-- BERLIN TOWN OFFICES --
STORMWATER TREATMENT PLAN
DESIGN REPORT

Date of Photo: Oct. 11, 2018

Location:	Berlin Town Offices 108 Shed Road Berlin, Vermont
Client:	Town of Berlin Central Vermont Regional Planning Commission
Town:	Berlin, Vermont
Consultant:	DuBois & King, Inc.
Date of Report:	March 29, 2019

TABLE OF CONTENTS

ATTACHMENTS

SECTION 1

1.0 DESCRIPTION OF PROJECT

1.1 General

1.1.1 Introduction

The Town of Berlin (Town), in conjunction with the Central Vermont Regional Planning Commission (CVRPC), has contracted DuBois & King, Inc. (D&K) for the final design and construction oversight for stormwater remediation (Project) at the Berlin Town Offices and Garage (Site). The following report includes a description of the existing conditions at the Town offices, the proposed treatment practice, the treatment efficacy of the proposed practices, an opinion of probable construction cost, and a cost/benefit analysis.

1.1.2 Purpose of Work

The project site is located east of Pond Brook, which is threatened by stormwater runoff. In addition, Pond Brook is a tributary to Stevens Branch, which was included on the 2016 stressed waters list, in part due to urban and road runoff. Currently, stormwater from the Site sheet flows over the existing impervious surface directly to Pond Brook, receiving limited treatment before entering the brook. The proposed plans will treat stormwater runoff from approximately 54% of existing impervious surfaces before it enters Pond Brook.

The treatment of stormwater in this area is driven in part by the Lake Champlain Total Maximum Daily Loads (TMDLs), published by the Environmental Protection Agency (EPA) in 2016. The Stevens Branch is part of the Winooski River Watershed, which ultimately drains to the Main Lake segment of Lake Champlain. Although the entire lake is stressed by phosphorus loading, the main lake segment is thought to contain approximately 25% of the total phosphorus loading within the lake. The EPA identified developed land and stream bank erosion as the largest sources of phosphorus loading in the Main Lake segments. Within developed land areas, impervious surfaces are the second leading source of phosphorus loading, next to back roads. In order to meet the Lake Champlain TMDL for the main lake, the priority strategies identified by the Vermont Department of Environmental Conservation (VTDEC) are stormwater management and flood resiliency practices. The implementation of the proposed work at the Berlin Town Offices and Garage will support the strategies identified by the VTDEC by managing and treating stormwater from impervious surfaces at the site. The proposed project is located in an area owned by the municipality.

Furthermore, new legislation is proposed that would require stormwater treatment for properties with impervious surfaces greater than 3 acres, which have not been previously permitted, or were permitted prior to the requirements of the Stormwater Management Manual from 2002 or later. The Project area would fall under this requirement, and thus this stormwater treatment practice would proactively provide coverage under the anticipated new permit.

1.2 Description of Project

1.2.1 Location

The Berlin Town Offices and Garage are situated between Interstate 89 and Vermont Route 62, east of Pond Brook.

Latitude: 44.211800°
Longitude: -72.577908°

From Interstate 89, head east on Route 62 for approximately a quarter of a mile. Turn right on Paine Turnpike N. After another quarter of a mile, turn right onto Crosstown Road. Shed Road is then the first right off Crosstown Road.

See Figure 1 – Locus Plan

1.3 Existing Conditions

1.3.1 Existing Conditions Plan

The existing conditions of the Site are shown on Sheet 2 of the 90% Design Plans. The Site includes three buildings, a paved parking lot, a paved access road to the Offices, and a gravel access road (between the offices and garage), as well as open storage areas. The total impervious surface in the project area is 3.11 acres, out of a total of 3.98 acres. The topography of the area slopes gently to the west, before encountering a steep bank at the edge of the Pond Brook.

SECTION 2

2.0 PROPOSED CONDITIONS

2.1 Subsurface Gravel Wetland Overview

2.1.1 General Description

Subsurface gravel wetlands (SGW) are generally designed as a series of flow through cells that maximize the flow path of water in the gravel wetland through the use of such features as berms, baffles, and islands. The main treatment area is preceded by a forebay, which is designed to remove excess sediment before it reaches the treatment cells, to provide for easier maintenance and routine cleaning, as well as stormwater treatment.

2.1.2 Treatment Overview

SGWs provide several types of treatment for stormwater runoff. Sediment removal is provided by the forebay, as well as further sediment removal as water infiltrates the gravel wetland cells. As water moves through the wetland plants some treatment is provided as these plants remove nutrients and pollution. The main method of treatment, however, occurs in the gravel layer, where treatment involves filtration, sorption, uptake and storage, and microbial mediated transformation of nutrients such as nitrogen. The maintenance of the water level near the surface of the gravel wetland promotes anaerobic conditions which are necessary for a functioning SGW.

Standing water is not anticipated in the design of gravel wetlands, except after large precipitation events. However, the wetland soils are designed to be continuously saturated below a depth of 4 inches by the placement of the outlet elevation. This promotes the growth of wetland vegetation and water quality treatment.

During design storm events, water is ponded on top of the treatment cells until it is filtered into and through the gravel layer, and discharged to receiving waters after treatment. During larger storms, an emergency spillway releases water with less treatment, which prevents the degradation or failure of the gravel wetland berm, while still retaining some water for full treatment.

2.1.3 Design Specifications for Project Area

As shown on the Design Plans, a forebay is proposed to the east of Shed Road and west of the Town Offices parking area. Stormwater will be directed to the forebay via sheet flow from the east and a stormwater swale and culvert from the north. The area draining to the SGW is approximately 1.49 acres, with approximately 0.80 acres of impervious surface.

From the forebay, stormwater will flow into the SGW, located at the southeast corner of the parking area. Stormwater will pass through bays 1 and 2 for treatment, then be discharged through a four-foot diameter concrete outlet structure located in the southwest corner of the wetland. Stormwater will be discharged to an existing 18-inch diameter CMP culvert which outfalls to a vegetated area west of Shed Road, prior to entering the Pond Brook.

In conjunction with the construction of the SGW, described above, the project proposes a grassed-lined swale along the southern edge of the parking area which will convey water to the SGW. A portion of the gravel access road will be re-graded, in order to direct water to the SGW via a proposed grass-lined swale and culvert to the north of the access road and pavement. Additionally, the construction of the grass-lined swale will reduce the amount of impervious gravel area on-site, as well as further gravel reductions to the west of the garage access road through revegetation. See Design Plans for additional information.

2.2 Filter Strips and Vegetated Buffers

2.2.1 General Description

Filter strips are generally engineered vegetated areas adjacent to impervious surfaces. Vegetated buffers are generally undisturbed or restored natural areas such as meadows, or forest areas. Filter strips and vegetated buffers are designed to slow stormwater runoff, filter it through plants and other vegetation, and provides some infiltration to the soil.

2.2.2 Treatment Overview

Filter strips and vegetated buffers provide several types of treatment for stormwater runoff. Sediment removal is provided by the presence of a stone diaphragm and vegetation, which reduces runoff velocity, allowing sediment to settle from the water. Treatment of other pollutants is provided through plant adsorption as runoff moves through the vegetated area. Additionally, stormwater runoff can infiltrate into the soils where further pollutant removal will be provided before the water combines with groundwater.

2.2.3 Design Specifications for Project Area

As shown on the Design Plans, the filter strip and vegetated buffer will be located along the northwest edge of the site. Stormwater will be directed to the filter strip via sheet flow from the east. The area draining to the treatment practice is approximately 1.05 acres, with approximately 0.87 acres of impervious surface.

Stormwater runoff will flow through a two-foot wide by one-foot deep stone diaphragm prior to entering vegetated areas. The stone diaphragm is intended to slow stormwater to non-erosive velocities. Stormwater is then discharged to the filter strip and vegetated buffer for treatment. The engineered filter strip will be constructed along the northwest edge of the gravel storage area and will be approximately 10 feet wide by 275 feet long. The existing wooded area will remain undisturbed. Stormwater will travel through the vegetated areas, with partial infiltration to groundwater, before being discharged over the existing steep bank to the Pond Brook. To provide full treatment of the Water Quality Storm (WQv), the travel length of stormwater runoff over the vegetated area should be a minimum of 65 feet. Refer to the Design Plans for additional details.

SECTION 3

3.0 TREATMENT EFFICIENCY

The efficiency of all stormwater treatment practices depends on the use of the land draining to the practice, defined as the subcatchment area. Efficiency calculations also rely on which design storm is used. The State of Vermont requires stormwater treatment practices to address runoff from the WQv, which is considered to be a one-inch rainfall event. As Pond Brook is a tributary to the Stevens Branch, and ultimately Lake Champlain, the pollutant of concern is phosphorus. To calculate the amount of phosphorus removed each year by the subsurface gravel wetland, the following process was used.

The total site area draining to the SGW is approximately 1.49 acres, of which approximately 0.80 acres (54%) are impervious. Using HydroCAD to model this subcatchment, the runoff rate and depth were evaluated for the WQv storm, as shown in Attachment A. The average depth of runoff during the WQv storm event was calculated to be approximately 0.4 inches. Using the University of New Hampshire Stormwater Center's Best Management Practices Curve for gravel wetlands, included as Attachment B, it was estimated that this treatment practice would remove approximately 40% of phosphorus during the WQv design storm.

The total site area draining to the filter strip and vegetated buffer is approximately 1.05 acres, of which approximately 0.87 acres (83%) are impervious. Based on the research article titled "Surface Water Quality – Phosphorus Removal in Vegetated Filter Strips" from 2003 included as Attachment C, it was assumed that this treatment practice would provide a minimum of approximately 30% of phosphorus removal during the design storm.

The VTDEC provides the "Phosphorus Simple Method Calculations" Worksheet to estimate the amount of phosphorus in runoff from delineated subcatchments. Using the worksheet and the areas calculated previously, it was calculated that the subcatchment draining to the SGW has an annual load of approximately 2.66 pounds of phosphorus per year. Therefore, if the treatment practice is able to effectively remove 40% of phosphorus, the proposed Subsurface Gravel Wetland should remove 1.06 pounds of phosphorus per year. For the filter strip and vegetated buffer, the calculated annual load from the subcatchment is approximately 2.79 pounds of phosphorus per year. Therefore, if the treatment practice is able to effectively remove 30% of phosphorus, the proposed vegetated areas should remove 0.83 pounds of phosphorus per year. The total estimated phosphorus removal from the construction project is approximately 1.89 pounds. The Phosphorus Simple Method Calculations have been included with the report as Attachment D.

SECTION 4

4.0 OPINION OF PROBABLE CONSTRUCTION COST

Below is a table presenting our opinion of construction costs for the proposed Subsurface Gravel Wetland.

Note: In providing opinions of probable construction costs, the Client understands that DuBois & King, Inc. has no control over the cost or availability of labor, equipment or materials, or over market conditions or the Contractor's methods of pricing, and that our Opinion of Probable Construction Costs are made on the basis of our professional judgement and experience. DuBois & King, Inc. makes no warranty, expressed or implied, that the bids or the negotiated costs of the Work will not vary from the Opinion of Probable Construction Cost provided herein.

OPINION OF PROBABLE CONSTRUCTION COST

VTrans Code	DESCRIPTION	UNIT	UNIT COST	QUANTITY	AMOUNT
Site Preparation					
635.11	Mobilization/Demobilization	LS	$ 1,000.00	1	$ 1,000.00
653.476	Geotextile for Silt Fence	SY	$ 4.07	240	$ 976.80
727.04	Project Demarcation Fencing	LF	$ 1.59	200	$ 318.00
N/A	Construction Staking	HR	$ 90.00	8	$ 720.00
				Subtotal:	$ 3,014.80
Gravel Wetland and Filter Strip - Materials (with labor/trucking included)					
203.15	Common Excavation	CY	$ 9.50	520	$ 4,940.00
601.0905	12" CPEP Pipe	LF	$ 62.94	100	$ 6,294.00
601.0910	15" CPEP Pipe	LF	$ 65.00	100	$ 6,500.00
604.11	4' Diameter Catch Basin Structure with Frame and Grate	EACH	$ 3,500.00	1	$ 3,500.00
605.1	6" Underdrain Piping	LF	$ 20.86	100	$ 2,086.00
613.1	Stone Fill, Type I (Hydraulic Inlet)	CY	$ 43.91	10	$ 439.10
629.54	3/4" to 1 1/2" Crushed Stone (Washed Stone Bedding)	TON	$ 35.93	165	$ 5,928.45
649.31	Geotextile under Stone Fill	SY	$ 2.52	135	$ 340.20
651.15	Seed	LBS	$ 7.79	50	$ 389.50
651.35	Topsoil	CY	$ 31.48	197	$ 6,201.56
653.2	Temporary Erosion Matting	SY	$ 2.34	850	$ 1,989.00
656.41	Wetland Plants (Perennials [2 per sq ft])	EACH	$ 2.50	2300	$ 5,750.00
N/A	Wetland Plant Seeds	LBS	$ 125.00	10	$ 1,250.00
900.608	Pea Stone (Special Provision)	TON	$ 35.93	20	$ 718.60
900.608	Wetland Soil (Special Provision)	CY	$ 50.00	28	$ 1,400.00
				Subtotal: Plug Option	$46,476.41
				Subtotal: Seed Option	$41,976.41
Subtotal: Plug Option					$49,491.21
Subtotal: Seed Option					$44,991.21
	Construction Observation	HR	$ 80.00	32	$ 2,560.00
	Construction Contingency - 10%*	%		10	$ 4,949.12
	Incidentals to Construction - 5%*	%		5	$ 2,474.56
	Minor Additional Design Items - 5%*	%		5	$ 2,474.56
Total Cost: Plug Option					$61,900.00
Total Cost: Seed Option					$57,400.00
* Based on greater of two planting options, Plug Option.					

SECTION 5

5.0 COST/BENEFIT ANALYSIS

In providing the Opinion of Construction Cost and this Cost/Benefit Analysis, two planting options have been provided; wetland seeds and wetland planting plugs. These two options have been provided to the Town to highlight the cost difference that could occur depending on how the SGW is constructed. Using wetland seeds would provide a lower initial cost, however, there is potential for seeds to be washed away during a rain event. Additionally, seeds need more care to become established, including the right kind of light and moisture to germinate. Using wetland planting plugs generally increases the survival rate of the plants, especially in the first year of establishment. Plant plugs also generally allow for faster coverage of the planting area, reducing invasive or exotic plant species growth.

For the purposes of this report, the cost/benefit of both using wetland seeds, or wetland plant plugs, has been evaluated. Based on the estimated pollutant removal of the SGW and the filter strip-vegetated buffer, and the Opinion of Probable Construction Cost, the cost per pound of phosphorus removal is approximately $32,751 using wetland plant plugs and $30,370 using wetland seeds.

SECTION 6

6.0 PERMIT REQUIREMENTS

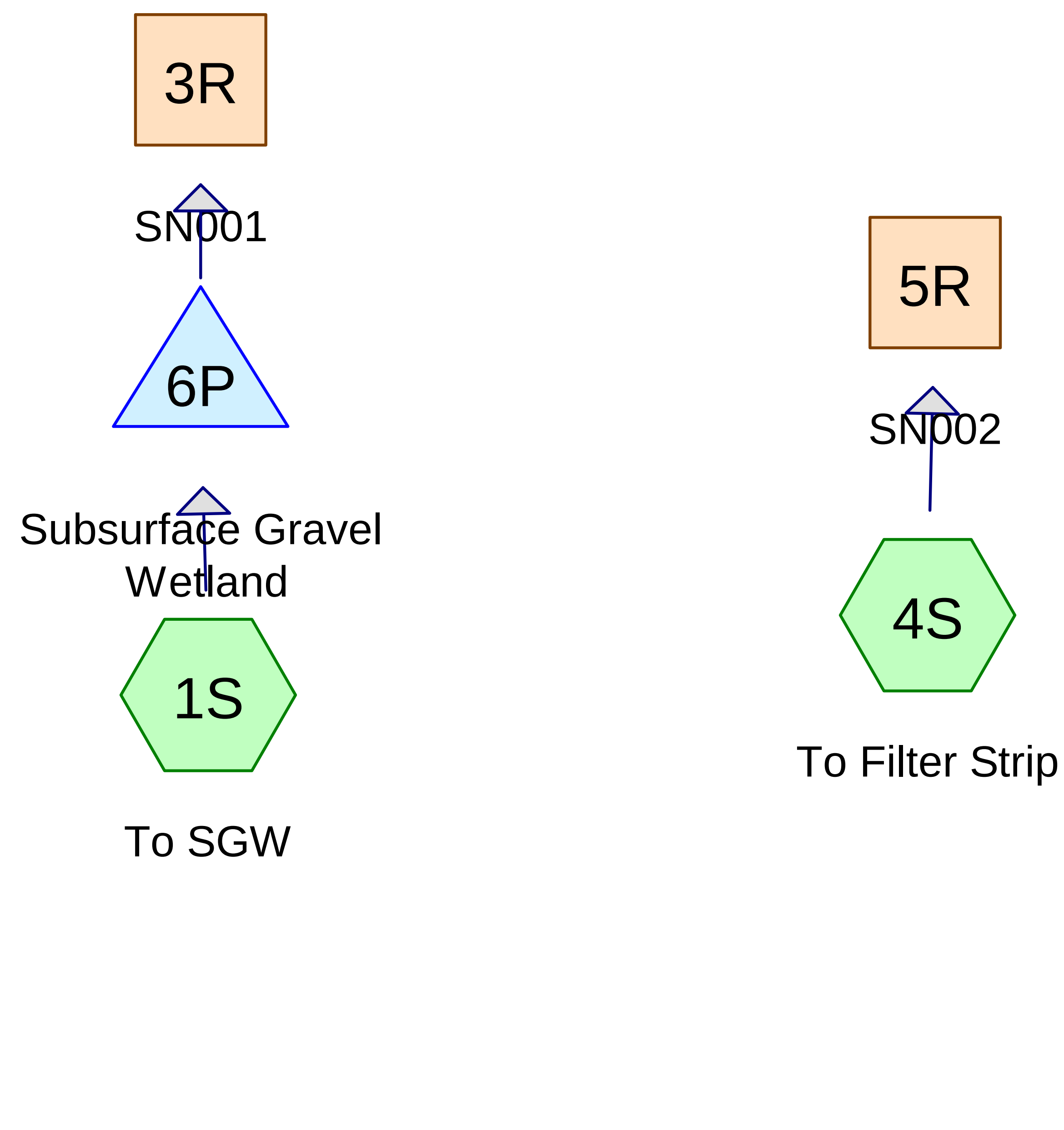
It is not anticipated that any permits will be required for this project. However, the Town Administrator indicated that the Design Plans would still be submitted to the Town of Berlin Development Review Board for approval.

Figures

DuBois & King inc. ENGINEERING · PLANNING · MANAGEMENT · DEVELOPMENT	TOWN OF BERLIN & CVRPC TOWN OFFICES & GARAGE STORMWATER TREATMENT PLAN LOCUS PLAN	DRAWN BY SMB	DATE FEB. 2019	FIGURE 1
		CHECKED BY CJR	D&K PROJECT # 124749	
		PROJ. ENG. MPH	SCALE 1" = 200'	

Attachment A:

HydroCAD Modeling



Routing Diagram for 20181106 Proposed Conditions
Prepared by Dubois & King;, Printed 2/7/2019

Area Listing (selected nodes)

Area (acres)	CN	Description (subcatchment-numbers)
0.765	84	50-75% Grass cover, Fair, HSG D (1S, 4S)
0.712	98	Paved parking, HSG D (1S)
1.110	98	Unconnected pavement, HSG D (4S)
0.128	98	Unconnected roofs, HSG D (1S)
2.716	**94**	**TOTAL AREA**

Time span=0.00-60.00 hrs, dt=0.05 hrs, 1201 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 1S: To SGW Runoff Area=67,508 sf 54.21% Impervious Runoff Depth=1.15"
Tc=5.0 min CN=92 Runoff=3.15 cfs 0.148 af

Subcatchment 4S: To Filter Strip Runoff Area=50,789 sf 95.23% Impervious Runoff Depth=1.57"
Tc=5.0 min CN=97 Runoff=3.01 cfs 0.153 af

Reach 3R: SN001 Inflow=0.28 cfs 0.076 af
Outflow=0.28 cfs 0.076 af

Reach 5R: SN002 Inflow=3.01 cfs 0.153 af
Outflow=3.01 cfs 0.153 af

Pond 6P: Subsurface Gravel Wetland Peak Elev=997.35' Storage=3,603 cf Inflow=3.15 cfs 0.148 af
Outflow=0.28 cfs 0.076 af

Total Runoff Area = 2.716 ac Runoff Volume = 0.301 af Average Runoff Depth = 1.33"
28.17% Pervious = 0.765 ac 71.83% Impervious = 1.951 ac

Summary for Subcatchment 1S: To SGW

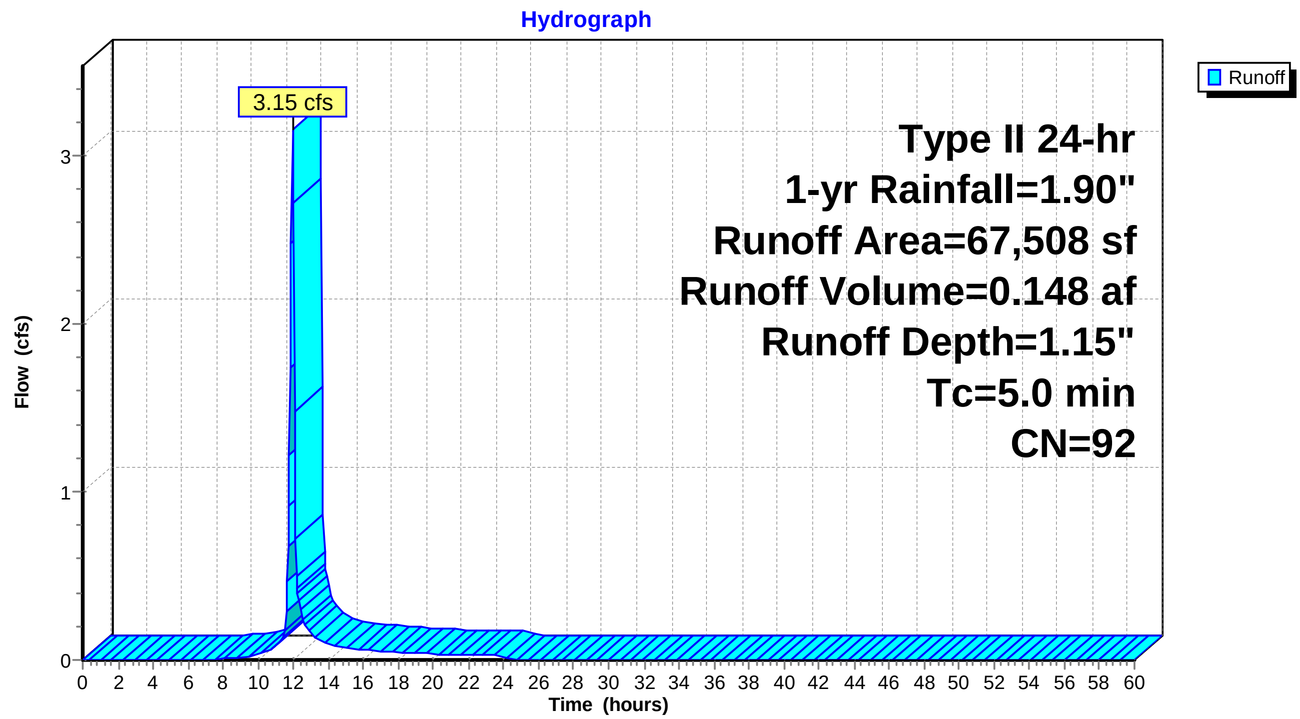
Runoff = 3.15 cfs @ 11.96 hrs, Volume= 0.148 af, Depth= 1.15"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 0.00-60.00 hrs, dt= 0.05 hrs
Type II 24-hr 1-yr Rainfall=1.90"

	Area (sf)	CN	Description
	5,583	98	Unconnected roofs, HSG D
	31,016	98	Paved parking, HSG D
*	30,909	84	50-75% Grass cover, Fair, HSG D
	67,508	92	Weighted Average
	30,909		45.79% Pervious Area
	36,599		54.21% Impervious Area
	5,583		15.25% Unconnected

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

Subcatchment 1S: To SGW



Summary for Subcatchment 4S: To Filter Strip

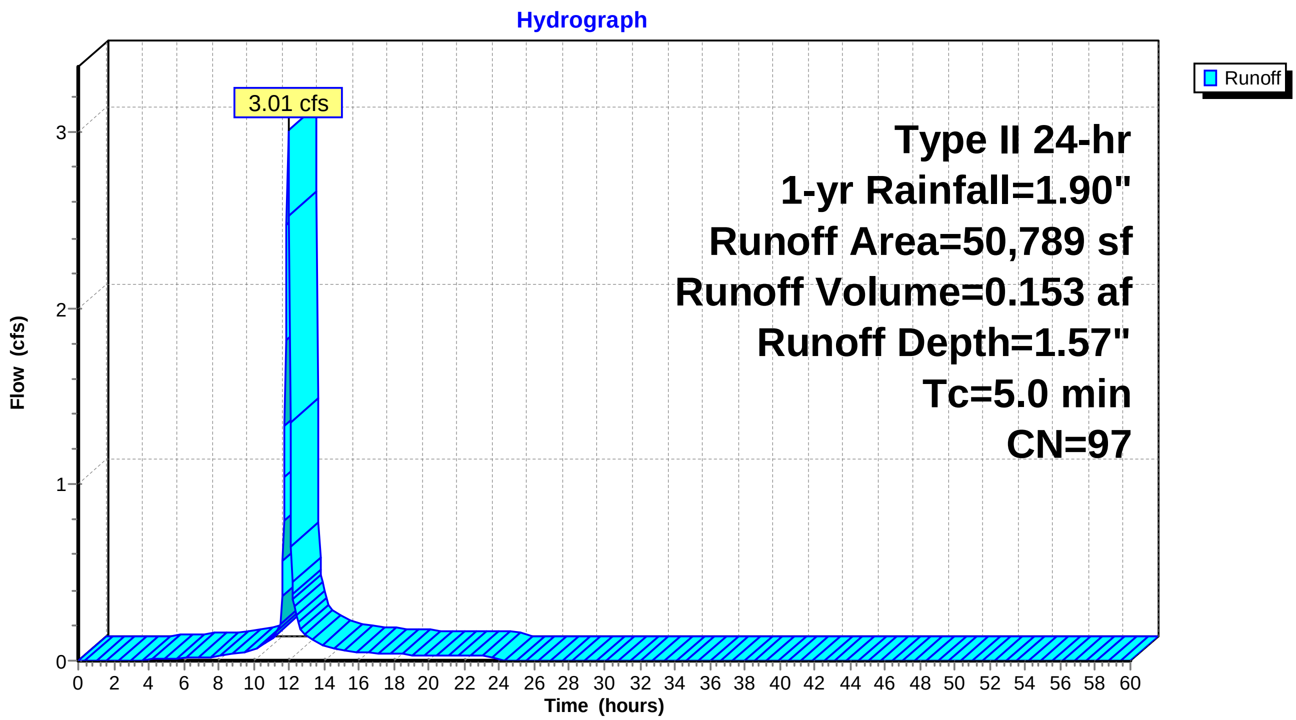
Runoff = 3.01 cfs @ 11.95 hrs, Volume= 0.153 af, Depth= 1.57"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 0.00-60.00 hrs, dt= 0.05 hrs
Type II 24-hr 1-yr Rainfall=1.90"

Area (sf)	CN	Description
48,368	98	Unconnected pavement, HSG D
2,421	84	50-75% Grass cover, Fair, HSG D
50,789	97	Weighted Average
2,421		4.77% Pervious Area
48,368		95.23% Impervious Area
48,368		100.00% Unconnected

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

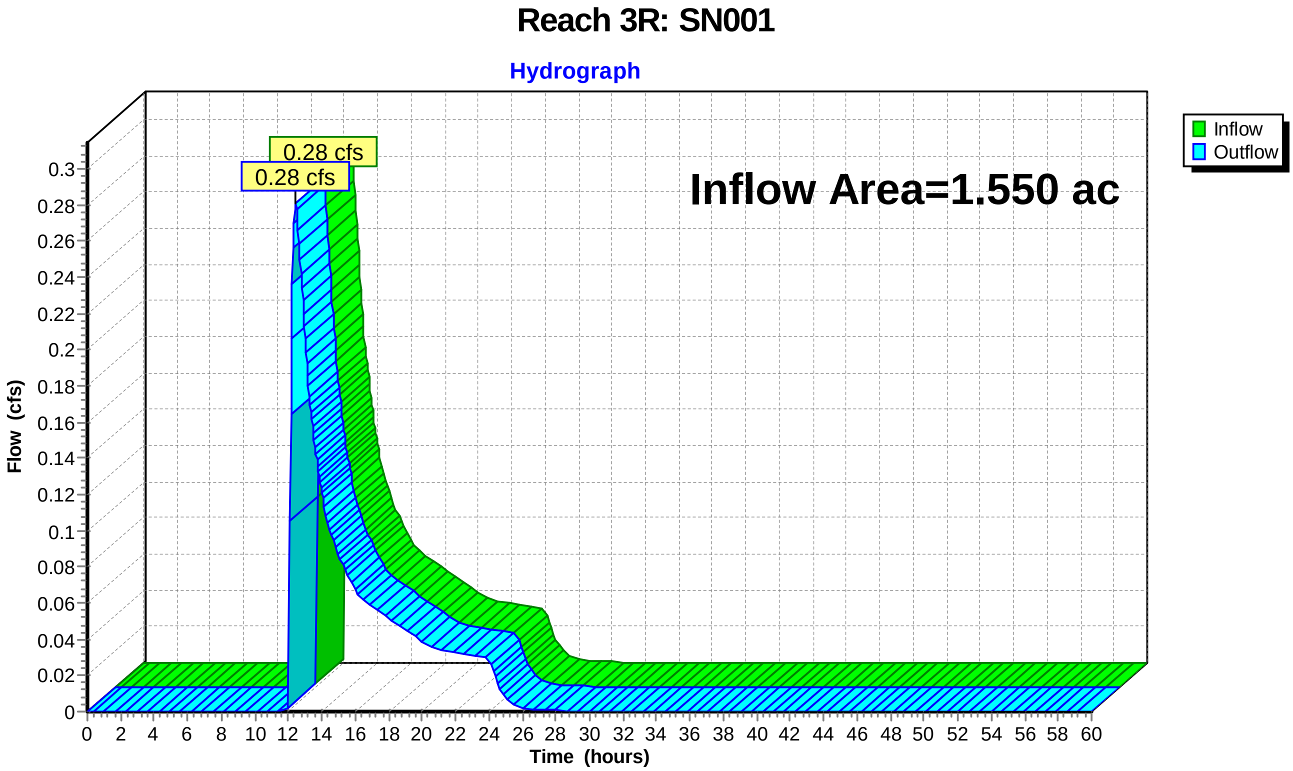
Subcatchment 4S: To Filter Strip



Summary for Reach 3R: SN001

Inflow Area = 1.550 ac, 54.21% Impervious, Inflow Depth = 0.59" for 1-yr event
Inflow = 0.28 cfs @ 12.46 hrs, Volume= 0.076 af
Outflow = 0.28 cfs @ 12.46 hrs, Volume= 0.076 af, Atten= 0%, Lag= 0.0 min

Routing by Stor-Ind+Trans method, Time Span= 0.00-60.00 hrs, dt= 0.05 hrs / 2

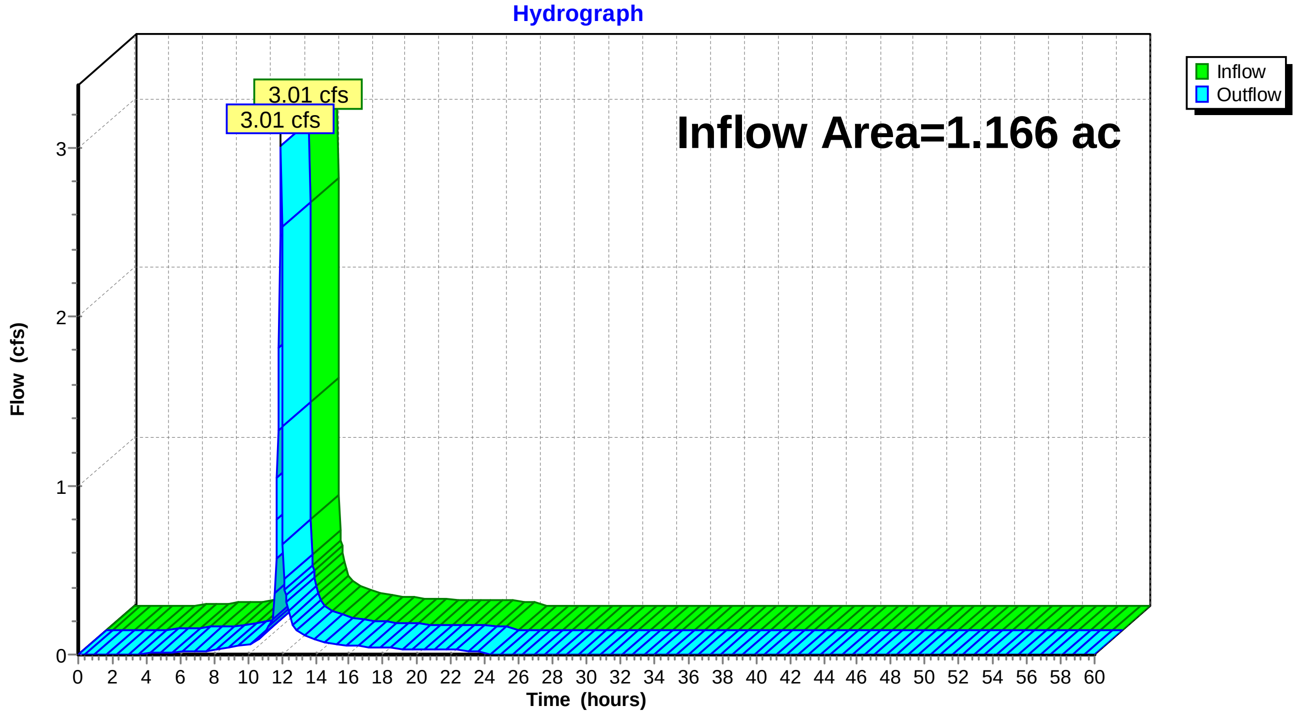


Summary for Reach 5R: SN002

Inflow Area = 1.166 ac, 95.23% Impervious, Inflow Depth = 1.57" for 1-yr event
Inflow = 3.01 cfs @ 11.95 hrs, Volume= 0.153 af
Outflow = 3.01 cfs @ 11.95 hrs, Volume= 0.153 af, Atten= 0%, Lag= 0.0 min

Routing by Stor-Ind+Trans method, Time Span= 0.00-60.00 hrs, dt= 0.05 hrs

Reach 5R: SN002



Summary for Pond 6P: Subsurface Gravel Wetland

Inflow Area = 1.550 ac, 54.21% Impervious, Inflow Depth = 1.15" for 1-yr event
Inflow = 3.15 cfs @ 11.96 hrs, Volume= 0.148 af
Outflow = 0.28 cfs @ 12.46 hrs, Volume= 0.076 af, Atten= 91%, Lag= 30.1 min
Primary = 0.28 cfs @ 12.46 hrs, Volume= 0.076 af

Routing by Stor-Ind method, Time Span= 0.00-60.00 hrs, dt= 0.05 hrs
Peak Elev= 997.35' @ 12.46 hrs Surf.Area= 3,044 sf Storage= 3,603 cf

Plug-Flow detention time= 264.5 min calculated for 0.076 af (51% of inflow)
Center-of-Mass det. time= 148.6 min (962.7 - 814.0)

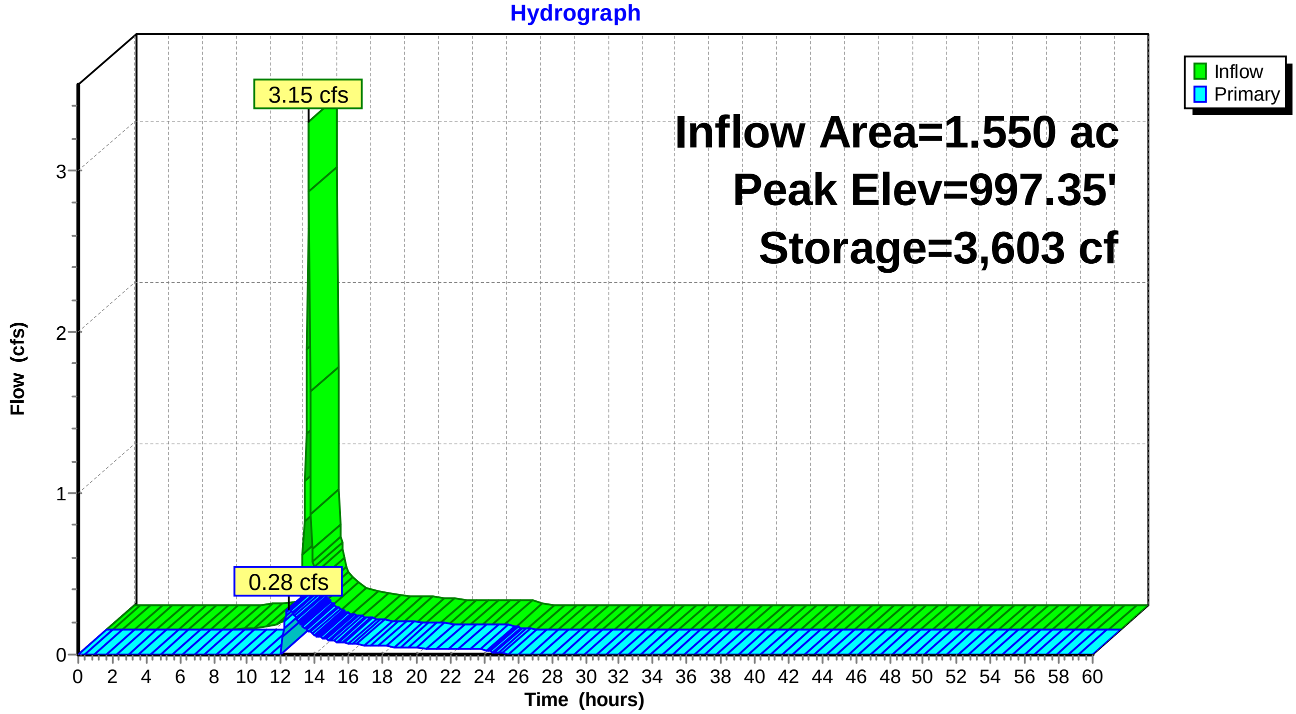
Volume	Invert	Avail.Storage	Storage Description
#1	995.80'	21,812 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc)

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
995.80	1,744	0	0
996.00	1,879	362	362
997.00	2,621	2,250	2,612
998.00	3,832	3,227	5,839
999.00	4,770	4,301	10,140
1,000.00	5,860	5,315	15,455
1,001.00	6,855	6,358	21,812

Device	Routing	Invert	Outlet Devices
#1	Primary	995.00'	**12.0" Round Culvert** L= 75.0' CPP, projecting, no headwall, Ke= 0.900 Inlet / Outlet Invert= 995.00' / 993.50' S= 0.0200 '/' Cc= 0.900 n= 0.013 Corrugated PE, smooth interior, Flow Area= 0.79 sf
#2	Device 1	997.20'	**18.0" W x 6.0" H Vert. CPv Orifice** C= 0.600
#3	Device 1	998.00'	**24.0" x 24.0" Horiz. Top of Structure X 3.00** C= 0.600 Limited to weir flow at low heads

Primary OutFlow Max=0.28 cfs @ 12.46 hrs HW=997.35' (Free Discharge)
└─**1=Culvert** (Passes 0.28 cfs of 4.06 cfs potential flow)
  ├─**2=CPv Orifice** (Orifice Controls 0.28 cfs @ 1.24 fps)
  └─**3=Top of Structure** (Controls 0.00 cfs)

Pond 6P: Subsurface Gravel Wetland



Time span=0.00-60.00 hrs, dt=0.05 hrs, 1201 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 1S: To SGW Runoff Area=67,508 sf 54.21% Impervious Runoff Depth=2.57"
Tc=5.0 min CN=92 Runoff=6.77 cfs 0.332 af

Subcatchment 4S: To Filter Strip Runoff Area=50,789 sf 95.23% Impervious Runoff Depth=3.08"
Tc=5.0 min CN=97 Runoff=5.65 cfs 0.300 af

Reach 3R: SN001 Inflow=4.24 cfs 0.259 af
Outflow=4.24 cfs 0.259 af

Reach 5R: SN002 Inflow=5.65 cfs 0.300 af
Outflow=5.65 cfs 0.300 af

Pond 6P: Subsurface Gravel Wetland Peak Elev=998.07' Storage=6,107 cf Inflow=6.77 cfs 0.332 af
Outflow=4.24 cfs 0.259 af

Total Runoff Area = 2.716 ac Runoff Volume = 0.632 af Average Runoff Depth = 2.79"
28.17% Pervious = 0.765 ac 71.83% Impervious = 1.951 ac

Summary for Subcatchment 1S: To SGW

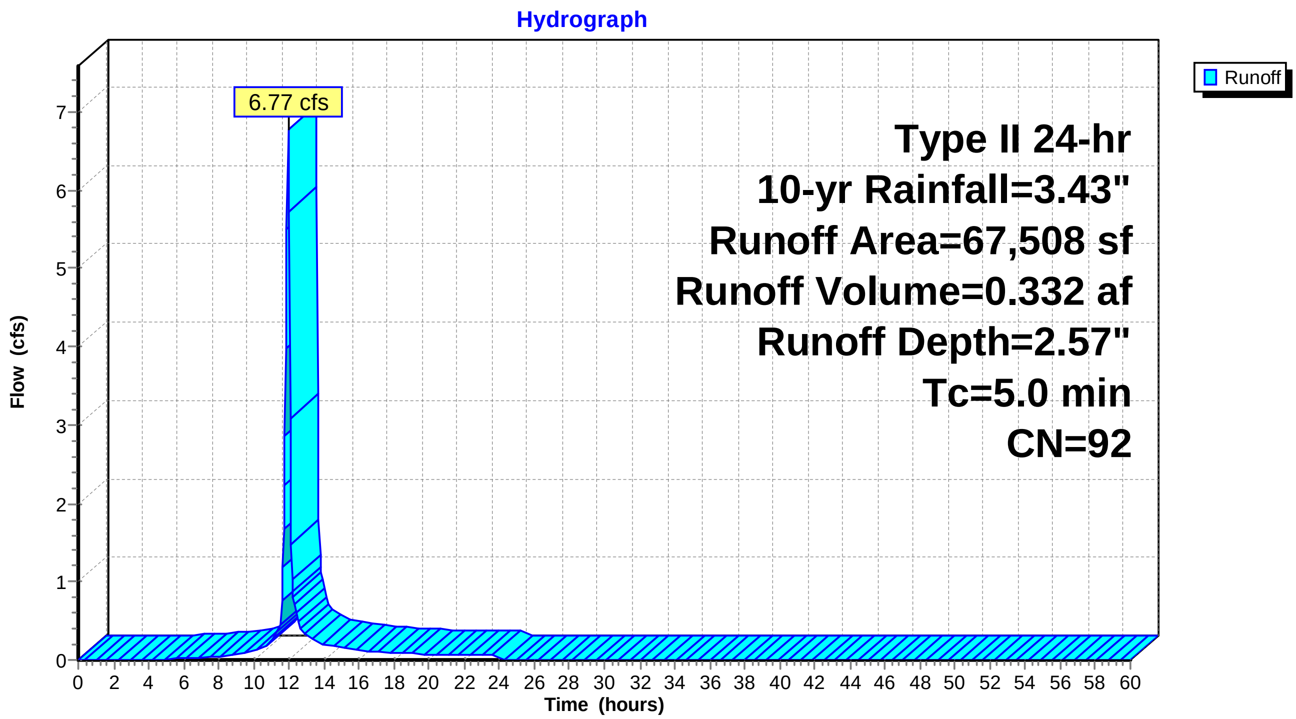
Runoff = 6.77 cfs @ 11.95 hrs, Volume= 0.332 af, Depth= 2.57"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 0.00-60.00 hrs, dt= 0.05 hrs
Type II 24-hr 10-yr Rainfall=3.43"

	Area (sf)	CN	Description
	5,583	98	Unconnected roofs, HSG D
	31,016	98	Paved parking, HSG D
*	30,909	84	50-75% Grass cover, Fair, HSG D
	67,508	92	Weighted Average
	30,909		45.79% Pervious Area
	36,599		54.21% Impervious Area
	5,583		15.25% Unconnected

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

Subcatchment 1S: To SGW



Summary for Subcatchment 4S: To Filter Strip

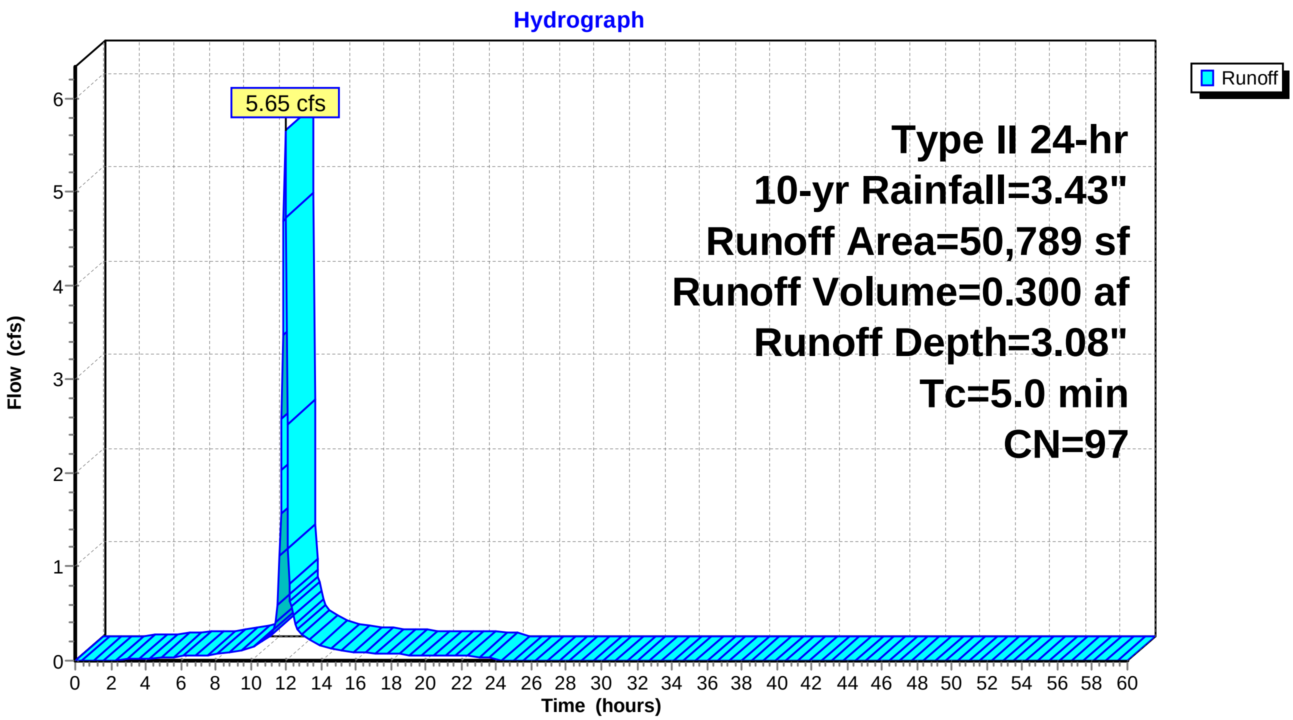
Runoff = 5.65 cfs @ 11.95 hrs, Volume= 0.300 af, Depth= 3.08"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 0.00-60.00 hrs, dt= 0.05 hrs
Type II 24-hr 10-yr Rainfall=3.43"

Area (sf)	CN	Description
48,368	98	Unconnected pavement, HSG D
2,421	84	50-75% Grass cover, Fair, HSG D
50,789	97	Weighted Average
2,421		4.77% Pervious Area
48,368		95.23% Impervious Area
48,368		100.00% Unconnected

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

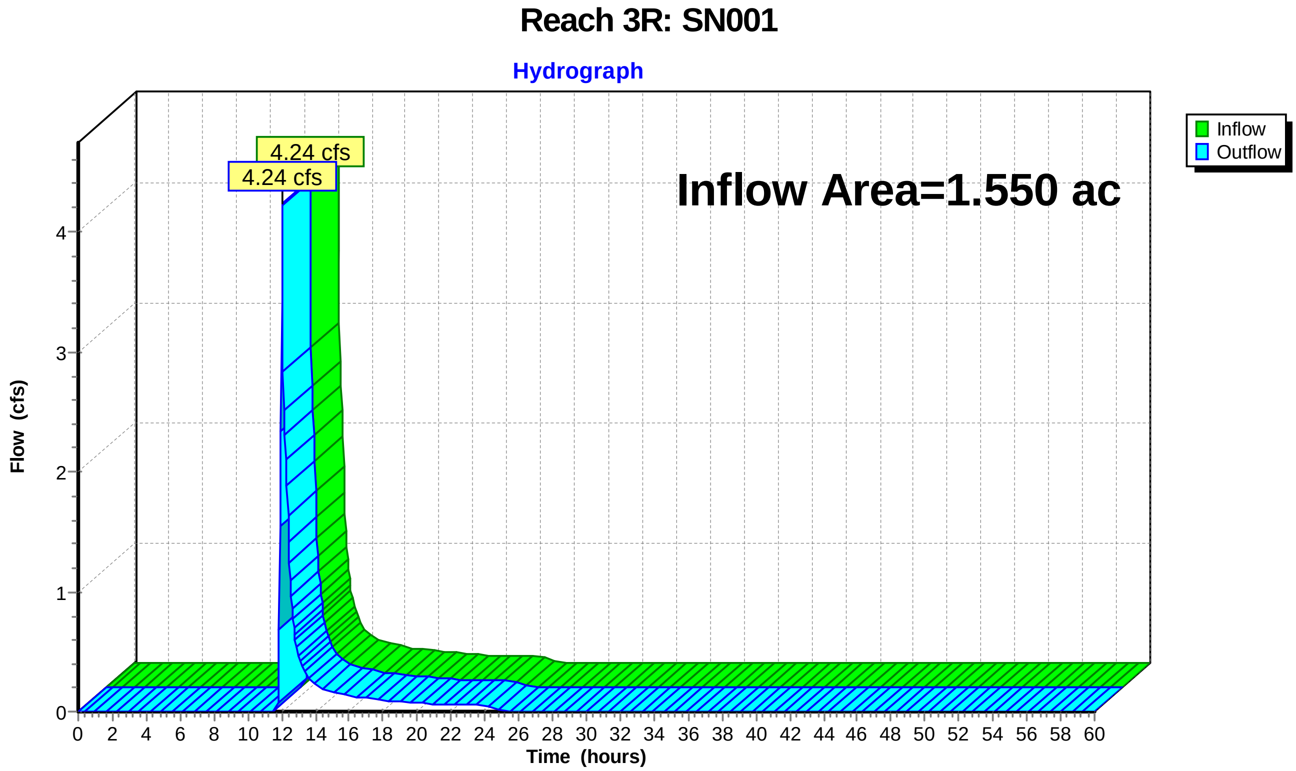
Subcatchment 4S: To Filter Strip



Summary for Reach 3R: SN001

Inflow Area =	1.550 ac,	54.21% Impervious,	Inflow Depth = 2.01"	for 10-yr event
Inflow =	4.24 cfs @	12.04 hrs, Volume=	0.259 af	
Outflow =	4.24 cfs @	12.04 hrs, Volume=	0.259 af,	Atten= 0%, Lag= 0.0 min

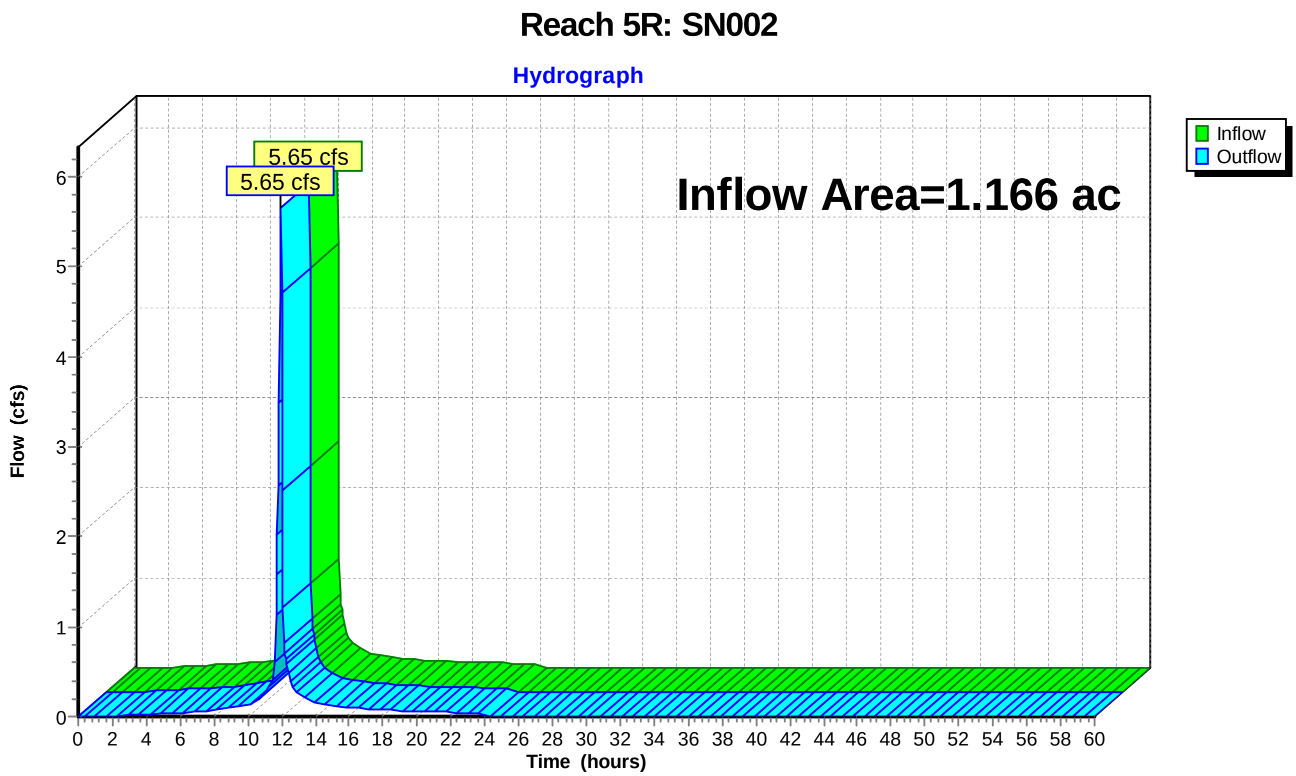
Routing by Stor-Ind+Trans method, Time Span= 0.00-60.00 hrs, dt= 0.05 hrs / 2



Summary for Reach 5R: SN002

Inflow Area =	1.166 ac, 95.23% Impervious, Inflow Depth = 3.08"	for 10-yr event	
Inflow =	5.65 cfs @ 11.95 hrs, Volume=	0.300 af	
Outflow =	5.65 cfs @ 11.95 hrs, Volume=	0.300 af, Atten= 0%, Lag= 0.0 min	

Routing by Stor-Ind+Trans method, Time Span= 0.00-60.00 hrs, dt= 0.05 hrs



Summary for Pond 6P: Subsurface Gravel Wetland

Inflow Area = 1.550 ac, 54.21% Impervious, Inflow Depth = 2.57" for 10-yr event
Inflow = 6.77 cfs @ 11.95 hrs, Volume= 0.332 af
Outflow = 4.24 cfs @ 12.04 hrs, Volume= 0.259 af, Atten= 37%, Lag= 5.4 min
Primary = 4.24 cfs @ 12.04 hrs, Volume= 0.259 af

Routing by Stor-Ind method, Time Span= 0.00-60.00 hrs, dt= 0.05 hrs
Peak Elev= 998.07' @ 12.04 hrs Surf.Area= 3,897 sf Storage= 6,107 cf

Plug-Flow detention time= 153.2 min calculated for 0.259 af (78% of inflow)
Center-of-Mass det. time= 68.5 min (859.6 - 791.2)

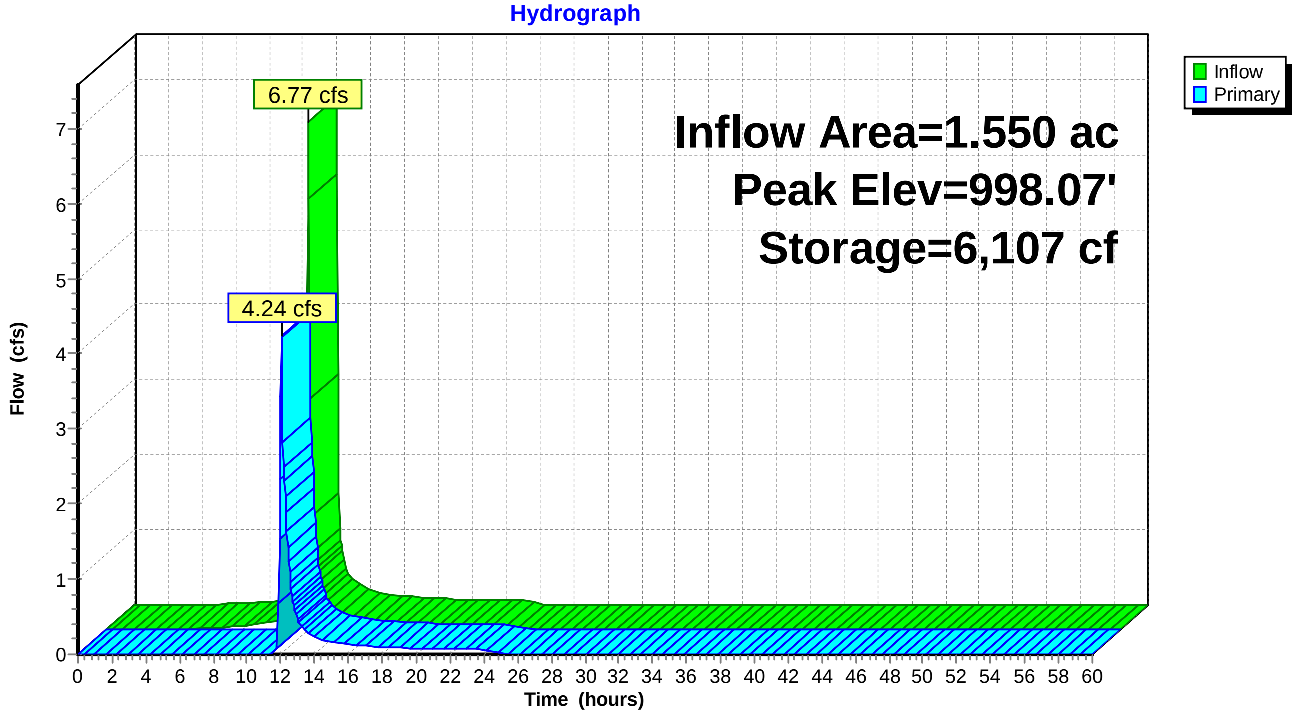
Volume	Invert	Avail.Storage	Storage Description
#1	995.80'	21,812 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc)

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
995.80	1,744	0	0
996.00	1,879	362	362
997.00	2,621	2,250	2,612
998.00	3,832	3,227	5,839
999.00	4,770	4,301	10,140
1,000.00	5,860	5,315	15,455
1,001.00	6,855	6,358	21,812

Device	Routing	Invert	Outlet Devices
#1	Primary	995.00'	**12.0" Round Culvert** L= 75.0' CPP, projecting, no headwall, Ke= 0.900 Inlet / Outlet Invert= 995.00' / 993.50' S= 0.0200 '/' Cc= 0.900 n= 0.013 Corrugated PE, smooth interior, Flow Area= 0.79 sf
#2	Device 1	997.20'	**18.0" W x 6.0" H Vert. CPv Orifice** C= 0.600
#3	Device 1	998.00'	**24.0" x 24.0" Horiz. Top of Structure X 3.00** C= 0.600 Limited to weir flow at low heads

Primary OutFlow Max=4.09 cfs @ 12.04 hrs HW=998.06' (Free Discharge)
└─**1=Culvert** (Passes 4.09 cfs of 4.78 cfs potential flow)
  ├─**2=CPv Orifice** (Orifice Controls 2.81 cfs @ 3.75 fps)
  └─**3=Top of Structure** (Weir Controls 1.28 cfs @ 0.83 fps)

Pond 6P: Subsurface Gravel Wetland



Time span=0.00-60.00 hrs, dt=0.05 hrs, 1201 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 1S: To SGW Runoff Area=67,508 sf 54.21% Impervious Runoff Depth=4.33"
Tc=5.0 min CN=92 Runoff=11.03 cfs 0.560 af

Subcatchment 4S: To Filter Strip Runoff Area=50,789 sf 95.23% Impervious Runoff Depth=4.90"
Tc=5.0 min CN=97 Runoff=8.76 cfs 0.476 af

Reach 3R: SN001 Inflow=5.32 cfs 0.487 af
Outflow=5.32 cfs 0.487 af

Reach 5R: SN002 Inflow=8.76 cfs 0.476 af
Outflow=8.76 cfs 0.476 af

Pond 6P: Subsurface Gravel Wetland Peak Elev=998.68' Storage=8,658 cf Inflow=11.03 cfs 0.560 af
Outflow=5.32 cfs 0.487 af

Total Runoff Area = 2.716 ac Runoff Volume = 1.035 af Average Runoff Depth = 4.58"
28.17% Pervious = 0.765 ac 71.83% Impervious = 1.951 ac

Summary for Subcatchment 1S: To SGW

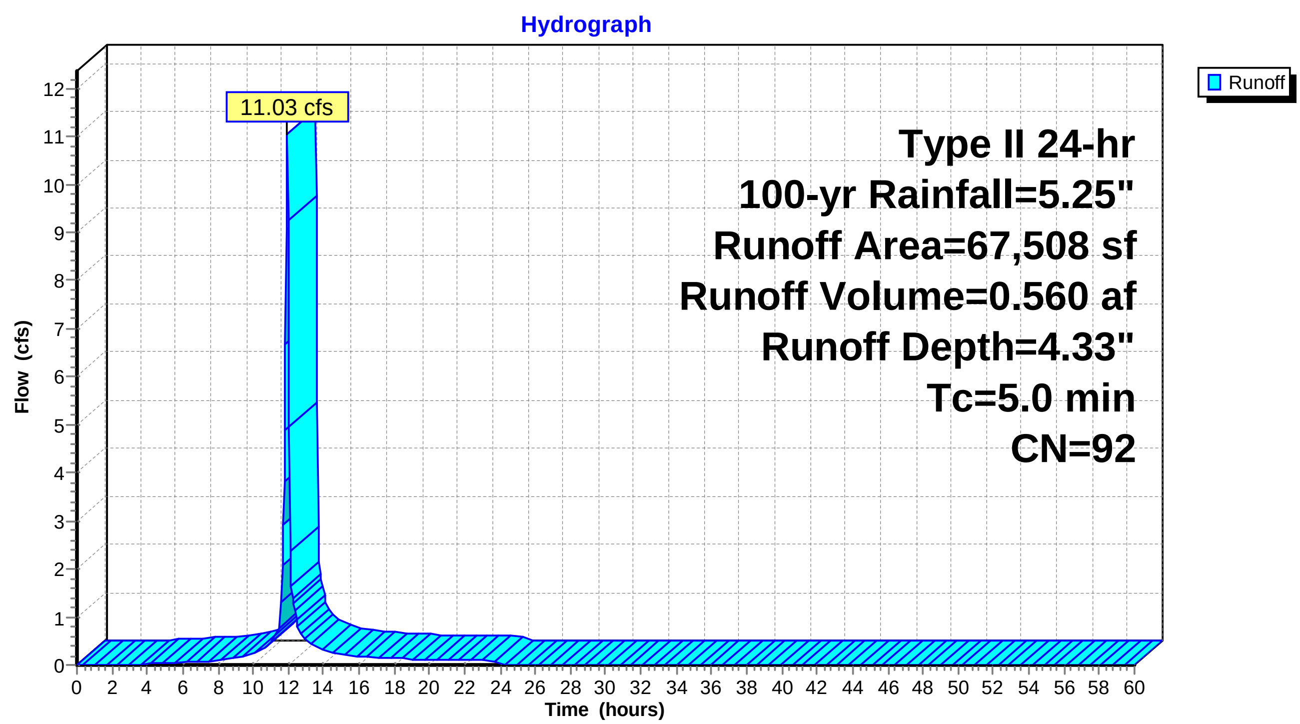
Runoff = 11.03 cfs @ 11.95 hrs, Volume= 0.560 af, Depth= 4.33"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 0.00-60.00 hrs, dt= 0.05 hrs
Type II 24-hr 100-yr Rainfall=5.25"

	Area (sf)	CN	Description
	5,583	98	Unconnected roofs, HSG D
	31,016	98	Paved parking, HSG D
*	30,909	84	50-75% Grass cover, Fair, HSG D
	67,508	92	Weighted Average
	30,909		45.79% Pervious Area
	36,599		54.21% Impervious Area
	5,583		15.25% Unconnected

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

Subcatchment 1S: To SGW



Summary for Subcatchment 4S: To Filter Strip

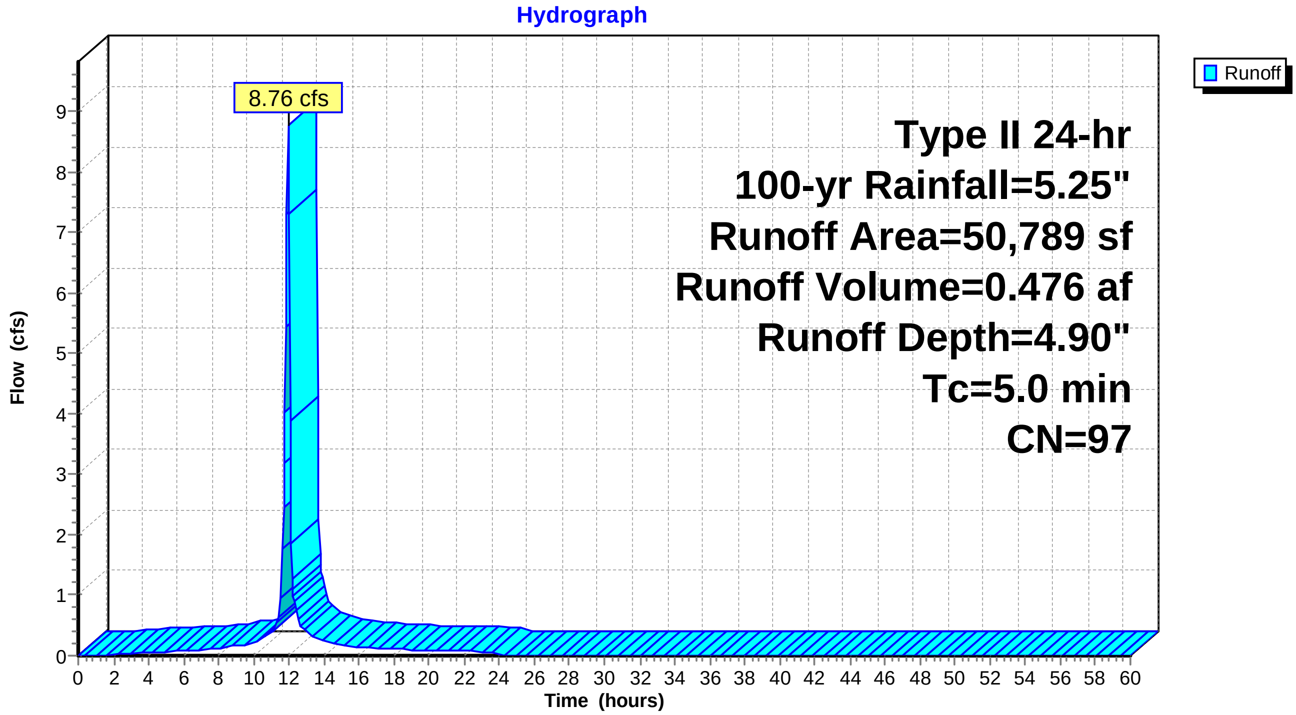
Runoff = 8.76 cfs @ 11.95 hrs, Volume= 0.476 af, Depth= 4.90"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 0.00-60.00 hrs, dt= 0.05 hrs
Type II 24-hr 100-yr Rainfall=5.25"

Area (sf)	CN	Description
48,368	98	Unconnected pavement, HSG D
2,421	84	50-75% Grass cover, Fair, HSG D
50,789	97	Weighted Average
2,421		4.77% Pervious Area
48,368		95.23% Impervious Area
48,368		100.00% Unconnected

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

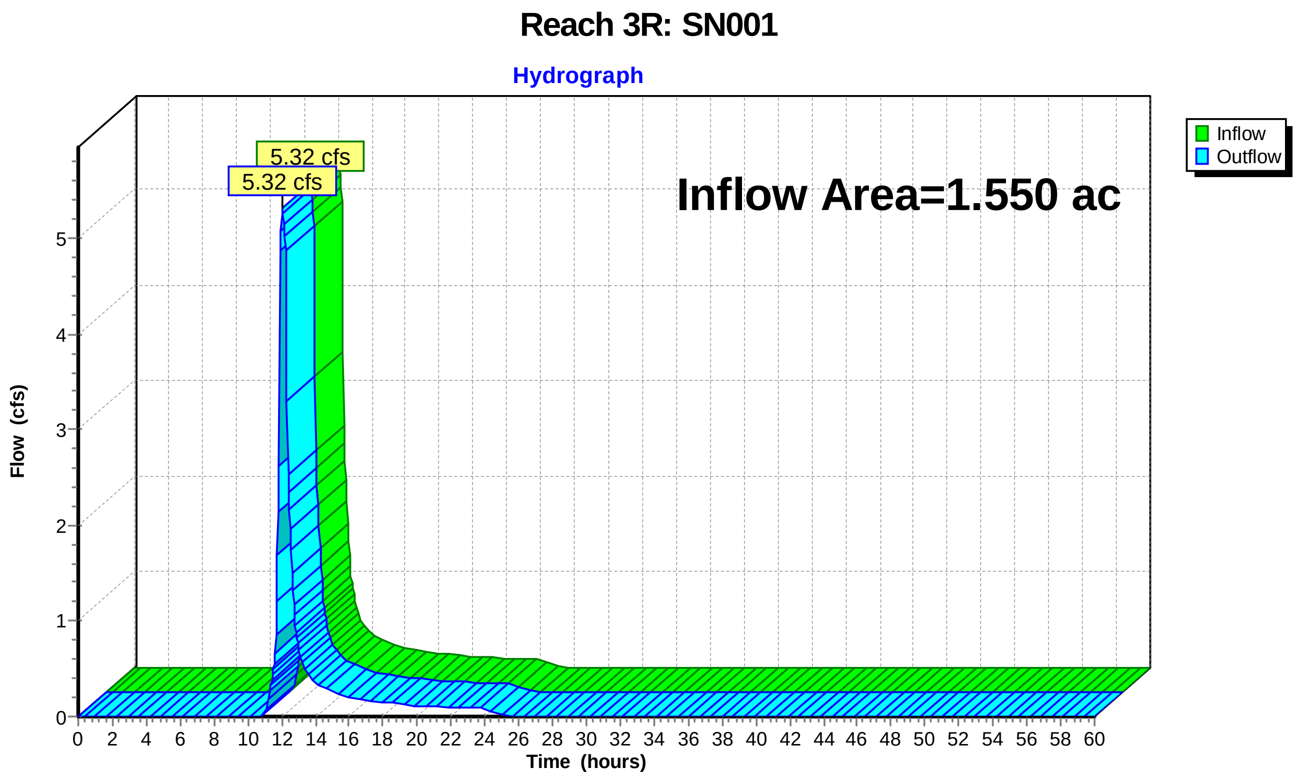
Subcatchment 4S: To Filter Strip



Summary for Reach 3R: SN001

Inflow Area =	1.550 ac, 54.21% Impervious,	Inflow Depth = 3.77"	for 100-yr event	
Inflow =	5.32 cfs @ 12.05 hrs,	Volume=	0.487 af	
Outflow =	5.32 cfs @ 12.05 hrs,	Volume=	0.487 af,	Atten= 0%, Lag= 0.0 min

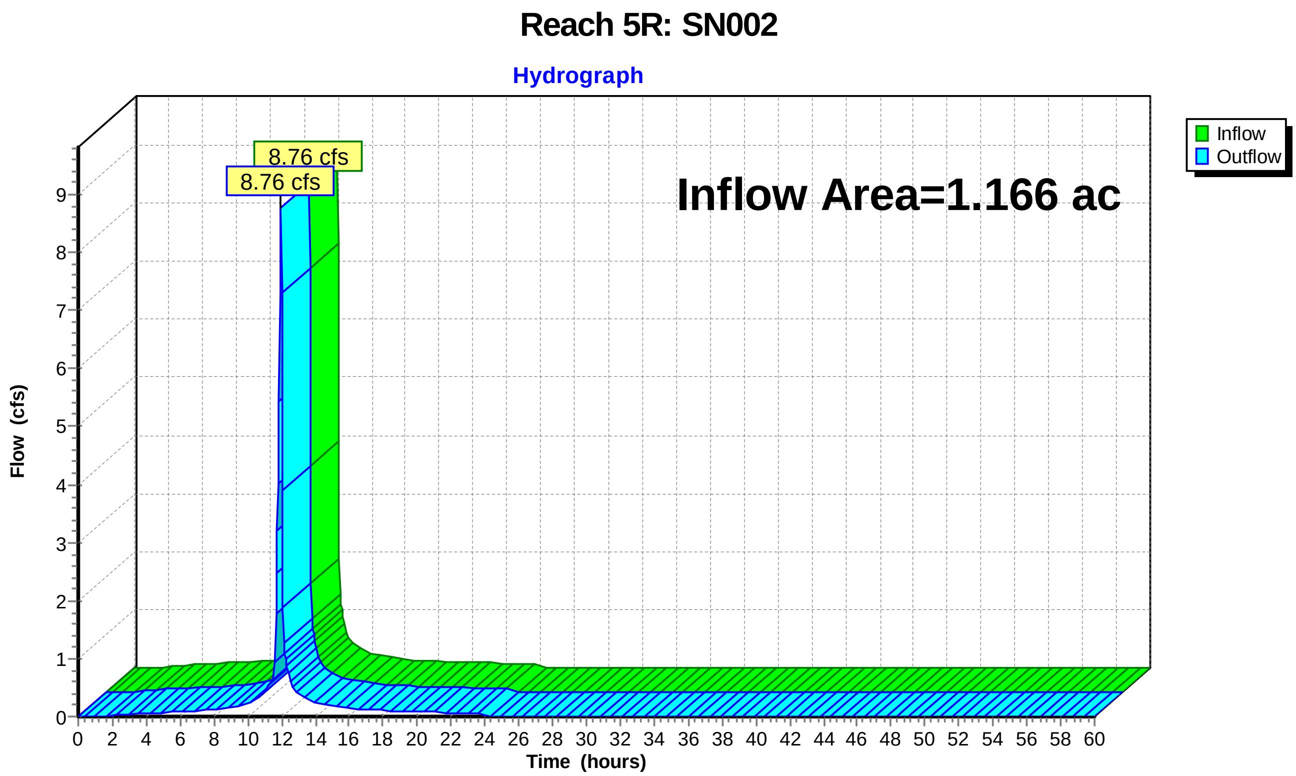
Routing by Stor-Ind+Trans method, Time Span= 0.00-60.00 hrs, dt= 0.05 hrs / 2



Summary for Reach 5R: SN002

Inflow Area =	1.166 ac, 95.23% Impervious, Inflow Depth = 4.90"	for 100-yr event
Inflow =	8.76 cfs @ 11.95 hrs, Volume=	0.476 af
Outflow =	8.76 cfs @ 11.95 hrs, Volume=	0.476 af, Atten= 0%, Lag= 0.0 min

Routing by Stor-Ind+Trans method, Time Span= 0.00-60.00 hrs, dt= 0.05 hrs



Summary for Pond 6P: Subsurface Gravel Wetland

Inflow Area = 1.550 ac, 54.21% Impervious, Inflow Depth = 4.33" for 100-yr event
Inflow = 11.03 cfs @ 11.95 hrs, Volume= 0.560 af
Outflow = 5.32 cfs @ 12.05 hrs, Volume= 0.487 af, Atten= 52%, Lag= 6.0 min
Primary = 5.32 cfs @ 12.05 hrs, Volume= 0.487 af

Routing by Stor-Ind method, Time Span= 0.00-60.00 hrs, dt= 0.05 hrs
Peak Elev= 998.68' @ 12.05 hrs Surf.Area= 4,469 sf Storage= 8,658 cf

Plug-Flow detention time= 118.9 min calculated for 0.487 af (87% of inflow)
Center-of-Mass det. time= 56.7 min (833.6 - 776.9)

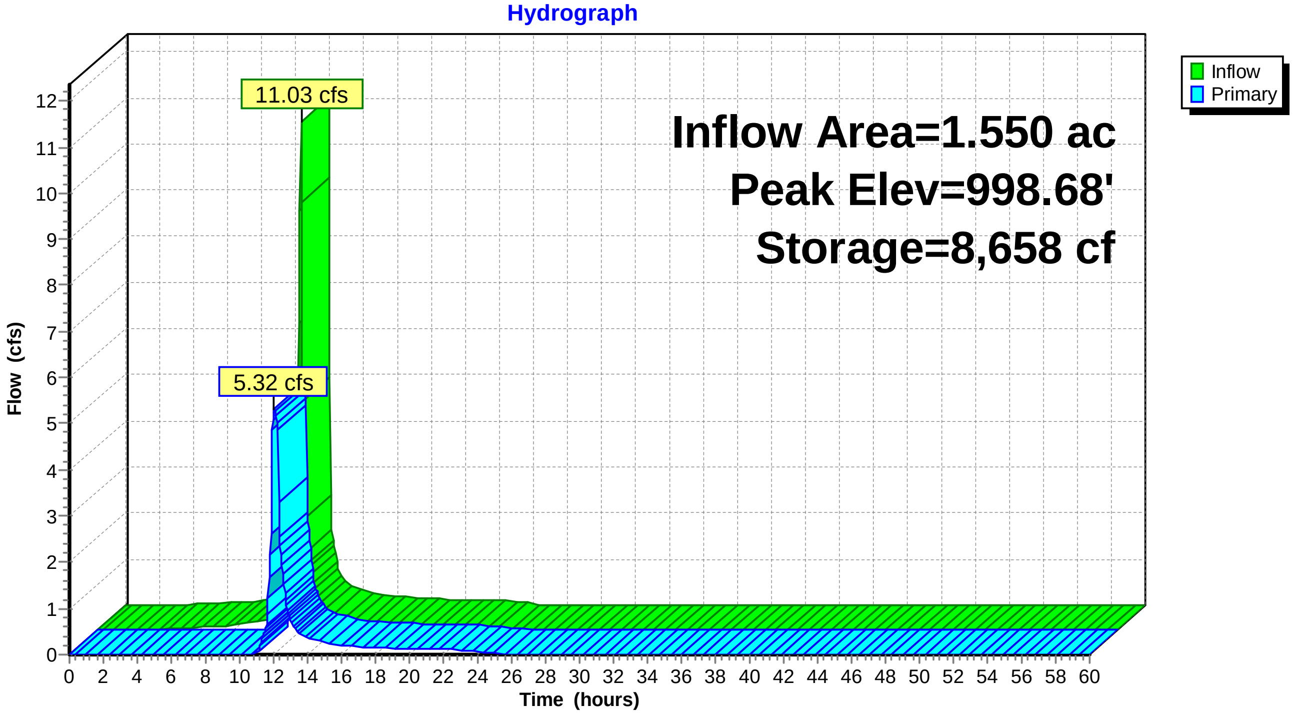
Volume	Invert	Avail.Storage	Storage Description
#1	995.80'	21,812 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc)

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
995.80	1,744	0	0
996.00	1,879	362	362
997.00	2,621	2,250	2,612
998.00	3,832	3,227	5,839
999.00	4,770	4,301	10,140
1,000.00	5,860	5,315	15,455
1,001.00	6,855	6,358	21,812

Device	Routing	Invert	Outlet Devices
#1	Primary	995.00'	**12.0" Round Culvert** L= 75.0' CPP, projecting, no headwall, Ke= 0.900 Inlet / Outlet Invert= 995.00' / 993.50' S= 0.0200 '/' Cc= 0.900 n= 0.013 Corrugated PE, smooth interior, Flow Area= 0.79 sf
#2	Device 1	997.20'	**18.0" W x 6.0" H Vert. CPv Orifice** C= 0.600
#3	Device 1	998.00'	**24.0" x 24.0" Horiz. Top of Structure X 3.00** C= 0.600 Limited to weir flow at low heads

Primary OutFlow Max=5.32 cfs @ 12.05 hrs HW=998.68' (Free Discharge)
└─**1=Culvert** (Inlet Controls 5.32 cfs @ 6.78 fps)
  ├─**2=CPv Orifice** (Passes < 3.99 cfs potential flow)
  └─**3=Top of Structure** (Passes < 43.75 cfs potential flow)

Pond 6P: Subsurface Gravel Wetland



Time span=0.00-60.00 hrs, dt=0.05 hrs, 1201 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 1S: To SGW Runoff Area=67,508 sf 54.21% Impervious Runoff Depth=0.40"
Tc=5.0 min CN=92 Runoff=1.12 cfs 0.052 af

Subcatchment 4S: To Filter Strip Runoff Area=50,789 sf 95.23% Impervious Runoff Depth=0.71"
Tc=5.0 min CN=97 Runoff=1.42 cfs 0.069 af

Reach 3R: SN001 Inflow=0.00 cfs 0.000 af
Outflow=0.00 cfs 0.000 af

Reach 5R: SN002 Inflow=1.42 cfs 0.069 af
Outflow=1.42 cfs 0.069 af

Pond 6P: Subsurface Gravel Wetland Peak Elev=996.86' Storage=2,264 cf Inflow=1.12 cfs 0.052 af
Outflow=0.00 cfs 0.000 af

Total Runoff Area = 2.716 ac Runoff Volume = 0.121 af Average Runoff Depth = 0.53"
28.17% Pervious = 0.765 ac 71.83% Impervious = 1.951 ac

Summary for Subcatchment 1S: To SGW

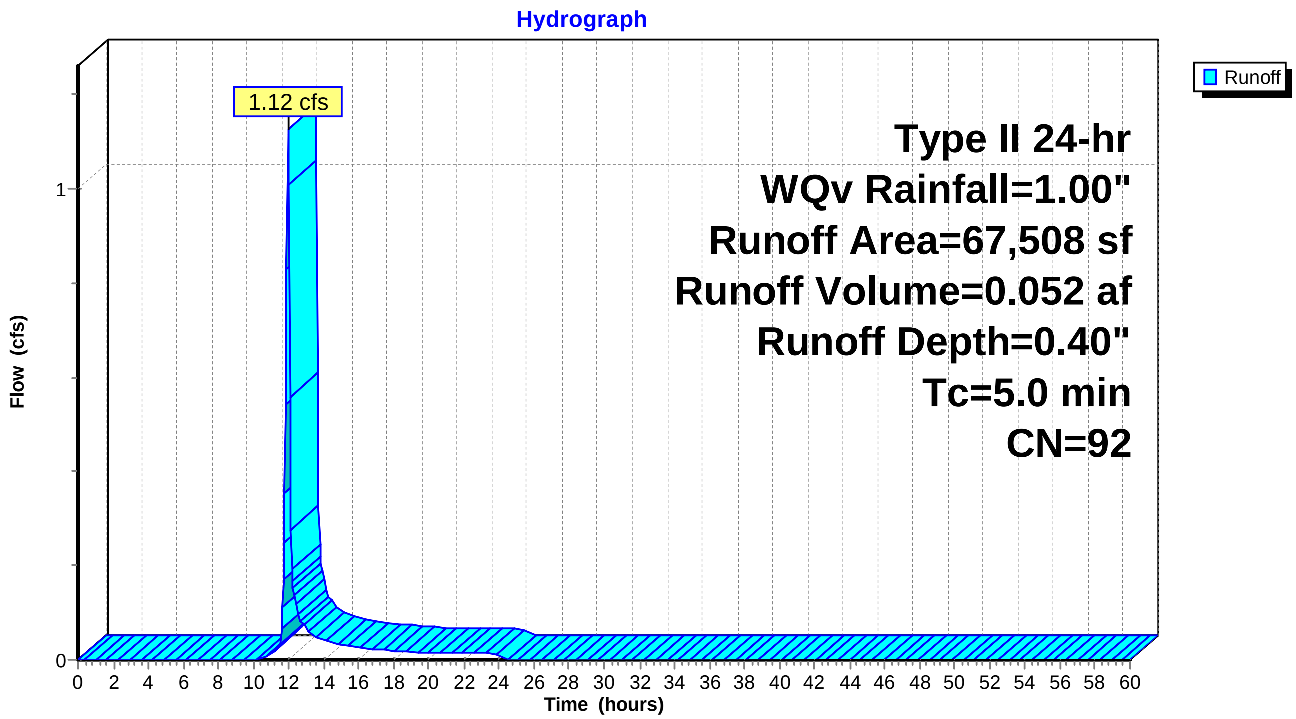
Runoff = 1.12 cfs @ 11.96 hrs, Volume= 0.052 af, Depth= 0.40"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 0.00-60.00 hrs, dt= 0.05 hrs
Type II 24-hr WQv Rainfall=1.00"

	Area (sf)	CN	Description
	5,583	98	Unconnected roofs, HSG D
	31,016	98	Paved parking, HSG D
*	30,909	84	50-75% Grass cover, Fair, HSG D
	67,508	92	Weighted Average
	30,909		45.79% Pervious Area
	36,599		54.21% Impervious Area
	5,583		15.25% Unconnected

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

Subcatchment 1S: To SGW



Summary for Subcatchment 4S: To Filter Strip

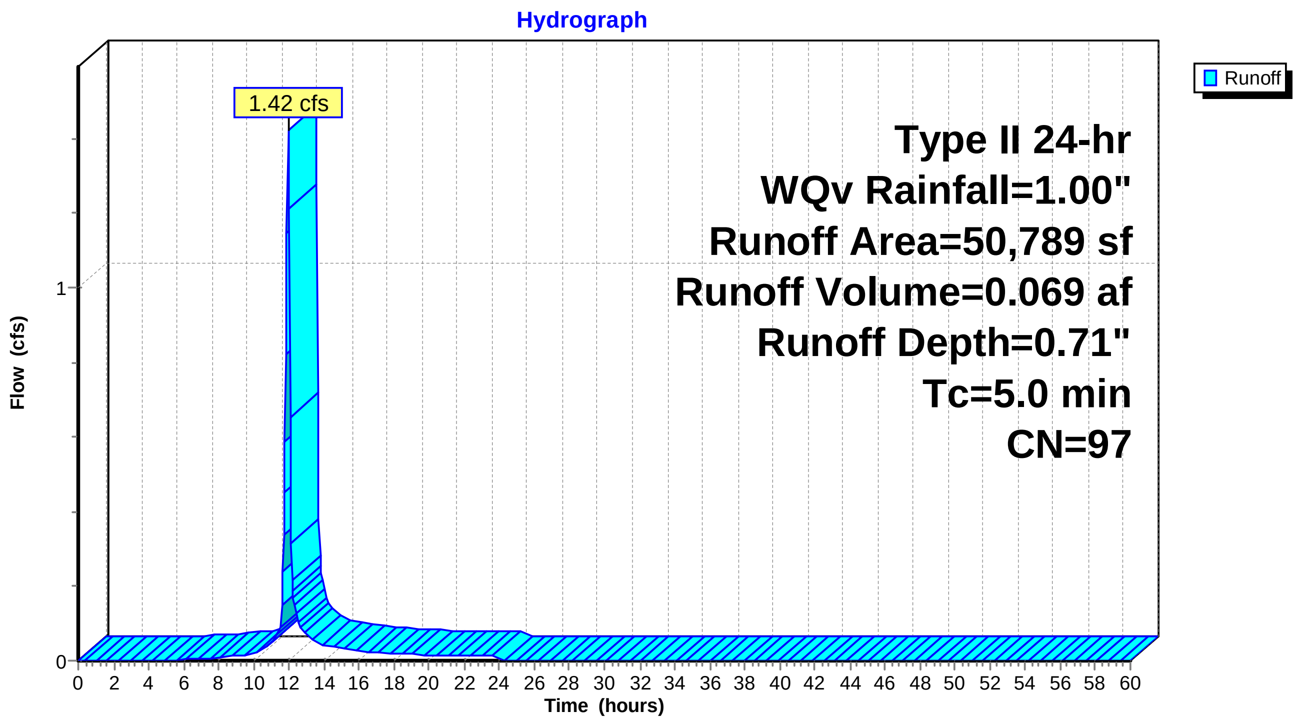
Runoff = 1.42 cfs @ 11.95 hrs, Volume= 0.069 af, Depth= 0.71"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 0.00-60.00 hrs, dt= 0.05 hrs
Type II 24-hr WQv Rainfall=1.00"

Area (sf)	CN	Description
48,368	98	Unconnected pavement, HSG D
2,421	84	50-75% Grass cover, Fair, HSG D
50,789	97	Weighted Average
2,421		4.77% Pervious Area
48,368		95.23% Impervious Area
48,368		100.00% Unconnected

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

Subcatchment 4S: To Filter Strip

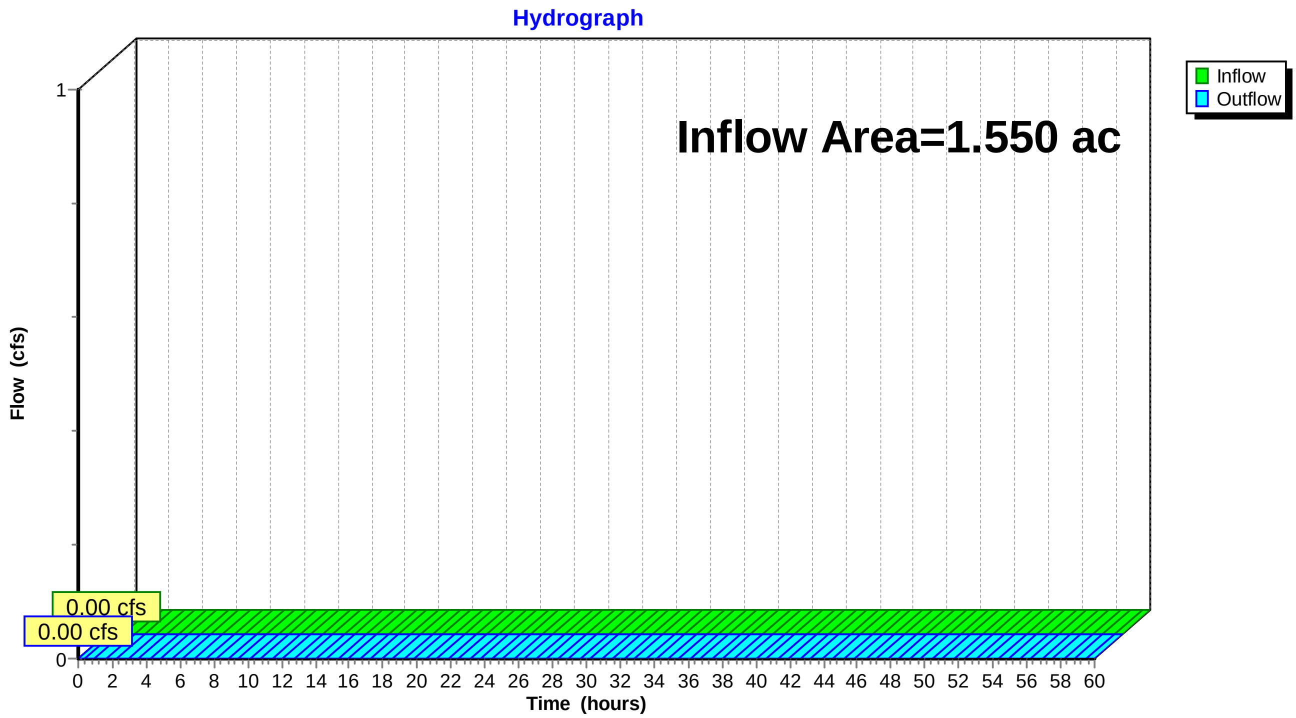


Summary for Reach 3R: SN001

Inflow Area = 1.550 ac, 54.21% Impervious, Inflow Depth = 0.00" for WQv event
Inflow = 0.00 cfs @ 0.00 hrs, Volume= 0.000 af
Outflow = 0.00 cfs @ 0.00 hrs, Volume= 0.000 af, Atten= 0%, Lag= 0.0 min

Routing by Stor-Ind+Trans method, Time Span= 0.00-60.00 hrs, dt= 0.05 hrs / 2

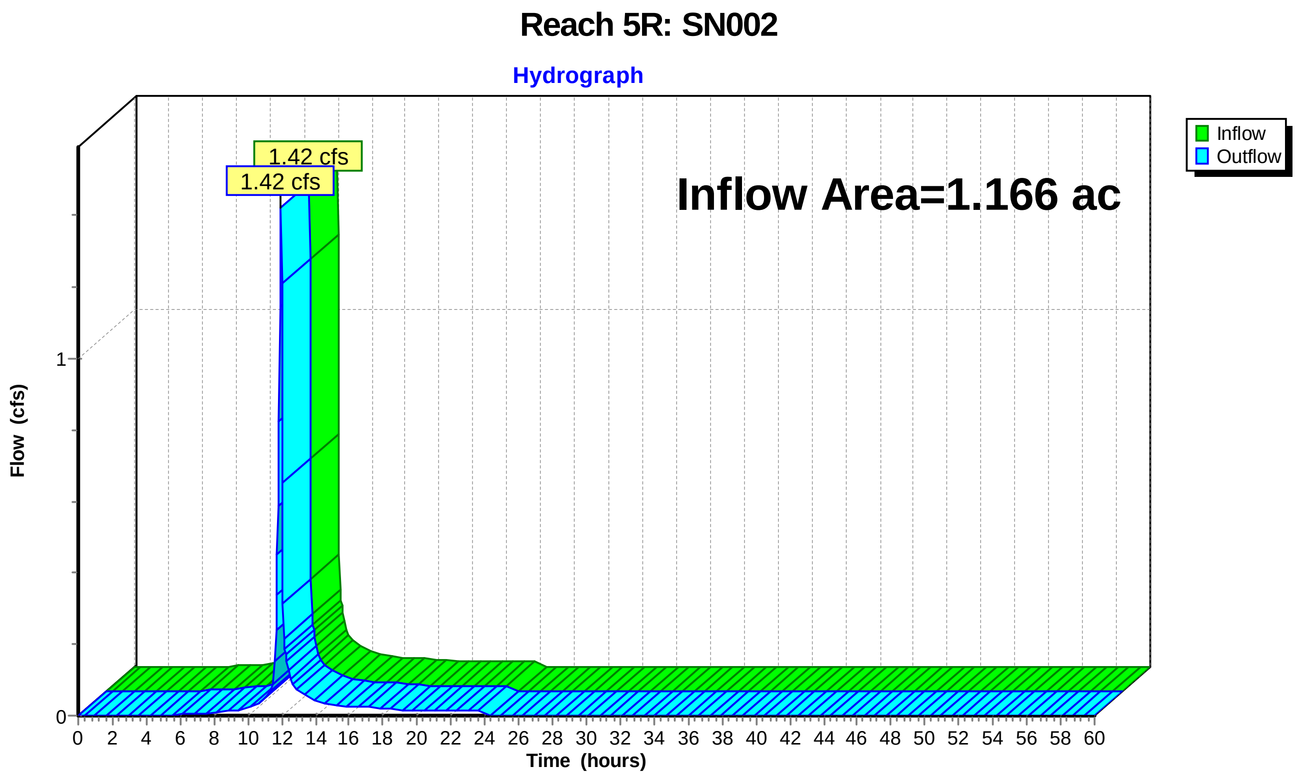
Reach 3R: SN001



Summary for Reach 5R: SN002

Inflow Area =	1.166 ac, 95.23% Impervious,	Inflow Depth = 0.71"	for WQv event	
Inflow =	1.42 cfs @ 11.95 hrs,	Volume=	0.069 af	
Outflow =	1.42 cfs @ 11.95 hrs,	Volume=	0.069 af,	Atten= 0%, Lag= 0.0 min

Routing by Stor-Ind+Trans method, Time Span= 0.00-60.00 hrs, dt= 0.05 hrs



Summary for Pond 6P: Subsurface Gravel Wetland

Inflow Area = 1.550 ac, 54.21% Impervious, Inflow Depth = 0.40" for WQv event
Inflow = 1.12 cfs @ 11.96 hrs, Volume= 0.052 af
Outflow = 0.00 cfs @ 0.00 hrs, Volume= 0.000 af, Atten= 100%, Lag= 0.0 min
Primary = 0.00 cfs @ 0.00 hrs, Volume= 0.000 af

Routing by Stor-Ind method, Time Span= 0.00-60.00 hrs, dt= 0.05 hrs
Peak Elev= 996.86' @ 24.35 hrs Surf.Area= 2,520 sf Storage= 2,264 cf

Plug-Flow detention time= (not calculated: initial storage exceeds outflow)
Center-of-Mass det. time= (not calculated: no outflow)

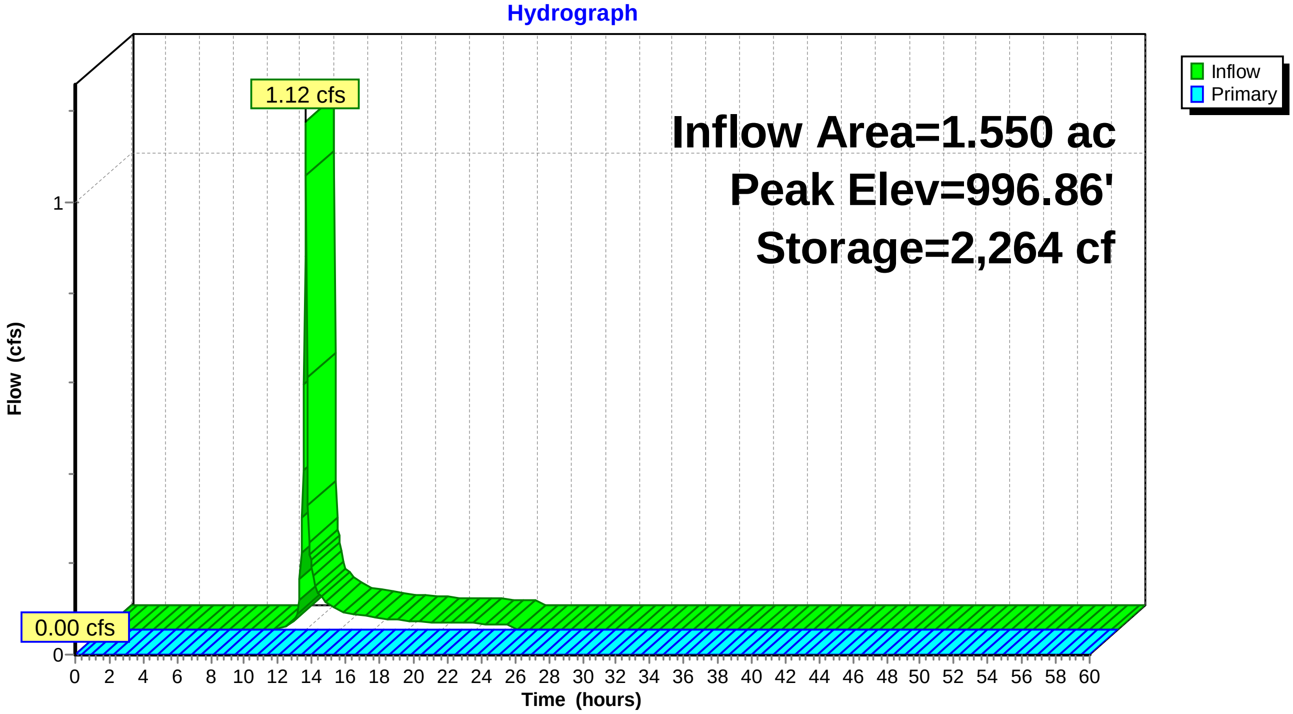
Volume	Invert	Avail.Storage	Storage Description
#1	995.80'	21,812 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc)

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
995.80	1,744	0	0
996.00	1,879	362	362
997.00	2,621	2,250	2,612
998.00	3,832	3,227	5,839
999.00	4,770	4,301	10,140
1,000.00	5,860	5,315	15,455
1,001.00	6,855	6,358	21,812

Device	Routing	Invert	Outlet Devices
#1	Primary	995.00'	**12.0" Round Culvert** L= 75.0' CPP, projecting, no headwall, Ke= 0.900 Inlet / Outlet Invert= 995.00' / 993.50' S= 0.0200 '/' Cc= 0.900 n= 0.013 Corrugated PE, smooth interior, Flow Area= 0.79 sf
#2	Device 1	997.20'	**18.0" W x 6.0" H Vert. CPv Orifice** C= 0.600
#3	Device 1	998.00'	**24.0" x 24.0" Horiz. Top of Structure X 3.00** C= 0.600 Limited to weir flow at low heads

Primary OutFlow Max=0.00 cfs @ 0.00 hrs HW=995.80' (Free Discharge)
└─**1=Culvert** (Passes 0.00 cfs of 1.62 cfs potential flow)
  ├─**2=CPv Orifice** (Controls 0.00 cfs)
  └─**3=Top of Structure** (Controls 0.00 cfs)

Pond 6P: Subsurface Gravel Wetland



Culvert Report

Hydraflow Express Extension for Autodesk® AutoCAD® Civil 3D® by Autodesk, Inc.

Circular Culvert

Invert Elev Dn (ft)	=	998.50
Pipe Length (ft)	=	95.00
Slope (%)	=	0.84
Invert Elev Up (ft)	=	999.30
Rise (in)	=	15.0
Shape	=	Circular
Span (in)	=	15.0
No. Barrels	=	1
n-Value	=	0.013
Culvert Type	=	Circular Culvert
Culvert Entrance	=	Rough tapered inlet throat
Coeff. K,M,c,Y,k	=	0.519, 0.64, 0.021, 0.9, 0.5

Embankment

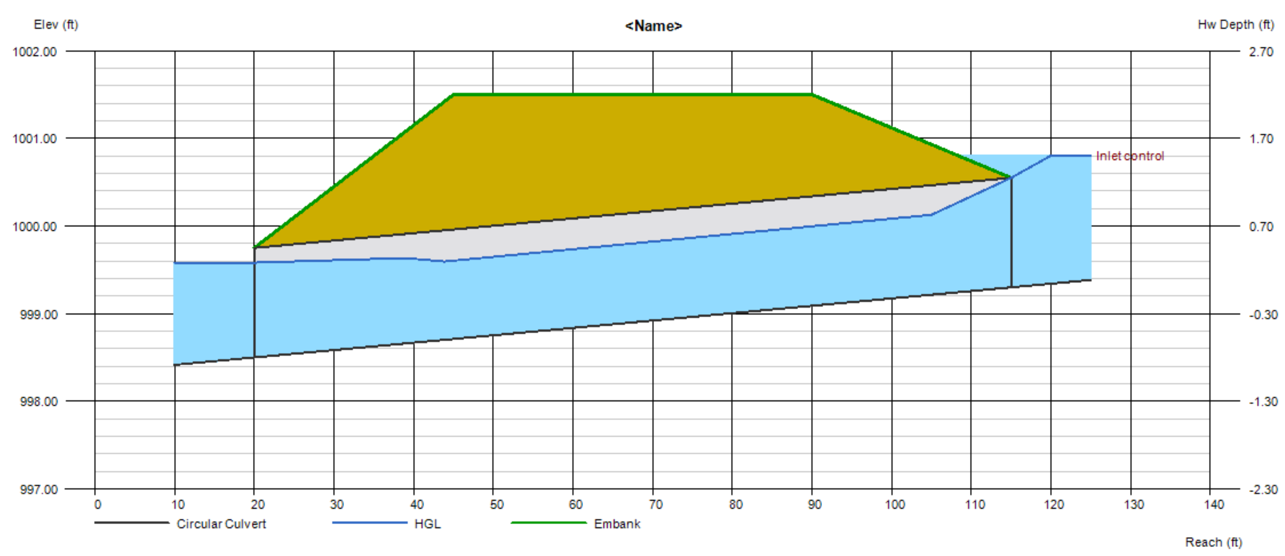
Top Elevation (ft)	=	1001.50
Top Width (ft)	=	45.00
Crest Width (ft)	=	45.00

Calculations

Qmin (cfs)	=	5.10
Qmax (cfs)	=	5.10
Tailwater Elev (ft)	=	(dc+D)/2

Highlighted

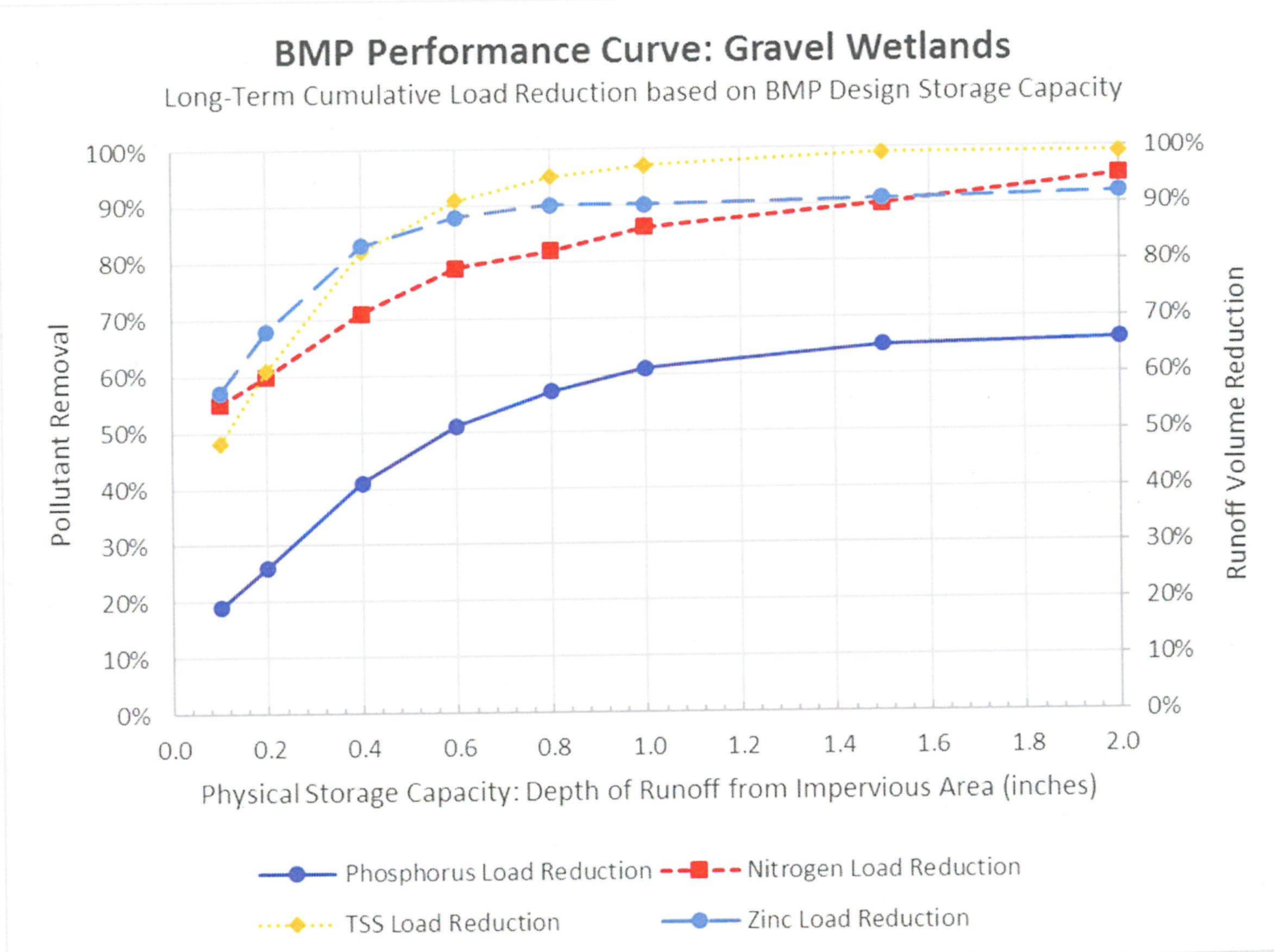
Qtotal (cfs)	=	5.10
Qpipe (cfs)	=	5.10
Qovertop (cfs)	=	0.00
Veloc Dn (ft/s)	=	4.52
Veloc Up (ft/s)	=	5.30
HGL Dn (ft)	=	999.58
HGL Up (ft)	=	1000.22
Hw Elev (ft)	=	1000.80
Hw/D (ft)	=	1.20
Flow Regime	=	Inlet Control



Attachment B:

BMP Performance Curve for Gravel Wetlands

BMP Performance Curve for Gravel Wetlands



University of New Hampshire Stormwater Center Research Based approach to better stormwater management and non-point source pollution control

Attachment C:

Phosphorus Removal Efficiency in Vegetated Filter Strips

Surface Water Quality

Phosphorus Removal in Vegetated Filter Strips

Majed Abu-Zreig,* Ramesh P. Rudra, Hugh R. Whiteley, Manon N. Lalonde, and Narinder K. Kaushik

ABSTRACT

Vegetated filter strips (VFS) are used recently for removal, at or near the source, of sediment and sediment-bound chemicals from cropland runoff. Vegetation within the flowpath increases water infiltration and decreases water turbulence, thus enhancing pollutant removal by sedimentation within filter media and infiltration through the filter surface. Field experiments have been conducted to examine the efficiency of vegetated filter strips for phosphorus removal from cropland runoff with 20 filters with varying length (2 to 15 m), slope (2.3 and 5%), and vegetated cover, including bare-soil plots as control. Artificial runoff used in this study had an average phosphorus concentration of 2.37 mg L^{-1} and a sediment concentration of 2700 mg L^{-1}. The average phosphorus trapping efficiency of all vegetated filters was 61% and ranged from 31% in a 2-m filter to 89% in a 15-m filter. Filter length has been found to be the predominant factor affecting P trapping in VFS. The rate of inflow, type of vegetation, and density of vegetation coverage had secondary influences on P removal. Short filters (2 and 5 m), which are somewhat effective in sediment removal, are much less effective in P removal. Increasing the filter length beyond 15 m is ineffective in enhancing sediment removal but is expected to further enhance P removal. Sediment deposition, infiltration, and plant adsorption are the primary mechanisms for phosphorus trapping in VFS.

During the last 20 years, the effects of nonpoint-source (NPS) pollution have received increasing attention globally. Efforts to reduce NPS pollution from cropland were first aimed at reducing surface runoff and erosion within fields. Improvements in land management practices such as no-till practices, contouring, crop rotation, and timely application of fertilizers and herbicides were investigated. Later on, means of treating cropland runoff at field edges were considered (Becker and Mills, 1972). Sediment-control structures and vegetative filter strips (VFS) were among the techniques that have been used to reduce NPS at or near its source (USEPA, 1976).

Vegetated filter strips can be defined as bands of cropland adjacent to streams or drainage ditches that are set aside from crop production to be planted with permanent vegetation. When cropland runoff flows across the VFS, it undergoes a decrease in pollutant concentration and volume. These changes reduce the loading of pollutants in the receiving watercourse. In Canada, the use of VFS has been included in the Ontario Environmental Farm Plan and the Best Management Practices for Water Management and for Soil Management. In the United States, since 1988, filter strips are an approved USDA cost-share practice under the Conservation Reserve Program of the Food Security Act of 1985.

Phosphorus (P) exists in many forms in soil, water, and sediments. In runoff, P is generally divided into particulate and dissolved fractions by filtration through a 0.45-μm filter. Particulate forms (i.e., sediment-bound P) include sorbed P, organic P, and mineral P phases. Dissolved forms are normally considered to be orthophosphate, inorganic polyphosphates, and organic P compounds (McDowell and Sharpley, 2001a; Nelson and Logan, 1983). These P compounds exist in dynamic equilibrium between their dissolved and particulate forms. The desorption of soil P for individual runoff events has been related to the P content of surface soil, duration and volume of runoff event, and sediment load (McDowell and Sharpley, 2001b; Sharpley, 1985). Once in surface runoff, phosphorus can deposit along with sediments, adsorb to suspended solids, adsorp to surface soil and vegetation, be assimilated by microorganisms and plants, infiltrate down into soil profile, or move downslope with the runoff (Lee et al., 1989).

While sediment-removal studies are abundant, research studies that have dealt with P removal in VFS are very limited and the sparse results are somewhat contradictory. In a VFS field experiment, Dillaha et al. (1987) found that total P removal was closely related to sediment removal when runoff had high particulate P concentration. They found that P removal efficiency in 4.6-m-long filters varied from 49 to 73%, while corresponding sediment removal was slightly higher at 53 to 86%. Longer filters of 9.1 m were more efficient, with P removal ranging from 65 to 93% and sediment removal ranging from 70 to 98%. In this study more than 90% of the total phosphorus content was sediment bound. Another study (Magette et al., 1989) reported that VFS were less efficient in P removal compared with that of sediment removal. They found that the average total P removal for the 4.6- and 9.1-m-long filters was only 27 and 46%, respectively. The corresponding sediment removal efficiencies for the same study were 66 and 82%, respectively.

In a two-year VFS study under natural rainfall conditions, Daniels and Gilliam (1993) found that 6-m-long filters retained, on average, 60% of the total P load, and retained about 50% of the soluble P load. A similar

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Abbreviations: PTE, phosphorus-trapping efficiency; VFS, vegetated filter strip.

study was conducted by Patty et al. (1997), who investigated the removal of soluble P load in VFS with 12 filters with lengths of 6, 12, and 18 m under natural rainfall conditions. They found that the average soluble P removal was 40, 52, and 87% for lengths of 6, 12, and 18 m, respectively. Corresponding average sediment load removal was 92, 98, and 99%, respectively. Infiltration was suggested as the main removal mechanism for P removal, especially in the case of longer filter strips.

Many other studies have suggested that infiltration is the primary mechanism of P removal, especially for runoff with high soluble P content such as runoff from land area receiving manure applications (Overcash et al., 1981; Chaubey et al., 1994; Srivastava et al., 1996). In Ontario, VFS for treatment of beef feedlot and dairy yard runoff are designed to allow for total infiltration of the design storm, as infiltration is more easily quantified than other VFS treatment effects (Toombs, 1997).

The first objective of the study reported here was to examine the efficiency of P removal under Ontario, Canada conditions for VFS that varied in length, slope, type of vegetation, and density of vegetative cover. A second objective was to identify P removal mechanisms in vegetated strips and record their relative importance.

MATERIALS AND METHODS

A total of 20 field experiments were conducted on filters with varying length, slope, and vegetation cover with simulated or artificial runoff with various flow conditions. The filters were constructed on a field near Elora, Ontario, Canada. The soil type of the field is characterized as silt loam with sand, silt, and clay percentage of 38, 54, and 8%, respectively. The organic content of the soil was 4%. Four filter lengths (2, 5, 10, and 15 m) with two slope values (2.3 and 5%) and three types of vegetation cover were used in the experiments. Three 5-m-long plots with bare soil were used as control filters. The width of all filters was 1.20 m. The vegetation covers were denoted as A for perennial ryegrass (*Lolium perenne* L.), B for legume and creeping red fescue (*Festuca rubra* L.) mix, C for bare filters, and D for native grass species. Experiments were performed in triplicates except for the Type A filters. Soil bulk densities varied in average from 1133 kg m^{-3} for the A, B, and C filter strips to 1417 kg m^{-3} for the native vegetation Type D filters.

A fully replicated range of strip lengths was tested for red fescue mix (Type B), but only 5-m strips of the control (Type C), native (Type D), and perennial rye grass (Type A) treatments were studied. The perennial rye grass strip was unreplicated and the strips of native vegetation were twice as steep as the other strips. The A and B types were recently established and had lower density of coverage than the well-established Type D. The vegetation density, reported as percentage of vegetation cover, was measured for each filter by visual estimation of vegetation cover and by counting and measuring the diameter of grass punches within a 25-cm square frame. Table 1 summarizes the physical characteristics of each filter tested in this study.

For a standardized comparison of test results between different strips, the tests were conducted with a runoff of consistent rates and constituents. An experimental system capable of producing artificial runoff was designed. As in previous studies involving the use of artificial runoff (Choi, 1992; Mickelson and Baker, 1993; van Dijk et al., 1996), the pollutant load in runoff is created by mixing soil with water. Soil used in the artificial runoff was collected from the surface of the experimental field and characterized as silt loam.

Table 1. Characteristics of the experimental vegetated filter strips used in this study.

Filter strip†	Filter length	Filter slope	Vegetation type‡	Mean vegetation coverage	Initial soil water content	Test duration
	m	%		%	%	min
B2-1	2	2.3	B	65	27	57
B2-2	2	2.3	B	50	26	64
B2-3	2	2.3	B	45	26	59
B5-1	5	2.3	B	40	25	64
B5-2	5	2.3	B	65	30	63
B5-3	5	2.3	B	58	29	64
B5-1§	5	2.3	B	45	37	101
B10-1	10	2.3	B	63	27	70
B10-2	10	2.3	B	61	26	91
B10-3	10	2.3	B	30	26	83
B15-1	15	2.3	B	41	25	79
B15-2	15	2.3	B	58	27	83
B15-3	15	2.3	B	50	23	76
D5-1	5	5	D	70	61	78
D5-2	5	5	D	78	55	96
D5-3	5	5	D	83	55	90
A5-1	5	2.3	A	70	37	90
C5-1	5	2.3	C	0	25	56
C5-2	5	2.3	C	0	21	54
C5-3	5	2.3	C	0	22	68

† The letter represents vegetation type, the first number represents filter length (m), and the second number indicates experiment replication.

‡ A, perennial ryegrass (fast growth); B, mix of creeping red fescue and birdsfoot trefoil; C, bare; D, existing native riparian vegetation (wild oat, quack, fescue, dandelion, etc.).

§ Test was carried out five months later compared with the previous B5-1 filter.

The experimental pollutant load was selected to represent an expected edge-of-field water quality. A difficulty arose in defining typical cropland runoff because this type of runoff has highly variable characteristics. The literature shows that there is a wide range of sediment and phosphorus concentrations found in cropland runoff. Total suspended solids of farm runoff ranged from 90 mg L^{-1} (Shaeffer, 1982) to as high as 7000 mg L^{-1} (Hayes and Hairston, 1983). Sharpley and Smith (1989) found an average phosphorus concentration of 0.24 mg L^{-1} with values ranging from 0.03 to 2.67 mg L^{-1}. For highly disturbed areas, however, runoff sediment concentrations up to 50 000 mg L^{-1} have been reported (Robinson et al., 1996). In their VFS experiments, Mickelson and Baker (1993) used an artificial runoff with 10 000 mg L^{-1} of sediment. A concentration of 4000 mg L^{-1} was arbitrarily selected for this study that, in turn, governed the P content of the artificial runoff. The resultant average concentration of total P in the artificial runoff was 2.37 mg L^{-1}. Soluble P, estimated by measuring dissolved orthophosphate that had filtrated through a 0.45-μm opening filter, varied between 0.10 and 0.30 mg L^{-1}.

A typical test run was divided into five different phases: a wetting phase, an unsaturated phase (Q1A), and three consecutive saturated phases (Q1B, Q.65, and Q.3) with flow rates of 1.0, 1.0, 1.0, 0.65, and 0.3 L s^{-1}, respectively. During the wetting phase, clear water was applied at a rate of 1.0 L s^{-1} onto the filter strip. Most of this water infiltrated into the soil, as the strip was initially dry. As soon as runoff started at the filter's outlet, the inflow was switched from clear water to artificial runoff at 1.0 L s^{-1}, thus starting Phase Q1A. Soil water conditions in the surface layer during this phase moved from unsaturated to near saturation by the end. The unsaturated phase lasted until the flow rate at the outlet became steady, which indicated that near-saturated soil conditions were obtained. Following this soil saturation, application of artificial runoff continued in three consecutive phases of 15-min duration: Q1B, Q.65, and Q.3 with flow rates of 1.0, 0.65, and 0.3 L s^{-1}, respectively.

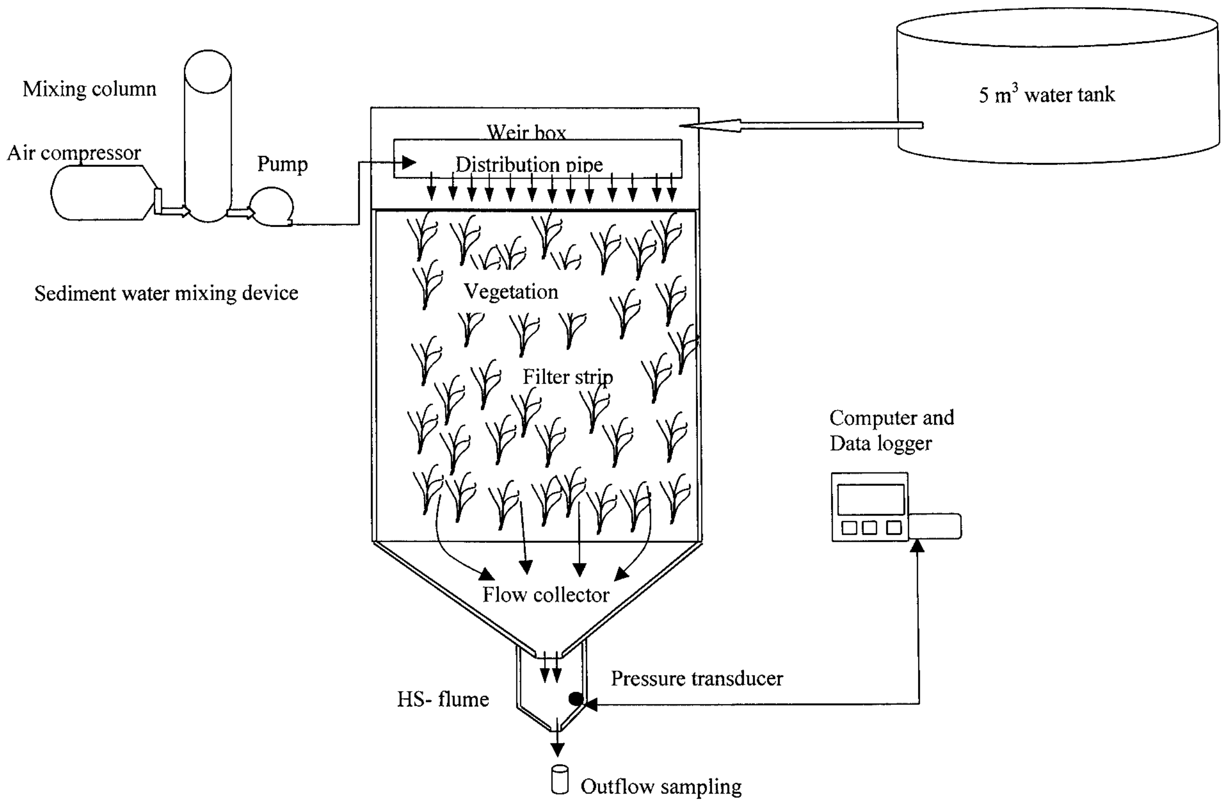

Fig. 1. Schematic diagram of the experimental supply and monitoring system for artificial runoff.

Sediment and phosphorus load was introduced into the influent water from a separate premixed sediment tank, which was made of a 1.2-m-high PVC pipe with a 0.15-m diameter. The soil and water mixture was kept homogenized by an air jet placed at the bottom of the tank operating at 400 kPa. The sediment–water mixture was supplied to the filter influent by a peristaltic pump and mixed with clear water before it entered the filter inlet as artificial runoff. The average inlet sediment and P concentrations were kept constant at 2700 and 2.37 mg L^{-1}, respectively. A schematic diagram of the experimental setup is shown in Fig. 1.

The influent and effluent water flow and P concentrations were monitored, and the infiltrated volume, outflow volume, and phosphorus-trapping efficiencies (PTEs) were calculated. Trapping efficiency is defined as the percentage P mass trapped within the filter. Outflow rate was continuously measured with an HS flume equipped with a pressure transducer. The outflow P concentrations were estimated from grab samples obtained at the discharge point of the outlet flume at 4-min intervals. Total P concentrations were determined by digestion with sulfuric and nitric acid, whereas dissolved P was measured in the filtrate that passed through a 0.45-μm filter in accordance with American Public Health Association standard methods (Greenberg et al., 1992, p. 2-53 to 2-59 and 4-108 to 4-114). The conditions of the VFS experiments are summarized in Table 1. Lalonde (1998) reported detailed experimental procedures and methods of analyses.

RESULTS AND DISCUSSION

Phosphorus content in runoff was mainly in particulate form, accounting for about 94% of the total P content. Others also reported high concentrations of particulate P in cropland runoff, ranging from 70 to 90% (Dillaha et al., 1987; Sharpley and Smith, 1989). In this study, the average orthophosphate concentration (P passing through a 0.45-mm filter) in 48 runoff samples was 0.15 mg L^{-1}, which accounted for only 6% of the total P mean concentration.

Performance in Phosphorus Removal

Performance of VFS for phosphorus removal was assessed from total P load calculated from influent concentrations and outflow rate compared with influent runoff and P concentration. Excluding results from filter strips B2-2 and B10-1, for which flow-rate measurements were inaccurate, the phosphorus-trapping efficiency (PTE) varied widely from 31% (for Filter B2-1) to 89% (for Filter B15-2) with an average of 61% for all filters. This PTE is 28% lower and had higher variation (coefficient of variation [CV] = 26.6% and ranged from 31 to 89%) than that of the mean sediment-trapping efficiency (CV = 9.5% and ranged from 68 to 98%) reported by Abu-Zreig et al. (2002) for the same plots. Higher CV and range in P removal was also observed in previous studies with similar experimental conditions (Dillaha et al., 1987; Magette et al., 1989; Daniels and Gilliam, 1993). Phosphorus trapping efficiencies reported here are comparable with those found in the literature. In a two-year study under natural rainfall conditions, Daniels and Gilliam (1993) found that the average PTE for 3- and 6-m-long filter strips vegetated with fescue was 55 and 70%, respectively. Their results are within the range obtained in the present study for the D-type filters with well-established natural vegetation but higher than that obtained with B-type filters with recently established legumes and fescue. In another study, Dillaha et al. (1989) reported trapping efficiencies of 73 and 93% for 4.6- and 9.1-m-long strips with a slope of 11%. With a 16% slope, the corresponding trapping efficiencies were 49 and 65% for the 4.6- and 9.1-m-long strips. Despite differences on the experimental conditions of the work presented here, such as the use of artificial runoff and the absence of rainfall, phosphorous trapping efficiencies with vegetative filters were quite comparable with other studies.

Effect of Filter Length

The effect of flowpath length on PTE was determined by comparing trapping efficiencies for the Type B strips, excluding filter strips B2-2 and B10-1. The results are shown in Fig. 2. Phosphorus-trapping efficiency increased steadily with length of filter strip and the increase is highly significant ($p = 0.003$) using multiple range variance analysis at a 95% probability level. However, the increase in performance with length decreased rapidly as filter length increased beyond 10 m. A power regression line seemed to fit the PTE data versus filter length very well (PTE = 24.78 [length]$^{0.437}$; $R^2 = 0.88$), and the results are shown in Fig. 2. The average phosphorus trapping efficiencies of the 2-, 5-, 10-, and 15-m-long strips were 32, 54, 67, and 79%, respectively. These are lower than the sediment-trapping efficiencies reported by Abu-Zreig et al. (2002). The difference between sediment and phosphorus trapping appears to be large for short strips and small for longer strips. Hence, while shorter strips offer good sediment control, they offer much less control over phosphorus. Increasing the filter length from 10 to 15 m increased the PTE by 12% (Table 2), but had negligible influence on sediment trapping as reported by Abu-Zreig et al. (2002). This is probably due to the dilution of phosphorus in filter strips being higher in long filters compared with short ones. Other researchers have also observed a uniform decrease in P concentration in overland flow with flowpath length without vegetation (McDowell and Sharpley, 2002). Dilution was hypothesized as the major factor for this decrease. In the presence of vegetation and enhanced sediment deposition the decrease in P concentration will be even more profound.

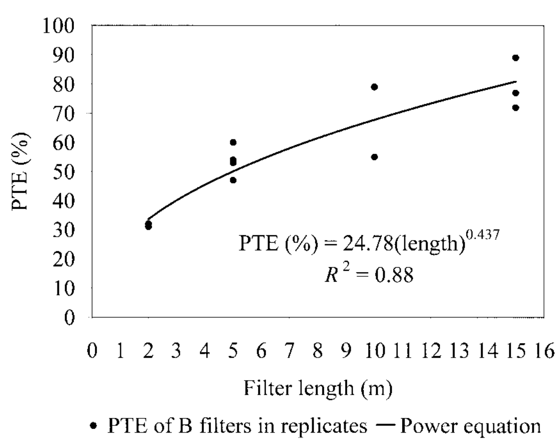

Fig. 2. The influence of length on phosphorus-trapping efficiency (PTE) of Type B filter strips in replicates.

Table 2. Water retention and phosphorus trapping efficiency of various filters.

Filter strip†	Water supplied	Water retention	Inflow P mass	Outflow P mass	P trapping efficiency
	L	%	mg		%
B2-1	2925	25	6560	4500	31
B2-2	2285	67	5080	1920	62‡
B2-3	2760	14	5080	3420	33
B5-1	2745	44	6310	3370	47
B5-2	3265	37	4888	2230	54
B5-3	2960	40	8060	3240	60
B5-1§	4030	46	6630	4090	53
B10-1	3095	91	7440	490	93‡
B10-2	3125	63	7300	1540	79
B10-3	3425	60	6400	2890	55
B15-1	4400	58	8710	2010	77
B15-2	4425	77	6340	690	89
B15-3	3970	36	8040	2230	72
D5-1	3680	44	8820	2790	68
D5-2	4700	58	7790	2210	72
D5-3	4240	39	7520	2670	65
A5-1	4900	41	7330	2590	65
C5-1	2835	25	6560	3960	40
C5-2	2665	25	6070	4450	27
C5-3	3310	16	6560	4090	38

† The letter represents vegetation type, the first number represents filter length (m), and the second number indicates experiment replication. For vegetation type: A, perennial ryegrass (fast growth); B, mix of creeping red fescue and birdsfoot trefoil; C, bare; D, existing native riparian vegetation (wild oat, quack, fescue, dandelion, etc.).

‡ B2-2 and B10-1 filters were excluded from the analysis.

§ Test was carried out five months later compared with the previous B5-1 filter.

Effect of Incoming Runoff Flow Rate

The results of average PTE calculated for each phase for all filters irrespective of their length or vegetation type are shown in Table 3 and Fig. 3. Generally, the highest trapping efficiencies were observed during the phase with the lowest incoming flow rates, Phase Q.3. The average PTE values increased from 53%, to 54%, and then to 78% as inflow rate decreased from 1.0, to 0.65, and then to 0.3 L s^{-1}. But this increase is only significant in the case of the last phase, Q.3. The PTE of the first phase, Q1A, showed a higher efficiency, though not significant at a 0.05 probability level, than that of Phase Q1B for all filters (Fig. 3, Table 3). This result shows the effect of the initial water content of Phase Q1A being much smaller than that of Phase Q1B, resulting in higher infiltration volume and subsequently higher PTE in Phase Q1A.

The accumulation of sediments and phosphorus in filter strip media may result in a performance decrease with continuing flow events, especially for short filters as they become saturated with sediments. Thus, running different flow rates consecutively might be expected to produce lower trapping efficiencies for subsequent phases. This would probably explain why the trapping efficiencies of the Phase Q.65 of the B2 and B5 filters gave lower trapping efficiencies compared with that of Phase Q1B (Table 3). The selective erosion of fine particles, which have a higher P content compared with coarse particles, by initial overland flow events might also contribute to the decrease of PTE of initial phases (Q1A

Table 3. Average trapping efficiency of phosphorus for various filters in relation to inflow phase.†

Inflow phase	Average inflow rate	Phosphorus trapping efficiency: Filter type A5	B2‡	B5	B10‡	B15	D5	C5
	L min^{-1}	%						
Q1A	1.05	64	43	59	68	68	64	47
Q1B	1.07	56	31	49	60	60	60	46
Q.65	0.70	64	25	43	61	61	72	25
Q.3	0.34	90	36	68	92	92	92	40
Average phosphorus trapping		65	32	54	67	79	68	35
Average water retention		41	20	42	62	57	47	22
Average vegetation cover		70	53	52	51	50	77	0

† Average of three replicates except A5 filters, for which one experiment was done.
‡ B2-2 and B10-1 filters were excluded from the analysis.

and Q1B) compared with later ones (Q.3) (McDowell and Sharpley, 2002). Nevertheless, visual observations revealed that no sediment washoff has been observed during the experimental phases. Therefore, the effect of accumulating sediment is assumed negligible compared with that of reducing flow rate, and PTE is expected to increase with a decrease in the overland flow rate of VFS.

Effect of Vegetation Type

The influence of vegetation type is shown in Fig. 4, where the average and range of PTE values of the 5-m-long filters were plotted against vegetation type. As shown in Fig. 4, the PTE of Type D filters showed a higher PTE, 68% on average and ranging from 65 to 72%, compared with that of Type A (65% on average) and B (54% on average) filters, which ranged from 47 to 60%. The Tukey HSD multiple comparisons test was performed between filters of similar length assuming that the single PTE value of the A filter is an average of 3 with a standard deviation similar to that of D5 filters. The test has shown that PTE values of D5 filters were significantly higher than those of B5 filters (P = 0.04) and also higher than those of A5 filters, with no significant difference. The PTEs of A5 filters were somewhat higher than those of B5 filters (p = 0.12). The advantages of native vegetation (Type D strips) under low-flow conditions, Phases Q.65 and Q.3, were even more profound. As shown in Table 3, the PTEs of D5 filters in phases Q.65 and Q.3 were 72 and 92%, respectively, which were equal or even higher than PTEs of the 10- and 15-m-long B filters. Considering that the slope of Type D filters was double that of other filters and a decrease in PTE would be expected, as reported by Dillaha et al. (1989), the actual PTE of native vegetation filters (Type D) could be greater than reported.

The higher PTE values of D filters were probably caused by the higher percentage of vegetation cover (77% on average and ranging between 70 and 83%) compared with A filters (70%) and B filters (52%) (range 40–65%). A plot of PTE with vegetation cover for all filters, shown in Fig. 5, reveals that PTE steadily increased with an increase in vegetation cover irrespective of filter length. A linear regression was performed on filters having similar lengths of 5 m and the results are shown in Fig. 5. The linear equation was significant at the 0.05 probability level with $R^2 = 0.88$ (PTE = 0.42 vegetation cover % + 34.38). It should be noted that experimental evaluation of vegetation type on filter performance is very difficult because constructing filters that are identical in all properties except vegetation type is virtually impossible.

Careful inspection of the results in Table 3 suggests that P removal mechanisms are affected by the type of vegetation and not just by the amount of infiltration, as reported in the literature (Overcash et al., 1981; Chaubey et al., 1994; Srivastava et al., 1996). For example, PTE values for the B5 and A5 filters were 54% (range 47–60%) and 65% on average, respectively, even though the amount of average water retention in these filters was practically similar at 42%.

Mechanisms other than sedimentation and infiltration can enhance P removal in VFS. Possible additional mechanisms include adsorption to plant and soil surfaces and absorption of soluble P by plants. Improved P performance in Type D filter strips can be linked to these mechanisms since Type D vegetation had higher vegetation coverage, a rougher flow surface, and the presence of a decaying thatch near the ground surface. Generally, Type D filter strips had higher water retention (39–58%) than Type B strips (37–44%), and also had average flow velocities of 0.04 m s^{-1}, which were half of the Type B strips, with water velocities of 0.09 m s^{-1}. Lower flow velocities and greater water retention resulted in more contact time with the vegetation and soil, less erosive power, and less transport capacity, especially for fine particles with high P content (McDowell and Sharpley, 2002).

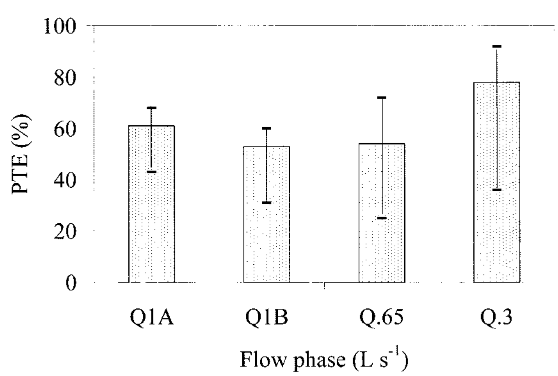

Fig. 3. The effect of flow rate on the average and range of phosphorus-trapping efficiency (PTE) for all vegetated filters.

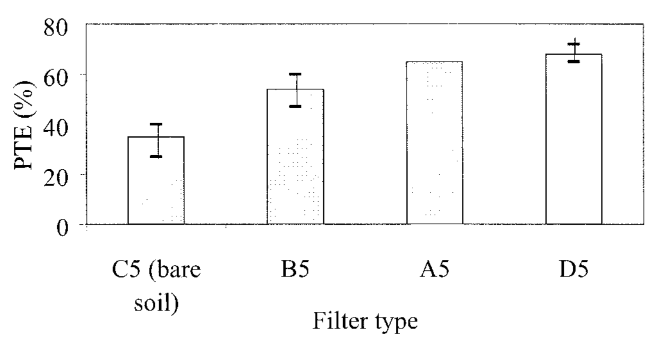

Fig. 4. Influence of vegetation type on the average and range of phosphorus-trapping efficiency (PTE) for the 5-m-long filters.

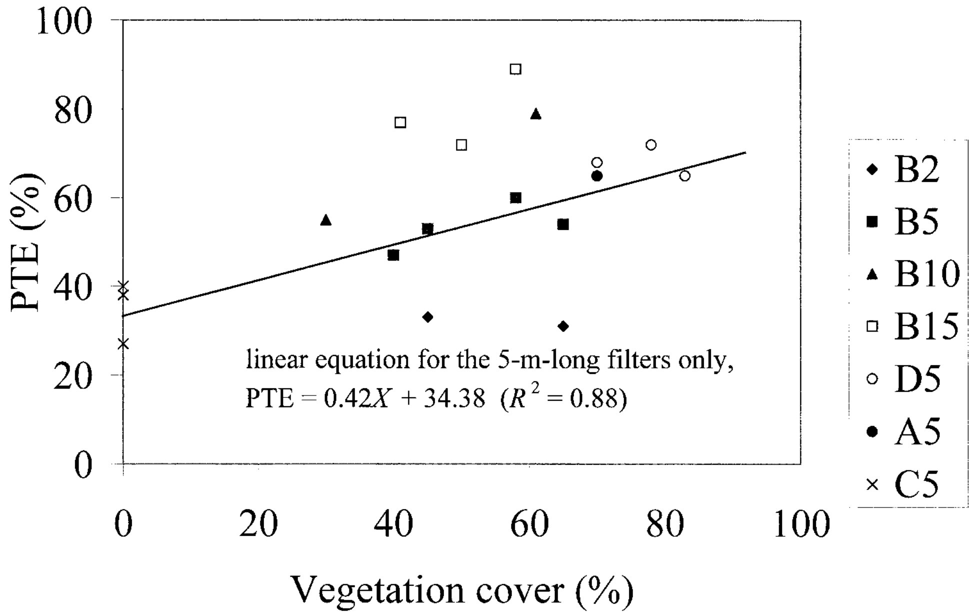

Fig. 5. Variation of phosphorus-trapping efficiency (PTE) with vegetation cover.

Phosphorus Removal in Relation to Sediment Removal

Experimental results presented here have shown that the relative importance of mechanisms for P removal is different from that of suspended solids. The average P removal in VFS (61%) was less than that of suspended solids (84%) (Abu-Zreig et al., 2002). Furthermore, the removal of P was seen to increase more steadily with filter length compared with the removal of suspended solids. Sediment trapping efficiencies for the 2-, 5-, 10-, and 15-m-long Type B filters were 65, 81, 92, and 91%, respectively (Abu-Zreig et al., 2002). The corresponding phosphorus trapping efficiencies of B filters were 32, 54, 67, and 79%, respectively. Increasing the length of filter strips from 2 to 15 m would increase the PTE by 47% compared with only 25% in the case of sediment trapping.

The main reason for this difference is the change in relative importance of the removal mechanisms in relation to the uneven distribution of P in different size classes of aggregates or soil particles. In this study more than 90% of P concentration in the runoff was sediment bound. Phosphorus tends to be more present in the particles smaller than 100 microns, that is, silt and clay fractions (He et al., 1995). It is also known that sediment settling in VFS is directly related to particle size. In a simulation study, Abu-Zreig (2001) found that the sediment trapping efficiency in a 3-m-long filter for sand (d = 0.2 mm), silt (d = 0.01 mm), and clay (d = 0.002 mm) particles was about 90, 60, and 2%, respectively.

Hence, while filter strips 2 m long were efficient in trapping sand and similar-sized large aggregates (Abu-Zreig et al., 2002), they were not efficient in removing clay particles, which contain most of the P. The PTE of the 15-m-long filters (79%) was higher than that of short filters because longer filters retain smaller particles better than short filters via deposition and provide more infiltration opportunity of overland flow.

CONCLUSIONS

Vegetated filter strips have been found to be effective in removing phosphorus from cropland runoff. Filter length had the highest and most significant effect on P removal while inflow rate, vegetation type, and density of vegetative coverage had secondary influences. The phosphorus trapping efficiencies of the 2-, 5-, 10-, and 15-m-long Type B filters were 32, 54, 67, and 79%, respectively. While short filters (5 m) are quite effective for removal of sediment, they are not very effective for P removal. For sediment trapping, increasing filter length beyond 15 m is not at all effective in increasing sediment removal but it is expected to further increase P removal.

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Attachment D:

Phosphorus Simple Method Calculations Worksheets

Simple Method Pollutant Loading Calculation Worksheet- Phosphorus

The Simple Method estimates pollutant loading of stormwater runoff for urban and developed areas. This worksheet includes the data and calculations to be used for computation of existing and post-development loads under the *Interim Procedure for Offsets for Discharges of Phosphorus to Lake Champlain and Waters that Contribute to the Impairment of Lake Champlain*. *Fill in the shaded fields bas ed on the project site attributes.*

$L = 0.226 * P * P_j * R_v * A * C$ Additional informaiton on the Simple Method can be found on the 'Guidance' tab

Where:

- L = Annual load (lbs)
- P = Yearly rainfall depth (in)
- P_j = Fraction of rainfall events producing runoff (use 0.9)
- A = Site area (acres)
- C = Average annual pollutant concentration (mg/l), see 'Guidance'
- 0.226 = Unit conversion factor

And:

$Rv = 0.05 + 0.009 * I_a$

Where:

- R_v = Runoff Coefficient
- I_a= Whole number percent impervious

Offset Calculations

Project Name:	Town Offices Stormwater Design - SGW	
P_j	0.9	
Project P*	37.4	from US Climate Data
*http://www.ncdc.noaa.gov/cdo-web/datatools/normals		

Pre-Development Condition

For undeveloped sites use these equations:

Existing Land Use	Loading Rate	Site area (ac)	Load (lbs)
Choose Land Use	0.00		0.00
Choose Land Use	0.00		0.00

OR

For sites with existing development, use the Simple Method :

Simple Method	Land Cover type	Site Area (ac)	Imp. Area (ac)	I_a (%)	R_v	C (mg/L)	Load (lbs)
Existing Conditions	Developed	1.49	0.8	54	0.533221477	0.44	2.66
	Pre-Dev. Total						2.66

Post-Development

	Land Cover	Site Area (ac)	Imp. Area (ac)	I_a (%)	R_v	C (mg/L)	Load (lbs)
	Developed	1.49	0.8	54	0.533221477	0.44	2.66
	Post-Dev. Total						2.66
	Load reduction from treatment (%) (see guidance!)						40
	Post-dev. load after treatment is provided						1.60

Load Difference	Lbs to be offset	None

If the final load difference says "none", no further action is needed. If the number is positive, an offset is required. There are several different options for satisfying offset requirements including the use of additional on-site treatment, the purchase of an existing offset (if available), or the development of an offsite offset project within the same lake segment drainage area.

Last revised 11/24/15

Simple Method Pollutant Loading Calculation Worksheet- Phosphorus

The Simple Method estimates pollutant loading of stormwater runoff for urban and developed areas. This worksheet includes the data and calculations to be used for computation of existing and post-development loads under the *Interim Procedure for Offsets for Discharges of Phosphorus to Lake Champlain and Waters that Contribute to the Impairment of Lake Champlain*. *Fill in the shaded fields bas ed on the project site attributes.*

$L = 0.226 * P * P_j * R_v * A * C$ Additional informaiton on the Simple Method can be found on the 'Guidance' tab

Where:

- L = Annual load (lbs)
- P = Yearly rainfall depth (in)
- P_j = Fraction of rainfall events producing runoff (use 0.9)
- A = Site area (acres)
- C = Average annual pollutant concentration (mg/l), see 'Guidance'
- 0.226 = Unit conversion factor

And:

$Rv = 0.05 + 0.009 * I_a$

Where:

- R_v = Runoff Coefficient
- I_a = Whole number percent impervious

Offset Calculations

Project Name:	Town Offices Stormwater Design - FS
P_j	0.9
Project P*	37.4
*http://www.ncdc.noaa.gov/cdo-web/datatools/normals	

Pre-Development Condition

For undeveloped sites use these equations:

Existing Land Use	Loading Rate	Site area (ac)	Load (lbs)
Choose Land Use	0.00		0.00
Choose Land Use	0.00		0.00

OR

For sites with existing development, use the Simple Method :

Simple Method	Land Cover type	Site Area (ac)	Imp. Area (ac)	I_a (%)	R_v	C (mg/L)	Load (lbs)
Existing Conditions	Developed	1.04	0.87	84	0.802884615	0.44	2.79
	Pre-Dev. Total						2.79

Post-Development

Land Cover	Site Area (ac)	Imp. Area (ac)	I_a (%)	R_v	C (mg/L)	Load (lbs)
Developed	1.04	0.87	84	0.802884615	0.44	2.79
Post-Dev. Total						2.79
					Load reduction from treatment (%) (see guidance!)	30
					Post-dev. load after treatment is provided	1.96

Load Difference	Lbs to be offset	None

If the final load difference says "none", no further action is needed. If the number is positive, an offset is required. There are several different options for satisfying offset requirements including the use of additional on-site treatment, the purchase of an existing offset (if available), or the development of an offsite offset project within the same lake segment drainage area.

Last revised 11/24/15

Attachment E:

Photographic Log

PHOTOGRAPHIC LOG

Project Name:	Site Location:	Project No.:
Berlin Town Offices and Garage Stormwater Treatment	Berlin, Vermont	124749

Photo No.:	Date:
1	10/11/2018

Direction Photo Taken:
Looking Northeast

Photographer:
Christopher J. Rivet (CJR)

Description:
View of the proposed project area from the edge of Shed Road, looking northeast toward the Town Offices and Garage buildings/parking areas.

Photo No.:	Date:
2	10/11/2018

Direction Photo Taken:
Looking North

Photographer:
CJR

Description:
View of the Town Garage and open storage area, taken from near the edge of the gravel access road to the garage.

DuBois & King inc.

PHOTOGRAPHIC LOG

Project Name: Berlin Town Offices and Garage Stormwater Treatment	**Site Location:** Berlin, Vermont	**Project No.:** 124749

Photo No.: 3	**Date:** 10/11/2018

Direction Photo Taken:
Looking South

Photographer:
CJR

Description:
View of existing infrastructure (fire hydrant), in the foreground, located near the proposed project area, which is located in the background of the photo beyond the edge of the parking lot pavement.

Photo No.: 4	**Date:** 10/11/2018

Direction Photo Taken:
Looking South

Photographer:
CJR

Description:
View of the proposed project area, from the parking lot near the Town Offices.

DuBois & King inc.

PHOTOGRAPHIC LOG

Project Name:	Site Location:	Project No.:
Berlin Town Offices and Garage Stormwater Treatment	Berlin, Vermont	124749

Photo No.: 5

Date: 8/23/2018

Direction Photo Taken:
Looking West

Photographer:
CJR

Description:
View of the location of the proposed grass swale, running along the southern edge of pavement of the Town Offices parking lot.

Photo No.: 6

Date: 8/23/2018

Direction Photo Taken:
Looking Southwest

Photographer:
CJR

Description:
View of the proposed project area, from the parking lot near the Town Offices.

DuBois & King inc.		**PHOTOGRAPHIC LOG**
Project Name: Berlin Town Offices and Garage Stormwater Treatment	**Site Location:** Berlin, Vermont	**Project No.:** 124749

Photo No.: 7

Date: 8/23/2018

Direction Photo Taken:
Looking Southwest

Photographer:
CJR

Description:
View of the proposed project area, from the parking lot near the Town Offices.

Photo No.: 8

Date: 8/23/2018

Direction Photo Taken:
Looking southwest

Photographer:
CJR

Description:
View of the gravel road and open storage areas near the Town Garage; gravel can be seen encroaching upon vegetation.

PHOTOGRAPHIC LOG

Project Name:	Site Location:	Project No.:
Berlin Town Offices and Garage Stormwater Treatment	Berlin, Vermont	124749

Photo No.:	Date:	
9	8/23/2018	

Direction Photo Taken:
Looking north

Photographer:
CJR

Description:
View of the gravel road and open storage areas near the Town Garage; gravel can be seen encroaching upon vegetation.

Photo No.:	Date:	
10	8/23/2018	

Direction Photo Taken:
Looking north

Photographer:
CJR

Description:
View of the gravel road and open storage areas near the Town Garage.

PHOTOGRAPHIC LOG

Project Name:	Site Location:	Project No.:
Berlin Town Offices and Garage Stormwater Treatment	Berlin, Vermont	124749

Photo No.:	Date:
11	8/23/2018

Direction Photo Taken:
Looking Southeast

Photographer:
CJR

Description:
View of the Town Garage from the gravel access road.

Photo No.:	Date:
12	8/23/2018

Direction Photo Taken:
Looking South

Photographer:
CJR

Description:
View of the proposed location of a swale that will be used to collect stormwater runoff diverted from the Town Garage gravel access road and open storage areas.