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November 15, 2006

Mr. Scott Millar
Chief of Sustainable Watersheds
Rhode Island Dept of Environmental Management
235 Promenade Street
Providence, RI 02908-5767

Re: Narrow River Stormwater Abatement Study
Final Plan

Dear ~~Mr. Millar:~~ Scott

Enclosed is a copy of the Narrow River Stormwater Abatement Study Final Report and the Preliminary 75% Design Plan Set. As you requested, I will distribute copies of both to the project technical advisory committee. I have also enclosed a copy of our final invoice.

Thank you very much for the opportunity to work on this innovative and unique project. We look forward to the opportunity for future work together. If you have questions or need anything further, please contact me at (401) 861-3070 ext 4571.

Sincerely,

M. James Riordan, AICP
Project Manager

Enclosures (3)

cc: Narrow River Technical Advisory Committee
w/Final Report and Plan Set

The Foundry Corporate
Office Center
275 Promenade Street
Suite 350
Providence, RI 02908

t (401) 861-3070
(800) 286-2469
f (401) 861-3076

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Narrow River Stormwater Abatement Study
Final Report

Rhode Island Department of Environmental Management

Providence, Rhode Island

November 2006

FUSS & O'NEILL
Disciplines to Deliver

Fuss & O Neill
275 Promenade Street, Suite 350
Providence, Rhode Island 02908

NARROW RIVER STORMWATER ABATEMENT STUDY
FINAL REPORT
Rhode Island Department of Environmental Management

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EXECUTIVE SUMMARY

BACKGROUND:
Due to concerns with pathogens and nitrogen, the Narrow River, also known as the Pettaquamscutt River, has been the focus of many studies and environmental plans over the years. These include the:

- *Fecal Coliform TMDL for the Pettaquamscutt (Narrow) River Watershed, Rhode Island,* (RIDEM, 2001).
- *Narrow River Special Area Management Plan* (CRMC, 1987).
- *Narrow River Stormwater Study* (ASA et al., 1991).

Under the Narrow River Stormwater Abatement Project, Fuss & O'Neill, Inc. has developed conceptual designs for potential alternative controls to reduce bacterial loadings, nitrogen and recharge groundwater. Practices are analyzed using priority ranking system, which compares end-of-pipe and upland options for each subwatershed of the study area. The highest ranking alternatives were then developed into 75% complete designs.

STUDY GOAL:
The goal of this project has been to design BMPs to reduce pathogens and nutrients; and return baseflow to predevelopment levels. Pathogen reduction is to be in accordance with the Narrow River TMDL, which calls for a 54% reduction in total fecal coliform loadings from the Upper Narrow River and 58% reduction in total fecal coliform loadings from the Lower Narrow River.

STUDY OBJECTIVES:
The objectives of this study included the following:

- Assess watershed conditions.
- Conduct conceptual planning study.
- Select 4 subwatersheds and BMPs with stakeholder input.
- Design BMPs to 75%.
- Maximize infiltration and recharge as practicable.

WATERSHED CHARACTERISTICS:
The challenge of the Narrow River Stormwater Abatement Study is to treat the water quality volume (9.3 acre-feet of runoff) and recharge the groundwater recharge volume (13.11 acre-feet of runoff) in a highly urbanized residential area with very little available space to site BMPs. Characteristics of the study area include the following key aspects:

- Suburban residential development with typical lots sizes of 5,000 to 10,000 square feet.
- Study is essentially at full buildout and very few lots available for siting BMPs.
- HSG Type C soils dominate the upland half of the watershed and significantly limit opportunities for infiltration BMPs.
- Runoff curve numbers range from approximately 65 to 80, which is consistent with a fully developed suburban watershed.

- Total water quality volume 9.3 acre-feet and groundwater recharge volume of 13.11 acre-feet.

Discussion of watershed characteristics and the results of outfall reconnaissance can be found in Sections 2 and 3 of this report.

CONTROL STRATEGIES:
A range of BMPs for the Narrow River have been identified for their ability to treat bacteria and nitrogen as well as for their capacity to recharge groundwater baseflow. BMPs were considered for their effectiveness in various hydrologic scenarios: end-of-pipe, centralized upland areas, and source reduction on residential lots using LID.

Section 4.1 - 4.2 provide a detailed discussion of control strategies. Table 4.3 lists BMPs that were selected as most appropriate for the Narrow River study area.

Table 4.3
BMPs Considered for Conceptual Design

Practices and Strategies	End-of-Pipe	Upland	Source Reduction
Filtration and infiltration			
Sand filters	•	•	
Bioretention	•	•	•
Infiltration trenches	•	•	
Disconnected catch basins and proprietary infiltration units	•	•	
Dry wells			•
Permeable Pavement			•
Engineered vegetative strips and conveyances			
Vegetated strips			•
Impervious surface disconnection			
Roof leader disconnection			•

SCORING MATRIX:
We developed a scoring matrix to generate unbiased BMP selections. BMPs were ranked by their scores across all subwatersheds. Section 5 of this report provides a discussion the BMP-selection process. Table 5.3 provides scores and a scoring summary generated by the matrix rating tool.

Table 5.3
Scoring Summary

	SCORES							
	IH	PLS2	E1	E2	PTC	M1	M3	M4
Sand filter	29	62	57	17	78	21	22	25
Biorention (subdrain)	22	46	3	0	49	6	4	11
Biorention (infiltration)	42	58	5	0	77	11	7	21
Infiltration trench	46	26	74	23	119	35	33	41
Disconnected catch basin	51	28	82	25	132	38	37	45

Red highlight indicates two highest values
Yellow highlight indicates 3rd and 4th highest values
Green highlight indicates 5th through 8th highest values

SELECTION BY COMMITTEE:
Using the rating matrix, this report and other data, the Narrow River Technical Advisory Committee selected BMPs for further (i.e., 75%) design. Upland and end-of-pipe infiltration BMPs were selected as the principal form of treatment for Pettasquamscutt Terrace and Edgewater 1 and 2 based on ranking and other hydrologic factors. On-lot source reduction BMPs will be pursued across the watershed wherever property owners are willing to install them.

ANALYSIS OF TREATMENT EFFECTIVENESS:
Selected control strategies were analyzed for effectiveness in treating water quality volume (WQV) and groundwater recharge capacity (V_{GWR}) in each subwatershed of the Narrow River. Based on a recent survey, we assumed that 20% of residents would be willing to site LID BMPs on their property. We also assumed all the lots available in the study area could be used for BMPs. The stakeholder advisory committee made infiltration and filtration a focus due to their capacity to treat bacteria. Analysis of treatment effectiveness is discussed in Sections 4.3 to 4.7 of this report

ORDER-OF-MAGNITUDE OPINIONS OF COST:
Order-of-magnitude opinions of cost were developed for conceptual BMPs from literature values of construction cost per unit volume treated. Section 4.8 discusses development of the order-of-magnitude opinions of cost. Table 4.13 provides the lowest treatment cost per subwatershed and the corresponding percentage treated of Narrow River study area's WQV that can be achieved through a combination of upland treatment and end-of-pipe treatment.

Table 4.13
Treatment Opinion-of-Cost And
Percent Volume Treated

SUBWATERSHED	COST	% WQV	% GWR
Indian Head	$330,000	16	11
Petta Lake Shores 2	$710,000	28	20
Edgewater 1	$340,000	16	12
Edgewater 2	$80,000	4	3
Pettaquamiscutt Terrace Combo	$690,000	33	24
Mettatuxet 1	$370,000	18	13
Mettatuxet 3	$220,000	11	7
Mettatuxet 4	$260,000	13	9
TOTAL	$3,000,000	139	98

SEVENTY-FIVE PERCENT DESIGNS:
Seventy-five percent designs were developed for the Edgewater and Pettaquamscutt subwatersheds. Budget-level opinions of cost were developed for each of the proposed BMPs in these subwatersheds. Section 6 discusses seventy-five percent designs. Table 6.5 provides budget-level opinions of cost for each proposed BMP.

Table 6.5
Budget-Level Opinions of Cost for Best Management Practices in
Edgewater and Pettaquamscutt Terrace Subwatersheds

Best Management Practice	Budget-Level Opinion of Cost
Edgewater Infiltration System	$333,000
Edgewater Sand Filter	$444,000
Pettaquamscutt Terrace Infiltration System	$627,000
Pettaquamscutt Terrace Level Spreader	$202,000
Total Cost	$1,606,000

Using these practices, we anticipate 100 percent treatment of runoff from the water quality storm (i.e., 1 inch of runoff from the impervious surface). The WQV for the Edgewater and Pettaquamscutt Terrace subwatersheds is approximately 3.8 acre-feet and represents 40 percent of the WQV for the entire Narrow River study area. We, therefore, anticipate a 40 percent reduction in pollutants of concern entering the Narrow River from the study area during the water quality storm.

1.0 INTRODUCTION

The Narrow River, also known as the Pettaquamscutt River, is located in southern Rhode Island passing through North Kingstown and forms the boundary between the towns of South Kingstown and Narragansett (project location is depicted in Figure 1.1). The river's watershed is approximately ten (10) miles long, covering a total area of approximately fourteen (14) square miles.

1.1 Background

Due to its recognition as an important estuary, the Narrow River has been the focus of many studies and environmental plans over the years such as the Narrow River Special Area Management Plan (SAMP) (CRMC, 1987) and the Narrow River Stormwater Study (Tritown Study) (ASA et al 1991). The studies were funded by the Coastal Resources Management Council (CRMC) and Rhode Island Department of Environmental Management (RIDEM) respectively. The SAMP focused on policy changes in the municipalities within the river's watershed while the Tritown Study worked to further investigate the problem and implement those policies and reduce pollutants through potential best management practices (BMPs).

Loadings of pathogens to the Narrow River have prevented it from meeting its designated use and in its inclusion on the State's 303(d) list. The 303(d) list is prepared every two years by the Office of Water Resources in compliance with the federal Clean Water Act and includes all waterbodies that do not meet Rhode Island Water Quality Standards based on the most recent assessment of water quality conditions. A fecal coliform Total Maximum Daily Load (TMDL) has been developed for this river which was approved on April 29, 2002.

1.2 Management Goals

Section 8 of the TMDL provides recommendations to address the pathogen impairments to the Narrow River. These recommendations include addressing bacterial loads from storm water discharges to the river, which is noted to be the largest wet-weather source of bacteria to the Narrow River.

The TMDL reports that the twelve largest storm water outfalls represent an estimated ninety-three percent of the total fecal coliform load from outfalls to the Narrow River. Eleven of these outfalls have been evaluated for their potential to be retrofitted with controls as part of this project. The outfalls that were evaluated include (from north to south):

- Indian Trail Outfall @ Bow Run & Indian Trail
- Pettaquamscutt Lake 1 Outfall @ Waterberry & Woodsia Road
- Pettaquamscutt Lake 2 Outfall @ Woodsia Road and Shadbush Trail
- Pettaquamscutt Lake 3 Outfall @ Woodsia Road
- Edgewater 1 & 2 Outfalls @ Lakeside Drive & Bridgetown Road

- Pettaquamscutt Terrace 1 & 2 Outfalls @ Shore Drive & Pettaquamscutt Avenue
- Circuit Drive 1 & 2 (also known as Rio Vista 1 & 2) Outfalls @ Circuit Drive
- Mettatuxet 1 Outfall @ North River Drive & Old Pine Road
- Mettatuxet 2 Outfall @ North River Drive & Mettatuxet Road
- Mettatuxet 3 Outfall @ North River Drive & Shagbark Road
- Mettatuxet 4 Outfall @ North River Drive & Woodridge Road

The TMDL also recommends that "special consideration be given to those outfalls discharging to, or immediately upstream of , Segments 3 [Upper Narrow River] and 4 [Lower River] " as "these two segments are shallow and narrow with relatively little dilution volume available to absorb the impact of pollutant loadings " (RIDEM, 2001, p. 75). TMDL estimates that 54% reduction in total fecal coliform loadings is required in Upper Narrow River segment and a 58% reduction in total fecal coliform loading is required in the Lower Narrow River in order to achieve its designated use. The 11 outfalls evaluated in this study include all the outfalls that discharge to Segments 3 and 4.

Based on past RIDEM monitoring data, included in the TMDL, fecal coliform levels in these outfalls range from a few hundred fc/100 mL to tens of thousands fc/100mL. An estimated event mean concentration (EMC) of fecal coliform was calculated for each of these outfalls of 19,000/mL. Approximate loadings from each of the study outfalls are as follows as reported in the TMDL.

Table 1.1
Estimated Fecal Coliform Loading Rates

Outfall	Approximate fecal coliform loading per storm event
Shadbush Trail (i.e., Pettaquamscutt Lake Shores 1)	4.3×10^{10}
Lakeside Drive (i.e., Edgewater 1 &2 (north))	3.3×10^{10}
Old Pine Road (i.e., Mettatuxet 1)	3.2×10^{10}
Shagbark Road (i.e., Mettatuxet 3)	2.5×10^{10}
Pettaquamscutt Avenue (i.e., Pettaquamscutt Terrace 1 & 2)	2.2×10^{10}
Woodbridge Road (i.e., Mettatuxet 4)	1.9×10^{10}
Indian Trail	1.8×10^{10}
Mettatuxet Beach (i.e., Mettatuxet 2)	1.6×10^{10}
South Ferry Road (i.e., Edgewater 1 &2 (south))	8.3×10^{9}

1.3 Project Objectives

The objective of this project is to identify and develop conceptual designs for potential alternative controls to reduce bacterial loadings from the project area and then develop 75% complete designs for four (4) alternatives selected by the Stormwater Technical Committee. This committee is comprised of local stakeholders including the Town of Narragansett, Coastal Resources Center (CRC), CRMC, and Narrow River Preservation Association. This project is intended to develop controls that not only reduce bacteria loads but also provide the greatest cost-benefit. Other issues to be addressed by the project include permitting and long-term operation and maintenance. A workshop approach with the above mentioned stakeholders will be used to evaluate and determine the best management practice alternatives.

2.0 WATERSHED CONDITIONS

2.1 Watershed Description

The project's watershed contains a storm water sewer system that, for the most part, is in good condition. The outfalls (discussed in more detail in following sections) are also in good condition with the exception of the damaged pipes as discussed later.

The land uses in the area of Narragansett are almost exclusively residential in nature with varying densities, from medium density (1/4 to 1 acre lots) to medium-high density (1/8 to 1/4 acre lots). There is a significant amount of open space in this watershed including a large plot of land owned by the United States Department of Fish & Wildlife and other privately owned parcels (currently undeveloped).

The topography of the project's watershed slopes from east to west, finally terminating at the Narrow River (as depicted on Figure 2.1). In general, the slopes in this area are uniformly moderate (approximately 1%) with minimal variation.

The majority of the watershed has hydrologic group type "C" soils. The western border of the watershed, bordering the Narrow River is primarily type "A" soils with some pockets of type "D" intermixed. Type "D" soils typically represent areas with high groundwater tables such as wetlands. There are very few areas of hydrologic type "B" soils.

2.2 Delineation of Subwatershed Areas

Subwatershed areas for each outfall were determined based on topographic contours, physical features, and storm drain system hydraulics. Figure 2.1 identifies subwatershed areas for the eleven outfalls in the project area. Please note that for the purposes of this study, Narragansett's outfall and subwatershed names were used wherever possible. The names used in this study correspond to TMDL outfall names as shown in Table 2.1.

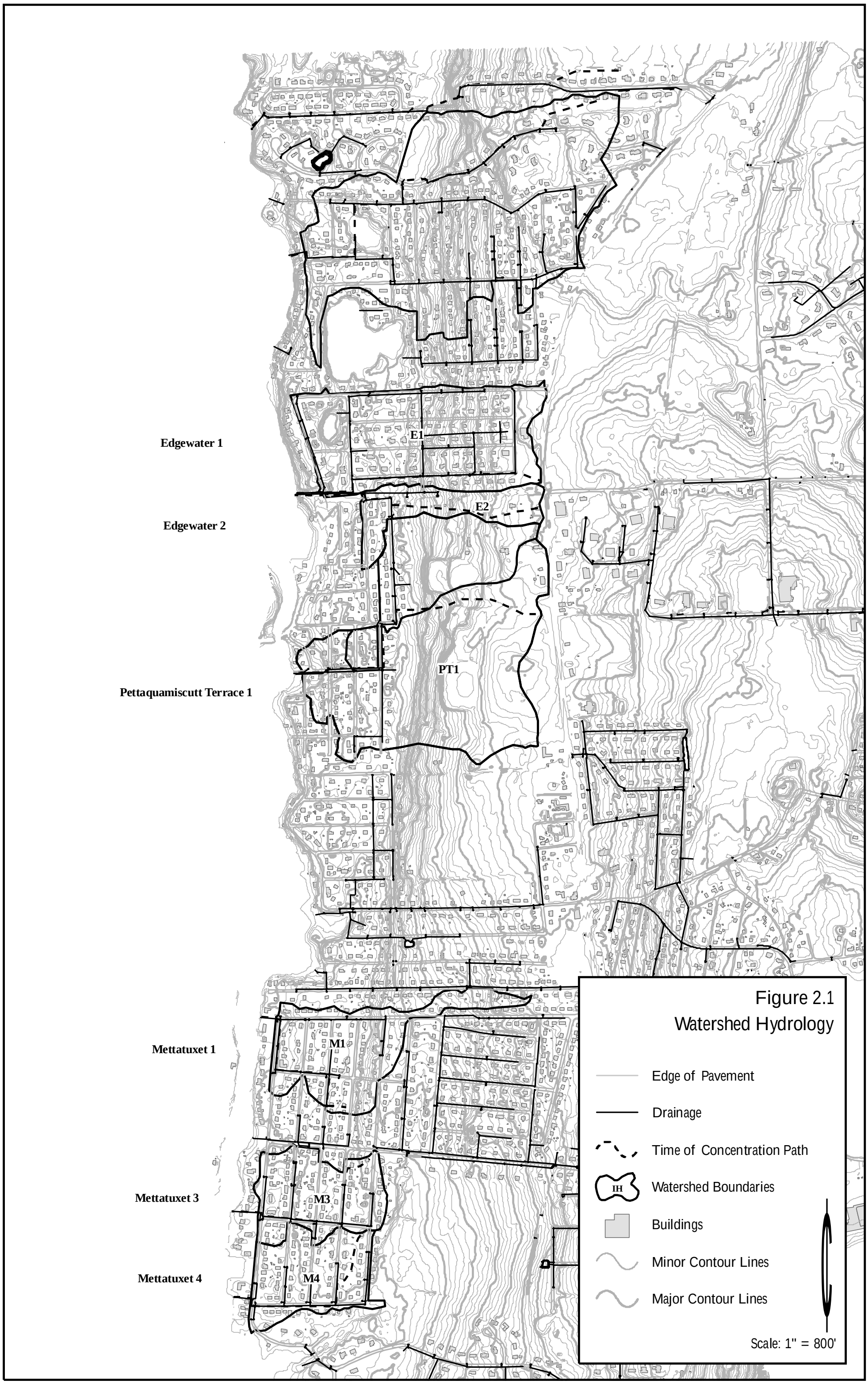

Edgewater 1
E1
Edgewater 2
E2
Pettaquamiscutt Terrace 1
PT1
Mettatuxet 1
M1
Mettatuxet 3
M3
Mettatuxet 4
M4
Figure 2.1
Watershed Hydrology
Edge of Pavement
Drainage
Time of Concentration Path
IH
Watershed Boundaries
Buildings
Minor Contour Lines
Major Contour Lines
Scale: 1" = 800'

Table 2.1
Subwatershed Identification Relationship

TMDL Subwatershed Names	Narragansett Subwatershed Names	Technical Memorandum Subwatersheds
Conanicus Road	Circuit Drive 2	Not assessed
Indian Trail	Indian Head	Indian Head (IH)
Lakeside Drive	Edgewater 1	Edgewater 1 (E1)
Mettatuxet Beach	Mettatuxet 2	Not assessed
Mettatuxet Road	No Listing (Upland outfall to stream)	Not assessed
Old Pine Road	Mettatuxet 1	Mettatuxet 1 (M1)
Pettaquamscutt Avenue	Pettasquamscutt Terrace 1 & 2	Pettasquamscutt Combination (PTC)
Shadbush Trail	Petta Lake Shores 1	Not assessed
Shagbark Road	Mettatuxet 3	Mettatuxet 3 (M3)
South Ferry Road	Edgewater 2	Edgewater 2 (E2)
Wampum Road	Circuit Drive 1	Not assessed
Woodbridge Road	Mettatuxet 4	Mettatuxet 4 (M4)
Woodsia Road – South	Petta Lake Shores 3	Not assessed
Woodsia Trail – North	Petta Lake Shores 2	Petta Lake Shores 2 (PLS2)

The eleven subwatersheds are represented as eight subwatersheds in this technical memorandum. This was done for the following two reasons:

- Two outfalls have relatively small subwatersheds and correspondingly small bacteria loads compared to the other subwatersheds. These two outfalls have drainage areas of approximately two acres each, and are identified as Petta Lake Shores 1 (PLS1) and Petta Lake Shores 3 (PLS3). We anticipate that these subwatersheds will be managed via controls in a neighboring subwatershed. If adjacent subwatersheds are selected, an approach for managing PLS1 and PLS3 will be determined during the design phase.

- Pettasquamscutt Terrace 1 (PT1) and Pettasquamscutt Terrace 2 (PT2) discharge at a twin outfall and much of the stormwater piping runs along the same road. Most of the available upland treatment areas as well as a significant end-of-pipe area are accessible for both subwatershed systems. Therefore Pettasquamscutt Terrace 1 (PT1) and Pettasquamscutt Terrace 2 (PT2) outfalls are considered as one subwatershed, referred to as Pettasquamscutt Terrace Combination (PTC)

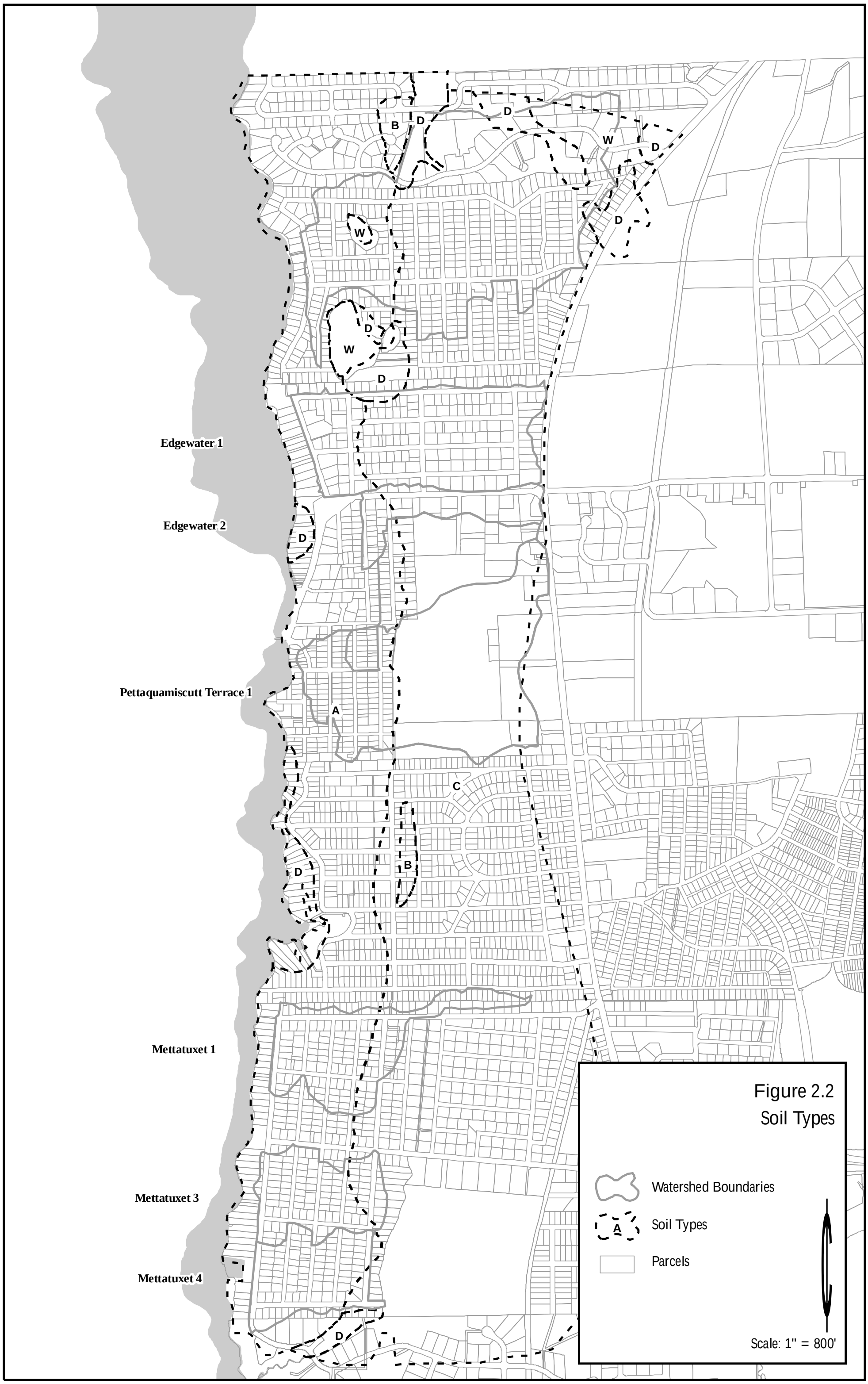
2.3 Subwatershed Hydrologic Calculations

The base data used for the calculations made in this task included geographical information system (GIS), which was provided through the Town of Narragansett and Rhode Island GIS (RIGIS). Fuss & O'Neill used the topographic contours, road alignments, and storm drain system layout to delineate the subwatersheds and map the time of concentration travel paths. Once the subwatersheds were delineated, Narragansett's GIS information was used to obtain the total area (A_{Total}), land use with corresponding soil type, and useable lots. Figure 2.1 shows the subwatershed delineation, Figure 2.2 shows soil types, and Figure 2.3 shows useable lots. Historic land use was determined using the RIGIS 1939 aerial photographs, which are shown on Figure 2.4. This information was used to determine undeveloped land uses areas by corresponding soil type.

The base data obtained were used to calculate the following hydrological data for each subwatershed:

- Curve Number (CN)
- Undeveloped or Historic Curve Number (CN_n)
- Impervious Area (A_{imp})
- Water Quality Volume (WQV)
- First-flush Volume (V_{1flush})
- Groundwater Recharge Volume (V_{GWR})
- Time of Concentration (T_c)
- 25-year Storm Event Total Volume (V_{25})
- 25-year Storm Event Peak Flow (Q_{25})

The results of the calculations are listed in Table 2.2. The following sections provide a discussion of the derivation and significance of each of these hydrologic calculations. Example calculations are provided in Appendix A.


Edgewater 1
Edgewater 2
Pettaquamiscutt Terrace 1
Mettatuxet 1
Mettatuxet 3
Mettatuxet 4
Figure 2.2
Soil Types
Watershed Boundaries
Soil Types
Parcels
Scale: 1" = 800'

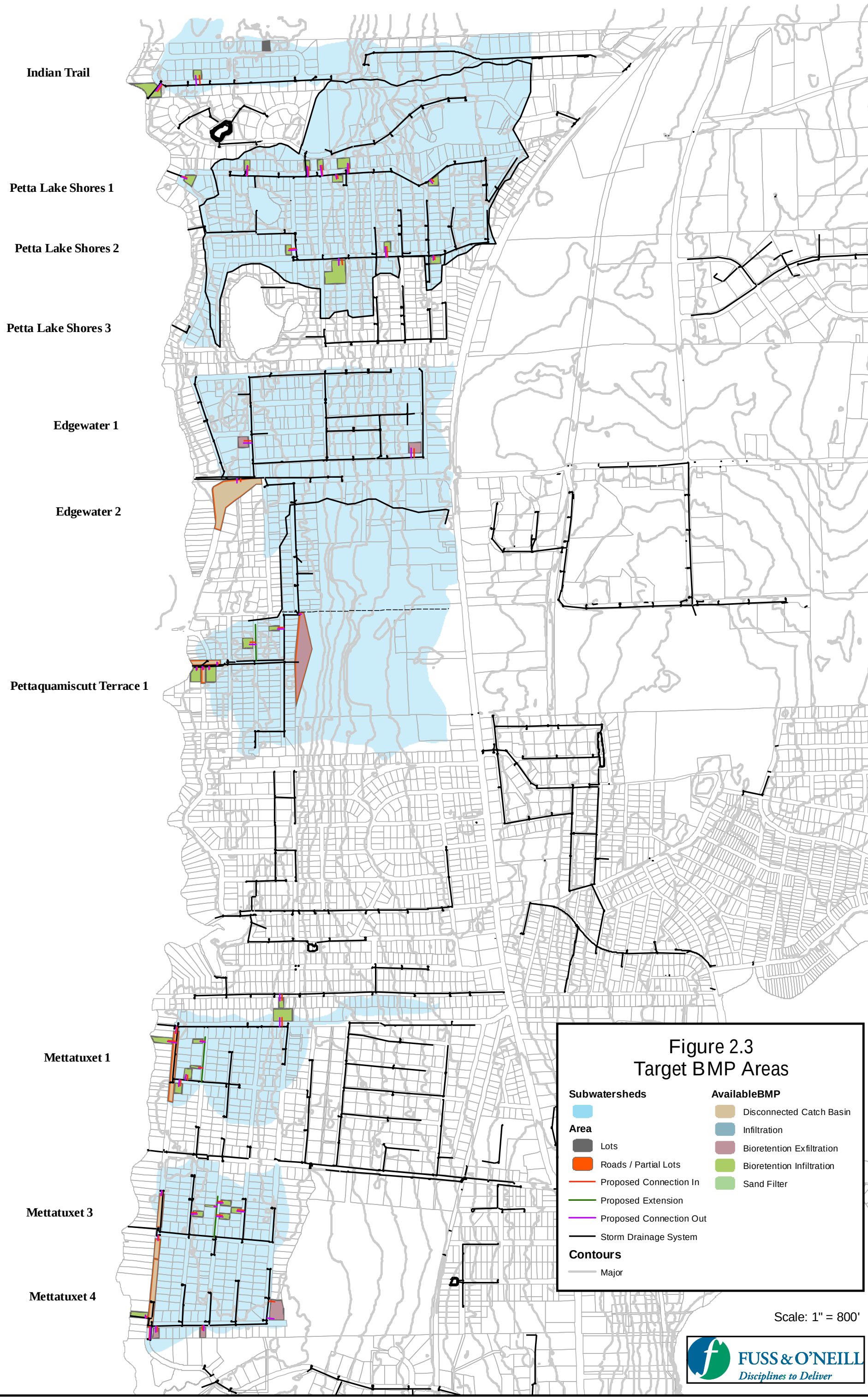


Figure 2.3
Target BMP Areas

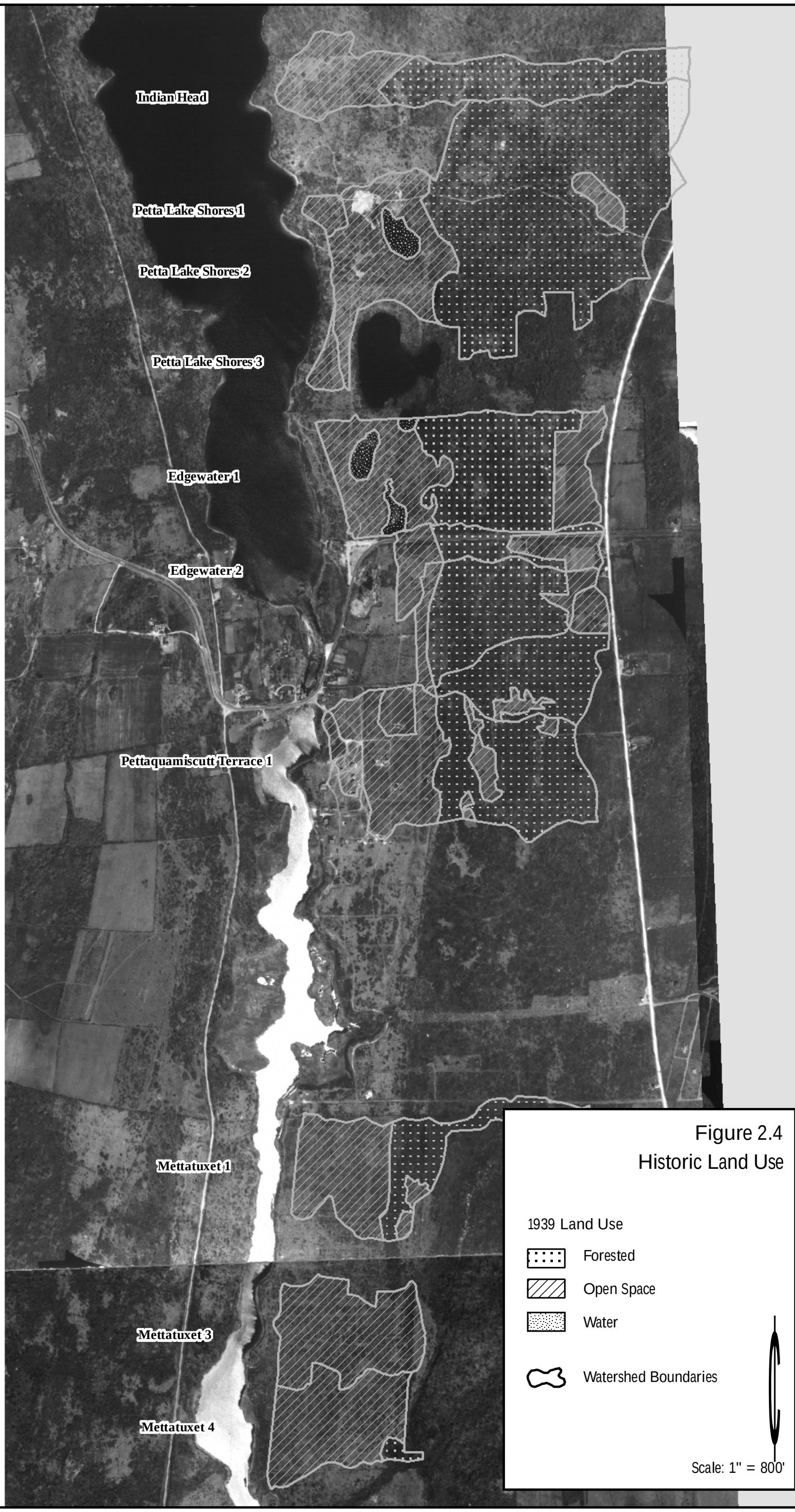


Figure 2.4
Historic Land Use

Table 2.2
Hydrologic Data By Subwatershed

Outfall	A_{Total} acres	A_{imp} acres	CN	CN_n	WQV acre-ft	V_{1flush} acre-ft	V_{GWR} acre-ft	V_{25} acre-ft	Q_{25} cfs
Indian Head	27.2	10.1	72.9	58.9	0.84	0.42	1.48	6.5	52.1
Petta Lake Shores 2	100.4	30.8	77.0	67.0	2.57	1.28	3.25	27.7	225.7
Edgewater 1	47.2	18.1	78.0	70.2	1.51	0.76	1.12	13.2	70.2
Edgewater 2	13.5	4.2	75.2	67.5	0.35	0.17	0.34	3.5	22.2
Pettasquamscutt Terrace Combo	89.2	23.2	74.9	64.7	1.94	0.97	3.12	22.8	119.0
Mettatuxet 1	26.8	10.2	68.6	54.8	0.85	0.42	1.64	5.6	51.3
Mettatuxet 3	20.1	7.6	65.3	54.8	0.64	0.32	0.98	3.7	35.9
Mettatuxet 4	19.5	7.2	62.3	50.8	0.60	0.30	1.18	3.2	27.7

Notes:
1. cfs – cubic feet per second
2. Values determined by methods described in following sections

2.3.1 Total Area and Impervious Area

The total area for each subwatershed was determined from GIS data and subwatershed delineations. The impervious area for each subwatershed was estimated by multiplying the average percent impervious area for each land use from *Urban Hydrology of Small Watersheds—Technical Report 55* (TR-55), Table 2.2 (a, b and c), by the area of the respective land use.

2.3.2 Pre- and Post-development Curve Numbers

This technical memorandum employs area-weighted average curve numbers to estimate volumes and flows for conceptual planning. Curve numbers were obtained for each land use and soil type from TR-55, Table 2.2 (a, b and c). Post-development (i.e., current-condition) land uses were determined from the GIS mapping provided by the Town. The undeveloped-condition land use and CN_n were determined by identifying TR-55 land uses as either good-condition forest, fair-condition open space, or water, from the 1939 aerial photograph.

2.3.3 Water Quality Volume

The water quality volume is the volume of stormwater runoff that must be captured and treated in order to effectively remove most stormwater pollutants on an average annual basis. In accordance with the draft *Rhode Island Stormwater Manual*, the WQV is determined by multiplying the impervious area in each subwatershed by one-inch. One inch is approximately the volume of runoff from the 90 percentile Type III 24-hour storm event.

2.3.4 Volume of First Flush

The first flush refers to that volume of runoff that a storm generates early and which carries the highest concentrations of pollution. While there is no single accepted first flush volume calculation, many stormwater practioners, including the Center for Watershed Protection, consider ½-inch of runoff as acceptable for design. The first flush volume was calculated by multiplying the impervious area in each subwatershed by ½-inch.

2.3.5 Groundwater Recharge Volume

When watersheds become urbanized and impervious surfaces replace naturally vegetated areas, rainwater, which previously percolated into the soil, runs off through the storm drain systems and does not recharge groundwater. This affects water tables and baseflow to nearby surface waters. Many states have established post-development recharge goals of ¼ - ½ inch over the impervious surface. However, lost recharge can be more accurately approximated by multiplying the pre- to post-development change in initial abstraction[1] by the area of impervious surface. For this study, change in initial abstraction (R) was based on a rearrangement of TR-55 Equation 2-1 and is calculated as follows:

$$R = 200/CN_n - 200/CN$$

Where:

CN_n = Pre-development curve number.
CN = Post-development (i.e., present-day) curve nuber.

And V_{GWR} was calculated as:

$$V_{GWR} = R \cdot A_{imp}$$

2.3.6 Time of Concentration

Time of concentration is the period it takes the first runoff to discharge at the end of the watershed (e.g., at an outfall) from the most hydrologically distant point in the watershed. to discharge from the end of the watershed (e.g., at an outfall). Time of concentration was calculated using the TR-55 method, which involves determining the travel times for three components–sheet flow, shallow concentrated flow and open channel flow. Example calculations and components of each T_c are provided in Appendix A. Travel paths are shown on Figure 2.1.

2.3.7 Storm-Event Volumes and Peak Flows

[1] For a discussion of initial abstraction, refer to TR-55.

The 25-year storm event volumes and peak flows were calculated using the computer model Hydraflow®. These values are to be used to size hydraulic elements of the proposed systems. The data input consisted of CN, A_{Total} and T_c for each subwatershed and 24-hour rainfall amounts for southern Rhode Island. The input and 25-year storm event summary page from the model output are provided in Appendix A.

2.4 Hydrogeologic Survey

As described above, infiltration practices are very dependent on physical conditions in the watershed. For example, infiltration will be constrained where high groundwater, high bedrock or poor soils exist. Figure 2.5 identifies hydrologic soil groups in the watershed. As shown, the soils in approximately two-thirds of the eastern portion of the watershed are classified as Hydrologic Soil Group C. These soils have intermittently high groundwater and low permeability rates. Therefore, they appear to have limited potential for infiltration.

The land use as it relates to the impermeability of the area also has an affect on the physical conditions and permeability of the watershed. A more intensive land use, such as a commercial land use will have more impervious area (e.g., roofs, parking lots, etc) than a low density residential area. Figure 2.5 also shows the land uses within the project area.

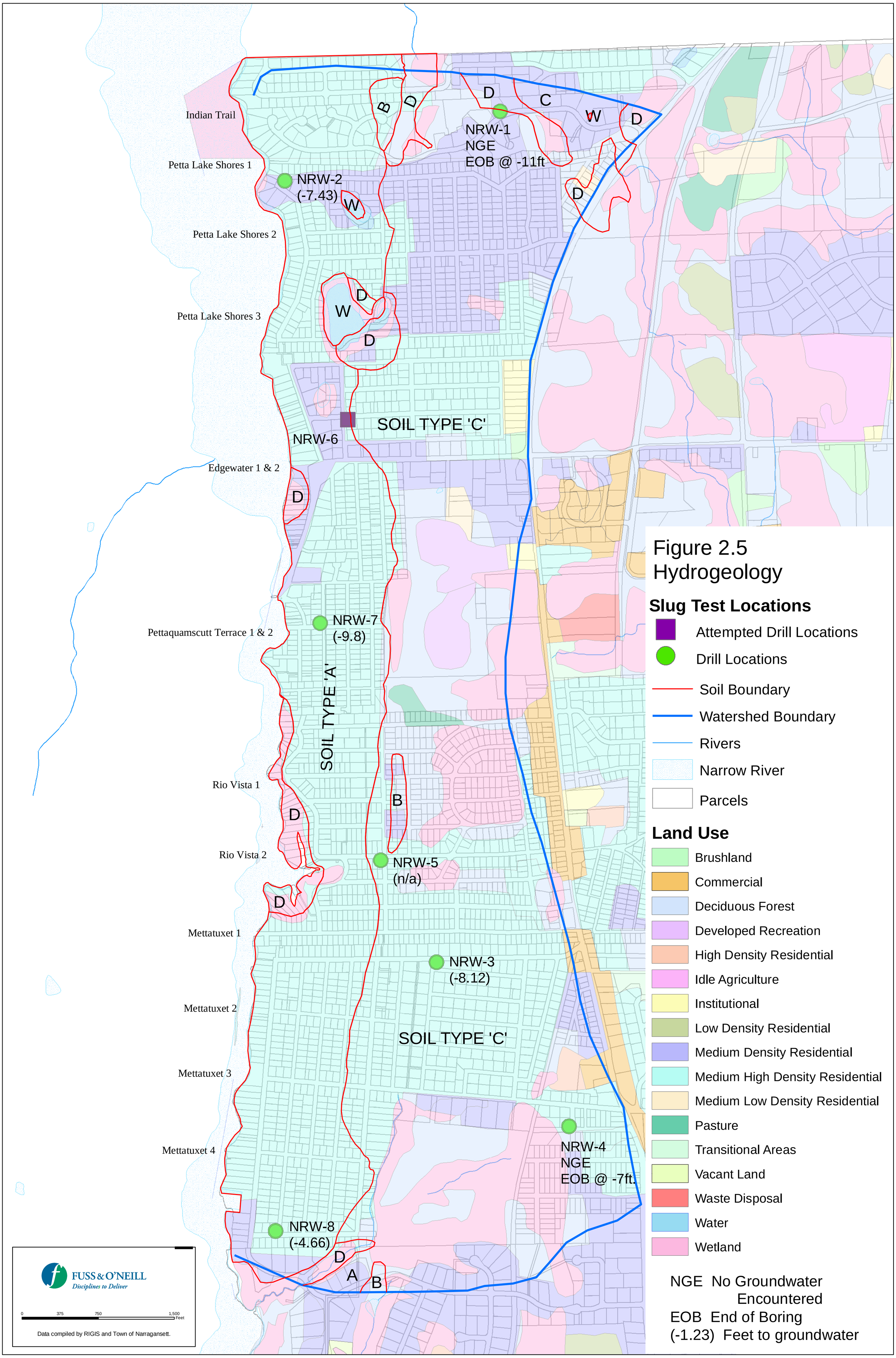
Since design and feasibility of infiltration practices are directly related to soil conditions, a hydrogeologic evaluation of the watershed was conducted. . This provided two key pieces of data (overall results are found in Table 2.2 below and Hager Geoscience, Inc. reports are included as Appendix B):

- Depth to groundwater. Seven monitoring wells were installed in various locations throughout the project area (Figure 2.5). These wells were monitored at the time of installation for the depth to water and will be monitored at various times during this project to determine the seasonal high groundwater table. It is important to note that Rhode Island's *Stormwater Design and Installation Standards Manual* (1993) (Stormwater Manual) requires 3 feet (min) of separation between the seasonal high groundwater table and the bottom of an infiltration BMP.

- Permeability. As opposed to using the estimated infiltration rates provided in the Stormwater Manual, infiltration rates are being calculated directly from permeability using Darcy's Law. In-situ slug testing was conducted as it is the most accurate method to determine permeability. It is also important to note that Stormwater Manual requires a soil infiltration rate between 1.0 in/hr and 7.5 in/hr for infiltration BMPs.

Table 2.3
Summary of Results From Hydrogeologic Evaluation

Well Location	Location ID	Depth to Groundwater (feet)	Permeability (K)


Indian Trail
Petta Lake Shores 1
Petta Lake Shores 2
Petta Lake Shores 3
Edgewater 1 & 2
Pettaquamscutt Terrace 1 & 2
Rio Vista 1
Rio Vista 2
Mettatuxet 1
Mettatuxet 2
Mettatuxet 3
Mettatuxet 4
NRW-1
NGE
EOB @ -11ft
NRW-2
(-7.43)
NRW-3
(-8.12)
NRW-4
NGE
EOB @ -7ft.
NRW-5
(n/a)
NRW-6
NRW-7
(-9.8)
NRW-8
(-4.66)
SOIL TYPE 'C'
SOIL TYPE 'A'
SOIL TYPE 'C'
A
B
C
D
W
Figure 2.5
Hydrogeology
Slug Test Locations
Attempted Drill Locations
Drill Locations
Soil Boundary
Watershed Boundary
Rivers
Narrow River
Parcels
Land Use
Brushland
Commercial
Deciduous Forest
Developed Recreation
High Density Residential
Idle Agriculture
Institutional
Low Density Residential
Medium Density Residential
Medium High Density Residential
Medium Low Density Residential
Pasture
Transitional Areas
Vacant Land
Waste Disposal
Water
Wetland
NGE No Groundwater Encountered
EOB End of Boring
(-1.23) Feet to groundwater
FUSS & O'NEILL
Disciplines to Deliver
0
375
750
1,500
Feet
Data compiled by RIGIS and Town of Narragansett.

Riverdell Drive near Cinnamon Lane	NRW-1	EOB[2] @ -11feet. No water encountered.	Unable to install monitoring well.
Winter Berry & Woodsia Road	NRW-2	-7.43	7.98 inch/hr 15.96 feet/day[3]
Old Pine Road & Fernleaf Trail	NRW-3	-8.12	0.02 inch/hr 0.04 feet/day
Hillside Road & Orchard Avenue	NRW-4	EOB[1] @ -7feet. No water encountered.	0.35 inch/hr 0.70 feet/day[4]
Saybrook Avenue & Wampum Road	NRW-5	EOB[1] @ -14feet. No water encountered.	0.13 inch/hr 0.26 feet/day
Bridgetown Road near intersection of Lakeside Drive & Bridgetown Road.	NRW-6	Failed drill location. No results.	
Pettaquamscutt Avenue & Lakeview Drive	NRW-7	-9.80	3.99 inch/hr 7.98 feet/day
South River Drive & Woodridge Road	NRW-8	-4.66	7.98 inch/hr 15.96 feet/day

2.5 Regulatory Constraints

Permitting can be complicated. Several state and local agencies are likely to become involved in the approval process. Permits required may include:

- CRMC assent
- Town of Narragansett building permit
- RIDEM – Underground Injection Control (UIC) permit
- RIDEM – Rhode Island Pollutant Discharge Elimination System (RIPDES) permit
- RIDEM – water quality certification

This may result in iterative design process as well as implementation and construction scheduling. Nevertheless, a number of the potential review agencies are currently involved in the project's steering committee and should be able to guide it in a manner that facilitates permit review.

2.6 Other Siting Constraints

As with any construction project, the characteristics of the project area impose limitations on what can be built. Many have to do with the moisture content of the soil. This includes whether the area is either within a wetland and if the seasonal high groundwater is close to the soil surface. The type of soil as mentioned above in Section 2.4 also plays a part in the efficiency to which water drains through the soil and the soils ability to receive and manage runoff.

2 EOB: end of boring
3 Unable to install a monitoring well at this location. Based on the nature of the soil encountered in NRW-2, the K value would be similar to that for NRW-8.
4 Test performed in open hole. No monitoring well installed at this location.

Habitat may also limit the area where BMPs may be installed. One significant constraint is the existence of an endangered or threatened species habitat. RIDEM maintains a database and associated RIGIS mapping layer which depicts endangered species areas. These areas are regulated by RIDEM and CRMC. They are depicted in Figure 2.6.

Installation of structures, particularly subsurface structures, may be considerably constrained by underground utilities and buildings. In this area of Narragansett, there are approximately six (6) different utility companies with subsurface and/or aboveground lines. These companies include the following:

- Town of Narragansett
  - Drinking water
  - Storm water
- New England Gas
- Narragansett Electric
- Cox Cable
- Verizon Telephone
- United Water

As part of this project all of the utility companies in the area were contacted and current mapping for the project area was requested. To date, Fuss & O'Neill has not yet received mapping from any of the utilities or return phone calls from some of the companies.

The installation of filtration and/or infiltration systems will also be constrained by their proposed distance from an existing individual sewage disposal system (ISDS) or private well. Figure 2.6 shows the known systems in the area. It should be noted that 175 of the 221 assessor's lots reportedly with ISDS systems (as provided by the town) were actually found on Narragansett's GIS mapping. The other approximately 20% were not found or nonexistent parcels.

2.7 Available Land

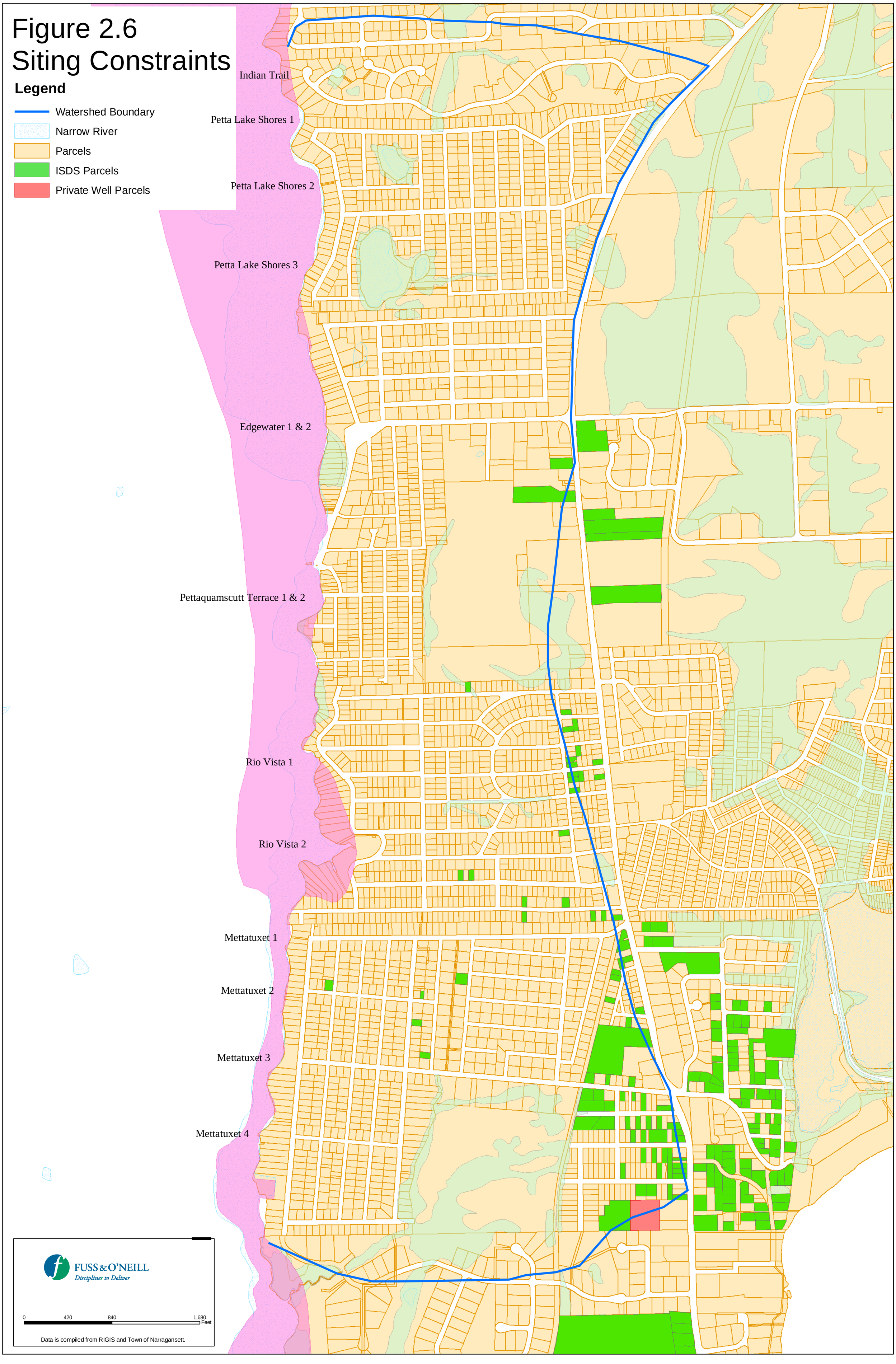
A possible constraint on the flexibility of this project is property ownership, or the lack thereof, by the town. A simple method of decreasing bacteria loading to the Narrow River may not be available given the limited public ownership in the most practical locations in terms of storm water treatment. The Steering Committee may need to explore the option of acquiring land or easement.

As stated above, two of the outfalls have associated drainage easements, two are near existing town-owned property, and two have undeveloped land nearby (see Figure 2.7). In the case of the two outfalls near undeveloped land, the town will need to establish an easement on or directly purchase the land in order to install treatment structures. In some cases subsurface storm water treatment practices could be installed within the road right-of-way. Infiltrating catch basins can directly replace existing catch basins to provide for

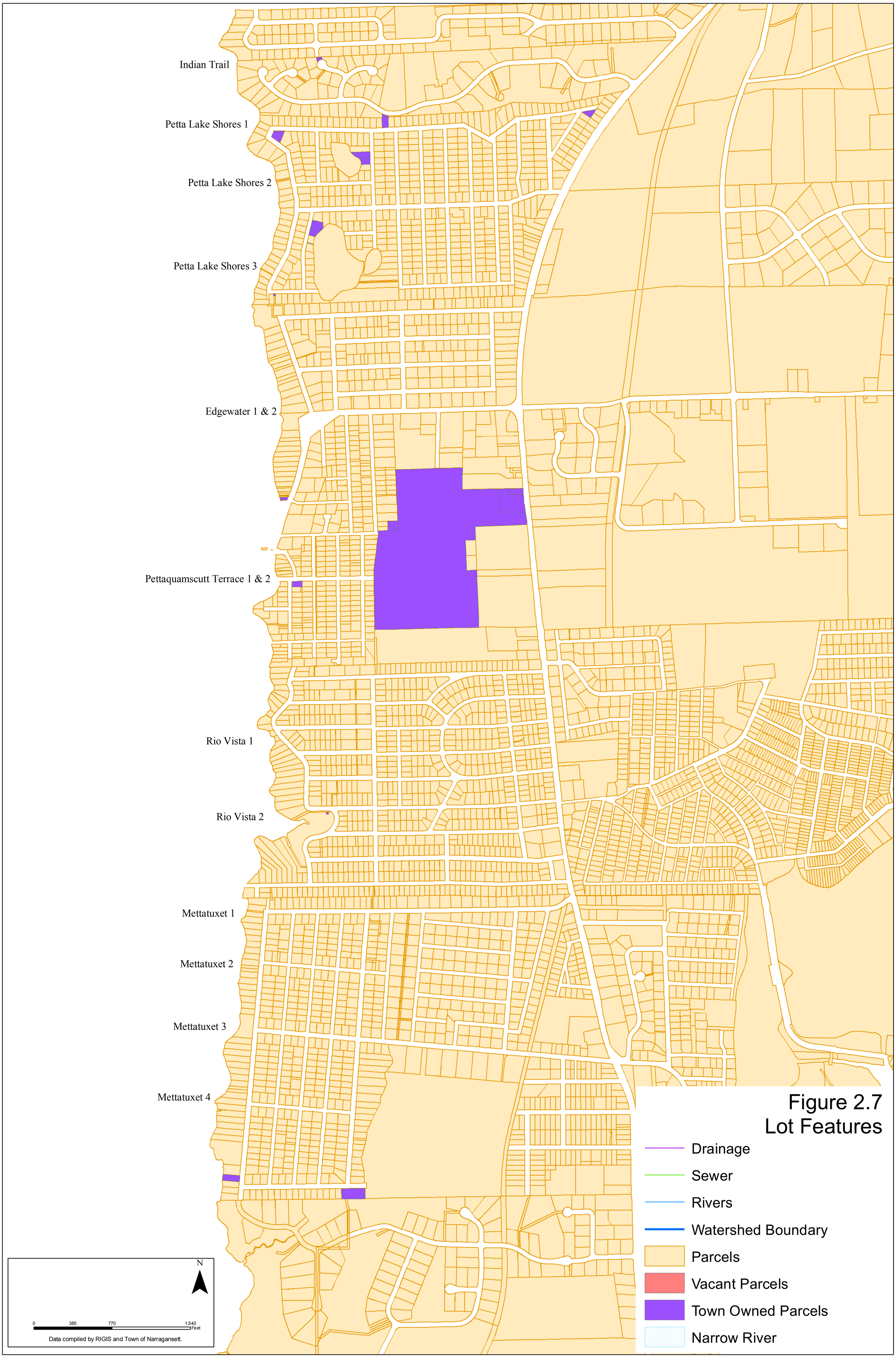
Figure 2.6
Siting Constraints

Legend

- Watershed Boundary
- Narrow River
- Parcels
- ISDS Parcels
- Private Well Parcels



Data is compiled from RIGIS and Town of Narragansett.


Indian Trail
Petta Lake Shores 1
Petta Lake Shores 2
Petta Lake Shores 3
Edgewater 1 & 2
Pettaquamscutt Terrace 1 & 2
Rio Vista 1
Rio Vista 2
Mettatuxet 1
Mettatuxet 2
Mettatuxet 3
Mettatuxet 4
Figure 2.7
Lot Features
Drainage
Sewer
Rivers
Watershed Boundary
Parcels
Vacant Parcels
Town Owned Parcels
Narrow River
N
0
385
770
1,540
Feet
Data compiled by RIGIS and Town of Narragansett.

treatment and many manufactured infiltration systems are designed to handle different loading such as that which is seen on residential roadway.

However, even in the locations where the town has an established easement or directly owns property, public support must still be established. This is of particular importance if an above-ground system is installed such as a water quality swale. Local residents will need to be educated regarding the importance of maintaining a clean path in the system for the storm water to flow and infiltrate; free of debris and yard waste.

3.0 OUTFALL RECONNAISSANCE

Participants of the July 1, 2005 watershed walkover investigated seven (7) outfalls. Below is a summary of investigation results. Following the below table is a more in-depth discussion of the outfalls including opportunities and constraints. Additionally, Appendix C contains additional information and photographs of the outfall, which was provided by the Town of Narragansett and included in their Phase II Storm Water Management Plan.

Table 3.1
Outfall Investigation Results

Outfall	Location	Land Availability	Comments
Indian Trail	Bow Run & Indian Trail	Upland parking lot (neighborhood beach). No easement associated with outfalls.	System should not compromise the proper flow of storm water either to or from outfall and catch basins.
Pettaquamscutt Lake Shores1	Waterberry & Woodsia Road	None – in road shoulder only	Outfall serves only one (1) catch basin (as depicted on town mapping).
Pettaquamscutt Lake Shores 2	Woodsia Road and Shadbush Trail	20-foot easement in between developed residential lots.	Space is limited.
Pettaquamscutt Lake Shores 3	Woodsia Road	None – in street only	Outfall serves only two (2) catch basins (as depicted on town mapping).
Edgewater 1 & 2	Lakeside Drive & Bridgetown Road	Long stretch of undeveloped land just upstream of outfalls. Owned by developer of the nearby subdivision. No easement associated with outfalls.	The outfall pipes show significant damage and are in need of repair or replacement.
Pettaquamscutt Terrace 1 & 2	Shore Drive & Pettaquamscutt Avenue	Town owned property slightly east and south of the outfall (partially developed with existing pump station)	Slope of the discharging pipe was shallow (flat). May have wetland plants around the discharge area.
Mettatuxet 1	North River Drive & Old Pine Road	10-foot easement across a developed residential lot.	Space is limited and many utilities in the upland roadway.
Mettatuxet 3	North River Drive & Shagbark Road	None – in street only	Space is limited and many utilities in the upland roadway.
Mettatuxet 4	North River Drive &	Town-owned property (partially developed with	No wetland observed.

	Woodridge Road	existing pump station) between two developed residential lots. Approximately 100 linear feet from the back of the pump station to the outfall.	

3.1.1 Indian Trail Outfall

The Indian Trail outfall is located near the intersection of Bow Run and Indian Trail as depicted on Figure 3.1. The outfall catchment includes the Forest Lakes neighborhood of the town. This is a medium-density residential area. Per town documents and mapping, this area is 100% sewered.

The outfall runs beneath a gravel parking lot for the neighborhood's beach. The parking lot has ample space for the installation of a subsurface structure(s) including an underground infiltration or sand filter system. The current rip-rap swale leading to the river could also be upgraded to a vegetated swale or infiltration trench. Although this drain line does not have a formal easement, the Forest Lakes Preservation Association is likely to cooperate with the town. Disconnected catch basin-infiltration units may also be possible in the upland area to decrease the amount of flow at the outfall.

3.1.2 Pettaquamscutt Lake Shores 1 Outfall

The Pettaquamscutt Lake Shores 1 Outfall is located near the intersection of Waterberry and Woodsia roads as depicted on Figure 3.2. Per town mapping, this outfall serves only one catch basin in the Pettaquamscutt Lake Neighborhood. This neighborhood is a densely populated residential area and according to town documents is 99% sewered.

The storm sewer lies between two developed lots and the town does not have a drainage easement for the area. Given that this system does not serve a large area and that there is a lack of space to install a treatment structure, this area should probably be removed from consideration for end-of-pipe treatment. Smaller disconnected catch basin-infiltration units may be possible given the limited space. Upland BMPs, particularly on-lot practices, will continue to be considered.

3.1.3 Pettaquamscutt Lake Shores 2 Outfall

The Pettaquamscutt Lake Shores 2 Outfall is located near the intersection of Woodsia Road and Shadbush Trail as depicted on Figure 3.3. This outfall drains the portion of Shadbush Trail west of the pond, north of the same road and west of Wake Robin Trail. The upland watershed is medium- to high-density residential with over 99% of the homes using sanitary sewer connections (per Town documents).

A 30-inch reinforced concrete pipe lies between two developed lots. This storm sewer line does, however, have associated drainage easements. These easements give the town a right-of-way width of 20 feet (10 feet per lot). The easements may allow for a small, efficiently

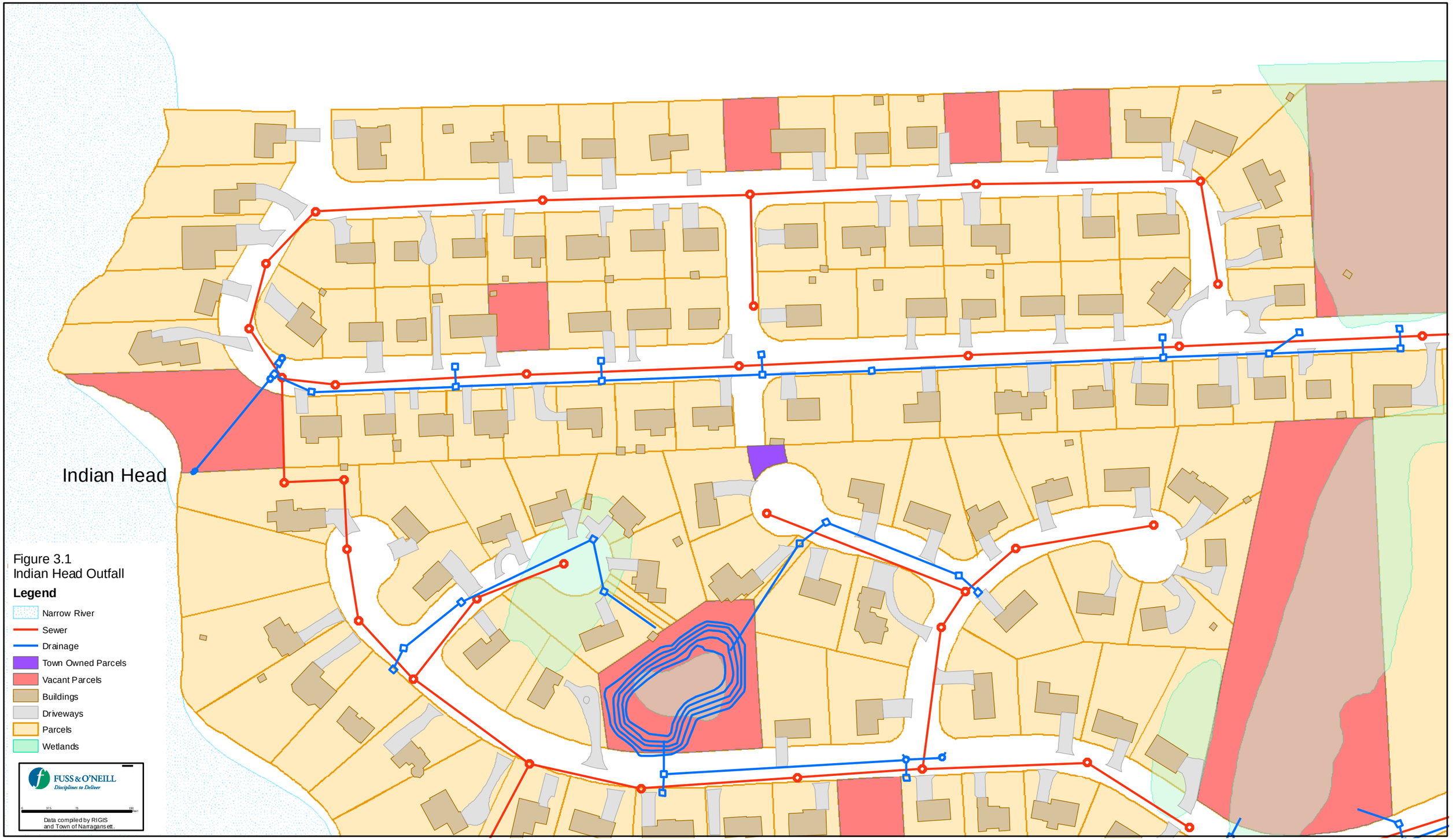
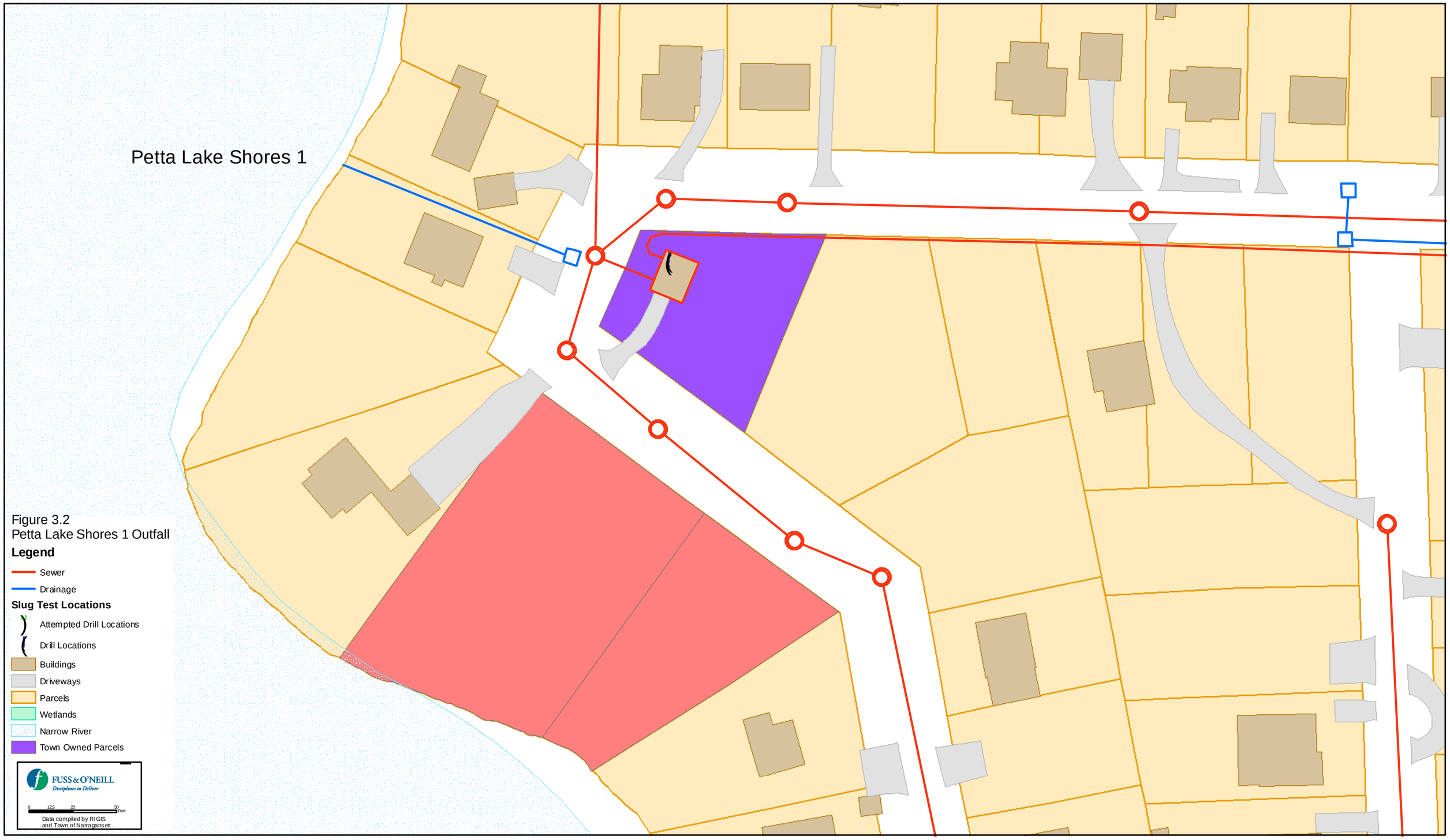
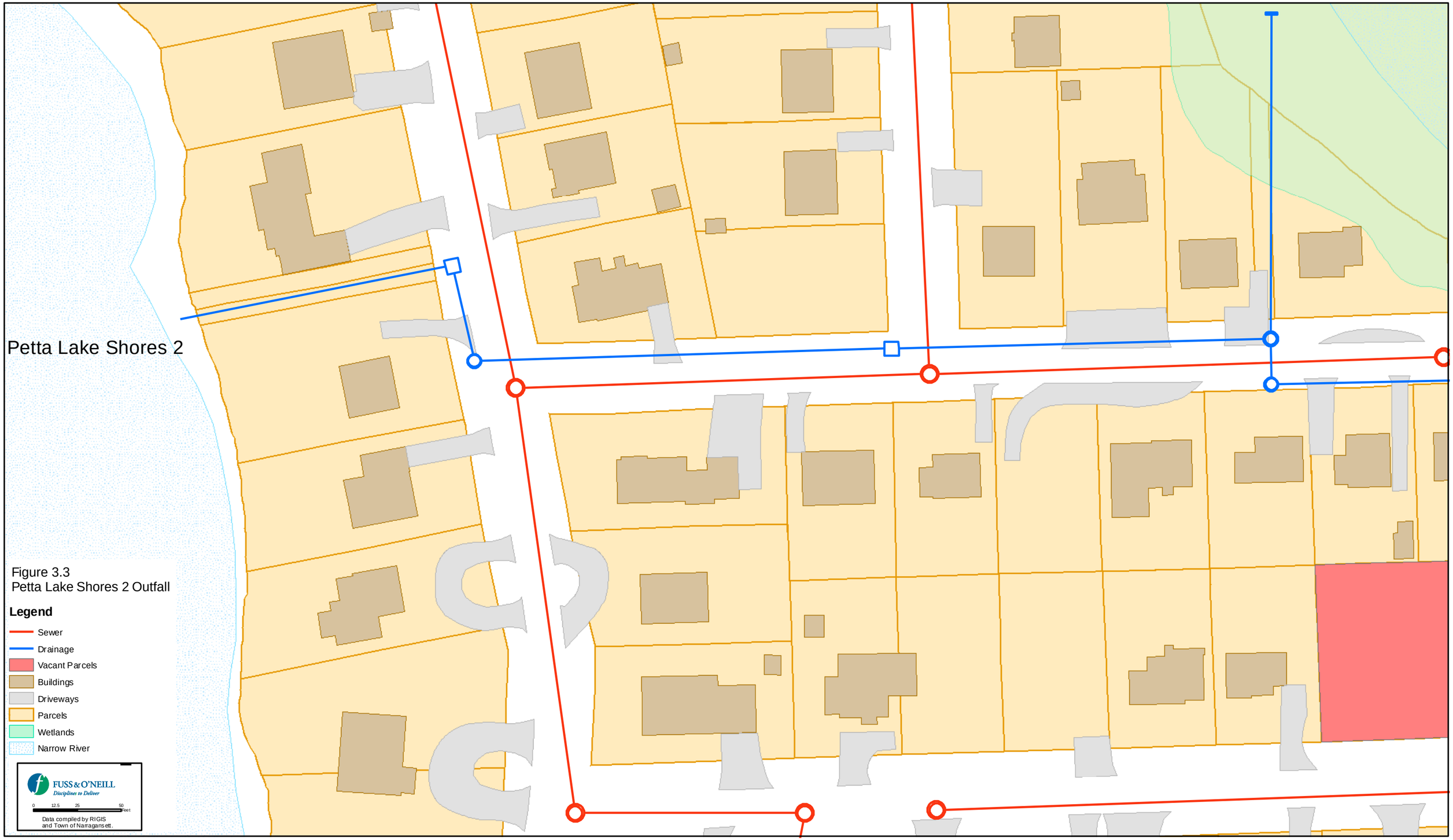


Figure 3.1
Indian Head Outfall


Petta Lake Shores 1
Figure 3.2
Petta Lake Shores 1 Outfall
Legend
Sewer
Drainage
Slug Test Locations
Attempted Drill Locations
Drill Locations
Buildings
Driveways
Parcels
Wetlands
Narrow River
Town Owned Parcels
FUSS & O'NEILL
Disciplines to Deliver
0 12.5 25 50 Feet
Data compiled by RIGIS
and Town of Narragansett.


Petta Lake Shores 2
Figure 3.3
Petta Lake Shores 2 Outfall
Legend
Sewer
Drainage
Vacant Parcels
Buildings
Driveways
Parcels
Wetlands
Narrow River
FUSS & O'NEILL
Disciplines to Deliver
0 12.5 25 50 Feet
Data compiled by RIGIS
and Town of Narragansett.

arranged end-of-pipe BMP such as an infiltration or sand filter system (to treat low volume of water). Disconnected catch basin-infiltration units may also be possible in the upland area to decrease the amount of flow at the outfall.

3.1.4 Pettaquamscutt Lake Shores 3 Outfall

The Pettaquamscutt Lake 3 Outfall is located north of the intersection of Woodsia Road and Baneberry Trail as depicted on Figure 3.4. This outfall discharges the storm water that is collected by two catch basins on Woodsia Road. This road is densely developed with residential properties. Reportedly, over 99% of the neighborhood is sewered.

An 8-inch reinforced concrete storm sewer line discharges to the river at the edge of a residential property. There is no town drainage easement associated with this outfall. Given that this system does not serve a large area and has limited space to install a treatment structure, this may not be an area for further consideration for end of pipe treatment. Smaller disconnected catch basin-infiltration units may be possible given the limited space. Upland BMPs, particularly lot based practices, will continue to be considered.

3.1.5 Edgewater 1 & 2 Outfalls

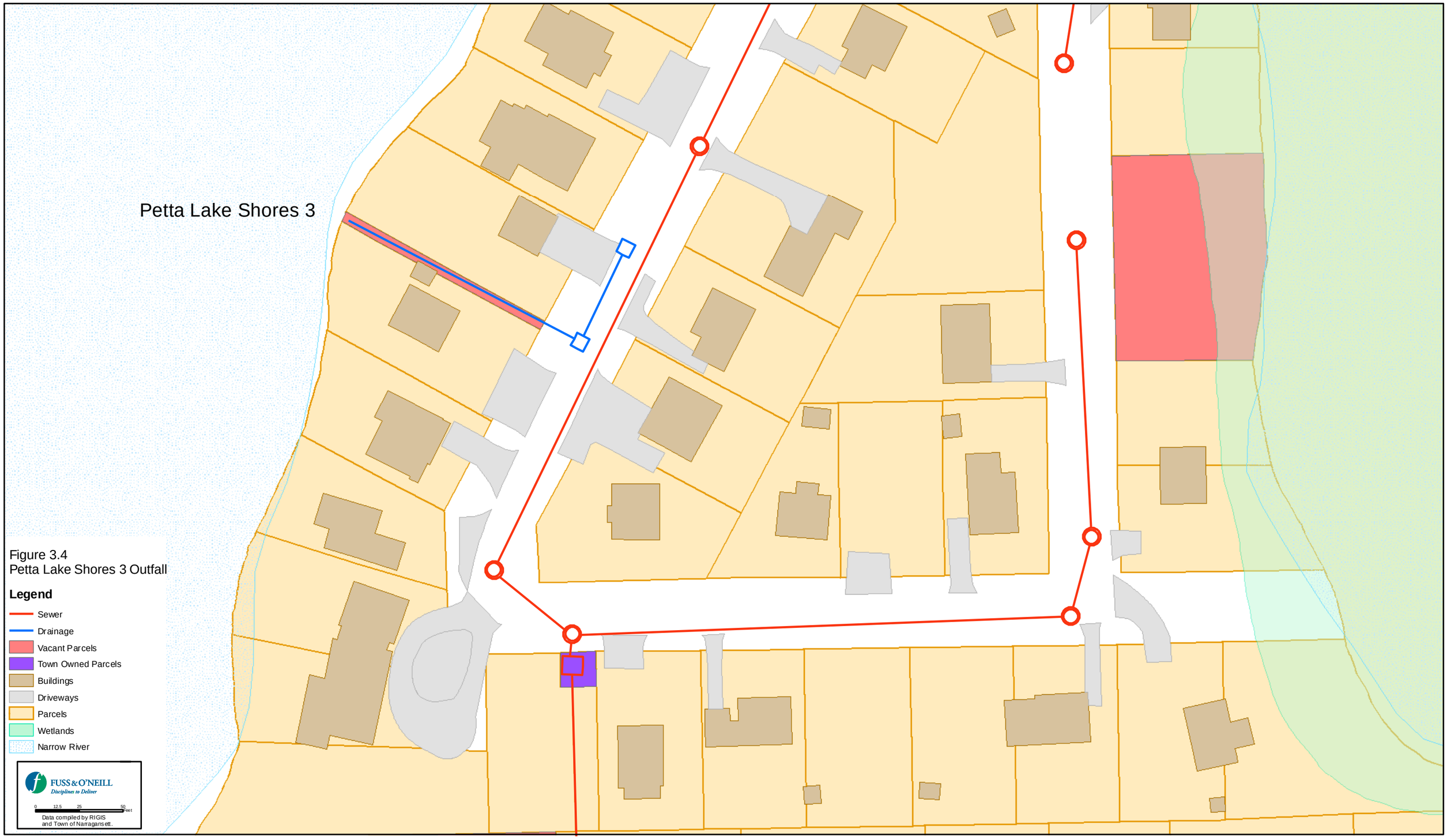
The Edgewater 1 & 2 outfalls are located west of the intersection of Lakeside Drive and Bridgetown Road as depicted on Figure 3.5. The Edgewater 1 Catchment includes the Edgewater Neighborhood while Edgewater 2 includes much of Bridgetown Road and parts of the Pettaquamscutt Terrace Neighborhood (Pontiac Road) to the south of the discharge point. The catchment of these outfalls is moderately densely populated with residential development. The town reports that 100% of the watershed is sewered.

Two outfall pipes lie beneath an undeveloped, but privately owned lot. Currently, the two reinforced concrete pipes are in need of repair. If the now-undeveloped land can be purchased for storm water development, this area could be used to site an end-of-pipe treatment structure of significant size such as a water quality swale or an underground infiltration or sand filter system. Disconnected catch basin-infiltration units may also be possible in the upland area to decrease the amount of flow at the outfall.

3.1.6 Pettaquamscutt Terrace 1 & 2 Outfalls

The Pettaquamscutt Terrace 1 & 2 outfalls are located slightly southwest of the intersection of Shore and Wilson Drives, in line with Pettaquamscutt Avenue as depicted on Figure 3.6. These storm sewer systems captures runoff from the Pettaquamscutt Terrace neighborhood, a densely populated residential area. Town documents indicated that 100% of the homes are connected to the sanitary sewer system installed in 1997.

The two reinforced concrete pipes discharge under a town right-of-way (60 feet wide) to the west of a town-owned lot containing a municipal sewer pump station. Although ample town-owned land exists for a future treatment system, field observations point to other constraints that may limit development, particularly high groundwater. High groundwater typically limits the permeability of the soil. There are also many utilities lines in this area


Petta Lake Shores 3
Figure 3.4
Petta Lake Shores 3 Outfall
Legend
Sewer
Drainage
Vacant Parcels
Town Owned Parcels
Buildings
Driveways
Parcels
Wetlands
Narrow River
FUSS & O'NEILL
Disciplines to Deliver
0 12.5 25 50 Feet
Data compiled by RIGIS
and Town of Narragansett.

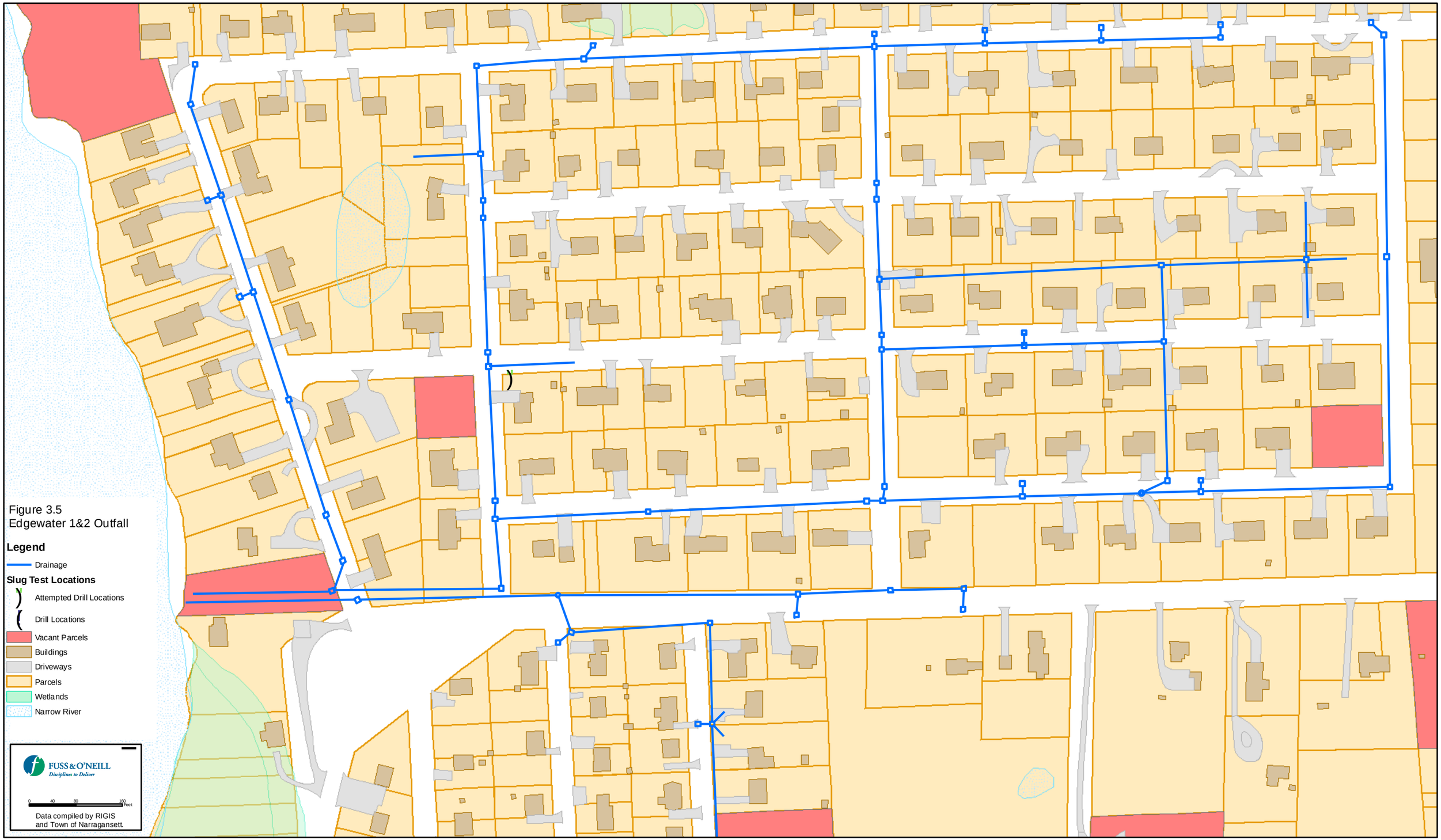


Figure 3.5
Edgewater 1&2 Outfall

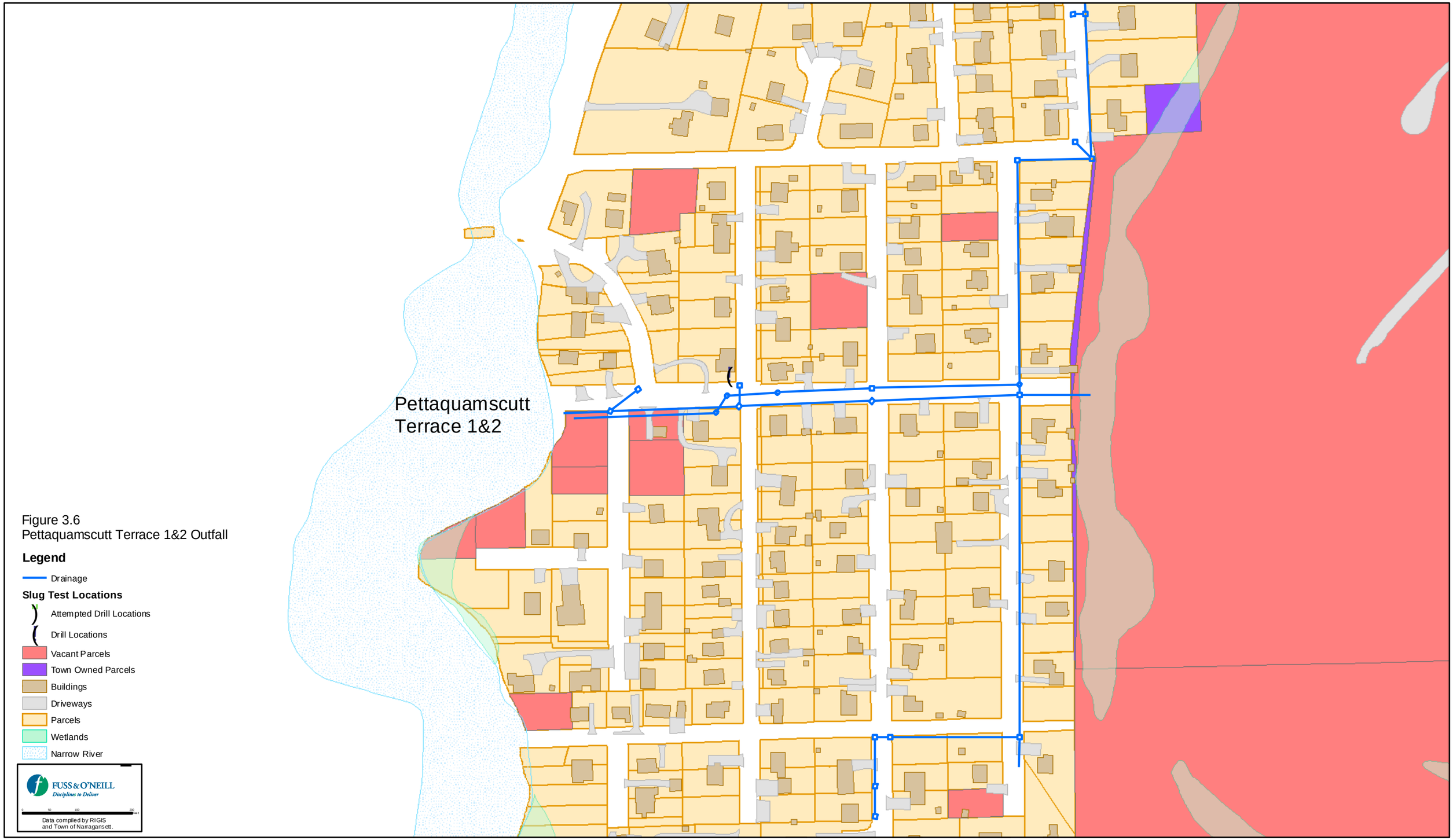


Figure 3.6
Pettaquamscutt Terrace 1&2 Outfall

which limit available space, even on the southern portion, which is currently wooded. This, as with all potential construction locations, will need to be further investigated for feasibility. If upland catch basins rerouting is possible, installation of an infiltration or sand filter system may be possible. If not, an alternative may be to install the systems within the roadway right-of way. Such a system will probably be limited to single-unit width as there are many utility lines in the area (i.e., gas, sewer, etc.). Upland BMPs, particularly lot-based practices, will continue to be considered.

3.1.7 Mettatuxet 1 Outfall

The Mettatuxet 1 outfall is located in line with Old Pine Road as depicted in Figure 3.7. This system captures runoff from a portion of the Mettatuxet neighborhood including some of Old Pine Road and Checkerberry Trail. This neighborhood is densely populated residential area. Town documents indicated that 100% of the homes are connected to the sanitary sewer system installed in 1997. Per town documents, over 99% of the houses are connected to the sanitary sewer system.

The 30-inch reinforces concrete pipe discharges through a privately owned lot into the Narrow River. The town has a 10-foot drainage easement associated with this outfall. Given that there is limited space to install treatment structures, this may not be an area for further consideration for end of pipe treatment. Smaller disconnected catch basin-infiltration units may be possible given the limited space. Upland BMPs, particularly lot based practices, will continue to be considered.

3.1.8 Mettatuxet 3 Outfall

The Mettatuxet 3 outfall is located near the intersection of South River Drive and Shagbark Road as depicted on Figure 3.8. This outfall drains storm water for the middle portion of the Mettatuxet neighborhood, as stated above, a densely populated residential area. This, as with Mettatuxet 2 and 4 watersheds, is a neighborhood where 99% of the homes are properly connected to the town's sanitary sewer system starting in the early 1980's.

The 30-inch reinforces concrete pipe discharges to the Narrow River at the edge of a developed residential lot. There is no town drainage easement associated with this outfall. Given that there is limited space to install treatment structures, this may not be an area for further consideration for end of pipe treatment. Smaller disconnected catch basin-infiltration units may be possible given the limited space. Upland BMPs, particularly lot based practices, will continue to be considered.

3.1.9 Mettatuxet 4 Outfall

The Mettatuxet 4 outfall is located near the intersection of North River Drive and Woodridge Road as depicted on Figure 3.9. The catchment of this outfall includes all of Woodridge Road and portions of roadways to the north of Woodridge running perpendicular to it. This neighborhood is densely populated with residential development. Reportedly, over 99% of the neighborhood is sewered as sanitary sewers were installed in the 1980's.

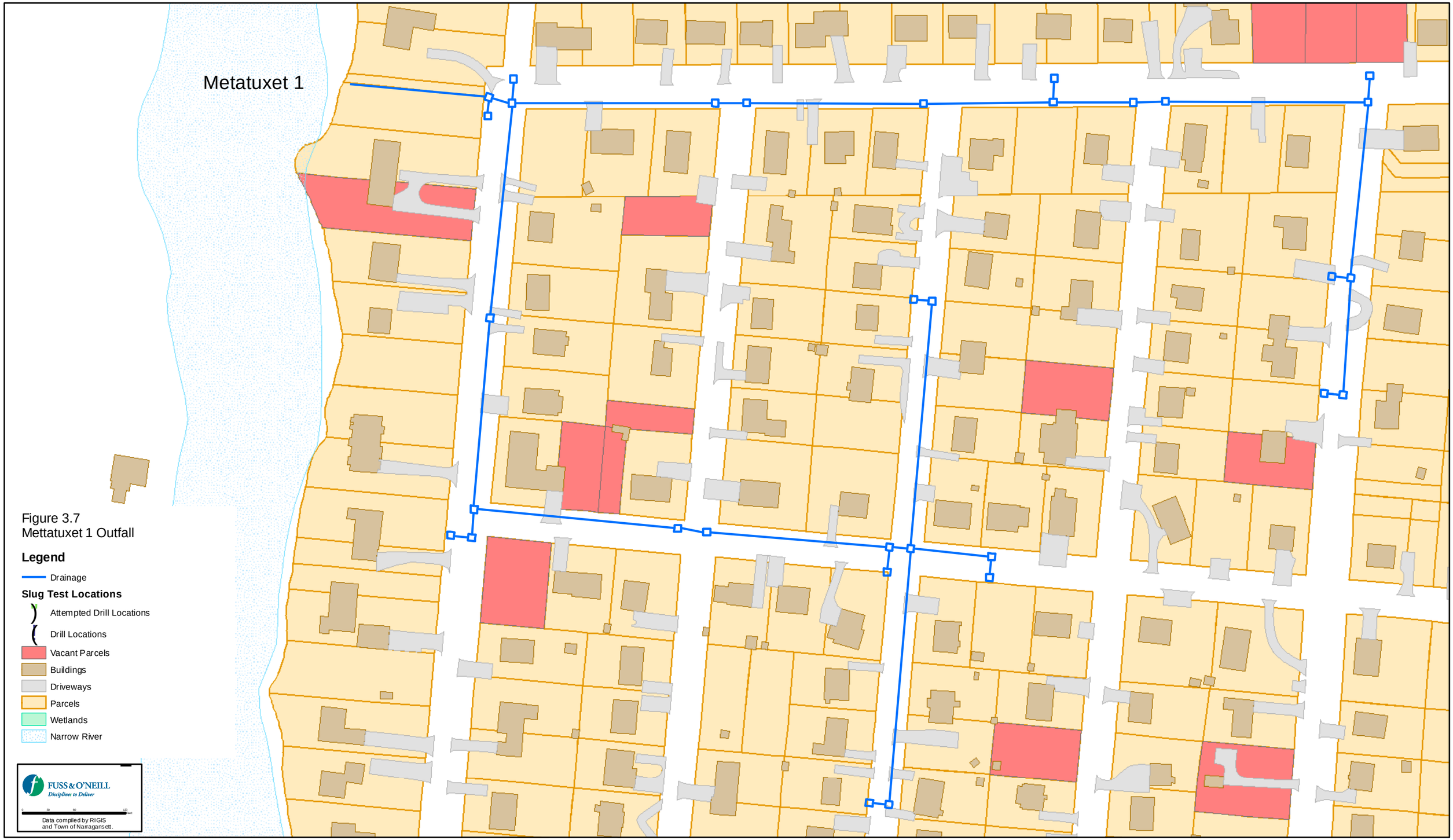
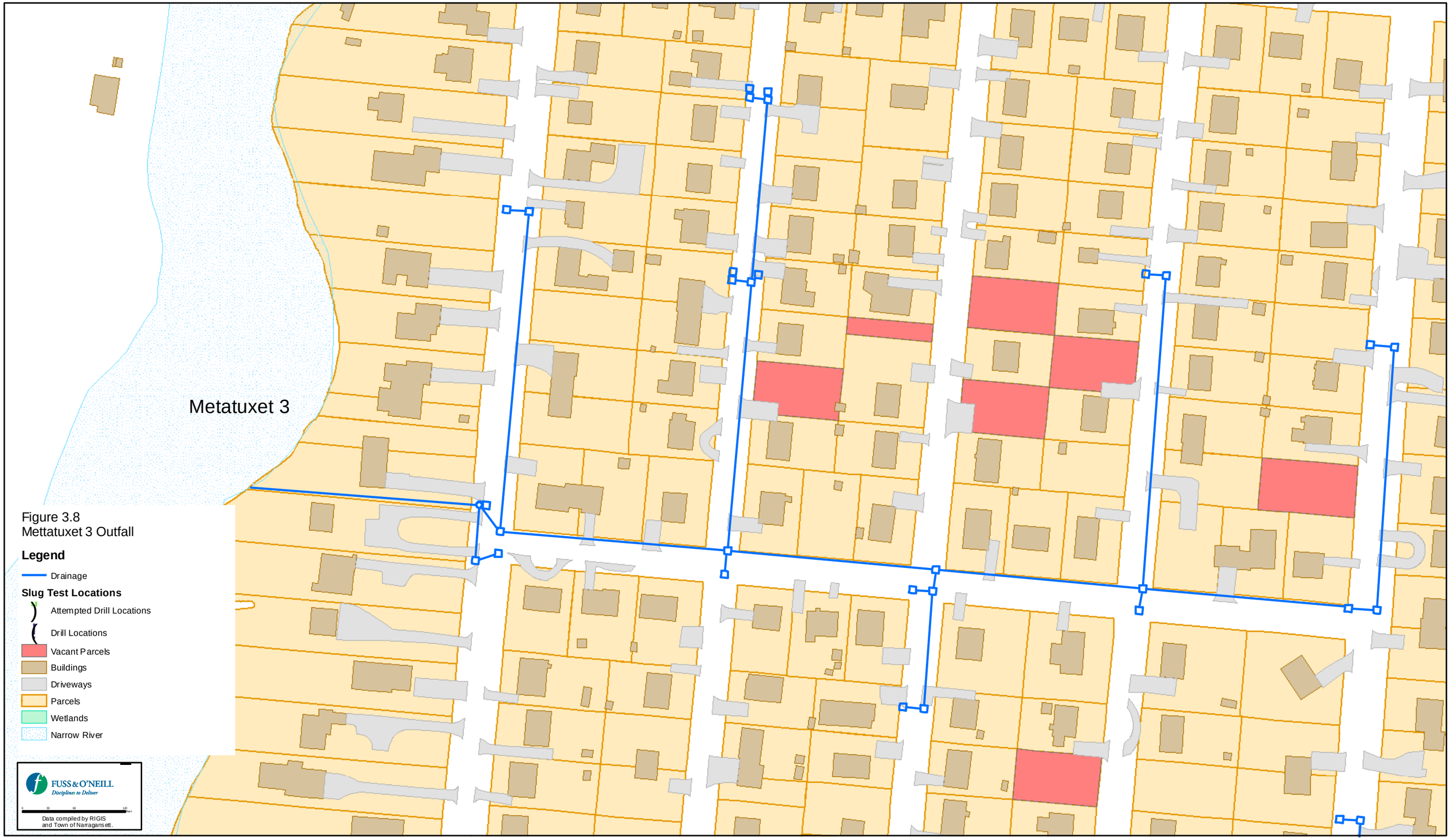
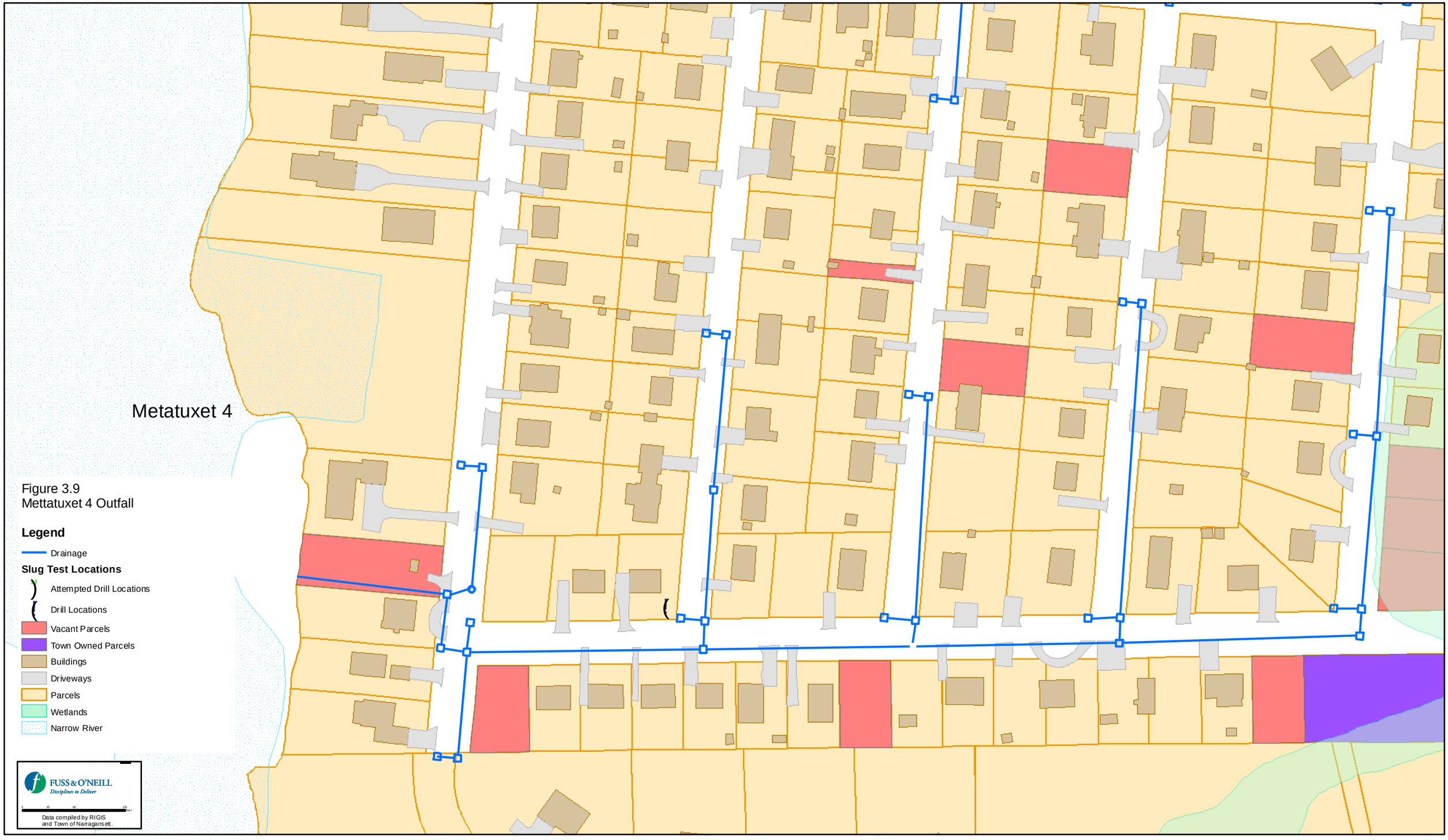


Figure 3.7
Mettatuxet 1 Outfall


Metatuxet 3
Figure 3.8
Mettatuxet 3 Outfall
Legend
Drainage
Slug Test Locations
Attempted Drill Locations
Drill Locations
Vacant Parcels
Buildings
Driveways
Parcels
Wetlands
Narrow River
FUSS & O'NEILL
Disciplines to Deliver
Data compiled by RIGIS
and Town of Narragansett.


Metatuxet 4
Figure 3.9
Mettatuxet 4 Outfall
Legend
Drainage
Slug Test Locations
Attempted Drill Locations
Drill Locations
Vacant Parcels
Town Owned Parcels
Buildings
Driveways
Parcels
Wetlands
Narrow River
FUSS & O'NEILL
Disciplines to Deliver
0
30
60
120
Feet
Data compiled by RIGIS
and Town of Narragansett.

The 30-inch reinforces concrete pipe discharges through a privately owned lot into the Narrow River. However, the town owns an adjacent lot just south of the discharge point. This lot is the location of one of the town's sanitary sewage pump stations. This appears to be a promising location for a storm water treatment structure. Possible treatments include an underground infiltration, sand filter system, or water quality swale. Disconnected catch basin-infiltration units may be possible in the upland area to reduce flow to the outfall; however, space is too limited for in-line systems to fit. It should be explored whether other nearby storm water sewers can be joined to discharge and thus be treated at this location.

4.0 CONTROL STRATEGIES AND CONCEPTUAL DESIGNS

Traditionally, stormwater has been managed using large, structural practices installed at the low end of development sites, essentially as an afterthought, on land segments left over after subdividing property. This approach, sometimes referred to as end-of-pipe management, yields the advantages of centralizing control, but has a limited capacity to abate both the water quality and hydrologic impacts of urbanization. End-of-pipe management can be especially difficult to implement in developed watersheds where available land may be limited or inappropriate for BMP construction. In the last decade, alternative BMP approaches that employ decentralized management practices and allow storage of stormwater in the upland have been established. These alternative approaches mimic undeveloped landscape and reduce reliance on end-of-pipe structures.

Among these approaches, source reduction is an innovative approach where the feasibility of retrofitting individual house lots with various stormwater management practices to reduce hydrologic loadings is investigated.

This study examines hybrid retrofit options and considers source controls as well as combinations of upland and end-of-pipe opportunities to provide advantageous solutions.

4.1 Potential Strategies

BMPs proposed in this technical memorandum are based on descriptions, terminology and standards in the draft Rhode Island Stormwater Manual. BMPs that may be used to attenuate bacteria and nitrogen loadings and recharge groundwater (i.e., baseflow) are listed below.

Practices and Strategies

Filtration and infiltration

- Sand filters
- Bioretention
- Infiltration trenches
- Disconnected catch basins and proprietary infiltration units
- Dry wells
- Subsurface perimeter and pocket filtration and infiltration units
- Permeable pavement

Sidewalk storage
Engineered vegetative strips and conveyances
Vegetated strips
Natural and vegetated conveyances
Impervious surface disconnection
Pavement disconnection
Roof leader disconnection
Preserved natural areas
Roof runoff detention (rain barrels and cisterns)
Pollution prevention
Soil amendments
Lawn conversion
Soil building
Grass selection
Mowing and thatch management
Minimizing fertilization
Weed and pest management
Sensible irrigation

Sections 4.1.1 –5 provide detailed descriptions of each BMP. The descriptions are provided to familiarize readers with the potential use of each BMP. Readers that are familiar with these BMPs may wish to proceed to Section 4.2, Identifying Appropriate Stormwater Practices for Narrow River Watershed (see page 18). It also includes specialized BMP applications, for example parking lot islands, which may involve the use of either filtration or infiltration BMPs on planted median strips in parking lots.

4.1.1 Filtration and Infiltration

Both filtration and infiltration percolate runoff through a media, such as graded sand, in order to reduce pollution by straining out particulates and chemically converting dissolved constituents (e.g., via denitrification). Infiltration provides the added benefit of groundwater recharge since treated effluent discharges to the underlying soil. Filtration and infiltration are both effective mechanisms for treatment of bacteria and nitrogen.

The capacities of filtration and infiltration practices are limited by their ability to drain water within 48 hours. Capacity is therefore a function of the infiltration rate of the filtering media (i.e., sand and/or soil) and the surface area of media over which effluent may be applied. Implications for treatment capacity in the Narrow River Watershed are discussed in Section 3.

The following is a general discussion of filtration and infiltration BMPs as well as some specialized BMP applications.

- Filtration and infiltration.[5]

[5] Filtration and infiltration BMPs are generally considered to be different categories of BMP; however, this memorandum groups them together as they use the same basic pollution removal mechanism (i.e., filtering) and

    - Sand filters.
    - Bioretention.
    - Infiltration trenches.
    - Disconnected catch basins and proprietary infiltration units.
    - Dry wells.
    - Subsurface perimeter and pocket filtration and infiltration units.
    - Permeable pavement.
    - Sidewalk storage.
- Engineered vegetative strips and conveyances.
    - Vegetated strips.
    - Natural and vegetated conveyances.
- Impervious surface disconnection.
    - Pavement disconnection.
    - Roof leader disconnection.
    - Preserved natural areas.
- Roof runoff detention (rain barrels and cisterns).
- Pollution prevention via grounds management.
    - Soil amendments.
    - Lawn conversion.
    - Soil building.
    - Grass selection.
    - Mowing and thatch management.
    - Minimizing fertilization.
    - Weed and pest management.
    - Sensible irrigation.

Sand filters

Sand filters capture and store stormwater, which flows through an engineered sand media for pollutant removal. Sand filters may be constructed at grade or subsurface. Sand filters are primarily for water quality control (i.e., treatment of WQV). Peak flow control typically requires a separate facility. Most sand filter systems consist of four design components:

- Inflow regulation to divert the water quality volume into the facility.
- Pretreatment to capture coarse sediments.
- Filter surface and media.
- Outflow mechanism to return treated flows back to the conveyance system or into the soil.

Sand filters are usually designed as off-line systems with a bypass for flows larger than WQV. In the storm drainage network, the water quality volume is diverted into a pretreatment settling chamber or forebay where coarse solids are allowed to settle. This reduces the amount of sediment that reaches the filter and improves filter efficiency. Water flows to the filter surface, where finer sediment and attached pollutants are trapped or

may be converted (i.e., infiltration to filtration or filtration to infiltration) with the addition or deletion of an underdrain system.

strained out; and breakdown and conversion of pollutants such as nitrogen may occur. A subdrain collects the effluent and returns it to the conveyance system.

Sand filters are commonly used to treat runoff from small sites, for example parking lots and small developments, areas with high pollution potential such as industrial sites, or highly urbanized areas where space is limited. A number of surface and underground stormwater filter design variations have been developed for these types of applications. Underground filters can be placed under parking lots and are well-suited to highly urbanized areas or space-limited sites since they do not consume surface space.

Bioretention

Diagram 4.1 Picture of Biorentention. Source: Adapted from Prince Georges County, 2001.

A bioretention system (Diagram 4.1) consists of a soil bed planted with native vegetation located above a sand layer. Bioretention systems may either infiltrate or return treated flows back to the storm drain system via a sub drain. In a subdrained system, stormwater runoff enters the bioretention system, filters through vegetation as well as a sand-soil mixture after which it enters an underdrain system to be conveyed back to the storm drain distribution system. Infiltrating bioretention systems have no subdrains, and therefore after treatment, effluent percolates into the underlying soil.

Bioretention systems are used to remove a wide range of pollutants, such as suspended solids, nutrients (including nitrogen), metals, hydrocarbons, and bacteria from stormwater runoff. Bioretention can also be used to provide a reduction in peak runoff rates. When designed to infiltrate, bioretention is also used to recharge to groundwater.

Bioretention systems are most effective when they receive runoff as close to the source of generation as possible. Bioretention systems can vary in size and can receive and treat runoff from a variety land uses. The systems can be installed in lawns, median strips, parking lot islands, unused lot areas, and easements.

Infiltration trenches

An infiltration trench (Diagram 4.2) is an excavated trench that has been back-filled with stone to form a subsurface collection area. Stormwater runoff is diverted into the trench

and is detained until it can be infiltrated into the soil, which should occur in a period of no more than 48 hours. Infiltration trenches are very adaptable and the availability of many practical configurations makes them ideal for small urban drainage areas. They are most effective and have a longer life cycle when some form of pretreatment is included in their design. Pretreatment may include techniques like vegetated filter strips or grassed swales. Care must be taken to avoid clogging of infiltration trenches, especially during site construction activities.

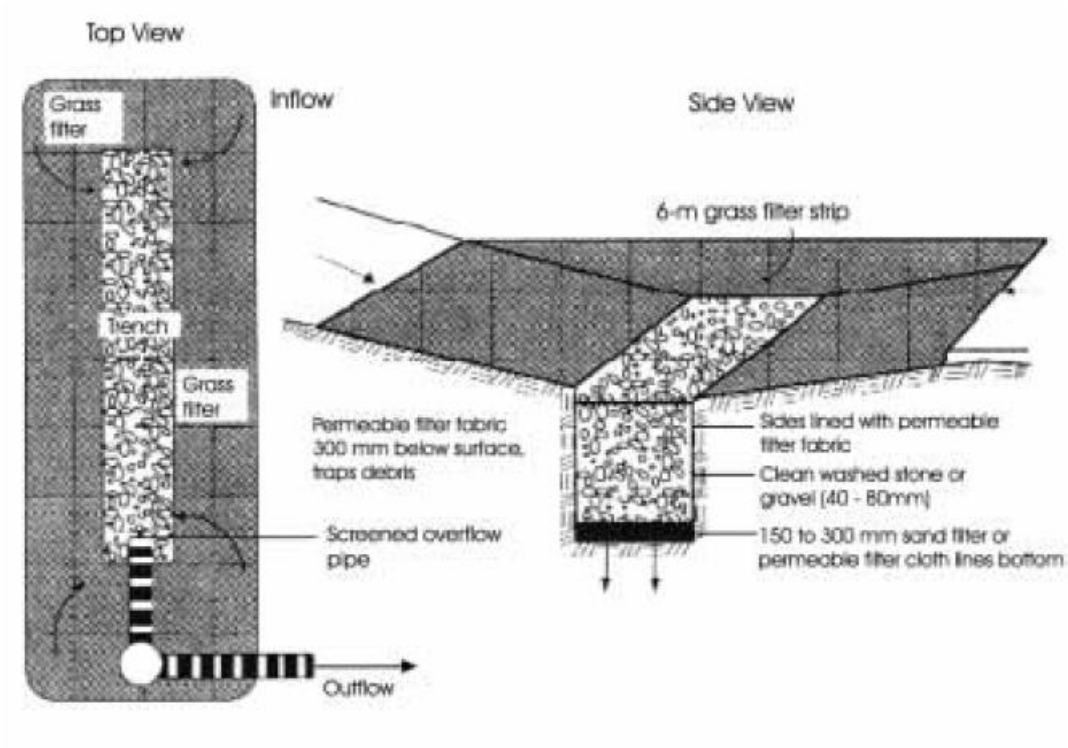


Diagram 4.2 – Infiltration Trench

Disconnected catch basins and proprietary infiltration units

Conventionally, storm sewer networks employ catch basins to collect surface water runoff, skim floatables and settle larger sediment particles such as road sand and convey runoff to drain pipes. Disconnected catch basins with proprietary infiltration units (referred to as disconnected catch basins) perform all these functions except that there is not a connection to a pipe network (with the exception of an overflow) and instead, infiltrate collected runoff through galleys, flow diffusers or proprietary infiltration units (e.g., Cultec, Stormceptor, Infiltrator, etc.). Disconnected catch basins are commonly sized to capture the water quality volume. Once the disconnected catch basins fill, larger volumes simply bypass the system. Disconnected catch basins may also be designed as off-line BMPs.

Dry wells

A dry well is a small, excavated pit, backfilled with stone aggregate. Dry wells function like disconnected catch basins, but are for control of roof runoff from residential or commercial buildings (see Diagram 4.3). Dry wells may also be used to treat runoff from residential

driveways, but are not typically used on parking lots or roadways where pollutants tend to concentrate at high levels.

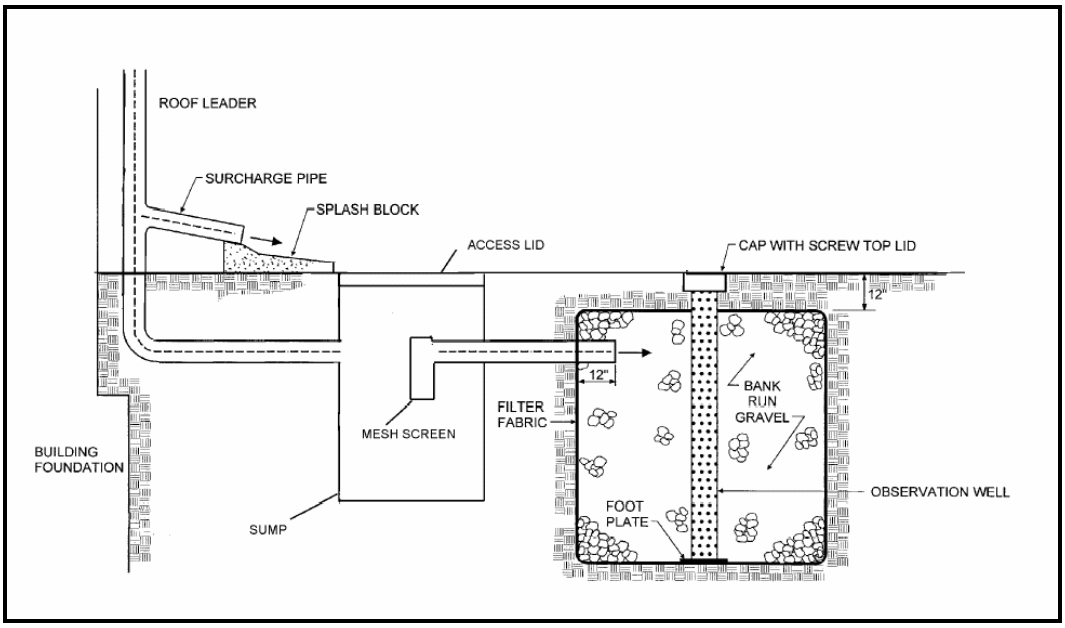


Diagram 4.3 Schematic of a drywell with optional sump to facilitate cleanout. Source: Adapted from New York, 2001.

Subsurface perimeter and pocket filtration and infiltration units

A number of management practices, such as filter strips, dry swales, sand filters and bioretention, lend themselves to small-scale applications. When used this way, they may be referred to as pocket systems because they fit into small unobvious pockets of land; or perimeter systems because they are sited on the edge or perimeter of a site. Two examples are depicted below in Diagrams 4.4 and 4.5.

Diagram 4.4: Parking lot island. Source: Adapted from Atlanta Regional Commission,

Diagram 4. 5: Cul-de-sac infiltration island accepts stormwater from surrounding pavement. Note flat curb. Source: Adapted from Connecticut, 2004.

Permeable pavement

Permeable pavement is designed to allow rain and snowmelt to infiltrate, thereby reducing runoff, promoting groundwater recharge, and filtering pollutants. Permeable paving materials include:

- Modular concrete paving blocks
- Modular concrete or plastic lattice
- Cast-in-place concrete grids
- Soil enhancement technologies
- Other materials such as gravel, cobbles, wood, mulch, brick, and natural stone.

Diagram 4.6 illustrates examples of common permeable pavement applications.

Diagram 4.6: Permeable pavement. Source: Adapted from Connecticut, 2004.

Porous pavement (i.e., porous asphalt, concrete or gap-graded pavement), which looks similar to traditional pavement but is manufactured without fine materials and incorporates additional void spaces, is only recommended for certain limited applications in Rhode Island due to potential for clogging and high failure rate in cold climates. Porous pavement is only recommended for sites that meet the following criteria:

- Low traffic applications (generally 500 or fewer average daily trips or ADT).
- The underlying soils are sufficiently permeable (see Design Considerations below).
- Road sand is not applied.
- Runoff from adjacent areas is directed away from the porous pavement by grading the surrounding landscape away from the site or by installing trenches to collect the runoff.
- Regular maintenance is performed (sweeping, vacuum cleaning).

This technical memorandum recommends that permeable pavement is considered by property owners as alternative to conventional pavements when repaving is to be done.

Sidewalk storage
As rainwater washes across streets and sidewalks it picks up pollutants such as bacteria. Runoff can be detained or infiltrated on and below impervious surfaces in urban areas to attenuate flows.

Most streets in the Narrow River Watershed do not have sidewalks. Where sidewalks exist, storage options will be considered in conjunction with upland treatment.

4.1.2 Engineered Vegetative Strips and Conveyances

Engineered vegetative strips and conveyances combine infiltration and the capacity to convey stormwater flow. These systems usually incorporate engineered soils and specialized vegetation.

Like filtration and infiltration, the treatment capacities of strips and conveyances are limited by their ability to infiltrate water into the underlying soil. Treatment is, therefore, a function of the infiltration rate and area of available land. Since these technologies convey very shallow flows, allowing for minimal detention and producing little head, water is treated less efficiently than infiltration or filtration systems. Water quality benefit and groundwater recharge can be achieved to some extent and may be enhanced with berms or check dams to encourage retention of small volumes.

Vegetated strips

Diagram 4.7 Vegetative filter strip. Source: Adapted from Connecticut, 2004.

A vegetated filter strip is an undisturbed densely vegetated area (e.g., well-tended lawn) contiguous with a developed area. These filter strips are most often located between a water resource and the developed portion of a site (see Diagram 4.7).

Filter strips serve to improve runoff water quality and may add wildlife habitat value. This type of BMP is best suited for complementing other structural methods utilized on-site for stormwater management. For this study, vegetative strips will be considered for use as source control and as potential adjuncts to upland and end-of-pipe BMPs.

4.8 a/b Source: Adapted from Atlanta Regional Commission, 2001.

Natural and Vegetated Drainage Ways

Natural drainage ways such as grass natural drainage systems (see 4.8 a/–b Diagrams) convey stormwater while providing some treatment and groundwater recharge.

The use of natural open channels allows for more storage of stormwater flows on-site, lower stormwater peak flows, a reduction in erosive runoff velocities, infiltration of a portion of the runoff volume, and the capture and treatment of stormwater pollutants. These systems are normally sized for specific volumes and flows. Like vegetative strips, natural drainage ways should be used as an enhancement to other water quality treatment BMPs.

4.1.3 Impervious Surface Disconnection

Disconnection BMPs utilize grading and level spreaders to encourage sheet flow across open spaces that are constructed and managed to allow for passive infiltration and recharge. By retaining part or all of the water quality volume from roofs and paved areas, they effectively eliminate a corresponding fraction of pollutant loads. Water quality treatment capacity of this BMP is limited to the first inch of runoff. The draft *Rhode Island Stormwater Manual* does not allow disconnection to be used for peak flow control.

Disconnection BMPs are generally less effective than more active practices like filtration and infiltration; however, when applied close to sources as part of treatment train, disconnection can form a key component of stormwater treatment. Disconnection may be especially beneficial for on-lot applications where active treatment may be impractical or inappropriate.

Pavement disconnection
Most runoff is generated by impervious surfaces. Impervious surfaces that are separated from drainage collection systems by pervious surface or infiltrating BMPs contribute less runoff and smaller pollutant loads. As grading and repaving are generally required for pavement disconnection and can be quite expensive, pavement disconnection is recommended for use when repaving is planned for other purposes.

The draft *Rhode Island Stormwater Manual* allows impervious surface disconnection to a pervious area, such as a lawn, for up to the first inch of runoff from the impervious surface. The area of the contributing impervious surface should not exceed 5,000 square feet. Diagram 4.9, below, demonstrates appropriate sizing and grading of a disconnection area.

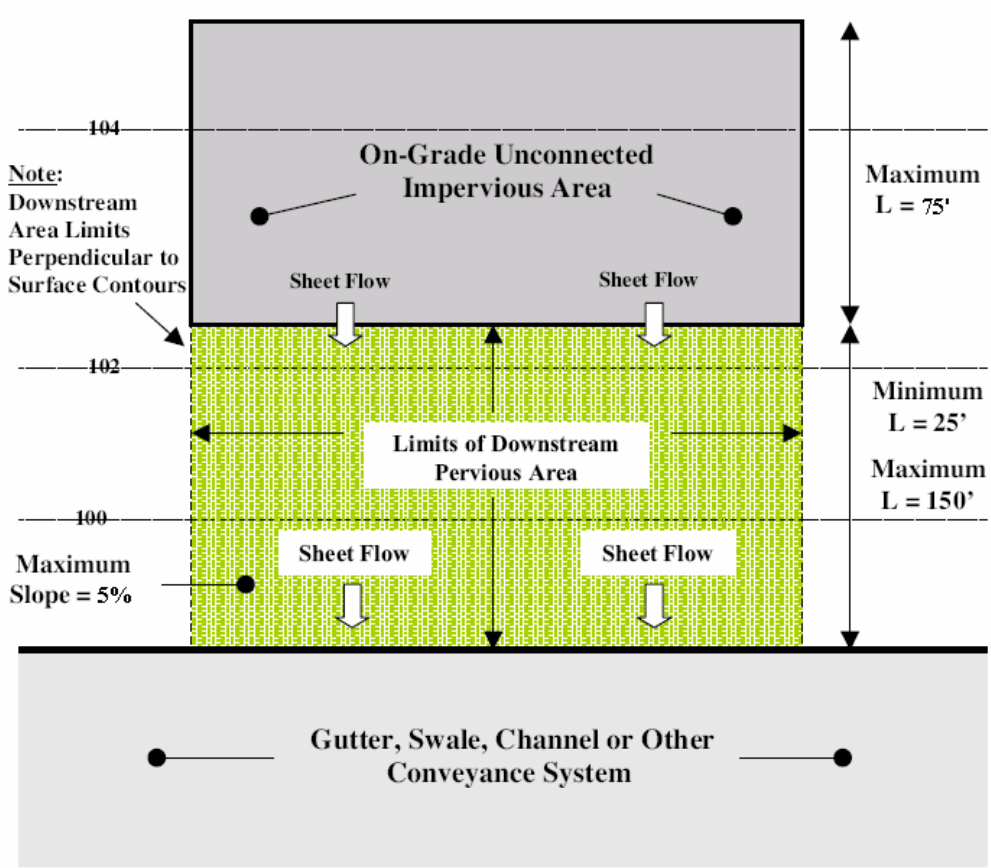


Diagram 4.9 Standards for disconnecting impervious surface via sheet flow. Source: Adapted from New Jersey Department of Environmental Protection, 2004.

Roof leader disconnection

Roof leader disconnection works similarly to pavement disconnection, except that flow from drain leaders must be managed to allow for expansion of shallow flow to sheet flow. Diagram 4.10 depicts appropriate sizing and grading. Roof leader disconnection is inexpensive, creates minimal disturbance and is generally applied as a source control BMP where many constructed practices may not be feasible. Due to the potential for drain leaders near driveways to reconnect, the draft *Rhode Island Stormwater Manual* only allows for disconnection of up to 75% of residential rooftops.

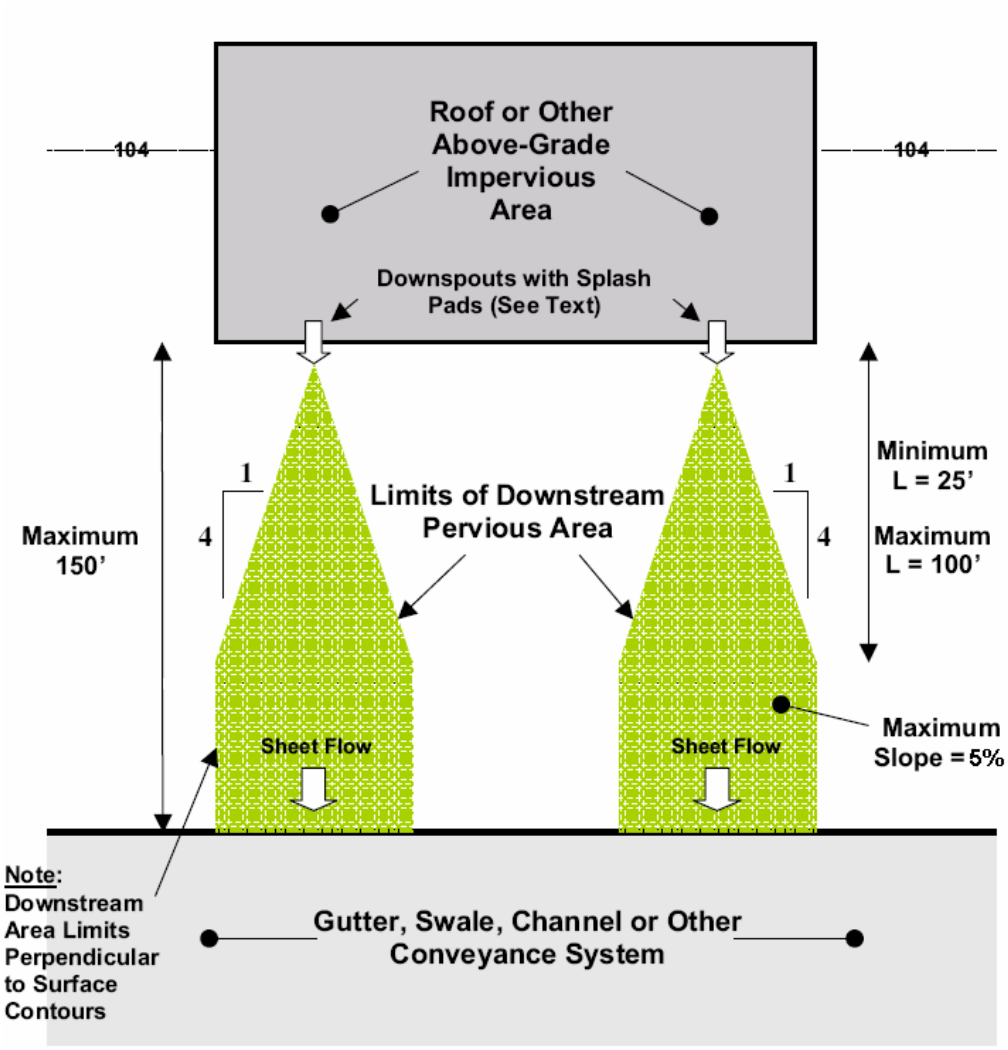


Diagram 4.10 Riparian buffer. Source: Adapted from Atlanta Regional Commission, 2001.

Preserved Natural Areas

Preserved natural areas may include woodlands, riparian corridors, areas contiguous to wetlands and other hydrologically sensitive and naturally vegetated areas. Natural areas can be one of the most important components within a development scheme, not only from a stormwater management perspective, but in reducing noise pollution and providing valuable wildlife habitat and scenic values. Development tends to fragment large tracts of undisturbed areas and displace plant and animal species; therefore it is essential to maintain these buffers in order to minimize impacts. Areas adjacent to waterbodies (both freshwater and coastal) are protected under Rhode Island state law and cannot be altered without a state agency (DEM or CRMC) permit.

For natural preservation areas to be used as a stormwater management practice, they must include a minimum of 10,000 square feet and be preserved under a conservation easement that ensures perpetual preservation. Runoff must enter the buffer as overland sheet flow. The average contributing slope should be no less than 1% and no more 3%. Maximum average slope may be increased to 5% if a flow spreader is installed across the entire contributing length followed by a flat (i.e., 0% slope) 10-foot shelf across the length.

Due to their relative hydraulic inefficiency (i.e., high surface area to treatment capacity requirement) when compared with filtration and infiltration BMPs. Preserved natural areas will be considered as adjuncts to other upland and end-of-pipe BMPs.

Diagram 4.11 Preserved Natural Area. Source: Adapted from Atlanta Regional Commission, 2001.

4.1.4 Roof Runoff Detention (Rain Barrels and Cistens)

Rain barrels and cisterns are rainwater collection and storage devices (see Diagrams 4.12-a and b). They are generally low-cost and easily maintainable. They are applicable, for purposes of retrofit, to residential, commercial and industrial sites to manage rooftop runoff. Rain barrels and cisterns are not generally given stormwater management credit on new development and are not reliable water quality management practices. Because of their unreliability, they are not recommended as a treatment practice.

Cisterns are generally larger than rain barrels, with some underground cisterns having a capacity of 10,000 gallons. Water collected in cisterns is typically used for irrigation or in some instances as a potable supply. Cisterns are not usually appropriate for single-family residences.

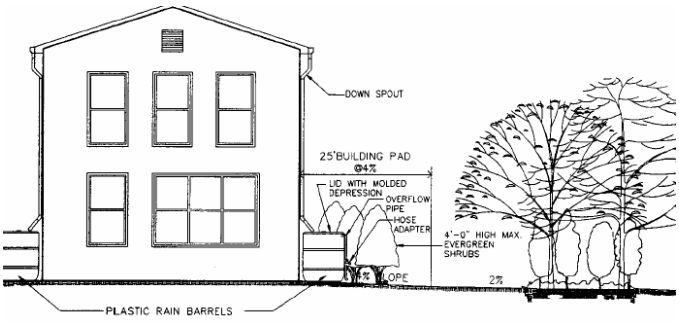


Diagram 4.12 Examples of rain barrels. Source: Prince George's County, Maryland, 2000.

4.1.5 Pollution Prevention via Soil Amendment and Grounds Management

The following text discusses a number of practices that interested individuals may use to improve water quality, enhance the quality of their landscaping and, in many cases, to save money.

While pollution prevention should form a key part of any stormwater management strategy, the pollution abatement benefits are often not easily quantifiable for two main reasons. First, the effectiveness relies on the ongoing participation and commitment of individuals to carry out recommended practices. Secondly, the prevention techniques are not designed to capture or treat specific volumes of runoff. As a result, this study does not attempt to quantify a specific water quality benefit for pollution prevention and recommends that pollution prevention be used to enhance primary treatment practices.

Intensive management of urban landscapes, mainly consisting of lawns, affects soil processes, increases pollutant loads to stormwater runoff, and places demands on water resources. Estimates of turf and lawn coverage in the United States are as high as 30 million acres, which, if lawns were classified as a crop, would rank as the fifth largest in the country after corn, soybeans, wheat, and hay (Swann and Schueler, 2000). This large area of managed landscape has the potential to contribute to urban runoff pollution due to overfertilization, overwatering, overapplication of pesticides, and direct disposal of lawn clippings, leaves, and trimmings. Also, erosion from bare patches of poorly managed lawns contributes sediment to watercourses, and disposal of lawn clippings in landfills can reduce the capacity of these facilities to handle other types of waste.

Lawn conversion

Grasses require more water and attention that alternative groundcovers, flowers, shrubs and trees. Alternatives are especially recommended for problem areas such as lawn edges, frost pockets, shady spots, steep slopes and soggy areas. Vegetation that is best suited to the local conditions should be chosen instead of turf.

Soil building
Grounds operation and maintenance should incorporate soil evaluation every 1 to 3 years to determine suitability for supporting a lawn and to determine how to optimize growing conditions. Consider testing soil characteristics such as pH, fertility, compaction, texture, and earthworm content.

Grass selection
Grass seed is available in a wide range of cultivated varieties, so homeowners, landscapers and grounds managers are able to choose the grass type that grows well in their particular climate, matches site conditions, and is consistent with the property owner's desired level of maintenance. When choosing ground cover, consideration should be given to seasonal variations in rainfall and temperature. Table 4.1 lists turfgrass types and their level of tolerance to drought:

Table 4.1
Drought Tolerance of Turfgrass Types

Turfgrass Type	Drought Tolerance
Fine-leaved Fescues	High
Tall Fescue	
Kentucky Bluegrass	
Perennial Ryegrass	
Bentgrasses	Low

Mowing and thatch management
To prevent insects and weed problems, property owners should mow high, mow frequently, and keep mower blades sharp. Lawns should not be cut shorter than 2 to 3 inches because weeds can grow more easily in short grasses. Grass can be cut lower in the spring and fall to stimulate root growth, but not shorter than 1-½ inches.

Minimize fertilization
Most lawns require little or no fertilizer to remain healthy. If fertilizing is desired, consider the following points:

- Fertilize no more than twice a year— once in May-June and once in September-October.
- Fertilizers are rated on their labeling by three numbers (e.g., 10-10-10 or 12-4-8). The percentage of nitrogen is the first number. Fertilize at a rate of no more than ½ pound per 1000 square feet, which can be determined by dividing 50 by the percentage of nitrogen in the fertilizer.
- Apply fertilizer carefully so as to avoid spreading on nongrowing surfaces (e.g., walkways, patios, etc).
- To encourage more complete uptake, use slow-release fertilizers that is those that contain 50 percent or more water-insoluble nitrogen (WIN).
- Grass blades retain 30-40 percent of fertilizer applied. Reduce fertilizer applications by 30 percent or eliminate the spring feeding by leaving clippings on the lawn.

- Fertilizer should not be applied when rain is expected. Not only does the rain decrease fertilizer effectiveness, it also increases the risk of surface and groundwater contamination.

Weed and pest management:
A property owner must decide how many weeds can be tolerated before action is taken to eradicate them. To the extent practicable, weeds should be dug or pulled out. If patches of weeds are present, they can be covered for a few days with a black plastic sheet, a technique called solarization. Solarization kills the weeds while leaving the grass intact. If weeds blanket a large enough area, the patch can be covered with clear plastic for several weeks, effectively "cooking" the weeds and their seeds. The bare area left behind after weeding should be reseeded to prevent weeds from growing back. As a last resort, homeowners can use chemical herbicides to spot-treat weeds.

Pest management:
Effective pest management begins with maintenance of a healthy, vigorous lawn that is naturally disease resistant. Property owners should monitor plants for obvious damage and should check for the presence of pest organisms. Learn to distinguish beneficial insects and arachnids, such as green lacewings, ladybugs, and most spiders, from ones that will damage plants. When damage is detected or when harmful organisms are present, property owners should determine the level of damage the plant is able to tolerate. No action should be taken if the plant can maintain growth and fertility. If controls are needed, there is an arsenal of low-impact pest management controls and practices to choose from, including the following:

- Visible insects can be removed by hand (with gloves or tweezers) and placed in soapy water or vegetable oil. Alternatively, insects can be sprayed off the plant with water or in some cases vacuumed off of larger plants.
- Store-bought traps, such as species-specific, pheromone-based traps or colored sticky cards, can be used.
- Sprinkling the ground surface with abrasive diatomaceous earth can prevent infestations by soft-bodied insects and slugs. Slugs also can be trapped in small cups filled with beer that are set in the ground so the slugs can get in easily.
- In cases where microscopic parasites, such as bacteria and fungi, are causing damage to plants, the affected plant material can be removed and disposed of. (Pruning equipment should be disinfected with bleach to prevent spreading the disease organism.)
- Small mammals and birds can be excluded using fences, netting, tree trunk guards, and, as a last resort, trapping. (In some areas trapping is illegal. Property owners should check local codes if this type of action is desired.)
- Property owners can promote beneficial organisms, such as bats, birds, green lacewings, ladybugs, praying mantis, ground beetles, parasitic nematodes, trichogramma wasps, seedhead weevils, and spiders that prey on detrimental pest species. These desirable organisms can be introduced directly or can be attracted to the area by providing food and/or habitat.

If chemical pesticides are used, property owners should try to select the least toxic, water soluble and volatile pesticides possible. All selected pesticides should be screened for their potential to harm water resources. Organophosphate pesticides, such as diazinon and chlorpyrifos, are popular because they target a broad range of pests and they are less expensive than newer, less toxic pesticides. Organophosphates rank among the worst killers of wildlife, however, and they often pose the greatest health risk. Synthetic pyrethroids are more selective and typically much less toxic than organophosphates, yet they can harm beneficial insects. When possible, pesticides that pose less risk to human health and the environment should be chosen. A list of popular pesticides, along with their uses, their toxicity to humans and wildlife, EPA's toxicity rating, and alternatives to the listed chemicals is available from The Audubon Guide to Home Pesticides, which is available online.

Sensible irrigation:
Most New England lawns will survive without irrigation. Grasses will normally go dormant in warm, dry periods (June-September) and resume growth when moister is more plentiful. However, if watering is desired, consider the following points:

- Established lawns need no more than one inch of water per week (including precipitation) to prevent dormancy in dry periods. Watering at this rate should wet soil to approximately 4-6 inches and will encourage analogous root growth.
- If possible use timers to water before 9:00 a.m., preferable in the early morning, to avoid evaporative loss.
- Use drought resistant grasses (see "grass selection," above) and cut grass at 2-3 inches to encourage deeper rooting and heartier lawns.

4.2 Identifying Appropriate Stormwater Practices for Narrow River Watershed

4.2.1 Hydrologic Location of BMPs— On Lot, Upland, End of Pipe

In order to optimize pollution reduction and groundwater recharge, the Narrow River stormwater study involves an approach where BMPs are evaluated for potential siting at a variety of hydrologic locations— on lot, other upland areas, and end of pipe.

The BMPs listed in Table 4.2 have been identified for their capacity to provide effective treatment of pathogens and nutrients as well as groundwater recharge. These BMPs are often applicable at more than one potential hydrologic location. Table 4.2 shows the range of potential applications for each BMP.

Table 4.2
Potential Application of BMPs

Practices and Strategies	End-of-Pipe	Upland	Source Reduction
Filtration and infiltration			
Sand filters	•	•	
Bioretention	•	•	•

Infiltration trenches	●	●	
Disconnected catch basins and proprietary infiltration units	●	●	
Dry wells			●
Subsurface perimeter and pocket filtration and infiltration units		●	
Permeable pavement			●
Sidewalk storage	●	●	
Engineered vegetative strips and conveyances			
Vegetated strips		●	●
Natural and vegetated conveyances		●	●
Impervious surface disconnection			
Pavement disconnection			●
Roof leader disconnection			●
Preserved natural areas	●	●	
Roof runoff detention (rain barrels and cisterns)			●
Pollution prevention			
Soil amendments			●
Lawn conversion			●
Soil building			●
Grass selection			●
Mowing and thatch management			●
Minimizing fertilization			●
Weed and pest management			●
Sensible irrigation			●

4.2.2 Appropriate BMPs for Conceptual Planning

Not all the BMPs shown in Table 4.2 are appropriate for consideration for preliminary design of stormwater pollution abatement practices for the Narrow River study area Table 4.3 shows the BMPs that were considered for this conceptual design study.

Table 4.3
BMPs Considered for Conceptual Design

Practices and Strategies	End-of-Pipe	Upland	Source Reduction
Filtration and infiltration			
Sand filters	•	•	
Bioretention	•	•	•
Infiltration trenches	•	•	
Disconnected catch basins and proprietary infiltration units	•	•	
Dry wells			•
Permeable Pavement			•
Engineered vegetative strips and conveyances			
Vegetated strips			•
Impervious surface disconnection			
Roof leader disconnection			•

The following discussion provides a list of BMPs from Table 4.2 that have been removed from further consideration in the conceptual planning phase of this study and the reasons for their removal.

- Subsurface perimeter units and pocket units and sidewalk storage
  Perimeter units, pocket units and sidewalk storage will also be considered in later phases as they are intended to be adjuncts to larger end-of-pipe and upland BMPs.
- Engineered vegetative strips and conveyances
  These BMPs have a quantifiable treatment benefit, but are generally used as pretreatment for sand filters and infiltration. Their use will be considered for upland and end-of-pipe use in later phases of design. Notwithstanding, vegetative filter strips are considered in this part of the study for on-lot use.
- Preserved natural areas
  Preserved natural areas have significant capacity for treatment, but are hydraulically much less efficient than infiltration and filtration per a unit of land.
- Roof runoff detention
  Techniques such as rain barrels and cisterns share many of the problems associated with pollution prevention in that they must be implemented and operated by laypeople. Additionally, they include no specific water quality treatment function, but instead simply provide a repository for rainwater to be stored.
- Pollution prevention
  These BMPs are not designed to treat any specific volume of water. Although desirable for their capacity to reduce pollution at the source, their effectiveness relies on proper implementation by laypeople, which introduces very significant uncertainty into the quantification of treatment effectiveness.

4.3 Calculating Water-Quality Treatment Capacity of BMPs

BMP effectiveness in this study is based capacity of BMP(s) to treat the WQV in a subwatershed of concern. This study opts to focus on BMPs that are best documented to remove the pollutants of concern. Given that a BMP is sized appropriately to manage the WQV, the treatment effectiveness is assumed to be the same for each BMP.

WQV approximates the runoff volume of a 90th percentile 24-hour Type III storm event. Thus, BMPs that treat WQV provide complete stormwater treatment of at least 90 percent of storm events. Taken in context with first-flush theory, which states that pollution concentration in runoff diminishes sharply after the first ½-inch of runoff, treatment of WQV (i.e., the first inch of runoff) can be assumed to amount to complete stormwater treatment for all storm events.

The methods used to calculate the volume that a BMP will be able to treat ($V_{treatable}$) are described in the following sections. The volume calculated depends on factors such as pollutant removal ability of BMPs, available area, permeability of the soil or filter media, configuration of the storage area, and allowable drain time.

4.3.1 Filtration BMP Capacity

Filtration BMP capacities were calculated for:

- Sand filters
- Bioretention

The capacities were calculated using the same method for both types of filtration BMPs. However, the area needed varies between the two types. Similar to an infiltration BMP, the capacity of a filtration BMP is a function of the permeability of its filtration media and the surface area of the media. The draft *Rhode Island Stormwater Manual* provides a discussion of appropriate filtration BMP sizing based on the equation:

$$A = \frac{(V)(d)}{[(k)(t)(h+d)]}$$

where:
$A =$ filter bed surface area (ft^2)
$V =$ water quality volume (ft^3)
$d =$ filter bed depth (ft)
$k =$ hydraulic conductivity of filter media (ft/day)
$t =$ time for the water quality volume to drain from the system (1 day)
$h =$ average height of water above filter bed during water quality design storm (ft)

If the filter bed surface area is known, this equation may be rearranged to solve for the capacity of the area to treat runoff. The rearranged equation is:

$$V = \frac{Akt(h+d)}{d}$$

Typically, filtration BMPs occupy approximately 80% of the surface area of a site. For a sand filter, the filter bed occupies approximately 50% of the useable area; therefore, for a sand filter A = 40% of $A_{Available}$. In this technical memorandum, the volume treatable ($V_{treatable}$) by filtration is calculated for A = $0.4A_{Available}$ for sand filters and A = $0.8A_{Available}$ for bioretention.

4.3.2 Infiltration BMP Capacity

Infiltration BMP capacities were calculated for:

- Infiltration trenches
- Disconnected catch basins with proprietary infiltration units (disconnected catch basins)
- Dry wells
- Permeable pavement

Three methods for infiltration capacity calculations were used, as described in the following sections.

Method 1 – Infiltration trenches and disconnected catch basins

The capacity of an infiltration BMP to treat a volume of stormwater is a function of the infiltration rate of the infiltration media (e.g., permeability of soil) and the area of application (i.e., surface area of the infiltration media). The draft *Rhode Island Stormwater Manual* provides a discussion of appropriate infiltration BMP sizing based on the equation:

$$A = \frac{cV}{Pnt}$$

Where:
A = effective bottom area of trench (ft^2) = 0.8 $A_{Available}$
c = conversion factor of 12 (in/ft)
V = volume of runoff to infiltrate, typically WQV (ft^3)
P = design infiltration rate of soil (in/hr) (one-half the minimum field measured infiltration rate)
n = porosity of storage media (0.4 for clean stone)[6]
t = maximum drain time (48 hours)

6 - Porosity of a proprietary infiltration system will be 1 since the void space is contained in a hollow apparatus. The values calculated for the treatable volume would be larger for a proprietary system; therefore if a proprietary system is used, the treatable volume may actually be larger than the values listed in this technical memorandum. The treatable volume presented are a conservative estimate based on infiltration trenches.

If the effective bottom area available to site a BMP is known, this equation may be rearranged to solve for the site's capacity to treat runoff. The rearranged equation is:

$$V = \frac{APnt}{c}$$

Typically, the effective bottom area (A) of an infiltration BMP occupies approximately 80% of the area of an available site ($A_{Available}$); therefore, in this technical memorandum, volume treatable ($V_{treatable}$) by infiltration is calculated for $A = 0.8A_{Available}$.

Method 2 – Dry wells

Dry wells were applied for source reduction from the hypothetical on-lot roof. The area needed to treat the WQV from the roof is much smaller than the area available on a hypothetical lot. Therefore, the capacity of a dry well was determined to be the WQV of the roof.

Method 3 – Permeable Pavement

Permeable pavement was applied to on-lot source reduction from the driveway of the hypothetical lot and is assumed to have a one-inch capacity. As infiltration is not allowed within 10 feet of a building, the first 10 feet of driveway from the house cannot be infiltrated with pervious pavement.

Per the draft *Rhode Island Stormwater Manual* permeable pavement may be designed to infiltrate up to the WQV of the driveway surface. Capacity of permeable pavement is measured by its ability to infiltrate stormwater into the ground through voids in the pavement. For this study, we assume permeable pavement will be located only in Type A soils, which should have ample infiltrative capacity to accept the WQV. We further assume that permeable pavement driveways will be designed with the capacity to store the WQV.

4.3.3 Vegetative Filter Strip Capacity

Vegetative filter strips (VFS) function on the same principle as infiltration. Water is collected within the BMP and percolated through vegetated soil. Vegetative filter strips differ from other infiltration practices in that they have a limited capacity to detain stormwater for infiltration. Due to their limited capacity, VFSs are only considered at residential sites. Vegetative filter strips will be considered as adjuncts to upland attenuation and end-of-pipe BMPs in subsequent phases of design. The capacity of a filter strip was calculated based on geometry of the storage area, subject to the assumptions listed below.

Two types of VFSs were investigated for the hypothetical house lot and are referred to as Conveyance VFS and Flat Storage VFS. The following assumptions were made to calculate the capacity of the two types of VFS systems. The capacities calculated are maximum per-lot capacities. Some lots may be able to be retrofitted to handle portions of the calculated capacities.

Conveyance VFS

- The topography of the area where the conveyance VFS is to be installed has an adequate slope and can be designed to manage the peak flows.
- Conveyance VFS systems are typically installed where multiple consecutive lots are available to replace the conventional stormwater pipe system. Construction of conveyance systems on multiple lots requires installation of a pipe below each driveway. Whether multiple or individual lots are used for the conveyance system, the calculated storage capacity per lot will be the same.
- The length of the VFS is equal to the lot frontage minus driveway width, which is 35-feet.
- The top width of the swale is 10-feet.
- The VFS has a bottom width of 4-feet.
- The VFS is installed at a 4% grade.
- The VFS is designed to detain water for no more than 24 hours at no greater than a 6-inch depth.
- The sides of the VFS are at a slope that maximizes use of the 10-foot top width, within a range of 4% to 33%. The side slope used for the capacity calculations was 17%.
- The effective bottom area of the VFS is equal to the bottom width (4-feet) multiplied by half of the storage area length.
- The storage area length of the VFS is determined using the maximum storage depth (6-inches) and the design grade (4%). The storage length used was 12.5-feet.
- The k value of the in-situ soil is greater than 0.9-feet per day. This includes Type A soils and some Type C soils.

Flat Storage VFS

- The topography of the lot is adequate to provide conveyance of the peak flows to the storm drain system while providing detention of the design capacity.
- The length of the VFS is equal to the lot frontage minus the driveway width, which is 35-feet.
- The top width of the swale is 10-feet.
- The VFS has a bottom width of 4-feet.
- The maximum depth of storage is 2-inches.
- The bottom of the VFS is level along its length.
- The sides of the VFS are at a slope that maximizes use of the 10-foot width, within a range of 4% to 33%. The side slope used for the capacity calculations was 5.6%.
- The effective bottom area of the VFS is equal to the bottom width (4-feet) multiplied by the length.
- The k value of the in-situ soil is greater than 0.3-feet per day. This includes Type A soils and some Type C soils.

4.3.4 Impervious Surface Disconnection Capacity

For the purposes of this study, the disconnection BMP capacities were calculated for roof leader disconnection. The area that roof leader disconnection uses from flow configuration is described in Appendix B.

The draft *Rhode Island Stormwater Manual* provides a method to calculate treatment capacity of disconnection using unit effectiveness ratios by hydrologic soil group for ½ to 1 inch. The method is applicable to on-lot source control as well as other hydrologic locations. The unit effectiveness ratios for open space are provided in Table 4.4. Using this information and given the size of the hypothetical lot size, the Volume treatable is equal to:

- 2:1 ratio of impervious surface to open space for 1 inch over the impervious surface in Type A soil
- 1:1 ratio of impervious surface to open space for 0.5 inches over the impervious surface in Type C soil.

Table 4.4
Unit Effectiveness of Open Space to Treat Runoff from Impervious Surface

Runoff (inches)	HSG Soil Type			
	A	B	C	D
1.0	*1:2*	4:1	N/A	N/A
0.9	1:3	2:1	N/A	N/A
0.8	1:4	1:1	N/A	N/A
0.7	1:8	1:2	N/A	N/A
0.6	1:8	1:3	2:1	N/A
0.5	1:8	1:6	*1:1*	N/A

Note:
1. Ratios in italics and bold are the ratios used to calculate effectiveness in Narrow River for the hypothetical lot.

4.4 Calculating Recharge Capacity of Different Management Practices

BMPs that infiltrate are capable of recharging groundwater. The following is a list of these BMPs. It includes the BMPs in Table 4.3 except for filtering practices (i.e., sand filters and subdrain bioretention):

Filtration and infiltration
- Infiltration trenches
- Disconnected catch basins and proprietary infiltration units
- Dry wells
- Bioretention (infiltrating only)
- Permeable Pavement

Engineered vegetative strips and conveyances
- Vegetated strips

Impervious surface disconnection

Roof leader disconnection

Each BMP listed above is capable of recharging a volume equal to its treatable volume as calculated in the previous sections.

4.5 Source Reduction Strategies

4.5.1 Target Locations and Management Practices Used

Table 4.5 lists BMPs that were considered for source control in Type A and C areas.

Table 4.5
On-Lot Retrofit Options By Soil Type

Type A	Type C
Disconnected Downspout Vegetated Filter Strip Dry Wells Bioretention (infiltration) Pervious Pavement [1]	Disconnected Downspout Bioretention (subdrain) [2]

Notes:

1. Pervious pavement is only appropriate when a driveway is planned to be repaved.
2. Bioretention is only appropriate in Type C soils when installed with a subdrain system and requires access to a stormwater sewer to convey flows from its subdrain.

Source controls generally rely on recharge and infiltration; therefore, must pass collected stormwater in the soil within 48 hours. Type C soils cannot usually infiltrate stormwater quickly enough to make infiltration and recharge BMPs feasible.

This technical memorandum targets source reduction strategies primarily to areas of Type A soils. Type C soils are considered for downspout disconnection, only. Source controls work best in Type A and B soils. The area of Type B soils is limited to approximately 1 acre in the Indian Head Subwatershed with no lots entirely comprised of Type B soils. Additionally, field measurements for soil permeability were not determined for Type B soils.

Figure 2.5 depicts the approximate locations of each hydrologic soil group in the watershed.

4.5.2 Evaluation of Effectiveness

To determine effectiveness, the following considerations regarding source control BMP installation and the configuration of lots were evaluated. The source reduction volumes are referred to as the water quality volume (WQV) and the groundwater recharge volume (GWR).

Homeowner Participation

For the purposes of this technical memorandum, a 20% participation rate is assumed homogenously throughout the subwatersheds of concern. This rate is an assumption for purposes of comparing alternatives and has yet to be verified. It is also assumed that participating homeowners will be able to apply a combination of source controls that results in the maximum achievable percent reduction of the WQV and GWR from the lot, by soil type, as discussed in below.

Narragansett recently surveyed homeowners in the Narrow River Watershed to inventory willingness to adopt on-lot source controls and is in the process of evaluating results. Once available, results of this survey will be used to estimate the maximum achievable rate of source control and anticipated benefit of implementation.

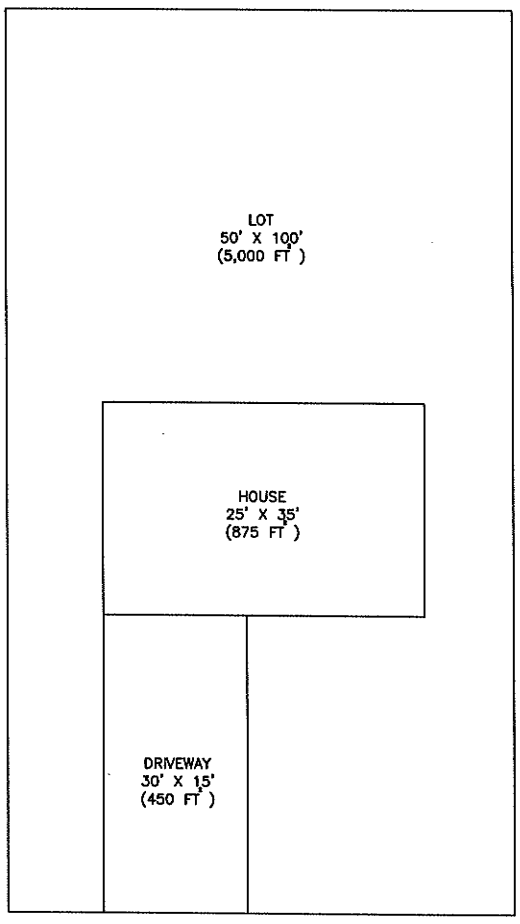
Hydrologic Equivalence

For conceptual design purposes, we have assumed that all lots in the study area replicate the hydrology of the hypothetical lot in terms of its size, impervious surface, WQV and GWR. The hypothetical lot was previously presented at the September 1, 2005 Narrow River Technical Advisory Committee meeting (see Figure 4.1). This lot occupies 5,000 square feet and is similar in size and layout to many lots in the watershed. Table 4.6 provides the area of each impervious surface on the lot and the associated treatment volumes to be managed.

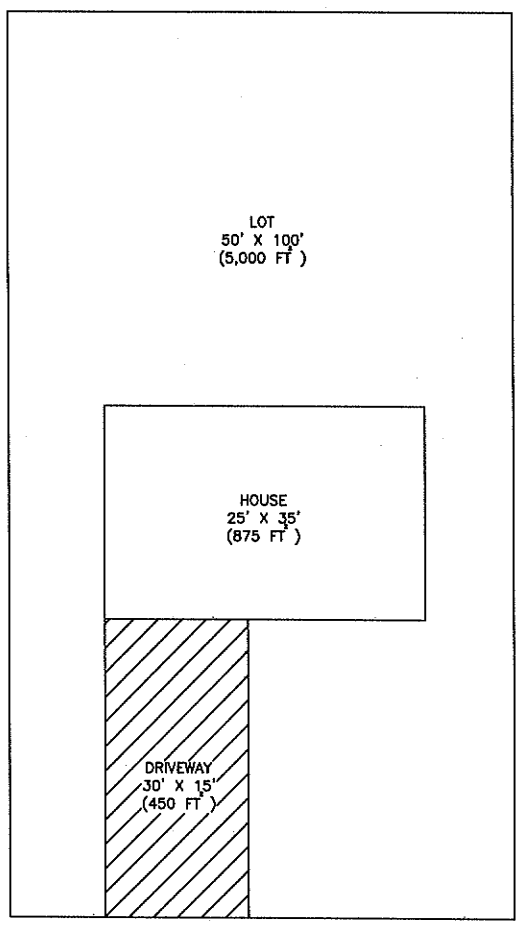
Table 4.6
Impervious Surface on Hypothetical Lot

SURFACE	AREA (ft^2)	WQV (ft^3)	GWR (ft^3)
Building footprint	875	72.9	102.9
Driveway	450	37.5	52.9

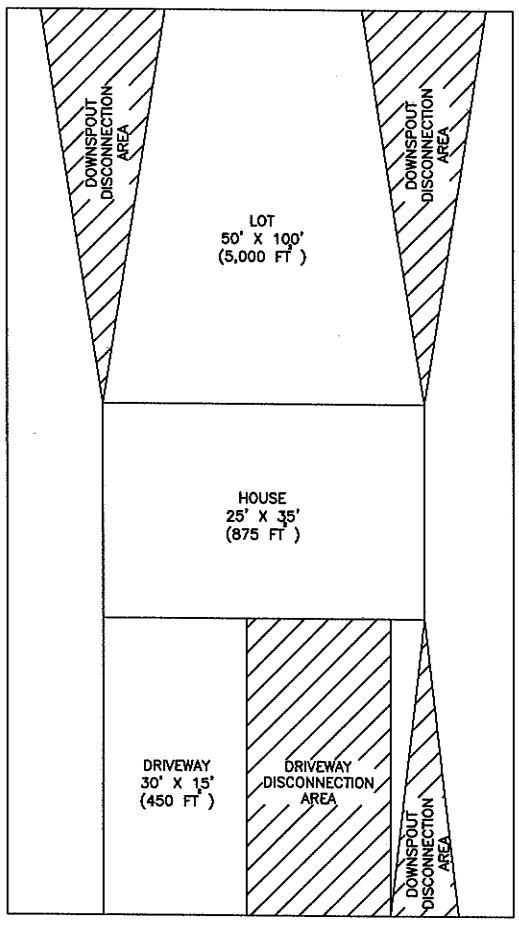
To simplify calculation of groundwater recharge, we assumed WQV divided by V_{GWR} for the study subwatersheds in aggregate equals WQV divided by GWR for the hypothetical house lot. This is a fairly blunt method of estimation as it does not account for changes in soil type and ground cover in the individual subwatersheds; however, we believe the method is appropriate given the conceptual nature of this evaluation.



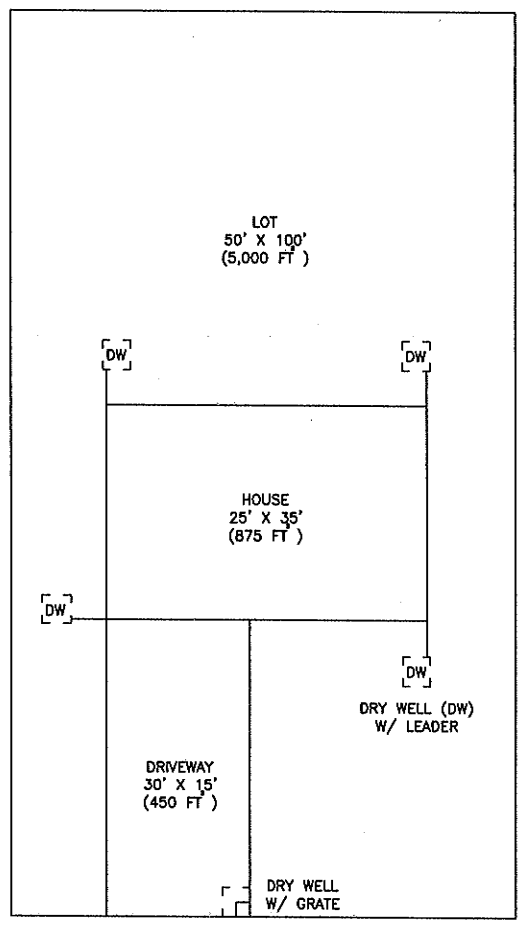
STANDARD LOT – NO CONTROLS



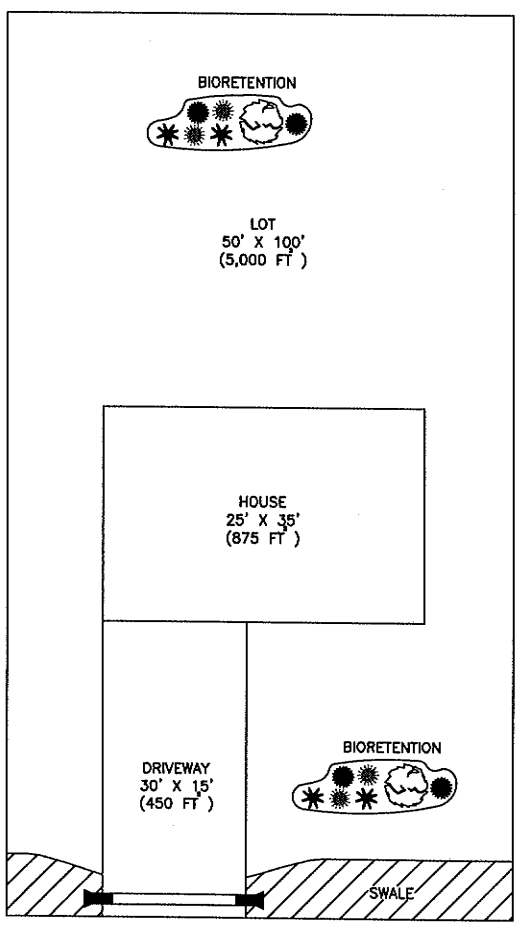
PERVIOUS PAVEMENT OR PAVERS OR CRUSHED STONE



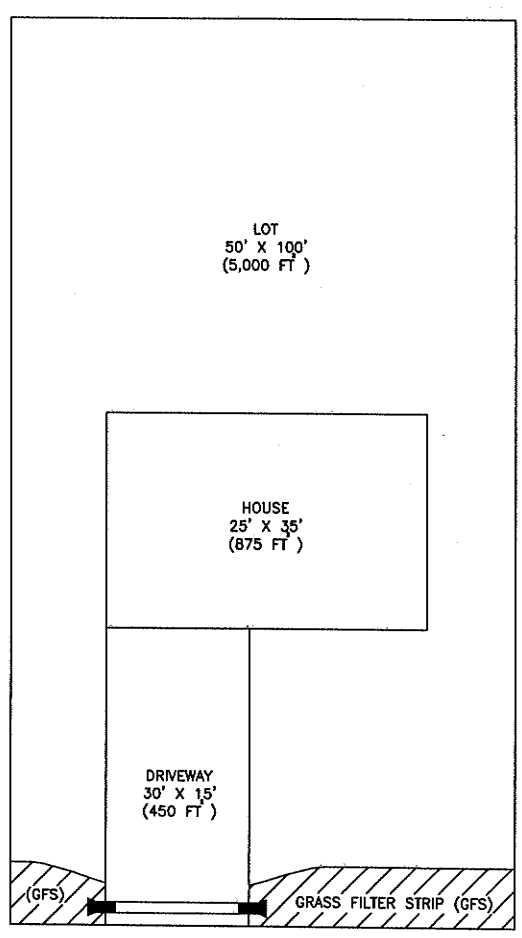
DISCONNECTION TO OVERLAND FLOW



DRY WELLS



BIORETENTION (I.E., RAIN GARDEN)



GRASS FILTER STRIPS

SCALE:	
HORZ.:	
VERT.:	
DATUM:	
HORZ.:	
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RHODE ISLAND DEPARTMENT OF ENVIRONMENTAL MANAGEMENT

SOURCE CONTROL LOT CONFIGURATIONS

DEVELOPING THE NARROW RIVER STORMWATER ABATEMENT PLAN

NARRAGANSETT RHODE ISLAND

PROJ. No.: 20041111.A10
DATE: SEPTEMBER 2005

FIGURE 4.1

CTB:
LMAN:
MS VIEW:
UCS:

The number of lots in each subwatershed by soil type was used to calculate the percent reduction. Some of the lots are not completely within the subwatershed or soil type, in which case, 50% of the partial lots were added to the completely contained number of lots for calculation purposes. The total number of lots included only Type A and Type C soils since Type B soils are virtually non-existent, and Type D soil lots can not be used for source reduction.

Effect of Soil Type

To determine the effectiveness of source reduction, we conceptually sized and applied source reduction strategies to a hypothetical lot in the Narrow River Watershed. To determine effectiveness in each subwatershed, we assumed that all participating lots would receive BMPs that maximize treatment in a manner appropriate for soil type. Table 4.7 shows percent of WQV and V_{GWR} controlled after application of each source reduction strategy to the hypothetical lot.

Table 4.7
Percent Reduction[3] in WQV and GWR per Lot by Source Control

Soil Type	Downspout Disconnection		Flat Storage Filter Strip[2]		Dry Well[4]		Permeable Pavement		Bioretention[5]		Best Available Treatment[6]	
	WQV	GWR	WQV	GWR	WQV	GWR	WQV	GWR	WQV	GWR	WQV	GWR
A	50	35	37	26	66	47	23	16	66	47	100	100
C	23	16	NA	NA	NA	NA	NA	NA	66	0	89	16

Notes:

1. Downspout disconnection can be used to treat stormwater from rooftops only, at a maximum of 75% of the roof.
2. Conveyance Filter Strips were also investigated, which provide less treatment volume. However, the conveyance filter strip is not likely a feasible retrofit option for the Narrow River study area and has not been included in the calculations.
3. Percent treatment is for runoff from building and driveway only.
4. The values shown for the dry well are for the roof only.
5. Bioretention is infiltration in Type A soil and subdrained in Type C soil.
6. Best available treatment requires downspout disconnection, dry well and bioretention in Type A soil; and downspout disconnection and bioretention in Type C soil.
7. BMPs that are not appropriate for the given conditions are shown as NA.

Table 4.8 shows the effectiveness of source control application by subwatershed, according to the assumptions and methods described above. These values were calculated by summing the reduction volumes for Type A lots and Type C lots in each subwatershed. The reduction volumes were determined for each subwatershed by multiplying the number of lots in each soil type by the maximum percent reduction per lot for each soil type and by 20 percent.

Table 4.8
WQV and GWR Reduction Effectiveness By Subwatershed
For 20% Participation

Subwatershed	Percent Treated (%)	
	WQV	V_{GWR}
Indian Head	6	3
Petta Lake Shores 2	9	4
Edgewater 1	6	5
Edgewater 2	7	7
Pettasquamscutt Terrace 1	7	6
Pettasquamscutt Terrace 2	11	6
Mettatuxet 1	11	6
Mettatuxet 3	10	9
Mettatuxet 4	11	8
Study Area (weighted average)[1]	8	6

Note:
[1] Study area weighted averages are calculated by multiplying percent treated by the area treated in each subwatershed and dividing by the total area treated in the study area.

4.6 Upland Attenuation

4.6.1 Target Locations

Figure 4.2 depicts target lots for both upland and end-of-pipe BMPs. For the purposes of conceptual design, this evaluation assumes that all town-owned lots, managed-open-space lots, stabilized lots, and vacant lots are available for stormwater controls.[7] Locations for BMPs in the upland were restricted to area that is located on available lots subject to the following criteria.

- Sites must be at least partially down-gradient in a stormwater drainage system (i.e., water must have begun to collect in a drain before reaching a target site).
- Sites must be proximal to a storm drain— either directly adjacent or no more than 300 feet away.
- Sites must not be classified as wetland, surface water, or Type D soil.
- Sites must not include slopes with grades steeper than 10% on average.
- Sites may be ruled out where ample and preferable lots exist down gradient.

Table 4.9 shows stormwater treatment capacity for each type of BMP in each subwatershed assuming that it is the only type of BMP installled. Capacities are calculated based on the previously described equations, assuming that all properties identified on Figure 4.2 are available for siting BMPs.

7 Actual availability of each lot is yet to be determined. We expect that at least some lots will be unavailable.

Table 4.9
Upland Treatment Capacity

	$V_{treatable}$			
	Filtration		Infiltration	
Subwatershed	Bioretention	Sand Filter	Infiltration Unit	Bioretention
IH	0.54	2.15	0.86	0.54
PLS2	3.77	15.09	0.75	0.75
E1	0.86	3.44	0.63	0.63
E2	0	0	0	0
PTC	3.12	12.47	0.93	0.93
M1	2.20	8.81	2.74	2.20
M3	0.96	3.85	1.54	0.96
M4	1.34	5.36	0.73	0.73

Note:
1. Units are in acre-ft

4.6.2 Evaluation of Effectiveness

If all available lots that have been identified are used for BMPs, water quality treatment of 62% - 96% of WQV and groundwater recharge of 32% - 47% V_{GWR}, can be expected for the aggregate of the eight subwatersheds.

Percent effectiveness in treating WQV and V_{GWR} has been calculated using the WQV and V_{GWR} from Table 2.2, Hydrologic Data by Subwatershed. Percent effectiveness is shown in Table 4.10 for each best management practice in the upland areas for each subwatershed.

BMPs with percent treatment shown in bold/italics display best available percent treatment for either WQV or V_{GWR} in the subwatershed of concern. If a BMP is used due to its effectiveness in one kind of treatment, its effectiveness for the other type of treatment will carry through independently of whether it is the desired level of treatment (e.g., if the only method to achieve 100% WQV is using a technique that does not infiltrate, V_{GWR} will be 0%; in some cases, to achieve a higher V_{GWR}, the WQV would have to be reduced). Therefore, treatment of WQV and V_{GWR} may become a tradeoff. Where this occurs, best available level of treatment (TOTAL) is listed as a range.

Table 4.10
Percent Effectiveness for Upland Bmps

Subwatershed	Filtration				Infiltration				Best Available Volumetric Capacity	
	Bioretention		Sand Filter		Infiltration Unit		Bioretention			
	WQV	V_{GWR}	WQV	V_{GWR}	WQV	V_{GWR}	WQV	V_{GWR}	WQV	V_{GWR}
IH	64%	0%	100%	0%	*100%*	*58%*	64%	36%	100%	58%
PLS2	*100%*	*0%*	*100%*	*0%*	*29%*	*23%*	*29%*	*23%*	29% - 100%	0% -23%
E1	57%	0%	*100%*	*0%*	*42%*	*56%*	*42%*	*56%*	42% - 100%	0% –56%
E2	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PTC	*100%*	*0%*	*100%*	*0%*	*48%*	*30%*	*48%*	*30%*	48% - 100%	0% –30%
M1	100%	0%	100%	0%	*100%*	*100%*	*100%*	*100%*	100%	100%
M3	100%	0%	100%	0%	*100%*	*100%*	100%	98%	100%	100%
M4	100%	0%	100%	0%	*100%*	*62%*	*100%*	*62%*	100%	62%
TOTAL									62% - 96%	32% - 47%

4.7 End-of-pipe Attenuation Strategies

4.7.1 Target Locations

Figure 2.3 depicts target lots for both upland and end-of-pipe BMPs. Figure 2.3 also shows road areas at the end-of-pipe that were used for treatment calculations. For the purposes of conceptual design, this evaluation assumes that all roads, town-owned lots, managed-open-space lots, stabilized lots, and vacant lots are available for stormwater controls.[8] Additionally, one lot in Indian Head is a privately owned lot that will likely be available for BMP construction. Locations for BMPs at the end-of-pipe were restricted to area that is located in the road or on available lots down-gradient of the last catch basin inlet along the storm drain system.

BMP sites have been identified for end-of-pipe attenuation strategies for each subwatershed based on best professional judgment using the following criteria.

Lots

- Sites must be proximal to an outfall, either directly adjacent or within 100 feet.
- Sites must not be classified as wetland, surface water or Type D soil.
- Sites must not include slopes with grades steeper than 10% on average.
- Site is contiguous with or very close to a town-owned lot, managed-open-space, stabilized lot, unmerged vacant lot or merged vacant lot where a BMP is targeted.

8 Actual availability of each lot is yet to be determined. We expect that at least some lots will be unavailable.

Road areas provide an abundance of town-owned land; however, this evaluation assumes that roadway areas are somewhat less desirable as BMP sites than open lots as installation beneath roads will involve pavement removal and replacement, traffic disruption and potential disruption of utility service. The following criteria were used to target BMPs sites under roadways:

Roadway Areas

- Roads are topographically conducive to BMP installation.
- Road area is relatively large to ensure economies of scale.
- Assume that 80% of a given road area is available to account for area needed for construction.

Table 4.11 shows stormwater treatment capacity for each type of BMP in each watershed assuming that it is the only type of BMP installed. Capacities are based on calculations described in previous sections, and assuming that all properties identified are available for siting BMPs.

Table 4.11
End-Of-Pipe Treatment Capacity

	$V_{treatable}$ (acre-ft)			
	Filtration		Infiltration	
Subwatershed	Bioretention	Sand Filter	Infiltration Unit	Bioretention
IH	0.90	3.60	1.44	0.90
PLS2	0.00	0.73	0.29	0.00
E1	0.00	6.40	2.55	0.00
E2	0.00	6.40	2.55	0.00
PTC	1.08	7.22	2.88	1.08
M1	0.00	4.61	1.84	0.00
M3	0.00	4.80	1.92	0.00
M4	0.36	5.04	2.01	0.36

4.7.2 Evaluation of Effectiveness

If all available lots and roadways are used for BMPs, water quality treatment of 78% - 80% of WQV and groundwater recharge of 73% V_{GWR}, can be expected for the aggregate of the eight subject subwatersheds.

Percent effectiveness in treating WQV and V_{GWR} has been calculated using the WQV and V_{GWR} from Table 2.2. Percent effectiveness is shown in Table 4.12 for each best management practice in each subwatershed. BMPs with percent treatment shown in bold/italics display best available percent treatment for either WQV or V_{GWR} in the subwatershed of concern. If a BMP is used due to its effectiveness in one kind of treatment,

its effectiveness for the other type of treatment will carry through independently of whether it is the desired level of treatment. Therefore, treatment of WQV and V_{GWR} may become a tradeoff. Where this occurs, best available level of treatment (TOTAL) is listed as a range.

Table 4.12
Percent Effectiveness for End-Of-Pipe BMPS

Subwatershed	Filtration				Infiltration				Best Possible Level of Treatment	
	Bioretention		Sand Filter		Infiltration Unit		Bioretention			
	WQV	V_{GWR}	WQV	V_{GWR}	WQV	V_{GWR}	WQV	V_{GWR}	WQV	V_{GWR}
IH	100%	0%	100%	0%	*100%*	*97%*	100%	61%	100%	97%
PLS2	0%	0%	*29%*	*0%*	*11%*	*9%*	0%	0%	11% - 29%	0% -9%
E1	0%	0%	100%	0%	*100%*	*100%*	0%	0%	100%	100%
E2	0%	0%	100%	0%	*100%*	*100%*	0%	0%	100%	100%
PTC	56%	0%	100%	0%	*100%*	*92%*	56%	35%	100%	92%
M1	0%	0%	100%	0%	*100%*	*100%*	0%	0%	100%	100%
M3	0%	0%	100%	0%	*100%*	*100%*	0%	0%	100%	100%
M4	60%	0%	100%	0%	*100%*	*100%*	60%	31%	100%	100%
TOTAL									78% - 80%	73%[1]

Note:
[1] Best possible V_{GWR} for the study area actually occurs as range, but the range is less than 1% and is, therefore, represented in this table as a single value (i.e., 73%).

4.8 Order-of-Magnitude[9] Opinion of Costs

We have calculated an order-of-magnitude opinion of construction cost of $3,000,000 for treatment for the study area as a whole. This cost opinion was calculated by assuming full use of available space for BMPs as well as implementation of the most cost-effective BMP in each subwatershed. Table 4.13 provides the lowest treatment cost per subwatershed and the corresponding percentage treated of Narrow River study area's WQV that can be achieved through a combination of upland treatment and end-of-pipe treatment. The treatment levels are expressed as a percent of the total WQV or GWR for the study area. The costs and treatment volumes provided do not include source controls. The costs have been provided as a comparison tool and should not be relied upon for construction estimates.

9 Order-of-magnitude opinion of costs refers to very rough cost estimates based on blunt assumptions and best professional judgment. They do not include design, permitting or land costs. The costs are provided for conceptual planning purposes only. Actual costs should be anticipated to differ substantially from the estimate—by a factor of two or more.

Table 4.13
Treatment Opinion-of-Cost And
Percent Volume Treated

SUBWATERSHED	COST	% WQV	% GWR
Indian Head	$330,000	16	11
Petta Lake Shores 2	$710,000	28	20
Edgewater 1	$340,000	16	12
Edgewater 2	$80,000	4	3
Pettaquamiscutt Terrace Combo	$690,000	33	24
Mettatuxet 1	$370,000	18	13
Mettatuxet 3	$220,000	11	7
Mettatuxet 4	$260,000	13	9
TOTAL	$3,000,000	139	98

4.8.1 Upland and End-of-pipe Treatment Costs

The cost and treatment benefit or effectiveness for the individual BMP options are provided in Table 4.14. The effectiveness is the volume of stormwater treated over the area of land used for the treatment system ($V_{treated}/A_{available}$). The costs are provided as dollars per volume treated. The cost sources included the EPA document *Urban Stormwater BMP Study*, dated August, 1999 (costs from 1997, adjusted at an annual inflation rate of 3% to 2005) for infiltration (trenches), sand filters, and bioretention. Proprietary detention structure costs were based on the average of cost information provided by Stormtech® and Stormceptor®.

Table 4.14
BMP Cost and Effectiveness

BMP location	Effectiveness (ft^3 of SW per ft^2 of area)	Unit Cost ($/$ft^3$)
Infiltration	2.6	5.1
Disconnected Catch Basin	2.6	3.8
Sand Filter	6.4	7.6
Bioretention	1.6	6.7

4.8.2 Source Control Costs

The cost of source controls per lot and the unit cost (per ft^3 of stormwater treated) are provided in Table 4.15. The cost per lot was determined through multiple sources, which are listed in Appendix A.

Table 4.15
On Lot Source Control Cost and Effectiveness

BMP Type	Cost per Lot $	Unit Cost $ per ft^3
Disconnection of Downspouts	120	1.65
Grass Filter Strip	525	12.87
Dry Wells - Downspouts	1049	14.39
Permeable Pavement	1950	78.00
Bioretention	6700	91.91

5.0 SELECTION BMPS FOR FURTHER DESIGN WORK

The intent of the second Narrow River Technical Committee meeting is to determine the combination of treatment technologies that will be designed and the three subwatersheds in which the technologies will be employed. The next phases of this study will focus on design of the chosen technologies and subwatersheds.

To aide in the selection process, Fuss & O'Neill developed a rating matrix based on information supplied by the Technical Committee. The rating matrix evaluates the use of the different treatment technologies in each subwatershed by assigning number values to a set of evaluation criteria. The evaluation criteria and rating matrix methods are described in the following sections.

Fuss & O'Neill performed an initial iteration of the rating matrix, which identified the results listed in Table 5.1. Table 5.1 provides a summary of two highest rated BMPs in each subwatershed.

Table 5.1
Rating Matrix Results for
Upland and End-Of-Pipe BMPS
In Each Subwatershed

Subwatershed	Highest Rated BMPs
Indian Head	1. Infiltration Trench 2. Disconnected Catch Basin
Petta Lake Shores 2	1. Bioretention (infiltration) 2. Sand Filter
Edgewater 1	1. Infiltration Trench 2. Disconnected Catch Basin
Edgewater 2	1. Infiltration Trench 2. Disconnected Catch Basin
Pettaquamiscutt Terrace Combo	1. Infiltration Trench 2. Disconnected Catch Basin
Mettatuxet 1	1. Infiltration Trench 2. Disconnected Catch Basin
Mettatuxet 3	1. Infiltration Trench 2. Disconnected Catch Basin
Mettatuxet 4	1. Infiltration Trench 2. Disconnected Catch Basin

5.1.1 Evaluation Criteria

Fuss & O'Neill introduced BMP selection criteria at the first committee meeting (September 1, 2005). Committee members were asked to participate by offering their own criteria and then ranking relative importance of the criteria on a scale of 1 to 3. Rankings submitted for each criterion were tallied and averaged. The averaged rank for each criterion was used to determine its relative importance for BMP selection.

Table 5.2 presents the criteria set, a scoring rubric for each criterion, the weight assigned to each criterion by the Narrow River technical advisory committee, and a list of reference materials used to inform the scoring. The scoring rubric and assigned weights for each criterion were used as the basis for rating each BMP option. The criteria are grouped into two categories, which are addend and multipliers. The addend criteria are multiplied by the assigned weight and then summed. The summed values are then multiplied by the multipliers.

Table 5.2
Criteria Measurement for BMP Options

Criteria	References	Scoring Rubric	Assigned Weight
Bacteria Load Reduction	Draft *Rhode Island Stormwater Manual*— Stormwater Management Benefits Text Boxes	= $\frac{WQV^1}{WQV_{total}^2}$ x bacteria reduction benefit factor Where the reduction benefit factor equals: Low or unknown benefit = 0 Partial benefit = 5 Significant benefit = 10	3
Nitrogen Reduction	Draft *Rhode Island Stormwater Manual*— Stormwater Management Benefits Text Boxes	= $\frac{WQV}{WQV_{total}^2}$ x nitrogen reduction benefit factor Where the reduction benefit factor equals: Low or unknown benefit = 0 Partial benefit = 5 Significant benefit = 10	3
Groundwater Recharge	Table 10, Upland Treatment and Table 12, End-of-Pipe Treatment	=$\frac{V_{GWR}^1}{V_{GWR\text{-}total}^2}$ x GWR factor Where the GWR factor equals: Infiltration or recharge BMP = 10 Filtration BMP = 0	2
Space Requirement/Land	Based on volume treated per square foot of land area (VPA) for each BMP.	= 10 – VPA (Table 15)	2
Construction Cost	Estimated cost per cubic foot of stormwater treated.	= 10 – unit cost (Table 15)	2
Operation & Maintenance (O&M)	Draft *Rhode Island Stormwater Manual*— Stormwater Management Benefits Text Boxes	O&M cost/ability low = 10 O&M cost/ability moderate = 5 O&M cost/ability high = 0	2
Reliability	Professional Experience	High reliability to function during range of storm events = 10 Little reliability to function during range of storm events = 0	1
Public Acceptance	Professional Experience	Finished project has limited impacts to neighborhood (perceived or otherwise) = 10 Finished project has significant impacts to neighborhood (perceived or otherwise) = 10	3
Ability to Implement	Professional Experience	Project has few impediments to being implemented (permitting, engineering, other approvals)=10 Project has significant impediments to being implemented (permitting, engineering, other approvals)=0	1
MULTIPLIERS			
Multiplier A – Treated Volume	Table 10, Upland Treatment and Table 12, End-of-Pipe Treatment	= $0.75(V_{treatable}^1/WQV) + 0.25(V_{treatable}/GWR)$ Where the upper limit of $V_{treatable}/WQV = 1$ $V_{treatable}/GWR = 1$	NA
Multiplier B – Type of Area Available	Narragansett's land use data	Fraction town-owned x 1 Fraction in roadway, managed open space or stabilized x 0.5 Fraction unmerged vacant land x 0.25 Fraction merged vacant land x 0.13	NA

Notes:

1. When rating potential BMPs, WQV, $V_{treatable}$, and V_{GWR} refer the values for the subwatershed where a potential BMP is to be sited.
2. WQV_{total} and $V_{GWR\text{-}total}$ indicate WQV or VGWR sum of subject subwatersheds.
3. VPA_{max} and $Cost_{max}$ indicate the maximum volume of stormwater treated per area available, which is 6.4 for sand filters or the maximum cost which is 7.6 for sand filters.

Fuss and O Neill developed methods to quantify the influence of each criterion for each proposed BMP and subwatershed location. The influence of each criterion is measured on a scale of 1 to 10 for addend scores. Bacteria and nitrogen reduction scores were then multiplied by the percent of WQV to account for the subwatershed loadings. Groundwater recharge was multiplied by percent of V_{GWR} for the same purpose.

The discussion below provides an explanation of each criterion in the rating matrix.

Bacteria Load Reduction

Research shows that certain BMPs are more effective at reducing bacteria in stormwater than others. Generally, these BMPs involve passing stormwater through a filter media (e.g., soil or sand). The draft *Rhode Island Stormwater Manual* presents information on effectiveness in the text box at the beginning of each BMP discussion. The reduction benefits are listed as low or unknown, partial, and significant. Point values are assigned in the scoring rubric to scale for relative benefit.

WQV in Table 4.9 and Table 4.11 is a volumetric measure of the stormwater volume requiring treatment in a given subwatershed. The WQV is divided by the aggregate WQV for the study area, which is used as a multiplier in the scoring rubric to indicate the benefit of treating the stormwater in each subwatershed using a given BMP for bacteria reduction.

Nitrogen Reduction

Research shows that certain BMPs are more effective at reducing nitrogen in stormwater than others. Generally, the best nitrogen-reduction BMPs involve vegetative and aerobic treatment. The draft *Rhode Island Stormwater Manual* presents information on effectiveness in the text box at the beginning of each BMP discussion. The reduction benefits are listed as low or unknown, partial, and significant. Point values are assigned in the scoring rubric to scale for relative benefit.

WQV in Table 4.9 and Table 4.11 is a volumetric measure of the stormwater volume requiring treatment in a given subwatershed. The WQV is divided by the aggregate WQV for the study area, which is used as a multiplier in the scoring rubric to indicate the benefit of treating the stormwater in each subwatershed using a given BMP for nitrogen reduction.

Groundwater Recharge

Only some BMPs are capable of recharging groundwater. Point values are assigned in the scoring rubric based on this capacity.

V_{GWR} in Table 4.9and Table 4.11 is a volumetric measure of the stormwater volume required to recharge groundwater to predevelopment levels in a given subwatershed. The V_{GWR} treated by a BMP in a subwatershed is divided by the aggregate V_{GWR} of the study subwatershed to be used as a multiplier in the scoring rubric.

Space Requirement/Land

The space requirement rubric was developed from the volume of stormwater treated per area used (VPA) values provided in Table 4.14. The value listed in the table was subtracted from 10 (the maximum score).

Construction Cost

The space requirement rubric was developed from the cost per volume of stormwater treated values (unit cost) provided in Table 4.14. The cost listed in the table was subtracted from 10 (the maximum score).

Operation & Maintenance

The draft *Rhode Island Stormwater Manual* presents information on relative cost of maintenance in the text boxes at the beginning of each BMP discussion. Maintenance costs are listed as low, moderate and high. Point values are assigned in the scoring rubric to scale for the relative cost.

Reliability

The reliability rating provides an indicator of how well the BMP can manage a range of storm events in a range of conditions. The BMPs discussed in this technical memorandum are relatively reliable if installed and maintained appropriately. The reliability values used in the rating matrix were developed taking into account considerations such as design, installation, and existing conditions.

Public Acceptance

Public acceptance can be difficult to determine because individuals may have drastically different reactions to the same BMP. Public acceptance also depends on the number of people affected and the way in which they are affected. To quantify the public acceptance factor, the long-term effects of neighbors were considered to be the main criteria, in which case, BMPs that are not noticeable or have the least impact on the neighborhood are given the highest rating.

Ability to Implement

Installing BMPs can be more or less difficult depending on factors such as regulatory or municipal requirements and the extent of engineering design. The ability to implement ratings were developed from our professional experience.

Multipliers

Perhaps the most significant constraint on stormwater management in the Narrow River Watershed is the availability of land. Most land in the watershed is privately owned and used by the owner. Many "vacant" lots have been merged with occupied lots to support improvements such as swimming pools. This rating matrix applies two multipliers.

The first multiplier, volume treated, involved quantifying the fraction of WQV and V_{GWR} treated in a subwatershed in relation to the aggregate WQV and V_{GWR} for the study area. The WQV and V_{GWR} are dependent on the total area available for construction of BMPs in a subwatershed.

The second multiplier, type of area available, applies classification of land from town records— town-owned, managed open space, stabilized, roadway, vacant unmerged, and vacant merged. BMP installation is assumed to be most acceptable on town-owned lots. Roadway areas, stabilized lots, and managed open space lots are considered to be the next most acceptable areas for siting BMPs, followed by unmerged vacant lots and finally merged vacant lots.

5.1.2 Rating Matrix

Table 5.3 provides the rating matrix used to quantify the relative value of applying BMP retrofits in each subwatershed based on the criteria discussed in the previous section. The rating matrix has been developed in an effort to develop a comparison of the subwatersheds to aide in choosing the most beneficial treatment technologies and locations.

To determine total values for BMPs in each subwatershed, the following three step process was applied:

1. Scores were developed for each criterion using the scoring rubric in Table 5.2.
2. Scores were multiplied by the weighting factors in Table 5.2.
3. Weighted scores were aggregated into a total value for each BMP in each subwatershed

Table 5.3
Rating Matrix

Indian Head

Location	Alternative	Criteria									SCORE
		Bacterial Removal	Nitrogen Removal	Ground-water Recharge	Space Requirements	Construction Cost	Operation & Maintenance	Reliability	Ability to Implement	Public Acceptance	
		3	3	2	2	2	2	1	1	3	
End-of-Pipe & Upland	Sand filter	9	5	0	6	4	8	2	10	5	10
	Biorention (subdrain)	5	5	0	2	8	7	3	5	8	3
	Biorention (infiltration)	9	5	10	2	8	7	3	5	7	3
	Infiltration trench	5	5	10	3	7	5	5	5	7	10
	Disconnected catch basin	9	5	10	3	7	4	6	5	7	10

Petta Lake Shores 2

Location	Alternative	Criteria									SCORE
		Bacterial Removal	Nitrogen Removal	Groundwater Recharge	Space Requirements	Construction Cost	Operation & Maintenance	Reliability	Ability to Implement	Public Acceptance	
		3	3	2	2	2	2	1	1	3	
End-of-Pipe & Upland	Sand filter	9	5	0	4	2	10	5	10	10	62
	Biorention (subdrain)	5	5	0	8	3	5	8	3	5	46
	Biorention (infiltration)	9	5	2	8	3	5	7	3	5	58
	Infiltration trench	2	2	3	7	5	5	7	10	10	26
	Disconnected catch basin	4	2	3	7	6	5	7	10	10	28

Edgewater 1

Location	Alternative	Criteria									SCORE
		Bacterial Removal	Nitrogen Removal	Groundwater Recharge	Space Requirements	Construction Cost	Operation & Maintenance	Reliability	Ability to Implement	Public Acceptance	
		3	3	2	2	2	2	1	1	3	
End-of-Pipe & Upland	Sand filter	9	5	0	4	2	10	5	10	10	57
	Biorention (subdrain)	3	3	0	8	3	5	8	3	5	3
	Biorention (infiltration)	5	3	6	8	3	5	7	3	5	5
	Infiltration trench	5	5	10	7	5	5	7	10	10	74
	Disconnected catch basin	9	5	10	7	6	5	7	10	10	82

Edgewater 2

Location	Alternative	Criteria									SCORE
		Bacterial Removal	Nitrogen Removal	Groundwater Recharge	Space Requirements	Construction Cost	Operation & Maintenance	Reliability	Ability to Implement	Public Acceptance	
		3	3	2	2	2	2	1	1	3	
End-of-Pipe & Upland	Sand filter	9	5	0	4	2	10	5	10	10	17
	Biorention (subdrain)	0	0	0	8	3	5	8	3	5	0
	Biorention (infiltration)	0	0	0	8	3	5	7	3	5	0
	Infiltration trench	5	5	10	7	5	5	7	10	10	23
	Disconnected catch basin	9	5	10	7	6	5	7	10	10	25

Pettasquamscutt Combination

Location	Alternative	Criteria									SCORE
		Bacterial Removal	Nitrogen Removal	Groundwater Recharge	Space Requirements	Construction Cost	Operation & Maintenance	Reliability	Ability to Implement	Public Acceptance	
		3	3	2	2	2	2	1	1	3	
End-of-Pipe & Upland	Sand filter	9	5	0	4	2	10	5	10	10	78
	Biorention (subdrain)	5	5	0	8	3	5	8	3	5	49
	Biorention (infiltration)	9	5	6	8	3	5	7	3	5	77
	Infiltration trench	5	5	10	7	5	5	7	10	10	119
	Disconnected catch basin	9	5	10	7	6	5	7	10	10	132

Mettatuxet 1

Location	Alternative	Criteria									SCORE
		Bacterial Removal	Nitrogen Removal	Groundwater Recharge	Space Requirements	Construction Cost	Operation & Maintenance	Reliability	Ability to Implement	Public Acceptance	
		3	3	2	2	2	2	1	1	3	
End-of-Pipe & Upland	Sand filter	9	5	0	4	2	10	5	10	10	21
	Biorention (subdrain)	5	5	0	8	3	5	8	3	5	6
	Biorention (infiltration)	9	5	10	8	3	5	7	3	5	11
	Infiltration trench	5	5	10	7	5	5	7	10	10	35
	Disconnected catch basin	9	5	10	7	6	5	7	10	10	38

Mettatuxet 3

Location	Alternative	Criteria									SCORE
		Bacterial Removal	Nitrogen Removal	Groundwater Recharge	Space Requirements	Construction Cost	Operation & Maintenance	Reliability	Ability to Implement	Public Acceptance	
		3	3	2	2	2	2	1	1	3	
End-of-Pipe & Upland	Sand filter	9	5	0	4	2	10	5	10	10	22
	Biorention (subdrain)	5	5	0	8	3	5	8	3	5	4
	Biorention (infiltration)	9	5	10	8	3	5	7	3	5	7
	Infiltration trench	5	5	10	7	5	5	7	10	10	33
	Disconnected catch basin	9	5	10	7	6	5	7	10	10	37

Mettatuxet 4

Location	Alternative	Criteria									SCORE
		Bacterial Removal	Nitrogen Removal	Groundwater Recharge	Space Requirements	Construction Cost	Operation & Maintenance	Reliability	Ability to Implement	Public Acceptance	
		3	3	2	2	2	2	1	1	3	
End-of-Pipe & Upland	Sand filter	9	5	0	4	2	10	5	10	10	25
	Biorention (subdrain)	5	5	0	8	3	5	8	3	5	11
	Biorention (infiltration)	9	5	9	8	3	5	7	3	5	21
	Infiltration trench	5	5	10	7	5	5	7	10	10	41
	Disconnected catch basin	9	5	10	7	6	5	7	10	10	45

Scoring Summary

	SCORES							
	IH	PLS2	E1	E2	PTC	M1	M3	M4
Sand filter	29	62	57	17	78	21	22	25
Biorention (subdrain)	22	46	3	0	49	6	4	11
Biorention (infiltration)	42	58	5	0	77	11	7	21
Infiltration trench	46	26	74	23	119	35	33	41
Disconnected catch basin	51	28	82	25	132	38	37	45

Red highlight indicates two highest values
Yellow highlight indicates 3rd and 4th highest values
Green highlight indicates 5th through 8th highest values

5.2 Conceptual Control Strategies

On January 19, 2006, a workshop was held with the Narrow River Technical Advisory Committee (TAC) to review the results of BMP analysis and select subwatersheds for further design work. Consensus was established that 75% engineering designs should be prepared for Pettaquamscutt Terrace Combination (PTC) as well as Edgewater 1. Edgewater 2 (E2) was also selected due to its hydrologic proximity to PTC and E2.

TAC members agreed that infiltration trenches and sand filters were generally the most appropriate BMPs for treatment of pathogens. Infiltration trenches are also noted for their capacity to recharge groundwater.

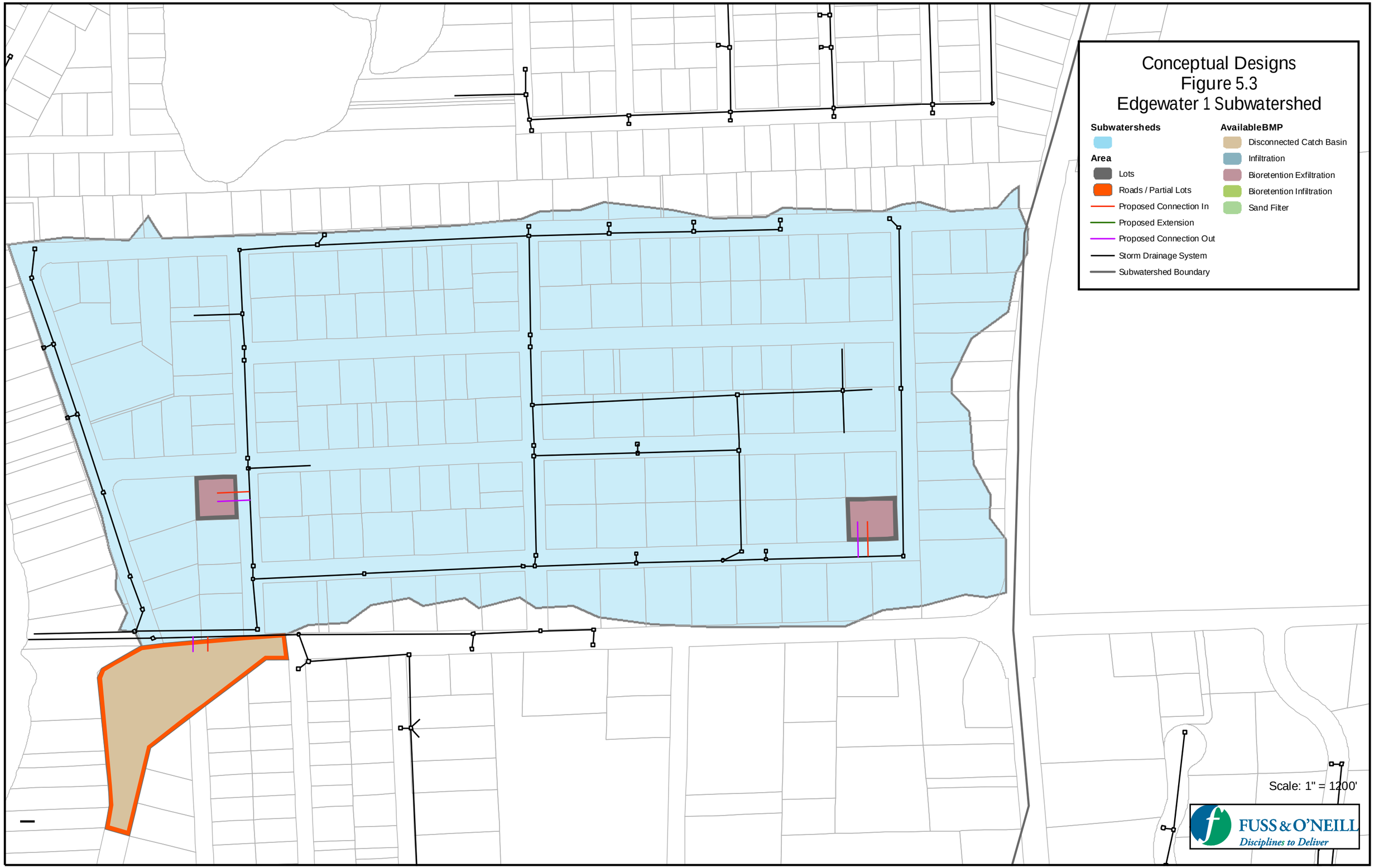
The TAC also expressed a preference for BMPs that reduce nitrogen loads. CRMC, in particular, expressed this preference and noted that nitrogen reduction is strongly encouraged in the Narrow River Special Area Management Plan.

Although the five types of BMP analyzed in sections 4.6 and 4.7 are all noted in technical literature to provide at least some limited nitrogen-reduction function, biorentention provides the strongest reduction value as it includes a vegetative component. Notwithstanding, bioretention systems require a significant amount of open area. While there are some parcels listed as "vacant" in Narragansett's Tax Assessor Records in the Edgewater and Pettaquamiscutt subwatersheds, the Town has no property rights or easements on theses lands. Bioretention is not feasible without the Town acquiring the rights to build BMPs on these areas.

Figures 5.1 - 5.8 provide plan view conceptual drawings of BMPs in each subwatershed. A schematic of bioretention, which has been adapted from the draft *Rhode Island Stormwater Design and Installation Standards Manual* (2006), is provided in Diagram 5.1. Diagram 5.2 provides a schematic of a disconnected catch basin.

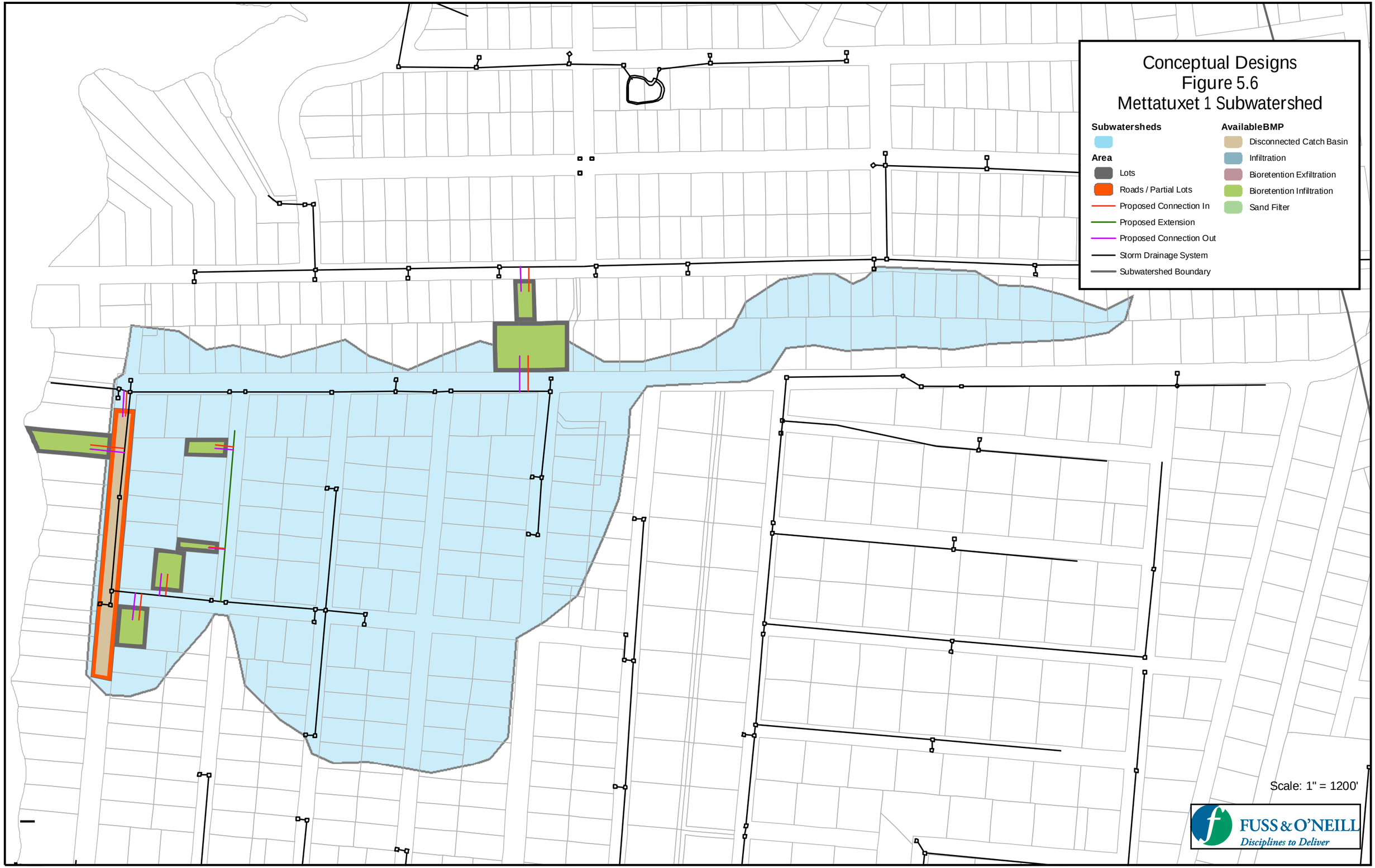
Conceptual Designs
Figure 5.1
Indian Head Subwatershed

Conceptual Designs
Figure 5.2
Petta Lake Shores 2
Subwatershed
Subwatersheds
Area
Lots
Roads / Partial Lots
Proposed Connection In
Proposed Extension
Proposed Connection Out
Storm Drainage System
Subwatershed Boundary
AvailableBMP
Disconnected Catch Basin
Infiltration
Bioretention Exfiltration
Bioretention Infiltration
Sand Filter
Scale: 1" = 1200'
FUSS & O'NEILL
Disciplines to Deliver


Conceptual Designs
Figure 5.3
Edgewater 1 Subwatershed
Subwatersheds
Area
Lots
Roads / Partial Lots
Proposed Connection In
Proposed Extension
Proposed Connection Out
Storm Drainage System
Subwatershed Boundary
AvailableBMP
Disconnected Catch Basin
Infiltration
Bioretention Exfiltration
Bioretention Infiltration
Sand Filter
Scale: 1" = 1200'
FUSS & O'NEILL
Disciplines to Deliver

Conceptual Designs
Figure 5.4
Edgewater 2 Subwatershed
Subwatersheds
Area
Lots
Roads / Partial Lots
Proposed Connection In
Proposed Extension
Proposed Connection Out
Storm Drainage System
Subwatershed Boundary
AvailableBMP
Disconnected Catch Basin
Infiltration
Bioretention Exfiltration
Bioretention Infiltration
Sand Filter
Scale: 1" = 1200'
FUSS & O'NEILL
Disciplines to Deliver

Conceptual Designs
Figure 5.5
Pettaquamiscutt Terrace
Subwatershed
Subwatersheds
Area
Lots
Roads / Partial Lots
Proposed Connection In
Proposed Extension
Proposed Connection Out
Storm Drainage System
Subwatershed Boundary
AvailableBMP
Disconnected Catch Basin
Infiltration
Bioretention Exfiltration
Bioretention Infiltration
Sand Filter
Scale: 1" = 1200'
FUSS & O'NEILL
Disciplines to Deliver


Conceptual Designs
Figure 5.6
Mettatuxet 1 Subwatershed
Subwatersheds
Area
Lots
Roads / Partial Lots
Proposed Connection In
Proposed Extension
Proposed Connection Out
Storm Drainage System
Subwatershed Boundary
AvailableBMP
Disconnected Catch Basin
Infiltration
Bioretention Exfiltration
Bioretention Infiltration
Sand Filter
Scale: 1" = 1200'
FUSS & O'NEILL
Disciplines to Deliver

Conceptual Designs
Figure 5.7
Mettatuxet 3 Subwatershed
Subwatersheds
Area
Lots
Roads / Partial Lots
Proposed Connection In
Proposed Extension
Proposed Connection Out
Storm Drainage System
Subwatershed Boundary
AvailableBMP
Disconnected Catch Basin
Infiltration
Bioretention Exfiltration
Bioretention Infiltration
Sand Filter
Scale: 1" = 1200'
FUSS & O'NEILL
Disciplines to Deliver

Conceptual Designs
Figure 5.8
Mettatuxet 4 Subwatershed
Subwatersheds
Area
Lots
Roads / Partial Lots
Proposed Connection In
Proposed Extension
Proposed Connection Out
Storm Drainage System
Subwatershed Boundary
AvailableBMP
Disconnected Catch Basin
Infiltration
Bioretention Exfiltration
Bioretention Infiltration
Sand Filter
Scale: 1" = 1200'
FUSS & O'NEILL
Disciplines to Deliver

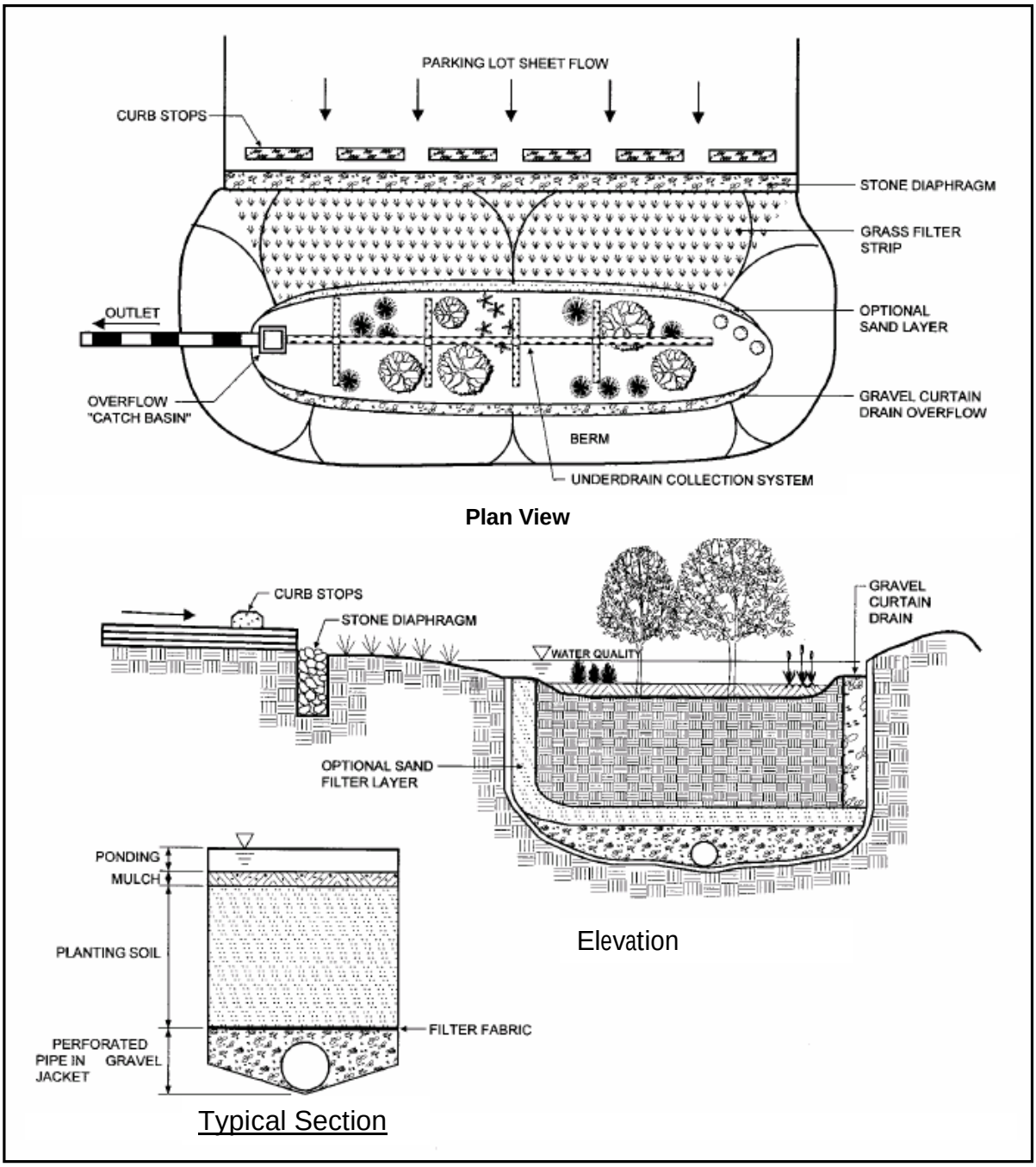
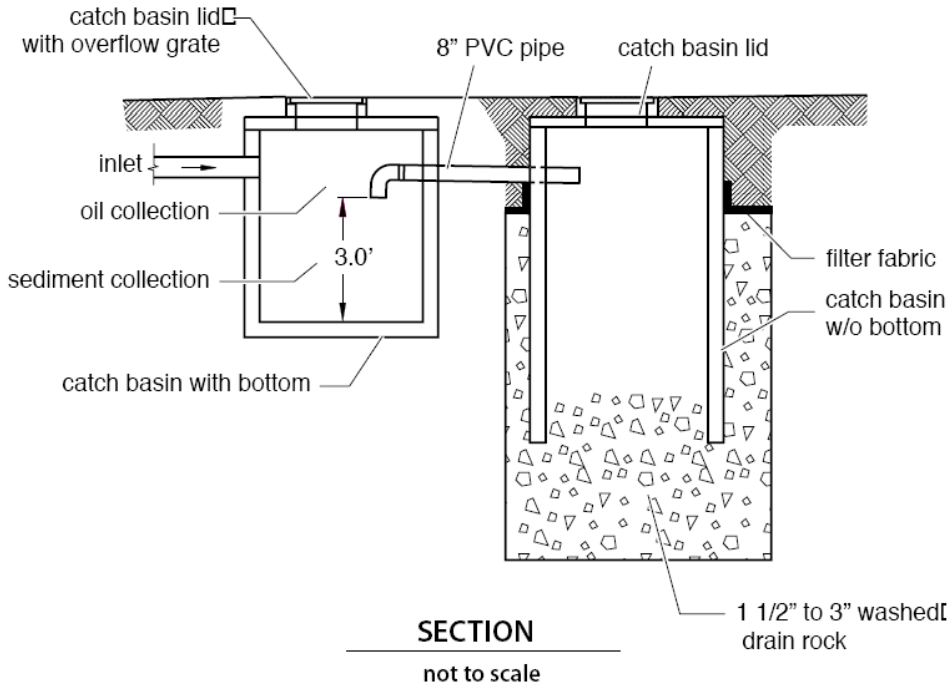


Diagram 5.1: Bioretentions: Adapted from Draft Rhode Island Stormwater Manual, 2005.

Diagram 5.2: Disconnected Catch Basin Source: Adapted from Atlanta Regional Commission, 2001.



6.0 SEVENTY-FIVE PERCENT DESIGNS

6.1 Control Strategies

Based on the rating matrix evaluation, infiltration and filtration control strategies were selected developed for the two Edgewater and two Pettaquamiscutt subwatersheds. These control strategies were selected based on the physical conditions in those subwatersheds and managing 100% of the WQV generated in those subwatersheds.

6.2 Design Criteria

Design criteria for controls in both the Edgewater and Pettaquamiscutt subwatersheds include the following:

- Manage all of the WQV generated in the subwatersheds through water quality control measures. The Water Quality Volume is calculated as defined in the *Rhode Island Stormwater Design and Installation Standards Manual*. That is the runoff generated by a 24-hour, Type III storm with 1.2 inches of precipitation.

- Controls designed and sized in accordance with the *Rhode Island Stormwater Design and Installation Standards Manual.*

- Some level of pretreatment is recommended prior to the primary treatment devices. For larger drainage areas, proprietary devices such as Aquaswirl™ or other type of similar system that can remove significant amounts of sediment as

well as floatables. These proprietary systems are desirable in this project area because they require little space. For smaller drainage areas, reconstructing existing catch basins with deep sumps and hoods are recommended since the smaller areas do not justify the cost of the proprietary pretreatment systems such as Aquaswirl™.

- Bypass around control systems will be designed for a 25-year frequency storm in order to minimize hydraulic overloading of the control systems where feasible.

- Incorporate woodchip-filled trenches into the design as a feature to reduce the level of nitrogen in stormwater runoff after it is infiltrated into the ground. Generally speaking, this is done by digging a trench below groundwater of the aquifer downstream of the BMP's subsurface discharge and backfilling it with woodchips to a point above the seasonal-high groundwater table. The woodchips are then covered with soil to grade. The plume of effluent from the upstream BMP then drains through the woodchip-filled trench. Woodchips adsorb pollutants. They also provide a carbon source and create an aerobic zone where denitrification may occur. The use of woodchip trenches as a feature of the design was requested by CRMC. It should be noted that there is a patented process that utilizes a woodchip mixture in trenches specifically for nitrogen removal from onsite wastewater soil absorption system effluent. The patented process and any associated royalties need to be further explored before the design of this element is completed.

6.3 Calculated Hydraulic Load

Hydraulic loads were calculated specifically for the design of the control systems proposed for these subwatersheds. Two methods were utilized to develop these loadings. The first approach consisted of utilizing a conventional TR-20 analysis with a composite curve number for the subwatershed. However, the problem with a conventional TR-20 analysis is that it is not intended to calculate flows for small, more frequent storms that would generate the WQV. This is because the SCS curve number method provides a singular "composite" or average curve numbers for developed areas, presuming that catchments respond to rain and generate runoff homogenously. For larger storms the assumption is valid, but during small storms (i.e., one inch or less) the assumption is invalid because roadways respond very quickly during those events (e.g., runoff is generated after 0.1 inches of rain), while pervious areas such as lawns tend to respond more slowly (e.g., runoff is generated after over an inch of rain).

In order to calculate more representative flows for WQV events (1.2 inches of precipitation), alternate calculations were completed where separate hydrographs were calculated for paved surfaces and these hydrographs were then added to the hydrographs generated for the remainder of the watershed using composite curve numbers. These calculations are somewhat conservative as they assume that all of these paved surfaces are connected and the subwatershed composite curve numbers were still used without recalculating a smaller composite curve number without pavement. For the purposes of these calculations, it was assumed that the average connected impervious area (including roads, building roofs,

driveways, etc.) was equivalent to thirty feet of pavement. The following table summarizes the calculated WQV loadings for his subwatershed.

Table 6.1
Calculated Hydraulic Loadings

	Conventional TR-20 - CN for entire subwatershed		*Pavement separated - CN for rest of watershed*	
Subwatershed	Peak Flow (cfs)	Runoff Volume (cf)	Peak Flow (cfs)	Runoff Volume (cf)
EC	1.5	23,000	8.1	53,900
PTC	1.2	22,700	3.9	36,500

For the purposes of sizing future control structures, the higher flows generated using the alternative method were used. Calculations are attached in Appendix A.

6.4 Results of Test Pits

Fuss & O'Neill, Inc. observed the excavation and subsequent backfill of five test pits on July 6, 2006. Test pits were dug by the Town of Narragansett DPW using a backhoe. Test pits were observed for soil type, evidence of mottling, and groundwater levels to a maximum depth of 10 feet. Two tests pits were excavated in EC (TP-1 and TP-2), two were excavated in PTC (TP-3 and TP-4), and one was excavated between the subwatersheds on Overlook Road (TP-5).

Similar soils were encountered at design depths in the other test pits. Groundwater was observed in TP-4 at a depth of 6 feet. Some slight mottling may have been observed in TP-2 at a depth of 6 feet, and groundwater was observed at the bottom of the test pit at about 10 feet. Bedrock was not encountered. A summary of the test pit observations is provided in Table 6.2.

Infiltration tests were performed at a depth of 4 feet in TP-1 and TP-3 using a Turf-Tec International Infiltrometer. The infiltration rates were measured in the field for the two test pits and are provided in Table 6.2. The maximum allowable infiltration rate for design is 7.5 feet per day (fpd); therefore, an infiltration rate of 7.5 fpd was used for design calculations rather than the field measured rates which were much higher. Due to the high infiltration rates, the infiltration surfaces will need to be amended to slow the infiltration rate to 7.5 fpd.

Table 6.2
Test Pit Observation Summary

ID	Soil Description		GS elevation (ft)	Bottom elevation (ft)	Groundwater/mottling	Notes
TP-1	0-1 '	Topsoil	14	4	Not encountered	K=2,160 fpd
	1-10 '	Medium to coarse clean lt. brown sand				
TP-2	0-0.5 '	Topsoil	16	6	Mottling at 6-8 'bgs (elev. 10) Groundwater at 10 'bgs	n/a
	0.5-8 '	Silty, gravelly lt. brown sand				
	8-10 '	Dense, fine to medium gray sand				
TP-3	0-0.5 '	Topsoil	20	10	Not encountered	K=66 fpd
	0.5-8 '	Loamy, silty lt. brown sand				
	8-10 '	Gravelly, coarse lt. to dark brown				
TP-4	0-0.5 '	Topsoil	20	10	Groundwater at 6-8 'bgs (elev. 14)	n/a
	0.5-8 '	Silty, gravelly lt. brown, rust, gray sand				
	8-10 '	Dense fine to medium gray sand				
TP-5	0-0.5 '	Topsoil	24	15.5	Not encountered	n/a
	0.5-5 '	Fine, silty lt. brown sand				
	5-8.5 '	Medium, clean lt. brn sand				

6.5 Utility Locations

The underground utilities present in the watershed include gas, water, sanitary sewer, and storm sewer. The locations of the Town utilities (water, sanitary sewer, and storm sewer) were provided as GIS data by the Town of Narragansett. Natural gas utilities were determined based on plans provided as paper maps from the New England Gas Company. Digsafe marked the locations of gas utilities within the subject subwatersheds (EC and PTC). The Town of Narragansett marked the locations of water, sanitary sewer, and storm sewer in the vicinity of test pit locations. Field located utility locations were compared to the provided mapping during test pit operations.

Elevations for the utilities were determined using as-built sanitary sewer plans. The plans included profile drawings that identified some of the elevations for other utilities, including water, storm sewer, and gas. The depth below ground surface for storm sewer inverts along Pettasquamscutt Avenue, Lakeside Drive, and Courtland Drive was measured in the field, where feasible. Some catch basins were not accessible and depths could not be measured. Where as-built elevation data was not available for storm sewers, the field measurements were used to determine invert elevations, based on the topographic contours provided.

6.6 Edgewater Subwatersheds

6.6.1 Physical Conditions

The Edgewater subwatersheds have several unique conditions that need to be considered when selecting storm water control strategies.

- Most of the watershed is developed. Undeveloped land in the subwatershed is largely limited to a couple of lots, a paper street and a parcel of land owned by a local neighborhood association. As a result, controls will need to be largely located within existing public rights-of-way. Homeowner improvements have been constructed in the road shoulders, thereby making the development of controls in those shoulders (e.g. grass swales) more difficult.

- Soils in most of the watershed have been mapped in the Rhode Island Soil Survey as Hydrologic Soil Group C. These soils have poor capacity to infiltrate water and have relatively high ground water tables. Infiltration controls will be limited to the smaller portion of the watershed where Hydrologic Soil Group A soils exists.

- There is a significant change in elevation near the watershed outfalls to the Narrow River. This change is elevation makes the use of a sand filter viable in this area which requires several feet of head to operate.

- Some open land exists at the bottom of the subwatershed in the Rhode Island Department of Transportation (RIDOT) right-of-way for Bridgetown Road. It is understood that RIDOT will consider the development of stormwater controls for this location.

- A pond exists in the lower portion of the watershed that does not appear to be hydraulically connected to the Narrow River based on the Town's storm drainage system mapping. This pond currently serves as a discharge point for some of the Town's drainage.

- Inadequate space exists for vegetative controls. Vegetative controls require a significant amount of open space, especially for large hydraulic loads as exist in this watershed. One alternative that can be considered is a level spreader and vegetative filter strip near the outfall to the river, however, the Town does not control this land.

6.6.2 Proposed Control Strategies

Two sets of control strategies have been proposed for the Edgewater subwatersheds as follows:

- Sand Filter near the Edgewater Outfalls

A sand filter was proposed in the available open space near the Edgewater Outfalls for several reasons.

- There is limited potential to manage the Water Quality Volume from the watershed with infiltration given existing grades and subsurface soil conditions (Hydrologic Soil Group C and A). A sand filter has significantly more hydraulic capacity per unit area than infiltration since the media is engineered and is subdrained.

- Open space exists near the Edgewater outfalls that also has almost a fifteen change in grape. Physical conditions at this outfall are good for a sand filter.

- Two sites exist at this outfall, one is in the undeveloped parcel where the outfalls now exist. The local neighborhood association has expressed concern with developing this parcel. As a result, design plans have been focused on constructing a sand filter in some open space on the RIDOT Bridgetown Road right-of-way.

- The sand filter has been sized to manage 40,600 cubic feet of the Water Quality Volume (as compared a total WQV of 53,900 cubic feet for the Edgewater watershed).

- Infiltration System along Tanglewood Trail

In order to manage the remaining WQV, a subsurface infiltration system has been proposed on Tanglewood Trail. This site was selected for several reasons:

- The road is relatively level and is located in Hydrologic Soil Group A soils near the interface with Hydrologic Group C soils. As a result, physical conditions for infiltration are adequate at this location with significant hydraulic conductivity in the soils. An amendment is recommended to be placed in the top six inches of the soils to reduce hydraulic conductivity to 7.5 feet per day.

- Groundwater is reasonably deep at this location. Groundwater was observed at the bottom of a test pit constructed at the intersection of Tanglewood Trail and Birchwood Road to a depth of ten feet. Some slight discoloration was observed in the soils to a depth of six to eight feet, which may be a weak indication of some mottling. However, water elevations in the pond just below the road appear to be about ten feet based on Town mapping indicating that actual groundwater elevations are closer to that elevation. The well draining soils in this part of the watershed would not expect to result in groundwater having a significant gradient to the pond.

- § The trail is located where it can intercept a significant amount of runoff between Edgewater Road and Birchwood Road.

- § The system is designed to manage 13,800 cubic feet of the WQV.

- Conveyance Issues

  The Edgewater Subwatershed historically has not had significant problems with drainage and flooding as reported by the Town of Narragansett. Peak, 25-year storm flows were calculated for the upper portion of the subwatershed that would drain to the system on Tanglewood Trail. That portion of the watershed generates a peak flow of about 44 cubic feet per second for a 25-year storm. The existing drainage system would not be adequate to convey such flows.

  Given the relatively low elevations on Tanglewood Trail, especially on the paper street between Tanglewood Trail and Bridgetown Road where elevations are only at elevation 13, significant reconstruction would be required to manage the calculated peak flows but would also reduce the effectiveness of the proposed treatments systems. Improving the capacity of the system would likely mean lowering much of it which would also lower the infiltration components of the treatment system closer to groundwater such that the desired three-foot separation could no longer be achieved. As a result, no significant conveyance improvements have been proposed in this subwatershed.

  The proposed infiltration systems along Tanglewood Trail will improve overall drainage by diverting some of the runoff away from the trunk storm drain and allowing it to infiltrate. Diversion structures have been designed to allow the infiltration systems to fill before storm water is bypassed into the trunk storm drain system.

6.7 Pettaquamiscutt Subwatershed

6.7.1 Physical Conditions

The Pettaquamiscutt Subwatershed has several unique conditions that need to be considered when selecting storm water control strategies.

- A significant part of this watershed is undeveloped. This undeveloped land is largely located in the eastern portion of the subwatershed and is comprised of Town-owned open space. This land is relatively steep with Hydrologic Soil Group C soils. As a result, this undeveloped land has significant potential for runoff.

- This open space also has poor potential for locating storm water control structures given its steep slopes and poor soils. Wetlands and high groundwater exist at the bottom edge of this undeveloped area making this area undesirable for development of stormwater controls.

- Other open space in the subwatershed is largely limited to a couple of lots, and a paper street. As a result, controls will need to be largely located within existing public rights-of-way. Homeowner improvements have been constructed in the road shoulders, thereby making the development of controls in those shoulders (e.g. grass swales) more difficult.

- Soils in the developed portion of the watershed are largely mapped in the Rhode Island Soil Survey as Hydrologic Soil Group A. Slug testing and test pit/permeability testing confirms this classification. As a result, infiltration is a viable option to manage storm water runoff in this subwatershed.

- Siting controls in the lower portion of the subwatershed along the river will be more difficult. There are more significant slopes in the right-of-ways and grades near the river are close to mean high tide and groundwater elevations.

6.7.2 Proposed Control Strategies

Two sets of control strategies have been proposed for the Pettaqamiscutt subwatersheds as follows:

- Infiltration System

  A subsurface infiltration system has been proposed in the right of ways between Lakeview and Courtland Drive in order to manage most of the WQV generated in these subwatersheds. A subsurface infiltration system was selected for the following reasons at this location.

  § The physical conditions in this portion of the watershed are good for infiltration systems. Slopes are relatively flat and soils have good hydraulic conductivity. Some modification to these soils is recommended to reduce infiltration rates as recommended in the *Rhode Island Stormwater Manual*. The depth to groundwater in this location is relatively low.

  § Infiltration is not proposed along Courtland Drive because groundwater levels are still elevated because of the wetlands located to the east of the road.

  § This system has been designed to manage all of the WQV that drains to it, approximately 33,900 cubic feet (out of a total WQV of 36,500 cubic feet). A total of 2056 linear feet of infiltration trench has been proposed.

  § The road right-of-ways in these locations are relatively flat, allowing the construction of a level infiltration system that acts as a single system.

  § The system is designed to collect flows from the Pettaquamiscutt drainage system and drain those flows into the infiltration system. The

flows from the Beach Avenue area would be collected and discharged on the opposite side of the system. This approach was taken such that the undersized, and flat storm drain between Pettaquamiscutt and Beach on Courtland Avenue can be abandoned.

- Level Spreader/Vegetated Filter Strip

About 7.5 acres of the subwatershed will not drain to the proposed infiltration system. This lower portion of the subwatershed has limited options for new controls due to steeper slopes, high groundwater and low elevations along the river as well as limited space. In order to manage this small remaining area, a level spreader and vegetated filter strip control was developed to maximize infiltration through the soils as well as provide some level of vegetative treatment at the end of Pettaquamiscutt Avenue. The following paragraphs further describe this system.

§ A diversion chamber will divert the WQV from the storm sewer outfalls to the level spreader.

§ The WQV will be pretreated using a proprietary pretreatment unit such as AquaswirlTM or equal.

§ The drains conveying runoff to the level spreader will be perforated in order to allow to ponding within the system.

§ A level spreader will distribute runoff across a vegetated filter strip which will drain to the river. The level spreader is designed to safely convey peak flows across the filter strip, once vegetation has been established.

- Conveyance Issues

The Town has reported significant drainage issues in this subwatershed, specifically along Courtland Drive. As a result, this design was developed to improve drainage in this subwatershed. This design includes the following elements:

§ The drainage system in Pettaquamiscutt Avenue and Courtland Drive needs to be raised to drain to the infiltration system. As a result, this drainage system is proposed to be upgraded to manage a 25-year frequency storm.

§ The Courtland Drive storm drain between Pettaquamiscutt Avenue and Beach Avenue will be abandoned. Instead, runoff at the northern end of Courtland Drive will be directed into the northern end of the

infiltration system and runoff at the southern end will be discharged into the southern end of the system.

§ The infiltration system will both improve overall drainage by removing the WQV from the storm drainage system. The infiltration system is also designed to surcharge higher flows through the system to an engineered outlet.

§ The conveyance system was not upgraded between the infiltration system outfall and the discharge point to the river because this area was not reported as a historic flooding problem and significant work would have to be done, thereby increasing project costs.

6.8 Permits Likely to be Required

Permitting can be complicated. Several state and local agencies are likely to become involved in the approval process. Permitting will include:

- CRMC assent
- Town of Narragansett building permit
- RIDEM – Underground Injection Control (UIC) permit
- RIDEM – Rhode Island Pollutant Discharge Elimination System (RIPDES) permit

This may result in iterative design process and will affect implementation and construction scheduling. Nevertheless, a number of the potential review agencies are currently involved in the project's steering committee and should be able to guide it in a manner that facilitates permit review.

6.9 Erosion and Sediment Control

Much of the work proposed will have limited potential for significant erosion and sedimentation. However, controls have been proposed to reduce the potential for erosion and sedimentation during construction. These controls include the following elements:

§ Silt Fence/Hay Bales is proposed along the limits of disturbance at low points where runoff from the project will directly drain into wetlands or the river. They are also been proposed at the toe of the fill sections for the embankment proposed for the sand filter.

§ Silt sacks are proposed in each of the catch basins within the limit of disturbance to capture sediment before it enters the catch basins.

§ Erosion control matting is proposed in the newly disturbed area down gradient of the proposed Pettaquamiscutt level spreader to stabilize the soils before plant growth is fully established.

6.10 BMP Maintenance

Although often overlooked, maintenance is critical to the function of stormwater. The discussion, which was adapted from the draft *Rhode Island Stormwater Manual* provides our recommended inspection and maintenance for each of the BMPs designed for the Edgewater and Pettaquamscutt Terrace subwatersheds. BMP maintenance described in this section will be the responsibility of the Town of Narragansett.

Sand Filter (Edgewater 1 & 2 Subwatersheds)
Maintenance is critical for the proper operation of filtering systems. This practice is one of the most sensitive to maintenance.

a) Filtering practices should be inspected after every major storm in the first few months following construction. The filter should be inspected at least every six months thereafter. Inspections should focus on:
   - Checking the filter surface for standing water or other evidence of clogging such as discolored or accumulated sediments
   - Checking the sedimentation chamber or forebay for sediment accumulation, trash, and debris
   - Checking inlets, outlets, and overflow spillway for blockage, structural integrity, and evidence of erosion
b) Sediment should be removed from the sedimentation chamber or forebay when it accumulates to a depth of more than 12 inches or 10 percent of the pretreatment volume. The sedimentation chamber or forebay outlet devices should be cleaned when drawdown times exceed 36 hours.
c) Sediment should be removed from the filter bed when the accumulation exceeds one inch or when there is evidence that the infiltration capacity of the filter bed has been significantly reduced (i.e., observed water level above the filter exceeds the design level or drawdown time exceeds 36 hours). As a rule-of-thumb, the top several inches of the filter bed (typically discolored material) should be removed and replaced annually or more frequently if necessary. The material should be removed with rakes where possible rather than heavy construction equipment to avoid compaction of the filter bed. Heavy equipment could be used if the system is designed with dimensions that allow equipment to be located outside the filter, while a backhoe shovel reaches inside the filter to remove sediment. Removed sediments should be dewatered (if necessary) and disposed of in an acceptable manner.

Table 6.3 summarizes recommended long-term maintenance activities for filtering practices.

Table 6.3
Typical Maintenance Activities for Filtering Practices

Activity	Schedule
First six months: • Inspect filter, check for: q Standing water or other evidence of clogging q Sediment accumulation, trash, and debris in sedimentation chamber or forebay q Blockages, structural integrity, and evidence of erosion at inlets, outlets, and overflow spillways	After every major storm event that generates 1 inch or more of precipitation
After first six months: • Inspect filter (see above for details)	Every six months
• Remove sediment from sedimentation chamber or forebay	Depth > 12 inches or 10% of pretreatment volume
• Remove sediment from the filter bed	Depth > 1 inch or when infiltration capacity significantly reduced
• Remove and replace top several inches of the filter bed material	Annually

Infiltration System (Edgewater 1 & 2 and Pettaquamscutt Terrace Combination Subwatersheds)

Infiltration practices are susceptible to clogging by suspended solids in stormwater runoff and must be inspected and maintained regularly to ensure that they are functioning properly. The following are general recommended maintenance procedures for an infiltration system.

a) Pretreatment devices should be inspected and cleaned at least twice a year.
b) For the first few months after construction infiltration facilities should be inspected after every major storm. Inspections should focus on the duration of standing water in a facility or in the observation well of a facility after a storm. Ponding water after 48 hours indicates that the bottom of the infiltration facility may be clogged. If the bottom of the facility becomes clogged, all of the stone aggregate and filter fabric must be removed and replaced with new material. The bottom of the facility may need to be tilled to enhance infiltration. Water ponded at the surface of a facility may indicate only surface clogging.
c) After the first few months of operation, maintenance schedules for infiltration practices should be based on field observations, although inspections should be performed at least twice per year. Observations should include accumulated sediment, leaves and debris in the pretreatment device, clogging of inlet and outlet pipes, and ponded water inside the facility. For infiltration facilities, observations should include differential accumulation of sediment, erosion of the facility floor.

d) Sediment should be removed from infiltration facilities when the sediment is dry (visible cracks) and readily separates from the floor of the facility to minimize smearing the facility floor.

Table 6.4 summarizes recommended long-term maintenance activities for infiltration practices.

Table 6.4
Typical Maintenance Activities for Infiltration Practices

Activity	Schedule
• Inspect and clean pretreatment devices	Bi-Annually
First few months: • Inspect facilities – focus on the duration of standing water	After every major storm
After first few months: • Inspect facilities	Bi-Annually
• Clean and remove debris from inlet and outlet pipes. • Replace upper layer of stone and filter fabric.	As needed
• If subdrains are required, monitor water levels in observation wells to confirm proper long term performance of system.	Annually

Level Spreader/Vegetated Filter Strip (Pettaquamscutt Terrace Combination Subwatershed)

Although somewhat less complex than maintenance for sand filters and infiltration systems, regular maintenance is critical for the effectiveness of filter strips, especially to ensure that flow does not short-circuit the system.

a) Filter strips should be inspected at least quarterly during the first year of operation and semiannually thereafter. Evidence of erosion and concentrated flows within the buffer must be corrected immediately. Eroded spots must be reseeded and mulched to enhance a vigorous growth and prevent future erosion problems.
b) Procedures for soil preparation and seeding should be done in accordance with the most recent version of the Permanent Vegetative Cover section in chapter 4 of the *RI Soil Erosion and Sediment Control Handbook.*
c) The bulk of accumulated sediments will be trapped at the top of the filter strip. These deposited sediments should be removed manually at least once per year or when accumulating sediments cause a change in the grade elevation. Reseeding may be necessary to repair areas damaged during the sediment removal process.
d) Grass filter strips should be mowed only once per year, leaving vegetation a minimum of 4 inches in height. Mowing operations are to be conducted during the growing season, but preferably after mid August. This management technique maintains a tall vigorous growth and protects the young of ground nesting animals.

6.11 Budget-Level Opinions of Cost

We have prepared budget-level opinions of cost for the best management practices proposed for the Pettaquamscutt Terrace Combination and Edgewater 1 & 2 subwatersheds. As discussed in sections 6.4 and 6.5, best management practices will include infiltration systems for both Edgewater and Pettaquamscutt Terrace, a sand filter for Edgewater and a level spreader in Pettaquamscutt Terrace. Table 6.5 lists the budget-level opinion of cost of each management practice.

Table 6.5
Budget-Level Opinions of Cost for Best Management Practices in Edgewater and Pettaquamscutt Terrace Subwatersheds

Best Management Practice	Budget-Level Opinion of Cost
Edgewater Infiltration System	$333,000
Edgewater Sand Filter	$444,000
Pettaquamscutt Terrace Infiltration System	$627,000
Pettaquamscutt Terrace Level Spreader	$202,000
Total Cost	$1,606,000

Costs have been rounded to the nearest $1,000 and were calculated in 2006 dollars. Itemized budget-level opinions of cost for each of the four best management practices can be found in Appendix D. These costs do not include the costs for the construction of the wood filled trench as that work needs to be further designed and patent issues/royalties could significantly increase its costs.

6.12 Anticipated Pollutant Reduction

Under this study, stormwater management practices have been designed in accordance with the *Rhode Island Storm Water Design and Installation Standards Manual* and as such are capable of treating the water quality volume from each of the subwatersheds of concern. We, therefore anticipate 100 percent treatment of runoff from the water quality storm (i.e., 1 inch of runoff from the impervious surface). The WQV for the Edgewater and Pettaquamscutt Terrace subwatersheds is approximately 3.8 acre-feet and represents 40 percent of the WQV for the entire Narrow River study area. We, therefore, anticipate a 40 percent reduction in pollutants of concern entering the Narrow River from the study area during the water quality storm.

APPENDIX A

EXAMPLE CALCULATIONS AND DATA TABLES

APPENDIX A CALCULATIONS

- Calculation set 1 of 4
  - CN
  - CN_n
  - A_{imp}
- Calculation set 2 of 4
  - WQV
  - $V_{treatable}$
  - $A_{available}$
- Calculation set 3 of 4
  - R
  - V_{GWR}
- Calculation set 4 of 4
  - T_c
  - V_{25}
  - Q_{25}
- On-lot Costs
- Source Control Treatment % of Subwatershed
- Treatment Costs

Fuss & O'Neill Inc. *Consulting Engineers*

memorandum

Subject: Narrow River

Project Number 20041111.A10

Date: 11/10/05
Revision from DEA review 11/9/05

To REVISIONS

From Prepared by: KMK

Revision 1 —

Per DEA review the following changes were made:

① CN for woods from good condition to fair condition

② CN for open space from good to fair condition

Both CN changes were made to existing conditions NOT historical

Changes made to calculation sets 1, 3 & 4

Revision 2 —

see set 4

Revision 3 —

see set 2

CC: _____

F&O #190

Revision 1 11/10/05

Curve Numbers and Impervious Area

Introduction

The study area for Narrow River consists of 11 sub-watersheds for which current and historical runoff curve numbers and impervious areas were calculated. The following provides data used, example calculations, and a table of the results (calculated using excel, following the attached example calculations).

Source Data

Land use data and corresponding acreages were determined using GIS data provided by the Town of Narragansett for current condition CNs

Land use data and corresponding acreages were determined using the 1939 aerial photograph. Land uses were good condition forest, fair condition openspace and water.

Watersheds were delineated by KMK & reviewed by DEA (11/3/05).

Method

Curve numbers were determined by land use and soil type using the SCS runoff curve numbers.

The curve number for each sub-watershed was calculated by finding the area-weighted average of landuse/soil type CNs as shown in the following example for the Edgewater 1 sub-watershed

A_{imp} was calculated by multiplying each land use area by the SCS average % impervious area.

Example calculations for Edgewater 1

① $$CN = \frac{\Sigma(\text{area} \cdot CN)}{\Sigma \text{area}}$$

$$CN = \frac{[.55ac(\cancel{65}\ 70) + 1.92ac(\cancel{70}\ 73) + 3.07ac(91) + 7.81ac(57) + 1.46ac(81) + .06ac(86) + 2.36ac(61) + 28.0ac(83) + .71ac(87) + 1.3ac(98) + .001ac(98)]}{(1.55 + 1.92 + 3.07 + 7.81 + 1.46 + .06 + 2.36 + 28.0 + .71 + 1.3 + .001)\text{acres}}$$

$$\boxed{CN = \cancel{71.8}\ 78.0}$$

② $$A_{imp} = \Sigma A_{landuse} \cdot \%_{imp\ landuse} = .72(3.07ac) + .3(9.33) + .38(31.03) + 1(1.33) = \boxed{18.1 acre}$$

CN changes 11/10/05

CN

p. 2 of 8

Table 2-2a.—Runoff curve numbers for urban areas[1]

Cover description		Curve numbers for hydrologic soil group—			
Cover type and hydrologic condition	Average percent impervious area[2]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.)[3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only)[4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation)[5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

Rec, OS transition

Institutional

1-1/4 lots

1-2

$CN_n \approx CN_D$

[1]Average runoff condition, and $I_a = 0.2S$.
[2]The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.
[3]CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.
[4]Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.
[5]Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4, based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

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Table 2-2c.—Runoff curve numbers for other agricultural lands[1]

Cover description		Curve numbers for hydrologic soil group—			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range—continuous forage for grazing.[2]	Poor	68	79	86	89
	Fair	49	69	79	84 CN_D
	Good	39	61	74	80 X
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element.[3]	Poor	48	67	77	83
	Fair	35	56	70	77 CN_D
	Good	[4]30	48	65	73 X
Woods—grass combination (orchard or tree farm).[5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods.[6]	Poor	45	66	77	83
	Fair	36	60	73	79 CN_D
Best	Good	[4]30	55	70	77 CN_D
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

[1]Average runoff condition, and $I_a = 0.2S$.

[2]*Poor:* <50% ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: >75% ground cover and lightly or only occasionally grazed.

[3]*Poor:* <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.

[4]Actual curve number is less than 30; use CN = 30 for runoff computations.

[5]CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

[6]*Poor:* Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

HISTORIC CURVE NUMBERS - 2 PAGES

12/19/2005

Watershed (Total)		Soil A		Soil B		Soil C		Soil D		Water
Edgewater 1 Water (2.98)	98	2.49		x		0.21		0.29		
Edgewater 1 Open (21.25)		9	49	x		12.11	79	0.14	84	
Edgewater 1 Forested (22.99)		x	30	x		22.64	70	0.35	77	
Edgewater 1 Total area	47.23	11.49				34.96		0.78		
CN	70.1719									
Edgewater 2 Open (8.27)		3.61	49	x		4.66	79	x		
Edgewater 2 Forested (5.25)		x		x		5.25	70	x		
Edgewater 2 Total area	13.52	3.61				9.91				
CN	67.4948									
Indian Trail Open (9.13)		9.13	49	x		x		x		
Indian Trail Forested (18.08)		3.34	30	1.1	55	8.11	70	5.53	77	
Indian Trail Total area	27.21									
CN	58.86									
Mettatuxet 1 Open (16.26)		15.04	49	x		1.22	79	x		
Mettatuxet 1 Forested (10.58)		2.58	30	x		8	70	x		
Mettatuxet 1 Total area	26.84	17.62				9.22				
CN	54.7966									
Mettatuxet 3 Open Space (20.13)		16.21	49	x		3.92	79	x		
Mettatuxet 3 Total area	20.13	16.21				3.92				
CN	54.842									
Mettatuxet 4 Open (18.57)		18.05	49	x		0.52	79	x		
Mettatuxet 4 Forested (0.94)		teeny	30	x		0.94	70	x		
Mettatuxet 4 Total area	19.51	18.05				1.46				
CN	50.8114									
Petta Lake Shores 1 Open (1.95)		1.95	49	x		x		x		

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Petta Lake Shores 2 Water (1.87)	98	0.98		x		x		x		0.89
Petta Lake Shores 2 Open (22.76)		19.32	49	x		3.44	79	x		
Petta Lake Shores 2 Forested (75.24)		0.39	30	x		67.7	70	7.7	77	
Petta Lake Shores 2 Total area	100.42	19.71				71.14		7.7		1.87
CN	67.1709									
Petta Lake Shores 3 Open (2.1)		2.1	49	x		x		x		
Pettaquamiscutt Terrace 1 Open (21.36)		17.25	49	x		7.82	79	x		
Pettaquamiscutt Terrace 1 Forested (23.1)		0.17	30	x		38.43	70	x		
Pettaquamiscutt Terrace 1 Total area	63.67									
CN	65.3091									
Pettaquamiscutt Terrace 2 Open (10.45)		4.99	49	x		1.75	79	x		
Pettaquamiscutt Terrace 2 Forested (34.27)		2.1	30	x		16.65	70	x		
Pettaquamiscutt Terrace 2 Total area	25.49									
CN	63.2115									
PTC	64.7094									

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11/10/05 Current land use acreage by soil type and CN and impervious area

Code	Name	Land Use	Feet	Acres	CN	Soil A	Soil B	Soil C	Soil D	Water	percent	imp area
M4	*Mettatuxet 4*	Deciduous Forest (>80% hardwoo	13969.54	0.32	73			0.32			0	0
								73				
		Medium Density Residential (1 to	41534.55	0.95	57	0.95					0.3	0.285
						57						
		Medium High Density Residential (	793878.68	18.22	62.364	17.09		1.13			0.38	6.9236
						61		83				
		Wetland (not to be classified)	207.79	0.0048	98			0.0048			1	0.0048
								98				
				19.495	**62.286**	**18.04**		**1.4548**				**7.2134**
M3	*Mettatuxet 3*	Medium High Density Residential (	876720.7	**20.13**	**65.284**	16.21		3.92			0.38	7.6494
						61		83				
												7.6494
M1	*Mettatuxet 1*	Medium High Density Residential (	1169338.98	**26.84**	**68.557**	17.62		9.22			0.38	10.1992
						61		83				
												10.1992
PT1	*Pettaquamiscutt Terrace 1*	Deciduous Forest (>80% hardwoo	609016.15	19.1	70.675	1.2		17.9			0	0
						36		73				
		Developed Recreation (all recreati	212791.03	11.98	79			11.98			0	0
								79				
		Medium High Density Residential (	705746.38	16.26	61.054	16.22		0.04			0.38	6.1788
						61		83				
		Med Density Residential		2.66	81			2.66				
								81				
		Pasture (agricultural not suitable fo	31700.54	0.73	79			0.73			0	0
								79				
		Institutional		1.15	81			1.15				
								81				
		Wetland (not to be classified)	377310.23	11.79	98			11.79			1	11.79
								98				
				63.67	**75.558**	**1.2**		**46.25**				**17.9688**
PT2	*Pettaquamiscutt Terrace 2*	Deciduous Forest (>80% hardwoo	496862.59	6.29	73			6.29			0	0
								73				
		Developed Recreation (all recreati	450297.01	3.24	79			3.24			0	0
								79				
		Institutional (schools, hospitals, ch	50169.09								0.72	0
		Medium Density Residential (1 to	329696.91	4.91	81			4.91			0.3	1.473
								81				
		Medium High Density Residential (	267472.85	8.62	64.981	7.06		1.56			0.38	3.2756
						61		83				

		Medium Low Density Residential (	96078.78	2.21	77			2.21			0.12	0.2652
								77				
		Wetland (not to be classified)	146636.56	0.24	98	0.03		0.21			1	0.24
						98		98				
				25.51	**73.174**	**7.09**		**18.42**				**5.2538**
E2	*Edgewater 2*	Brushland (shrub and brush areas	16232.18	0.37	70			0.37			0	0
								70				
		Deciduous Forest (>80% hardwoo	21533.19	0.49	73			0.49			0	0
								73				
		Medium Density Residential (1 to	349531.1	8.02	80.252	0.25		7.77			0.3	2.406
						57		81				
		Medium High Density Residential (	185419.46	4.62	67.048	3.35		1.27			0.38	1.7556
						61		83				
				13.5	**75.189**	**3.6**		**9.9**				**4.1616**
E1	*Edgewater 1*	Brushland (shrub and brush areas	24042.65	0.55	70			0.55			0	0
								70				
		Deciduous Forest (>80% hardwoo	83458.72	1.92	73			1.92			0	0
								73				
		Institutional (schools, hospitals, ch	133545.98	3.07	91			3.07			0.72	2.2104
								91				
		Medium Density Residential (1 to	406424.57	9.33	60.942	7.81		1.46	0.06		0.3	2.799
						57		81	86			
		Medium High Density Residential (	1351568.2	31.03	81.418	2.36		27.96	0.71		0.38	11.7914
						61		83	87			
		Wetland (not to be classified)	57985.61	1.33	98	1.3294			0.0006		1	1.33
						98						
				47.23	**77.988**	**11.4994**		**34.96**	**0.7706**			**18.1308**
PLS3	*Petta Lake Shores 3*	Medium High Density Residential (	91312.72	**2.1**	**61**	2.1					0.38	0.798
						61						
												0.798
PLS2	*Petta Lake Shores 2*	Deciduous Forest (>80% hardwoo	499713.6	12.51	73.972	0.26		8.62	3.63		0	0
						36		73	79			
		Medium Density Residential (1 to	2794397.42	64.14	78.972	6.23		55.56	1.8	0.55	0.3	19.242
						57		81	86	100		
		Medium High Density Residential (	812970.83	19.23	67.643	13.52		5.18	0.53		0.38	7.3074
						61		83	87			
		Medium Low Density Residential (	15017.12	0.35	78.143			0.27	0.08		0.12	0.042
								77	82			
		Water	44434.44	1.02	100					1.02	1	1.02
										100		
		Wetland (not to be classified)	138767.27	3.18	98			1.5	1.68		1	3.18
								98	98			
				100.43	**76.993**	**20.01**		**69.63**	**7.72**	**1.57**		**30.7914**
PLS1	*Petta Lake Shores 1*	Medium Density Residential (1 to	77522.5	1.78	57	1.78					0.3	0.534

							57						
		Medium High Density Residential (	7301.29	0.17	61		0.17					0.38	0.0646
							61						
				1.95	**57.349**								**0.5986**
IH	***Indian Head***	Deciduous Forest (>80% hardwoo	105698.76	2.43	73.424		0.17	0.00001	1.04	1.22		0	0
							36	60	73	79			
		Medium Density Residential (1 to	256393.99	5.89	83.368				3.1	2.79		0.3	1.767
									81	86			
		Medium High Density Residential (	742672.93	17.05	66.512		12.4	1.1	3.43	0.12		0.38	6.479
							61	75	83	87			
		Transitional Areas (urban open)	241.19	0.006	49		0.006					0	0
							49						
		Wetland (not to be classified)	79662.71	1.83	98				0.42	1.41		1	1.83
									98	98			
				27.206	**72.893**		**12.576**	**1.10001**	**7.99**	**5.54**			**10.076**

D8018

FUSS & O'NEILL *Disciplines to Deliver*	PREPARED BY	DATE	CHECKED BY	DATE	PROJECT NO.
	KMK	11/21/05			20041111.A10

Revision 3 - Available Areas — calc set 2 of 4

SHEET NO. 1 of 1

This revision includes modifications to the total Available Area cfor

- Remove Lot AG
- Add lots in catergory (from GIS) stabilized/MOS
- ID merged vs. unmerged lots - no changes to Aav.
- PLS 2 Road Area

→ this revision does not include DELETION OF TYPE C LOTS ←
ie TYPE C lots are part of available area

→ this revision modified the variables in this set:
(Vinf, Vsand, Vbio, Aavailable)

V_{Flush}, WQV, V_{inf}, V_{sand}, V_{bio}, $A_{available}$

Revision 1
Revision 3

Introduction

The study area for the Narrow River consists of 11 sub-watersheds. Example calculations for the WQV, V_{inf}, V_{sand}, V_{bio} & $A_{available}$, data sources used & the results for each watershed tabulated from an excel worksheet are provided.

V_{Flush} - First Flush Volume
WQV - Water Quality Volume

$V_{treatable}$:
- V_{inf} - Volume of runoff that can be treated in the $A_{available}$ using infiltration calculated for upland $V_{inf\text{-}up}$ and end of pipe $V_{inf\text{-}EOP}$
- V_{sand} - volume of runoff that can be treated in the $A_{available}$ using sand filters calculated for upland $V_{sand\text{-}up}$ and end of pipe $V_{sand\text{-}EOP}$
- V_{bio} - volume of runoff that can be treated in the $A_{available}$ w/ bioretention calculated for lots only in the upland $V_{bio\text{-}up}$ and end of pipe $V_{bio\text{-}EOP}$

$A_{available}$ - Area available for treatment. Areas include roads at EOP and vacant town owned lots located proximal to the storm drain system. This does NOT factor the actual availability (irrigated, private etc.)

Source Data

GIS data provided by the Town of Narragansett was used to determine $A_{available}$, A_{total}. A_{imp} was determined from Curve Number.

Method

The Draft RI Stormwater Manual was used to calculate WQV, V_{inf}, V_{sand} & V_{bio}

A_{imp} was calculated by multiplying each land use area by the average % impervious area as provided by the SCS.

$A_{available}$ was determined selecting areas according to the criteria listed in Technical Memorandum 2. This area is subject to approval from the Town (emailed Nicole Reilly 11/8/05)

V_{Flush} was calculated as half of the WQV, or ½" over the impervious surface.

VOLUMES

		Total acre	Impervious acre	WQV ac-ft	V_{1flush} ac-ft	V_{GWR} ac-ft	End of pipe: Area (acre) Lots	End of pipe: Area (acre) Road	End of pipe: $V_{treatable}$ (acre-ft) Filtration Bio	End of pipe: $V_{treatable}$ (acre-ft) Filtration Sand	End of pipe: $V_{treatable}$ (acre-ft) Filtration Infiltration	Upland technologies: Area (acre) Type A	Upland technologies: Area (acre) Type C	Upland technologies: $V_{treatable}$ (acre-ft) Filtration Bio	Upland technologies: $V_{treatable}$ (acre-ft) Filtration Sand	Upland technologies: $V_{treatable}$ (acre-ft) Infiltration	
IH	***Indian Head***	27.21	10.1	0.84	0.42	1.48	0.56		0.90	3.60	1.44	0.34	0.00	0.54	2.15	0.86	**IH**
PLS2	***Petta Lake Shores 2***	100.43	30.8	2.57	1.28	3.18		0.11	0.00	0.73	0.29	0.28	2.08	3.77	15.09	0.75	**PLS2**
E1	***Edgewater 1***	47.23	18.1	1.51	0.76	1.12		1.00	0.00	6.40	2.55	0.25	0.29	0.86	3.44	0.63	**E1**
E2	***Edgewater 2***	13.50	4.2	0.35	0.17	0.34		1.00	0.00	6.40	2.55	0.00	0	0.00	0.00	0.00	**E2**
PTC	***Pettaquamiscutt Terrace Combo***	89.18	23.2	1.94	0.97	3.12	0.68	0.45	1.08	7.22	2.88	0.35	1.59	3.12	12.47	0.93	**PTC**
M1	***Mettatuxet 1***	26.84	10.2	0.85	0.42	1.64		0.72	0.00	4.61	1.84	1.07	0.30	2.20	8.81	2.74	**M1**
M3	***Mettatuxet 3***	20.13	7.6	0.64	0.32	0.98		0.75	0.00	4.80	1.92	0.60	0	0.96	3.85	1.54	**M3**
M4	***Mettatuxet 4***	19.49	7.2	0.60	0.30	1.18	0.23	0.56	0.36	5.04	2.01	0.28	0.55	1.34	5.36	0.73	**M4**

Ka	7.98 ft/day	Kbio	1 ft/day
Pa	1.995 in/hr	Ksf	8 ft/day
Kc	0.0440 ft/day		
Pc	0.011 in/hr		

Notes:

1. V able to treat derived from equations in stormwater manual times 80% to account for amount of lot available for installation of the system.
2. Sand Filter numbers based on a K value of 8ft/d and 50% of the available lot size
3. Biofilter values based on an installed K value of 1ft/d
4. Area is the estimated area of town-owned lots, chosen based on assumptions listed in the Technical Memo
5. WQV calculated as 1" over the impervious area of the catchment, based on CN
6. $V_{recharge}$ calculated as R times the total area of the catchment
7. End of pipe area in Type A soil
8. V_{1flush} is 1/2" times the impervious area of catchment
9. Vtreatable for sand filters is calculated assuming that the limiting k value is that of the filter media (sw discharge back to system or Type A soil)
10. End of pipe: Bio does not include roads, Sand and Infiltration both include roads and lots
11. Upland: lots in either soil type are included in the Vtreatable calculations

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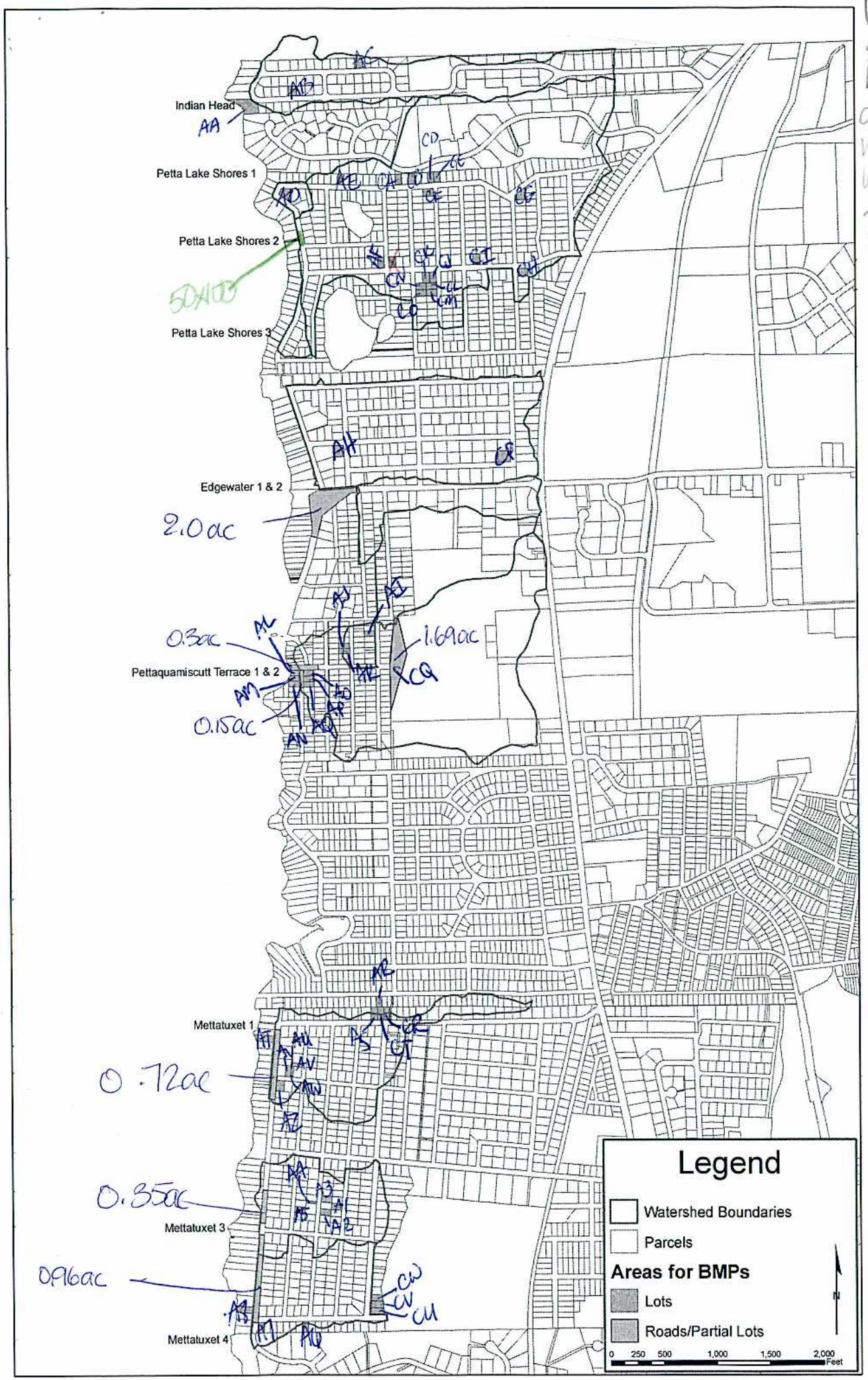
See hand drawn watershed map for lot IDs.

11/8/05



12/19/05

AREA AVAILABLE FOR BMPs

		End of pipe				Upland							
		lots		road		lots					road		
		ft2	acres	ft2	acres	total ft2	Type A	acres	Type C	acres	ft2	acres	
IH	***Indian Head***	24511	0.56	0	0	14665	14665	0.34	0	0.00	0		4500
PLS1	***Petta Lake Shores 1***	8943	0.21	0	0	0	0	0	0	0	0		
PLS2	***Petta Lake Shores 2***	0	0	5000	0.11	102677	12222	0.28	90455	2.08	0		
PLS3	***Petta Lake Shores 3***	0	0	0	0	0	0	0	0	0	0		
E1	***Edgewater 1***	0	0		1.00	23412	10717	0.25	12695	0.29	0		
E2	***Edgewater 2***	0	0		1.00	0	0	0	0	0	0	0.00	
PT2	***Pettaquamiscutt Terrace 2***	29532	0.68		0.45	84861	15417	0.35	69444	1.59	0		
PT1	***Pettaquamiscutt Terrace 1***	shared			0								
M1	***Mettatuxet 1***	0	0		0.72	59932	46714	1.07	13218	0.30	0		
M3	***Mettatuxet 3***	0	0		0.75	26202	26202	0.60	0	0	0		
M4	***Mettatuxet 4***	9891	0.23	0	0.56	36456	12372	0.28	24084	0.55	0		

acres/ft	2.30E-05
ft/acre	43560

12222

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PREPARED BY	DATE	CHECKED BY	DATE	PROJECT NO.
				20241111.A10

SHEET NO. 5 of 10

BMP areas by soil type/subwat ershed

AX - Type A soil, ID: X on map
EOP - End of pipe

IH	area (ft²)	
AA	24511	- EOP (not town owned, but likely available)
AB	7458	
AC	7207	

PLS2	NO EOP
AE	6189
CA	6106
CB	6113
CD	5824
CE	6189
CF	7190
CG	7832
CH	6920
AF	6033
CI	6800
CJ	6569
CK	6683
CL	5932
CM	6179
CN	5968
CO	6150

PLS1	
AD	8943 EOP

PLS3	no EOP, no lots

E1	NO EOP lots
Road	1 acre (split w/ E2) 3ac
CP	12695
AH	10717

E2	NO LOTS
Road	1 acre

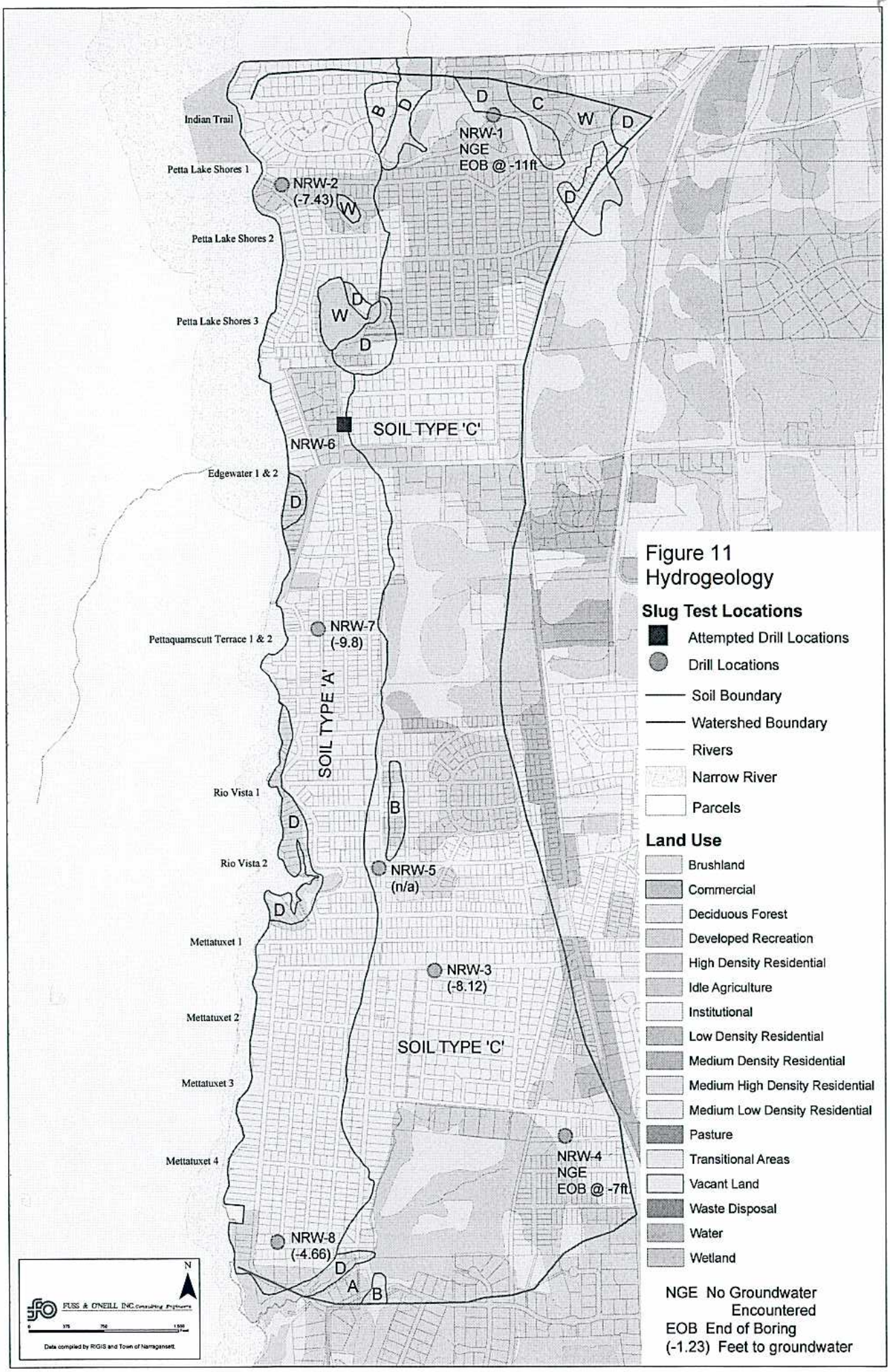
PT2/PT1		
CQ (partial)	0.45 acres	
AI	5144	
AJ	5091	
AK	5182	
AL	3914	EOP
AM	5027	EOP
AN	5047	EOP
AO	4822+670	EOP/upland
AP	4413+597	EOP/upland
AQ	5042	EOP/upland

M1	no EOP lots
Road	0.72 ac
AR	5207
AS	7357
CR	6144
CT	7074
AU	4603
AV	3040
AW	2493
AY	5060
AZ	7443
AT	11511

M3	no EOP lots
Road	.35 + .4* acres
A1	5987
A2	6090
A3	6066
A4	1996
A5	6063

M4		
A6	6004	
A7	6368	
A8	9891	EOP
CW	6968	
CV	7901	
CU	9215	
Road	0.56* acres	

* 0.96 acres shared between SWs.


Indian Trail
Petta Lake Shores 1
Petta Lake Shores 2
Petta Lake Shores 3
Edgewater 1 & 2
Pettaquamscutt Terrace 1 & 2
Rio Vista 1
Rio Vista 2
Mettatuxet 1
Mettatuxet 2
Mettatuxet 3
Mettatuxet 4
NRW-1
NGE
EOB @ -11ft
NRW-2
(-7.43)
NRW-6
NRW-7
(-9.8)
NRW-5
(n/a)
NRW-3
(-8.12)
NRW-4
NGE
EOB @ -7ft
NRW-8
(-4.66)
SOIL TYPE 'C'
SOIL TYPE 'A'
SOIL TYPE 'C'
Figure 11
Hydrogeology
Slug Test Locations
Attempted Drill Locations
Drill Locations
Soil Boundary
Watershed Boundary
Rivers
Narrow River
Parcels
Land Use
Brushland
Commercial
Deciduous Forest
Developed Recreation
High Density Residential
Idle Agriculture
Institutional
Low Density Residential
Medium Density Residential
Medium High Density Residential
Medium Low Density Residential
Pasture
Transitional Areas
Vacant Land
Waste Disposal
Water
Wetland
NGE No Groundwater Encountered
EOB End of Boring
(-1.23) Feet to groundwater
N
FUSS & O'NEILL INC.
Data compiled by RIGIS and Town of Narragansett

HAGER GEOSCIENCE, INC.
596 MAIN STREET, WOBURN, MASSACHUSETTS 01801-2924
TELEPHONE: (781) 935-8111 FAX: (781) 935-2717

To: Jim Riordan

From: Jutta Hager

Date: July 28, 2005

Re: Narrow River Stormwater Abatement Project, Narragansett, RI

Appended are logs, monitoring well installation forms, and slug test results for the borings drilled on July 5th and 6th, 2005. As you noted in your memo of July 12th, 7 of 8 proposed borings were completed. NRW-6, at the intersection of Lakeside Drive and Bridgetown Road, could not be drilled because of interfering utilities.

Wells were installed in NRW-2, NRW-3, NRW-5, NRW-7, and NRW-8. Slug tests were conducted in NRW-3, NRW-5, NRW-7, and NRW-8 after well installation, and in the NRW-4 open hole. Calculated K values are as follows:

NRW-3: $K = 3.66 \times 10^{-4}$ inch/min
$K = 4.40 \times 10^{-2}$ feet/day type C

use lowest K value for each soil type as conservative estimate

NRW-4: $K = 5.82 \times 10^{-3}$ inch/min
$K = 6.99 \times 10^{-1}$ feet/day

NRW-5: $K = 2.12 \times 10^{-3}$ inch/min
$K = 2.55 \times 10^{-1}$ feet/day

NRW-7: $K = 6.65 \times 10^{-2}$ inch/min
$K = 7.98$ feet/day Type A

NRW-8: $K = 1.33 \times 10^{-1}$ inch/min
$K = 15.96$ feet/day

Based on the nature of the sand encountered in NRW-2, the K calculated K value would be similar to that for NRW-8.

Meeting w DEA & MNR – use new Draft SW manual

Method for calculating V_{inf}, V_{sand}, V_{bio}

RI SWM page 11-P3-11 – Infiltration

$$A_{treatable} = \frac{12WQV}{Pt}$$

$$P = \frac{1}{2}K\left(\frac{ft}{hr}\right)$$

$$WQV = \frac{APt}{12}$$

$$\frac{ft}{d} \cdot \frac{1d}{24hr} \cdot \frac{12''}{1ft}$$

solve for WQV, which becomes $V_{treatable}$

RI SWM page 11-P4-6 – FILTRATION

$d = 18''$

A_f = Area available for treatment

~~$K = 3.5\ ft/d$~~ 11/5/05 use $K_{sand} = 8\ ft/d$, $K_{bio} = 1\ ft/d$

$t = 1$ day

$h = 1.5'$

$$WQV = \frac{A(Kt(h+d))}{d}$$

solve for WQV which becomes $V_{treatable}$ for BMP type

$500ft^2 = 3500\ cft$

Calculate #s

Check Excel Calcs worksheet - Available Area & WQV @ area

Infiltration EOP — IH

Indian Head

$$A = \frac{WQV \cdot 12}{P \cdot t} \qquad A = \frac{12 WQV}{Pnt} \quad WQV = \frac{APnt}{12}$$

$$WQV_{IH} = \frac{APt}{12} = (.56 \text{ acres}) \frac{1}{2} \cdot \frac{7.98 ft}{d} \cdot \frac{1 d}{24 hr} \cdot 48 hr \cdot \frac{1}{2} (0.4$$

$$= 0.29792 \text{ acre-ft}$$

~~FILTRATION EOP~~ — IH

$$A_f = \frac{(WQV)d}{kt(h+d)}$$

$$WQV = \frac{A_f kt(h+d)}{d} = (0.56 \text{ acres})\frac{(7.98 ft)}{d} \cdot 1 d \cdot \frac{(1.5+1.5)'}{1.5'} (.8)$$

$$= 7.15 \text{ acre-ft}$$

see revised calcs 11/8/05

Infiltration upland — M1

Northeast 1

$$WQV = \frac{APt}{12}_A + \frac{APt}{12}_C = \left(1.07 ac \cdot \frac{7.98 ft}{d} + 0.3 ac \cdot \frac{.044 ft}{d}\right) \frac{1}{2} (0.8)(2d) \frac{1}{12}$$

$$= .57 \text{ ac-ft}$$

~~FILTRATION Upland~~ — E1

$$WQV = \frac{A_f kt(h+d)}{d}(A+C) = \left[(.25 ac)\frac{(7.98 ft)}{d} + .29 ac \frac{(.044 ft)}{d}\right] \frac{1 d (1.5+1.5)'}{1.5'} (0.8)$$

$$= \cancel{1.5} \; 0.8 \text{ ac-ft}$$

3.21

Revised 11/8/05

OK

Infiltration Example Calculations

Sand filter From RISWM: $A = WQV \cdot d / (Kt(h+d))$

$$WQV = \frac{AKt(h+d)}{d} f_1 f_2$$

For Pettaquamscutt Shores 2 Upland

$$WQV = (0.5)(0.8)\frac{(2.51ac)(8.0 ft/d)(1d)(1.5'+1.5')}{1.5'}$$

$$\boxed{WQV = 16.06\ ac \cdot ft}$$

where $WQV = V_{sand}$
$A = A_{available}$
$K = 8.0\ ft/d$
$h = 1.5'$
$d = 1.5'$
$t = 1\ day$
✓ $f_1 = 80\%$ for portion of area that is constructable
✓ $f_2 = 50\%$ for area needed for portions of the system beyond filter media

Bioretention

$$WQV = \frac{Akt(h+d)}{d} f_1$$

where $WQV = V_{bio}$
$A = A_{available}$ - can only be lots - no road
$K = 1.0\ ft/d$ from Georgia SW Manual
$h = 1.5'$
$d = 1.5'$
$t = 1\ day$
✓ $f_1 = 80\%$ for portion of area that is constructable

for Mettatuxet 4 end of pipe

$$WQV = \frac{.8(.23ac)(1.0 ft/d)(1.5'+1.5')}{1.5'}$$

$$\boxed{WQV = 0.368\ ac \cdot ft}$$

R, V_{GWR}

Revision 1 11/10/05

Introduction

The study area for the Narrow River consists of 81 subwatersheds, 2 of which are not investigated because of their size (~2 acres each) and 2 of which are combined due to their configuration (PT1 & PT2). The groundwater recharge goal & volume have been calculated according to the following method & example calculations and a table calculated in excel showing the results for the included catchments.

Source Data

GIS data provided by the Town of Narragansett and hand drawn catchment areas drawn by F&O were used to calculate CNs (as shown in the CN calculation package) and to determine total catchment areas.

Method

The GW recharge goal, R was calculated using:

$$R = \frac{200}{CN_n} - \frac{200}{CN_D}$$

where R is in inches
CN_D = CN developed/current
CN_n = CN undeveloped

Example Calculation

Pettalake Shores 2

$$R = \frac{200}{67.2} - \frac{200}{76.6} = \underline{0.38 \text{ inches}}$$

$$V_{GWR} = (0.38'')(100.4 \text{ acres})(1'/12'') = \underline{3.2 \text{ acre}\cdot\text{ft}}$$

R AND $V_{RECHARGE}$ RESULTS

12/19/2005

		Area	Impervious	CN	Historic CN	R (in)	V_{GWR} acre-ft	WQV
IH	***Indian Head***	27.21	10.1	72.9	58.9	0.654144	1.483053	0.84
PLS1	***Petta Lake Shores 1***	2.00	0.6	57.3	49.0	0.594196	0.099033	
PLS2	***Petta Lake Shores 2***	100.43	30.8	77.0	67.2	0.379846	3.178996	2.57
PLS3	***Petta Lake Shores 3***	2.10	0.8	61.0	49.0	0.802944	0.140515	
E1	***Edgewater 1***	47.23	18.1	78.0	70.2	0.285643	1.124245	1.51
E2	***Edgewater 2***	13.50	4.2	75.2	67.5	0.303223	0.341126	0.35
PT2	***Pettaquamiscutt Terrace 2***	25.51	5.3	73.2	63.2	0.430774	0.915754	
PT1	***Pettaquamiscutt Terrace 1***	63.67	18.0	75.6	65.3	0.415378	2.203925	
PTC	***Pettaquamiscutt Terrace Combo***	89.18	23.2	74.9	64.7	0.41967	3.118845	1.94
M1	***Mettatuxet 1***	26.84	10.2	68.6	54.8	0.732599	1.638579	0.85
M3	***Mettatuxet 3***	20.13	7.6	65.3	54.8	0.583308	0.978499	0.64
M4	***Mettatuxet 4***	19.49	7.2	62.3	50.8	0.725151	1.178056	0.60

Fuss & O'Neill Inc. *Consulting Engineers*

memorandum

Subject: Narrow River

Project Number 20041111.A10

Date: 11/11/05

KMK

To Revision 2

From T_c, Q_{25}, V_{25}

Measured Tc flow paths from GIS data
and revised L and corresponding Tc
Also ran Hydraflow w/ new Tc for V_{25} & Q_{25}

CC: _____

F&O #190

Revision 1 11/10/05
Revision 2 11/11/05

T_c, $V_{25\text{-year}}$, $Q_{peak\text{-}25}$

Introduction

The Narrow River Study area consists of 11 catchments, 2 of which are not investigated due to size (~2 acres) and 2 of which are combined into 1 catchment because of the stormdrain configuration (PT1 & PT2). The time of concentration (T_c), 25-year storm event volume ($V_{25\text{-year}}$) and 25 year storm event peak discharge ($Q_{peak\text{-}25}$) were calculated using the methods described below.

Source data

The data used to determine these calculations was provided in GIS format by the Town of Narragansett. Measurements made from the maps are listed.

Methods

T_c was calculated using TR-55 methods for components of time (T_t). The T_t consist of 3 components - sheet flow, shallow concentrated flow and channelized flow. TR-55 was used to determine sheet flow & shallow concentrated flow. Channelized flow was determined using a velocity of 5 ft/s.

$V_{25\text{-year}}$ and $Q_{peak\text{-}25}$ were calculated using Hydraflow software. The input data and output summary are attached.

TR-55 Tc Calculation Equations

Sheet flow

$$T_t = \frac{0.007(nL)^{0.8}}{(P_2)^{1/2}\, S^{0.4}}$$

$P_2 = 3.4''$
$n_{res} = 0.24$
$n_{forest} = 0.80$

$$\text{H} \rightarrow T_t = \frac{.007(0.24 \cdot 125)^{0.8}}{(3.4)^{1/2}\,(3/50)^{0.4}} = 0.324\ hr = 19.5\ min$$

Shallow concentrated flow

$$T_t = \frac{L}{V}$$

V from Fig 3.1 (ft/s)

Open channel flow

$V = 5\ ft/s$

$$T_t = \frac{L}{5\ ft/s}$$

$T_{type\,A} = 7.98\ ft/day$
$T_{type\,C} = 0.044\ ft/day$

PB87-101580

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United States
Department of
Agriculture

Soil
Conservation
Service

Engineering
Division

Technical
Release 55

June 1986

Urban Hydrology for Small Watersheds

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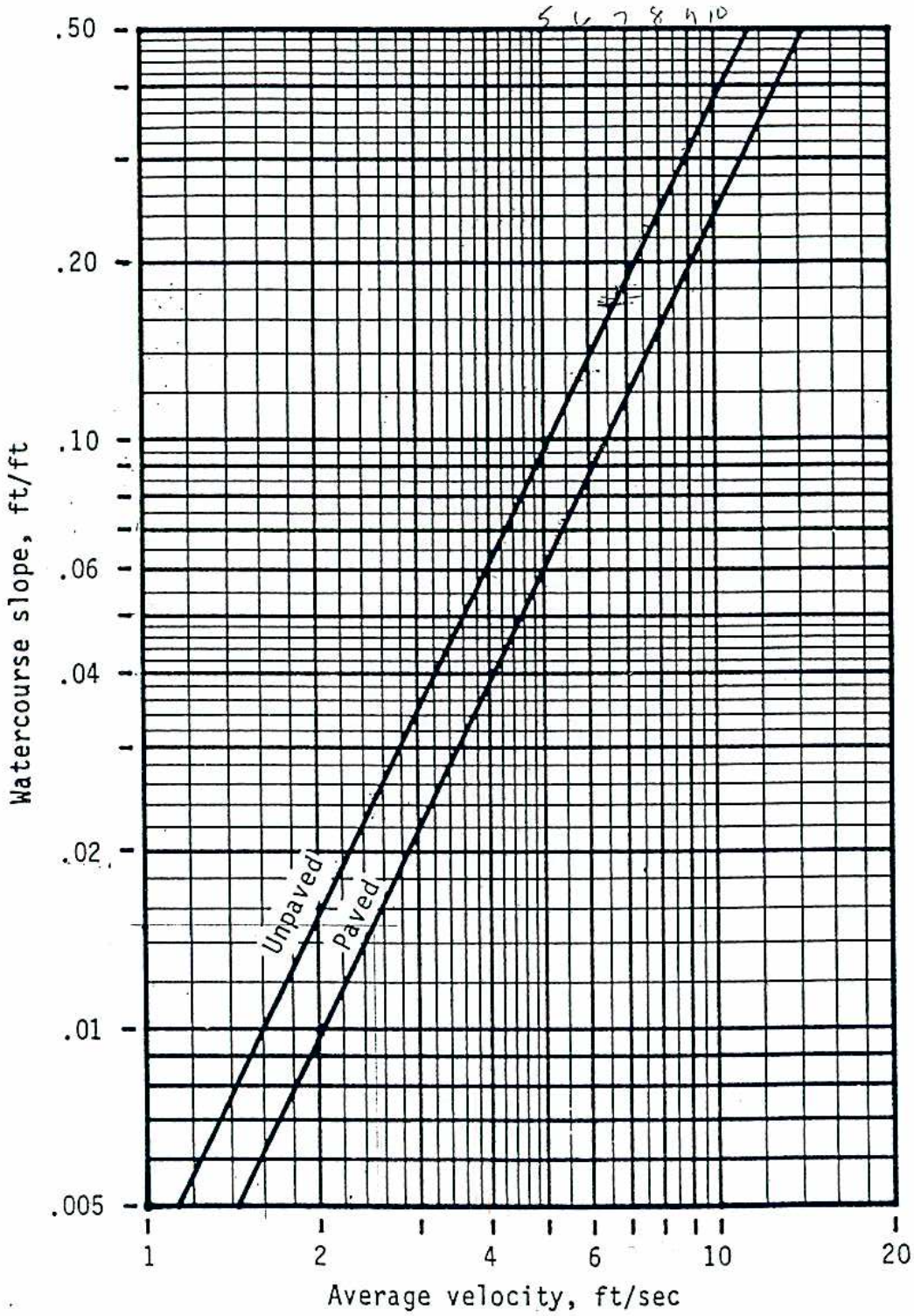


Figure 3-1.—Average velocities for estimating travel time for shallow concentrated flow.

Sheet flow

Sheet flow is flow over plane surfaces. It usually occurs in the headwater of streams. With sheet flow, the friction value (Manning's n) is an effective roughness coefficient that includes the effect of raindrop impact; drag over the plane surface; obstacles such as litter, crop ridges, and rocks; and erosion and transportation of sediment. These n values are for very shallow flow depths of about 0.1 foot or so. Table 3-1 gives Manning's n values for sheet flow for various surface conditions.

For sheet flow of less than 300 feet, use Manning's kinematic solution (Overton and Meadows 1976) to compute T_t:

sheet flow not channel

$$T_t = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5}\, s^{0.4}} \qquad \text{[Eq. 3-3]}$$

Table 3-1.—Roughness coefficients (Manning's n) for sheet flow

Surface description	n[1]
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover ≤20%	0.06
Residue cover >20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses[2]	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods:[3]	
Light underbrush	0.40
Dense underbrush	0.80

[1]The n values are a composite of information compiled by Engman (1986).
[2]Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.
[3]When selecting n, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

where

T_t = travel time (hr),
n = Manning's roughness coefficient (table 3-1),
L = flow length (ft),
P_2 = 2-year, 24-hour rainfall (in), and
s = slope of hydraulic grade line (land slope, ft/ft).

This simplified form of the Manning's kinematic solution is based on the following: (1) shallow steady uniform flow, (2) constant intensity of rainfall excess (that part of a rain available for runoff), (3) rainfall duration of 24 hours, and (4) minor effect of infiltration on travel time. Rainfall depth can be obtained from appendix B.

Shallow concentrated flow

After a maximum of 300 feet, sheet flow usually becomes shallow concentrated flow. The average velocity for this flow can be determined from figure 3-1, in which average velocity is a function of watercourse slope and type of channel. For slopes less than 0.005 ft/ft, use equations given in appendix F for figure 3-1. Tillage can affect the direction of shallow concentrated flow. Flow may not always be directly down the watershed slope if tillage runs across the slope.

After determining average velocity in figure 3-1, use equation 3-1 to estimate travel time for the shallow concentrated flow segment.

Open channels

Open channels are assumed to begin where surveyed cross section information has been obtained, where channels are visible on aerial photographs, or where blue lines (indicating streams) appear on United States Geological Survey (USGS) quadrangle sheets. Manning's equation or water surface profile information can be used to estimate average flow velocity. Average flow velocity is usually determined for bank-full elevation.

Example T_c calculation

for Pettaquamscutt Shores 2

SHEET FLOW T_t

$$T_t = \frac{0.007(nL)^{0.8}}{P_2^{0.5} \cdot S^{0.4}}$$

where T_t in hours
n = Manning's roughness coefficient from table for dense grass or forest
L = flow length (ft)
P_2 = 2-year, 24hr rainfall = 3.4"
S = slope

$$T_t = \frac{0.007(0.24 \cdot 100')^{0.8}}{(3.4")^{.5}(2\%/100')^{.4}} \cdot \frac{60\,min}{1\,hr} = 16.7\,min$$

Shallow concentrated T_t

$$T_t = \frac{L}{V_{F3.1}}$$

where L = travel length
$V_{F3.1}$ = velocity from Figure 3.1 at a slope of $8'/410' = 0.02$
$V_{F3.1} = 2.25$ ft/s

$$T_t = \frac{\cancel{410'}\ 570'}{2.25\,ft/s} \cdot \frac{1\,min}{60\,s}$$

$$T_t = \cancel{3.04}\ 4.22\,min$$

Channelized T_t

$$T_t = \frac{L}{V}$$

where $V = 5$ ft/s
L = travel length in road or pipe

$$T_t = \frac{3270\,ft}{5\,ft/s} \cdot \frac{1\,min}{60\,s} = 10.9\,min$$

$$T_c = \sum T_t = 16.7\,min + \cancel{3.0}\ 4.2\,min + 10.9\,min = \cancel{30.6}\ 31.8\,min$$

Tc, Tt components and data for storm event modeling

11/11/2005

	Sheet flow					Shallow Concentrated					Open channel						
	L (ft)	n	s (ft/ft)	Tt1 (hr)	Tt1 (min)	L (ft)	s (ft/ft)	V (ft/s)	Tt2 (s)	Tt2 (min)	L (ft)	V (ft/s)	Tt3 (s)	Tt3 (min)	Tc (min)	Area (acres)	CN
IH	125	0.24	0.01333	0.3244	19.46	490	0.0195	2.23	219.73	3.66	3060	5	612	10.20	**33.3**	27.2	72.9
PLS2	100	0.24	0.0125	0.2785	16.71	570	0.0195	2.23	255.61	4.26	3320	5	664	11.07	**32.0**	100.4	77.0
E1	150	0.8	0.01111	1.0578	63.47	60	0.0667	4.2	14.286	0.24	2190	5	438	7.30	**71.0**	47.2	78.0
E2	125	0.8	0.02105	0.708	42.48	1290	0.0575	3.95	326.58	5.44	1020	5	204	3.40	**51.3**	13.5	75.2
PT2	150	0.8	0.0125	1.0091	60.55	1280	0.0537	3.7	345.95	5.77	1520	5	304	5.07	**71.4**	25.5	73.2
PT1	125	0.8	0.01053	0.9342	56.05	1470	0.0448	3.4	432.35	7.21	1280	5	256	4.27	**67.5**	63.7	75.6
PTC															**71.4**	89.2	74.9
M1	125	0.24	0.01905	0.2813	16.88	40	0.025	2.55	15.686	0.26	1470	5	294	4.90	**22.0**	26.8	68.6
M3	100	0.24	0.025	0.211	12.66	170	0.02	2.25	75.556	1.26	1540	5	308	5.13	**19.1**	20.1	65.3
M4	125	0.24	0.02	0.2758	16.55	450	0.0133	1.8	250	4.17	1210	5	242	4.03	**24.7**	19.5	62.3

	n
Res	0.24
Woods	0.8

P2 (in)	3.4

V (ft/s)	5

P.8 of 16

Hydrograph Plot

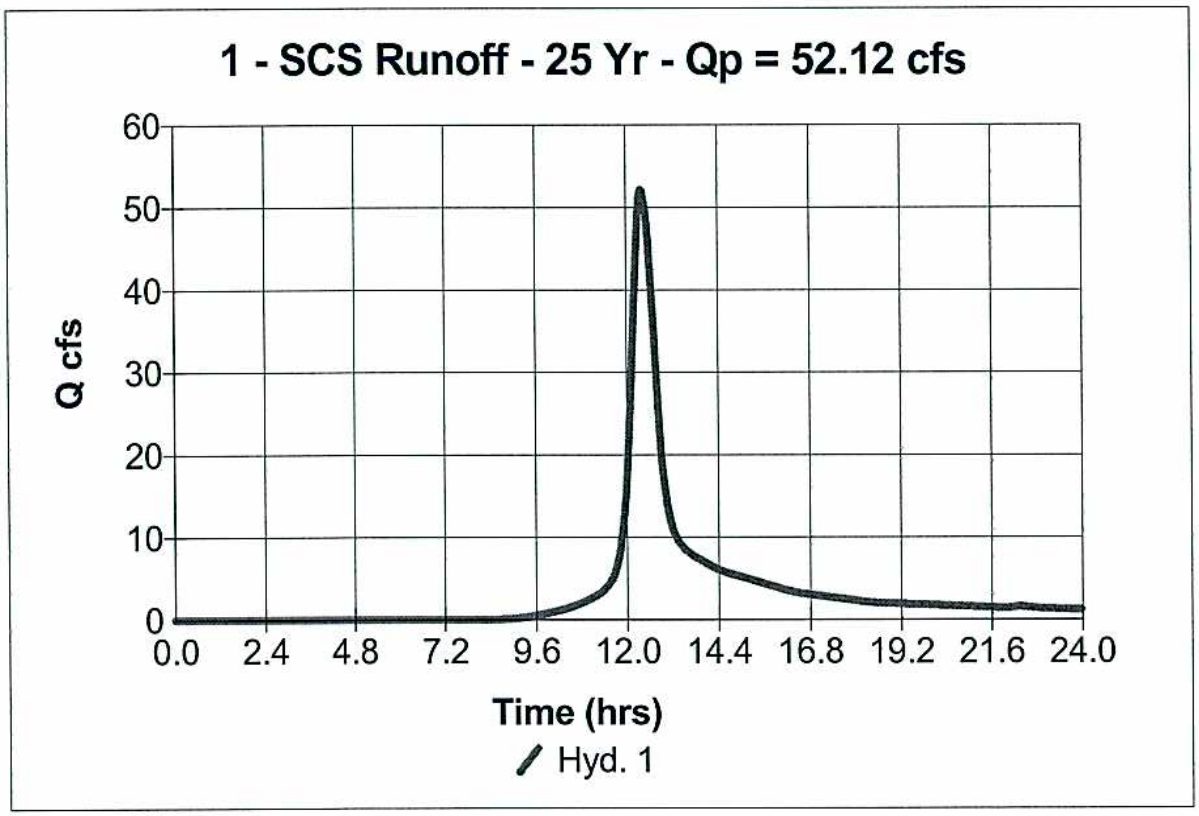
Hydraflow Hydrographs by Intelisolve

Hyd. No. 1

Indian Head

Hydrograph type	= SCS Runoff	Peak discharge	= 52.12 cfs
Storm frequency	= 25 yrs	Time interval	= 1 min
Drainage area	= 27.20 ac	Curve number	= 72.9
Basin Slope	= 0.0 %	Hydraulic length	= 0 ft
Tc method	= USER	Time of conc. (Tc)	= 33.3 min
Total precip.	= 5.80 in	Distribution	= Type III
Storm duration	= 24 hrs	Shape factor	= 484

Hydrograph Volume = 284,270 cuft



Hydrograph Plot

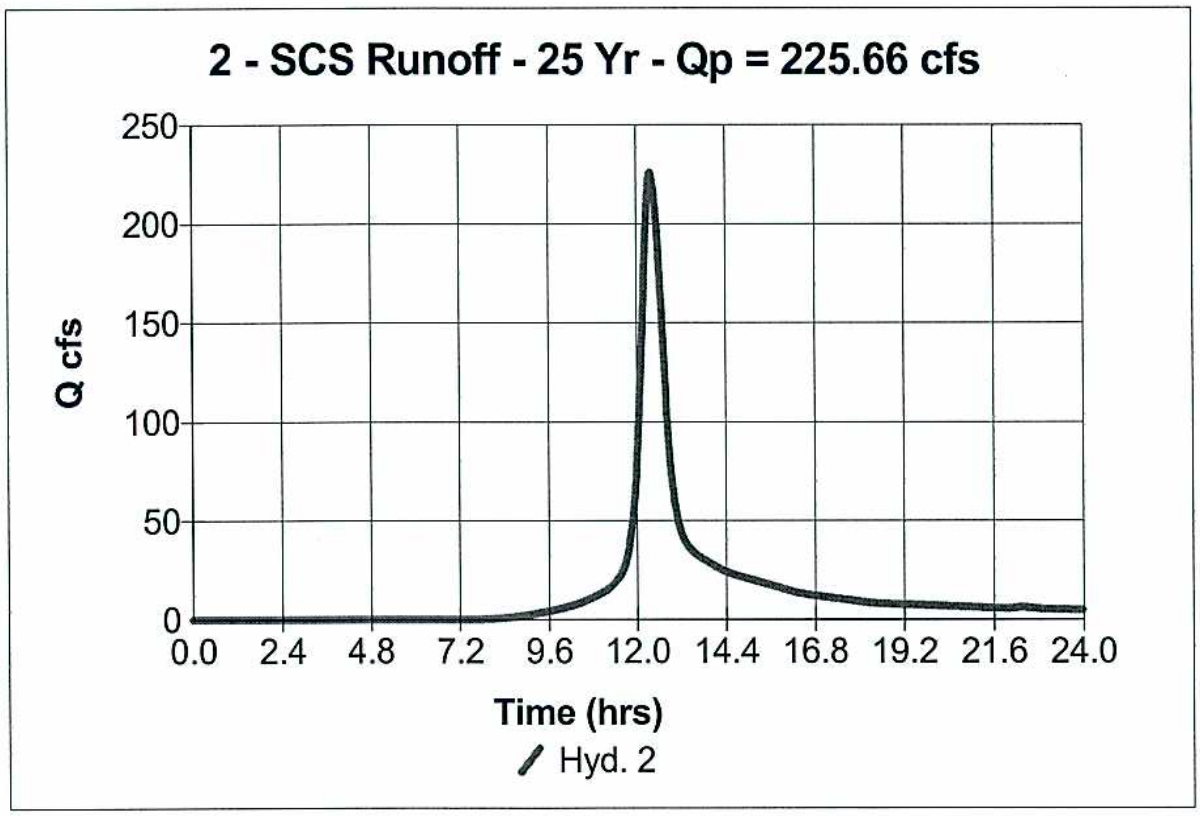
Hydraflow Hydrographs by Intelisolve

Hyd. No. 2

Petta Lake Shores 2

Hydrograph type	= SCS Runoff	Peak discharge	= 225.66 cfs
Storm frequency	= 25 yrs	Time interval	= 1 min
Drainage area	= 100.40 ac	Curve number	= 77
Basin Slope	= 0.0 %	Hydraulic length	= 0 ft
Tc method	= USER	Time of conc. (Tc)	= 32 min
Total precip.	= 5.80 in	Distribution	= Type III
Storm duration	= 24 hrs	Shape factor	= 484

Hydrograph Volume = 1,206,171 cuft



Hydrograph Plot

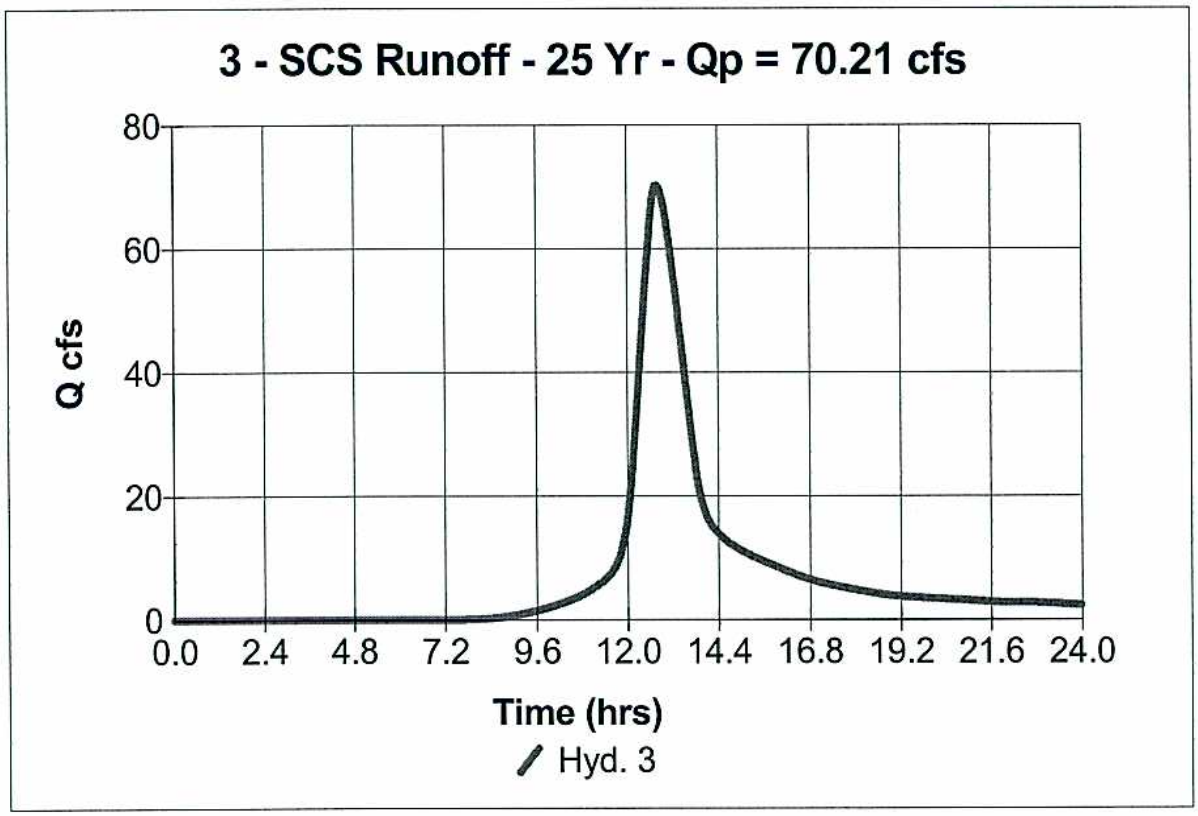
Hydraflow Hydrographs by Intelisolve

Hyd. No. 3

Edgewater 1

Hydrograph type	= SCS Runoff	Peak discharge	= 70.21 cfs
Storm frequency	= 25 yrs	Time interval	= 1 min
Drainage area	= 47.20 ac	Curve number	= 78
Basin Slope	= 0.0 %	Hydraulic length	= 0 ft
Tc method	= USER	Time of conc. (Tc)	= 71 min
Total precip.	= 5.80 in	Distribution	= Type III
Storm duration	= 24 hrs	Shape factor	= 484

Hydrograph Volume = 576,262 cuft



Hydrograph Plot

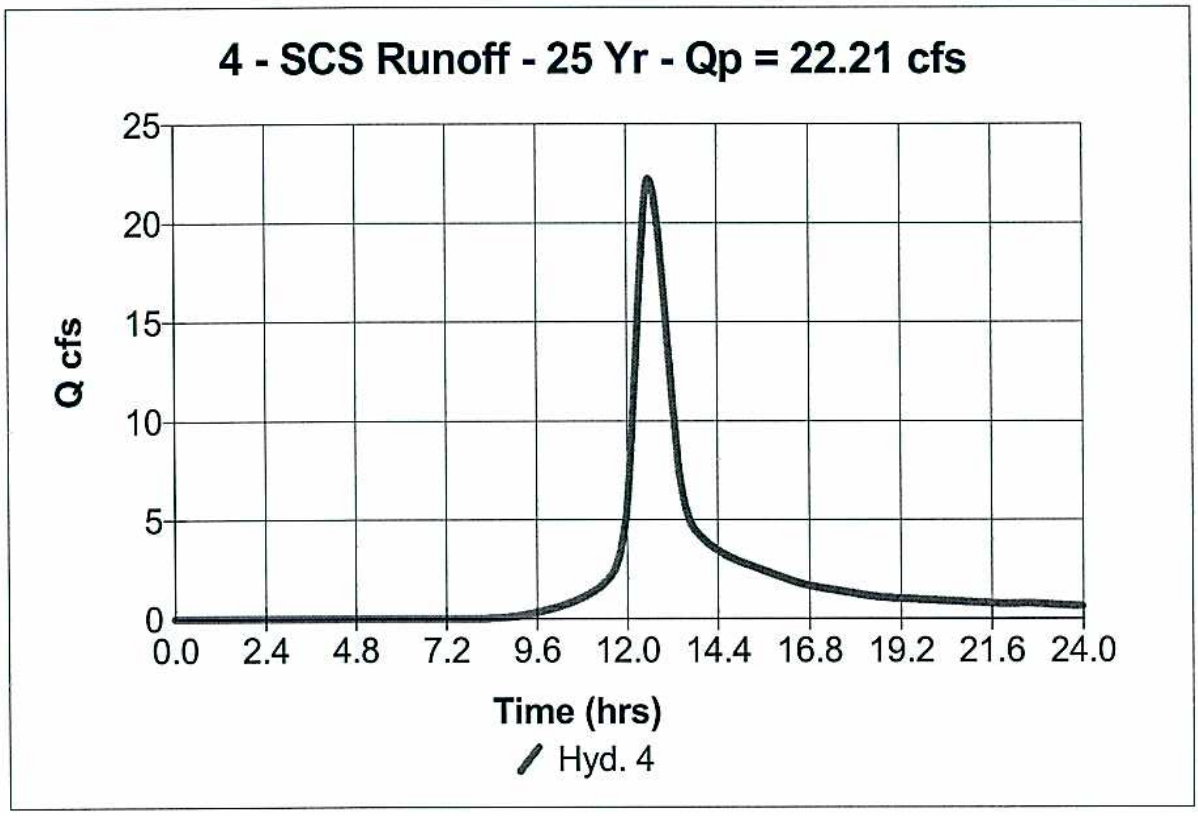
Hydraflow Hydrographs by Intelisolve

Hyd. No. 4

Edgewater 2

Hydrograph type	= SCS Runoff	Peak discharge	= 22.21 cfs
Storm frequency	= 25 yrs	Time interval	= 1 min
Drainage area	= 13.50 ac	Curve number	= 75.2
Basin Slope	= 0.0 %	Hydraulic length	= 0 ft
Tc method	= USER	Time of conc. (Tc)	= 51.3 min
Total precip.	= 5.80 in	Distribution	= Type III
Storm duration	= 24 hrs	Shape factor	= 484

Hydrograph Volume = 152,709 cuft



Hydrograph Plot

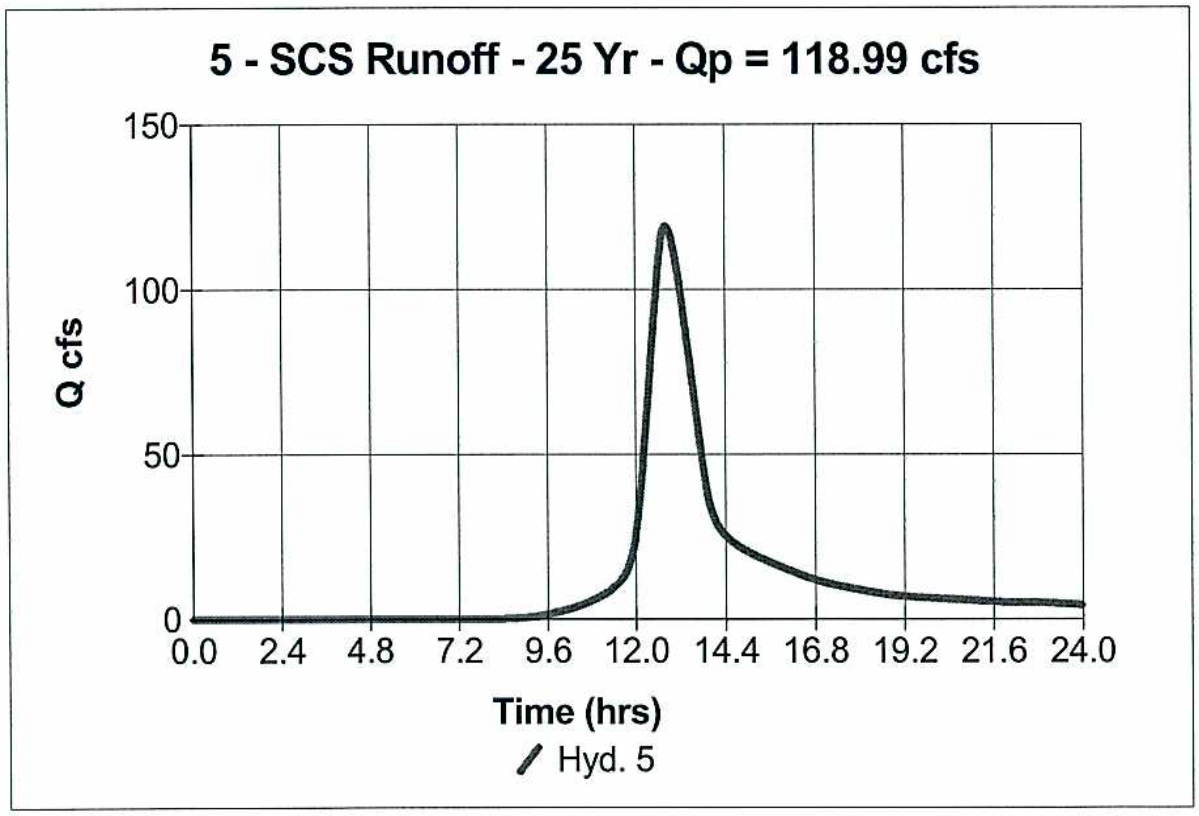
Hydraflow Hydrographs by Intelisolve

Hyd. No. 5

Petta Terrace Combo

Hydrograph type	= SCS Runoff	Peak discharge	= 118.99 cfs
Storm frequency	= 25 yrs	Time interval	= 1 min
Drainage area	= 89.20 ac	Curve number	= 74.9
Basin Slope	= 0.0 %	Hydraulic length	= 0 ft
Tc method	= USER	Time of conc. (Tc)	= 71.4 min
Total precip.	= 5.80 in	Distribution	= Type III
Storm duration	= 24 hrs	Shape factor	= 484

Hydrograph Volume = 994,925 cuft



Hydrograph Plot

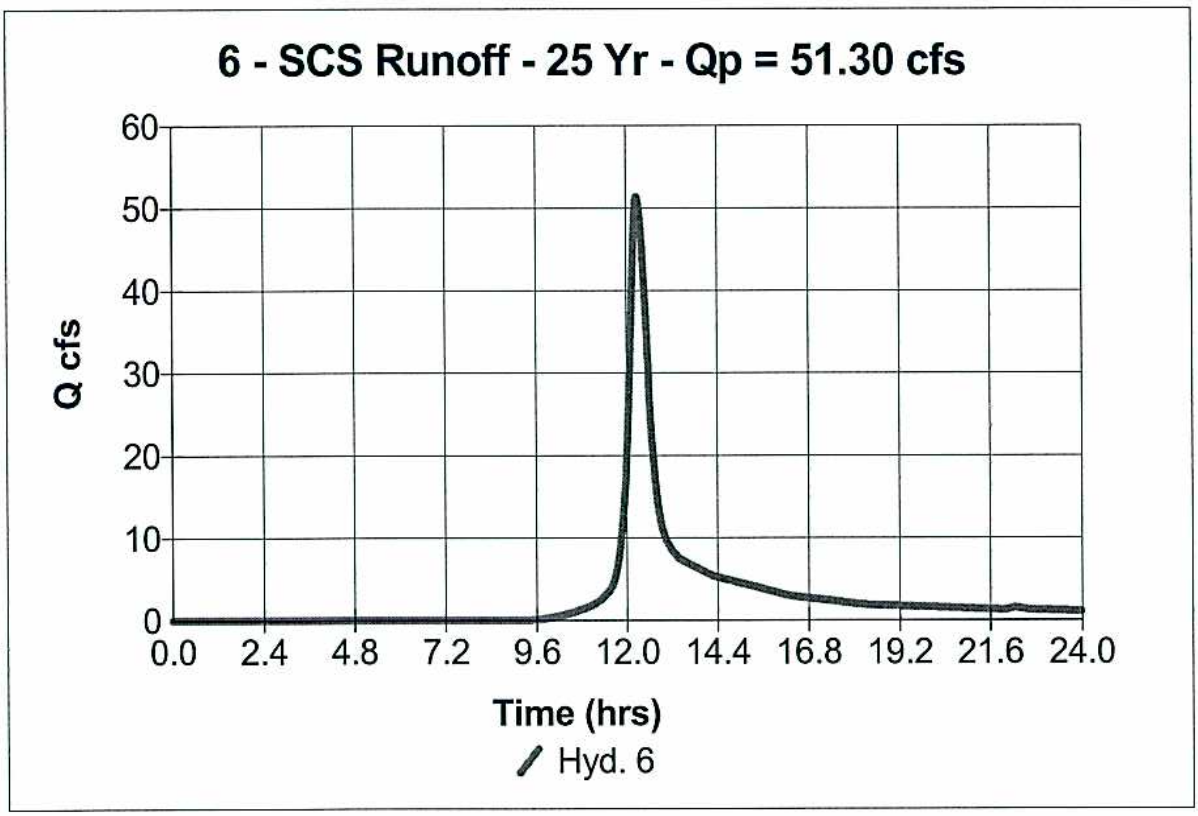
Hydraflow Hydrographs by Intelisolve

Hyd. No. 6

Mettasquamscutt 1

Hydrograph type	= SCS Runoff	Peak discharge	= 51.30 cfs
Storm frequency	= 25 yrs	Time interval	= 1 min
Drainage area	= 26.80 ac	Curve number	= 68.6
Basin Slope	= 0.0 %	Hydraulic length	= 0 ft
Tc method	= USER	Time of conc. (Tc)	= 22 min
Total precip.	= 5.80 in	Distribution	= Type III
Storm duration	= 24 hrs	Shape factor	= 484

Hydrograph Volume = 242,066 cuft



Hydrograph Plot

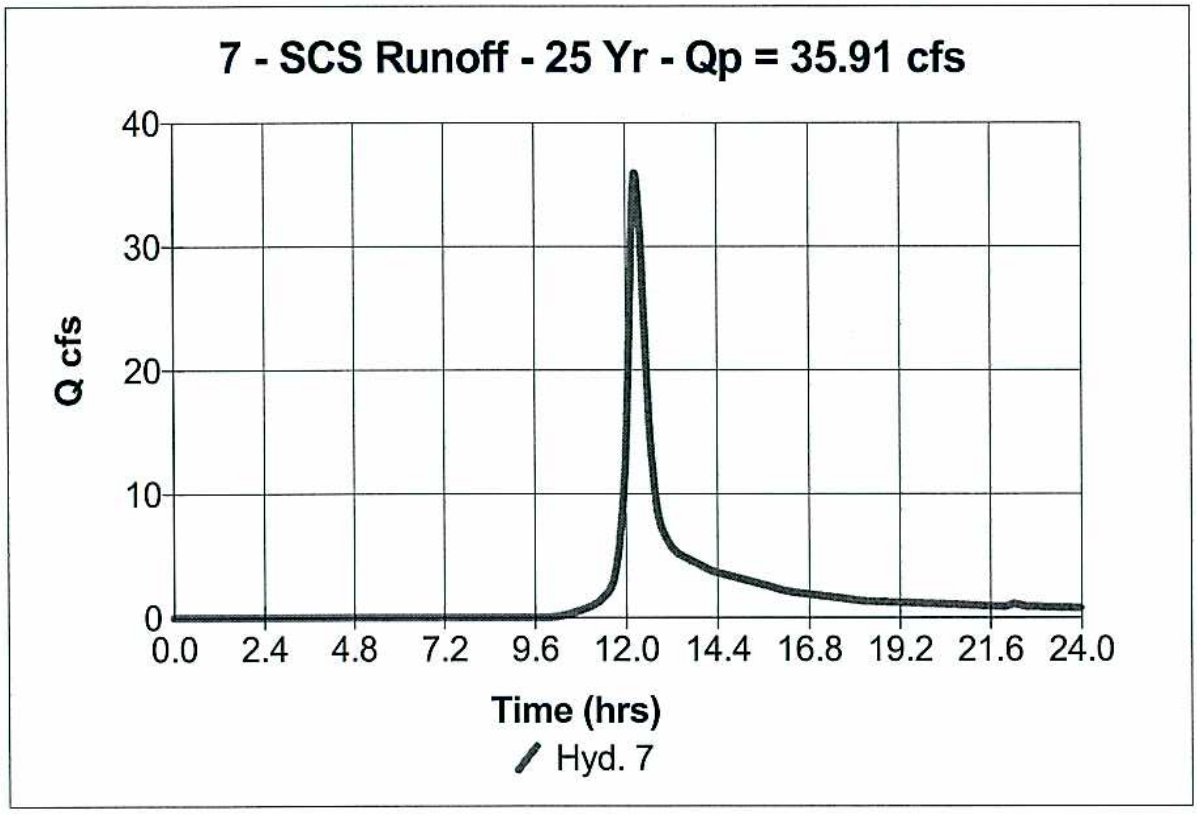
Hydraflow Hydrographs by Intelisolve

Hyd. No. 7

Mettasquamscutt 3

Hydrograph type	= SCS Runoff	Peak discharge	= 35.91 cfs
Storm frequency	= 25 yrs	Time interval	= 1 min
Drainage area	= 20.10 ac	Curve number	= 65.3
Basin Slope	= 0.0 %	Hydraulic length	= 0 ft
Tc method	= USER	Time of conc. (Tc)	= 19.1 min
Total precip.	= 5.80 in	Distribution	= Type III
Storm duration	= 24 hrs	Shape factor	= 484

Hydrograph Volume = 162,259 cuft



Hydrograph Plot

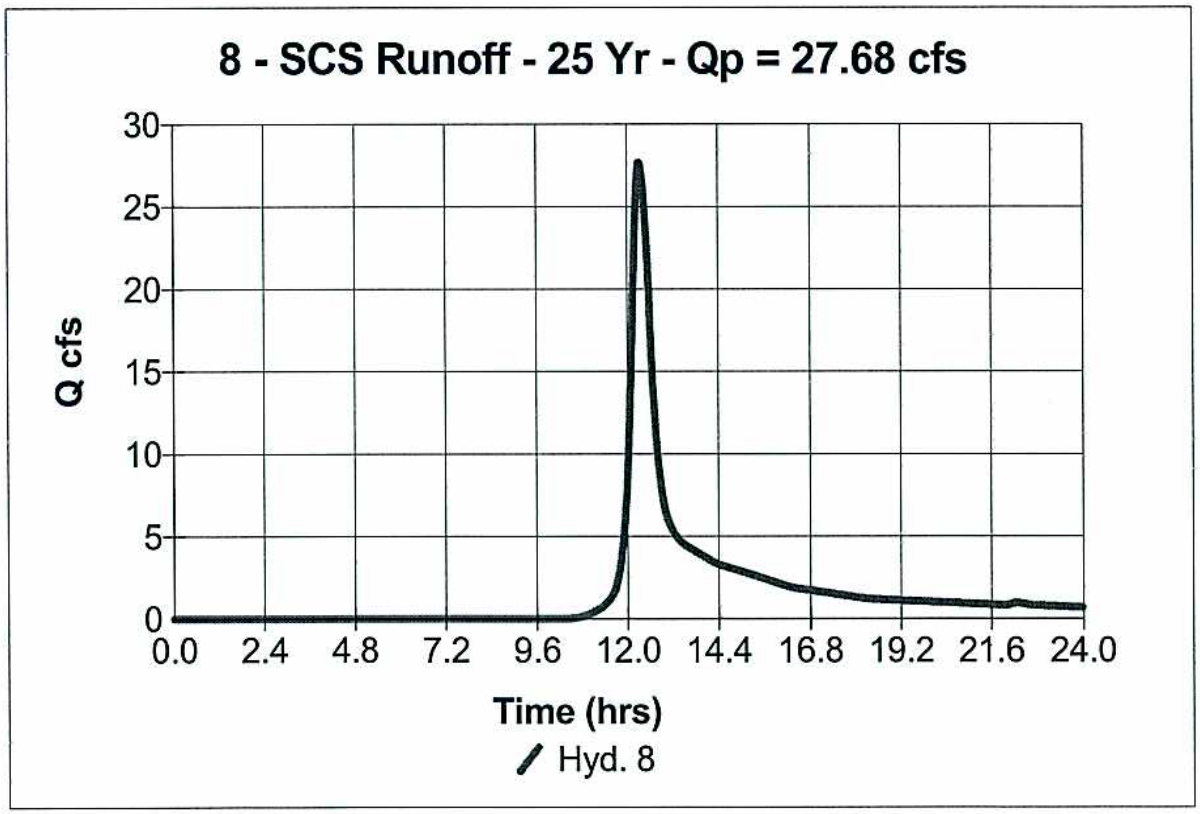
Hydraflow Hydrographs by Intelisolve

Hyd. No. 8

Mettasquamscutt 4

Hydrograph type	= SCS Runoff	Peak discharge	= 27.68 cfs
Storm frequency	= 25 yrs	Time interval	= 1 min
Drainage area	= 19.50 ac	Curve number	= 62.3
Basin Slope	= 0.0 %	Hydraulic length	= 0 ft
Tc method	= USER	Time of conc. (Tc)	= 24.7 min
Total precip.	= 5.80 in	Distribution	= Type III
Storm duration	= 24 hrs	Shape factor	= 484

Hydrograph Volume = 139,391 cuft



Hydrograph Summary Report

Hyd. No.	Hydrograph type (origin)	Peak flow (cfs)	Time interval (min)	Time to peak (min)	Volume (cuft)	Inflow hyd(s)	Maximum elevation (ft)	Maximum storage (cuft)	Hydrograph description
1	SCS Runoff	52.12	1	743	284,270	6.5 ----	------	------	Indian Head
2	SCS Runoff	225.66	1	742	1,206,171	27.7 ----	------	------	Petta Lake Shores 2
3	SCS Runoff	70.21	1	767	576,262	13.2 ----	------	------	Edgewater 1
4	SCS Runoff	22.21	1	755	152,709	3.5 ----	------	------	Edgewater 2
5	SCS Runoff	118.99	1	768	994,925	22.8 ----	------	------	Petta Terrace Combo
6	SCS Runoff	51.30	1	737	242,066	5.4 ----	------	------	Mettasquamscutt 1
7	SCS Runoff	35.91	1	735	162,259	3.7 ----	------	------	Mettasquamscutt 3
8	SCS Runoff	27.68	1	739	139,391	3.2 ----	------	------	Mettasquamscutt 4

Proj. file: 102505kmk.gpw	Return Period: 25 yr	Run date: 11-11-2005

FIGURE
Revision 1

ON-LOT SOURCE CONTROL COSTS and Volume treated

INTRODUCTION

The costs for the following on-lot source controls were calculated based on the described assumptions and cost sources. The on-lot source controls for which costs were developed are:

1. Disconnect Roof Downspouts
2. Pervious Pavement
3. Dry Wells
4. Bioretention
5. Grass filter strip

Assumptions:

1. The values provided are for the 'hypothetical lot' as shown on the attached figure.

$A_{roof} = 875 ft^2$ $\quad$ $A_{drive} = 450 ft^2$

$WQV_{roof} = 875 ft^2 (\frac{1}{12}")$
$= 72.9 ft^3$
$= 545$ gal

$WQV_{drive} = 37.5$ cf
$= 280.5$ gal

$WQV_{total} = 110.4$ cf

2. Labor costs have not been included for disconnected roof downspouts that homeowners can install on their own

3. Unit Effectiveness Curve DRAFT Sw manual & TM2 tables

1:2 ⇒ 1 acre open space to treat 2 acres of impervious area

For 1" of runoff,

Open Space	1:2	} For type A soil ONLY
Natural Area	1:3	

Disconnect roof downspouts

Assume homeowner performs work (no labor)

Cost (per downspout)

Downspout extender/attachments (Home Depot website)	$20
splash guard (Ace Hardware website)	$10
	$30/downspout

cost = $120 (for 4 downspouts)
$V_{treated}$ = 72.9 ft³ (whole roof)
unit cost = ~~$1.64/ft³~~

Revision 1

if all roof is treated by disconnect (Type A soil)

Pervious pavement

source: www.lid-stormwater.net

porous concrete $2-6.50/sf
grass/gravel pavers $1.5-5.75/sf

cost = $\frac{\$6.50}{sf}$ (20')(15') = $1950 (does not include 10' from house)

$V_{treated}$ = 20'(15')($\frac{1}{12}$') = 25 cf (if all driveway, except 10' closest to house, is treated)

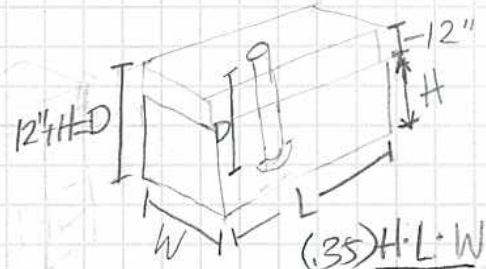
unit cost = $78/ft³

Dry Wells 1/2

EQUIPMENT
surcharge pipe
splash block

filter fabric
observation well (4" Ø PVC)
cap
pipe
foot plate
gravel

1. Install "V" for surcharge pipe
2. Excavate for substructures
3. Install dry well



$A_{roof} = 875 ft^2$

$(.35)\frac{H \cdot L \cdot W}{4 downspouts} = A_{roof} \cdot (0.9)(1$

Assume: Work to be done by contractor not homeowner & no sump
Dimensions of dry well

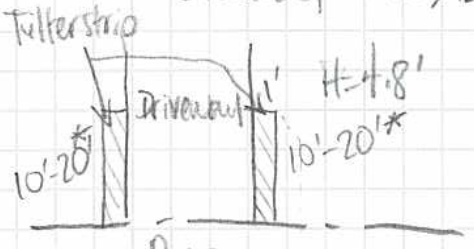
$A_{roof}(.9)(\frac{1''}{12''}) = 66 ft^3$ $\quad HLW = \frac{66 cf}{.35} = \frac{187.5 cf}{4 downspouts}$

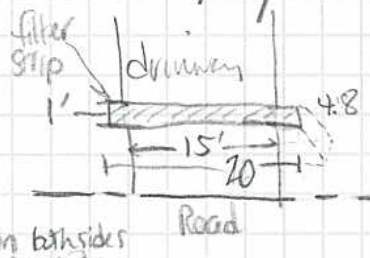
$= 47 cf/downspout$

$H = 4', L = 4', W = 3' \Rightarrow HLW = 48 cf$

Excavation is $H = 5', V = 60 cy$
$\sim 2.5 cy$

$A_{driveway}(.9)(1/12')(\frac{1}{.35}) = 96.4 cf = 3.6 cy$
$\sim 4 cy$





H=4.8'
L=20'
W=1' HLW

*length depending on whether filter strip is on both sides or one side

filter fabric surface area

$A_{downspout} = 2(4 \cdot 4 + 4 \cdot 3 + 4 \cdot 3) = 80 sf$

$A_{driveway} = 2(1 \cdot 20 + 1 \cdot 4.8 \cdot 4.8 \cdot 20) = 241.6 sf$

top area
Driveway 205sf
Downspout (72sf + 5sf) 4

Dry wells (con't)
2/2

COST

Downspouts

Modify downspout connections (see Disconnecting Roof Downspouts)	$30
Excavation (4 - 2.5cy excavations) $100/hr, 4 hrs	$400
Filter fabric (4·80sf) $1/sf	$320
Monitoring well supplies 4" PVC - 5' long cap	$10
gravel - 2cy per excavation (8cy) $35.50/cy means p. 32	$284
revegetation (3sy) $0.41/sy	$5
TOTAL	$1049

cost = $1049 (for 4 downspouts)
Vtreated = 72.9cf
unit cost = $14.39/cf

Driveway - Does not include grading modifications of drive

Excavation 4cy $100/hr 2hr	$200
Filter fabric 242sf	$242
Monitoring well	$10
gravel - 3.6cy	$128
revegetation 20sf	$5
TOTAL	$585

cost = $585
Vtreated = 37.5cf
unit cost = $15.60/cf

1

Bioretention

Cost = Bioretention (single lot) $6700/lot
Construction & closeout phases from www.lid-stormwater.net

$V_{treated}$ = Assume this can only treat roof 72.9 cf

unitcost = Cost/ft³ = 6700/72.9cf = $91.91

GRASS FILTER STRIP

Assume culvert under driveway is not used – Type A soil only

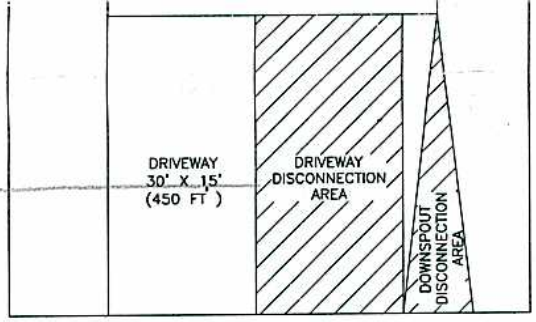
Cost for swale per linear foot $15/LF $525
LF = 50 - 15' = 35'
cost from www.lgpc.state.ny.us

Type A soil Area used : Area treated = 1:2

$L_{swale} \cdot W_{swale}$ = 35'(7') = 245 ft² Area treated = 490 ft²

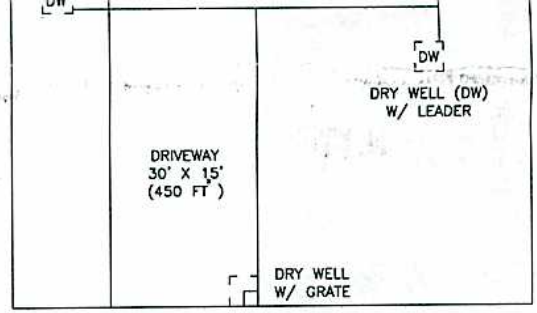
$V_{treated}$ = (490 ft²)(1/12') = 40.8 cf

unit cost = $12.87/ft³



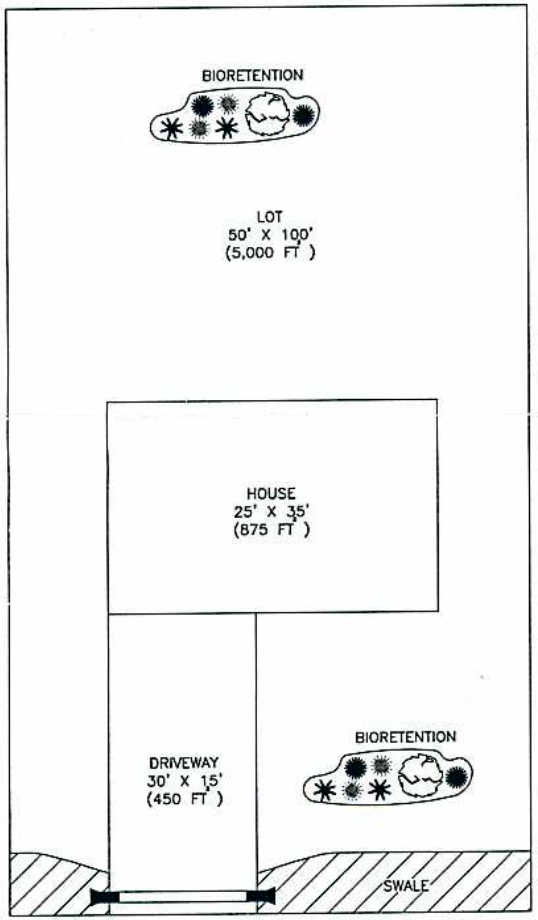
?

DISCONNECTION TO OVERLAND FLOW



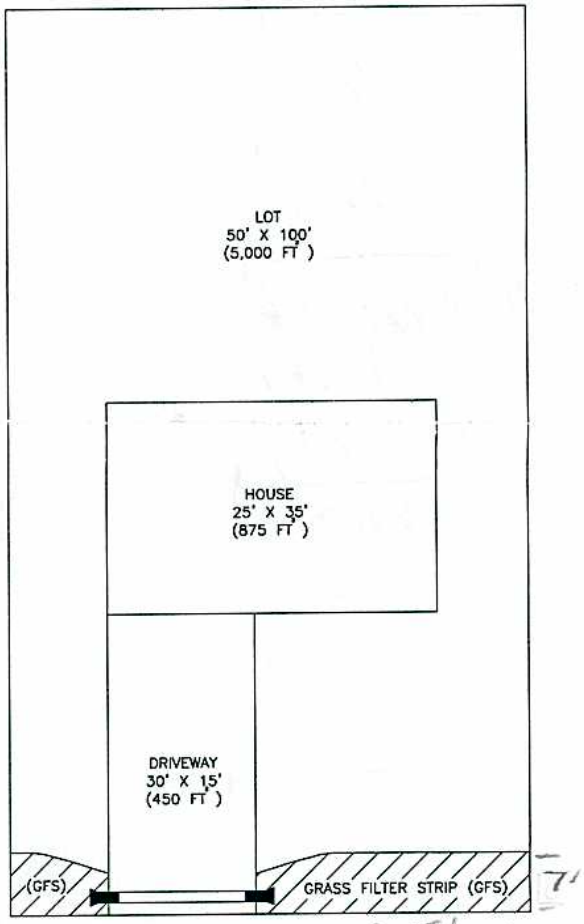
DRY WELLS

$6.9/ft³ treated
112 ft³ treat



BIORETENTION (I.E., RAIN GARDEN)

$0.65/ft²
112 treat



GRASS FILTER STRIPS ← 35' →

SCALE: HORZ.: VERT.: DATUM: HORZ.: VERT.: 0 GRAPHIC SCALE	FUSS & O'NEILL INC. *Consulting Engineers* 275 PROMENADE STREET, SUITE 350, PROVIDENCE, RI 02908 401.861.3070 www.FandO.com	RHODE ISLAND DEPARTMENT OF ENVIRONMENTAL MANAGEMENT RUNOFF VOLUME REDUCTION AND UPLAND ATTENUATION DEVELOPING THE NARROW RIVER STORMWATER ABATEMENT PLAN NARRAGANSETT RHODE ISLAND

PROJ. No.: 20041111.A10
DATE: SEPTEMBER 2005

SHEET

CTB: LMAN: MS VIEW: UCS:

FUSS & O'NEILL *Disciplines to Deliver*	PREPARED BY	DATE	CHECKED BY	DATE	PROJECT NO.
	KMK	12/1/05			20041111.A10

Revision 1 - modifications for rating matrix

SHEET NO. R1 of R3

Disconnect roof Downspouts

For Type A soil:
75% of roof is treated ∴ $V_{treated} = 54.7\ ft^3$

cost = \$30(3) = \$90 (3 downspouts)
unit cost = \$1.64/ft³

For Type C soil:
~~75% of roof is treated~~
only ½ inch (not full 1-inch) is treated
~~∴ $V_{treated} = 72.9\ ft^3 (.5)(.75) = 27.3\ ft^3$~~
cost = \$90 (3 downspouts)
~~unit cost = \$3.30/ft³~~

$618\ ft^2 = A_{DD(3/4)} = .71\%\ (A_{house})$

For type C
$V_{treated} = 618\ ft^2 (.5'') = 25.75\ ft^3$
unit cost = \$3.50/ft³

Vegetated Filter Strip

Introduction:

These calculations have been prepared to determine the storage volume of two types of vegetated filter strips (VFS), conveyance type & flat storage type.

Assumptions

For conveyance:

1. Lots must be sloped adequately to convey water
2. Side slopes are set to use maximum 10' WIDTH (3:1 max, 4% min)
3. 4% slope for conveyance along length
4. Half of storage length is available for effective bottom area

For flat storage:

1. Lot grading must allow for overflow berm to street for conveyance of peak flows
2. Side slopes are set to use max 10' width (3:1 max, 4% min)
3. Flat storage will only be for 2" depth

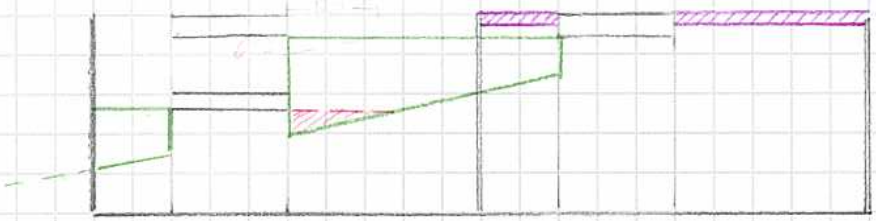
Method

Areas/volumes were calculated using basic geometry

$\frac{V_s}{A_b}$ Was calculated to determine the depth of water that needs to be infiltrated through the effective bottom area

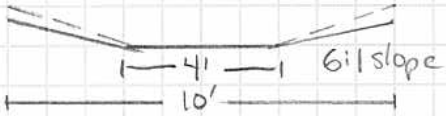
K min was calculated as depth of water to be infiltrated over 24 hours.

Plan view
1" = 25'

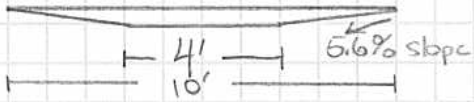


Profile view
hor. 1" = 25'
Vert. 1" = 1'

Conveyance



flat storage



Cross-Sections
1" = 1'

$A'_{bottom} = 4'\frac{(12.5')}{2}$

$A'_b = 25\,sf$

$A_{cs} = (4+3)(.5') = 3.5\,sf$

$V_{storage} = (7')\frac{(.5+0)}{2}(12.5') = \underline{21.9\,cf}$

$\frac{V_s}{A'_b} = \frac{21.9\,cf}{25\,sf} = 0.9\,ft$

$K \geq \underline{0.9\,ft/d}$

$A'_{bottom} = 4'(35') = 140\,sf$

$A_{cs} = (4'+3')\left(\frac{2}{12}'\right) = 1.17\,sf$

$V_{storage} = 7'\left(\frac{2}{12}'\right)(35') = \underline{40.8\,cf}$

$\frac{V_s}{A'_b} = \frac{40.8\,cf}{140\,sf} = 0.3\,ft$

$K \geq \underline{0.3\,ft/d}$

FUSS & O'NEILL *Disciplines to Deliver*	PREPARED BY	DATE	CHECKED BY	DATE	PROJECT NO.
	KMK	12/12/05			20041111.A10

Narrow River - TM2

SHEET NO. 1 of 1

Source Control treatment % of Subwatershed

INTRODUCTION

The % of a subwatershed's WQV or GWR that can be treated through source controls in that subwatershed depends on the # of lots in each soil type, the participation rate, the volume that can be treated per lot and the total WQV & GWR of the subwatershed.

Data & Calculations

% & ft of lot impervious area volume that can be treated

Volume	Type A		Type C	
WQV	100%	110.4 ft³	89%	98.3 ft³
GWR	100%	155.9 ft³	16%	25.8 ft³

% of subwatershed treated w/ source controls

For E1, WQV = 1.51 ac·ft

Type A lots = 49
Type C lots = 162 For 20% participation

WQV treated = 0.2(49·110.4 + 162·98.3) = 4267 ft³
= 0.098 ac·ft

$$\%WQV = \frac{0.098\ ac\cdot ft}{1.51\ ac\cdot ft} = \underline{6.5\%}$$

For M1, GWR = 1.64 ac·ft

Type A lots = 124.5
Type C lots = 61 For 20% participation

GWR treated = 0.2(124.5·155.9 + 61·28.5) = 4230 ft³ = 0.097 ac·ft

$$\%GWR = \frac{0.097\ ac\cdot ft}{1.64\ ac\cdot ft} = \underline{5.9\%}$$

Treatment Costs

INTRODUCTION

The cost per unit of treated stormwater was determined from readily available sources and adjusted for inflation. The costs calculated are unit costs for each BMP - infiltration trenches, disconnected catch basin infiltration units, bioretention, and sand filters.

SOURCES

- "EPA - Urban Stormwater BMP Study"
  for infiltration trenches, bioretention, & sandfilters
- Stormceptor & Stormtech sales representatives
  for proprietary infiltration units (Disconnected CBs)

ASSUMPTIONS

The costs do not include design, testing, legal fees, land costs, permitting and are for planning purposes. These costs should not be used for estimating purposes.

The costs do not include the catch basin or pretreatment systems.

The costs do not include reestablishment of ground cover.

Cost information from sales reps was not adjusted for inflation.

Inflation was assumed to be 3% per year.

The high end of a range was used when costs were listed as a range.

Size does not affect cost.

Example calculation

$$P = C\left(1+\frac{r}{n}\right)^{nt}$$

P = current value
C = listed value (past)
r = interest rate (3%)
n = 1 yearly
t = 8 years (1997-2005)

For infiltration trenches
$C = \$4/ft^3$

$$P = \frac{\$4}{ft^3}\left(1+\frac{.03}{1}\right)^{1\cdot 8}$$

$$P = \$5.10/ft^3$$

Example calculation (con't)

For proprietary infiltration units, the average of the cost information was used

Stormceptor $4/ft^3

Stormtech $3.5/ft^3

Average = $3.75/ft^3

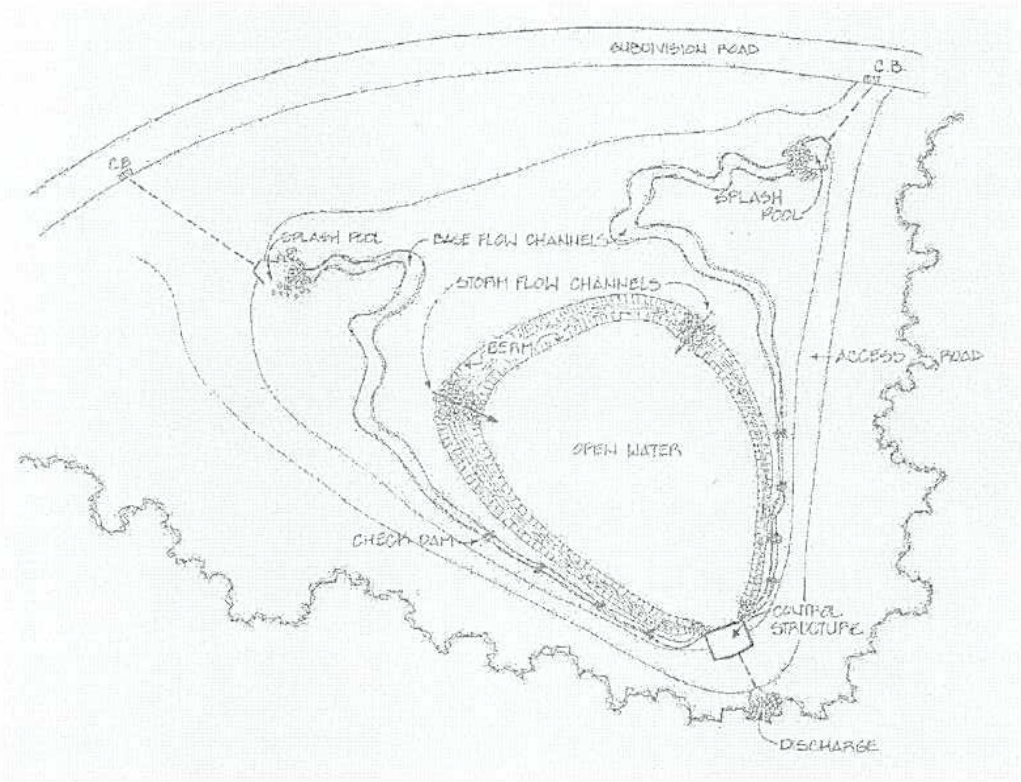
United States
Environmental Protection
Agency

Office of Water (4303)
Washington, DC 20460

EPA-821-R-99-012
August 1999

p. 3 of 5

EPA Preliminary Data Summary of Urban Storm Water Best Management Practices



experimental and proprietary products, as well as some conventional structures such as water quality inlets. They are not included in this analysis because sufficient data are not available to support either the performance or the cost of these practices.

6.1.1 Base Capital Costs

The base capital costs refer primarily to the cost of constructing the BMP. This may include the cost of erosion and sediment control during construction. The costs of design, geotechnical testing, legal fees, land costs, and other unexpected or additional costs are not included in this estimate. The cost of constructing any BMP is variable and depends largely on site conditions and drainage area. For example, if a BMP is constructed in very rocky soils, the increased excavation costs may substantially increase the cost of construction. Also, land acquisition costs vary greatly from site to site.[4] In addition, designs vary slightly among BMP types. A wet pond may be designed with or without various levels of landscaping, for example. The data in Table 6-1 represent typical unit costs (dollars per cubic foot of treated water volume) from various studies, and should be considered planning level. In the case of retention and detention basins, ranges are used to reflect the economies of scale involved in designing these BMPs.

[4] Land cost is the largest variable influencing overall BMP cost.

Table 6-1. Typical Base Capital Construction Costs for BMPs

BMP Type	Typical Cost* ($/cf)	Notes	Source
Retention and Detention Basins	0.50-1.00	Cost range reflects economies of scale in designing this BMP. The lowest unit cost represents approx. 150,000 cubic feet of storage, while the highest is approx. 15,000 cubic feet. Typically, dry detention basins are the least expensive design options among retention and detention practices.	Adapted from Brown and Schueler (1997b)
Constructed Wetland	0.60-1.25	Although little data are available to assess the cost of wetlands, it is assumed that they are approx. 25% more expensive (because of plant selection and sediment forebay requirements) than retention basins..	Adapted from Brown and Schueler (1997b)
Infiltration Trench	4.00	Represents typical costs for a 100-foot long trench.	Adapted from SWRPC (1991)
Infiltration Basin	1.30	Represents typical costs for a 0.25-acre infiltration basin.	Adapted from SWRPC (1991)
Sand Filter	3.00-6.00	The range in costs for sand filter construction is largely due to the different sand filter designs. Of the three most common options available, perimeter sand filters are moderate cost whereas surface sand filters and underground sand filters are the most expensive.	Adapted from Brown and Schueler (1997b)
Bioretention	5.30	Bioretention is relatively constant in cost, because it is usually designed as a constant fraction of the total drainage area.	Adapted from Brown and Schueler (1997b)
Grass Swale	0.50	Based on cost per square foot, and assuming 6 inches of storage in the filter.	Adapted from SWRPC (1991)
Filter Strip	0.00-1.30	Based on cost per square foot, and assuming 6 inches of storage in the filter strip. The lowest cost assumes that the buffer uses existing vegetation, and the highest cost assumes that sod was used to establish the filter strip.	Adapted from SWRPC (1991)

* Base year for all cost data: 1997

In some ways there is no such value as the "average" construction cost for some BMPs, because many BMPs can be designed for widely varying drainage areas. However, there is some

APPENDIX B

HAGER GEOSCIENCE, INC.
HYDROGEOLOGIC REPORT

HAGER GEOSCIENCE, INC.
596 MAIN STREET, WOBURN, MASSACHUSETTS 01801-2924
TELEPHONE: (781) 935-8111 FAX: (781) 935-2717

To: Jim Riordan

From: Jutta Hager

Date: July 28, 2005

Re: Narrow River Stormwater Abatement Project, Narragansett, RI

Appended are logs, monitoring well installation forms, and slug test results for the borings drilled on July 5th and 6th, 2005. As you noted in your memo of July 12th, 7 of 8 proposed borings were completed. NRW-6, at the intersection of Lakeside Drive and Bridgetown Road, could not be drilled because of interfering utilities.

Wells were installed in NRW-2, NRW-3, NRW-5, NRW-7, and NRW-8. Slug tests were conducted in NRW-3, NRW-5, NRW-7, and NRW-8 after well installation, and in the NRW-4 open hole. Calculated K values are as follows:

NRW-3: $K = 3.66 \times 10^{-4}$ inch/min
$K = 4.40 \times 10^{-2}$ feet/day

NRW-4: $K = 5.82 \times 10^{-3}$ inch/min
$K = 6.99 \times 10^{-1}$ feet/day

NRW-5: $K = 2.12 \times 10^{-3}$ inch/min
$K = 2.55 \times 10^{-1}$ feet/day

NRW-7: $K = 6.65 \times 10^{-2}$ inch/min
K = 7.98 feet/day

NRW-8: $K = 1.33 \times 10^{-1}$ inch/min
K = 15.96 feet/day

Based on the nature of the sand encountered in NRW-2, the K calculated K value would be similar to that for NRW-8.

BORING LOG

HAGER GEOSCIENCE, INC.
596 Main Street
Woburn, Massachusetts

BORING **NRW-1**
Job No. **200540**
Date: **7/5/2005**

Project: **Narrow River Stormwater Abatement Project, Narragansett, RI**

Location: **Riverdell Drive near Cinnamon Lane**

Client: **Fuss & O'Neill**

Geo/Eng.: **HGI/Jon Brinkmann**
Driller: **Subsurface Engineering**
Mobile B-61; 4-1/4 HSA

Sampling SPT continuous

Depth in Feet	Sample Type	Sample No.	Blows Rec.	SPT N	USC Symbol	Sample Description
	SS	1	4-13-14-12 (9")	27	SM	**SILTY SAND**, fine-grained, med. dense, 10-15% silt, 5-10% f-c angular gravel, rootlets, moist, dark yellowish brown.
	SS	2	12-26-15-13 (10.5")	41	SM	**SILTY SAND**, f-c-grained, dense, 10-15% silt, 15-20% f-c angular gravel, rootlets, moist, dark yellowish brown.
5	SS	3	13-12-14-16 (16")	26	SP	**SAND**, fine-grained, med. dense, <5% silt, moist, med. gray, trace organics.
	SS	4	24-25-19-19 (14.5")	44	SM	**SAND**, fine-grained, dense, 10-15% silt, 10-15% f-c gravel, moist, brownish gray, 15-20% organic matter (spoon cored gravel).
10	SS	5	45-35 (9.5")	>50	SM-GM	**GRAVELLY SILTY SAND**, f-c grained, very dense, 15-20% silt, ~40% f-c angular gravel, moist, dark yellowish brown.
	SS	6				Refusal @ 9.' Possible top of rock.
						Driller augered to 11 feet through gravel & cobbles.
	SS	7				
						EOB @ 11'. No water encountered.
15	SS	8				No well installed.
	SS	9				
	SS	10				
20						

Summary

Boring Depth	11.0'
Water Level	no water encountered

BORING LOG

HAGER GEOSCIENCE, INC.
596 Main Street
Woburn, Massachusetts

BORING **NRW-2**
Job No. **200540**
Date: **7/5/2005**

Project: **Narrow River Stormwater Abatement Project, Narragansett, RI**

Location: **Winter Berry & Woodsia Road**

Client: **Fuss & O'Neill**

Geo/Eng.: **HGI/Jon Brinkmann**
Driller: **Subsurface Engineering**
Mobile B-61; 4-1/4 HSA

Sampling: SPT continuous

Depth in Feet	Sample Type	Sample No.	Blows Rec.	SPT N	USC Symbol	Sample Description
	SS	1	4-13-10-5 (11.5")	23	SM	**SILTY SAND**, mostly fine-grained, med. dense, 10-15% silt, 10-15% f-c angular gravel, organic laminae, moist, dark yellowish brown.
	SS	2	4-2-2-2 (14.5")	4	SM	**SILTY SAND**, mostly fine-grained, v. loose, 10-15% silt, 10-15% fine angular gravel, moist, dark yellowish brown.
5	SS	3	5-7-6-6 (17")	13	SP	**SAND**, fine-grained, med. dense, <5% silt, 5-10% fine sub-rounded gravel, moist, brownish gray. Med. sand lens, ~ 1" thick.
	SS	4	11-19-38-10 (8")	57	SP	**SAND**, f-m, very dense, <5% silt, 5-10% f-c sub-rounded gravel, wet, dark yellowish brown (hit cobble).
10	SS	5	9-7-5-5 (8")	12	SP	**SAND**, mostly f-m, med. dense, <5% silt, 5-10% f-c sub-rounded gravel, wet, moderate brown.
	SS	6	1-4-6-7 (10")	10	SP	**SAND**, mostly f-m, med. dense, <5% silt, 5-10% fine sub-rounded gravel, wet, moderate brown.
	SS	7	5-5-5-6 (12")	10	SP	**SAND**, mostly f-m, med. dense, <5% silt, 5-10% fine sub-rounded gravel, wet, moderate brown.
15	SS	8	7-7-18 (4")	25	SP	**SAND**, mostly f-m, med. dense, <5% silt, 5-10% fine sub-rounded gravel, wet, moderate brown. Note: Spoon full after 1'; sand blowing up into augers.
						EOB @ 16'. Driller unable to recover additional samples.
20						Well installed @ 14'.

Summary

Boring Depth	16.0'
Water Level	7.5 ' during drilling

BORING LOG

HAGER GEOSCIENCE, INC.
596 Main Street
Woburn, Massachusetts

BORING **NRW-3**
Job No. **200540**
Date: **7/5/2005**

Project: **Narrow River Stormwater Abatement Project,**

Location: **Old Pine Road & Fernleaf Trail**

Client: **Fuss & O'Neill**

Geo/Eng.: **HGI/Jon Brinkmann**
Driller: **Subsurface Engineering**
Mobile B-61; 4-1/4 HSA

Sampling: SPT continuous

Depth in Feet	No.	Blows Rec.	SPT N	USC Symbol	Sample Description
	1	6-7-9-9 (14.5")	16	SM	**SILTY SAND**, mostly fine-grained, med. dense, 10-15% silt, 10-15% f-c angular gravel, rootlets, moist, dark yellowish brown.
	2	14-16-20-25 (18.5")	36	SP	**SAND**, fine-grained, dense, <5% silt, 5-10% fine gravel, moist, med. gray, trace organics.
5	3	18-11-8-8 (13")	29	SM	**SILTY SAND**, fine-grained, med. dense, 15-20% silt, 15-20% f-c subrounded gravel, moist, dark brownish gray. Mica flakes.
	4	11-8-8-8 (11.5")	26	SM	**SILTY SAND**, fine-grained, med. dense, 20-30% silt, 15-20% f-c subrounded gravel, moist, dark yellowish brown. Mica flakes.
10	5	7-10-12-16 (12")	22	SM	**SILTY SAND**, fine-grained, med. dense, micaceous, 20-30% silt, 15-20% subrounded gravel, moist, dark yellowish brown.
	6	11-16-18-18 (14")	34		**Weathered schist bedrock** w/relict texture; dense, micaceous, light brown. Bottom 11" wet.
	7	17-21-30 (12")	51		**Weathered schist bedrock** w/relict texture; very dense, micaceous, light brown, wet.
15	8				EOB @ 13.5' in competent bedrock.
	9				Well installed @ 10'.
	10				
20					

Summary

Boring Depth	13.5'
Water Level	9.4' during drilling.

BORING LOG

HAGER GEOSCIENCE, INC.
596 Main Street
Woburn, Massachusetts

BORING **NRW-4**
Job No. **200540**
Date: **7/5/2005**

Project: **Narrow River Stormwater Abatement Project,**

Location: **Hillside Road & Orchard Avenue**

Client: **Fuss & O'Neill**

Geo/Eng.: **HGI/Jon Brinkmann**
Driller: **Subsurface Engineering**
Mobile B-61; 4-1/4 HSA

Sampling: SPT continuous

Depth in Feet	No.	Blows Rec.	SPT N	USC Symbol	Sample Description
	1	5-12-13-18 (9.5")	25	SM	**SILTY SAND**, mostly fine-grained, med. dense, 10-15% silt, 10-15% f-c angular gravel, moist, dark yellowish brown.
	2	11-11-9-9 (11")	20	SM	**SILTY SAND**, mostly fine-grained, med. dense, 15-20% silt, 5-10% f-c angular gravel, moist, dark yellowish brown.
5	3	>50/6" 5"	>50	SP	**SAND**, f-c, very dense, <5% silt, 10-20% fine angular gravel, moist, moderate yellowish brown.
	4				Refusal @ 4.5'. Roller bit to 7 feet.
	5				EOB @ 7'. No water encountered.
10					No well installed.
	6				
	7				
15	8				
	9				
	10				
20					

Summary

Boring Depth	7.0'
Water Level	no water encountered

BORING LOG

HAGER GEOSCIENCE, INC.
596 Main Street
Woburn, Massachusetts

BORING **NRW-5**
Job No. **200540**
Date: **7/6/2005**

Project: **Narrow River Stormwater Abatement Project, Narragansett, RI**

Location: **Saybrook Avenue & Wampum Road**

Client: **Fuss & O'Neill**

Geo/Eng.: **HGI/Jon Brinkmann**
Driller: **Subsurface Engineering**
Mobile B-61; 4-1/4 HSA

Sampling: SPT continuous

Depth in Feet	Sample Type	Sample No.	Blows Rec.	SPT N	USC Symbol	Sample Description
	SS	1	1-7-12-11 (10.5")	19	SM	**SILTY SAND**, fine-grained, med. dense, 10-15% silt, 5-10% f-c angular gravel, rootlets, moist, dark grayish brown.
	SS	2	7-8-12-20 (11.5")	20	SM	**SILTY SAND**, fine-grained, med. dense, 15-20% silt, moist, dark yellowish brown. Cored schist cobble.
5	SS	3	4-9-10-6 (12")	19	SM	**ORGANIC SILTY SAND,** fine grained, med. dense, 15-20% silt, moist, black.
	SS	4	5-7-9-12 (16.5")	16	SM	**SILTY SAND**, fine-grained, med. dense, 20-25% silt, 20-30% f-c gravel, moist, moderate brown.
10	SS	5	23-52 (6")	>50	SP-SM	**SAND**, fine grained, very dense, 10-15% silt, 5-10% fine gravel, moist, moderate brown.
	SS	6	10-13-22-33 (18")	35		**Weathered schist bedrock** w/relict texture; med. dense, micaceous, moist, moderate brown.
	SS	7	40-35-38-37 (17")	73		**Weathered schist bedrock** w/relict texture; very dense, micaceous, moist, moderate brown.
15	SS	8				Weathered bedrock @ 9.0'
						Competent bedrock @ 13.5'
	SS	9				
						EOB @ 14' in competent bedrock.
	SS	10				Well installed @ 9'.
20						

Summary

Boring Depth	14.0'
Water Level	no water encountered.

BORING LOG

HAGER GEOSCIENCE, INC.
596 Main Street
Woburn, Massachusetts

Project: **Narrow River Stormwater Abatement Project, Narragansett, RI**

Client: **Fuss & O'Neill**

Sampling: SPT continuous

BORING **NRW-7**
Job No. **200540**
Date: **7/6/2005**

Location: **Pettaquamscutt Avenue & Lakeview Drive**

Geo/Eng.: **HGI/Jon Brinkmann**
Driller: **Subsurface Engineering**
Mobile B-61; 4-1/4 HSA

Depth in Feet	Sample Type	Sample No.	Blows Rec.	SPT N	USC Symbol	Sample Description
	SS	1	1-4-6-6 (11")	10	SP	**SAND**, fine-grained, loose, <5% silt, dry, dark yellowish brown.
	SS	2	6-5-6-8 (17")	11	SP	**SAND,** fine grained, med. dense, <5% silt, moist, pale yellowish brown.
5	SS	3	7-5-7-8 (19.5")	12	SP	**SAND,** fine grained, med. dense, <5% silt, moist, pale yellowish brown.
	SS	4	5-5-6-5 (17.5")	11	SP	**SAND,** fine grained, med. dense, <5% silt, moist, pale yellowish brown.
10	SS	5	5-4-4-4 (18.5")	8	SP	**SAND,** fine grained, loose, <5% silt, wet, moderate yellowish brown. Wet @ 8.5'.
	SS	6	3-3-4-4 (14.5")	7	SP	**SAND,** fine grained, loose, <5% silt, wet, brownish gray.
	SS	7	3-4-4-6 (23")	8	SP	**SAND,** fine grained, loose, <5% silt, wet, brownish gray.
15	SS	8	4-4-4-4 (19.5")	8	SP	**SAND,** fine grained, loose, <5% silt, wet, brownish gray.
	SS	9	3-4-4-5 (21")	8	SP	**SAND,** fine grained, loose, <5% silt, wet, brownish gray.
20	SS	10	5-6-7-7 (22")	13	SP	**SAND,** fine grained, med. dense, <5% silt, wet, brownish gray.
						EOB @ 20'.
						Well installed @ 14'.

Summary

Boring Depth 20.0'
Water Level 9.4' during drilling.

BORING LOG

HAGER GEOSCIENCE, INC.
596 Main Street
Woburn, Massachusetts

BORING **NRW-8**
Job No. **200540**
Date: **7/6/2005**

Project: **Narrow River Stormwater Abatement Project, Narragansett, RI**

Location: **South River Drive & Woodridge Road**

Client: **Fuss & O'Neill**

Geo/Eng.: **HGI/Jon Brinkmann**
Driller: **Subsurface Engineering**
Mobile B-61; 4-1/4 HSA

Sampling: SPT continuous

Depth in Feet	Sample Type	Sample No.	Blows Rec.	SPT N	USC Symbol	Sample Description
	SS	1	3-4-4-6 (15.5")	8	SP	**SILTY SAND**, fine-grained, loose, 10-15% silt, moist, dark yellowish brown. (Drilled through asphalt top 2.5".)
	SS	2	5-7-11-13 (17")	18	SP/SM	Top 12": **SAND**, f-m grained, med. dense, < 5% silt, <5% fine subrounded gravel, moist, moderate brown. Bottom 5": **SILTY SAND**, mostly fine-grained, med. dense, 10-15% silt, < 5% fine gravel, wet, brownish gray.
5	SS	3	7-10-12-10 (16.5")	22	SM-SP	**SILTY SAND**, mostly fine-grained, med. dense, 10-15% silt, wet, brownish gray. Thin m-c sand lenses.
	SS	4	6-10-12-11 (23.5")	22	SP	**SAND**, f-c, mostly medium, med. dense, <5% silt, wet, brownish gray.
10	SS	5	4-7-9-12 (24")	16	SP	**SAND**, f-c, mostly medium, med. dense, <5% silt, 5-10% f-c gravel, brownish gray.
	SS	6	3-9-29-32 (24")	12*	SP	**SAND**, f-c, mostly medium, med. dense, <5% silt, 5-10% f-c gravel, brownish gray.
	SS	7				Driller drove to 15' and attempted to take another sample.
15	SS	8	7-14 (12")	21*	SP	**SAND**, f-c, mostly medium, med. dense, <5% silt, 10-15% f-c gravel, brownish gray.
	SS	9				EOB @ 16'.
	SS	10				Well installed @ 12'.
20						
						*Spoon full after 1 foot.

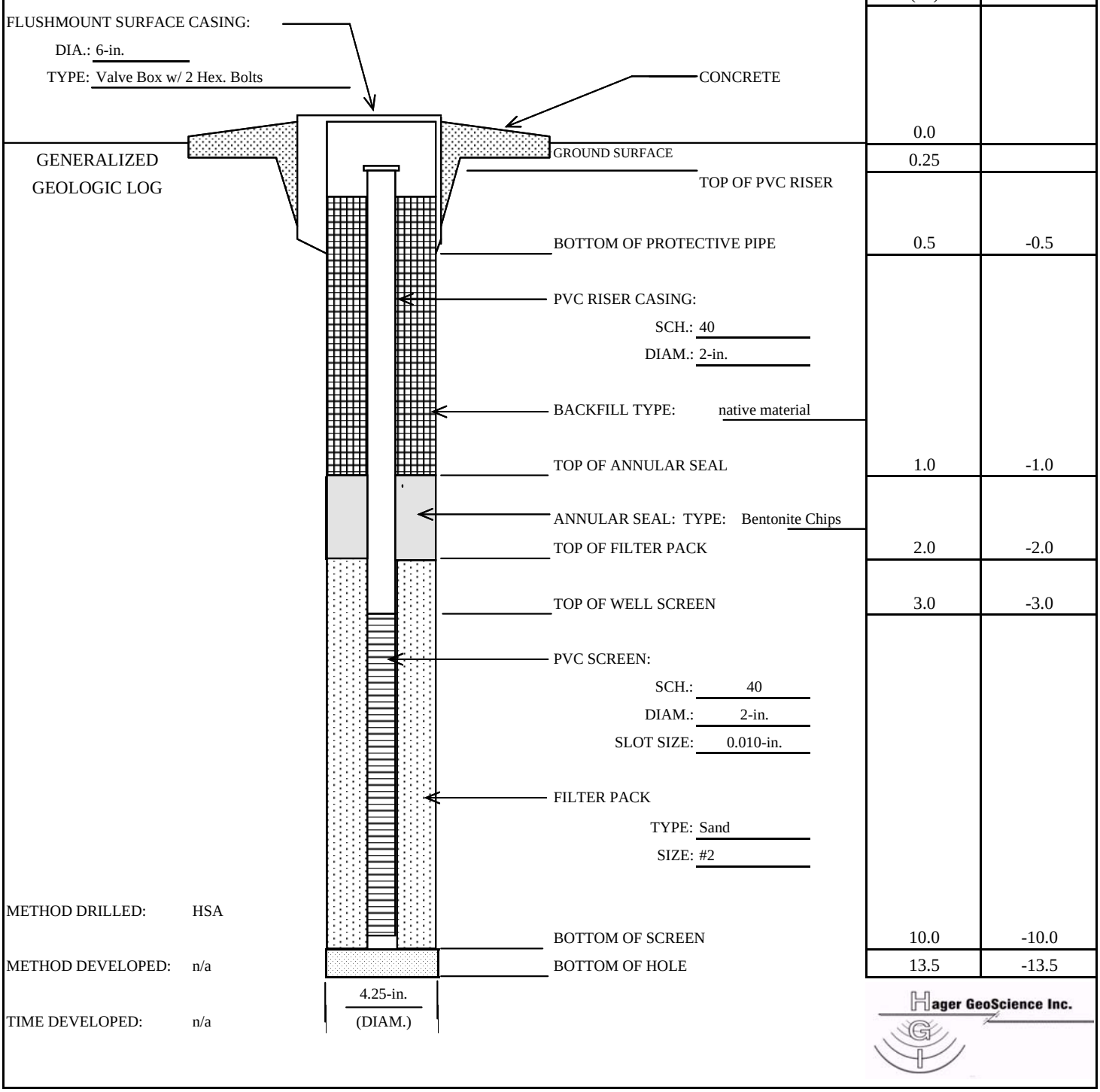
Summary

Boring Depth	16.0'
Water Level	4.6' during drilling.

MONITORING WELL INSTALLATION LOG

PROJECT: **Narrow River Stormwater Abatement Project, Narragansett, RI**	JOB NO. **200540**	WELL NO. **NRW-3**
DRILLING CONTRACTOR: **Subsurface Drilling**	LOCATION: **Old Pine Rd. & Fernleaf Trail**	
BEGUN: **7/5/2005**	GEO/ENG: **HGI/Jon Brinkmann**	WATER LEVEL (Depth/Elev.)
FINISHED: **7/5/2005**	DRILLER: **John & Brad**	**Depth: 8.12' / Elevation: '**

COMMENTS: WL 7/05/06 @ 10:30 am **9.40'**
WL 7/07/06 @ 10:55 am **8.12'**



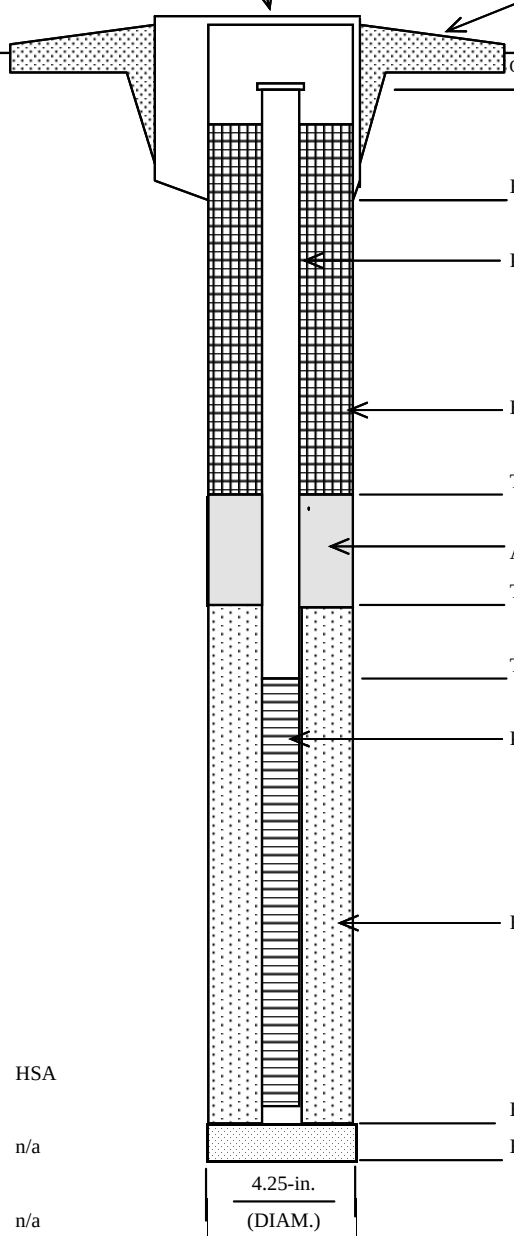
	DEPTH BGS HEIGHT AGS (FT)	ELEV. (FT) NGVD DATUM
	0.0	
	0.25	
	0.5	-0.5
	1.0	-1.0
	2.0	-2.0
	3.0	-3.0
	10.0	-10.0
	13.5	-13.5

MONITORING WELL INSTALLATION LOG

PROJECT: **Narrow River Stormwater Abatement Project, Narragansett, RI**	JOB NO. **200540**	WELL NO. **NRW-5**
DRILLING CONTRACTOR: **Subsurface Drilling**	LOCATION **Saybrook Ave. & Wampum**	
BEGUN: **7/6/2005**	GEO/ENG: **HGI/Jon Brinkmann**	WATER LEVEL (Depth/Elev.)
FINISHED: **7/6/2005**	DRILLER: **John & Brad**	**Depth: n/a' / Elevation: '**

COMMENTS: WL 7/06/06 @ 9:30 am **dry**
WL 7/07/06 @ 11:05 am **dry**

GENERALIZED GEOLOGIC LOG



	DEPTH BGS HEIGHT AGS (FT)	ELEV. (FT) NGVD DATUM
FLUSHMOUNT SURFACE CASING: DIA.: 6-in. TYPE: Valve Box w/ 2 Hex. Bolts; CONCRETE	0.0	
GROUND SURFACE	0.3	
TOP OF PVC RISER		
BOTTOM OF PROTECTIVE PIPE	0.5	-0.5
PVC RISER CASING: SCH.: 40 DIAM.: 2-in.		
BACKFILL TYPE: native material		
TOP OF ANNULAR SEAL	1.0	-1.0
ANNULAR SEAL: TYPE: Bentonite Chips		
TOP OF FILTER PACK	2.0	-2.0
TOP OF WELL SCREEN	3.0	-3.0
PVC SCREEN: SCH.: 40 DIAM.: 2-in. SLOT SIZE: 0.010-in.		
FILTER PACK TYPE: Sand SIZE: #2		
BOTTOM OF SCREEN	9.0	-9.0
BOTTOM OF HOLE	14.0	-14.0

METHOD DRILLED: HSA

METHOD DEVELOPED: n/a

TIME DEVELOPED: n/a

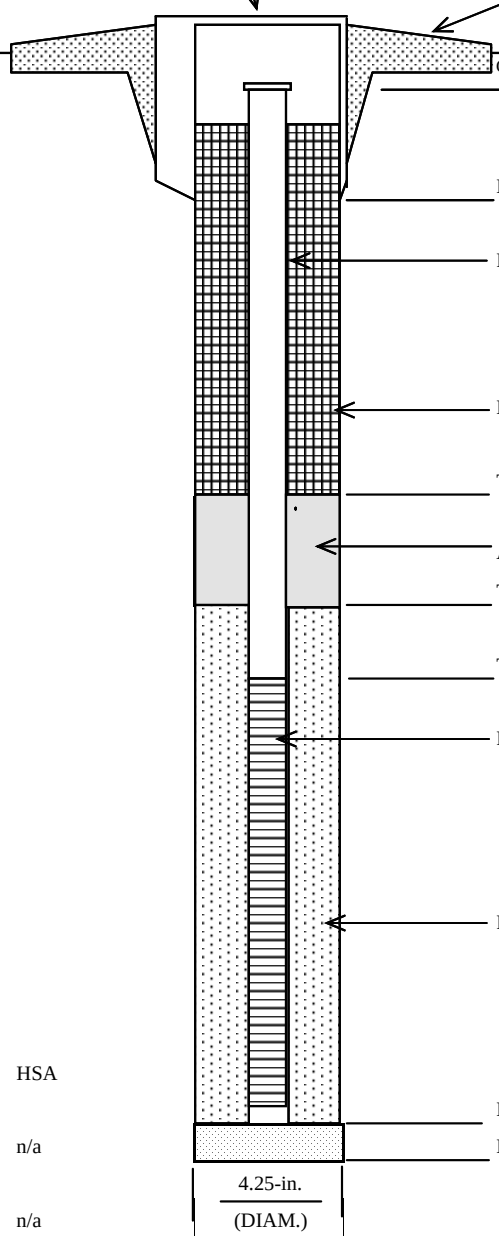
Hager GeoScience Inc.

MONITORING WELL INSTALLATION LOG

PROJECT: **Narrow River Stormwater Abatement Project, Narragansett, RI**	JOB NO. **200540**	WELL NO. **NRW-7**
DRILLING CONTRACTOR: **Subsurface Drilling**	LOCATION: **Pettaquamscutt Ave. & Lakeview**	
BEGUN: **7/6/2005**	GEO/ENG: **HGI/Jon Brinkmann**	WATER LEVEL (Depth/Elev.)
FINISHED: **7/6/2005**	DRILLER: **John & Brad**	**Depth: 9.80 ' / Elevation: '**

COMMENTS: WL 7/06/06 @ 1:30 pm **9.40'**
WL 7/07/06 @ 11:25 am **9.80'**

GENERALIZED GEOLOGIC LOG



	DEPTH BGS HEIGHT AGS (FT)	ELEV. (FT) NGVD DATUM
FLUSHMOUNT SURFACE CASING: DIA.: 6-in. TYPE: Valve Box w/ 2 Hex. Bolts; CONCRETE	0.0	
GROUND SURFACE	0.375	
TOP OF PVC RISER		
BOTTOM OF PROTECTIVE PIPE	0.5	-0.5
PVC RISER CASING: SCH.: 40 DIAM.: 2-in.; BACKFILL TYPE: native material		
TOP OF ANNULAR SEAL	2.0	-2.0
ANNULAR SEAL: TYPE: Bentonite Chips		
TOP OF FILTER PACK	3.0	-3.0
TOP OF WELL SCREEN	4.0	-4.0
PVC SCREEN: SCH.: 40 DIAM.: 2-in. SLOT SIZE: 0.010-in.; FILTER PACK TYPE: Sand SIZE: #2		
BOTTOM OF SCREEN	14.0	-14.0
BOTTOM OF HOLE	20.0	-20.0

METHOD DRILLED: HSA

METHOD DEVELOPED: n/a

TIME DEVELOPED: n/a

Hager GeoScience Inc.

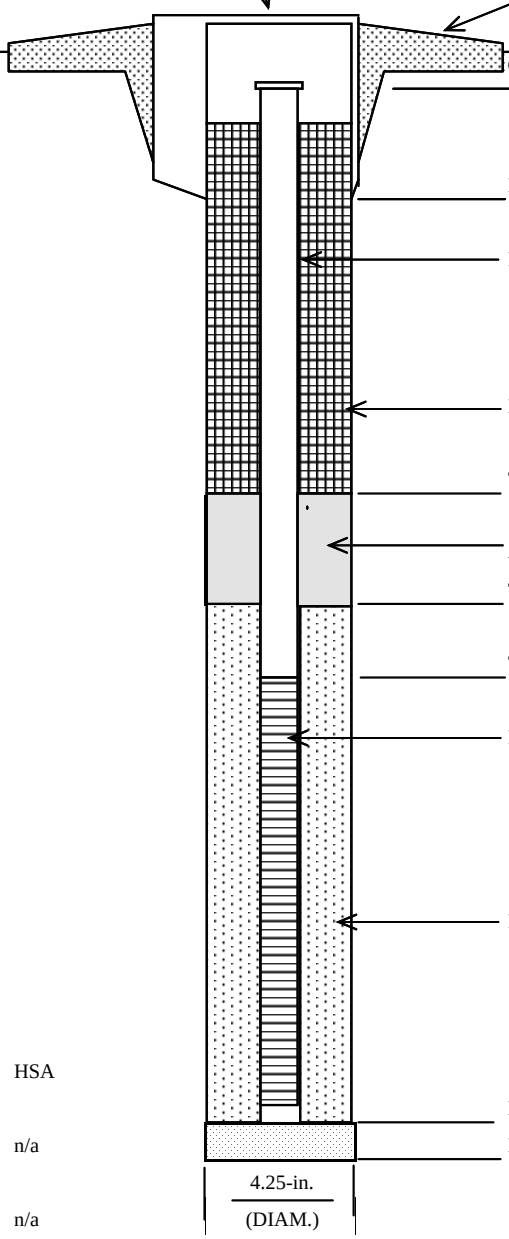
MONITORING WELL INSTALLATION LOG

PROJECT: **Narrow River Stormwater Abatement Project, Narragansett, RI**	JOB NO. **200540**	WELL NO. **NRW-8**
DRILLING CONTRACTOR: **Subsurface Drilling**	LOCATION: **South River Drive & Woodridge**	
BEGUN: **7/6/2005**	GEO/ENG: **HGI/Jon Brinkmann**	WATER LEVEL (Depth/Elev.)
FINISHED: **7/6/2005**	DRILLER: **John & Brad**	**Depth: 4.66 ' / Elevation: '**

COMMENTS: WL 7/06/06 @ 3:30 pm **4.55'**
WL 7/07/06 @ 10:40 am **4.66'**

FLUSHMOUNT SURFACE CASING:
DIA.: 6-in.
TYPE: Valve Box w/ 2 Hex. Bolts

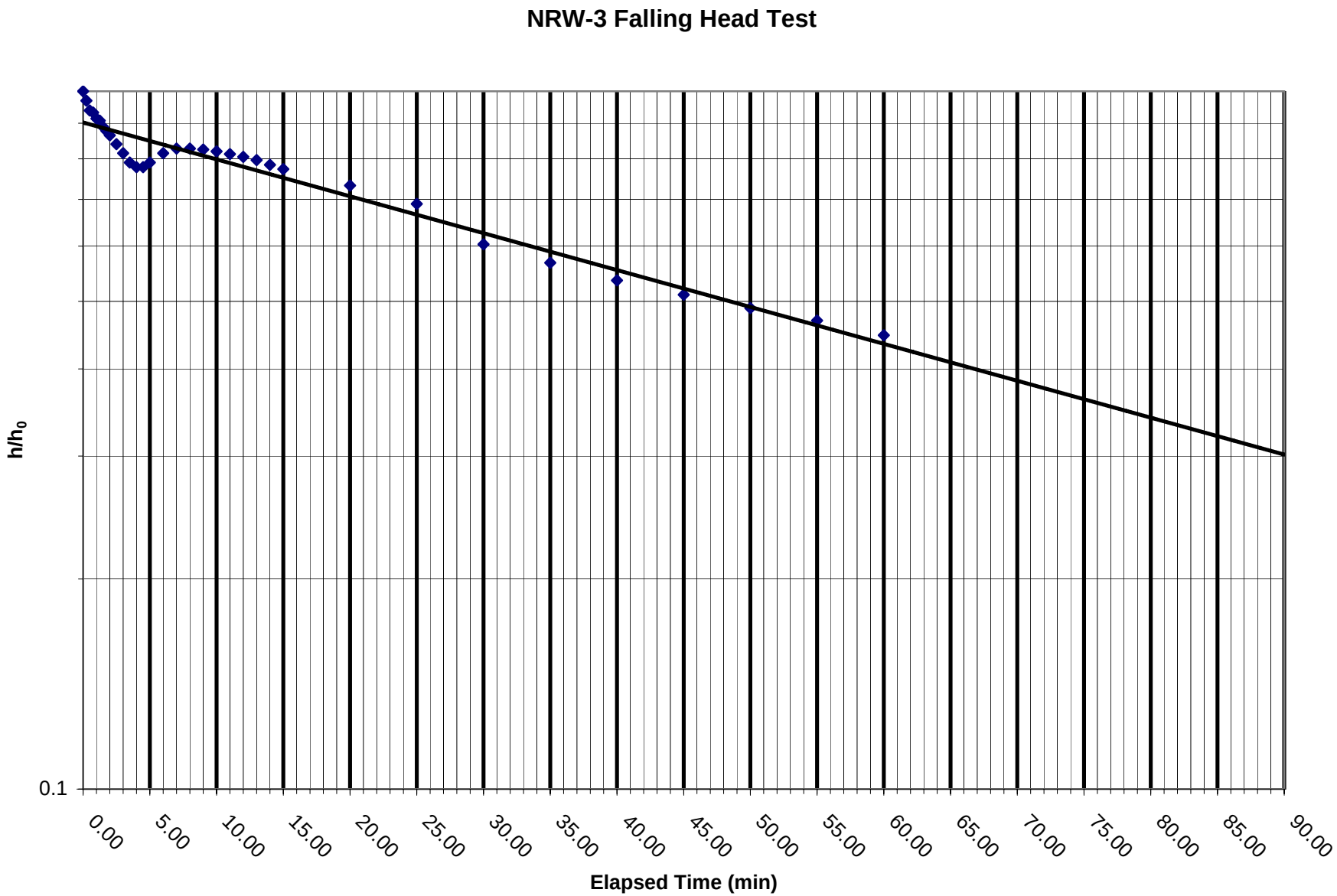
GENERALIZED GEOLOGIC LOG



	DEPTH BGS HEIGHT AGS (FT)	ELEV. (FT) NGVD DATUM
CONCRETE	0.0	
GROUND SURFACE	0.25	
TOP OF PVC RISER		
BOTTOM OF PROTECTIVE PIPE	0.5	-0.5
PVC RISER CASING: SCH.: 40; DIAM.: 2-in.		
BACKFILL TYPE native material		
TOP OF ANNULAR SEAL	1.0	-1.0
ANNULAR SEAL: TYPE: Bentonite Chips		
TOP OF FILTER PACK	1.5	-1.5
TOP OF WELL SCREEN	2.0	-2.0
PVC SCREEN: SCH.: 40; DIAM.: 2-in.; SLOT SIZE: 0.010-in.		
FILTER PACK: TYPE: Sand; SIZE: #2		
BOTTOM OF SCREEN	12.0	-12.0
BOTTOM OF HOLE	16.0	-16.0

METHOD DRILLED: HSA
METHOD DEVELOPED: n/a
TIME DEVELOPED: n/a

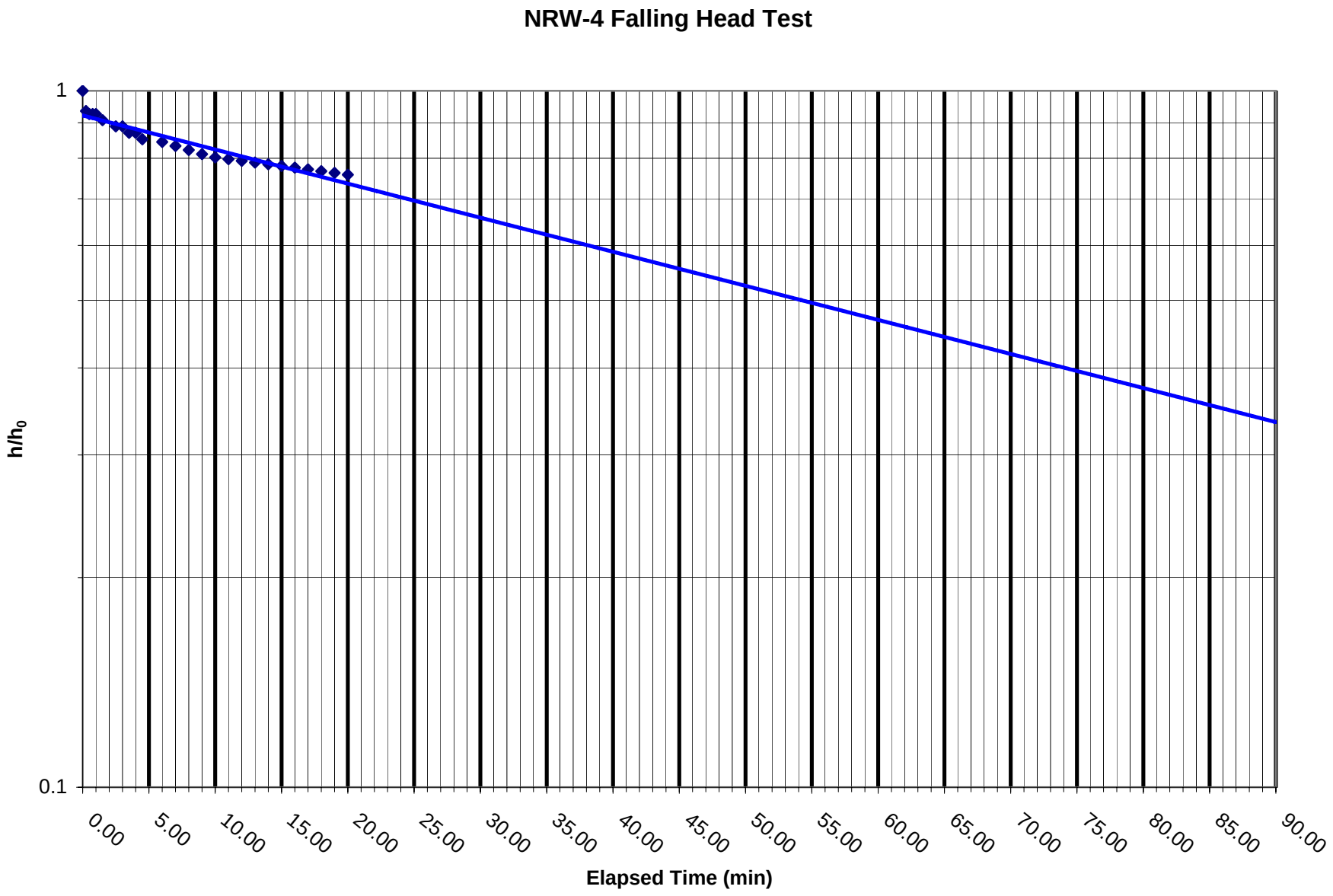
Hager GeoScience Inc.


NRW-3 Falling Head Test
h/h0
0.1
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00
80.00
85.00
90.00
Elapsed Time (min)

NRW-3

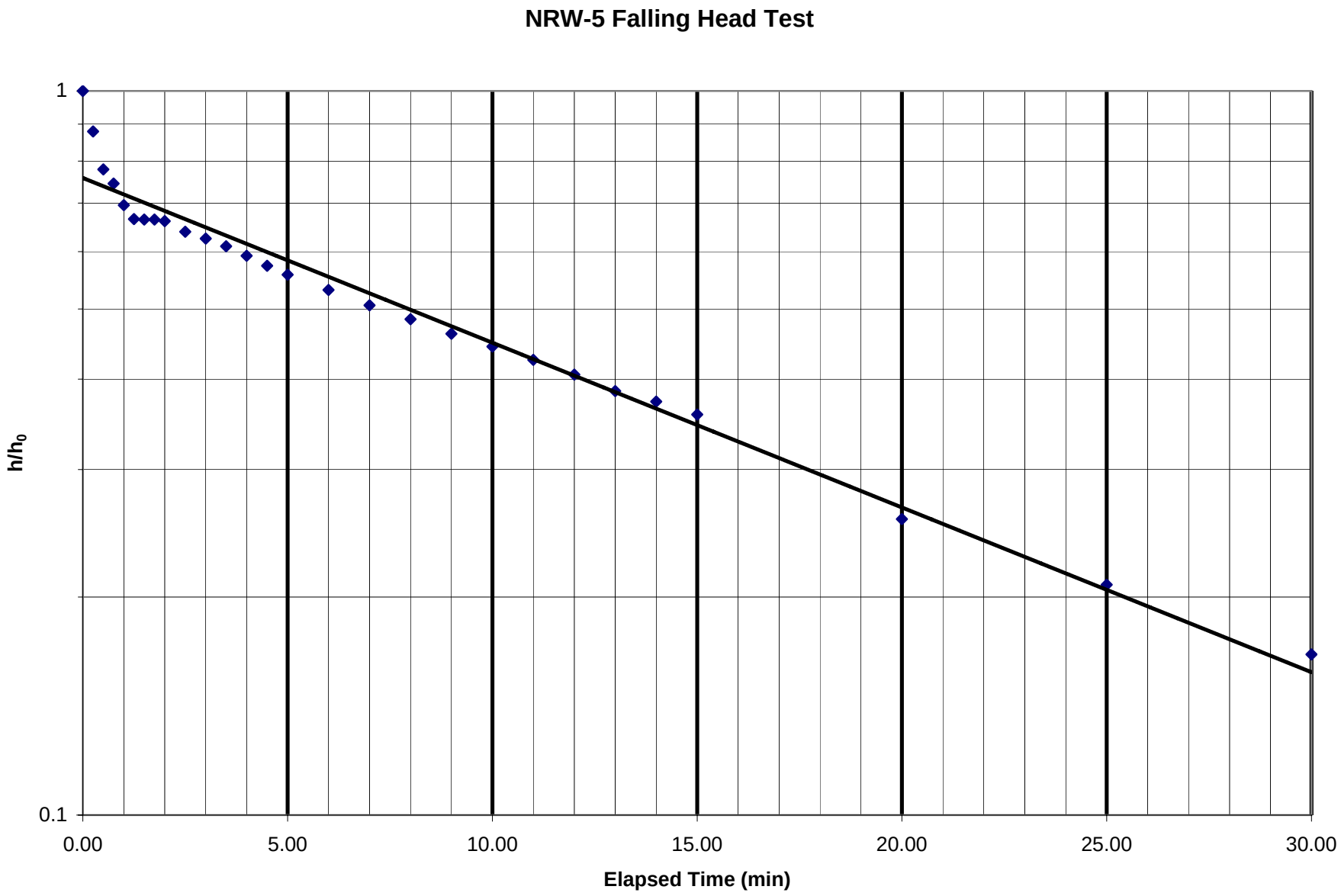
Water Depth Dropped (ft)	Time elapsed (min)	h/h_0
0.00	0.00	1
0.25	0.25	0.969212
0.50	0.50	0.938424
0.55	0.75	0.932266
0.70	1.00	0.913793
0.75	1.25	0.907635
0.90	1.50	0.889163
1.00	1.75	0.876847
1.10	2.00	0.864532
1.30	2.50	0.839901
1.50	3.00	0.815271
1.70	3.50	0.79064
1.80	4.00	0.778325
1.80	4.50	0.778325
1.70	5.00	0.79064
1.50	6.00	0.815271
1.40	7.00	0.827586
1.40	8.00	0.827586
1.42	9.00	0.825123
1.46	10.00	0.820197
1.52	11.00	0.812808
1.58	12.00	0.805419
1.65	13.00	0.796798
1.75	14.00	0.784483
1.84	15.00	0.773399
2.17	20.00	0.732759
2.52	25.00	0.689655
3.22	30.00	0.603448
3.51	35.00	0.567734
3.77	40.00	0.535714
3.97	45.00	0.511084
4.15	50.00	0.488916
4.31	55.00	0.469212
4.49	60.00	0.447044

h_0	8.12	feet
L	84.00	inches
r	1.00	inches
T_0	72	minutes
K	0.000366304	inch/min
K	0.043956516	feet/day


NRW-4 Falling Head Test
1
0.1
h/h0
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00
80.00
85.00
90.00
Elapsed Time (min)

Water Depth Dropped (ft)	Time elapsed (min)	h/h_0	NRW-4
0.00	0.00	1	
0.29	0.25	0.935185	3.5
0.33	0.50	0.925926	4
0.33	0.75	0.925926	4
0.33	1.00	0.925926	4
0.42	1.50	0.907407	5
0.50	2.50	0.888889	6
0.50	3.00	0.888889	6
0.58	3.50	0.87037	7
0.58	4.00	0.87037	7
0.67	4.50	0.851852	8
0.70	6.00	0.844444	
0.75	7.00	0.833333	
0.80	8.00	0.822222	
0.85	9.00	0.811111	
0.89	10.00	0.802222	
0.91	11.00	0.797778	
0.93	12.00	0.793333	
0.95	13.00	0.788889	
0.97	14.00	0.784444	
0.99	15.00	0.78	
1.01	16.00	0.775556	
1.03	17.00	0.771111	
1.05	18.00	0.766667	
1.07	19.00	0.762222	
1.09	20.00	0.757778	

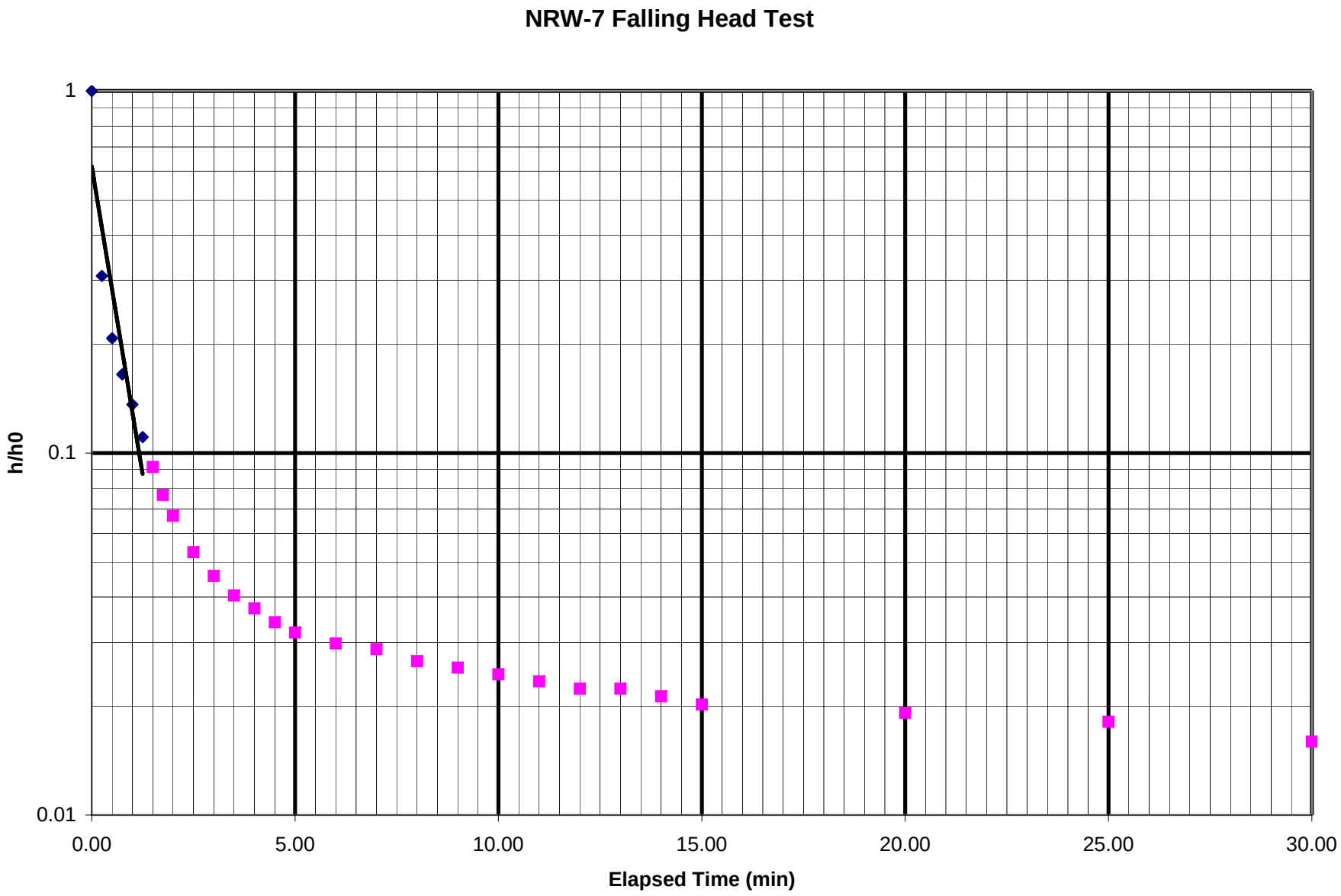
h_0	4.50	feet
L	54.00	inches
r	4.50	inches
T_0	80	minutes
K	0.005824	inch/min
K	0.698879995	feet/day

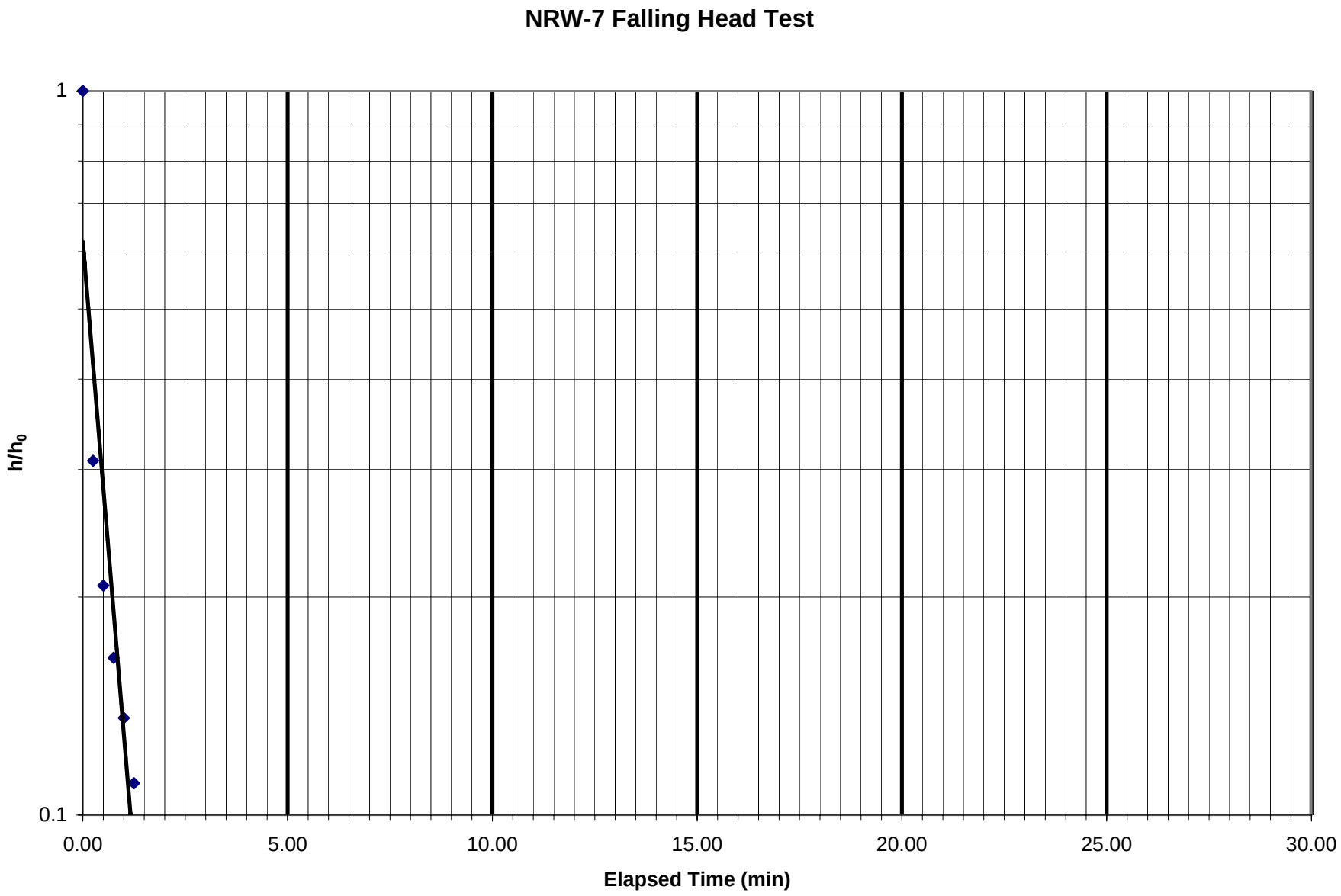

NRW-5 Falling Head Test
1
0.1
h/h0
0.00
5.00
10.00
15.00
20.00
25.00
30.00
Elapsed Time (min)

NRW-5

Water Depth Dropped (ft)	Time elapsed (min)	h/h_0
0.00	0.00	1
1.05	0.25	0.87931
1.92	0.50	0.77931
2.22	0.75	0.744828
2.65	1.00	0.695402
2.91	1.25	0.665517
2.92	1.50	0.664368
2.92	1.75	0.664368
2.95	2.00	0.66092
3.14	2.50	0.63908
3.26	3.00	0.625287
3.39	3.50	0.610345
3.55	4.00	0.591954
3.71	4.50	0.573563
3.85	5.00	0.557471
4.08	6.00	0.531034
4.30	7.00	0.505747
4.49	8.00	0.483908
4.68	9.00	0.462069
4.84	10.00	0.443678
5.00	11.00	0.425287
5.17	12.00	0.405747
5.35	13.00	0.385057
5.46	14.00	0.372414
5.59	15.00	0.357471
6.47	20.00	0.256322
6.89	25.00	0.208046
7.25	30.00	0.166667

h_0	8.70	
L	72.00	inches
r	1.00	inches
T_0	14	minutes
K	0.002121362	inch/min
K	0.254563459	feet/day

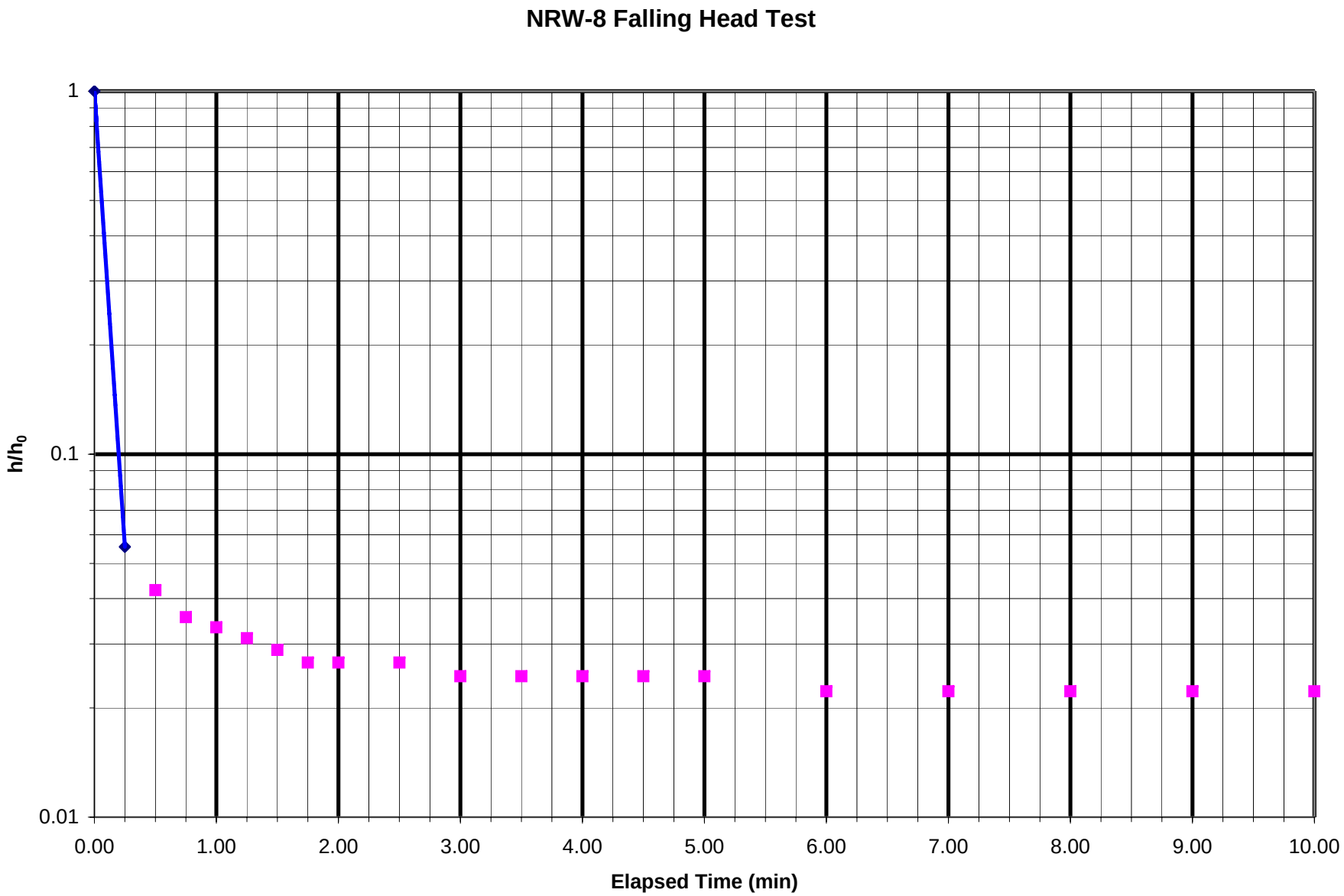

NRW-7 Falling Head Test
1
0.1
0.01
h/h0
0.00
5.00
10.00
15.00
20.00
25.00
30.00
Elapsed Time (min)

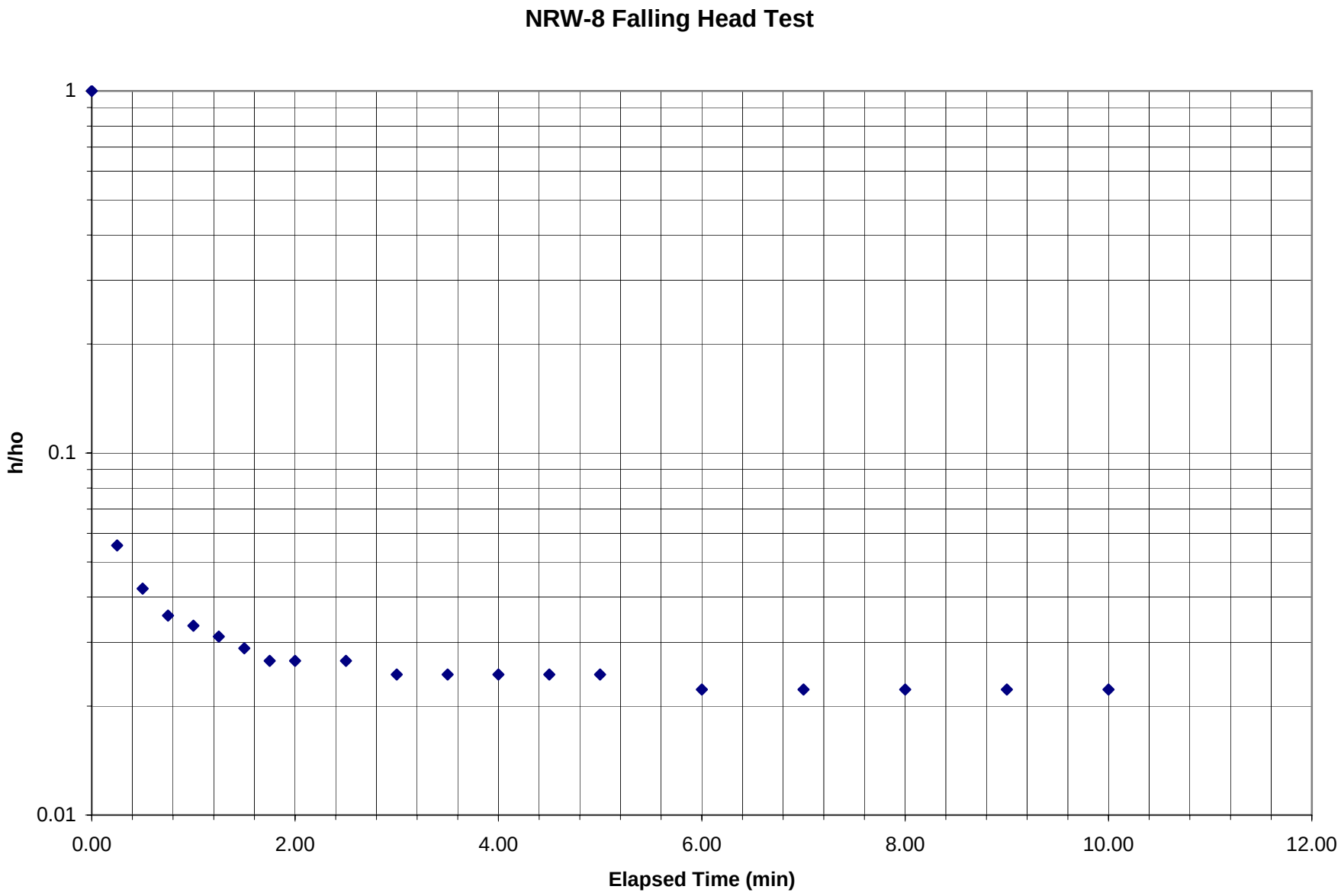

NRW-7 Falling Head Test
1
0.1
h/h0
0.00
5.00
10.00
15.00
20.00
25.00
30.00
Elapsed Time (min)

NRW-7

Water Depth Dropped (ft)	Time elapsed (min)	h/h_0
0.00	0.00	1
6.50	0.25	0.308511
7.45	0.50	0.207447
7.85	0.75	0.164894
8.12	1.00	0.13617
8.36	1.25	0.110638
8.54	1.50	0.091489
8.68	1.75	0.076596
8.77	2.00	0.067021
8.90	2.50	0.053191
8.97	3.00	0.045745
9.02	3.50	0.040426
9.05	4.00	0.037234
9.08	4.50	0.034043
9.10	5.00	0.031915
9.12	6.00	0.029787
9.13	7.00	0.028723
9.15	8.00	0.026596
9.16	9.00	0.025532
9.17	10.00	0.024468
9.18	11.00	0.023404
9.19	12.00	0.02234
9.19	13.00	0.02234
9.20	14.00	0.021277
9.21	15.00	0.020213
9.22	20.00	0.019149
9.23	25.00	0.018085
9.25	30.00	0.015957

h_0	9.40	
L	120.00	inches
r	1.00	inches
T_0	0.3	minutes
K	0.066492941	inch/min
K	7.979152905	feet/day


NRW-8 Falling Head Test
1
0.1
0.01
h/h0
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
Elapsed Time (min)


NRW-8 Falling Head Test
h/ho
1
0.1
0.01
0.00
2.00
4.00
6.00
8.00
10.00
12.00
Elapsed Time (min)

Water Depth Dropped (ft)	Time elapsed (min)	h/h_0	NRW-8
0.00	0.00	1	
4.25	0.25	0.055556	
4.31	0.50	0.042222	
4.34	0.75	0.035556	
4.35	1.00	0.033333	
4.36	1.25	0.031111	
4.37	1.50	0.028889	
4.38	1.75	0.026667	
4.38	2.00	0.026667	
4.38	2.50	0.026667	
4.39	3.00	0.024444	
4.39	3.50	0.024444	
4.39	4.00	0.024444	
4.39	4.50	0.024444	
4.39	5.00	0.024444	
4.40	6.00	0.022222	
4.40	7.00	0.022222	
4.40	8.00	0.022222	
4.40	9.00	0.022222	
4.40	10.00	0.022222	

h_0	4.50	
L	120.00	inches
r	1.00	inches
T_0	0.15	minutes
K	0.132985882	inch/min
K	15.95830581	feet/day

APPENDIX C

ADDITIONAL OUTFALL INFORMATION AND PHOTOGRAPHS (SOURCE: TOWN OF NARRAGANSETT)

INDIAN TRAIL OUTFALL

Location:	Plat N-K Lot 4
Property Owner:	Forest Lakes Preservation Association (no easement on record)
Size & Material:	18" R.C.P., Open-Pipe w/Rip-Rap Swale
Receiving Body:	Narrow River
Watershed Characteristics:	The Indian Trail outfall drains runoff from the Forest Lakes neighborhood to the Narrow River. Forest Lakes is a moderately densely populated neighborhood (R10 zoning) with both surface storm drains (near the bottom of the hill) and groundwater underdrains (near the top). Sanitary sewers were installed throughout the entire neighborhood in 2000, and 100% of the units are currently connected to the sewer system.
Potential Structural BMP's:	This outfall has the potential to be retrofitted with a combination of stormwater treatment technologies. The pipe to the outfall passes beneath the gravel parking area for the neighborhood beach, where there could be sufficient space to install a Vortechnic unit just upstream of the outfall. In addition, the rip-rap swale from the outfall to the river could possibly be replaced with a vegetative treatment pond or swale.

PETTAQUAMSCUTT LAKE SHORES 1 OUTFALL (no picture available)

Location:	Plat N-F Lot 2 & 3 (Woodsia Road)
Property Owner(s):	Private (no easement on record)
Size & Material:	8" V.C.P., Open Pipe (significantly blocked)
Receiving Body:	Narrow River
Watershed Characteristics:	The Pettaquamscutt Lake Shores 1 outfall drains runoff from a small portion of the Pettaquamscutt Lake Shores neighborhood to the Narrow River. Pettaquamscutt Lake Shores is a densely populated neighborhood (R10 zoning, many substandard lots) with numerous surface storm drains. Sanitary sewers were installed throughout the entire neighborhood in 1998, and over 99% of the units are currently connected to the sewer system.
Potential Structural BMP's:	This outfall has limited potential to be retrofitted with stormwater treatment technologies. The pipe to the outfall passes through private property between two private developed lots, and there is very limited space in which to install a Vortechnic unit or units upstream of the outfall – the neighborhood roads are relatively narrow, and already occupied by water lines, sanitary sewers, and storm drains. In addition, there is little space between the outfall and the river in which to install any type of treatment system.

PETTAQUAMSCUTT LAKE SHORES 2 OUTFALL

Location:	Plat N-F Lots 10 & 12 (Woodsia Road)
Property Owner(s):	Private (10' drainage easements across each lot on record)
Size & Material:	30" R.C.P., Reinforced Concrete Headwall
Receiving Body:	Narrow River
Watershed Characteristics:	The Pettaquamscutt Lake Shores 2 outfall drains runoff from the Pettaquamscutt Lake Shores neighborhood to the Narrow River. Pettaquamscutt Lake Shores is a densely populated neighborhood (R10 zoning, many substandard lots) with numerous surface storm drains. Sanitary sewers were installed throughout the entire neighborhood in 1998, and over 99% of the units are currently connected to the sewer system.
Potential Structural BMP's:	This outfall has limited potential to be retrofitted with stormwater treatment technologies. The pipe to the outfall passes through drainage easements across two private developed lots, and there is very little space in which to install a Vortechnic unit or units upstream of the outfall – the neighborhood roads are relatively narrow, and already occupied by water lines, sanitary sewers, storm drains, and gas lines in some locations. In addition, there is little space between the outfall and the river in which to install any type of treatment system.

PETTAQUAMSCUTT LAKE SHORES 3 OUTFALL

Location:	Plat N-F Lot 336-1 (Woodsia Road)
Property Owner(s):	Private (no easement on record)
Size & Material:	8" R.C.P., Masonry Headwall
Receiving Body:	Narrow River
Watershed Characteristics:	The Pettaquamscutt Lake Shores 3 outfall drains runoff from a small portion of the Pettaquamscutt Lake Shores neighborhood to the Narrow River. Pettaquamscutt Lake Shores is a densely populated neighborhood (R10 zoning, many substandard lots) with numerous surface storm drains. Sanitary sewers were installed throughout the entire neighborhood in 1998, and over 99% of the units are currently connected to the sewer system.
Potential Structural BMP's:	This outfall has limited potential to be retrofitted with stormwater treatment technologies. The pipe to the outfall passes through private property between two private developed lots, and there is very limited space in which to install a Vortechnic unit or units upstream of the outfall – the neighborhood roads are relatively narrow, and already occupied by water lines, sanitary sewers, and storm drains. In addition, there is little space between the outfall and the river in which to install any type of treatment system.

EDGEWATER 1 (left) & 2 (right) OUTFALLS

Location:	Plat N-F Lot 620 (Lakeside Road)
Property Owner(s):	Private (no easement on record)
Size & Material:	24" R.C.P., Open Pipe (damaged)
	18" R.C.P., Reinforced Concrete Headwall (damaged)
Receiving Body:	Narrow River
Watershed Characteristics:	The Edgewater 1 outfall drains runoff from the Edgewater neighborhood; the Edgewater 2 outfall drains runoff from Bridgetown Road and a portion of the Pettaquamscutt Terrace neighborhood to the south. Edgewater is a moderately densely populated neighborhood (R10 zoning) with numerous surface storm drains and some underdrains. Sanitary sewers were installed throughout the entire neighborhood in 1997, and 100% of the units are currently connected to the sewer system.
Potential Structural BMP's:	These outfalls have the potential to be retrofitted with stormwater treatment technologies. The pipes to each outfall pass through a private undeveloped lot owned by the original developer of the Edgewater neighborhood. Acquiring this lot would provide ample space for a combination of treatments, including a Vortechnic unit and/or a small vegetated swale or pond. In addition, there may be space between the outfall and the river in which to install some type of treatment.

PETTAQUAMSCUTT TERRACE 1 (left) & 2 (right) OUTFALLS

Location:	Plat N-A, Pettaquamscutt Ave. right-of-way
Property Owner(s):	Town Right-of-Way
Size & Material:	15" R.C.P., Reinforced Concrete Headwall
	24" R.C.P., Reinforced Concrete Flared End Section
Receiving Body:	Narrow River
Watershed Characteristics:	The Pettaquamscutt Terrace outfalls drain runoff from the Pettaquamscutt Terrace neighborhood. Pettaquamscutt Terrace is a densely populated neighborhood (R10 zoning, many substandard lots) with numerous surface storm drains. Sanitary sewers were installed throughout the entire neighborhood in 1997, and 100% of the units are currently connected to the sewer system.
Potential Structural BMP's:	These outfalls have the potential to be retrofitted with stormwater treatment technologies. Both outfalls are located completely in the Pettaquamscutt Avenue right-of-way, which is sixty (60) feet wide. The right-of-way has ample space for a combination of treatments, including a Vortechnic unit and/or a small vegetated swale.

RIO VISTA 1 OUTFALL (no picture available)

Location:	Plat N-E Lot 26B (Circuit Drive)
Property Owner(s):	Town of Narragansett
Size & Material:	36" R.C.P., Reinforced Concrete Headwall
Receiving Body:	Narrow River
Watershed Characteristics:	The Rio Vista 1 outfall drains runoff from the northern portion of the Rio Vista neighborhood to the Narrow River. Rio Vista is a moderately densely populated neighborhood (R10 zoning) with numerous surface storm drains. Sanitary sewers were installed throughout the entire neighborhood in the 1995, and 100% of the units are currently connected to the sewer system.
Potential Structural BMP's:	A retrofit for this outfall is currently under construction, and should be completed later this year. The retrofit consists of a series of vegetated ponds, including a sedimentation forebay, fine sediment settlement pond, and three vegetated basins for nutrient removal.

RIO VISTA 2 OUTFALL (no picture available)

Location:	Plat N-E Lot 26C (Circuit Drive)
Property Owner(s):	Town of Narragansett
Size & Material:	30" R.C.P., Reinforced Concrete Headwall
Receiving Body:	Narrow River
Watershed Characteristics:	The Rio Vista 2 outfall drains runoff from the southern portion of the Rio Vista neighborhood to the Narrow River. Rio Vista is a moderately densely populated neighborhood (R10 zoning) with numerous surface storm drains. Sanitary sewers were installed throughout the entire neighborhood in the 1995, and 100% of the units are currently connected to the sewer system.
Potential Structural BMP's:	A retrofit for this outfall is currently under construction, and should be completed later this year. The retrofit consists of a sedimentation forebay and a fine sediment settlement/nutrient removal pond.

METTATUXET 1 OUTFALL

Location:	Plat N-G Lot 3 (North River Drive)
Property Owner(s):	Private (10' drainage easement across lot on record)
Size & Material:	30" R.C.P., Masonry Headwall w/Metal Grate
Receiving Body:	Narrow River
Watershed Characteristics:	The Mettatuxet 1 outfall drains runoff from the northern end of the Mettatuxet neighborhood to the Narrow River. Mettatuxet is a densely populated neighborhood (R10 zoning, many substandard lots) with numerous surface storm drains. Sanitary sewers were installed throughout the entire neighborhood in the early 1980's, and over 99% of the units are currently connected to the sewer system.
Potential Structural BMP's:	This outfall has limited potential to be retrofitted with stormwater treatment technologies. The pipe to the outfall passes through a drainage easement across a private developed lot, and there is very little space in which to install a Vortechnic unit or units upstream of the outfall – the neighborhood roads are relatively narrow, and already occupied by water lines, sanitary sewers, storm drains, and gas lines in some locations. In addition, there is little space between the outfall and the river in which to install any type of treatment system.

METTATUXET 2 OUTFALL

Location:	Plat N-G Lot 237 (North River Drive)
Property Owner(s):	Mettatuxet Improvement Association (no easement on record)
Size & Material:	18" R.C.P., Reinforced Concrete Headwall, Concrete Flared End, Rip-Rap Swale
Receiving Body:	Narrow River
Watershed Characteristics:	The Mettatuxet 2 outfall drains runoff from the middle portion of the Mettatuxet neighborhood to the Narrow River. Mettatuxet is a densely populated neighborhood (R10 zoning, many substandard lots) with numerous surface storm drains. Sanitary sewers were installed throughout the entire neighborhood in the early 1980's, and over 99% of the units are currently connected to the sewer system.
Potential Structural BMP's:	A retrofit for this outfall is currently being designed by a joint effort of the Southern Rhode Island Conservation District and the Town of Narragansett. The proposed design includes a Vortechnic unit for initial sediment removal, and a combination of Cultec infiltrators and a traditional vegetated pond for nutrient and pathogen removal and fine sediment removal. The project will soon be submitted to the environmental regulatory agencies, and could be under construction later this year.

METTATUXET 3 OUTFALL

Location:	Plat N-G Lot 230 (South River Drive)
Property Owner(s):	Private (no easement on record)
Size & Material:	30" R.C.P., Masonry Headwall w/Metal Grate, Concrete Splash Pad
Receiving Body:	Narrow River
Watershed Characteristics:	The Mettatuxet 3 outfall drains runoff from the middle portion of the Mettatuxet neighborhood to the Narrow River. Mettatuxet is a densely populated neighborhood (R10 zoning, many substandard lots) with numerous surface storm drains. Sanitary sewers were installed throughout the entire neighborhood in the early 1980's, and over 99% of the units are currently connected to the sewer system.
Potential Structural BMP's:	This outfall has limited potential to be retrofitted with stormwater treatment technologies. The pipe to the outfall crosses a private developed lot, and there is very little space in which to install a Vortechnic unit or units upstream of the outfall – the neighborhood roads are relatively narrow, and already occupied by water lines, sanitary sewers, storm drains, and gas lines in some locations. In addition, there is little space between the outfall and the river in which to install any type of treatment system.

METTATUXET 4 OUTFALL

Location:	Plat N-G Lot 243 (South River Drive)
Property Owner(s):	Private (no easement on record)
Size & Material:	30" R.C.P., Masonry Headwall w/Metal Grate (partially obstructed)
Receiving Body:	Narrow River
Watershed Characteristics:	The Mettatuxet 4 outfall drains runoff from the southern end of the Mettatuxet neighborhood to the Narrow River. Mettatuxet is a densely populated neighborhood (R10 zoning, many substandard lots) with numerous surface storm drains. Sanitary sewers were installed throughout the entire neighborhood in the early 1980's, and over 99% of the units are currently connected to the sewer system.
Potential Structural BMP's:	This outfall has the potential to be retrofitted with stormwater treatment technologies. The pipe to the outfall crosses a private developed lot, but it is immediately adjacent to a Lot 242, which is owned by the Town of Narragansett for a sanitary sewage pump station. The portion of Lot 242 behind the pump station could provide sufficient space for a combination of treatments, including a Vortechnic unit and/or a small vegetated swale or pond.

APPENDIX D

BUDGET-LEVEL OPINIONS OF COST

FUSS & O'NEILL, INC.

275 Promenade Street, Suite 350
Providence, RI 02908

OPINION OF COST	DATE PREPARED : 10/13/2006	SHEET 1 OF 1
PROJECT : Narrow River	BASIS : 75% Design Plans	
LOCATION : Narragansett, RI	Pricing based on RIDOT (2005 and 2006), RS Means (2005), and proprietary sources	
DESCRIPTION: Stormwater Abatement Controls	Budget level Opinion of Construction Cost	
PROJECT NO. : 20041111.A10	ESTIMATOR : KMK	CHECKED BY : DEA

Since Fuss & O'Neill has no control over the cost of labor, materials, equipment or services furnished by others, or over the Contractor(s)' methods of determining prices, or over competitive bidding or market conditions, Fuss & O'Neill's opinion of probable Total Project Costs and Construction Cost are made on the basis of Fuss & O'Neill's experience and qualifications and represent Fuss & O'Neill's best judgment as an experienced and qualified professional engineer, familiar with the construction industry; but Fuss & O'Neill cannot and does not guarantee that proposals, bids or actual Total Project or Construction Costs will not vary from opinions of probable cost prepared by Fuss & O'Neill. If prior to the bidding or negotiating Phase the Owner wishes greater assurance as to Total Project or Construction Costs, the Owner shall employ an independent cost estimator.

ITEM NO.	ITEM DESCRIPTION	UNIT MEAS.	NO. UNITS	PER UNIT	TOTAL COST
	EC INFILTRATION UNITS				
1	Clearing	SY	510	$4	$2,100
2	Pavement demo	SY	540	$5	$2,700
3	6' wide pavement (pipes)	LF	850	$25	$22,000
4	10' wide pavement (EC chambers)	LF	510	$36	$19,000
5	seeding	SF	11000	$2	$22,000
6	12" HDPE	LF	170	$30	$5,100
7	Reset existing pipes	LF	810	$60	$49,000
8	Replace CB w/ DivMH	EA	2	$3,200	$6,400
9	Rebuild CB - sump/hood	EA	7	$1,900	$14,000
10	Rebuild CB - reset invert elevs.	EA	1	$2,000	$2,000
11	New MH	EA	2	$3,600	$7,200
12	New DivMH	EA	1	$4,100	$4,100
13	New CB	EA	2	$3,200	$6,400
14	Chambers	LS	1	$41,000	$41,000
15	Silt Fence/Haybales	LF	220	$4	$880
16	Maintain Controls	LS	1	$5,000	$5,000
17	Silt Sacks	EA	8	$60	$480
18	Soil Amendment	CY	170	$22	$3,800
19	Mobilization / Demobilization[1]	LS	2	$3,000	$6,000
	Subtotal				**$219,160**
20	Surveying	LS	1	$7,000	$7,000
21	Engineering/Oversight and QA/QC	LS	1	$40,000	$40,000
	PROJECT SUBTOTAL				$266,160
	CONTINGENCY (25%)				$66,540
	TOTAL COST (ROUNDED TO NEAREST $1,000)				**$333,000**

Assumptions / Concerns:

1) Survey must be updated to confirm project design.

FUSS & O'NEILL, INC.

275 Promenade Street, Suite 350
Providence, RI 02908

OPINION OF COST	DATE PREPARED : 10/13/2006	SHEET 1 OF 1
PROJECT : Narrow River	BASIS : 75% Design Plans	
LOCATION : Narragansett, RI	Pricing based on RIDOT (2005 and 2006), RS Means (2005), and proprietary sources	
DESCRIPTION: Stormwater Abatement Controls	Budget level Opinion of Construction Cost	
PROJECT NO. : 20041111.A10	ESTIMATOR : KMK	CHECKED BY : DEA

Since Fuss & O'Neill has no control over the cost of labor, materials, equipment or services furnished by others, or over the Contractor(s)' methods of determining prices, or over competitive bidding or market conditions, Fuss & O'Neill's opinion of probable Total Project Costs and Construction Cost are made on the basis of Fuss & O'Neill's experience and qualifications and represent Fuss & O'Neill's best judgment as an experienced and qualified professional engineer, familiar with the construction industry; but Fuss & O'Neill cannot and does not guarantee that proposals, bids or actual Total Project or Construction Costs will not vary from opinions of probable cost prepared by Fuss & O'Neill. If prior to the bidding or negotiating Phase the Owner wishes greater assurance as to Total Project or Construction Costs, the Owner shall employ an independent cost estimator.

ITEM NO.	ITEM DESCRIPTION	UNIT MEAS.	NO. UNITS	PER UNIT	TOTAL COST
	EC SAND FILTER				
1	Clearing	SY	1800	$4	$7,200
2	Pavement demo	SY	28	$5	$140
3	24' wide pavement	LF	370	$71	$27,000
4	6' wide pavement (pipes)	LF	24	$25	$600
5	gravel roads	LF	47	$25	$1,200
6	seeding	SF	37000	$2	$74,000
7	planting bushes	EA	82	$110	$9,100
8	6" HDPE perf	LF	650	$12	$7,800
9	8" HDPE	LF	300	$29	$8,700
10	8" HDPE perf	LF	160	$13	$2,100
11	24" HDPE	LF	150	$49	$7,400
12	30" HDPE	LF	500	$60	$30,000
13	Replace CB w/ DivMH	EA	1	$3,200	$3,200
14	New MH	EA	2	$3,600	$7,200
15	New DivMH	EA	1	$4,100	$4,100
16	Inlet structure	LS	1	$430	$430
17	SF - Outlet structure	LS	1	$3,000	$3,000
18	Aquaswirl	LS	1	$34,000	$34,000
19	Tide Gate	LS	1	$1,100	$1,100
20	Silt Fence/Haybales	LF	1100	$4	$4,400
21	Maintain Controls	LS	1	$5,000	$5,000
22	Silt Sacks	EA	3	$60	$180
23	Grading	CY	2400	$9	$22,000
24	Geotextile Liner - SF	SF	22000	$3	$66,000
25	Sand filter media	CY	380	$22	$8,400
26	Mobilization / Demobilization	LS	2	$10,000	$20,000
	Subtotal				**$325,850**
27	Surveying	LS	1	$4,000	$4,000
28	Engineering/Oversight and QA/QC	LS	1	$25,000	$25,000
	PROJECT SUBTOTAL				$354,850
	CONTINGENCY (25%)				$88,713
	TOTAL COST (ROUNDED TO NEAREST $1,000)				**$444,000**

Assumptions / Concerns:

1) Survey must be updated to confirm project design.

FUSS & O'NEILL, INC.

275 Promenade Street, Suite 350
Providence, RI 02908

OPINION OF COST	DATE PREPARED : 10/13/2006	SHEET 1 OF 1
PROJECT : Narrow River	BASIS : 75% Design Plans	
LOCATION : Narragansett, RI	Pricing based on RIDOT (2005 and 2006), RS Means (2005), and proprietary sources	
DESCRIPTION: Stormwater Abatement Controls	Budget level Opinion of Construction Cost	
PROJECT NO. : 20041111.A10	ESTIMATOR : KMK	CHECKED BY : DEA

Since Fuss & O'Neill has no control over the cost of labor, materials, equipment or services furnished by others, or over the Contractor(s)' methods of determining prices, or over competitive bidding or market conditions, Fuss & O'Neill's opinion of probable Total Project Costs and Construction Cost are made on the basis of Fuss & O'Neill's experience and qualifications and represent Fuss & O'Neill's best judgment as an experienced and qualified professional engineer, familiar with the construction industry; but Fuss & O'Neill cannot and does not guarantee that proposals, bids or actual Total Project or Construction Costs will not vary from opinions of probable cost prepared by Fuss & O'Neill. If prior to the bidding or negotiating Phase the Owner wishes greater assurance as to Total Project or Construction Costs, the Owner shall employ an independent cost estimator.

ITEM NO.	ITEM DESCRIPTION	UNIT MEAS.	NO. UNITS	PER UNIT	TOTAL COST
	PTC INFILTRATION UNITS				
1	Clearing	SY	1600	$4	$6,400
2	Pavement demo	SY	2000	$5	$10,000
3	6' wide pavement (pipes)	LF	1500	$25	$38,000
4	8' wide pavement (PTC chambers)	LF	2200	$31	$69,000
5	seeding	SF	1600	$2	$3,200
6	12" HDPE	LF	61	$30	$1,900
7	24" HDPE	LF	320	$49	$16,000
8	30" HDPE	LF	1200	$60	$72,000
9	Replace CB w/ DivMH	EA	2	$3,200	$6,400
10	Rebuild CB - sump/hood	EA	5	$1,900	$9,500
11	Rebuild CB - reset invert elevs.	EA	4	$2,000	$8,000
12	New MH	EA	6	$3,600	$22,000
13	New DivMH	EA	1	$4,100	$4,100
14	Chambers	LS	1	$130,000	$130,000
15	Aquaswirl	LS	1	$20,000	$20,000
16	Silt Fence/Haybales	LF	700	$4	$2,800
17	Maintain Controls	LS	1	$5,000	$5,000
18	Silt Sacks	EA	9	$60	$540
19	Soil Amendment	CY	480	$22	$11,000
20	Mobilization / Demobilization[1]	LS	2	$3,000	$6,000
	Subtotal				**$441,840**
21	Surveying	LS	1	$10,000	$10,000
22	Engineering/Oversight and QA/QC	LS	1	$50,000	$50,000
	PROJECT SUBTOTAL				$501,840
	CONTINGENCY (25%)				$125,460
	TOTAL COST (ROUNDED TO NEAREST $1,000)				**$627,000**

Assumptions / Concerns:

1) Survey must be updated to confirm project design.

FUSS & O'NEILL, INC.

275 Promenade Street, Suite 350
Providence, RI 02908

OPINION OF COST	DATE PREPARED : 10/13/2006	SHEET 1 OF 1
PROJECT : Narrow River	BASIS : 75% Design Plans	
LOCATION : Narragansett, RI	Pricing based on RIDOT (2005 and 2006), RS Means (2005), and proprietary sources	
DESCRIPTION: Stormwater Abatement Controls	Budget level Opinion of Construction Cost	
PROJECT NO. : 20041111.A10	ESTIMATOR : KMK	CHECKED BY : DEA

Since Fuss & O'Neill has no control over the cost of labor, materials, equipment or services furnished by others, or over the Contractor(s)' methods of determining prices, or over competitive bidding or market conditions, Fuss & O'Neill's opinion of probable Total Project Costs and Construction Cost are made on the basis of Fuss & O'Neill's experience and qualifications and represent Fuss & O'Neill's best judgment as an experienced and qualified professional engineer, familiar with the construction industry; but Fuss & O'Neill cannot and does not guarantee that proposals, bids or actual Total Project or Construction Costs will not vary from opinions of probable cost prepared by Fuss & O'Neill. If prior to the bidding or negotiating Phase the Owner wishes greater assurance as to Total Project or Construction Costs, the Owner shall employ an independent cost estimator.

ITEM NO.	ITEM DESCRIPTION	UNIT MEAS.	NO. UNITS	PER UNIT	TOTAL COST
	PTC LEVEL SPREADER				
1	Clearing	SY	160	$4	$640
2	Pavement demo	SY	160	$5	$800
3	24' wide pavement	LF	68	$71	$4,900
4	6' wide pavement (pipes)	LF	490	$25	$13,000
5	gravel roads	LF	150	$25	$3,800
6	seeding	SF	2900	$2	$5,800
7	planting grasses	SF	2200	$3	$6,600
8	12" HDPE	LF	6	$30	$180
9	12" HDPE perf	LF	4	$35	$140
10	Reset pipes	LF	490	$60	$30,000
11	Replace CB w/ DivMH	EA	1	$3,200	$3,200
12	Level spreader trench and concrete curb	EA	1	$5,300	$5,300
13	Aquaswirl	EA	1	$17,000	$17,000
14	Tide Gate	EA	1	$3,800	$3,800
15	Silt Fence/Haybales	LF	300	$4	$1,200
16	Dewatering	LS	1	$20,000	$20,000
17	Maintain Controls	LS	1	$5,000	$5,000
18	Silt Sacks	EA	5	$60	$300
19	Guard rail	LF	29	$100	$2,900
20	Grading	CY	930	$9	$8,400
21	Mobilization / Demobilization	LS	2	$3,000	$6,000
	Subtotal				**$138,960**
22	Surveying	LS	1	$2,500	$2,500
23	Engineering/Oversight and QA/QC	LS	1	$20,000	$20,000
	PROJECT SUBTOTAL				$161,460
	CONTINGENCY (25%)				$40,365
	TOTAL COST (ROUNDED TO NEAREST $1,000)				**$202,000**

Assumptions / Concerns:

1) Survey must be updated to confirm project design.