B1. Introduction

Woodbridge Township has participated in various federal, state, county and local government and private sector programs aimed at reducing flooding impacts within the Township. In the aftermath of Super Storm Sandy, the Township connected flood victims with the Federal Emergency Management Agency (FEMA) and other assistance agencies. Also, the Township participated in the New Jersey Department of Environmental Protection's Blue Acres Program, which has already acquired and removed 139 residential properties from the Township's Special Flood Hazard Areas (SFHAs). Despite such ongoing programs, flooding problems persist at a number of low-lying properties within the Township.

To reduce flood damages, and increasing flood-insurance costs, Woodbridge Township is in the process of joining Federal Emergency Management Agency's (FEMA's) Community Rating System (CRS) Program. This Program encourages and recognizes community floodplain management and planning activities that exceed the minimum requirements of the National Flood Insurance Program (NFIP). CRS rewards such activities by discounting flood insurance premiums for policy holders within a participating community. CRS goals are summarized as follows:

- to reduce and avoid flood damage to insurable property;
- to strengthen and support the insurance aspects of the NFIP; and
- to foster comprehensive floodplain management.

By supporting these common goals, Woodbridge Township property owners will become more flood resilient, and less burdened by rising insurance costs. Accordingly, this report was prepared to:

1. Help minimize risks to human life within hazardous floodplains, and reduce the amount of flood damage sustained during future flood events.

2. Enhance Township resilience and increase hazard mitigation preparedness by improving readiness for climate related emergency situations.

3.Strengthen the Township's economic vulnerability in relation to special flood hazard area's (SFHA) and sea level rise (based on global estimates by the year 2050).

4. Strengthen the Township's vulnerability to critical infrastructure and community assets in relation to special flood hazard area's (SFHA) and sea level rise (based on global estimates by the year 2050).

5. Protect and enhance natural floodplain functions in order to safeguard and promote biodiversity and ecological integrity.

Woodbridge Twp. Post-Super Storm Sandy

B2. Woodbridge Township Profile

Woodbridge Township is a large municipality occupying 24,507 square miles (63.473 km2) in Middlesex County, New Jersey (Figure 1a). The Township includes 23.213 square miles of land and 1.294 square miles of water. Woodbridge has several unincorporated communities and neighborhoods -- Avenel, Colonia, Fords, Iselin, Port Reading, Sewaren, Woodbridge Proper – which, collectively, make up Woodbridge Township (Figure 2). Other unincorporated communities, localities and place names located partially or completely within the township include Boynton Beach, Demarest Hill Top, Edgars, Fairfield, Hazelton, Hopelawn, Keasbey, Lynn Woodoaks, Menlo Park Terrace, Ostrander, Saint Stephens, Sand Hills, Shore View, Union and Woodbridge Oaks.

Woodbridge Township (Figure 1B) is bordered to the east by the Arthur Kill tidal strait and to the south by the tidal Raritan River. The Woodbridge River extends from its headwaters (in the northeastern corner of the Township) to the Arthur Kill. The Township has a history of tidal flooding in low-lying areas adjacent to these waterways, including: (a) the Woodbridge Proper section, along the Woodbridge River and its tributaries, (b) the Sewaren and Port Reading sections, along the Arthur Kill; and (c) the Keasbey section, along the Raritan River. Also, fluvial flooding occurs along Pumpkin Path Brook with flows northerly from Colonia to the Township of Clark, and from the South Branch Rahway River, which crosses western sections of the Township, within the Colonia and Iselin sections. Approximately 19% (5.5 square miles) of Woodbridge Township lies within FEMA's Special Flood Hazard Area (SFHA) (Figure 3), primarily areas adjacent to the Woodbridge River, Arthur Kill and South Branch Rahway River.

Woodbridge is an older community that was originally built to maximize waterfront access for regional industry (Middlesex County, 2010). Adjacent neighborhoods were built to support these industrial waterfront operations. Over 75 percent of the homes had been built before 1979, resulting in many vulnerable pre-FIRM structures. FEMA's statistics for Woodbridge Township indicate that there are presently 433 Pre-FIRM flood insurance policies in force (versus 119 Post-FIRM policies).

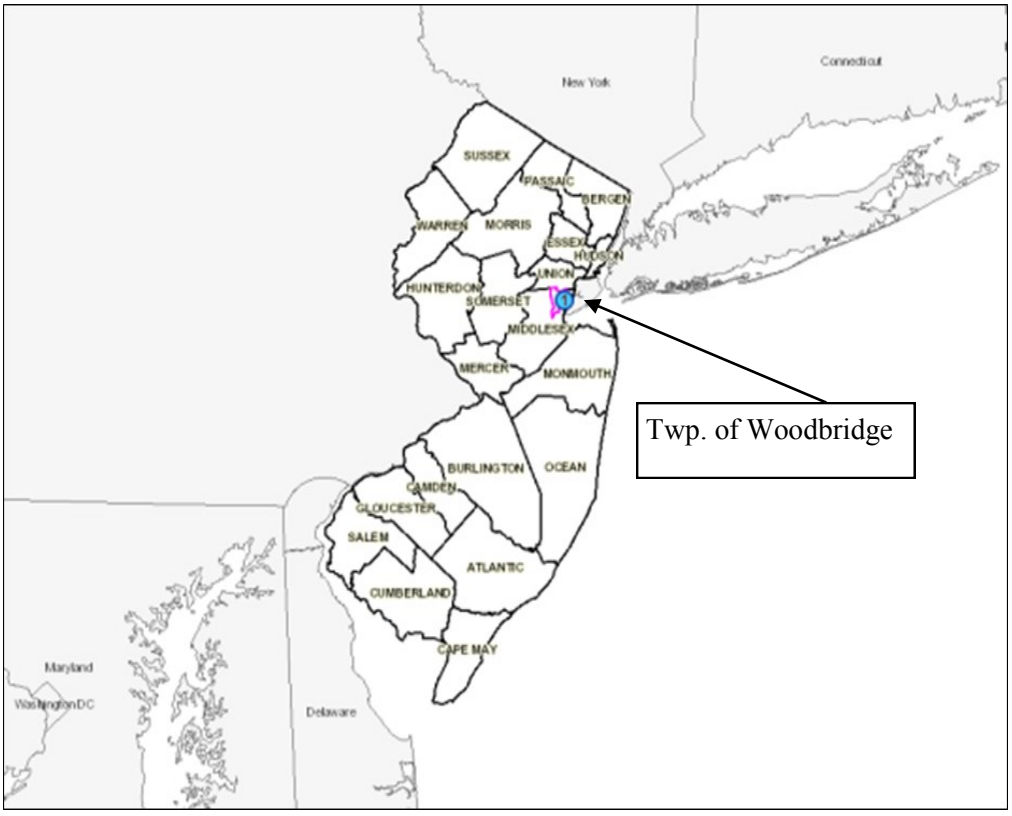


Figure 1A: Woodbridge Township location (Source: NJ GeoWeb))

B2. Woodbridge Township Profile (continued)

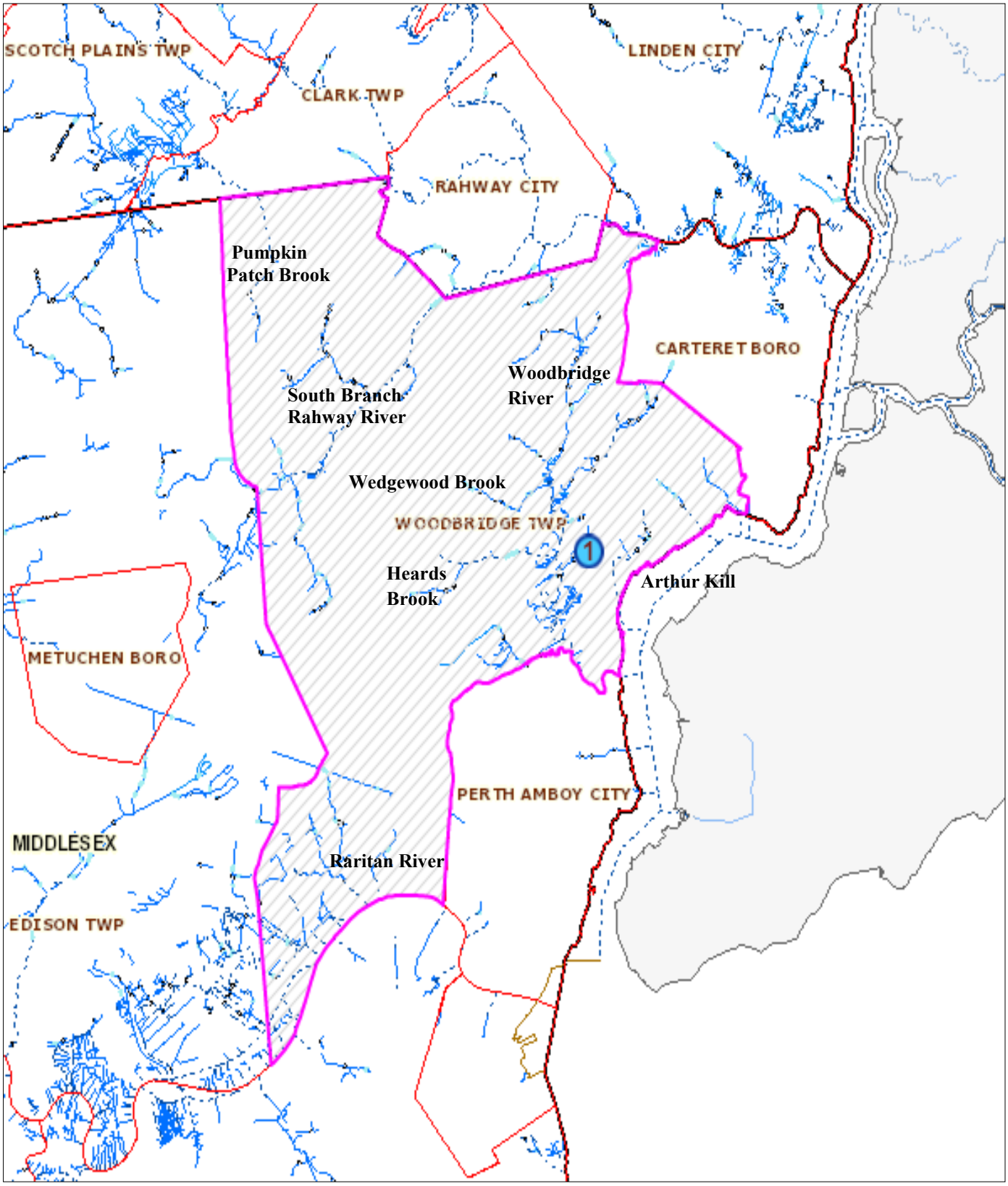


Figure 1B: Woodbridge Township water bodies. (Source: NJ GeoWeb)

B2. Woodbridge Township Profile (continued)

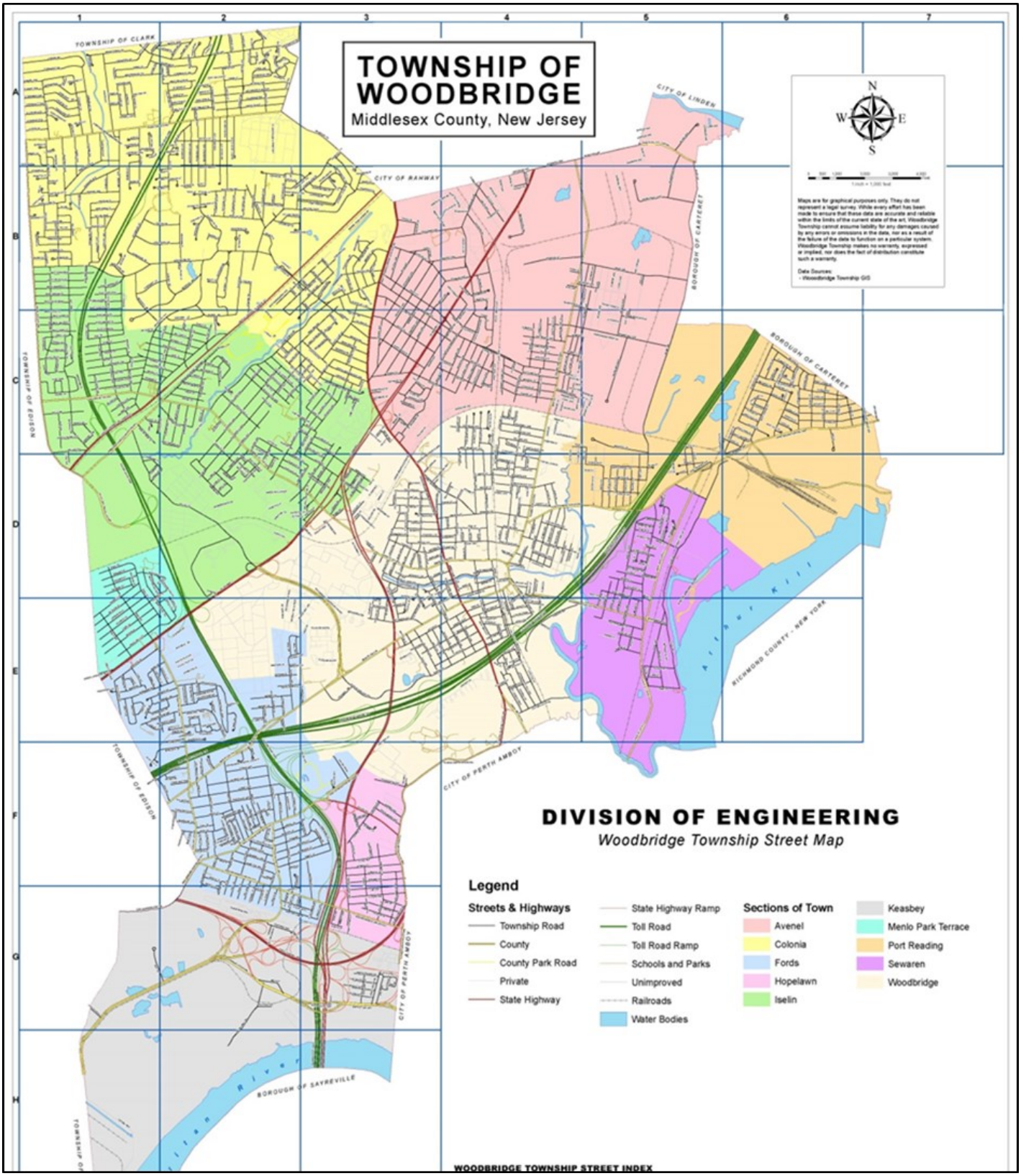


Figure 2: Woodbridge communities (Source: Woodbridge Township Engineering Department).

B2. Woodbridge Township Profile (continued)

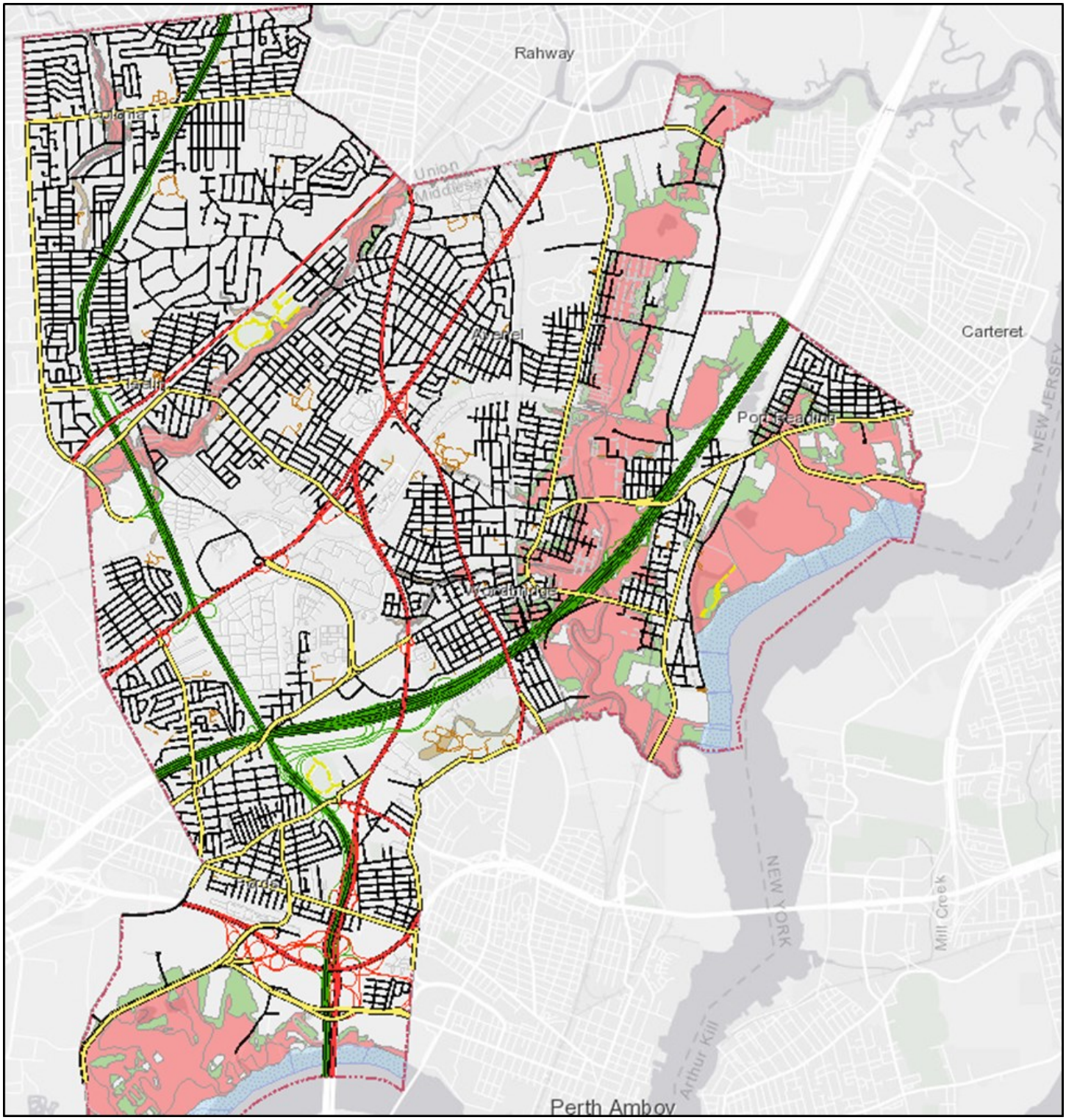


Figure 3: FEMA's 2014 Preliminary Flood Zones (Source: FEMA and Woodbridge Township GIS). Pink areas represent three SFHAs along: (1) South Branch Rahway River (western sections); (2) Woodbridge River (central sections); (3) Arthur Kill (eastern sections); and Pumpkin Patch Brook (north western section).

B3. Known Causes of Flooding (Assessing the Hazard)

Flood damages in Woodbridge Township are caused by tidal and fluvial flooding. Tidal flooding is caused by coastal storms, which consist of two general types: (1) tropical storms and hurricanes; and (2) extra-tropical storms or nor'easters. The former consist of warm-core, cyclonic systems generated in the tropics. These systems derive their energy from oceanic heat and evaporation. Nor'easters are cold core, cyclonic systems that usually form in areas where strong surface temperature gradients coincide with a strong jet stream aloft (Figure 4). Intense winds generated by both of these storms tend to pile water against the coast-line, and raise tide levels above normal to create a "storm surge." Other factors contributing to storm surge include falling atmospheric pressure levels, mildly sloping coasts and "setup" due to breaking waves.

As noted above, Woodbridge Township has a history of tidal flooding. The most extreme flooding occurred in 2012 during Super Storm Sandy, when the U.S. Geological Survey measured a High Water Mark (HWM) elevation of 12.5 feet NAVD88 at Station #NJMID07292, adjacent to the lower Woodbridge River. All low-lying areas adjacent to the Woodbridge River and Arthur Kill were inundated during this Storm, as illustrated in maps prepared by the U.S. Geological Service (Figure 5).

Sandy's peak storm tide of approximately 12.5 feet NAVD88 in the lower Woodbridge River was an extreme water level. Based on published scientific analyses conducted by NOAA, Super Storm Sandy corresponded approximately to a 295-year storm event at Sandy Hook, New Jersey, and a 1,570-year storm event at the Battery, New York. FEMA's 2014 Preliminary Flood Insurance Study (FIS) for Middlesex County reported 100-year Still Water Elevations (SWELs) of approximately 12-13 feet NAVD in the Woodbridge River. Presently, these relatively high 100-year SWELs are being revised by FEMA.

Besides Sandy, Woodbridge Township has experienced several other major coastal storm events, including Hurricane Donna (1960); the Great Nor'easter of December 1992, and Tropical Storm Irene (2011). While storm tide data are unavailable for Woodbridge River during such events, data are available at NOAA's primary gaging station at Sandy Hook, NJ. Here, measured peak storm tides are *typically about 10% lower* than in Woodbridge Creek. Figure 6 compares peak water levels for the ten highest recorded storm tides at Sandy Hook. As illustrated, the second tier of peak storm tides ranged from approximately 6-8 feet NAVD88 at Sandy Hook, or about 3-5 feet lower than Super Storm Sandy's peak tide.

Thus, these second-tier coastal storm events – which occur at decadal intervals, on-average -- also caused flooding in low-lying areas of the Township (i.e., where ground elevations are less than about 7-9 feet, NAVD88). As the lowest ground elevations at the outer edges of developed areas of the Township are approximately 5-6 feet NAVD88, these decadal storm events have the potential to cause up to 4 feet of inundation. Note that some of these events (e.g., Tropical Storm Irene and Floyd) were accompanied by intense rainfall, which exacerbated flooding impacts.

Woodbridge River

(B3. Known Causes of Flooding (continued)

Figure 4: Typical paths of nor'easter

Figure 5: Approximate area of inundation in Woodbridge during Super Storm Sandy (Source: USGS Sandy Storm Sandy Tide Mapper)

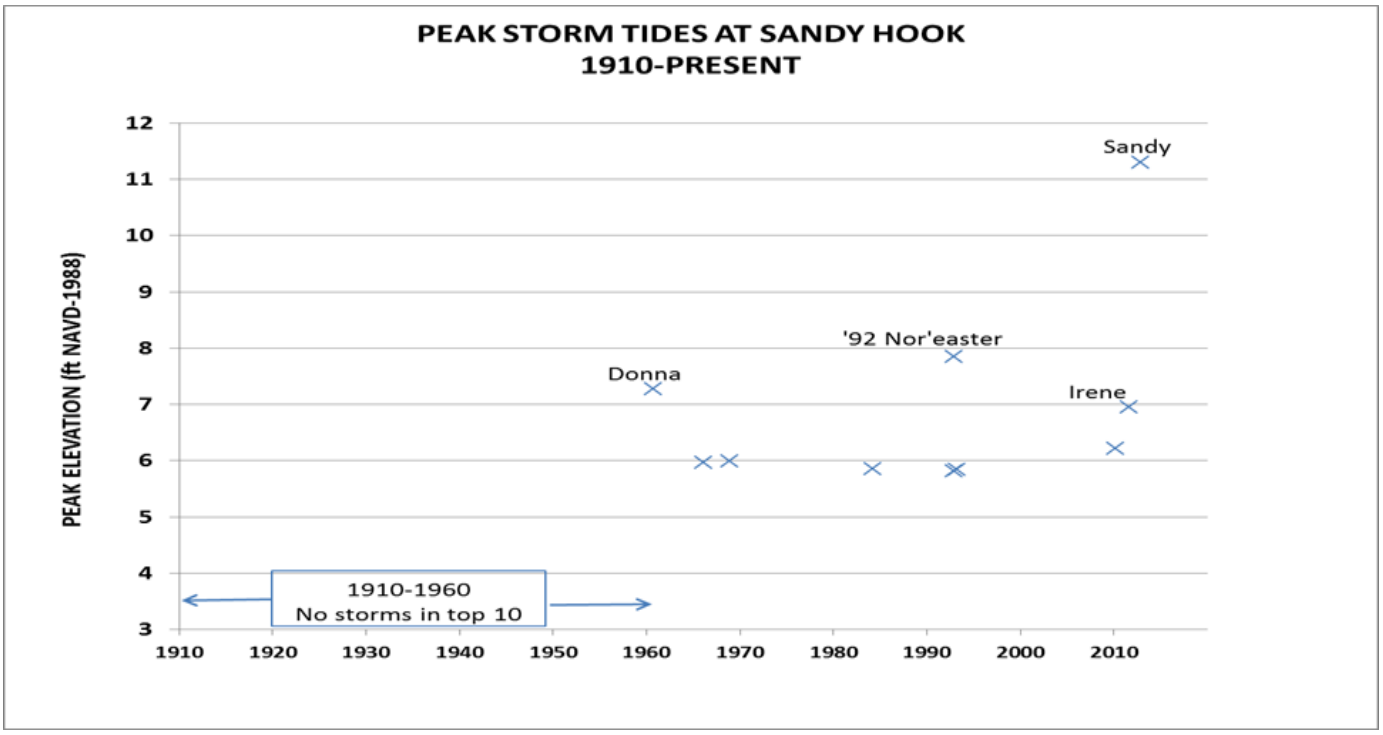


Figure 6: Top ten peak storm tide elevations at Sandy Hook, NJ (Data Source: NOAA CO-OPS). Peak storm tide at Sandy Hook is estimated. The highest tidal elevation recorded by NOAA at Sandy Hook during Super Storm Sandy was actually 10.4 feet NAVD88, when the tide gage stopped recording shortly before the peak tide occurred. NOAA estimates that that actual peak tide during Sandy was around 11.3 feet NAVD88, based on USGS HWMs for Sandy Hook sites NJMON07327 and NJMID072.

B3. Known Causes of Flooding (continued)

Besides tidal flooding, fluvial flooding damages structures and properties within certain areas of Woodbridge Township. Fluvial flooding in Woodbridge Township is exacerbated by its highly urbanized land cover distribution. Nearly 80 percent of the Township's land area has been classified as urban cover, which includes a mixture of industrial, commercial, and residential land uses. The Township has redeveloped some of its underutilized parcels and older industrial areas. Open space is limited primarily to parks and water areas.

The Township has a high degree of impervious cover, which limits infiltration. In addition, the Township has some steep slopes. Maximum topographic elevations range from about: (a) 120 feet above Mean Sea Level (MSL) in the Colonia, Iselin, Fords sections; (b) 80 feet above MSL in Avenel; (c) 40 feet above MSL in Woodbridge Proper, and (d) 20 feet above MSL in the Port Reading and Seawaren sections. The latter three areas slope downward to sea level. The combination of predominant impervious cover and fairly steep slopes results in "flashy," urban runoff conditions, with fluvial flooding impacts in poorly drained areas.

Areas where fluvial flooding occurs include the northwestern section of Woodbridge Township along the South Branch Rahway River and Pumpkin Patch Brook (e.g., in the Colonia section). The South Branch of the Rahway River's 11.6 square mile watershed drains intensively developed portions of four towns: Rahway, Woodbridge, Metuchen, and Edison. Repetitive flooding is associated with extreme rainfall events, especially in "flashy" areas having poor drainage. Common causes of such problems include:

⇒ Urbanization and limited infiltration of rainfall due to enlarged impervious surfaces;
⇒ Enhanced flood flows, stream bank erosion and sediment deposition in channel interiors;
⇒ Insufficient downstream conveyance of stream flood flows due to undersized culverts at bridge/road crossings and/or narrowed stream channels; and
⇒ Insufficient flood storage capacity within the watershed.

The high-flow, flashy nature of Woodbridge streams leads to increased flood flows and, in turn, results in higher flood elevations, increased velocities, and wider floodplains -- all leading to increased flood damages during major rainfall events. Urban development also contributes to fluvial flooding in the upper reaches of creeks and tributaries of the tidal Woodbridge River, especially when prolonged coastal storms (e.g., nor'easters) elevate water levels at their downstream boundaries. These include reaches of Heards Brook and upper Wedgewood Brook. The combined effect of tidal flooding, fluvial flooding and upstream flow constrictions increases the *duration* of flooding impacts in upper reaches of the Woodbridge River. This effect was demonstrated during a tidal monitoring study of the Woodbridge River (Najarian Associates 2001). This study included observations at four tide monitoring stations in Woodbridge during the January 3, 1999 nor'easter. Observed river tide records at each station are shown in Figure 7, along with corresponding tidal elevations monitored by NOAA at the tip of Manhattan Island at the Battery, New York. During this event, coastal sea levels rose approximately 2 feet (Figure 8) in response to this moderate storm, which was accompanied by 3 inches of local rainfall (Figure 8).

During this event, the tide at one of the aforementioned Najarian Associates monitoring stations (near the mouth of Woodbridge Creek) was slightly higher than the tide at Battery or Sandy Hook. Peak storm elevations (nearly 5 ft NAVD88 on January 3, 1999) were nearly the same at all stations within the Creek following this storm event. However, *nearly three days elapsed before water levels subsided* to pre-storm levels at the most upstream monitoring station 4 (near the Ideal Manufactured Home Park, IMHP), indicating slow drainage, but no further peak amplification.

B3. Known Causes of Flooding (continued)

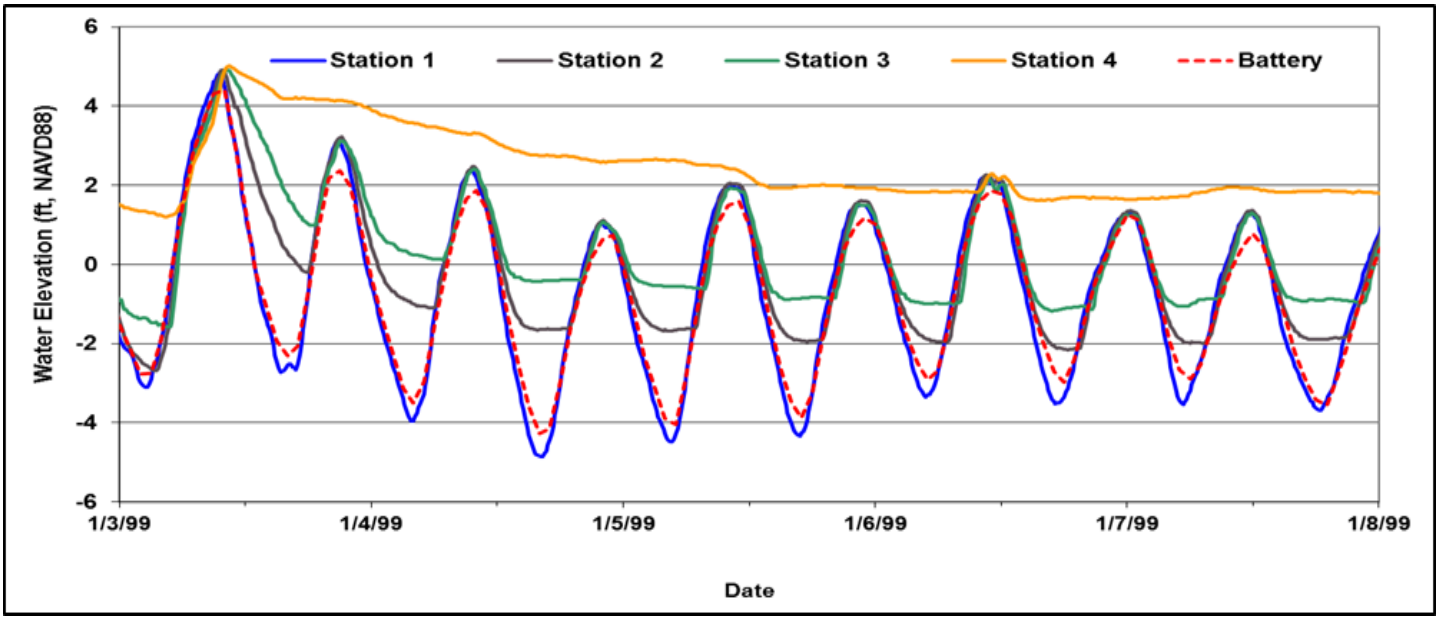


Figure 7

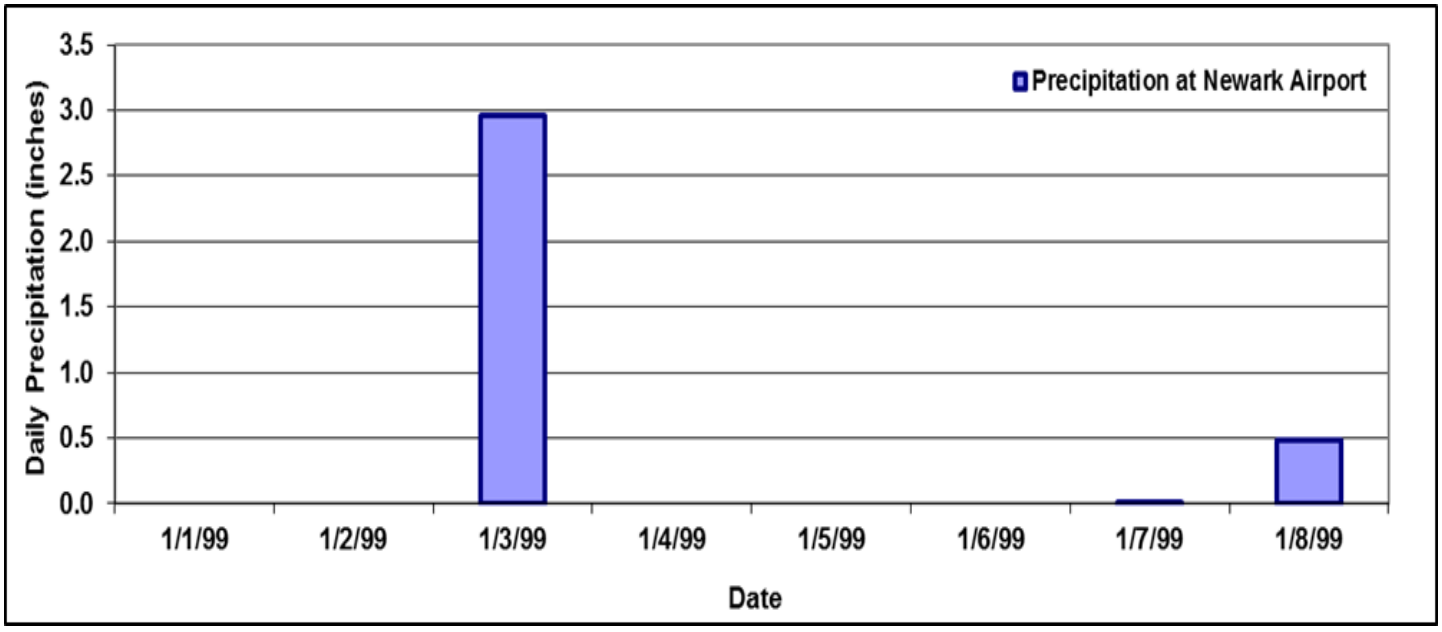


Figure 8

B4. Flooding Vulnerability

FEMA is in the process of updating the Flood Insurance Rate Maps (FIRMs) for Woodbridge Township. The previously adopted and effective FIRMs are dated July 6, 2010. The Preliminary FIRMS – which were issued in 2014 (presently being revised by FEMA) delineate the extent of FEMA's Special Flood Hazard Area (SFHA; a.k.a. 100-year floodplain), contoured Base Flood Elevations (BFEs; a.k.a. FEMA 100-year flood elevations), and various other flood-map features. Within the SFHAs depicted in these maps (expanded floodplain) many new structures are vulnerable to flooding impacts.

B4. Flooding Vulnerability (Continued)

Figure 10 (page 13) displays the distribution of flood-prone structures within SHHAs prior to the recent NJDEP Blue Acres Buyout Program. The displayed structures within the blue-shaded areas are located within the effective (2010), 100-year floodplain delineated below the 9 foot (NAVD88) ground elevation contour.

Historically, both the Crampton Avenue neighborhood (CAN) and Ideal Manufactured Home Park (IMHP) were considered to be among the most vulnerable to storm surge impacts (USACE 2007; Heyer, Gruel & Associates 2015). The CAN is located in the Woodbridge proper section and Woodbridge River's tidal floodplain, just upstream of the NJ Turnpike crossing (Figure 11). The IMHP is located in the Avenel Section of the River's tidal floodplain, just upstream of the Port Reading Railroad Bridge crossing (Figure 11). The flood vulnerability of these areas was assessed in a detailed reconnaissance study conducted by the USACE, New York District in 1999 (USACE 2007).

Flooding in the CAN is characterized as a recurring problem caused by tidal surges combined with stormwater runoff, which collectively impact low-lying residential areas with ground elevations of approximately 6-7 feet NAVD88 (USACE 2007). Tidal and riverine flooding at the IMHP is also recurring due to its location on the Woodbridge River tidal floodplain and its low ground elevations, which vary from 5-19 feet NAVD88. Also, the duration of flooding impacts is prolonged, as noted above.

In 2007, the Corps initiated the Woodbridge River Basin Flood Damage Reduction and Ecosystem Restoration Study to identify possible flood control and ecosystem restoration measures within the Basin, though no such measures were approved by the USACE. However, many structures in the CAN have already been acquired and demolished as a result of the ongoing Blue Acres Buyout Program. Figure 10 (page 13) displays the status of this Program in this neighborhood and surrounding areas

Figure 9: Heidelberg Ave. (CAN) Post-Super Storm Sandy

B4. Flooding Vulnerability (continued)

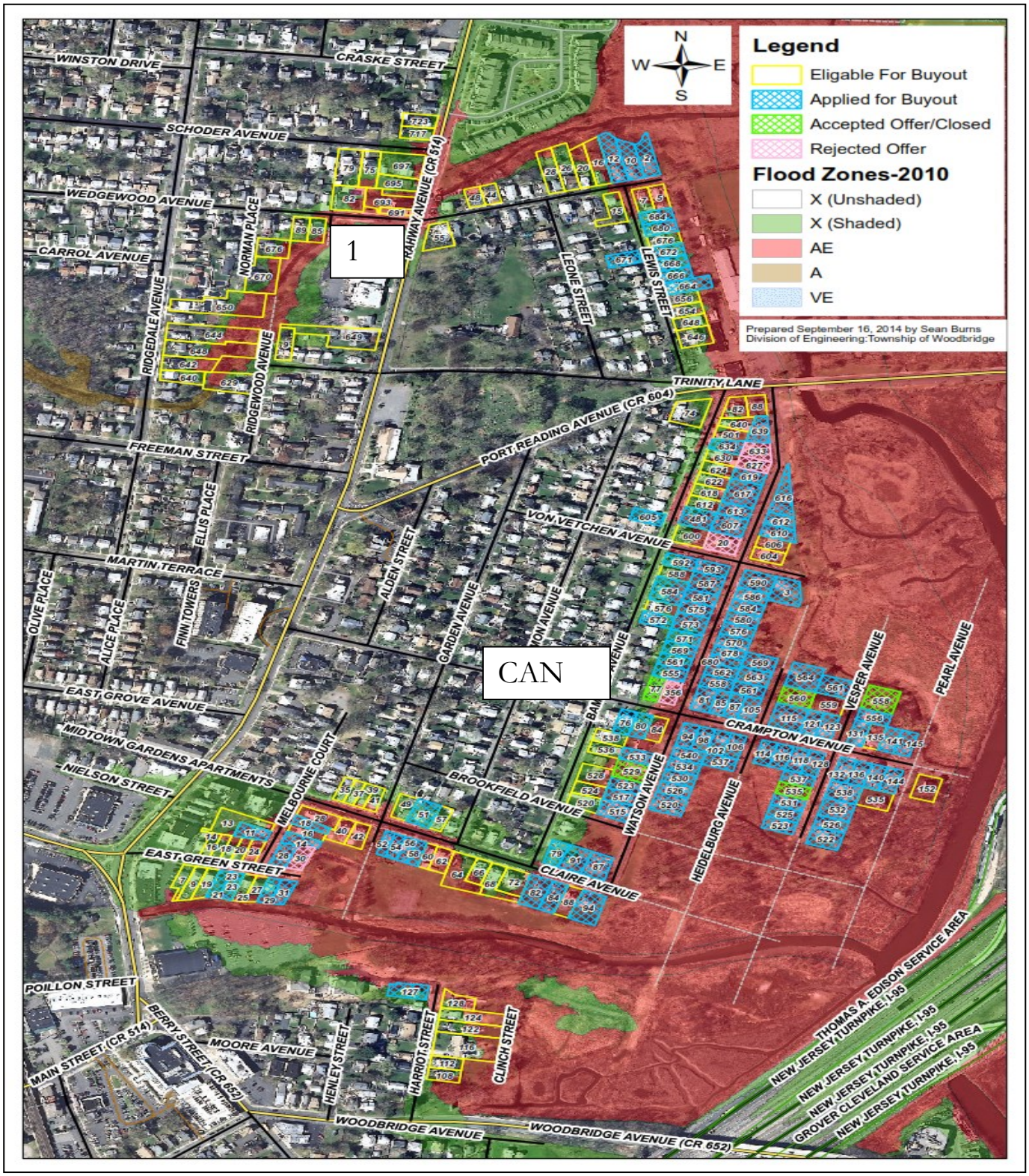


Figure 10: Status of Blue Acres Buyout program in CAN and Wedgewood Avenue Neighborhood (Area 1)

B4. Flooding Vulnerability (continued)

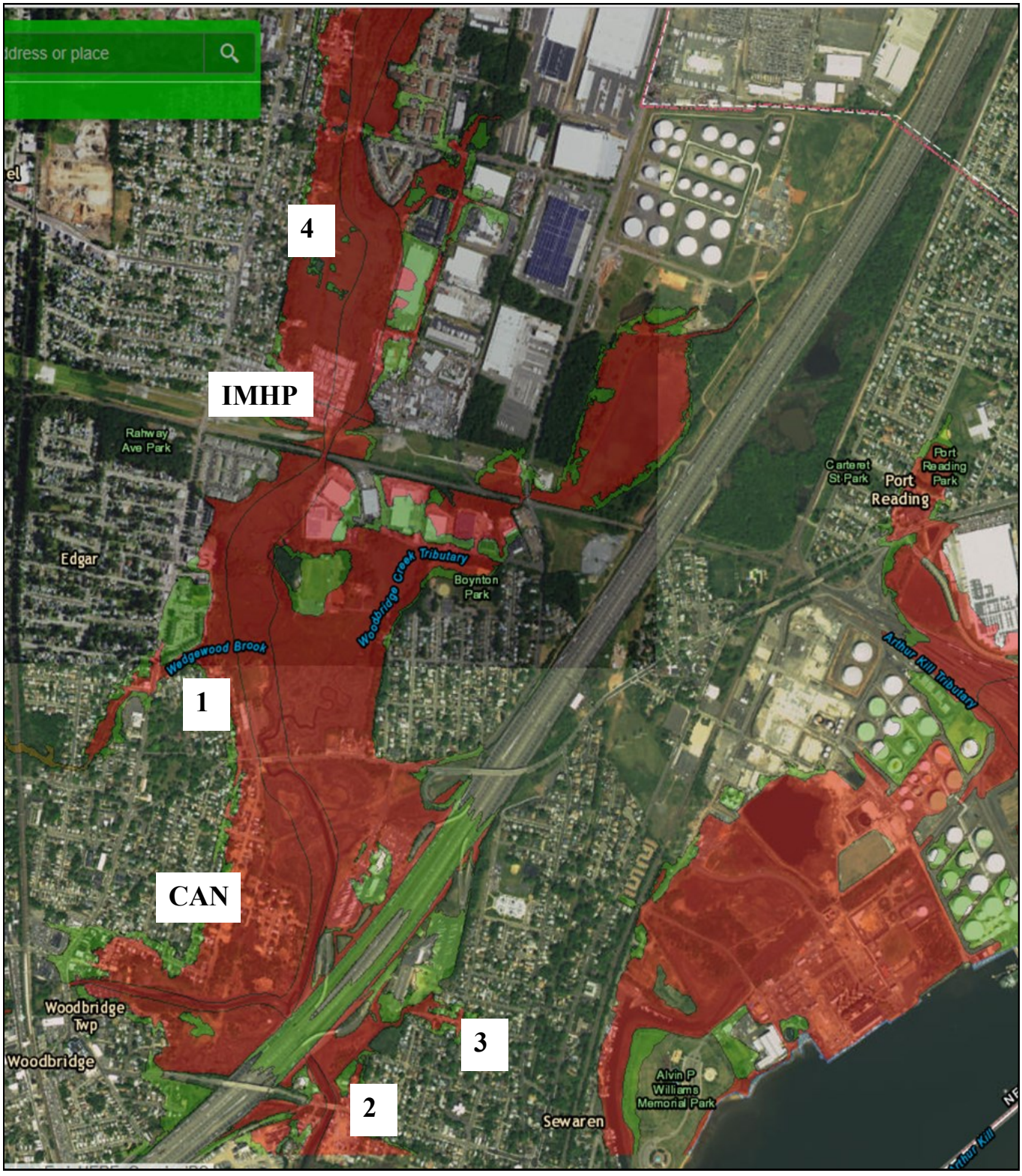


Figure 11: Location of neighborhoods vulnerable to tidal flooding (adopted 2010 FIRM SFHA below 9 feet NAVD88, as displayed on Woodbridge Township GIS)

B4. Flooding Vulnerability (Continued)

Besides the CAN and IMHP, there are several other low-lying developed areas near the Woodbridge River/ marshes that are susceptible to tidal flooding. As identified in Figure 11, these other areas include: (1) the Wedgewood Avenue neighborhood along Wedgewood Brook; (2) the Austin Street, South Roberts Street and Seawaren Avenue neighborhoods on the south side of the NJ Turnpike crossing (Figure 13); (3) the Vernon Street and Seawaren Avenue neighborhoods, also on the south side of the NJ Turnpike; (4) the upper Woodbridge River tidal floodplain along Blanford Avenue, Borman Avenue and Edgarton Boulevard in the Avenel section; and (5) the Fourth Street neighborhood in the Port Reading Section. Like the CAN, many structures are also being acquired and demolished in each of these areas as a result of the ongoing Blue Acres Buyout Program. The buyouts in neighborhood (1) along Wedgewood Avenue are displayed in Figure 10, while the buyouts in neighborhoods (2), (3), (4) and (5) are illustrated in Figures 12-17, respectively.

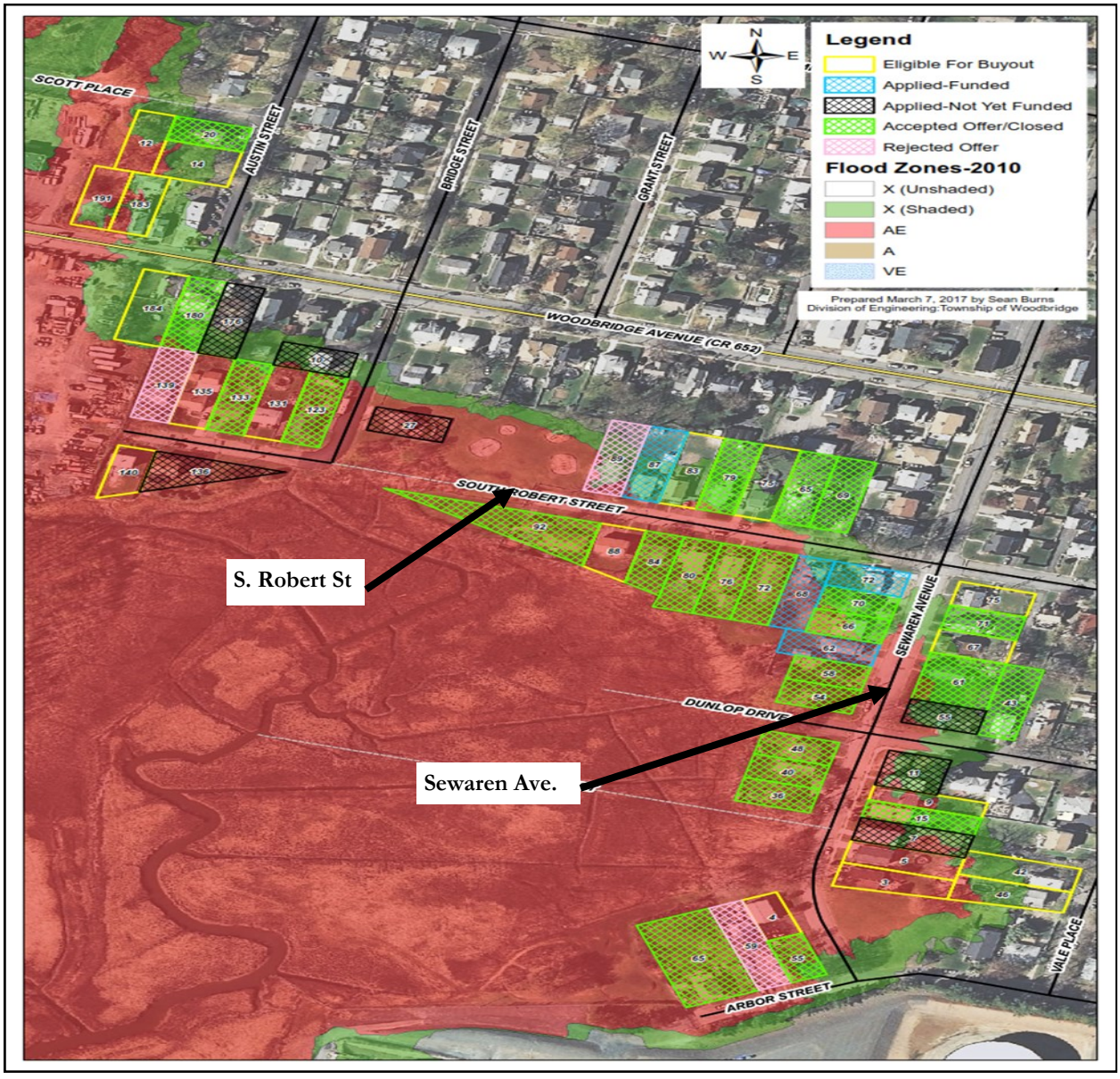


Figure 12: Status of Blue Acres Buyout program in S. Robert Street- Sewaren Avenue

B4. Flooding Vulnerability (Continued)

Figure 13: Status of Blue Acres Buyout program in Vernon Street Neighborhood (Area 3)

B4. Flooding Vulnerability (Continued)

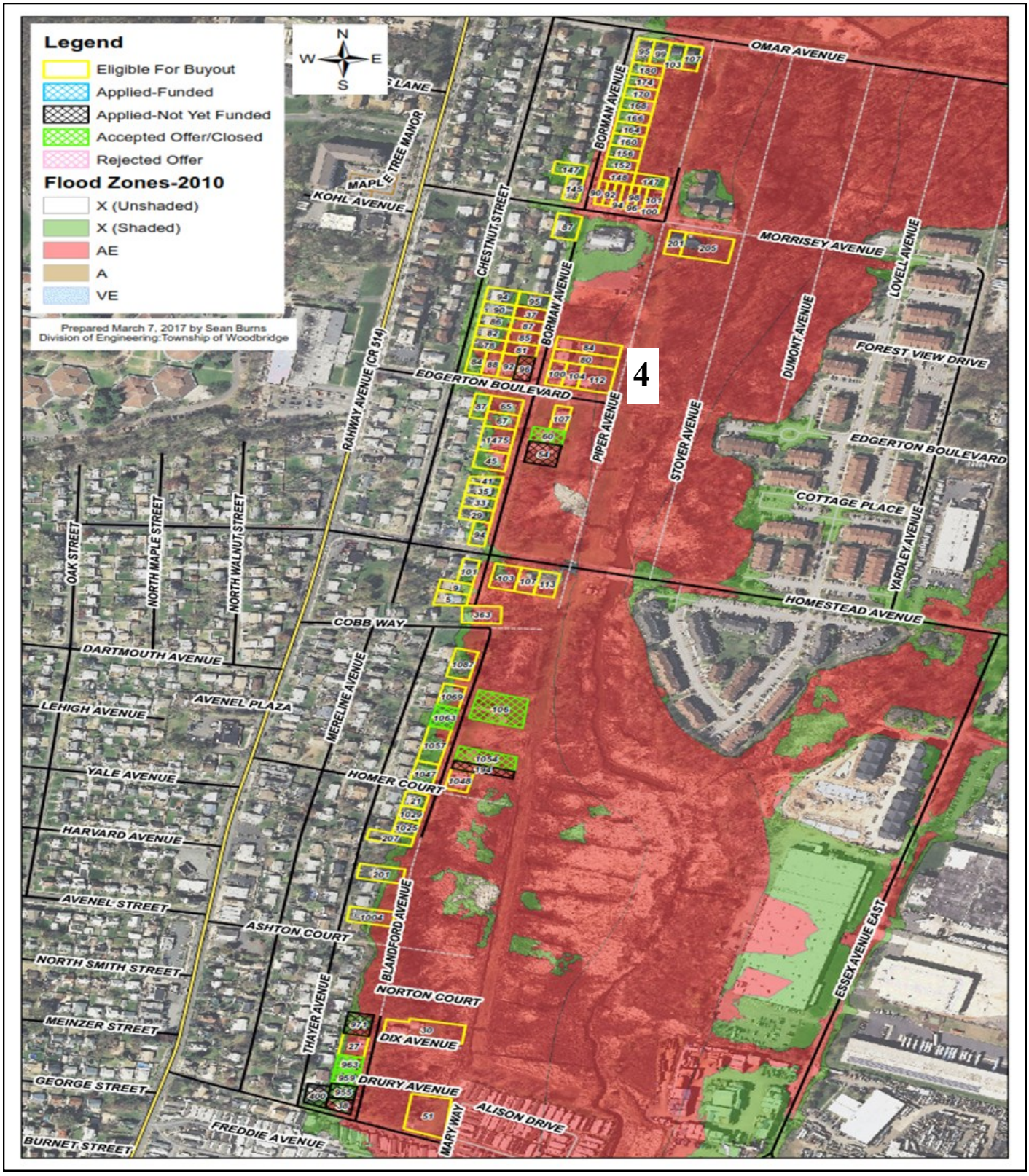


Figure 14 Status of Blue Acres Buyout program in Blanford Avenue, Borman Avenue, and Edgertown Boulevard Neighborhoods along upper Woodbridge River (Area 4)

B4. Flooding Vulnerability (Continued)

Figure 15: Status of Blue Acres Buyout program in Fourth Avenue Neighborhood (Area 5) In Port Reading section

B4. Flooding Vulnerability (Continued)

As illustrated, the Blue Acres Program has been highly effective in reducing the Township's vulnerability to future flooding impacts. It is anticipated that this program will eliminate over 139 structures from the most flood-prone areas of the Township.

While storm surge is an important concern, wind wave impacts are generally not significant in Woodbridge Township due to the inland location of most insured structures. Thus, Coastal A Zones are limited. In the Woodbridge Proper section, Coastal A Zones in the PFIRMs are confined to adjacent tidal marsh areas near the Turnpike crossing of the Woodbridge River, and appear to encroach on only two structures (Figure 16). Since this PFIRM is being revised by FEMA, no further information is available at this time.

Figure 16: Coastal A Zone in 2014 PFIRM around Woodbridge River marsh crosses two homes in CAN

B5. Flooding Vulnerability (Fluvial Emphasis)

Neighborhoods most vulnerable to *fluvial* flooding impacts are located mainly along the **South Branch Rahway River**, and **Pumpkin Patch Brook** within the western (and north western) sections of the Township (Figure 1B). Sub-urban development in Clark and Woodbridge Township has led to increased surface water run-off and long-standing cases of over-banking flooding along Pumpkin Patch Brook (Figure 19). In addition, Woodbridge, Rahway, Metuchen and Edison, are within the 11.6 square miles of the South Branch Rahway River Watershed. Reduced impervious cover in these areas has created a river with high flows, increased velocities, higher flood elevations and wider floodplains. The South Branch Rahway River, through Merrill Park, has experienced severe erosion and lost much aquatic/channel bank vegetation over the last two decades. Downstream flow constraints -- such as bridges, culverts or narrow channels -- cause backwater effects and contribute to upstream flooding. For example, during Hurricane Irene (August, 2011), the residents along McFarlane Road (Figure 17), Brookside Court and North Hill Road Figure 18) incurred significant flood damages. This flow conveyance problem is not easily solved, since there are always concerns that increasing the culvert/channel size at the Route 35 crossing may cause downstream impacts, and since land is unavailable for constructing adequate flood storage/detention basins. However, North Hill Road property owners have applied for Blue Acres Program buyouts, as illustrated in Figure 18.

B5. Flooding Vulnerability (Fluvial Emphasis)

Figure 17: Neighborhood vulnerable to fluvial flooding along South Branch Raritan River near Route 35 crossing (2010 FIRM SFHA, as displayed on Woodbridge Township GIS)

B5. Flooding Vulnerability (Fluvial Emphasis)

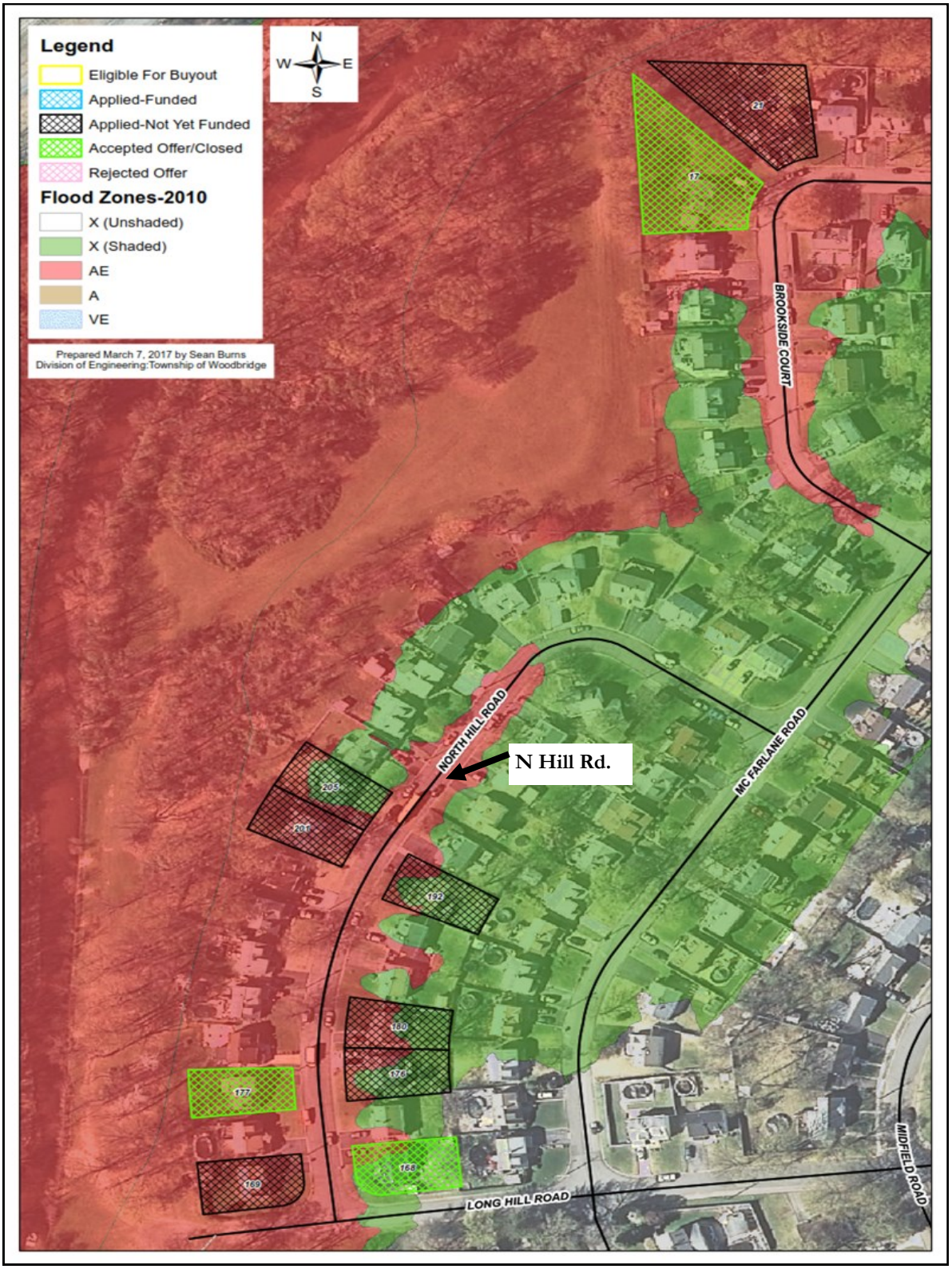


Figure 18: Status of Blue Acres Buyout Program for North Hill Road Neighborhood along South Branch Raritan River

B5. Flooding Vulnerability (Fluvial Emphasis)

To the south, riverine flooding also occurs in non-tidal streams that discharge to tidal rivers and creeks. For example, the high-flow, flashy nature of the reach of **Heards Brook** extending from just upstream of Elmwood Avenue to its confluence with the Woodbridge River has been improved to handle major storm events. The stream crossing at Elmwood Avenue (Figure 19) is 44 feet wide, at School Street is 42 feet wide, and the culvert from Pearl Street to Rahway Avenue is 25-to-30 feet wide and 9-to-10 feet high. The channel sections between crossings have also been improved, with a 30-foot width at the bottom and 50-foot width at the top. However, the Route 35 culvert, which is approximately 12 feet-wide by 6-feet high, has not been enlarged, and continues to cause flooding upstream of the crossing. For example, during Hurricane Irene (August of 2011) areas upstream of the Heards Brook's crossing at Route 35 were flooded, as the Route 35 crossing was overtopped.

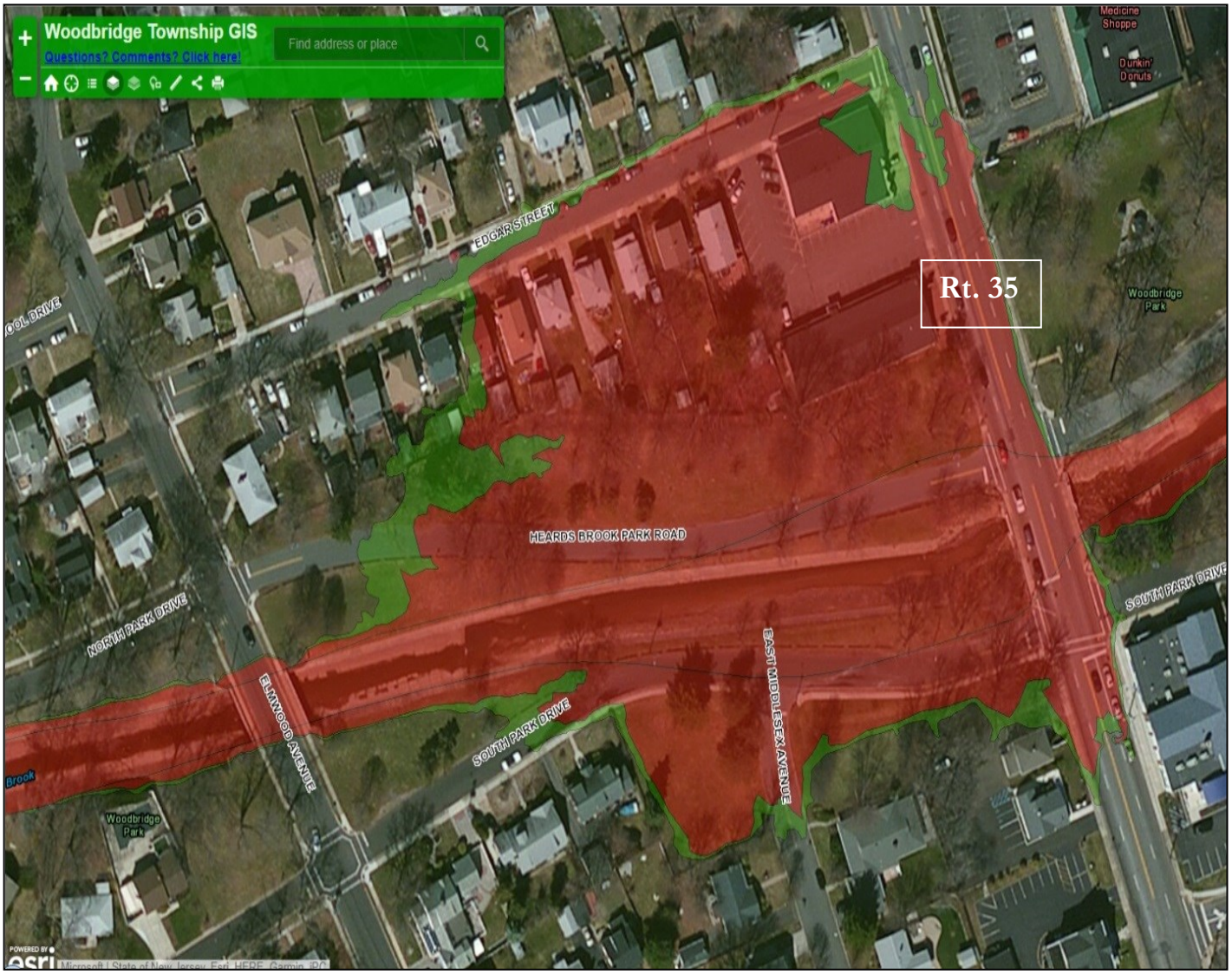


Figure 19: Neighborhood vulnerable to fluvial flooding along Heards Brook near Elmwood Avenue and Rt. 35 (2010 FIRM SFHA, as displayed on Woodbridge Township GIS)

B5. Flooding Vulnerability (Fluvial Emphasis)

Vulnerable, low-lying neighborhoods located upstream of this Route 35 crossing include a low point in Edgar Street (Figure 19), which extends to an elevation of approximately 24 feet NAVD88 at structures along the south side of Edgar Street. There is a second low point which has an elevation of less than 22 feet in the rear area of the homes on the south side of Edgar Street, between Edgar Street and N. Park Drive. N. Park Drive also has a low point of approximately 21.5 feet NAVD88, which floods during a 2-year storm event according to recent hydraulic studies (Najarian Associates, 2013). Hydraulic model studies suggest that the 100-year storm event has potential to flood the area to a depth of 3 feet (Najarian Associates, 2013).

Flooding south of Heards Brook occurs along S. Park Drive, which has a low point of approximately 22.5 feet, and may also flood during a 2-year storm event. Likewise, the high-flow, flashy nature of the non-tidal Wedgewood Brook (Figure 20) leads to flood damage during storm events. The main downstream flow constraint in Wedgewood Brook is the railroad crossing (Figure 20). This crossing consists of twin 48" culverts. Both the crossings upstream and downstream of this crossing are larger, and therefore have more capacity to carry flood flows. The upstream crossings at Barron Avenue (Figure 20) and Harrell Avenue crossings are 12 to 13 feet wide and 3 to 3.5 feet high; both larger than the Railroad Bridge culverts. During Hurricane Irene in late August of 2011, areas upstream of the Wedgewood Brook's crossing at the Railroad Bridge were flooded, including the Barron Avenue neighborhood.

The low point in Barron Avenue (Figure 20), at the Wedgewood Brook crossing, has an elevation of approximately 16.6 feet. Upstream of the Barron Avenue crossing is Harrell Avenue, which has a low point of approximately 19.6 feet. Model analyses (Najarian Associates, 2013) indicate that the 100-year storm has potential to flood the area to a depth of over 9 feet. Structures as far upstream as Greco Lane also have the potential to be flooded during a major storm event. Approximately 42 residential structures could be affected by the 100-year storm event. The Najarian Associates analysis also revealed that the railroad culverts downstream of the Barron Avenue neighborhood provide a major backwater effect to areas upstream. Since the Railroad Bridge is acting as a berm and creating storage in the floodplain upstream, any increase in the rate of flow through the railroad culvert would, unfortunately, increase flood elevations downstream of the railroad crossing.

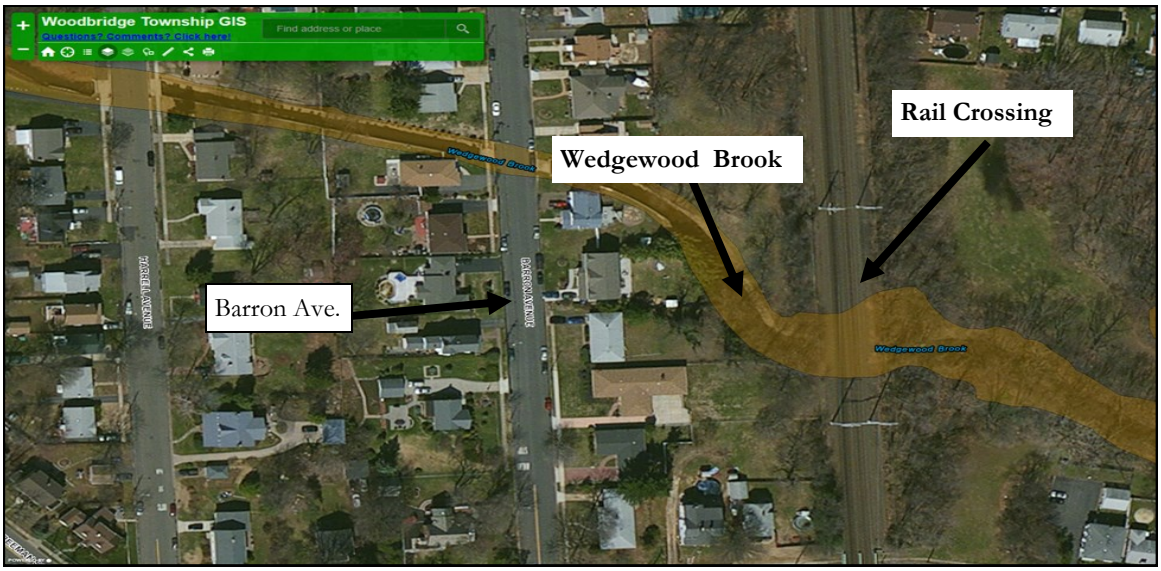
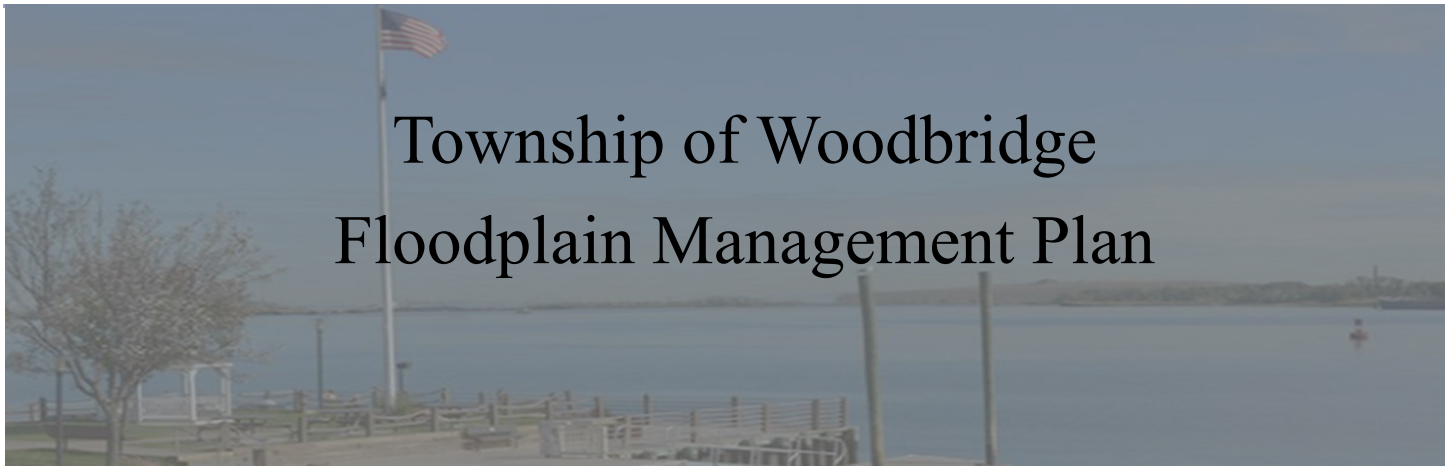


Figure 20: Neighborhood vulnerable to fluvial flooding along Wedgewood Brook near railroad crossing (2010 FIRM SFHA, as displayed on Woodbridge Township GIS)

B5. Flooding Vulnerability (Fluvial Emphasis)

To the north west, riverine flooding also occurs in non-tidal Category two stream known as **Pumpkin Patch Brook** which flows northerly towards the Township of Clark (Figure 21) . Pumpkin Patch Brook discharges to the Robinsons Branch of the Rahway River, and suffers similar drainage issues in regards to receiving high volumes of surface water run-off from impervious sub-urban development. For example, overbank flooding associated with the aforementioned water body has caused localized damage concerns in the Jordan Road neighborhood. Within this neighborhood (just upstream of the Inman Avenue crossing) the estimated ground elevation is 66.5 ft NAVD. Further, some flood-prone structures in this neighborhood possess basements and therefore are at an increased risk to receive flood damage, as the FEMA delineated 100 year flood elevation at this location is 66 ft. NAVD.

Figure 21: Neighborhood vulnerable to fluvial flooding along Pumpkin Patch Brook near Jordan Road (2010 FIRM SFHA, as displayed on Woodbridge Township GIS)



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