DRAINAGE CALCULATIONS
AND
STORMWATER MANAGEMENT PLAN

For The
Multi-Family Building

Located at
9-49 Homer Avenue
(Tax Map 14, Lots 352-354)
Ashland, Massachusetts

Submitted to:
Town of Ashland
101 Main Street
Ashland, MA 01721

Prepared for:
9-49 Homer Avenue, LLC
11 Placid Road
Newton, MA 02549

Prepared by

Engineering Alliance, Inc.
Civil Engineering & Land Planning Consultants

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COMMONWEALTH OF MASSACHUSETTS
RICHARD A. SALVO
CIVIL
No. 41851
REGISTERED PROFESSIONAL ENGINEER

April 22, 2021
REVISED AUGUST 9, 2023
REVISED SEPT. 20, 2023
REVISED October 20, 2023

Table of Contents

Proposed Mixed-Use Development
9-49 Homer Avenue
Ashland, Massachusetts

Project Description

The project consists of the re-development of three (3) parcels of land located between 9 and 49 Homer Avenue in Ashland Massachusetts. The total area between the three (3) parcels is approximately 39,658 +/- s.f. The project site is currently occupied by two commercial buildings (9-11 Homer Avenue and 19-25 Homer Avenue), two residential dwellings (35 Homer Avenue and 47-49 Homer Avenue), a residential garage, a commercial garage, bituminous concrete driveways and parking areas, and scattered landscaped area.

The three existing properties are to be combined into one single parcel with the new address 4-49 Homer Avenue. The project will include demolition of the existing structures at 19-25, 35, and 47-49 Homer Avenue, including the residential and commercial garages. The building containing 9-11 Homer Avenue will remain unaltered. After demolition, the project will consist of the construction of a proposed mixed used building with 40 residential units, 5 commercial units, drive under parking facility, bituminous concrete driveway and parking areas, utility connections, storm water management systems, landscaping and incidental site work.

Site Description

The site is comprised of three currently developed parcels. The first (Lot 352), contains two commercial buildings (9-11 and 19-25 Homer Avenue) with bituminous concrete parking area and scattered landscaping. The second (Lot 353), contains an existing residential dwelling with detached garage, bituminous concrete driveway and parking area, concrete walkway, and landscaped areas. The third (Lot 354) contains an existing residential dwelling (47-49 Homer Avenue), a commercial garage ("Mike's Collision"), bituminous concrete parking and driveway, concrete retaining walls, and minimal landscaping. The ground cover of the existing site is mainly impervious area consisting of building roof, bituminous concrete, or concrete. Minimal pervious area is scattered throughout the three existing parcels.

The site is relatively flat with a slight pitch to the north-east toward Alden Street. Elevations on site range between elevations 187.5 to 185 in an easterly direction toward Alden Street.

The Flood Insurance Rate Map for the Town of Ashland (Community Panel 25017C0514F with an effective date of July 7, 2014) describes the subject property as Zone X. Zone X is classified as an area of minimal flooding.

All lot lines, topography, utilities, and other existing site information used has been compiled from field surveys performed by Hawk Consulting, Inc on February 19, 2019 and March 22, 2021 and information acquired from Ashland Department of Public Works.

Pre-Development Condition

Technical Release 20 (TR-20) Program for Project Formulation Hydrology developed by the Soil Conservation Service (SCS) was employed to develop pre- and post-development peak flows. Drainage calculations were performed for the pre-development condition for the 2, 10, 25, and 100-year 24-hour storm events, utilizing Technical Paper 40 (TP-40) prepared by The National Weather Service. Refer to Appendix A for computer results, soil characteristics, cover descriptions and time of concentration calculations for pre-development conditions.

In the pre-development condition, a single watershed area totaling 39,658 s.f. was analyzed. The existing watershed encompasses the entirety of all three existing properties which flow unmitigated via surface flow easterly toward the closed drainage system in Homer Avenue. Since there are no existing stormwater management facilities onsite, all flows generated by the property are directed, untreated, toward the respective design point. The subject area consists mainly of asphalt, roof area, concrete and includes a small portion of landscaped area.

A summary of the peak rates of runoff during the Pre-Development Condition is as follows:

Pre-Development Condition Peak Discharge Summary:

	2-Year Storm (3.36 IN)	10-Year Storm (5.25 IN)	25-Year Storm (6.42 IN)	100-Year Storm (8.24 IN)
Design Point #1	2.78 CFS	4.60 CFS	5.72 CFS	7.45 CFS

Post-Development Condition
The proposed project includes the demolition of five (5) of the six (6) existing building structures and the construction of a 13,080 s.f. mixed use development. The proposed development will include 8,550 s.f. of commercial space accessed from Homer Avenue, 29 residential units above, and a drive under parking facility. The project will also include the construction of bituminous concrete driveway and parking areas, utility connections, stormwater management systems, landscaping and incidental site work.

In the pre-development condition, the subject property contained mainly impervious area without the benefit of stormwater management facilities. The proposed design includes the installation of a substantial amount of landscaping and the inclusion of a catch basin, water quality manhole and sub-surface infiltration facility that will mitigate stormwater flow. The additional landscaping will serve to reduce the rate and volume of stormwater being discharged from the subject property. A deep sump hooded catch basin and water quality manhole will improve the quality of storm water prior to discharge into the proposed subsurface infiltration system.

Refer to the Proposed Watershed Plan (PWP) in Appendix B for proposed site grading, drainage facilities, and the delineation of post-development drainage sub-areas. In the post-development condition, the same tributary area was analyzed as in the Pre-Development condition.

Again, drainage calculations were performed for the post-development condition for the 2, 10, 25, and 100-year type III 24-hour storm events, utilizing local rainfall intensities from TP-40. The same design points were analyzed as in the pre-development condition. Refer to Appendix B for computer results, soil characteristics, cover descriptions and time of concentration calculations. A summary of the peak rates of runoff during the Post-Development Condition is as follows:

Post-Development Condition Peak Discharge Summary:

	2-Year Storm (3.36 IN)	10-Year Storm (5.25 IN)	25-Year Storm (6.42 IN)	100-Year Storm (8.24 IN)
Design Point #1	0.01 CFS	0.36 CFS	1.83 CFS	5.32 CFS

Subsurface Infiltration System
In addition to storm water runoff being mitigated through the increase of landscaped area, two subsurface infiltration systems will be installed to gather runoff from all impervious surfaces as required by the Ashland Stormwater Management Bylaw. The first subsurface infiltration facility consists of 5 rows of 16 Cultec 330 XL chambers the second system consists of 14-LF of 12-inch perforated ADS pipe surrounded in an envelope of crushed stone and wrapped in filter fabric.

Storm water runoff generated by the new roof will be captured via roof drains and will discharge into the subsurface infiltration facility. Storm water runoff from the proposed driveway, parking area, and a portion of the landscaped area will drain via surface flow to a deep sump hooded catch basin and into a water quality manhole (CDS) before discharging into the subsurface infiltration system. The subsurface infiltration facility will include an outlet control structure for emergency overflow in large scale storm events that will discharge directly to the closed drainage system in Homer Avenue.

The subsurface infiltration facility has been designed to mitigate peak flows and volumes of stormwater runoff for all storms up to and including the 100-year storm event, resulting in a net decrease to the design point in all storms. On-site soil testing was performed on August 4, 2023. The estimated seasonal high groundwater table was determined by redoximorphic features that were observed at a depth of 66-inches or an elevation of 179.5. Water and weeping were observed at a depth of 93 & 94 inches. The parent soil material was comprised of a Loamy Sand. An infiltration rate of 2.41 in/hr associated with a Rawls Rate for loamy sand was utilized in the stormwater modeling.

Erosion and Siltation Control
Double staked haybales and silt fence will be placed at the downhill limit of work prior to the commencement of any construction activity. The integrity of the erosion control devices will be maintained by periodic inspection and replacement as necessary. The haybales and silt fence will remain in place until the first course of pavement has been placed and all side slopes have been loamed and seeded and vegetation has been established.

Conclusion

The stormwater management system has been designed to provide a high level of water quality, while increasing groundwater recharge potential of the site and reducing peak rates of runoff. All stormwater management facilities have been designed in accordance with the Town of Ashland Stormwater Management Bylaw. Provisions have been included in this report to ensure that all drainage infrastructure is adequately maintained, which will allow the stormwater management system to continue to function properly. In conclusion, the proposed development activities will not have an adverse impact on the capacity of the subject property in regards to flood control, water quality, groundwater recharge, and storm damage prevention.

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Civil Engineering & Land Planning Consultants

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PROJECT:

Plan of Land

47 Homer Avenue
(Tax Map 38 Block 275 Lot 27)
Ashland, MA 01721

PROJECT: 21-58508	DATE: February 16, 2021
SCALE: 1:25,000	DWG FILE NAME: Figures.dwg
DESIGNED BY: Max Friedman	CHECKED BY: Richard A. Salvo, P.E.

DRAWING TITLE:
FIGURE 1 - USGS LOCUS MAP

Page #:
1of5

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PROJECT:

Plan of Land

47 Homer Avenue
(Tax Map 38 Block 275 Lot 27)
Ashland, MA 01721

PROJECT: 21-58508	DATE: February 16, 2021
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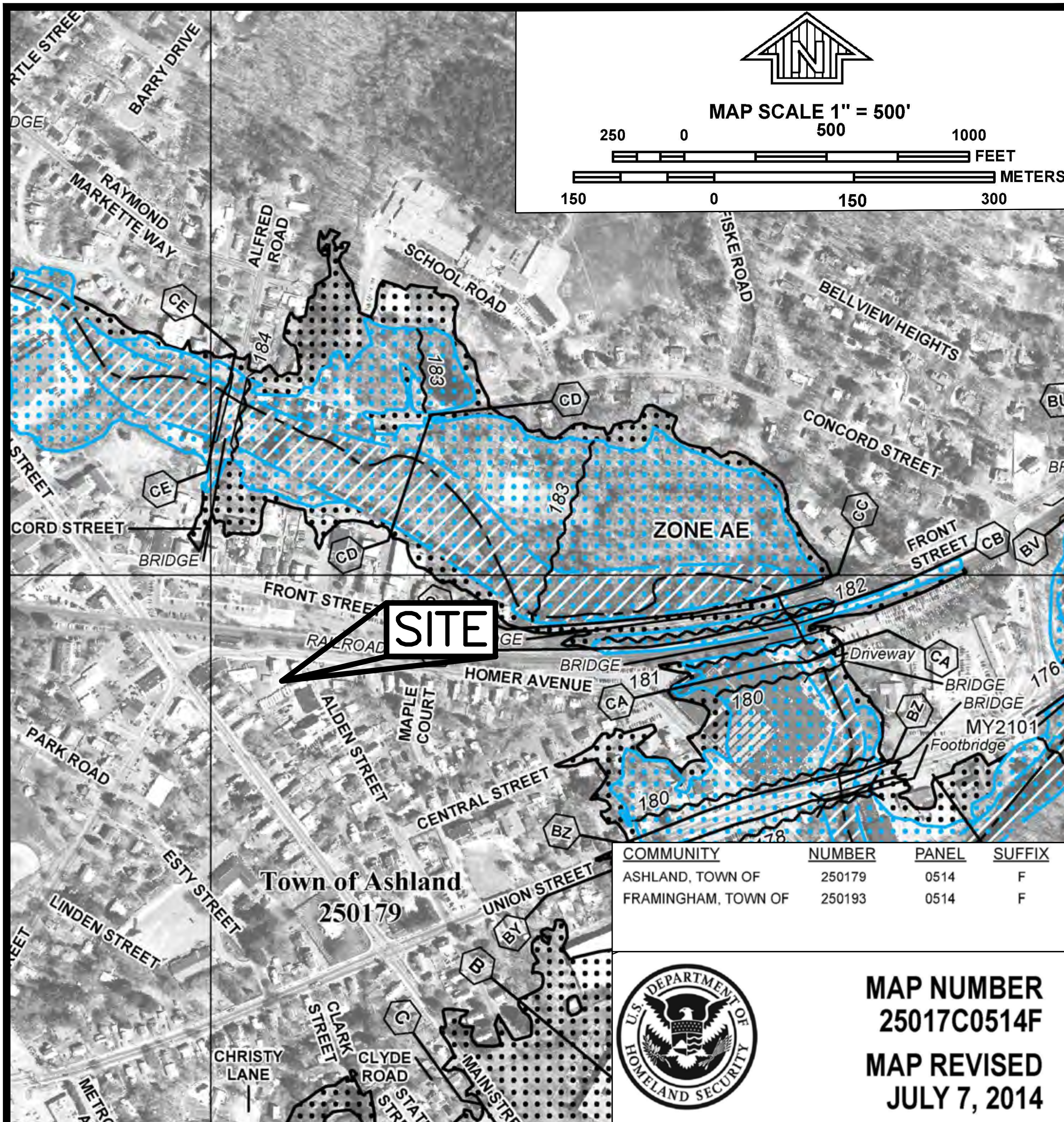
DESIGNED BY: Max Friedman	CHECKED BY: Richard A. Salvo, P.E.

DRAWING TITLE:

FIGURE 2 - ORTHO PHOTO



COMMUNITY	NUMBER	PANEL	SUFFIX
ASHLAND, TOWN OF	250179	0514	F
FRAMINGHAM, TOWN OF	250193	0514	F

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PROJECT:

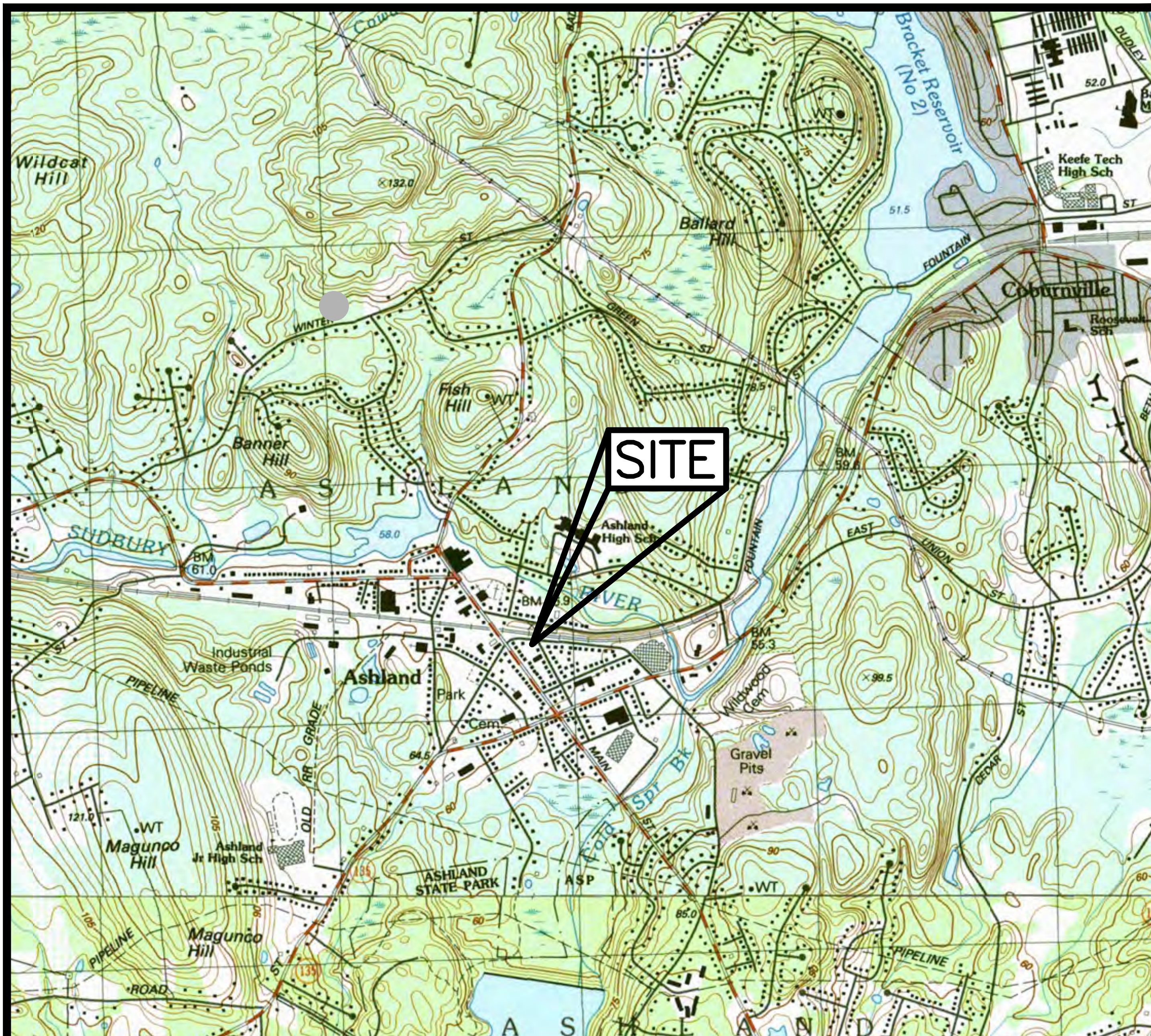
Plan of Land

7 Franklin Street
(Tax Map 33 Block 477 Lot 1)
Revere, MA 02151

PROJECT: 21-76201	DATE: February 11, 2021
SCALE: 1"=500'	DWG FILE NAME: Figures.dwg
DESIGNED BY: Max Friedman	CHECKED BY: Richard A. Salvo, P.E.

DRAWING TITLE:

FIGURE 3 - FEMA FLOOD MAP



LEGEND:

= NHESP CERTIFIED VERNAL POOL

= NHESP ESTIMATED HABITATS OF RARE SPECIES

= NHESP PRIORITY HABITATS OF RARE SPECIES

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DRAWING TITLE:

FIGURE 4 - NATURAL HERITAGE MAP

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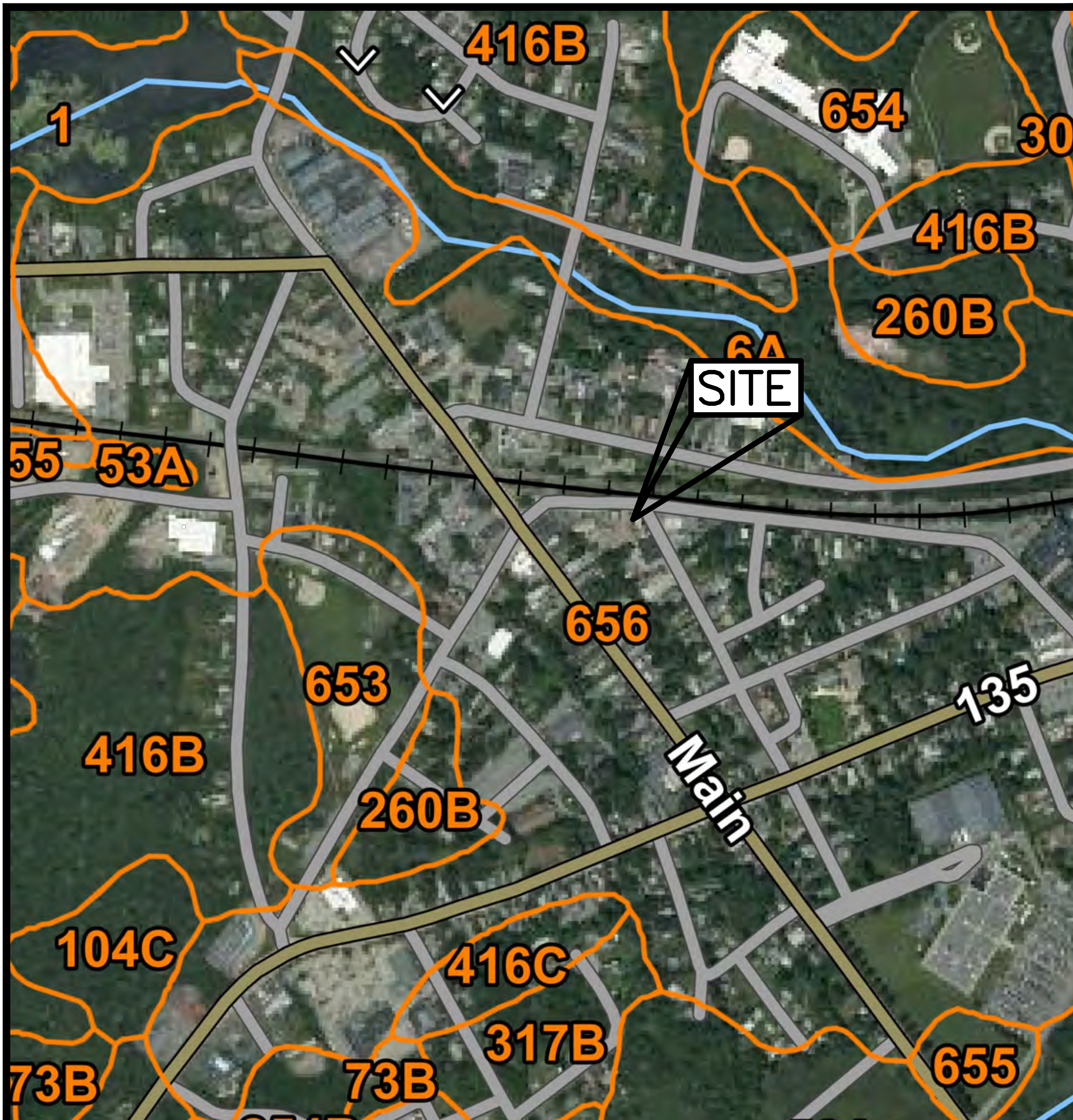

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47 Homer Avenue
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Ashland, MA 01721

PROJECT: 21-58508	DATE: February 16, 2021
SCALE: 1"=500'	DWG FILE NAME: Figures.dwg
DESIGNED BY: Max Friedman	CHECKED BY: Richard A. Salvo, P.E.

DRAWING TITLE:

FIGURE 5 - SOILS MAP

Description of Udorthents, Wet Substratum

Setting

Parent material: Loamy alluvium and/or sandy glaciofluvial deposits and/or loamy glaciolacustrine deposits and/or loamy marine deposits and/or loamy basal till and/or loamy lodgment till

Properties and qualities

Slope: 0 to 8 percent
Depth to restrictive feature: More than 80 inches
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None

Minor Components

Urban land

Percent of map unit: 8 percent
Landform position (two-dimensional): Footslope
Landform position (three-dimensional): Base slope
Down-slope shape: Linear
Across-slope shape: Linear

Freetown

Percent of map unit: 4 percent
Landform: Depressions, bogs
Landform position (two-dimensional): Toeslope
Landform position (three-dimensional): Dip
Down-slope shape: Concave
Across-slope shape: Concave
Hydric soil rating: Yes

Swansea

Percent of map unit: 3 percent
Landform: Bogs, depressions
Landform position (two-dimensional): Toeslope
Landform position (three-dimensional): Dip
Down-slope shape: Concave
Across-slope shape: Concave
Hydric soil rating: Yes

656—Udorthents-Urban land complex

Map Unit Setting

National map unit symbol: 995k
Elevation: 0 to 3,000 feet
Mean annual precipitation: 32 to 54 inches
Mean annual air temperature: 43 to 54 degrees F
Frost-free period: 110 to 240 days
Farmland classification: Not prime farmland

Map Unit Composition

Udorthents and similar soils: 45 percent
Urban land: 35 percent
Minor components: 20 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Udorthents

Setting

Parent material: Loamy alluvium and/or sandy glaciofluvial deposits and/or loamy glaciolacustrine deposits and/or loamy marine deposits and/or loamy basal till and/or loamy lodgment till

Properties and qualities

Slope: 0 to 15 percent
Depth to restrictive feature: More than 80 inches
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None

Description of Urban Land

Setting

Landform position (two-dimensional): Footslope
Landform position (three-dimensional): Base slope
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Excavated and filled land

Minor Components

Canton

Percent of map unit: 10 percent
Landform: Hills
Landform position (two-dimensional): Backslope, toeslope
Landform position (three-dimensional): Side slope, base slope
Down-slope shape: Linear
Across-slope shape: Convex
Hydric soil rating: No

Merrimac

Percent of map unit: 5 percent
Landform: Plains, terraces
Landform position (two-dimensional): Shoulder
Landform position (three-dimensional): Tread, rise
Down-slope shape: Convex
Across-slope shape: Convex
Hydric soil rating: No

Paxton

Percent of map unit: 5 percent
Landform: Hillslopes

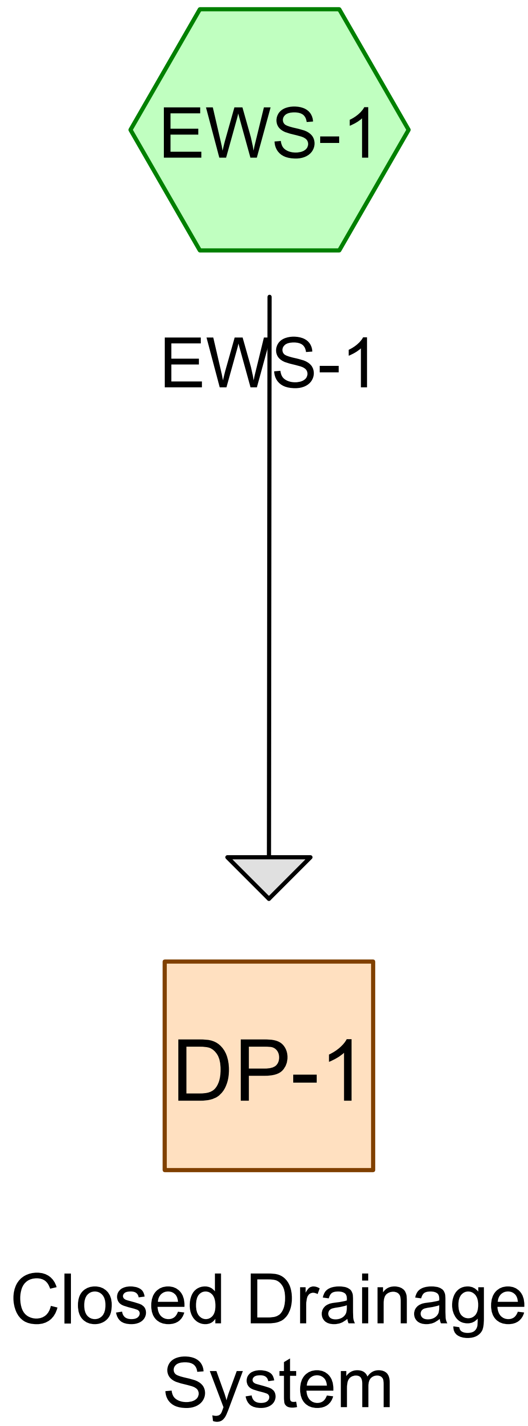
Landform position (two-dimensional): Backslope, summit
Landform position (three-dimensional): Head slope, side slope
Down-slope shape: Convex
Across-slope shape: Convex
Hydric soil rating: No

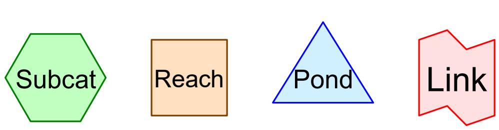
Data Source Information

Soil Survey Area: Middlesex County, Massachusetts
Survey Area Data: Version 20, Jun 9, 2020

APPENDIX A

Existing Conditions Drainage Calculations
Existing Watershed Plan





Routing Diagram for Existing Conditions
Prepared by Engineering Alliance, Inc., Printed 9/26/2023

Area Listing (all nodes)

Area (sq-ft)	CN	Description (subcatchment-numbers)
1,100	39	>75% Grass cover, Good, HSG A (EWS-1)
8,858	84	Gravel Parking Area (EWS-1)
15,011	98	Paved parking, HSG A (EWS-1)
14,689	98	Roofs, HSG A (EWS-1)
39,658	**93**	**TOTAL AREA**

Summary for Subcatchment EWS-1: EWS-1

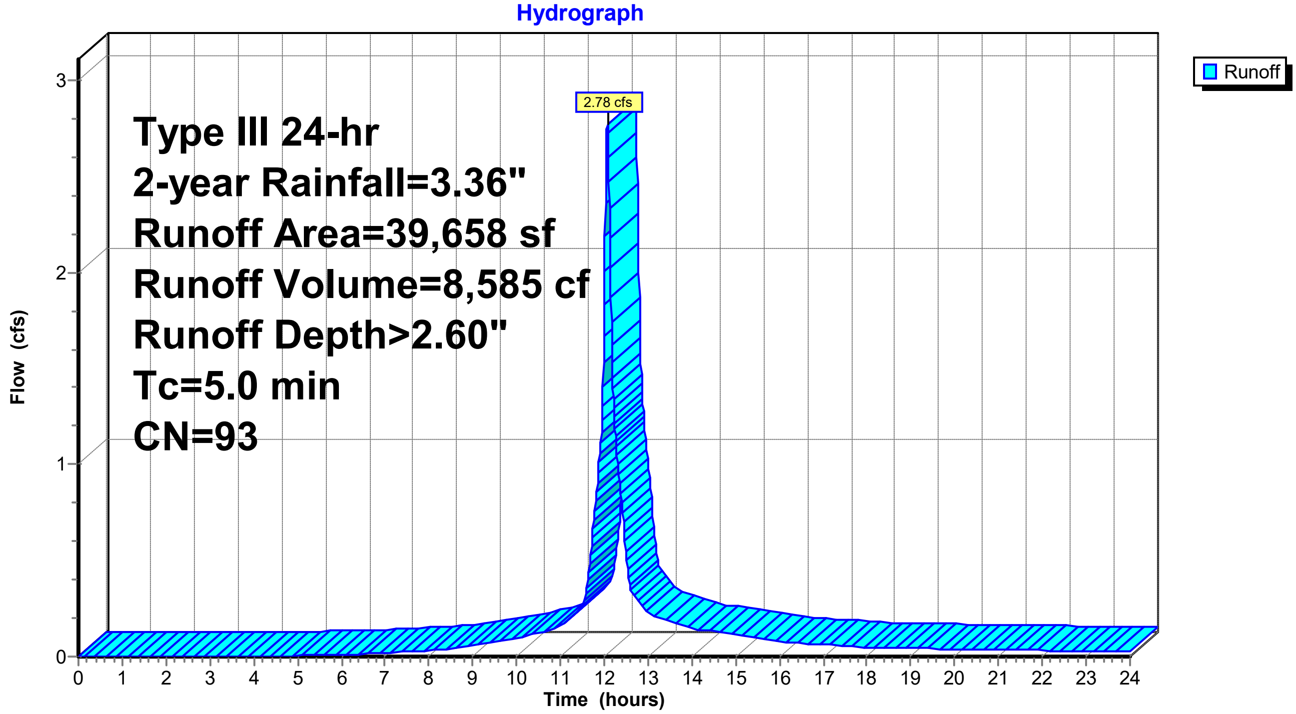
Runoff = 2.78 cfs @ 12.07 hrs, Volume= 8,585 cf, Depth> 2.60"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 0.00-24.00 hrs, dt= 0.01 hrs
Type III 24-hr 2-year Rainfall=3.36"

	Area (sf)	CN	Description
	15,011	98	Paved parking, HSG A
	10,709	98	Roofs, HSG A
*	8,858	84	Gravel Parking Area
	1,100	39	>75% Grass cover, Good, HSG A
	3,980	98	Roofs, HSG A
	39,658	93	Weighted Average
	9,958		25.11% Pervious Area
	29,700		74.89% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
5.0					**Direct Entry,**

Subcatchment EWS-1: EWS-1

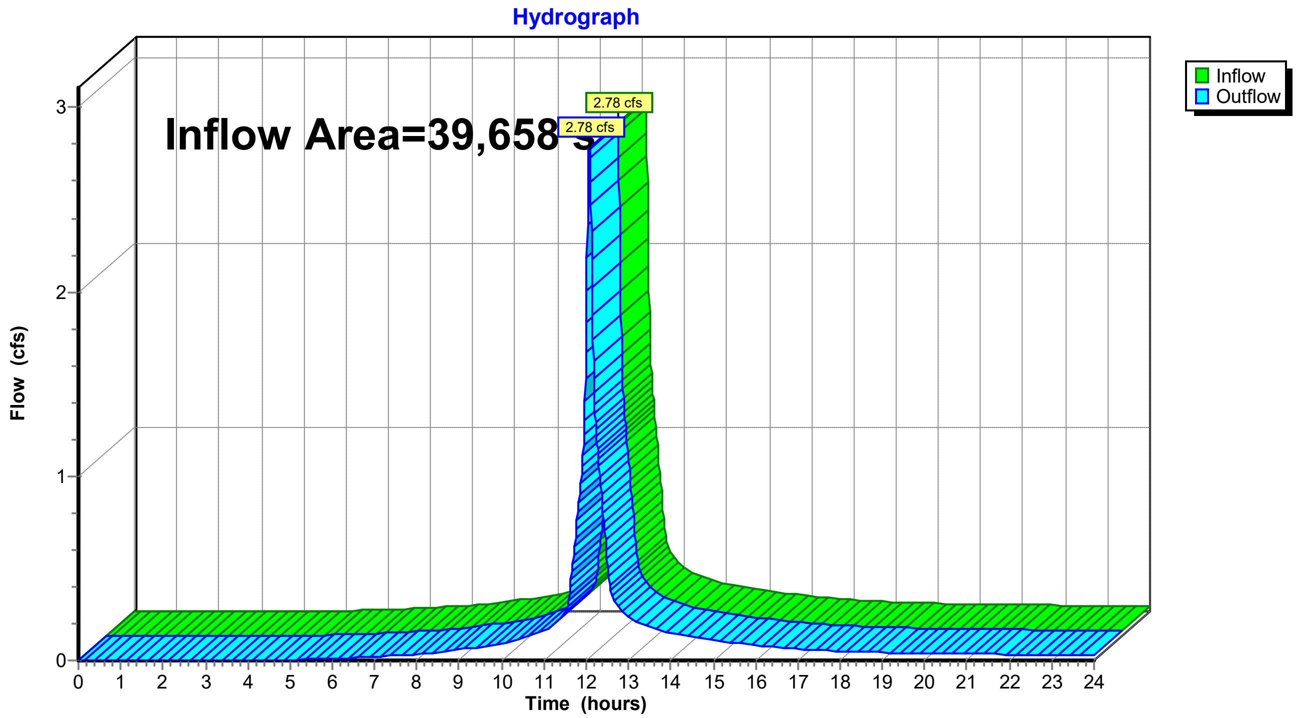


Summary for Reach DP-1: Closed Drainage System

Inflow Area = 39,658 sf, 74.89% Impervious, Inflow Depth > 2.60" for 2-year event
Inflow = 2.78 cfs @ 12.07 hrs, Volume= 8,585 cf
Outflow = 2.78 cfs @ 12.07 hrs, Volume= 8,585 cf, Atten= 0%, Lag= 0.0 min

Routing by Stor-Ind+Trans method, Time Span= 0.00-24.00 hrs, dt= 0.01 hrs

Reach DP-1: Closed Drainage System



Summary for Subcatchment EWS-1: EWS-1

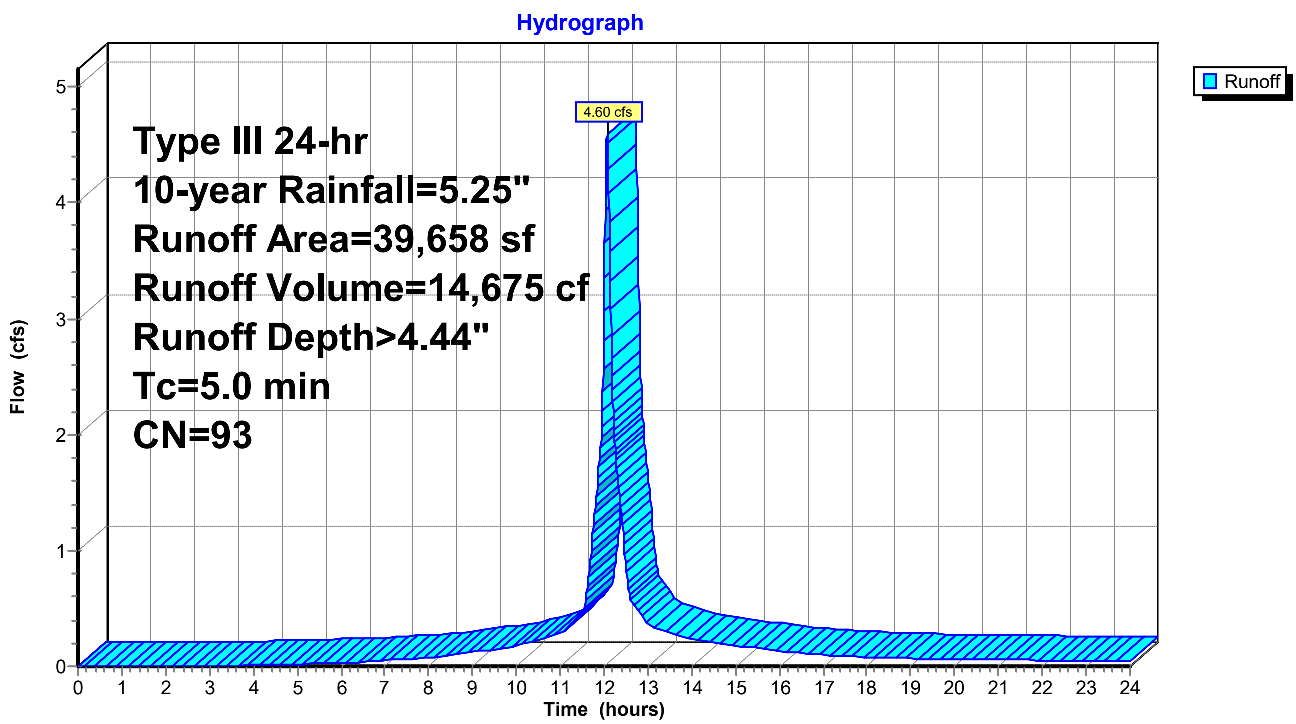
Runoff = 4.60 cfs @ 12.07 hrs, Volume= 14,675 cf, Depth> 4.44"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 0.00-24.00 hrs, dt= 0.01 hrs
Type III 24-hr 10-year Rainfall=5.25"

	Area (sf)	CN	Description
	15,011	98	Paved parking, HSG A
	10,709	98	Roofs, HSG A
*	8,858	84	Gravel Parking Area
	1,100	39	>75% Grass cover, Good, HSG A
	3,980	98	Roofs, HSG A
	39,658	93	Weighted Average
	9,958		25.11% Pervious Area
	29,700		74.89% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
5.0					**Direct Entry,**

Subcatchment EWS-1: EWS-1

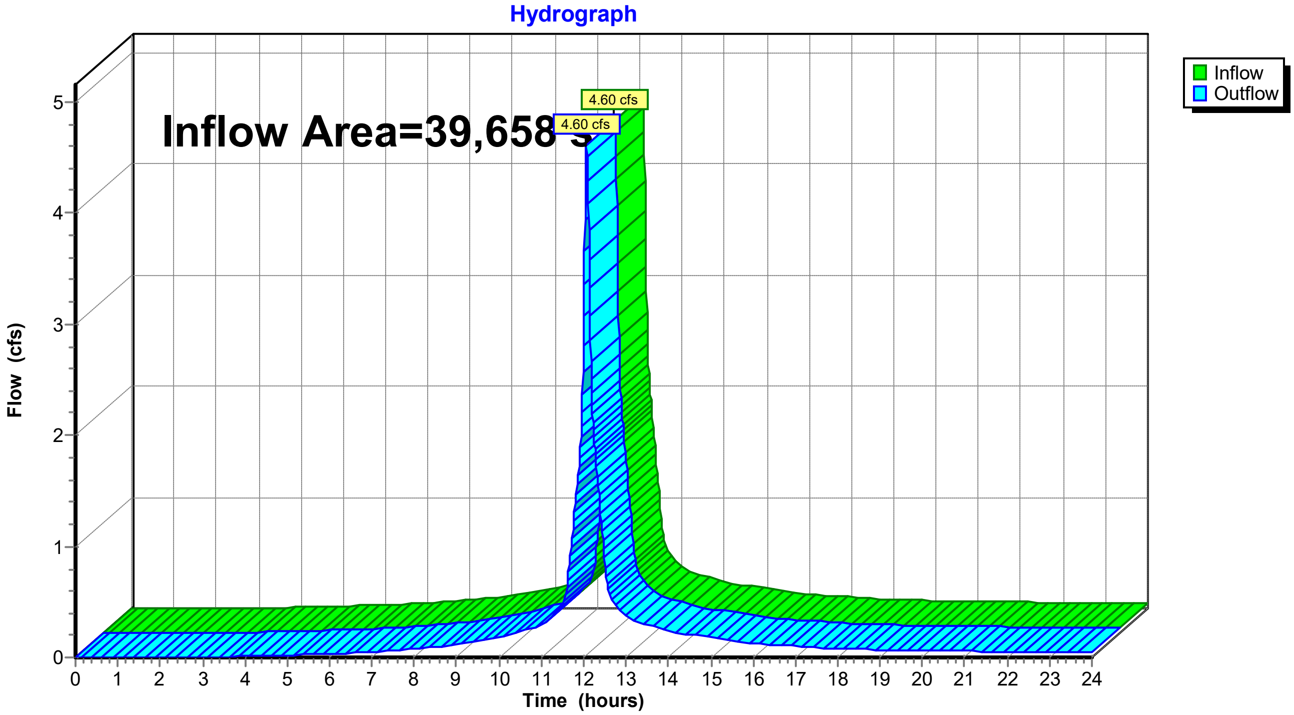


Summary for Reach DP-1: Closed Drainage System

Inflow Area =	39,658 sf,	74.89% Impervious,	Inflow Depth > 4.44"	for 10-year event
Inflow =	4.60 cfs @	12.07 hrs, Volume=	14,675 cf	
Outflow =	4.60 cfs @	12.07 hrs, Volume=	14,675 cf,	Atten= 0%, Lag= 0.0 min

Routing by Stor-Ind+Trans method, Time Span= 0.00-24.00 hrs, dt= 0.01 hrs

Reach DP-1: Closed Drainage System



Summary for Subcatchment EWS-1: EWS-1

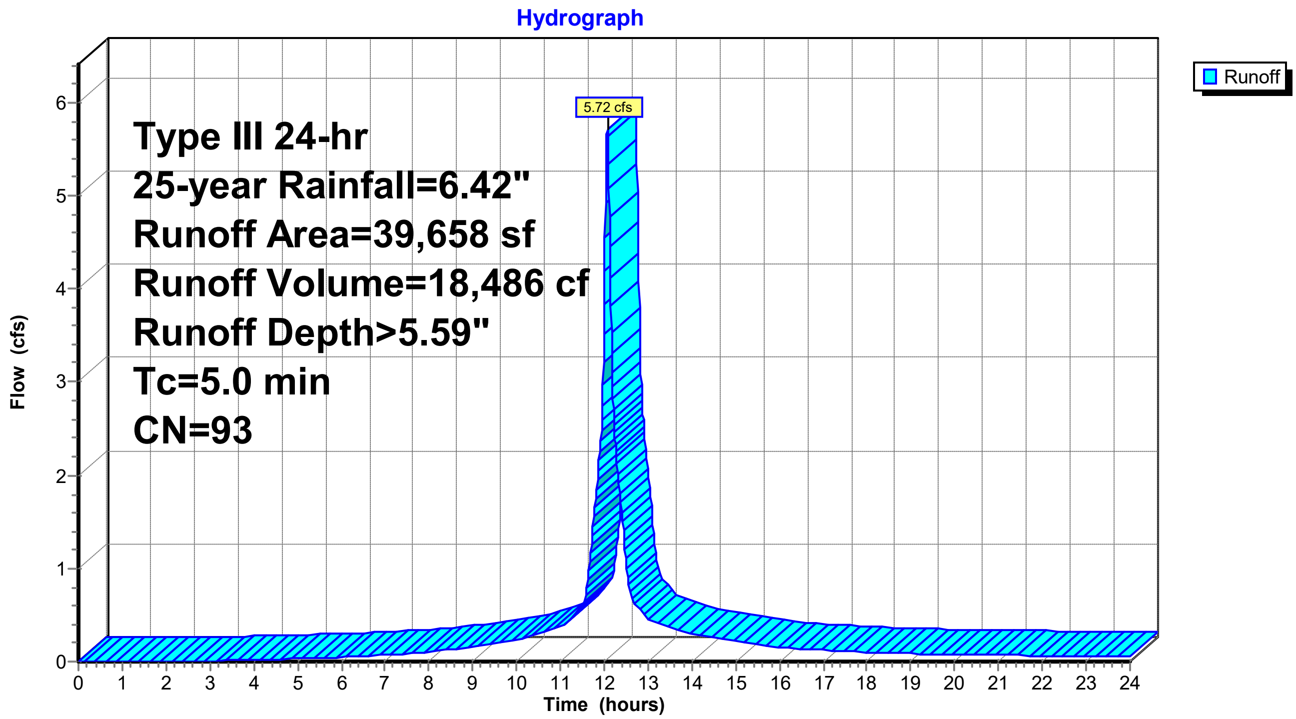
Runoff = 5.72 cfs @ 12.07 hrs, Volume= 18,486 cf, Depth> 5.59"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 0.00-24.00 hrs, dt= 0.01 hrs
Type III 24-hr 25-year Rainfall=6.42"

	Area (sf)	CN	Description
	15,011	98	Paved parking, HSG A
	10,709	98	Roofs, HSG A
*	8,858	84	Gravel Parking Area
	1,100	39	>75% Grass cover, Good, HSG A
	3,980	98	Roofs, HSG A
	39,658	93	Weighted Average
	9,958		25.11% Pervious Area
	29,700		74.89% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
5.0					**Direct Entry,**

Subcatchment EWS-1: EWS-1

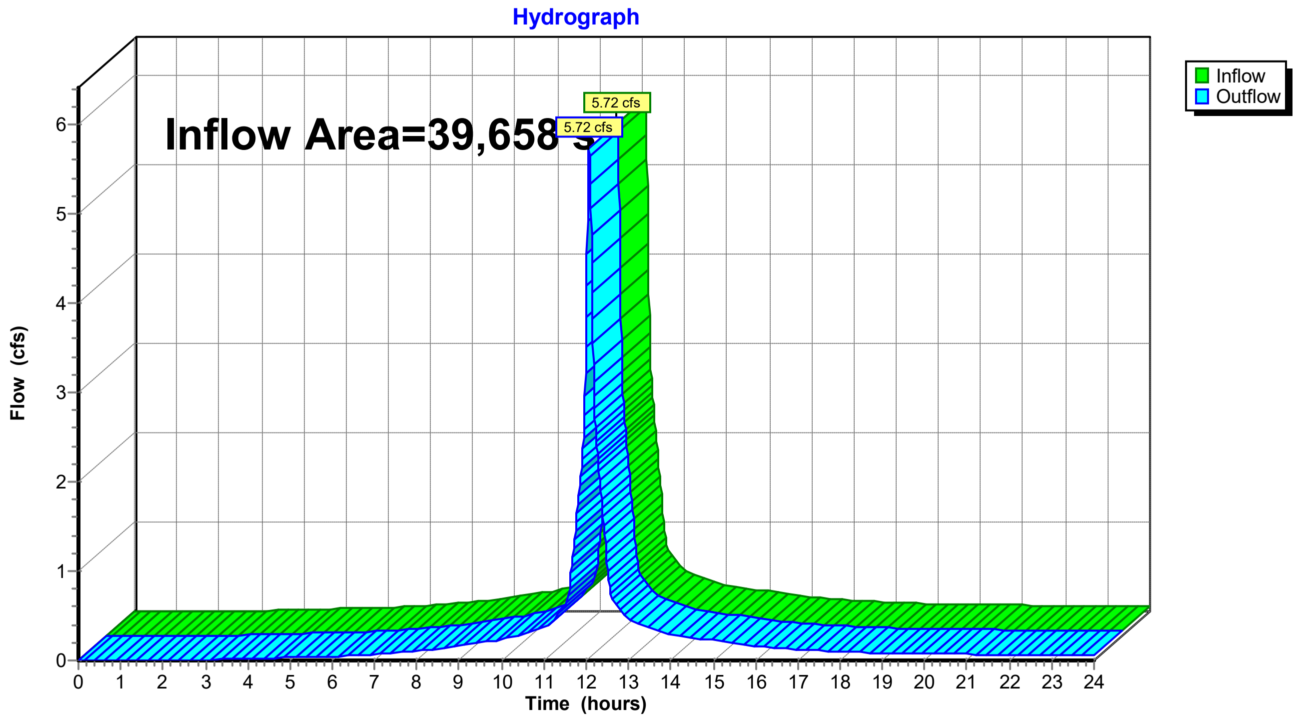


Summary for Reach DP-1: Closed Drainage System

Inflow Area = 39,658 sf, 74.89% Impervious, Inflow Depth > 5.59" for 25-year event
Inflow = 5.72 cfs @ 12.07 hrs, Volume= 18,486 cf
Outflow = 5.72 cfs @ 12.07 hrs, Volume= 18,486 cf, Atten= 0%, Lag= 0.0 min

Routing by Stor-Ind+Trans method, Time Span= 0.00-24.00 hrs, dt= 0.01 hrs

Reach DP-1: Closed Drainage System



Summary for Subcatchment EWS-1: EWS-1

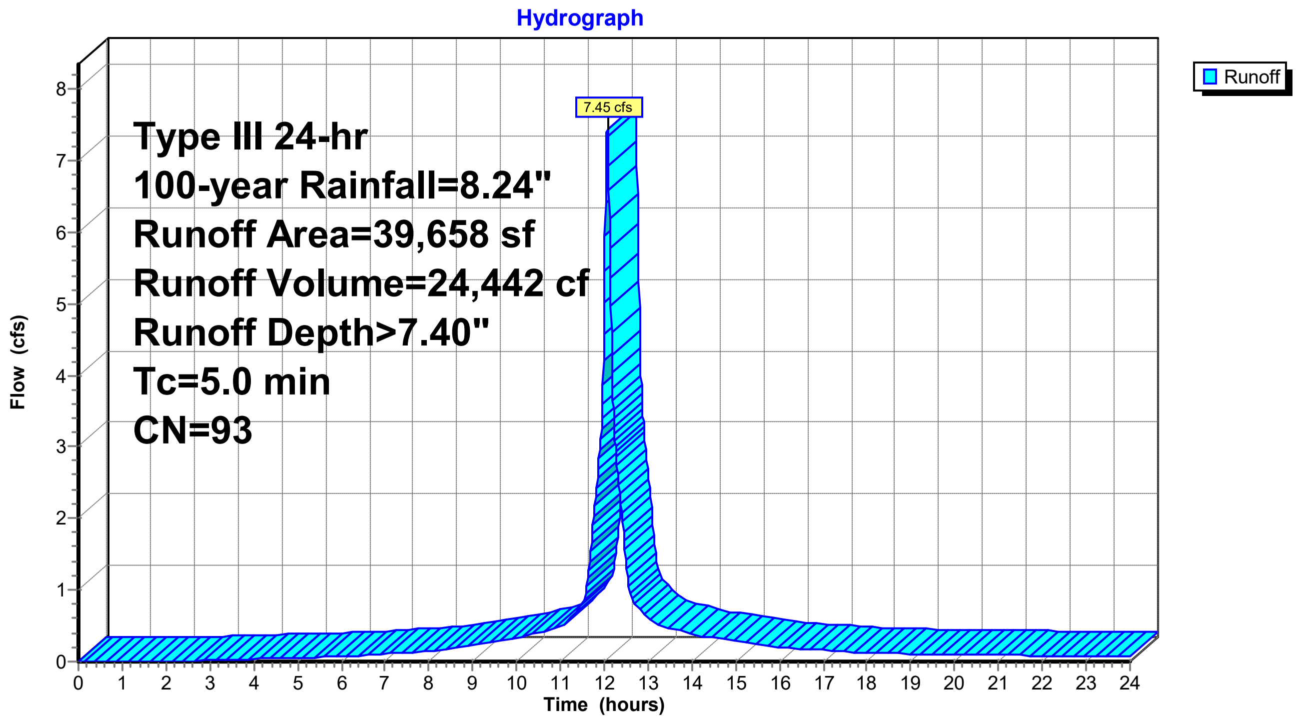
Runoff = 7.45 cfs @ 12.07 hrs, Volume= 24,442 cf, Depth> 7.40"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 0.00-24.00 hrs, dt= 0.01 hrs
Type III 24-hr 100-year Rainfall=8.24"

	Area (sf)	CN	Description
	15,011	98	Paved parking, HSG A
	10,709	98	Roofs, HSG A
*	8,858	84	Gravel Parking Area
	1,100	39	>75% Grass cover, Good, HSG A
	3,980	98	Roofs, HSG A
	39,658	93	Weighted Average
	9,958		25.11% Pervious Area
	29,700		74.89% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
5.0					**Direct Entry,**

Subcatchment EWS-1: EWS-1



Summary for Reach DP-1: Closed Drainage System

Inflow Area =	39,658 sf,	74.89% Impervious,	Inflow Depth > 7.40"	for 100-year event
Inflow =	7.45 cfs @	12.07 hrs, Volume=	24,442 cf	
Outflow =	7.45 cfs @	12.07 hrs, Volume=	24,442 cf,	Atten= 0%, Lag= 0.0 min

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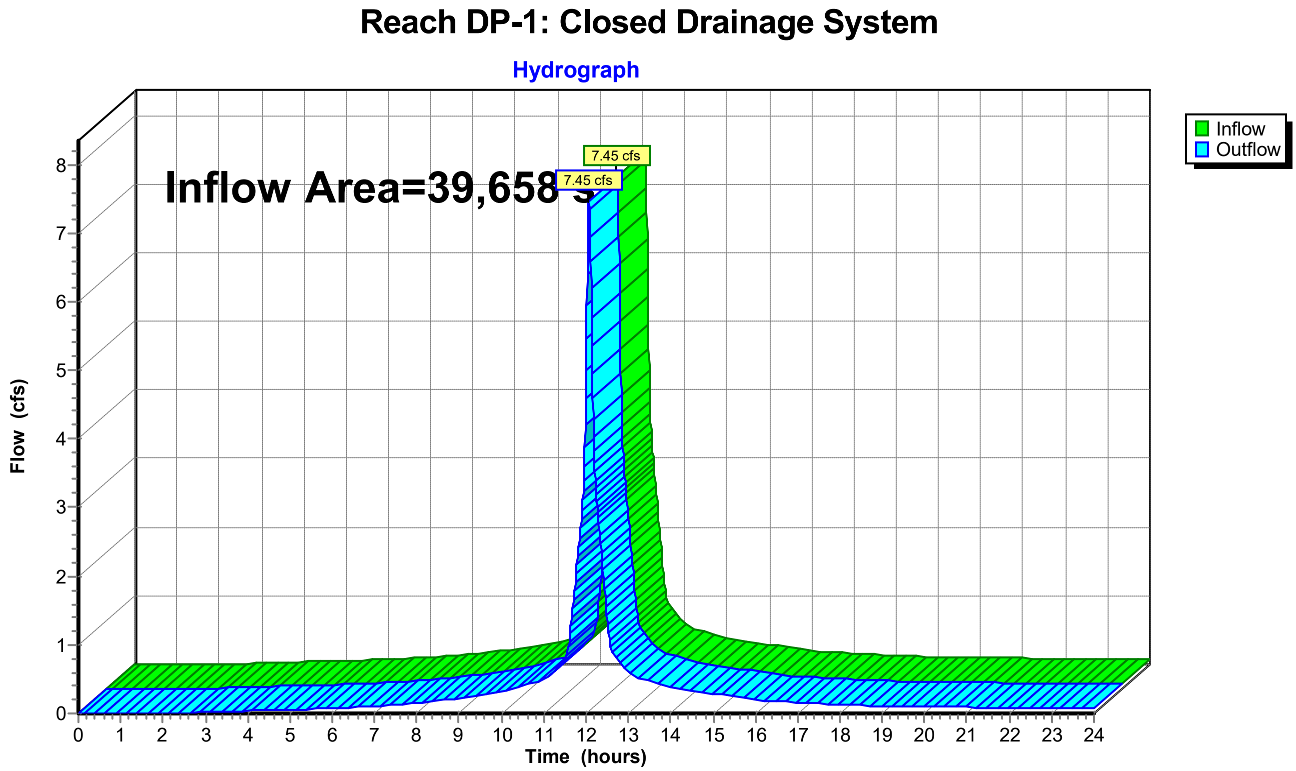

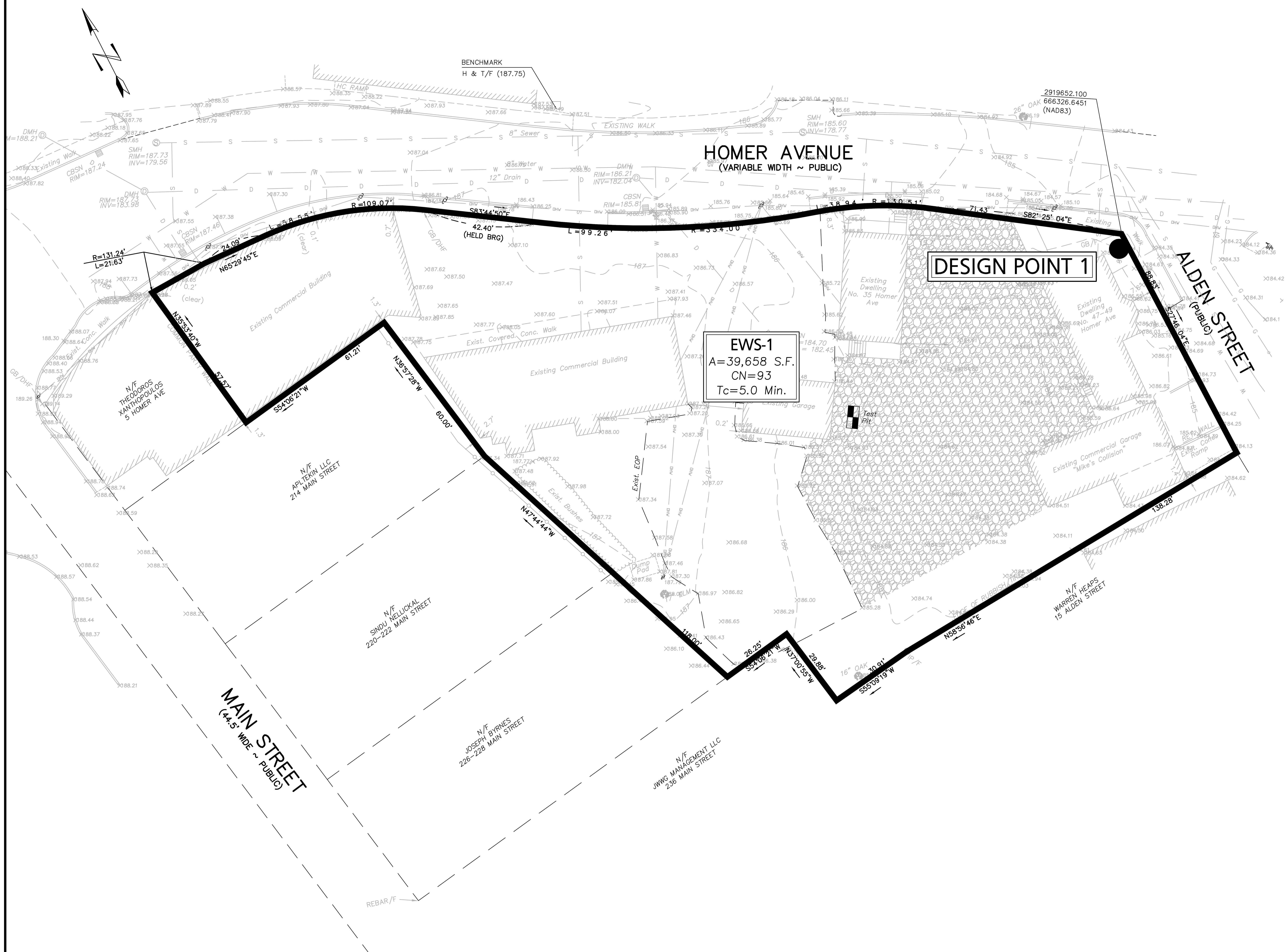

DATE	DESCRIPTION OF REVISION
8/9/23	ISSUED FOR PLANNING BOARD REVIEW
7/28/23	MODIFIED PER PEER REVIEW COMMENTS

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PROJECT:

Site Plan
9-49 Homer Avenue
(Tax Map 14 Lots 352-354)
Ashland, Massachusetts

PROJECT #: 21-58508	DATE: April 1, 2021
SCALE: AS NOTED	DWG FILE NAME: 21-58508.dwg
DESIGN BY: Eric Bradanese, P.E.	CHECKED BY: Richard A. Salvo, P.E.

COMMONWEALTH OF MASSACHUSETTS RICHARD A. SALVO CIVIL No. 41851 REGISTERED PROFESSIONAL ENGINEER

Professional Engineer for Engineering Alliance, Inc.

APPLICANT:

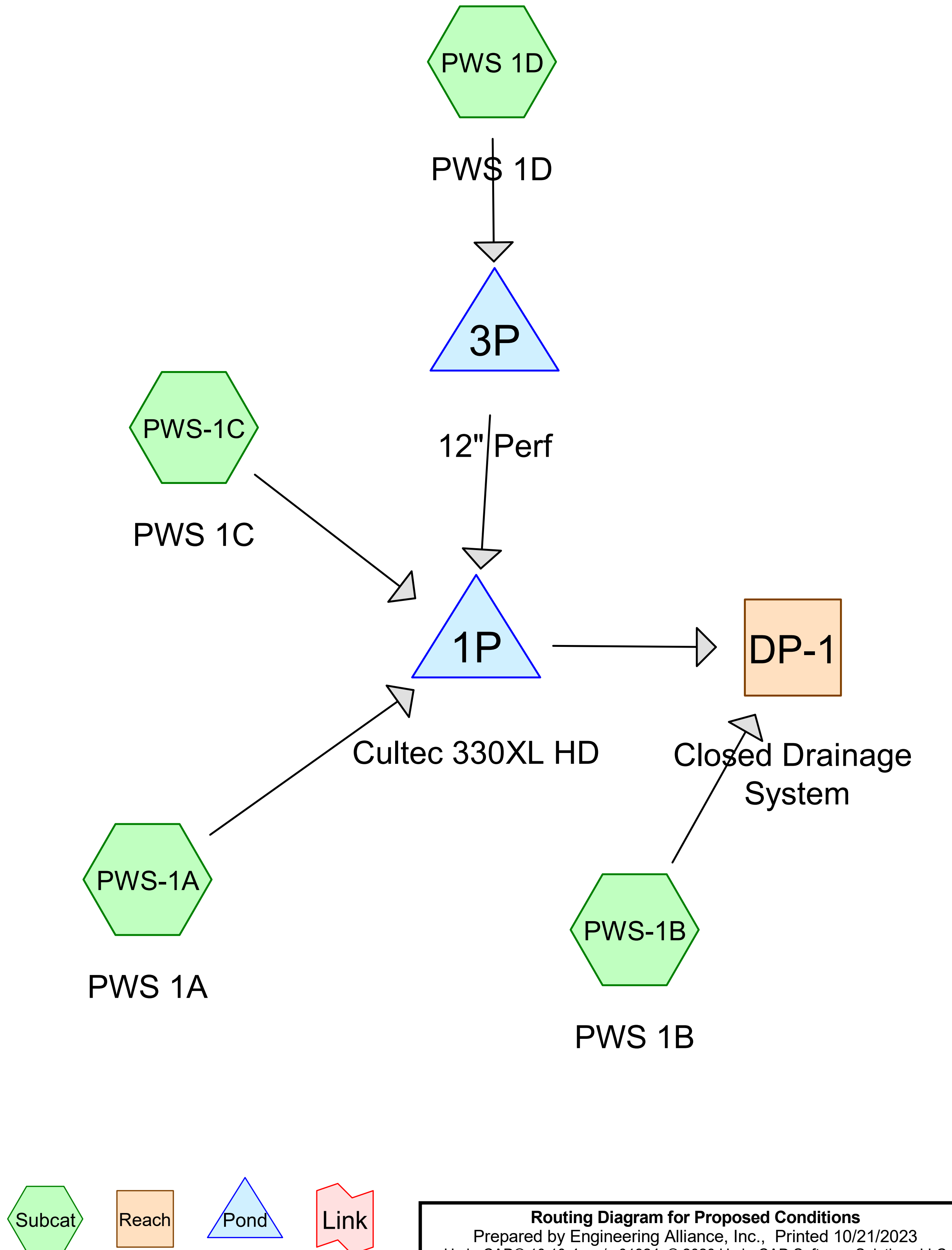
9-49 Homer Avenue, LLC
11 Placid Road
Newton, MA 02459

DWG. NO. 1of1

DRAWING TITLE: Existing Watershed Plan

APPENDIX B

Proposed Conditions Drainage Calculations
Proposed Watershed Plan



Routing Diagram for Proposed Conditions
Prepared by Engineering Alliance, Inc., Printed 10/21/2023

Area Listing (all nodes)

Area (sq-ft)	CN	Description (subcatchment-numbers)
6,879	39	>75% Grass cover, Good, HSG A (PWS-1A, PWS-1B)
788	98	Conc. Walks HSG A (PWS-1A)
1,310	86	Green Roof (PWS 1D)
10,056	98	Paved parking, HSG A (PWS-1A)
1,775	98	Paved parking, HSG C (PWS 1D)
620	98	Paved walkways, HSG C (PWS 1D)
17,060	98	Roofs, HSG A (PWS-1A, PWS-1C)
1,169	98	Walkway, HSG A (PWS-1B)
39,657	**87**	**TOTAL AREA**

Soil Listing (all nodes)

Area (sq-ft)	Soil Group	Subcatchment Numbers
35,952	HSG A	PWS-1A, PWS-1B, PWS-1C
0	HSG B	
2,395	HSG C	PWS 1D
0	HSG D	
1,310	Other	PWS 1D
39,657		**TOTAL AREA**

Ground Covers (all nodes)

HSG-A (sq-ft)	HSG-B (sq-ft)	HSG-C (sq-ft)	HSG-D (sq-ft)	Other (sq-ft)	Total (sq-ft)	Ground Cover	Su Nu
6,879	0	0	0	0	6,879	>75% Grass cover, Good	
788	0	0	0	0	788	Conc. Walks	
0	0	0	0	1,310	1,310	Green Roof	
10,056	0	1,775	0	0	11,831	Paved parking	
0	0	620	0	0	620	Paved walkways	
17,060	0	0	0	0	17,060	Roofs	
1,169	0	0	0	0	1,169	Walkway	
35,952	**0**	**2,395**	**0**	**1,310**	**39,657**	**TOTAL AREA**	

Pipe Listing (all nodes)

Line#	Node Number	In-Invert (feet)	Out-Invert (feet)	Length (feet)	Slope (ft/ft)	n	Diam/Width (inches)	Height (inches)	Inside-Fill (inches)
1	3P	181.76	181.76	50.0	0.0000	0.012	12.0	0.0	0.0

Time span=0.00-24.00 hrs, dt=0.01 hrs, 2401 points
Runoff by SCS TR-20 method, UH=SCS, Weighted-CN
Reach routing by Stor-Ind+Trans method - Pond routing by Stor-Ind method

Subcatchment PWS 1D: PWS 1D Runoff Area=3,705 sf 64.64% Impervious Runoff Depth>7.52"
Tc=5.0 min CN=94 Runoff=0.70 cfs 2,320 cf

Subcatchment PWS-1A: PWS 1A Runoff Area=26,688 sf 89.64% Impervious Runoff Depth>7.28"
Tc=5.0 min CN=92 Runoff=4.98 cfs 16,182 cf

Subcatchment PWS-1B: PWS 1B Runoff Area=5,284 sf 22.12% Impervious Runoff Depth>2.61"
Tc=5.0 min CN=52 Runoff=0.36 cfs 1,151 cf

Subcatchment PWS-1C: PWS 1C Runoff Area=3,980 sf 100.00% Impervious Runoff Depth>7.99"
Tc=5.0 min CN=98 Runoff=0.77 cfs 2,652 cf

Reach DP-1: Closed Drainage System Inflow=5.32 cfs 8,020 cf
Outflow=5.32 cfs 8,020 cf

Pond 1P: Cultec 330XL HD Peak Elev=184.59' Storage=5,895 cf Inflow=6.35 cfs 20,031 cf
Discarded=0.17 cfs 10,373 cf Primary=5.00 cfs 6,869 cf Outflow=5.17 cfs 17,243 cf

Pond 3P: 12" Perf Peak Elev=182.39' Storage=114 cf Inflow=0.70 cfs 2,320 cf
Discarded=0.03 cfs 1,123 cf Primary=0.63 cfs 1,197 cf Outflow=0.66 cfs 2,320 cf

Total Runoff Area = 39,657 sf Runoff Volume = 22,305 cf Average Runoff Depth = 6.75"
20.65% Pervious = 8,189 sf 79.35% Impervious = 31,468 sf

Summary for Subcatchment PWS 1D: PWS 1D

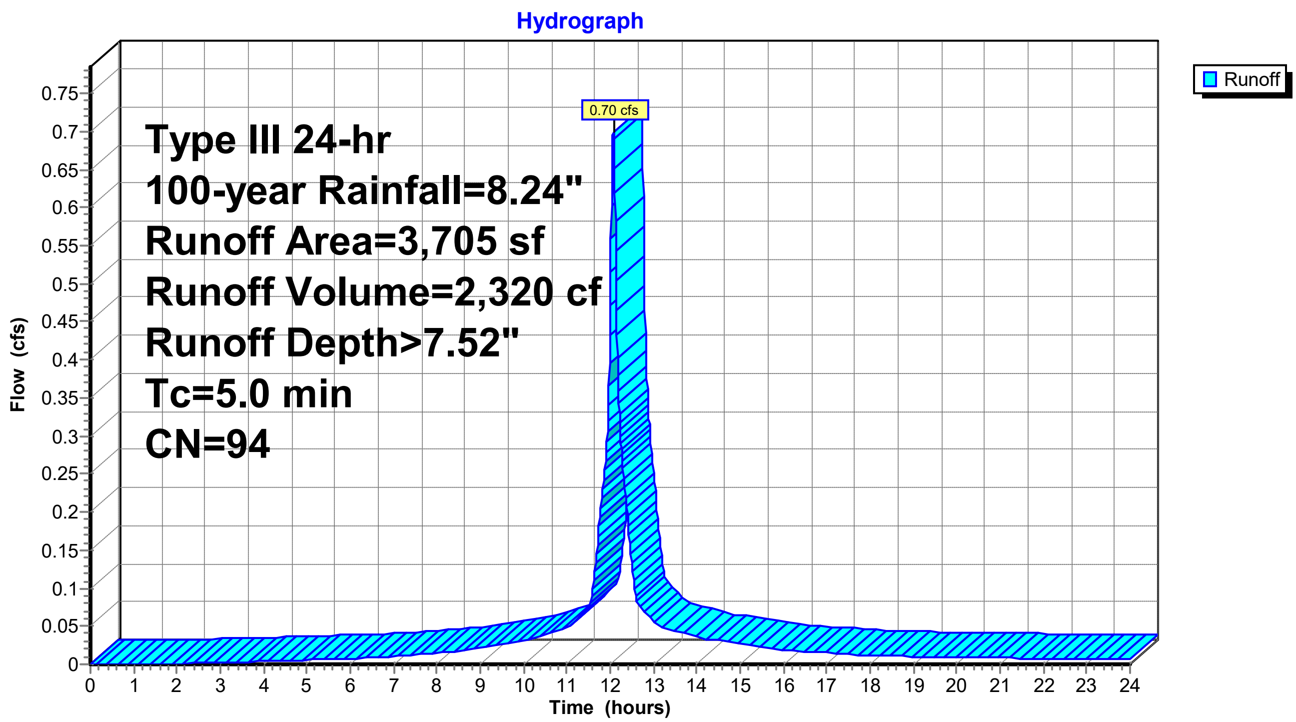
Runoff = 0.70 cfs @ 12.07 hrs, Volume= 2,320 cf, Depth> 7.52"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 0.00-24.00 hrs, dt= 0.01 hrs
Type III 24-hr 100-year Rainfall=8.24"

	Area (sf)	CN	Description
*	1,310	86	Green Roof
	1,775	98	Paved parking, HSG C
*	620	98	Paved walkways, HSG C
	3,705	94	Weighted Average
	1,310		35.36% Pervious Area
	2,395		64.64% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
5.0					**Direct Entry,**

Subcatchment PWS 1D: PWS 1D



Summary for Subcatchment PWS-1A: PWS 1A

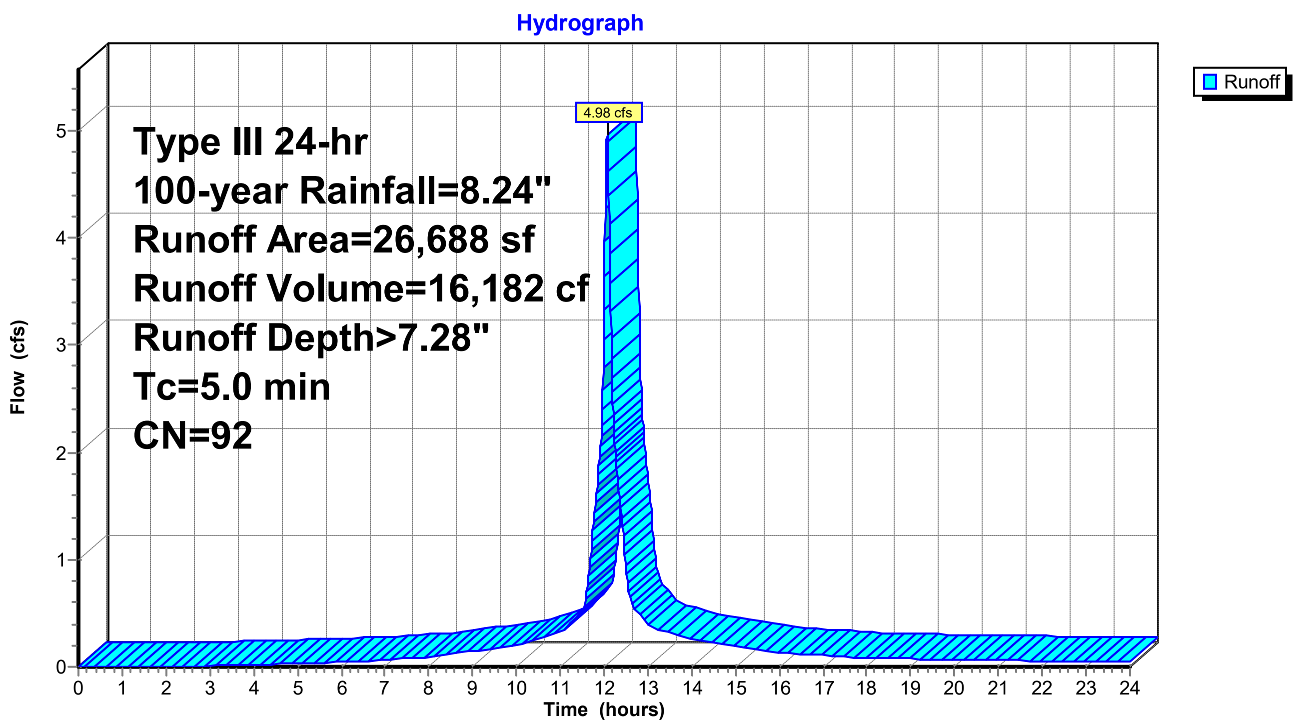
Runoff = 4.98 cfs @ 12.07 hrs, Volume= 16,182 cf, Depth> 7.28"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 0.00-24.00 hrs, dt= 0.01 hrs
Type III 24-hr 100-year Rainfall=8.24"

	Area (sf)	CN	Description
	13,080	98	Roofs, HSG A
	10,056	98	Paved parking, HSG A
*	788	98	Conc. Walks HSG A
	2,764	39	>75% Grass cover, Good, HSG A
	26,688	92	Weighted Average
	2,764		10.36% Pervious Area
	23,924		89.64% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
5.0					**Direct Entry,**

Subcatchment PWS-1A: PWS 1A



Summary for Subcatchment PWS-1B: PWS 1B

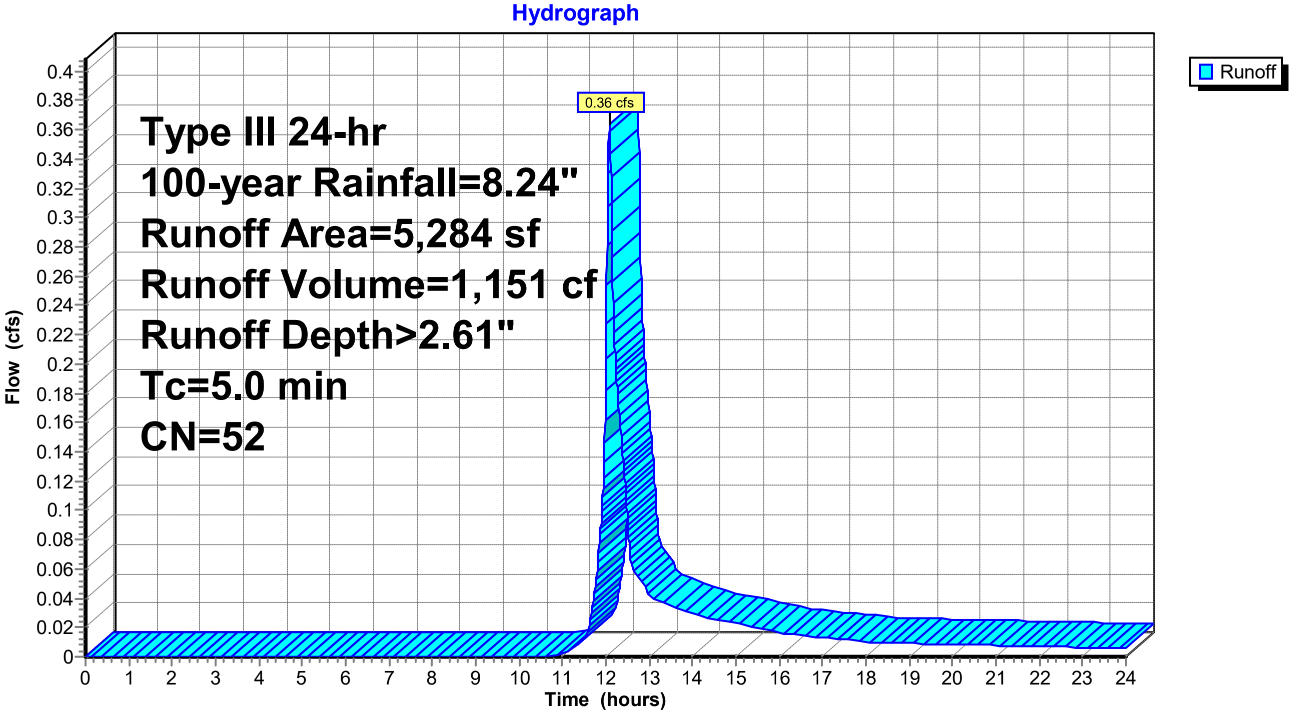
Runoff = 0.36 cfs @ 12.08 hrs, Volume= 1,151 cf, Depth> 2.61"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 0.00-24.00 hrs, dt= 0.01 hrs
Type III 24-hr 100-year Rainfall=8.24"

	Area (sf)	CN	Description
	4,115	39	>75% Grass cover, Good, HSG A
*	1,169	98	Walkway, HSG A
	5,284	52	Weighted Average
	4,115		77.88% Pervious Area
	1,169		22.12% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
5.0					**Direct Entry,**

Subcatchment PWS-1B: PWS 1B



Summary for Subcatchment PWS-1C: PWS 1C

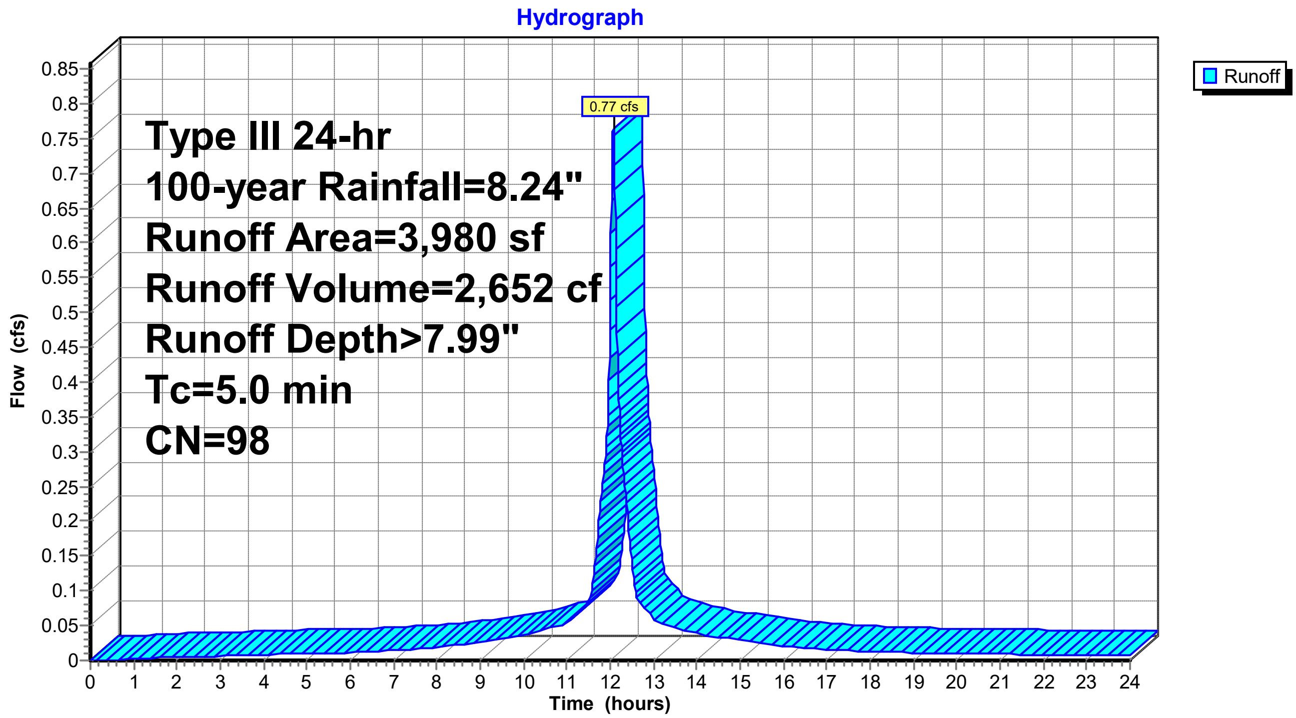
Runoff = 0.77 cfs @ 12.07 hrs, Volume= 2,652 cf, Depth> 7.99"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 0.00-24.00 hrs, dt= 0.01 hrs
Type III 24-hr 100-year Rainfall=8.24"

Area (sf)	CN	Description
3,980	98	Roofs, HSG A
3,980		100.00% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
5.0					**Direct Entry,**

Subcatchment PWS-1C: PWS 1C

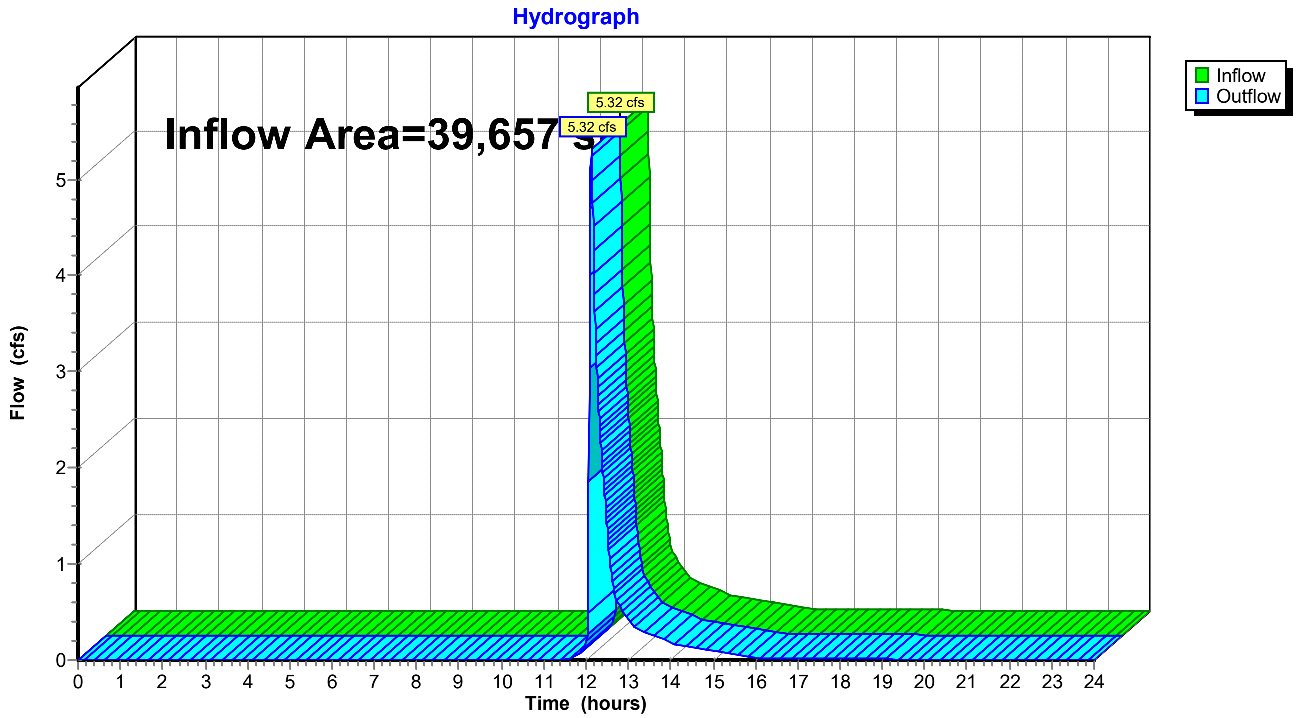


Summary for Reach DP-1: Closed Drainage System

Inflow Area = 39,657 sf, 79.35% Impervious, Inflow Depth > 2.43" for 100-year event
Inflow = 5.32 cfs @ 12.13 hrs, Volume= 8,020 cf
Outflow = 5.32 cfs @ 12.13 hrs, Volume= 8,020 cf, Atten= 0%, Lag= 0.0 min

Routing by Stor-Ind+Trans method, Time Span= 0.00-24.00 hrs, dt= 0.01 hrs

Reach DP-1: Closed Drainage System



Summary for Pond 1P: Cultec 330XL HD

Inflow Area =	34,373 sf, 88.15% Impervious,	Inflow Depth > 6.99"	for 100-year event	
Inflow =	6.35 cfs @ 12.07 hrs,	Volume=	20,031 cf	
Outflow =	5.17 cfs @ 12.13 hrs,	Volume=	17,243 cf,	Atten= 19%, Lag= 3.3 min
Discarded =	0.17 cfs @ 9.01 hrs,	Volume=	10,373 cf	
Primary =	5.00 cfs @ 12.13 hrs,	Volume=	6,869 cf	

Routing by Stor-Ind method, Time Span= 0.00-24.00 hrs, dt= 0.01 hrs
Peak Elev= 184.59' @ 12.13 hrs Surf.Area= 2,964 sf Storage= 5,895 cf

Plug-Flow detention time= 147.8 min calculated for 17,235 cf (86% of inflow)
Center-of-Mass det. time= 88.6 min (849.9 - 761.3)

Volume	Invert	Avail.Storage	Storage Description
#1A	181.76'	1,915 cf	**25.67'W x 115.50'L x 3.04'H Field A** 9,017 cf Overall - 4,228 cf Embedded = 4,789 cf x 40.0% Voids
#2A	181.76'	4,228 cf	**Cultec R-330XLHD** x 80 Inside #1 Effective Size= 47.8"W x 30.0"H => 7.45 sf x 7.00'L = 52.2 cf Overall Size= 52.0"W x 30.5"H x 8.50'L with 1.50' Overlap Row Length Adjustment= +1.50' x 7.45 sf x 5 rows
		6,144 cf	Total Available Storage

Storage Group A created with Chamber Wizard

Device	Routing	Invert	Outlet Devices
#1	Discarded	181.76'	**2.410 in/hr Exfiltration over Surface area**
#2	Primary	184.00'	**4.0' long x 1.0' breadth Broad-Crested Rectangular Weir** Head (feet) 0.20 0.40 0.60 0.80 1.00 1.20 1.40 1.60 1.80 2.00 2.50 3.00 Coef. (English) 2.69 2.72 2.75 2.85 2.98 3.08 3.20 3.28 3.31 3.30 3.31 3.32

Discarded OutFlow Max=0.17 cfs @ 9.01 hrs HW=181.79' (Free Discharge)
└─**1=Exfiltration** (Exfiltration Controls 0.17 cfs)

Primary OutFlow Max=4.99 cfs @ 12.13 hrs HW=184.59' (Free Discharge)
└─**2=Broad-Crested Rectangular Weir** (Weir Controls 4.99 cfs @ 2.11 fps)

Pond 1P: Cultec 330XL HD - Chamber Wizard Field A

Chamber Model = Cultec R-330XLHD (Cultec Recharger® 330XLHD)
Effective Size= 47.8"W x 30.0"H => 7.45 sf x 7.00'L = 52.2 cf
Overall Size= 52.0"W x 30.5"H x 8.50'L with 1.50' Overlap
Row Length Adjustment= +1.50' x 7.45 sf x 5 rows

52.0" Wide + 6.0" Spacing = 58.0" C-C Row Spacing

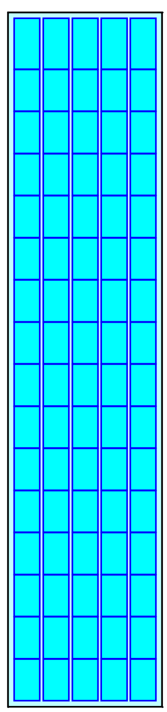
16 Chambers/Row x 7.00' Long +1.50' Row Adjustment = 113.50' Row Length +12.0" End Stone x 2 = 115.50' Base Length
5 Rows x 52.0" Wide + 6.0" Spacing x 4 + 12.0" Side Stone x 2 = 25.67' Base Width
30.5" Chamber Height + 6.0" Stone Cover = 3.04' Field Height

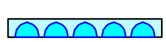
80 Chambers x 52.2 cf +1.50' Row Adjustment x 7.45 sf x 5 Rows = 4,228.4 cf Chamber Storage

9,017.0 cf Field - 4,228.4 cf Chambers = 4,788.6 cf Stone x 40.0% Voids = 1,915.4 cf Stone Storage

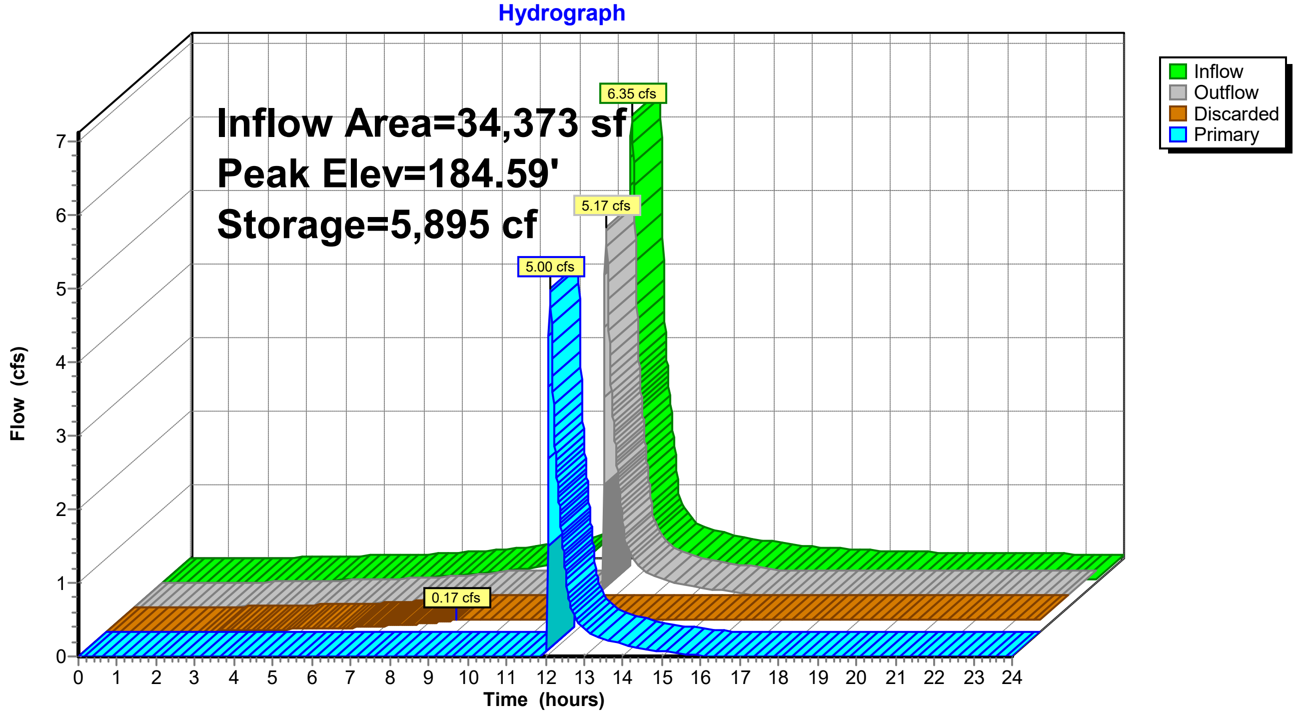
Chamber Storage + Stone Storage = 6,143.9 cf = 0.141 af
Overall Storage Efficiency = 68.1%
Overall System Size = 115.50' x 25.67' x 3.04'

80 Chambers
334.0 cy Field
177.4 cy Stone





Pond 1P: Cultec 330XL HD



Summary for Pond 3P: 12" Perf

Inflow Area = 3,705 sf, 64.64% Impervious, Inflow Depth > 7.52" for 100-year event
Inflow = 0.70 cfs @ 12.07 hrs, Volume= 2,320 cf
Outflow = 0.66 cfs @ 12.10 hrs, Volume= 2,320 cf, Atten= 6%, Lag= 1.6 min
Discarded = 0.03 cfs @ 9.45 hrs, Volume= 1,123 cf
Primary = 0.63 cfs @ 12.10 hrs, Volume= 1,197 cf

Routing by Stor-Ind method, Time Span= 0.00-24.00 hrs, dt= 0.01 hrs
Peak Elev= 182.39' @ 12.10 hrs Surf.Area= 456 sf Storage= 114 cf

Plug-Flow detention time= 5.0 min calculated for 2,319 cf (100% of inflow)
Center-of-Mass det. time= 4.8 min (764.1 - 759.3)

Volume	Invert	Avail.Storage	Storage Description
#1A	181.76'	329 cf	**3.21'W x 142.00'L x 2.13'H Field A**
			969 cf Overall - 147 cf Embedded = 822 cf x 40.0% Voids
#2A	182.18'	113 cf	**ADS N-12 12"** x 7 Inside #1
			Inside= 12.2"W x 12.2"H => 0.81 sf x 20.00'L = 16.2 cf
			Outside= 14.5"W x 14.5"H => 1.05 sf x 20.00'L = 20.9 cf
		442 cf	Total Available Storage

Storage Group A created with Chamber Wizard

Device	Routing	Invert	Outlet Devices
#1	Discarded	181.76'	**2.410 in/hr Exfiltration over Surface area**
#2	Primary	181.76'	**12.0" Round Culvert**
			L= 50.0' CPP, projecting, no headwall, Ke= 0.900
			Inlet / Outlet Invert= 181.76' / 181.76' S= 0.0000 '/' Cc= 0.900
			n= 0.012, Flow Area= 0.79 sf

Discarded OutFlow Max=0.03 cfs @ 9.45 hrs HW=181.78' (Free Discharge)
↑—**1=Exfiltration** (Exfiltration Controls 0.03 cfs)

Primary OutFlow Max=0.63 cfs @ 12.10 hrs HW=182.39' (Free Discharge)
↑—**2=Culvert** (Barrel Controls 0.63 cfs @ 1.75 fps)

Pond 3P: 12" Perf - Chamber Wizard Field A

Chamber Model = ADS N-12 12" (ADS N-12® Pipe)
Inside= 12.2"W x 12.2"H => 0.81 sf x 20.00'L = 16.2 cf
Outside= 14.5"W x 14.5"H => 1.05 sf x 20.00'L = 20.9 cf

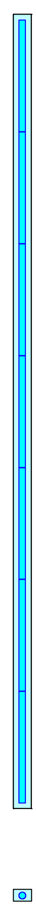
7 Chambers/Row x 20.00' Long = 140.00' Row Length +12.0" End Stone x 2 = 142.00' Base Length
1 Rows x 14.5" Wide + 12.0" Side Stone x 2 = 3.21' Base Width
5.0" Stone Base + 14.5" Chamber Height + 6.0" Stone Cover = 2.13' Field Height

7 Chambers x 16.2 cf = 113.4 cf Chamber Storage
7 Chambers x 20.9 cf = 146.5 cf Displacement

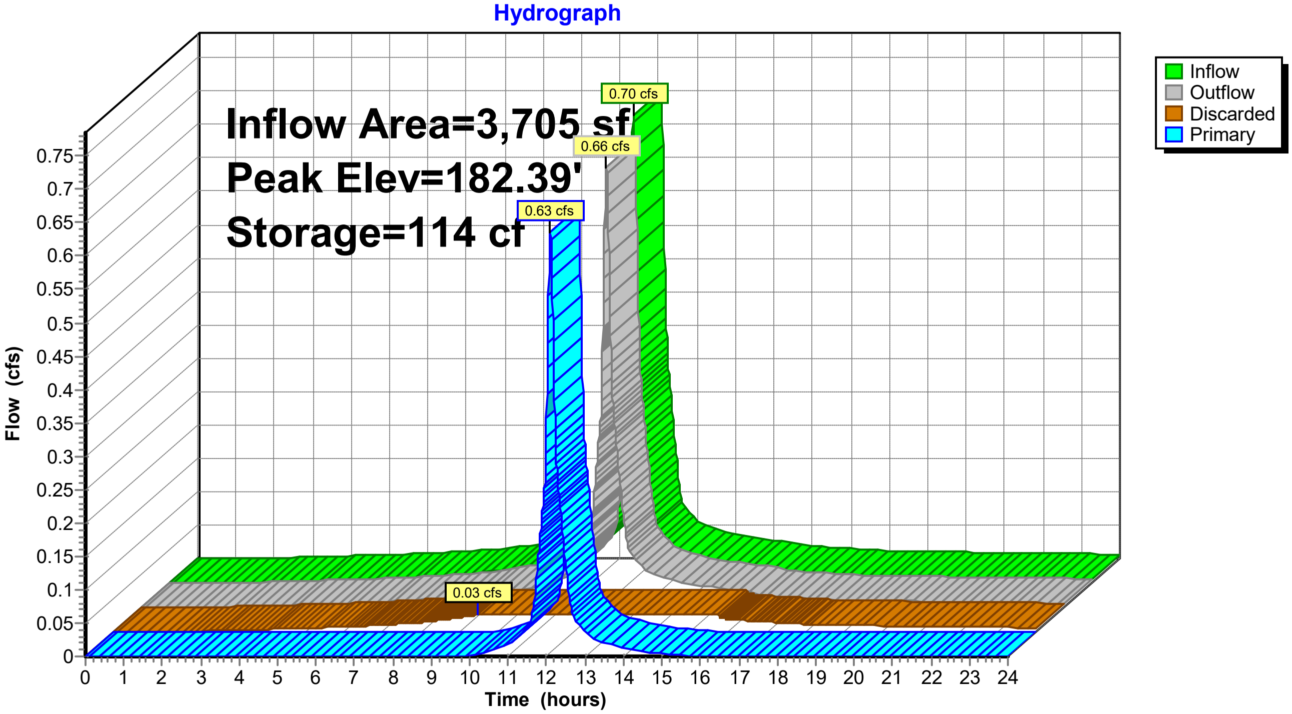
968.5 cf Field - 146.5 cf Chambers = 822.0 cf Stone x 40.0% Voids = 328.8 cf Stone Storage

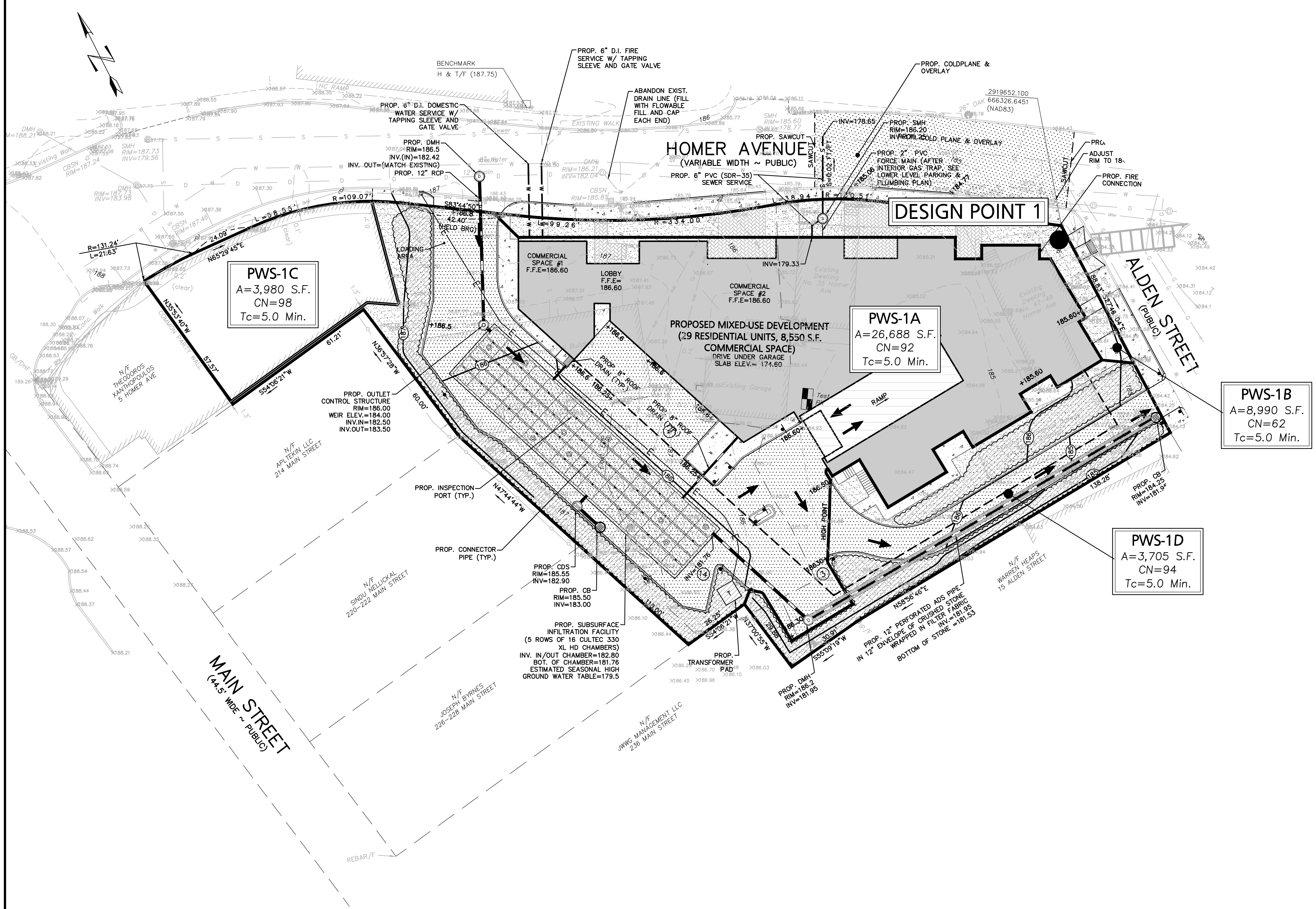
Chamber Storage + Stone Storage = 442.2 cf = 0.010 af
Overall Storage Efficiency = 45.7%
Overall System Size = 142.00' x 3.21' x 2.13'

7 Chambers
35.9 cy Field
30.4 cy Stone



Pond 3P: 12" Perf





DATE	DESCRIPTION OF REVISION
10/20/23	REVISE PER GCG COMMENT
9/20/23	REVISE PER GCG COMMENT
8/9/23	ISSUED FOR PLANNING BOARD REVIEW
7/28/23	MODIFIED PER PEER REVIEW COMMENTS

PREPARED BY:

Engineering Alliance, Inc.
Civil Engineering & Land Planning Consultants
194 Central Street
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Tel: (781) 231-1349
Fax: (781) 417-0020
1950 Lafayette Road
Portsmouth, NH 03801
Tel: (603) 6107100
Fax: (603) 6107101

PROJECT:

Site Plan
9-49 Homer Avenue
(Tax Map 14 Lots 352-354)
Ashland, Massachusetts

PROJECT #: 21-58508
DATE: April 1, 2021
SCALE: AS NOTED
DWG FILE NAME: 21-58508.dwg
DESIGN BY: Eric Bradanese, P.E.
CHECKED BY: Richard A. Salvo, P.E.

Professional Engineer for Engineering Alliance, Inc.

APPLICANT:
9-49 Homer Avenue, LLC
11 Plaid Road
Newton, MA 02459

DRAWING TITLE:
Proposed Watershed Plan

DWG. NO.
1of1

APPENDIX C

BMP Operation and Maintenance Plan

BEST MANAGEMENT PRACTICES MAINTENANCE PLAN

For The

Proposed Mixed Use Development

Located at

9 - 49 Homer Avenue

(Tax Map 14, Lots 352-354)

Ashland, Massachusetts

Submitted to:

Town of Ashland
101 Main Street
Ashland, MA 01721

Prepared for:

9-49 Homer Avenue, LLC
11 Placid Road
Newton, MA 02549

Prepared by:

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April 22, 2021
REVISED AUGUST 9, 2023

BEST MANAGEMENT PRACTICES MANAGEMENT PLAN

An Operations and Maintenance Plan is summarized below and will be incorporated into the construction documents for this project.

In accordance with the Stormwater Management Policy issued by the Department of Environmental Protection (DEP), Engineering Alliance, Inc. has prepared the following operation and maintenance plan for the proposed development located at 9-49 Homer Avenue (Tax Map 14 Lots 352-354) in Ashland, Massachusetts. This plan is broken into two major sections. The first section is construction-related erosion and sedimentation controls. The second section is devoted to a post-development operation and maintenance plan.

Basic Information

Owner: 9-49 Homer Avenue, LLC
11 Placid Road
Newton, MA 02549

In the event that the property ownership changes, this Operation and Maintenance Plan shall continue to run with the land and apply to any successors or assigns. Upon the conveyance of land, the Town of Ashland shall be notified in writing indicating the new ownership's contact information within 48 hours of the conveyance.

Prior to the conveyance of the property, an educational meeting shall be held between the current owner, the new owner and the parties responsible for the maintenance of the stormwater management facility. The purpose of the meeting will be to educate the new owner on the maintenance responsibilities for the stormwater management facility including, but not limited to:

- Description of system components
- Required maintenance of each component
- Frequency of maintenance of each component

This document shall be updated to indicate the time and date of the meeting as well as the contact information for the new property owner.

Time and Date of Educational Meeting: ______________________________

New Owner Information

____

____

____

____

Acknowledgement of Storm Water Management Maintenance Responsibilities:

______________________________ ____________________
Owner Signature Date

Acknowledgement of Storm Water Management Maintenance Responsibilities:

____ ____________________
Management Company Representative Signature Date

Maintenance Budget

A compounding annual budget of **$2,000 per year** shall be set aside to maintain and/or replace the stormwater management system. This budget shall cover the cost of:

- Parking Lot Sweeping
- Cleaning of Catch Basins, Outlet Structure & Water Quality Unit
- Cleaning of Roof Gutters, Downspouts and Roof Leaders
- Cleaning of Subsurface Infiltration Chambers
- Replacement of Porous Asphalt and Subsurface Infiltration System Stone Bed

Section 1 Construction Activities

1. Contact the Ashland Planning Department at least three (3) days prior to start of construction.
2. A stabilized construction entrance shall be established prior to construction. Vehicle wash down shall occur on the gravel surface that is adjacent to or part of the stabilized construction entrance.
3. Install straw waddles and silt fence around the proposed work zone to prevent sediment from leaving the subject property.
4. The contractor shall only disturb the minimum area necessary.
5. Proper erosion and sediment control must be employed around all material stockpile areas. Regular provisions for dust control must be used, via a water truck or other acceptable method.
6. The entire project area shall be swept upon completion of construction and prior to removal of the erosion control devices.

Section 2 Post-Development Activities

1. Paved Areas (Bituminous Concrete) - Paved areas shall be swept by street sweepers periodically during dry weather to remove excess sediments, reducing the amount of sediments that the drainage system will have to remove from the runoff. Salt for de-icing on the paved areas during the winter months should be limited as much as possible, as this will reduce the need for removal and treatment. Sand containing the minimum amount of calcium chloride (or approved equivalent) needed for handling may be applied as part of the routine winter maintenance activities. **At a minimum all paved areas must be swept two times annually, in the fall and in the spring.**

2. Catch Basins & Outlet Control Structure – Catch basins and Outlet Control Strucutrue shall be inspected monthly for the initial twelve-month period following the completion of the construction of the paved areas. Debris shall be removed from the catch basin grates, sumps and outlet pipes and disposed of in compliance with local, state and federal guidelines.

   Upon a period beginning twelve months after the completion of the site, all catch basins shall be inspected and maintained four times annually and should include once in April and once in November in addition to two other times throughout the year. Debris shall be removed from the catch basin grates, sumps and outlet pipes and disposed of in compliance with local, state and federal guidelines. Whenever the sediment deposit is greater than or equal to one half of the depth from the bottom of the invert of the lowest pipe, the system shall be cleaned.

3. Water Quality Manhole: Contech CDS unit with manhole cover should be maintained bi-annually, after a large rain event, and when sediment levels exceed maintenance volumes, as required by the manufacturer. **At a minimum, water quality manholes shall be serviced every spring and fall.**

4. Subsurface Infiltration Facility – The sub-surface infiltration system shall be inspected immediately following heavy rain events for the initial twelve-month period following the completion of construction. Should the system or stone surrounding the system become clogged, then the system must be vacuumed and stone must be replaced with washed stone. **After the initial twelve-month period following completion of construction, the subsurface infiltration facilities shall be inspected twice per year (once in the spring and once in the fall).**

5. Roof Drain Inlet, Roof Drain Gutter and Leader – The gutter system, downspout and drain leader shall be inspected a minimum of two times per year. The system shall be cleaned of any debris and the downspouts shall be jetted as required. Any debris collected shall be disposed of off-site in accordance with all Local, State and Federal requirements.

6. Snow removal and storage - Plowed snow shall be placed in the pervious area located along the parking lot, where it can slowly infiltrate. Sediments shall be removed from this area every spring. When the amount of snow exceeds the capacity of the snow storage areas, it shall be removed from the site and disposed of properly immediately after each storm at the owner's expense.

7. Pesticides, Herbicides, and Fertilizers **-** Pesticides and herbicides shall not be used within the limits of the 100-foot buffer zone to any wetland resource areas as defined under 310 CMR 10.00. In addition, fertilizers that are used within this zone should be restricted to the use of organic fertilizers only.

8. Maintenance Responsibilities **-** All post construction maintenance activities should be documented and kept on file and made available to the Conservation Commission upon request. All post construction maintenance activities shall survive the Order of Conditions and shall run with the title of the property.

All structural BMP's as identified on the site plans will be owned and maintained by the owner of the property until such time that an association is created to manage the maintenance responsibilities.

29 Unit Mixed Use development

9-49 Homer Avenue

Stormwater BMP Maintenance Log

BMP STRUCTURE	INSPECTOR (NAME)	WORK PERFORMED	DATE PERFORMED	COMMENTS
Parking Lot Sweeping				
Catch Basin				
Outlet Control Structure				
Roof Gutter				
Downspout				
Roof Leader				
Infiltration Facility				

Additional Comments:

APPENDIX D

Quality Structure Sizing Information
TSS Removal Calculations
Phosphorous (TP) Report
Illicit Discharge Statement

Hydrodynamic Separation Product Calculator

Homer Avenue

CDS-1

CDS 2015-4

Project Information					
Project Name	Homer Avenue			**Option #**	A
Country	UNITED_STATES	**State**	Massachusetts	**City**	Ashland

Contact Information			
First Name	Eric	**Last Name**	Bradanese
Company	Engineering Alliance, Inc.	**Phone #**	781-231-1349
Email	ebradanese@eaicivil.com		

Design Criteria					
Site Designation	CDS-1			**Sizing Method**	Net Annual
Screening Required?	No	**Drainage Area (ac)**	0.23	**Peak Flow (cfs)**	4.83
Groundwater Depth (ft)	5 - 10	**Pipe Invert Depth (ft)**	0 - 5	**Bedrock Depth (ft)**	10 - 15
Multiple Inlets?	No	**Grate Inlet Required?**	No	**Pipe Size (in)**	12.00
Required Particle Size Distribution?	No	**90° between two inlets?**	N/A	**180° between inlet and outlet?**	No
Runoff Coefficient	0.90	**Rainfall Station**	69 - Boston Airport, MA	**TC (Min)**	5

Treatment Selection					
Treatment Unit	CDS	**System Model**	2015-4		
Target Removal	80%	**Particle Size Distribution (PSD)**	125	**Predicted Net Annual Removal**	93.13%

Hydrodynamic Separation Product Calculator

Homer Avenue

CDS-1

CDS 2015-4

CDS ESTIMATED NET ANNUAL SOLIDS LOAD REDUCTION BASED ON THE RATIONAL RAINFALL METHOD								
Rainfall Intensity[1] (in/hr)	% Rainfall Volume[1]	Cumulative Rainfall Volume	Rainfall Volume Treated	Total Flowrate (cfs)	Treated Flowrate (cfs)	Operating Rate (%)	Removal Efficiency (%)	Incremental Removal (%)
0.0200	10.17%	10.17%	10.17%	0.0041	0.0041	0.59%	100.00%	10.17%
0.0400	9.65%	19.82%	9.65%	0.0083	0.0083	1.19%	100.00%	9.65%
0.0600	9.45%	29.27%	9.45%	0.0124	0.0124	1.77%	100.00%	9.45%
0.0800	7.74%	37.01%	7.74%	0.0166	0.0166	2.37%	100.00%	7.74%
0.1000	8.57%	45.58%	8.57%	0.0207	0.0207	2.96%	100.00%	8.57%
0.1200	6.30%	51.88%	6.30%	0.0248	0.0248	3.54%	100.00%	6.30%
0.1400	4.66%	56.54%	4.66%	0.0290	0.0290	4.14%	100.00%	4.66%
0.1600	4.64%	61.18%	4.64%	0.0331	0.0331	4.73%	100.00%	4.64%
0.1800	3.54%	64.72%	3.54%	0.0373	0.0373	5.33%	100.00%	3.54%
0.2000	4.34%	69.06%	4.34%	0.0414	0.0414	5.91%	100.00%	4.34%
0.2500	8.00%	77.06%	8.00%	0.0518	0.0518	7.40%	99.93%	7.99%
0.3000	5.59%	82.65%	5.59%	0.0621	0.0621	8.87%	99.64%	5.57%
0.3500	4.37%	87.02%	4.37%	0.0725	0.0725	10.36%	99.34%	4.34%
0.4000	2.53%	89.55%	2.53%	0.0828	0.0828	11.83%	99.04%	2.51%
0.4500	2.53%	92.08%	2.53%	0.0932	0.0932	13.31%	98.75%	2.50%
0.5000	1.38%	93.46%	1.38%	0.1035	0.1035	14.79%	98.45%	1.36%
0.7500	5.04%	98.50%	5.04%	0.1553	0.1553	22.19%	96.97%	4.89%
1.0000	1.01%	99.51%	1.01%	0.2070	0.2070	29.57%	95.49%	0.96%
1.5000	0.00%	99.51%	0.00%	0.3105	0.3105	44.36%	92.53%	0.00%
2.0000	0.00%	99.51%	0.00%	0.4140	0.4140	59.14%	89.58%	0.00%
3.0000	0.48%	99.99%	0.48%	0.6210	0.6210	88.71%	83.66%	0.40%
								99.58%
Removal Efficiency Adjustment[2] =								6.45%
Predicted % Annual Rainfall Treated =								93.54%
Predicted Net Annual Load Removal Efficiency =								93.13%
1 - Based on 10 years of hourly precipitation data from NCDC Station 770, Boston WSFO AP, Suffolk County, MA								
2 - Reduction due to use of 60-minute data for a site that has a time of concentration less than 30-minutes.								

SECTION (_____)
STORM WATER TREATMENT DEVICE

1.0 GENERAL

1.1 This item shall govern the furnishing and installation of the CDS® by Contech Engineered Solutions LLC, complete and operable as shown and as specified herein, in accordance with the requirements of the plans and contract documents.

1.2 The Contractor shall furnish all labor, equipment and materials necessary to install the storm water treatment device(s) (SWTD) and appurtenances specified in the Drawings and these specifications.

1.3 The manufacturer of the SWTD shall be one that is regularly engaged in the engineering design and production of systems deployed for the treatment of storm water runoff for at least five (5) years and which have a history of successful production, acceptable to the Engineer. In accordance with the Drawings, the SWTD(s) shall be a CDS® device manufactured by:

Contech Engineered Solutions LLC
9025 Centre Pointe Drive
West Chester, OH, 45069
Tel: 1 800 338 1122

1.4 Related Sections

1.4.1 Section 02240: Dewatering
1.4.2 Section 02260: Excavation Support and Protection
1.4.3 Section 02315: Excavation and Fill
1.4.4 Section 02340: Soil Stabilization

1.5 All components shall be subject to inspection by the engineer at the place of manufacture and/or installation. All components are subject to being rejected or identified for repair if the quality of materials and manufacturing do not comply with the requirements of this specification. Components which have been identified as defective may be subject for repair where final acceptance of the component is contingent on the discretion of the Engineer.

1.6 The manufacturer shall guarantee the SWTD components against all manufacturer originated defects in materials or workmanship for a period of twelve (12) months from the date the components are delivered to the owner for installation. The manufacturer shall upon its determination repair, correct or replace any manufacturer originated defects advised in writing to the manufacturer within the referenced warranty period. The use of SWTD components shall be limited to the application for which it was specifically designed.

1.7 The SWTD manufacturer shall submit to the Engineer of Record a "Manufacturer's Performance Certification" certifying that each SWTD is capable of achieving the specified removal efficiencies listed in these specifications. The certification shall be supported by independent third-party research

1.8 No product substitutions shall be accepted unless submitted 10 days prior to project bid date, or as directed by the Engineer of Record. Submissions for substitutions require review and approval by the Engineer of Record, for hydraulic performance, impact to project designs, equivalent treatment performance, and any required project plan and report (hydrology/hydraulic, water quality, stormwater pollution) modifications that would be required by the approving jurisdictions/agencies. Contractor to coordinate with the Engineer of Record any applicable modifications to the project estimates of cost, bonding amount determinations, plan check fees for changes to approved documents, and/or any other regulatory requirements resulting from the product substitution.

2.0 MATERIALS

2.1 Housing unit of stormwater treatment device shall be constructed of pre-cast or cast-in-place concrete, no exceptions. Precast concrete components shall conform to applicable sections of ASTM C 478, ASTM C 857 and ASTM C 858 and the following:

- 2.1.1 Concrete shall achieve a minimum 28-day compressive strength of 4,000 pounds per square-inch (psi);
- 2.1.2 Unless otherwise noted, the precast concrete sections shall be designed to withstand lateral earth and AASHTO H-20 traffic loads;
- 2.1.3 Cement shall be Type III Portland Cement conforming to ASTM C 150;
- 2.1.4 Aggregates shall conform to ASTM C 33;
- 2.1.5 Reinforcing steel shall be deformed billet-steel bars, welded steel wire or deformed welded steel wire conforming to ASTM A 615, A 185, or A 497.
- 2.1.6 Joints shall be sealed with preformed joint sealing compound conforming to ASTM C 990.
- 2.1.7 Shipping of components shall not be initiated until a minimum compressive strength of 4,000 psi is attained or five (5) calendar days after fabrication has expired, whichever occurs first.

2.2 Internal Components and appurtenances shall conform to the following:

- 2.2.1 Screen and support structure shall be manufactured of Type 316 and 316L stainless steel conforming to ASTM F 1267-01;
- 2.2.2 Hardware shall be manufactured of Type 316 stainless steel conforming to ASTM A 320;
- 2.2.3 Fiberglass components shall conform to applicable sections of ASTM D-4097
- 2.2.4 Access system(s) conform to the following:
- 2.2.5 Manhole castings shall be designed to withstand AASHTO H-20 loadings and manufactured of cast-iron conforming to ASTM A 48 Class 30.

3.0 PERFORMANCE

3.1 The SWTD shall be sized to either achieve an 80 percent average annual reduction in the total suspended solid load with a particle size distribution having a mean particle size (d_{50}) of 125 microns unless otherwise stated.

3.2 The SWTD shall be capable of capturing and retaining 100 percent of pollutants greater than or equal to 2.4 millimeters (mm) regardless of the pollutant's specific gravity (i.e.: floatable and neutrally buoyant materials) for flows up to the device's rated-treatment capacity. The SWTD shall be designed to retain all previously captured pollutants addressed by this subsection under all flow conditions. The SWTD shall be capable of capturing and retaining total petroleum hydrocarbons. The SWTD shall be capable of achieving a removal efficiency of 92 and 78 percent when the device is operating at 25 and 50 percent of its rated-treatment capacity. These removal efficiencies shall be based on independent third-party research for influent oil concentrations representative of storm water runoff (20 ± 5 mg/L). The SWTD shall be greater than 99 percent effective in controlling dry-weather accidental oil spills.

3.3 The SWTD shall be designed with a sump chamber for the storage of captured sediments and other negatively buoyant pollutants in between maintenance cycles. The minimum storage capacity provided by the sump chamber shall be in accordance with the volume listed in Table 1. The boundaries of the sump chamber shall be limited to that which do not degrade the SWTD's treatment efficiency as captured pollutants accumulate. The sump chamber shall be separate from the treatment processing portion(s) of the SWTD to minimize the probability of fine particle re-suspension. In order to not restrict the Owner's ability to maintain the SWTD, the minimum dimension providing access from the ground surface to the sump chamber shall be 16 inches in diameter.

3.4 The SWTD shall be designed to capture and retain Total Petroleum Hydrocarbons generated by wet-weather flow and dry-weather gross spills and have a capacity listed in Table 1 of the required unit.

3.5 The SWTD shall convey the flow from the peak storm event of the drainage network, in accordance with required hydraulic upstream conditions as defined by the Engineer. If a substitute SWTD is proposed, supporting documentation shall be submitted that demonstrates equal or better upstream hydraulic conditions compared to that specified herein. This documentation shall be signed and sealed by a Professional Engineer registered in the State of the work. All costs associated with preparing and certifying this documentation shall be born solely by the Contractor.

3.6 The SWTD shall have completed field tested following TARP Tier II protocol requirements

4.0 <u>EXECUTION</u>

4.1 The contractor shall exercise care in the storage and handling of the SWTD components prior to and during installation. Any repair or replacement costs associated with events occurring after delivery is accepted and unloading has commenced shall be borne by the contractor.

4.2 The SWTD shall be installed in accordance with the manufacturer's recommendations and related sections of the contract documents. The manufacturer shall provide the contractor installation instructions and offer on-site guidance during the important stages of the installation as identified by the manufacturer at no additional expense. A minimum of 72 hours notice shall be provided to the manufacturer prior to their performance of the services included under this subsection.

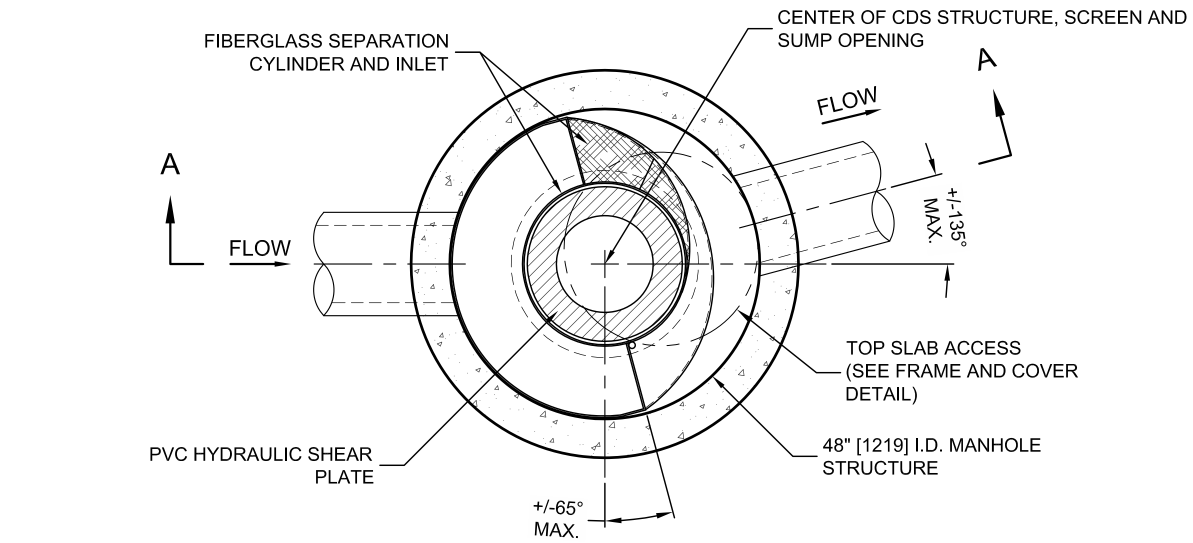
4.3 The contractor shall fill all voids associated with lifting provisions provided by the manufacturer. These voids shall be filled with non-shrinking grout providing a finished surface consistent with adjacent surfaces. The contractor shall trim all protruding lifting provisions flush with the adjacent concrete surface in a manner, which leaves no sharp points or edges.

4.4 The contractor shall removal all loose material and pooling water from the SWTD prior to the transfer of operational responsibility to the Owner.

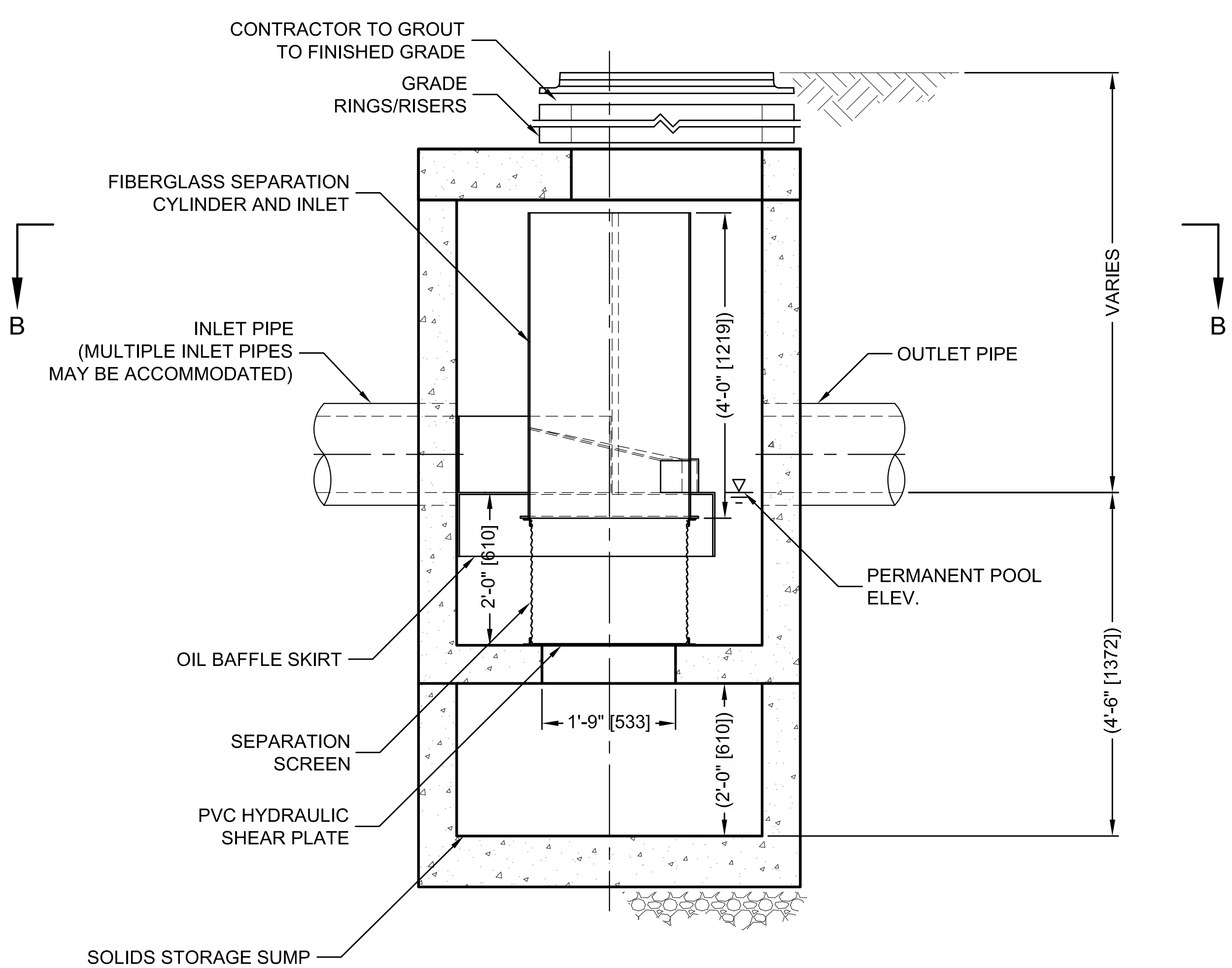
TABLE 1
Storm Water Treatment Device
Storage Capacities

CDS Model	Minimum Sump Storage Capacity $(yd^3)/(m^3)$	Minimum Oil Storage Capacity (gal)/(L)
CDS2015-4	0.9(0.7)	61(232)
CDS2015-5	1.5(1.1)	83(313)
CDS2020-5	1.5(1.1)	99(376)
CDS2025-5	1.5(1.1)	116(439)
CDS3020-6	2.1 (1.6)	184(696)
CDS3025-6	2.1(1.6)	210(795)
CDS3030-6	2.1 (1.6)	236(895)
CDS3035-6	2.1 (1.6)	263(994)
CDS3535-7	2.9(2.2)	377(1426)
CDS4030-8	5.6(4.3)	426(1612)
CDS4040-8	5.6 (4.3)	520(1970)
CDS4045-8	5.6 (4.3)	568(2149)
CDS5640-10	8.7(6.7)	758(2869)
CDS5653-10	8.7(6.7)	965(3652)
CDS5668-10	8.7(6.7)	1172(4435)
CDS5678-10	8.7(6.7)	1309(4956)
CDS7070-DV	3.6(2.8)	914 (3459)
CDS10060-DV	5.0 (3.8)	792 (2997)
CDS10080-DV	5.0 (3.8)	1057 (4000)
CDS100100-DV	5.0 (3.8)	1320 (4996)

END OF SECTION



PLAN VIEW B-B
N.T.S.



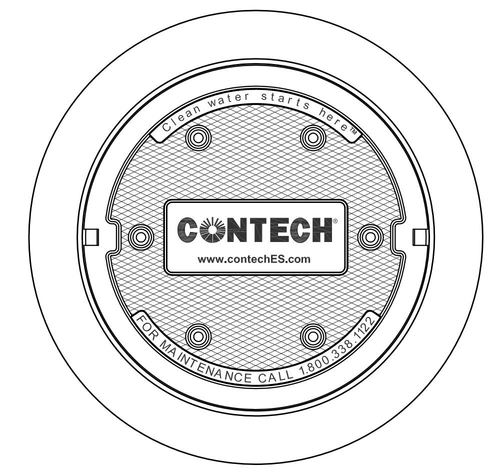
ELEVATION A-A
N.T.S.

THIS PRODUCT MAY BE PROTECTED BY ONE OR MORE OF THE FOLLOWING U.S. PATENTS: 5,788,848; 6,641,720; 6,511,595; 6,581,783; RELATED FOREIGN PATENTS, OR OTHER PATENTS PENDING.

CDS2015-4-C DESIGN NOTES

THE STANDARD CDS2015-4-C CONFIGURATION IS SHOWN. ALTERNATE CONFIGURATIONS ARE AVAILABLE AND ARE LISTED BELOW. SOME CONFIGURATIONS MAY BE COMBINED TO SUIT SITE REQUIREMENTS.

CONFIGURATION DESCRIPTION
GRATED INLET ONLY (NO INLET PIPE)
GRATED INLET WITH INLET PIPE OR PIPES
CURB INLET ONLY (NO INLET PIPE)
CURB INLET WITH INLET PIPE OR PIPES
SEPARATE OIL BAFFLE (SINGLE INLET PIPE REQUIRED FOR THIS CONFIGURATION)
SEDIMENT WEIR FOR NJDEP / NJCAT CONFORMING UNITS



FRAME AND COVER
(DIAMETER VARIES)
N.T.S.

SITE SPECIFIC DATA REQUIREMENTS

STRUCTURE ID			
WATER QUALITY FLOW RATE (CFS OR L/s)			*
PEAK FLOW RATE (CFS OR L/s)			*
RETURN PERIOD OF PEAK FLOW (YRS)			*
SCREEN APERTURE (2400 OR 4700)			*
PIPE DATA:	I.E.	MATERIAL	DIAMETER
INLET PIPE 1	*	*	*
INLET PIPE 2	*	*	*
OUTLET PIPE	*	*	*
RIM ELEVATION			*
ANTI-FLOTATION BALLAST		WIDTH	HEIGHT
		*	*
NOTES/SPECIAL REQUIREMENTS:			

* PER ENGINEER OF RECORD

GENERAL NOTES
1. CONTECH TO PROVIDE ALL MATERIALS UNLESS NOTED OTHERWISE.
2. DIMENSIONS MARKED WITH ( ) ARE REFERENCE DIMENSIONS. ACTUAL DIMENSIONS MAY VARY.
3. FOR FABRICATION DRAWINGS WITH DETAILED STRUCTURE DIMENSIONS AND WEIGHTS, PLEASE CONTACT YOUR CONTECH ENGINEERED SOLUTIONS LLC REPRESENTATIVE. www.contechES.com
4. CDS WATER QUALITY STRUCTURE SHALL BE IN ACCORDANCE WITH ALL DESIGN DATA AND INFORMATION CONTAINED IN THIS DRAWING.
5. STRUCTURE SHALL MEET AASHTO HS20 AND CASTINGS SHALL MEET HS20 (AASHTO M 306) LOAD RATING, ASSUMING GROUNDWATER ELEVATION AT, OR BELOW, THE OUTLET PIPE INVERT ELEVATION. ENGINEER OF RECORD TO CONFIRM ACTUAL GROUNDWATER ELEVATION.
6. PVC HYDRAULIC SHEAR PLATE IS PLACED ON SHELF AT BOTTOM OF SCREEN CYLINDER. REMOVE AND REPLACE AS NECESSARY DURING MAINTENANCE CLEANING.

INSTALLATION NOTES
A. ANY SUB-BASE, BACKFILL DEPTH, AND/OR ANTI-FLOTATION PROVISIONS ARE SITE-SPECIFIC DESIGN CONSIDERATIONS AND SHALL BE SPECIFIED BY ENGINEER OF RECORD.
B. CONTRACTOR TO PROVIDE EQUIPMENT WITH SUFFICIENT LIFTING AND REACH CAPACITY TO LIFT AND SET THE CDS MANHOLE STRUCTURE (LIFTING CLUTCHES PROVIDED).
C. CONTRACTOR TO ADD JOINT SEALANT BETWEEN ALL STRUCTURE SECTIONS, AND ASSEMBLE STRUCTURE.
D. CONTRACTOR TO PROVIDE, INSTALL, AND GROUT PIPES. MATCH PIPE INVERTS WITH ELEVATIONS SHOWN.
E. CONTRACTOR TO TAKE APPROPRIATE MEASURES TO ASSURE UNIT IS WATER TIGHT, HOLDING WATER TO FLOWLINE INVERT MINIMUM. IT IS SUGGESTED THAT ALL JOINTS BELOW PIPE INVERTS ARE GROUTED.

CONTECH ENGINEERED SOLUTIONS LLC
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9025 Centre Pointe Dr., Suite 400, West Chester, OH 45069
800-338-1122 513-645-7000 513-645-7993 FAX

CDS2015-4-C
INLINE CDS
STANDARD DETAIL

Engineering Alliance, Inc.
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194 Central Street
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1950 Lafayette Road
Portsmouth, NH 03801
Tel: (603) 610-7100
Fax: (603) 610-7101

TSS Removal Calculations

Name: Proposed Mixed Use Development
Ashland, MA
Client: Legacy

Proj. No.: 21-58508
Date: 8/9/2023
Computed by: CR
Checked by: RAS

A BMP	B TSS Removal Rate	C Starting TSS Load*	D Amount Removed (BxC)	E Remaining Load (C-D)
Street Sweeping	10	1.00	0.1	0.90
Deep Sump Hooded Catch Basins	25	0.90	0.23	0.68
CDS UNIT	93.13	0.68	0.63	0.05

Infiltration Basin Total TSS Removal= 95%

Notes:
*Starting TSS Load for first BMP= 1.00. TSS load for subsequent BMP's is equal to the Remaining Load (E) from the previous BMP.

VORTECHNICS TREATMENT OF PARKING LOT RUNOFF

Susan Mary Board

B.S., University of Connecticut, 1999

A Thesis
Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Science
At the University of Connecticut
2001

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LITERATURE REVIEW

VORTECHNICS™ TREATMENT OF PARKING LOT RUNOFF

INTRODUCTION

A 27-month study was conducted to determine the efficiency of a Vortechnics™ unit in treating parking lot runoff. This study is the longest continuously monitored evaluation of a Vortechnics™ unit to date. The performance of the unit in retaining total suspended solids, nitrogen, phosphorus, heavy metals, bacteria, and petroleum hydrocarbons from parking lot runoff was assessed. Sampling techniques are also compared.

This thesis has two sections. The first is a literature review that discusses urban runoff, pollutants found in urban runoff, and the operating system of Vortechnics™ units. The second section is a manuscript entitled "Vortechnics™ Treatment of Parking Lot Runoff", which was written following the format specified by the journal *Environmental Science and Technology*. The manuscript discusses the efficiency of a Vortechnics™ unit in treating parking lot runoff during the 27-month study.

LITERATURE REVIEW

VORTECHNICS™ TREATMENT OF PARKING LOT RUNOFF

INTRODUCTION

The passage of the Clean Water Act in 1972 established the National Pollution Discharge Elimination System (NPDES) to regulate pollutants from industrial and municipal point sources. In 1987, the Clean Water Act was amended to include stormwater discharges. These discharges are frequently carriers of nonpoint source pollution. According to the Environmental Protection Agency (US EPA, 1983), nonpoint source pollution represents more than half of the remaining water quality problems in the United States. Nonpoint source pollution contributes bacteria, sediment, nutrients, and toxic materials to Long Island Sound (US EPA, 1991). This pollution originates from precipitation, imperviousness (accumulation and washoff), dry atmospheric deposition, traffic emissions, leaching, solids accumulation in sewers, discharges from cars, and application of fertilizers (Smolen *et al.*, 1990). Nonpoint source pollution is also known as diffuse pollution and includes urban runoff, wet and dry atmospheric deposition, and activities on land that generate wastes and contaminants (Novotny and Olem, 1994).

Stormwater management objectives concentrate on protecting the beneficial uses of water, developing a watershed-wide approach, involving the stakeholders, and meeting regulations (Roesner *et al*., 1998). Stormwater management focuses on impervious surfaces found mainly in urban areas. Currently, 16% of the land cover in Connecticut is classified as urban (CT DEP, 1997). After agriculture, pollutant loadings from runoff of urban areas were the most frequent problem reported by states from Section 305(b) of the Clean Water Act (US

EPA, 1998). In areas with storm sewers, all of the pollution on impervious surfaces that has not been removed by street cleaning, wind, or decay will end up in surface runoff (Smolen *et al*., 1990). The pollutants accumulate in the watershed over time, and loading tends to be chronic rather than episodic (DE DNR, 1997). Higher amounts of runoff increase the potential for nonpoint source pollution. Myers *et al*. (1985) reported that in Connecticut, agriculture and irrigation were localized problems, with less than half of the waters affected, whereas construction and urbanization were identified as widespread problems, and fifty percent or more of the waters were affected.

Parking Lots

Arnold and Gibbons (1996) stated that developers consistently build 51% more parking spaces than needed. Parking lots were identified by Bannerman *et al*. (1993) as critical sources of pollutant loads. Steuer *et al*. (1997) found parking lots to have the highest concentrations of polycyclic aromatic hydrocarbon (PAH) compounds. The most extremely toxic samples were found in combined sewer overflows as reported by Novotny (1991), followed by parking lot runoff. Schueler (1994) classified parking lots as hotspots; areas with significantly greater loadings of hydrocarbons and trace metals. The Long Island Sound Study began out of concern that urbanization, particularly parking lots and highways, increases the pollutants added to the Sound (CT DEP, 1989). Pitt *et al*. (1995) found that parking lot runoff contained the highest observed concentrations of organic toxicants. Parking lots were identified as sources of high amounts of metals, including copper, lead, and zinc (Line *et al*., 1996; Owe *et al*., 1982). The EPA (1993) reported that impervious surfaces act as heat collectors, and stated that intensive urbanization can increase stream temperature as much as 5-10°C during storm events.

The objectives of this literature review are to: 1) describe typical urban stormwater pollutants in runoff, and 2) assess a Vortechnics™ unit and its ability to retain these stormwater pollutants.

URBAN RUNOFF

Urban runoff is frequently a major source of contaminants, and the storm sewers associated with runoff decrease the opportunity for infiltration and create a very efficient system of deliverance for stormwater (Baumann *et al*., 1980). Urbanization is linked to the degradation of urban waterways (US EPA, 1993). The word stormwater encompasses many types of runoff: snowmelt runoff, stormwater runoff, surface runoff, and street wash waters related to street cleaning or maintenance (Smolen *et al*., 1990). Roesner *et al.* (1998) described pollutants as being constituents in stormwater runoff that have concentrations and discharges that cause an impairment of designated beneficial uses of receiving waters.

According to Novotny and Olem (1994), soil erosion from all areas is the major cause of diffuse pollution. Sediment yields from urban areas can reach values up to 50,000 tonnes^{-1} km^{-2} yr^{-1}. Sediment is a primary carrier of metals, ammonium ions, phosphates, and organic toxics, all of which are pollutants of concern to US waterbodies (Novotny and Olem, 1994). Pollutants such as these are known as critical: they occur frequently in urban stormwater and their concentrations are high relative to the EPA's water quality criteria (US EPA, 1991).

Critical pollutants impact water in a number of ways: by physical impairment or habitat disruption to biota, enrichment and subsequent eutrophication of receiving waters, and exposure and physiological response to toxic substances by aquatic biota (US EPA, 1991).

Impervious materials such as asphalt prevent water from soaking into the ground (US EPA, 1989). Streets paved with asphalt have 80% higher loadings of pollutants, such as total solids, than concrete (Novotny and Olem, 1994). Runoff from nonpoint sources contributes the most waterborne lead, iron, and suspended solids to Long Island Sound and is a major source of nutrients, heavy metals, and pesticides (US EPA, 1989). Heavy metals are the most prevalent priority pollutants in urban runoff, and coliform bacteria are present at high levels (US EPA, 1983).

From 1978 to 1983, the EPA conducted a five-year study to assess the quality of loads in urban runoff. The study, which involved monitoring 28 sampling sites across the country, was titled the Nationwide Urban Runoff Program (NURP). The NURP studies evaluated the event mean concentrations (EMCs), defined as the total constituent mass discharge divided by the total runoff volume during a storm event (US EPA, 1983). Comparisons between NURP and two other studies of parking lot runoff are found on Table 1. NURP data indicates higher fecal coliform amounts than the other three studies. Also, the median lead and zinc concentrations are higher. Steuer et al. (1997) reported the highest

	Median Event Mean Concentrations			
Pollutant	**EPA, 1983**	**Bannerman et al., 1993**	**Rabanal and Grizzard, 1995**	**Steuer et al., 1997**
TSS (mg L^{-1})	69	58	20.8	138
TKN (mg L^{-1})	1.179	----	1.94	1.50
TP (mg L^{-1})	0.201	0.19	0.27	0.21
NH_3-N (mg L^{-1})	----	----	0.02	0.19
NO_3-N (mg L^{-1})	0.572	----	0.28	0.30
FC (FCU 100ml^{-1})	12000	1758	----	4200
Total Cu (ug L^{-1})	29	15	10.2	25
Total Pb (ug L^{-1})	104	22	6.9	40
Total Zn (ug L^{-1})	226	178	144	178
TPH (mg L^{-1})			7.0	

Table 1. Pollutant concentrations for urban land use.

concentration of total suspended solids, followed by NURP. Total Kjeldahl nitrogen and total phosphorus concentrations are similar in every study.

First Flush Effect

Novotny and Olem (1994) stated that first flush occurred when concentrations of pollutants peaked before the peak of the hydrograph. In some studies, first flush is the first inch of runoff and carries 90% of the pollution (FL DEP, 1988). Chang *et al*. (1998) described first flush as the first 0.25 in of runoff, observing highly impervious (>90%) areas. The study reported that the first half-inch carries 40% of the total storm load. Table 2 lists common stormwater pollutants that exhibit the first flush effect, together with their sources.

Common stormwater pollutants studied by researchers are: total suspended solids (TSS), total Kjeldahl nitrogen (TKN), total phosphorus (TP), nitrate+nitrite-nitrogen (NO_3-N), ammonia-nitrogen (NH_3-N), total copper (Cu), total lead (Pb), total zinc (Zn), fecal coliform bacteria (FC), and total petroleum hydrocarbons (TPH). Each of these, along with the sources of these pollutants, is listed on Table 3. The following sections describe each pollutant and explain each pollutant's importance.

Total Suspended Solids

Total suspended solids is a common stormwater pollutant, mainly because of its ability to transport other pollutants that are attached to it, including nutrients, metals, and hydrocarbons (ASCE, 1994; Makepeace *et al*., 1995). Sediment can also cover and

Table 2. Stormwater pollutants and references to first flush.

Pollutant	Reference
TSS	A, B, E, H, K, M
NH_3-N	B, I, J
NO_3-N	B, J
TKN	B, J, K
TP	B, J
FC	B, C
Cu	B, D, J, L
Pb	B, D, J
Zn	B, D, J, L
TPH	F, G

A: Adams and Strong, 1997
B: Chang *et al*., 1998
C: Davis *et al*., 1977
D: Good, 1993
E: Griffin *et al*., 1980
F: Hoffman *et al*., 1982
G: Hunter *et al*., 1979
H: Novotny, 1991
I: Pitt and Field, 1998
J: Randall *et al*., 1981
K: Richards *et al*., 1981
L: Sansalone and Buchberger, 1997
M: Sartor *et al*., 1974

Table 3. Sources and effects of stormwater pollutants (CT DEP, 1995)

Pollutant	**Sources**	**Effects**
Sediment	parking lot runoff	detrimental to aquatic life
TSS	landscaping practices	adversely affect fish and wildlife
	industrial activities	transports other pollutants
	construction activities	recreation/aesthetic loss
Nutrients	parking lot runoff	excessive growth of vegetation and algae which leads to eutrophication
NH_3-N	landscaping activities	contributes to hypoxia
NO_3-N	industrial activities	
TKN	construction activities	
TP	illegal dumping	
Bacteria	parking lot runoff	beach and shellfish closures
FC	landscaping practices	human infection
	construction activities	
	illegal dumping	
Oil and Grease	parking lot runoff	beach closures
TPH	landscaping practices	adversely affect lake, pond, and wetland ecology
	industrial activities	
	construction activities	
	illegal dumping	
Heavy Metals	parking lot runoff	toxic to aquatic life
Cu	landscaping practices	bioaccumulate in food chain
Pb	industrial activities	contamination of drinking water, including groundwater
Zn	construction activities	
	illegal dumping	

destroy an aquatic biological community and fill up lakes and impoundments (Baumann *et al*, 1980). Suspended sediment and turbidity are detrimental to aquatic life because they interfere with photosynthesis, respiration, growth, and reproduction (US EPA, 1991). Siltation also impacts receiving waters through loss of benthic habitat, reduced water storage capacity, impaired oxygen exchange, decreased light penetration, and increased water treatment costs (ASCE, 1994; US EPA, 1993). Compared to treatment plant discharges, urban runoff contributes high levels of TSS to receiving waterbodies (US EPA, 1983).

Griffin *et al*. (1980) reported that suspended sediment generally exhibits the first flush phenomena. This is confirmed by Sansalone and Buchberger (1997), who reported that all solids exhibit a first flush. Novotny (1991) studied first flush in sewer systems and found that if suspended solids are extensive in a drainage system, peak concentration and pollutant loads will precede peak flow and volume. Therefore, TSS contributes to the first flush effect (Table 2).

There is a significant correlation between the concentration of heavy metals and particle sizes, particularly small particles (<15 μm) (Sansalone *et al*., 1995). Baumann *et al*. (1980) reported between 70% and 90% of total phosphorus and lead is found on fine, clay-sized fractions. Renwick and Edenborn (1983) correlated metal concentration with sediment size, stating that finer sediments are more likely to have higher levels of organic matter. Organic matter can readily adsorb metals, as well as provide nutrients for bacteria. Sartor *et al*. (1974) found thirty to fifty percent of nutrients and slightly over half of metals were associated with smaller particle sizes (<43μm). The EPA (1991) reported that toxics attached to suspended sediment in discharge may accumulate in the bottom sediment of receiving waters where they may persist for a long time.

Since Vortechnics™ units are designed to remove 80% TSS from runoff, the amount of toxins, metals, phosphorus, and bacteria in stormwater is potentially reduced.

Nitrogen

Nitrogen has led to hypoxia problems in Long Island Sound, because increased N concentrations contribute to the growth of algae in estuaries (CT DEP, 1995; Frink, 1991; US EPA, 1991). Nitrogen occurs in many forms, including organic-N, NH_3-N, NO_3-N, and total Kjeldahl-N. NO_3-N is most readily used by plants and the most mobile (Smolen *et al.*, 1990). Line *et al*. (1996) reported that nitrate concentrations in streams were highest downstream of urban areas; however, the drinking water standard of 10 mg L^{-1} was rarely exceeded. NH_3-N is very toxic to aquatic organisms above 7 mg L^{-1} (Makepeace *et al*., 1995). The forms of nitrogen in stormwater and their ranges in concentrations reported by Makepeace *et al*. (1995) are listed in Table 4. Frink (1991) estimated the nutrient exports to estuaries, concluding that exports of N and P from urban land are underestimated.

The NURP study evaluated TN in urban stormwater and estimated an EMC of 3.31 mg L^{-1} (US EPA, 1983). Chesters and Schierow (1985) stated that more than 90% of total nitrogen in urban stormwater comes from nonpoint source pollution, and Line *et al*.

Table 4. Nitrogen forms and concentrations in stormwater (Makepeace *et al*., 1995)

Forms of Nitrogen	Stormwater Range (mg/l)
TN	0.32-16.00
Inorganic N	0.09-5.44
Organic N	0.32-16.00
NO_3-N	0.01-12.00
NO_2-N	0.02-1.49
NH_3-N	0.01-4.30
TKN	0.32-16.00

(1997) reported the figure as 94%. There is an abrupt increase in total nitrogen when the imperviousness of a site increases past 40-50% of the total land area in a watershed (Griffin *et al*., 1980).

Nitrogen sources include the atmosphere, with more than 2.9 metric tons deposited a year in the U.S. (Puckett, 1995). Randall *et al*. (1981) reported an areal loading range for TKN of 0.002 to 0.03 kg ha^{-1}. Yang *et al.* (1996) estimated 8.3 kg ha^{-1} yr^{-1} wet and dry N deposition in CT. Puckett (1995) stated that deposition occurs primarily in the northeastern states, and 38% of this atmospheric source can be attributed to automobiles, trucks, and buses. The largest sources of nitrogen were from predominantly urban watersheds.

Nitrogen eventually washes off surfaces on which it has deposited in the early stages of precipitation and enters the hydrologic cycle through runoff (Randall *et al*., 1981). Nitrogen in urban runoff exhibits the effects of first flush (Table 2). Halverson et al. (1984) reported that precipitation contributed most of the nitrogen found in runoff from roofs and paved surfaces.

Phosphorus

Sources of phosphorus in stormwater include tree leaves, fertilizers, industrial wastes, detergents, and lubricants (Makepeace *et al*., 1995). Lubricants are typically used in vehicles, which links P to parking lots. Total P in stormwater has been found at a concentration range of 0.01 to 7.30 mg L^{-1} (Makepeace *et al*., 1995). Increased P concentrations contribute to the acceleration of eutrophication in lakes (Frink, 1991).

Novotny and Olem (1994) discussed cohesive sediments, describing them as the clay and organic fractions of washload. Cohesive sediments effectively adsorb pollutants such as phosphates (Novotny and Olem, 1994). The ASCE (1994) stated that nutrients attached to sediments delivered during storm events may eventually settle out and later be resuspended.

Total P is deposited onto surfaces by the atmosphere with an areal loading range of $1.6 \times 10^{-5} - 2.5 \times 10^{-4}$ kg ha^{-1} (Randall *et al*., 1981). In CT, P deposition is estimated around 0.042 kg ha^{-1} yr^{-1} (Yang *et al*., 1996). Phosphorus moves by adsorption or in solution (Smolen *et al*., 1990), and also exhibits first flush (Table 2). Typically, P is the most important nutrient to control in freshwaters while nitrogen is limiting in coastal waters (Frink, 1991). The EPA (1991) discussed P loadings from urban and woodland areas and found loading from urban areas to be three to seven times greater than from undeveloped woodlands.

Chesters and Schierow (1985) found P loading to receiving surface waters from nonpoint sources such as cropland, pasture, and rangeland as 70% of total loads. In urban residential areas, Chester and Schierow (1985) estimated that overuse of fertilizers where water is directly led to storm sewers leads to 100% delivery ratios of N and P. However, a literature review by Line *et al*. (1997) stated that 52% of P loading to streams is caused by nonpoint sources. EPA (1998) discussed nutrients as the leading pollutants to lakes, ponds, reservoirs, and estuaries. Nutrients were the second most prevalent pollutants to rivers, following siltation (US EPA, 1998).

Fecal Coliform Bacteria

Bacteria was listed as the second leading pollutant in estuaries to nutrients (US EPA, 1996). Fecal coliform bacteria (FC) in stormwater have a range of 0.2 to 1.9 x 10^6 CFU 100 ml^{-1} (Makepeace *et al*., 1995). The drinking water standard for FC is 0 FCU 100 ml^{-1} (Makepeace *et al*., 1995). Levels above 1100 FCU 100 mL^{-1} in stormwater have led to the closure of beach and shellfish areas in coastal Connecticut (CT DEP, 1995). The EPA (1983) reported that coliform bacteria are present at high levels in urban runoff, and exceeded water quality criteria during and immediately after storm events.

O'Shea and Field (1992) described coliform bacteria as gram-negative, nonspore-forming, and lactose-fermenting bacilli which produce gas within 48 hours at 35°C. They recommended a maximum density in stormwater of 200 FCU 100 ml^{-1}. It was also reported by O'Shea and Field (1992) that the presence of salmonella increases sharply above 200 FCU 100 ml^{-1} when FC are present. They concluded that separate storm drainage systems, not just combined sewers, present a potential health hazard.

Schillinger and Gannon (1985) reported that stormwater was a common and largely uncontrolled source of microbial pollution. Their study also discovered that bacterial adsorption to stormwater-borne particles resulted in increased settling velocities. Through this finding, it was concluded that sedimentation of attached bacteria may cause FC concentrations to be reduced in polluted surface waters.

Fecal coliform has been described as a good indicator of a possible presence of pathogenic or disease-carrying pollution (Baumann *et al*., 1980; Schillinger and Gannon, 1985). Chesters and Schierow (1985) reported that total coliforms were found in more than 90% of nonpoint sources of stormwater samples.

Bacterial density peaked at or before the hydrograph peak, confirming the first flush (Table 2) in a study by Davis *et al*. (1977). In Buzzard's Bay, MA, an assessment of sources and transport pathways of coliform bacteria revealed that urban storm drains contributed the most FC to the Bay (Line *et al*., 1997). The sources of FC in stormwater include fecal material from dogs, cats, rodents, and birds (Makepeace *et al*., 1995). Novotny and Olem (1994) reported that there are 21 times less FC in winter than summer in stormwater.

Metals

Copper (Cu), lead (Pb) and zinc (Zn) raise concern in stormwater because they can be toxic to aquatic organisms, may contaminate drinking water supplies, and can bioaccumulate (US EPA, 1983). Runoff is a major source of heavy metals (Renwick and Edenborn, 1983; US EPA, 1983). Copper, lead, and zinc in particular account for about 90% of the dissolved heavy metals in stormwater and 90-98% of the total metals (FL DEP, 1988). It is estimated that 60-70% of Zn and 40-60% of Cu in stormwater comes from nonpoint sources (Chesters and Schierow, 1985).

Myers *et al*. (1985) reported that Cu, Pb, and Zn are significant pollutants that come from transportation practices. Owe *et al*. (1982) found Cu, Pb, and Zn in parking lot runoff, and that Pb and Zn loadings were directly correlated with percent imperviousness. EPA (1983) found that metals and inorganics are the urban runoff contaminants having the greatest potential for long-term impacts on aquatic life.

Sansalone and Buchberger (1997) conducted a study that found Zn and Cu exhibit a first flush in pavement sheet flow (Table 2). Pb did not exhibit a first flush, because it is particulate-bound. Sansalone and Buchberger (1997) also related the deposition and accumulation of metals as resulting from traffic activities, vehicular component wear, pavement degradations, roadway maintenance, and fluid leakages. Sansalone and Buchberger (1997) stated that dissolved metals are readily bioavailable and very mobile. Control strategies for dissolved metals must provide for adsorption, ion exchange, or precipitation, as well as trap particulate-bound elements. Sansalone *et al*. (1995) reported a significant correlation between heavy metals and suspended sediment during long duration events (2.2-79.5 hr). There is a strong correlation between metal concentration and small particle sizes (<15 μm) (Richards *et al*., 1981; Sansalone *et al*., 1995).

CT DEP (1996) described the origins of metals and their effects on the environment. Copper is naturally occuring, and in low concentrations is a minor nutrient for plants and animals. At higher levels, however, it becomes toxic. Copper also originates from brake pads on vehicles, combustion of lubricating oils, and shows a correlation with the intensity of vehicular traffic (Makepeace *et al*., 1995). Lead is a toxic carcinogen that becomes airborne through auto exhaust and is difficult to isolate and control (CT DEP, 1996; Chesters and Schierow, 1985). It is associated with solids in stormwater runoff, and had the highest concentration in samples from traffic and parking related areas (Makepeace *et al*., 1995; Novotny, 1991). Zinc is a highly toxic metallic element that is widespread in Connecticut, originating from rubber tires, diesel fuel and gasoline exhaust, and galvanized metal. Good (1993) found Cu, Pb, and Zn to exceed water quality criteria in roof runoff samples. Of these three, the concentration of Zn was the greatest. Metal concentrations in the Vortechnics™ unit were studied, knowing that parking lots are a source of Cu, Pb, and Zn, and loads of sediment from the parking lot potentially contained sediment-bound metals.

Petroleum Hydrocarbons

Total petroleum hydrocarbons (TPH) are important because of their toxicity and ubiquity (Whipple and Hunter, 1979). Hydrocarbon compounds are toxic to aquatic organisms (CT DEP, 1995). The main sources of TPH include leaks from engines, spills at fueling stations, and overfilled tanks (CT DEP, 1995; Hoffman *et al*., 1982; Hunter *et al*., 1979; Whipple and Hunter, 1979). Steuer et al. (1997) reported that parking lots contained the highest concentrations of polycyclic aromatic hydrocarbon compounds, at 300 $\mu g\ L^{-1}$.

Schueler (1994) found that hydrocarbons are a major contributing factor to sediment contamination. This finding agrees with Whipple and Hunter (1979) and Hoffman *et al*. (1982); both stated that most oil in runoff is assimilated to particles. Hunter *et al*. (1979) studied urban runoff and hydrocarbon pollution, and found that 86% of hydrocarbons in urban stormwater were associated with particulate matter. Both Hoffman *et al*. (1982) and Hunter *et al*. (1979) confirmed that a first flush of hydrocarbons occurs in stormflow (Table 2). The most common method of treatment for TPH is an oil grit separator (OGS) (Schueler, 1994).

Anthropogenic sources of hydrocarbons have much greater impacts on water bodies than those from biogenic sources (Fam *et al*., 1987). Controlling high hydrocarbon producing areas, such as parking lots, can produce significant reductions in total mass emissions, even if these areas comprise a small fraction of the total area (Fam *et al*., 1987). Whipple and Hunter (1979) found that larger quantities of hydrocarbons occurred during storm periods, with few hydrocarbons originating during times of low flow. This agrees with Fam *et al*. (1987), who reported that water quality parameters do vary during storm events, with the higher concentration occurring at the peak. Hoffman et al. (1982) stated that chronic discharges of petroleum contributed more oil to waterbodies (in total mass) than large spills.

Toxicity

Typically, toxicity is determined by bioassays in which test organisms are exposed to various doses of concentrations of a pollutant. The lethal concentration (LC) of a pollutant implies that the test organism has died. The 50% survival concentration is also known as the LC_{50} and is representative of the acute toxicity of the pollutant (Novotny and Olem, 1994).

A literature review by Makepeace *et al*. (1995) found that copper is the major aquatic toxic metal in stormwater. The toxicity of Cu on aquatic life is between 0.017 and 10.24 mg/l at a hardness of 50 mg/l (Makepeace *et al*., 1995). The same review reported that a sample containing 9.2% of a Cu solution was toxic to 50% of *D. pulex*. Toxic metals were by far the most prevalent priority pollutants in the NURP study (US EPA, 1983). Novotny (1991) reported that the most toxic samples were found in combined sewer overflows, followed by parking lot runoff.

Good (1993) sampled the first flush of runoff to characterize the worst-case contaminant concentrations and aquatic toxicity (Table 2). That study reported that roof runoff was a major source of stormwater contamination and aquatic toxicity. Pitt *et al*. (1995) collected 87 stormwater samples and found 9% were extremely toxic, 32% were moderately toxic, and 59% had no evidence of toxicity. Toxicity definitions were suggested for 35-minute exposures. A highly toxic sample had a light decrease >60% in a photo-degradation test, and moderately toxic had a light decrease between 20 and 60%. Vehicle service and parking lot runoff samples had many of the highest observed concentrations of organic toxicants (Pitt *et al*., 1995). On the other hand, Novotny and Olem (1994) reported that the particulates contributed by traffic are inorganic.

Vortechnics™

The Vortechnics™ system is known as a structural best management practice (BMP), i.e. one constructed to aid removal of nonpoint source pollution (Richards *et al*., 1981). The Vortechnics™ system combines swirl-concentrator and flow-control technologies to eliminate turbulence within the system and remove grit, contaminated sediments, metals, hydrocarbons, and floating contaminants found in stormwater (Vortechnics™ Inc., 1998). There are three sections in a Vortechnics™ unit: the grit chamber, oil chamber and baffle wall, and the flow control chamber (Figure 1).

The primary purpose of the Vortechnics™ system is to prevent turbulence and “wash-outs” (ME DEP, 1996). There are two ways the system accomplishes this: 1) settleable particles are swept to the center of the swirl chamber, known as a vortex action, where particles then migrate toward the center and settle, and 2) flow controls within the system are sized to adjust the water depth and raise the previously trapped floatables out of the way of incoming flow (ME DEP, 1996; US EPA, 1996). Vortechnics™ units are designed to provide 80% TSS removal on a mass basis (Vortechnics™ Inc., 1998).

Reported advantages of the Vortechnics™ system are its ability to handle large capacities, up to 0.71 $m^3 s^{-1}$; units can also handle storm events as small as 0.08 $m^3 s^{-1}$ (ME DEP, 1996). This is reportedly a key factor in the success of Vortechnics™, since the vast bulk of precipitation occurs in smaller and more frequent storms (DE DNR, 1997). The baffle is always submerged, preventing sediments and pollutant residues from being flushed out (ME DEP, 1996). Oil grit separators require minimal land area, can be adapted to all regions of the US, and have a high longevity (US EPA, 1993).

Stormwater that enters the Vortechnics™ unit typically travels from a catch basin located

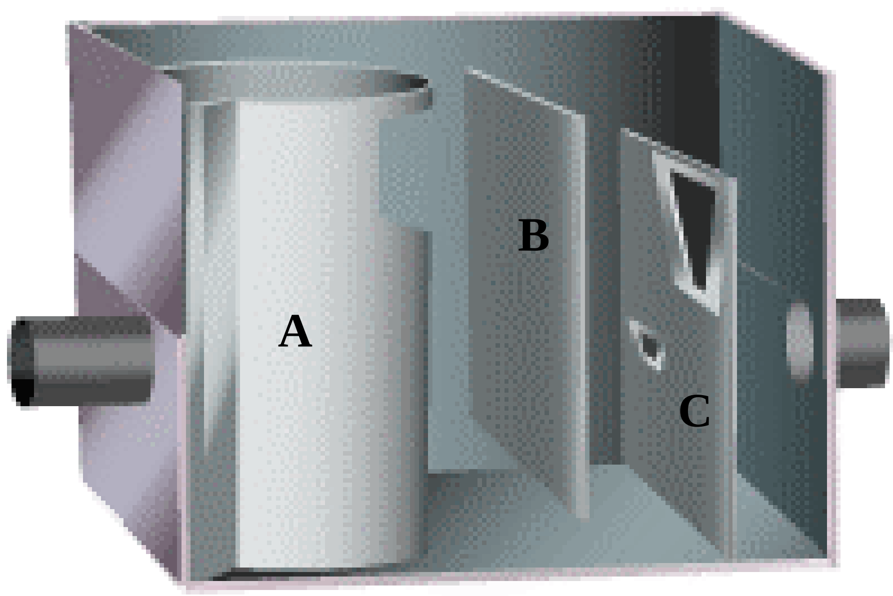

Figure 1. Cross-section of a Vortechnics™ unit. A: Grit chamber, B: Baffle wall, C: Flow control chamber (Vortechnics Inc., 1998).

upstream. Pitt and Field (1998) found that significant ($P = 0.05$) pollutant removals found with conventional catch basins were 30% of suspended solids and 20% of total solids on a concentration basis. Catch basins trap appreciable portions of coarse sediment, however relatively few pollutants are bound to coarser solids (Pitt and Field, 1998; Sartor *et al*., 1974). EPA (1993) reported probable percent removal ranges for catch basins as follows: TSS: 10-25%, TP: 5-10%, TN: 5-10%, Pb: 10-15%, and Zn: 5-10%.

Monitoring results of various Vortechnics™ units are summarized in Table 5. Results from all three studies exceeded the manufacturer's claim for a TSS removal efficiency of 80%. Greenway (2001) studied a Vortechnics™ unit in combination with a sand filter in treating stormwater concentrations on the side of a New Jersey highway. The concentration obtained in the study is higher than the manufacturer's claims, at 95% removal on a concentration basis for the Vortechnics™ unit alone. DeLorme Publishing Company in Yarmouth, Maine installed a Vortechnics™ 11000. Over 20 storms, 82% TSS was retained on a concentration basis (DeLorme, 2000). A study in Lake George, NY by West *et al*. (2001) had 88% TSS removal from stormwater on a mass basis. Their study used Manning™ vacuum pumps, whereas the other two utilized ISCO™ peristaltic pumps.

Samplers

When sampling for water quality data, many types of sampling equipment are employed. ISCO™ and Sigma™ samplers use peristaltic pumps to draw, measure, and deposit water into appropriate sample bottles (USGS, 1995). Manning™ samplers use a vacuum pump

Table 5. Results of monitoring three Vortechnics™ systems.

	DeLorme, 2001	Greenway, 2001	West et al., 2001
Pollutant	------------------	Removal Efficiency (%)	-----------------
TSS	82	95	88
TPH	----	79	----
TP	----	----	3
Number of Samples	20	5	13
Location	Yarmouth, ME	Harding, NJ	Lake George, NY
Area (ha)	2.83	1.21	3.78
Model No.	11000	4000	11000

to draw the sample into a measurement chamber that collects the water before deposition into a sample bottle (USGS, 1995). In a study comparing vacuum and peristaltic samplers in Wisconsin, cross contamination of samples was twice as high in the vacuum samplers as it was in the peristaltic samplers (USGS, 1995).

A study evaluating automatic water quality samplers tested whether a representative particle size distribution for the 20 µm to 128 µm range could be collected using ISCO™ and Manning™ samplers (USGS, 1995). The ISCO samplers took an increased volume of water as the depth increased, indicating volume accuracy may be problematic (USGS, 1995). The Manning™ sampler had very good volume repeatability. All samplers took a good representative sample for the desired particle size distribution. However, Sartor *et al.* (1974) reported that 6% of stormwater is less than 43 µm, whereas 38% is between 43 and 246 µm, and the remaining 57% is greater than 246µm. Thus, much of the particle size fraction found in stormwater was not tested.

An evaluation of an oil/grit separator in Madison, WI reported that there was a 24% difference between the estimated amount of TSS removed and the actual removal, because the ISCO™ automatic samplers could not effectively collect the material (Waschbusch, 1999). Some researchers prefer to use a Coshocton wheel for stormwater sampling because Coshcoton wheels provide for continuously composited and flow-weighted samples; a constituent concentration is then gathered for the entire storm flow (Rabanal and Grizzard, 1995; USDA, 1979).

CONCLUSIONS

Urban areas, and in particular parking lots, contribute nonpoint source pollutants to waterbodies and impair use. Nutrients, metals, and sediment are pollutants found in urban stormwater runoff that degrade water quality. Heavy metals are the most prevalent pollutants in urban runoff. Pollutants are delivered in the first flush of stormwater.

Applications of structural BMPs, such as Vortechnics™ and other oil/grit separators, are increasing. Recently completed studies have shown devices such as Vortechnics™ units effectively remove solids and other pollutants from stormwater. These studies agree with the manufacturer's claims of 80% suspended sediment removal. Retaining sediment in oil/grit separators aids retention of other pollutants, since sediment is a primary carrier of metals, nutrients, and organic toxics. The reduction of pollutants in stormwater will lead to cleaner surface waters, improve stream and river quality, and decrease eutrophication.

Researchers need more information on sampling devices. The various brands of sampling devices capture stormwater differently, some more effectively than others. Additional information is recommended in order that researchers can choose the best sampler for their studies. Samplers of different brands should be compared testing larger sediment particle sizes, which are more typical of stormwater runoff.

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VORTECHNICS™ TREATMENT OF PARKING LOT RUNOFF

ABSTRACT

Urban runoff contributes to the degradation of rivers, lakes, estuaries, and wetlands in the U.S. Several stormwater treatment devices are being developed to treat runoff from urban areas, but their performance has not been extensively tested. The effectiveness of a Vortechnics™ unit in treating stormwater runoff from a 7,900 m^2 school parking lot was evaluated after monitoring from January 1999 through April 2001 in South Windsor, CT. Flow-weighted composite samples were collected from the Vortechnics™ inflow and outflow. A peristaltic sampler (outlet) and a Coshocton wheel (inlet) were used to collect samples. The Vortechnics™ retained total-Kjeldahl nitrogen (TKN) (18%), total phosphorus (TP) (67%), nitrate (NO_3-N) (54%), total suspended solids (TSS) (77%), copper (Cu) (56%), lead (Pb) (46%), and zinc (Zn) (85%) on a mass basis but not ammonia (NH_3-N) (-1%). The Vortechnics™ unit significantly reduced the concentrations of TKN, TP, NO_3-N, TSS, Cu, Pb, and Zn found in parking lot runoff.

INTRODUCTION

Stormwater runoff contributes pollutants to waterbodies that impair beneficial uses of water. Runoff from parking lots is a critical source of pollutant loads (3). Parking lots were classified by Schueler (21) as hotspots; places where greater loads of hydrocarbons and trace metals are found in the runoff. Systems such as Vortechnics™ were designed to treat parking lot runoff more effectively than catch basins alone. The Vortechnics™ unit contains a cylindrical grit chamber, where runoff from parking lots enters tangentially and swirls around (Figure 1). Within the swirl chamber, sediment is expected to settle. A baffle wall suspended from above potentially traps floating oil, grease, and debris as flow moves toward the outlet. Before exiting, water enters a flow control chamber containing a weir and an orifice. The manufacturer claims that this device will remove 80% total suspended solids.

The objective of this study was to determine how well the Vortechnics™ unit retained nutrients, metals, and total suspended solids from parking lot runoff. This study also determined how well total petroleum hydrocarbons, fecal coliform bacteria, and toxicity were reduced in stormwater runoff. Finally, this paper reports the influence of seasons on stormwater treatment.

Since this project began, monitoring of other Vortechnics™ units was initiated in the Northeast. In these other studies, there was a lack of long-term continuous monitoring. A study in Lake George, New York monitored select storm events for 11 months, in New Jersey five storm events were sampled, and in Maine, twenty storms were sampled.

METHODS

Runoff from a parking lot at Timothy Edwards Middle School in South Windsor, CT was sampled to evaluate the performance of a Vortechnics™ unit. The monitoring occurred weekly for 27 months, capturing low-flow as well as storm events. The 0.79 ha watershed was 80% impervious, with 82 parking spaces (Figure 2). On average, fifty percent of the parking spaces were utilized during a normal school day. Runoff was collected at five

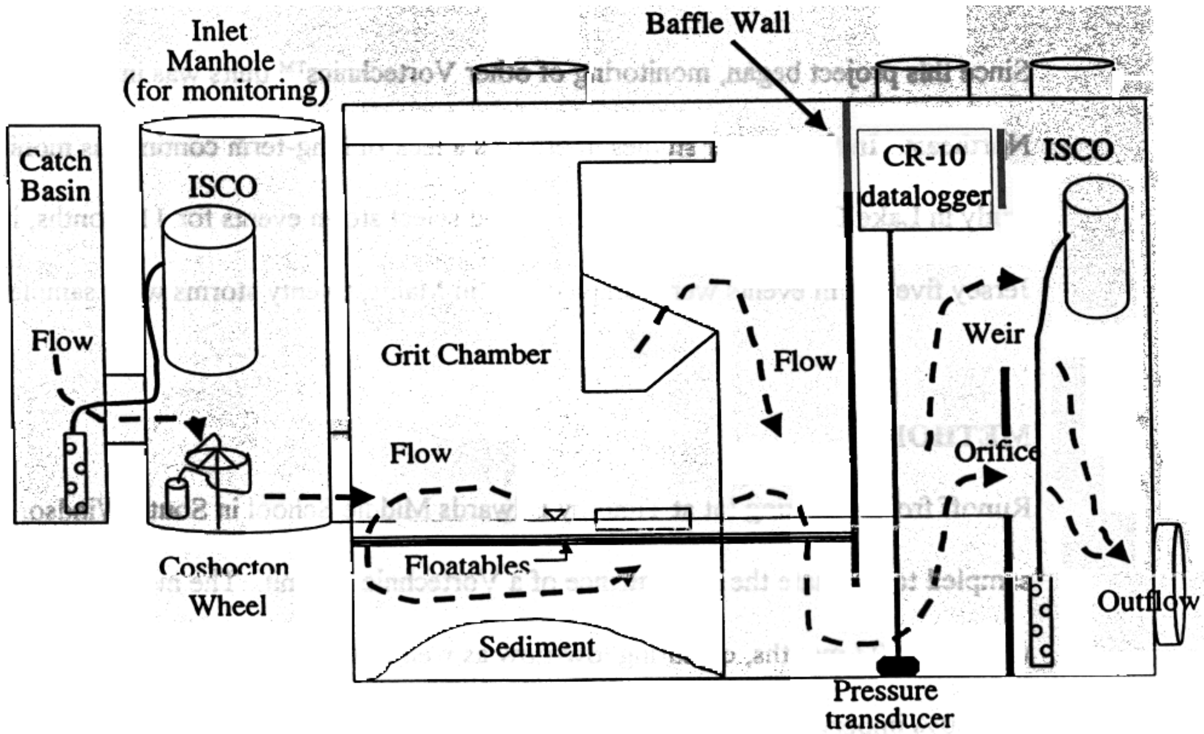


Figure 1. Cross-section of the Vortechnics™ unit, including sampling equipment and direction of flow.

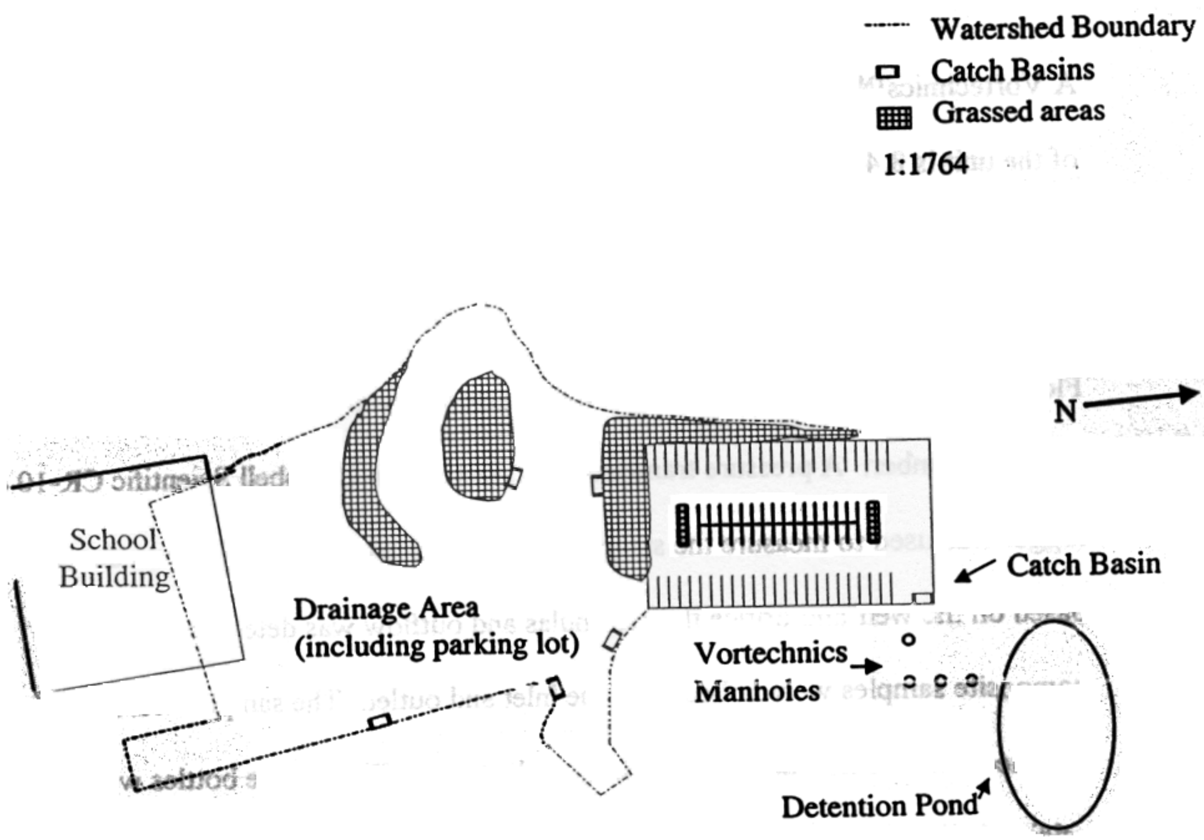


Figure 2. Vortechnics™ watershed area, South Windsor, CT.

catch basins and directed to a sixth, upstream of the Vortechnics™ unit. Between December and March of each winter, about 13.6 tonnes of sand and salt were applied to the parking lot. Fertilizer was applied to the surrounding grass and spilled onto the asphalt in the fall of 2000.

This study evaluated the performance of the Vortechnics™ unit in treating total-Kjeldahl nitrogen (TKN), total phosphorus (TP), nitrate (NO_3-N), ammonia (NH_3-N), total suspended solids (TSS), copper (Cu), lead (Pb), zinc (Zn), fecal coliform bacteria (FCU), total petroleum hydrocarbons (TPH), and toxicity from parking lot runoff. Monitoring was continuous, rather than select events, and was conducted over two years.

A Vortechnics™ model 5000 (Figure 1) was installed in November 1998. The base area of the unit is 8.4 m^2 (6). The Model 5000 is designed to store 2.48 m^3 of sediment and has a peak design flow of 0.24 $m^3 s^{-1}$.

Flow through the Vortechnics™ unit was measured by monitoring the stage in the flow control chamber. A pressure transducer connected to a Campbell Scientific CR-10 data logger was used to measure the stage. A stage-discharge relationship was developed based on the weir and orifice flow formulas and outflow was determined. Weekly composite samples were collected at the inlet and outlet. The samples were split into two acidified and one non-acidified bottle at each station. The sample bottles were pre-acidified with H_2SO_4 for nutrient analysis and HNO_3 for metals analysis. Flow-weighted samples were collected using a model N-1 Coshocton Wheel in the inlet and an ISCO 2900 peristaltic sampler in the outlet. The data logger recorded weekly precipitation, which was measured with a tipping-bucket rain gauge.

Weekly samples were analyzed for TKN, TP, NO_3-N, NH_3-N, and TSS. Monthly composite samples were analyzed for Cu, Pb, and Zn. Grab samples were analyzed for TPH, FCU and toxicity.

A Lachat autoanalyzer was used to measure TKN, TP, NO_3-N, and NH_3-N concentrations by colorimetric flow injection (10). After collection, nutrient samples were analyzed within 28 days. Non-acidified samples were collected to measure TSS using gravimetric methods (2). FC was analyzed using the membrane filter technique (2). TPH was analyzed using methylene chloride extraction (24). The lethal concentration test was performed on toxicity samples, using 50% mortality as the median concentration (LC50) and *Daphnia pulex* as the test organism (2). Pb concentrations were analyzed using atomic absorption furnace methods, and Cu and Zn analyses utilized plasma emission spectroscopy (9).

Data was statistically analyzed using SAS (20). Concentrations of NO_3-N were sometimes below the detection limit. In these cases, half of the detection limit was entered as the concentration. For all other variables measured, values reported were above detection limits. Differences between influent and effluent on both a mass and concentration basis were analyzed using a paired *t* test. The Shapiro-Wilks test was used to determine the normality of concentration data (Appendix B1). Most data followed a log-normal distribution and the log transformation was utilized. Percent retention on a mass basis was calculated by subtracting the outlet load from the inlet load and dividing by the inlet load. Seasonal differences in mass loading as well as seasonal differences in percent retention were tested by analysis of variance (ANOVA) and Duncan's multiple range test (Appendix B2-4). Regression analyses were used to assess the relationship between influent and effluent concentrations, as well as percent retention and influent concentrations. Correlation analysis was performed to determine if loadings were related to precipitation. Log-transformed nutrient and metals concentrations were analyzed to check for correlation to TSS concentrations.

RESULTS AND DISCUSSION

Fifty-eight paired composite samples were collected during the 27-month study of influent and effluent from the Vortechnics™. Hartford's average annual precipitation over the 27 months was 973 mm yr^{-1}, a -13.2% difference from the normal annual precipitation of 1121 mm yr^{-1} (11). Weekly precipitation collected at the site and that collected in Hartford showed no significant (t = 1.94, P = 0.08) differences. Hartford precipitation data was used since rainfall was not measured at the site for the entire 27-month study.

Concentration

The mean influent concentrations of nutrients, metals, TPH, and FCU were similar to those reported by the Nationwide Urban Runoff Program (NURP) (16). The influent concentrations of TSS were consistently higher than effluent concentrations (Figure 3). TSS influent concentrations were significantly (P = 0.05) higher in winter and spring,

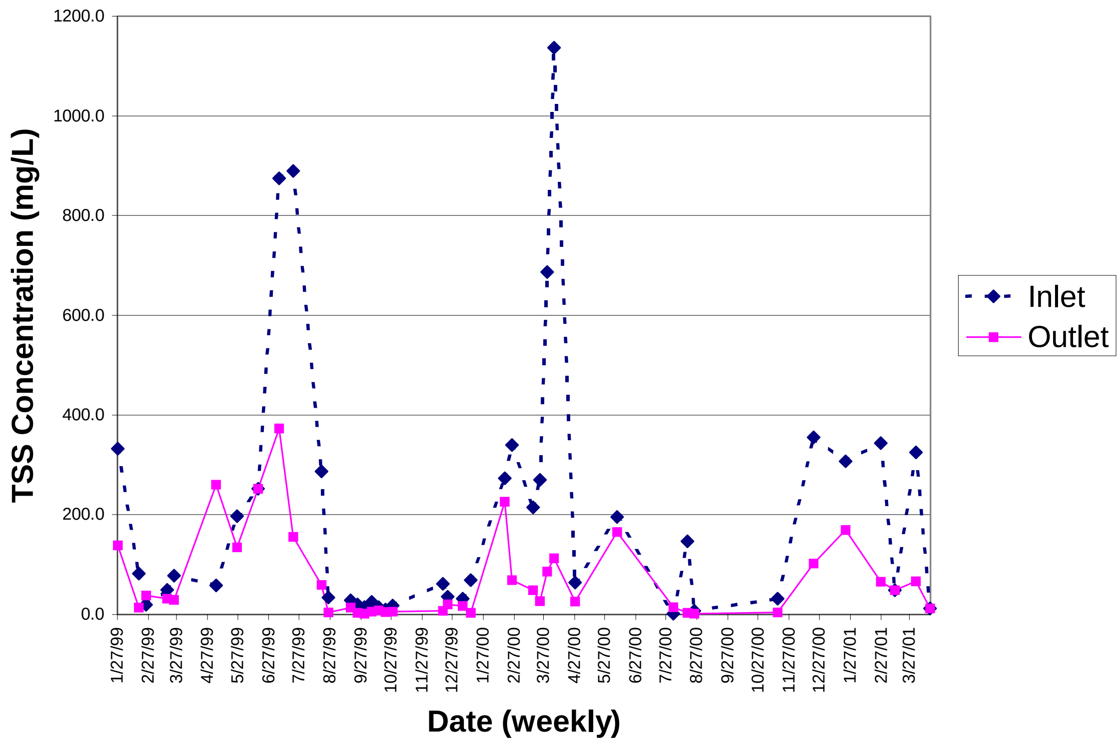


Figure 3. Vortechnics™ unit influent and effluent TSS concentrations over time, January 1999-April 2001.

probably due to winter applications of sand (Appendix B4). The mass loading of TSS was lowest in the fall (Appendix B3). TSS, NO_3-N, and Cu mean influent concentrations were similar to NURP data (Table 1). The exceptions were Zn, which was higher, and FCU and Pb, which were lower than the NURP results. However, the median influent concentration at Vortechnics™ for NH_3-N was 0.16 mg L^{-1}, similar to Steuer *et al*. (23), who reported 0.19 mg L^{-1} in urban runoff. Rabanal and Grizzard (15) reported a TPH median concentration of 7.0 mg L^{-1} in commercial site runoff, which was higher than that observed at the Vortechnics™.

A study conducted on a Vortechnics™ model 11000 in Lake George, New York sampled urban residential runoff for 13 storm events from February to December 2000 (26). The median influent TP concentration at Lake George was 0.14 mg L^{-1}, similar to the South Windsor Vortechnics™ influent value of 0.25 mg L^{-1}. The Lake George total nitrogen influent concentration was also similar. However, the TSS influent concentration from Lake George was 88% higher than observed at South Windsor and the value reported by NURP.

Based on the paired *t* test, there were significant reductions in concentrations (P = 0.05) from the influent to the effluent for all variables except NH_3-N, TPH, and FCU (Table 1). However, mean concentrations were near the detection limit for NH_3-N. Thirty-two percent of NO_3-N influent concentrations were below the detection limit of 0.2 mg L^{-1} (Appendix A1).

Table 1. Median concentrations in runoff from the NURP results, anti-log mean concentrations for the Vortechnics™ unit, and *t* value and *P* value from paired *t* test of influent and effluent means (January 27, 1999-April 30, 2001).

		VORTECHNICS				
Variable	Median (1)	# paired samples	Influent mean	Effluent mean	*t* value	*P* =0.05
TKN (mg L^{-1})	1.179	53	1.0	0.8	2.31	0.025
TP (mg L^{-1})	0.201	51	0.175	0.065	4.58	<0.0001
NO_3-N (mg L^{-1})	0.572	53	0.4	0.2	4.59	<0.0001
NH_3-N (mg L^{-1})	0.02	54	0.16	0.13	1.06	0.293
TSS (mg L^{-1})	69	43	89	29	6.79	<0.0001
Cu (ug L^{-1})	29	20	26	13	5.23	<0.0001
Pb (ug L^{-1})	104	13	18	11	2.77	0.017
Zn (ug L^{-1})	226	20	416	73	9.93	<0.0001
FCU	12,000	7	395.8	422.6	-1.16	0.290
TPH (mg L^{-1})	6.6	6	0.44	0.37	0.77	0.475

(1) USEPA (16), except for TPH (22) and NH_3-N (15).

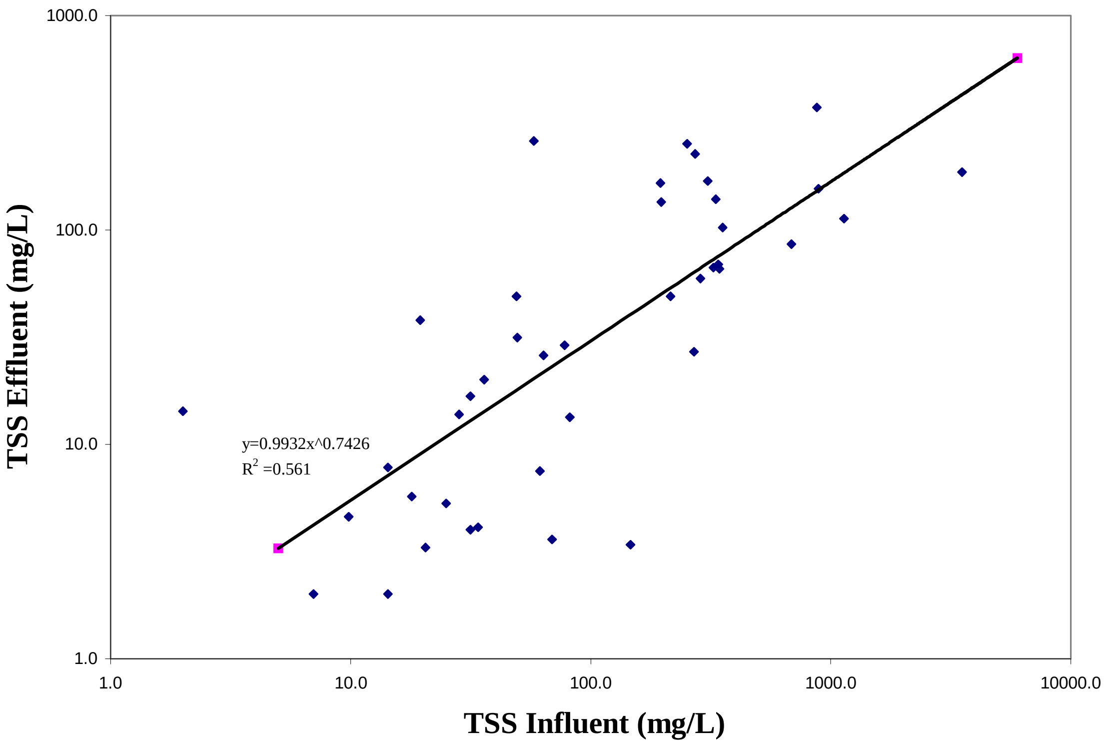
Of variables studied, NO_3-N, Cu, and Pb have drinking water Action Levels set by the EPA (12). NO_3-N influent and effluent concentrations were below the EPA's level of 10 mg L^{-1} 100% of the time. Cu was also below the Action Level of 1300 µg L^{-1} for 100% of the study. Pb concentrations exceeded the drinking water Action Level of 15 µg L^{-1} 69% of the time in the influent and 31% of the time in the effluent.

Effluent concentrations were significantly related to influent concentrations for TKN ($P < 0.001$, r = 0.554), TP ($P = 0.003$, r = 0.392), NO_3-N ($P < 0.001$, r = 0.507), TSS ($P < 0.001$, r = 0.749), and Cu ($P = 0.002$, r = 0.623) (Appendix B5-6). For example, the effluent concentration of TSS increased with a corresponding increase in influent concentration (Figure 4).

In a Vortechnics™ study in New Jersey, five storms from May 1999 to November 2000 were sampled (5). The Vortechnics™ unit was used to treat a 1.21 ha parking lot. Automatic samplers collected raw stormwater directly from the surface of the parking lot. Removal efficiencies were calculated based on influent and effluent concentrations. The Vortechnics™ unit retained 93% of the TSS and 67% of the TPH. In the Lake George study, the Vortechnics™ unit treated a 3.78 ha watershed that was 95% impervious (26). The 13 events that were sampled between February and December 2000 indicate that the system retained 88% of the TSS and 3% of TP on a concentration basis.

Nutrient and metal concentrations have been correlated to TSS concentrations in other studies of stormwater runoff (4, 14, 17, 18). For example, Sansalone *et al.*, (18) found a

Figure 4. Regression analysis of effluent concentration versus influent concentration of



TSS in the Vortechnics™ unit, January 1999-April 2001.

positive correlation during runoff events between metal and suspended solids concentrations.

This finding agrees with the correlation results from the South Windsor Vortechnics™ unit, which indicated that TKN (r = 0.470), NO_3-N (r = 0.386), Cu (r = 0.894), and Zn (r = 0.592) were positively correlated (P = 0.05) with TSS, and NH_3-N (r = -0.417) was negatively correlated with TSS. Based on the ANOVA and Duncan's mutiple range tests, NO_3-N concentrations in influent were significantly (P = 0.05) lower in summer than in the other three seasons. TKN influent concentrations were significantly (P = 0.05) higher in spring and summer than in winter. Cu concentrations were significantly (P = 0.05) higher in winter and spring than in fall (Appendix B4).

Results of the toxicity testing showed no reductions between influent and effluent. Only one influent sample had a mortality rate of *Daphnia pulex* that was less than 100%. However, there was no significance (P = 0.05) in paired data.

Mass Retention

Loading to the Vortechnics™ unit was lower than reported for the NURP results for commercial site runoff (16) (Table 2). TP, TSS, and Zn had higher mass loadings than the ranges reported by Novotny and Olem for commercial runoff (13). Stormwater runoff from an urban area in Madison, Wisconsin had loadings of 1.12 kg ha^{-1} yr^{-1} for TP, 0.90 kg ha^{-1} yr^{-1} for NH_3-N, 1.48 kg ha^{-1} yr^{-1} for NO_3-N, and 429 kg ha^{-1} yr^{-1} for TSS (1). The Vortechnics™ in South Windsor had similar values, except for TSS, which was higher (Table 2).

Table 2. Annual loading and cumulative mass retention of the South Windsor, CT Vortechnics™, and typical mass loading values for commercial land use.

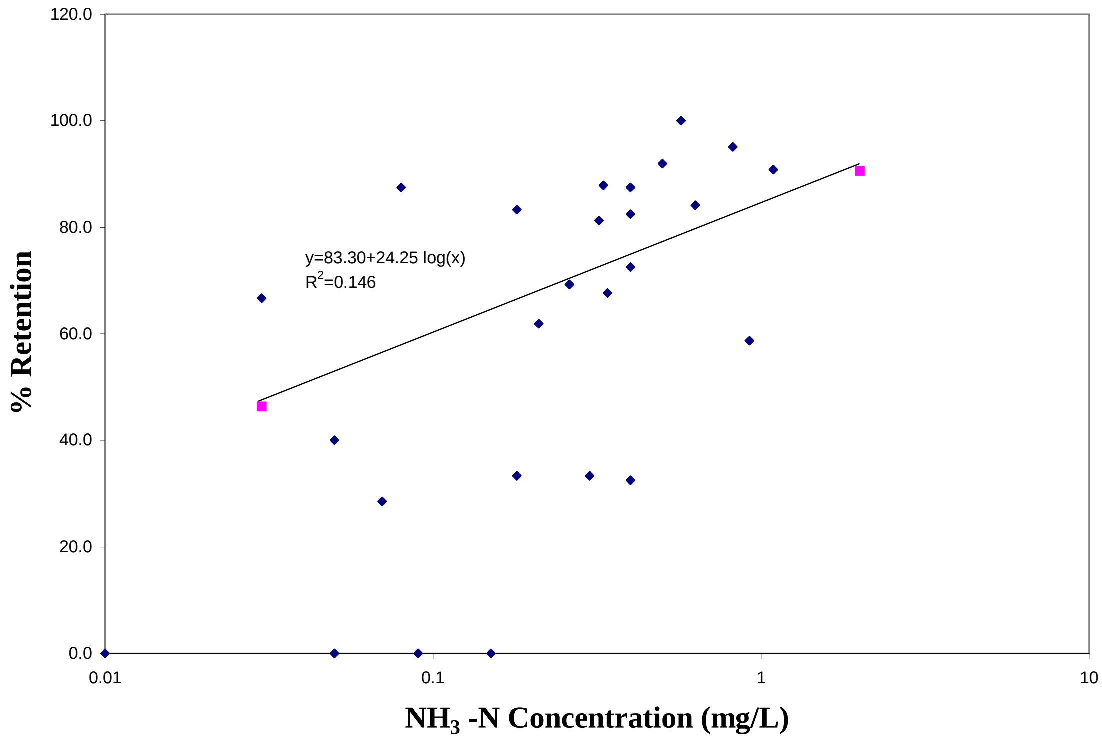
Variable	Annual Loading kg/ha/yr	Cumulative Mass Retention (%)	USEPA (1983) kg/ha/yr	Novotny and Olem (1994) kg/ha/yr
TKN	3.87	18	15.4	1.9-11
TP	1.34	67	3.4	0.1-0.9
NO_3-N	1.85	54	7.0	---
NH_3-N	0.88	-1	---	---
TSS	990.40	77	1460	50-830
Cu	0.056	56	0.35	0.07-0.13
Pb	0.02	46	1.48	0.17-1.1
Zn	0.96	85	1.64	0.25-0.43
FC	14.44	-6	---	---

In South Windsor, the unit retained 18% TKN, 67% TP, 54% NO_3-N, -1% NH_3-N, and 77% TSS on a mass basis (Table 2). In addition, the Vortechnics™ in the South Windsor study retained 56% Cu, 46% Pb, and 85% Zn. FC was not retained (<0%). The *t* test performed on paired weekly samples of mass input and export indicated significant (P = 0.05) reductions for TP, NO_3-N, TSS, Cu, Pb, and Zn. TKN, NH_3-N, TPH, and FCU did not have significant differences between mass input and export. There was no significant (P = 0.05) trend in TSS retention over the life of the study.

As the concentrations of TKN and NH_3-N in parking lot runoff increased, percent retention values also increased significantly (P = 0.05) (Figure 5). However, TP, NO_3-N, TSS and metals retention was not related to inlet concentration. TP loadings were significantly (P = 0.05) related to precipitation (r = 0.356), but no other variables were significantly related to precipitation. TKN and NO_3-N percent retentions were lower in winter than the other three seasons (Appendix B3). TKN mass loads were significantly higher in spring and summer than winter or fall.

CONCLUSIONS

The Vortechnics™ unit significantly reduced effluent concentrations of TKN, TP, NO_3-N, TSS, Cu, Pb, and Zn. The mean influent and effluent concentrations of NH_3-N were near detection limits and retention was not significant. Annual loading to the Vortechnics™ was moderate compared to other studies. Existing studies on the Vortechnics™ system are smaller and less extensive than the one in South Windsor, CT. There was a lack of long-term continuous monitoring in the studies in New York, New Jersey, and Maine.



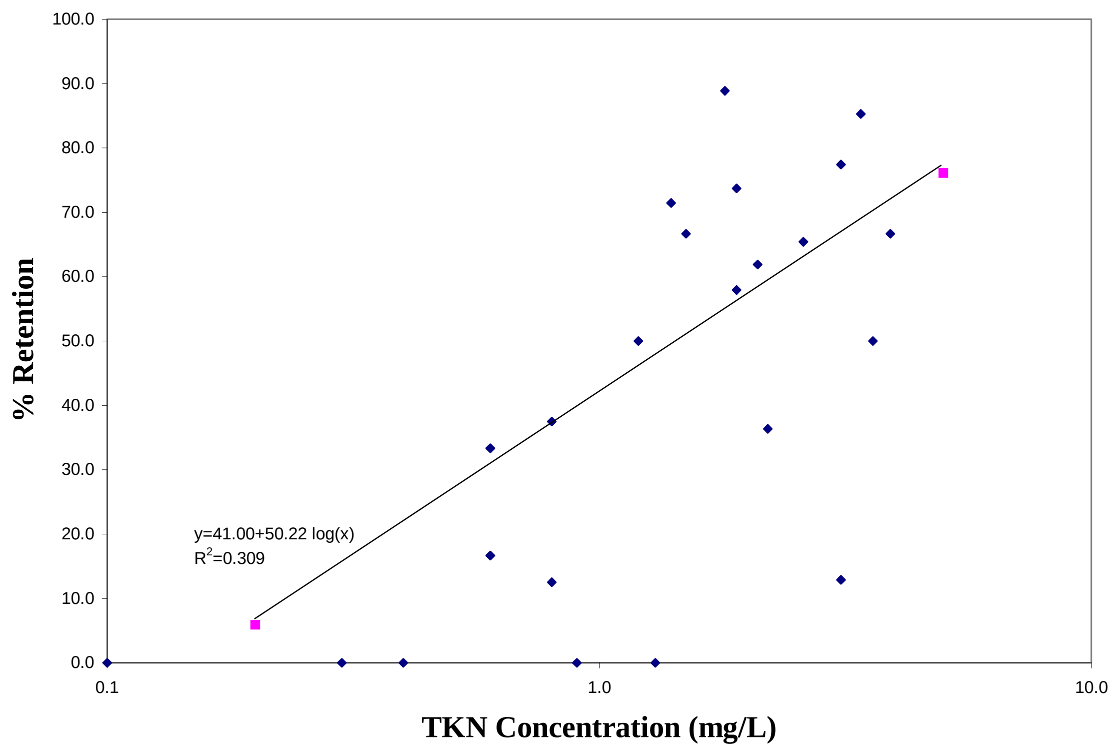


Figure 5. Percent retention versus NH_3-N and TKN influent concentration for the Vortechnics™ unit, January 1999-April 2001.

Regression analyses indicate that as concentrations of TKN and NH_3-N increased, percent retention also increased. TP was positively correlated with precipitation. TKN, NO_3-N, Cu, and Zn were positively correlated with TSS, and NH_3-N was negatively correlated. Retention of TSS in the Vortechnics™ unit was 77% on a mass basis.

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APPENDICES

APPENDIX A

DATA SUMMARY

Appendix **A1. Summary of weekly nutrient, TSS, FCU, TPH, and toxicity influent and effluent concentrations, as well as flow and** precipitation data at the **Vortechnics™ unit.**

DATE	LAB NO.	STA.**	Precip	Flow	TKN	TP	NO3+2	NH3	TSS	FCU	TPH	Toxicity
mm/dd/yy			in	cf/wk	mg/l	mg/l	mg/l	mg/l	mg/l	#/100 ml	mg/l	% mortality
12/08/98	8054	1								60	0.215	
12/22/98	8070	1								1000		
01/27/99	8155	1	1.14	10850.8	0.4	0.163	1.3	0.15	332.5			
02/03/99	8159	1	4.04	197.8	0.3	0.142	0.7	0.18	280.0			
02/10/99	8166	1	0.23	47.826	0.2	0.053	0.9	0.1	64.5			
02/17/99	8172	1	0.25		0.7	0.570	0.5	0.17	82.0			
02/24/99	8184	1	0.78		0.2	0.050	0.8	0.11	19.5			
03/03/99	8200	1	1.69	20947	0.4	0.202	0.8	0.21	86.0			
03/10/99	8210	1	0.98	23745.5	0.3	0.169	0.7	0.09	185.0			
03/17/99	8215	1	0.42	0	0.4	0.075	0.4	0.05	49.5			
03/24/99	8224	1	1.47	7911.4	0.6	0.084	0.6	0.07	78.0			
03/31/99	8246	1	0.57	13016.4	0.7	0.115	0.3	0.02	126.0			
04/07/99		1	0.02	0								
04/14/99	8253	1	0.20	2148.6	1.4	0.222	1.4	0.222	101.0			
04/21/99		1	0.42	4480.14								
04/28/99	8275	1	0.46	341.22	2.0	0.147	2.0	0.147	110.0			
05/05/99	8278	1	0.67	1747.7		0.135	0.6	0.07	58.0			
05/13/99		1	0.18	0								
05/19/99			1.27	0								
05/26/99	8298	1	1.11		3.7	0.422	0.1	0.08	197.0			
06/02/99		1	0.00	0								
06/09/99		1	0.03	0								
06/16/99	8308	1	0.47	0					252.0			
06/23/99		1	0.14	0								
06/30/99		1	0.09	15670.2								
07/07/99	8321	1	1.25	4554.2	3.6	0.995	0.1	0.4	874.8			
07/14/99		1	0.08	0								

Appendix A1. Summary of weekly nutrient, TSS, FCU, TPH, and toxicity influent and effluent concentrations, as well as flow and precipitation data at the Vortechnics™ unit (cont.).

DATE	LAB NO.	STA.**	Precip	Flow	TKN	TP	NO3+2	NH3	TSS	FCU	TPH	Toxicity
mm/dd/yy			in	cf/wk	mg/l	mg/l	mg/l	mg/l	mg/l	#/100 ml	mg/l	% mortality
07/21/99	8334	1	1.22	5,014.9	3.9	0.639	0.1	0.66	889.7			
07/28/99	8338	1	0.04	998.4	3.8	0.858	0.1	0.82	236.2			
08/04/99		1	0.00	0								
08/11/99	8351	1	0.33	2829.46	2.6	0.652	0.1	0.27	267.5			
08/18/99	8359	1	1.68	2694.8	3.4	0.016	0.1	0.67	287.0			
08/25/99	8364	1	0.49	0	1.8	0.198	0.6	0.19	34.0			
09/02/99		1	0.16	929.46								
09/09/99	8387	1	0.98	2806.68	0.4	0.339	0.1	0.08	11.3			
09/16/99	8387	1	8.84	18,379.1	0.4	0.653	0.1	0.05	28.3			
09/16/99	8395	1									0.76	
09/21/99	8407	1									1.49	100
09/23/99	8409	1	0.62	21130.5	0.3	0.019	0.2	0.01	20.5			
09/30/99	8418	1	0.78	405.2	2.1	0.054	2.3	0.82	14.3			
10/07/99	8435	1	0.93	2732.1	0.6	0.119	0.3	0.01	25.0			
10/14/99	8441	1	0.98	1106.7	1.6	0.201	1.1	0.13	14.3			
10/20/99	8446	1								396	0.3	
10/21/99	8450	1	1.05	7366.2	0.6	0.089	0.3	0.03	9.8			85
10/28/99	8467	1	0.58	3239.5	0.6	0.039	1.0	0.08	18.0			
11/04/99	8469	1	1.42	3715.6	1.9	0.392	1.5	0.5	28.0			
11/23/99	8500	1	0.20		1.1	0.285	1.1	0.27	22.0			
12/03/99	8521	1	1.90	29288.4	0.6	0.277	0.3	0.4	11.5			
12/09/99	8530	1	0.57	1175.5	1.2	0.047	0.8	0.48	31.1			
12/17/99	8532	1	1.02	296.7	0.8	0.135	0.7	0.28	61.5			
12/22/99	8541	1	0.88	2307.5	0.1	0.005	0.2	0.06	36.0			
01/06/00	8554	1	0.77	2633.2	0.1	0.005	0.8	0.3	31.5			
01/14/00	8559	1	1.44	543.4	0.1	0.005	0.5	0.1	69.0			
02/14/00	8626	1								25	11.5	100

Appendix A1. Summary of weekly nutrient, TSS, FCU, TPH, and toxicity influent and effluent concentrations, as well as flow and precipitation data at the Vortechnics™ unit (cont.).

DATE	LAB NO.	STA.**	Precip	Flow	TKN	TP	NO3+2	NH3	TSS	FCU	TPH	
mm/dd/yy			in	cf/wk	mg/l	mg/l	mg/l	mg/l	mg/l	#/100 ml	mg/l	% mortality
02/17/00	8633	1	1.10	5378.1	0.6	0.254	0.4	0.13	273.0			
02/24/00	8636	1	0.41	4902.9	0.8	0.239	0.2	0.06	340.0			
03/02/00	8650	1	0.65	11915.5	1.5	0.843	1.2	0.26	199.0			
03/16/00	8658	1	2.05	6634.7	1.4	0.559	1.0	0.4	215.0			
03/23/00	8670	1	0.62	6383.8	1.8	0.392	1.6	0.4	269.7			
03/30/00	8676	1	1.03	4575.5	3.1	0.627	1.3	0.57	687.0			
04/06/00	8684	1	0.48	941.1	2.2	0.345	1.5	0.4	1137.0			
04/13/00			0.83	9840.06								
04/20/00	8700	1	0.22	1117.2	1.1	0.558	0.2	0.21				
04/27/00	8705	1	2.64	25888.6	0.1	0.320	0.5	0.18	63.7			
05/04/00	8725	1	0.10	3501.4	2.0	0.281	2.1	0.35	130.0			
05/10/00	8726	1	0.87	6140.6	1.9	0.490	0.8	0.75	662.2			
05/18/00	8743	1	0.96	187.2			0.9	0.63				
05/25/00	8748	1	2.54	44877.4								
06/06/00	8768	1								420		
06/08/00	8772	1	5.15	11682.3	1.5	0.335	0.2	0.5	195.1			
06/15/00	8773	1	1.01	6549	1.7	0.255			111.3			
07/20/00	8846	1	1.23	15600	3.1	0.438	0.7	0.81	2.5			
07/27/00	8849	1									0.45	
08/03/00	8860	1	0.90	2706.2	0.6	0.025	0.2	0.01	2.0			
08/17/00	8875	1	2.58	31829.1	0.2	0.146	0.1	0.18	146.8			
08/24/00	8885	1	0.23	0	1.1	0.067	0.5	0.53	7.0			
11/02/00	8952	1	0.00	0	1.5	0.084	0.5	0.47				
11/10/00	8954	1								10	0.22	
11/15/00	8989	1	0.05	3097.4	0.8	0.120	0.1	0.32	31.5			
11/30/00	9000	1	0.90	0	0.8	0.159	0.1	0.24				
12/14/00	9012	1	0.64	0	0.7	0.169	0.1	0.08	143.0			

Appendix A1. Summary of weekly nutrient, TSS, FCU, TPH, and toxicity influent and effluent concentrations, as well as flow and precipitation data at the Vortechnics™ unit (cont.).

DATE	LAB NO.	STA.**	Precip	Flow	TKN	TP	NO3+2	NH3	TSS	FCU	TPH	Toxicity
mm/dd/yy			in	cf/wk	mg/l	mg/l	mg/l	mg/l	mg/l	#/100 ml	mg/l	% mortality
12/21/00	9016	1	2.53	10051.7	0.9	0.255	0.1	0.05	355.1			
01/11/01	9047	1	0.25	0	3.5	0.329	1.6	0.42				
01/22/01	9063	1	0.56	1266.2	1.1	0.416	0.5	0.09	307.0			
01/29/01	9148	1	0.00	0	2.2	0.557		0.03				
02/05/01	9154	1	2.19	689.4	1.5		0.4	0.15	755.0			
02/12/01	9159	1	0.28	0	1.3	0.541	0.6	0.25	161.0			
02/19/01	9169	1	0.29	0	1.6	0.387	0.9	0.06				
02/26/01	9180	1	0.68	10661.1	0.8	0.401	0.5	0.21	344.0			
03/05/01		1	0.45	150.3								
03/12/01	9195	1	0.65	0	1.6		1.3	0.09	49.0			
03/19/01	9207	1	0.89	4598.4	0.9	0.363	0.1	0.09	3521.0			
03/26/01	9211	1	2.31	12676.1	1.1	0.357	0.1	0.08	300.0			
03/30/01	9231	1								860		
04/02/01	9234	1	1.83	12918.3	1.3	0.221	0.1	0.34	325.0			
04/09/01	9244	1	0.84	4116.6	1.9	0.844	0.1	0.33	350.0			
04/16/01	9252	1	0.26	1012.2	2.6	0.051	0.1	1.09	12.0			
04/23/01	9257	1	0.05	364.9	3.1	0.578	1.5	0.19	645.0			
04/30/01	9263	1	0.07	351.4	5.2	1.154	2.3	0.92				

Appendix A1. Summary of weekly nutrient, TSS, FCU, TPH, and toxicity influent and effluent concentrations, as well as flow and precipitation data at the Vortechnics™ unit (cont.).

DATE	LAB NO.	STA.**	Precip	Flow	TKN	TP	NO3+2	NH3	TSS	FCU	TPH	Toxicity
mm/dd/yy			in	cf/wk	mg/l	mg/l	mg/l	mg/l	mg/l	#/100 ml	mg/l	% mortality
12/08/98	8055	2								240	0.466	
12/22/98	8071	2								390		
01/27/99	8157	2	1.14	10850.8	1.7	0.0025	0.1	0.82	139.0			
02/03/99		2	4.04	197.8								
02/10/99		2	0.23	47.826								
02/17/99	8173	2	0.25		0.2	0.041	0.8	0.005	13.4			
02/24/99	8185	2	0.78		0.1	0.044	0.4	0.05	38.0			
03/03/99		2	1.69	20947								
03/10/99		2	0.98	23745.5								
03/17/99	8216	2	0.42	0	0.4	0.067	0.4	0.07	31.5			
03/24/99	8225	2	1.47	7911.4	0.5	0.067	0.5	0.05	29.0			
03/31/99		2	0.57	13016.4								
04/07/99		2	0.02	0								
04/14/99		2	0.20	2148.6								
04/21/99		2	0.42	4480.14								
04/28/99		2	0.46	341.22								
05/05/99	8278	2	0.67	1747.7	0.0	0.196	0.4	1.49	260.0			
05/13/99		2	0.18	0								
05/19/99		2	1.27	0								
05/26/99	8299	2	1.11		1.1	0.175	0.1	0.18	135.0			
06/02/99		2	0.00	0								
06/09/99		2	0.03	0								
06/16/99		2	0.47	0					252.0			
06/23/99		2	0.14	0								
06/30/99		2	0.09	15670.2								
07/07/99	8322	2	1.25	4554.2	1.8	0.438	0.1	0.27	372.9			
07/14/99		2	0.08	0								

Appendix A1. Summary of weekly nutrient, TSS, FCU, TPH, and toxicity influent and effluent concentrations, as well as flow and precipitation data at the Vortechnics™ unit (cont.).

DATE	LAB NO.	STA.**	Precip	Flow	TKN	TP	NO3+2	NH3	TSS	FCU	TPH	Toxicity
mm/dd/yy			in	cf/wk	mg/l	mg/l	mg/l	mg/l	mg/l	#/100 ml	mg/l	% mortality
07/21/99	8335	2	1.22	5,014.9	3	0.210	0.1	0.78	155.6			
07/28/99		2	0.04	998.4								
08/04/99		2	0.00	0								
08/11/99		2	0.33	2829.46								
08/18/99	8360	2	1.68	2694.8	0.5	0.105	0.1	1.16	59.5			
08/25/99	8365	2	0.49	0					4.1			
09/02/99		2	0.16	929.46								
09/09/99		2	0.98	2806.68								
09/16/99	8388	2	8.84	18,379.1	0.4	0.005	0.3	0.03	13.8			
09/16/99	8396	2									0.28	
09/21/99	8408	2									1.52	
09/23/99	8410	2	0.62	21130.5	0.3	0.005	0.1	0.01	3.3			100
09/30/99	8419	2	0.78	405.2	0.8	0.005	0.8	0.04	2.0			
10/07/99	8436	2	0.93	2732.1	0.5	0.005	0.2	0.21	5.3			
10/14/99	8442	2	0.98	1106.7	5.8	0.816	0.2	0.28	7.8			
10/20/99	8447	2								792	0.2	100
10/21/99	8451	2	1.05	7366.2	0.4	0.058	0.1	0.01	4.6			
10/28/99	8468	2	0.58	3239.5	0.4	0.022	0.1	0.1	5.7			
11/04/99	8470	2	1.42	3715.6	0.8	0.036	0.2	2.94				
11/23/99	8501	2	0.20									
12/03/99	8522	2	1.90	29288.4	0.3	0.175	0.1	0.07	1.7			
12/09/99	8531	2	0.57	1175.5	0.6	0.005			0.0			
12/17/99	8533	2	1.02	296.7	0.5	0.005	0.2	0.51	7.5			
12/22/99	8542	2	0.88	2307.5					20.0			
01/06/00	8555	2	0.77	2633.2	0.4	0.025	0.2	0.2	16.8			
01/14/00	8560	2	1.44	543.4	0.8	0.005	0.2	1.55	3.6			
02/14/00	8627	2								19		100

Appendix A1. Summary of weekly nutrient, TSS, FCU, TPH, and toxicity influent and effluent concentrations, as well as flow and precipitation data at the Vortechnics™ unit (cont.).

DATE	LAB NO.	STA.**	Precip	Flow	TKN	TP	NO3+2	NH3	TSS	FCU	TPH	Toxicity
mm/dd/yy			in	cf/wk	mg/l	mg/l	mg/l	mg/l	mg/l	#/100 ml	mg/l	% mortality
02/17/00	8634	2	1.10	5378.1	0.8	0.244	0.2	1.79	226.0			
02/24/00	8637	2	0.41	4902.9					69.2			
03/02/00	8651	2	0.65	11915.5	0.5	0.162	0.4	0.08				
03/16/00	8659	2	2.05	6634.7	0.4	0.023	0.2	0.07	49.0			
03/23/00	8671	2	0.62	6383.8	0.2	0.005	0.2	0.05	27.0			
03/30/00	8677	2	1.03	4575.5	0.7	0.052	0.2	0	86.0			
04/06/00	8685	2	0.48	941.1	1.4	0.067	0.2	0.11	113.0			
04/13/00		2	0.83	9840.06								
04/20/00		2	0.22	1117.2								
04/27/00	8706	2	2.64	25888.6	0.1	0.082	0.1	0.03	26.0			
05/04/00		2	0.10	3501.4								
05/10/00		2	0.87	6140.6								
05/18/00	8744	2	0.96	187.2			0.4	0.1	88.2			
05/25/00	8749	2	2.54	44877.4	0.8	0.097	0.2	0.02	10.0			
06/06/00	8769	2								610		
06/08/00	8773	2	5.15	11682.3	1.7	0.239	0.2	0.04	165.2			
06/15/00		2	1.01	6549								
07/20/00		2	1.23	15600								
07/27/00	8850	2									0.38	
08/03/00	8861	2	0.90	2706.2	0.0	0.197	0.3	0.09	14.3			
08/17/00	8876	2	2.58	31829.1	0.3	0.031	0.3	0.12	3.4			
08/24/00	8887	2	0.23	0	0.4	0.033	0.1	0.29	2.0			
11/02/00	8953	2	0.00	0	2.0	0.117	0.1	1.41				
11/10/00	8955	2								220	0.16	
11/15/00	8990	2	0.05	3097.4	0.7	0.176	0.1	0.06	4.0			
11/30/00	9001	2	0.90	0	1.1	0.131	0.1	0				
12/14/00	9013	2	0.64	0	1.0	0.167	0.1	0				

Appendix A1. Summary of weekly nutrient, TSS, FCU, TPH, and toxicity influent and effluent concentrations, as well as flow and precipitation data at the Vortechnics™ unit (cont.).

DATE	LAB NO.	STA.**	Precip	Flow	TKN	TP	NO3+2	NH3	TSS	FCU	TPH	Toxicity
mm/dd/yy			in	cf/wk	mg/l	mg/l	mg/l	mg/l	mg/l	#/100 ml	mg/l	% mortality
12/21/00	9017	2	2.53	10051.7	1.4	0.322	0.2	0.05	102.5			
01/11/01	9048	2	0.25	0	0.7	0.049	0.3	0.04				
01/22/01	9064	2	0.56	1266.2	1.7		0.3	0.09	169.5			
01/29/01	9149	2	0.00	0	2.3	0.213	0.1	1.24				
02/05/01	9155	2	2.19	689.4	1.7		0.3	0.15				
02/12/01	9160	2	0.28	0	1.1	0.268	0.6	0.17				
02/19/01	9170	2	0.29	0	1.3	0.292	0.8	0.11				
02/26/01	9181	2	0.68	10661.1	1.4	0.149	0.2	0.08	66.0			
03/05/01		2	0.45	150.3								
03/12/01	9196	2	0.65	0	1.6	0.125	1.3	0.09	49.0			
03/19/01	9208	2	0.89	4598.4	0.9	0.208	0.1	0.09	186.4			
03/26/01	9212	2	2.31	12676.1	1.3	0.267	0.1	0.01				
03/30/01	9232	2								687		
04/02/01	9235	2	1.83	12918.3	1.3	0.075	0.1	0.11	66.8			
04/09/01	9245	2	0.84	4116.6	0.5	0.043	0.1	0.04				
04/16/01	9253	2	0.26	1012.2	0.9	0.091	0.6	0.1	12.0			
04/23/01	9258	2	0.05	364.9	2.7	0.359	1.3	0.39				
04/30/01	9264	2	0.07	351.4	5.6	1.265	1.9	0.38				

**Station 1=inlet, 2=outlet

Appendix A2. Summary of monthly metals influent and effluent concentrations at the Vortechnics unit.

DATE	LAB NO.	STA.**	Flow	Cu	Zn	Pb
			cf/wk	ug/L	ug/L	ug/L
Jan-99	8186	1	10850.8	26	301	15
Feb-99	8187	1	122.813	19	288	6
Mar-99	8248	1	7911.4	15	289	
Apr-99	8276	1	1742.49	17	286	11
May-99	8298	1	1747.7	17	413	9
Jul-99	8344	1	4784.6	43	642	42
Aug-99	8378	1	2694.8	32	173	22
Sep-99	8427	1	13304.9	8	315	
Oct-99	8471	1	3611.1	7	253	
Nov-99	8510	1	3715.6	16	387	
Dec-99	8548	1	1259.9	30	310	12
Jan-00	8621	1	1588.3	17	217	5
Feb-00	8663	1	5140.5	30	219	
Mar-00	8678	1	7377.4	81	1416	47
Apr-00	8737	1	13414.8	61	1032	19
May-00	8756	1	187.2	94	633	26
Aug-00	8906	1	17267.6	8	75	4
Nov-00	9005	1	3097.4	12	546	
Dec-00	9041	1	10051.7	24	302	22
Jan-01	9177	1	1266.2	51	1710	25
Feb-01	9219	1	5675.3	51	1620	27
Mar-01	9222	1	5808.30	50	442	22
Apr-01	9268	1	3752.7	28	292	7
Jan-99		2	10850.8			
Feb-99		2	122.813			
Mar-99	8249	2	7911.4	10	39	
Apr-99		2	1742.49			
May-99	8299	2	1747.7	14	55	12
Jul-99	8345	2	4784.6	20	100	20
Aug-99	8379	2	2694.8	12	76	6
Sep-99	8428	2	13304.9	5	53	
Oct-99	8472	2	3611.1	5	150	
Nov-99	8511	2	3715.6	8	60	
Dec-99	8549	2	1259.9	14	32	6
Jan-00	8622	2	1588.3	11	44	7
Feb-00	8664	2	5140.5	14	80	
Mar-00	8679	2	7377.4	16	62	9
Apr-00	8737	2	13414.8	12	51	6
May-00	8756	2	187.2	9	65	7
Aug-00	8906	2	17267.6	6	83	
Nov-00	9005	2	3097.4	8	60	
Dec-00	9041	2	10051.7	23	100	25
Jan-01	9178	2	1266.2	53	173	29
Feb-01	9220	2	5675.3	29	201	16
Mar-01	9223	2	5808.30	17	68	13
Apr-01	9269	2	3752.7	23	77	8

**Station 1=inlet, 2=outlet

Appendix A3. Summary of weekly nutrient, TSS, FCU, and TPH catch basin and Vortechnics™ inlet concentrations, as well as flow and precipitation data.

DATE	LAB NO.	STA.**	Precip	Flow	TKN	TP	NO3+2	NH3	TSS	FCU	TPH
mm/dd/yy			in	cf/wk	mg/l	mg/l	mg/l	mg/l	mg/l	#/100 ml	mg/l
07/20/00	8847	3	1.23	15600	0.1	0.037	4.1	0.08	17.3		
08/03/00	8862	3	0.90	2706.2	0.3	0.051	0.6	0.17	8.7		
08/17/00	8877	3	2.58	31829.1	0.2	0.076	3.9	0.33	16.4		
08/24/00	8888	3	0.23	0	0.2	0.021	0.4	0.79	5		
11/10/00	8956	3								30	
11/15/00	8991	3	0.05	3097.4	0.8	0.165	0.1	0.05	8		
11/30/00	9002	3	0.90	0	0.8	0.097	0.1	0			
12/14/00	9014	3	0.64	0							
12/21/00	9018	3	2.53	10051.7	1.3	0.364	1.4	0.08	351		
01/11/01	9049	3	0.25	0	2.5	0.482	1.5	0.45			
01/22/01	9065	3	0.56	1266.2	1.7		0.3	0.11	243		
01/29/01	9150	3	0.00	0	1.3	0.204	0.1	1			
02/05/01	9156	3	2.19	689.4	1.9		0.5	0.18	589.9		
02/12/01	9161	3	0.28	0	1.2	0.324	1.1	0.16	80.7		
02/19/01	9171	3	0.29	0	3.3	0.1	1.4	0.336			
02/26/01	9182	3	0.68	10661.1	1.9	0.247	0.9	0.15	31.7		
03/05/01		3	0.45	150.3							
03/12/01	9197	3	0.65	0	1.3	0.212	0.1	0.23	38.5		
03/19/01	9209	3	0.89	4598.4	1.8	0.293	0.1	0.08	207.1		
03/26/01	9213	3	2.31	12676.1	0.8	0.122	0.4	0.1	28.6		
03/30/01	9233	3								10	0.05
04/02/01	9236	3	1.83	12918.3	1.2	0.079	0.1	0.11			
04/09/01	9246	3	0.84	4116.6	0.7	0.085	1.7	0.12	38.6		
04/16/01	9254	3	0.26	1012.2	1	0.069	5.9	0.05	65		
04/23/01	9259	3	0.05	364.9	1.6	0.138	1.1	0.27	10.36		
04/30/01	9265	3	0.07	351.4	3.8	0.392	2.2	0.31			

Appendix A3. Summary of weekly nutrient, TSS, FCU, and TPH catch basin and Vortechnics™ inlet concentrations, as well as flow and precipitation data (cont.).

DATE mm/dd/yy	LAB NO.	STA.**	Precip in	Flow cf/wk	TKN mg/l	TP mg/l	NO3+2 mg/l	NH3 mg/l	TSS mg/l	FCU #/100 ml	TPH mg/l
07/20/00	8846	1	1.23	15600	3.1	0.438	0.7	0.81	2.5		
08/03/00	8860	1	0.90	2706.2	0.6	0.025	0.1	0.01	2.0		
08/17/00	8875	1	2.58	31829.1	0.2	0.146	0.1	0.18	146.8		
08/24/00	8886	1	0.23	0	1.1	0.067	0.5	0.53	7.0		
11/10/00	8954	1								10	
11/15/00	8989	1	0.05	3097.4	0.8	0.120	0.1	0.32	31.5		
11/30/00	9000	1	0.90	0	0.8	0.159	0.1	0.24			
12/14/00	9012	1	0.64	0	0.7	0.169	0.1	0.08	143.0		
12/21/00	9016	1	2.53	10051.7	0.9	0.255	0.1	0.05	355.1		
01/11/01	9047	1	0.25	0	3.5	0.329	1.6	0.42			
01/22/01	9063	1	0.56	1266.2	1.1	0.416	0.5	0.09	307.0		
01/29/01	9148	1	0.00	0	2.2	0.557		0.03			
02/05/01	9154	1	2.19	689.4	1.5		0.4	0.15	755.0		
02/12/01	9159	1	0.28	0	1.3	0.541	0.6	0.25	161.0		
02/19/01	9169	1	0.29	0	1.6	0.387	0.9	0.06			
02/26/01	9180	1	0.68	10661.1	0.8	0.401	0.5	0.21	344.0		
03/05/01		1	0.45	150.3							
03/12/01	9195	1	0.65	0	1.6		1.3	0.09	49.0		
03/19/01	9207	1	0.89	4598.4	0.9	0.363	0.1	0.09	3521.0		
03/26/01	9211	1	2.31	12676.1	1.1	0.357	0.1	0.08	300.0		
03/30/01	9231	1								860	0.05
04/02/01	9234	1	1.83	12918.3	1.3	0.221	0.1	0.34	325.0		
04/09/01	9244	1	0.84	4116.6	1.9	0.844	0.1	0.33	350.0		
04/16/01	9252	1	0.26	1012.2	2.6	0.051	0.1	1.09	12.0		
04/23/01	9257	1	0.05	364.9	3.1	0.578	1.5	0.19	645.0		
04/30/01	9263	1	0.07	351.4	5.2	1.154	2.3	0.92			

**Station 3=Catch basin, 1=Vortechnics™ inlet

Appendix A4. Summary of monthly catch basin and Vortechnics™ inlet metals concentrations for the catch basin.

DATE	LAB NO.	STA.**	Flow	Cu	Zn	Pb
			cf/wk	ug/L	ug/L	ug/L
Jul-00	8868	3	15600	7	3	53
Aug-00	8908	3	17267.6	84	51	220
Nov-00	9007	3	3097.4	14		83
Dec-00	9043	3	10051.7	16	12	57
Jul-00	8867	1	15600	63	16	1369
Aug-00	8906	1	17267.6	8	4	75
Nov-00	9005	1	3097.4	12		546
Dec-00	9041	1	10051.7	24	22	302

**Station 3=Catch basin, 1=Vortechnics™ inlet

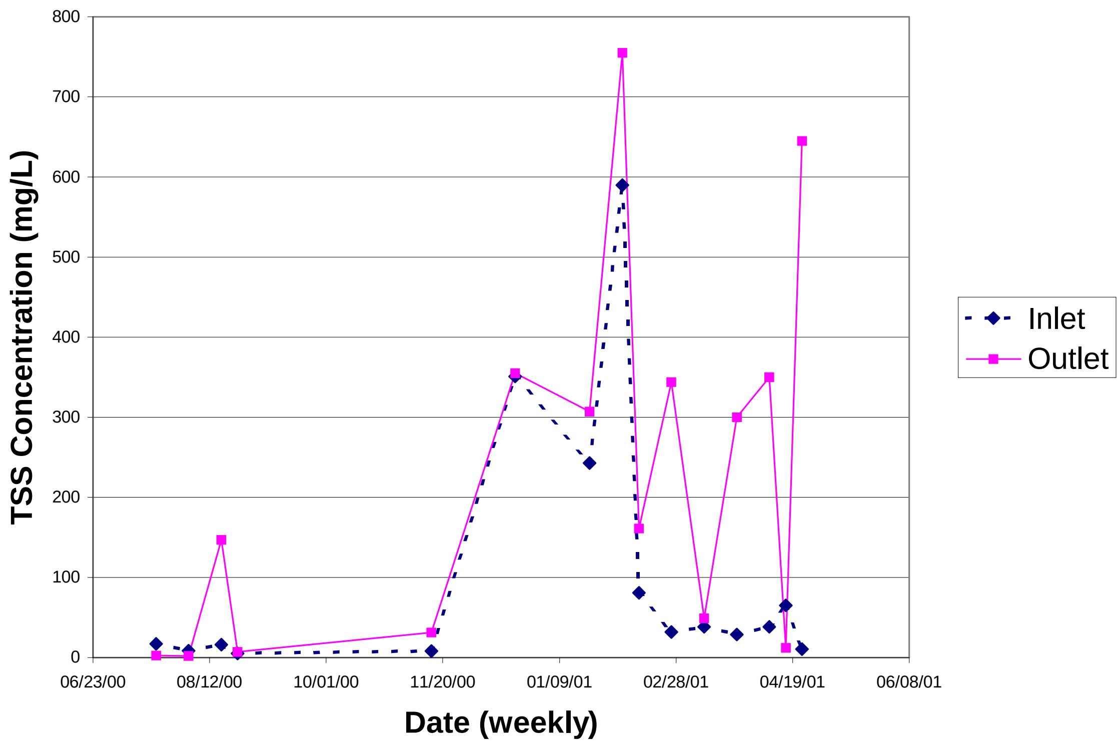
Appendix A5. Anti-log mean concentrations of the catch basin directly upstream of the Vortechnics™ unit, and *t* value and *P* value of the paired *t* test (July 2000-April 2001).

Variable	# Paired Samples	Influent Mean	Effluent Mean	*t* value	*P* value
TKN (mg L^{-1})	20	0.9	1.4	-1.61	0.123
TP (mg L^{-1})	18	0.130	0.245	-3.43	0.003
NO_3-N (mg L^{-1})	19	0.6	0.3	2.28	0.034
NH_3-N (mg L^{-1})	20	0.17	0.18	0.02	0.987
TSS (mg L^{-1})	15	42	92	-2.04	0.059
Cu (ug L^{-1})	4	19	20	-0.03	0.981
Pb (ug L^{-1})	4	86	361	-1.58	0.212
Zn (ug L^{-1})	3	12	11	0.07	0.951
TPH (mg L^{-1})	1	0.05	0.05	---	---
FCU	2	17	93	-0.60	0.654

Appendix A6. Annual loading and cumulative mass retention of the South Windsor catch basin located directly upstream of the Vortechnics™ unit.

Variable	Annual Loading kg/ha/yr	Cumulative Mass Retention (%)	Expected Retention (9)
TKN	4.12	9	5-10%
TP	0.66	-81	5-10%
NO_3-N	8.19	91	---
NH_3-N	0.84	-4	---
TSS	319.9	-417	10-25%
Cu	0.08	75	---
Pb	0.22	71	10-15%
Zn	0.05	-30	5-10%
FC	<1	-2075	---

Appendix A7. Catch basin influent and effluent TSS concentrations over time, July 2000-April 2001.



APPENDIX B

STATISTICAL ANALYSIS DATA

Appendix B1. Summary of W statistic for non-transformed and log-transformed Vortechnics™ concentration data.

Station	Variable	Non-transformed		Log-Transformed	
		W statistic	p<0.005	W statistic	p<0.005
1	TSS	0.456727	<0.0001	0.979311	0.6206
2	TSS	0.778481	<0.0001	0.949391	0.0566
1	TKN	0.883363	0.0001	0.948048	0.0241
2	TKN	0.681968	<0.0001	0.976927	0.4049
1	TP	0.887885	0.0002	0.926642	0.0037
2	TP	0.629414	<0.0001	0.928538	0.0044
1	NO_3-N	0.853135	<0.0001	0.890911	0.0002
2	NO_3-N	0.647694	<0.0001	0.869678	<0.0001
1	NH_3-N	0.870242	<0.0001	0.948635	0.0217
2	NH_3-N	0.599474	<0.0001	0.96401	0.1236
1	FC	0.864801	0.1671	0.887623	0.2625
2	FC	0.950655	0.7357	0.790663	0.0331
1	Cu	0.88984	0.0267	0.96126	0.5693
2	Cu	0.774627	0.0004	0.974136	0.8386
1	Pb	0.92407	0.2845	0.925276	0.2952
2	Pb	0.832344	0.0170	0.892203	0.1046
1	Zn	0.77096	0.0003	0.951697	0.3936
2	Zn	0.815861	0.0015	0.954861	0.4469
1	TPH	0.795755	0.0538	0.906053	0.4109
2	TPH	0.700516	0.0063	0.913349	0.4588

Appendix B2. Summary of ANOVA-duncan's test on seasonal differences in mass input. Groups with the same letters are not significantly different.

Variable	F value	*P* = F	Duncan Grouping		Mean	N	Season
TKN	3.01	0.043		A	2.48	5	summer
			B	A	2.19	12	spring
			B		1.83	11	winter
			B		1.74	10	fall
TSS	4.48	0.010		A	4.40	11	winter
				A	4.33	6	summer
				A	4.32	9	spring
			B		3.12	8	fall

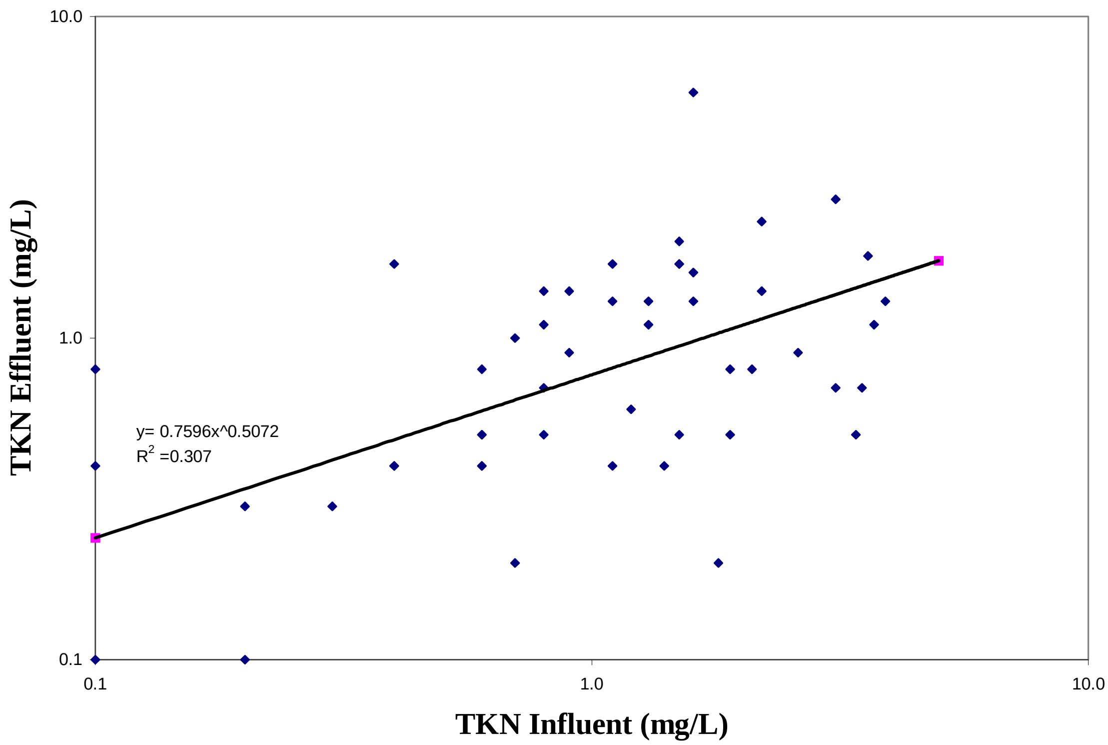
Appendix B3. Summary of ANOVA-duncan's test on seasonal differences in percent retention. Groups with the same letters are not significantly different.

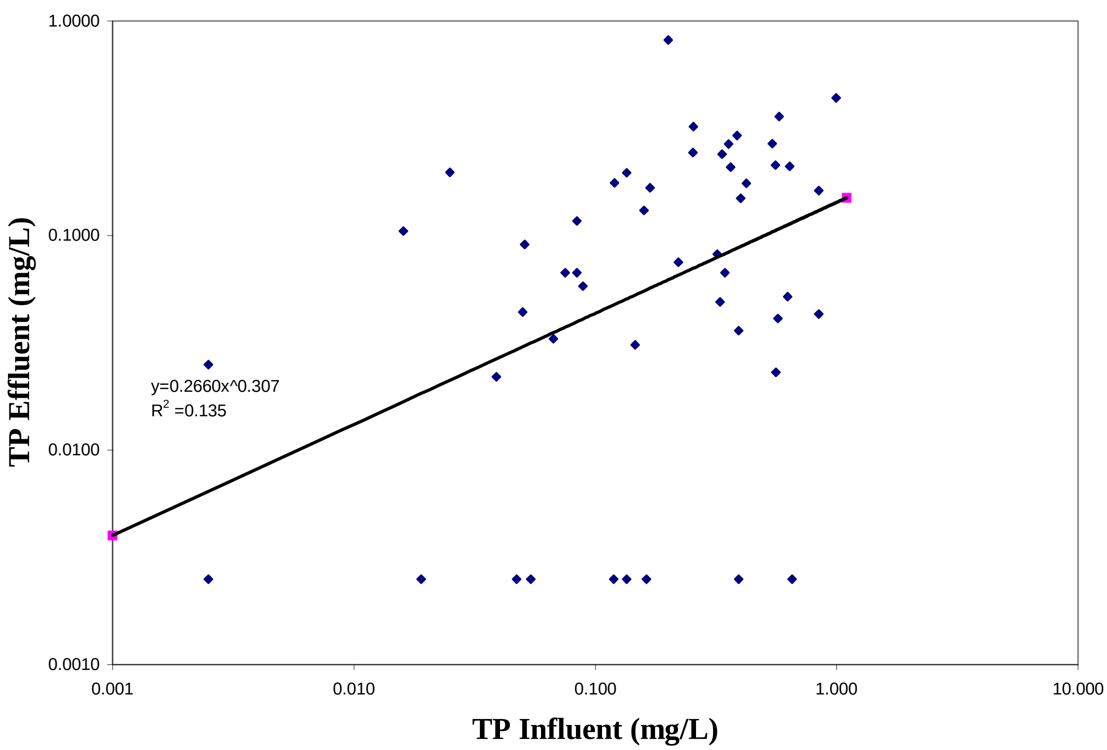
Variable	F value	*P* = F	Duncan Grouping		Mean	N	Season
TKN	3.05	0.044		A	38.0	4	summer
				A	33.2	10	spring
			B	A	4.51	9	fall
			B		-142	10	winter
NO_3-N	3.19	0.040		A	68.1	8	fall
				A	44.9	10	winter
				A	-2.49	10	spring
			B		-150	3	summer
NH_3-N	4.39	0.015		A	81.0	3	fall
				A	76.4	11	spring
				A	65.1	8	winter
			B		37.8	4	summer

Appendix B4. Summary of ANOVA-duncan's test on seasonal differences in influent concentration. Groups with the same letters are not significantly different.

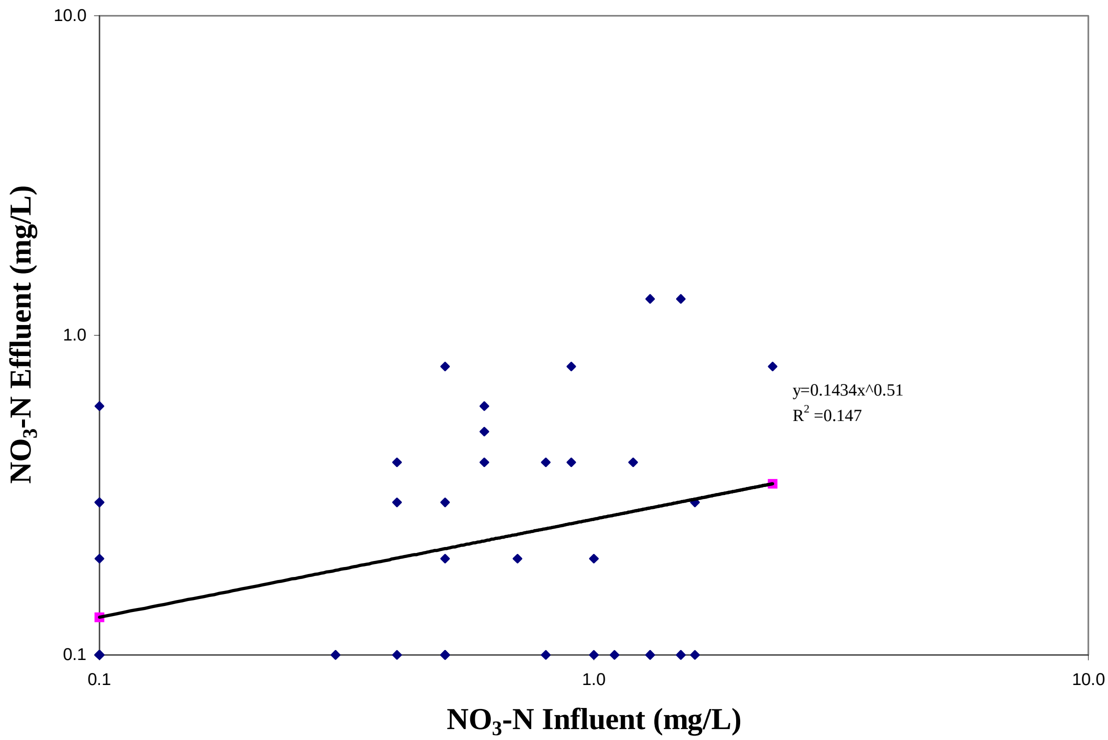
Variable	F value	*P* = F	Duncan Grouping	Mean	N	Season
TKN	4.83	0.004	A	0.191	20	spring
			A	0.145	12	summer
			B A	-0.050	15	fall
			B	-0.214	25	winter
NO_3-N	4.09	0.010	A	-0.258	24	winter
			A	-0.286	21	spring
			A	-0.347	15	fall
			B	-0.761	11	summer
TSS	7.75	0.001	A	2.26	19	spring
			A	2.19	22	winter
			B	1.74	12	summer
			B	1.39	13	fall
Cu	4.36	0.020	A	1.60	7	spring
			A	1.50	6	winter
			B A	1.35	3	summer
			B	1.01	4	fall

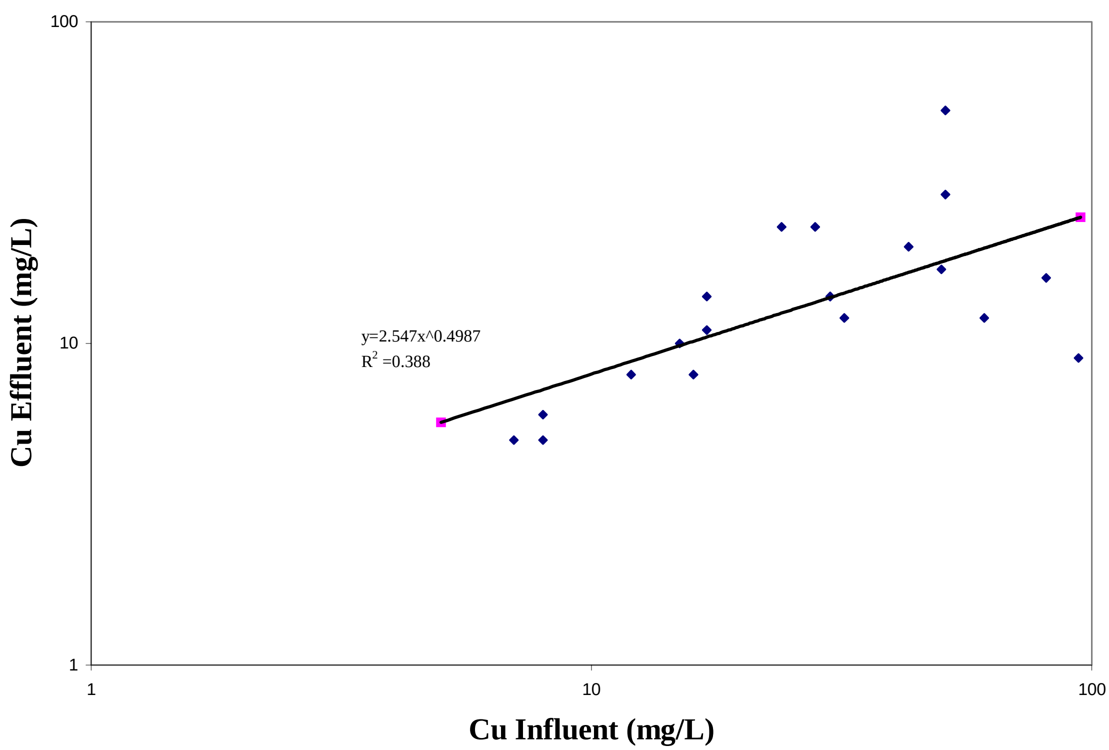
Appendix B5. Regression analysis of effluent concentration versus influent concentration of TKN and TP in the Vortechnics™ unit, January 1999-April 2001. Many of the TP concentrations were below the detection limit of 0.005 mg L^{-1}, therefore, half the detection limit was entered.





Appendix B6. Regression analysis of effluent concentration versus influent concentration of NO_3-N and Cu in the Vortechnics™ unit, January 1999-April 2001. Many of the NO_3-N concentrations were below the detection limit of 0.2 mg L^{-1}, therefore, half the detection limit was entered.





ILLICIT DISCHARGE COMPLIANCE STATEMENT

In accordance with the Wetland Regulations found in 310 CMR 10.05(6) and the *Massachusetts Stormwater Handbook* published by the Massachusetts Department of Environmental Protection, the stormwater management system for the proposed project located at 9-49 Homer Avenue in Ashland, Massachusetts shall accept no illicit discharges. Illicit discharges are defined as discharges not entirely comprised of stormwater and include, but are not limited to, wastewater discharges and discharges of stormwater contaminated by contact with process wastes, raw materials, toxic pollutants, hazardous substances, oil, or grease.

Engineering Alliance, Inc. has performed an investigation of the existing site conditions and did not find any illicit discharges. Prior to construction, additional investigations will take place to identify and remove any and all illicit discharges currently onsite. These actions include, without limitation, visual screening, dye or smoke testing, and the removal of any sources of illicit discharges to the stormwater management system.

Should any illicit discharges enter the stormwater management system after construction has been completed, immediate steps to remove the discharges and their source shall be taken to return the system to its proper working state.

______________________________	______August 9, 2023__
Richard A. Salvo, P.E. for Engineering Alliance, Inc.	Date

APPENDIX E

NOAA Atlas 14 Data

NOAA Atlas 14, Volume 10, Version 3
Location name: Ashland, Massachusetts, USA*
Latitude: 42.2596°, Longitude: -71.4635°
Elevation: 185.67 ft**
* source: ESRI Maps
** source: USGS

POINT PRECIPITATION FREQUENCY ESTIMATES

Sanja Perica, Sandra Pavlovic, Michael St. Laurent, Carl Trypaluk, Dale Unruh, Orlan Wilhite

NOAA, National Weather Service, Silver Spring, Maryland

PF_tabular | PF_graphical | Maps_&_aerials

PF tabular

PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.333 (0.259-0.425)	0.401 (0.311-0.512)	0.511 (0.396-0.655)	0.602 (0.464-0.778)	0.728 (0.543-0.981)	0.823 (0.601-1.13)	0.922 (0.655-1.32)	1.03 (0.696-1.51)	1.19 (0.774-1.81)	1.33 (0.839-2.05)
10-min	0.472 (0.367-0.603)	0.568 (0.441-0.725)	0.724 (0.561-0.929)	0.854 (0.658-1.10)	1.03 (0.770-1.39)	1.17 (0.853-1.61)	1.31 (0.928-1.87)	1.46 (0.986-2.14)	1.69 (1.10-2.56)	1.88 (1.19-2.90)
15-min	0.555 (0.432-0.709)	0.668 (0.519-0.853)	0.852 (0.661-1.09)	1.00 (0.773-1.30)	1.21 (0.906-1.64)	1.37 (1.00-1.89)	1.54 (1.09-2.20)	1.72 (1.16-2.52)	1.99 (1.29-3.01)	2.21 (1.40-3.41)
30-min	0.761 (0.592-0.972)	0.915 (0.711-1.17)	1.17 (0.904-1.50)	1.38 (1.06-1.77)	1.66 (1.24-2.24)	1.88 (1.37-2.59)	2.11 (1.50-3.01)	2.36 (1.59-3.45)	2.72 (1.76-4.12)	3.02 (1.91-4.66)
60-min	0.967 (0.753-1.24)	1.16 (0.904-1.49)	1.48 (1.15-1.90)	1.75 (1.35-2.25)	2.11 (1.58-2.84)	2.39 (1.74-3.28)	2.67 (1.90-3.82)	3.00 (2.02-4.38)	3.45 (2.24-5.23)	3.83 (2.42-5.91)
2-hr	1.23 (0.963-1.56)	1.49 (1.16-1.89)	1.90 (1.48-2.42)	2.25 (1.75-2.88)	2.73 (2.05-3.67)	3.08 (2.28-4.24)	3.47 (2.49-4.96)	3.92 (2.65-5.70)	4.61 (3.00-6.93)	5.20 (3.30-7.97)
3-hr	1.42 (1.11-1.79)	1.72 (1.35-2.17)	2.21 (1.73-2.80)	2.61 (2.03-3.33)	3.17 (2.40-4.25)	3.58 (2.66-4.92)	4.03 (2.92-5.78)	4.58 (3.10-6.63)	5.43 (3.53-8.13)	6.16 (3.92-9.40)
6-hr	1.81 (1.44-2.27)	2.20 (1.74-2.77)	2.84 (2.24-3.58)	3.37 (2.64-4.27)	4.10 (3.12-5.46)	4.63 (3.46-6.32)	5.22 (3.80-7.44)	5.94 (4.04-8.54)	7.08 (4.62-10.5)	8.06 (5.14-12.2)
12-hr	2.30 (1.83-2.86)	2.80 (2.23-3.49)	3.62 (2.87-4.53)	4.30 (3.39-5.41)	5.24 (4.01-6.93)	5.93 (4.45-8.03)	6.68 (4.89-9.45)	7.61 (5.19-10.9)	9.04 (5.93-13.4)	10.3 (6.58-15.5)
24-hr	2.73 (2.19-3.38)	3.36 (2.69-4.16)	4.39 (3.51-5.46)	5.25 (4.17-6.56)	6.42 (4.95-8.45)	7.29 (5.51-9.82)	8.24 (6.07-11.6)	9.42 (6.45-13.4)	11.3 (7.40-16.5)	12.9 (8.25-19.2)
2-day	3.03 (2.45-3.73)	3.79 (3.06-4.66)	5.03 (4.05-6.21)	6.06 (4.84-7.52)	7.47 (5.80-9.79)	8.51 (6.48-11.4)	9.65 (7.18-13.6)	11.1 (7.64-15.7)	13.5 (8.88-19.6)	15.5 (9.99-23.0)
3-day	3.28 (2.66-4.01)	4.09 (3.31-5.01)	5.41 (4.37-6.65)	6.51 (5.22-8.04)	8.02 (6.25-10.5)	9.12 (6.97-12.2)	10.3 (7.72-14.5)	11.9 (8.21-16.7)	14.4 (9.53-20.9)	16.6 (10.7-24.6)
4-day	3.52 (2.86-4.29)	4.35 (3.54-5.32)	5.72 (4.64-7.01)	6.86 (5.52-8.45)	8.42 (6.57-10.9)	9.56 (7.32-12.7)	10.8 (8.09-15.1)	12.4 (8.59-17.4)	15.0 (9.93-21.7)	17.3 (11.1-25.4)
7-day	4.21 (3.45-5.10)	5.09 (4.17-6.18)	6.54 (5.33-7.97)	7.74 (6.26-9.48)	9.39 (7.35-12.1)	10.6 (8.14-14.0)	11.9 (8.90-16.4)	13.6 (9.41-18.9)	16.1 (10.7-23.2)	18.4 (11.9-26.9)
10-day	4.88 (4.01-5.89)	5.79 (4.76-7.01)	7.29 (5.96-8.85)	8.53 (6.93-10.4)	10.2 (8.03-13.1)	11.5 (8.83-15.1)	12.9 (9.59-17.6)	14.5 (10.1-20.1)	17.0 (11.3-24.3)	19.2 (12.4-27.9)
20-day	6.88 (5.69-8.25)	7.86 (6.50-9.44)	9.46 (7.79-11.4)	10.8 (8.83-13.1)	12.6 (9.95-15.9)	14.0 (10.8-18.1)	15.4 (11.5-20.6)	17.1 (11.9-23.4)	19.3 (12.9-27.4)	21.2 (13.8-30.7)
30-day	8.51 (7.08-10.2)	9.54 (7.92-11.4)	11.2 (9.27-13.5)	12.6 (10.3-15.2)	14.5 (11.5-18.2)	16.0 (12.3-20.4)	17.5 (12.9-23.0)	19.0 (13.3-25.9)	21.1 (14.2-29.8)	22.7 (14.8-32.7)
45-day	10.5 (8.78-12.5)	11.6 (9.66-13.8)	13.3 (11.1-15.9)	14.8 (12.2-17.7)	16.8 (13.3-20.8)	18.3 (14.1-23.2)	19.8 (14.6-25.8)	21.3 (15.0-28.8)	23.1 (15.6-32.5)	24.5 (16.0-35.1)
60-day	12.2 (10.2-14.4)	13.3 (11.1-15.8)	15.1 (12.5-17.9)	16.5 (13.7-19.8)	18.6 (14.7-23.0)	20.2 (15.6-25.4)	21.7 (16.0-28.1)	23.1 (16.3-31.2)	24.7 (16.7-34.6)	25.8 (16.9-37.0)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

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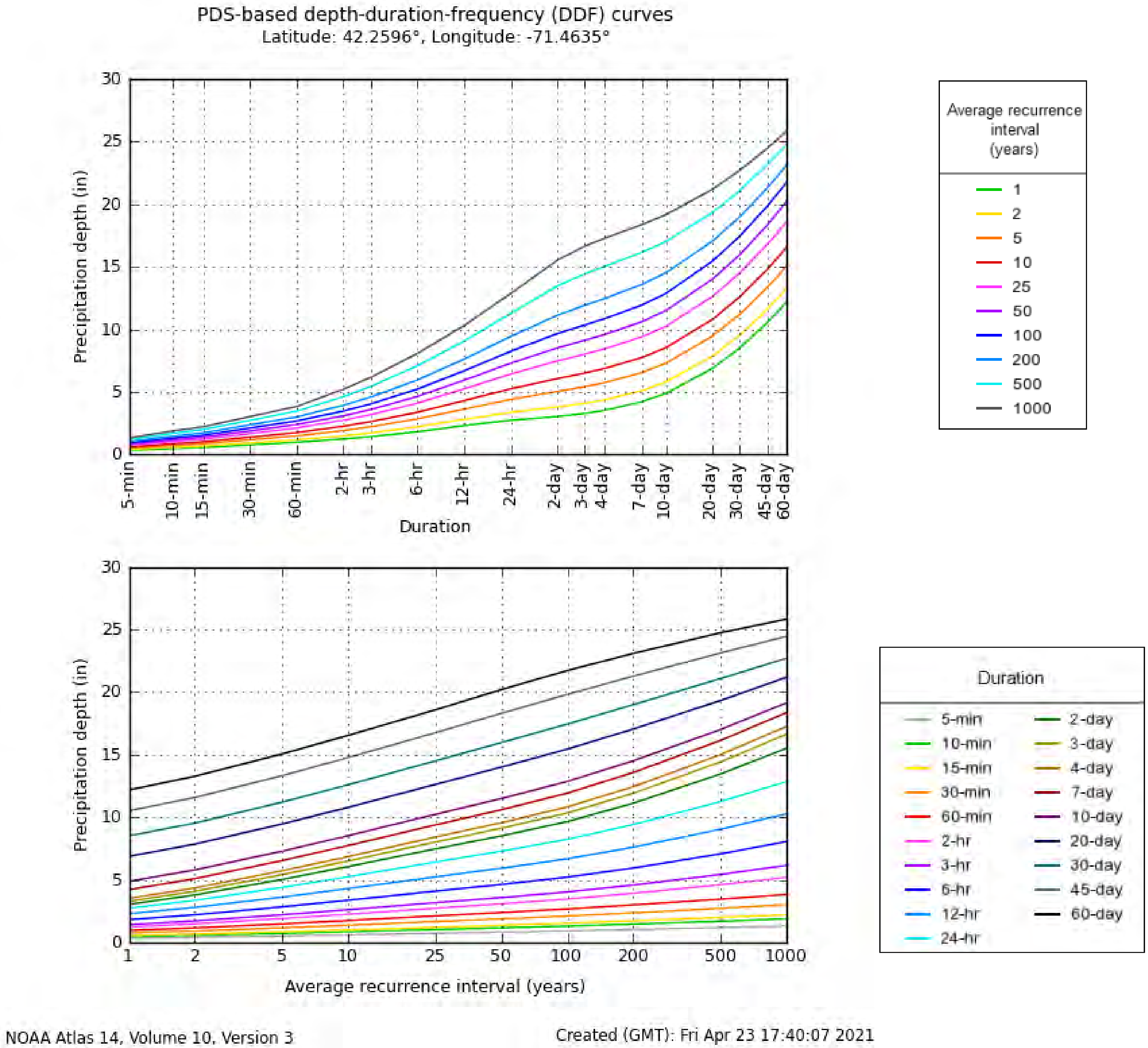
PF graphical



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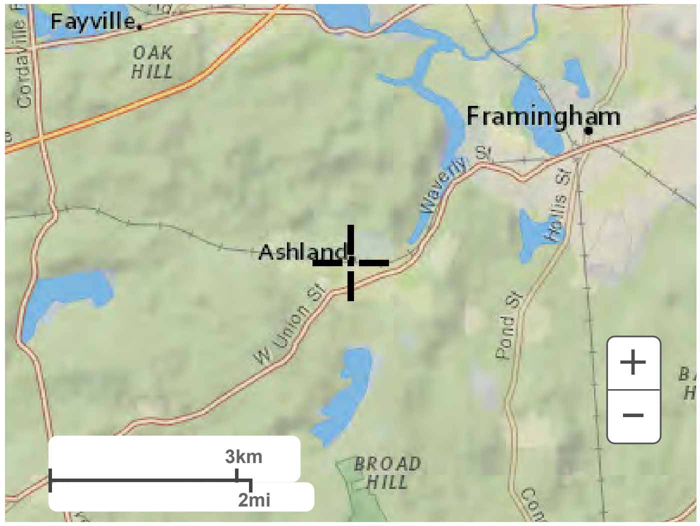
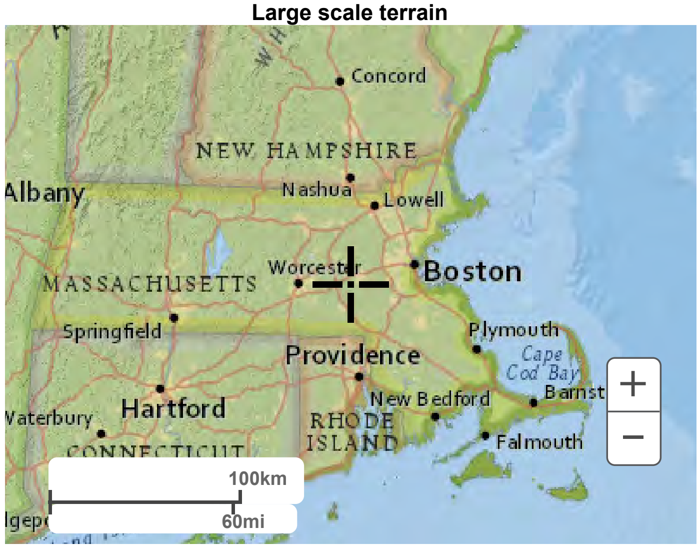
Maps & aerials

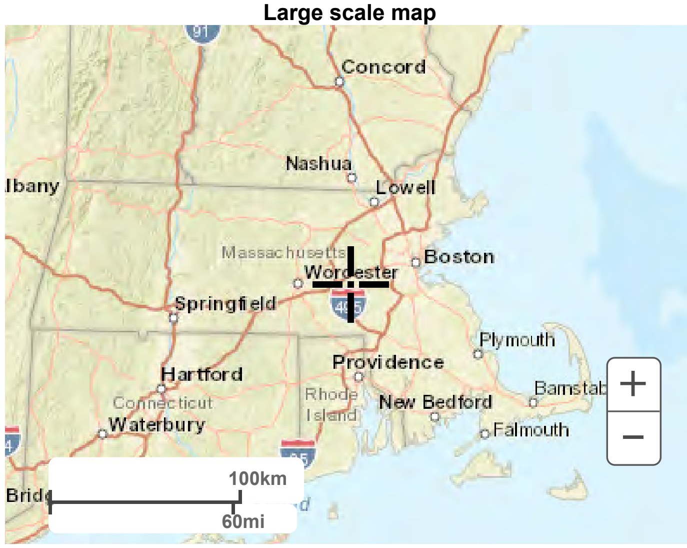
Small scale terrain



Large scale terrain



Large scale map



Large scale aerial

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