OBG

REPORT

Upper Bowman Pond Modifications Study

DASNY
DORMITORY AUTHORITY STATE OF NEW YORK

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Prepared for:

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DORMITORY AUTHORITY STATE OF NEW YORK

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2D	Two-Dimensional
CEA	Critical Environmental Area
CFR	Code of Federal Regulations
CY	Cubic Yards
DASNY	The Dormitory Authority of the State of New York
EAF	Environmental Assessment Form
ECL	Environmental Conservation Law
EIS	Environmental Impact Statement
ESA	Endangered Species Act
FT	Feet
FEMA	Federal Emergency Management Agency
GML	General Municipal Law
GOSR	Governor's Office of Storm Recovery
HEC-HMS	Hydrologic Engineering Center's Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center's River Analysis System
HUC	Hydrologic Unit Code
MS4	Municipal Separate Storm Sewer Systems
NEPA	National Environmental Policy Act
NHP	Natural Heritage Program
USGS	United States Geological Survey
USACE	United State Army Corps of Engineers

1. PROJECT BACKGROUND AND OBJECTIVES

The Blind Brook watershed (United States Geological Survey (USGS) Hydrologic Unit Code (HUC) 12-011000060405), tributary to the Long Island Sound, is located in southeastern New York state and southwestern Connecticut and contains portions of the Town of Greenwich, Connecticut, the City of Rye, the Town of Harrison, and the Villages of Rye Brook and Portchester, New York. The watershed location is shown in **Figure 1**. It has a drainage area of approximately 8,610 acres (13.45 square miles), is approximately 9 miles long from north to south and its width varies between approximately 0.5 and 2 miles east to west. The upstream portion of the watershed is moderately steep with an average slope of 0.7% and includes the Westchester County Airport, which contributes a significant portion of runoff volume during storm events (Parsons Brinckerhoff, 2014a). The downstream portion of the watershed slopes at a rate of approximately 0.1% and drains to Milton Harbor. The parameters of the watershed were estimated by O'Brien & Gere Engineers, Inc. (OBG) based on available GIS data for the area. The drainage area of the Blind Brook watershed is shown in **Figure 2**.

The City of Rye, NY (the City) is located in Westchester County, approximately 7 miles north of New York City. The City has experienced flooding associated with heavy rainfall events, resulting in significant property damage, especially within a neighborhood known as Indian Village, located adjacent to Blind Brook and between interstate highways I-287 and I-95. In 2007, two major events, one on March 2, and a second on April 15, left the community, businesses and roadways flooded and caused widespread power losses. On August 28, 2011, Hurricane Irene made landfall directly over the area causing extreme flooding and significant property loss. The following year, on October 29, 2012, Superstorm Sandy brought coastal flooding together with high winds and significant rainfall causing once again significant disruption and property loss to the community.

Several studies have been conducted to date regarding the flooding along Blind Brook, mainly focusing on providing recommendations for how to reduce the impact of flooding on the local community. In 2014, the City of Rye retained Parsons Brinckerhoff to provide a comprehensive evaluation of the previously completed studies and to develop further recommendations to reduce and mitigate the flooding and its impacts on the local community. In its *Hydrologic and Hydraulic Analysis Report* (Parsons Brinckerhoff, 2014a), Parsons Brinckerhoff summarized previously conducted studies and examined ways to mitigate flooding in Indian Village. The analysis presented by Parsons Brinckerhoff examines the following alternatives:

- Hydrologic and hydraulic analysis of proposed additional detention areas in the watershed
- Hydraulic analysis of Upper Pond resizing (with associated cost estimate)
- Review and development of sluice gate operating algorithms at the Bowman Avenue Dam

Parsons Brinkerhoff reported that increasing the volume of the Upper Pond, combined with modifications to the rules governing the operation of the sluice gate installed at the Bowman Avenue Dam, could provide a collective reduction in downstream water elevations ranging between 0.2 feet and 2 feet, depending on location and for flood events with return periods between 2-years and 100-years[1]. Parsons Brinckerhoff estimated the cost of the modifications to the Upper Pond at the Bowman Avenue Dam to exceed $6 million (Parsons Brinckerhoff, 2014a).

[1] **Flood Frequency magnitude**

Return Period	Exceedance Probability
2-years	50%
10-years	10%
25-years	4%
50-years	2%
100-years	1%

The Dormitory Authority of the State of New York (DASNY), on behalf of the Governor's Office of Storm Recovery (GOSR), has retained OBG to further analyze possible modifications to the Upper Pond and to assess the rules governing the operation of the sluice gate at the Bowman Avenue Dam. The analysis of modifications to the Upper Pond would help assess how the pond could be modified (*i.e.*, how much soil could be removed from the pond perimeter), given that the currently available funding for the design and construction improvements is $2 million.

The scope of work completed by OBG and presented in this report is summarized as follows:

- **TASK 1**: Review previous studies to assess the recommendations made to the City of Rye to date. The review also included evaluation of the United States Army Corps of Engineers Hydrologic Engineering Center's River Analysis System (HEC-RAS) model utilized by Parsons Brinckerhoff in its study, which was provided to OBG by the City of Rye.
- **TASK 2**: Perform a field investigation of Blind Brook in order to review the configuration of the Bowman Avenue Dam, sluice gate, and the Upper Pond, in order to further OBG's understanding of the Blind Brook watershed hydrologic characteristics. An additional objective of the site visit was to review site conditions relative to the HEC-RAS model input to develop an understanding of the appropriateness of selected model inputs and identify potential opportunities for model improvement
- **TASK 3**: Identify and evaluate an Upper Pond expansion alternative, given the available design and construction budget of $2 million.
- **TASK 4**: Evaluate the previously developed sluice gate operational algorithms at the Bowman Avenue Dam and analysis of potential operational adjustments to those algorithms (algorithm update) due to a potential expansion of Upper Pond identified in Task 3.

2. REVIEW OF EXISTING REPORTS

The City of Rye provided OBG with electronic copies of reports from previously conducted studies addressing flood management in the Blind Brook watershed. To support performance of Tasks 2, 3, and 4, OBG reviewed the following reports:

1. *Westchester County, NY, Flood Insurance Study* – FEMA – 2014
2. *Flood Mitigation Study – Bowman Avenue Dam Site*, Chas. H. Sells, Inc., March 12 2008. (Sells Report)
3. *Hydrologic and Hydraulic Analysis – Bowman Avenue Dam Project – Study for Resizing the Upper Pond Reservoir*, Paul C. Rizzo Engineering, New York, PLLC, September 2012. (Rizzo Report)
4. *Hydrologic and Hydraulic Analysis Report – Blind Brook Watershed Study*, Parsons Brinckerhoff, August 2014. (Parsons Brinckerhoff Report).

This section summarizes the findings and recommendations for reports 1 through 4 identified above, while focusing on the analysis targeting Upper Pond resizing and sluice gate operation. The selected reports provide the most relevant information that pertains to this study. Additional reports identified as informative and consequently reviewed but not fully summarized in this section due to their limited scope include:

5. *Watershed Plan and EIS – Blind Brook Watershed*, USDA Soil Conservation Service, July 1979
6. *Update to the 1999 Storm Water Management Plan. Westchester County Airport*, TRC Engineers, December 2010
7. *Flood Mitigation Study – Lower Pond Supplemental*, Chas. H. Sells, Inc., March 12 2008
8. *Memorandum: Bowman Avenue Sluice Gate Operation Analysis for the April 30 to May 1, 2014 Rainfall Event* **-** Parsons Brinckerhoff, August 2014

9. *Memorandum: Field Trip to Identify Potential Stream Gauge Locations on November 14, 2014* - Parsons Brinckerhoff, August 2014
10. *Memorandum: Impact of Various Flood Mitigation Measures on Flooding Situations within Indian Village* - Parsons Brinckerhoff, March 2015
11. *City of Rye Flood Mitigation Plan* – Tessier Environmental Consulting, November, 2001.

Item 8 in the above list provides valuable information regarding the implementation of the Sells algorithm to operate the Bowman Avenue Dam sluice gate. The document is an analysis of a recent flood event which occurred between April 30 and May 1, 2014. Detailed information about the sluice gate configuration and the experienced operating sequence are analyzed.

Item 9 is a summary of a field visit, conducted by Parsons Brinckerhoff, to identify potential stream gauge locations in support of the sluice gate operating algorithm. The memorandum also provides a discussion on the use of an upstream location for a stream gauge in order to provide flood magnitude forecasting. The summary of the reports 1 through 4 is presented below:

Report 1 - *Westchester County, NY, Flood Insurance Study* – FEMA – 2014

The Federal Emergency Management Agency (FEMA) performed hydraulic studies for the Blind Brook watershed as part of the National Flood Insurance Program (NFIP). In 2007, as a result of the study, FEMA released Flood Insurance Maps designating portions of the watershed adjacent to Blind Brook with corresponding floodplain limits for 100-year and 500-year flood events. An updated analysis conducted by FEMA in 2014 resulted in the release of the updated, preliminary floodplain boundaries and the corresponding flow magnitudes for a number of locations within the watershed. **Figure 3** shows the boundaries for the 100-year and 500-year floods for the Bowman Avenue Dam and its vicinity. The report provides information on the spatial extent of the flooding which demonstrates the extent of the local community affected by flooding.

Report 2 – *Flood Mitigation Study – Bowman Avenue Dam Site*, Chas. H. Sells, Inc., March 12, 2008

The study by Chas. H. Sells, Inc. (Sells), involves a feasibility analysis of various flood damage reduction measures at the Bowman Avenue Dam site. This work, performed by Sells, was motivated by the City's Flood Mitigation Plan, adopted in November 2001, in which the City identified a conceptual plan for providing downstream flood control. The intent of the report was to analyze several alternatives and compare the cost-to-benefit ratio of each of the proposed alternatives. The report aims to guide the City in implementing meaningful flood mitigation measures and to provide a basis for securing hazard mitigation grant funding.

The alternatives proposed in the study were analyzed based on the overall cost and the potential for lowering the water surface elevation downstream of the Bowman Avenue Dam, specifically between interstate highways I-287 and I-95. Among the presented alternatives, the report identifies installation of an automated sluice gate at the Bowman Avenue Dam as a preferred alternative (the dam's orifice at the time of the Sells' report was constricted by wooden logs leaving an approximately 20- ft^2 opening at the bottom of the dam). The proposed sluice gate, when installed, would allow for adjusting the outflow effective area based on flood event magnitude, and serve as a flood control structure.

An additional alternative showing significant potential for lowering downstream water surface during extreme rainfall events involves resizing of the Upper Pond by excavating soil and rock to maximize the storage potential in the pond. Two resizing scenarios with varying degrees of excavation were considered. The benefits associated with pond excavation were assessed both individually and in conjunction with benefits associated with sluice gate installation. The authors of the report recognized that the resizing of the Upper Pond would be associated with a significant cost and would require further investigations (*e.g.,* rock probes, soil testing for contamination).

Sells also proposed an algorithm for sluice gate operation where the magnitude of a flood event is determined by measuring water surface elevation directly at the dam. The algorithm relates flood magnitude to the precalculated gate opening of the sluice gate to maximize the downstream water surface reduction. During normal flow conditions the gate remains closed. The report assumes that following automated sluice gate installation, the 'closed gate' condition would maintain the same size of the bottom opening, which was estimated at approximately 20.2 ft^2 at the time. The details of the sluice gate control algorithm developed by Sells are presented in Section 7.1.

After installation of the automated sluice gate, the Sells algorithm was implemented to control the position of the gate during flood events. The details of the implementation of the algorithm and the corresponding parameters controlling the gate are presented in the memorandum developed by Parsons Brinckerhoff (Item 8 on the list above).

The methodology for estimating changes to the downstream water surface associated with the proposed measures included detailed hydrologic and hydraulic analysis using a HEC-RAS model. Cross sectional data, Manning 'n' values, and bridge geometry were obtained from FEMA's 1979 preliminary Flood Insurance Study (FIS) for Westchester County. The flow rates for the analysis were developed by Sells, using WinTR-20 software. The summary of main results is presented in **Table 2** at the end of this section.

Report 3 – *Hydrologic and Hydraulic Analysis – Bowman Avenue Dam Project – Study for Resizing the Upper Pond Reservoir*, Paul C. Rizzo Engineering, New York, PLLC, September 2012.

Paul C. Rizzo Engineering (RIZZO) was retained by Sells, Inc. to perform a hydrologic and hydraulic analysis to evaluate the potential benefits of resizing of the Upper Pond in order to increase available flood water storage capacity in the watershed. As part of the modeling process, the Blind Brook watershed was divided into six sub-watersheds according to the topographic and hydrologic conditions. To evaluate how changes to the Upper Pond would affect hydrographs associated with given design storms, a full hydrologic model was developed using the United States Army Corps of Engineers Hydrologic Engineering Center's – Hydrologic Modeling System (HEC-HMS) software. Geographic Information System (GIS) software was used to support the modeling by providing spatial information regarding soil type and land cover use. RIZZO was also asked to consider optimizing the sluice gate operation to increase potential benefits from the proposed automated sluice gate at the Bowman Avenue Dam site.

The hydrographs obtained as a result of the hydrologic simulation of the six sub-watersheds were consequently used as input data to a HEC-RAS model for further analysis. The evaluation of the results presented in the report focused on the area most affected by frequent flooding and located between interstate highways I-287 and I-95 (Indian Village).

The following alternative scenarios were analyzed:

- No-build alternative, serving as existing conditions model
- Revision of the sluice operation rules proposed by Sells
- Analysis of the Upper Pond resizing alternatives, which assumes excavation of 110,000 cubic yards of material (*i.e.* 96,000 cubic yards of soil and up to 14,000 cubic yards of rock)
- Analysis of the additional benefits from maximizing the resizing of Upper Pond, which assumes excavation of 130,000 cubic yards of material (*i.e.* 109,000 cubic yards of soil and up to 21,000 cubic yards of rock)
- Combined benefit of resizing Upper Pond and optimal sluice gate operation.

The results from the analysis of alternatives presented in the report indicate that utilizing the sluice gate in conjunction with resizing Upper Pond show the most benefit in terms of downstream water surface elevation reduction. The reductions are most significant (up to 1.3 ft.) for larger storm events (25- to 100-year return period). The report also shows that the incremental benefit gained from maximizing the Upper Pond is insignificant when compared to the initial resizing alternative. According to RIZZO, the sluice gate operation should be controlled by monitoring water surface elevation directly in Upper Pond by an automated water surface elevation sensor. The rules for operating the gate assume keeping the gate closed for storms with return periods less than 5-years, adopting the Sells gate operating rules for storms with return periods between 5- and 10-years, and setting the gate to be fully open for floods with return periods greater than 10-years. A detailed description of the algorithm is provided in Section 7.1.

The direct comparison of the results presented by RIZZO to those provided by Sells is difficult, due to the difference in discharge values implemented in the simulation process. The comparison of the peak discharges associated with different flood magnitudes for both Sells and RIZZO are shown in **Table 1**. The values are reported for the Purchase St. location.

Table 1: Peak Discharge Values Comparison Between Sells and RIZZO (Estimated at Purchase St.)

HYDROGRAPH PEAK FLOW RATES (CFS)*		
STORM EVENT	SELLS	RIZZO
2-year	781	1036
5-year	1275	2143
10-year	1663	2883
25-year	2292	3429
50-year	2767	4084
100-year	3346	4673

*Values reported by RIZZO, 2012.

The differences between the discharge values can be explained by the approach used by the authors in modeling the discharge values for the watershed (*e.g.,* software used, model input data, and analysis method). **Table 2** at the end of this section provides the summary of results presented by RIZZO.

Report 4 – *Hydrologic and Hydraulic Analysis Report – Blind Brook Watershed Study*, Parsons Brinckerhoff, August 2014.

The report by Parsons Brinckerhoff summarizes six reports previously submitted to the City of Rye, which focused on flood mitigation in the Blind Brook watershed. The assessment of the previously developed reports had been requested by the City as part of an effort to evaluate additional and previously presented flood reduction measures. Besides providing a comprehensive review of the previously completed studies, the report identified ten new sites as potential detention basins within the watershed area that could serve as temporary flood water storage to reduce the extent of downstream flooding. The impact of the detention basins on the downstream flooding was evaluated separately and in conjunction with other measures (*i.e.,* resizing of the Upper Pond and modified sluice gate operation). Finally, the report proposes alternative operating algorithms for the sluice gate operation at the Bowman Avenue Dam and documents and evaluation of the performance of the revised sluice gate algorithm both separately and in conjunction with the Upper Pond resizing alternative.

The sluice gate operating algorithm developed by Parsons Brinckerhoff assumes that the gate will stay fully open during normal flow conditions and that the gate will be closed when the water surface elevation, monitored by a sensor installed at a location between the interstate highways I-287 and I-95, reaches a specific threshold. The threshold value that triggers the closing of the gate was estimated for a range of flood magnitudes and for two alternative control gauge locations (a location immediately downstream of interstate highway I-287 and a second location in the center of Indian Village). The details of the operating algorithm proposed by Parsons Brinckerhoff are presented in Section 7.1.

The Parsons Brinckerhoff report recommended the following future steps to be taken by the City:

1. Attainment of stream cross-section survey to improve the accuracy of the hydrologic model. the topographic data used by Parsons Brinkerhoff was derived directly from a LiDAR dataset and did not contain the detailed geometry of the stream cross section below water surface.
2. Installation of stream gauges within Blind Brook in order to calibrate the model using measured discharges and water surface elevation data to better represent the existing condition.
3. Development of detailed detention pond grading plans, outfall structures and elevation-discharge relationships for the selected potential detention areas.

The hydrologic analysis of the system related to the Upper Pond resizing and sluice gate control was conducted with the use of HEC-RAS and HEC-HMS software packages. The peak discharge values estimated by Parsons Brinckerhoff differed from those used by Sells and those of RIZZO. The differences in flow values ranges between 2% and 7% between the reports and can be attributed to different sub-divisions of the watershed leading to different timings between contributing hydrographs, selection of updated soils data information, and other differences in the overall modeling approach.

Summary of the Review

The review of the previously completed studies identified the following:

- The reports focused on examining alternatives that can help mitigate flood extent along Blind Brook between interstate highways I-287 and I-95.
- Among studied alternatives, the combination of optimal sluice gate operation and resizing of Upper Pond appeared to be the most effective way in mitigating downstream flooding conditions.
- Two Upper Pond excavation scenarios were analyzed by RIZZO and Parsons Brinckerhoff. The added benefit associated with maximizing the Upper Pond does not justify the extra cost associated with excavation of additional material within the pond area. Maximizing the pond storage volume would provide relatively negligible reductions in water surface elevation (*e.g.* between 0.1 and 0.3 feet for most flood scenarios). The excavation scenario recommended by Parsons Brinckerhoff assumes removal of ~110,000 CY of material from Upper Pond with the associated cost exceeding $6 million.
- Three alternative sluice gate operating algorithms have been investigated. The detailed analysis of the sluice gate and the proposed operating rules are presented in Section 6.
- Differences in modeling approach, data sources used, and assumptions within the models should be taken into consideration when making a direct comparison between the results presented in the reports.
- OBG considered the approach and the results provided by each of the analyzed reports and concluded that the HEC-RAS model utilized by Parson Brinckerhoff and the associated channel geometry and input data are appropriate for use as the basis for the analysis presented in this report.
- The three proposed sluice gate operating algorithms all assume that the decision to control the gate is to be based on an event magnitude. This implies an existence of an event forecasting ability – an ability to forecast the event's magnitude as it happens with enough lead time, allowing for decision making. Without this capability, sluice gate operating algorithms cannot be successfully implemented.

Table 2 compares results for the main findings reported in previously completed studies with focus on resizing of Upper Pond and optimizing sluice gate operation.

Table 2: Comparison of Main Results from Previous Studies. Water Surface Elevation Reduction (ft)

STORM EVENT	SLUICE GATE				RESIZING + SLUICE GATE			
2-year	**Sells**	**RIZZO**	**PB-IV***	**PB-I-287***	**Sells**	**RIZZO**	**PB-IV***	**PB-I-287***
D/S of I-287	0.0	0.0	0.0	-0.1	-0.3	-0.6	0.0	-0.1
Purchase St	0.0	0.0	0.0	-0.1	-0.3	-0.6	0.0	-0.1
U/S of I-95	-0.7	0.0	0.0	-0.1	-0.4	-0.5	0.0	-0.1
10-year								
D/S of I-287	-0.5	**	-0.2	-0.2	-1.3	-0.2	-0.4	-0.6
Purchase St	-0.6	**	-0.3	-1.0	-2.2	-0.5	-0.8	-1.1
U/S of I-95	-0.8	**	-0.4	-1.5	-3.1	-0.7	-0.8	-1.1
50-year								
D/S of I-287	-0.5	-0.2	-0.5	-0.5	-0.9	-0.4	-0.5	-0.7
Purchase St	-1.7	-0.4	-0.9	-1.0	-2.9	-0.6	-1.0	-1.2
U/S of I-95	-4.2	-0.5	-1.6	-2.0	-5.3	-1.0	-1.5	-1.8
100-year								
D/S of I-287	-0.4	-0.2	-0.2	-0.4	-0.9	-0.4	-0.2	-0.6
Purchase St	-0.9	-0.2	-0.5	-0.9	-1.9	-0.6	-0.4	-1.0
U/S of I-95	-1.1	-0.5	-0.8	-1.7	-2.1	-1.3	-0.7	-1.5

All algorithms assume the same Upper Pond resizing scenario.
* PB-IV – Parsons Brinckerhoff algorithm with gate control location in Indian Village, PB-I-287 – Parson Brinkerhoff algorithm with gate control location downstream of I-287
**Assumes Sells algorithm results

When analyzing the above results, one must take into account the inherent differences in the modeling approach utilized by respective authors, such as software used, geometry data, sluice gate parameters, land use, and rainfall statistics data used for flow calculations.

The relatively large water surface elevation reductions for the 50-year flood event reported by Sells can be attributed to flow values used in the report and the associated change in the flow regime from the free surface to pressure flow at the I-95 culvert. A more detailed explanation of this situation is provided by RIZZO, 2012.

3. SITE VISIT SUMMARY

On September 21, 2016, OBG performed a site visit to Blind Brook to review the configuration of the Bowman Avenue Dam, the sluice gate, and Upper Pond. Field observations of Blind Brook, the upstream and downstream sections of Upper Pond, and the Bowman Avenue Dam site were made. The visit provided an opportunity to verify the representativeness of the HEC-RAS models in capturing the geometry of the main structures along Blind Brook and to identify locations of potential hydraulic model improvements.

An on-site review of HEC-RAS model input parameters associated with Blind Brook cross section geometry, bridge configurations, and Manning's 'n' values were compared to field observations. Photo documentation was collected of the main structures along Blind Brook within the HEC-RAS model domain. The area most affected by frequent flooding (the Indian Village neighborhood) was visited with assistance from the City's engineers and planners who identified the extent of past flooding. The main observations made and the information collected during the site visit are summarized below:

- The sluice gate is not currently utilizing any operating algorithm. For all events the gate remains in the closed position.

- The status and the accuracy of the water surface elevation data collected by the automated sensor installed at the upstream side of the Bowman Avenue Dam requires further investigation to evaluate whether the gauge can be used in future applications.
- Upper Pond and the immediate upstream and downstream sections of Blind Brook are heavily vegetated and their representation in the HEC-RAS model is adequate.
- The physical dimensions for the main structures (*i.e.,* bridges, culverts) appear to be appropriately represented in the model.
- The placement and elevation of the ineffective flow areas, which are a HEC-RAS model feature, representing flow around structures (*i.e.,* bridges, culverts), were visually assessed in the field and compared to their model representation. The associated findings were implemented as part of the HEC-RAS model review process (see Section 4).
- The configuration of the culvert under interstate highway I-95, the adjacent railroad corridor, a sequence of turns and structures immediately downstream of I-95 may limit the flow of water during large storm events, and consequently affect the water surface upstream of I-95 and into the Indian Village neighborhood. This observation was later confirmed by the results obtained from the HEC-RAS model, showing significant difference in water surface elevation between the upstream and downstream sections of the interstate I-95 culvert. This is further discussed in Section 8.
- No bathymetric survey data is associated with the HEC-RAS model provided to OBG, so discrepancies between the model's geometry and the physical dimensions of the channel may exist.
- The HEC-RAS model is limited in its spatial extent and does not cover areas downstream of interstate highway I-95. This prevents evaluations of how changes to Upper Pond and utilization of the sluice gate can affect areas beyond the model's coverage.

The information collected during the site visit was essential in evaluating the previously conducted studies, reviewing the hydrologic model, developing alternatives for Upper Pond excavation, and developing sluice gate operating scenarios.

4. REVIEW OF THE HEC-RAS MODEL

Following the review of the previously conducted studies and the site visit, OBG conducted an assessment of the HEC-RAS model. The model developed by RIZZO, and further updated by Parsons Brinckerhoff, was provided to OBG by the City.

The model covers a portion of the main brook reach starting near the intersection of Lincoln Avenue and Crawford Road and continues downstream for approximately 3 miles to Locust Avenue. The model limits are shown in **Figure 4**. The cross sections are spaced tightly along the main channel with separating distance varying between 15 and 50 feet. The cross-sectional geometry is based on LiDAR derived data. Except for bridge sections, the model employs a single Manning's 'n' value to represent the hydrologic roughness throughout the modeled Blind Brook reach. The selected value of 0.045 would indicate a straight, minor channel with some weeds and stone and a vegetated floodplain with trees (Chow, 1959). This description generally fits the conditions in the stream, but more detailed analysis of roughness conditions in the channel presents an opportunity for future model improvement.

During the review process, adjustments were made to the model with the intent to improve the overall performance of the model. Descriptions of these adjustments are provided below.

- <u>Adjustment and/or removal of a number of "ineffective flow areas".</u> An ineffective flow area is often associated with a culvert or a bridge, where the free flow of water is constrained by the structure and the flow velocity is significantly reduced before the flow can pass the structure. Information collected during the site visit helped identify a number of cross sections in the model where the ineffective flow area parameters could be further adjusted in height and location.

- Adjustment of model parameters, boundary conditions and initial conditions. The execution of a HEC-RAS model run is controlled by a number of parameters specified by the user. By controlling the parameters, a modeler can significantly affect the model's outcome and computational accuracy. In the case of unsteady flow simulations, the accuracy of a model and its stability need to be balanced through user's input to allow for the model to successfully run while providing valuable information. The selection of boundary and initial conditions and the parameters controlling a model are often a matter of users' experience and unique site characteristics. OBG tested a number of parameter configurations with the intent to improve the model's output accuracy without compromising the quality of the results or the stability of the model. Some of the HEC-RAS parameters that were affected by this step included: adjustment of the implicit weighting factor "theta", which serves as a way to control the accuracy and the stability of the model; modification of the water surface calculation tolerance, resulting in lower acceptable errors associated with calculations of the water surface; and the adjustment of the calculation time step in order to achieve a higher temporal resolution of the results.
- Model geometry and flow conditions. The model provided to OBG consisted of a number of geometry files, defining the physical shape and parameters of the model as well as a number of flow conditions, defining shape and peak values for hydrographs associated with flood events between 2-year and 100-year storms. The availability of multiple geometry and flow condition files shows a rich history of the modeling effort associated with the Blind Brook watershed. As part of the model review process, OBG identified differences between geometries and flow conditions and selected those most representative of the conditions that were being modeled within the scope of this project (*i.e.,* the geometries associated with the additional upstream water detention areas developed by Parsons Brinckerhoff and the Upper Pond maximum resizing alternatives were removed, together with initial boundary conditions associated with the proposed, but not yet implemented flood mitigation measures at the Westchester Airport).
- Pilot channel implementation. The cross-sectional geometry of the model, derived directly from LiDAR data, shows high natural variability typically associated with remotely sensed data. This, together with a number of tightly spaced cross sections, leads to the relatively complex geometry of the channel bottom. This leads to instability in model outputs often seen as "oscillation" of the results, typically most pronounced for low-flow conditions. To reduce this instability, OBG implemented a section of a pilot channel in the upstream reach of the model. A pilot channel is a built-in HEC-RAS module, which serves to smooth the bottom of a channel reach and removes the low-flow instabilities, without affecting the model's overall results.

After review of the model and making minor adjustments identified above, OBG concluded that the HEC-RAS model obtained from the City of Rye was appropriate for use in evaluating additional flood mitigation alternatives with the following assumptions:

- The model was not calibrated by observational data. Due to the lack of operational stream gauges along Blind Brook, no stage or flow information is currently being recorded that could be used as basis for full model calibration. As recommended by Parsons Brinckerhoff, installation and maintenance of stream gauges along Blind Brook presents another opportunity that could lead to improved accuracy of modeling over time (*i.e.,* 10+ years).
- The uncertainties associated with the results (*i.e.*, absolute values for water surface elevation and associated flows) provided in the report should be recognized. Those uncertainties are associated with the fact that the HEC-RAS model used throughout the report had not been calibrated (calibration data was not available). Nevertheless, the relative differences in calculated water surface elevations for tested alternative scenarios can provide useful information when comparing alternative flood mitigation methods.

5. EVALUATION OF RESIZING OF UPPER POND

5.1 SITE DESCRIPTION

The Bowman Avenue Dam is located within the Village of Rye Brook, immediately upstream of the interstate highway I-287. The dam, together with the Upper Pond, serves as the only flood mitigation structure along Blind Brook. The Bowman Avenue Dam, and the adjacent Upper and Lower Ponds are shown in **Figure 5**. Constructed in the 1900s, the dam and Upper Pond were originally used for ice production. In 1941 the dam collapsed and was rebuilt as a reinforced concrete gravity dam founded on ledge rock. The dam is 119 feet long by 13 feet high (measured to the spillway). The outlet, located at the bottom, is 15 feet wide by 11.5 feet high and the top spillway is 20 feet wide by 2 feet high. In 2013, the City of Rye installed an automated sluice gate capable of varying the dam's opening between approximately 22 ft^2 (gate closed) and approximately125 ft^2 (gate fully open). A schematic depiction and a photo of the dam's existing condition are shown in **Figure 6**. Based on the analysis of historic aerial photographs, it can be observed that the Upper Pond site has changed considerably over the years due to siltation (Parsons Brinckerhoff, 2014, estimated that the Upper Pond is now approximately 25% of its original size). The capacity of the Upper Pond has been estimated at 145 acre-feet (Sells 2008) when measured from the normal pool elevation to the crest of the dam at elevation 57.3 feet.

Downstream of the dam is Lower Bowman Pond, which also serves as the confluence with East Branch Blind Brook. The Lower Pond, originally used as a quarry, was abandoned in 1976 and subsequently flooded to form the pond. Lower Bowman Pond provides minimal additional flood storage and is not considered a flood control structure. The report *Flood Mitigation Study – Lower Pond Supplemental* (Sells, 2008) provides a detailed analysis of the Lower Pond and examines an alternative to convert it into a flood control structure, but the associated significant construction cost compared to the relatively limited additional reduction in water surface elevation estimated by RIZZO (between 3 and 6 inches), resulted in the elimination of the project from the list of feasible flood mitigation alternatives.

Previously performed studies (Sells, 2008; Rizzo, 2012; Parsons Brinckerhoff, 2014a) concluded that conducting a $6 million project to expand the pond can provide reductions in water surface elevations during flood events. A component of the project scope of work was to identify the downstream water surface elevation reductions that may be achieved by conducting a $2 million project to expand the Upper Pond. The analysis utilized a HEC-RAS model that was developed by RIZZO and Parsons Brinckerhoff and was slightly revised after further adjustments by OBG (see Section 4 for details). The results of the analysis are reported for three locations downstream of the Bowman Avenue Dam that are historically associated with property damage during flood events. The locations used for results comparison are shown in **Figure 7**.

5.2 SUMMARY OF PREVIOUSLY PROPOSED UPPER POND EXCAVATION PLANS

The previously conducted studies by Sells, RIZZO and Parsons Brinckerhoff, concluded that creating additional storage volume behind the Bowman Avenue Dam by resizing the Upper Pond, can help reduce downstream water surface elevation during flood events.

The extent of the excavation proposed by RIZZO, and further evaluated by Parsons Brinkerhoff, includes removal of approximately 96,000 CY of soil and between 6,000 and 14,000 CY of rock from the pond's perimeter. The downstream reduction in water surface elevation achieved by creating the additional storage is evaluated by comparing the existing conditions model results with results of the model accounting for the proposed Upper Pond modifications. **Table 3** summarizes those benefits as reported by Parsons Brinckerhoff (Parsons Brinkerhoff, 2014a).

Table 3: Water Surface Elevation Reductions Associated with Upper Pond Resizing Estimated by Parsons Brinckerhoff (2014)

STORM EVENT	LOCATION	WSE REDUCTION (FT)
2-year	D/S of I-287	-0.14
	Purchase St	-0.14
	U/S of I-95	-0.10
10-year	D/S of I-287	-0.47
	Purchase St	-0.80
	U/S of I-95	-1.00
50-year	D/S of I-287	-0.33
	Purchase St	-0.64
	U/S of I-95	-1.30
100-year	D/S of I-287	-0.1
	Purchase St	-0.32
	U/S of I-95	-0.63

Parsons Brinckerhoff estimated the construction cost associated with the resizing of Upper Pond to be approximately $6 million. Unit costs for the study have been developed by Parsons Brinckerhoff based on the *Weighted Average Item Price Report by Item, Region and Quarter* (US Customary Contract Let, July 2012 – June 2013) provided by the Office of Engineering, Design Quality Assurance Bureau, New York State DOT website. The itemized cost estimate developed by Parsons Brinckerhoff for the Upper Pond resizing is provided in **Table 4**.

Table 4: Parsons Brinckerhoff Cost Estimate Associated with Upper Pond Resizing.

ITEM DESCRIPTION	UNITS	QUANTITY	UNIT COST ($)	COST ($)
Mobilization	LS	1	100,000	100,000
Clearing & Grubbing	AC	15.5	7,800	120,900
Rock Excavation	CY	6,246	100	624,642
Soil Excavation	CY	97,861	40	3,914,424
Water Handling	LS	1	100,000	100,000
Soil Erosion & Sediment Control	LS	1	200,000	200,000
			Sum	5,059,966
			Contingency 20%	1,011,993
			Total	**6,071,960**

Based on the Parsons Brinckerhoff itemized construction costs and the available construction budget of $2 million, OBG developed a limited Upper Pond resizing alternative in which the quantity of rock and soil to be removed is reduced, and using the unit prices included in the Parsons Brinckerhoff estimate. The resulting cost estimate associated with this alternative is shown in **Table 5**.

Table 5: OBG Cost Estimate Associated with Limited Upper Pond Resizing Assuming Parsons Brinckerhoff Unit Costs.

ITEM DESCRIPTION	UNITS	QUANTITY	UNIT COST ($)	COST ($)
Mobilization	LS	1	100,000	100,000
Clearing & Grubbing	AC	2.5	7,800	19,500
Rock Excavation	CY	0	100	0
Soil Excavation	CY	31,000	40	1,240,000
Water Handling	LS	1	100,000	100,000
Soil Erosion & Sediment Control	LS	1	200,000	200,000
			Sum	1,659,500
			Contingency 20%	331,900
			Total	**1,991,400**

The excavation plan associated with this alternative assumes that the bottom of the pond after excavation would have an elevation of 41 feet above mean sea level eliminating the need to excavate the underlying rock[2]. The total volume of soil that would be excavated based on the above assumptions was estimated at approximately 31,000 CY. An analysis of the estimated benefit associated with the downstream water surface elevation reduction is presented below.

5.3 31,000 CY EXCAVATION ALTERNATIVE

To evaluate the effect of the limited, 31,000 CY Upper Pond resizing alternative, a HEC-RAS model geometry associated with existing conditions was updated to reflect the changes in topography. OBG utilized LiDAR data from the Westchester County online GIS system[3] to generate a high resolution digital elevation model for the Upper Pond area. When selecting the excavation perimeter, the following set of conditions was considered:

- The pond expansion area was selected such that it would involve excavation of undisturbed and non-contaminated soil to reduce costs associated with soil disposal. The information about the distribution of the non-hazardous contaminated soil (class C) within the Upper Pond is identified in the Parsons Brinckerhoff's report (2014a), Figure 33, which shows the results of the soil survey conducted by RIZZO in 2012.
- The additional volume created by excavation should be utilized during flood events with magnitudes corresponding to floods up to 100-year in frequency (*i.e.,* the location and limits of the resizing were selected to avoid removal of soil in areas that are unlikely to be flooded by frequent events).
- A focused excavation area was selected to limit the area required for clearing and grubbing.
- Access for construction equipment is a component of the project. An expansion area located close to an existing point of access has cost advantages.
- Selecting a location that minimized the need for water handling (Blind Brook flows) and erosion and sediment control.
- The excavated volume should be approximately 31,000 CY.

After identifying an area based on the conditions listed above, the digital elevation model was modified to reflect the changes. A graphical representation of the digital elevation model before and after modification is presented in **Figure 8**. The modified digital elevation model was consecutively used to update the cross sections of the

[2] The survey by RIZZO identified the elevation of rock to be below 41 ft above mean sea level in the excavation area.
[3] http://giswww.westchestergov.com/wcgis/Lidar.htm

HEC-RAS model. The updated model geometry accounting for the 31,000 CY of soil removal was used to evaluate the benefit associated with the excavation in terms of downstream water reduction. The results for this analysis are presented in **Table 6**. The calculations assume that the sluice gate remains closed for all flood events and the bottom opening area is 22.6 ft^2.

Table 6: Water Surface Reductions Associated with the 31,000 CY Upper Pond Resizing.

STORM EVENT/LOCATION	EXISTING CONDITIONS WATER SURFACE ELEVATION (FT)	31,000 CY EXCAVATION WATER SURFACE ELEVATION (FT)	DIFFERENCE (FT)
2-year			
D/S of I-287	32.80	32.47	-0.33
Purchase St	26.99	26.77	-0.22
U/S of I-95	22.01	21.67	-0.34
10-year			
D/S of I-287	35.11	35.03	-0.08
Purchase St	30.97	30.89	-0.08
U/S of I-95	25.69	25.49	-0.20
50-year			
D/S of I-287	36.13	36.11	-0.02
Purchase St	32.33	32.26	-0.07
U/S of I-95	28.73	28.59	-0.14
100-year			
D/S of I-287	36.49	36.47	-0.02
Purchase St	33.22	33.15	-0.07
U/S of I-95	30.42	30.03	-0.12

The values reported in **Table 6** (and **Table 8** in section 5.4) were developed using a HEC-RAS model which was subject to the changes described in Section 4 and consequently, the values presented as "existing conditions differ from those presented in previous reports.

5.4 UPPER POND RESIZING - REVISED COST ESTIMATE

A cost estimate for soil transportation and disposal was not included in Parsons Brinkerhoff's $6 million construction cost estimate. OBG developed a new cost estimate that includes the cost for soil transportation and disposal to identify a more representative volume of soil that could be removed from the Upper Pond for $2 million. The description of the items included in the cost estimate and the associated unit prices are presented in **Table 7**.

Table 7: OBG Class 5 Cost Estimate Associated with Limited Upper Pond Resizing and OBG Unit Costs.

ITEM DESCRIPTION	UNITS	QUANTITY	UNIT COST ($)	COST ($)
Mobilization	LS	1	82,300	82,300
Equipment Cost	LS	1	60,000	60,000
Clearing & Grubbing	AC	2.5	16,200	40,500
Access Road	LF	150	485	72,600
Soil Excavation	CY	13,500	14.84	200,340
Soil Disposal	TN	22,950	46	1,044,225
Water Management	LS	1	145,500	145,500
			Subtotal	1,645,465
			Contingency 30%	407,300
			Total	**2,052,765**

The following assumptions are associated with the estimate presented in **Table 7**:

1. The estimate is categorized as Class 5 (concept screening) by the Association for the Advancement of Cost Engineering (AACE).
2. Westchester County prevailing wages for labor cost.
3. Soils are not contaminated and can be disposed of at a landfill within 50 miles of the site.
4. Work can be completed without interruption.
5. No obstructions exist that would prevent work.
6. The area is easily accessible.
7. 30% contingency.
8. No significant delays or cost impacts associated with permitting (See **Table 9**).
9. Costs associated with storage or treatment of water are not included.
10. Rock excavation is not required.
11. Water management includes: diesel pumps (6”-8”), Super Sacks, HDPE Pipe (~200’ bypass) and labor for daily maintenance.
12. No engineering or construction management costs are included.

The revised estimate results in a 13,500 CY volume of soil being removed from the Upper Pond for an estimated cost of $2 million.

5.5 13,500 C.Y. EXCAVATION ALTERNATIVE

Based on the revised cost estimate, a second excavation scenario involving 13,500 CY of soil removal was evaluated with respect to the downstream water surface evaluation reduction. The area designated for excavation and the proposed grading plan are shown in **Figure 9**. The selection of the area was guided by the same set of conditions as the 31,000 CY excavation plan (described in Section 5.2). The revised grading plan was subsequently used to update the HEC-RAS model geometry and allow for evaluation of the proposed excavation plan with respect to the downstream water surface elevation reduction. The relative changes of the water surface elevations between interstate highways I-287 and I-95 is presented in **Table 8** for three selected locations.

Table 8: Water Surface Reductions Associated with the 13,500 CY Upper Pond Resizing.

STORM EVENT/LOCATION	EXISTING CONDITIONS WSE [FT]	13,500 CY EXCAVATION WSE [FT]	DIFFERENCE [FT]
2-year			
D/S of I-287	32.80	32.59	-0.21
Purchase St	26.99	26.79	-0.20
U/S of I-95	22.01	21.69	-0.32
10-year			
D/S of I-287	35.11	35.07	-0.04
Purchase St	30.97	30.92	-0.05
U/S of I-95	25.69	25.59	-0.10
50-year			
D/S of I-287	36.13	36.12	-0.01
Purchase St	32.33	32.30	-0.03
U/S of I-95	28.73	28.66	-0.07
100-year			
D/S of I-287	36.49	36.48	-0.01
Purchase St	33.22	33.18	-0.04
U/S of I-95	30.42	30.36	-0.06

The limited Upper Pond resizing alternatives presented here, show that expansion of the Upper Pond by 31,000 CY or 13,500 CY can lower the water surface elevation in the Indian Village by up to approximately 0.3 feet during relatively frequent flood events (2-year and less). Water surface elevation reductions for storms greater than 2-year are negligible. It should be noted that the precision of the reported results is beyond the accuracy of the HEC-RAS model but was reported to capture the limited differences in the effect of the evaluated Upper Pond excavation.

5.6 UPPER POND CLEARING AND MAINTENANCE

The Upper Pond is thickly vegetated with trees and brush. The City of Rye has expressed concern regarding the risk of fallen trees being washed downstream and causing property damage. OBG's conceptual construction cost estimate for clearing the nine-acre pond of vegetation is approximately $75,000 to $100,000. This activity may require installation of an access road which may cost an additional $100,000. As an alternative to clearing the nine-acre pond, a program could be implemented to annually identify fallen trees and remove them from the Upper Pond. A conceptual cost estimate was not developed for this alternative, however this activity could be addressed further in the Inspection and Maintenance Plan developed for Bowman Dam.

6. PERMITTING AND APPROVALS

A review of required permitting and approvals associated with a potential Upper Pond expansion was performed. Based on a review of the NYSDEC's Environmental Resource Mapper (http://www.dec.ny.gov/gis/erm/), these alternatives would likely require the permits and approvals from federal, state, and local agencies that are summarized in **Table 9**. Additional considerations regarding potential permits and approvals include:

- Blind Brook is designated Class SC by the NYSDEC and, therefore, should not be protected pursuant to 6 NYCRR Part 608; Article 15 of the ECL (Protection of Waters).
- No mapped freshwater wetlands that are protected pursuant to 6 NYCRR Parts 663 – 664; Article 24 of the ECL (New York State Freshwater Wetlands) were identified on-site.
- According to the U.S. Fish & Wildlife's Information for Planning and Conservation (IPaC) database, there are no federally listed endangered species known to occur on-site (https://ecos.fws.gov/ipac/).

If design and construction efforts associated with an Upper Pond expansion were to proceed, coordination with agencies should commence as soon as practicable after the development of conceptual design documents, such that the requirements can be clarified and applications submitted.

Table 9. Potential Permits and Approvals

	PERMIT	ACTIVITY	AGENCY
	Federal		
1	Section 404 of the Clean Water Act (Joint Application)	Discharge of dredged or fill material into waters of the United States (delineation of wetlands required for application). Nationwide Permits vs. Project-Specific Permit.	USACE
	State		
2	Section 401 of the Clean Water Act (401 Water Quality Certification) (Joint Application)	Certification is used to ensure that federal agencies issuing permits or carrying out direct actions, which may result in a discharge to waters of the United States do not violate New York State's water quality standards or impair designated uses.	NYSDEC
3	SPDES General Permit for Stormwater Discharges from Construction Activity (GP-0-15-002)	Stormwater discharges from construction phase activities disturbing one-acre or greater. Includes preparation and implementation of SWPPP.	NYSDEC
4	SEQRA (Article 8 of the ECL; 6 NYCRR Part 617)	Review of potential environmental impacts. Preparation of Short or Full EAF.	Lead & Involved Agencies (coordinated vs. uncoordinated review)
5	Federal & State Preservation Laws (36 CFR 800; 9 NYCRR Part 428; Sections 3.09 and 14.09 of the NYS Parks, Recreation and Historic Preservation Law)	Activities affecting historic, architectural, archaeological and cultural resources. Involved State agency determines need for consultation with NYSOPRHP. Consultation via NYSOPRHP's Cultural Resource Information System (CRIS). Initial consultation includes submission of project description and location, photographs, and documentation of prior disturbance and/or cultural resource investigation. Goal is to obtain "No Effect" letter from NYSOPRHP.	NYSOPRHP – Field Services Bureau
6	ESA (Section 7 of ESA)	Consultation process to identify whether a Federally- or State-listed, proposed or candidate species and/or critical habitat may occur within the proposed project area.	USFWS NYSDEC NHP
7	Floodplain Development Permit	Work within 100-year floodplain. Approval process is typically delegated to local floodplain administrator.	City of Rye
	Local (Municipal)		
8	Site Plan Approval	Approval of site modifications. Coordinate with municipal Code Enforcement Officer to identify process.	Village of Rye Brook Planning Board of Appeals

	PERMIT	ACTIVITY	AGENCY
9	GML 239-m	County Planning Board review of activities located within 500-feet of State or County highway, municipal boundary or park.	County Planning Board
10	Chapter 241, Article III of the Westchester County Administrative Code	Work within 100-feet of Blind Brook	Westchester County Department of Public Works & Transportation
11	Village of Rye Brook Code Section 235	Approval to remove trees	Village of Rye Brook

Notes/Assumptions

1. Typical timeframes (actual timeframes may differ).
2. Additional ministerial and/or discretionary permits, approvals, and reviews may apply.

7. BOWMAN AVENUE DAM SLUICE GATE EVALUATION

As described in the 2008 report by Sells, during normal (low) flow conditions, water passes beneath the Bowman Avenue Dam through a 15-feet wide opening with a varying height, depending on the sluice gate elevation. For storm events exceeding approximately 1450 cubic feet per second (between 2-year and 5-year design storm), the flowing water overtops the crest of the dam and flows into the overflow channel, before joining the main channel of Blind Brook just downstream of the dam. Prior to this study, three operating algorithms were developed to control the automatic sluice gate installed at the dam.

7.1 SUMMARY OF PREVIOUSLY DEVELOPED SLUICE GATE OPERATION ALGORITHMS

OBG reviewed the previously developed algorithms and compared the effects of each of the sluice gate control methods on the downstream water surface elevation using the HEC-RAS model. A summary of the previously developed sluice gate operating algorithms is presented below.

Sells Algorithm

As previously described, an automatic sluice gate was installed in 2013, replacing a wooden-log-based structure which served to restrict flow through the dam. The installation of the sluice gate was evaluated in the study by Sells (Sells, 2008), in which a number of alternative gate opening sizes and their effect on flood reduction downstream were analyzed. The Sells report recommended that to maximize the benefit from the newly installed gate, the gate opening should be set to a given size based on flood magnitude. The Sells report included estimated opening size values for controlling the gate during a flood event, as summarized in **Table 10**.

Table 10: Bowman Avenue Dam Sluice Gate Opening Rules Developed by Sells, 2008.

STORM EVENT	ORIFICE SIZE [FT^2]	ESTIMATED GATE HEIGHT [FT]
2-year	20.2	0 (Gate Closed)
5-year	45.6	1.69
10-year	72.1	3.46
25-year	105.6	5.69
50-year	139.1	7.93 (Gate Fully Open)
100-year	139.1	7.93 (Gate Fully Open)

The gate's current configuration creates an opening at the bottom of the gate even when the gate is fully closed. Sells used an approximated area of 20.2 ft^2 allowing for flow through the gate to represent the "fully closed" gate conditions. The estimated gate height values from **Table 10** were estimated by OBG assuming a 15 feet wide orifice opening. It is important to note that the gate height of 7.93 feet associated with full opening is not achievable in existing conditions since the gate's maximum opening is reported at 7.3 feet (Parsons Brinckerhoff, 2014b). The results obtained by Sells showing the effectiveness of the sluice gate in lowering the downstream water surface elevation are presented in **Table 11**.

Table 11: Water Surface Elevation – Optimal Sluice Gate Operation (Sells, 2008).

STORM EVENT	EXISTING CONDITIONS WSE (FT)	WITH OPTIMAL SLUICE GATE OPENING (FT)	DIFFERENCE (FT)
2-year		**Orifice opening: 20.2 ft^2**	
D/S of I-287	31.7	31.7	0
Purchase St	25.65	25.65	0
U/S of I-95	20.77	20.80	0.03
5-year		**Orifice opening: 45.6 ft^2**	
D/S of I-287	32.15	31.62	-0.53
Purchase St	27.20	26.61	-0.59
U/S of I-95	22.95	22.36	-0.59
10-year		**Orifice opening: 72.1 ft^2**	
D/S of I-287	32.73	32.27	-0.46
Purchase St	28.33	27.73	-0.60
U/S of I-95	24.59	23.89	-0.70
25-year		**Orifice opening: 105.6 ft^2**	
D/S of I-287	33.44	32.87	-0.57
Purchase St	30.06	29.21	-0.85
U/S of I-95	26.93	26.19	-0.74
50-year		**Orifice opening: 139.1 ft^2**	
D/S of I-287	34.11	33.66	-0.45
Purchase St	31.91	30.18	-1.73
U/S of I-95	30.56	26.41	-4.15
100-year		**Orifice opening: 139.1 ft^2**	
D/S of I-287	34.97	34.54	-0.43
Purchase St	33.44	32.55	-0.89
U/S of I-95	32.17	31.12	-1.05

RIZZO Algorithm

RIZZO, in its 2012 report, proposed a sluice gate operation algorithm that results in the gate being closed for storms with return periods of 5-years or less, adopting the Sells gate operating algorithm for storms with return periods between 5- and 10-years, and setting the gate to "fully open" for events greater than 10-years. The operating logic for the RIZZO algorithm is captured in **Table 12**.

Table 12: Bowman Avenue Dam Sluice Gate Opening Rules Developed by RIZZO, 2012.

STORM EVENT [YEARS]	ORIFICE SIZE [FT^2]	ESTIMATED GATE HEIGHT [FT]
< 5	27	0 (Gate Closed)
5 - 10	52.4 - 72.1	1.7 - 3
> 10-years	145.9	7.93 (Gate Fully Open)

The report by RIZZO assumes that the minimal gate opening associated with the closed gate is 27 ft^2 (compared to 20.2 ft^2 used by Sells, 2008). The estimated flood reduction benefits associated with adopting the RIZZO sluice gate operating algorithm are summarized in **Table 13**.

Table 13: Water Surface Elevation – Optimal Sluice Gate Operation (RIZZO, 2012).

STORM EVENT	EXISTING CONDITIONS WSE (FT)	WITH OPTIMAL SLUICE GATE OPENING (FT)	DIFFERENCE (FT)
2-year		**Orifice opening: 27 ft^2**	
D/S of I-287	33.8	33.8	0
Purchase St	28.3	28.3	0
U/S of I-95	23.4	23.4	0
5-year		**Orifice opening: 52.4 ft^2**	
D/S of I-287	34.5	*	*
Purchase St	29.8	*	*
U/S of I-95	24.7	*	*
10-year		**Orifice opening: 78.9 ft^2**	
D/S of I-287	35.1	*	*
Purchase St	31.0	*	*
U/S of I-95	26.1	*	*
25-year		**Orifice opening: 145.9 ft^2**	
D/S of I-287	33.5	35.4	-0.1
Purchase St	31.7	31.6	-0.1
U/S of I-95	27.3	27.2	-0.1
50-year		**Orifice opening: 145.9 ft^2**	
D/S of I-287	35.9	35.7	-0.2
Purchase St	32.5	32.1	-0.4
U/S of I-95	28.7	28.2	-0.5
100-year		**Orifice opening: 145.9 ft^2**	
D/S of I-287	36.3	36.1	-0.2
Purchase St	33.2	33.0	-0.2
U/S of I-95	30.2	29.7	-0.5

* Assumes Sells operating sequence and corresponding results.

Both Sells and RIZZO proposed using a water surface elevation sensor installed at the Bowman Avenue Dam, or within the Upper Pond, to categorize an ongoing flood event magnitude and consequently control the sluice gate.

Parsons Brinkerhoff Algorithm

Parsons Brinckerhoff studied the operational rules for the sluice gate at the Bowman Avenue Dam in order to evaluate alternatives to the methods proposed by Sells and RIZZO. The first modification proposed by Parsons Brinckerhoff involved moving the sensor controlling the sluice gate to a location downstream from the Bowman Avenue Dam. By using a downstream location, the water surface elevation reduction from gate operation could be optimized for the area most affected by flooding. Two alternative locations for gate control were evaluated – one just downstream of the interstate highway I-287 and a second one in the center of Indian Village. **Figure 10** identifies both locations.

The second modification included change to the operating principle for the Bowman Avenue Dam. Unlike the Sells and RIZZO algorithms, the Parsons Brinckerhoff algorithm considers that the sluice gate should stay fully open during normal flow conditions, and it should be fully closed once the water surface elevation at the control location reaches a pre-defined elevation. Implementation of the Parsons Brinckerhoff algorithm involves calculation of an appropriate gate control value, which maximizes the reduction in water surface elevation based on the gauge control location and flood magnitude. The specific methodology for calculating the control values is presented in the Parsons Brinckerhoff report.

The resulting reductions in water surface elevation for flood events with return periods between 2-years and 100-years reported by Parsons Brinckerhoff for selected downstream locations are presented in **Table 14**.

Table 14: Water Surface Elevation – Optimal Sluice Gate Operation (Parsons Brinckerhoff, 2014).

STORM EVENT	EXISTING CONDITIONS* WSE (FT)	PARSONS BRINCKERHOFF ALGORITHM CONTROL LOCATION AT I-287	DIFFERENCE (B-A) (FT)	PARSONS BRINCKERHOFF ALGORITHM CONTROL LOCATION AT INDIAN VILLAGE	DIFFERENCE (D-A) [FT]
Column	A	B	C	D	E
2-year					
D/S of I-287	33.28	33.28	0.00	33.27	-0.01
Purchase St	27.74	27.74	0.00	27.73	-0.01
U/S of I-95	22.95	22.95	0.00	22.95	0.00
5-year					
D/S of I-287	34.42	34.28	-0.14	34.46	0.04
Purchase St	29.54	29.23	-0.31	29.49	-0.05
U/S of I-95	24.31	24.08	-0.23	24.26	-0.05
10-year					
D/S of I-287	35.31	34.87	-0.44	35.10	-0.21
Purchase St	31.22	30.37	-0.85	30.88	-0.34
U/S of I-95	27.77	25.40	-0.83	25.80	-0.43
25-year					
D/S of I-287	35.82	35.36	-0.46	35.53	-0.29
Purchase St	32.15	31.28	-0.87	31.64	-0.51
U/S of I-95	27.73	26.70	-1.03	26.96	-0.77
50-year					
D/S of I-287	36.37	35.85	-0.52	35.90	-0.47
Purchase St	33.24	32.27	-0.97	32.38	-0.86
U/S of I-95	29.83	28.38	-1.45	28.26	-1.57
100-year					
D/S of I-287	36.59	36.37	-0.22	36.41	-0.18
Purchase St	33.75	33.32	-0.43	33.22	-0.53
U/S of I-95	30.87	30.17	-0.70	30.06	-0.78

*The Existing Conditions WSE values (Column A) assume flows expected after completion of the planned[4] improvements to the Westchester County Airport stormwater infrastructure, and labeled "Future 2011 scenario" in the Parsons Brinckerhoff report.

Summary of the Sluice Gate Operating Algorithms

The comparison of the results reported for the three previously proposed sluice gate algorithms is difficult, due to the inherent differences between the modeling approaches utilized by each of the reports. In addition, each of the algorithms was developed assuming different sluice gate configurations and varying Upper Pond geometries. The algorithms and the associated water surface reductions are based on the approximated characteristics of

[4] Design of improvements consisting of construction of additional detention basins was finalized in May 2016.

the sluice gate, they are dependent on proper implementation of the algorithms, availability of real-time water surface elevation data and would require updates if the geometry of Upper Pond was to be changed.

To allow for a meaningful comparison of the sluice gate operating rules, and to account for the evaluated Upper Pond expansion, OBG modeled each of the previously developed algorithms using HEC-RAS model with unified control parameters[5] and utilizing a channel geometry that assumes the 13,500 CY Upper Pond expansion has been implemented. By utilizing the same set of conditions (*i.e.,* boundary conditions, initial conditions, simulation parameters, model geometry) and modifying only sluice gate operating rules, OBG compared relative benefits associated with each of the algorithms separately for a range of flood events. The evaluated Upper Pond expansion, if completed, would require an update to the algorithm design proposed by Parsons Brinckerhoff, specifically the sluice gate control values. The values triggering closing of the sluice gate, initially developed by Parsons Brinckerhoff for the two gate control locations presented earlier in **Figure 10**, were updated by OBG to maximize the downstream water surface elevation reductions assuming the 13,500 CY Upper Pond modification was implemented.

The analysis of the HEC-RAS model output of the sluice gate algorithms allowed OBG to identify potential additional modifications to the gate operating rules, which, if implemented, could provide further benefit to the Parsons Brinckerhoff-developed method. The update to the Parsons Brinckerhoff algorithm associated with the 13,500 CY Upper Pond resizing and sluice gate modifications are presented in the following section.

7.2 UPDATES TO THE PARSONS BRINCKERHOFF SLUICE GATE OPERATING ALGORITHM

The implementation of the sluice gate algorithms developed by Parsons Brinckerhoff in the HEC-RAS model indicated that after the initial sluice gate closing, the gate will be returned to its initial (open) position as soon as the water surface elevation at the control location returns to levels less than the trigger values. The analysis of the HEC-RAS output revealed that such implementation may lead to a rapid increase in the volume of water being released from the Upper Pond and consequently additional increase in the water surface elevation downstream of the dam. For more frequent events (less than 5-year return period), this effect can create a surge in the downstream water elevation, overtopping the initial peak flow conditions. An example that illustrates this situation is presented in **Figure 11** where a 2-year flood event hydrograph for a downstream location is shown for two alternative scenarios. The red line shows the change in the water surface elevation if the sluice gate at the dam remained closed throughout the event (existing conditions), while the blue line shows the Parsons Brinckerhoff sluice gate algorithm implementation. As seen in the figure, the initial closing of the sluice gate (according to the estimated control values) does not provide significant reduction in the water surface elevation, as expected, based on **Table 14**. After the peak flow is achieved, the water starts receding and the algorithm dictates that the gate can be returned to its initial (open) position. The opening causes a rapid increase in the downstream water surface elevation visible as a "bump" in **Figure 11**. The sequence of gate opening and closing is repeated three times by the algorithm until most of the water stored in the Upper Pond is released. To avoid this potentially unintended consequence, a modification to the Parsons Brinckerhoff algorithm could be implemented, as follows:

- The sluice gate should not be operated for events with return periods less than 5-years because expected reductions in water surface elevation assuming "optimal" algorithm performance would be less than 1 inch.
- For events with return periods greater than 5-years, the gate should be closed according to the logic developed by Parsons Brinckerhoff and the estimated gate control values. Once engaged, the gate should remain closed until normal flow conditions are observed, in order to avoid a rapid release of water stored in the Upper Pond. The operating algorithm can be further refined based on hydraulic modeling and by collecting water surface elevation data from downstream sensors after the algorithm is implemented.

As previously explained, the evaluated modification of the Upper Pond would require the Parsons Brinckerhoff developed sluice gate algorithm to be updated to account for the change in pond's geometry (i*.e.,* to account for

[5] All alternatives use the same set of model parameters, boundary and initial conditions and channel geometry files.

the additional storage volume). Assuming the same gate control locations as those proposed by Parsons Brinckerhoff (**Figure 10**), OBG used the procedure presented in the Parsons Brinckerhoff report to develop an updated set of gate control values for a range of flood conditions. The updated values for the control location downstream of the interstate highway I-287 are presented in **Table 15**, while the values for the control location located in Indian Village are presented in **Table 16**.

Table 15: Updated Gate Control Values for the I-287 Location.

GATE POSITION FOR NORMAL FLOWS: OPEN		
GATE CONTROL LOCATION AT MODEL XS: 2230.179 (Downstream of I-287)		
Event Return Period [years]	WSE to Close the Gate (OBG) [ft]	WSE to Close the Gate (Parsons Brinkerhoff [ft]
2	32.5	31.72
5	34.1	33.24
10	34.6	34.62
25	35.1	35.13
50	35.7	36.68
100	36.1	36.00

Table 16: Updated Gate Control Values for the Indian Village Location.

GATE POSITION FOR NORMAL FLOWS: OPEN		
GATE CONTROL LOCATION AT MODEL XS: 890.597 (Indian Village)		
Event Return Period [years]	WSE to Close the Gate (OBG) [ft]	WSE to Close the Gate (Parsons Brinkerhoff [ft]
2	23	23.69
5	25.3	24.09
10	26.6	25.69
25	27.7	27.19
50	29.0	29.09
100	30.0	30.01

Figure 12 summarizes the reductions in water surface elevation associated with the updated Parsons Brinkerhoff algorithm and provides a comparison to the Sells and RIZZO methods as modeled by OBG, using a set of unified model control conditions, the updated gate control values, and the modified logic, assuming that the gate will remain closed until normal flow conditions return. The models associated with the results presented in **Figure 12** also include a 13,500 CY expansion of Upper Pond.

The three previously developed sluice gate algorithms by Sells, RIZZO, and Parsons Brinckerhoff operate with the assumption that the magnitude of the flood event can be classified by its return period as the event occurs. The successful implementation of each of the algorithms and the potential reductions in the water surface elevation would depend on the quality of such classification. To provide means for event classification, OBG proposes installation of a water surface elevation sensor upstream of the Bowman Avenue Dam. The upstream gauge would be used to determine the event's peak flow, which could then be translated to the event's return period. The known return period for the event would be used to trigger gate closing based on the control values presented in **Tables 15 and 16**. The location of the gauge would be selected to provide sufficient lead time, allowing for characterization of the event's return period before the decision to close the sluice gate is made. The proposed method and a potential location of the proposed upstream sensor are presented in **Figure 13**. The figure shows that the delay in the travel-time of the peak discharge, between the upstream gauge location and the dam, should be considered to allow for the system to properly classify the event return period. The decision to close the gate would be made before the peak discharge reaches the dam. Preliminary analysis showed, that for many flood conditions, the location close to the Hutchinson River Parkway would provide sufficient lead time. Identifying the specific location for the upstream water elevation sensor would require further study, which is outside of the scope of this report. A similar approach has been previously proposed by Parsons Brinckerhoff in its 2015 memorandum to the City of Rye, titled *Field Trip to Identify Potential Stream Gauge Locations on November 14, 2014*.

Based on information presented in **Figure 12**, the updated Parsons Brinkerhoff algorithm results in the largest reductions in water surface elevations when compared to Sells and RIZZO algorithms. Its implementation would require installation of at least two additional water surface elevation sensors, one for a downstream location (*i.e.,* a stream gauge to control the sluice gate) and one for a location upstream of the Bowman Avenue Dam (*i.e.,* a stream gauge to characterize event magnitude).

It is important to note that the reductions in water surface elevation reported in **Figure 12** are based on an uncalibrated hydrologic model. The reported values and the associated gate control values for the Parsons Brinckerhoff sluice gate algorithm are likely to be affected by computational uncertainty and would need to be re-evaluated after the proposed changes are implemented. In operational practice, the full capability of the algorithm would be achieved over time by carefully analyzing data collected by upstream and downstream water surface elevation sensors and by adjusting the algorithm periodically to incorporate the empirical data.

8. THE SIGNIFICANCE OF CULVERTS DOWNSTREAM OF INDIAN VILLAGE

Based on the review of the FEMA flood insurance rate maps, the site visit, and the hydraulic modeling completed as part of this report, it is concluded that the spatial extent of flooding in Indian Village can be in part attributed to the limited capacity of the culverts located under the interstate highway I-95, the neighboring railroad bridge, and the culvert at the intersection of Theodore Fremd Avenue and Elm Place. Both the size and the configuration of the outlet create conditions that during flood events can cause significant headwater buildup. The headwater results in additional backwater upstream from the culvert which can be seen in the HEC-RAS model profile presented in **Figure 14** and on the FEMA maps presented in **Figure 3**. The water surface elevation longitudinal profile in **Figure 14** also presents the results of a supplemental HEC-RAS analysis performed by OBG. The analysis demonstrates that by increasing the flow capacity of the I-95 culvert and by creating additional routes for the flow to pass this section of Blind Brook, the water surface elevation conditions immediately upstream of the I-95 highway can be improved by up to 2 feet during significant flood events.

Identification of specific improvements that could be made to these culverts to reduce upstream water surface elevations was not within the scope of this study. If a separate study was undertaken to further evaluate this, it should consider the following:

- Permitting and approval challenges associated with adding additional hydraulic capacity to cross significant infrastructure features such as interstate I-95 and the railroad bridge.
- Potential increases in downstream flooding associated with adding additional hydraulic capacity at these locations. Additional improvements may be required to mitigate these effects.
- The existing model ends at Locust Avenue and it would likely have to be extended further downstream to appropriately assess the potential impact of increased downstream flow.

9. SUMMARY

- OBG reviewed and analyzed technical reports by others previously submitted to the City of Rye, focusing on methods to reduce the effect of flooding in the Blind Brook watershed. The review identified that previous studies focused on the area most prone to frequent flooding, between the interstate highways I-287 and I-95, known as Indian Village. Among the proposed flood mitigation methods, the combined effect of the resizing of the Upper Pond and the utilization of the automated sluice gate installed at the Bowman Avenue Dam had been selected as the preferred alternative. As part of the review process, OBG received and reviewed a HEC-

RAS model developed by RIZZO and Parsons Brinckerhoff for the corresponding section of Blind Brook. OBG made minor modifications to the model prior to conducting a series of modeling activities for the purpose of this report.

- A site visit was performed by OBG to further understand the hydraulic characteristics of the Blind Brook watershed, the configuration of Upper Pond, and the associated Bowman Avenue Dam. During the visit a number of observations were made, which served to verify the configuration of the associated HEC-RAS model. Following the visit, OBG utilized the HEC-RAS model for performing additional evaluations after making minor model modifications as described in Section 4. OBG also recognized that the configuration of the culverts under interstate highway I-95, the adjacent railroad bridge, and at the intersection of Theodore Fremd Avenue and Elm Place, cause a significant increase in Blind Brook water surface elevations in the vicinity of Indian Village.
- Two alternative Upper Pond resizing scenarios were evaluated using hydraulic modeling. Based on a $2 million construction budget, OBG estimated the amount of soil that could be excavated from Upper Pond based on a construction cost estimate included in a Parsons Brinckerhoff report (2014a), which resulted in a 31,000 CY excavation plan. After developing a revised cost estimate, a more representative 13,500 CY excavation plan was evaluated. The maximum downstream water surface elevation reduction resulting from an Upper Pond expansion of 13,500 CY was estimated at approximately 0.3 feet.
- OBG conducted a detailed review of the previously developed Bowman Avenue Dam sluice gate operating algorithms. The review included implementation and modeling of each of the sluice gate algorithms for a range of flood scenarios. Based on the analysis, OBG identified that the algorithm previously developed by Parsons Brinckerhoff results in the greatest water surface elevation reductions at locations downstream of the Bowman Avenue Dam. An updated set of control values was developed for the Parsons Brinckerhoff sluice gate algorithm, accounting for a potential 13,500 CY Upper Pond expansion. The combined effect of the utilization of the Parsons Brinckerhoff sluice gate control algorithm and the 13,500 CY Upper Pond expansion can lead to reductions in water surface elevation in Indian Village of up to 1 foot, depending on flood magnitude and gate control location. The majority of this reduction is attributed to operation of the sluice gate, and the reduction attributed to the Upper Pond expansion is negligible. Therefore, it is not recommended that a 13,500 CY Upper Pond expansion be constructed.
- The HEC-RAS model utilized during this study is an uncalibrated hydrologic model, due to the lack of stream gauges in Blind Brook. The results of the analysis provide valuable information when making a relative comparison between different flood mitigation measures. However, the absolute values reported may be subject to uncertainties, which can be refined in the future through model calibration.

10. RECOMMENDATIONS

OBG has identified recommendations for potential next project steps. The recommendations are described below, and where applicable, discussion of previous recommendations made by Parsons Brinkerhoff in their 2014 and 2015 analyses is also included.

This study identified the potential for up to 1 foot of water surface elevation reduction in the Indian Village neighborhood by implementing a 13,500 CY expansion of Upper Pond and implementing the sluice gate operation algorithm identified by Parsons Brinkerhoff. Appropriate operation of the sluice gate will require design and installation of stream gauges upstream and downstream of the Bowman Avenue Dam, active monitoring of the gauges, maintenance of the gauges, and periodic updates to the sluice gate operating algorithm based on the stream gauge data that is collected (*i.e.*, the algorithm would be refined based on collected data). Costs associated with design and installation of these gauges have not been estimated, nor have the costs associated with monitoring and maintenance.

In addition, the benefits associated with the potential for mitigating property damage by operating the sluice gate have not been quantified. As stated in Section 9 and summarized in **Figure 12**, the potential water surface elevation reductions that may be realized through operation of the sluice gate and expanding Upper Pond by 13,500 CY are approximately 1 foot. However, the work performed to date by Parsons Brinkerhoff and OBG utilized an uncalibrated hydraulic model. Though studies by Parsons Brinkerhoff and OBG have estimated potential water surface elevation reductions that may be realized, the accuracy of the water surface elevations associated with the existing and proposed conditions is unknown. If the accuracy of the model was refined through calibration, the benefits associated with the potential for mitigating property damage could then be estimated by performance of a benefit cost analysis utilizing a methodology developed by the Federal Emergency Management Agency (FEMA).

Given this background, OBG has identified the following two alternative paths forward for further progressing the City of Rye's flood mitigation capabilities.

ALTERNATIVE 1

Recognizing that developing a calibrated model will require design and installation of one or more stream gauges and a period of time to collect a representative data set after the gauges are installed, an approximate benefit cost analysis may be performed utilizing the currently available uncalibrated model, the most recent Flood Insurance Rate Mapping and Flood Insurance Study developed by FEMA, and dwelling information previously collected by the City of Rye and analyzed by Parsons Brinkerhoff (2015). The benefit cost analysis would assist the City of Rye in deciding whether making additional expenditures to operate the sluice gate is economically viable.

Based on the outcome of the benefit cost analysis, recommendations identified in Alternative 2 could be implemented. Or, Alternative 1 could be foregone in favor of Alternative 2.

ALTERNATIVE 2

If the City of Rye decides to collect stream gauge data and operate the sluice gate, OBG recommends design, construction, and operation of stream gauges to calibrate the model and to assist in operation of the sluice gate as described in Section 7. Additional details associated with this alternative are provided below.

- In addition to installing a gauge downstream of Bowman Avenue Dam, the gauge and sluice gate operation system should include installation and operation of a stream gauge upstream of Bowman Avenue Dam to classify flood events as described in Section 7.2. This recommendation aligns with previous work performed by Parsons Brinkerhoff (2015).
- After the stream gauges are installed, collected data should be utilized to calibrate the hydrologic and hydraulic model prior to operation of the sluice gate.
- The hydraulic analysis conducted by OBG indicates that, when properly implemented, the Parsons Brinckerhoff algorithm can provide approximately 1-ft of reduction in downstream water surface elevation. This level of water surface elevation reduction can be achieved for significant flood events (*i.e.,* 25-year or greater return period). For more frequent flood events, with return periods less than 5-years, the benefit of utilizing the analyzed sluice gate operating strategy is on the order of several inches. If the gauges are installed and the sluice gate is actively operated using an algorithm related to stream gauge information, given the limited benefit of operating the sluice gate during more frequent flood events (*i.e.,* events with return period less than 5 years), OBG recommends that the gate remain fully open.
- It is recommended that Parsons Brinkerhoff's proposed sluice gate operation algorithm be modified to limit gate opening when a substantial amount of water is stored in the Upper Pond. This consideration is also relevant to other previously proposed sluice gate operating algorithms. The release of stored water should take place through the bottom opening at Bowman Avenue Dam until normal pond levels are achieved. Implementing this recommendation would prevent a rapid release of water from the dam from amplifying downstream water surface elevations, as illustrated in **Figure 11**.
- Parsons Brinkerhoff (2014a) recommended performance of a topographic survey of the channel. The benefits of undertaking this effort are unknown. The previously collected topographic information may be sufficient for the analyses performed given the relatively large flow rates associated with the extreme flood events being evaluated (*e.g.,* 25-year, 50-year, 100-year storms). It is recommended that several

sample cross sections be surveyed and compared to the topography utilized in the model to further assess the benefits of a more comprehensive topographic survey.

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Figures

FIGURE 1

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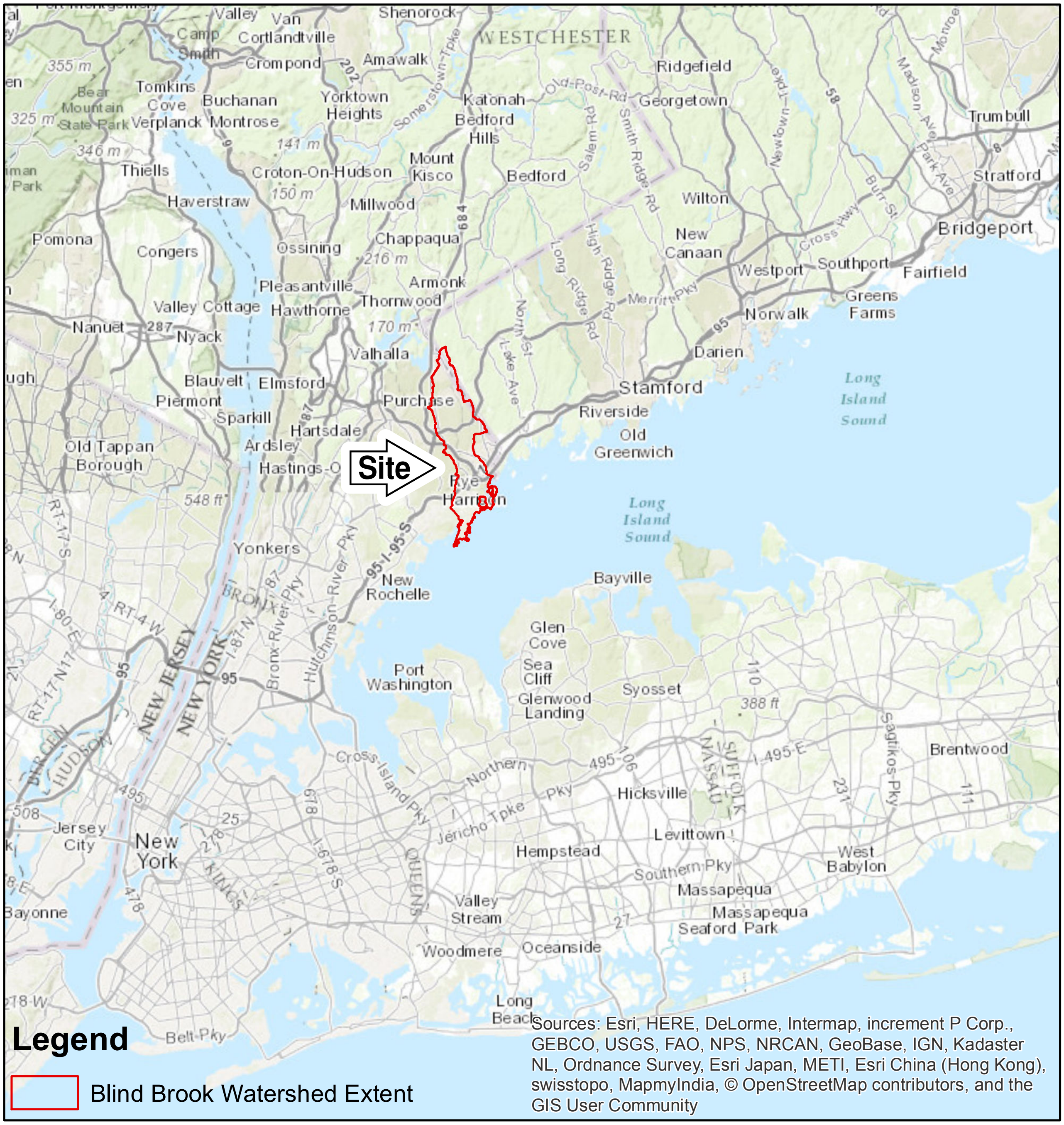

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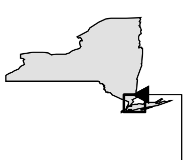
UPPER BOWMAN POND
MODIFICATIONS STUDY
RYE, NEW YORK



MAP LOCATION

SITE LOCATION

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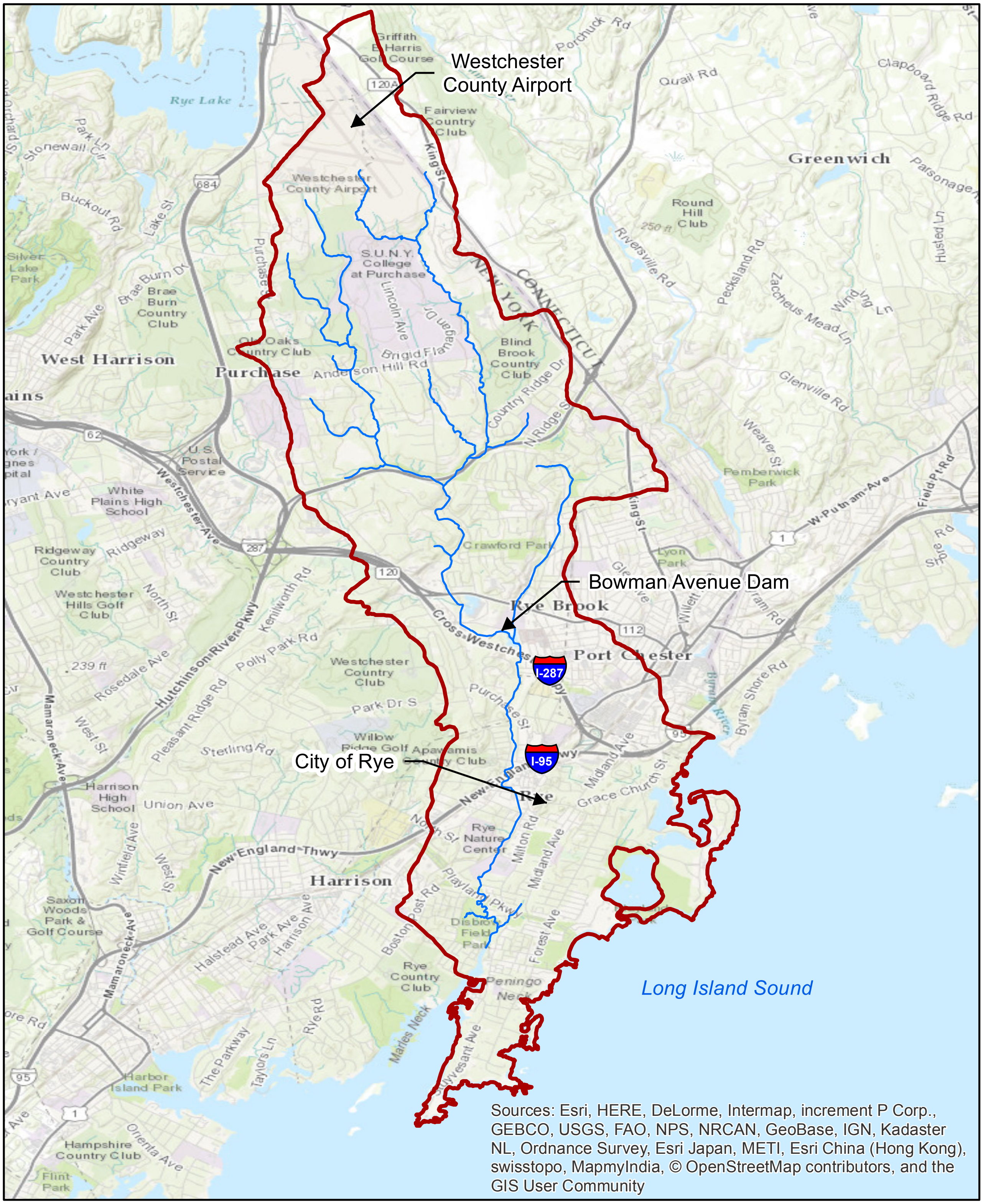

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LEGEND

- Flowlines
- Blind Brook Watershed Extent

UPPER BOWMAN POND
MODIFICATIONS STUDY
RYE, NEW YORK

BLIND BROOK WATERSHED

N

0 3,500 7,000 14,000
Feet

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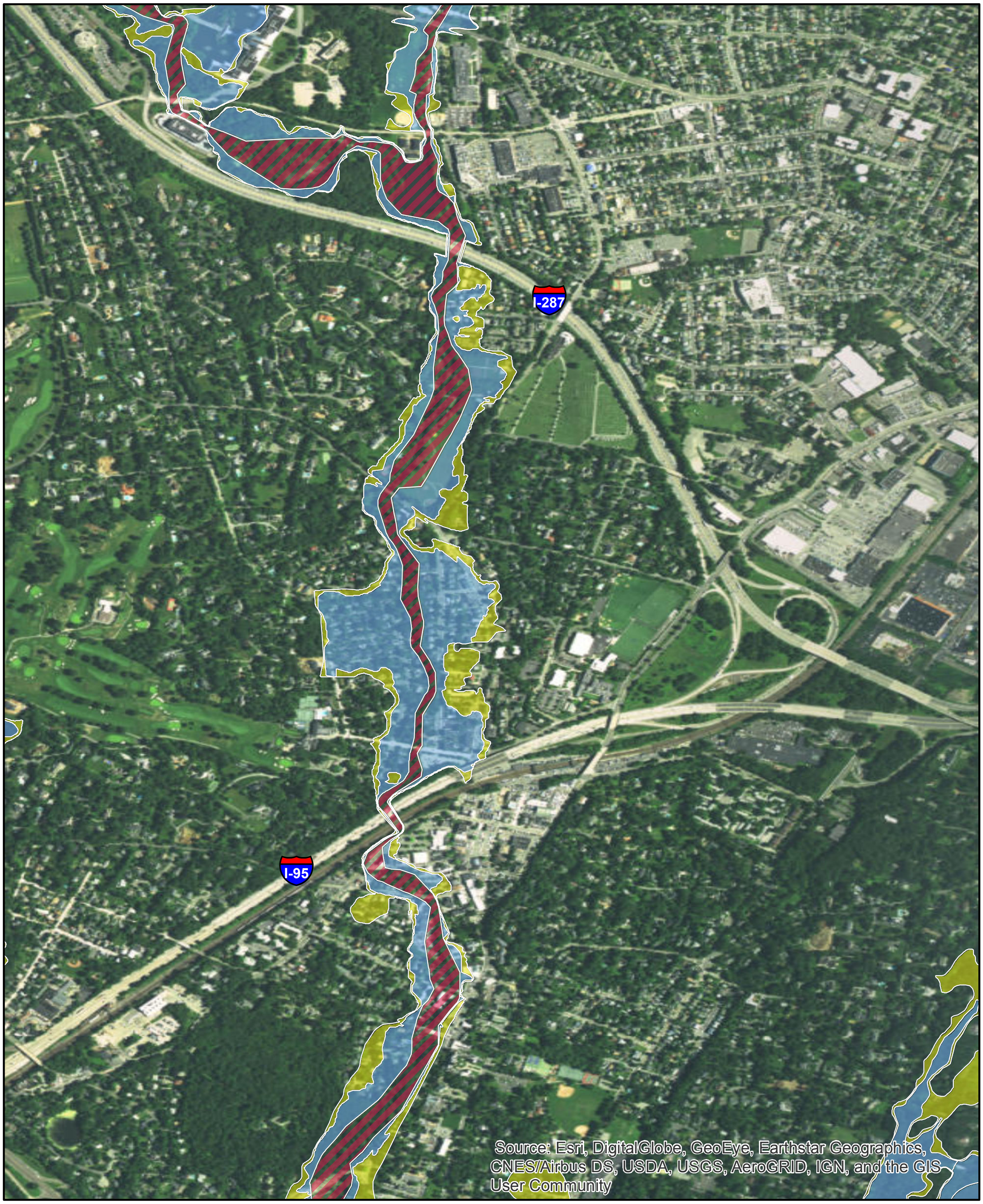

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LEGEND

- Regulatory Floodway
- 1% Annual Chance Flood Hazard
- 0.2% Annual Chance Flood Hazard

UPPER BOWMAN POND
MODIFICATIONS STUDY
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FLOOD INSURANCE RATE MAP (FIRM)

0 750 1,500 3,000
Feet

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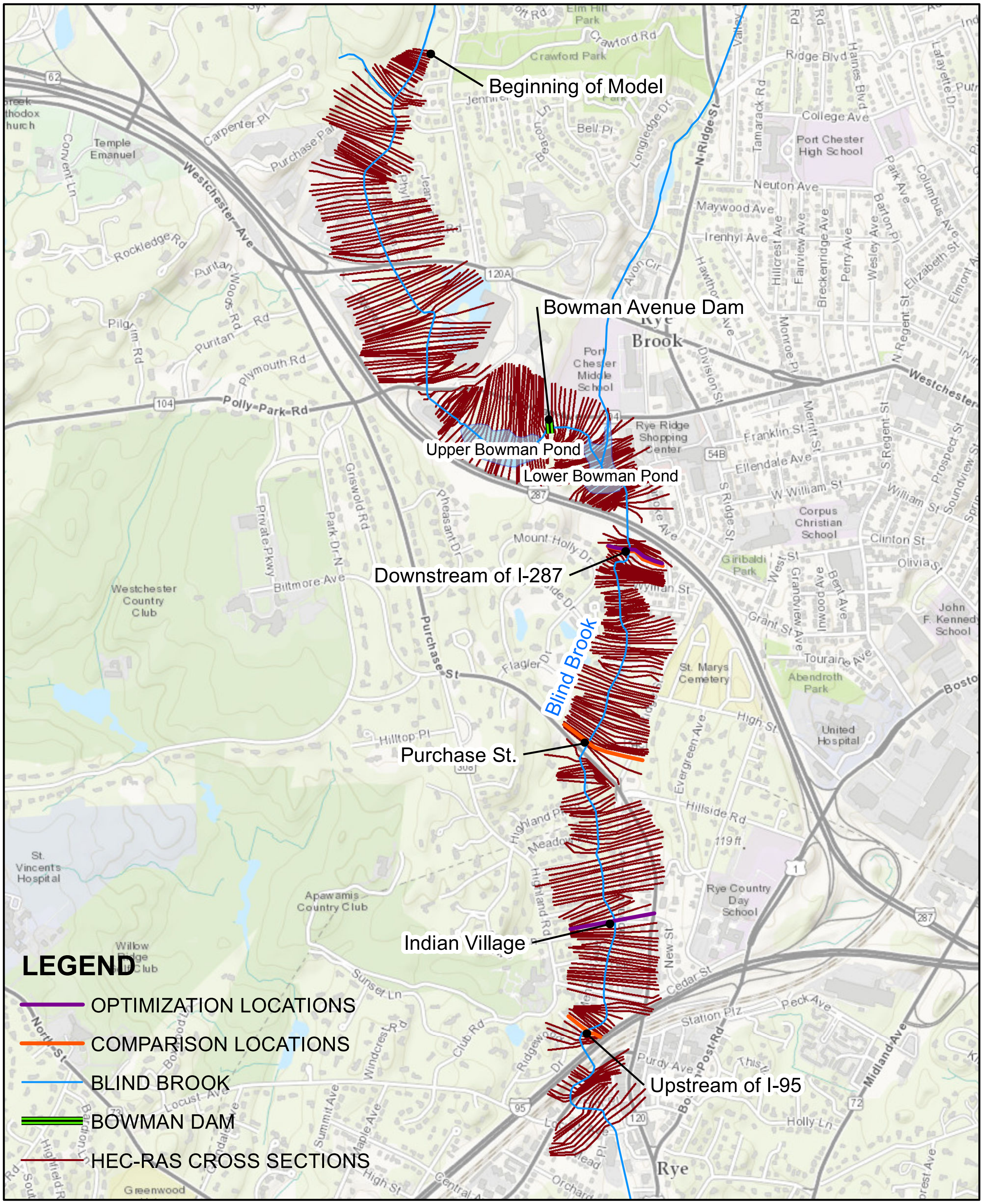

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HEC-RAS MODEL EXTENT

0 800 1,600 3,200
Feet

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LEGEND

- Bowman Dam
- Blind Brook

UPPER BOWMAN POND
MODIFICATIONS STUDY
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BOWMAN AVENUE DAM LOCATION

0 200 400 800
Feet

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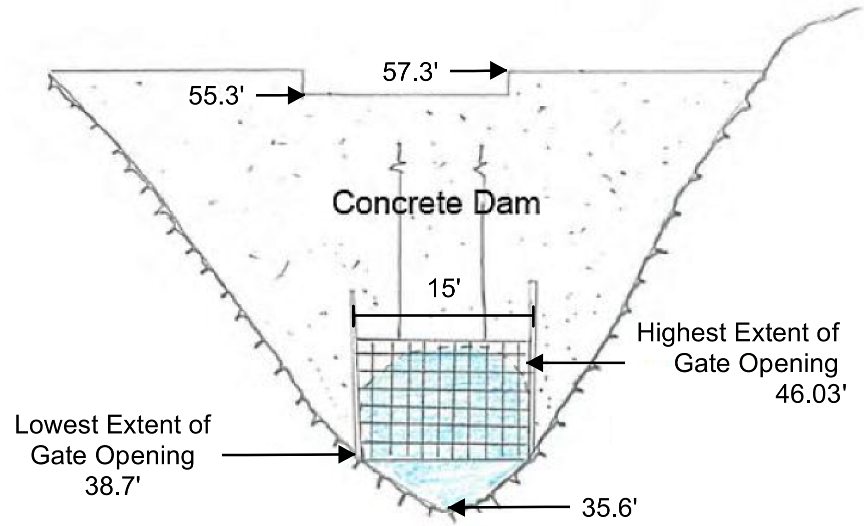
Sluice Gate Photograph - 9/21/2016

Sluice Gate Conceptual Diagram



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RYE, NEW YORK

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BOWMAN AVENUE DAM SLUICE GATE

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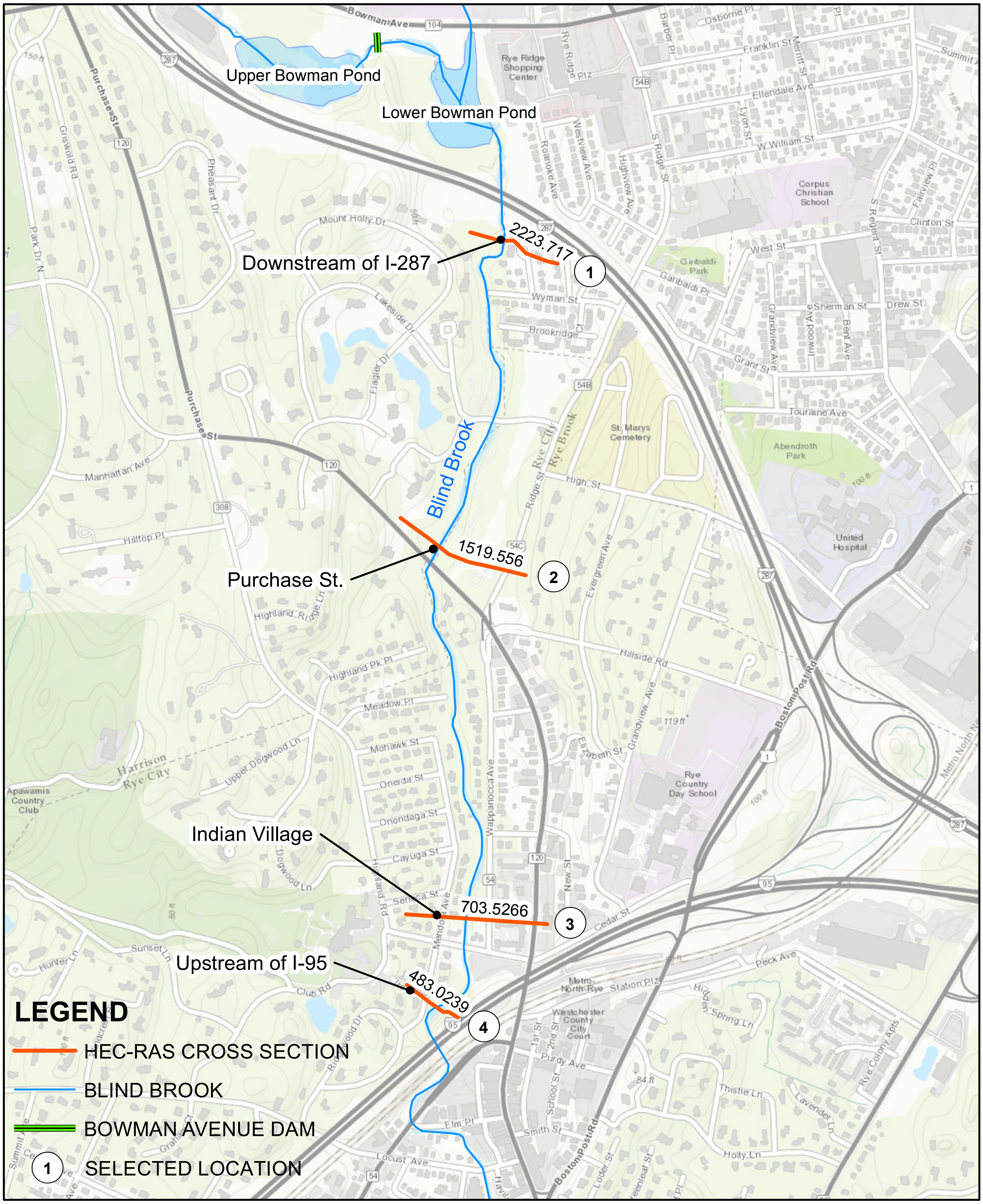

I:\Nys-Dorm.12145\63832.Blind-Brook-Flo\Docs\DWG\MXD\FIG 07 Comparison XS Locations_Rev.mxd

UPPER BOWMAN POND
MODIFICATIONS STUDY
RYE, NEW YORK

BOWMAN AVENUE DAM
COMPARISON LOCATIONS

0 500 1,000 2,000
Feet

N

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MARCH 2017

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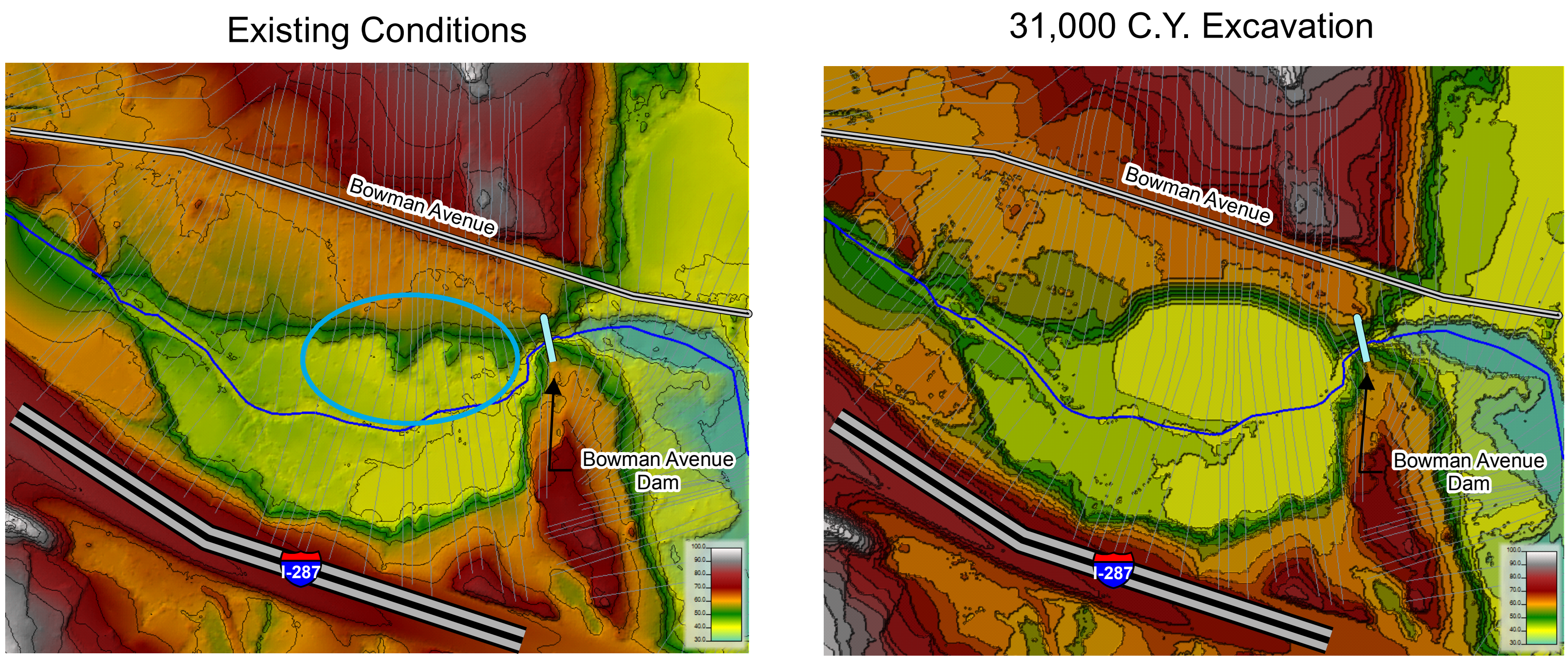

Excavation Bottom Elevation: 41' AMSL

Legend

31,000 CY Excavation Limit

UPPER BOWMAN POND
MODIFICATIONS STUDY
RYE, NEW YORK
31,000 CY UPPER POND RESIZING LIMITS

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FIGURE 9

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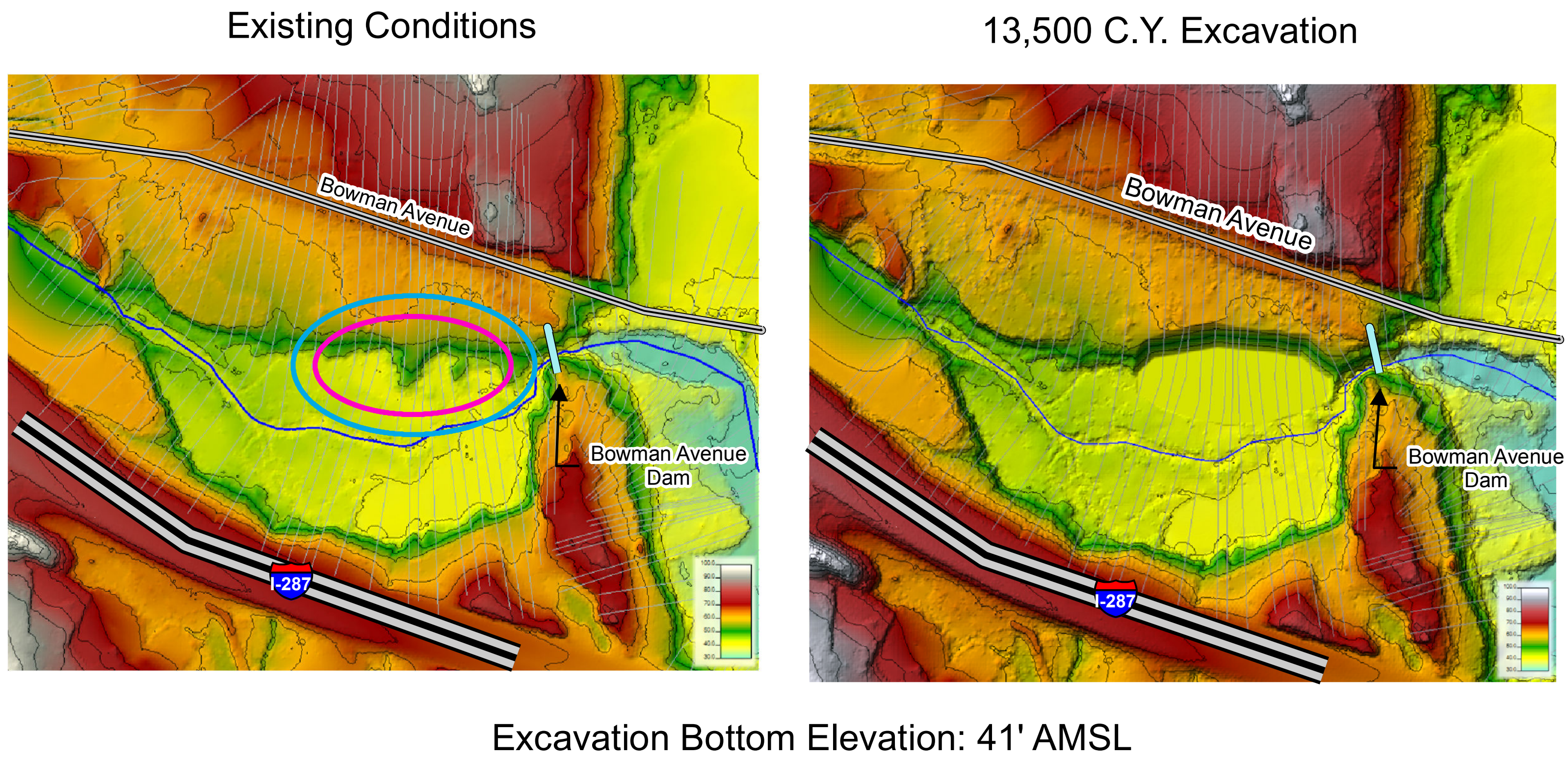

Legend

- 13,500 CY Excavation Limit
- 31,000 CY Excavation Limit

UPPER BOWMAN POND
MODIFICATIONS STUDY
RYE, NEW YORK

13,500 CY UPPER POND RESIZING LIMITS

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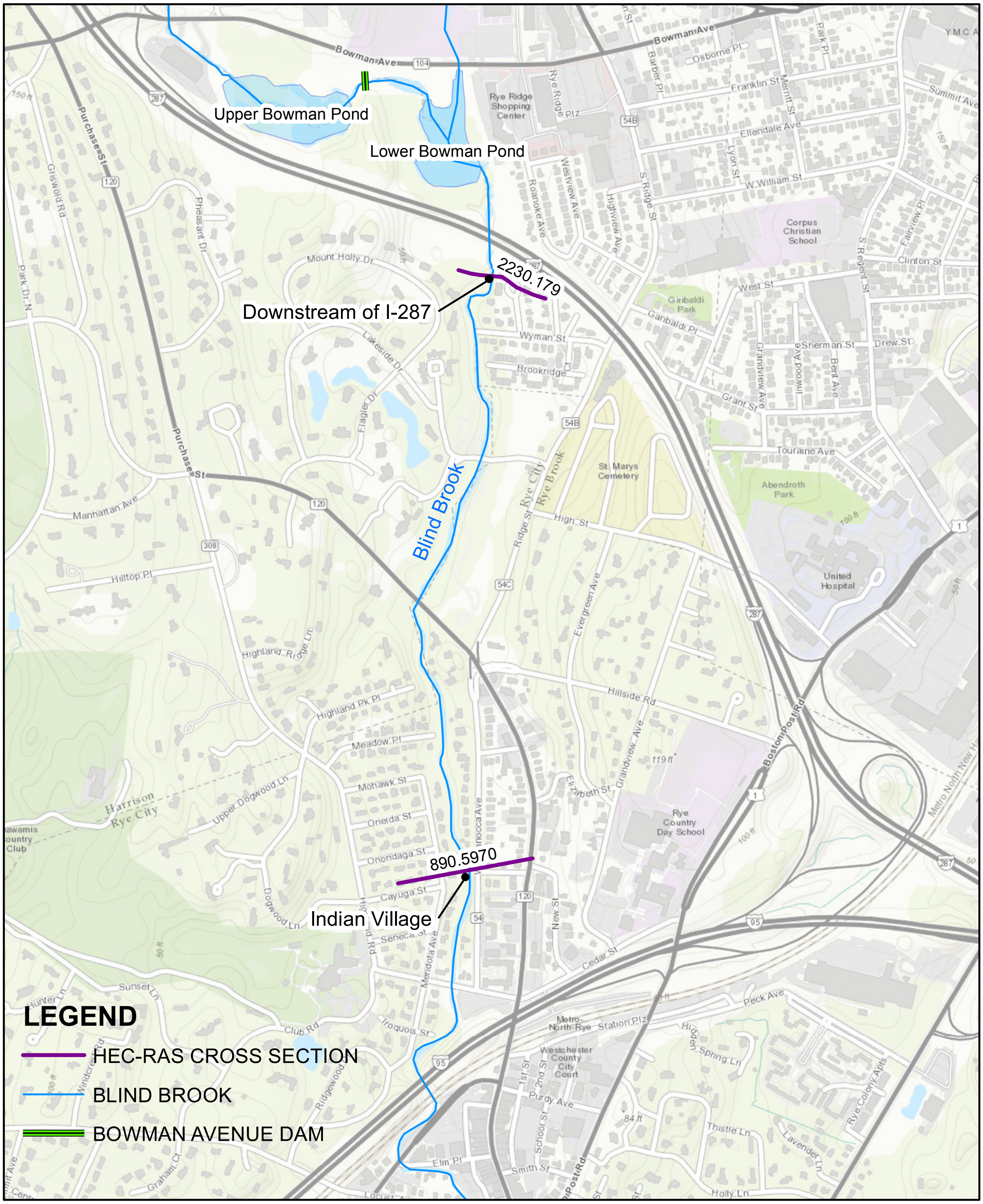

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UPPER BOWMAN POND
MODIFICATIONS STUDY
RYE, NEW YORK

BOWMAN AVENUE DAM
GATE CONTROL LOCATIONS

0 500 1,000 2,000
Feet

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MARCH 2017

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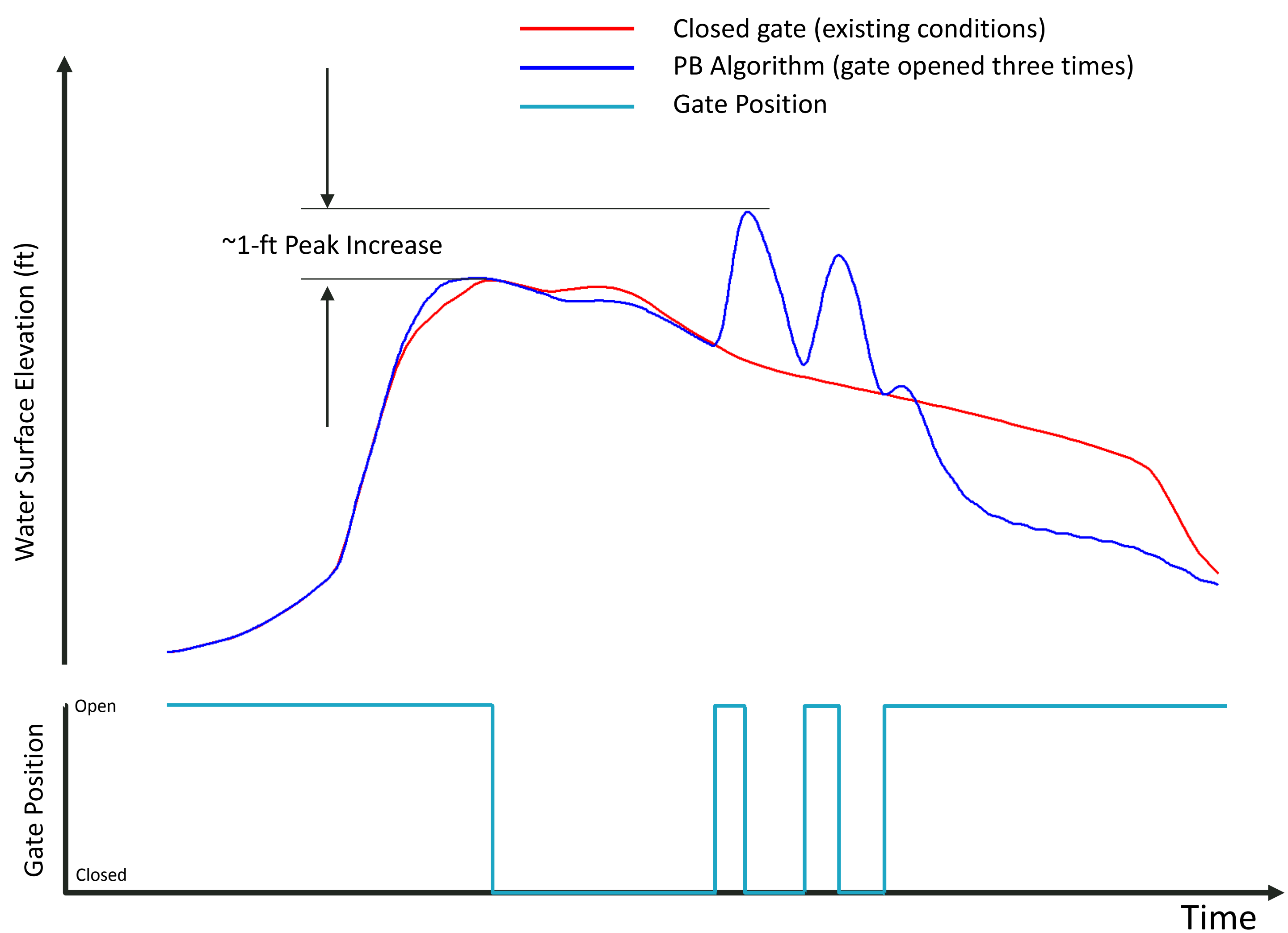
FIGURE 11



UPPER BOWMAN POND
MODIFICATIONS STUDY
RYE, NEW YORK

PB ALGORITHM
2-YEAR EVENT

MARCH 2017

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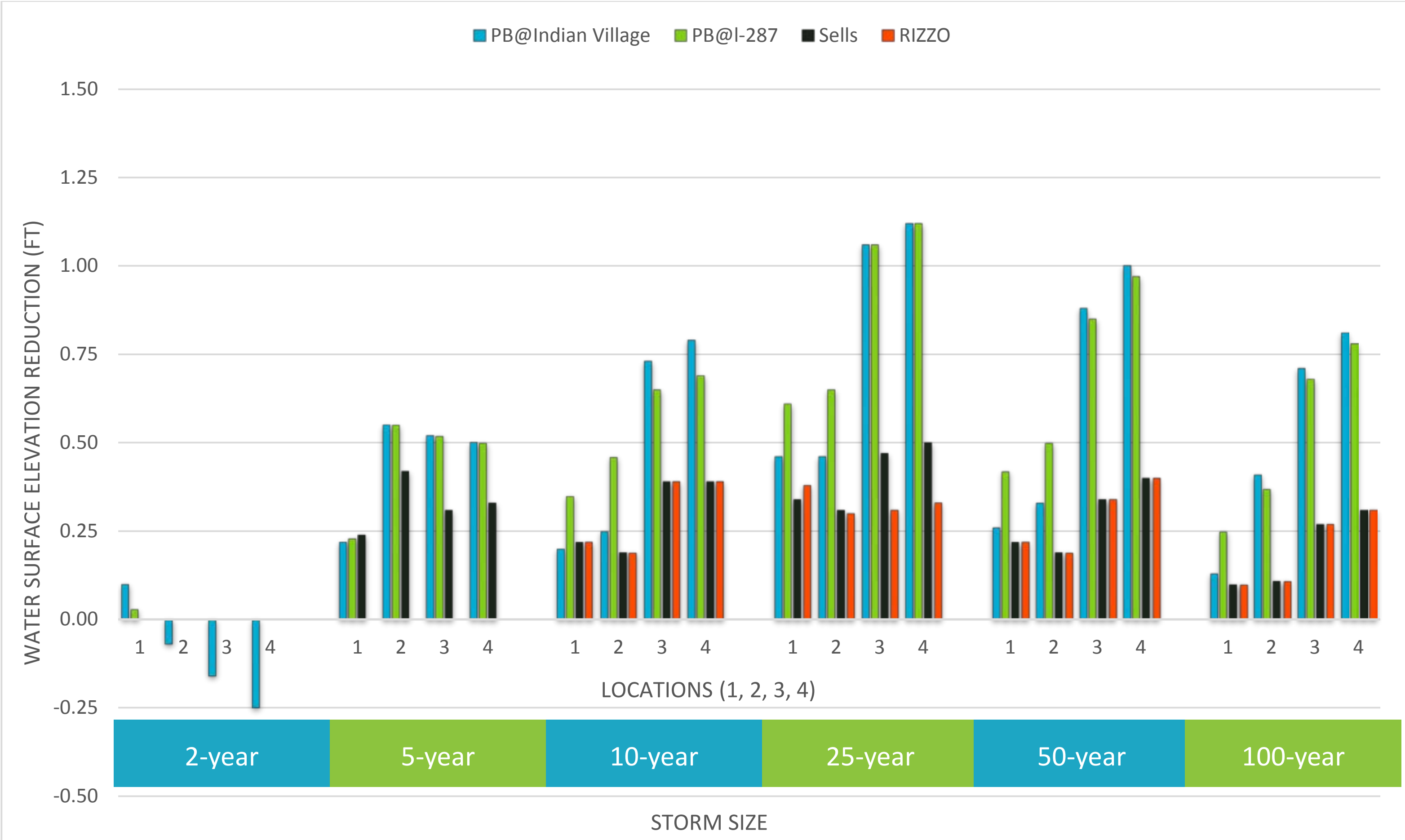
FIGURE 12



UPPER BOWMAN POND
MODIFICATIONS STUDY
RYE, NEW YORK

WATER SURFACE ELEVATION REDUCTION RESULTS COMPARISON

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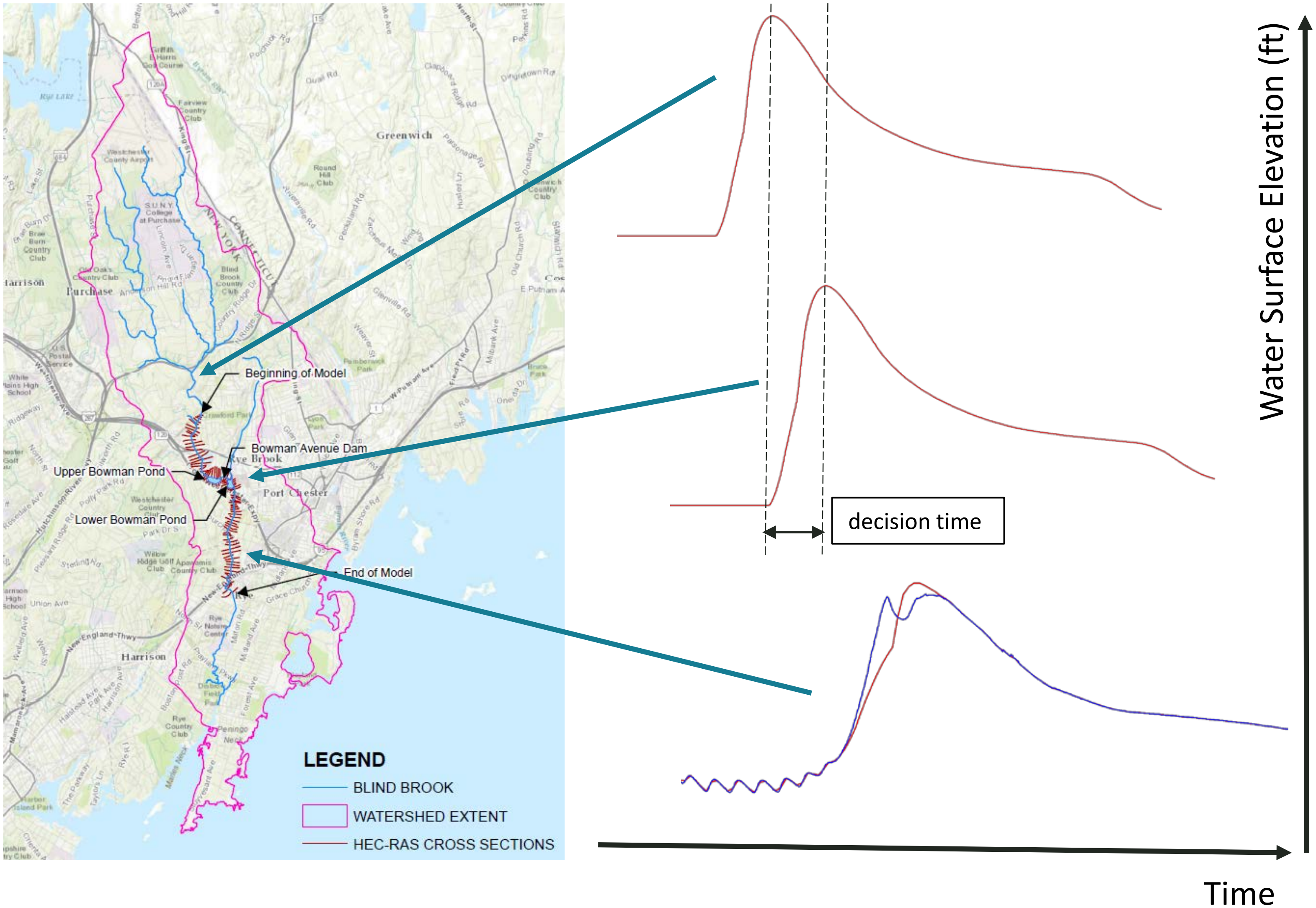
MARCH 2017

FIGURE 13



UPPER BOWMAN POND
MODIFICATIONS STUDY
RYE, NEW YORK

EVENT FREQUENCY FORECASTING SYSTEM

MARCH 2017

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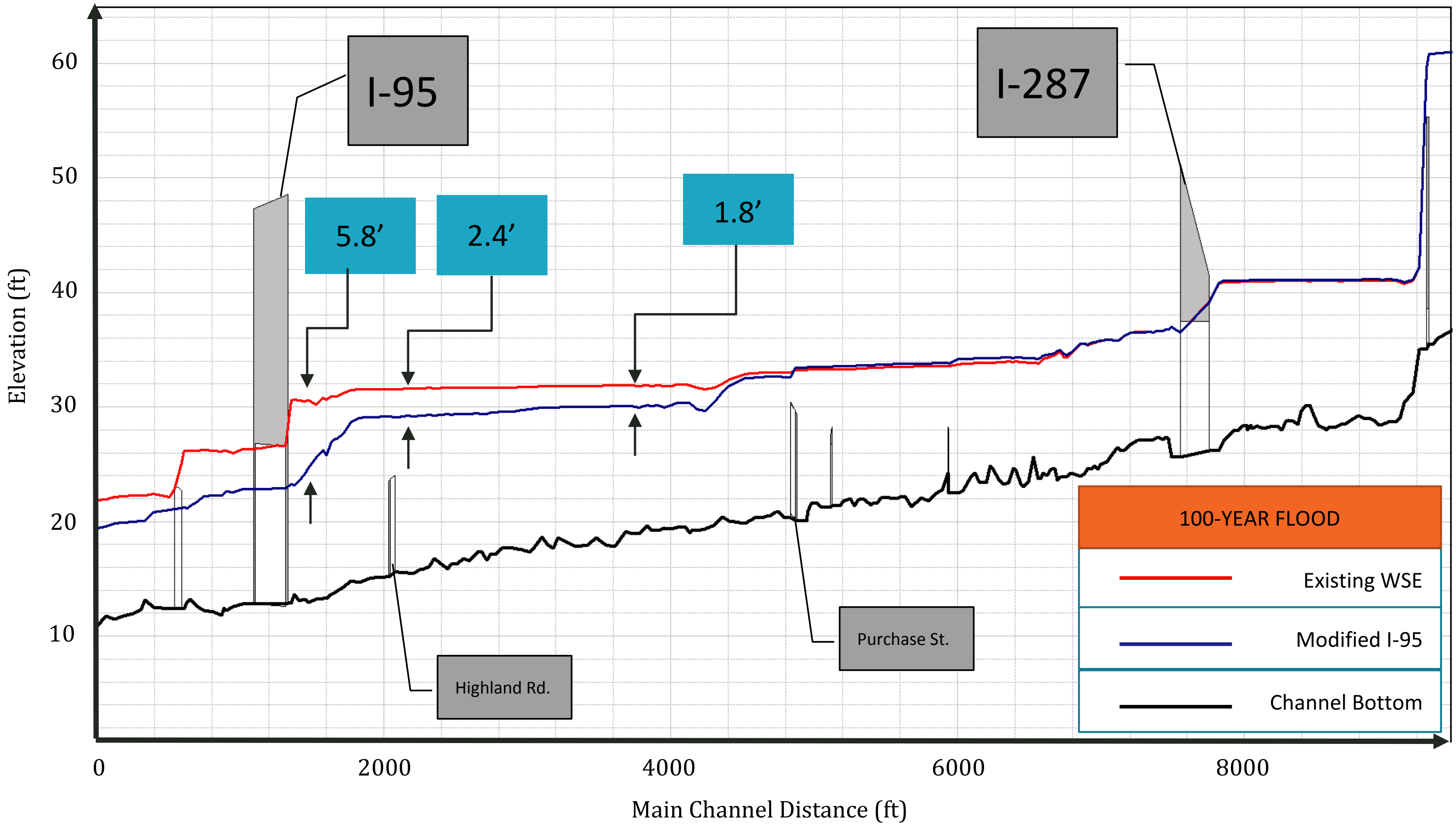

UPPER BOWMAN POND
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INDIAN VILLAGE WATER SURFACE ELEVATION PROFILE