mile based on preprocessed data	17.4
Total stream length in miles	1.85
Length of associated Longest Flow Path in miles	2.81
Percent of area covered by forest	8.83
Percent of area covered by urban land use	62.4
Percent of area covered by wetland land use	18
Average basin elevation in feet	78.9

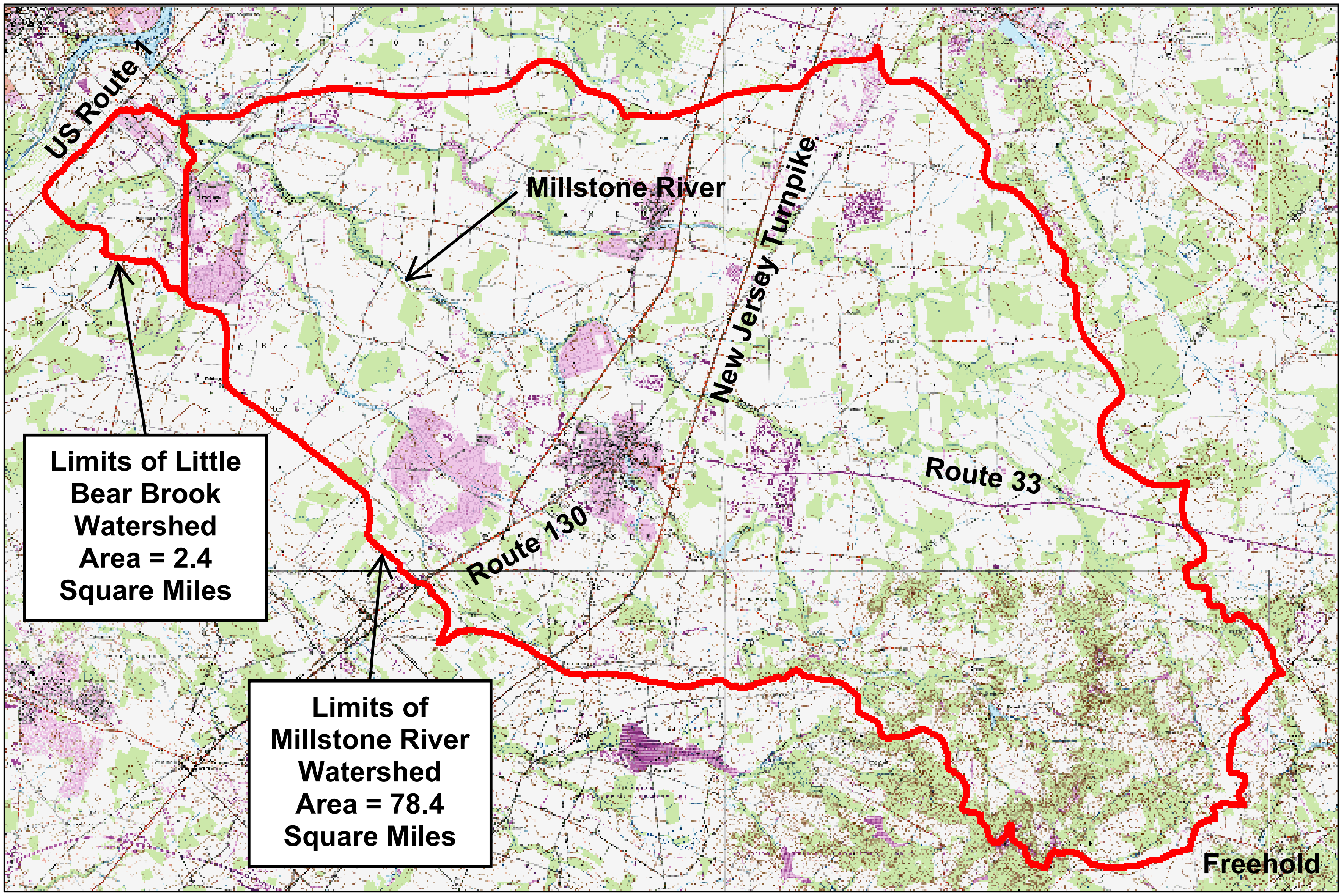
2.2 Millstone River:

The limits of both the 2.39-square mile Little Bear Brook watershed and the much larger, 78.4-square mile Millstone watershed at the mouth of the Brook are shown for comparison purposes in Figure 8. As shown in the Figure, the Millstone River originates in western Monmouth County in the northern portion of Freehold Township and flows in a general westerly direction under the New Jersey Turnpike and U.S. Route 1. Due to its more than 30 times larger drainage area and longer waterway length, the Millstone River can be expected to have much larger peak discharges that occur much later during or after a rainfall event than those produced by the same rainfall on Little Bear Brook. For example, based upon Millstone River streamflow gage records and a rainfall-runoff analysis of Little Bear Brook, peak flow in Little Bear Brook can typically be expected to occur approximately 12 to 18 hours before the Millstone River peak, depending, in part, on the pattern and duration of rainfall and the direction and speed of the storm's movement.

Figure 9 depicts the Millstone River watershed and waterway characteristics at the mouth of Little Bear Brook as computed by StreamStats software developed by the U.S. Geological Survey (USGS). As can be seen in the Figure, approximately 36 percent of the 78.4-square mile watershed is comprised of urban land use with approximately 12 percent wooded and approximately 26 percent covered by open water or wetlands. Similar to Figure 7, these percentages are based upon the 2002 National Land Cover Dataset (NLCD) land-use data. The percentage of urban land use is approximately 40 percent less than that in the Little Bear Brook watershed, while the percentages of woodland and water or wetlands are similar to the Little Bear Brook watershed.

In addition, Figure 9 also shows that the Millstone River has a flatter average slope (5.7 feet per mile or approximately 0.1 percent) than Little Bear Brook (17.4 feet per mile or approximately 0.3 percent). In addition to the much larger watershed area, the River has a similarly longer total flow path (approximately 23 miles) than the Brook (approximately 2.8 miles). As will be discussed in greater detail below, these Millstone River watershed and waterway characteristics result in greater River peak discharges, higher peak River water surface elevations, and slower River response times at the River's confluence with Little Bear Brook than those generated at this location by the Brook itself.

<u>Figure 8</u>
Limits of Little Bear Brook and Millstone River Watersheds
Little Bear Brook Flood Hazard Assessment



Base Map: USGS 7.5-Minute Series Topographic Mapping

Figure 9
USGS StreamStats – Millstone River Watershed and Waterway Characteristics
Little Bear Brook Flood Hazard Assessment

USGS
New Jersey StreamStats

Basin Characteristics Report

Date: Wed Jun 25 2014 09:07:25 Mountain Daylight Time
NAD27 Latitude: 40.3289 (40 19 44)
NAD27 Longitude: -74.6240 (-74 37 26)
NAD83 Latitude: 40.3290 (40 19 44)
NAD83 Longitude: -74.6236 (-74 37 25)

Parameter	Value
Drainage area in square miles	78.4
Percent of area covered by water and wetland.	26.1
Mean population density, people per square mile, 2000 census block data.	919
10-85 slope in feet per mile based on preprocessed data	5.73
Total stream length in miles	152
Length of associated Longest Flow Path in miles	23.1
Percent of area covered by forest	12.1
Percent of area covered by urban land use	35.6
Percent of area covered by wetland land use	24.9
Average basin elevation in feet	124

3. <u>Basis of Analysis</u>

The Flood Hazard Assessment of Little Bear Brook described herein was based upon a range of data and sources provided by West Windsor Township, Princeton Hydro LLC among other individuals, agencies, and organizations. This data was used during the Flood Hazard Assessment to determine both the current risk of flooding of roads, properties, and structures along Little Bear Brook and the ultimate source of the floodwaters. These data sources and details are itemized below:

3.1 <u>Property Owner Questionnaire</u>:

Based upon a review of the properties within the approximate limits of the Little Bear Brook 500-Year floodplain shown in Figure 4, West Windsor Township identified and invited the owners of 350 properties in the Township by mail to participate in a Property Owner Questionnaire regarding the nature, frequency, and severity of past flooding on their properties. A copy of this Questionnaire and a Township summary of the responses are contained in **Appendix B – Property Owner Questionnaire and Summary of Responses**. A discussion of the responses is provided below in **4. <u>Results of Flood Hazard Analysis</u>**.

3.2 <u>Project Meetings</u>:

A total of three meetings were held with Township officials and/or members of the public. All meetings were held at the West Windsor Township municipal building. A Project Kick-Off team meeting was held on September 5, 2013 with Mayor Shing-Fu Hsueh, Community Development Director M. Patricia Ward, Township Engineer Francis Guzik, PE, and staff members from the Department of Community Development. Also in attendance were project personnel from Princeton Hydro, LLC who were responsible for the development of the Regional Stormwater Management Plan for the Township's Redevelopment Area as outlined in the Township's Request for Engineering Services contained in **Appendix A**. A copy of the Kick-Off Meeting Agenda is contained in **Appendix C – Project Meetings**.

A public meeting was then held on September 16, 2013 with the West Windsor Township Council to describe the scope and goals of both the Little Bear Brook Flood Hazard Assessment and Redevelopment Area Regional Stormwater Management Plan. A description of the purpose and content of the Property Owner Questionnaire described above was also presented. Project managers from both SWM Consulting, LLC and Princeton Hydro, LCC also answered questions about the Flood Hazard Analysis and Regional Stormwater Management Plan from Council members and members of the public in attendance. A copy of the PowerPoint presentation given at the Council Meeting on both the Flood Hazard Analysis and Regional Stormwater Management Plan is contained in **Appendix C**.

A second public meeting was held on June 30, 2014 with members of the public and representatives of the West Windsor Township Council, Community Development

Department, and Environmental Commission. Project managers from both SWM Consulting, LLC and Princeton Hydro, LCC reported on the progress to date of the Flood Hazard Analysis and Regional Stormwater Management Plan and obtained information from those in attendance regarding the accuracy of the preliminary flood frequencies for the roadway, property, and structure flooding presented at the meeting. A copy of the PowerPoint presentation given at the Public Meeting on both the Flood Hazard Analysis and Regional Stormwater Management Plan is also contained in **Appendix C**.

3.3 <u>April 30 - May 1, 2014 Flood Event</u>:

On Wednesday, April 30, 2014, approximately 5 inches of rain fell in the Millstone watershed, including the Little Bear Brook subwatershed, in approximately 24 hours. This rainfall resulted in flooding of Fisher Place and Washington and Alexander Roads along Little Bear Brook beginning in the evening of April 30th and extending through May 1st. Peak flood levels along these roadways occurred at mid-day on May 1st.

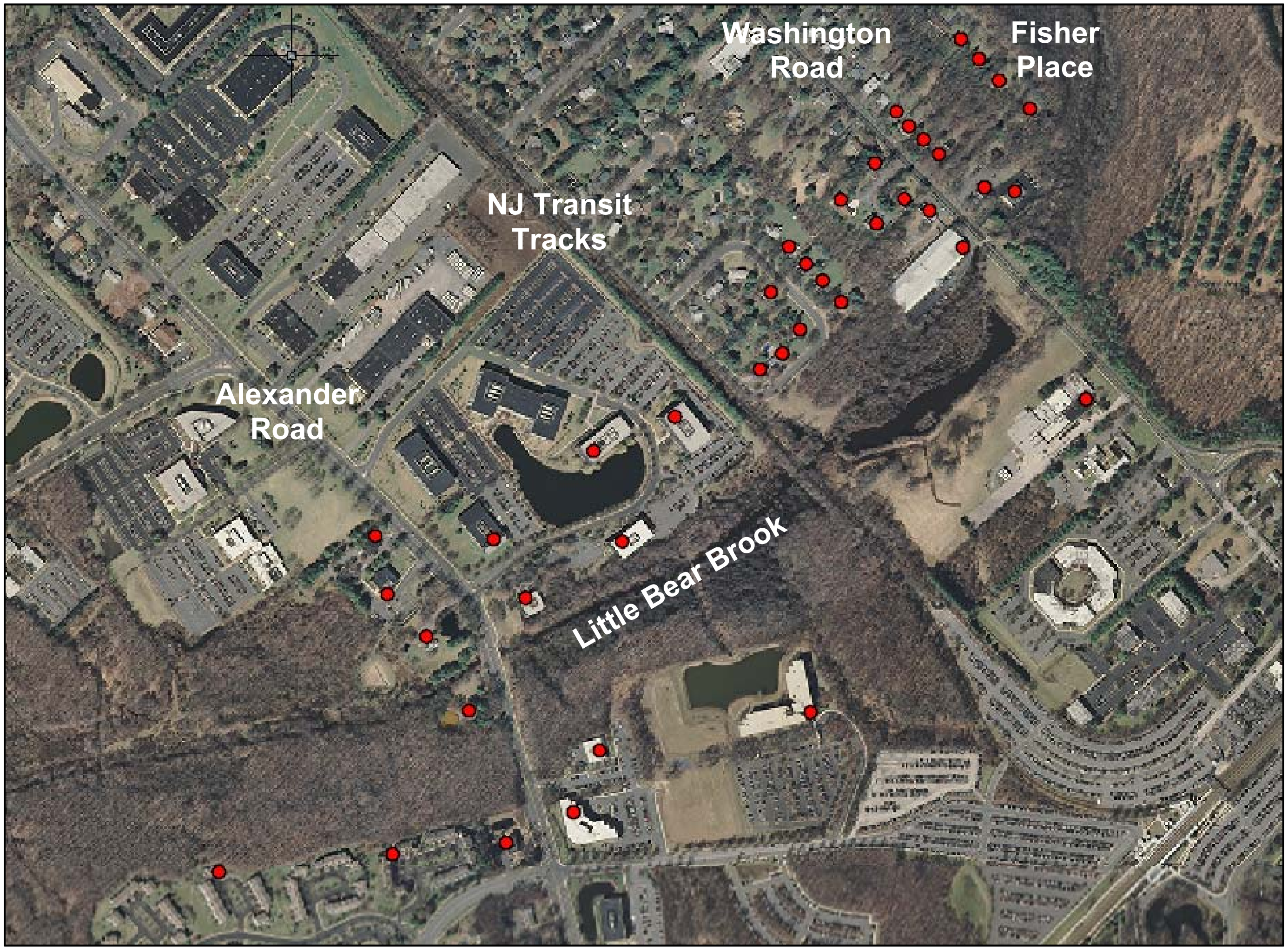
High water marks (HWMs) along the Millstone River at the Carnegie Lake Dam, the Delaware and Raritan (D&R) Canal culvert, and the U.S. Route 1 Bridge and along Little Bear Brook at Washington Road and Alexander Park Drive were identified by SWM Consulting and Princeton Hydro personnel. In addition, HWMs along Fisher Place and Fieldston and Alexander Roads were identified by personnel from the West Windsor Township Division of Engineering. The elevations of all HWMs were subsequently surveyed by SWM Consulting and Princeton Hydro personnel. These surveyed HWMs were then used to both directly analyze the flood hazard risk at these locations and the predicted flood risks developed by computer models of the Millstone River and Little Bear Brook. Finally, the surveyed HWMs were used to evaluate the responses in the Property Owner Questionnaire regarding past flood events along Little Bear Brook.

Rainfall data for the April 30th – May 1st event within and near the Millstone River watershed are contained in **Appendix D – April 30 - May 1, 2014 Flood Data**. This Appendix also contains the location and photographs of the HWMs obtained during the event as well as photographs of the flooding on Fisher Place, Washington and Fieldston Roads, and both upstream and downstream of the U.S. Route 1 Bridge over the Millstone River.

3.4 <u>Structure Elevation Surveys</u>:

In addition to determining the various levels and frequencies of flooding, assessment of the flood hazard risk along Little Bear Brook required a determination of the elevations of the first above-grade habitable floors at key residential, office, and commercial structures within the Brook's floodplain. This was achieved by field surveying these elevations at 40 such structures. These field surveys were conducted by Pickering, Corts, and Summerson under contract to Princeton Hydro, LLC. The locations of these surveyed structures are shown in Figure 10 and in **Appendix E – Surveyed Structure Elevations**. A summary of the surveyed elevations at each a structure is also contained in **Appendix E**.

Figure 10
Location of Field Surveyed Structures in Little Bear Brook Floodplain
Little Bear Brook Flood Hazard Assessment

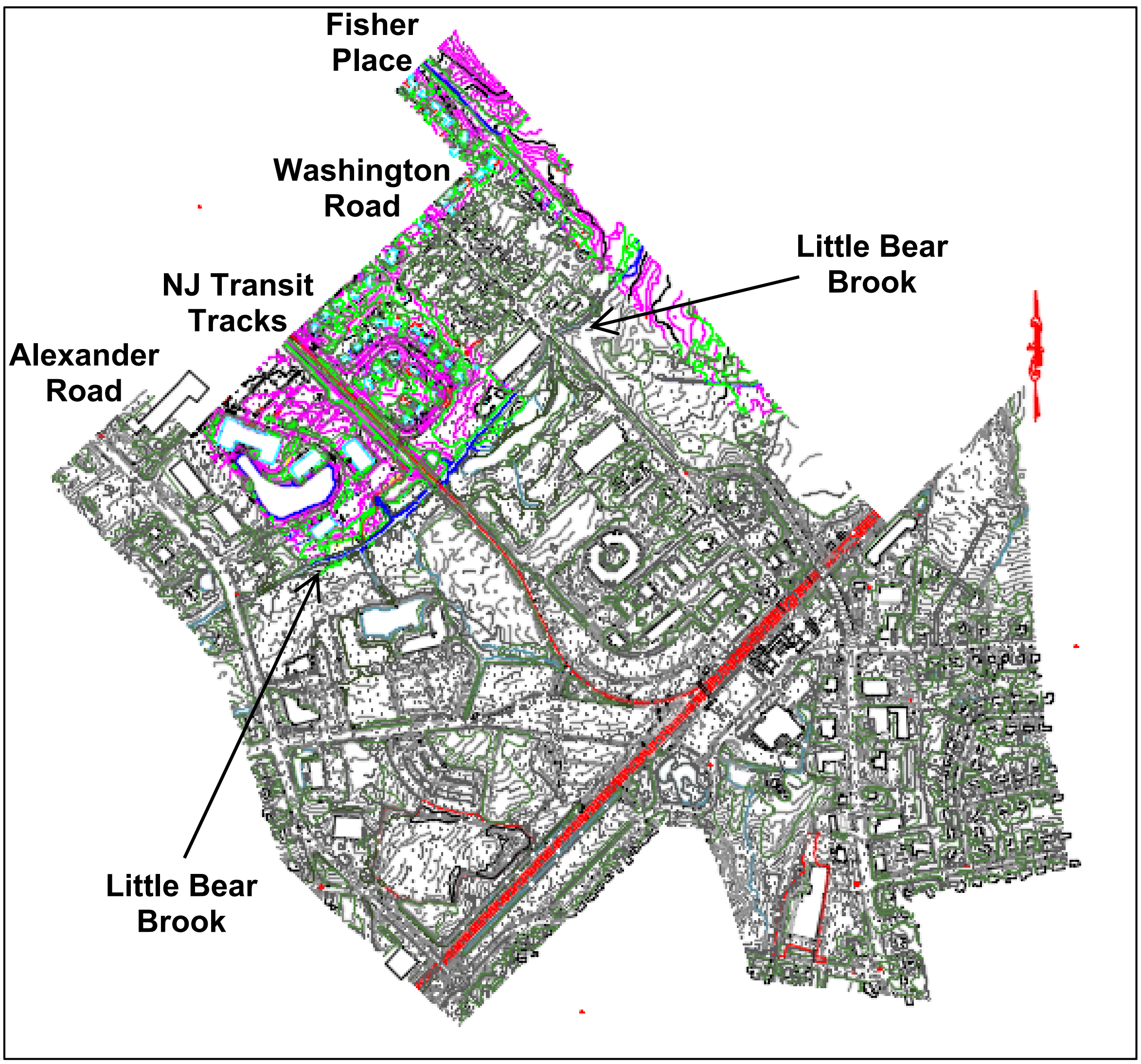


Base Map: New Jersey Office of GIS 2012 Orthophotography

3.5 Topographic Mapping:

In addition to the U.S. Geological Survey 7.5-Minute Series topographic mapping of the Little Bear Brook and Millstone watersheds (as shown in Figures 2 and 8, respectively), topographic mapping was specifically developed for both the Flood Hazard Assessment and Regional Stormwater Management Plan project areas. This topographic mapping was based upon new 1 inch = 400 feet aerial photography flown in 2012 and was prepared at a 1-foot contour interval and a scale of 1 inch = 50 feet. The limits of this project area topographic mapping are shown in Figure 11.

Figure 11
Limits of New Project Area Topographic Mapping
Little Bear Brook Flood Hazard Assessment



3.6 <u>FEMA Flood Insurance Study and NJDEP Flood Plain Delineation</u>:

Preliminary hydrologic and hydraulic information regarding both Little Bear Brook and the Millstone River was obtained from the 1984 FEMA West Windsor Township Flood Insurance Study (FIS) and NJDEP Delineation of Floodways and Flood Hazard Areas along the Brook and River. This information also included computer models of the Brook and River developed for both the FEMA FIS and NJDEP Delineation using the *HEC-2 Water Surface Profiles* computed software. However, due to the age of the FEMA FIS, NJDEP Delineations, and the associated HEC-2 models, updated computer models were developed for both Little Bear Brook and the reach of the Millstone River generally from the U.S. Route 1 Bridge upstream to the mouth of the Brook.

The 10, 50, 100 and 500-Year flood profiles for Little Bear Brook contained in the 1984 West Windsor FIS are shown in Figure 12 below. As can be seen in the Figure, the water surface profiles for these flood events (which are shown in the NGVD 1929 vertical datum) are essentially horizontal from the mouth of the Brook at its confluence with the Millstone River to the upstream limits of the profiles approximately 12,000 feet upstream. As indicated by the note stating *"Backwater from Millstone River"* (highlighted in the red box), such profiles are a clear indication that, for the 10 to 500-Year floods, the maximum water surface elevations along Little Bear Brook are determined by the maximum flows and water surface elevations in the Millstone River at the mouth of the Brook and not those in the Brook itself. Such dominant backwater effects are important to know when attempting to determine the cause of flooding and develop flood mitigation strategies and measures along the Brook.

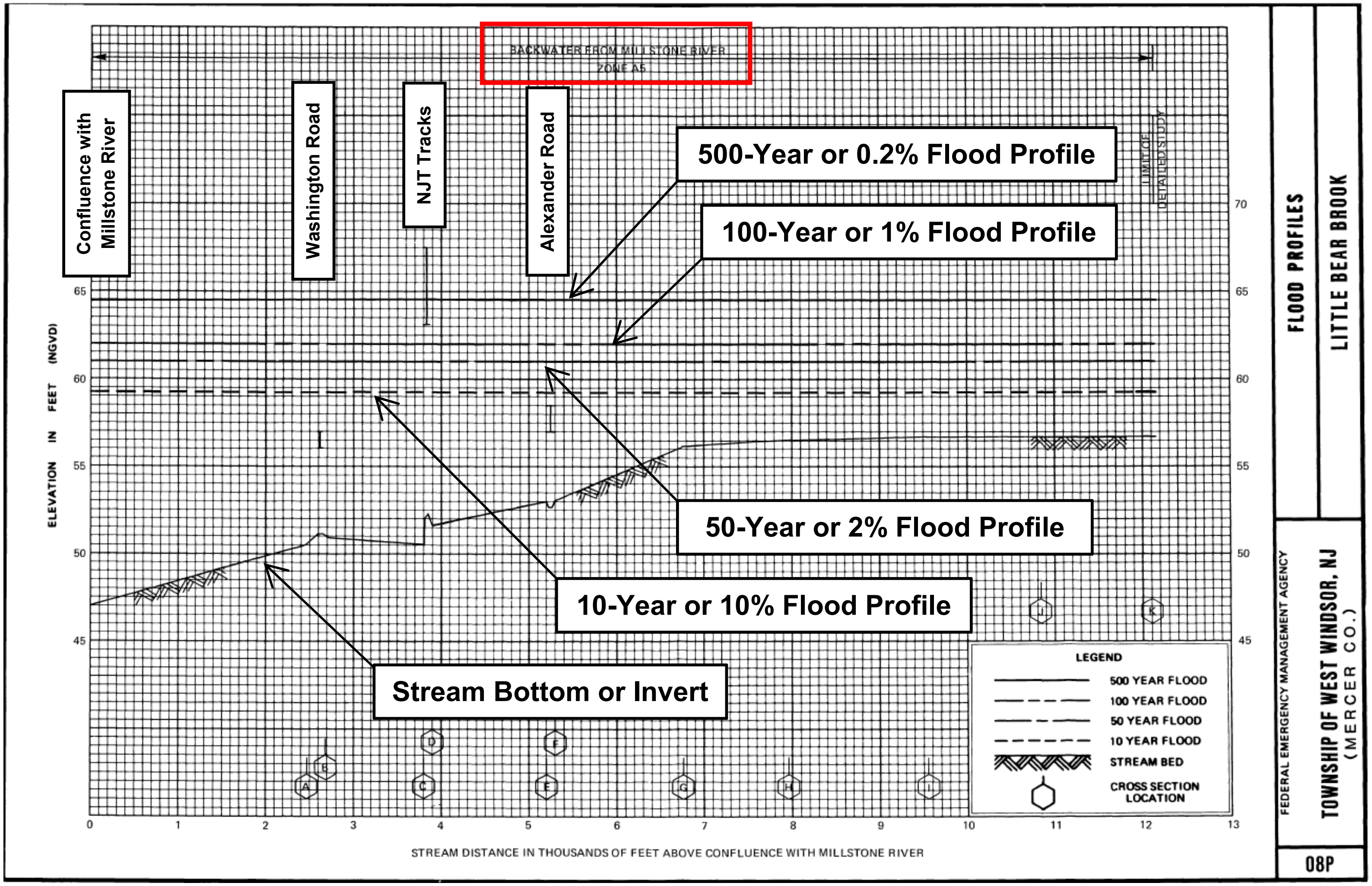
3.7 <u>Hydrologic and Hydraulic Computer Models</u>

The final analysis of the Little Bear Brook Flood Hazard Assessment was based upon new hydrologic and hydraulic computer models of Little Bear Brook and the Millstone River. The hydrologic models of the Little Bear Brook watershed were based upon Version 10 of the *HydroCAD* computer software while the hydraulic models of the Brook and Millstone River were based upon Version 4.1 of the *HEC-RAS – River Analysis System* computer software. As noted above, the new HEC-RAS models were based in part on the HEC-2 computer models developed for the 1984 FEMA FIS and NJDEP Delineations. In addition, the HEC-RAS model of the Millstone River was based upon model data submitted to and approved by the NJDEP's Division of Land Use Regulation as part of the 2009 NJDOT application for the replacement of the U.S. Route 1 Bridge over the River.

As noted above, the new HEC-RAS models of the Millstone River and Little Bear Brook developed due to the age of the steady flow HEC-2 models of the River and Brook that were developed for the 1984 West Windsor FIS and NJDEP Delineations. Due to their age, the HEC-2 models did not include current roadway elevations and bridge sizes at U.S. Route 1 or Washington and Alexander Roads. In addition, as described in more detail **4. <u>Results of Flood Hazard Analysis</u>**, use of an unsteady flow HEC-RAS model of Little Bear Brook was considered a more accurate way to analyze the Brook.

Figure 12

Little Bear Brook Water Surface Profiles from 1984 West Windsor FIS
Little Bear Brook Flood Hazard Assessment



Base Map: 1984 FEMA FIS for West Windsor Township

4. Results of Flood Hazard Analysis

4.1 Property Owner Questionnaire:

According to data provided by West Windsor Township, a total of 68 Property Owner Questionnaires were completed and submitted to the Township from a total of 350 distributed by mail and through the Township's website. This represents an approximately 19 percent response percentage. The responses indicated a range of flooding conditions along Little Bear Brook, ranging from frequent, chronic flooding of roadways and properties to less frequent but more destructive flooding of residential structures.

According to the Questionnaire responses, the worst structure flooding occurred as a result of Tropical Storm Irene on September 28, 2011 when flood levels above the first floor elevation were reported at six residential structures. The second-worst reported structure flooding occurred as a result of Tropical Storm Floyd on September 19, 1999. These were the only two flood events when residential structure was reported in the Questionnaires. However, many respondents reported more frequent flooding on their properties and/or the roadways at or near their residences. These roadways included Washington, Alexander, and Fieldston Roads, and Fisher Place.

A copy of the Property Owner Questionnaire and a Township summary of the responses in contained in **Appendix B – Property Owner Questionnaire and Summary of Responses.**

4.2 April 30 - May 1, 2014 Flood Event:

As indicated by the surveyed HWMs, roadway, yard, parking lot, and driveway flooding along Washington, Alexander, and Fieldston Roads, Fisher Place, and Alexander Park Drive occurred during the April 30 – May 1, 2014 flood. In addition, commercial structures on Washington Road adjacent to Little Bear Brook were also flooded. These were the only observed structures to be flooded. A summary of the surveyed HWM elevations on Washington, Alexander, and Fieldston Roads, and Fisher Place along Little Bear Brook and both upstream and downstream of the U.S. Route 1 Bridge over the Millstone River is presented in Table 1 below.

As can be seen in the Table, the flood event of April 30 – May1, 2014 resulted in flood depths that completely overtopped portions of Washington, Fieldston, and Alexander Roads and Fisher Place with maximum road flooding depths ranging from approximately 1.8 to 2.0 feet at the lowest roadway edges and 1.3 to 1.5 feet at the lowest roadway centerlines.

A summary of the surveyed HWM elevations at the three business structures on Washington Road adjacent to Little Bear Brook is presented in Table 2 below. As can be seen in the Table, all three Washington Road businesses experienced maximum exterior flood depths of approximately 1.7 feet. Two of the three structures also experienced interior flooding ranging from approximately 0.6 to 1.1 feet.

Table 1
Summary of Flooded Roadway HWM Elevations for April 30 – May 1, 2014 Flood
Little Bear Brook Flood Hazard Assessment

Roadway HWM Location	Surveyed HWM Elevation (NAVD88)	Low Road Elevation (NAVD88)	Maximum Road Flood Depth (Feet)	Low Road Centerline Elevation (NAVD88)	Maximum Road Overtopping Depth (Feet)
DS of U.S. Route 1	56.0	62.0	0	62.5	0
US of U.S. Route 1	56.4	62.0	0	62.5	0
Fisher Place	58.5	56.6	1.9	57.2	1.3
Washington Road	58.7	56.9	1.8	56.9	1.8
Fieldston Road	58.7	56.7	2.0	57.3	1.4
Alexander Road	58.8	57.0	1.8	57.5	1.3

Table 2
Summary of Flooded Structure HWM Elevations for April 30 – May 1, 2014 Flood
Little Bear Brook Flood Hazard Assessment

Structure HWM Location	Surveyed HWM Elevation (NAVD88)	Low Ground Elevation at Structure (NAVD88)	Maximum Exterior Flood Depth (Feet)	Lowest Floor Elevation (NAVD88)	Maximum Interior Flood Depth (Feet)
89 Washington Rd	58.7	57.0	1.7	57.6	1.1
92 Washington Rd	58.7	57.0	1.7	58.1	0.6
95 Washington Rd	58.7	57.0	1.7	61.3	0

As noted above in **3. Basis of Analysis**, the HWM data obtained from the April 30 – May 1, 2014 flood not only helped to verify the flood information provided in the Property Owner Questionnaire, but also helped to determine the existing threshold elevations for both roadway and structure flooding caused by Little Bear Brook and/or the Millstone River. From the HWM elevations in Table 1, Fieldston Road, with a 2-foot flood depth at the roadway edge, was identified as the first roadway most likely to experience ponding water along the roadway edges due to Brook and/or River flooding.

However, due to an inherent degree of uncertainty in precisely identifying and surveying HWMs and the inherently variable nature of flood dynamics, it can also be seen in Table 1 that all four roadways, with maximum roadway edge flood depths ranging from 1.8 to 2.0 (i.e., 0.2 feet or approximately 10 percent) can all be expected to experience ponding along their edges at approximately the same time and elevation from Brook and/or River water surface elevations.

In addition, from the HWM elevations in Table 1, Washington Road, with a maximum flood depth of 1.8 feet above the lowest road centerline elevation, was identified as the first roadway most likely to be overtopped and thereby technically incapable of allowing traffic movement, including by police, fire, and emergency vehicles.

Similarly, from the HWM elevation data in Table 2, all three Washington Road business structures, with maximum exterior flood depths of approximately 1.7 feet, were identified as being equally likely to experience exterior flooding from a Brook and/or River flood event. However, as also shown in Table 2, the HWM data clearly indicates that the business at 89 Washington Road, with a maximum interior flood depth of approximately 1.1 feet, will be the first structure to experience interior flooding from a Brook and/or River flood event, followed by the business at 92 Washington Road.

Further analysis of the HWM data in Tables 1 and 2 was conducted to 1) estimate the frequency or annual chance of the April 30 – May 1, 2014 flood event and 2) determine whether the Brook or River was primarily responsible for excessive water surface elevations and the resulting roadway and structure flooding. To do this, relationships between water surface elevation (or stage) and flood frequency (or annual chance) for both the Little Bear Brook at the flood locations described above and the Millstone River at the mouth of the Brook were computed from the new HEC-RAS computer models of both waterways.

The computed water surface elevation vs. flood frequency relationship for the Millstone River at the mouth of Little Bear Brook used in the Flood Hazard Assessment is shown in Figure 13. The data shown in this Figure is based upon the Millstone River water surface profiles computed with the new HEC-RAS model of the River described above. In addition, based upon the difference in surveyed HWM elevations at Fisher Place and Washington and Alexander Roads shown in Table 1, a maximum Millstone River water surface elevation of 58.2 NAVD88 was assumed at the mouth of Little Bear Brook. As shown in Figure 13, this assumed maximum water surface elevation for the April 30 – May 1, 2014 flood has an estimated recurrence interval of approximately 20 years.

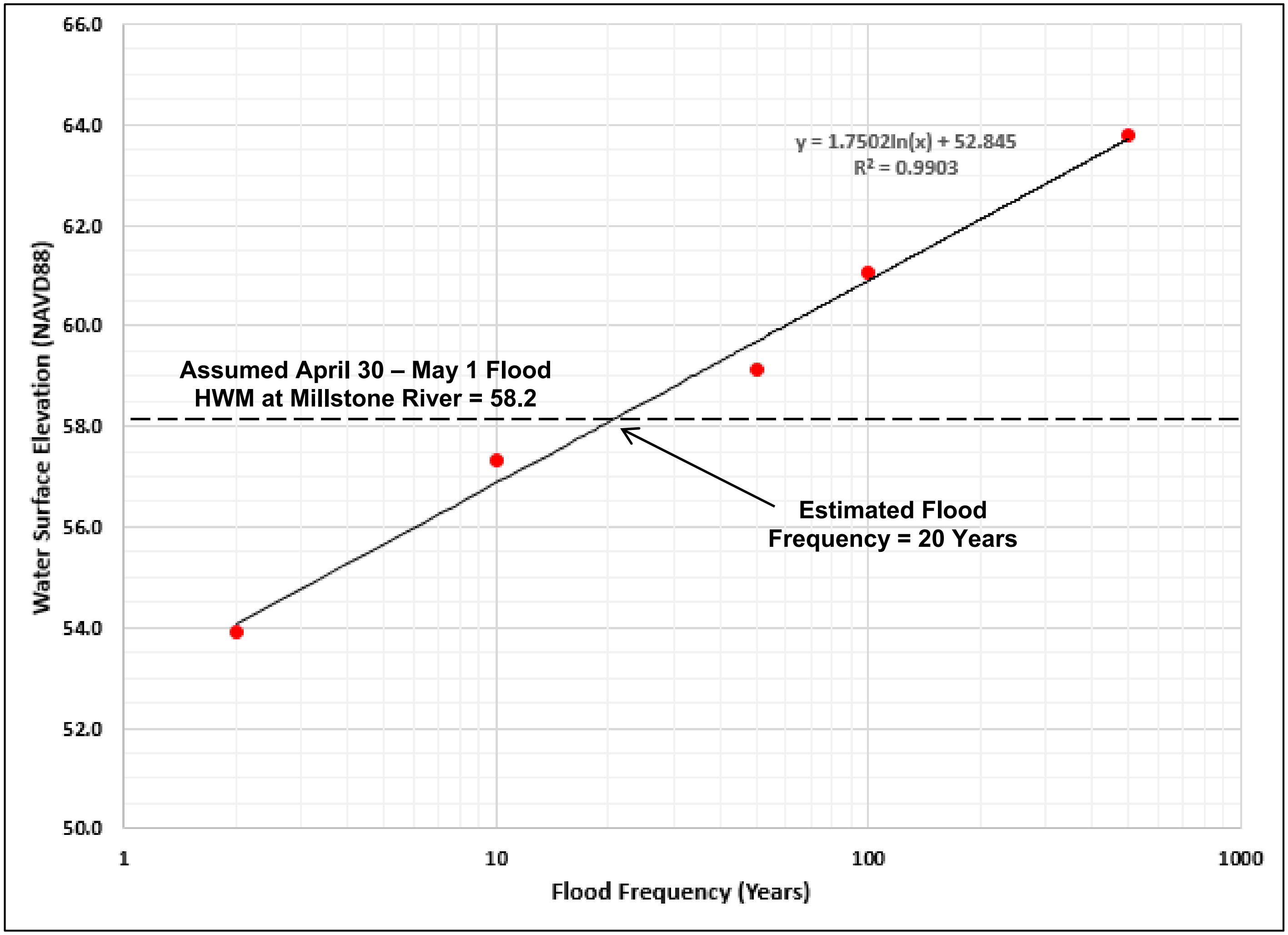
The water surface elevation vs. flood frequency relationships for Little Bear Brook at Washington and Alexander Roads are shown in Figures 14 and 15. The data shown in these Figures are based upon the new unsteady flow HEC-RAS computer models of the Brook that, as described above in **3. <u>Basis of Analysis</u>**, were based on some of the data in the HEC-2 computer models developed for the 1984 FEMA FIS and NJDEP Delineations as well as updated Washington and Alexander Road data.

However, it is important to note that, unlike the water surface profiles of Little Bear Brook contained in the 1984 FEMA FIS and NJDEP Delineations (and shown in Figure 12 above), the unsteady flow HEC-RAS models of Little Bear Brook do not include the effects of Millstone River backwater. Instead, these unsteady flow HEC-RAS models reflect free discharge conditions at the mouth of the Brook based upon normal depth water surface elevations. As described in more detail below in **4.3 <u>Little Bear Brook Analysis</u>**, the use of normal flow depths at the mouth of the Brook instead of Millstone River backwater elevations allowed the Brook's own ability to convey flood flows to be independently computed and evaluated without being influenced by water levels on the Millstone River. As a result, the flooding effects of both the Brook and River could be evaluated separately in order to determine which waterway was primarily responsible for the frequent Washington and Alexander Road flooding and the less frequent road, property, and structure flooding along the Brook.

Figure 13

Millstone River Water Surface Elevation – Flood Frequency Relationship at Mouth of Little Bear Brook

Little Bear Brook Flood Hazard Assessment



Source: HEC-RAS Computer Model of Millstone River

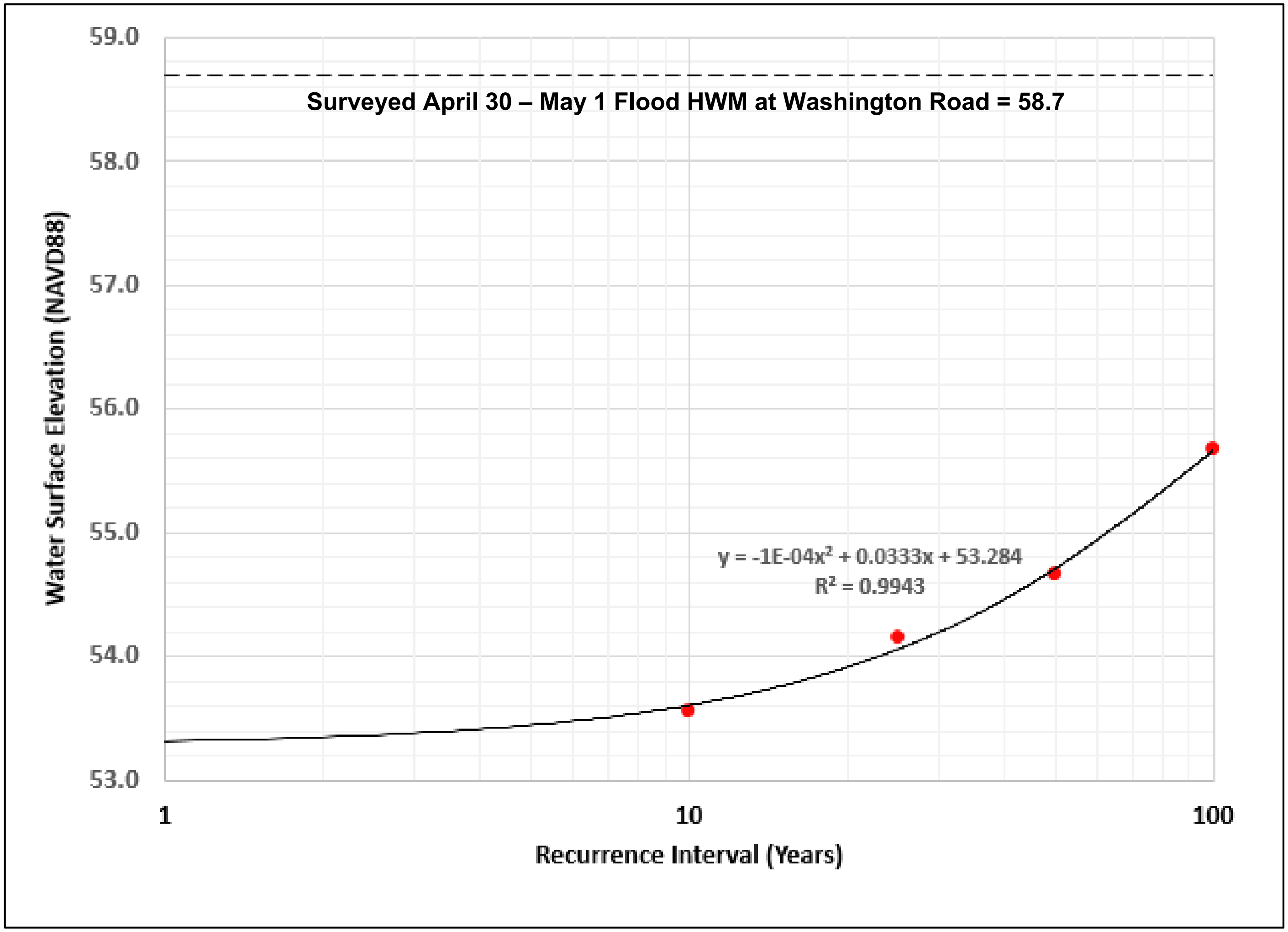
As can be seen in Figures 14 and 15, the surveyed HWM elevations of 58.7 and 58.8 NAVD88 recorded on Washington and Alexander Roads, respectively, for the April 30 – May 1, 2014 flood would both have estimated recurrence intervals in excess of 100 years if the Little Bear Brook were under free discharge conditions independent of Millstone River backwater. Since such free discharge conditions did not occur at the time of high water during the flood event, it is clear from the data in Figures 13, 14, and 15 that the flooding that was experienced on April 30 – May 1, 2014 was the result of excessive water levels on the Millstone River (with an estimated frequency of approximately 20 years) and not due to the lack of flow capacity on Little Bear Brook.

This conclusion regarding the April 30 – May 1, 2014 flood event is supported by an analysis of the rainfall recorded in the Millstone watershed for the event. The results of this analysis are shown in Figure 15, which depicts the relationship between rainfall duration and depth for various rainfall event frequencies for the Hamilton rainfall gage in the N.J. Weather & Climate Network. Also depicted on Figure 15 are the maximum recorded rainfalls at the Hamilton gage for time periods ranging from 1 to 24 hours during the April 30 – May 1 event.

As can be seen in Figure 15, the maximum recorded 24-hour rainfall depth for the April 30 – May 1 event lies on the 10-Year recurrence interval curve. This rainfall duration is important since, due to the River's relatively large watershed size, flat slope, and subsequent slow response time, peak Millstone River discharges and water surface elevations near Little Bear Brook are primarily influenced by rainfall depths falling within approximately a 24-hour period rather than those that occur in shorter time periods (that are more likely to strongly influence discharges and water surface elevations on waterways with smaller watershed sizes like Little Bear Brook). Based upon this data, and due to the average antecedent rainfall and moisture conditions that existed in the watershed prior to the April 30 – May 1, 2014 event, it is not unexpected that the estimated recurrence interval of the HWMs recorded for the April 30 – May 1, 2014 flood event (approximately 20 years) reasonably match the recurrence intervals of the critical rainfall recorded in the Millstone watershed.

Finally, this conclusion can be further supported by the finding that the maximum recorded 1 to 6-hour rainfalls shown in Figure 15 have estimated recurrence intervals of only 1 to 2-Years. Since Figures 13 and 14 demonstrate that a flood event in excess of a 100-Year recurrence interval would be required for Little Bear Brook to independently cause the HWMs recorded for the April 30 – May 1, 2014 event, it is further demonstrated that the lack of flow capacity on the Brook was not the cause of the flooding.

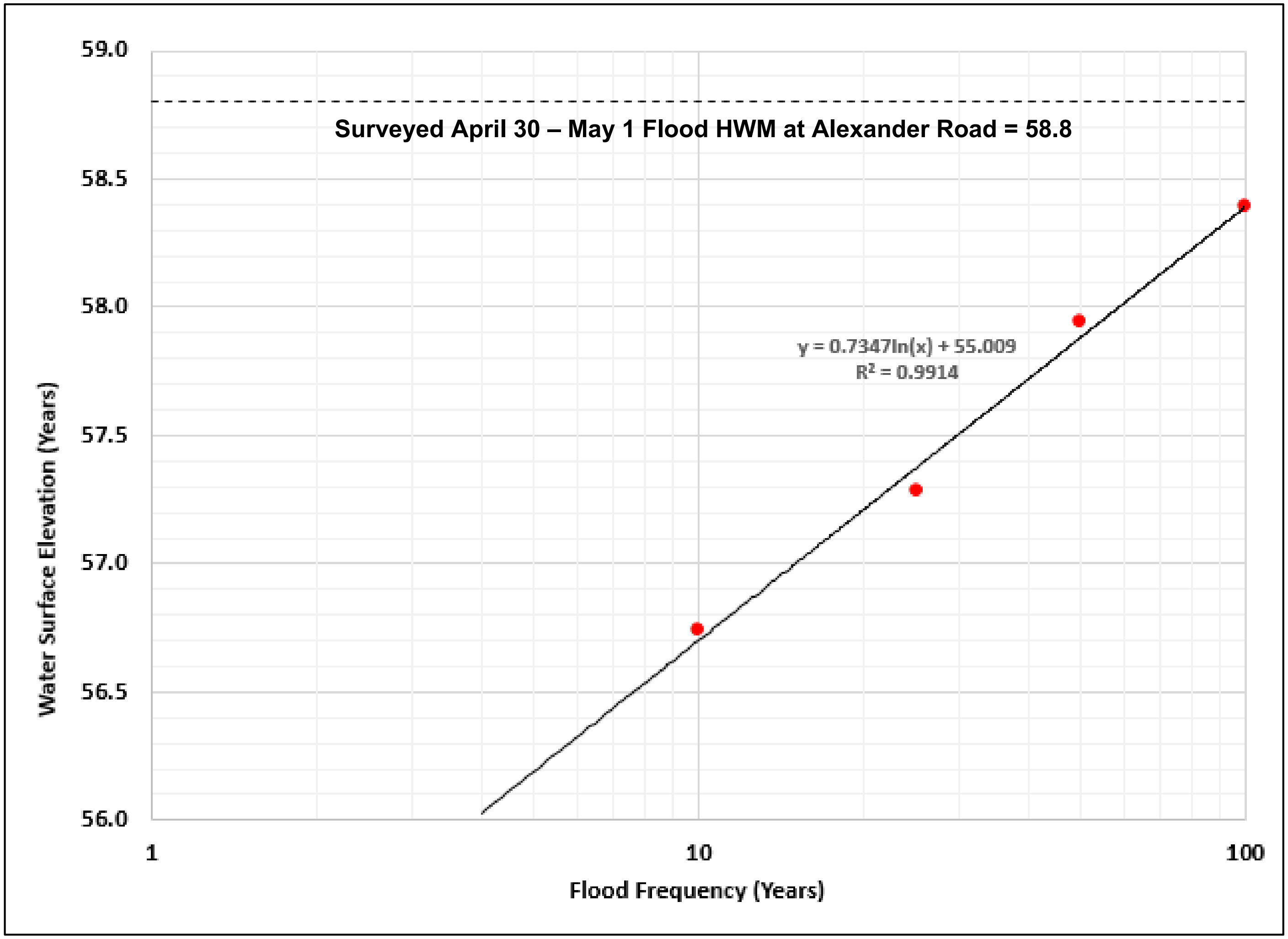
<u>Figure 14</u>
Little Bear Brook Frequency – Water Surface Elevation Relationship at Washington Road
Little Bear Brook Flood Hazard Assessment



Source: Little Bear Brook Unsteady Flow HEC-RAS Model without Millstone River Backwater

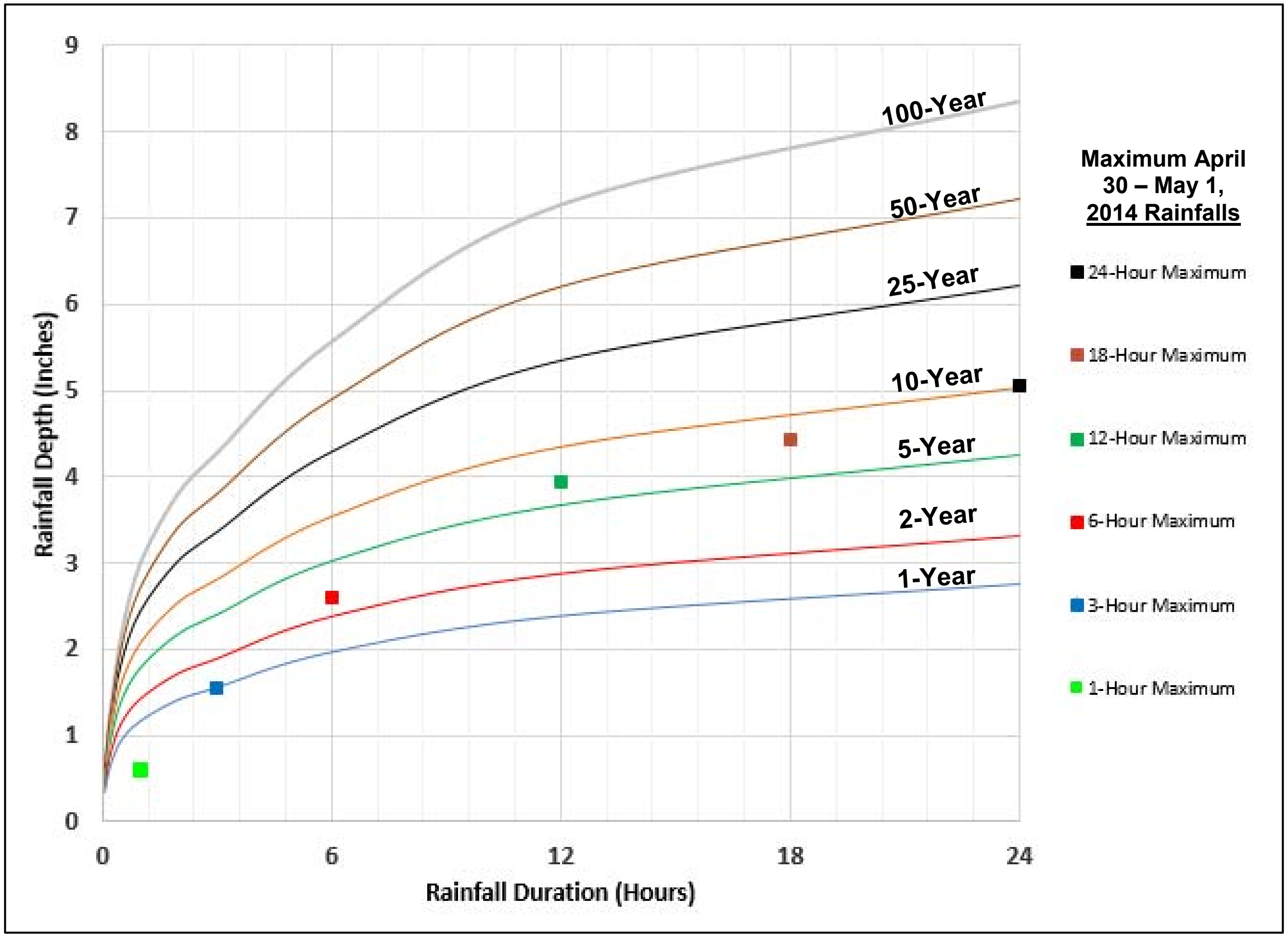
<u>Figure 15</u>

Little Bear Brook Frequency – Water Surface Elevation Relationship at Alexander Road
Little Bear Brook Flood Hazard Assessment



Source: Little Bear Brook Unsteady Flow HEC-RAS Model without Millstone River Backwater

Figure 16
Millstone Watershed Rainfall Duration – Depth – Frequency Relationship
Little Bear Brook Flood Hazard Assessment



Sources: NOAA Precipitation Data Frequency Server and N.J. Weather Climate Network Hamilton Rain Gage

4.3 **Little Bear Brook Analysis**:

As described above in **4.2 April 30 - May 1, 2014 Flood Event**, the analysis of Little Bear Brook's ability to independently convey various frequency flood flows without the influence of Millstone River backwater was based upon an unsteady flow HEC-RAS model of the Brook. This model was developed, in part, from the HEC-2 computer model data used to develop both the 1984 FEMA West Windsor Township FIS and the NJDEP Floodway and Flood Hazard Area Delineations of the Brook. This HEC-2 data was updated at the Washington and Alexander Road Bridges with information from both field surveys and the project area topographic mapping described above in **3. Basis of Analysis**. An unsteady flow HEC-RAS model was selected for the analysis of the Brook since it was better able to model the effects of the large floodplain storage volumes along the Brook than a steady flow model. A copy of pertinent HEC-RAS model data in contained in **Appendix F - HEC-RAS Models**.

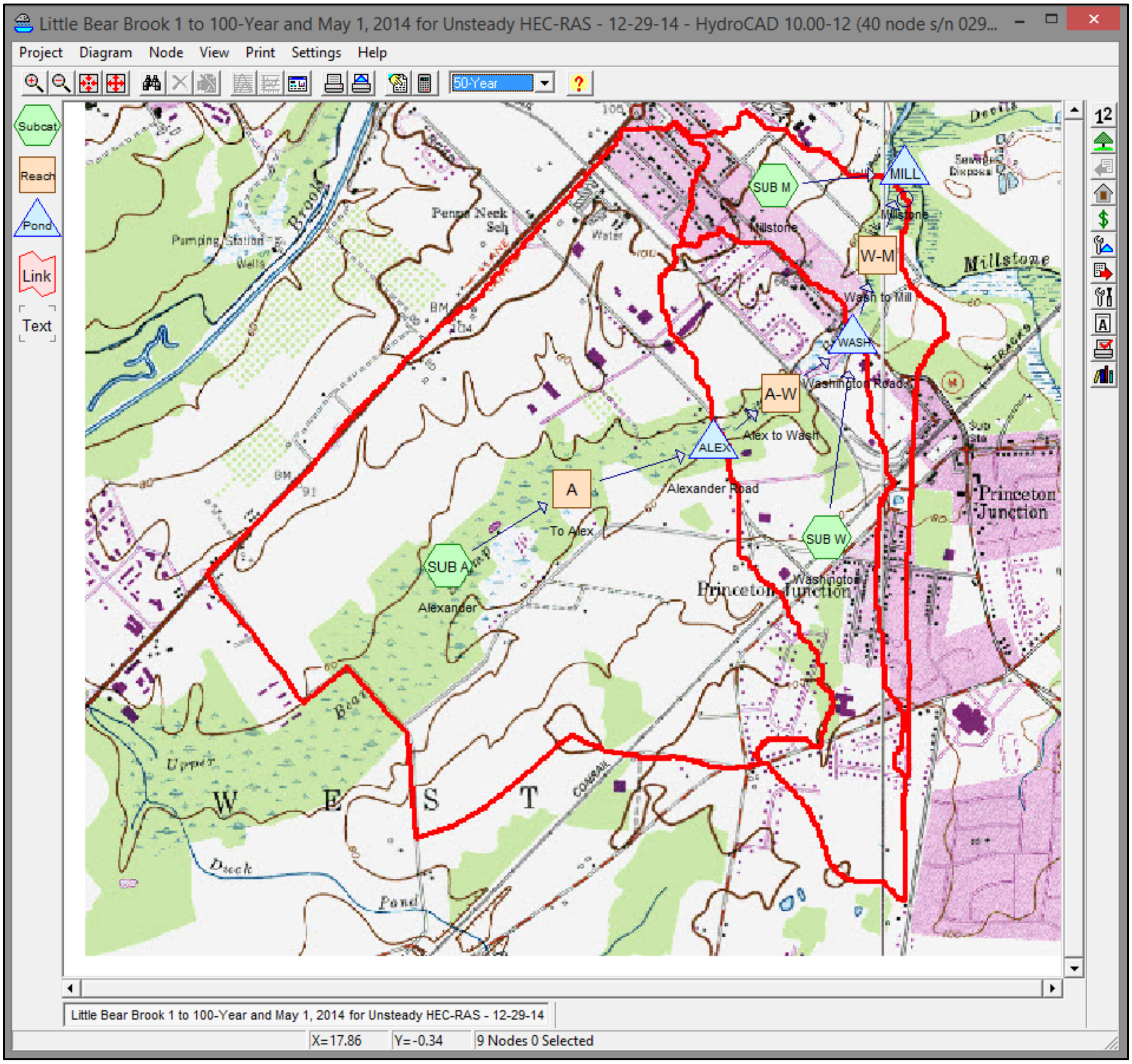
As described above in **3. Basis of Analysis,** runoff hydrographs to the Brook at Alexander Road, Washington Road, and the Brook's confluence with the Millstone River were developed from a computer model of the Little Bear Brook subwatershed using Version 10 of computer program HydroCAD. This model was based upon the drainage subareas limits and areas shown above in Figures 5 and 6 and below in Figure 17 and the NRCS rainfall-runoff methodology. Rainfall depths were chosen for the Little Bear Brook subwatershed from the NOAA Precipitation Frequency Data Server and temporally distributed using the NRCS 24-hour Type III Storm. NRCS Runoff Curve Numbers (CNs) for each drainage subarea were based upon the land covers and NRCS Hydrologic Soil Groups (HSGs) shown in Figures 5 and 6 and Tables 2-2 a, b, c ,and d in the NRCS *Technical Release 55 – Urban Hydrology for Small Watershed* (TR-55). Drainage subarea Times of Concentration (TC) were developed using the project area and USGS topographic mapping and the methodology contained in Chapter 3 of TR-55.

A summary of the runoff characteristics of the three Little Bear Brook drainage subareas used in the HydroCAD computer model is presented in Table 3 below. A schematic view of the overall HydroCAD model is shown in Figure 17. It should be noted that the runoff hydrographs for these three drainage subareas were used as input hydrographs to the unsteady HEC-RAS model of the Brook. A copy of all pertinent HydroCAD model data is contained in **Appendix G – Little Bear Brook HydroCAD Model**.

Table 3
Summary of Little Bear Brook Drainage Subarea Characteristics
Little Bear Brook Flood Hazard Assessment

Drainage Subarea Location	HydroCAD Subarea Name	Area (Acres)	Runoff Curve Number	TC (Hours)
To Alexander Road	Sub A	1,189	60	1.0
To Washington Road	Sub W	416	58	2.0
To Mouth	Sub M	224	55	2.0

Figure 17
Little Bear Brook HydroCAD Model Schematic
Little Bear Brook Flood Hazard Assessment



Similar to the analysis of the April 30 – May 1, 2014 flood event described above, the flood hazard assessment of Little Bear Brook was based upon the free discharge conditions at the Brook's confluence with the Millstone River. This was done to independently analyze the Brook's capacity to convey flow and to create and/or contribute to flooding without the influence of Millstone River backwater. As also described above, these free discharge conditions were based upon the assumption of normal depth flow conditions at the mouth of the Brook.

The results of this independent (i.e., without Millstone River backwater) flood hazard analysis of Little Bear Brook using the HydroCAD drainage subarea hydrographs and unsteady HEC-RAS computer model of the Brook are shown in Figure 18 below. This Figure depicts the maximum 10, 25, 50, and 100-Year water surface profiles in Little Bear Brook computed by the unsteady flow HEC-RAS model under free discharge conditions at the mouth of the Brook. Also shown in the Figure are the approximate low road elevations for Fisher Place and Washington, Fieldston, and Alexander Roads shown in Table 1 above.

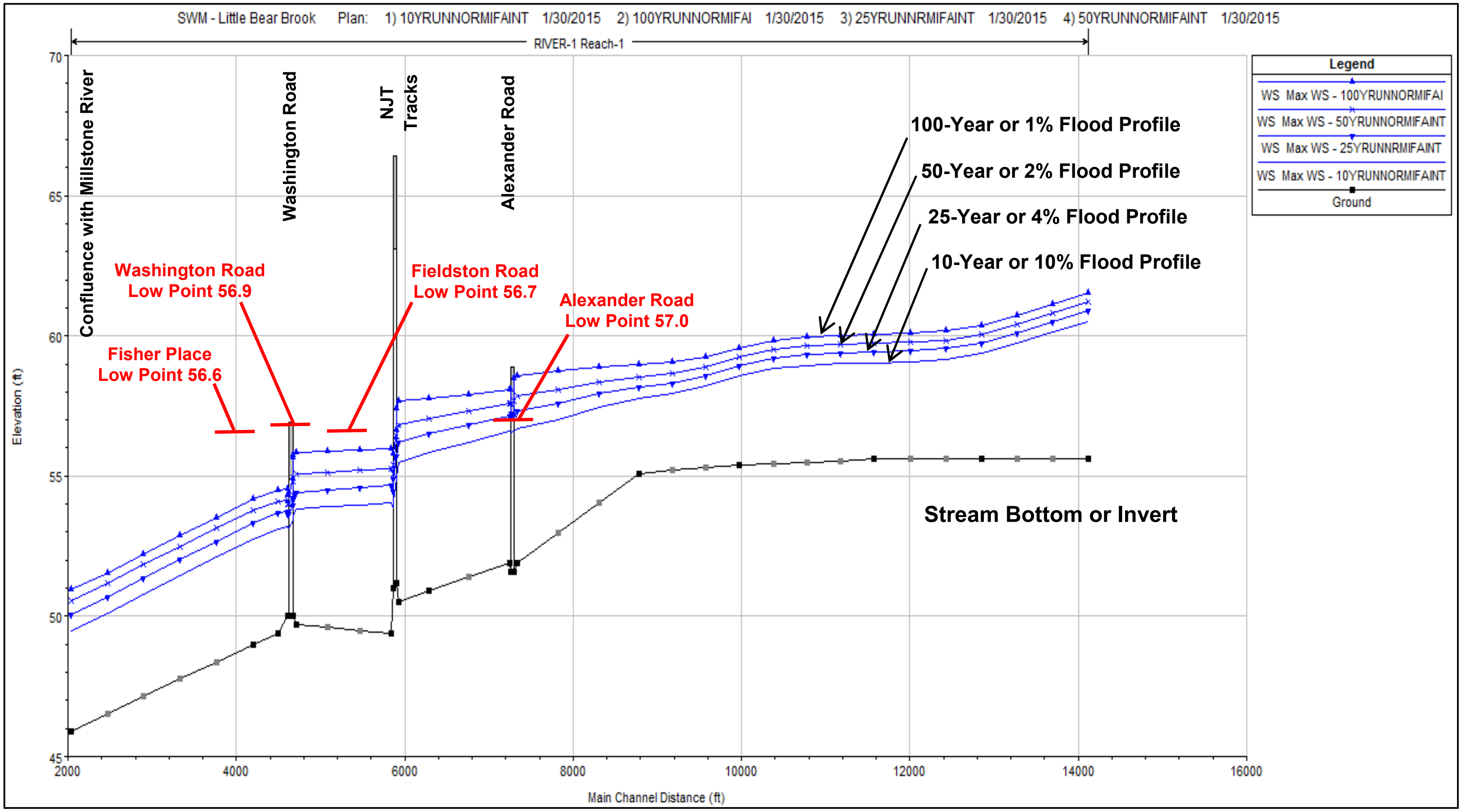
As can be seen in Figure 18, the approximate low road elevations on Fisher Place and Washington and Fieldston Roads are approximately one foot or more above the maximum computed 100-Year Little Bear Brook water surface elevation at each roadway. This indicates that, without the influence of Millstone River backwater, flooding at these three roadways and contiguous areas by Little Bear Brook would have a recurrence interval in excess of 100 years. Such a recurrence interval greatly exceeds the reported frequency of flooding that has occurred at these locations. As noted above in **4.1 <u>Property Owner Questionnaire</u>**, both the questionnaire responses and public meeting input also indicate that flooding of Washington Road has occurred on multiple occasions during certain years, including as recently as 2014.

It can also be seen in Figure 18 that the approximately low road elevation at Alexander Road lies between the maximum computed 10 and 25-Year Little Bear Brook water surface elevations (without Millstone River backwater) at the upstream side of the Road. Similar to Fisher Place and Washington and Fieldston Roads discussed above, such a recurrence interval greatly exceeds the reported frequency of flooding that has occurred at Alexander Road. In addition, similar to above roadways, both the questionnaire responses and public meeting input indicate that flooding of Alexander Road has also occurred on multiple occasions during certain years, including as recently as 2014.

The results shown in Figure 18 are also presented in a different manner in Figures 19 and 20. These Figures depict the same water surface elevation vs. flood frequency relationships for Little Bear Brook at Washington and Alexander Roads, respectively, without the effects of Millstone River backwater as shown above in Figures 14 and 15. However, instead of also depicting the surveyed HWMs at each road for the April 30 – May 1, 2014 flood event, Figures 19 and 20 instead depict the approximate low elevation in each roadway.

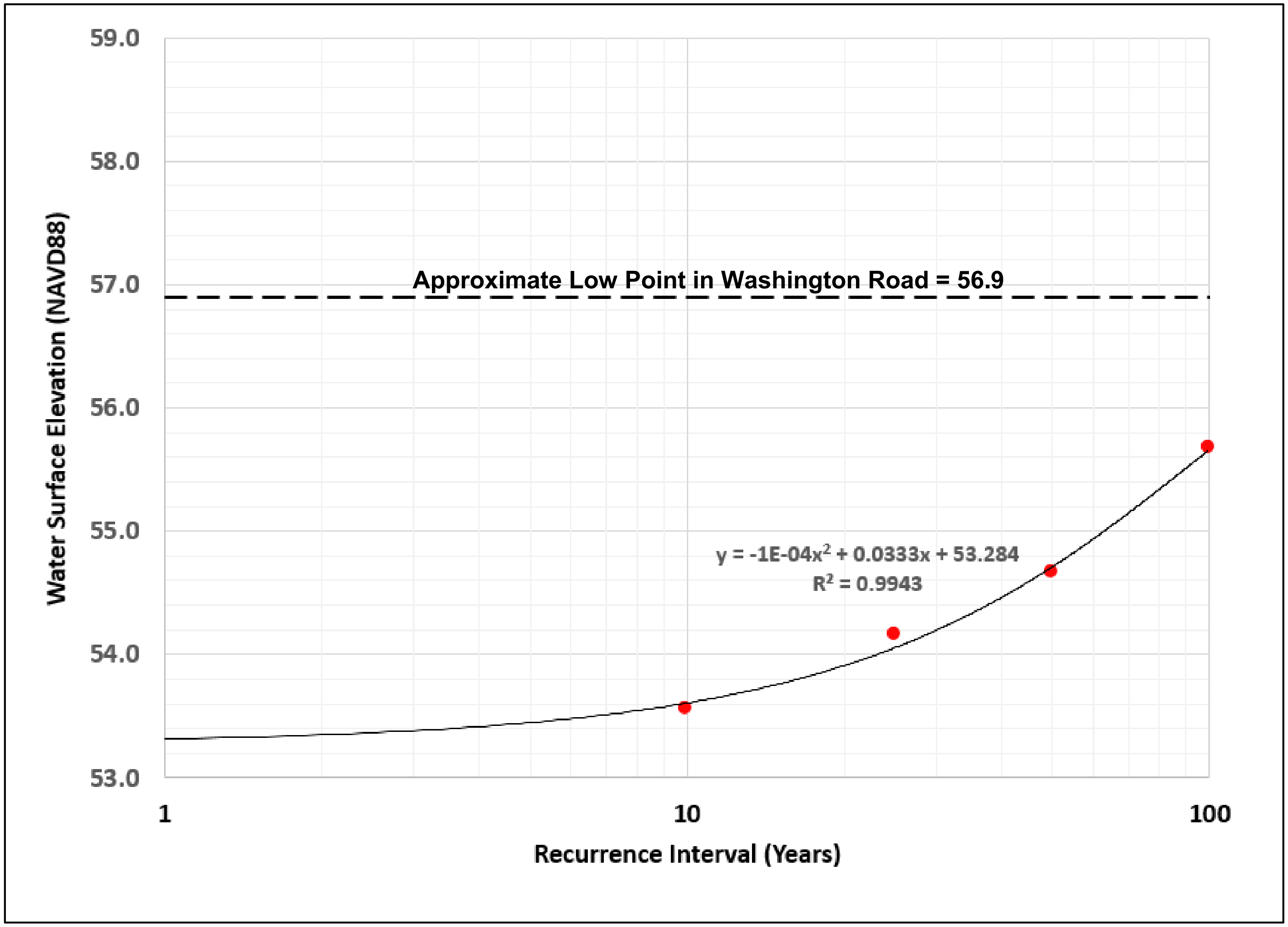
As can be seen in Figure 19, the low roadway elevation in Washington Road exceeds the computed Little Bear Brook water surface for the 100-Year flood. In Figure 20, the low roadway elevation in Alexander Road lies between the computed Little Bear Brook water surface elevations for the 10 and 25-Year floods. As noted above, the computed Little Bear Brook water surface elevations shown in both Figures do not include the effects of Millstone River backwater.

Figure 18
Little Bear Brook Unsteady Flow HEC-RAS Maximum Water Surface Profiles without Millstone Backwater
Little Bear Brook Flood Hazard Assessment



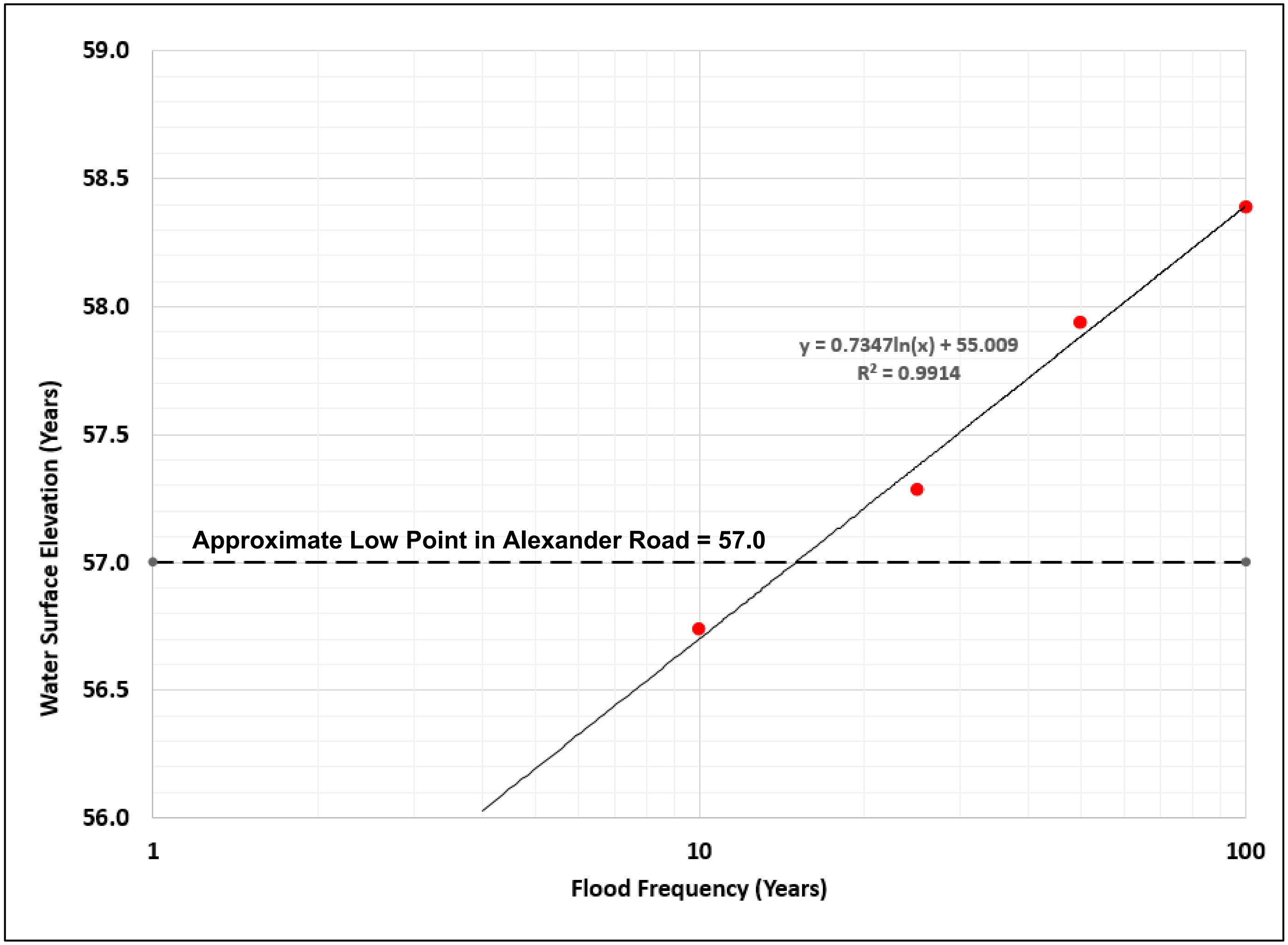
Source: Little Bear Brook Unsteady Flow HEC-RAS Model without Millstone River Backwater

Figure 19
Little Bear Brook Frequency – Water Surface Elevation Relationship at Washington Road
Little Bear Brook Flood Hazard Assessment



Source: Little Bear Brook Unsteady Flow HEC-RAS Model without Millstone River Backwater

<u>Figure 20</u>
Little Bear Brook Frequency – Water Surface Elevation Relationship at Alexander Road
Little Bear Brook Flood Hazard Assessment



Source: Little Bear Brook Unsteady Flow HEC-RAS Model without Millstone River Backwater

Therefore, it can be concluded from the above that, similar to the flooding that occurred during the April 30 – May 1, 2014 event, neither the frequent, chronic flooding of Washington and Alexander Roads nor the less frequent but more destructive flooding of residential, commercial, and office structures along Little Bear Brook is the result of a lack of flow capacity in Little Bear Brook itself. As such, other potential causes of both the roadway and structure flooding must be investigated.

One such potential cause was first reported by the West Windsor Township Engineer and subsequently observed in the field during a reconnaissance of Little Bear Brook. As shown in Figure 21 taken approximately 100 feet downstream of Washington Road, this potential cause of flooding, particularly at Washington and/or Alexander Roads, was the creation of a beaver dam across the Little Bear Brook channel. Such dams can both raise the starting water surface elevation in the Brook prior to a flood event and decrease the flow capacity of the channel during an event.

Figure 21
Beaver Dam in Little Bear Brook Channel Downstream of Washington Road
Little Bear Brook Flood Hazard Assessment

To analyze the potential effects of a beaver dam on the flow capacity of Little Bear Brook and determine whether such an obstruction could result in flooding at either Washington or Alexander Roads, the unsteady flow HEC-RAS model developed for Little Bear Brook was modified to simulate the presence of a beaver dam immediately downstream of both roadways. This modification consisted of inserting an inline weir at a HEC-RAS cross section downstream of the roadways with a weir crest elevation equal to the top of the channel banks at the section. Such an inline weir at a HEC-RAS cross section approximately 100 feet downstream of Washington Road is illustrated in Figure 22. This location of the simulated beaver dam is at the same location of the actual beaver dam observed in the field and shown in Figure 21. For the analysis of Alexander Road, the simulated beaver dam was located approximately 20 feet downstream of the Road.

The results of the simulated beaver dam analysis at both Washington and Alexander Roads are shown in Figures 23 and 24 below. These Figures depict the same low roadway elevations and Little Bear Brook water surface elevation vs. flood frequency relationships for Washington and Alexander Roads, respectively, without the effects of Millstone River backwater as shown above in Figures 18 and 19. However, the Figures also depict revised elevation vs. frequency relationships resulting from the simulated beaver dams downstream of each roadway.

As shown in Figure 23, the simulated beaver dam raised the water surface elevations upstream at Washington Road by approximately 1 to 2 feet for a given frequency flood event. However, the maximum computed 100-Year water surface elevation at Washington Road with the simulated beaver dam remains slightly below the approximate low point in the roadway. As such, while an actual beaver dam downstream of Washington Road may raise starting water surface elevations prior to the start of a rainfall event, it would not be expected to raise the normal (i.e., without beaver dam) 100-Year water surface elevation above the approximate low point in Washington Road.

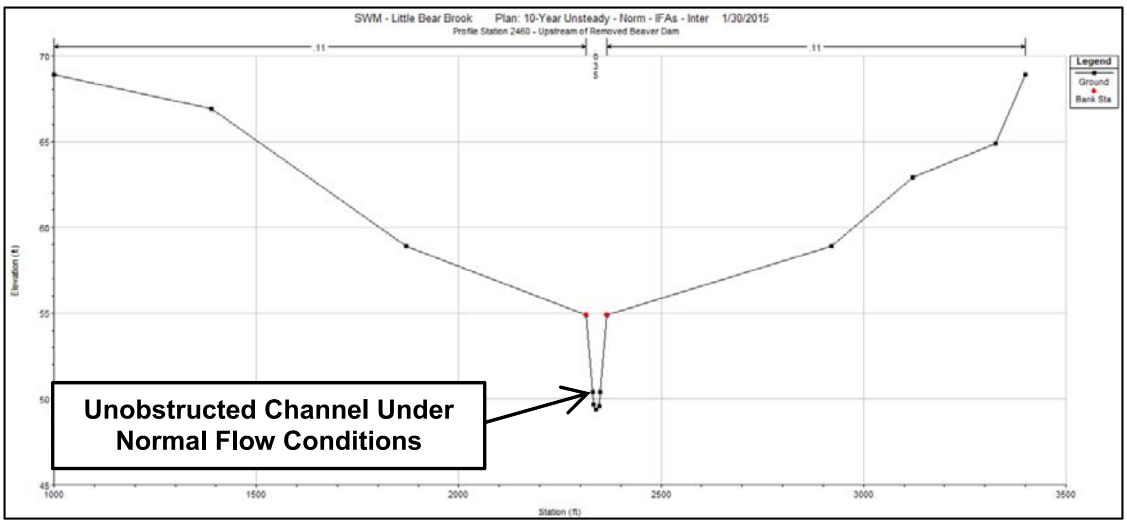
Therefore, it can be concluded that the presence of a beaver dam downstream of Washington Road would not sufficiently decrease the Brook's flow capacity to cause flooding of the roadway for flood events up to a 100-Year event. It can then be further concluded that the presence of a beaver dam downstream of Washington Road does not make Little Bear Brook responsible for either the frequent, chronic flooding of the roadway or the less frequent but more destructive upstream flooding of residential, commercial, and office structures along the Brook that have occurred in the past.

As shown in Figure 24, the simulated beaver dam had virtually no effect on water surface elevations upstream at Alexander Road for the 1 to 100-Year floods. Therefore, similar to the Washington Road analysis discussed above, it can be concluded again that the presence of a beaver dam downstream of Alexander Road does not make Little Bear Brook responsible for either the frequent, chronic flooding of the roadway or any less frequent but more destructive upstream flooding of residential, commercial, and/or office structures along the Brook that may have occurred in the past.

It is important to note, however, the presence of a beaver dam may contribute to the frequent, chronic flooding of Washington or Alexander Roads by creating artificially high tailwater levels downstream of the existing storm sewer systems in these roadways. It may also contribute towards nuisance flooding of yards and parking lots. A flood hazard analysis of the existing roadway storm sewer systems, including the potential impacts of beaver dams, will be performed in the next phase of the project.

<u>Figure 22</u>
HEC-RAS Section Downstream of Washington Road Without and With Simulated Beaver Dam
Little Bear Brook Flood Hazard Assessment

<u>Without Simulated Beaver Dam</u>



<u>With Simulated Beaver Dam</u>

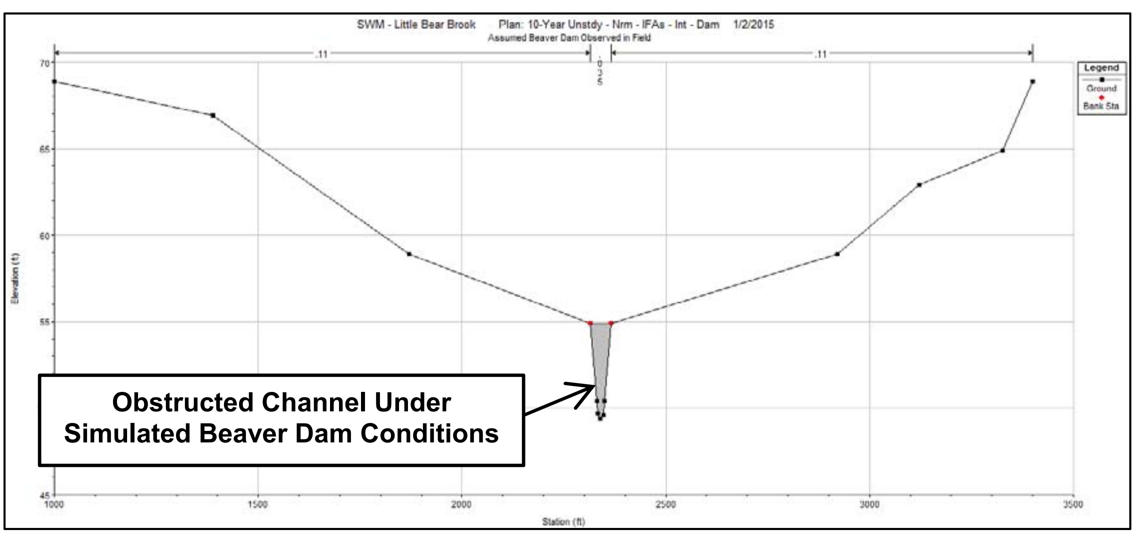
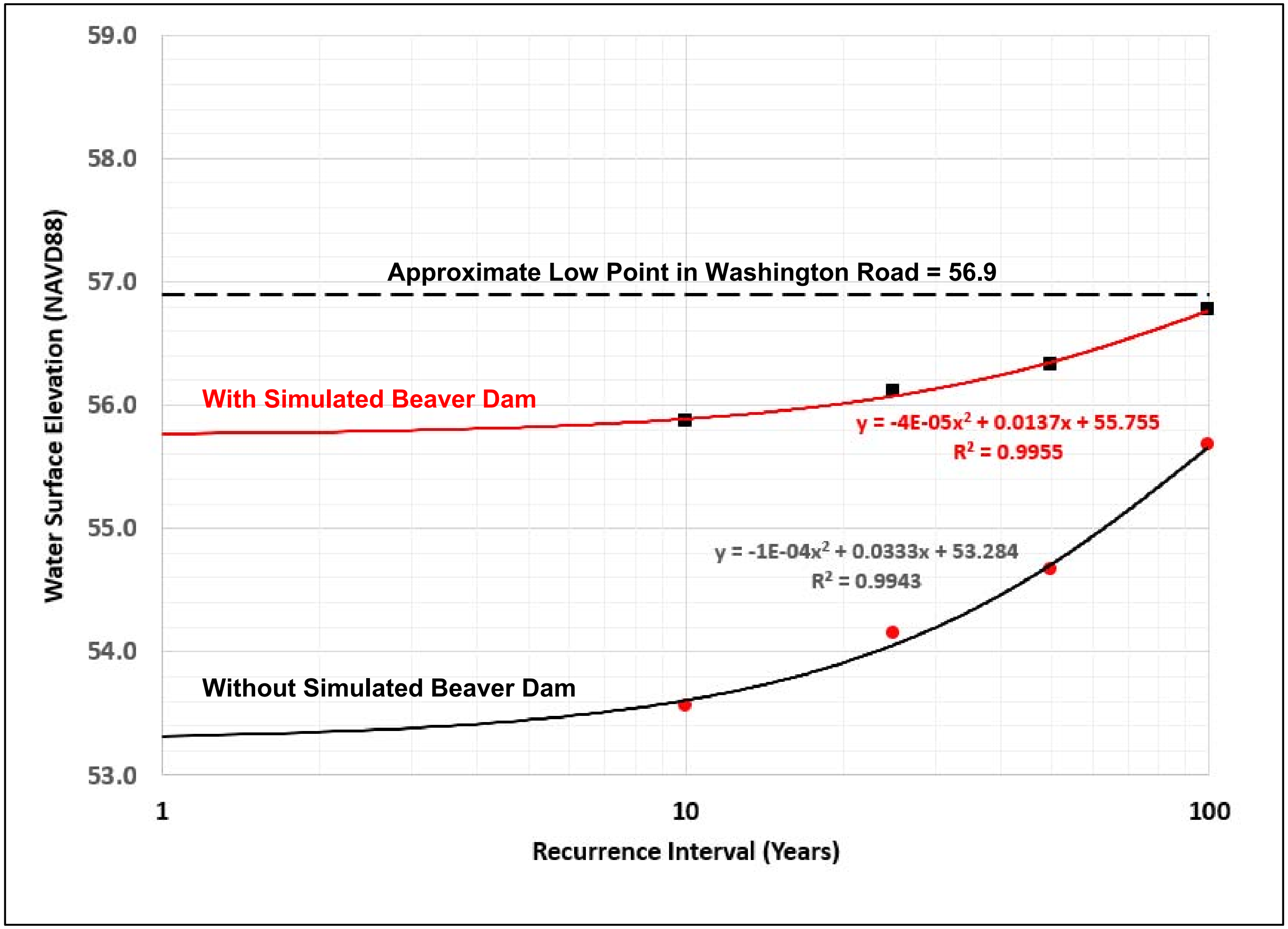


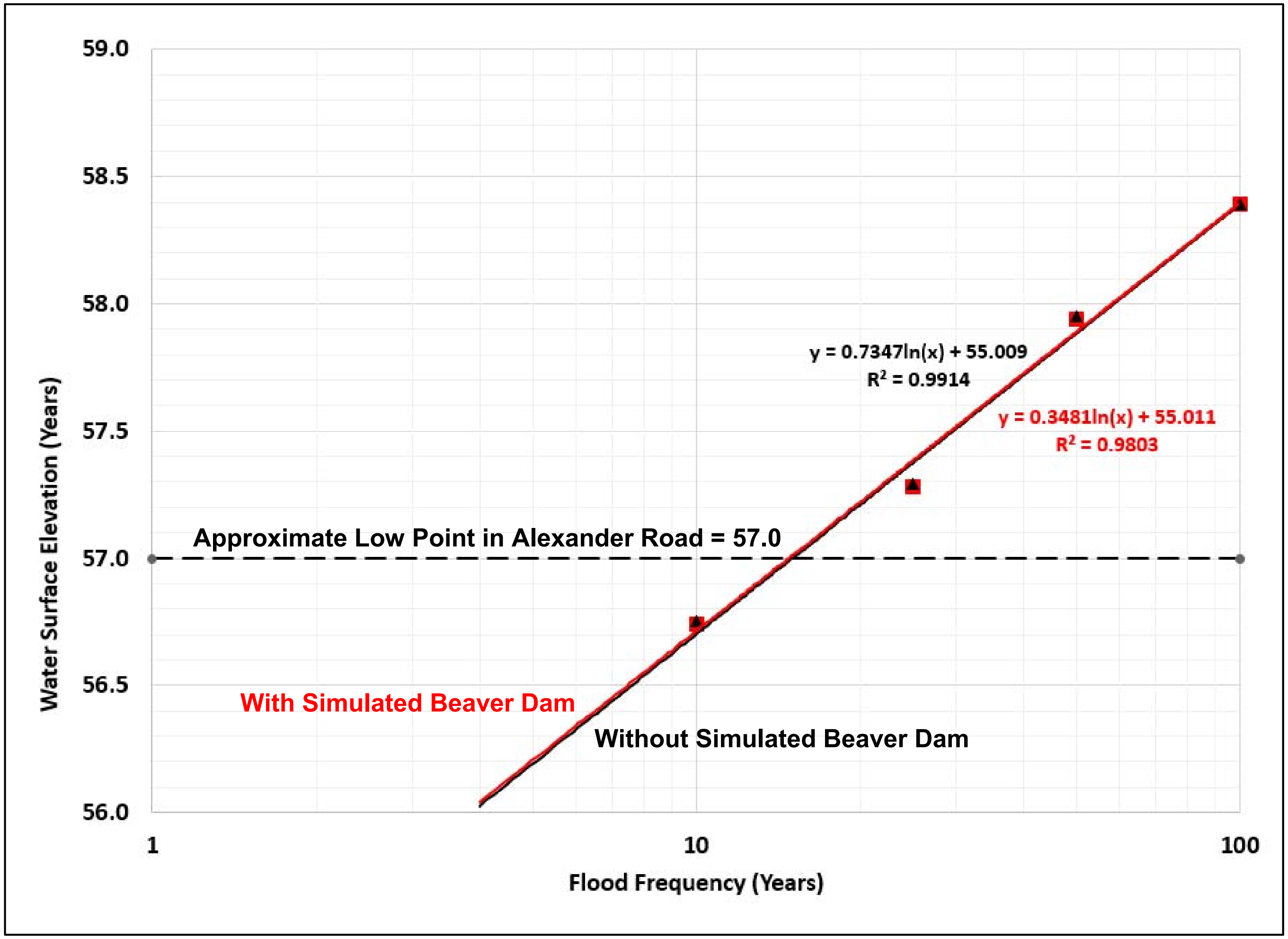
Figure 23
Little Bear Brook Frequency – Water Surface Elevation Relationship at Washington Road
Without and With Simulated Beaver Dam
Little Bear Brook Flood Hazard Assessment



Source: Little Bear Brook Unsteady Flow HEC-RAS Model without Millstone River Backwater

Figure 24

Little Bear Brook Frequency – Water Surface Elevation Relationship at Alexander Road
Without and With Simulated Beaver Dam
Little Bear Brook Flood Hazard Assessment



Source: Little Bear Brook Unsteady Flow HEC-RAS Model without Millstone River Backwater

4.4 **<u>Millstone River Analysis</u>:**

As noted above in **3. <u>Basis of Analysis</u>**, hydrologic and hydraulic information regarding the Millstone River was obtained from the 1984 FEMA West Windsor Township Flood Insurance Study (FIS) and associated NJDEP Delineation of Floodways and Flood Hazard Areas along the Brook and River. This information also included Millstone River data contained in the 1984 Princeton Township and 2010 Middlesex County FIS. The West Windsor and Princeton FIS information included HEC-2 computer models of the River developed for both the FEMA FIS and NJDEP Delineation. The final analysis of the Millstone River was based upon the FEMA FIS, NJDEP Delineation, and associated HEC-2 computer models described above and the new HEC-RAS hydraulic computer model of the River from a point approximately 1000 feet downstream of the U.S. Route 1 Bridge to a point approximately 1700 feet upstream of the River's confluence with Little Bear Brook. As noted above, this HEC-RAS model was based upon model data submitted to the NJDEP in support of the 2009 Flood Hazard Area Permit application for the replacement of the U.S. Route 1 Bridge over the River.

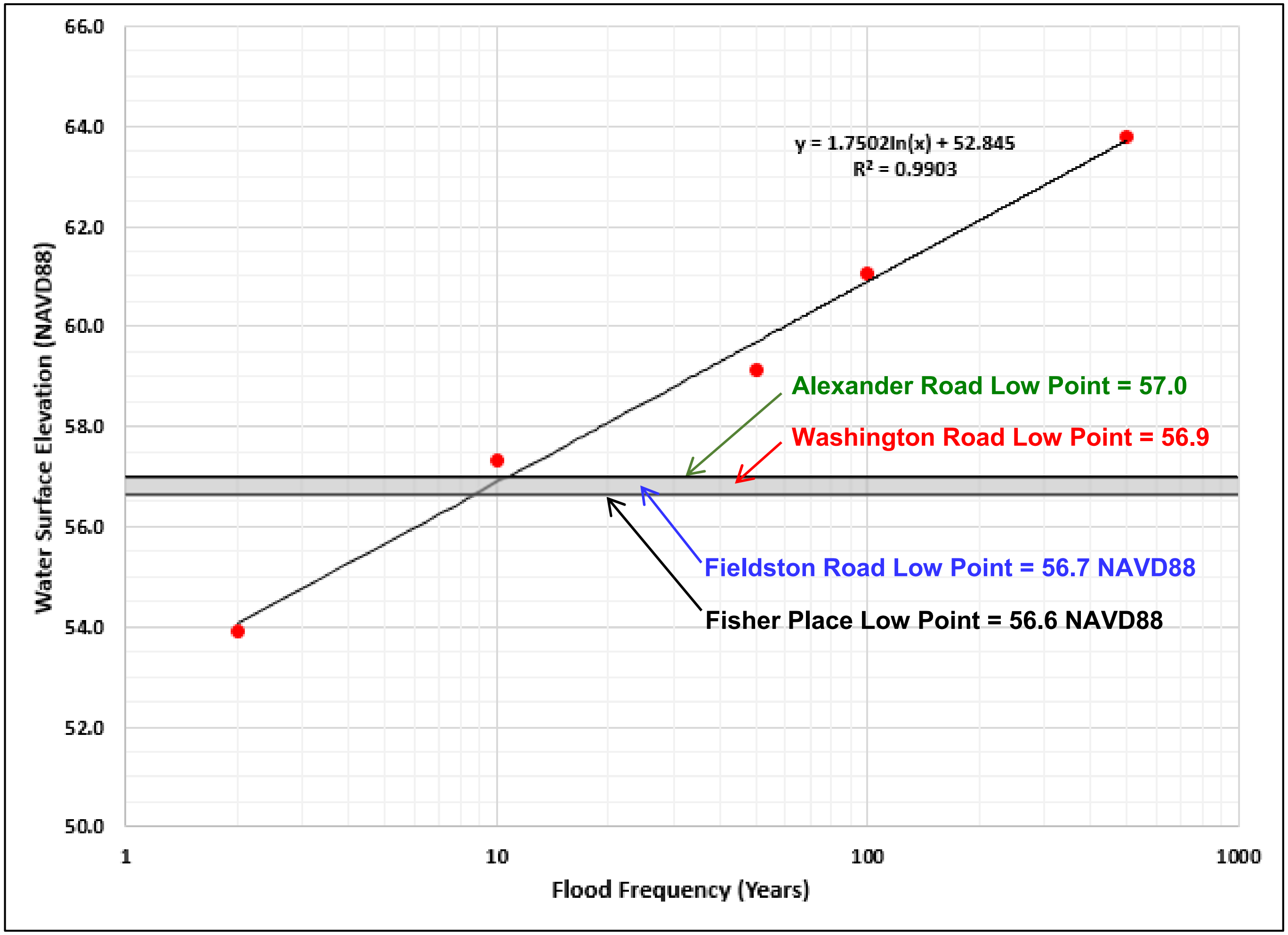
It should be noted that the HEC-RAS model described above was used to estimate Millstone River backwater-induced flood frequencies on Little Bear Brook as well as the potential impacts of the U.S Route 1 Bridge on flooding upstream on the Millstone River and Little Bear Brook. This HEC-RAS model was used for these analyses since the 1984 West Windsor and 2010 Middlesex County FEMA FIS and NJDEP Delineations are based upon the previous U.S. Route 1 Bridge over the Millstone that was replaced in 2010. A copy of all pertinent HEC-RAS model data is contained in **Appendix F – HEC-RAS Models**.

As described in detail above in **4.3 <u>Little Bear Brook Analysis</u>**, the analysis of the April 30 – May 1, 2014 flood event on Little Bear Brook determined that, while neither the Brook or the River were directly responsible for the frequent, chronic flooding of Washington and Alexander Roads, the Millstone River was responsible for the less frequent structural and adjacent roadway flooding along the Brook. In light of this determination, the HEC-RAS model of the Millstone described above was used to estimate the approximate frequencies (or annual risks) of floods that would initiate flooding at the various flood-prone roadways and structures along Little Bear Brook. The results of this analysis are presented below in Figures 25 and 26.

These Figures depict the same frequency – water surface elevation relationship for the Millstone River at the mouth of Little Bear Brook as shown in Figure 13. However, rather than depicting the April 30 – May 1, 2014 HWM at the mouth of Little Bear Brook described above, Figure 25 contains the same low road elevations at Fisher Place and Washington, Fieldston, and Alexander Roads shown in Table 1 above. Similarly, Figure 26 contains the same lowest floor elevations of the three surveyed structures on Washington Road shown in Table 2 above as well as the lowest floor elevations of the surveyed structures on Fisher Place and Fieldston and Alexander Roads. Please note that, due to the small differences in elevations, the low road elevations shown in Figure 25 are depicted as a single line that encompasses all four roads.

Figure 25

Millstone River Frequency – Water Surface Elevation Relationship at Mouth of Little Bear Brook With Approximate Low Road Elevations on Fisher Place and Washington, Fieldston, and Alexander Roads
Little Bear Brook Flood Hazard Assessment

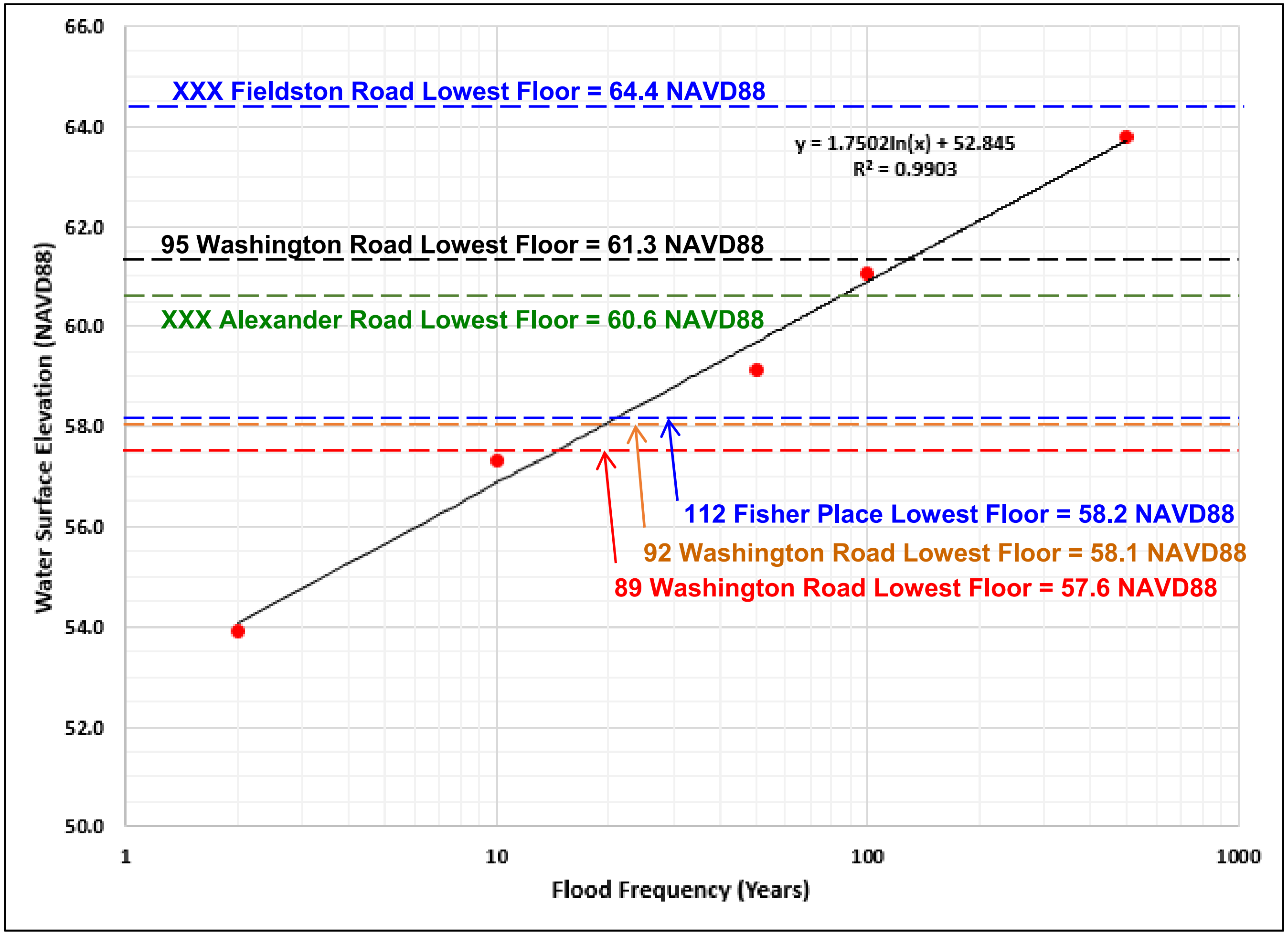


Source: Millstone River HEC-RAS Model and Project Topographic Mapping

Figure 26

Millstone River Frequency – Water Surface Elevation Relationship at Mouth of Little Bear Brook With Approximate Lowest Floor Elevations at Fisher Place and Washington, Fieldston, and Alexander Road Structures

Little Bear Brook Flood Hazard Assessment



Source: Millstone River HEC-RAS Model and Project Structure Survey

As shown in Figure 25, the low points in all of the roadways have estimated Millstone River flood thresholds of approximately 10-Years. A summary of the computed Millstone River flood threshold frequency of each roadway's low point is presented in Table 4. It is important to remember that these flood thresholds at the roadways are due to excessive water levels on the Millstone River at the mouth of Little Bear Brook. As noted above, both Washington and Alexander Roads have experienced more frequent flooding in the past which, as discussed above in **4.3 Little Bear Brook Analysis**, is not due to lack of flow capacity on the Brook. Therefore, as discussed above in **1. Introduction**, the existing storm sewer systems in these roadways will be analyzed for their connection to this roadway flooding in Phase II of the Little Bear Brook Flood Hazard Assessment.

Table 4
Estimated Roadway Flood Thresholds Due to Millstone River Flooding
Little Bear Brook Flood Assessment

Roadway	Approximate Roadway Low Point Elevation (NAVD88)	Estimated Millstone River Flood Threshold (Years)
Fisher Place	56.6	8
Fieldston Road	56.7	9
Washington Road	56.9	10
Alexander Road	57.0	10

As shown in Figure 26, the lowest floor elevations at 89 and 92 Washington Road and 112 Fisher Place have the lowest estimated Millstone River flood threshold frequencies ranging between approximately 15 and 20-Years. A summary of the computed Millstone River flood threshold frequency for each of the structures shown in Figure 26 is presented in Table 5. It is important to note that, as shown in the Table, these estimated flood thresholds are based upon the elevation of the lowest surveyed above-grade floor elevations and, as such, do not reflect the flood thresholds for any basement floors or the ground surface on the exterior of the structures.

Table 5
Estimated Lowest Floor Flood Thresholds Due to Millstone River Flooding
Little Bear Brook Flood Assessment

Structure Location	Approximate Lowest Above-Grade Floor Elevation (NAVD88)	Estimated Millstone River Flood Threshold (Years)
89 Washington Road	57.6	14
92 Washington Road	58.1	19
112 Fisher Place	58.2	20
XXX Alexander Road	60.6	78
95 Washington Road	61.3	116
XXX Fieldston Road	64.4	600+

Following the computation of the estimated Millstone River flood thresholds presented above, the next step in the Millstone River analysis was to determine if there were any specific downstream structures or features on the River that may be significantly contributing to this flooding. This analysis included the Millstone River data and HEC-2 models used in the West Windsor, Princeton, and Middlesex County Flood Insurance Studies, the Millstone River HEC-RAS model of the U.S. Route 1 Bridge, and the observations and HWM data for the April 30 – May 1, 2014 flood. The specific downstream structures included in the analysis were 1) the Carnegie Lake Dam, 2) the culvert that conveys the Millstone River beneath the Delaware & Raritan Canal Aqueduct into Carnegie Lake, and 3) the U.S Route 1 Bridge. Summaries of the analyses of these structures are presented below. The locations of all three structures are shown in Figure 27.

Carnegie Lake Dam: To determine the potential impacts of the Carnegie Lake Dam on Millstone water surface elevations upstream at the mouth of Little Bear Brook, observations of the water levels downstream and upstream of the Dam were made prior to and at the approximate time of maximum water surface during the April 30 – May 1, 2014 flood event. These observations are shown in the two photographs in Figure 28 that were provided by Princeton University shortly after the flood event.

Photograph 1 in Figure 28 shows the Millstone water surfaces downstream and upstream of the Carnegie Lake Dam at mid-day on April 30, 2014 when only approximately 1.5 inches (28 percent) of the storm's total rain of 5.3 inches had fallen. In this photograph, which was taken approximately 24 hours prior to the peak Millstone River water surface at the Dam (which occurred at approximately 12 PM on May 1, 2014), the difference in water surface elevations downstream and upstream of the Dam can be clearly seen. However, in Photograph 2 in Figure 28, which was taken at mid-day on May 1, 2014 when the Millstone River was approximately at its peak water surface at the Dam, no significant difference in water surface elevation can be seen between downstream and upstream of the Dam.

Therefore, it can be seen that, while the Carnegie Lake Dam creates higher Millstone River water surfaces upstream of the Dam during both periods of dry weather and relatively small rainfalls, the Dam does not cause Millstone River water surface increases during larger rainfalls that can cause flooding upstream in West Windsor, particularly at the mouth of Little Bear Brook. This lack of effect on higher upstream, flood-producing Millstone River water surfaces is due to increased backwaters on the River downstream of the Dam that submerge the River's flow over the Dam.

From the above, it can be concluded that modification or removal of the Carnegie Lake Dam or lowering of the Carnegie Lake water surface prior to a flood-producing rainfall will not help reduce Millstone River water surface elevations or flood frequencies upstream at the mouth of Little Bear Brook.

<u>**Figure 28**</u>

Locations of Carnegie Lake Dam, Delaware & Raritan Canal Aqueduct, And U.S. Route 1 Bridge

Little Bear Brook Flood Hazard Assessment

Base Map: New Jersey Office of GIS 2012 Orthophotography

Figure 28
April 30 – May 1, 2014 Flood Photographs – Millstone River at Carnegie Lake Dam
Little Bear Brook Flood Hazard Assessment

Photograph 1 - Millstone River at Carnegie Lake Dam – April 30, 2014

Photograph 2 – Millstone River at Carnegie Lake Dam – May 1, 2014

Note: Photographs Provided by Princeton University

<u>Delaware & Raritan Canal Aqueduct</u>: To determine the potential impacts of the Delaware & Raritan Canal Aqueduct on Millstone water surface elevations upstream at the mouth of Little Bear Brook, the Millstone River data in the Middlesex County FIS and associated NJDEP HEC-2 computer models were analyzed. Figure 29 contains the Millstone River water surface profiles for the 10, 50, 100, and 500-Year floods at the Delaware & Raritan Canal Aqueduct taken from the 2010 Middlesex County FIS. The computed Millstone River water surface elevations downstream and upstream of the Aqueduct taken from the NJDEP HEC-2 model of the Millstone River used to develop these water surface profiles are summarized in Table 6.

<u>Table 6</u>
Millstone River Water Surface Elevations at Delaware & Raritan Canal Aqueduct
Little Bear Brook Flood Hazard Assessment

Flood (Years)	Downstream WSEL (NAVD88)	Upstream WSEL (NAVD88)	Difference (Feet)
10	54.90	55.39	0.49
50	56.13	56.58	0.45
100	56.77	57.16	0.39
500	59.50	59.67	0.17

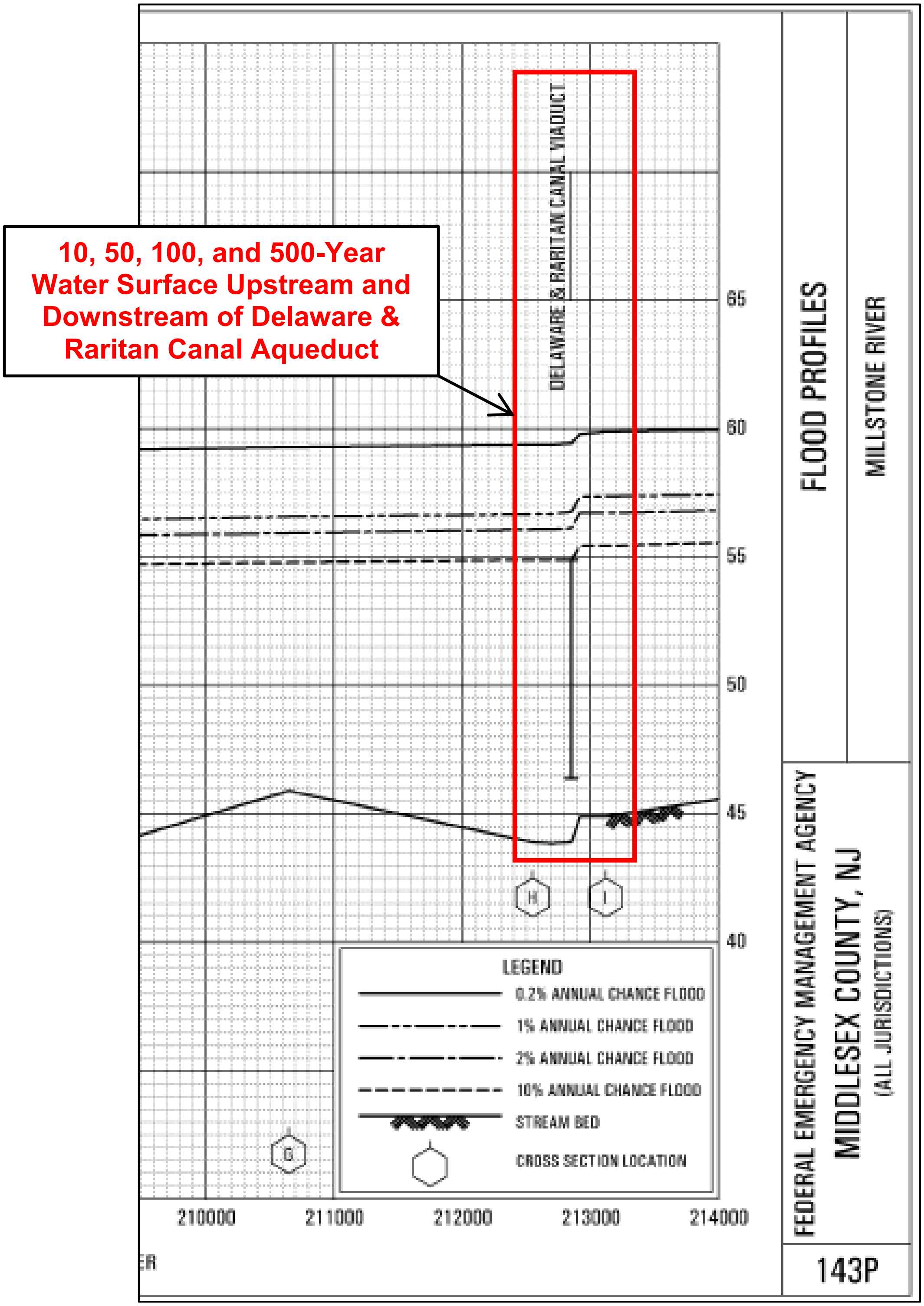
Source: NJDEP Millstone River HEC-2 Model

As can be seen in the Table, the differences between the computed water surface elevations downstream and upstream of the Delaware & Raritan Canal Aqueduct range from approximately 0.5 feet for the 10-Year flood to approximately 0.2 feet for the 500-Year flood. Therefore, these computed results indicate that, for a flood event similar to the April 30 – May 1, 2014 flood that is estimated in **<u>April 30 - May 1, 2014 Flood Event</u>** above to have a recurrence of 25 years, the difference in peak Millstone River water surface elevations between the downstream and upstream side of the Delaware & Raritan Canal Aqueduct would be approximately 0.5 feet.

To help verify these computed FIS results, high water marks (HWMs) downstream and upstream of the Aqueduct for the April 30 – May 1, 2014 flood event were identified and surveyed. The general upstream and downstream locations are of these HWMs are shown in Figure 30. The field surveys of these HWMs shows that the elevation difference between the downstream and upstream HWMs is approximately 0.2 feet. This surveyed difference is similar to the 0.5-foot computed difference in the Middlesex County FIS and, as such, helps verify the FIS computations.

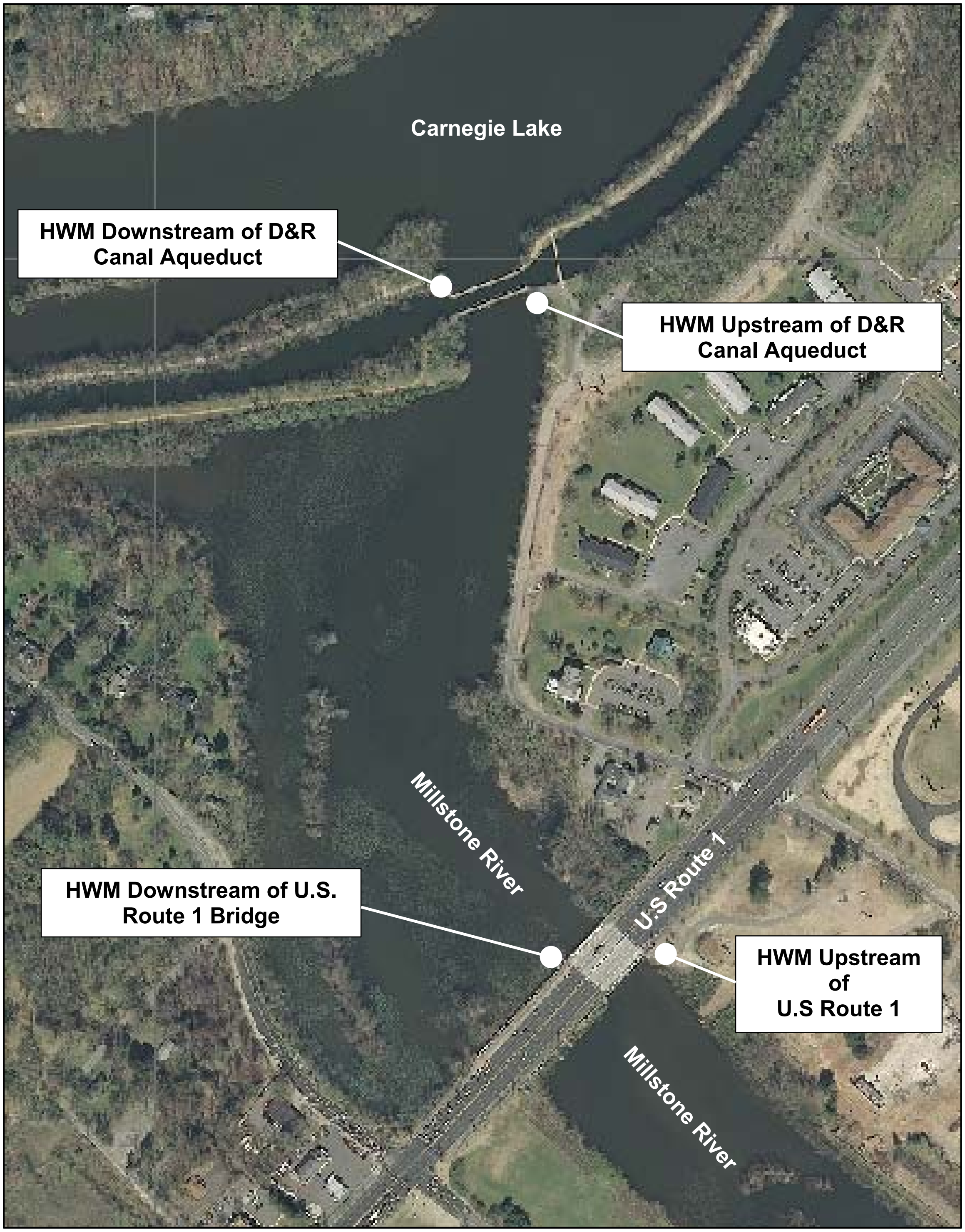
Therefore, from the above findings and the fact that the Delaware & Raritan Canal Aqueduct is located more than 6,000 feet downstream of Little Bear Brook's confluence with the Millstone River, it can be seen that any reduction in Millstone River water surfaces upstream of the Aqueduct that might be achieved by increasing the flow capacity of the existing River culvert beneath the Aqueduct would not be expected to significantly reduce the River's water surface elevations or flood frequencies at the mouth of Little Bear Brook.

Figure 29
Millstone River Water Surface Profiles at Delaware & Raritan Canal Aqueduct
Little Bear Brook Flood Hazard Assessment



Source: 2010 Middlesex County Flood Insurance Study

Figure 30
April 30 – May 1, 2014 Millstone River High Water Mark Locations
Delaware & Raritan Canal Aqueduct and U.S. Route 1 Bridge
Little Bear Brook Flood Hazard Assessment



Base Map: 2012 NJGIS Orthophotography

U.S Route 1 Bridge: To determine the potential impacts of the U.S Route 1 Bridge on Millstone water surface elevations upstream at the mouth of Little Bear Brook, the results from the Millstone River HEC-RAS model that included the current Bridge as described above were analyzed. It should be noted that this HEC-RAS model, which includes the existing U.S. Route 1 Bridge constructed in 2010, was used for this analysis since the NJDEP HEC-2 model of the River (used in the 1984 West Windsor and effective 2010 Middlesex County FIS) included the previous U.S. Route 1 Bridge. Finally, the analysis also included a comparison of the HEC-RAS model results with the April 30 – May 1, 2014 HWMs identified and surveyed downstream and upstream of the Bridge. The general upstream and downstream locations of these HWMs are shown in Figure 30.

Summarized in Table 7 below are the average computed water surface elevations downstream and upstream of the Bridge from the HEC-RAS model described above. It should be noted that the elevations in the Table are based upon an average of the computed HEC-RAS model water surface elevations directly at the faces of the Bridge and those downstream and upstream of the Bridge, respectively. These average differences were considered more appropriate for comparison with the surveyed HWMs for the April 30 – May 1, 2014 flood due to the differences in the locations of the HEC-RAS model cross sections and surveyed HWMs.

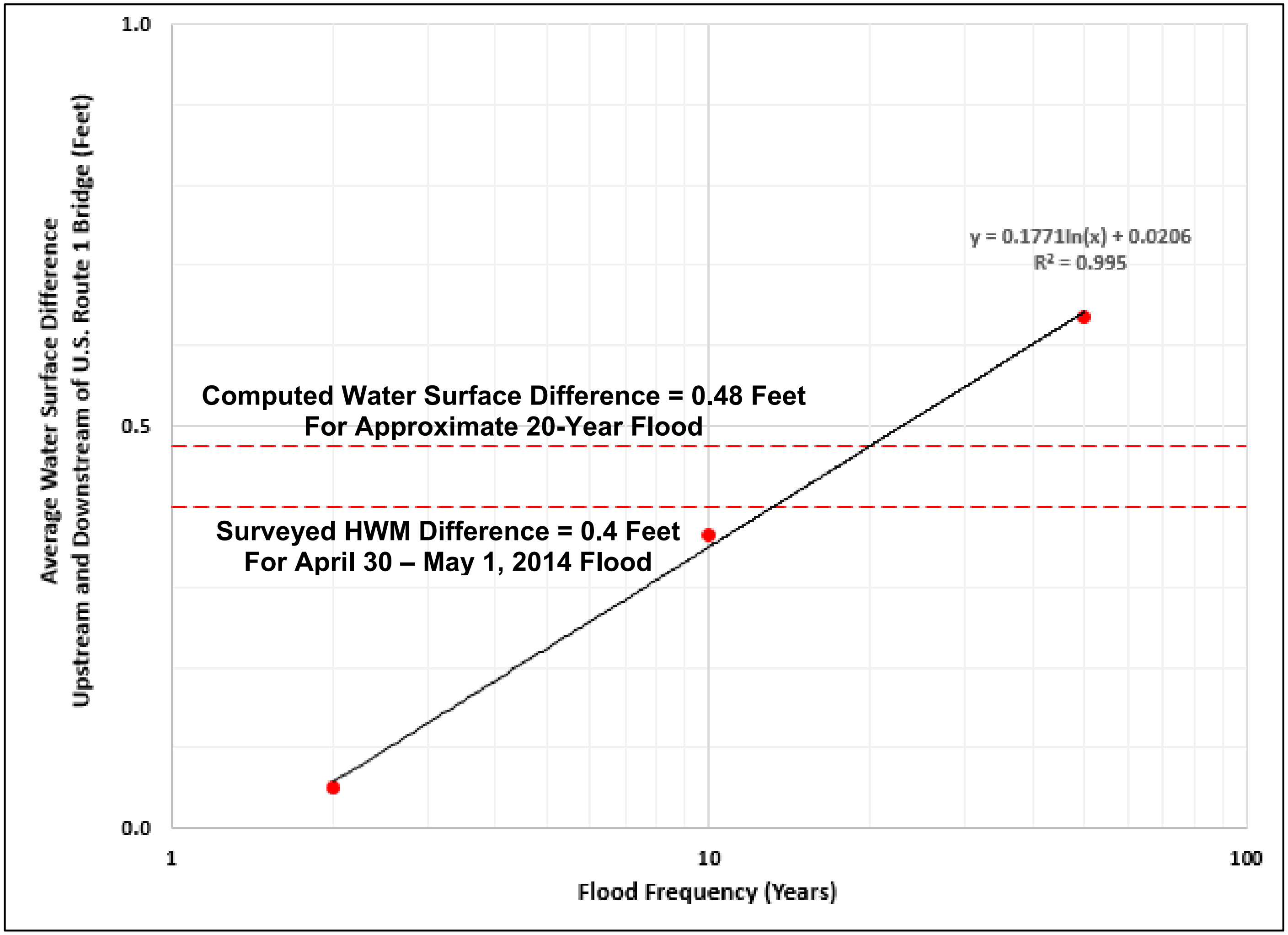
Table 7
Computed Millstone River Water Surface Elevations at U.S. Route 1 Bridge
Little Bear Brook Flood Hazard Assessment

Flood Event (Years)	Average Downstream WSEL (NAVD88)	Average Upstream WSEL (NAVD88)	Difference (Feet)
2	53.42	53.47	0.05
10	55.56	55.93	0.37
50	56.86	57.49	0.63
100	57.54	59.89	2.35

Source: Millstone River HEC-RAS Model

As shown in Table 7, the differences between the average computed water surface elevations downstream and upstream of the existing U.S Route 1 Bridge, which has a 104-foot long span and an average opening height of approximately 12 feet, range from 0.05 feet for the 2-Year flood to 2.35 feet for the 100-Year flood. To help verify these differences and the Millstone River HEC-RAS model used to develop them, they were used to develop a flood frequency – water surface difference relationship for the U.S. Route 1 Bridge. This relationship is illustrated in Figure 31 below. Also shown in the Figure is the resulting average water surface elevation difference at the Bridge for a 20-Year flood (the estimated frequency of the April 30 – May 1, 2014 flood) computed from the relationship and the difference between the surveyed HWM elevations downstream and upstream of the Bridge for that event.

Figure 31
Millstone River Flood Frequency – Average U.S. Route 1 Bridge Water Surface Differences
Little Bear Brook Flood Hazard Assessment



Source: Millstone River HEC-RAS Model

As shown in Figure 31, the computed difference between the average water surface elevations downstream and upstream of the U.S. Route 1 Bridge for a 20-Year flood (i.e., the estimated frequency of the April 30 – May 1, 2014 flood on the Millstone River at the mouth of Little Bear Brook) is approximately 0.5 feet. This compares favorably with the 0.4-foot difference between the surveyed HWMs for this flood on the River downstream and upstream of the Bridge.

To estimate the effects that these water surface differences at the U.S. Route 1 Bridge may have on water surface elevations and flood frequencies upstream at the mouth of Little Bear Brook, the existing Bridge in the HEC-RAS model of the Millstone River described above was modified to produce two hypothetically larger Bridges at the highway. Figure 32 contains the Millstone River water surface profiles for the 2, 10, 50, and 100-Year floods computed with the Millstone River HEC-RAS model noted above from the existing U.S Route 1 Bridge upstream to the mouth of the Brook.

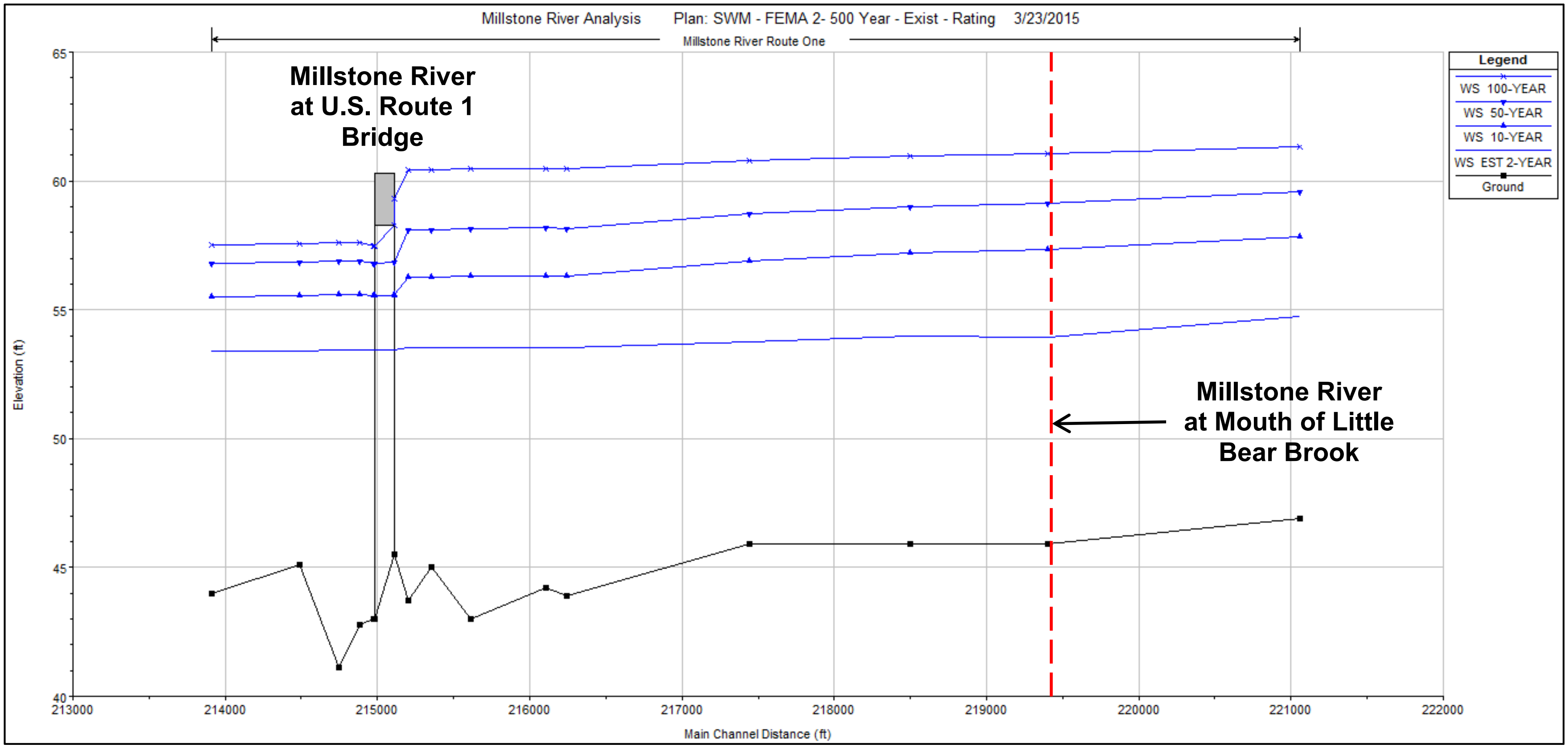
The first of these hypothetical bridges was based upon adding a second, 104-foot span and 12-foot height opening next to the existing bridge and widening the existing River channel at the Bridge to include both openings. The purpose of this model was to estimate how much lower the Millstone River water surfaces upstream at Little Bear Brook might be if a hypothetical bridge with double the waterway opening of the existing bridge was constructed in place of the existing one.

The second hypothetical U.S. Route 1 Bridge that was analyzed with the Millstone River HEC-RAS model was achieved by completely removing all data regarding the existing bridge from the model. The resulting model represented a hypothetical bridge at the highway that would not have any effect on upstream Millstone River water surface elevations. As such, the resulting water surfaces upstream at the mouth of Little Bear Brook represent the maximum hypothetical reductions that could be achieved through enlarging and/or replacing the existing bridge.

The results of these two hypothetical bridge models on Millstone River water surface elevations at the mouth of Little Bear Brook are summarized in Table 8 below. Included in the Table are the 2, 10, 50, and 100-Year River water surfaces at the mouth of the Brook for the existing and two hypothetical Bridges described above.

As shown in Table 8, doubling the size of the waterway opening of the existing U.S. Route 1 Bridge would reduce the Millstone River water surface elevations at the mouth of Little Bear Brook by 0.5 feet or less for the 2 to 50-Year floods on the River. This range of flood events is important to consider since, as shown in Figures 24 and 25 and Tables 4 and 5, the estimated existing flood thresholds at Fisher Place and Washington, Fieldston, and Alexander Roads range from 11 to 14-Years and the lowest above-grade first floor structures on Fisher Place and Washington and Alexander Roads have existing flood thresholds ranging from 18 to 62-Years.

Figure 32
Millstone River Existing Condition Water Surface Profiles at U.S Route 1 Bridge
Little Bear Brook Flood Hazard Assessment



Source: Millstone River HEC-RAS Model

Table 8
Estimated Reductions in Existing Millstone River Water Surfaces At Little Bear Brook With Hypothetical U.S. Route 1 Bridges Little Bear Brook Flood Hazard Assessment

Flood Event (Years)	Millstone Water Surface Elevations at Little Bear Brook (NAVD88)				
	With Existing Bridge	With Doubled Bridge	Difference (Feet)	Without Bridge	Difference (Feet)
2	53.9	53.8	-0.1	53.8	-0.1
10	57.3	57.0	-0.3	57.0	-0.3
50	59.2	58.7	-0.5	58.5	-0.7
100	61.1	59.4	-1.7	59.2	-1.9

A summary of the effects of both hypothetical U.S. Route 1 Bridges described above on these existing Millstone River flood thresholds for the roadways and structures noted above is presented in Table 9 below. These revised thresholds were based upon the results of the two modified HEC-RAS models that contained these hypothetical bridges. These results are illustrated in Figure 33.

From the results shown in Table 9 and Figure 33, the following two conclusions can be reached regarding potential changes to the U.S. Route 1 Bridge and the impacts on upstream water surfaces and flood thresholds at the mouth of Little Bear Brook:

1. A comparison of the reduced flood thresholds in Table 9 and the frequency-elevation relationships in Figure 32 for the two hypothetical U.S. Route 1 Bridges illustrates that there are no significant differences between the HEC-RAS results for the Doubled and No Bridge models.

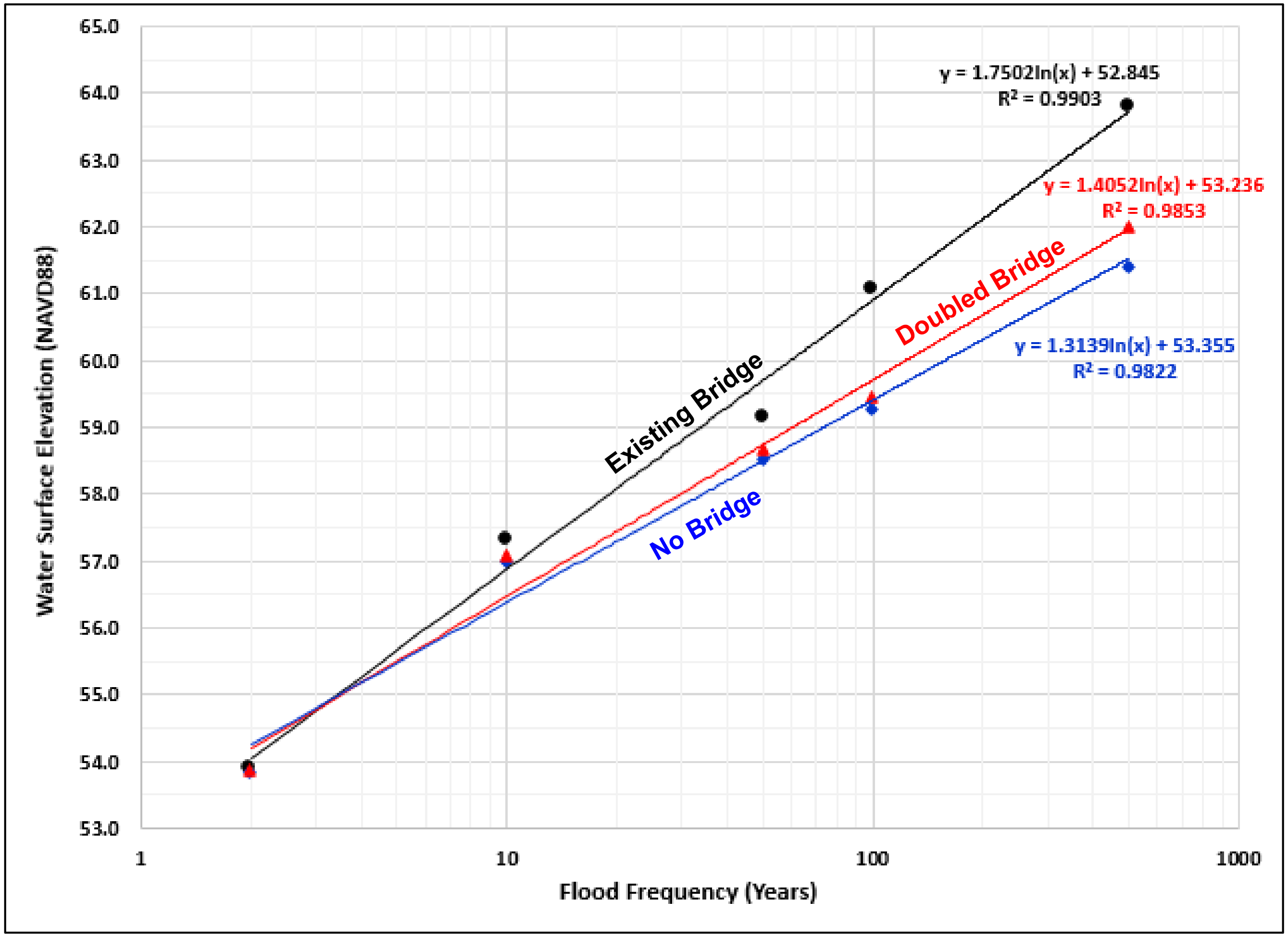
2. The reduced flood threshold amounts and percentages in Table 9 indicate that even a doubling of the existing U.S. Route 1 Bridge would only achieve modest reductions in Millstone River water surface elevations and flood thresholds at the mouth of Little Bear Brook, particularly at the roadways and structures that experience the most frequent flooding.

Therefore, from the above findings, it can be seen that any enlargement of the Bridge's waterway opening would not be expected to significantly reduce the River's water surface elevations or flood frequencies at the mouth of Little Bear Brook.

Table 9
Estimated Increases in Existing Millstone River Flood Thresholds Along Little Bear Brook With Hypothetical U.S Route 1 Bridges Little Bear Brook Flood Hazard Assessment

Type	Location	Millstone Flood Thresholds Along Little Bear Brook (Years)				
		With Existing Bridge	With Doubled Bridge	Percent Difference	Without Bridge	Percent Difference
Road	Fisher Place	8	10	25%	12	50%
Road	Fieldston Road	9	11	22%	13	33%
Road	Washington Road	10	13	30%	15	50%
Road	Alexander Road	10	14	40%	16	60%
Structure	89 Washington	14	21	50%	25	79%
Structure	92 Washington	19	30	58%	36	89%
Structure	112 Fisher Place	20	32	60%	39	95%
Structure	XXX Alexander	78	170	118%	235	200%

Figure 33
Millstone River Frequency – Water Surface Elevation Relationship at Mouth of Little Bear Brook
For Existing and Hypothetical U.S. Route 1 Bridges
Little Bear Brook Flood Hazard Assessment



Source: Millstone River HEC-RAS Models

5. <u>Potential Flood Mitigation Measures</u>

As described in **1. Introduction**, the Little Bear Brook Flood Hazard Assessment was performed for West Windsor Township to define and address flooding that occurs along the Brook. During the course of the Assessment, two types of flooding were identified. The first type of flooding is the relatively frequent but shorter duration flooding of Washington and Alexander Roads that cross Little Bear Brook. The second type is the less frequent but longer duration, more damaging flooding of these and other roadways as well as residential, commercial, and other structures located within the Brook's floodplain. Examples of this latter type include the flooding during Tropical Storm Floyd in 1999, Tropical Storm Irene in 2011, and, to a lesser extent, the recent flood of May 1, 2014.

As noted above, this Report presents the results of Phase I of the Little Bear Brook Flood Hazard Assessment. This Phase focused on the less frequent, more damaging flooding of structures and roadways along the Brook described above. According to the hydrologic and hydraulic analyses of the Brook and River and information provided by West Windsor Township described in detail above, this type of flooding is not the result of excessive discharges and associated water surface elevations on Little Bear Brook itself, but on the Millstone River near the mouth of the Brook. Additional analyses indicates that such flooding has an approximately 5 to 10 percent chance annually of affecting structures and roadways, respectively. These annual flood risks can also be expressed as approximately 20-Year (for structures) and 10-Year (for roadways) flood recurrence intervals.

Since such flooding is induced by discharges and water levels on the Millstone River, the identification of potential measures to reduce or mitigate its impacts focused on the four flood mitigation strategies listed in Table 10 below. Selection of these particular strategies was based, in part, on their inclusion in the Township's Scope of Work for the Little Bear Brook Flood Hazard Assessment contained in Appendix A.

<u>Table 10</u>
Potential Flood Mitigation Strategies
Little Bear Brook Flood Hazard Assessment

No.	Flood Mitigation Strategy
1	Reducing damaging Millstone River discharges and/or water levels.
2	Raising flood-prone structures and roadways above Damaging Millstone River water levels.
3	Constructing barriers between the flood-prone structures and roadways and damaging Millstone River water levels.
4	Improving weather and Millstone River flood data collection methods and dissemination programs to provide residents, owners, employees, officials, and motorists with additional time to prepare for and protect against such flooding.

It is important to note that the final design and construction and/or implementation of any of the strategies listed above typically includes a comprehensive, risk or frequency-based analysis of each strategy's costs and benefits. It also typically includes a thorough review and understanding of each one's environmental, social, and economic impacts and regulatory constraints. However, due to the conceptual character of the Little Bear Brook Flood Assessment (that is intended to assist West Windsor Township in identifying feasible flood mitigation measures for further consideration), developing potential mitigation to this degree of detail exceeded both the scope of the assessment and the practical need for such information at this stage of the Township's flood mitigation efforts.

Using the four general flood mitigation strategies listed above, the potential flood mitigation measures shown in Table 11 below were developed and analyzed.

Table 11
Potential Flood Mitigation Measures
Little Bear Brook Flood Hazard Assessment

No.	Flood Mitigation Measure
1	Reducing excessive peak Millstone River discharges at the mouth of Little Bear Brook through upstream flood storage and controlled release.
2	Raising Washington and Alexander Roads to less flood-prone elevations.
3	Floodproofing flood-prone structures.
4	Constructing levees and floodwalls along the Millstone River and Little Bear Brook to block floodwaters from reaching flood-prone structures and roadways.
5	Installing a remotely-sensed Millstone River water level gage.

Details of each potential mitigation measure are presented below. It is important to note that the hydraulic analyses of Carnegie Lake Dam, the D&R Canal Aqueduct, and the U.S. Route One Bridge described in detail above in **4. Results of Flood Hazard Analysis** also represent flood mitigation measures that were based upon the strategy of reducing damaging water levels of the Millstone River (Strategy No.1 in Table 10). However, as detailed above, none of these measures were found to be effective in reducing damaging River levels at the mouth of Little Bear Brook.

5.1 Reducing Peak Millstone River Discharges:

As shown in Table 4 above in **4.4 Millstone River Analysis**, the threshold for flooding of Washington, Alexander Roads, and Fieldston Roads and Fisher Place by the Millstone River has an estimated recurrence interval of approximately 8 to 10 Years. As shown in Table 5, threshold flooding of residential, commercial and other structures on Washington Road and Fisher Place by the River has an estimated recurrences interval of approximately 15 to 20 Years. To prevent flooding of these roadways and structures from more severe River floods (i.e., those with peak water levels higher than the threshold floods), a flood detention analysis of the Millstone River was conducted. This analysis estimated the volume of flood storage that would be required in a potential Millstone River detention basin to reduce the peak 25, 50, and 100-Year River discharges to the estimated 10-Year flood threshold frequency of the Little Bear Brook roadways noted above. Similarly, the analysis also estimated the required detention basin storage volumes to reduce the peak 50 and 100-Year River discharges to the estimated 20-Year flood threshold frequency of the Brook's structures noted above.

This analysis was based on the assumption that the detention basin would be provided through the creation of a dam or other flow barrier on the Millstone River upstream of the mouth of Little Bear Brook. Based upon the detention analysis, it was determined that such a barrier would need to be located no farther upstream of Little Bear Brook than the River's confluence with Cranbury and Big Bear Brooks. As shown in Figure 34, the River's confluences with Cranbury and Big Bear Brook are located immediately upstream and downstream, respectively, of the NJ Transit's Northeast Corridor Line's bridge over the River. As indicated by the flood detention analysis, a detention basin located any further upstream on the River or on one of the River's tributaries would not be able to store and control a sufficient percentage of the River's flow volume to effectively reduce peak River discharges to the required Little Bear Brook roadway and structure flood thresholds.

The results of the Millstone River detention analysis described above are summarized in Tables 12 and 13 and illustrated in Figure 34 below. As shown in Table 12, the estimated storage volumes required to reduce the peak 25, 50, and 100-Year Millstone River discharges to a rate equal to the River's peak 10-Year discharge (i.e., the approximate Little Bear Brook roadway threshold flood) are approximately 2200, 3400, and 4700 acre-feet, respectively. In addition, the estimated required volumes to reduce the River's peak 50 and 100-Year discharges to a 20-Year peak rate (i.e., the approximate Little Bear Brook structure threshold flood) are 2400 and 3500 acre-feet, respectively.

Table 12
Summary of Millstone River Detention Analysis Required Storage Volumes
Little Bear Brook Flood Hazard Assessment

Flood Frequency (Years)	Estimated Storage Volumes for Indicated Outflows	
	10-Year Basin Outflow for Roadway Protection (Acre-Feet)	20-Year Basin Outflow for Structure Protection (Acre-Feet)
25	2200	(See Note Below)
50	3400	2400
100	4700	3500

Note: Required 25-Year storage volumes for 20-Year structure protection outflow not estimated due to small difference between flood frequencies.

To estimate the approximate maximum detention basin surface area and depth that would be required to create each of the estimated Millstone River storage volumes shown in Table 12, each basin was assumed to be located immediately upstream of the NJ Transit's Northeast Corridor Line bridge across the Millstone River. At this location, it was assumed that NJ Transit's track embankment would act as the required dam or flow barrier described above. In addition, it was assumed that the area along the River and both Cranbury and Big Bear Brooks from the NJ track embankment upstream to the PSE&G power line right-of-way and Township's bike and walking path approximately 1.5 miles upstream would be used as the detention basins' storage area. These assumed detention basin limits on the Millstone River are shown in Figure 34 below.

Based upon the area of each waterway's 100-Year floodplain as delineated in the effective 2010 Middlesex and preliminary 2013 Mercer County Flood Insurance Studies between these downstream and upstream limits (and also shown in Figure 34), such a detention basin area would be approximately 400 acres in size. Based upon this assumed basin area, the required maximum flood storage depths for each basin shown in Table 12 above is presented in Table 13 below.

Table 13
Summary of Millstone River Detention Analysis Required Storage Depths
Little Bear Brook Flood Hazard Assessment

Flood Frequency (Years)	Estimated Depths in 400-Acre Storage Area for Indicated Outflows	
	10-Year Basin Outflow for Roadway Protection (Feet)	20-Year Basin Outflow for Structure Protection (Feet)
25	5	(See Note Below)
50	9	6
100	12	9

Note: Required 25-Year storage depths for 20-Year structure protection outflow not estimated due to small difference between flood frequencies.

As can be seen in the Table 13, the maximum required storage depths in an assumed 400-acre Millstone River detention basin shown in Figure 34 are 5, 9, and 12 feet for basins designed to provide 25, 50, and 100-Year levels of protection, respectively, for the Little Bear Brook roadways. Similarly, an assumed 400-acre Millstone River basin that is intended to provide 50 and 100-Year levels of protection for the Little Bear Brook structures are estimated to require 6 and 9-foot storage depths, respectively.

In reviewing the estimated storage depths shown in Table 13, it should be noted that, for any Millstone River detention basin be effective, it must provide these depths and their associated storage volumes above the existing elevation of the maximum flood that it would be intended to control. For example, a Millstone River detention basin designed to reduce a 100-Year flood inflow to the 10-Year flood outflow needed to protect the Little Bear Brook roadways, the basin would have to store this inflow approximately 12 feet higher than the River's present 100-Year water surface in the assumed detention basin area. Similarly, a Millstone River basin designed to reduce a 100-Year flood inflow to the 20-Year flood outflow needed to protect the Little Bear Brook structures would have a maximum surface approximately 9 feet higher than the River's present 100-Year water surface.

However, as shown in Figure 34, the existing 100-Year floodplain limits in the assumed detention basin area along the Millstone River and both Cranbury and Big Bear Brooks already extend into developed areas and onto roadways. As such, any of the assumed Millstone River detention basins summarized in Tables 12 and 13 above would require damaging increases in the River's peak water surfaces and floodplain limits and, therefore, would not be practical or permissible under the New Jersey Flood Hazard Area Control Act (NJAC 7:13).

Alternatively, if any of the estimated flood storage volumes shown in Table 12 were to be obtained through floodplain excavation rather than above the existing floodplain water levels and limits, the required volume of such excavation would be excessive. For example, if the required excavation was equal the 2,200 acre-feet of additional flood storage required to provide only 25-Year flood protection to the Little Bear Brook roadways shown in Table 12 above, such excavation would total approximately 3,550,000 cubic yards. Based upon a conservatively low unit excavation cost of $10 per cubic yard, the cost of this excavation alone would be more than $35 million. Such excavation would not be environmentally sound or permissible under the New Jersey Flood Hazard Area Control Act or Freshwater Wetland Protection Act (NJAC 7:7A).

In light of the above, it can be seen that reducing the Millstone River-induced flooding of roadways and/or structures along Little Bear Brook could not be practically achieved through an upstream Millstone River detention basin. As such, this type of flood mitigation strategy is not recommended for further study by West Windsor Township.

5.2 Raising Washington and Alexander Roads:

As shown in Table 11 above, the second flood mitigation measure analyzed was the potential raising of both Washington and Alexander Roads above the elevation of Millstone River flood levels. Since both roadways have approximately a 10-Year flood threshold, this analysis investigated potential road raisings to the maximum 25, 50, and 100-Year Millstone River water surface elevations at the mouth of Little Bear Brook. The required height and extent of these various road raisings were based upon the Millstone River flood frequency vs. water surface elevation data shown in Figure 25, the roadway low point elevation data shown in both Figure 25 and Table 4, and the project area topographic mapping described above. Due to the conceptual nature of the analysis, it was assumed for simplicity that both raised roads would have flat longitudinal slopes. The results of this analysis are summarized in Table 14 and illustrated in Figures 35 and 36 below.

Figure 34
Existing 100-Year Floodplains and Upstream and Downstream Limits of Assumed Millstone River Detention Basin
Little Bear Brook Flood Hazard Assessment

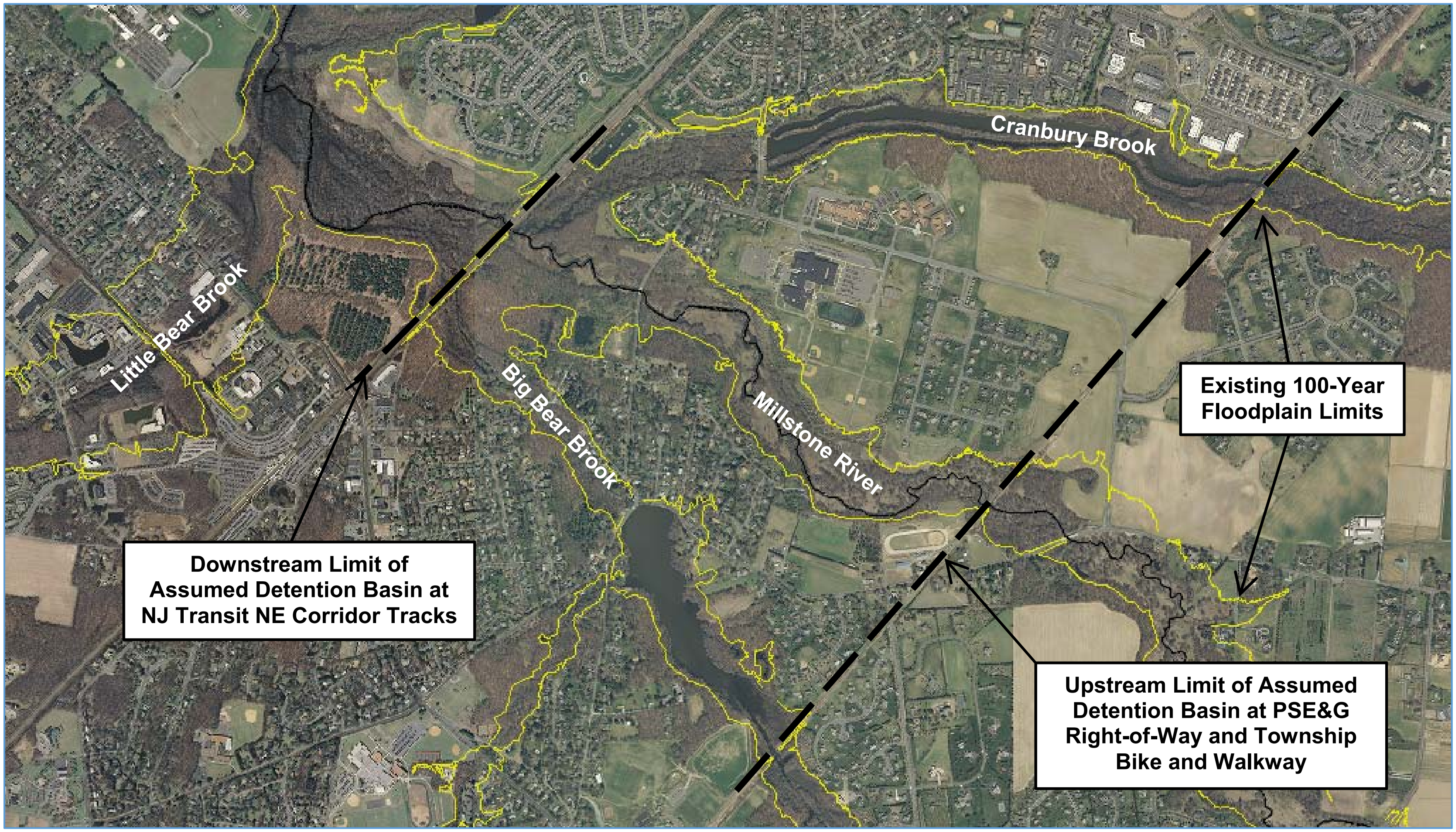


Table 14
Summary of Washington and Alexander Road Raising Analysis
Little Bear Brook Flood Hazard Assessment

Flood Frequency (Years)	Approximate Required Maximum Road Raising Height (Feet)[1]		Approximate Required Road Raising Length (Feet)[2]	
	Washington	Alexander	Washington	Alexander
25	1.6	1.5	770	320
50	2.3	2.2	920	920
100	4.2	4.1	1290	1340

Notes: 1. Approximate Maximum Height based upon raising roadway to Millstone River water surface elevation without freeboard.
2. Approximate Length based upon 0% longitudinal roadway slope.

Figure 35
Estimated Required Lengths of Assumed Washington Road Raisings
Little Bear Brook Flood Hazard Assessment

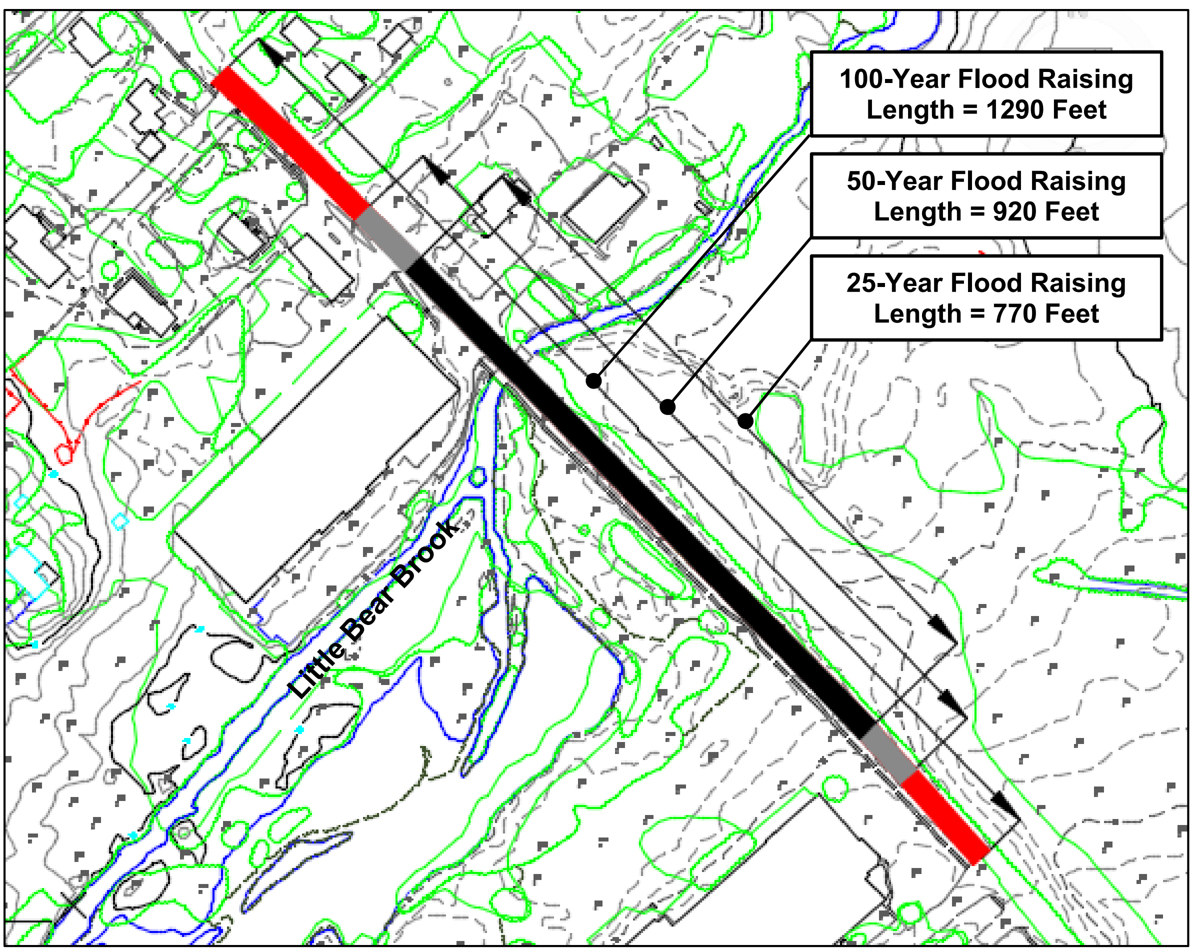
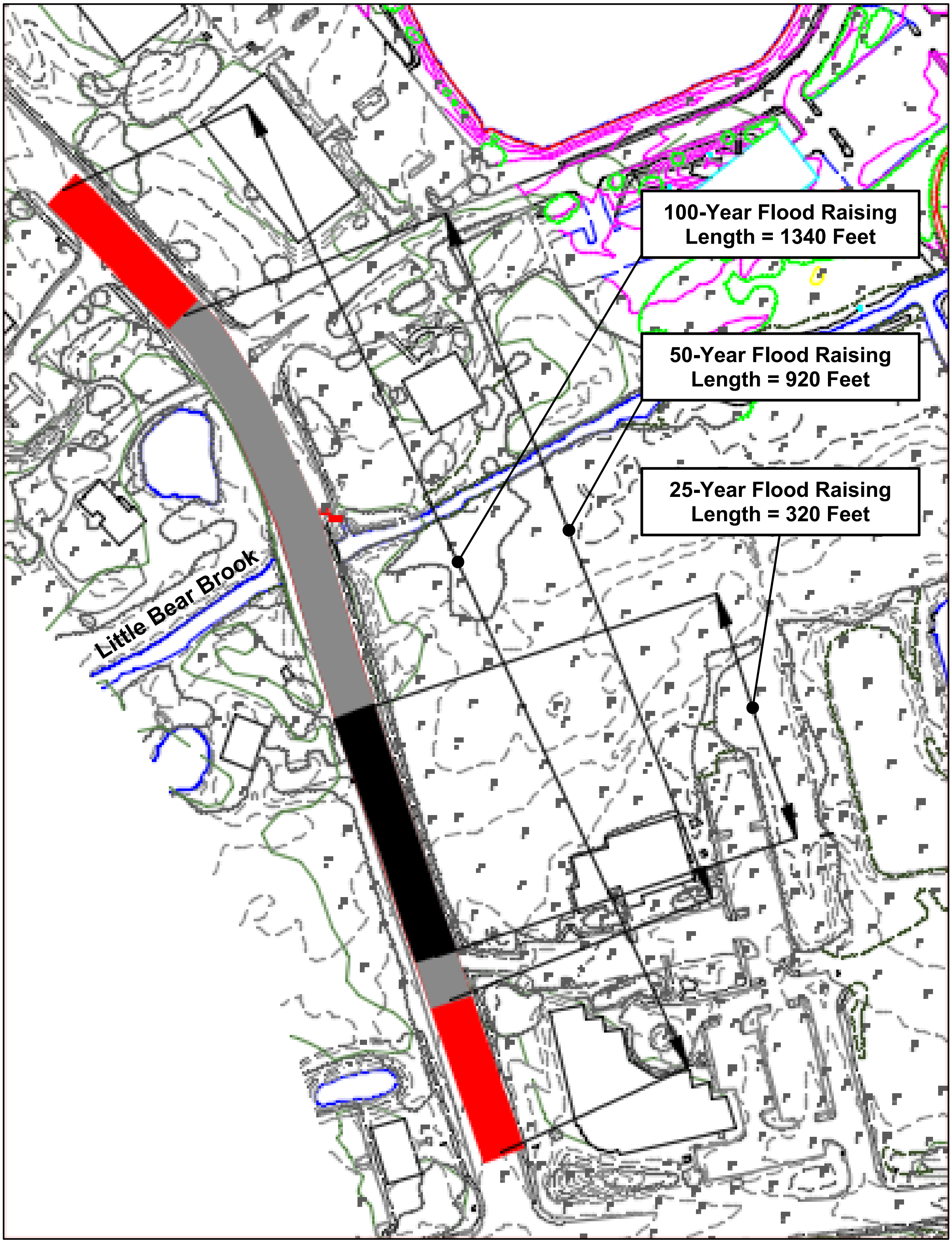


Figure 36
Estimated Required Lengths of Assumed Alexander Road Raisings
Little Bear Brook Flood Hazard Assessment



As shown in Table 14, the required road raising lengths and maximum raising heights for Washington and Alexander Roads increase with increasing level of flood protection. To increase both roads' existing flood thresholds from approximately 10-Years to 25-Years would require approximately 770 feet of Washington Road and approximately 320 feet of Alexander Road to be raised. The maximum heights of both raisings would be approximately 1.6 and 1.5 feet, respectively. However, increasing Washington and Alexander Roads' existing flood thresholds to 100-Years would require approximately 1,290 and 1,340 feet of each road, respectively, to be raised. The maximum raising heights for this level of protection at Washington and Alexander Roads would be approximately 4.2 and 4.1 feet, respectively. In addition, to offset the loss of overflow over the roadway, the width of the existing Alexander Road Bridge would have to increase from 20 to 30 feet, which would require the construction of a new bridge.

In reviewing these estimated road raising lengths and maximum heights, it is important to note that such road raisings must also include the construction of roadway embankment side slopes and/or retaining walls to grade the raised road surfaces down to the adjacent existing ground surface. Doing so may adversely encroach into the front or side yards of properties along the roads.

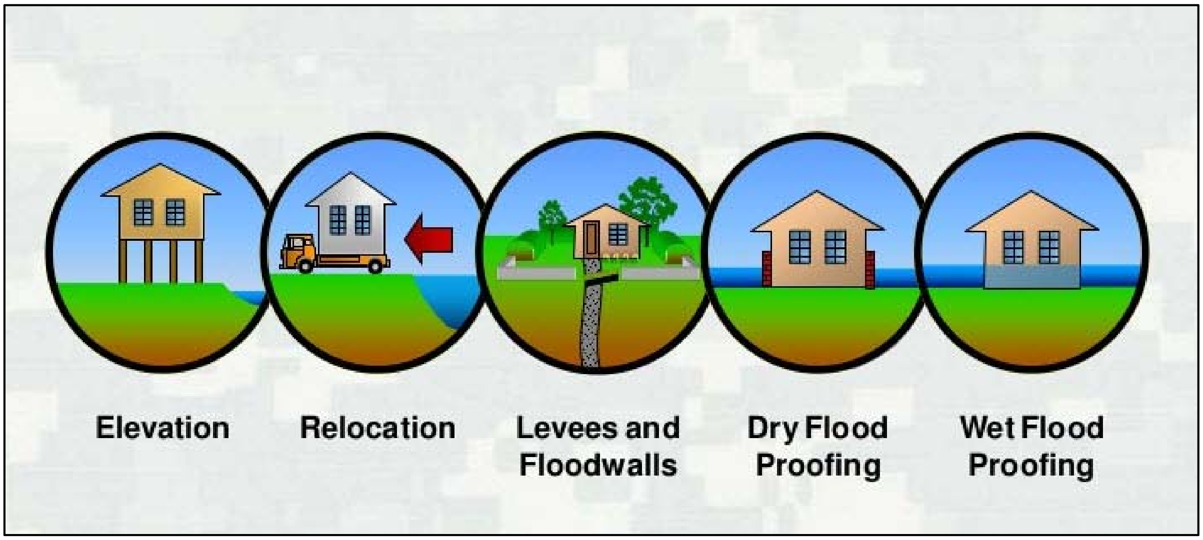
In addition, significantly flatter and longer roadway embankment side slopes must be provided at the raised roads' intersections with driveways and other roadways. Such flatter side slopes will require further encroachment into front and side yards and intersecting roadways. Particularly in the case of driveways, there may not be sufficient distance between edge of the raised road and an existing garage or other structure located on an adjacent property to provide the required flatter side slopes without relocation or realignment of the driveway. Finally, new stormwater drainage systems may need to be installed along the raised roads to provide drainage to low areas isolated by the raised roads. Due to its conceptual nature, such details were beyond the scope of the Phase I Flood Hazard Assessment but will need to be addressed if West Windsor Township elects to develop these flood mitigation measures further. Finally, any road raising must meet the requirements of the New Jersey Flood Hazard Area Control Act and Freshwater Wetland Protection Act.

5.3 Floodproofing Flood-Prone Structures:

As shown in Table 11 above, the third flood mitigation measure analyzed was floodproofing of flood-prone structures located within the limits of the Millstone River and Little Bear Brook floodplains. As shown in Figure 37 and described in detail below, there are five basic structure floodprooding techniques:

- Elevation
- Relocation
- Levees and Floodwalls
- Dry Floodproofing
- Wet Floodproofing

<u>Figure 37</u>
Basic Types of Structure Floodproofing
Little Bear Brook Flood Hazard Assessment



Source: U.S. Army Corps of Engineers

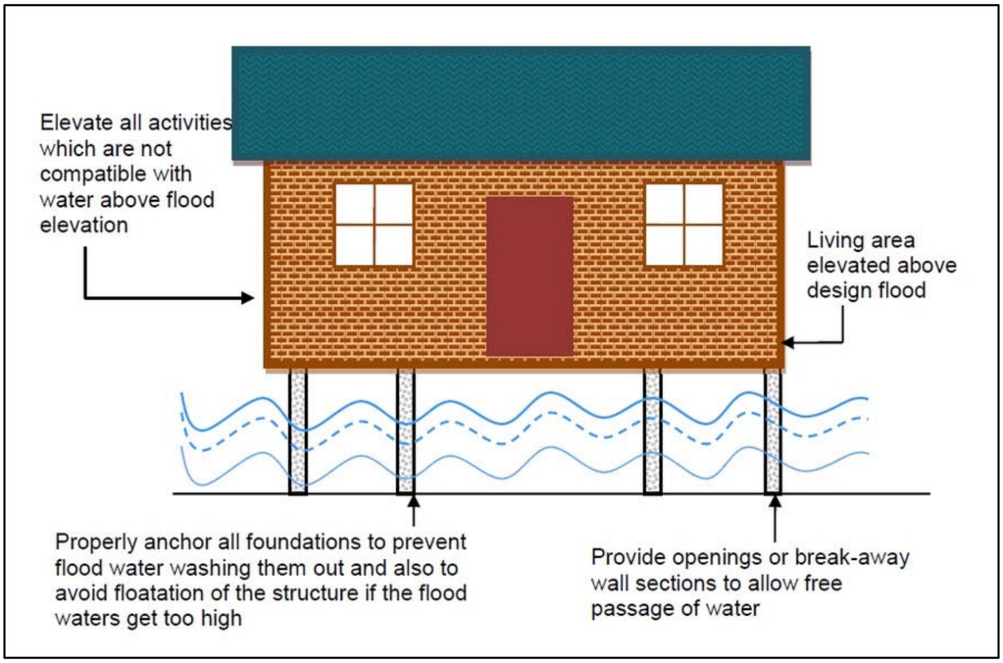
In general, structure **elevation** involves raising a structure so that the first or lowest above-ground floor is at or above the maximum water surface elevation of a selected design flood. Additional details of structure elevation are illustrated in Figure 38.

Structure **relocation** involves moving a structure to higher ground outside the floodplain limits of a selected frequency flood. For an individual structure, **levees and floodwalls** involve the construction of walls or earthen levees around the outside of a structure. Similar to structure elevation, the top elevation of these walls or levees would be set at or above the maximum water surface elevation of a selected design flood.

Dry floodproofing requires the creation of a water-proof barrier on the exterior surface of a structure's walls along with either the elimination or installation of similarly waterproof barriers in doors, windows, and other wall openings. Similar to structure elevation and levees and floodwalls, the top elevation of these waterproof barriers would be set at or above the maximum water surface elevation of a selected design flood. Additional details of structure dry floodproofing are illustrated in Figure 39.

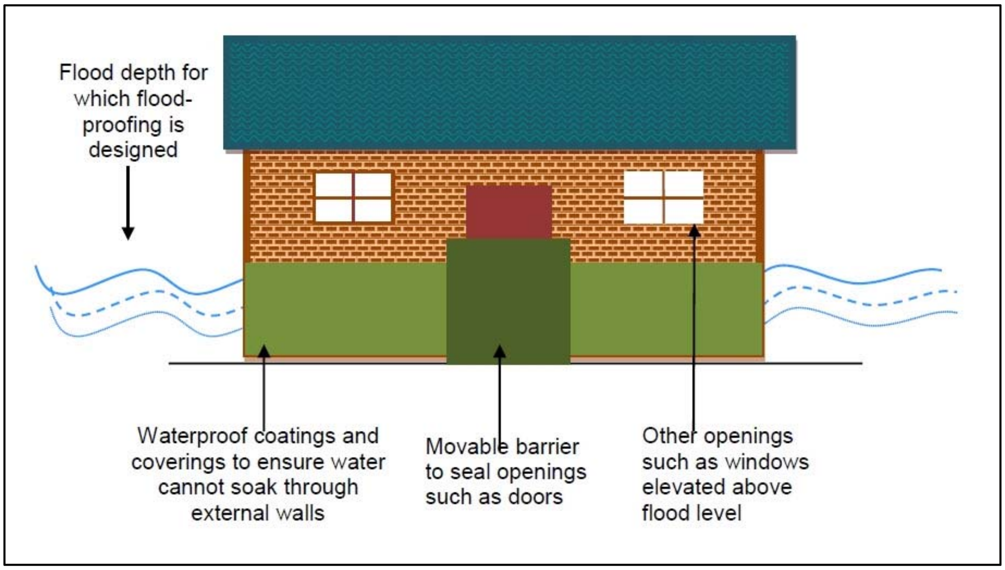
Finally, **wet floodproofing** primarily involves the relocation of utilities, equipment, and other structure facilities to an existing or new area of the structure that is at or above the maximum water surface elevation of a selected frequency flood. As such, while the structure areas in which the utilities, equipment, and facilities were previously located remain subject to flooding, the extent and cost of flooding is reduced and post-flood recovery times are reduced due to the relocations. Additional details of wet floodproofing are illustrated in Figure 40.

<u>**Figure 38**</u>
Typical Structure Elevation Components
Little Bear Brook Flood Hazard Assessment



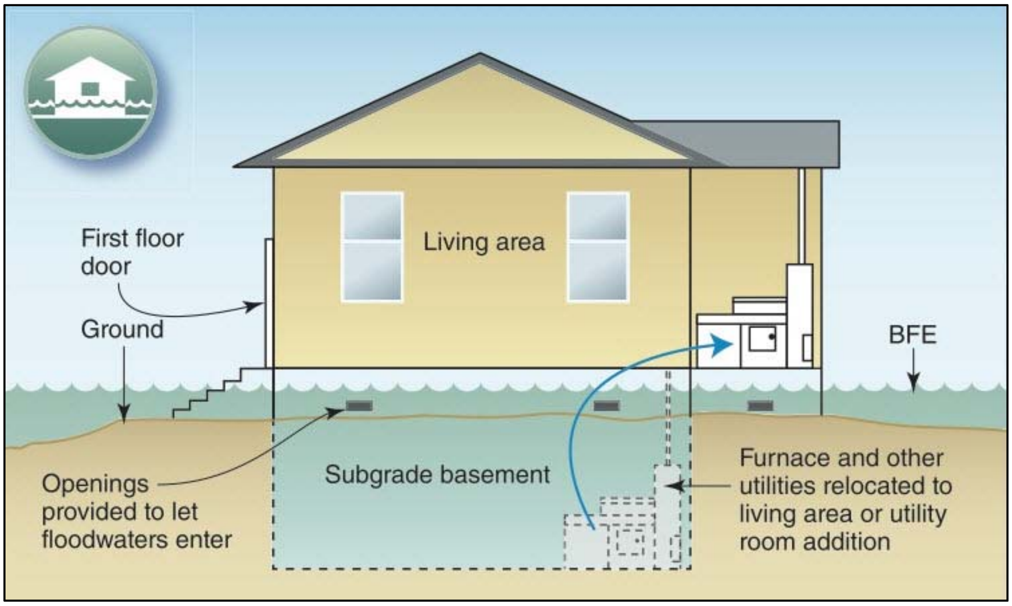
Source: www.climatetechwiki.org

<u>**Figure 39**</u>
Typical Dry Floodproofing Components
Little Bear Brook Flood Hazard Assessment



Source: www.climatetechwiki.org

<u>Figure 40</u>
Typical Wet Floodproofing Components
Little Bear Brook Flood Hazard Assessment



Source: www.climatetechwiki.org

It is important to note that the selection of the most effective, appropriate, and economical floodproofing technique involves consideration of several factors, including but not limited to the following:

- Height of the selected frequency design flood above the structure floor level to be protected.
- Velocity of floodwaters at the structure location.
- Age, type, materials, utilities, structural strength, and stability of the structure.
- Type, strength, and thickness of the structure foundation soils.
- Availability, reliability, details, and timeliness of advance flood warning information.
- Ability to store, access, and install temporary and moveable flood barriers in a timely manner.
- Relative costs of constructing, operating, and maintaining the selected floodproofing technique.
- Relative benefits of both various selected design floods and floodproofing techniques.

As can be seen in the list presented above, the selection of the most appropriate floodproofing technique for each of the 40 structures included in the Little Bear Brook Flood Hazard Assessment is beyond the scope of the Flood Hazard Assessment. However, to assist West Windsor Township and structure owners to further evaluate the potential for structure floodproofing, the data in **Appendix E – Surveyed Structure**

Elevations has been prepared. In addition to a location plan, Appendix E also contains the street address, block and lot number, surveyed first above-grade habitable floor elevation, and lowest ground elevation at the 40 structures described in **3.4 <u>Structure Elevation Surveys</u>** and shown in Figure 10 above. It should be noted that the lowest ground elevations were estimated from the project area topographic mapping **3.5 <u>Topographic Mapping</u>**.

Also included in **Appendix E** are the estimated differences between the Millstone River's 100-Year water surface elevation and each structure's surveyed first floor and estimated lowest ground elevations. Water surface elevations above the first floor or lowest ground elevations at each structure are shown in **bold** as positive values. Water surface elevations below either the first floor or lowest ground are shown as negative values. These differences can be used as a general guide to begin determining the severity of existing flooding and the need for and most appropriate type of floodproofing that might be used at each structure currently subject to flooding. It should be noted that the final elevation of a selected floodproofing measure or component is typically set 1 foot higher than the maximum design flood water surface elevation. This additional height, known as freeboard, provides a factor of safety to the floodproofing design.

Additional information regarding all five structure floodproofing techniques is available from the Federal Emergency Management Agency (FEMA), the U.S. Army Corps of Engineers (USACE), and other organization and agencies, including the following websites:

- www.slideshare.net/BZjoe/floodproofing-methods-that-work-in-west-virginia
- www.climatetechwiki.org/content/flood-proofing
- www.fema.gov/media-library/assets/documents/3001
  (For Residential Structures)
- www.fema.gov/media-library/assets/documents/15599
  (For Nonresidential Structures)

Finally, it should be noted that structures that have experienced repetitive flood losses may be eligible for a buy-out under either the FEMA Hazard Mitigation Assistance Program or the New Jersey Blue Acres program. Additional details regarding both programs can be found at the following websites:

- www.fema.gov/application-development-process/hazard-mitigation-assistance-property-acquisition-buyouts
- www.state.nj.us/dep/greenacres/blue_flood_ac.html

5.4 <u>Constructing Levees and Floodwalls</u>:

As shown in Table 11 above, the fourth flood mitigation measure analyzed was the potential construction of levees and floodwalls around flood-prone areas along Little Bear Brook. As shown below in Figures 41 and 42, both levees and floodwalls are based upon the flood mitigation strategy shown in Table 10 that utilizes the construction of barriers along the Millstone River and Little Bear Brook to block floodwaters from reaching flood-prone structures and roadways. In doing so, levees are typically used where there is sufficient room for their larger footprint since they are relatively less expensive than floodwalls. Where there is not sufficient room for a levee, a floodwall is typically used despite its greater cost.

Photographs of both a levee and floodwall constructed by the U.S. Army Corps of Engineers in Bound Brook Borough, Somerset County as part of the Green Brook Flood Control Project are shown below in Figures 43 and 44. The photographs were provided by the Somerset County Division of Engineering.

In addition to serving as a barrier to prevent the entrance of floodwaters into a protected area, it is important to note that levees and floodwalls can also block the normal outflow of runoff that collects behind them. As such, the use of levees and/or floodwalls typically requires the construction of interior drainage storage areas and/or pumping stations on their protected sides as well as new or revised storm drainage systems to safely convey the runoff to them.

It is also important to note that, as barriers, the use of levees and/or floodwalls must also accommodate road, railroads, and driveways that they intersect and need to cross. If the top elevation of the road, railroad, or driveway is at or above the top of the levee or floodwall, then the levee or floodwall can be tied into the road, railroad, or driveway embankment. However, if this embankment is below the top of the levee or floodwall, then two alternative methods can be used to maintain the required levee or floodwall elevation across the embankment.

The first method is to raise the top elevation of the intersecting road, railroad, or driveway embankment to match the top elevation of the levee or floodwall. This incorporates the raised embankment into the levee or floodwall system and maintains the required top elevation to provide the design level of flood protection. The second method is to leave the road, railroad, or driveway at its existing elevation and construct a watertight closure structure across the road, railroad, or driveway with a top elevation equal to the levee or floodwall. This structure remains open during non-flood periods to allow normal use of the road, railroad, or driveway but is closed during flood periods to complete the flood barrier and maintain the required top elevation. Such closures may be either permanent swing or roller-type gates or temporary panels that are installed prior to a flood event. A photograph of a roller-type gate constructed by the U.S. Army Corps of Engineers in Bound Brook, Somerset County, New Jersey as part of the Green Brook Flood Control Project is shown below in Figure 45. The photograph was also provided by the Somerset County Division of Engineering.

Figure 41
Typical Levee Components
Little Bear Brook Flood Hazard Assessment

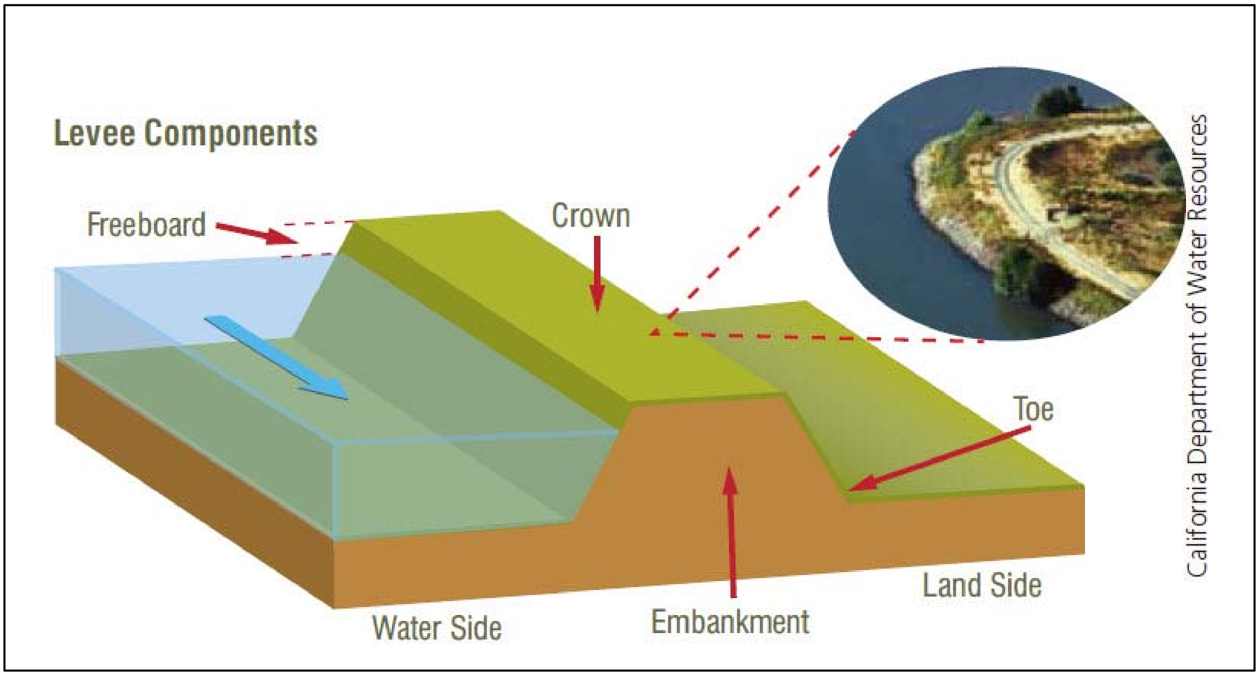


Figure 42
Typical Floodwall Components
Little Bear Brook Flood Hazard Assessment

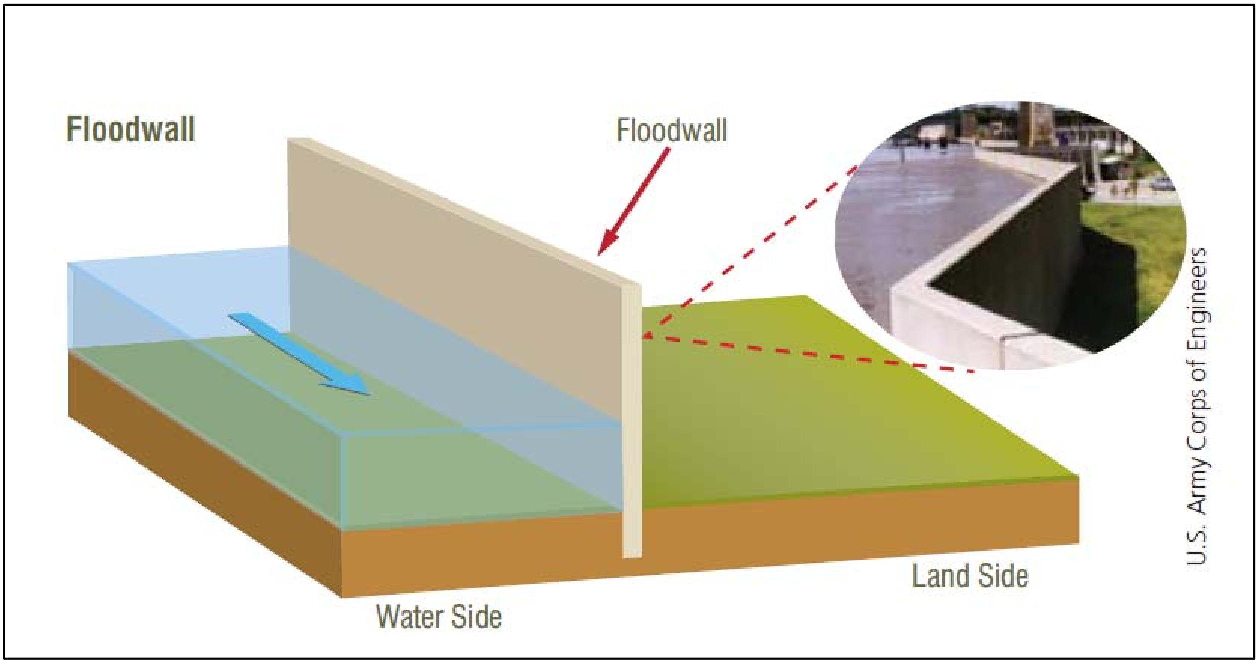


Figure 43
Green Brook Flood Control Project Levee
Little Bear Brook Flood Hazard Assessment

Source: Somerset County Division of Engineering

Figure 44
Green Brook Flood Control Project Floodwall
Little Bear Brook Flood Hazard Assessment

Source: Somerset County Division of Engineering

Figure 45
Green Brook Flood Control Project Roller-Type Closure Gate
Little Bear Brook Flood Hazard Assessment

Closure Gate in Open Position

Closure Gate in Closed Position

The determination of which type of method is most appropriate when a levee or floodway crosses a lower-elevation roadway, railroad, or driveway depends upon many factors including, as discussed above in **5.2 Raising Washington and Alexander Roads**, the availability of sufficient room to raise the road, railroad, or driveway and the impacts of such raising would have on adjacent properties.

In addition, as barriers, the use of levees and/or floodwalls requires that their ends extend to existing ground elevations that are as high as their required top elevation. Such "closure" of the levee and/or floodwall system insures that a continuous barrier of sufficient height has been constructed against floodwaters.

Finally, as barriers that typically protect large, contiguous areas with multiple structures, the top elevation of a levee and/or floodwall system is typically constructed 3 or more feet above the maximum design flood water surface elevation. Similar to the much smaller scale levees and floodwalls used to floodproof individual structures as discussed above in **5.3 Floodproofing Flood-Prone Structures**, this additional vertical height (known as "freeboard") provides a factor or safety both in the level of flood protection provided by the levee/floodwall system as well as against levee or floodwall overtopping by floods greater than the system's design flood. For this reason, the minimum design flood frequency for a levee/floodwall system is typically 100-Years or greater.

Based upon a review of the relative locations of the flood-prone structures included in Phase I of the Little Bear Brook Flood Hazard Assessment (see Figure 10 above), it was determined that those structures located along the northwest side Little Bear Brook between Fisher Place and the NJ Transit track embankment could be considered for protection from Millstone River flooding by a potential levee/floodwall system. Due to the greater dispersion of flood-prone structures on both sides of the Brook upstream of the NJ Transit track embankment, protection of these structures by a levee/floodwall system was not investigated further.

Conceptual views of two potential levee/floodwall systems that were investigated along the northwest side of Little Bear Brook between Fisher Place and the NJ Transit track embankment are shown in Figures 46 and 47 below. The design flood frequency for both systems was assumed to be the 100-Year flood on the Millstone River. As shown in both Figures, the systems are closed by tying the ends of the levees into high ground along Fisher Place at the downstream end and the NJ Transit track embankment at the upstream end. The potential system shown in Figure 46 is based upon raising Washington Road to the same elevation as the top of the levees and floodwalls while the system shown in Figure 47 leaves Washington Road at its existing elevation and includes a closure structure across the road. It should be noted that determining the locations of various internal drainage components such as runoff storage areas and pumping stations was beyond the scope of the Phase I Assessment and, therefore, are not shown in the Figures.

Preliminary details of both potential levee/floodwall systems shown in Figures 46 and 47 are summarized below in Table 15.

Figure 46
Conceptual Levee/Floodwall System with Washington Road Raised
Little Bear Brook Flood Hazard Assessment

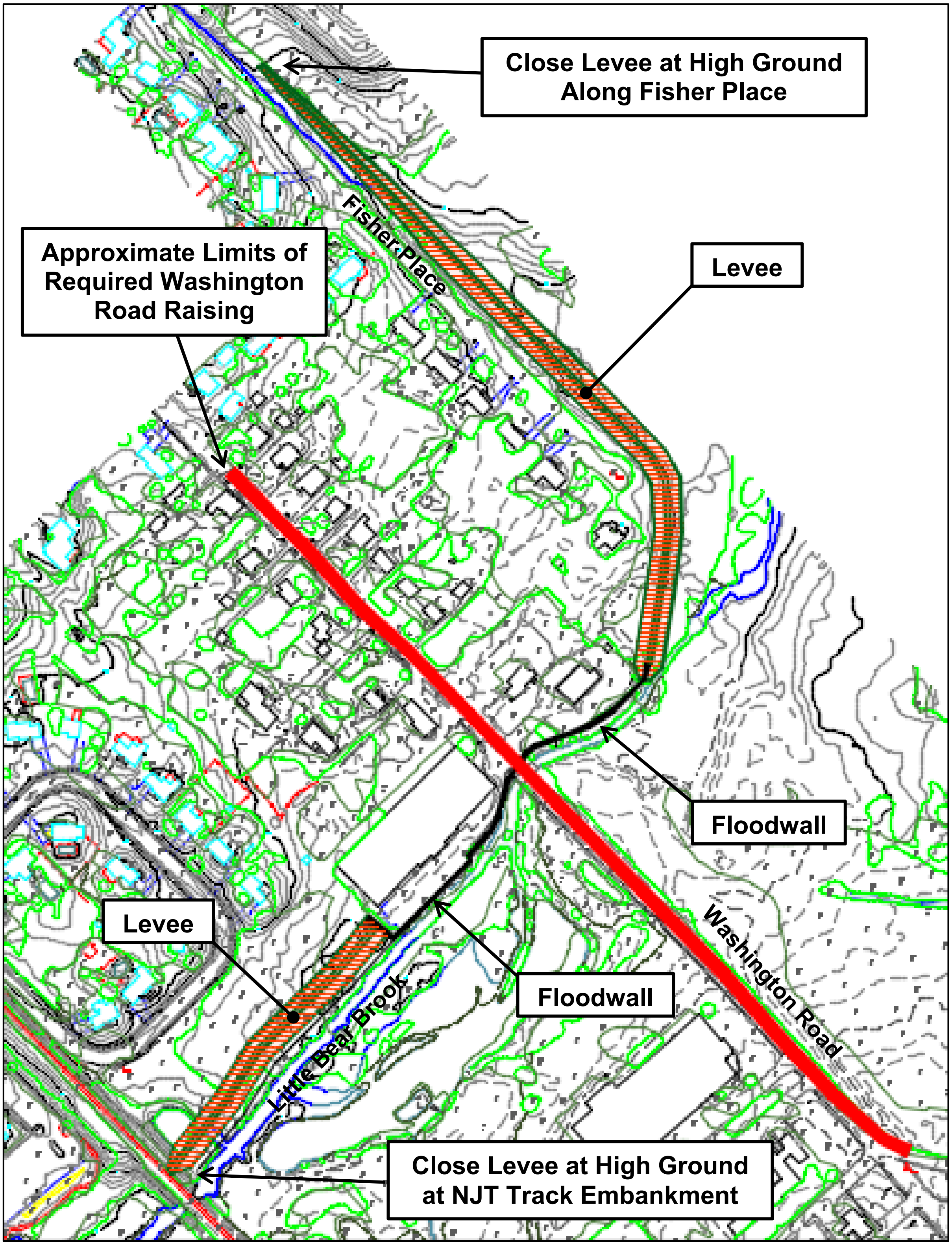


Figure 47
Conceptual Levee/Floodwall System with Washington Road Closure
Little Bear Brook Flood Hazard Assessment

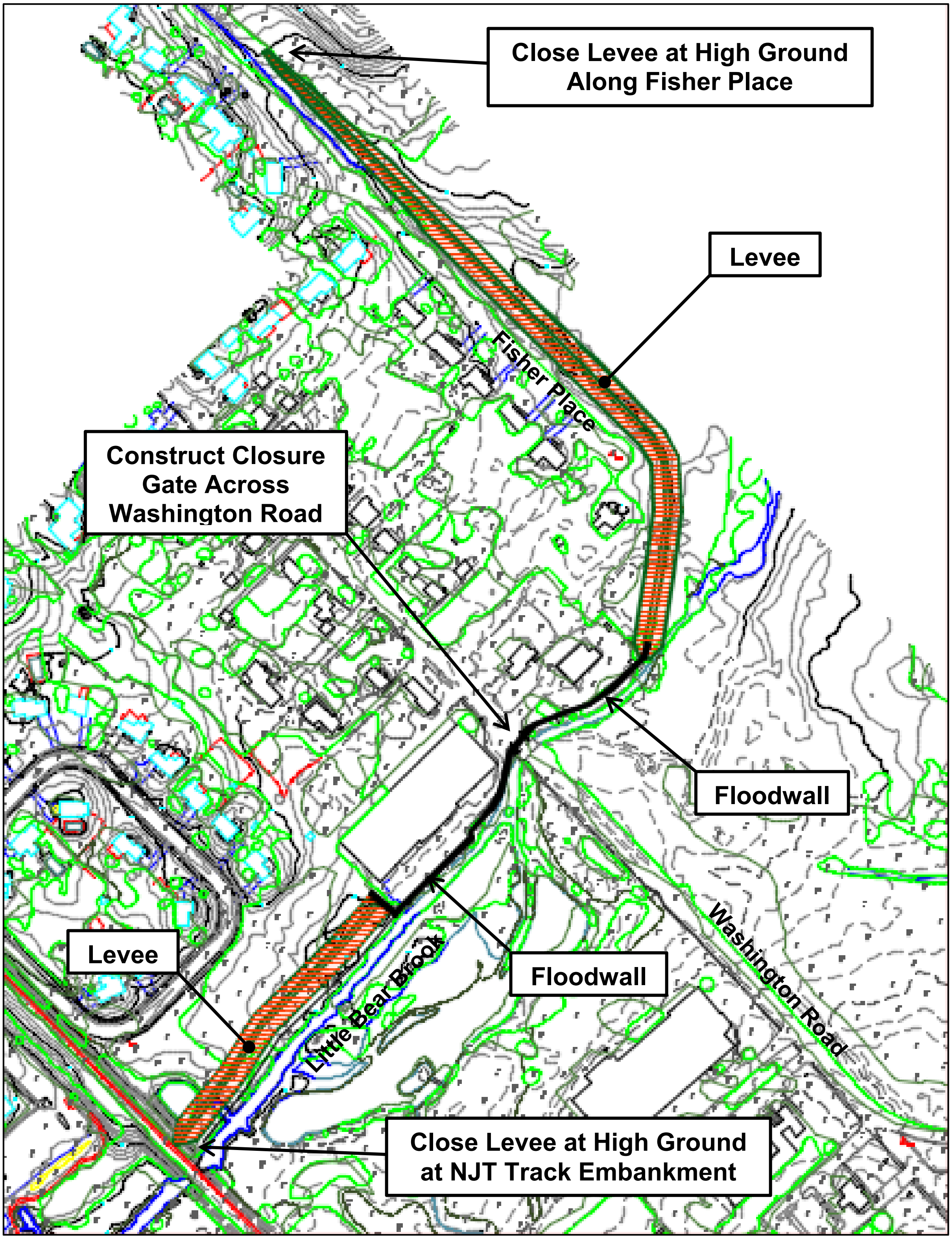


Table 15
Summary of Potential Levee/Floodwall System Features
Little Bear Brook Flood Hazard Assessment

Levee/Floodwall System Feature	With Washington Road Raising	With Washington Road Closure
Design Flood (Years)	100	100
Design WSEL (NAVD)	61	61
Top Elevation (NAVD)	64	64
Freeboard (Feet)	3	3
Levee Length (Feet)	2300	2300
Floodwall Length (Feet)	900	850
Maximum Height (Feet)	8	8
Levee Top Width (Feet)	10	10
Levee Side Slope (H to V)	2.5 to 1	2.5 to 1
Road Closure?	No	Yes
Length of Washington Road Raising (Feet)	2,000	Not Required

In reviewing the information regarding the two potential levee/floodwall systems shown in Table 15 and Figures 45 and 46, it should be noted that the use of floodwalls along the structures and parking lots on Washington Road was required due to the lack of available room to construct levees. As shown in Table 15 above, an 8-foot high levee with a 10-foot top width and 2.5 to 1 slide slopes would have a bottom width of 50 feet.

In addition, it is important to note that, similar to the potential Washington Road raising discussed in **5.2 Raising Washington and Alexander Roads** and shown in Table 14 and Figure 35 above, including the raising of Washington Road in the potential levee/floodwall system shown in Figure 45 above will allow the road to be used during a Millstone flood event up to a 100-Year flood frequency. In addition, operation of the closure structure included in the levee/floodwall system shown in Figure 46 below will not be necessary.

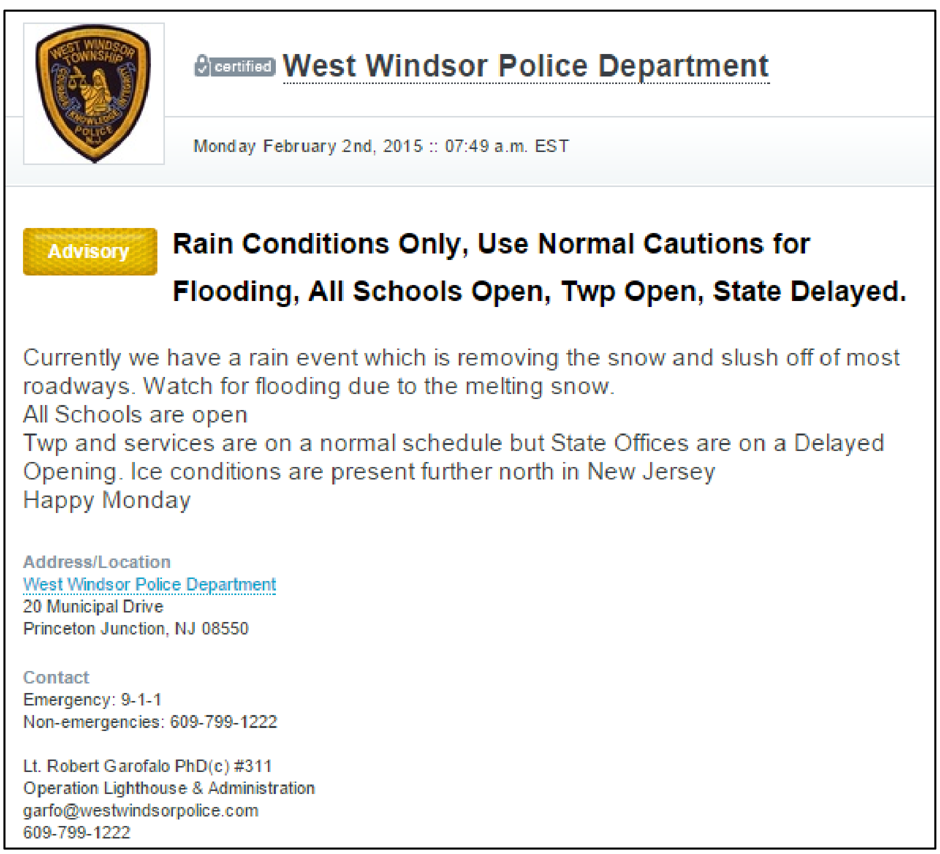
However, as shown in Table 15 and illustrated in Figure 45, including the raising of Washington Road in a levee/floodwall system that provides protection against a 100-Year Millstone River flood will require approximately 2,000 feet of road raising to a maximum height of 8 feet. At this length and height (both of which exceed the values shown in Table 14 and Figure 35 due to the need for freeboard in a levee/floodwall system), such road raising must successfully address the same type of grading and access problems on adjacent properties along Washington Road discussed above in **5.2 Raising Washington and Alexander Roads**. However, due to the greater length and height of the raising required for inclusion in the potential levee/floodwall system, these problems can be expected to be more numerous and acute.

5.5 <u>Installation of a Millstone River Water Level Gage</u>:

As shown in Table 11 above, the final flood mitigation measures analyzed included the installation of a remotely-sensed water level gage that would automatically report Millstone River water levels near or at the mouth of Little Bear Brook. It is important to note that West Windsor Township presently operates an efficient and effective system for disseminating public safety and service information to residents, commuters, and business owners and employees.

This notification system is based upon a service provided by Nixle, LLC, a privately held U.S. corporation that offers free and paid notification services for police departments, emergency management offices, and other municipal government agencies. The Nixle service allows these government agencies to send messages to local residents via phone, email and web. In West Windsor Township (as well as surrounding and nearby municipalities), email is the primary means of disseminating weather and flood forecasts and conditions. Further details of these forecasts and conditions can then be accessed through the Internet. An example of an Advisory issued by the West Windsor Police Department regarding forecast rainfall and potential flooding problems on February 2, 2015 is shown below in Figure 48.

<u>Figure 48</u>
Example West Windsor Police Department Nixle Weather and Flood Advisory
Little Bear Brook Flood Hazard Assessment



certified West Windsor Police Department

Monday February 2nd, 2015 :: 07:49 a.m. EST

Advisory **Rain Conditions Only, Use Normal Cautions for Flooding, All Schools Open, Twp Open, State Delayed.**

Currently we have a rain event which is removing the snow and slush off of most roadways. Watch for flooding due to the melting snow.
All Schools are open
Twp and services are on a normal schedule but State Offices are on a Delayed Opening. Ice conditions are present further north in New Jersey
Happy Monday

Address/Location
West Windsor Police Department
20 Municipal Drive
Princeton Junction, NJ 08550

Contact
Emergency: 9-1-1
Non-emergencies: 609-799-1222

Lt. Robert Garofalo PhD(c) #311
Operation Lighthouse & Administration
garfo@westwindsorpolice.com
609-799-1222

To more fully utilize this notification system and enhance the Township's present flood warning and response capabilities, it is recommended that a remotely-sensed gage that can monitor and automatically report Millstone River water levels at or near the mouth of Little Bear Brook be installed. Possible locations include the upstream or eastern side of the U.S. Route 1 Bridge over the Millstone River or on the downstream side of the Washington Road Bridge over Little Bear Brook. Both of these locations afford ready access to the gage by installation and maintenance personnel as well as nearby electrical power for the gage.

Of these two locations, Millstone River water level data from a gage at the U.S. Route 1 Bridge location would need to be interpreted and adjusted to provide estimated Millstone River levels approximately 4,400 feet (approximately 0.8 miles) upstream of the Bridge and gage at the mouth of Little Bear Brook. Such adjustments are not uncommon and can be made using the HEC-RAS computer model of the Millstone River described in detail above in **3.7 <u>Hydrologic and Hydraulic Computer Models</u>** and used in the hydraulic analysis of the U.S. Route 1 Bridge in **4.4 <u>Millstone River Analysis</u>** above. However, Millstone River water level data from a gage at the Washington Road Bridge location would not require such adjustments and would, therefore, be inherently more accurate.

Communication of the water level data from the gage can be made by telephone, radio, or satellite uplink to an internet site. A solar panel and battery is typically installed at the gage to provide an additional power supply. The gage can also be equipped with additional sensors including precipitation, temperature, and wind speed and direction. A photograph of a combination precipitation and water level gage is shown below in Figure 49. This photograph was provided by the Somerset County Division of Engineering that operates the County's Flood Information System.

Once collected, the real-time Millstone River water level data can then be compared to the flood threshold elevations at Washington, Alexander, and Fieldston Roads and Fisher Place shown above in Table 4 and Figure 25 and at the flood-prone structures along these roads shown above in Table 5 and Figure 26 to evaluate the severity of a potential or real, ongoing flood threat. In addition, the data shown in these Tables and the individual structure data contained in **Appendix E** can be used to evaluate the flood potential of each structure and help establish a focused notification system for various Millstone River levels.

It should be noted that the New Jersey Water Science Center of the U.S. Geological Survey (USGS) currently operates many such water level gages on waterways throughout the state, including four on the Millstone River jointly operated with the Somerset County Flood Information System (SCFIS). Data from these gages is transmitted by satellite uplink and accessible on the Internet, including the USGS website http://waterdata.usgs.gov/nj/nwis/current/?type=flow. If West Windsor Township selects the installation of such a gage for further study, it is recommended that this effort begin with a meeting with representatives of the USGS' New Jersey Water Science Center located nearby in Lawrenceville, New Jersey.

<u>Figure 49</u>
Photograph of a Remotely-Sensed Precipitation and Water Level Gage
Little Bear Brook Flood Hazard Assessment

Source: Somerset County Flood Information System

6. Summary, Conclusions, and Recommendations

6.1 Summary

At the request of West Windsor Township, Mercer County, New Jersey, an assessment of the existing flood hazard risk to roadways, properties, and structures along Little Bear Brook, a tributary of the Millstone River, has been conducted. This assessment was conducted in response to the following flood problem areas in the Township:

- Frequent, chronic flooding of Washington and Alexander Roads that cross Little Bear Brook between U.S. Route 1 and the NJ Transit Northeast Corridor railroad tracks and Princeton Junction Station.

- Less frequent but more damaging flooding of residential, commercial, and other structures as well as Washington, Alexander, and other roadways located within the Brook's floodplain.

The Little Bear Brook Flood Hazard Assessment was conducted concurrently with the development of a Regional Stormwater Management Plan for the Township's Redevelopment Area, an approximately 350-acre area surrounding the New Jersey Transit Princeton Junction Train Station. Since a large portion of the Redevelopment Area is located within the Little Bear Brook watershed, the Little Bear Brook Flood Hazard Assessment and the Redevelopment Area Regional Stormwater Management Plan were conducted concurrently in order to determine, in part, whether regional stormwater management facilities constructed in the Redevelopment Area could also help reduce the existing flooding along Little Bear Brook.

The scope of work for the overall Little Bear Brook Flood Hazard Assessment included the following Tasks:

- Public Meetings and Outreach
- Compile and Review Existing Data
- Flood Hazard Assessment
- Analysis of Mitigation Strategies
- Action Plan
- Final Report and Presentation

Additional information regarding the Scope of Work of the Little Bear Brook Flood Hazard Assessment is presented above in **1. <u>Introduction</u>**.

The existing data used in the Phase I Flood Hazard Assessment included the following:

- Published Little Bear Brook and Millstone River waterway and watershed characteristics including FEMA Flood Insurance Studies and NJDEP Floodway and Flood Hazard Area Delineations.

- Property Owner Questionnaire distributed to property owners in the Little Bear Brook floodplain.

- Information obtained from Township officials and residents at three project meetings.

- Data and observations from the April 30 – May 1, 2014 flood event.

- Elevation survey of 40 structures located within the Little Bear Brook floodplain.

- Topographic mapping of the Little Bear Brook Flood Hazard Assessment and Regional Stormwater Management Plan project areas.

Additional information regarding the existing data used in the Assessment is presented above in **2. <u>Waterway and Watershed Characteristics</u>** and **3. <u>Basis of Analysis</u>**.

In general, the Flood Hazard Assessment found different causes for the two flood problems West Windsor Township has experienced along Little Bear Brook. Based upon a detailed analysis of the Brook and Millstone River that included computer models of both waterways based upon the U.S Army Corps of Engineers' *HEC-RAS River Analysis System* computer software, the primary source of the frequent, relatively short duration flooding of both Washington and Alexander Roads was neither Little Bear Brook nor the Millstone River but, instead, inadequate capacity of the storm sewer systems draining the roadways. Further analysis of both waterways also demonstrated that the source of the less frequent but more damaging flooding of Washington, Alexander, and Fieldston Roads, Fisher Place, and the residential, commercial, and office structures located along these roads was excessive water levels on the Millstone River.

In light of these findings, the original scope of the Little Bear Brook Flood Hazard Assessment and the Regional Stormwater Management Plan was revised to also include an analysis of the existing Washington and Alexander Road storm sewer systems and the development of preliminary system improvements to reduce the frequency and severity of this frequent roadway flooding. The data, analyses, and results of this storm sewer system analysis, including the potential use of stormwater management facilities both within and outside the Redevelopment Area will be presented in the separate Phase II Report on the Little Bear Brook Flood Hazard Assessment. As such, the information presented in this Phase I Report addresses the less frequent but more damaging flooding caused by the Millstone River.

In general, the Flood Hazard Assessment determined that Millstone River-induced flooding of Washington, Alexander, and Fieldston Roads and Fisher Place begins to occur at approximately a 10-Year frequency flood on the River. In addition, the Assessment also determined that Millstone-induced flooding of the residential, commercial, and office structures along these roads begins to occur at approximately a 20-Year frequency flood on the River.

Additional information regarding the above flood determinations, including specific estimates of flood threshold frequencies at each roadway and selected structures located along them, is presented above in **4. Results of Flood Hazard Analysis**. This section also includes the results of an analysis of the potential effects of the removal or enlargement of structures on the Millstone River downstream of Little Bear Brook.

Finally, to address these Millstone-induced flood problems, five flood mitigation measures were investigated for effectiveness, feasibility, regulatory requirements, and approximate cost. These five potential mitigation measures were:

- Reducing excessive Millstone River discharges at the mouth of Little Bear Brook through upstream flood storage and controlled release.
- Raising Washington and Alexander Roads to less flood-prone elevations.
- Floodproofing flood-prone structures.
- Constructing levees and floodwalls along the Millstone River and Little Bear Brook to block floodwaters from reaching flood-prone structures and roadways.
- Enhancing West Windsor Township's flood warning and response capabilities by installing a remotely-sensed Millstone River water level gage.

Additional information regarding these potential flood mitigation measures, including the mitigation strategies they are based upon and the preliminary details of each potential measure is presented above in **5. Potential Flood Mitigation Measures**.

6.2 Conclusions and Recommendations

From the data, analysis, observations, and results of Phase I of Little Bear Brook Flood Hazard Assessment, the following conclusions and recommendations can be reached:

1. Phase I of the Little Bear Brook Flood Hazard Assessment identified the sources or causes of the two flooding problems that West Windsor Township is seeking to address along the Brook. Contrary to original expectations, these sources did not include the Brook itself but rather the Millstone River and inadequate roadway storm sewer systems.

2. Phase I of the Flood Hazard Assessment also provided West Windsor Township useful information regarding flood mitigation strategies and measures that have the potential to address Millstone River-induced flooding along Little Bear Brook and, therefore, warrant further investigation.

3. Phase I of the Flood Hazard Assessment also identified flood mitigation strategies and measures that do not have a realistic potential to address Millstone River-induced flooding along the Brook. Such information will allow West Windsor to expend its future flood mitigation efforts more productively.

4. The frequent, relatively short duration flooding of Washington and Alexander Roads is not caused solely by excessive flows and resultant water levels on Little Bear Brook but, instead, by inadequate storm sewer system capacity in the Roads. This storm sewer-induced roadway flooding, which can be exacerbated by high Brook water levels at the systems' outlets, will be analyzed and addressed in more detail in Phase II of the Little Bear Brook Flood Hazard Assessment

5. The less frequent, longer duration, and more damaging flooding of Washington, Alexander, and Fieldston Roads, and Fisher Place and the residential, commercial, and office structures along them is also not caused by excessive flows and resultant water levels on Little Bear Brook but, instead, by excessive flows and water levels on the Millstone River at the mouth of the Brook.

6. Based upon the data, analyses, and results of the Phase I Flood Hazard Assessment, the following recommendations can be made regarding the five potential flood mitigation measures investigated to address Millstone River-induced flooding along Little Bear Brook:

   A. Downstream hydraulic modifications at Carnegie Lake Dam, the Delaware & Raritan Canal Aqueduct, and the U.S. Route 1 Bridge would not significantly reduce excessive Millstone River water levels at Little Bear Brook and, therefore, do not warrant further study.

   B. Reducing excessive Millstone River water levels at Little Bear Brook through the construction of an upstream flood detention basin is not practical due to high required storage volumes, severe regulatory constraints and environmental impacts, and high construction costs.

   C. Raising Washington and Alexander Roads to reduce existing Millstone-induced flooding may warrant further study, particularly for 25-Year or other moderate level of flood protection. In addition, such raising would also help address storm sewer-induced flooding of these roads by increasing the amount of available room for potential storm sewer system upgrades and reducing the adverse influence of Little Bear Brook and Millstone River tailwaters at the system outlets.

D. Large-scale levee/floodwall systems can provide effective protection against Millstone River-induced flooding. However, based upon the conceptual system developed as part of the Phase I Flood Hazard Assessment, such a system does not appear to be cost effective. Since a cost-benefit analysis is beyond scope of Phase I Assessment, West Windsor Township may wish to verify this conclusion by performing a preliminary cost-benefit analysis and investigating the potential for State and/or Federal design and construction assistance by meeting with New Jersey Department of Environmental Protection and the New York District of the U.S. Army Corps of Engineers.

E. Individual structure floodproofing through one of the five primary techniques presented in the Phase I Report may be both practical and cost-effective. However, final determination of these results are highly dependent on the extent and frequency of flooding, the structural characteristics, and the owner of each flood-prone structure. West Windsor Township may wish to assist interested owners with further research into floodproofing techniques and programs.

F. Installing a remotely-sensed gage that can monitor and automatically transmit real-time Millstone River water level data should be discussed with U.S. Geological Survey's New Jersey Water Science Center. In addition, the West Windsor Police Department and Office of Emergency Management should consider developing a focused list of structures, locations, owners, flood thresholds, and contacts for the flood-prone structure contained in the Little Bear Brook Structure and Water Surface Elevation data tabulated in **Appendix E**.