HYDROLOGIC AND HYDRAULIC ANALYSIS

BOWMAN AVENUE DAM PROJECT
STUDY FOR RESIZING
THE UPPER POND RESERVOIR

BLIND BROOK, CITY OF RYE

PREPARED FOR:

WSP-SELLS
BRIARCLIFF MANOR, NEW YORK

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1.0 PURPOSE

The City of Rye is located in Westchester County, New York, approximately 7 miles north of the New York City line. It is bounded on the south and east by the Long Island Sound, on the west by the Village of Mamaroneck, on the north by the Village of Rye Brook, to the northwest by the Town/Village of Harrison, and on the northeast by the Village of Port Chester. The City shares three watersheds with these other communities: Blind Brook, Beaver Swamp Brook, and coastal Long Island Sound.

As a result of its position on the coast and at the base of two watersheds, Rye experiences chronic flooding and wind damage from coastal and inland storms. Previous studies (***Reference 2&4***) show that overall flooding problems within the watershed are caused by a narrow channel width, obstructed flows, vegetative growth in stream banks, constricted bridge openings, low banks, sedimentation in tidal reaches, years of wetland filling and floodplain encroachment. Over the past several years, certain areas of the Blind Brook watershed have experienced extreme flooding and wind damage from inland and coastal storm events. Flooding causes repetitive property losses. The City of Rye has developed and implemented flood mitigation solutions to decrease risks related to flooding.

Paul C. Rizzo Engineering – New York, PLLC (RIZZO) was retained by WSP Sells to perform a Hydrologic and Hydraulic (H&H) analysis to determine the potential benefits of resizing the Upper Pond in order to increase temporary storage capacity during significant storm events. The intention is to retime storm water flow in order to decrease water surface profiles within the Blind Brook River between Interstates I-287 and I-95. RIZZO was also asked to consider optimizing the sluice gate operation to increase potential benefits from the new sluice gate.

2.0 REFERENCES

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11. Federal Emergency Management Agency (FEMA), 1979, Flood Insurance Study.

12. U.S. Department of Commerce, January 1963, Technical Paper No.40 (TP-40): "Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years".

3.0 METHODOLOGY

In order to determine the impacts of proposed resized Upper Pond alternatives on water surface profiles between Interstates I-287 and I-95 and optimized the sluice gate operation sequencing, RIZZO performed a comprehensive hydrologic and hydraulic analysis of the entire Blind Brook Watershed. RIZZO utilized the most current data available to perform its study. This includes:

- Additional large storm events, which occurred subsequent to WSP Sells 2008 study (***Reference 4***);
- Light Detection and Ranging (LIDAR) data which represents the most current and highest resolution available topographic data; and,
- State-of-the-practice analytical techniques.

Precipitation events with 2, 5, 10, 25, 50 and 100-year storm return periods were considered in this analysis for comparison to the 2008 WSP Sells Study. Precipitation was determined using the methodology presented in the National Weather Service's Technical Paper No. 40 (TP 40) (***Reference 12***).

Inflow hydrograph events were computed as the runoff from the precipitation events described above using the Hydrologic Modeling System computer software HEC-HMS (version 3.3) developed by the United States Army Corps of Engineers (USACE).

The Geographic Information System (GIS) software ArcGIS was used to manage and analyze the most current topographic and hydrologic data available in order to create the HEC-HMS. Arc-Hydro tools (ArcGIS Application) were used to delineate the watershed.

The U.S. Department of Agriculture-Natural Resources Conservation Service (NRCS) – Curve Number (CN) and the Snyder Transform Methods were respectively used to model the hydrologic loss and to transform the rainfall excess into runoff hydrographs.

Finally, inflow hydrographs obtained from HEC-HMS for the different storm events serve as input into the HEC-RAS model. The analytical model starts in the vicinity of Crawford Park and ends approximately 800 feet downstream of I-95. This is an unsteady flow HEC-RAS model, which uses the full dynamic, Saint-Venant equation with an implicit, finite difference method to calculate equation solutions. This approach allows storm event flood waves to be routed within rivers while modeling hydrographs variation in space, time, and flood wave attenuation. The results represent a very accurate modeling of real flooding phenomena.

4 HYDROLOGIC ANALYSIS

4.1 Watershed Delineation and Area of Study

The Blind Brook Watershed, which originates in the vicinity of the Westchester County Airport, drains an area of approximately 10.9 square miles into the Long Island Sound. The area encompasses several municipalities including the City of Rye, Village of Rye Brook, Village of Port Chester, and Town/Village of Harrison. A second tributary to the east joins the main branch south of the Bowman Avenue Dam in the Village of Rye Brook. From the dam, the brook flows south, under Interstate I-287 and through the City business district to Milton Harbor.

Principal land uses in the Upper Blind Brook Watershed are the airport, large campus offices, golf courses, forests, wetlands and residential areas. Within the City of Rye, as described in ***Reference 2,*** the watershed is dominated by low and medium density residential development, institutional and recreational uses, open space, and a small central business district. The area along the brook is highly developed, with many residences, businesses and public buildings adjacent to the watercourse. Photographs taken during site inspections are available in ***Appendix A***.

For integration into the HEC-HMS model, the Blind Brook Watershed was subdivided into six sub-watersheds according to topographic and hydrologic (i.e. stream and ponds topology) conditions. Sub-watersheds areas are provided in ***Table 1***.

TABLE 1
SUBWATERSHEDS VERSUS AREAS

Sub-watersheds	Areas [mi^2]
Blind Brook Country Club (SW1)	2.10
Lincoln Avenue (SW2)	3.28
Bowman Avenue (SW3)	1.46
I-287 (SW4)	1.19
Purchase Street (SW5)	0.68
I-95 (SW6)	0.44
	Total 9.15

4.2 Storm Determination

National Weather Service's Technical Paper No.40 (TP-40 - ***Reference 12***), which has published data for estimating hypothetical frequency-based storms, was used in this study. The rainfall frequency (isopluvial) maps presented in TP-40 are for selected durations of time. A 24-hour rainfall duration was selected for the Blind Brook Watershed, which adequately exceeds the time of concentration for the watershed.

As the intensity of rainfall varies considerably during a storm, as well as for various geographic regions of the United States, NRCS developed four synthetic 24-hour rainfall distributions (I, IA, II and III) from available National Weather Service (NWS) duration frequency data (Hershfield 1961; Frederick et al., 1977) or local storm data (***Reference 10***). The approximate geographic boundaries for NRCS (SCS) rainfall distributions are given in ***Appendix B.*** A type III distribution, corresponding to the location of the Blind Brook Watershed, was selected for this analysis. For example, in ***Table 2***, a 100-year flood/24 hours duration, a conservative value of 7.2 inches of rain was considered and implemented into the HEC-HMS Model.

TABLE 2
PRECIPITATION DEPTHS FOR 24 HOUR RAINFALL

Storm Event	Precipitation Depth [inches]
2-years	3.3
5-years	4.3
10-years	5.1
25-years	5.7
50 years	6.4
100 years	7.2

Source: ***Reference 12***

4.3 Runoff Model

Runoff is simulated in HEC-HMS using mathematical methods describing the rainfall-runoff relations for a drainage basin. The input components include basin model, meteorological model, time series data, paired data, and control specification. Runoff for the watershed was estimated using the Natural Resources Conservation Service (NRCS), Runoff Curve Number (CN) method available in HEC-HMS.

The CN Number is an empirical parameter used for predicting direct runoff from rainfall excess. This method is widely used and has been proven efficient to determine the approximate amount of direct runoff from a rainfall event in a particular area. CN Numbers are based on the area's hydrologic soil group, land use and land cover. Blind Brook Watershed characteristics were determined using Geographic Information System (GIS) data. ArcGIS, a state-of-the-art GIS software program, was used to treat and analyze both Digital Elevation Model (USGS 2009 – ***Reference 3***), Land Cover Data (USGS 2011 – ***Reference 1***) and Soil Data (NRCS 2006 – ***Reference 6***). ***Appendix C*** presents this information. ***Table 3*** presents the composite CN Numbers for the different sub watersheds considered. Input files are includes on the CD provided in ***Appendix F***.

TABLE 3
COMPOSITE CN NUMBERS

Sub-watersheds	Composite CN Numbers
Blind Brook Country Club (SW1)	75
Lincoln Avenue (SW2)	73
Bowman Avenue (SW3)	74
I-287 (SW4)	75
Purchase Street (SW5)	67
I-95 (SW6)	62

4.4 Transform Method

The NRCS Curve Number method described above has been applied to determine runoff from initial rainfall. The method transforms excess precipitation into a simulated discharge hydrograph at the outlet of the watershed.

The Clark Unit Hydrograph method has been used in HEC-HMS for the Blind Brook watershed hydrographs development (***Reference 7***). This method has been shown to provide accurate results when used for small watersheds. The Clark Method requires three parameters to calculate hydrographs: T_c, the time of concentration for the basin, R, a storage coefficient, and a time-area curve. The time-area curve is used to develop the translation hydrograph resulting from a precipitation event and is input into HEC-HMS. The T_c and R calculations are presented here in ***Table 4***.

TABLE 4
CLARK METHOD PARAMETERS

Sub-watersheds	Time of Concentration (hours)	Storage Coefficient (hours)
Blind Brook Country Club (SW1)	3.01	1.24
Lincoln Avenue (SW2)	2.51	0.89
Bowman Avenue (SW3)	1.4	0.56
I-287 (SW4)	1.89	0.99
Purchase Street (SW5)	1.16	0.63
I-95 (SW6)	0.77	0.43

4.5 Hydrologic Analysis Results

Output from the hydrologic analysis consists of hydrographs obtained for the six sub-watersheds composing the Blind Brook Watershed Basin. The hydrographs are used as input data for the hydraulic analysis described in this report. ***Table 5*** presents the hydrograph peak flows for storm events ranging from 2 to 100 year period of return.

TABLE 5
HYDROGRAPH PEAK FLOW VALUES IN CFS

Storm Event	Blind Brook & Lincoln Av. (SW1&SW2)	Bowman Avenue (SW3)	I-287 (SW4)	Purchase Street (SW5)	I-95 (SW6)
2-years	1054.2	540.9	336.4	221.3	163.9
5-years	1602.8	790.6	491.3	328	244.1
10-years	2073.2	1001.9	622.2	420.1	314.1
25-years	2539.7	1165.2	723.2	492.2	369.3
50 years	3023.6	1359.7	843.5	578.9	436.1
100 years	3560.7	1585.9	983.3	680.8	515.1

Complete hydrographs are available on the CD provided in ***Appendix G***.

5 HYDRAULIC ANALYSIS

5.1 Model Data and Geometry

5.1.1 Model Data

LIDAR data that was used to build the HEC-RAS Model of the Blind Brook, was downloaded from Westchester County. LIDAR data was used to extract cross-section geometric dated for the hydraulic model. This data, acquired in 2009, was processed in ArcGIS. For the proposed resized Upper Pond Alternatives, RIZZO processed topographic data obtained by WSP Sells from a field survey performed on April 2012 and merged the topographic information into the general model. The HEC-GeoRAS extension versions 4.1 for ArcGIS 9.3 was used to delineate, extract, and import the cross sections into the HEC-RAS model.

5.1.2 Model Geometry

The analyzed portion of the Blind Brook was constructed as a single reach in the model. The model starts in the vicinity of Crawford Park and ends approximately 800 feet downstream of I-95 for a total length of 3 miles (see ***Appendix E – Figure E-2***). The model includes bridges, ponds and the Bowman Avenue Dam structure. Bridge geometries were taken both from the 2006 FEMA Model (***Reference 2***) provided by WSP Sells and RIZZO field investigations performed in February and May 2012. Areas for the Upper and Lower Pond were modeled into HEC-RAS using topographic survey data provided by WSP Sells. Proposed pond resizing alternative geometries were provided by WSP Sells and imported into HEC-RAS. Bowman Avenue Dam was also incorporated into the model along with the gate operation sequence. Bowman Dam and Spillway was modeled into HEC-RAS as an inline structure. The dam sluice gate was coded in the inline structure along with the bottom opening located at the invert of the dam.

Cross sections required to develop the model were chosen at representative locations throughout the Brook and at locations where changes occur in discharge, slope, shape and roughness. Cross-sections were cut from the LIDAR Data to define the creek (see ***Appendix E – Figure E-2***). Afterward, cross section extrapolations were performed within the creek in order to reach a density of one cross-section for each 40 ft. of creek for a total number of 387 cross sections. Areas of the Upper and Lower Pond were modeled using more closely spaced cross-sections at 25 to 50 feet intervals so that HEC-RAS performs fully dynamic unsteady flow routing through the ponds and downstream of the Bowman Dam. This was also done for the resized pond alternatives. ***Appendix D*** presents the plan views of the resized pond alternatives.

5.2 Manning Roughness Coefficient (n)

Manning's roughness coefficients for the streambed, and overbanks were selected from the 2006 FEMA HEC-RAS model supported by engineering judgment. The original Manning's n-values reported in the old FEMA model were adjusted where necessary in the hydraulic modeling phase on a cross section by cross section basis. Values ranging from 0.045 to 0.065 were used for the stream and the overbanks areas. For numerical stability of the HEC-RAS model the higher manning values (i.e. 0.065) were used during low flow simulations.

5.3 Inflow Hydrographs and Boundary Conditions

The unsteady HEC-RAS model was developed for the selected study limits. As discussed in section 4.1, the hydrologic software HEC-HMS was used to develop storm inflow hydrographs for input into the unsteady flow model. These hydrographs were further used to conduct the hydraulic modeling with HEC-RAS.

Within the unsteady HEC-RAS model, the inflow hydrographs were used as inputs into the model. The locations of the boundary conditions are listed in ***Table 6***. Boundary conditions allow HEC-RAS to initiate its calculation (i.e. solving the St. Venant equation)

TABLE 6
INFLOW HYDROGRAPHS AND BOUNDARY CONDITIONS

HEC-RAS River Station	Reference Location	Boundary Condition
4603.397	Lincoln Avenue	Inflow hydrograph
3556.227	Inflow to Upper Pond at Westchester Avenue	Lateral Inflow
2796.049 IS	Bowman Avenue Dam	Internal boundary (i.e., gate operation using HEC-RAS Rule Operations)
2630.106	Tributary to Lower Pond at Bowman Avenue confluence with East Branch Blind Brook	Lateral inflow hydrograph
2108.907-1432.194	Between I-287 and Purchase Street	Uniform lateral inflow
1432.194-31.82327	Between Purchase Street and downstream of I-95	Uniform lateral inflow
13.83771	Downstream of I-95	Normal depth

Local inflows were modeled as lateral inflows in the HEC-RAS model. ***Table 6*** lists the point of lateral inflow and the corresponding HEC-RAS cross sections are presented below:

- Local drainage from Blind Brook and Lincoln Avenue sub-watershed is modeled as upstream inflow hydrograph at cross-section 4603.397.
- Local drainage from Bowman Avenue Dam sub-watershed is modeled as lateral inflow to Upper Pond at Westchester Avenue at cross-section 3556.227.
- Local drainage from I-287 sub-watershed is modeled as lateral inflow to Lower Pond at Bowman Avenue at cross-section 2630.106.

- Local drainage from Purchase Street sub-watershed is modeled as uniform inflow between I-287 and Purchase Street between cross sections 2108.907 and 1432.194.

- Local drainage from I-95 sub-watershed is modeled as uniform inflow Between Purchase Street to downstream of I-95 between cross-sections 1432.194 and 31.82327.

For all scenarios, the normal depth method was used for the downstream boundary condition. The gradient was estimated between the last few downstream cross-sections of the river reach, to be approximately 0.002 ft/ft.

When there is an inline structure in HEC-RAS, no cross-section in the model can go dry, therefore, a constant base flow of 200 cfs was set as the minimum flow throughout the Blind Brook River at all times for numerical stability at low flow within the HEC-RAS environment.

5.4 Scenarios Analyzed

The analysis aims to determine the potential impacts of the proposed resized Upper Pond Alternatives on water surface profiles between Interstates I-287 and I-95. It also considers an optimized sluice gate operating sequence. Water levels corresponding to the 2-year, 5-year, 10-year, 25-year, 50-year and 100-year return storm events were determined.

The following scenarios were analyzed:

- Case A: Existing Condition
- Case B: Sluice Gate Installation
- Case C: Proposed Resized Upper Pond
- Case D: Proposed Maximized Resized Upper Pond
- Case E: Combination Resized Upper Pond and Sluice Gate \

Case A consists of the existing condition with the timber logs installed at the dam bottom and the 15-feet wide by 2.5-foot high orifice opening at the dam invert. Water surface elevations for Case A were used to establish the baseline hydraulic characteristics of the Blind Brook River between Interstates I-287 and I-95.

Case B represents RIZZO's proposed optimized gate sequence operation consisting of keeping the gate closed for the 5-year storm, adopting the WSP-Sells gate operation procedure for return period ranging from 5 to 10 years and setting the gate fully open for floods greater than 10 years.

Case C consists on resizing the Upper Pond by excavating 104,000 cubic yards of material (i.e. 96,000 cubic yards of soil and 14,000 cubic yards of rock). Case D is a maximized resized alternative aiming to remove approximately 130,000 cubic yards of material (i.e. 109,000 cubic yards of soil and 21,000 cubic yards of rock).

Case E is a combination of the Cases A and C consisting of a simulation with the Resized Upper Pond and the Sluice Gate Installed.

6.0 RESULTS AND FINDINGS

A summary of anticipated water surface elevations for the 5 cases are presented in ***Table 7***. To compare the different cases with each other, summary results are presented for five representative cross-sections. The locations are:

- Downstream of I-287
- Purchase Street
- Mendota Avenue
- Highland Road
- Upstream of I-95

Results of this study show a potential reduction in downstream water elevations resulting from the sluice gate installation for large storm events (i.e. floods with return periods between 25 and 100 years). Overall, water elevations are projected to be approximately 6 inches lower after sluice gate installation for the 50 and 100 return period floods.

Results also show that between the two resized pond alternatives, Cases C and D, the incremental benefit gained with the maximized resized alternative (Case C) is insignificant. By implementing the smaller resized pond alternative (Case D), potential water elevations are between 8 and 10 inches lower for the smaller storm events (i.e. 2 to 10 year period of return storms) and around 4 or 5 inches lower for the larger storm events (i.e. 50 and 100 year period of return).

Case E, which models the smaller resized pond alternative with the sluice gate installed, shows overall potential water surface level decrease of 10 to 15 inches between I-287 and I-95 during larger storm events.

GIS Files, HEC-HMS and HEC-RAS models used and all the pertinent data are placed on CDs and are provided in ***Appendix F, G and H.***

TABLE 7
SUMMARY OF RESULT SHOWING SURFACE ELEVATIONS AND WATER LEVEL DIFFERENTIAL FOR THE 5 ANALYZED CASES

Flood (Period of Return)	Locations	Existing Cond. (CASE A)	Sluice Gate Inst. (CASE B)	Resized Upper Pond- Alt. 2 (Case C)	Max. Upper Pond - Alt. 1 (Case D)	Resized Upper Pond - Alt 2 & SG (Case E)	Difference (Inches)			
							Case A&B	Case A&C	Case A&D	Case A&E
2 Year	D/S of I-287	33.8	33.8	33.2	33.1	33.2	0	-7	-8	-7
	Purchase Street	28.3	28.3	27.7	27.6	27.7	0	-7	-8	-7
	Mendota Avenue	24.9	24.9	24.4	24.3	24.4	0	-6	-7	-6
	Highland Road	24.5	24.5	23.8	23.7	23.8	0	-8	-9	-8
	U/S I-95	23.4	23.4	22.9	22.9	22.9	0	-5	-6	-5
5 Year	D/S of I-287	34.5	*	34.1	34.0	34.0	*	-5	-6	*
	Purchase Street	29.8	*	29.0	28.8	28.8	*	-10	-12	*
	Mendota Avenue	26.6	*	25.7	25.5	25.5	*	-11	-13	*
	Highland Road	26.5	*	25.5	25.3	25.3	*	-12	-14	*
	U/S I-95	24.7	*	23.8	23.7	23.7	*	-10	-11	*
10 Year	D/S of I-287	35.1	*	34.9	34.9	34.9	*	-2	-3	*
	Purchase Street	31.0	*	30.6	30.5	30.5	*	-5	-6	*
	Mendota Avenue	27.8	*	27.3	27.3	27.3	*	-6	-6	*
	Highland Road	27.7	*	27.2	27.2	27.2	*	-6	-7	*
	U/S I-95	26.1	*	25.5	25.4	25.4	*	-8	-9	*
25 Year	D/S of I-287	35.5	35.4	35.4	35.4	35.3	-2	-1	-1	-3
	Purchase Street	31.7	31.6	31.5	31.4	31.4	-2	-3	-4	-4
	Mendota Avenue	28.7	28.6	28.2	28.2	28.3	-1	-5	-6	-4

	Highland Road	28.6	28.5	28.2	28.1	28.3	-1	-5	-6	-4
	U/S I-95	27.3	27.2	26.8	26.7	26.9	-1	-6	-7	-5
50 Year	D/S of I-287	35.9	35.7	35.9	35.9	35.5	-3	-1	-1	-5
	Purchase Street	32.5	32.1	32.3	32.3	31.9	-5	-2	-3	-8
	Mendota Avenue	29.8	29.4	29.4	29.4	29.0	-6	-5	-6	-10
	Highland Road	29.8	29.3	29.4	29.3	28.9	-6	-5	-6	-10
	U/S I-95	28.7	28.2	28.2	28.2	27.7	-6	-5	-6	-11
100 Year	D/S of I-287	36.3	36.1	36.2	36.2	35.9	-2	-1	-1	-5
	Purchase Street	33.2	33.0	33.1	33.1	32.6	-3	-2	-2	-8
	Mendota Avenue	31.2	30.8	30.8	30.8	30.1	-5	-4	-5	-14
	Highland Road	31.2	30.7	30.8	30.7	30.0	-5	-5	-5	-14
	U/S I-95	30.2	29.7	29.7	29.7	28.9	-6	-5	-6	-15

* Refer to WSP-Sells gate operation sequence (***Reference 4***)

7.0 COMPARISON BETWEEN RIZZO AND 2008 WSP SELLS ANALYSIS

7.1 DISCHARGE FLOW VALUES

Table 8 presents a comparison of discharge flow values from the present study and the 2008 WSP-Sells study (***Reference 4***).

TABLE 8
DISCHARGE FLOW VALUES COMPARISON

Storm Event Return Periods (years)	Location*	Peak Discharge (cfs)	
		WSP-Sells	RIZZO
2	D/S of I-287	781	1023
	Purchase St	781	1036
	U/S of I-95	928	1024
5	D/S of I-287	1275	2098
	Purchase St	1275	2143
	U/S of I-95	1534	2057
10	D/S of I-287	1663	2829
	Purchase St	1663	2883
	U/S of I-95	1982	2780
25	D/S of I-287	2292	3346
	Purchase St	2292	3429
	U/S of I-95	2594	3300
50	D/S of I-287	2767	3995
	Purchase St	2767	4084
	U/S of I-95	3078	3849
100	D/S of I-287	3346	4633
	Purchase St	3346	4673
	U/S of I-95	3583	4389

* Comparisons between WSP Sells model and RIZZO model are approximate due to differences in model geometry and cross sections.

WSP-Sells used discharge flow values from its August 2007 Hydrologic study for the Blind Brook Watershed (***Reference 4***). This study used peak flow data from USGS Gage 01300000 located downstream of the I-95 culvert to calculate peak discharge rates of various return periods.

The discharges reported in ***Table 8*** were computed using a probabilistic approach (i.e. Log-Pearson Type III method) using annual peak discharges recorded between 1944 and 1999. In order to account for recent development in the watershed, only the last 20 years of records were used for the analysis.

Discharge flow values obtained by RIZZO were computed using a deterministic approach to model physical processes (e.g., surface runoff, infiltration, evapotranspiration, and channel flow) in response to rainfall events within a hydrologic model (HEC-HMS) and routing these flows downstream in a hydraulic model (HEC-RAS). The HEC-HMS and HEC-RAS models were developed using the most current topographic and hydrologic data available for the watershed. This data reflects watershed conditions present within the last five years.

By way of comparison, RIZZO also performed a probabilistic analysis on the USGS Stream Gage 01300000 data using a Log Pearson Type III distribution. However, the data were supplemented by estimating discharge rates of two significant floods that occurred in the last 5 years (i.e. in 2007 and 2011). By incorporating these new data, the estimated peak discharge rates for floods of different return periods went up significantly. Summary of results are presented in ***Table 9*** below. Due to the uncertainty surrounding the probabilistic estimates, the HEC-RAS modeling was done using the deterministic analyses discussed above.

TABLE 9
RIZZO UPDATED PROBABILITY PEAK FLOW ANALYSIS

Storm Event Return Periods (years)	Location*	Peak Discharge (cfs)
2	D/S of I-95	1024
5		1893
10		2639
25		3793
50		4817
100		5992

7.2 Model Geometry

The model geometry between the RIZZO model and the WSP Sells model is different. The WSP Sells model utilized geometry from the FEMA Flood Insurance Study (FIS) model, which was developed using Digital Elevation Model (DEM) data. The vertical accuracy of this data is approximately 2 feet.

The RIZZO model makes use of more recently available LIDAR data, which has a horizontal resolution of 9 feet and a vertical accuracy of 7 inches. While this data is more accurate than the topographic data from the FEMA FIS, it does not necessarily indicate that the newer topography yields significantly more accurate results. For comparison, a sample cross section is shown below that highlights topographical differences between the model geometries.

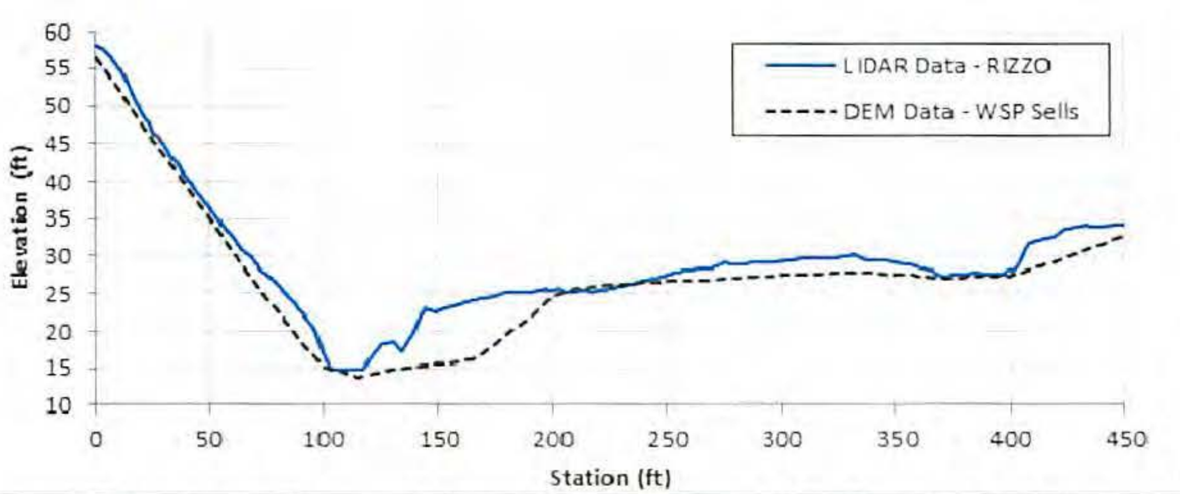


Figure 1: Cross Section Geometry Comparison Downstream of Highland Road and Upstream of the I-95 Culvert

Additionally, RIZZO model is composed of 387 cross-sections (average spacing of 40 feet) versus 39 cross-sections for the 2006 FEMA HEC-RAS model (See both model plan view in ***Appendix E***) which was used in the WSP-Sells 2008 Study (***Reference 3***).This different level of accuracy between the two models leads to differences in water levels.

7.3 Steady Versus Unsteady Analyses

The HEC-RAS model used by WSP Sells is a steady flow model. The peak flow from the flood hydrograph released from Bowman Avenue Dam was used in the HEC-RAS model as a constant value. This peak discharge value was temporally and spatially constant. Therefore, at every cross section the flow rate is a constant value. The only variability is the cross sectional area of the flow and the flow velocity. Alternatively, RIZZO's HEC-RAS model is an unsteady flow model.

The flood hydrograph is routed through the reach so the flood discharge changes with time and space. An unsteady flow regime allows the flood hydrograph to attenuate as it moves downstream (*See Figure 2*). The output from an unsteady flow model is more representative of the way water levels rise and fall during a flood. An unsteady flow model allows for storage, spatial, and temporal changes in the water levels as the flood wave propagates downstream.

Figure 2: Comparison between Unsteady and Steady Flow Modeling

7.4 SLUICE GATE OPTIMIZATION

Part of the RIZZO's scope of work was to consider ways to optimize the sluice gate operation. The purpose of this was to determine if adjustments in gate operation settings could lead to an additional decrease in water levels downstream of the Bowman Avenue Dam. Along with the other points mentioned above, the different mode of gate operation between RIZZO and the WSP-Sells models did lead to different water levels within the downstream area of interest.

7.5 FLOW DYNAMICS THROUGH THE I-95 CULVERT

A significant difference between the WSP-Sells and RIZZO HEC-RAS models is the predicted flood levels for the 50-year flood (See *Figure 3*). In the WSP Sells model, the effect of the sluice gate operation on the 50-year flood levels is significant, lowering the flood levels by as much as 4.15 ft upstream of the I-95 culvert. With the RIZZO model, the benefit is significantly smaller (0.5 ft). Making a direct comparison between these results is not easy due to the differences discussed above. Multiple variables changed between the two analyses.

Nevertheless, the large flood level reduction at the 50-year discharge rate in the WSP Sells model is due to a change in the flow regime (i.e. from free surface flow to orifice flow) through the I-95 culvert. Without the sluice gate, the discharge rate is large enough that it submerges the inlet of the I-95 culvert. As a result, a headwater builds up on the upstream side of the culvert to provide the necessary hydraulic head to pass the flow through the culvert. This headwater at the culvert results in backwater effects upstream. With the installation of the sluice gate, the peak discharge rate is sufficiently less such that the discharge rate can flow through the culvert without submerging the inlet. Therefore, the flow passes through the culvert as a free surface flow and does not create backwater effects upstream. In comparison, in the RIZZO model, both cases (i.e. with and without the sluice gate) are orifice flows and consequently do not lead to a significant decrease in water level (See ***Figure 3***).

This phenomenon is not apparent in the 25-year flood levels or the 100-year flood levels because in both cases, the reduction in the peak discharge rate attributable to the sluice gate does not cause a transition in the flow regime. For the 25-year flood, the discharge flow with and without the sluice gate does not submerge the I-95 culvert. Therefore, the flow passes through the culvert as a free surface flow. The flow transition occurs at a higher flow rate, on the order of the predicted 50-year flood. For the 100-year flood, the predicted benefit of the sluice gate is significantly less. The reduction in the flood levels for the 100-year flood due to the sluice gate is approximately 1 ft. With or without the sluice gate, the flood is large enough that the I-95 culvert is submerged, and as a result creates backwater effects (i.e., flooding) upstream.

Figure 3: Representation of hydraulic conditions at the I-95 Culvert for the 50-year flood

APPENDIX A

SITE INSPECTION PHOTOGRAPHS

APPENDIX A
SITE INSPECTION PHOTOGRAPHS

PHOTOGRAPH NO. 1: BOWMAN AVENUE DAM - FEBRUARY 13, 2012

PHOTOGRAPH NO.2: BOWMAN AVENUE DAM - OUTLET OPENING WITH TIMBER LOGS – FEBRUARY 13, 2012

PHOTOGRAPH NO. 3: UPPER POND RESERVOIR - MAY 1, 2012

PHOTOGRAPH NO. 4: RIVERVIEW AT PURCHASE CULVERT - MAY 1, 2012

PHOTOGRAPH NO. 5: CROSS WESTCHESTER EXPRESSWAY (I-287) CULVERT MAY 1, 2012

PHOTOGRAPH NO. 6: BLIND BROOK DIRECTLY DOWNSTREAM OF PURCHASE STREET CULVERT - MAY 1, 2012

APPENDIX A
SITE INSPECTION PHOTOGRAPHS

PHOTOGRAPH NO. 7: DAMAGED HOUSE ON MOHAWK STREET (INDIAN VILLAGE)MAY 1, 2012

**PHOTOGRAPH NO. 8: DAMAGED HOUSE ON MENDOTA AVENUE (INDIAN VILLAGE)
MAY 1, 2012**

APPENDIX A
SITE INSPECTION PHOTOGRAPHS

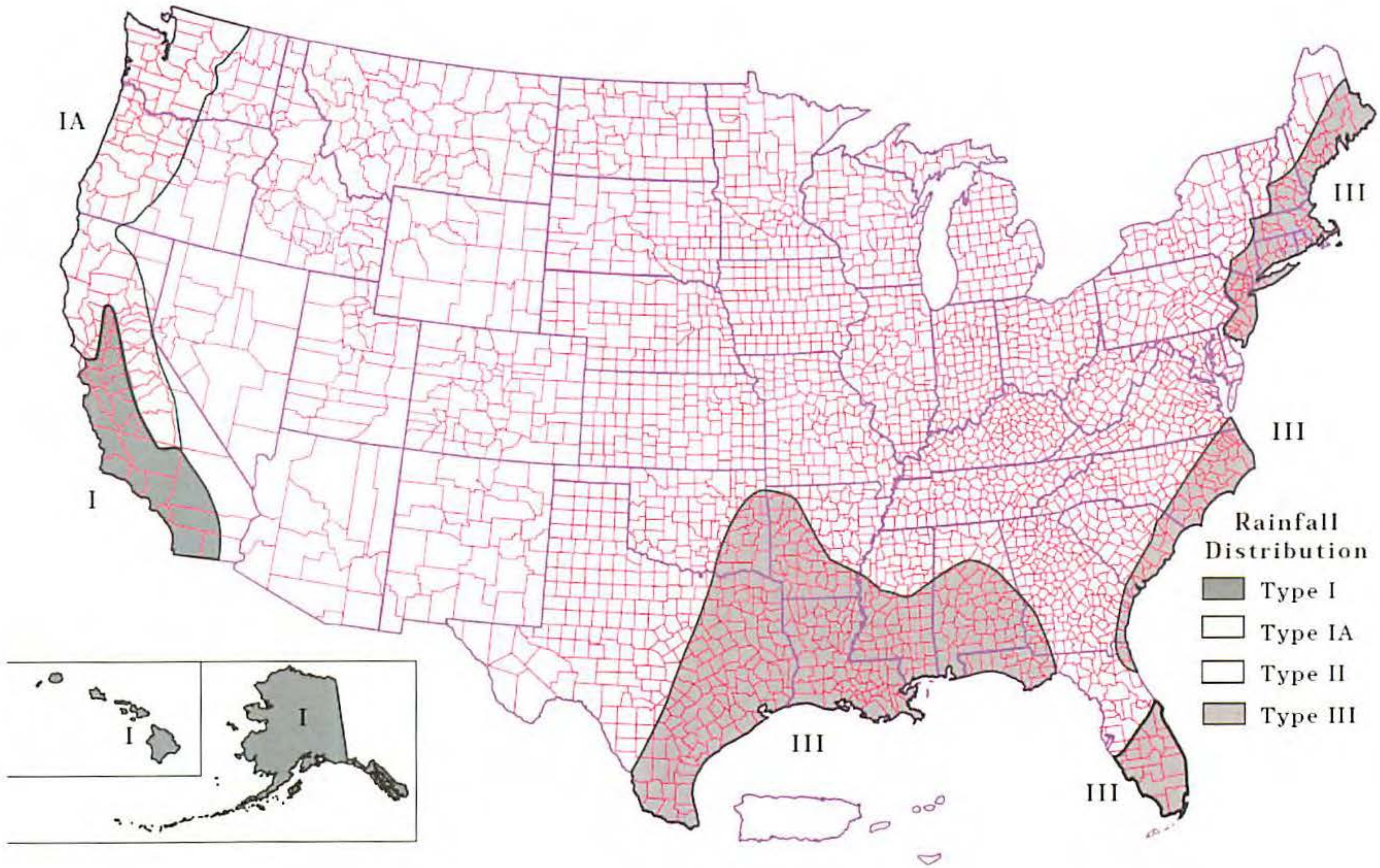
PHOTOGRAPH NO. 9: BLIND BROOK DRIRECTLY DOWSNTREAM OF THE HIGHLAND ROAD BRIDGE - MAY 1, 2012

PHOTOGRAPH NO. 10: NEW ENGLAND THRUWAY CULVERT (I95) - MAY 1, 2012

APPENDIX B

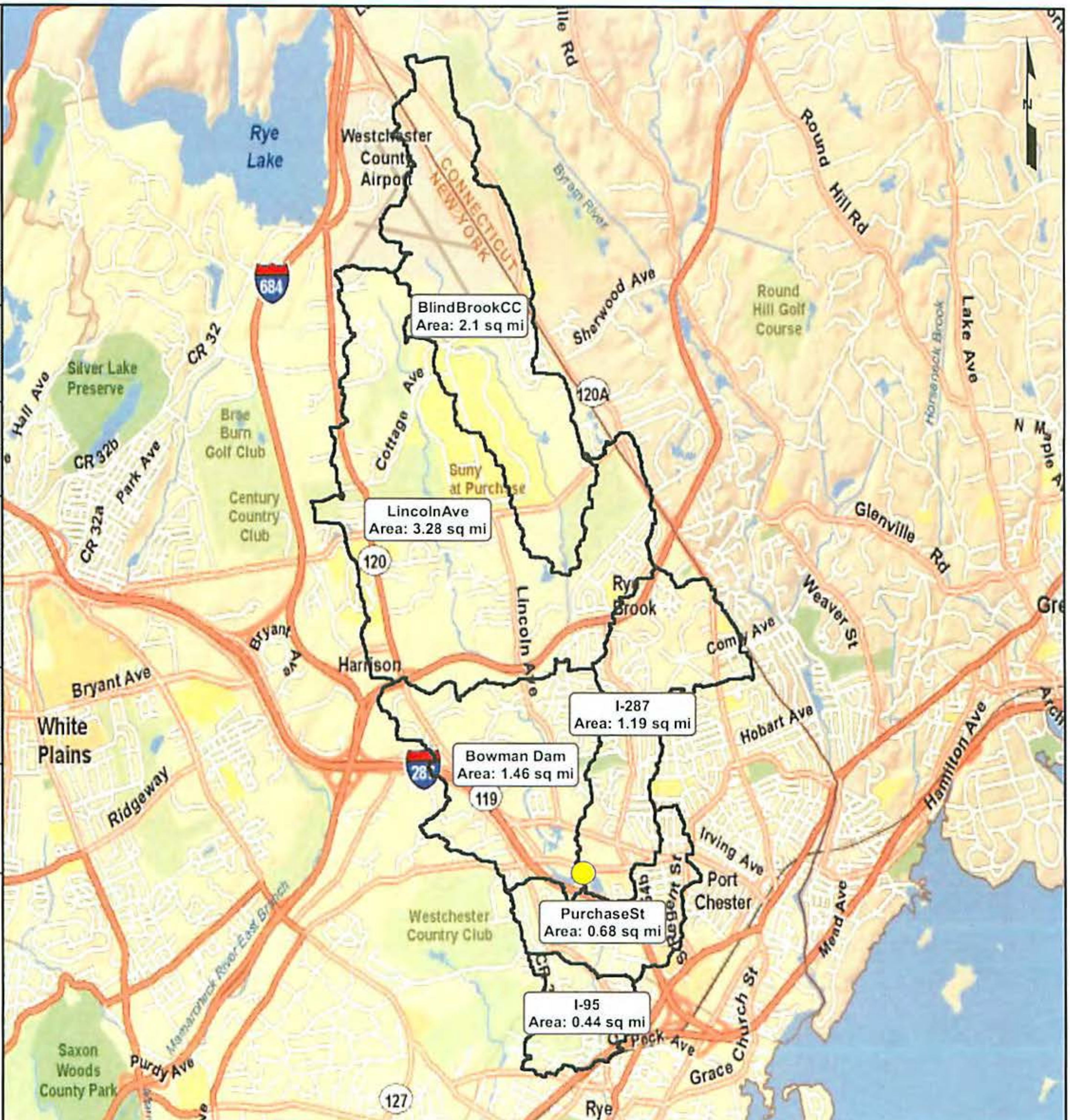
APPROXIMATE GEOGRAPHIC BOUNDARIES FOR NRCS (SCS) RAINFALL DISTRIBUTIONS (FROM REFERENCE 9)

APPENDIX B


IA
I
III
III
III
III
I
I
Rainfall
Distribution
Type I
Type IA
Type II
Type III

APPENDIX C

BLIND BROOK WATERSHED – PHYSICAL PARAMETERS



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	9/18/2012	9/18/2012
GIS FILE NUMBER		

LEGEND

- Bowman Dam
- Subwatersheds
- World Street Map

0.5 0.25 0 0.5 1 Miles

FIGURE C-1

Site Location and Subwatershed Delineation

DATUM: NAD 83
PROJECTION: State Plane New York East- Feet

REFERENCE(S): ESRI World Street Map

PREPARED FOR

WSP Sells
Briarcliff Manor, NY

Paul C. Rizzo Engineering – New York, PLLC
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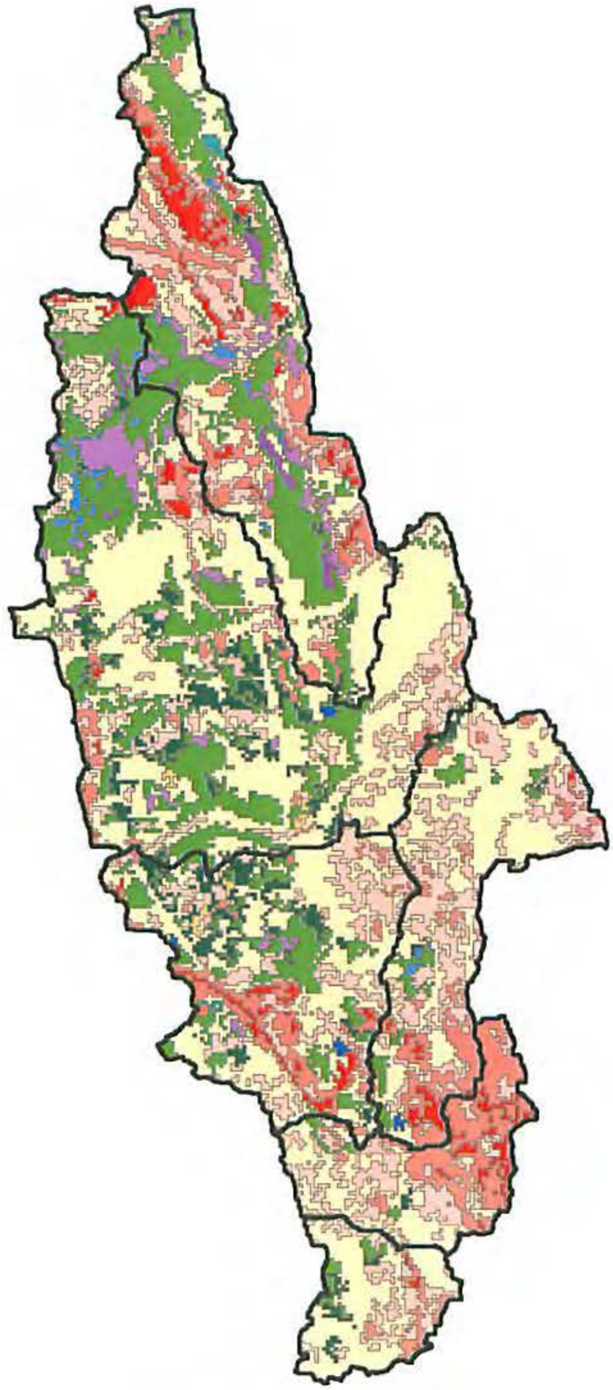

DRAWN BY	CHECKED BY	APPROVED BY	GIS FILE NUMBER
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9/18/2012	9/18/2012	9/18/2012	

LEGEND

- Subwatersheds
- Deciduous Forest
- Developed, High Intensity
- Developed, Low Intensity
- Developed, Medium Intensity
- Developed, Open Space
- Evergreen Forest
- Grassland
- Mixed Forest
- Open Water
- Pasture
- Shrub
- Woody Wetlands

0.5 0.25 0 0.5 1 Miles

DATUM: NAD 83
PROJECTION: State Plane New York East- Feet

REFERENCE(S): United States Geological Survey, 2011, "LBCD 2006 Land Cover", 1st ed., http://www.mrlc.gov/nlcd2006.php

FIGURE C-2

Land Use and Land Cover Types

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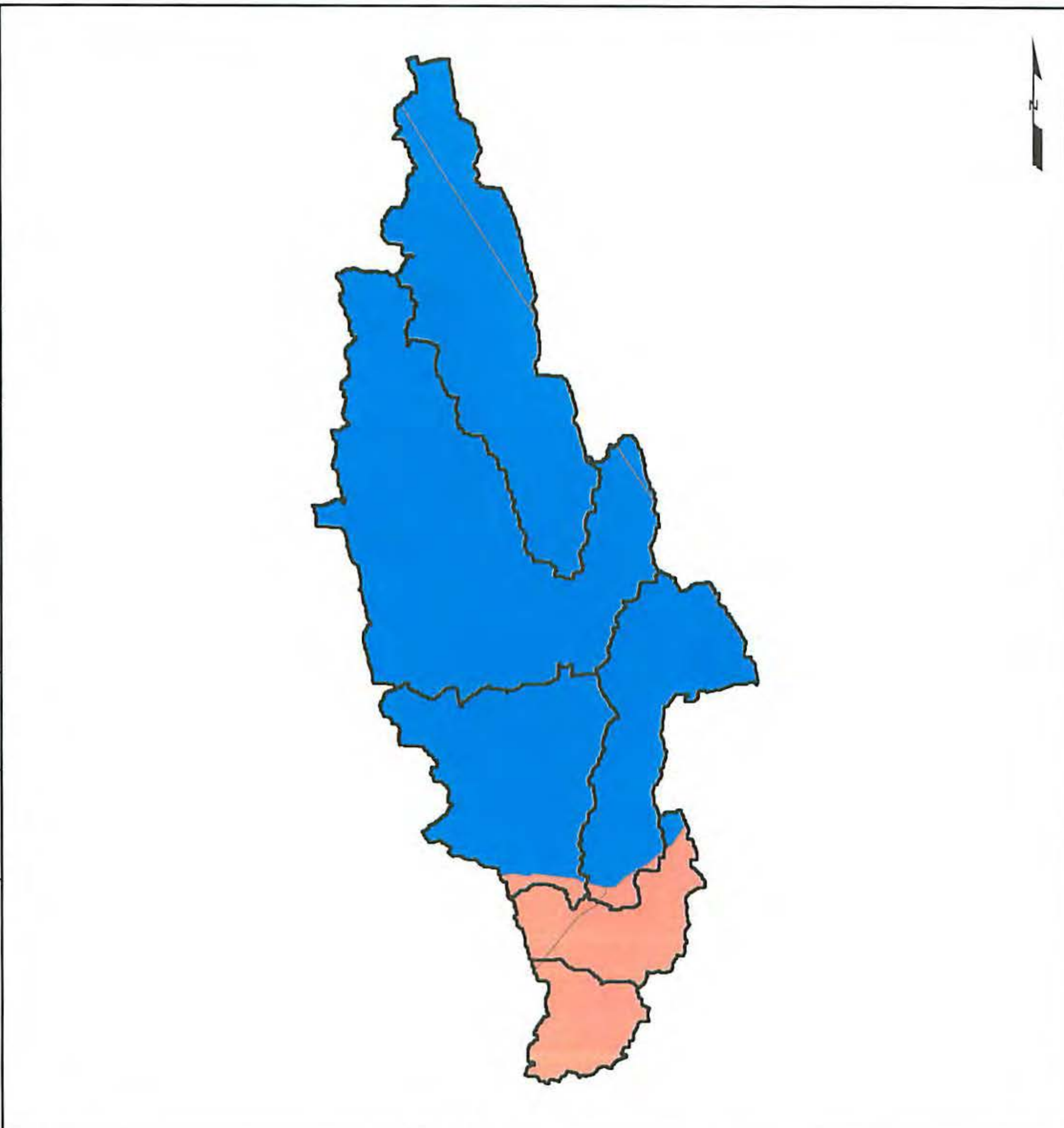
	9/18/2012	APPROVED BY	WB	9/18/2012	



LEGEND

- Subwatersheds
- Soil Type B
- Soil Type C

0.5 0.25 0 0.5 1 Miles

FIGURE C-3

STATSGO Soils (Hydro Group ID)

DATUM: NAD 83
PROJECTION: State Plane New York East- Feet

REFERENCE(S): Natural Resources Conservation Service,2006, "Digital General Soil Map of U.S.", NY and CT, US Department of Agriculture, http://soildatamart.nrcs.usda.gov

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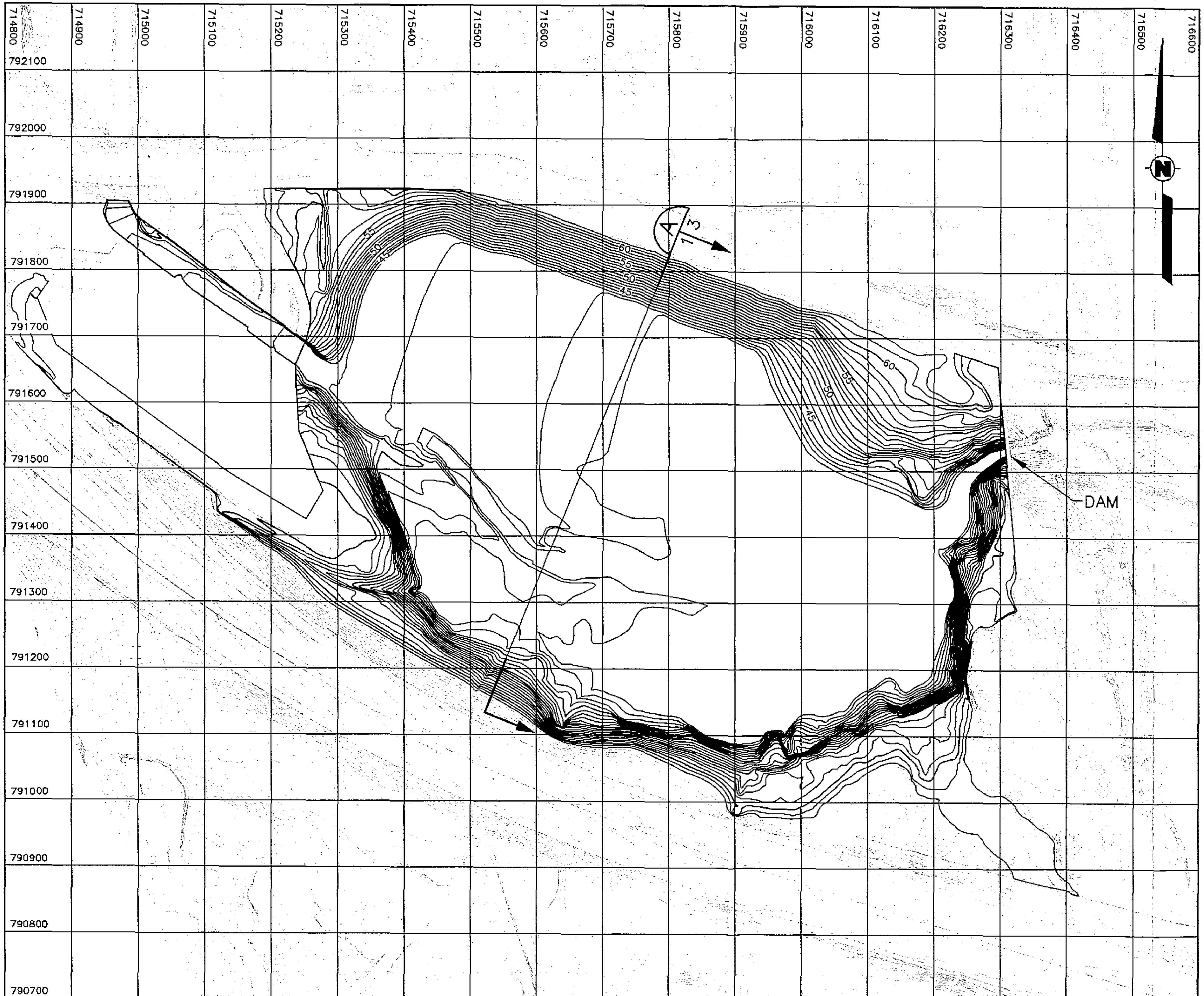
Table C-1

Composite Curve Number Result Summary

Subwatershed	Land Use	Soil	CN	Area (sq ft)	Area (sq mi)	% in Basin	Total Area (sq mi)	Composite CN
Bowman Dam (SW3)								
	Deciduous Forest	B	55	143,656	0.0052	0.35%		
		C	70	6,342,515	0.2275	15.61%		
	Developed, High Intensity	B	81	119,515	0.0043	0.29%		
		C	85	1,648,905	0.0591	4.06%		
	Developed, Low Intensity	B	65	315,116	0.0113	0.78%		
		C	77	7,323,192	0.2627	18.03%		
	Developed, Medium Intensity	B	70	166,884	0.0060	0.41%		
		C	80	4,043,798	0.1451	9.96%		
	Developed, Open Space	B	61	771,463	0.0277	1.90%		
		C	74	15,341,263	0.5503	37.77%		
	Evergreen Forest	B	55	79,657	0.0029	0.20%		
		C	70	3,380,825	0.1213	8.32%		
	Mixed Forest	C	70	319,806	0.0115	0.79%		
	Open Water	C	100	196,257	0.0070	0.48%		
	Pasture	C	74	321,217	0.0115	0.79%		
	Shrub	C	65	106,562	0.0038	0.26%	1.4571	74.28
I-287 (SW4)								
	Deciduous Forest	B	55	133,877	0.0048	0.40%		
		C	70	1,890,467	0.0678	5.68%		
	Developed, High Intensity	B	81	401,384	0.0144	1.21%		
		C	85	515,619	0.0185	1.55%		
	Developed, Low Intensity	B	65	95,353	0.0034	0.29%		
		C	77	10,068,450	0.3612	30.27%		
	Developed, Medium Intensity	B	70	642,086	0.0230	1.93%		
		C	80	4,237,936	0.1520	12.74%		
	Developed, Open Space	B	61	254,641	0.0091	0.77%		
		C	74	14,423,413	0.5174	43.37%		
	Evergreen Forest	C	55	324,841	0.0117	0.98%		
	Grassland	C	74	155,000	0.0056	0.47%		
	Open Water	B	100	96,558	0.0035	0.29%		
		C	100	19,691	0.0007	0.06%	1.1930	75.33
Purchase St (SW5)								
	Deciduous Forest	B	55	415,425	0.0149	2.19%		
	Developed, High Intensity	B	81	1,574,872	0.0565	8.29%		
	Developed, Low Intensity	B	65	5,025,071	0.1802	26.47%		
		C	77	91,653	0.0033	0.48%		
	Developed, Medium Intensity	B	70	5,659,173	0.2030	29.81%		
		C	80	717,263	0.0257	3.78%		
	Developed, Open Space	B	61	5,395,997	0.1936	28.42%		
	Evergreen Forest	B	55	106,562	0.0038	0.56%	0.6810	67.03
I-95 (SW6)								
	Deciduous Forest	B	55	599,452	0.0215	4.91%		
	Developed, High Intensity	B	81	176,175	0.0063	1.44%		
	Developed, Low Intensity	B	65	2,495,551	0.0895	20.46%		
	Developed, Medium Intensity	B	70	1,021,564	0.0366	8.38%		
	Developed, Open Space	B	61	7,230,547	0.2594	59.28%		
	Evergreen Forest	B	55	674,483	0.0242	5.53%	0.4375	62.23
Lincoln Ave (SW2)								
	Deciduous Forest	C	70	23,537,217	0.8443	25.74%		
	Developed, High Intensity	C	85	1,194,454	0.0428	1.31%		
	Developed, Low Intensity	C	77	11,496,453	0.4124	12.57%		
	Developed, Medium Intensity	C	80	3,435,645	0.1232	3.76%		
	Developed, Open Space	C	74	41,403,850	1.4852	45.27%		
	Evergreen Forest	C	70	5,402,921	0.1938	5.91%		
	Grassland	C	74	1,038,098	0.0372	1.14%		
	Mixed Forest	C	70	3,290,495	0.1180	3.60%		
	Open Water	C	100	125,937	0.0045	0.14%		
	Pasture	C	74	306,021	0.0110	0.33%		
	Woody Wetlands	C	90	222,812	0.0080	0.24%	3.2805	73.41
Blind Brook CC (SW1)								
	Deciduous Forest	C	70	14,739,677	0.5287	25.17%		
	Developed, High Intensity	C	85	4,433,604	0.1590	7.57%		
	Developed, Low Intensity	C	77	8,572,354	0.3075	14.64%		
	Developed, Medium Intensity	C	80	9,046,369	0.3245	15.45%		
	Developed, Open Space	B	61	10,664	0.0004	0.02%		
		C	74	16,476,863	0.5910	28.13%		
	Evergreen Forest	C	70	699,179	0.0251	1.19%		
	Grassland	C	74	533,845	0.0191	0.91%		
	Mixed Forest	C	70	2,599,257	0.0932	4.44%		
	Pasture	C	74	125,937	0.0045	0.22%		
	Shrub	C	65	319,687	0.0115	0.55%		
	Woody Wetlands	C	90	1,007,498	0.0361	1.72%	2.1007	75.19

APPENDIX D

RESIZED UPPER POND ALTERNATIVES



ELEVATION/AREA RELATIONSHIP	
ELEVATIONS (ft)	AREA (ACRES)
41	5.59
42	7.47
43	9.77
44	10.74
45	11.16
46	11.50
47	11.87
48	12.22
49	12.50
50	12.76
51	13.01
52	13.27
53	13.51
54	13.77
55	14.04
56	14.33
57	14.69
58	15.21
59	15.82
60	16.50
61	17.71
62	18.56

NOTE:

1. Projection is NAD83 New York State Plane, East Zone, US foot.

SCALE

150 0 150 FEET

FIGURE D-1

NORMAL RESIZED POOL SCENARIO

BOWMAN AVENUE DAM SITE

UPPER POND RESERVOIR RESIZING PROJECT

PREPARED FOR

WSP SELLS

MANOR, NEW YORK

Paul C. Rizzo Associates, Inc.

ENGINEERS / CONSULTANTS / CM

CAD FILE NUMBER 11-4626-B1

AE 09.13.2012

WB 09.13.2012

CHECKED BY

APPROVED BY

CVL 05-14-12

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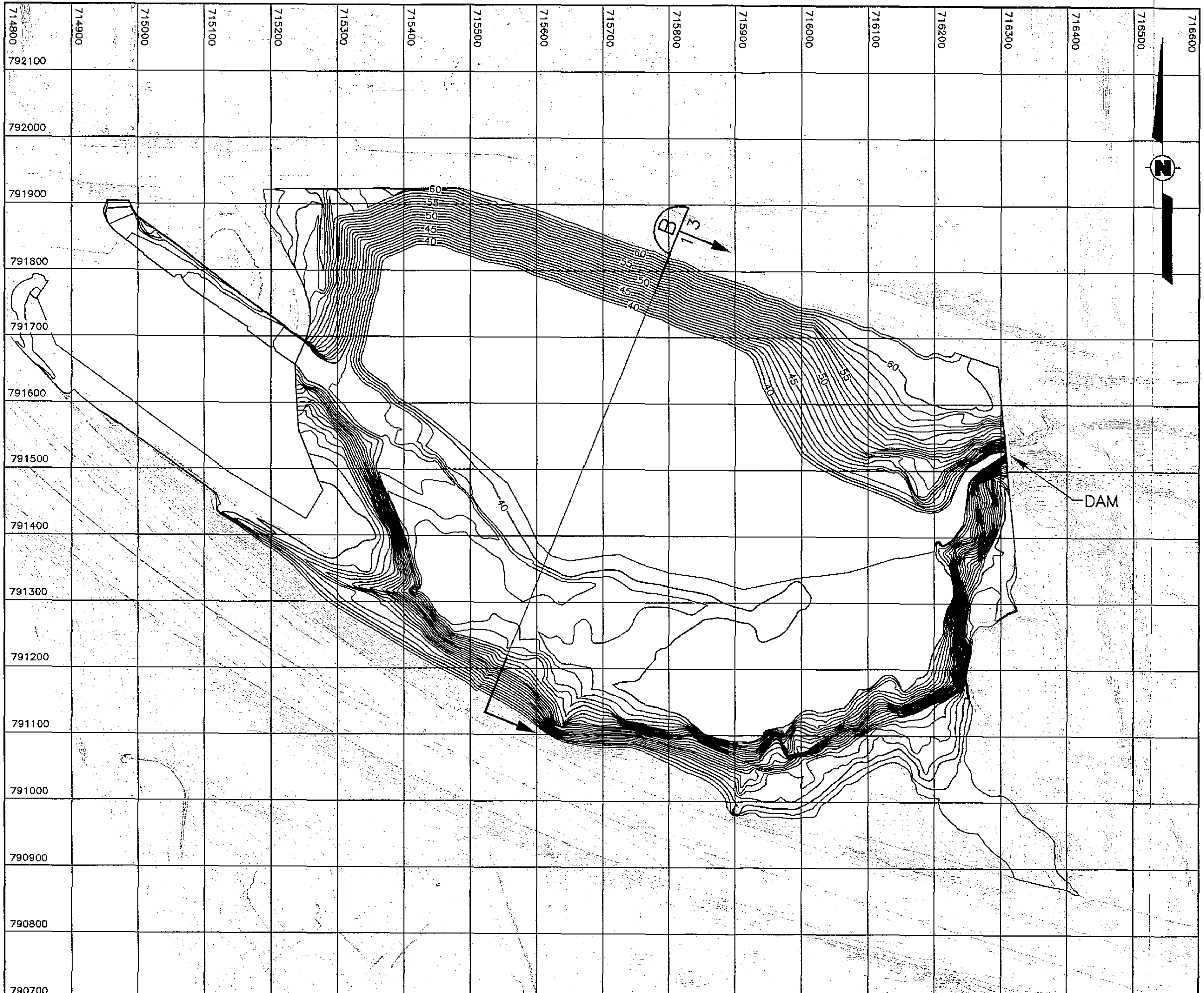

ELEVATION/AREA RELATIONSHIP	
39	5.50
40	7.67
41	8.57
42	9.60
43	10.25
44	10.78
45	11.22
46	11.55
47	11.93
48	12.27
49	12.56
50	12.84
51	13.10
52	13.35
53	13.60
54	13.85
55	14.12
56	14.41
57	14.75
58	15.22
59	15.82
60	16.51
61	17.87
62	18.64

NOTE:

1. Projection is NAD83 New York State Plane, East Zone, US foot.

SCALE

150 0 150 FEET

FIGURE D-2

MAXIMUM POOL ELEVATION AREAS

BOWMAN AVENUE DAM SITE

UPPER POND RESERVOIR RESIZING PROJECT

PREPARED FOR

WSP SELLS

MANOR, NEW YORK

Paul C. Rizzo Associates, Inc.

ENGINEERS / CONSULTANTS / CM

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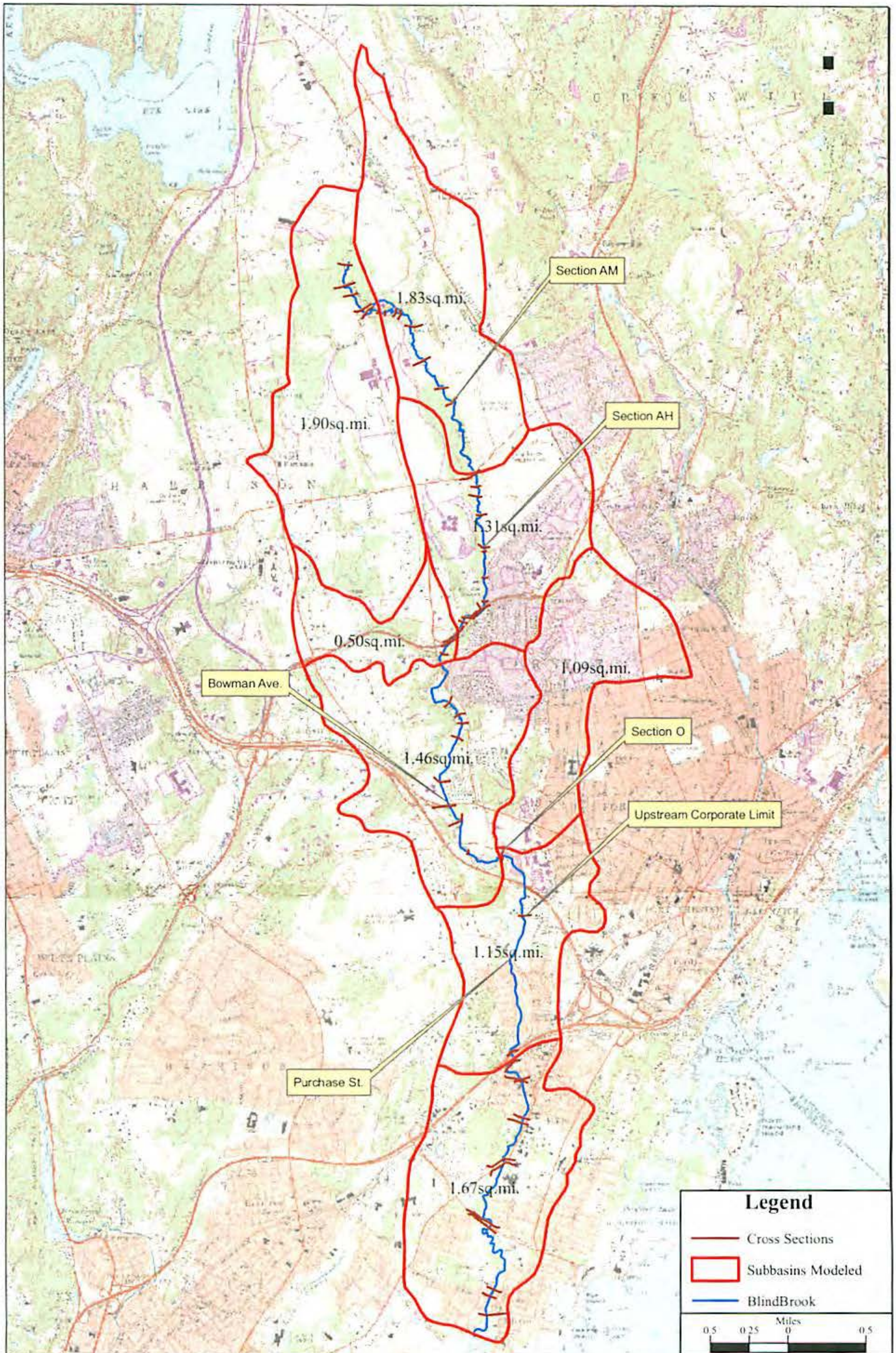
APPROVED BY	WB 09.13.2012
CAD FILE NUMBER	11-4626-B2

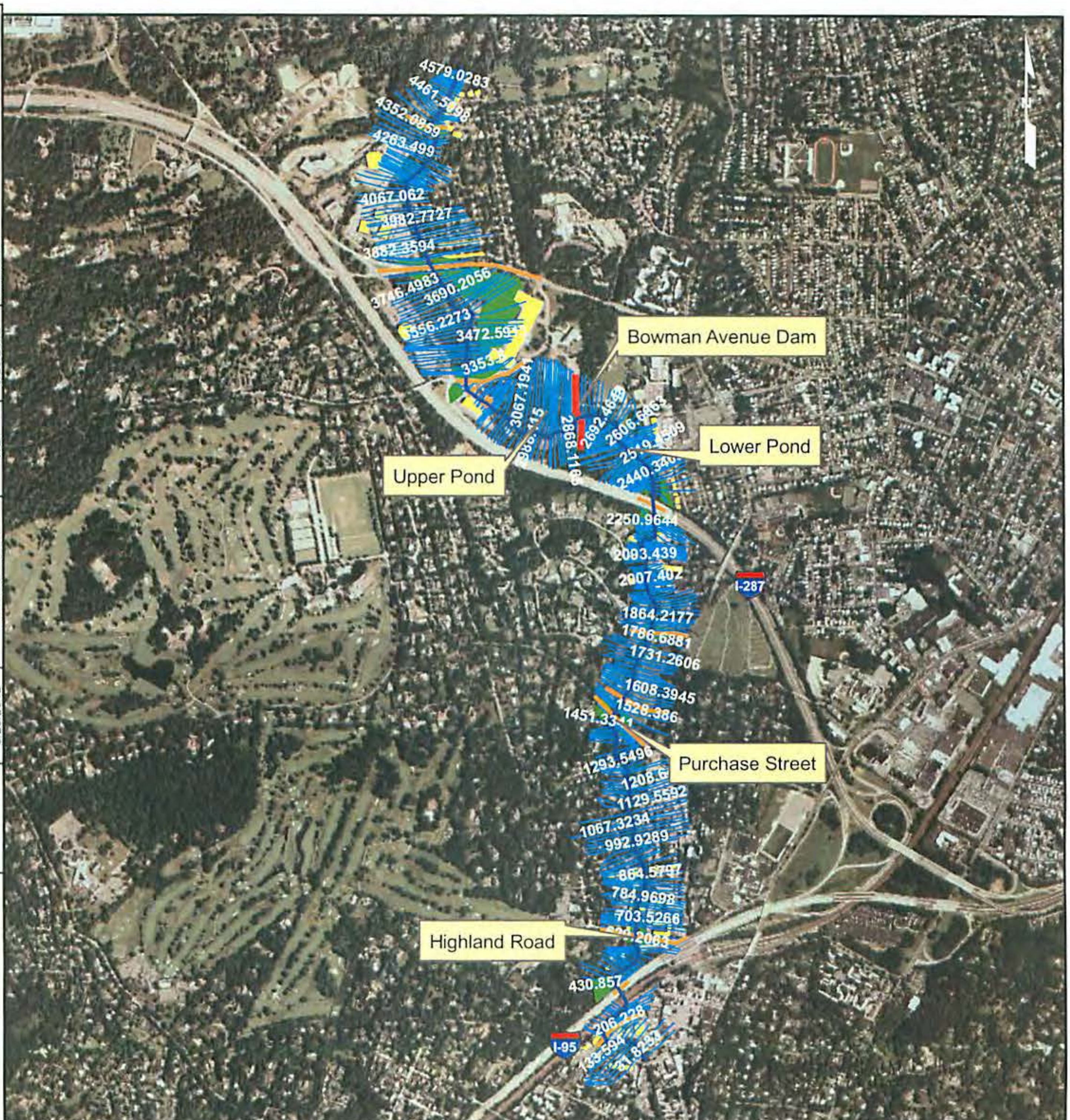
APPENDIX E

PLAN VIEW OF BOTH THE 2006 FEMA HEC-RAS MODEL AND RIZZO HEC-RAS MODEL WITH ORTHOIMAGERY



U.S. Army Corps of Engineers New York District	Labeled Cross Section Locations (2006 FEMA Study)	Job No.	Date	Figure No.
		66905	Mar 2009	4

FIGURE E-1
Plan View of 2006 -FEMA HEC-RAS Model



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AE	WB	
	9/20/2012	9/20/2012
GIS FILE NUMBER		

LEGEND

- Stream Centerline
- Bridges
- InlineStructures
- XS Cutlines
- Blocked Obstructions
- Ineffective Flow Areas

0.10.05 0 0.1 0.2 Miles

DATUM: NAD 83
PROJECTION: UTM Zone 18N

REFERENCE(S): ESRI World Imagery

FIGURE E-2

Plan View of RIZZO HEC-RAS Model with Orthoimagery

PREPARED FOR

WSP Sells
Briarcliff Manor, NY

PCR Paul C. Rizzo Engineering – New York, PLLC
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APPENDIX F

GIS DATA

APPENDIX G

RIZZO HEC-HMS MODEL

APPENDIX H

RIZZO HEC-RAS MODEL