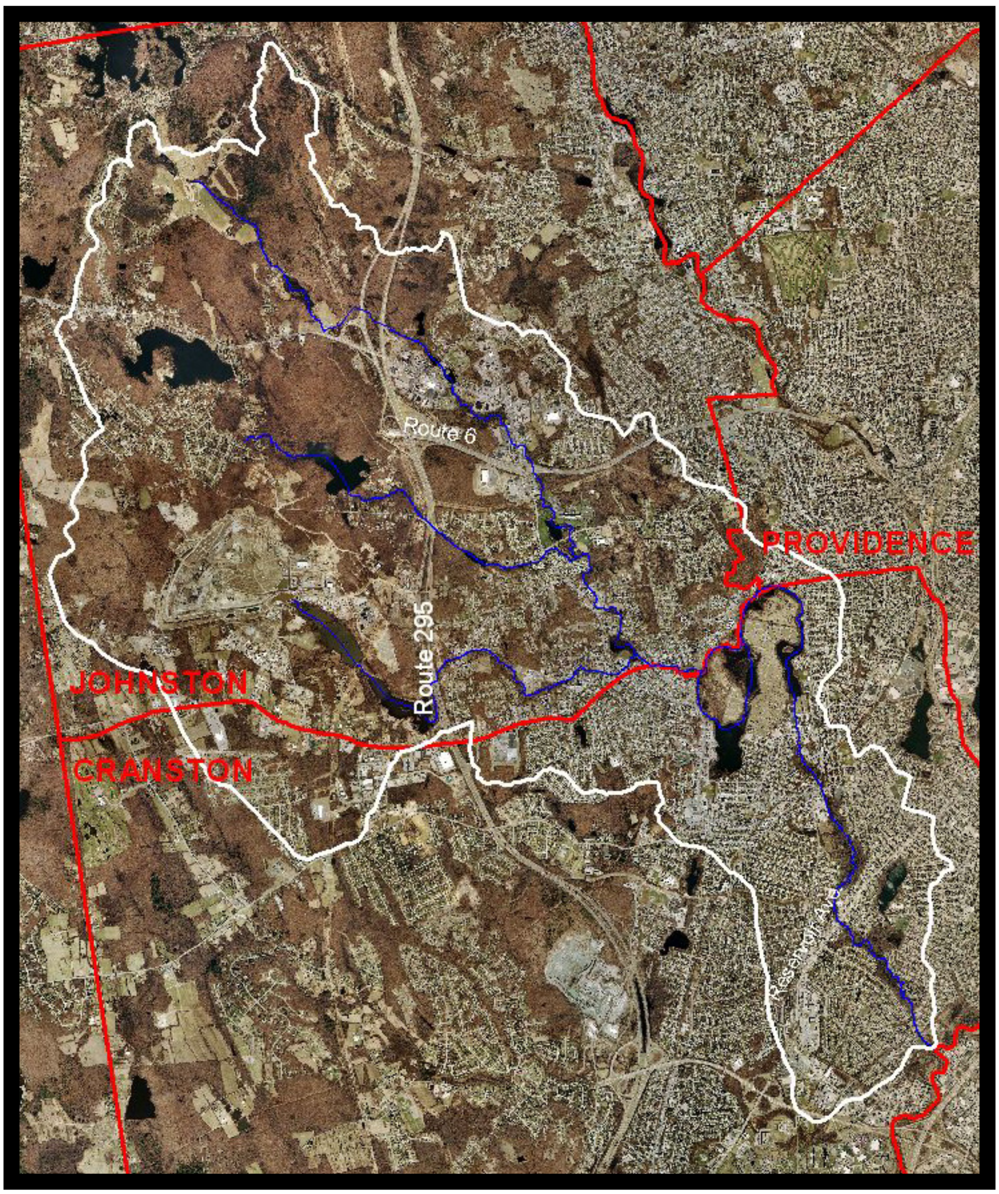
United States Department of Agriculture

Natural Resources Conservation Service

Report No. RI-TP-2006-2

Flood Plain Management Study: Pocasset River Watershed, Providence County, Rhode Island



Cover Photo: Aerial Photos of Pocasset River Watershed, Providence County, RI. (RI NRCS File Photo)

June 2007

ABSTRACT

The Pocasset River Flood Plain Management Study is the first phase in the development of a Watershed Plan to mitigate flooding and the associated damages caused by flooding along the Pocasset River. The FPMS is comprised of two documents: The "Popular Report" and the "Technical Report". The Popular Report sets forth the current and future conditions relating to flooding in the Pocasset River Watershed and provides alternatives to mitigate the flooding. The Technical Report provides a detailed description of the methods used and assumptions made to develop the hydrology and hydraulics for the computer models used in the analysis. The Popular Report contains the Flood Plain maps and cross-sections for the existing and future flooding condition.

This "Technical Report" is comprised of two main sections. The "Introduction" describes the purpose of the Study, the local and federal coordination, and a brief flooding history. The "Engineering Methods" describes hydrology and hydraulic models' development, evolution, and assumptions made in the models. The "Engineering Methods" also describes model results and comparisons to the storm event in October of 2005.

PREPARED BY: USDA Natural Resources Conservation Service

Written by:

Joel Schmidt, Hydraulic Engineer

Joseph Bachand, Resource Conservationist

Contributions from:

Clyde Giaquinto, Civil Engineer

EA Engineering

In Cooperation with the:

City of Cranston
Town of Johnston
Rhode Island Department of Environmental Management
Northern Rhode Island Conservation District
Rhode Island Emergency Management Agency

TABLE OF CONTENTS

TABLES

FIGURES

APPENDICES

1.0 INTRODUCTION

1.1 PURPOSE OF STUDY

The Pocasset River Flood Plain Management Study (FPMS) was initiated because of a storm event that occurred in August of 1999. The USDA Natural Resources Conservation Service (NRCS) was contacted by the Town of Johnston to determine if there was funding available to restore several eroded areas of stream banks along the Pocasset River and Simmons Brook. NRCS applied to our National Office to fund two projects through the Emergency Watershed Program (EWP). The first project was the restoration of the stream bank at Morgan Mill Road on the Pocasset River, and stabilization of the stream bank on Simmons Brook located at St. Rocco's Church. Both projects were successfully completed in cooperation with the Town of Johnston.

1.2 COORDINATION

In March of 2000, the Town of Johnston requested federal assistance for watershed protection and flood prevention under the provisions of the Watershed Protection and Flood Prevention Act (Public Law 83-566) for the Pocasset River Watershed. Although the Town of Johnston made the application, the policy of NRCS is to address flooding problems on a watershed basis. The City of Cranston was contacted and subsequently it made a request to become part of the study. A small portion of the watershed is within the City of Providence and, while they are not a formal applicant, this portion of the watershed was included in the study.

1.3 FLOOD HISTORY

The major flooding-related problems identified by local governments, community organizations and residents include loss of property value, damage to residential, commercial and industrial properties, increase in local government cost and damage to roads and bridges. Other losses include decreased property value in flood prone areas and loss of potential sites for commercial and industrial development.

Flooding in the Pocasset River Watershed has been a problem since the 1950's, according to residents living within the river's flood plain. In 1979, a storm on January 31 caused "The Great Flood of 79". Local newspapers reported an excess of $900,000 in damages from the flood, with Fletcher Avenue being one of the harder hit sections of the City of Cranston. The fire department had to respond to over 250 water emergencies. In 1982, a storm of just under six inches of rainfall caused some of the most serious flooding in the history of the City. The City was declared a disaster area by the then Governor J. Joseph Garrahy. There was 1.5 million dollars of damages within the City.

The severity and frequency of flooding has increased over the past twenty years. In March 2001, two significant flood events occurred within a one-week period.

The two storms occurred on March 21 and March 30 and had rainfall amounts of 3.11 and 2.88 inches, respectively, as measured at the T.F. Green Airport.

A number of areas have been significantly affected by flooding during these last two floods. Atwells Avenue in the Town of Johnston is impacted just south of the intersection of Atwood Avenue (Routes 5) and Hartford Pike (Route 6) where the Pocasset River passes through a bridge on Route 5. A number of commercial properties are flooded, including a commercial development, which contains a supermarket, a commercial storefront, and several restaurants. Economic losses in this area have included a reduction in business, increased police and fire costs, and direct property damage. Stream bank scouring has occurred, causing business owners to attempt installation of stabilization practices.

Another area impacted by flooding is located at the intersection of Central Avenue and Atwood Avenue, where Dry Brook discharges into the Pocasset River. The Factory Mutual Global office park is located just northeast of the intersection and outlying buildings owned by FM Global have been flooded.

The Morgan Mill Road Industrial Park has experienced instances of severe flooding. There are approximately nine light industrial facilities located in the park. In 1999, flooding caused damage to Morgan Mill Road and the bridge that crosses the Pocasset River and the associated riverbanks. The Town of Johnston requested Emergency Watershed Program (EWP) funding to restore the riverbanks. Funding was provided through NRCS, and a stone revetment was installed. Flooding still occurred in March of 2001 but no damage resulted, (due to the bank being protected from erosion by the revetment).

South of Morgan Mill Road is the residential community made up of River Drive, Melody Lane, and South Bennett Drive. Many of the homes are located adjacent to the River or adjacent to a large flood plain wetland located on the river. The floods of 2001 caused significant damage including loss of property and riverbank erosion resulting in substantial cleanup costs.

South of the River Drive community is River Road located on the Cranston-Johnston border adjacent to the intersection of Route 5 (Atwood Avenue) and Route 14 (Plainfield Street). This is the area where Simmons Brook enters the Pocasset River. Flooding causes significant impacts to both commercial and residential properties located in the area adjacent to River Road, as well as properties located along Simmons Brook. Losses from the 2001 floods included damage to residential properties, loss of industrial materials, stream bank erosion, clean up costs, and loss of production time. At least one industrial mill complex located on Simmons Brook still has vacant areas due to previous flood damage.

Flooding in 2001 was severe enough in this area to cause stream bank erosion along Simmons Brook. Again, the Town of Johnston applied for EWP assistance through NRCS. A portion of Simmons's Brook adjacent to St. Rocco's parking lot needed to be stabilized and construction was completed in October of 2002.

The most impacted area along the Pocasset River is Fletcher Avenue located in City of Cranston just south of Plainfield Street. The area is a mixture of industrial, commercial, and residential properties. There are many varied operations in the industrial park including: a food processing company, the City of Cranston school bus garage, auto body shops and polishing operations. The industrial park is located within the flood plain of the Pocasset River. Local officials and residents have stated that the site was used as a dump for many years prior to being developed for industrial use. This area sustains some of the highest losses due to flooding. Losses include property damage, temporary loss of housing, loss of business, loss of wages and loss of development potential.

The last neighborhood with extreme flooding problems is located just west of Pontiac Avenue upstream from where the Pocasset River flows under the Pontiac River Bridge. The area is made up of a number of streets, including Davis Court, Myrtle Street, Autumn Street, and Sheridan Street. The neighborhood is mainly residential and damages include damage to buildings, loss of personal items, increased police and fire assistance and cleanup cost. The periodic flooding also decreases property values.

2.0 ENGINEERING METHODS

2.1 METHODS SUMMARY

This section is intended to provide information regarding the hydrology and hydraulic methods used for this study. It begins with a summary of the final methods used for evaluation. Following the summary is a detailed description of how the original model has changed since its original development. The purpose of including the original models' development and evolution is to provide an understanding of the differences between the model results, and why additional refinement to the models was considered necessary for obtaining reasonable results. Since many of the inherent assumptions made in the hydrology and hydraulic models remained the same despite changes to the model, these assumptions are presented in the description of the original model. Deviations from these original assumptions are presented in later descriptions of changes made to the models.

2.2 FINAL MODEL DESCRIPTION

The final hydrology model was developed by using Win-TR20 to generate hydrographs. The final hydrology model contains 25 sub areas. Different approaches were used for routing the hydrographs through the channel reaches. In the upper tributaries, the hydrographs were routed through culverts, bridges, and dams using the structure routing methods in Win-TR20. Since the culverts are closely spaced and the channel gradients in these tributaries are steep, no reach routing sections were used between hydraulic structures. In the lower reaches of the main Pocasset channel (Atwood Ave. down to the outlet), unsteady flow techniques were used to route the hydrographs through culverts, bridges, and the channel. This technique was chosen because it allowed the backwater effects of hydraulic structures to be considered without having to reach a solution though iterations between the hydrology and hydraulic model. For the final hydraulic analysis, flow values were taken from the Win-TR20 hydrology model and the unsteady flow model and placed in a steady model. Since the unsteady flow model did not include all the tributaries in the study, a steady model was chosen for final evaluation and flood map development. Flood events of the magnitude 1, 2, 5, 10, 25, 50, 100, and 500-year were selected for analysis. Flood plain maps were developed using the 100-year storm event for both the present and future condition.

2.3 ORIGINAL MODEL DEVELOPMENT

The original hydrology model of the watershed was accomplished using Technical Release 20 (TR-20-Project Formulation Hydrology Computer Program 1983). TR-20 is a computer program, which calculates direct runoff from any natural or synthetic rainstorm. It develops flood hydrographs from input parameters of contributing drainage area, runoff curve numbers, time of concentration, and rainfall. It then routes the flow through streams and reservoirs. The process that TR-20 uses is derived from the methods presented in the NRCS National Engineering Handbook, Part 630, Hydrology (Numerous Authors, 1985-2000).

The Hydrologic Engineering Center River Analysis System (HEC-RAS) (v. 3.1.1) model was used to perform the hydraulic analysis of the Pocasset River and its tributaries to estimate the water surface elevation for the selected storm intervals.

2.3.1 ASSUMPTIONS IN MODEL

Hydrologic modeling can be very complex. Several simplifying assumptions were made to create the hydrology model. One assumption is the rainfall is distributed evenly throughout the watershed even though in actual storms the rainfall may vary significantly from one place to another within the watershed. Without a dense system of rainfall gages with a long period of record, there is no way to estimate how rainfall is spread over a watershed, therefore, it is assumed to be an evenly distributed. Another assumption inherent in this hydrology method is that each sub watershed is hydrologically homogeneous, meaning that it can be described by a single parameter, the runoff curve number. For small sub-areas, there are fewer different types of land cover soil complexes so the curve number is more accurate. An antecedent runoff condition (ARC) of II is assumed. The ARC is an index of the runoff potential before a storm event. It estimates the existing soil moisture condition by using the rainfall received in the 5 days prior to the storm event of interest. ARC II is a typical condition where there is some rainfall occurring prior to the storm but the ground is generally not saturated. The ARC can be modified up to III for an extremely wet soil condition, saturated soil condition or for frozen ground and lowered to I for a very dry condition.

The hydraulic analysis was performed assuming steady flow conditions meaning that no changes occur in pressure and density from one cross-section to another and the discharge does not vary over time at a cross-section. The basic computational procedure used in HEC-RAS for steady flow is based on the solution of the one-dimensional energy equation with an iterative procedure called the standard step method. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion. The momentum equation is utilized in situations where the water surface is rapidly varied. These situations include hydraulic jumps, hydraulics of bridges, and evaluating profiles at river confluences.

2.3.2 HYDROLOGIC ANALYSIS

The rainfall distribution describes fractional amounts of total rainfall versus time for either an actual or a synthetic storm. NRCS has developed synthetic 24-hour rainfall distributions from available National Weather Service duration-frequency data and local storm data. One of these rainfall distributions is the Type III, which is used for Atlantic Coastal Regions (including all of Rhode Island). The Type III is a moderate intensity distribution with the most intense period of rainfall occurring from hour 11 to hour 13. The Type III is influenced mainly by coastal tropical storms, which tend to produce large volumes of rain. Figure 2.1-NRCS Rainfall Distribution shows the Type III distribution plotted with the fraction of the total rainfall as the vertical *(y)* axis and the time from zero to 24 hours as the horizontal (*x*) axis. Table 2.1-Rainfall for Providence County, RI shows the rainfall depths used for evaluation for in the hydrology model.

Figure 2.1 NRCS Rainfall Distribution

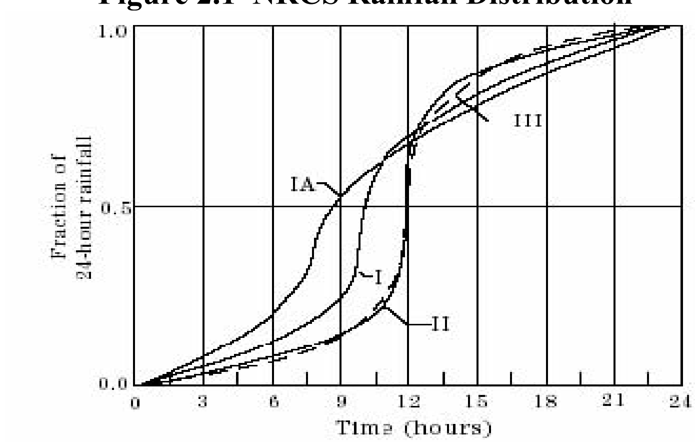


Table 2.1 Rainfall for Providence County, RI[1]

Return Period (Years)	Probability	Rainfall Depth (Inches)
100	0.01	7.0
25	0.04	5.6
10	0.10	4.8
2	0.50	3.3

The watershed was originally divided into 12 sub-areas (See Appendix A – Sub areas Delineated for Original Model). The sub-areas were chosen based on similar land use, topography and a definable outlet. SCS Runoff Curve Number (CN) method was used to represent runoff from each individual sub-area. The major factors that determine CN are hydrologic soil group (HSG), cover type, treatment, hydrologic condition, and antecedent runoff condition. The curve number information was calculated with Arc View GIS 3.2 and the 1995 land use data layer, along with the 1996 SSURGO soils data layer. Travel times (Tt) and times of concentration (Tc) were computed for each sub-area. Tt is the time it takes for water to travel from one location in the sub-area to another. Tt is a component of Tc, which is the time for runoff to travel from the hydraulically most distant point of the watershed to a point of interest. The time of concentration was computed using the velocity method and included sheet, shallow concentrated, and channel flow. For future land use conditions, the 1995 land use data layer was modified based on the comprehensive plans for Johnston and Cranston. The modified land use data layer was used with the soils layer to develop new curve numbers for the projected land use. The times of concentration were assumed to remain the same because no information is available to estimate how they will change as a result of additional development in the watershed.

The model was used to route runoff hydrographs through structures and reservoirs within the watershed. Survey data was collected by NRCS engineering staff to develop stage-storage discharge relationships for each structure or reservoir. Reservoirs that were routed in the original hydrology model include Oak Swamp Reservoir, Almy Reservoir, Pocasset Pond, Upper Simmons, Lower Simmons, and Cranston Print Works Pond. Table 2.2 shows the drainage area, present and future conditions runoff curve numbers, and Tc input values of each sub watershed used in the hydrology model.

[1] Technical Paper 40, Rainfall Atlas of the United States.

Table 2.2 Original Hydrologic Data Input

River / Brook	Sub Area	Drainage Area (Sq. Miles)	RCN		Tc (Hrs.)
			Present	Future	
Pocasset River	1	3.11	81	82	3.26
	2	2.16	76	77	0.38
	3	0.97	71	75	1.61
	4	2.31	74	82	2.21
	5a	0.42	70	75	1.23
	5b	2.46	66	70	2.08
Dry Brook	6	1.06	75	78	0.44
	7	1.31	67	77	1.02
	8	0.82	67	73	1.41
Simmons Brook	9	1.78	73	78	1.36
	10	1.69	77	82	1.64
	11	2.52	77	83	1.78

2.3.3 HYDRAULIC ANALYSIS

Originally, flow and geometry information for the hydraulic model was taken from the Flood Insurance Study (FIS) for the City of Cranston, RI (Community Number 445396, May 1984) and the FIS for the Town of Johnston, RI (Community Number 440018, November 1993). Model geometry from the two FIS were from HEC-2 and WSP-2 input files and from surveys performed by the Rhode Island staff during January through and April 2001. No evidence was located in the text for the above flood insurance studies that either model was calibrated with any known or observed high water marks.

In 2001 and 2002, a contract was secured for aerial flight data in the form of a digital terrain model (DTM) of the watershed. The photogrammetry for the DTM was completed at a scale of 1” = 100’ with a contour interval of 2 feet and a NAVD 88 vertical datum. The original hydraulic model geometry described above was abandoned in favor of a hydraulic model developed using the recent DTM in conjunction with computer technology (Arc View GIS 3.2, HEC-RAS ver. 3.1.1) that would enable the presentation of flood inundation mapping of the watershed. Survey information completed by the Rhode Island staff in 2001 was also used in this model to enhance the geometry presented at bridge and culvert crossings as well as to verify and adjust the channel bottom elevations of the data extracted from the DTM, since the geometry used from the aerial flight data did not extend below the surface of the water.

Very limited data were available for the hydraulic calibration of the HEC-RAS model upon its completion in June 2004. The rainfall distribution for the storm of record dated 21-22 March 2001 was run through the TR-20 program and the subsequent flow values were modeled in HEC-RAS. The storm of record was from the Providence, R.I. Airport, WBAN # 14765 (cumulative total = 2.59 inches) and was adjusted hourly by RIBCON OBSERVERS DAILY PRECIPITATION March 2001 where the Johnston, R.I. gage recorded 0.31 inch and 3.11 inches for the 21st and 22nd March 2001 respectively. High-water marks were surveyed from where the Pocasset River splits upstream of the Pocasset Cemetery in the City of Cranston, RI to a point in the Town of Johnston near the Morgan St. Bridge. Two points were also surveyed in Simmons Brook and two upstream of the Garden City Bridge and one point near the Pontiac Ave. Br. in the lower reach of the Pocasset River (Cranston Lower Reach). The survey was conducted based upon photographic evidence and uncertainty exists as to whether the water was in recession at the time of the survey and whether the high water marks in some cases were influenced by other sources, such obstructions, rather than the high water of the Pocasset River.

The initial hydrology and hydraulic model developed for the calibration event resulted in water surface elevations below the observed high water marks. The weather conditions preceding the 21-22 March 2001 events were obtained from the NOAA's National Climatic Data Center. Upon review, it was determined that the conditions likely caused there to be an indeterminate amount of frozen ground in portions of the Pocasset River watershed. The hydrology model for this calibration event was modified with an increased ARC III. As expected, the resulting flow rates were much higher with the ARC III. The resulting water surfaces were higher than all but one of the observed high water marks. Using both the ARC II and III resulted in water surface elevations both above and below the observed high water marks. The indeterminate amount of frozen ground may have resulted in conditions best represented between these two antecedent runoff conditions.

In the fall of 2004, a contract was signed with GZA GeoEnvironmental (with EA Engineering, Science, and Technology, Inc. as a subcontractor) to provide a review of the hydrology and hydraulic model and to complete preliminary designs of flood protection measures. The following section describes the models' evolution as a result of changes made by EA Engineering.

2.4 CHANGES MADE BY EA ENGINEERING

"EA's primary revisions to the hydrology model consisted of recreating the model using the newly released WinTR-20 [WinTR-20 System Controller / Editor, Version 1.00, 10/04] software including the effects of bridges and culverts along the river system. EA recreated the original NRCS model in WinTR-20 and retained the basic watershed parameters from NRCS's original model, including the 12 sub catchments with their respective times of concentration, acreages, and curve numbers." …"Each structure is described in WinTR-20 by a rating curve, which is a set of data relating stage, discharge, and storage. The rating curves were generated from data contained within the existing HEC-RAS hydraulic model and then entered into WinTR-20." "Because the rating curves are calculated using the hydraulic model, with flow rate data from the hydrologic model, the two models were therefore dependent on each other and must be run iteratively until the flow rates converge."

"Primary revisions to the HEC-RAS model incorporated new flow data from the revised WinTR-20 hydrology model. The river geometry and hydraulic structure data established by NRCS was reused without change with the exception of an adjustment to the first Mill Street bridge on Simmons Brook (river station 2976 in the model). In the original hydraulic model, the data defining the upstream edge of the bridge deck was truncated before spanning the main channel. The result was that the deck was defined for the downstream edge but not fully for the upstream edge. This caused a localized spike in the water surface elevation and caused an error in HEC-RAS. Although this issue only caused a localized problem, EA redefined the upstream edge of the bridge deck using best engineering judgment to eliminate the problem."

"Another revision to the hydraulic model consisted of changing the locations and increasing the number of flow change locations." … "The flow locations were designated as the first cross-section downstream of each hydraulic structure." "At the first cross-section downstream of each hydraulic structure in HEC-RAS, a flow rate was entered that corresponded to the peak outflow from WinTR-20 for the reach beginning with the same cross-section." "Rather than vary the Manning "n" values along the channel length, EA felt it was appropriate to select a single value for the entire channel length and settled on a value of 0.06 based on the range of values used by NRCS, photographs taken by NRCS, and EA's own observations." (EA Memo)

2.5 NRCS REVIEW OF MODEL CHANGES

In the fall of 2005, NRCS used the base hydrology model developed by EA in WinTR-20 to run various scenarios involving the lowering of water levels in various in-line reservoirs to create additional flood storage. Upon detailed review of the reservoir rating curves, it was discovered that the storms were being routed through the reservoirs with little or no water stored in them. After NRCS discovered the issue, EA was notified and they completed a sensitivity analysis to determine how much this affected the resulting flows. They made the following observations: a 25% increase in flows in Dry Brook with a 15% increase in flows along the Pocasset downstream of the confluence of the Dry Brook, diminishing to a 7% increase at Morgan Mill Road. They deemed anything less than 10% as not significant. They also determined that of the nine reservoirs in the hydrology model, five were significantly affected by the erroneous empty condition and needed to be incorporated into the model (Almy Reservoir, Upper Pocasset Pond, Lower Pocasset Pond, Insurance Company Pond, and the Print Works Dam).

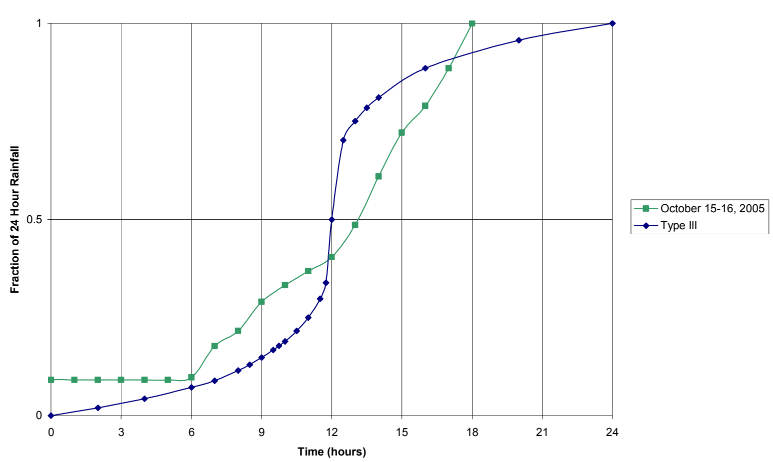
2.6 OCTOBER 15-16, 2005 STORM EVENT

Before any changes could be made to the reservoirs in the hydrology model, a large rainfall event of approximately 6.38 inches occurred. Approximately 5.8 inches of this rainfall occurred between 8:00 pm on October 14th and 9:00 am on

October 15th. The 100 year, 12-hour storm is 6.0 inches (United States Department of Commerce, Weather Bureau, 1961). Since this storm event produced a rainfall depth much closer in magnitude to the 100 year, 24 storm rainfall depth used for evaluation, the event is considered the preferred storm of record. Rainfall depths and distributions were obtained from hourly/daily rain data from NOAA'S forecast systems. The recorded rainfall information was obtained from the Providence Airport station. Figure 2.2 shows the October 15-16 rainfall distribution and the Type III rainfall distribution for comparison. The October event was observed and modeled as a 24 hour storm; however, for comparison the rainfall distribution was translated by 6 hours and truncated to show the most intense portion of the distribution approximately symmetric with the Type III distribution. While this station is not located in the watershed, other local rainfall measurements and observations indicate the system produced high rainfall depths in the watershed vicinity. The same station also measured 5.36 inches in the 6 days leading up to the October 14-15 event. High water marks were field located and later surveyed by representatives of GZA Geoenvironmental. This storm event was considered by many to be the most significant rainfall event in the watershed for many years. The event provided an ideal opportunity to evaluate the model predictions compared with observed flooding.

This rainfall depth and distribution, when placed in the hydrology and hydraulic model, predicted water surface elevations well above those observed in the field (using ARC II). The largest difference was behind the Morgan Street Bridge, with a predicted water surface elevation over 6 feet higher than the observed high water mark. Additionally, one may argue that modeling this event with a typically assumed ARC II may not truly represent the actual event given the precipitation produced in the days preceding the event. Increasing the antecedent runoff condition to an ARC III to represent more saturated watershed soils would create even larger discrepancies. For comparison, the October event was run twice with an ARC II and an ARC III. The results are shown in Table 2.4.

Figure 2.2 Rainfall Distribution, October 15-16, 2005



2.7 NRCS REVIEW OF MODEL STRUCTURE

The location of these water surface discrepancies presented several concerns and challenges for future flood protection design. Since flow measurements were not made during the large event, only high water marks are available for model calibration and therefore discrepancies could be attributed to either the hydrology or the hydraulic model. Flood protection design will be based on a Type III rainfall distribution with anticipated built out conditions, so one would not necessarily expect flood levels from the October event to reach those predicted by the design event. The hydraulic model has undergone scrutiny by NRCS, EA, and GZA, and only after changing channel geometry and roughness characteristics well beyond reasonable values could water surfaces elevations be lowered to near those observed. An evaluation of the modeled October event, however, did demonstrate that the hydrology model is likely over-predicting peak discharges throughout the channel. Some of the locations where water surfaces are being drastically over predicted correspond to the locations of proposed flood protection. While design conservatism is desired, conservatism that places floodwalls six to eight feet higher than necessary in residential backyards will cause adverse and unnecessary social impacts, costs, and will reduce project feasibility.

2.8 NRCS CHANGES TO THE HYDROLOGY

To gain a better understanding of how the model may be over predicting peak discharges, NRCS and GZA took an 'on the ground' look at the upper portion of the watershed, as well as reviewed the existing hydrology model. The observed watershed characteristics were compared to the watershed characteristics used in WinTR-20 (drainage area, runoff curve number, and time of concentration). A sensitivity analysis was also completed. Only after changing hydrologic parameters outside a reasonable range of values could the flow rates and resulting water surface elevations be lowered to within several feet of the observed elevations. Our field observations did include a number of hydraulic structures adjacent to the Pocasset River in the upper portion of the watershed not included in the hydrology model. Many of these hydraulic structures are not within the aerial flight data area and therefore no detailed topography is available for developing stage-storage-discharge relationships for these structures. The decision was made to include these structures in the hydrology model using the best topographic information available.

The adjacent structures chosen for addition to the model was based on availability of information and a need for model refinement in specific location where modeled water surfaces deviated significantly from observed water surfaces in proposed floodwall design locations for the modeled October event (from Rotary Drive to the split upstream of Randall Pond). Other structures were identified (detention between Route 6 and Rotary Drive), and the model's accuracy may have benefited from the additional refinement, but due to lacking hydraulics and topographic information, they were not included. This likely adds some additional conservatism in these locations and downstream.

The base hydrology model completed by EA was used as a starting point, but since the reservoirs' WinTR-20 stage-storage relationships reflected an empty pool as discussed earlier, the stage-storage relationships was modified for Almy Reservoir, Upper Pocasset Pond, Lower Pocasset Pond, Insurance Company Pond, and the Print Works Dam to reflect a permanent pool. The Oak Swamp Reservoir was also added to model, which was in the original model but was omitted during EA's revision, presumably since it was never contained within the hydraulic model, where their model's other rating curves was generated. The Lower Simmons Reservoir was also added back into the model. This reservoir was also likely missed in EA's revision of the model because it was modeled simply as a cross-section rather than an in-line structure.

The stage-discharge relationships for the structures adjacent to the channel were developed with pipe diameters, lengths, and inlet conditions gathered from field observations and notes, photographs, and archived Rhode Island Department of Transportation plans. Stage-storage relationships were approximated from the best topographic information available. At most structure sites, the USGS quadrangle 10-foot contour map was used. Since detailed information for some structures could not be obtained, best engineering judgment and conservatism was exercised.

The following hydraulic structures were added to the hydrology model. (The name designation is the one used in the WinTR-20 model).

SB295: The 60-inch diameter culvert under I-295 between the Route 6 and the Hartford Interchanges.

SUPEAST: The 30-inch diameter culvert under I-295 in the upper portion of the watershed.

SUPWEST: The 48-inch diameter culvert under I-295 in the upper portion of the watershed.

BRNSTN: The small rock culvert under Brown Street just downstream of sub area 5A.

ADJMEM: Concrete weir structure just upstream and adjacent to Memorial Park Pond.

WETCHAN: A flat wetland portion of the channel just downstream of Brown Street on the main Pocasset River channel.

HART: The 24-inch diameter culvert under the commercial buildings on Hartford Avenue just east of the Johnston Town Hall.

FILL: A fill area over the main channel in the upper Pocasset River. The water is impounded behind and flows through the rock fill.

Several other changes were made to structure rating curves within the model. After a field visit to Almy Reservoir, representatives from NRCS and GZA determined that the effective flow area was limited to approximately 15 feet. The rating curve was changed to reflect this change. The bridge geometry used to generate the rating curve where I-295 crosses Dry Brook shows the bridge on a skew, and therefore contains the low median area in the cross-section. This allows flow to overtop the road at a much lower elevation. This is not reasonable as the interstate road deck is actually much high than its representation in the model. A new geometry file was created and a new rating curve was generated to accurately reflect this additional attenuation and reduced flow capacity.

The addition of these adjacent hydraulic structures required the further subdivision of the original 12 sub areas into 25 sub areas to allow for appropriate entry into each sub areas' respective channel after attenuation (see Appendix A – Sub areas Delineated for Final Model*)*. This subdivision also required new runoff curve numbers and times of concentration to be computed. The runoff curve numbers were spatially calculated using the same 1995 land use data layer. The volumes of runoff between the hydrology model constructed by EA and the model modified by NRCS were checked to verify that there was no net volume changes produced during the same storm event. The times of concentration for those sub areas not subdivided were not changed; however, the times of concentration for each newly subdivided areas were recomputed using aerial photographs for land cover and existing topographic information for slope and flow path. The velocity method was used for calculating the times of concentration. While detailed flow path information was not available for calculating all the time of concentrations, in most cases the hydraulic and storage characteristics of the structures more significantly dictates the shape and magnitude (peak discharge) of the hydrograph entering the main channel of the Pocasset River. Table 2.3 contains a summary of the 25 sub areas' hydrologic characteristics.

Table 2.3 Revised Hydrologic Data Input

River / Brook	Sub Area	Drainage Area (Sq. Miles)	RCN		Tc (Hours)
			Present	Future	
Pocasset River	1	3.11	81	82	3.26
	2	2.16	76	77	0.38
	3	0.97	71	75	1.61
	4-1	0.53	78	82	0.74
	4-2-1	0.28	83	87	0.10
	4-2-2	0.26	82	84	0.14
	4-3-1	0.35	72	78	0.38
	4-3-2	0.06	70	75	0.19
	4-3-3	0.29	66	75	1.05
	4-3-4	0.16	68	73	0.20
	4-4	0.39	65	88	0.39
	5a	0.42	70	75	1.23
	5b-1	0.21	64	70	1.27
	5b-2	0.53	62	63	2.22
	5b-3	0.25	64	73	0.72
	5b-4	0.25	80	84	1.06
	5b-5	1.04	66	69	3.13
	5b-6	0.18	64	70	1.51
Dry Brook	6	1.06	75	78	0.44
	7	1.31	67	77	1.02
	8-1	0.41	68	74	1.36
	8-2	0.40	67	73	1.39
Simmons Brook	9	1.78	73	78	1.36
	10	1.69	77	82	1.64
	11	2.52	77	83	1.78

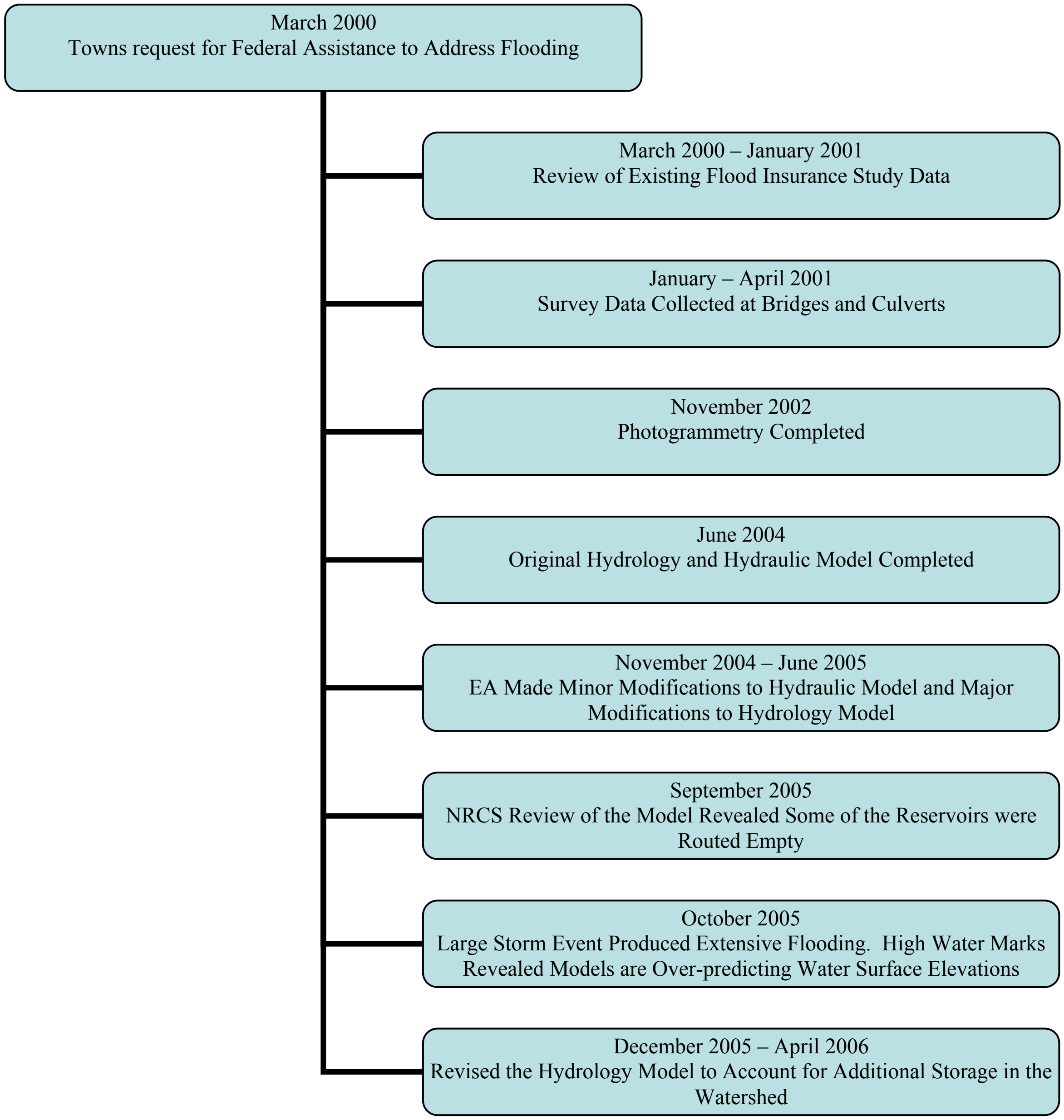
Some investigations were performed to research the complexity of converting a portion of the HEC-RAS model to run unsteady flow. Because the upper portion of the Pocasset, Dry Brook and Simmons Brook have steep channel slopes with rapidly changing water surface elevations and flow regimes, difficulty in stabilizing an unsteady model was predicted and found. For these reaches, the hydrologic approximation used by the WinTR-20 structure routing methodology was considered reasonable for use because of the complexity of stabilizing an unsteady flow model. The middle and lower reaches of the Pocasset River (from Atwood Avenue down to the outlet) is comprised of flatter channel slopes and larger culverts and more open span bridges. This channel geometry is more conducive to unsteady modeling techniques, and therefore the decision was made to convert the middle and lower Pocasset into an unsteady flow model for comparison to the resulting flows in the hydrology model. The unsteady model also allows an easier evaluation of potential mitigation alternatives without the process of iterating between the hydrology and hydraulic model to evaluate changes in storage as well as hydraulic capacity.

To stabilize the unsteady flow model, several changes had to be made to the geometry. Most of these changes involved modifications to the height of ineffective flow areas upstream of bridges and culverts. Unsteady flow models evaluate flow (and resulting water surfaces) with respect to time, therefore hydrographs are entered as oppose to instantaneous peak flow values. The WinTR-20 hydrographs were entered into the model in appropriate locations along the channel length. In locations where tributaries (Simmons and Dry Brook) and the upper Pocasset enter the main channel, the hydrographs were entered as lateral inflow. In downstream sub areas, the hydrographs were entered as uniform lateral inflow. This more appropriately reflects the sub areas runoff contribution over a length rather than a specific discharge point.

One of the ultimate goals of the model development was to create a group of models (hydrology and hydraulic) that could be used to generate a map of high hazard maps and inundation maps for various storm events. With only a partially working unsteady flow model of the middle and lower end of the Pocasset, a flood map generation would be difficult and flood stage elevations would need to be pieced from the unsteady flow model in the middle and lower Pocasset to a steady model in the upper Pocasset and the two tributaries, Dry Brook and Simmons Brook. For this reason, the flow values were pulled from the unsteady flow model and were entered into the steady model. Some conservatism was expected from this approach because the steady state model generates a water surface assuming a maximum tail water condition. In other words, this approach assumes that the channel will peak instantaneously, when in reality, the upper portions of the channel peak before the lower end. A comparison of the high water marks from the unsteady flow model and the steady model demonstrated that this approach did not introduce a great deal of conservatism. This may be attributed to the fact that the water surface elevations are heavily influenced by the presence of a large number of in-channel hydraulic structures and these structures cause frequent backwater.

The hydrology and hydraulic model has undergone a significant evolution since the original development in 2001. Figure 2.3 shows the models' development, changes, and current state.

Figure 2.3 Timeline Showing the Models' Evolution



2.9 MODEL RESULTS FOR THE OCTOBER 15-16, 2005 EVENT

The inclusion of the additional storage decreased the peak flows near many of the conflicting high water marks in the steady flow evaluation using only WinTR20 structure routings. The addition of the unsteady flow model between Atwood Avenue and the outlet further reduced the peak discharges and resulting water surface elevations. The reservoir routing method used assumes that the each pool area is level. One disadvantage of this method is that it does not accurately account for the flow travel time between each bridge and culvert as the flood wave propagates downstream. The iterative reservoir method as previously discussed may have reached a closer convergence with the unsteady flow model if additional iterations were completed. This methodology was necessary with the hydrology model because Muskingum-Cunge methodology used by WinTR-20 does not account for the backwater created by restricted bridges and culverts. Table 2.4 contains a comparison of the observed high water marks and modeled high water elevations for the October event, also shown are modeled October event peak discharges.

The water surfaces were not determined for the 'NRCS added storage without unsteady' model because these flow values were not run through the hydraulic model. The location of the major differences of the peak discharge values are between Rotary Drive (59% reduction from EA's model) and the Reservoir Avenue bridge (29% reduction). The use of the unsteady flow model actually increased the peak discharge values from the WinTR-20 model between the Willowbrook Apartments and the Garden City Bridge (approximately 20-25% increase). This is likely the result of the lowest sub area's contribution uniformly along the channel as oppose to a point entry at the sub area's downstream most point. It should also be noted that the seemingly straightforward task of collecting high water marks could introduce notable error. The observed high water near the Park Place Apartments was 1.8 feet higher than the one marked upstream of the Bennet and Melody Streets area. The perceived high water can sometimes be the rising or falling water surface elevation. The presence of hydraulic structures and obstructions can also cause localized differences in the water surface not predicted in a one-dimensional model.

Additional refinements to the model could include an evaluation of the unidentified storage behind hydraulic structures in the Simmons Brook sub areas and the lower portions of the Pocasset. The original assumptions in these areas were not as closely scrutinized because the identified problem areas were upstream. Some conservatism is likely incorporated into the hydrology model downstream of the confluence of Simmons Brook and the Pocasset River; however, with increased flood plain widths, larger channel dimensions, and larger spanning hydraulic structures, the resulting high water elevations may not be as sensitive to over estimated peak discharges. Since only high water marks were gathered and no flow data was taken following the October event, the peak discharges cannot be specifically calibrated in the hydrology model. Flow meters or a record of water surfaces at hydraulic structures during a major storm would have been useful for additional model calibration.

Since the October 2005 rainfall event was the event most similar in rainfall depth and intensity to the design event, this event was chosen for validation. No attempt was made to revisit the March 2001 event with the revised hydrology model.

Table 2.4 Water Surfaces and Discharges for the October 2005 Event

Model	EA Hydrology / Hydraulics		NRCS Added Storage Without Unsteady				NRCS Added Storage With Unsteady				Observed
Arc	II		II		III		II		III		n/a
Location	EL* (ft)	Q (cfs)	EL* (ft)	Q (cfs)	EL* (ft)	Q (cfs)	EL* (ft)	Q (cfs)	EL* (ft)	Q (cfs)	EL* (ft)
Atwood	123.4	679	+	631	N/A	802	125.5	613	125.8	781	125.4
Rotary	101.2	1851	+	1130	N/A	1622	97.3	760	99.0	1132	96.7
Morgan St.	100.9	1851	+	1130	N/A	1622	96.4	760	98.0	1132	94.8
Morgan Mill	87.7	1851	+	1006	N/A	1404	86.9	1060	87.3	1432	86.1
Bennet/Melody	86.2	2941	+	2144	N/A	3249	83.8	1110	85.7	1507	82.5
Park Place	86.2	2941	+	2144	N/A	3249	83.8	1110	85.7	1507	84.3
Plainfield Pike	84.8	2941	+	2144	N/A	3249	80.6	1786	84.7	2818	79.0
Reservoir Ave.	30.9	2086	+	1605	N/A	2332	28.8	1489	31.8	2471	29.7
Willowbrook	25.5	1867	+	1388	N/A	2253	24.6	1759	27.0	2480	23.8
Garden City	25.3	1960	+	1341	N/A	2059	24.4	1668	26.9	2413	22.7

* Elevations are in NAVD 88

+ Water surface elevations were not determined because the flow values were not placed in the hydraulic model.

2.10 RESULTS COMPARISON

Table 2.5 contains a comparison of the modeled October 2005 event, the 100-year, 24-hour type III storm event with an ARC II. The modeling results demonstrate that the additional rainfall depth and higher intensity increased the flow and flood depths. The 100-year, 24-hour Type III storm event with an ARC II and future development will be used as the evaluation storm for all the alternatives considered for flood protection.

Table 2.5 Water Surfaces and Discharges Comparing the Modeled October 2005 Event to the Evaluation Storms (100-year, 24 hour, Type III, ARC II, future development)

Location	Present				Future	
	Oct. 2005		100-Year, 24-Hour		100-Year, 24-Hour	
	EL* (ft)	Q (cfs)	EL* (ft)	Q (cfs)	EL* (ft)	Q (cfs)
Atwood	125.5	613	125.8	831	126.1	1027
Rotary	97.3	760	98.4	1038	99.4	1264
Morgan St.	96.4	760	97.3	1038	98.4	1264
Morgan Mill	86.9	1060	87.1	1249	87.4	1470
Bennet/Melody	83.8	1110	84.4	1305	85.3	1549
Park Place	83.8	1110	84.4	1305	85.3	1549
Plainfield Pike	80.6	1786	80.6	1927	84.3	2419
Reservoir Ave.	28.8	1489	30.4	1739	31.4	2415
Willowbrook	24.6	1759	25.9	2116	26.8	2370
Garden City	24.4	1668	25.7	1863	26.7	2271

*Elevations are in NAVD 88.

3.0 REFERENCES

Memo from Brian Stone to Chuck Katuska, June 22, 2005. Pocasset Flood Plain Management documentation folder (cited as EA Memo).

Part 630 Hydrology, National Engineering Handbook (formerly NEH-4). Numerous authors, 1985-2000.

Technical Paper 40 Rainfall Atlas of the United States, 1961. United States Department of Commerce, Weather Bureau.

Technical Release 20 - Project Formulation Hydrology Computer Program, 1983. USDA, Soil Conservation Service.

WinTR-20 System Controller / Editor, Version 1.00, 10/04. USDA, Natural Resources Conservation Service.

4.0 GLOSSARY

Aerial Flight Data - Data and photography taken from special flight instruments during flyovers.

Anadromous Fish – Fish that migrate upstream from the sea to breed in freshwater.

Antecedent Moisture Condition (AMC) – Same meaning as ARC (AMC is the older term.)

Antecedent Runoff Condition (ARC) - The index of runoff potential before a storm event. It estimates the existing soil moisture condition by using the rainfall received in the 5 days prior to the storm event of interest. (Updated term)

Attenuation - Lessening in amount, force, or value.

Backwater - Water backed up or retarded in its course as compared with its normal or natural condition of flow.

Calibrate - See hydraulic calibration.

CFS – Cubic feet per second, the typical units of flow measurement.

Channel Flow - Where flow converges in gullies, ditches, and natural or man-made water conveyances (including pipes not running full.)

Channel Slope - The steepness of the channel expressed as a percent.

Confluence - The point of juncture of two or more streams.

Conservatism - As related to this flood study – tending to err on the safe side of design values (structures will be larger/stronger than may be required.)

Contour Interval - The numerical value between adjacent contour lines that indicates the accuracy level to which the topographic survey was taken.

Cross Section - The shape of a channel or stream viewed across its axis. This area includes adjacent flood plains.

Culvert - Metal, concrete, or plastic pipe put under the road that is crush resistant and conveys water.

Curve Number - See Runoff Curve Number.

Discharge - The quantity of water flowing at a given point, usually expressed in CFS.

Flood routing – Computation of the changes in the amount of stream flow as a flood moves downstream or through reservoirs or structures.

Flood plain - Normally dry land adjacent to a body of water such as a river, stream, lake, or ocean that is susceptible to inundation by floodwaters.

Floodwalls - A constructed barrier of resistant material, such as concrete, masonry block, or sheet pile designed to keep water away from a structure.

Flow Regimes - The type of flow: sub-critical, critical, or supercritical.

Groundwater - Water in the ground that is in the zone of saturation and from which wells and springs draw their water sources.

Headwaters – The upper parts of a river drainage system.

Homogenous - Material characterized by properties that are identical everywhere.

Hydraulic Calibration - The process of using historical data in a model to verify design assumptions and parameters as an accuracy check.

Hydraulic Capacity - The maximum flow that a particular stream, channel or structure is capable of carrying.

Hydraulic Model – A model to determine velocity and elevation of flows

Hydrograph - A graphical representation of stream discharge plotted versus time.

Hydrologic Soil, Group (HSG) - Classification system of soils developed by NRCS based on the permeability and infiltration rates of the soils. 'A' type soils are primarily sandy in nature with a high permeability while 'D' type soils are primarily clayey in nature with a low permeability.

Hydrology - The applied science concerned with the waters of the earth, their occurrences, distribution, and circulation through the unending hydrologic cycle of: precipitation, consequent runoff, infiltration, and storage; eventual evaporation; and so forth.

Hydrology or Hydrologic Model – A model used to determine the amount of flow at a given location.

In-Channel Hydraulic Structures - Physical structures directly in the flow path that affect the rate and direction of water conveyed through a channel.

Ineffective Flow Areas - Areas not contributing to flow in the downstream direction. They are typically located near structures (bridges & culverts) or in a very wide flood plain.

Inlet conditions - The flow conditions around an inlet that primarily relate to elevation, quantity, and velocity of flow and type of structure.

Inline Structure - See in-channel hydraulic structures.

Inundate - To cover completely with water; especially flood waters.

Land Cover Soil Complex - The classification of a selected land area for runoff potential, which relates the land type to the Hydrologic Soil Group (HSG).

Mitigate - To make or become less severe or intense.

Outlet - The exit point for a body of water or structure where waters are released.

Photogrammetry - The use of aerial photography in the production of maps and charts.

Reach – Any designated length of a river selected for design and/or evaluation.

Recession curve - The receding portion of a hydrograph showing the decreasing rate of runoff following a period of rain or snowmelt.

Runoff - Water that enters a stream during and after a storm. May consist of surface runoff and groundwater flow.

Runoff Curve Number - A dimensionless number of 100 or less that relates runoff to the soil-cover complex of the watershed. Higher numbers mean greater runoff.

Sensitivity Analysis - A series of computer model runs where selected parameters are changed to test the variability of output data to the input data.

Shallow Concentrated Flow - Begins where sheet flow converges to form small rills or gullies and swales.

Sheet flow - Flow that occurs overland in places where there are no defined channels and the floodwater spreads out over a large area at a uniform depth.

Stage - The level of the water surface above a given datum at a given location.

Stage Discharge Relationship - A graph showing the relation between the gage height, usually plotted as ordinate, and the amount of water flowing in a channel, expressed as volume per unit of time.

Stage Storage Relationship – Storage versus elevation.

Storage - Water artificially impounded in surface or underground reservoirs for future use.

Sub area - A watershed that is a portion of a larger watershed.

Subcatchment - A smaller area within a defined watershed. Also known as sub area.

Topography - Graphic representation of the surface features of a place or region on a map, indicating their relative positions and elevations.

Tributary - A stream or river that flows into a larger stream or river.

Unsteady Flow - A characteristic of a flow system where the magnitude and/or direction of the specific discharge changes with time.

Vertical Datum - Established elevation reference.

Water surface elevation - The vertical elevation value of the stream surface at a given location and point in time.

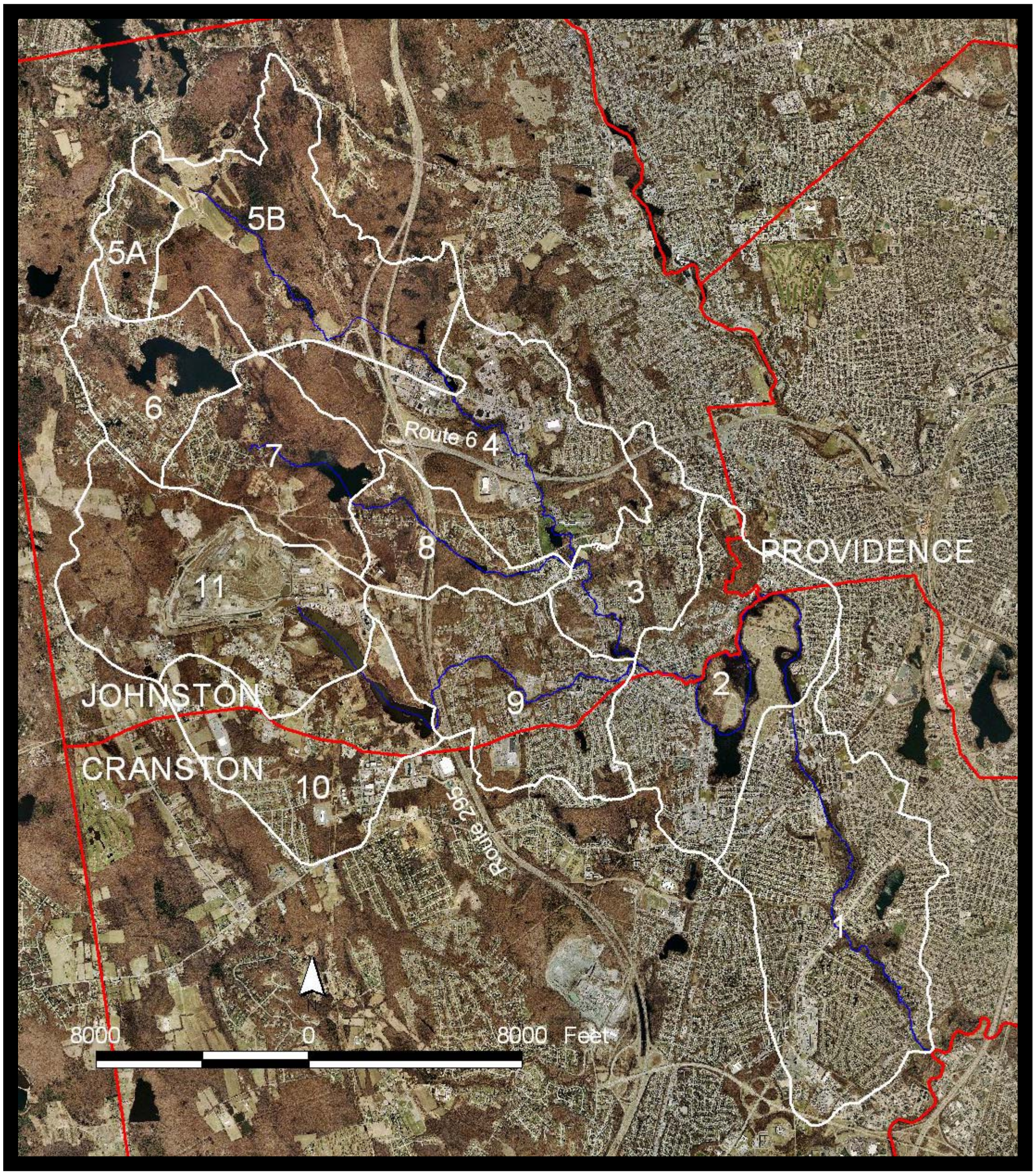
Water Table – Elevation or depth of the phreatic surface of a zone of saturation, where the body of ground water is not confined by an overlying impermeable zone.

Watershed - A defined land area drained by a river, stream, or drainage way, or system of connecting rivers, streams, or drainage ways such that all surface water within the area flows through a single outlet.

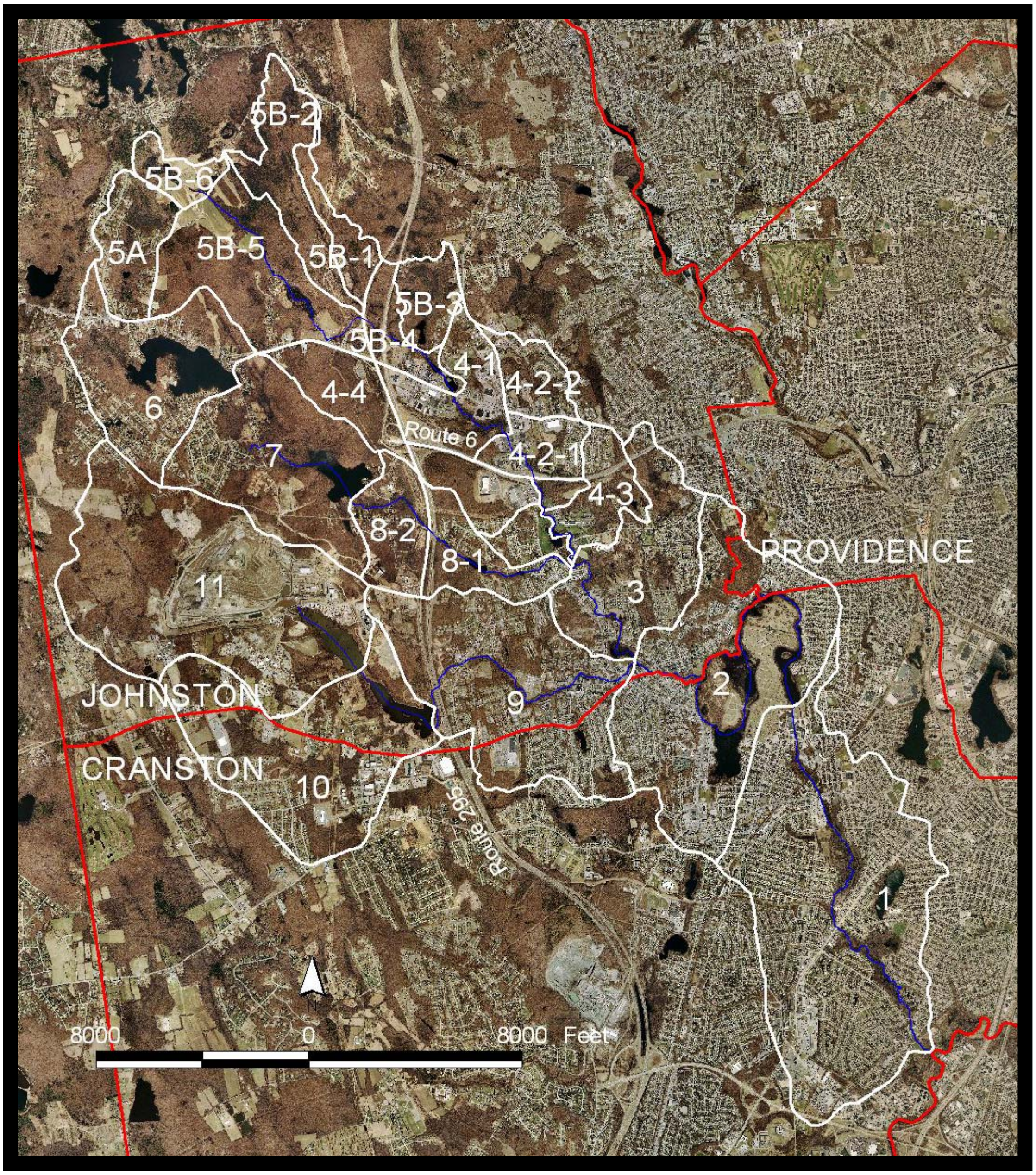
Weir - A wall or plate placed in an open channel to regulate or measure the flow of water.

APPENDIX A
WATERSHED AERIAL PHOTOGRAPHS AND MAPS

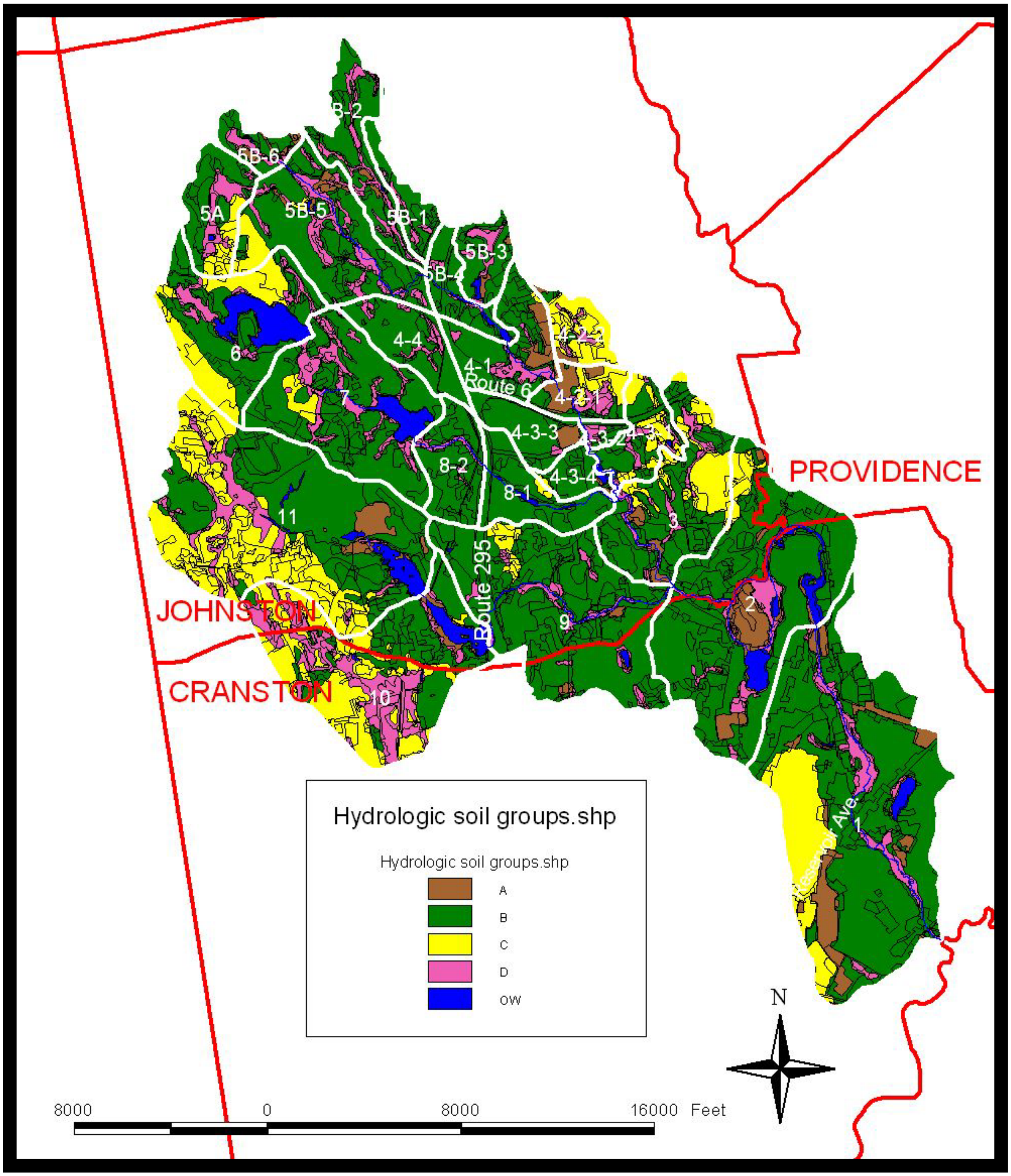
Appendix A-1 – Subareas Delineated for Original Model



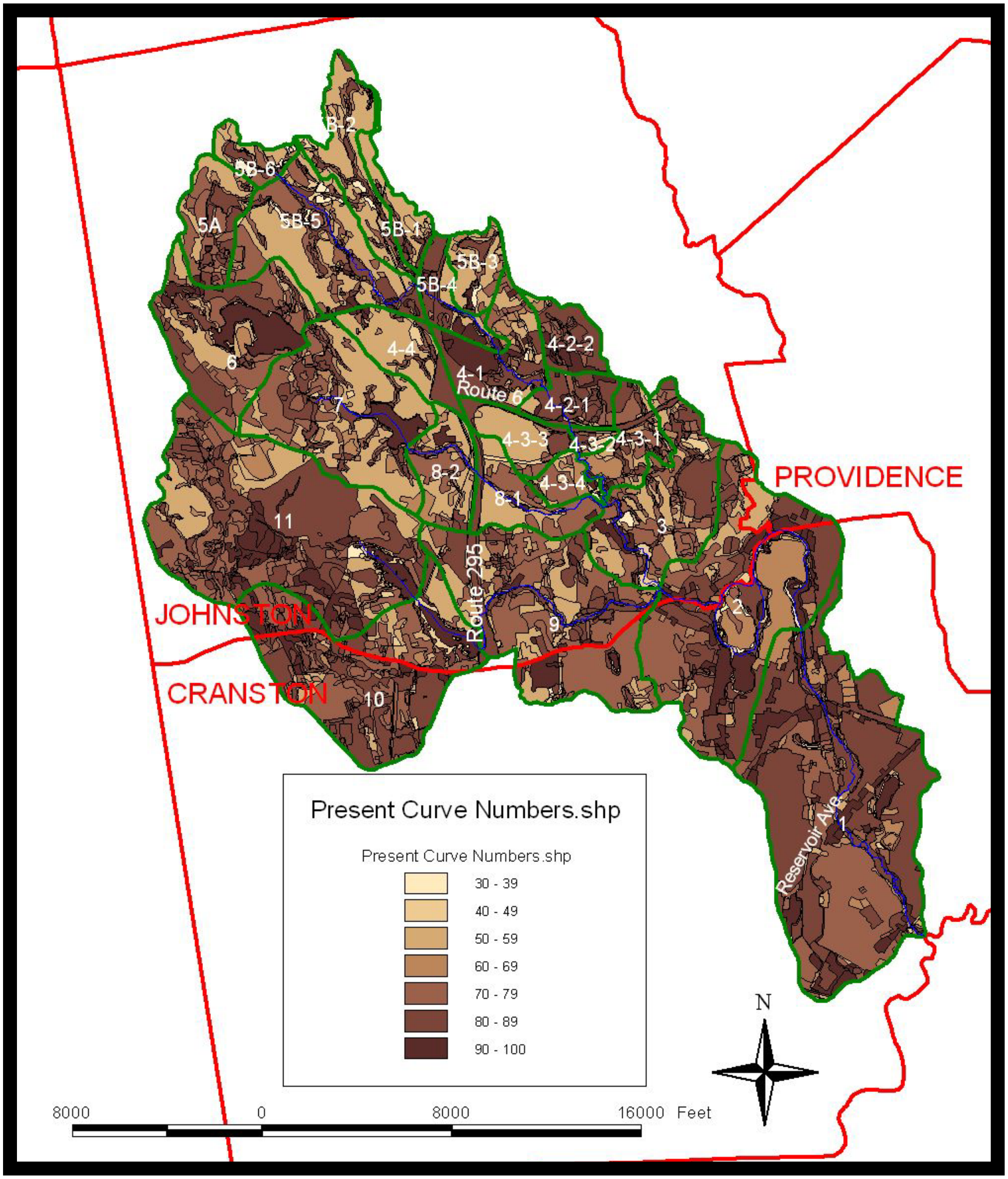
Appendix A-2 – Subareas Delineated for Final Model



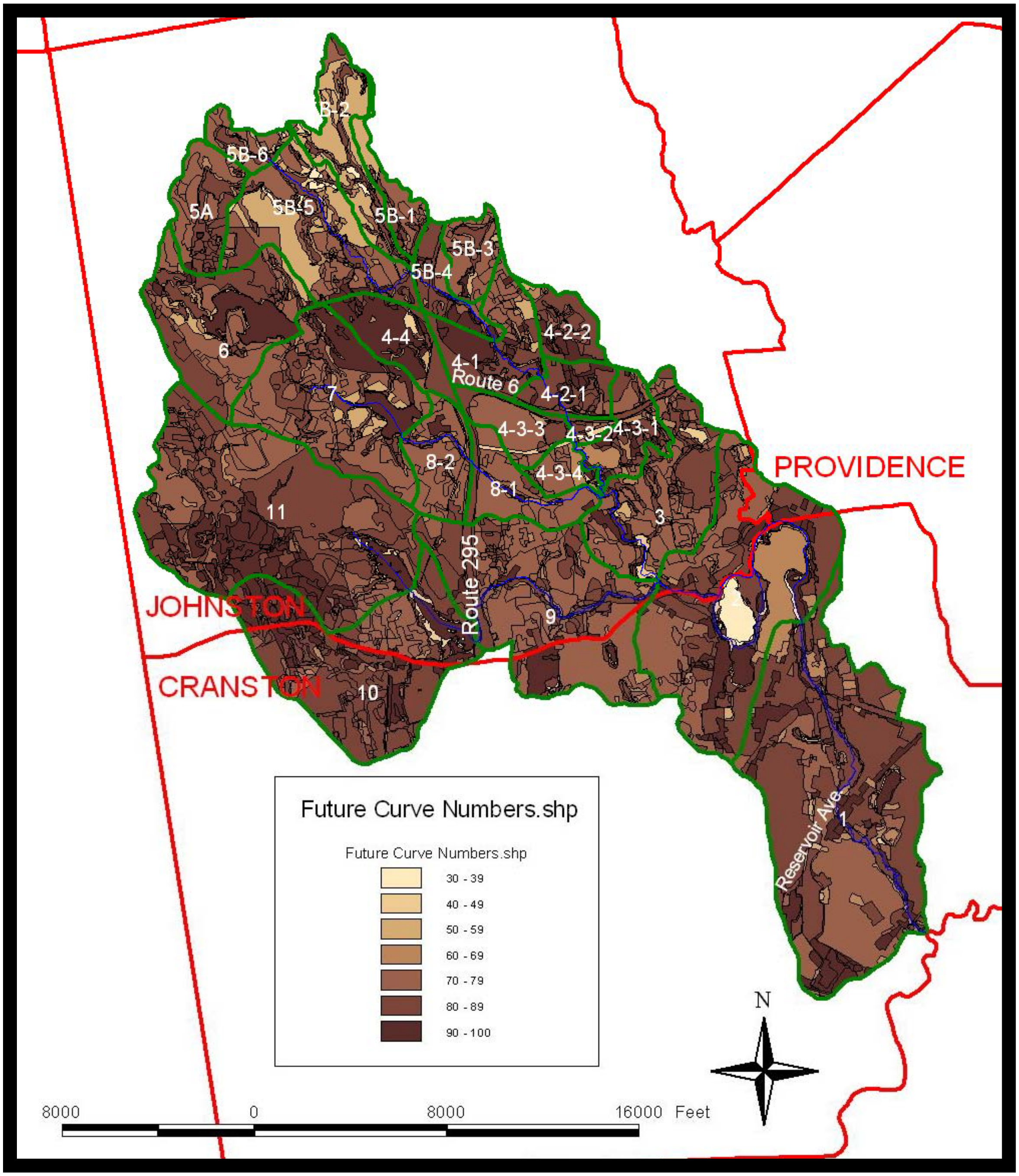
Appendix A-3 – Hydrologic Soil Group Map



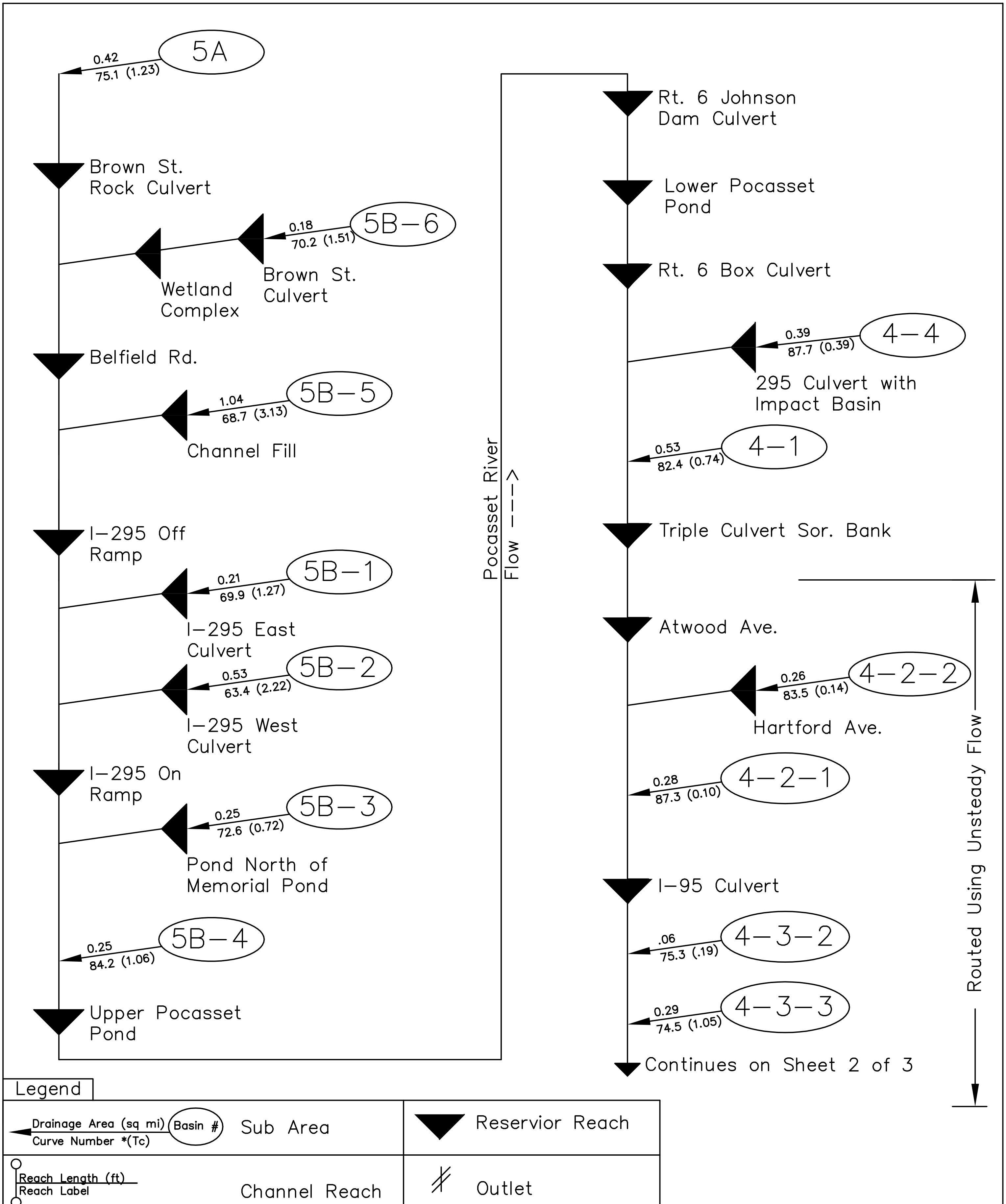
Appendix A-4 – Present Curve Number Map



Appendix A-5 – Future Curve Number Map



APPENDIX B
WINTR-20 SCHEMATIC

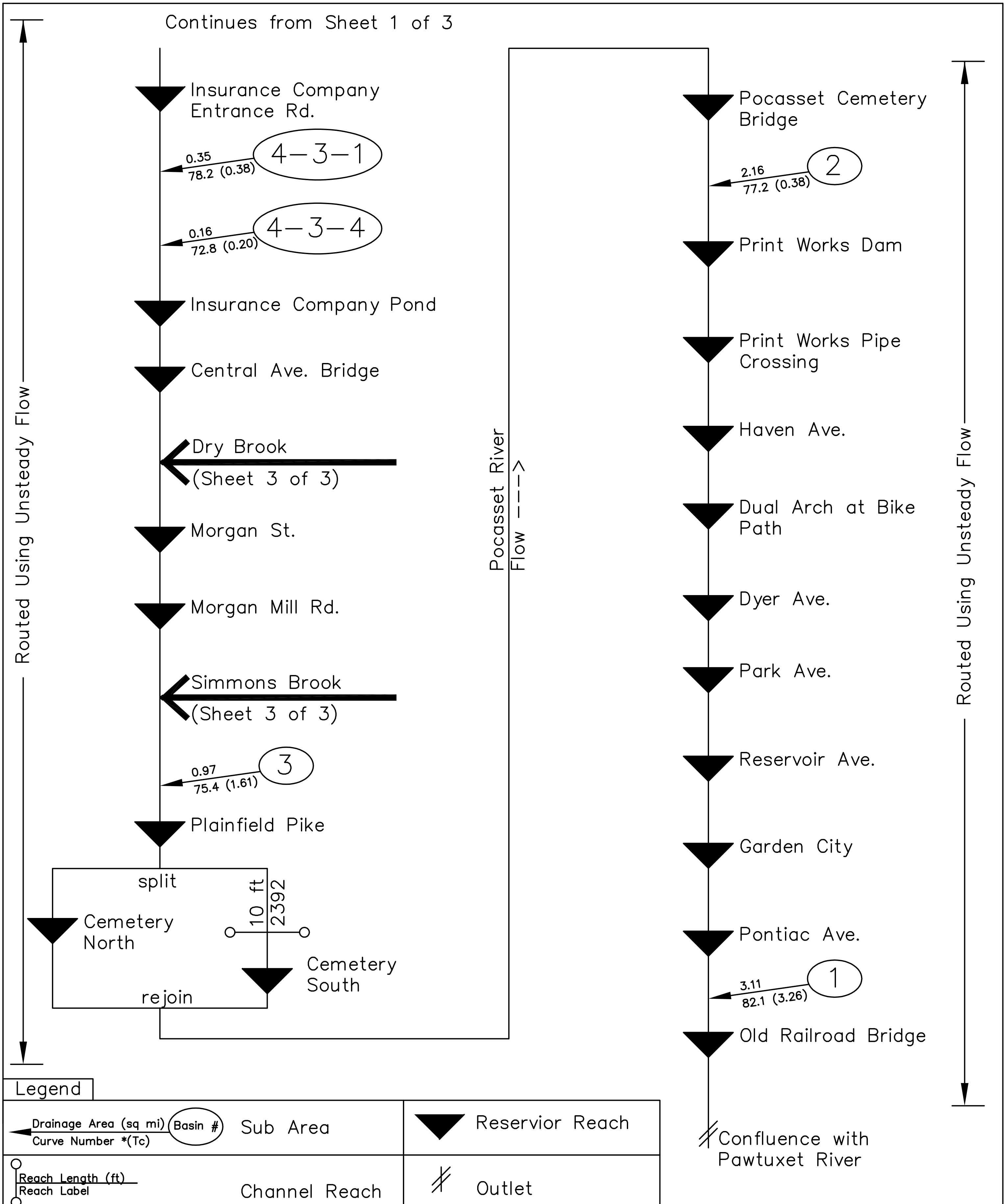


NRCS
Natural Resources Conservation Service
United States Department of Agriculture

Hydrology Schematic
Pocasset River Watershed
Johnston and Cranston, RI
Main Pocasset Channel
November, 2006

Appendix B
Pocasset Floodplain Management
Technical Report
B-1

Sheet 1 of 3

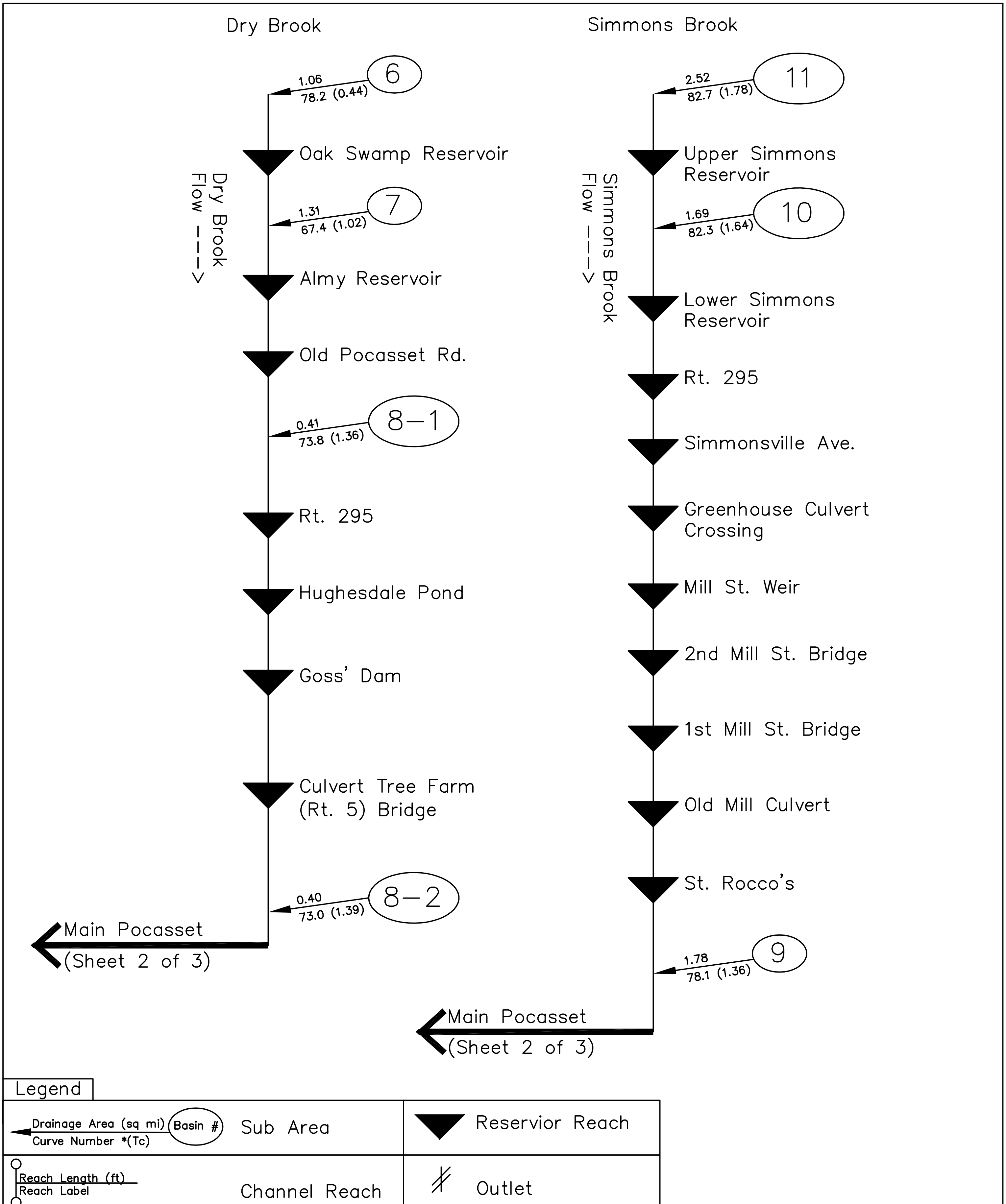


Natural Resources Conservation Service
United States Department of Agriculture

Hydrology Schematic
Pocasset River Watershed
Johnston and Cranston, RI
Main Pocasset Channel
November, 2006

Appendix B
Pocasset Floodplain Management Technical Report
B-2

Sheet 2 of 3



NRCS
Natural Resources Conservation Service
United States Department of Agriculture

Hydrology Schematic
Pocasset River Watershed
Johnston and Cranston, RI
Dry & Simmons Brook
June, 2006

Appendix B
Pocasset Floodplain Management Study Technical Report
B-3

Sheet 3 of 3