Draft Appendix CII

Hydraulics

Rahway River Basin, New Jersey
Flood Risk Management Feasibility Study

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New Jersey
Department of
Environmental Protection

U.S. Army Corps of Engineers
New York District

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1.0 INTRODUCTION

1.1 Area of Study

The Rahway River Basin is located in northeastern New Jersey. It lies within the metropolitan area of New York City and occupies approximately 15 percent of Essex County, 35 percent of Union County, and 10 percent of Middlesex County. The basin is approximately 83.3 square miles (53,300 acres) in area. Its greatest width is approximately 10 miles in the east-west direction, from the City of Linden to the City of Plainfield. Its greatest length is approximately 18 miles in a north–south direction, from West Orange to Metuchen. A map of the Rahway River Study area and the municipalities that it lies within, is shown on Figure 1.

1.2 Present Flooding Problems

Periodic storms have caused severe fluvial flooding along the Rahway River. There are two main areas with high flood risk, the Township of Cranford and the Robinsons Branch in Rahway. Flooding along the Rahway River at Cranford is caused by low channel capacity, constrictions of several bridges and dams along the river and two 90 degree bends forming a “U” turn at the Springfield Ave. just upstream of the center of the Township. The flood waters backup from the main Cranford area into the area of Lenape Park Detention Basin and Kenilworth Township. In City of Rahway at Robinson’s Branch the high risk of flooding is due to low channel capacity, the constrictions of several bridges, and the backwater from the main stem of the Rahway River, which is independent of the hydraulic conditions in the Robinson’s Branch.

1.3 Objective

The objective of this study is to identify the most cost effective mean of managing the risk of flooding in the most affected areas of the Rahway River basin, while meeting safety, environmental and cultural requirements. The flood risk management concepts included in this study are: channel modification, bridge replacement, creation and/or modification of hydraulic structures (i.e. dam, levee) and non-structural plans.

2.0 RAHWAY RIVER DESCRIPTION

2.1 General

The head waters of the Rahway River start at the East and West Branch of the Rahway River. The head water for the East Branch is located in the vicinity of City of Orange, flowing downstream through South Orange and Maplewood Townships. The head water for the West Branch is located in the vicinity of West Orange, flowing downstream through the South Mountain Reservation into the Township of Millburn. The Branches merge into the main stem Rahway River at Springfield and Union Township and flows in a north-south direction for approximately 2.5 miles from I-78 to Route 22. From this point it flows directly into Cranford, Winfield and Clark Township, meeting with the Robinson's Branch at Rahway. Approximately half a mile downstream it meets the South Branch and keep flowing downstream meeting Linden and Carteret Townships.

The channel side slopes are moderate and vary from 5 to 15 ft. in height. The channel bottom in the Rahway River has a variable slope, approximately 2.0 ft./mile at the tidal influenced area, 8.0 ft./mile from Robinson's Branch to Cranford and 3.0 ft./mile from Cranford to the confluence between the East and West Branches. The West Branch of the Rahway River by the Township of Millburn and the South Mountain Reservation the slope becomes steep, approximately 55 f./mile. In the affected areas of the Robinson's Branch the slope of the channel is approximately 10 ft./mile. The width of the channel at the banks varies in width from 30 to 40 ft. in the East and West Branches to 50 to 60 ft. just downstream of Route 22 to approximately 30 to 40 ft. through the Lenape and Nomahegan Parks (by Cranford Township), widening to 50 to 70 ft. near the confluence with Robinson's Branch.

Overall, although is a highly develop sub-burb of New Jersey, the banks of the river are densely cover by trees and shrubs. Areas adjacent to the river are mostly protected by the non-federal sponsor (NJDEP) and the Green and Blue Acres Program. The debris produced by the high vegetation in combination with the quick rising flows results in floods in many areas of the Rahway River Basin.

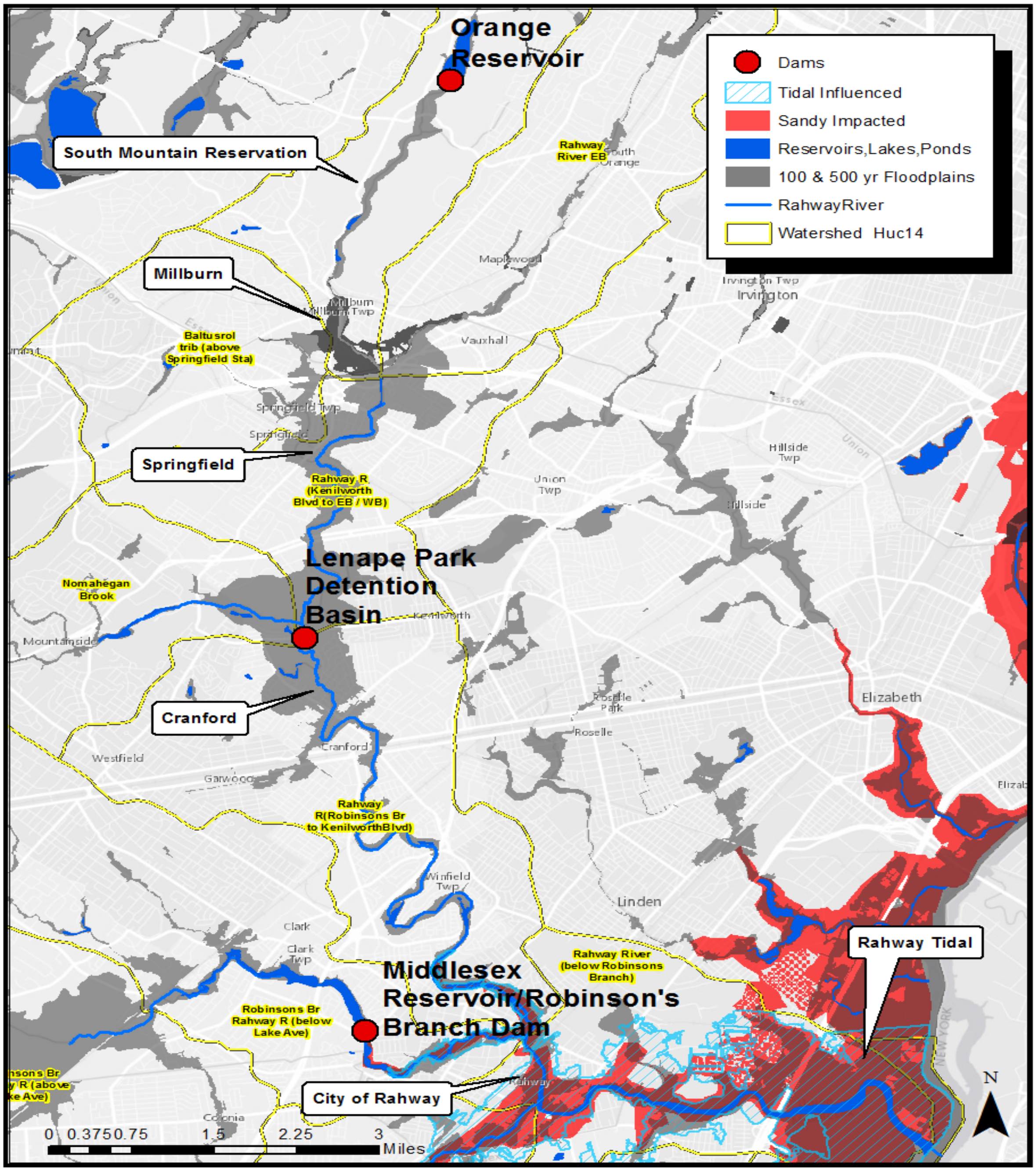


Figure 1: Rahway River Study Area and communities.

2.2 Flood Prone Areas

The Rahway River in the Township of Cranford and Robinson's Branch at Rahway begin to experience fluvial flooding at and above the 10% chance of annual exceedance (10-yr) event. See Figure 17 for inundation of the Cranford area.

At this stage the low-lying area between Park Dr. and Springfield Ave. near the Nomahegan Park Back experiences flooding due to back water from a tributary of the Rahway River and some street flood upstream of Hansel Dam. For peak flows between the 10% chance of annual exceedance (10-yr) and the 4% chance of annual exceedance (25-yr) events, water surface elevations (WSEs) in the Rahway River overtop the Nomahegan Park levees. Although there are some inconsistencies in the top elevation of the levees, both sides of the levee system can contain approximately the same event. For storm events above the 4% chance of annual exceedance (25-yr), the stage of the Rahway River waters starts producing floods in the following areas:

1. Kenilworth residential area due to backwater caused by the constrictions of the Kenilworth Blvd. Bridge.
2. At the right overbank between Willow St. and Brookside Place, near Cranford High School.
3. At the left and right sides overbanks and behind the existing levee system, the residential area at the residential area surrounding Riverside Dr., Brookdale Rd., Edgewood Rd., Glenwood Rd., Summit Rd., Edgar Ave., Franklin Ave., Balmiere Pkwy. and Doering Way.
4. And the commercial area surrounding Chestnut St.

Floods above the 20% chance of annual exceedance (5-yr) produce damages in the low lying areas of Robinson's Branch, and on the Rahway River between its confluences with Robinson's and South Branches. Other areas upstream, in the Robinson's Branch between Maple Ave. and St. Georges, start suffering damages at the 4% chance of annual exceedance (25-yr) events.

2.3 Existing and Proposed Hydraulic Features Along the Rahway River at Cranford

Some areas along the Rahway River have seen a decrease in flood risk due to improvements implemented through the years. These are several of the existing federal and non-federal projects in place:

1. Nomahegan levee system: The Nomahegan Park levee system is located on both sides of the banks in the Rahway River; protecting a commonly flooded

residential area in Cranford. The left and right bank levees are approximately 1,800 ft. and 4,000 ft. long respectively. The levees are approximately 4 to 6 ft. high and have approximately a 6 ft. top width. There is also a flood reduction plan developed by the Township of Cranford in regards to the levees. It includes the construction of interior drainage stormwater pipes, pump stations for the east and west side of the existing levees, improvements to the stormwater sewer system and improvements of the existing levees. The Township plans are divided into the following phases:

Phase 1: Drainage swale approximately 500ft north of Belmont Ave. and express stormwater sewer pipeline, constructed in 2006.

Phase 2: Riverside drive stormwater pump station, and north and south gravity storm sewer interconnection, constructed in 2008.

Phase 3 & 4: Improvements to the Nomahegan Park and residential area existing levee system, currently on hold.

Phase 5: Park Ave. pumping station, Penn Rd. stormwater sewer pipeline and local collector system, currently on hold.

2. Lenape Park Dam: The dam creates dry detention area with a capacity of approximately 2100 acre-ft. at the top of the embankments, enough to hold a 1% chance of annual exceedance events (100-yr) without flood without overtopping. The secondary, or emergency, spillway is designed to overflow for the 4% chance of annual exceedance event (25-yr). The dam consist of a concrete spillway 100 ft. long and approximately 25 ft. high and earthen embankments approximately 10,000 ft. long with an approximately 10 ft. top width and one vertical to thee horizontal (1V:3H) side slopes. The right dam embankments located in the township of Cranford and Westfield are fairly well maintained. By contrast, the left embankment in Kenilworth, has a considerable amount of vegetation and trees growing on top.

3. Springfield Levees: The levee system is located in the right bank of the Rahway River in Springfield Township. The system is divided into three (3) segment with varying top elevations. The north segment is approximately 1,560 long with a variable top elevation between 88.5 and 90 ft. NAVD 88. The middle segment is approximately 1,500 ft. long with a top elevation of approximately 86 ft. NAVD 88. This segment has the lowest top elevation of the three, with the smallest top width and is lacking in maintenance. The most downstream segment is approximately 1,900 ft. long and has with a top elevation of approximately 88 ft.

NAVD 88. The upstream end of the system is located at the Springfield Ave. Bridge (just downstream of I-78) and ends just upstream of the confluence between the Rahway River and Van Winkles Brook.

4. USACE South Branch Flood Control Project of 1968. This is a combination of levees, floodwalls and channel modification. There are levees along the right bank of the Rahway River by the City of Rahway and floodwalls and channel modification along the river and left bank in South Branch. This system was constructed in the 1970's, it is fairly well maintained. This levee system is periodically inspected by the USACE.

3.0 HYDRAULC BASIS OF DESIGN

3.1 Model Development

The hydraulic analysis of the Rahway River documented herein consists of a combination of steady and unsteady state numerical modelling using the Hydrologic Engineering Center (HEC) River Analysis System (HEC-RAS) software. The first analysis of the Rahway River was performed with HEC-RAS version 4.2. The geo-spatial boundaries of the model are: to the north from West Orange by the Orange reservoir and to the south in Cranford township. This combination of steady and unsteady flow models was used to develop the without and with project conditions for this area only. Alternatives that included modification and/or a new reservoir were analyzed with the Hydrologic Modeling System (HEC-HMS) hydrologic model, and later input to the HEC-RAS model as discharge inflow hydrographs.

This hydraulic model was later improved by conversion to a complete unsteady state model. It was then extended to include the West Branch of the Rahway River, the main stem from Cranford to Arthur Kill and the tributaries Robinson's Branch and South Branch. This model was created using HEC-RAS version 5.0. This later version was used for the without and with project conditions of Robinson's Branch.

The first model geometry was created using surveyed topographic data for the area of Cranford and 2007 LiDAR of New Jersey for the upstream areas of Springfield and Millburn. In Cranford the channel cross sections were placed no more than 300 ft. apart, supplemented with 2 ft. contour topographic map from June 2009 to create overbanks cross sections. The 2009 topographic mapping was developed by Roger Surveying, PLLC. and included the survey of utilities, bridges and weirs. For the areas of Millburn and Springfield, channel cross sections, bridges and weirs were obtained from the FEMA

– Flood Insurance Study (FIS) HEC-RAS model. The FEMA channel cross section were supplemented with LiDAR to create the overbanks cross sections.

The improved second model geometry, created for the extended Rahway River model, use additional surveyed topographic mapping for Robison's Branch, developed in 2012 by McKim & Creed. This survey also included channel cross sections (which were placed no more than 300 ft. apart), utilities, bridges and weirs. Additional LiDAR and FEMA – FIS data were used to develop the geometry for the tidal portions of the Rahway River, South Branch and Upper Robinson's Branch.

3.2 Model Calibration and Validation

The HEC-RAS model was calibrated with data from two floods. The nor'easter flood of April 15-19 2007 was used for the first model in the areas of Cranford and Springfield. The August 27-31 2011 flood, caused by Tropical Storm Irene, was used for the second improved model which included the Robinson's Branch. A hydrologic analysis of the Rahway River Basin performed HEC-HMS software provided discharge hydrographs for the April 2007 nor'easter and Tropical Storm Irene floods. The flows and hydrographs computed by the HEC-HMS model of the Rahway River Basin were referenced to cross sections and locations in the HEC-RAS riverine geometry using the HEC-HMS hydrologic nodal diagram of the Rahway River Basin.

In the first step of calibration; visual observations, Arc-GIS land cover and aerial photographs, were used to characterize the initial Manning's n-value. The overbanks varied from open spaces and parking lots to areas with high density vegetation or structures. Initial n-values were set between 0.025 and 0.045 for the channel, and overbank n-values were estimated to range between 0.025 and 1.5. Manning's n-values of 1.5 in the geometry file implies areas with no flow and high obstructions. Ineffective flow areas were identified in the overbanks, at bridges and bends to better represent the effects of structures and topography on flow conveyance. Contraction and expansion coefficients for the open channel sections were initially set at 0.1 and 0.3, and for bridge sections, at 0.3 and 0.5.

In the second step of calibration, field surveys provided a total of 26 high water marks (HWMs) for the Township of Cranford and 16 HWMs for the Robinson's Branch. Further adjustments to Manning's n-values, contraction and expansion coefficients, weir coefficients, ineffective flow areas, and other loss coefficients were made in order to reproduce the WSEs to within ±0.5 ft. of the observed HWMs. Tables 1 and 2 show the HWMs elevations for the April 2007 nor'easter and TS Irene, as well as the location and computed WSEs. Figures 2 thru 5 are the HEC-RAS WSEs calibration profiles for April 2007 and Irene storm events respectively.

Table 1: TS Irene peak observed HWMs and HEC-RAS calibration.

River Reach	HEC-STA	Computed WSE (ft., NAVD88)	HWM Elevation (ft., NAVD88)	Difference (ft.)	Location
Robinson's Branch	8847.78	25.41	25.50	-0.09	***01396000 Robinson's Branch***
Robinson's Branch	6724.74	19.96	19.82	0.15	644 Maple
Robinson's Branch	5922.51	19.85	19.72	0.13	941 JEFFERSON
Robinson's Branch	5902.69	19.65	19.76	-0.11	Jeff-Elm-Bouman
Robinson's Branch	5282.55	19.28	19.58	-0.30	633 Bouman
Robinson's Branch	4008.99	18.78	18.99	-0.21	1229 St. Georges
Robinson's Branch	2583.05	18.29	18.30	-0.01	1452 Church
Robinson's Branch	1950.95	17.10	17.00	0.10	360 Hamilton
Robinson's Branch	962.53	16.80	16.80	0.00	277 Hamilton
Robinson's Branch	777.87	16.10	15.91	0.19	Irving 1653
Millburn&Springf	82722.00	76.61	76.02	0.59	***01394500 Springfield***
Cranford&Clark	75673.94	71.15	72.55	-1.40	***01394620 Kenilworth***
Cranford&Clark	33116.94	19.59	19.81	-0.22	***01395000 Rahway***
Cranford&Clark	28743.80	15.03	14.98	0.05	182 Grand
Rahway	27995.02	14.49	14.43	0.06	***Confluence***
Rahway	26897.93	11.52	11.60	-0.08	Monroe Ave.

Table 2: April 15, 2007 peak observed HWMs and HEC-RAS calibration.

River Reach	HEC-STA	HEC Calibration WSE (ft., NAVD88)	HWM Elevation (ft., NAVD88)	Difference (ft.)	Location
Springfield	22865.14	74.24	74.44	-0.20	***01394500 Springfield***
Rahway River 1	15541.78	72.1	71.97	0.13	Lenape Park Dam Upstream
Rahway River 1	15289.71	69.51	69.17	0.34	Kenilworth Blvd. Upstream
Rahway River 1	15220.78	68.89	68.57	0.32	Kenilworth Blvd. Downstream
Rahway River 1	10200.53	68.44	68.22	0.22	Footbridge
Rahway River 1	8356.55	67.45	67.22	0.23	Springfield Ave. Upstream
Rahway River 1	8239.93	67.1	66.77	0.33	Springfield Ave. Downstream
Rahway River 1	7093.82	66.22	66.22	0.00	Eastman St. Upstream
Rahway River 1	7035.95	66.16	66.02	0.14	Eastman St. Downstream
Rahway River 1	6034.42	65.79	65.47	0.32	Eastman St. Upstream
Rahway River 1	5979.88	65.39	65.27	0.12	Eastman St. Downstream
Rahway River 1	5390.42	65.25	65.02	0.23	Alden St.
Rahway River 1	4857.53	65.1	64.82	0.28	Springfield Ave. Upstream
Rahway River 1	4807.32	65.02	64.62	0.40	Springfield Ave. Downstream

Rahway River 1	3481.18	64.55	64.07	0.48	Hansel's Dam Upstream
Rahway River 1	3249.36	64.2	63.92	0.28	Union Ave. N Upstream
Rahway River 1	3201.12	63.01	63.32	-0.31	Union Ave. N Downstream
Rahway River 1	2351.8	62.5	62.77	-0.27	North Ave. E Upstream
Rahway River 1	2882.7	61.59	61.07	0.52	North Ave. E Downstream
Rahway River 1	2076.15	61.88	61.42	0.46	Railroad Bridge Upstream
Rahway River 1	1769.88	61	61.02	-0.02	South Ave. E Upstream
Rahway River 1	1265.99	60.2	60.22	-0.02	Chestnut St.
Rahway River 1	20.6	59.31	59.52	-0.21	Droescher's Dam Upstream
Rahway River 1	11.46	58.24	58.17	0.07	Lincoln Ave. Bridge Upstream
Rahway River 1	11.45	57.78	57.67	0.11	Lincoln Ave. Bridge Downstream
Rahway River 1	11.319*	56.21	56.07	0.14	940 ft. Below Lincoln Ave.

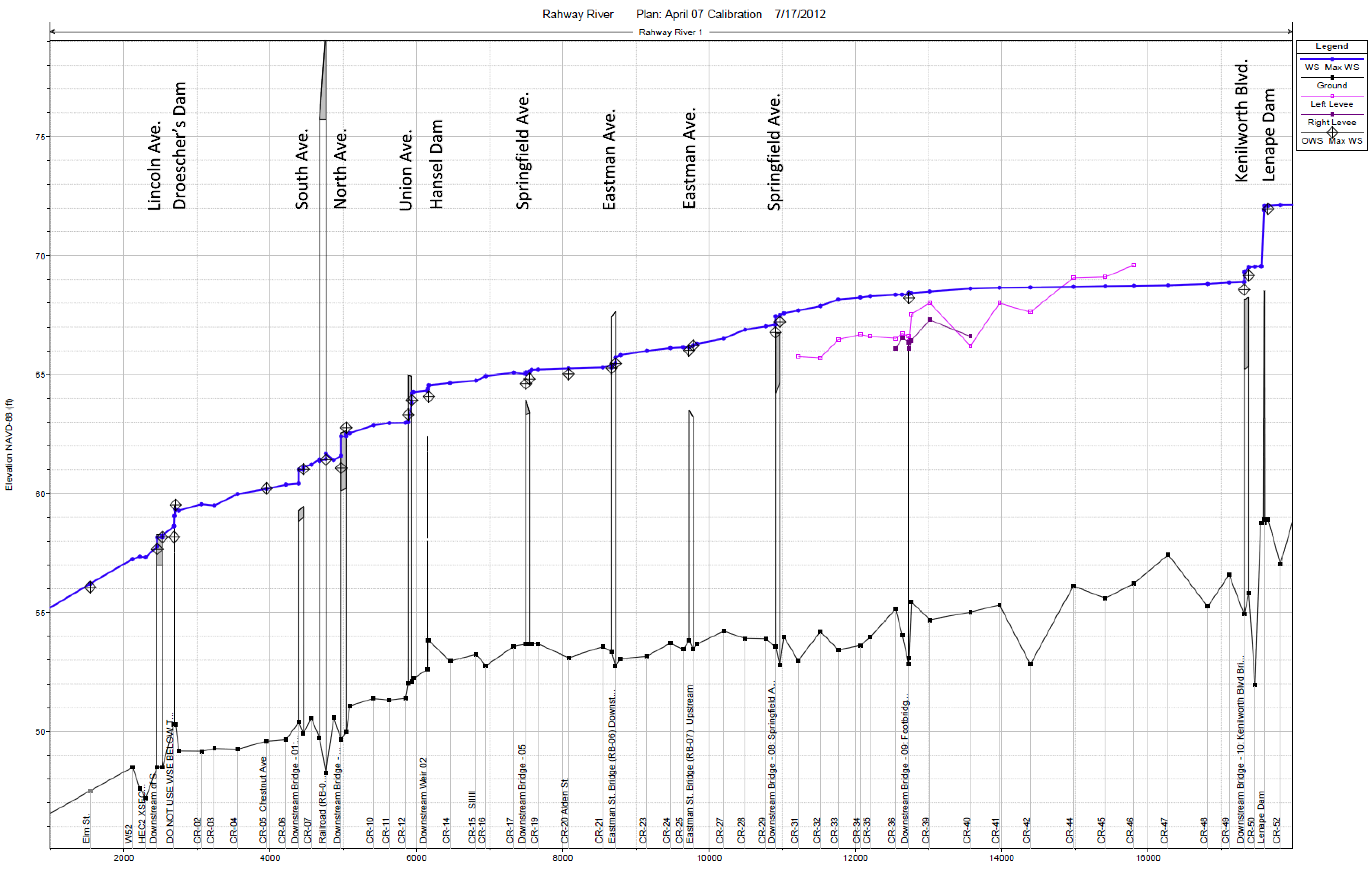
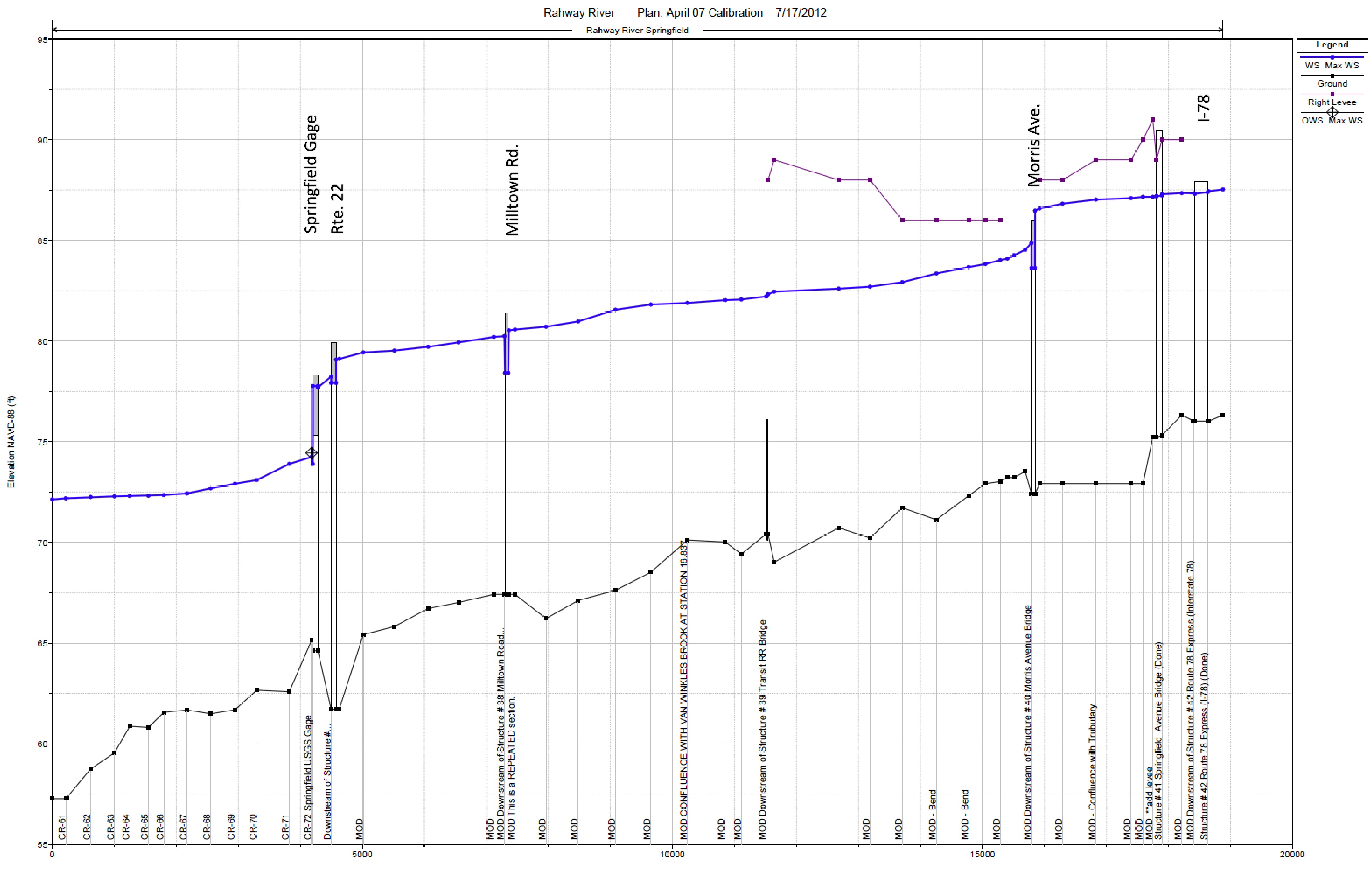


Figure 2: Computed water surface profile and observed HWMs for the April 2007 event in the Rahway River at Cranford Township.



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4 Figure 3: Computed water surface profile and observed HWMs for the April 2007 event in the Rahway River at Cranford and Springfield Townships.

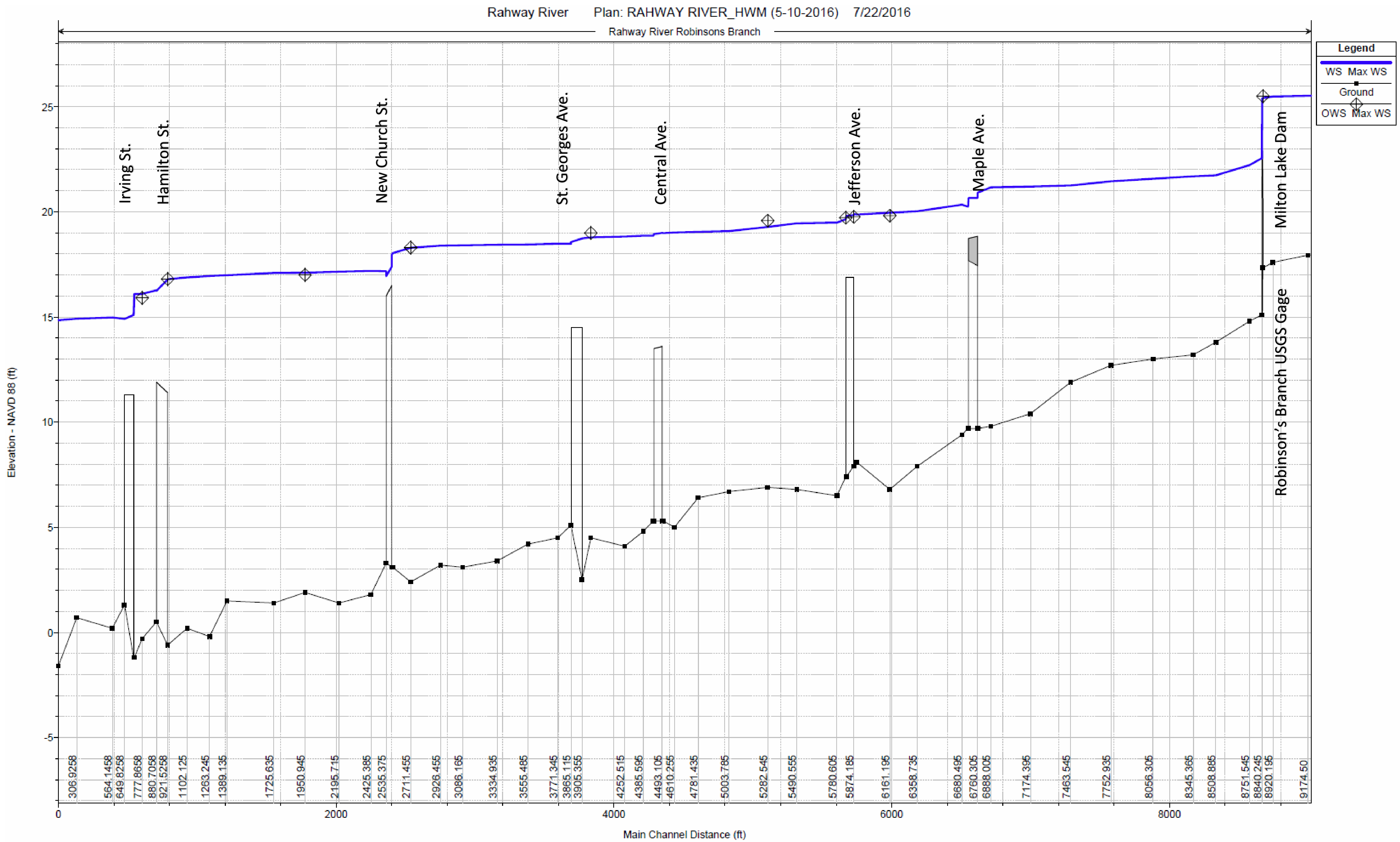

Figure 4: Computed water surface profile and observed HWMs for TS Irene in Robinson's Branch.

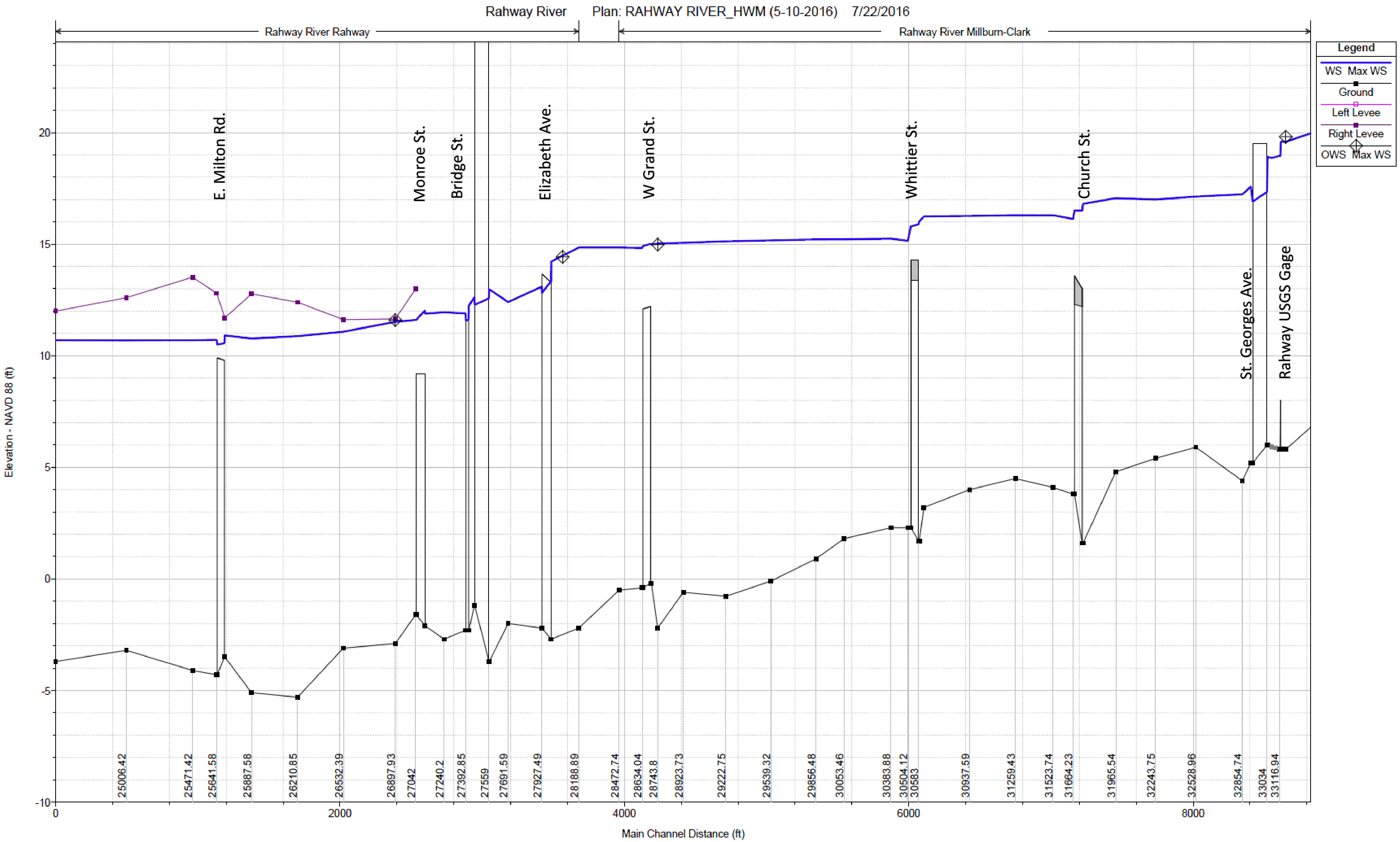

Figure 5: Computed water surface profile and observed HWMs for TS Irene in the Rahway River, from the confluence with the South Branch to the USGS gage at Rahway.

The next step of the calibrating process is to replicate the USGS rating curves (RC) and observed annual peak stages at the USGS gages. This allowed an accurate determination of WSEs for a wide range of flows. This additional calibration step was only performed for the unsteady, or second, hydraulic model. The calibration and comparison between HEC-RAS computed RC, the USGS RC and the observed annual peak flows can be seen in Figures 6 thru 9. In these figures the blue line is represent the HEC-RAS computed RC, the black line represents the USGS RC and the dots represent the observed annual peak flows. All elevations for the RC and hydrographs are in NAVD 88. Most of the computed RC are within ±0.5 ft. of the USGS RC, except at the Rahway and Millburn gages. The HEC-RAS-computed rating curves differ from the USGS rating curves at their upper ends for several reasons. First, the USGS rating curves are subject to error at higher flows because very few flow measurements are made, and are available for, large floods. Second, overbank flow is much harder to measure and predict than channel flow. Third, USGS rating curves are extrapolated to high flow values from orders of magnitude lower flow observations. Another factor is the tidal influence on the Rahway River at Rahway USGS stream gage. The unsteady HEC-RAS model was further validated by simulating and reproducing TS Irene stage hydrographs at USGS gage, shown in Figures 10 thru 12. In these figures the blue line is represent the HEC-RAS computed stage hydrograph, the black line represents the USGS RC and the green line represent the observed flows hydrographs. All hydrographs elevations are in NAVD 88. The compute stage and flow hydrographs replicated the observed stage and flow hydrographs for the gages at Springfield, and on Robinson's Branch. During TS Irene the Rahway gage was submerged by the coastal surge and the gage records are discontinuous, therefore the TS Irene stage and flow hydrographs for the Rahway gage are not reliable for this event.

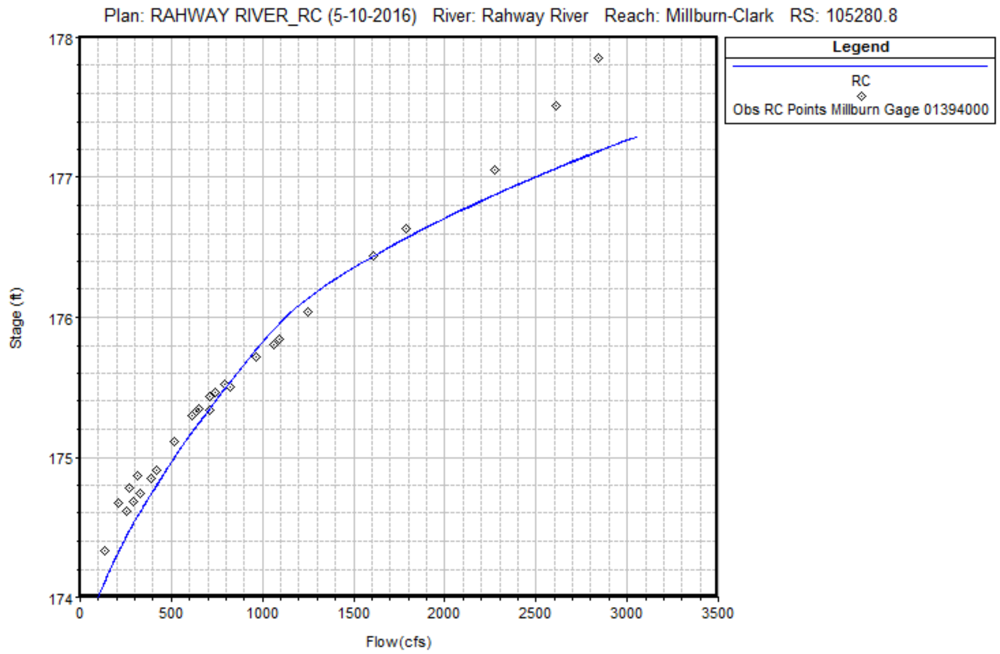

Figure 6: Observed annual peaks flows for USGS gage No.01394000 at Millburn.

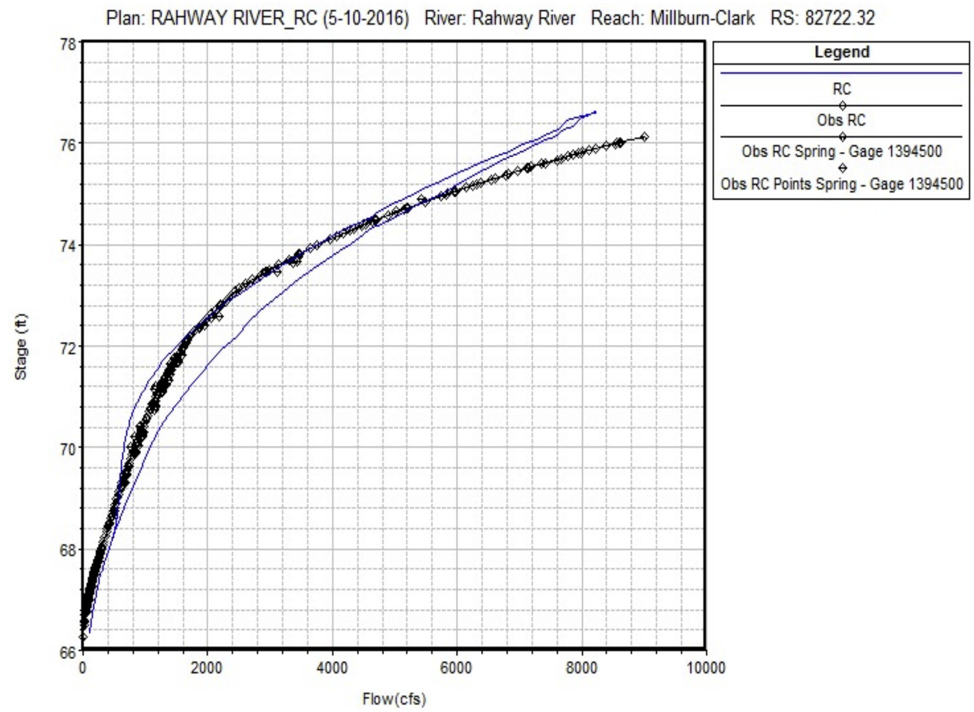

Figure 7: Observed annual peak flows and RC for USGS gage No. 01394500 at Springfield.

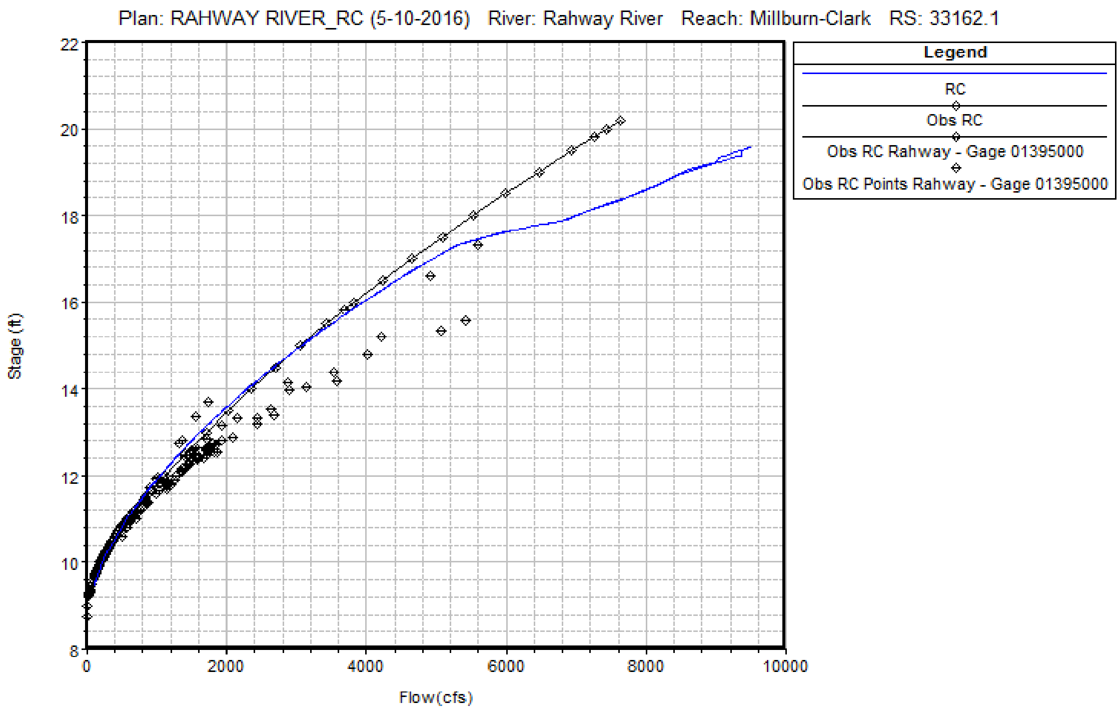

Figure 8: Observed annual peaks flow and RC for USGS No. gage 01395000 at Rahway.

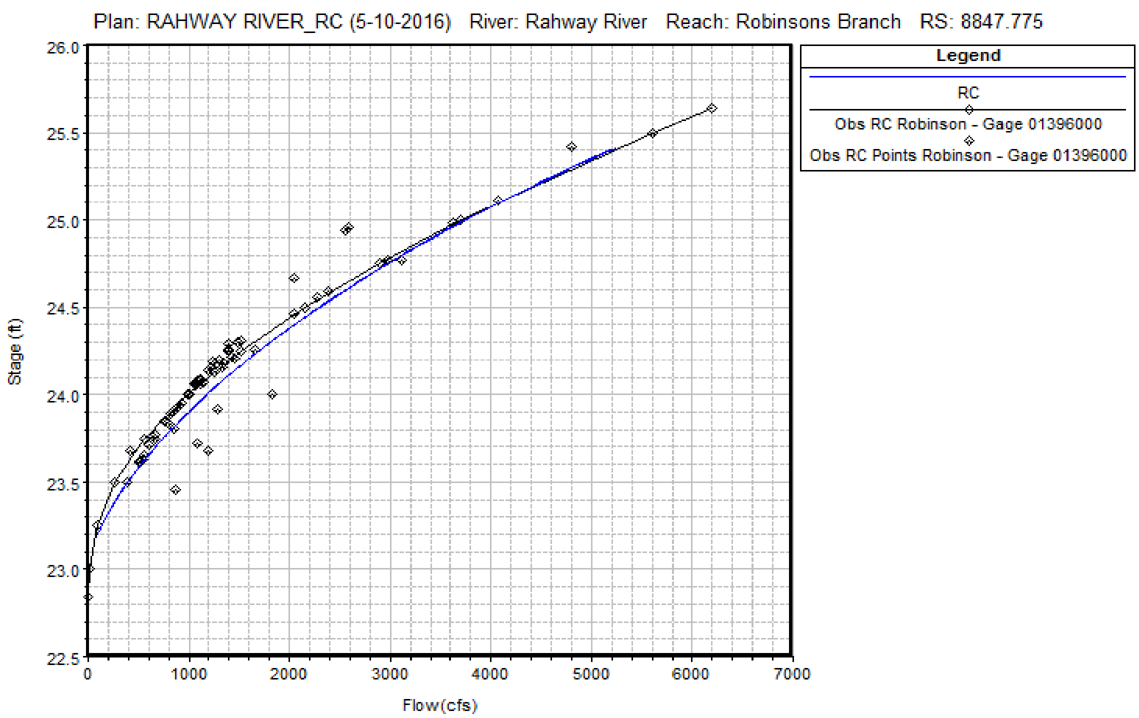

Figure 9: Observed annual peak flows and RC for USGS gage No.01396000 at Robinson's Branch.

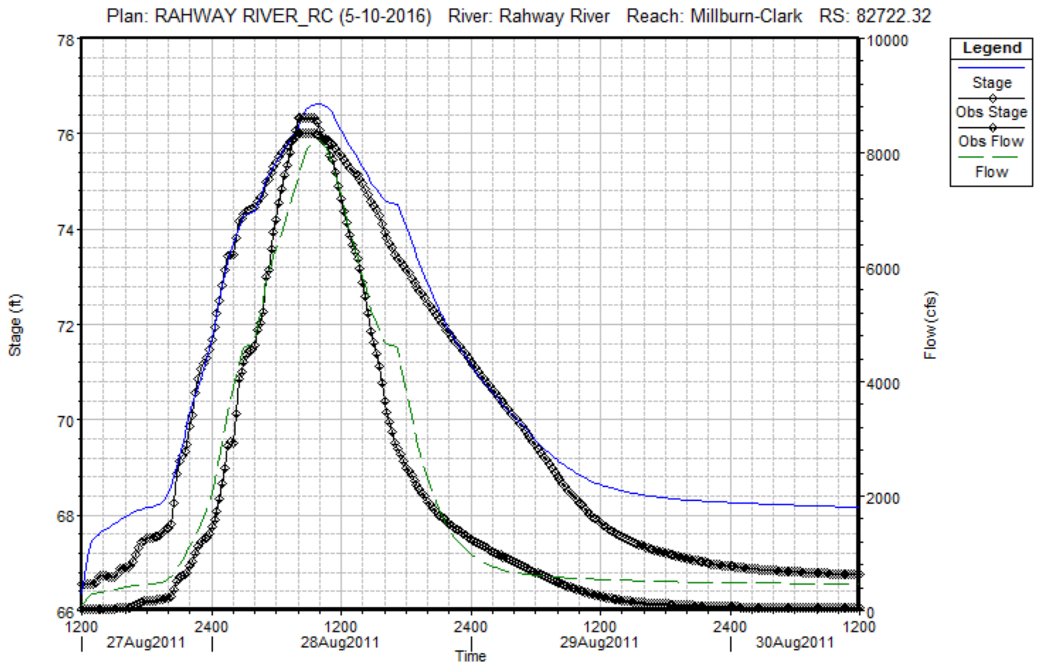

Figure 10: Observed and computed stage and flow hydrograph for USGS gage No.01394500 at Springfield.

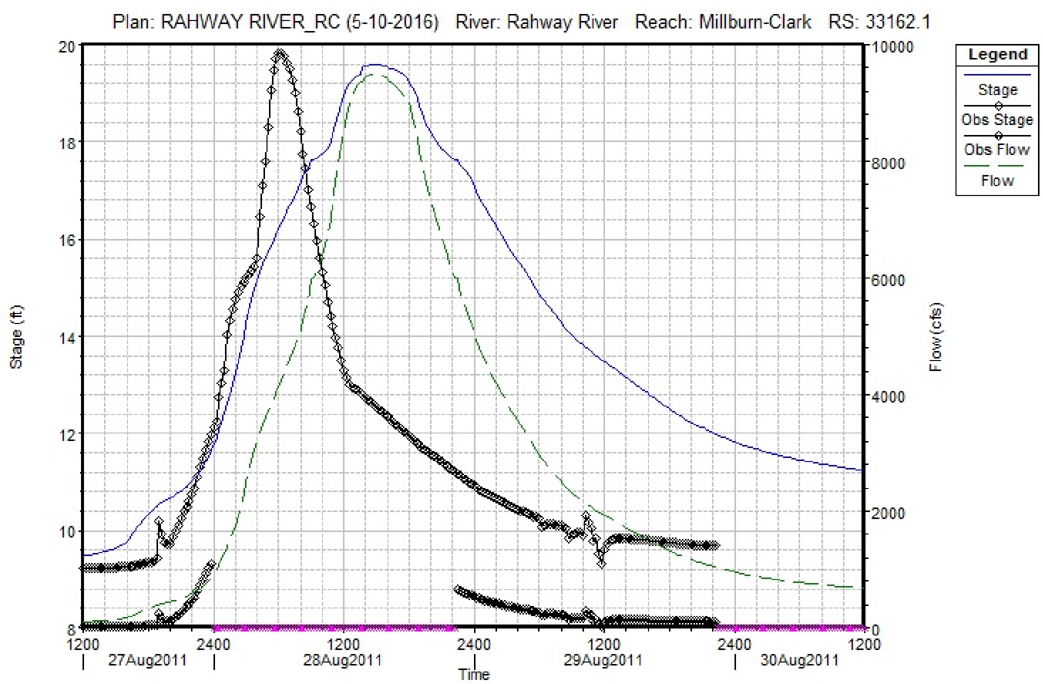

Figure 11: Observed and computed stage and flow hydrograph at USGS No. 01395000 at Rahway.

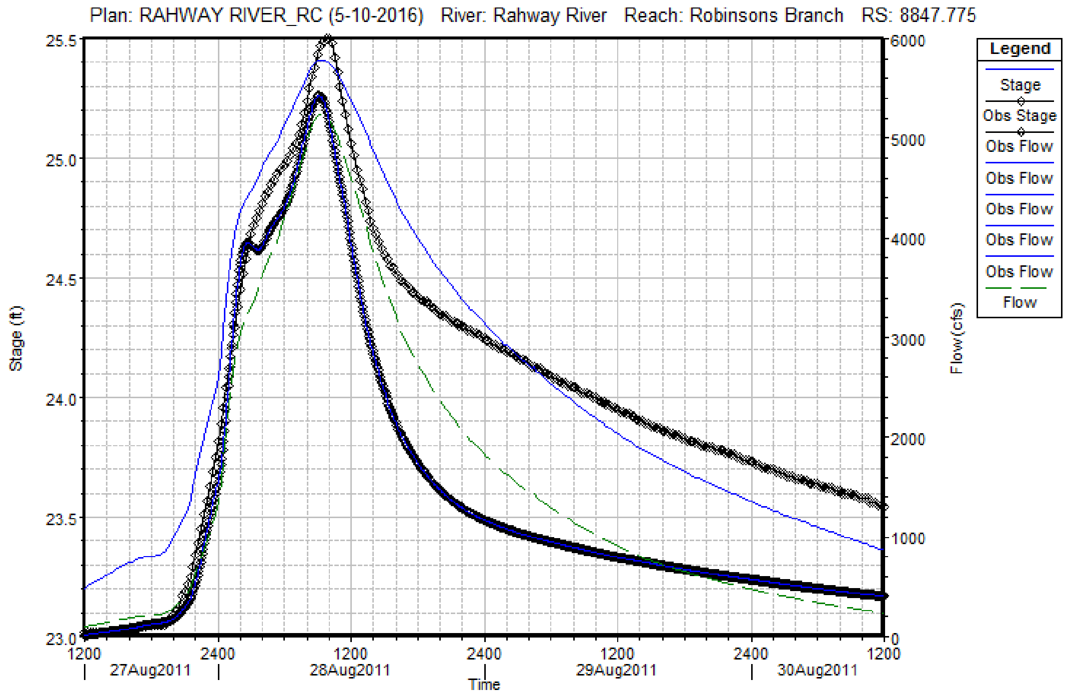

Figure 12: Observed and computed stage and flow hydrographS at USGS No. 01396000 at Robinson's Branch.

3.3 Tidal Influenced areas and Fluvial/Tidal Joint Probability

3.3.1 Boundary Conditions

In order to run a hydraulic model of the Rahway River with a set of hypothetical events, a starting elevation or boundary condition had to be established for the mouth of the River. Since the Rahway River flows into the Arthur Kill (a tidal strait), it was necessary to perform a tidal-fluvial correlation to establish the backwater elevations that may occur due to tide and surge during a typical fluvial event. In this analysis, both the tidal gage at Bergen Point (ID: 8519483) and the fluvial gage at Rahway (USGS No. 10395000) were used to correlate harbor data with matching fluvial data. Only significant yearly fluvial events and the corresponding maximum tidal stage were used in the correlation analysis. The available simultaneous data for both gages is approximately 34 years. The results shows that there is a 99.9% probability during the 50 years project period that the tidal stages will be at or below the 20% chance of annual exceedance event (5-yr) for any given fluvial flood. In addition, the results showed that most fluvial events are coupled with tidal events below the 100% of annual exceedance events (1-yr). Figure 13 shows the frequency of significant flow events plotted with the frequency of the maximum tide for those events all at the Rahway gage.

Based on this analysis the follow tidal boundary conditions were established. The 100% annual exceedance fluvial event (1-yr) was coupled with the 100% annual exceedance tidal event (1-yr). The 50% annual exceedance fluvial event (2-yr) was coupled with the 50% annual exceedance tidal event (2-yr). All other fluvial events were coupled with the 20% chance annual exceedance tidal event (5-yr).

The North Atlantic Coast Comprehensive Study (NACCS) coastal stage-frequency curve at Rahway at mouth (node ID: 11659) was used to develop stages hydrographs for the tidal boundary condition. The shape of the tidal stage hydrographs were develop using the Bergen Point gage tide cycle characteristics. Each hypothetical stage frequency hydrographs peak was set to be coincidental to each hypothetical flow hydrograph peak at the mouth of the Rahway River. Figure 14 shows the tidal stage hydrographs boundary condition for each fluvial event.

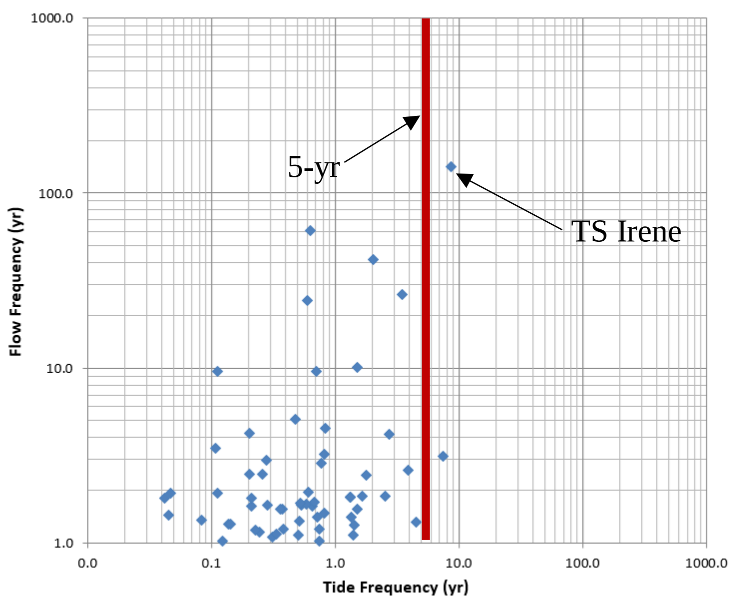

Figure 13: Significant fluvial events and the maximum tide during the event.

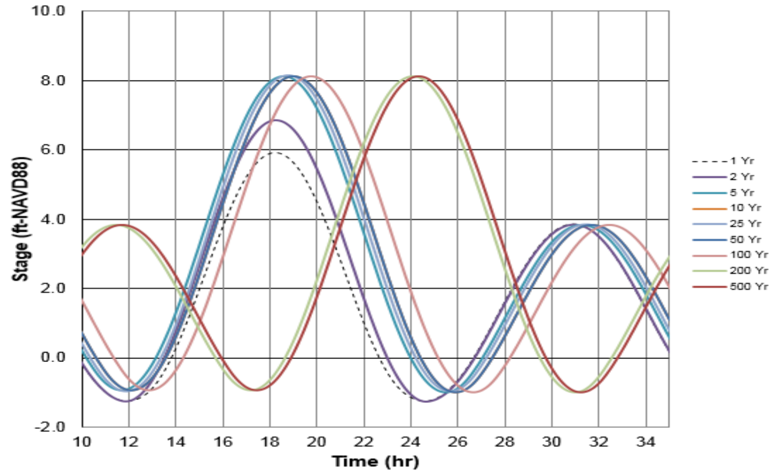

Figure 14: Stage hydrograph for each fluvial frequency event for the Rahway River at mouth.

3.3.2 Joint Stage-Probability Curves

In the lower portions of the Rahway River and the Robinson's Branch, flood stages are produced by both fluvial and tidal events. To account for the probability of a particular location to get flooded by a tidal and fluvial event, a joint probability analysis was performed. New joint fluvial and tidal stage-frequency probability curves were developed for each cross section within the tidally influence area. The new curves were computed for with and without project condition. By using joint probability curves the benefits of reducing the risk of flooding from both fluvial and coastal events was accounted for.

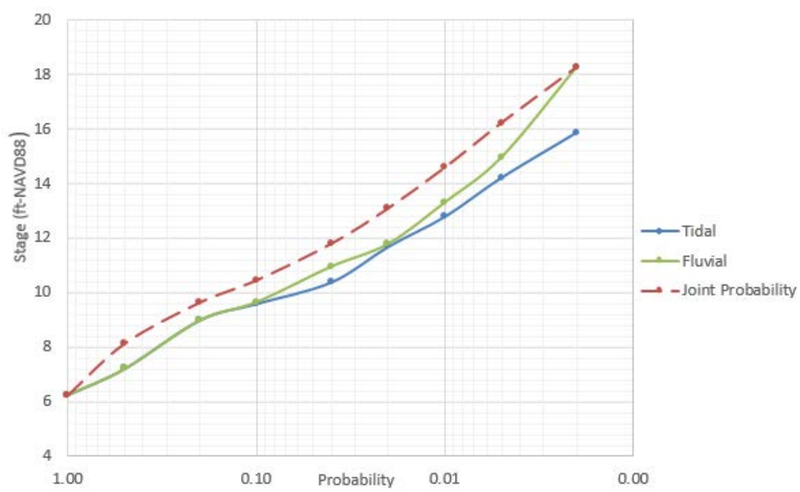

Figure 15: Joint probability curve for Robinson's Branch at mouth.

3.3.3 Sea Level Change (SLC)

Department of the Army, Engineering Regulation ER 1100-2-8162 provides guidance on incorporating the effect if projected SLC across the project life of USACE projects. Technical Letter ETL 1100-2-1 requires the use of at least three scenarios to estimate future sea levels. The USACE low rate of future SLC is based in the historic rate in the vicinity of the project area. Figure 16 shows the sea level rise trends and 33 years of data from the NOAA tide gage # 8519483 at Bergen Point, New York. This value was used to compute the expected low rate of SLC. The intermediate and high rates of future SLC are determined from the modified National Research Council (NRC -1987) eustatic sea-level change scenarios and the IPCC (2007) Types I and III respectively. The effects of vertical land movement (VLM) was also considered as a component of sea-level rise. The projected low, intermediate and high SLC scenarios are shown in Table 3.

Table 3: Projected SLC for the period of analysis of 50 years at Bergen Point #8519483, and NRC/IPCC SLC scenarios.

Year	**USACE Net SLC (ft.)**		
	Low	**Intermediate**	**High**
2015	0.00	0.00	0.00
2018	0.05	0.00	0.00
2023	0.12	0.10	0.18
2028	0.20	0.21	0.38
2033	0.27	0.32	0.60
2038	0.35	0.43	0.84
2043	0.43	0.55	1.09
2048	0.50	0.68	1.37
2053	0.58	0.80	1.66
2058	0.66	0.94	1.97
2063	0.73	1.07	2.30
2068	0.81	1.22	2.65

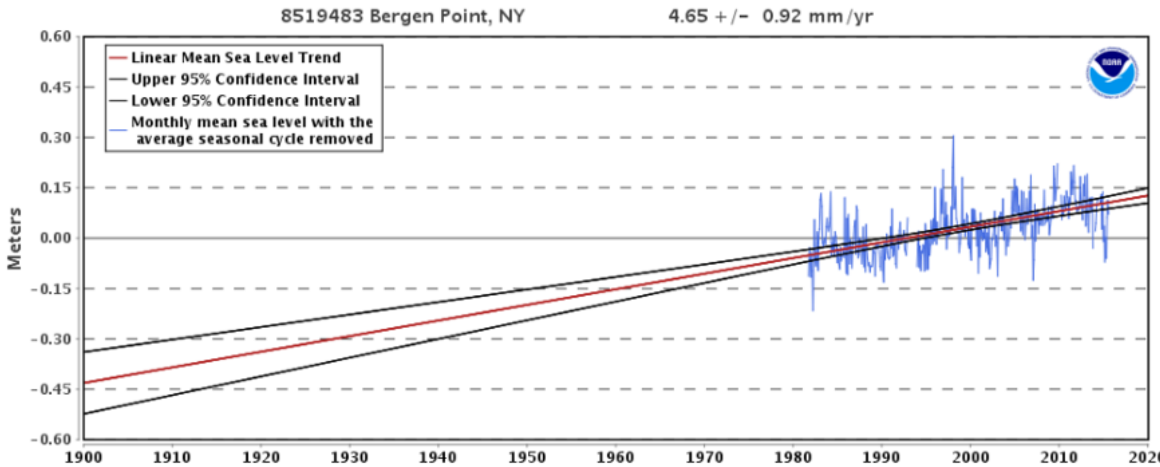

Figure 16: Sea level rise trends and monthly mean seal level at NOAA tide gage No. 8519483 at Bergen Point.

Sea level rise is expected to have impacts on direct coastal flooding along the Rahway River tidal influenced area, including impacts to properties and critical infrastructure. However, this study is limited to fluvial flood events. Future conditions, with and without project includes the historic local rate of SLR, projected 50 years into the future. All future conditions runs used tidal stage hydrograph boundary conditions that included the historic rate of SLR. The impact of SLR projections are implicit to the hydraulic and economic computation due to the use of joint stage-probability curves that were modified for future conditions to included SLR.

3.4 Present and Future Conditions - Hydraulic Profiles

3.4.1 Flow Line Computation

The calibrated HEC-RAS models of the Rahway River was used to determine the present and future, with and without project conditions WSEs for the 0.2, 0.5, 1, 2, 4, 10, 20, 50 and 100% chance of annual exceedance events (1, 2, 5, 10, 25, 50, 100, 250, and 500-yr frequency). Inundation maps for without project condition in Cranford and Robinson's Branch are shown in Figure 17 and Figure 18. Table 4 shows the expected increase in WSEs due to urbanization in the next 50 years for the 4%, 1% and 0.2% annual chance of exceedance events (25, 100 and 500-yr). This results demonstrate a minimal increase in flooding due to expected future urbanization of the basin.

Figure 19 and**Error! Reference source not found.** shows the without project present conditions WSEs profiles for the Rahway River in Cranford and Millburn-Springfield Townships, developed with the first hydraulic model. Figure 21**Error! Reference source not found.** thruFigure 28 show the without project present conditions WSEs profiles for the Rahway River of downstream of Cranford Township, Robinson's and South Branch, developed with the second or improved hydraulic model.

Table 4: Difference in WSEs between future and present without project condition.

Town	**Location**	**W/O Project Future Increase in WSEs (ft.)**		
		4% (25-yr)	1% (100-yr)	0.2% (500-yr)
Springfield/Millburn	Downstream of I-78	0.20	0.15	0.17
Springfield	Just downstream of Morris Ave. Bridge	0.03	0.12	0.03
Springfield	Upstream of Route 22	0.03	0.08	0.03
Cranford	Lenape Park	0.01	0.03	0.01
Cranford	Kenilworth Area	0.04	0.14	0.04
Cranford	Nomahegan Park	0.04	0.10	0.04
Cranford	Below Nomahegan Park - Footbridge	0.04	0.10	0.04
Cranford (Town)	McConnell Park	0.04	0.11	0.04
Cranford (Town)	Hansel Dam Park - Casino Brook Area	0.05	0.10	0.05
Cranford (Town)	From Union Ave. to North Ave. Bridge	0.02	0.07	0.02
Cranford	South Ave. Bridge	0.10	0.13	0.10
Cranford	Just downstream of Lincoln Ave. Bridge	0.13	0.13	0.13

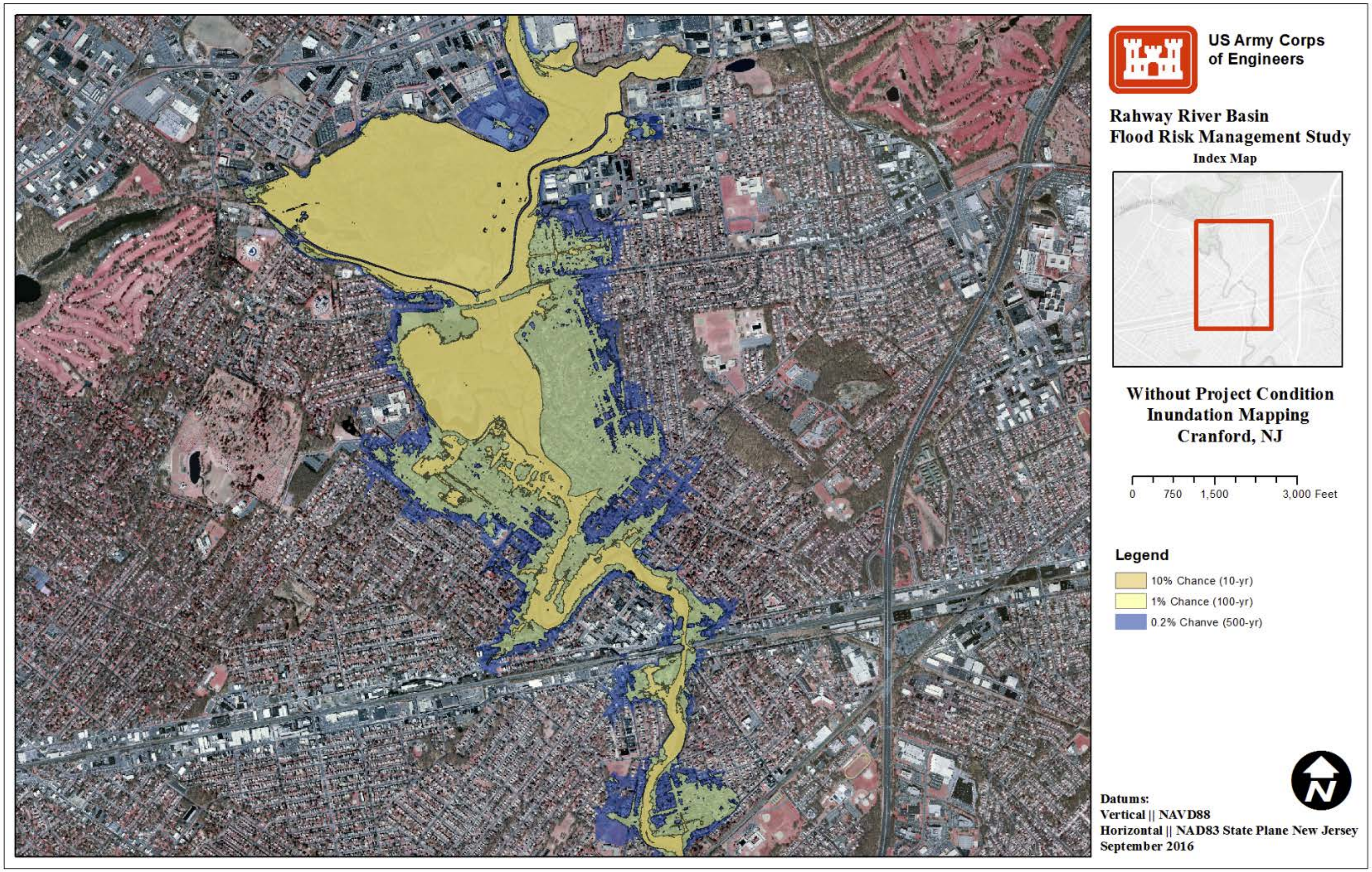

Figure 17: Without project condition inundation map in Cranford Township.

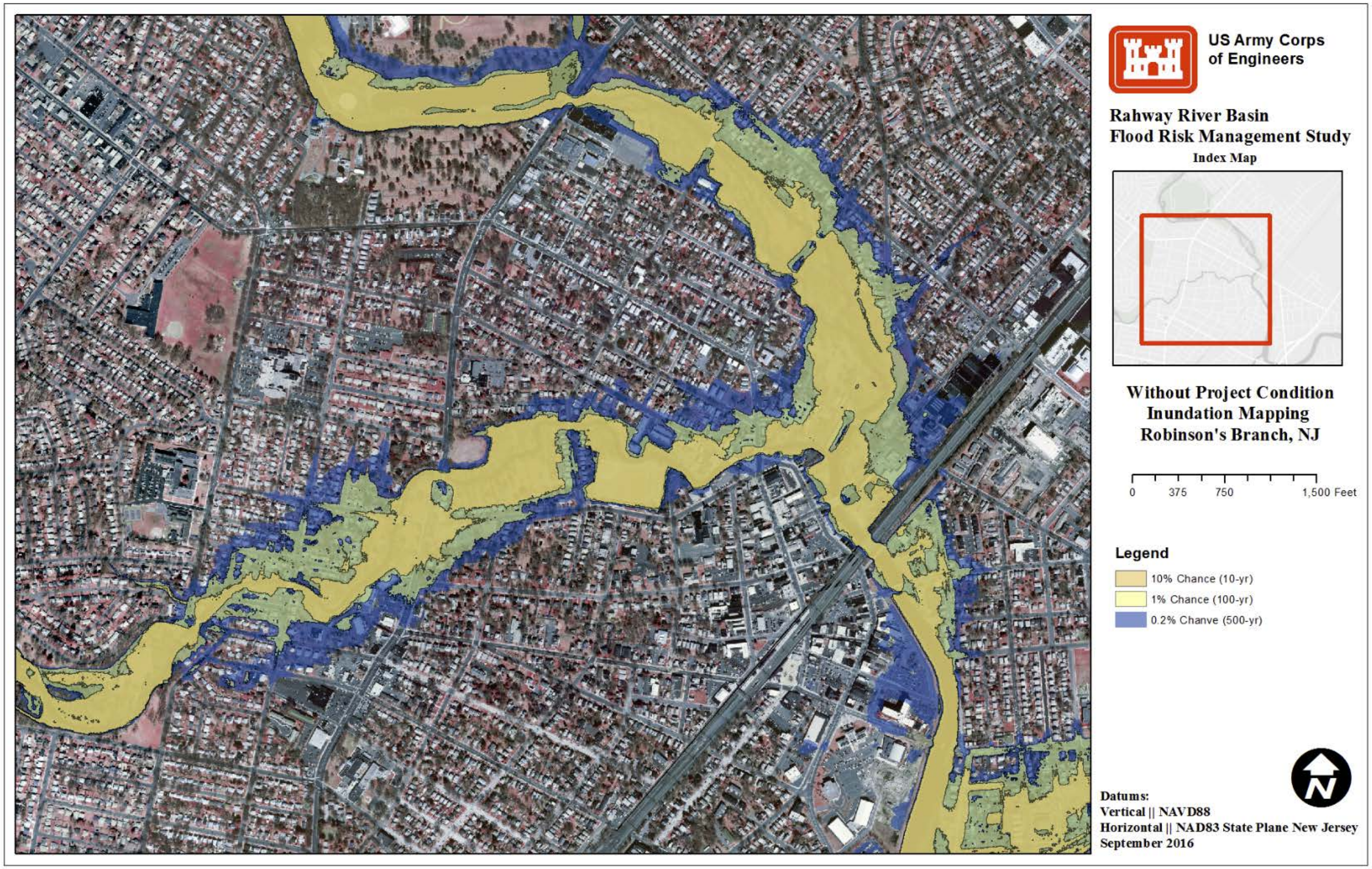

Figure 18: Without project condition inundation map in Robinson's Branch.

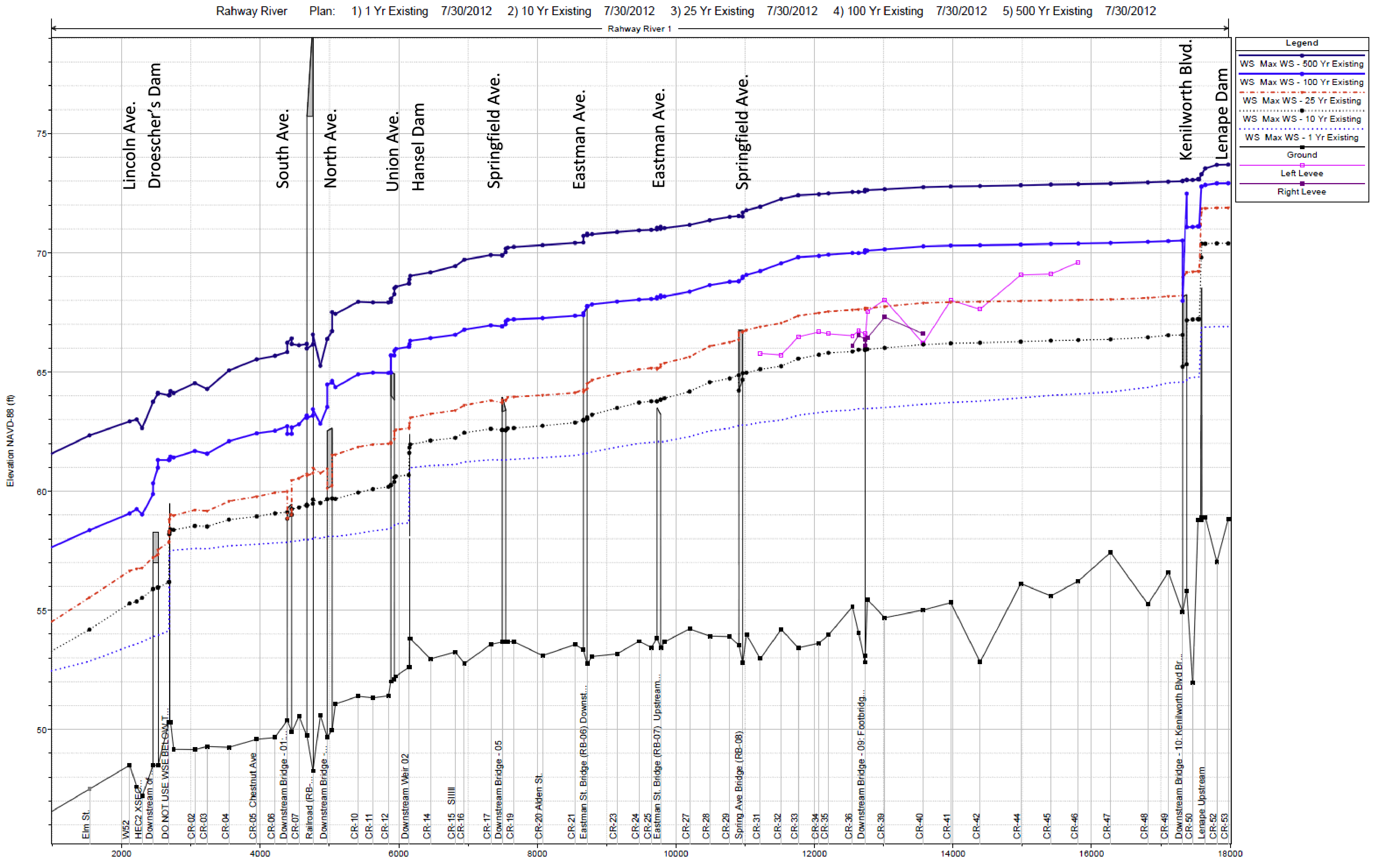

Figure 19: Without project condition computed water surface profile for the 99.9, 4, 1 and 0.2% chance of annual exceedance (1-yr, 25-yr, 100-yr and 500-yr) events.

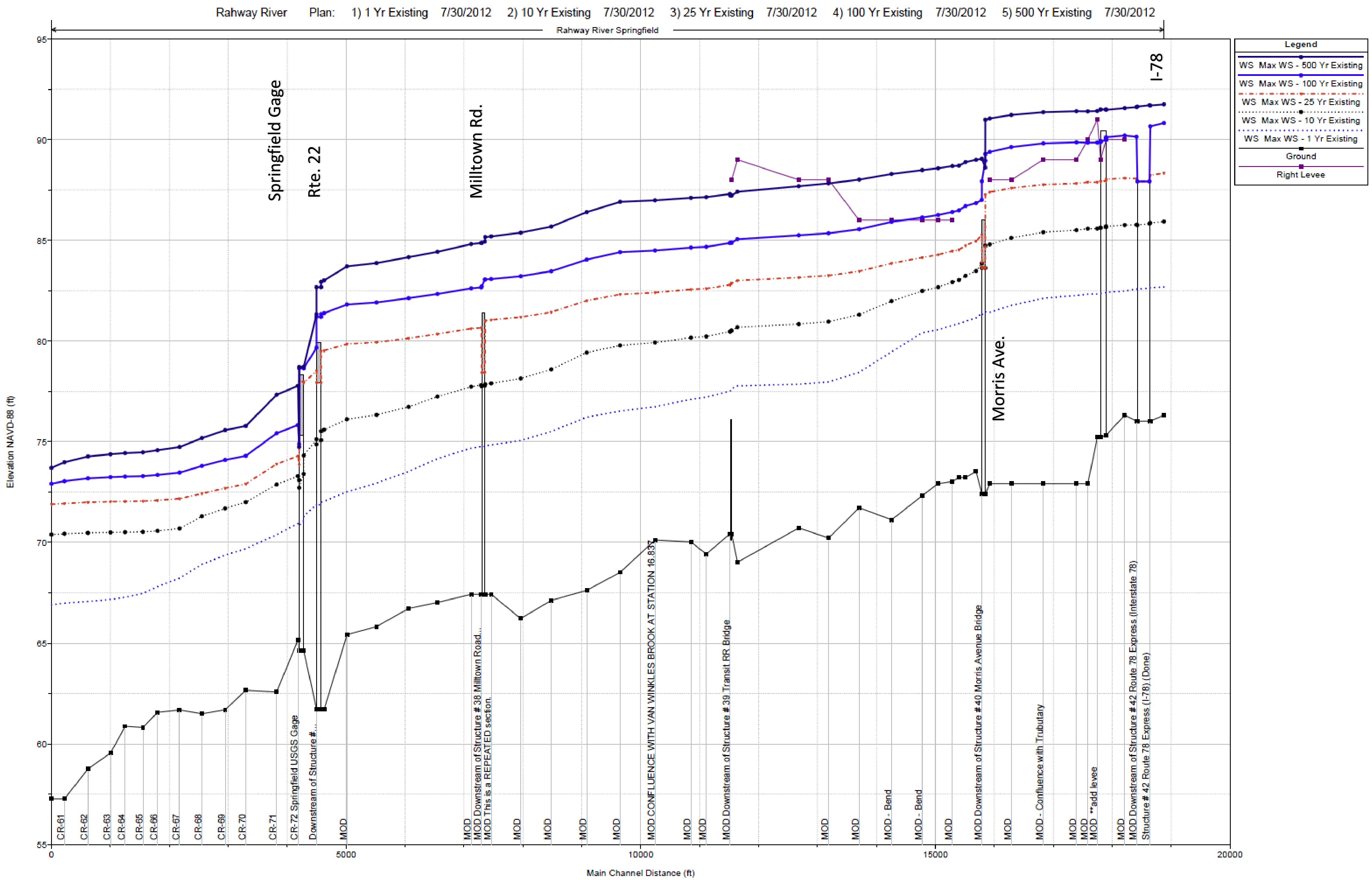

Figure 20: Without project condition computed water surface profile for the 99.9, 4, 1 and 0.2% chance of annual exceedance (1-yr, 25-yr, 100-yr and 500-yr) events.

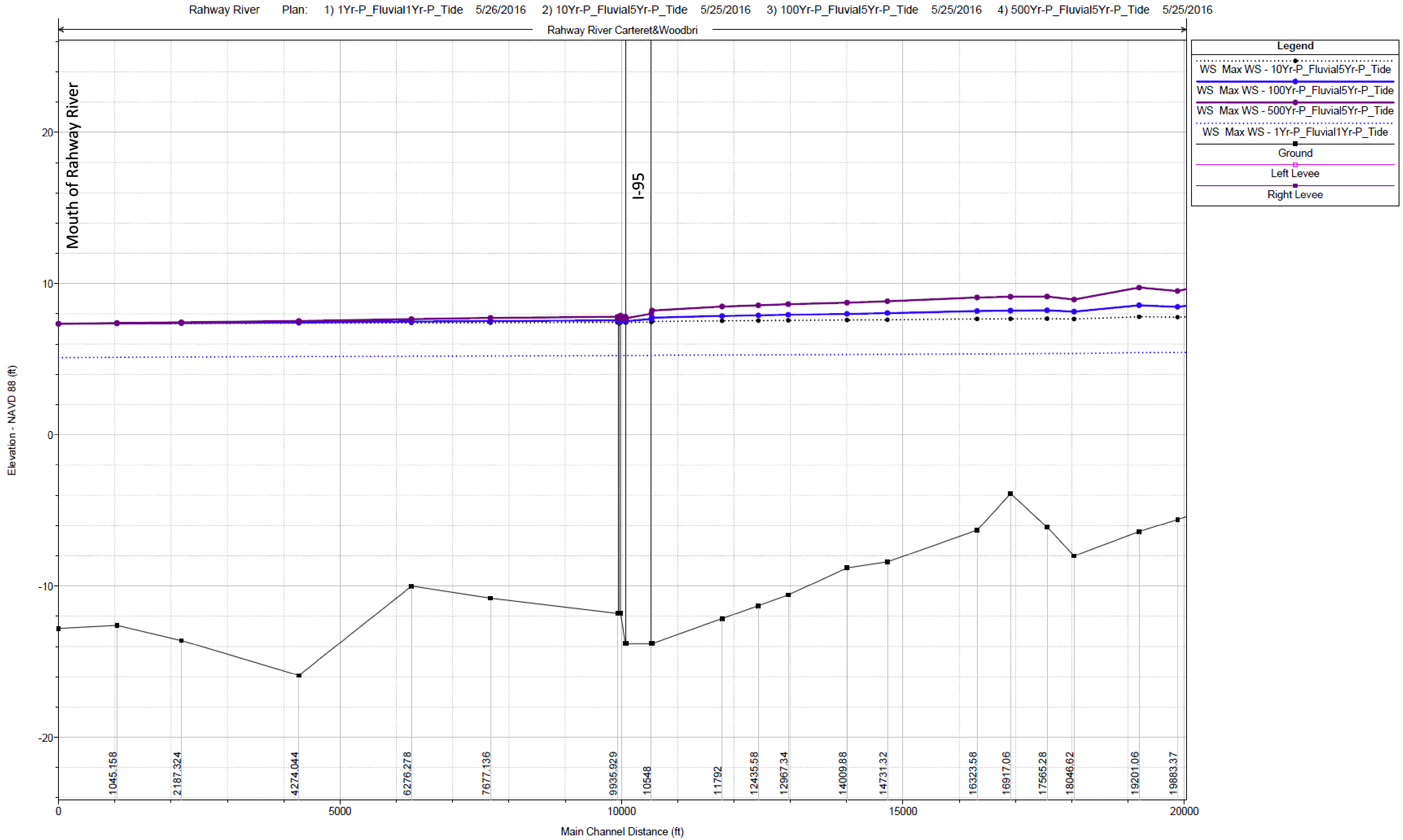

Figure 21: Without project condition computed water surface profile for the 99.9, 4, 1 and 0.2% chance of annual exceedance (1-yr, 25-yr, 100-yr and 500-yr) events.

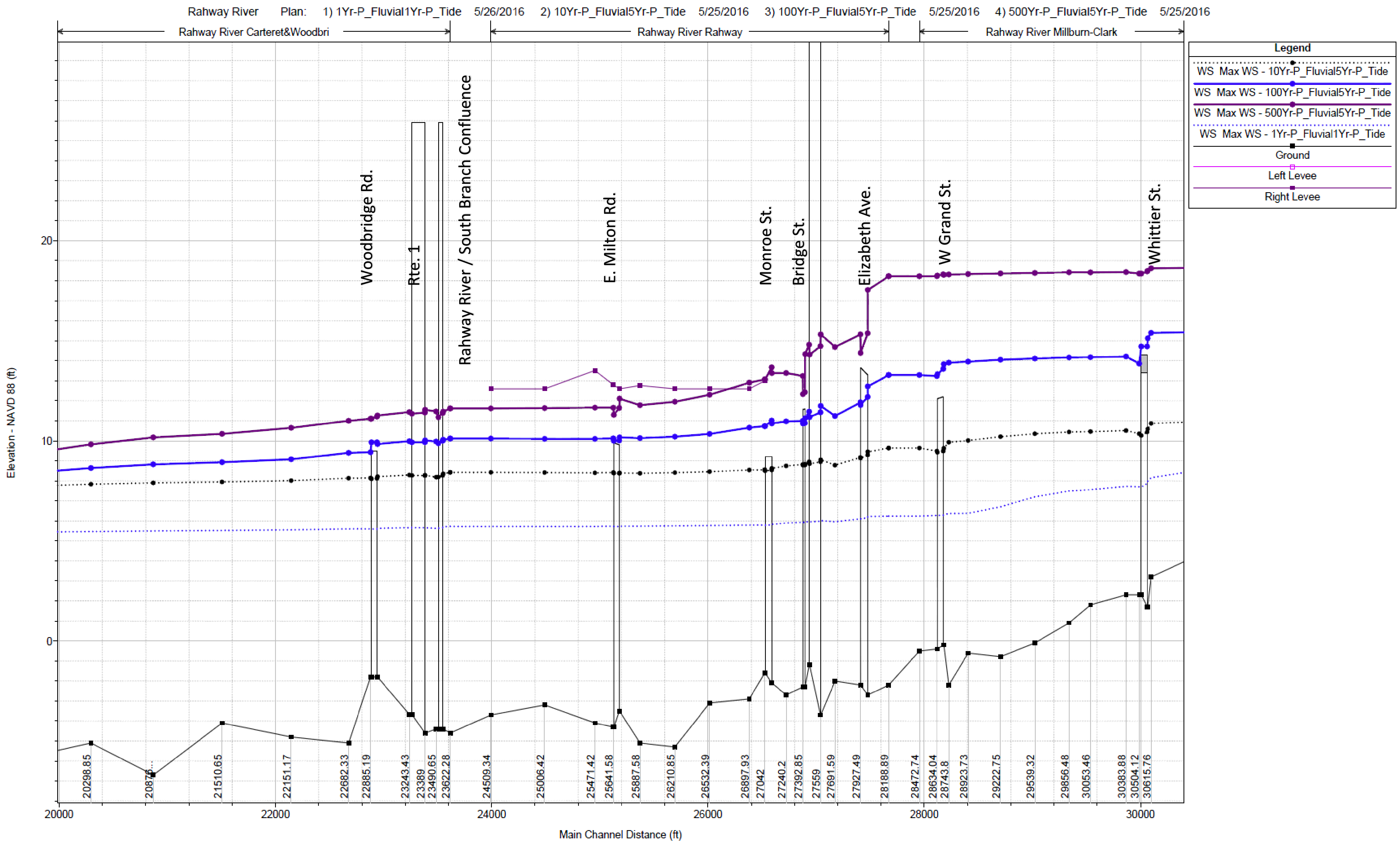

Figure 22: Without project condition computed water surface profile for the 99.9, 4, 1 and 0.2% chance of annual exceedance (1-yr, 25-yr, 100-yr and 500-yr) events.

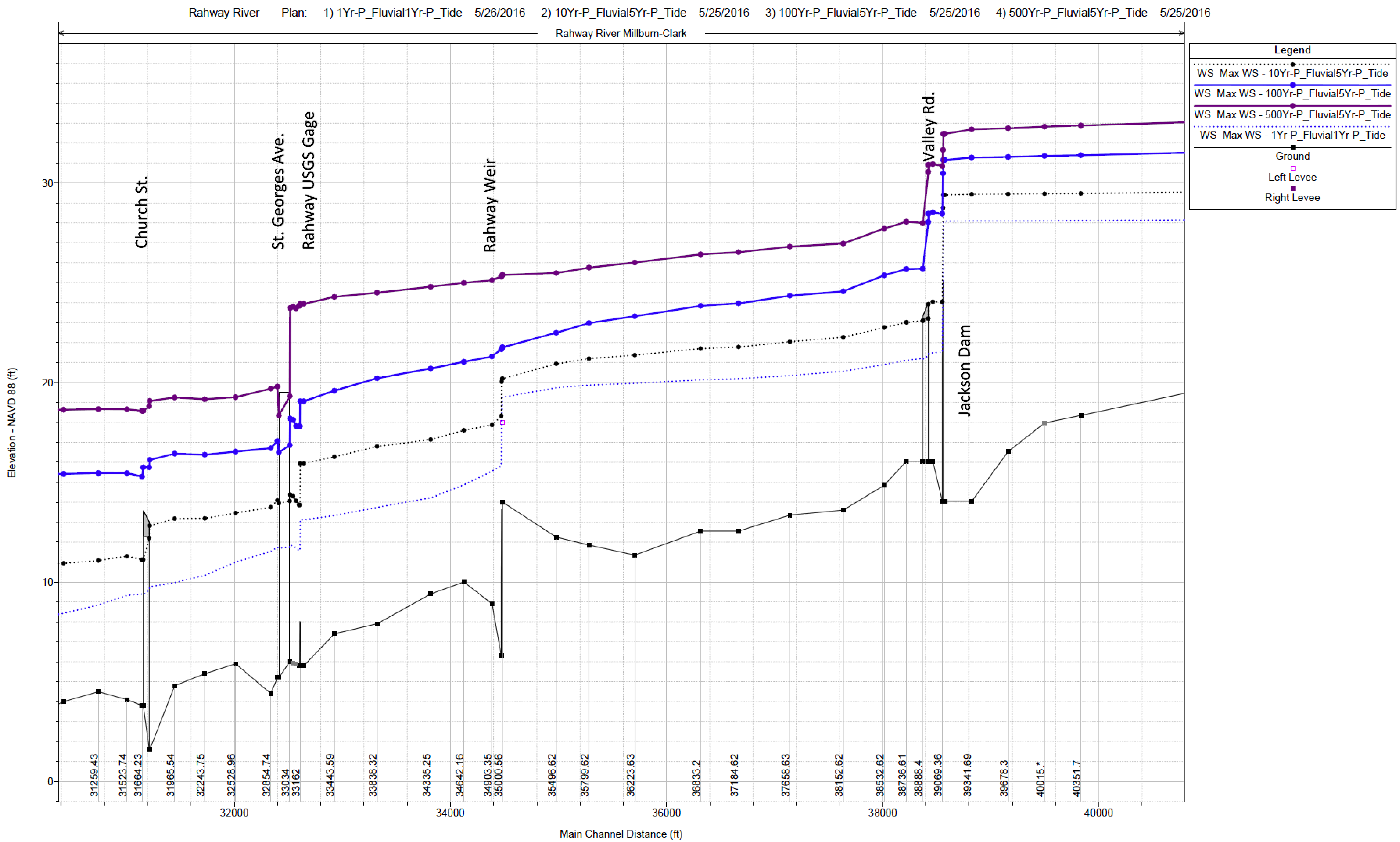

Figure 23: Without project condition computed water surface profile for the 99.9, 4, 1 and 0.2% chance of annual exceedance (1-yr, 25-yr, 100-yr and 500-yr) events.

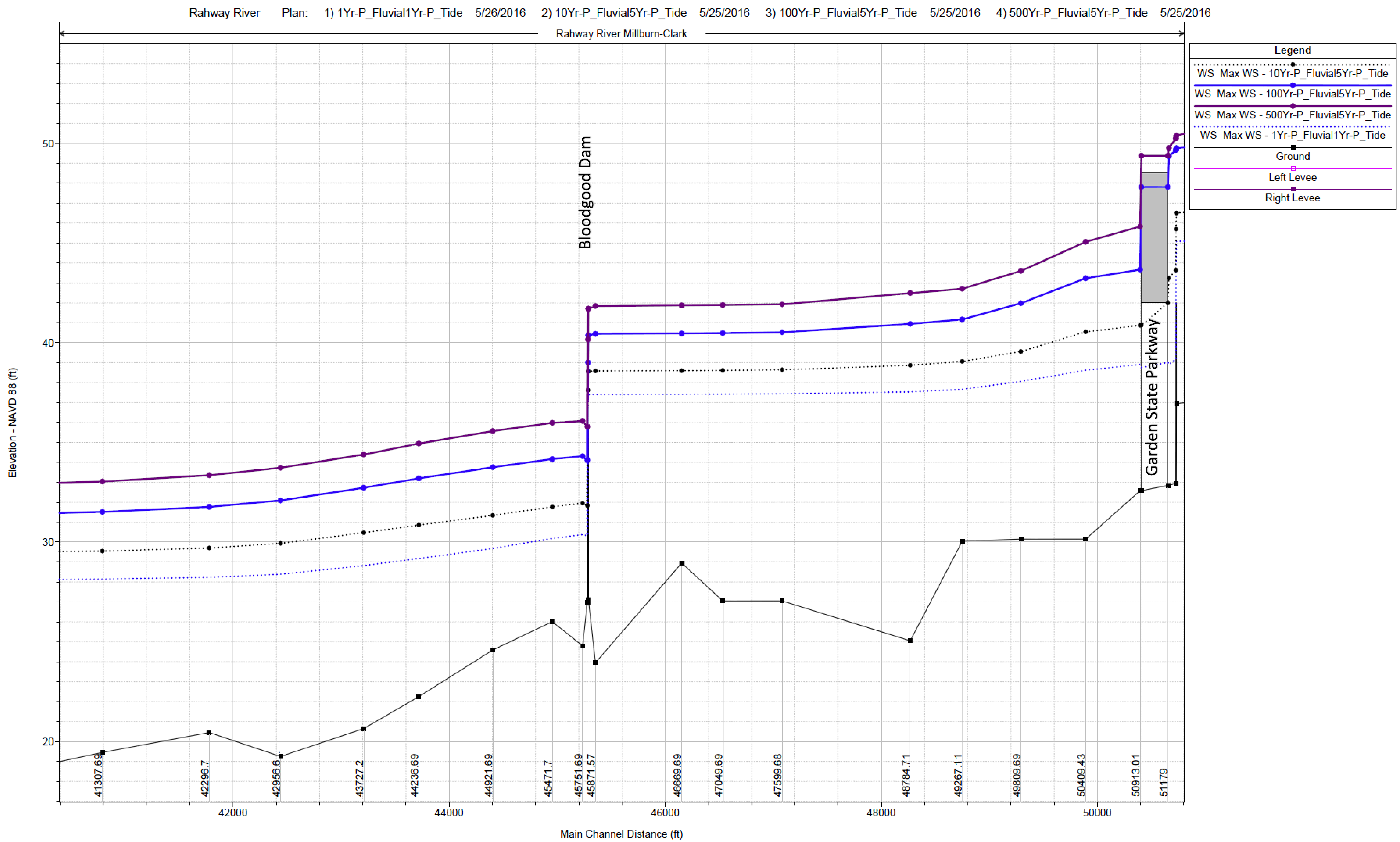

Figure 24: Without project condition computed water surface profile for the 99.9, 4, 1 and 0.2% chance of annual exceedance (1-yr, 25-yr, 100-yr and 500-yr) events.

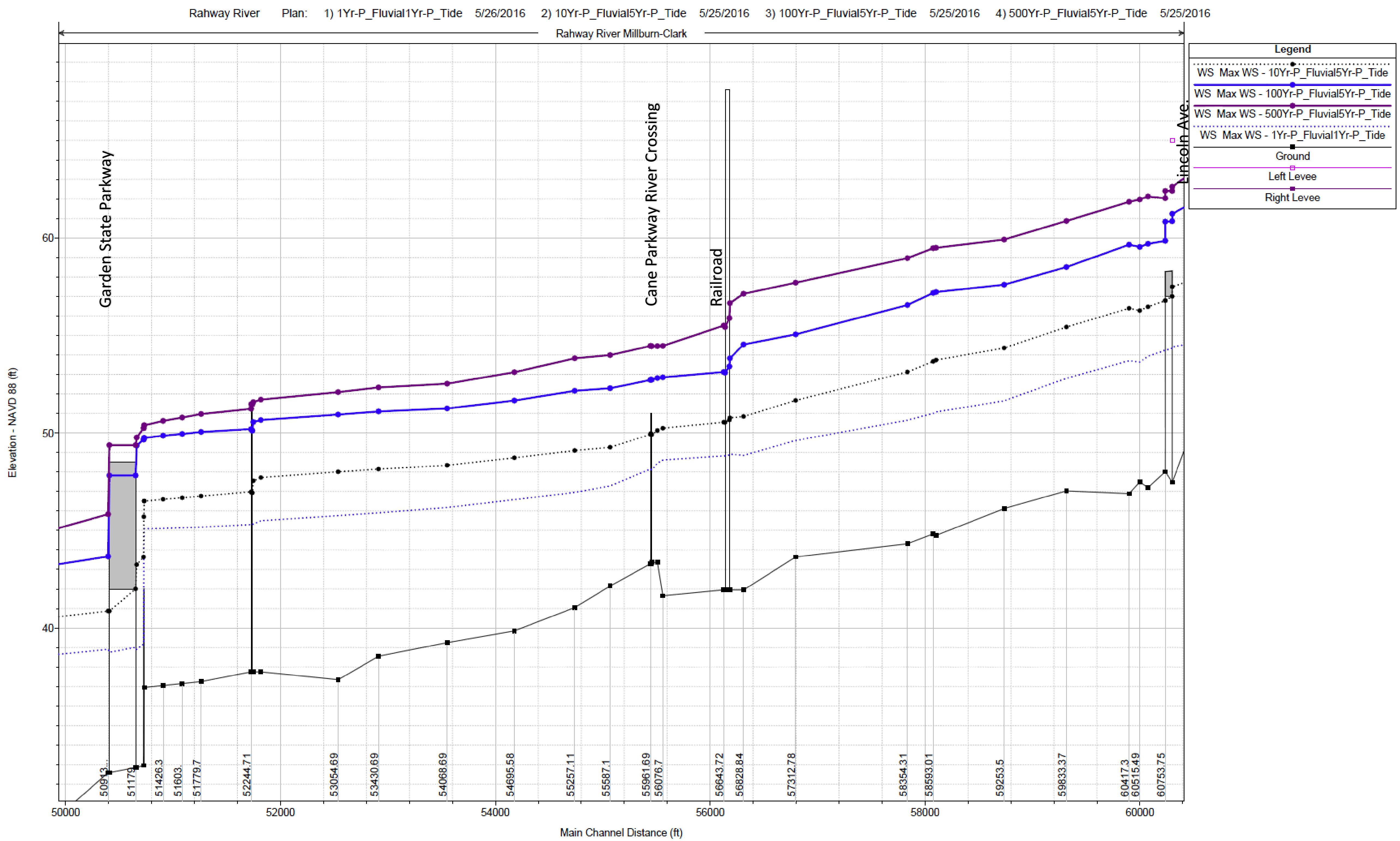

Figure 25: Without project condition computed water surface profile for the 99.9, 4, 1 and 0.2% chance of annual exceedance (1-yr, 25-yr, 100-yr and 500-yr) event.

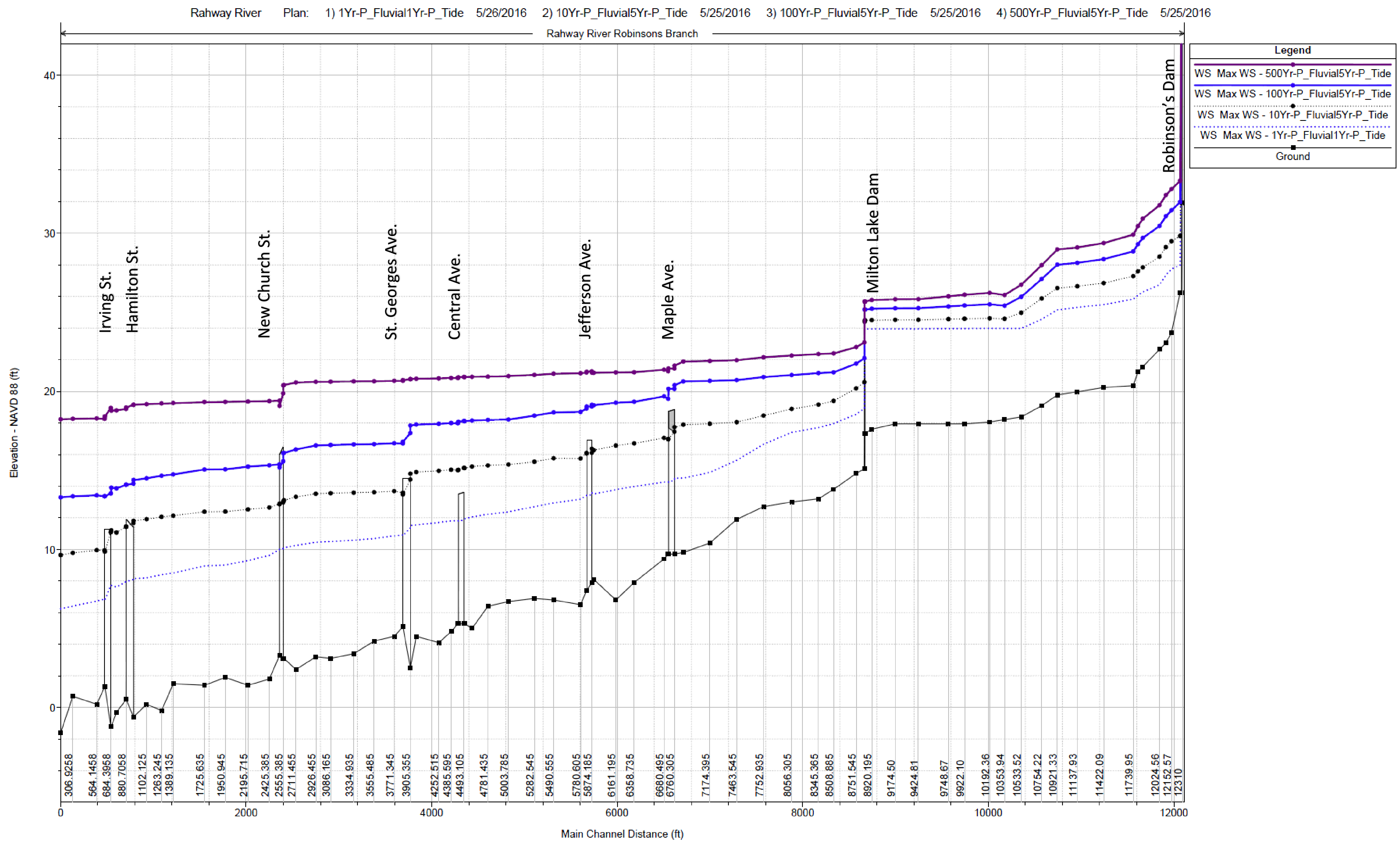

Figure 26: Without project condition computed water surface profile for the 99.9, 4, 1 and 0.2% chance of annual exceedance (1-yr, 25-yr, 100-yr and 500-yr) event.

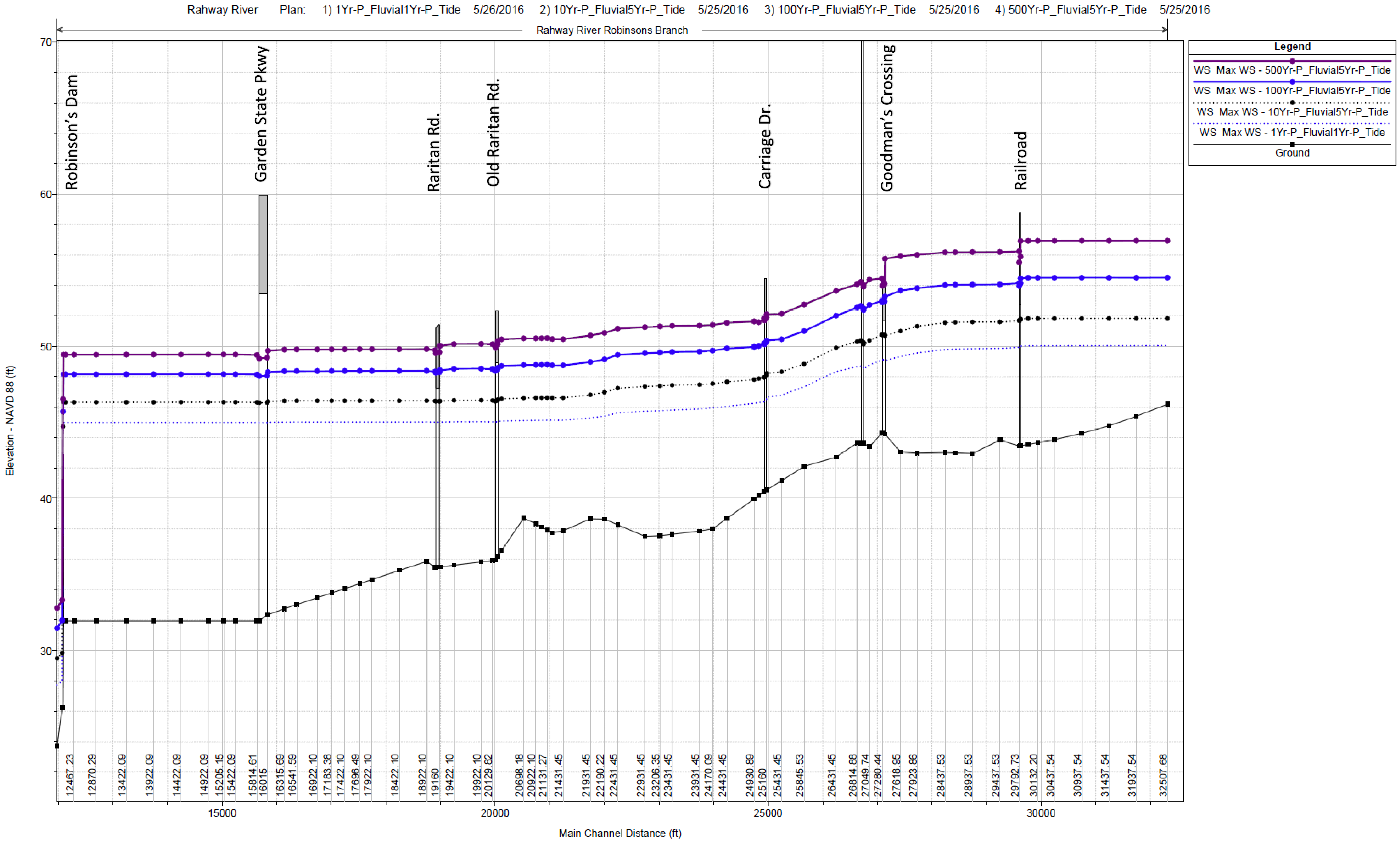

Figure 27: Without project condition computed water surface profile for the 99.9, 4, 1 and 0.2% chance of annual exceedance (1-yr, 25-yr, 100-yr and 500-yr) event.

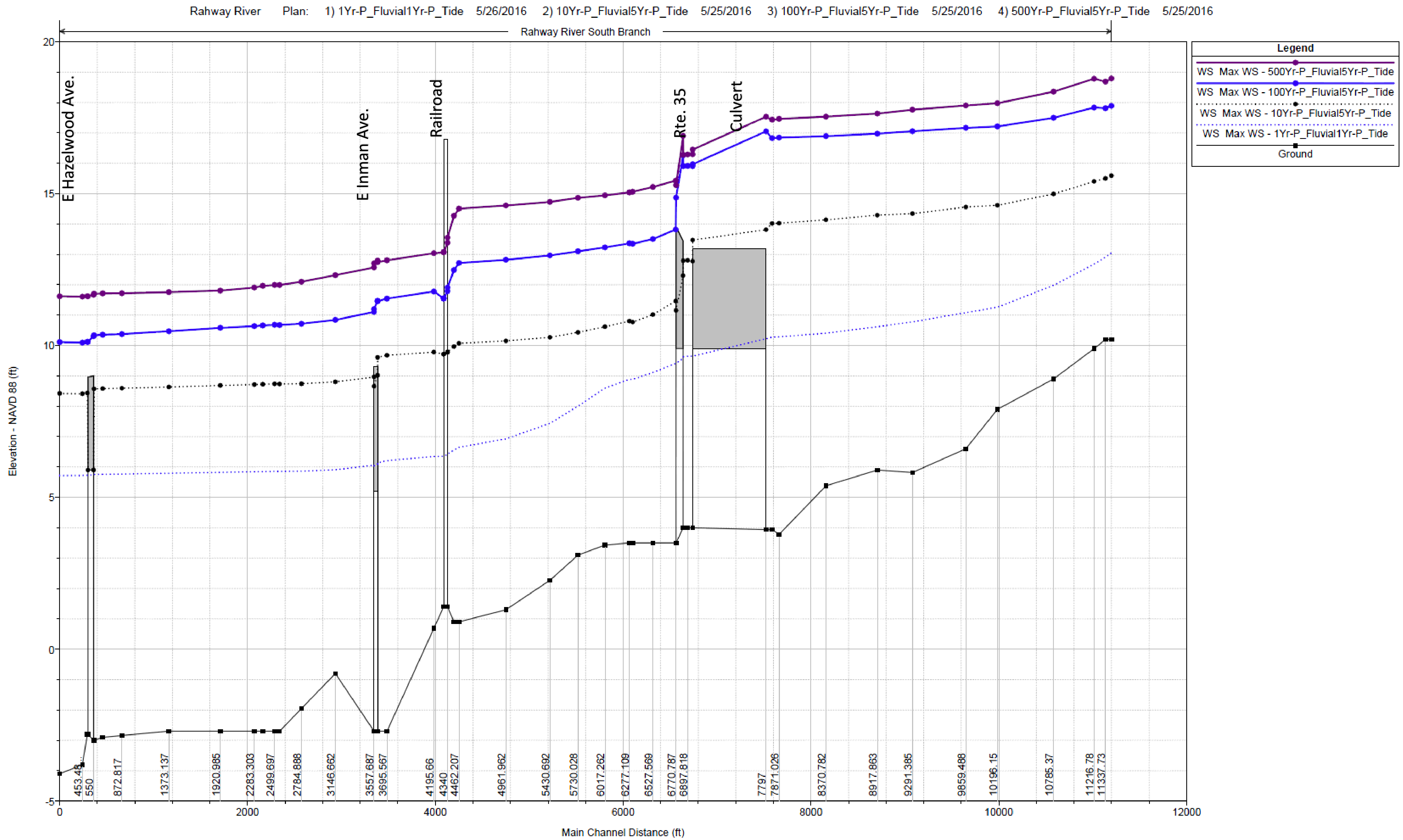

Figure 28: Without project condition computed water surface profile for the 99.9, 4, 1 and 0.2% chance of annual exceedance (1-yr, 25-yr, 100-yr and 500-yr) event.

4.0 DEVELOPMENT OF ALTERNATIVES

4.1 General

The evaluated alternatives include channel work, levees, floodwalls, reservoirs detention, non-structural, and/or a combination of the above. The alternatives were focused on reducing flood risk in the areas of Cranford Township and City of Rahway on the Robinson's Branch. Other alternatives were preliminary evaluated, but screened out, because of low levels of performance, high cost and potentially high environmental impacts. Modification to Echo Lake Dam, Diversion culvert under Riverside Dr. and modifications to Robinson's Branch Dam (Middlesex Reservoir) are examples of alternatives that were screened out.

4.2 No Action Alternative

This plan involves no federal action to provide flood risk damage reduction in the Rahway River Basin. The no action alternative provides some indication as to what future conditions would be in the absence of the project. The no action alternative would avoid environmental and other impacts associated with implementation of other plans for flood risk damage reduction. The population in the area is stable, the types of industries are stable, the retail structures are expected to turnover without any net change and the climate change trends indicate a small increase in flooding. The local governments are unlikely to fund a large scale flood risk management project. The result would be the continuation and potential exacerbation of flooding problems in the study area.

4.3 Alternatives for Cranford

4.3.1 Alternative #1:

Major channel modification of the Rahway River in Cranford Township, and modification to Lenape Park Detention Basin. This alternative is likely to have a 1% chance of annual exceedance flood (100-yr event) in Cranford Township. The Lenape dam modifications will include:

1. Replacing the existing Lenape Dam spillway structure and raising by 6 ft.
2. Widening the spillway by 100 ft.
3. Widening the low orifice to 40 ft. and lowering by 0.5 ft.
4. Modifying 10,000 ft. dam embankments by raising them 6 ft.
5. Providing a 100 ft. wide vegetation free zone centered around the dam embankments.
6. Widening the auxiliary spillway to 400 ft.
7. Adding 6 ft. of floodwalls to the existing embankments in the northern area of Lenape Park near Fadem Rd. at Springfield Township.

This plan also includes approximately 15,500 ft. of channel work throughout the extent of the Rahway River in Cranford Township, from Kenilworth Blvd., just downstream of Lenape Dam, to a point approximately 1,500 ft. downstream of the Lincoln Avenue Bridge. Approximately 1,400 ft. of the channel work is expected in Nomahegan Park. The designed slope is approximately 2.6 ft./mile with a maximum deepening of about 3.7 ft. near Hansel Dam. The new trapezoidal channel will consist of a combination of a natural channel bed or riprap material and a 60 ft. bottom width. The side slopes ranges from one vertical on two horizontal (1:2), to one vertical on two and a half horizontal (1:2.5). There will be approximately 2,000 ft. of new and removed/replaced retaining walls. Also, the Union Ave. and North Ave. Bridges will be removed and replaced. This alternative is shown in Figure 29 and Figure 30.

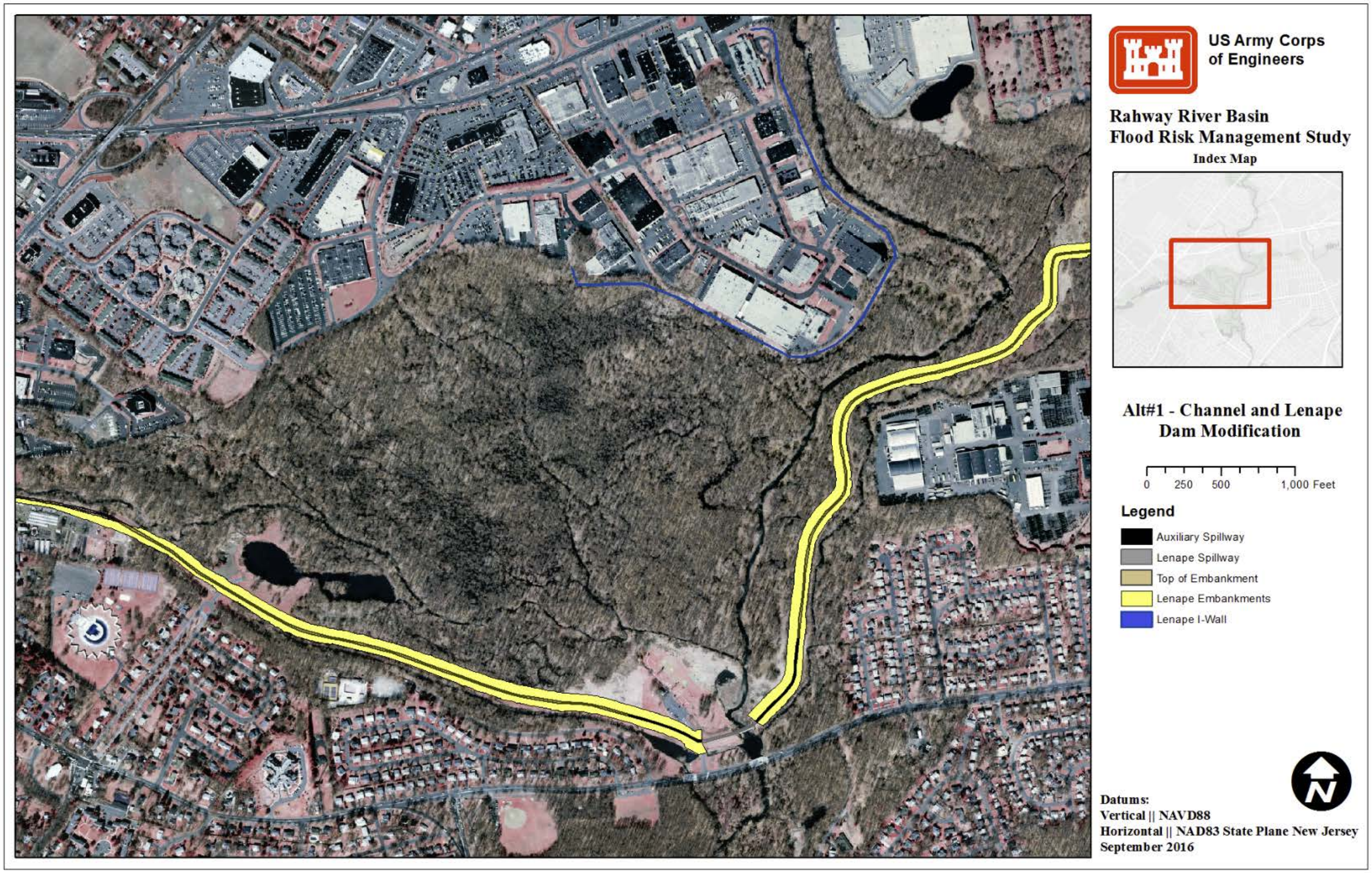

Figure 29: Lenape modification footprint.

Figure 30: Channel modification footprint from Lenape Dam to Lincoln Ave. Bridge.

4.3.2 *Alternative #2:*

Limited channel modification of the Rahway River in Cranford Township, and modification to the Nomahegan levees and Lenape Park Detention Basin. This alternative is likely to have a 1% chance of annual exceedance flood (100-yr event) in Cranford Township. Modification to Lenape Dam are similar to modifications included in alternative #1, see Figure 29 for the Lenape Dam plan view details. The Lenape dam modifications includes:

1. Replacing the existing Lenape Dam spillway structure and raising by 6 ft.
2. Widening the spillway by 100 ft.
3. Widening the low orifice to 40 ft. and lowering by 0.5 ft.
4. Modifying 10,000 ft. dam embankments by raising them 6 ft.
5. Providing 100 ft. wide vegetation free zone centered around the dam embankments.
6. Widening the auxiliary spillway to 400 ft.
7. Adding 6 ft. of floodwalls to the existing embankments in the northern area of Lenape Park near Fadem Rd. at Springfield Township.

The levee system to be modified is located in the Nomahegan Park area. The proposed levees and floodwalls are approximately 6 ft. higher than the existing levees. A 15 foot wide vegetation free zone will be added to each side of the reconstructed levees. Because of environmental considerations and the negative impact of a channel through Nomahegan Park, this plan includes reducing channel work to approximately 9,700 ft. throughout the extent of the Rahway River in Cranford Township. The channel work extends from about 200 ft. upstream of Springfield Ave. Bridge to a point approximately 1,000 ft. downstream of the Lincoln Ave. Bridge. The designed slope is approximately 2.7 ft./mile with a maximum deepening of about 4 ft. near Hansel Dam. The trapezoidal channel will consist of a natural channel bed or riprap material and a 70 ft. bottom width. The side slopes ranges from one vertical on two horizontal (1 on 2), to one vertical on two and a half horizontal (1 on 2.5). There will be approximately 3,400 ft. of new and removed/replaced retaining walls. Also, the Union Ave. and North Ave. Bridges will be removed and replaced. See Figure 31 for detailed plan view of the Nomahegan Levees and channel modification and Figure 29 for the Lenape Park Dam modification.

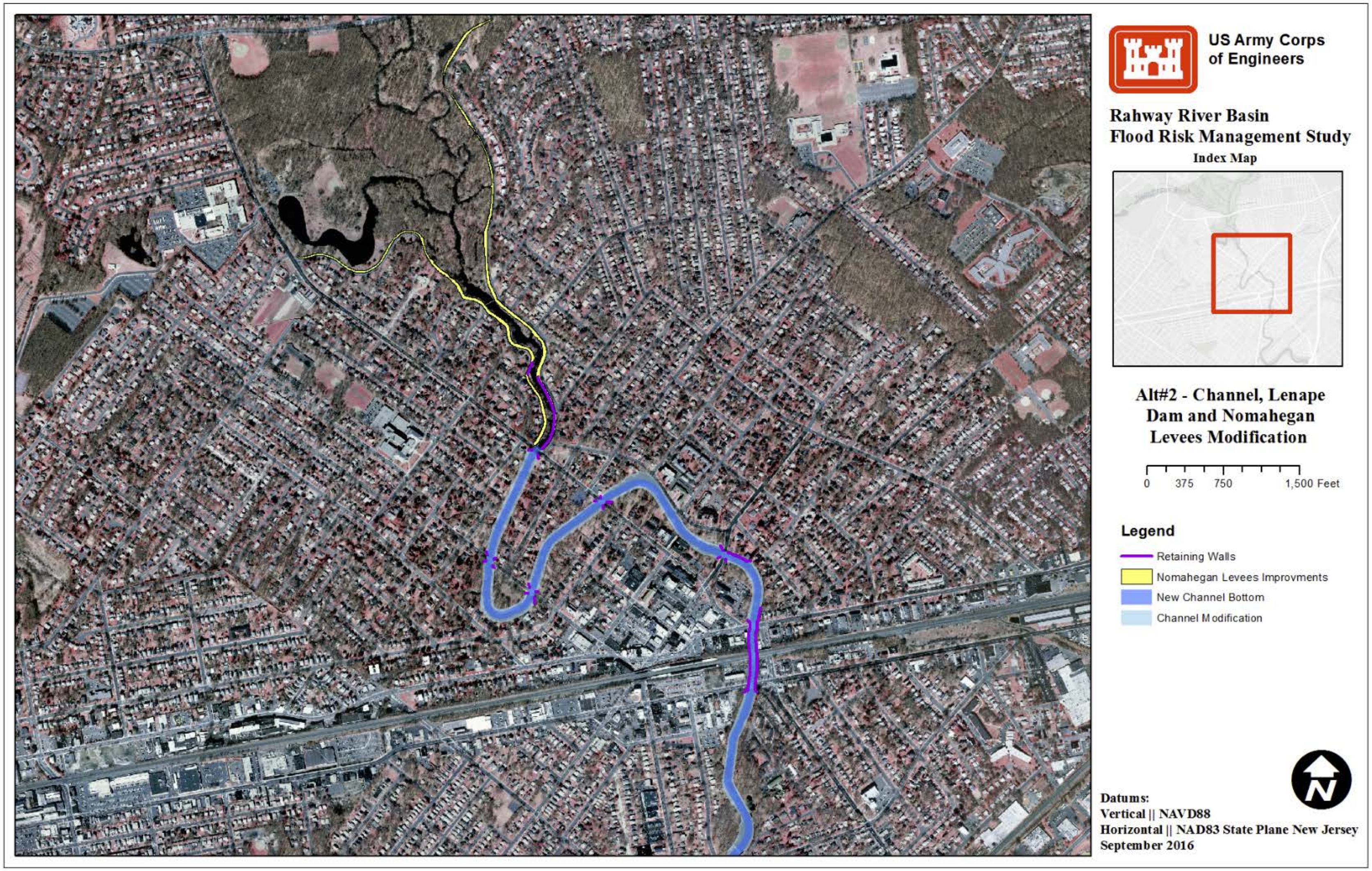

Figure 31: Channel and Nomahegan Levee modification footprint.

4.3.3 *Alternative #3: (this plan was highly cost ineffective therefore no figures have been provided)*

Dredging Orange Reservoir to increase storage capacity and major channel modification of the Rahway River in Cranford Township. This alternative is likely to have between a 2% to a 1% chance of annual exceedance flood (50yr to a100-yr event) in Cranford Township.

This plan includes approximately 15,500 ft. of channel work throughout the extent of the Rahway River in Cranford Township, from Kenilworth Blvd, just downstream of Lenape Dam, to a point approximately 1,500 ft. downstream of the Lincoln Avenue Bridge. Approximately 1,400 ft. of the channel work is expected in Nomahegan Park. The designed slope is approximately 2.6 ft./mile with a maximum deepening of about 3.7 ft. near Hansel Dam. The new trapezoidal channel will consist of a combination of natural channel bed or riprap material and a 60 ft. bottom width with side slopes ranging from one vertical on two horizontal (1:2), to one vertical on two and a half horizontal (1:2.5). There will be approximately 2,000 ft. of new and removed/replaced retaining walls. Also, the Union Ave. and North Ave. Bridges will be removed and replaced. Channel modification in this alternative is similar to modifications included in alternative #1, see Figure 30 for the channel modification plan view details.

In addition, this plan includes the use and operation of Orange Reservoir for flood water storage. This included the dredging of approximately 375,000 cyd. of sediment in the reservoir, to return it to its original maximum capacity, and installing additional outlet pipes in the dam structure. The area to be dredge is approximately 65 acres. See Figure 33 for plan view of the reservoir. The additional pipes will help lower the reservoir prior to a storm to maximize the effective use of the new storage capacity of the reservoir.

4.3.4 *Alternative #4:*

Orange Reservoir Dam modifications and channel modification in Cranford Township. This alternative is likely to have between a 2% to a 1% chance of annual exceedance flood (50-yr to a 100-yr event) in Cranford Township.

The plan requires minimum modification to Orange Dam that includes two additional 36 in. diameter outlet pipes at the dam and operation two days prior to a storm event. The required drawdown is approximately 15 ft., from a maximum depth of about 30 ft. to a depth of about 15 feet. This plan requires little to no dredging in the reservoir. See Figure 33 for plan view and footprint of the dam.

This plan also includes approximately 15,500 ft. channel work throughout the extent of the Rahway River in Cranford Township, from Kenilworth Blvd, just downstream of Lenape Dam, to a point approximately 1,500 ft. downstream of the Lincoln Avenue Bridge. Approximately 1,400 ft. of the channel work is expected in Nomahegan Park. The designed slope is approximately 2.6 ft./mile with a maximum deepening of about 3.7 ft. near Hansel Dam. The new trapezoidal channel will consist of a combination of natural channel bed or riprap material and a 60 ft. bottom width with side slopes ranging from one vertical on two horizontal (1:2), to one vertical on two and a half horizontal (1:2.5). There will be approximately 2,000 ft. of replaced retaining walls. Also, the N. Union Ave. and North Ave. Bridges will be removed and replaced. Channel modification in this alternative is similar to modifications included in alternative #1, see Figure 30 for the channel modification plan view details. Channel modification in this alternative is similar to modifications included in alternative #1, see Figure 30 for the channel modification plan view details.

4.3.5 Alternative #4A - Tentatively Selected Plan (TSP):

Replacement in-kind of Orange Dam (see Figure 33) with outlet modifications and limited channel modification in Cranford Township. This alternative is likely to have a 2% to 4% chance of annual exceedance flood (25-yr event ~ 50-yr event) in Cranford Township. The plan requires two additional 36 in. diameter outlet pipes at the dam and operation two days prior to a storm event. The required drawdown is approximately 15 ft., from a maximum reservoir depth of about 30 ft. to a depth of about 15 feet. A recent bathymetric survey determined that the reservoir has 200 ac-ft. more storage capacity at the spillway elevation (see Figure 32) than was assumed earlier in this study. Thus, the recommended final drawdown elevation will be adjusted based on acceptable reservoir re-fill times, environmental consideration and the desired level of protection. This plan requires little to no dredging in the reservoir.

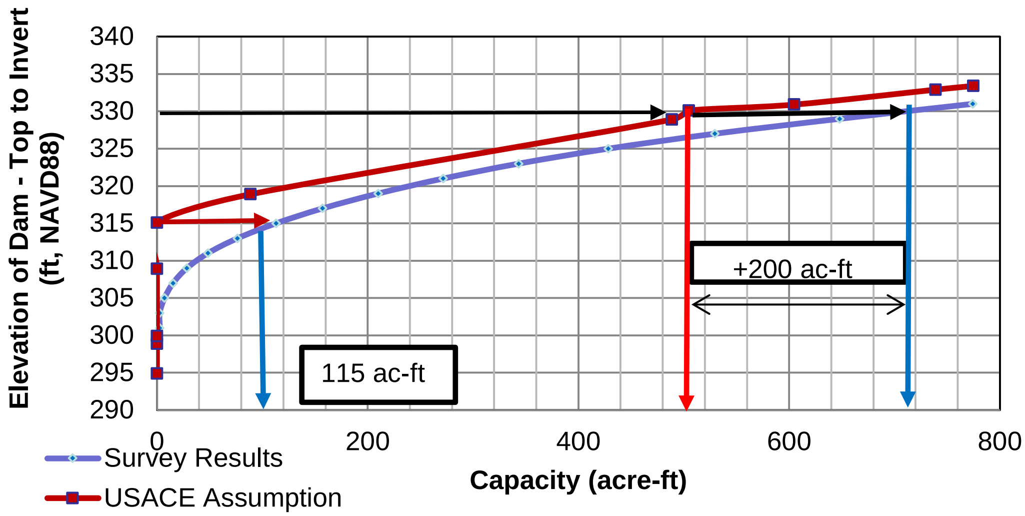

Figure 32: Capacity determined by bathymetry survey of Orange Reservoir during the summer of 2015.

This plan also requires approximately 8,930 ft. of channel modification. The proposed channel modification starts in the vicinity of the footbridge by Nomahegan Park and ends approximately 650 ft. downstream of South Ave. E. The designed slope is approximately 2.6 ft./mile with a maximum deepening of about 1.9 ft. in the vicinity Hansel Dam. The new trapezoidal channel will consist of a natural channel bed with a 35 to 45 ft. bottom width and side slopes of one vertical on two and a half horizontal (1:2.5). There is some riprap material in a small segment of the river near the Eastman Ave. Bridge at McConnell Park. No dam or bridge removals in the vicinity of Cranford were included in this alternative. See Figure 34 for plan view details of the modified channel.

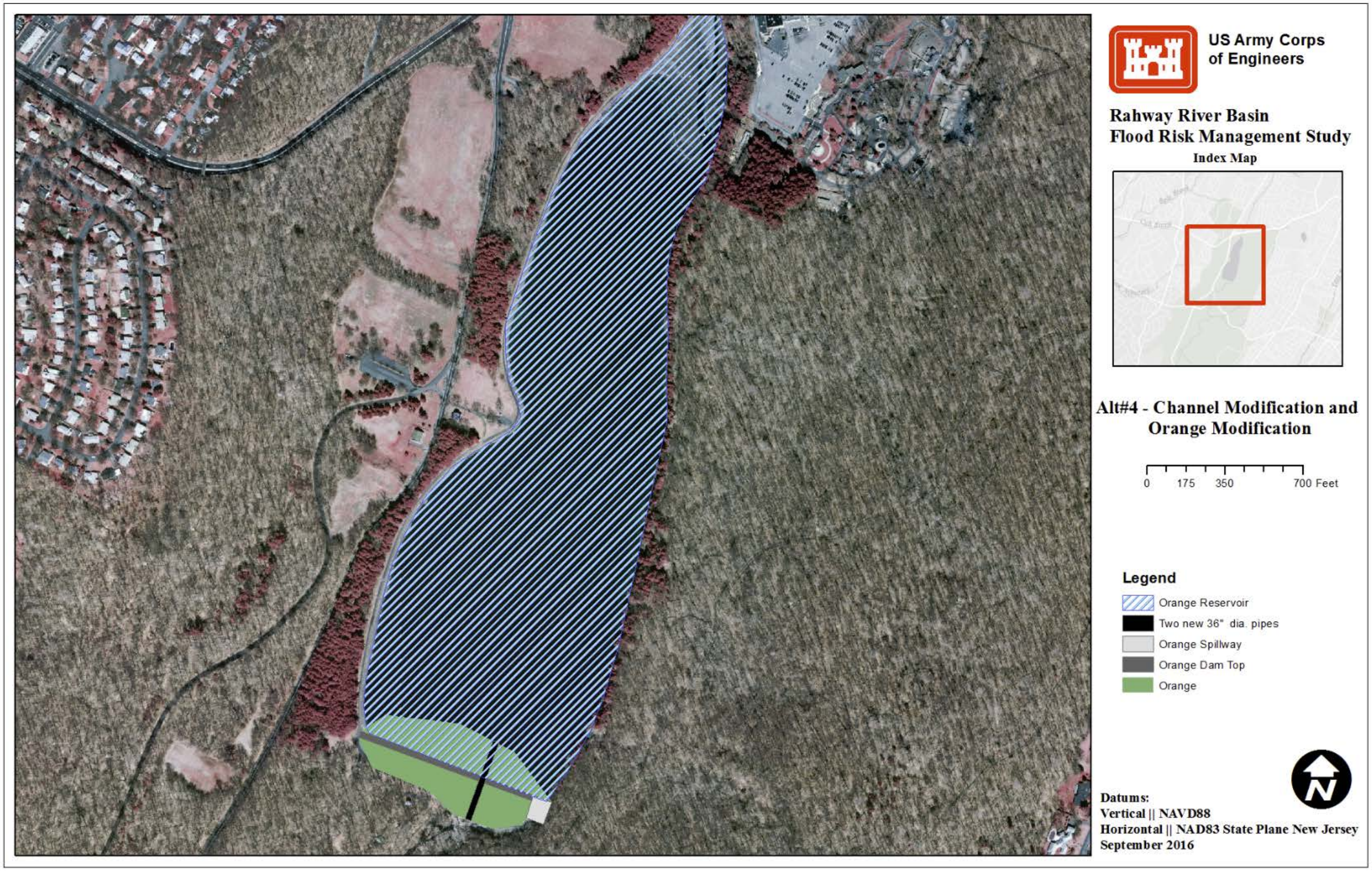

Figure 33: Orange Reservoir and dam footprint.

Figure 34: Reduced channel modification along the Rahway River in Cranford.

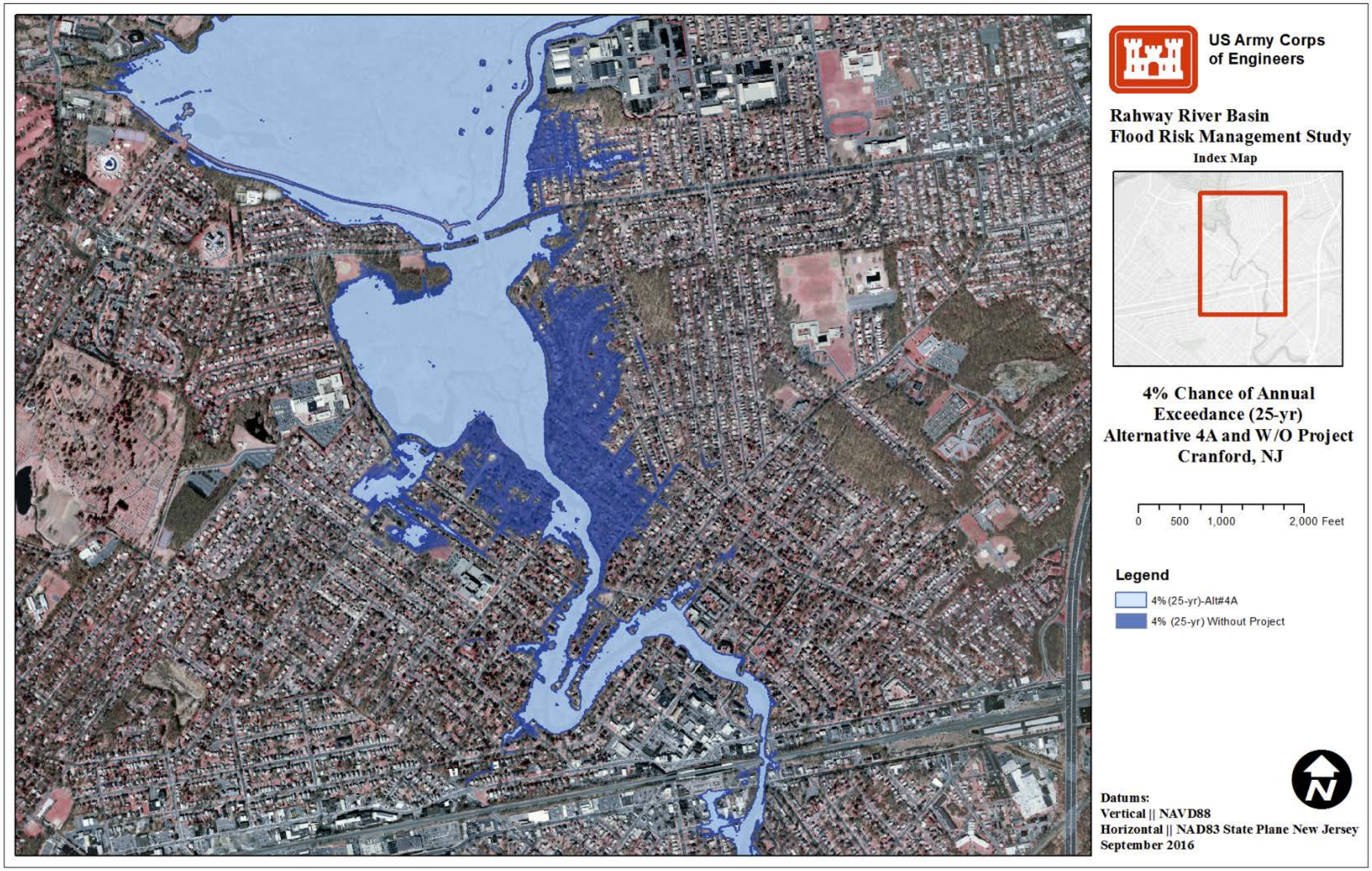

Figure 35: Alternative #4A 4% chance of annual exceedance (25-yr) inundation map

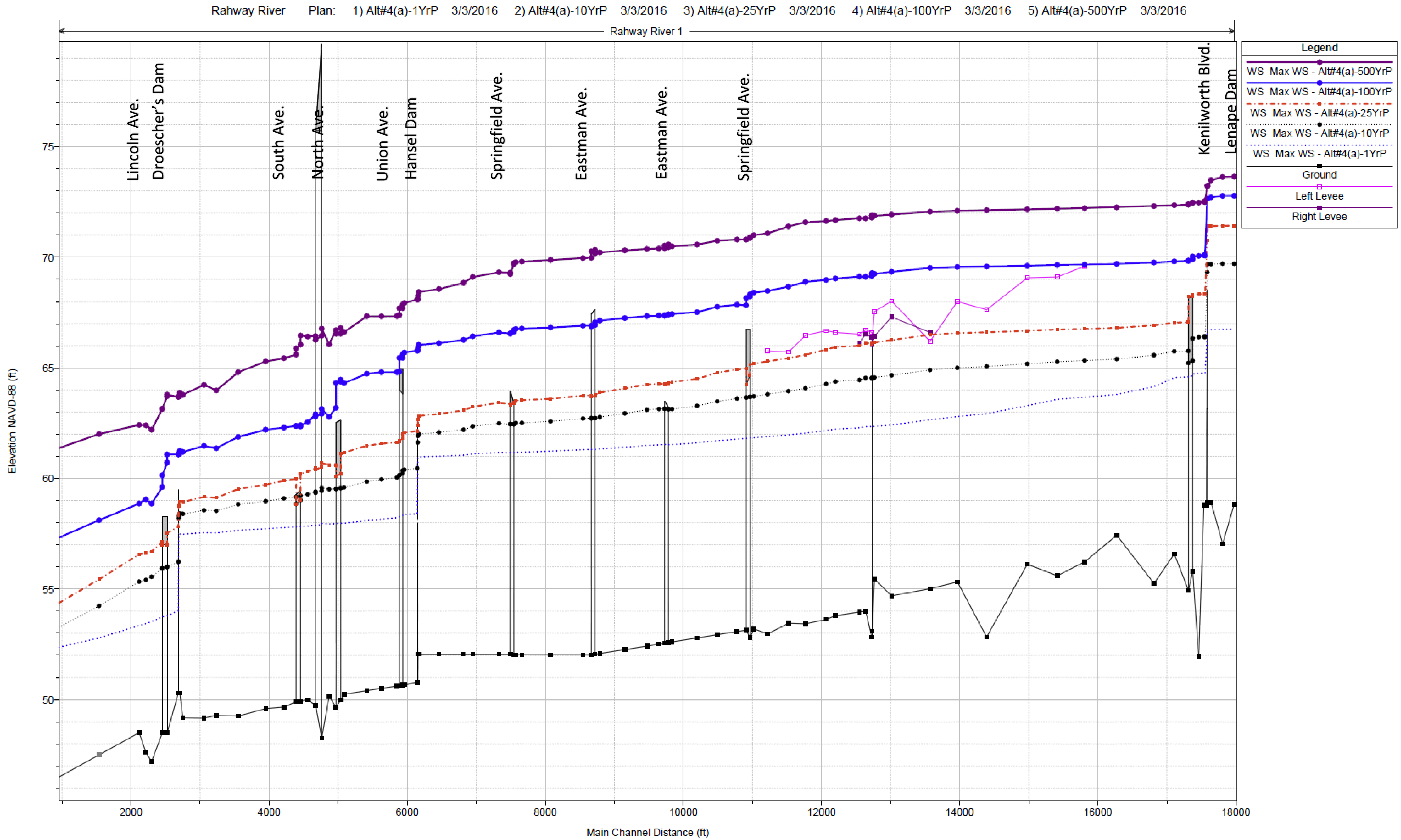

Figure 36: Alternative #4A computed water surface profile for the 99.9, 4, 1 and 0.2% chance of annual exceedance (1-yr, 25-yr, 100-yr and 500-yr) events in Cranford, NJ.

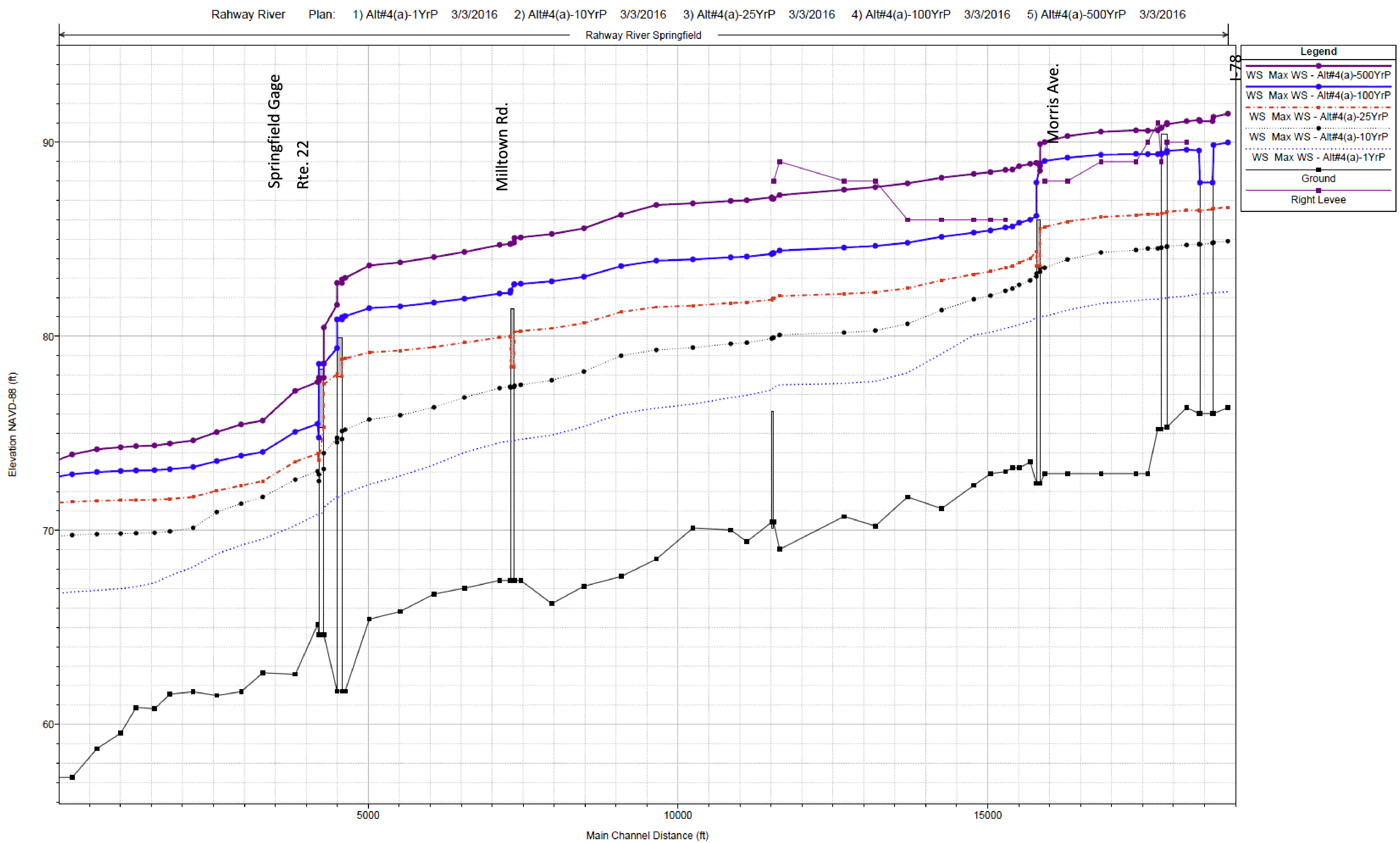

Figure 37: Alternative #4A computed water surface profile for the 99.9, 4, 1 and 0.2% chance of annual exceedance (1-yr, 25-yr, 100-yr and 500-yr) events in Springfield, NJ.

4.3.6 Alternative #5:

The plan consist of channel modification at the Rahway River at Cranford Township and the construction of a South Mountain Dry Detention Basin with Brookside Drive relocated to provide uninterrupted traffic access. The alternative is likely to have a 1% chance of annual exceedance (100-yr event) in Cranford Township.

This plan includes approximately 15,500 ft. channel work throughout the extent of the Rahway River in Cranford Township, from Kenilworth Blvd., just downstream of Lenape Dam, to a point approximately 1,500 ft. downstream of the Lincoln Avenue Bridge. Approximately 1,400 ft. of channel work is expected in Nomahegan Park. The designed slope is approximately 2.6 ft./mile with a maximum deepening of about 3.7 ft. near Hansel Dam. The trapezoidal channel will consist of a combination of natural bed channel or riprap material, a 60 ft. bottom width with side slopes ranging from one vertical on two horizontal (1:2), to one vertical on two and a half horizontal (1:2.5). There will be approximately 2,000 ft. of new and removed/replaced retaining walls. Also, the Union Ave. and North Ave. Bridges will be removed and replaced. Channel modification in this alternative is similar to modifications included in alternative #1, see Figure 30 for the channel modification plan view details.

In addition, this plan includes a new dry detention structure in South Mountain Reservation just upstream of Campbell’s Pond. The structure will be approximately 810 ft. long by 75 ft. high. The area flooded during a storm event of 0.2% chance of exceedance (500-yr event) is approximately 85 acres and the dam structure will have a footprint of approximately 6.6 acres. The dry detention structure will provide approximately 2,500 acre-ft. of flood water storage to the downstream communities.

This plan also requires the relocation of approximately 3,000 ft. Brookside Drive and a steel truss maintenance bridge across the spillway of the dam. The relocated road relocated along the left bank of dam, allowing traffic flow during flood events and access to the top of the dam for maintenance and emergency operation. Currently this road gets flooded during the less frequent events. See Figure 38 for a plan view of South Mountain dry detention dam.

Figure 38: Proposed South Mountain dry detention dam and Brookside Drive relocation.

4.3.7 Alternative #6:

The plan consist of a new dry detention structure in South Mountain Reservation (standalone) with Brookside Drive relocated to provide uninterrupted traffic access. The structure will be approximately 810 ft. long by 75 ft. high. The area flooded during a storm event of 0.2% chance of exceedance (500-yr event) is approximately 85 acres and the dam structure will have a footprint of approximately 6.6 acres. The dry detention structure will provide approximately 2,500 acre-ft. of flood water storage to the downstream communities.

This plan also requires the relocation of approximately 3,000 ft. Brookside Drive and a steel truss maintenance bridge across the spillway of the dam. The relocated road relocated along the left bank of dam, allowing traffic flow during flood events and access to the top of the dam for maintenance and emergency operation. Currently this road gets flooded during the less frequent events. See Figure 38 for a plan view of South Mountain dry detention dam.

4.3.8 Alternative #7A and 7B:

Nonstructural Plans with a 10% and 1% chance of annual exceedance (10-yr and 100-yr) along the Rahway River in Cranford. The non-structural flood proofing measures considered in this project were:

- *Dry Flood Proofing*. Dry flood proofing measures allow flood waters to reach the structure but diminish the flood threat by preventing the water from getting inside the structure. Dry flood proofing measures considered in this screening make the portion of a building that is below the flood level watertight through attaching watertight closures to the structure in doorway and window openings.
- *Wet Flood Proofing*. Wet flood proofing measures allow flood water to get inside lower, non-living space areas of the structure via vents and openings in order to reduce the effects of hydrostatic pressure and, in turn, reduce flood-related damages to the structure’s foundation.
- *Elevation (aka. Raise)*. Elevation involves raising the lowest finished floor of a building to a height that is above the flood level. In some cases, the structure is lifted in place and foundation walls are extended up to the new level of the lowest floor.
- *Buyouts*. It involves the purchase and elimination of flood damaged structures, allowing owners to move to places away from flood risk.

One structural measure that was included in these plans was:

- *Barriers (aka. Ringwall)*. Barriers usually surround the building but are not attached, such as in the case of ringwalls, levees, or berms. It is used where the elevation isn't feasible.

Nonstructural measures are being finalized for approximating 700 structures contained in the 1% annual exceedance (100-yr event) and approximating 100 structures contained in the 10% annual exceedance (10-yr event) flood inundation areas for the Rahway River in Cranford. All structures will be treated to an elevation of one foot above the 1% annual exceedance event. Completed non-structural plans for the 10% and 1% annual exceedance events are summarized in Table 5 and shown in Figure 39.

Table 5: Number of structures to be treated in Rahway River at Cranford Non-structural Plan for the 10% and 1% annual exceedance events.

Nonstructural Flood Proofing Measure	10% (10-yr) Annual Exceedance			1% (100-yr) Annual Exceedance		
	Residential	Non-Residential	Sub Total	Residential	Non-Residential	Sub Total
Dry Flood proofing	0	0	0	7	4	11
Wet Flood proofing	1	0	1	326	0	326
Barriers	1	0	1	32	5	37
Raise	62	0	62	310	1	311
Buyout	2	0	2	36	5	41
Total of Structures	66	0	**66**	711	15	**726**

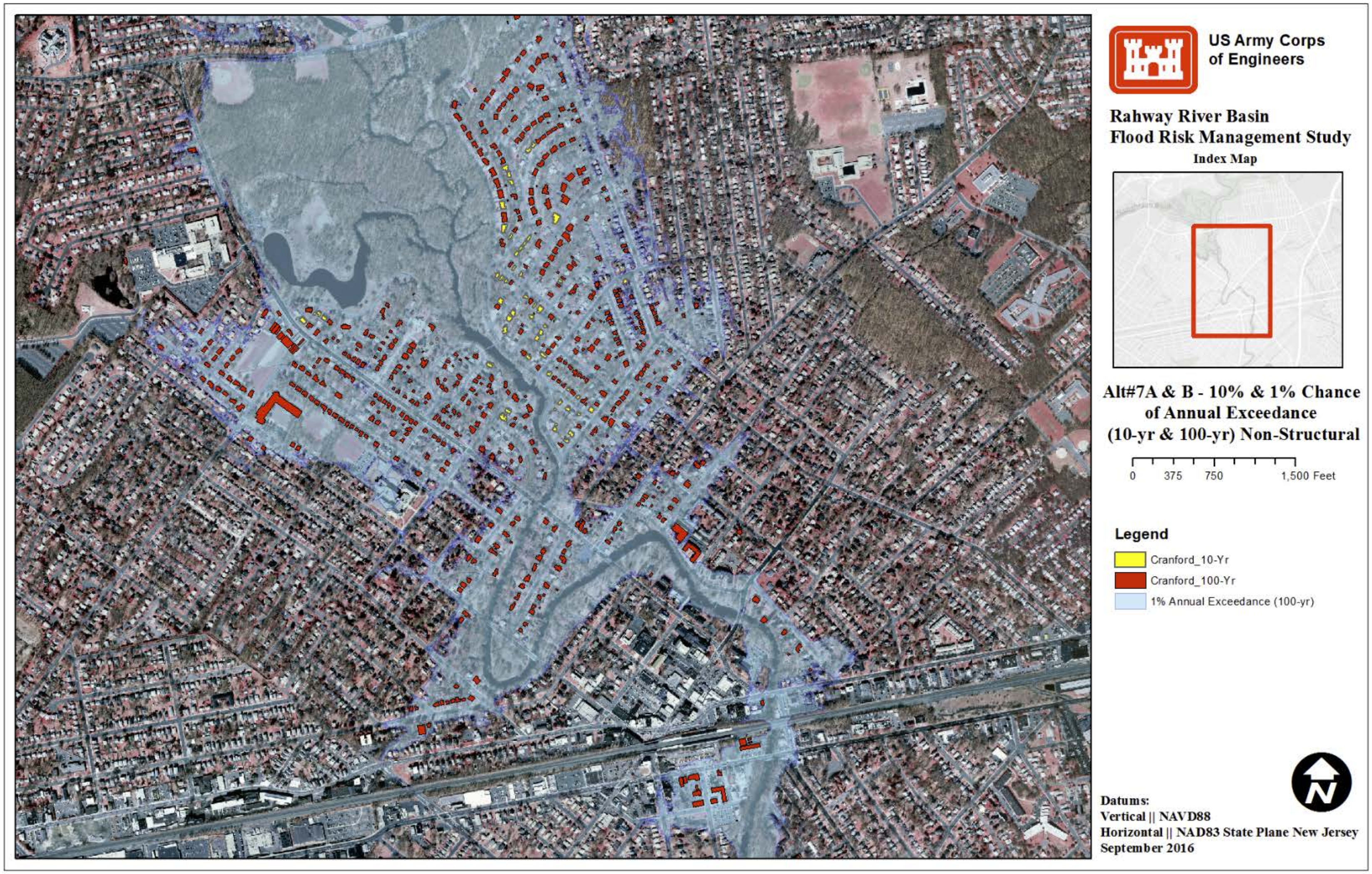

Figure 39: 10% and 1% chance of annual exceedance non-structural alternative in Cranford Township.

4.3.9 Alternative #8:

The alternative consist on the replacement of Lenape and Orange Dams. The Lenape dam replacement will include:

1. Replacing the existing Lenape Dam spillway structure and raising by 6 ft.
2. Widening the spillway by 100 ft.
3. Widening the low orifice to 40 ft. and lowering by 0.5 ft.
4. Removing approximately 10,000 ft. existing earthen dam embankments and replacing with a 6 ft. higher embankment. Also widening the top of the embankments to 25 ft.
5. Providing a 100 ft. wide vegetation free zone centered around the dam embankments.
6. Widening the auxiliary spillway to 400 ft.
7. Adding 6 ft. of floodwalls to the existing embankments in the northern area of Lenape Park near Fadem Rd. at Springfield Township.

The plan requires the replacement in-kind of Orange Dam and includes two additional 36 in. diameter outlet pipes and operation two days prior to a storm event. The required drawdown is approximately 15 ft., from a maximum reservoir depth of about 30 ft. to a depth of about 15 ft. This plan requires little to no dredging in the reservoir. The plan views of the alternative is shown in Figure 29 and 33.

4.3.10 Alternative #9:

The alternative consist on the replacement of Lenape and Orange Dams, and limited channel modification in Cranford. The Lenape dam replacement includes:

1. Replacing the existing Lenape Dam spillway structure and raising by 6 ft.
2. Widening the spillway by 100 ft.
3. Widening the low orifice to 40 ft. and lowering by 0.5 ft.
4. Removing approximately 10,000 ft. existing earthen dam embankments and replacing with a 6 ft. higher embankment. Also widening the top of the embankments to 25 ft.
5. Providing a 100 ft. wide vegetation free zone centered around the dam embankments.
6. Widening the auxiliary spillway to 400 ft.
7. Adding 6 ft. of floodwalls to the existing embankments in the northern area of Lenape Park near Fadem Rd. at Springfield Township.

There will be approximately 8,930 ft. channel work throughout the extent of the Rahway River in Cranford Township, from the footbridge at Nomahegan Park to a point approximately 650ft. downstream of the South Ave. Bridge. The general designed slope of the channel cut will be approximately 2.6 ft./mile with a maximum deepening of about 1.9 ft. in the vicinity of Hansel Dam. The new trapezoidal channel will consist of a natural bed channel with a 35 to 45 ft. bottom width and side slopes of one vertical on two and a half horizontal (1:2.5). There is some riprap material in a small segment of the river near the Eastman Ave. Bridge at McConnell Park. No dam or bridge removal in Cranford is expected in this alternative. The plan view of the proposed channel in this alternative is shown in Figure 34.

The plan requires the replacement in-kind of Orange Dam and includes two additional 36 in. diameter outlet pipes and operation two days prior to a storm event. The required drawdown is approximately 15 ft., from a maximum depth of about 30 ft. to a depth of about 15 ft. This plan requires little to no dredging in the reservoir. The plan views of the remaining features of this alternative is shown in Figure 29.

4.4 Cranford Alternatives Results

The improved hydraulic condition analysis shows that the alternatives with the greatest flood risk reduction are alternatives #1 and #5. Both of these alternatives have major channel modification along the Rahway River at Cranford and an upstream detention feature that mitigates for the downstream induced damages. Detention features, as the proposed South Mountain Dry Detention Basin and the modifications to Orange Reservoir, would produce additional benefits to Millburn and Springfield. Reduction in WSEs raging between 4 and 5 ft. are expected with these alternatives in the Township of Cranford, as seen in Table 6 thruTable 8. The economic analysis concluded that alternative #4A is the most cost effective alternative, but the reduction in WSEs in Cranford is small compared to other alternatives. This alternative still produces benefits to Millburn and Springfield Townships. Optimization of the alternative #4A channel depth, width and length, as well the operation of Orange Reservoir Dam is the next step of the hydraulic analysis.

Table 6: Decrease in flood elevation from without project condition for the 4% chance of annual exceedance (25-yr) flood.

Town	Location	*Reduction in the 25yr WSE ft. (Existing -Alternatives)							
		Alt #1	Alt #2	Alt#4	Alt#4A	Alt#5	Alt#6	Alt#8	Alt#9
Springfield/Millburn	Downstream of I-78	0.0	0.0	1.6	1.6	3.0	3.1	1.6	1.6
Springfield	Just downstream of Morris Ave. Bridge	0.0	0.0	1.0	1.0	1.8	1.8	1.0	1.0
Springfield	Upstream of Route 22	0.0	0.0	0.7	0.7	1.6	1.5	0.7	0.7
Cranford	Lenape Park	-1.4	-1.8	0.9	0.5	1.4	0.8	-0.7	-0.7
Cranford	Kenilworth Area	5.7	2.3	4.6	0.9	5.2	1.2	1.5	2.2
Cranford	Nomahegan Park	5.4	2.4	4.2	1.3	4.9	1.1	1.2	2.2
Cranford	Below Nomahegan Park - Footbridge	5.9	3.0	4.6	1.5	5.3	1.1	1.3	2.5
Cranford (Town)	McConnell Park	4.8	5.9	3.6	0.9	4.2	0.9	1.1	1.6
Cranford (Town)	Hansel Dam Park - Casino Brook Area	4.2	5.4	3.0	0.4	3.7	0.7	1.0	0.9
Cranford (Town)	From Union Ave. to North Ave. Bridge	3.5	4.6	2.2	0.4	3.1	0.9	1.5	1.1
Cranford	Downstream South Ave. Bridge	2.8	3.8	1.5	0.1	2.6	0.5	0.6	0.5
Cranford	Just downstream of Lincoln Ave. Bridge	1.0	3.0	0.1	0.1	2.3	0.8	1.0	0.8

*Negative numbers denote an increase in flood elevation.

Table 7: Decrease in flood elevation from without project condition for the 1.0% chance of annual exceedance (100-yr) flood.

Town	Location	*Reduction in the 100yr WSE ft. (Existing -Alternatives)							
		Alt #1	Alt #2	Alt#4	Alt#4A	Alt#5	Alt#6	Alt#8	Alt#9
Springfield/Millburn	Downstream of I-78	0.0	0.0	0.5	0.5	2.7	2.7	0.5	0.5
Springfield	Just downstream of Morris Ave. Bridge	0.0	0.0	0.9	0.9	2.0	1.9	0.9	0.9
Springfield	Upstream of Route 22	0.0	0.0	0.3	0.4	0.8	0.8	0.3	0.4
Cranford	Lenape Park	-4.0	-4.0	0.4	0.1	0.9	0.4	-3.7	-3.9
Cranford	Kenilworth Area	3.3	1.3	2.0	1.0	3.1	1.2	1.3	1.4
Cranford	Nomahegan Park	4.2	1.6	3.1	0.7	4.1	0.9	1.1	1.9
Cranford	Below Nomahegan Park - Footbridge	4.5	2.0	3.3	0.8	4.3	0.9	1.1	2.0
Cranford (Town)	McConnell Park	4.1	4.9	3.1	0.7	3.9	1.0	1.3	1.8
Cranford (Town)	Hansel Dam Park - Casino Brook Area	3.8	4.6	2.8	0.3	3.5	0.9	1.2	1.3
Cranford (Town)	From Union Ave. to North Ave. Bridge	2.8	3.7	1.7	0.2	2.6	0.8	1.3	1.4
Cranford	Downstream South Ave. Bridge	2.2	3.0	1.4	0.2	2.2	1.3	1.8	1.8
Cranford	Just downstream of Lincoln Ave. Bridge	1.0	2.8	0.2	0.2	2.2	1.0	1.3	1.4

*Negative numbers denote an increase in flood elevation.

Table 8: Decrease in flood elevation from without project condition for the 0.2% chance of annual exceedance (500-yr) flood.

Town	Location	*Reduction in the 500yr WSE ft. (Existing -Alternatives)							
		Alt #1	Alt #2	Alt#4	Alt#4A	Alt#5	Alt#6	Alt#8	Alt#9
Springfield/Millburn	Downstream of I-78	0.0	1.5	0.8	0.8	1.7	1.7	0.8	0.7
Springfield	Just downstream of Morris Ave. Bridge	0.0	2.2	0.1	0.1	2.3	2.3	0.1	0.1
Springfield	Upstream of Route 22	0.0	2.0	0.1	0.1	1.2	1.2	0.1	0.1
Cranford	Lenape Park	-4.0	-4.0	0.1	0.1	0.5	0.4	-3.8	-4.0
Cranford	Kenilworth Area	1.1	1.0	1.0	0.6	2.9	1.2	0.6	0.9

Cranford	Nomahegan Park	2.3	1.2	2.0	0.7	3.1	1.2	0.6	1.0
Cranford	Below Nomahegan Park - Footbridge	2.3	1.4	2.1	0.8	3.2	1.3	0.6	1.1
Cranford (Town)	McConnell Park	2.2	2.7	1.9	0.6	3.1	1.3	0.5	0.7
Cranford (Town)	Hansel Dam Park - Casino Brook Area	1.8	2.5	1.6	0.6	2.7	1.4	0.4	0.4
Cranford (Town)	From Union Ave. to North Ave. Bridge	1.3	2.1	1.3	0.6	2.6	2.2	0.1	0.1
Cranford	Downstream South Ave. Bridge	1.4	1.9	1.0	0.2	2.8	1.4	0.9	1.0
Cranford	Just downstream of Lincoln Ave. Bridge	0.8	2.3	0.2	0.5	3.3	1.9	1.2	1.4

*Negative numbers denote an increase in flood elevation.

4.5 Alternatives for Robinson's branch

4.5.1 Alternative #1:

This alternative is a reevaluation of the 1985 GRR Plan which consists of levees, floodwalls and channel modification. This plan includes approximately 8,300 ft. of channel work throughout the Robinson's Branch and Rahway River. In Robinson's Branch, the channel starts about 600 ft. downstream of Maple Ave. Bridge and ends in the confluence with Rahway River. In the Rahway River, the channel starts about 75 ft. upstream of W Grand Ave. Bridge and ends approximately 550 ft. downstream of the Monroe Ave. Bridge. All channel cuts generally consist of a 35 ft. wide trapezoidal channel with natural bed and one vertical on two and a half horizontal (1:2.5) side slopes. There are also a few sections with rectangular cuts of 60 ft. width and 20 ft. wide pilot channels, in Robinson's Branch. Riprap protection is proposed at the upstream end of the channel modification in Robinson's Branch and between the Elizabeth Ave. and Rail Road Bridges in the Rahway River.

There are also approximately 1,350 ft. of levees and 4,000 ft. of floodwalls included in this plan. These levees and floodwalls were divided into three systems. The Robinson's Branch right bank, System 1 extends from high ground near W Milton Ave. down to St. Georges Ave. (approx. 1,300 ft. of levee/floodwall) and System 2 extends a short distance from Hamilton St. to Irving St. (approx.150 ft. of floodwall). The Robinson's Branch left bank, System 3 extends from New Church St. downstream to high ground on the right bank of the Rahway river near Whittier St. (approx. 3,900 ft. of levee/floodwall). Other features included in this plan are four road closure gates located at Central Ave, Hamilton St., Irving St. and W Gran Ave., and two ponding areas located near Hamilton St. and near Allen St. See Figure 40 for plan view details.

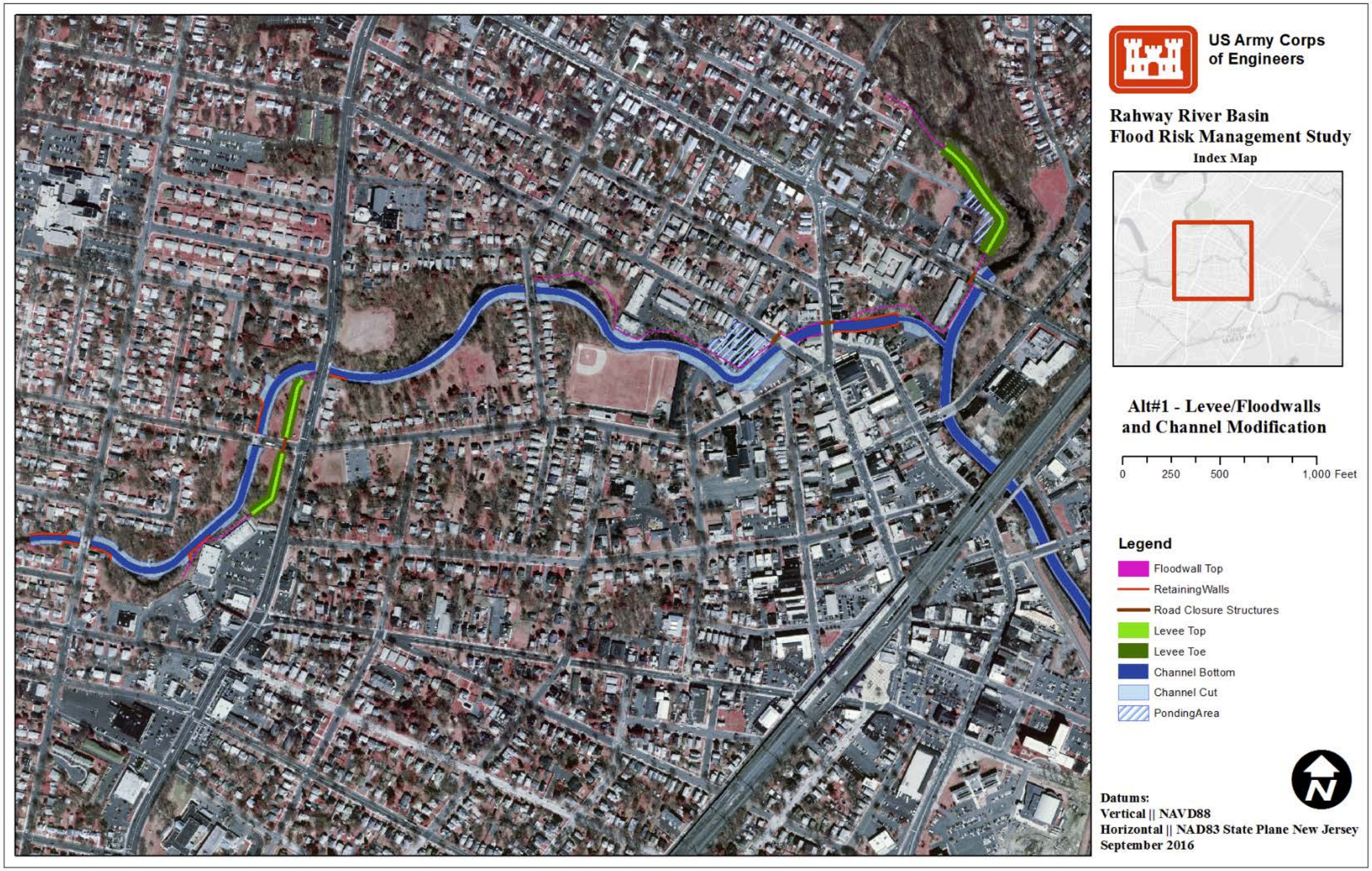

Figure 40: Alternative #1 for the Robinson's Branch.

4.5.2 Alternative #2:

Several analyses were performed for the Middlesex Reservoir, on Robinson's Branch: a combination with several new outlet pipes/gate, operation before and during the storm event, and spillway modification. All the analyzed plans resulted with a low performance of flood risk reduction in the Robinson's Branch. This is due to several reasons:

(1) Rahway River Flood - Backwater from the Rahway River prevents a reduction in flooding for much of the Robinson's Branch.
(2) Lack of storage capacity – Assuming a drawdown of half the capacity of the reservoir, the storage capacity would be approximately 200 ac-ft., which is the volume between elevations 42.9 ft. NAVD 88 to 38.0 ft. NAVD 88 (reservoir half full). This is not enough to significantly reduce flood risk.

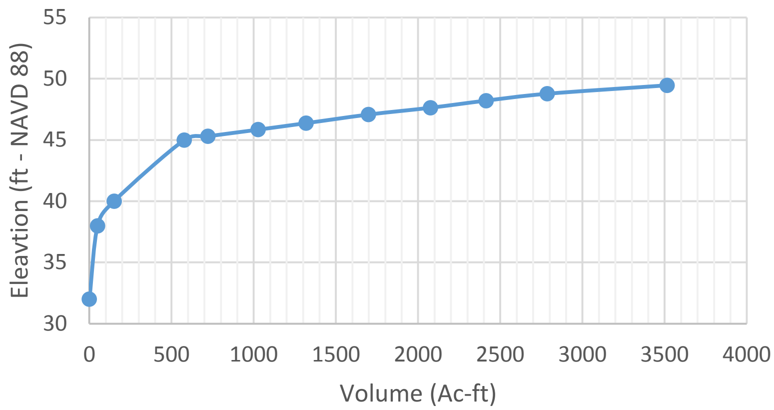

Figure 41: Estimated storage – elevation in Middlesex Reservoir.

There are other disadvantages with the plan:

(1) Additional storage will delay the peak flow in Robinson's Branch making it more coincidental with the Rahway River peak flow. This might result in higher WSE at the confluence with the Rahway River.
(2) Complex operation of gates.
(3) Possible induced flooding upstream or downstream due to uncertainty in the storm event prediction and the associated operation of the dam.
(4) High cost associated with the dam modification and possible replacement.

Due to the low performance and significant disadvantages there was no further analysis on the Middlesex Reservoir. Similar results were concluded during the 1980's Robinson's Branch analysis.

4.5.3 Alternative #3:

This alternative consists of non-structural treatments for structures within the 1% and 10% chance of annual exceedance (100-yr and 10-yr) floodplains of Robinson's Branch and the Rahway River in Clark. Nonstructural Flood Proofing measures considered in this project were:

- Dry Flood Proofing. Dry flood proofing measures allow flood waters to reach the structure but diminish the flood threat by preventing the water from getting inside the structure walls. Dry flood proofing measures considered in this screening make the portion of a building that is below the flood level watertight through attaching watertight closures to the structure in doorway and window openings.
- Wet Flood Proofing. Wet flood proofing measures allow flood water to get inside lower, non-living space areas of the structure via vents and openings in order to reduce the effects of hydrostatic pressure and, in turn, reduce flood-related damages to the structure's foundation.
- *Elevation (aka. Raise)*. Elevation involves raising the lowest finished floor of a building to a height that is above the flood level. In some cases, the structure is lifted in place and foundation walls are extended up to the new level of the lowest floor.
- *Buyouts*. It involves the purchase and elimination of flood damaged structures, allowing owners to move to places away from flood risk.

A structural measure of barriers was also considered:

- *Barriers (aka. Ringwall)*. Barriers such as ringwalls, levees, or berms generally surround the building but are not attached. It is used where the elevation isn't practical or feasible.

Non-structural measures were evaluated for approximately 430 structures contained in the 1% annual exceedance (100-yr event) flood inundation area and approximately 90 structures contained in the 10% annual exceedance (10-yr event) flood inundation area for the Robinson's Branch and the Rahway River in Clark, NJ, respectively. All structures will be treated to an elevation of one foot above the 1% annual exceedance event. The structures to be treated in the non-structural plan for the 10% and 1% annual exceedance events are summarized in Table 9 and shown in Figure 42.

Table 9: Number of structures treated for Rahway River at Robinson's Branch non-structural plan for the 10% and 1% annual exceedance events.

Nonstructural Flood Proofing Measure	10% Annual Exceedance (10-yr)			1% Annual Exceedance (100-yr)		
	Residential	Non-Residential	Total	Residential	Non-Residential	Total
Dry Flood proofing	0	0	0	11	7	18
Wet Flood proofing	1	1	2	2	3	5
Barriers	2	4	6	3	10	13
Raise	13	0	13	188	0	188
Buyout	0	0	0	0	0	0
Total of Structures	16	5	**21**	204	20	**224**

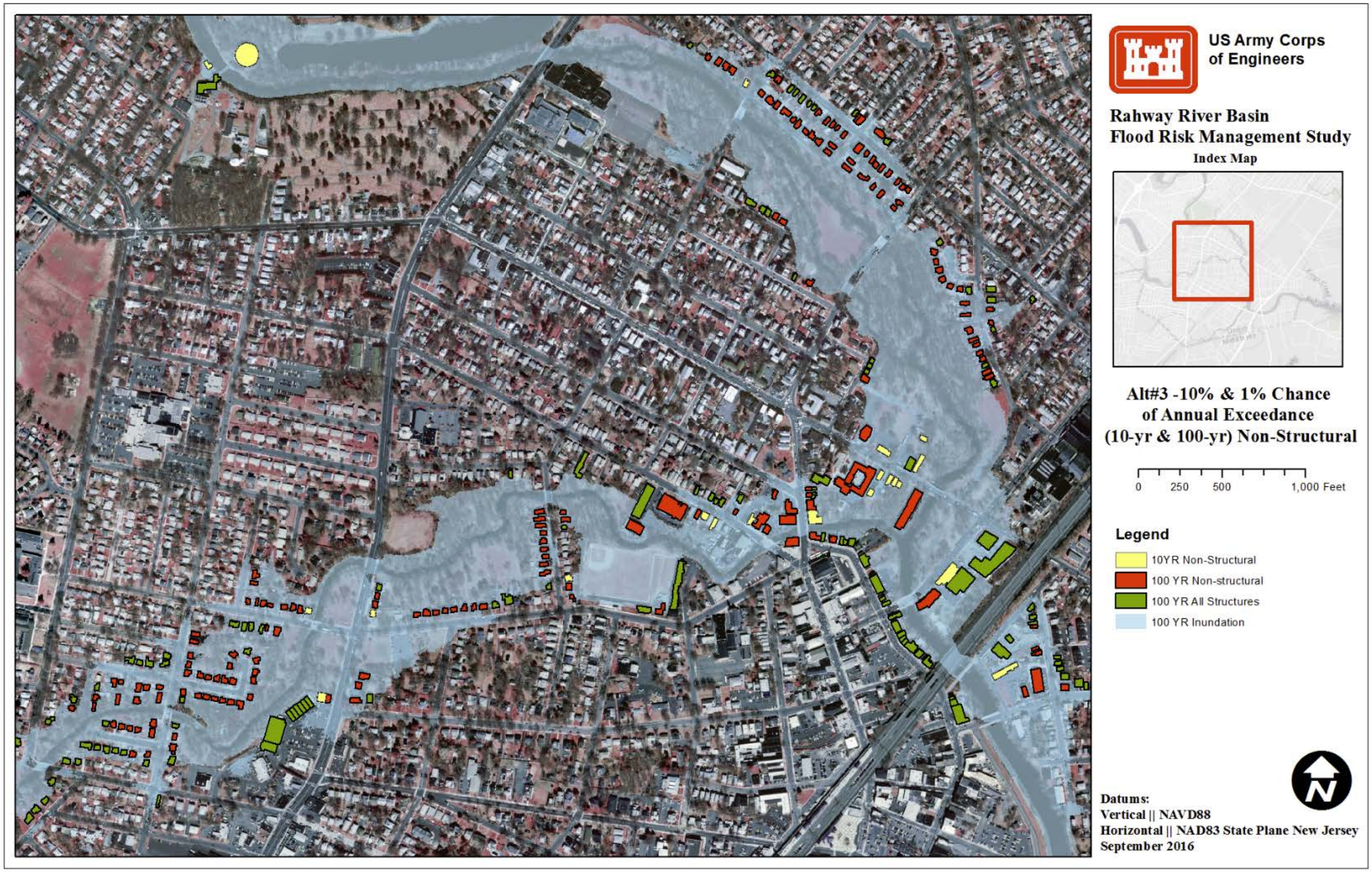

Figure 42: 10% and 1% chance of annual exceedance non-structural alternative in Cranford Township.

5.0 UNCERTAINTY ANALYSIS ON EXISTING AND FUTURE WITH AND WITHOUT PROJECT CONDITIONS

The steady and unsteady analyses required a different approach to estimate the uncertainty. Initially, the uncertainty in the computed WSEs was evaluated by conducting a sensitivity analysis. The goal was to develop realistic upper and lower uncertainty bands on the computed stage for a given discharge. The hydraulic characteristics considered in developing the upper and lower bounds were the Manning's n-value, debris jams at bridges, weir coefficients and gate openings at the existing weirs. A 20% reduction and a 40% increase to the n-values were assigned to help bracket the upper and lower uncertainty bands. This was applied to the majority of cross sections in the hydraulic model. For improved conditions in dam/reservoirs alternatives, 10% decrease in storage capacity and obstruction in spillways and orifices were assumed. The average value was computed per reach and the upper and the lower stages for each frequency were be provided to economics. The average value for most of the reaches between the upper and lower bands it was below 2.0 ft. As a result a standard deviation of 0.5 ft. was used as the method and minimum uncertainty value. As the model developed from a steady and unsteady hybrid hydraulic model to a full unsteady model it became evident that the flow years of record would sufficed to create an acceptable upper and lower uncertainty bands. In addition, the North Atlantic Coast Comprehensive Study uncertainty bands for Rahway at mouth (node ID: 11659), were used for the downstream boundary conditions. The uncertainty boundary are in compliance with the recommended procedure provided in the EM 1110-2-1619 (USACE 1996).