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Stormwater Retrofits around Lake Pocotopaug in East Hampton, Connecticut using Low Impact Sustainable Development (LISD) Practices

May 14, 2019

Introduction

Stormwater runoff is the leading cause of water quality degradation in stream and lakes. Pollutants in stormwater runoff are known as non-point source pollutants as they do not occur at a single point but are very dispersed in the developed environment. The primary non-point source pollutants which significantly adversely affect a lake are Total Suspended Solids (TSS) and Total Phosphorous (TP). TSS can carry metals and hydrocarbons on fine sediment particles to the lake. TP, both in particulate and soluble forms can provide a food source for invasive vegetation and algae in a lake.

In today's field of land development, the paradigm of storm water management has been slowly evolving from simply reducing the peak rate of runoff for developed conditions to match the peak rate from existing conditions to a paradigm of addressing water quality issues and reducing the volume of storm water runoff. The implementation of the small treatment practices of Low Impact Sustainable Development (LISD) strategies, while demonstrating how the various types of LISD systems work as well as reducing the annual pollutant loads associated with non-point source runoff. The following is a discussion of the impacts from the various types of non-point source pollutants on the aquatic environment.

Ongoing research at many academic institutions, such as the University of New Hampshire Stormwater Center, the Stormwater Engineering Group at North Carolina State University, along with the Wisconsin Department of Natural Resources have documented the adverse impacts storm water pollutants can have on our environment. Some of these same institutions are also researching and evaluating many different types of storm water treatment systems in real world conditions to demonstrate how effective the systems are at removing various pollutants from storm water runoff. The water quality impacts associated with storm water runoff is called non-point source pollution. The United States Environmental Protection Agency defines non-point source pollution as follows:

Non-point source (NPS) pollution, unlike pollution from industrial and sewage treatment plants, comes from many diffuse sources. NPS pollution is caused by rainfall or snowmelt moving over and through the ground. As the runoff moves, it picks up and carries away natural and human-made pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters, and even our underground sources of drinking water. These pollutants include:

A. *Excess fertilizers, herbicides, and insecticides from agricultural lands and residential areas;*
B. *Oil, grease, and toxic chemicals from urban runoff and energy production;*
C. *Sediment from improperly managed construction sites, crop and forest lands, and eroding stream banks;*
D. *Salt from irrigation practices and acid drainage from abandoned mines;*
E. *Bacteria and nutrients from livestock, pet wastes, and faulty septic systems;*
F. *Atmospheric deposition and Hydro modification are also sources of non-point source pollution.*

The most common pollutants which are found in non-point source runoff are Litter, Sediment and Total Suspended Solids (TSS), Total Nitrogen (TN), Total Phosphorus (TP), Metals, such as Zinc (Zn) and Copper (Cu), Hydrocarbons, Thermal Impacts, Oxygen demanding substances and Pathogens. Each pollutant and its impact on the natural environment are stated below.

Litter

Litter while not causing toxic impacts on the environment, the presence of litter is an aesthetic issue that is not well received by the public.

Total Suspended Solids (TSS)

Total Suspended Solids are fine soil particles, such as silts and clay which are dissolved in water. In excessive amounts it causes turbidity in water. The turbidity blocks light in the water column which causes reduced photosynthesis, which in turn reduces the oxygen levels in the water. Coarse and fine sediments can clog the gravel substrate in breeding streams thus affecting the biological community ability to reproduce. Common sources of TSS and sediment are runoff from construction sites, winter sanding operations, atmospheric deposition and decomposition of organic matter, such as leaves. Turbidity is measured as NTU. A range of turbidity levels are shown in Figure 1 below.

Figure 1 - Range of Turbidity in water samples

Nutrients

Phosphorus and nitrogen are commonly found in non-point runoff with the primary source being lawn fertilizers. Excessive levels of phosphorus in freshwater systems are a concern as this nutrient cause's excess growth of non-native aquatic plants and algae in lakes. As a result of increased nutrient loads, toxic algae blooms are becoming more prevalent in lakes in Connecticut, including Bantam Lake. These toxic algae blooms have resulted in beach closures as exposure to the algae blooms can cause adverse health issues in humans. A further problem occurs, when the algae dies off, the decomposition process of organic matter removes oxygen from the water column, thus reducing oxygen levels in the water. The reduced oxygen levels in the waterbody can result in fish kills. Nitrogen, in the form of nitrate, is a direct human health hazard and an indirect hazard in some areas where it leads to a release of arsenic from sediments. While not a major concern for freshwater systems, nitrate can cause environmental impacts in tidal regions, even though the source of nitrate can be far away from coastal regions. Sources of nutrients are organic and inorganic fertilizers, animal manure, bio solids and failing sewage disposal systems.

Figure 2 - Phosphorus impacts on a freshwater pond

Metals

Metals in non-point source runoff are very toxic to aquatic life. The adverse effects of metals are far reaching for both aquatic and human health. Many metals can bio accumulate in the environment, which can affect higher living organisms. While the concentration of zinc or copper in stormwater generally is not high enough to bother humans, these same concentrations can be deadly for aquatic organisms. Many microorganisms in soil are especially sensitive to low concentrations of cadmium. Zinc, Copper, and Cadmium found in non-point source runoff result from the movement and wear and tear of automobiles on our roadways.

Of the above discussed metals, zinc and copper are the two metals which are found dominantly in non-point source runoff. Metals commonly bind themselves to sediment and organic matter in stormwater and thus are transported to the receiving waters. Since natural rainfall is slightly acidic, metal roofs or components on the roof can be a significant source of the zinc or copper concentrations in stormwater.

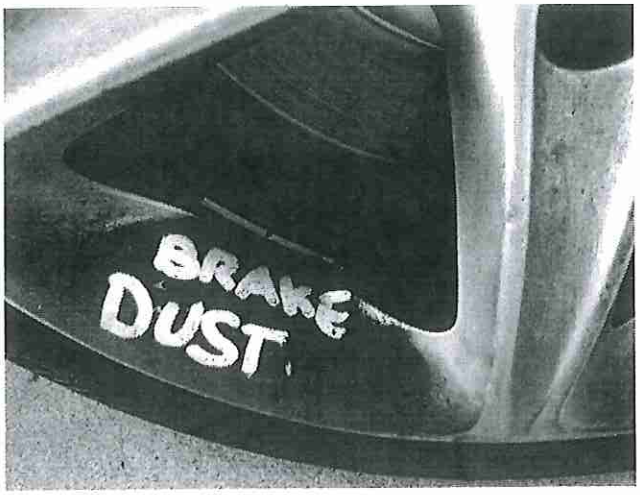

Figure 3 - Primary source of zinc (automobile brake pads)

Hydrocarbons

Total Petroleum Hydrocarbons (TPH) are highly toxic in the aquatic environment, especially to aquatic invertebrates. The primary sources of petroleum hydrocarbons are oil, grease drops from an automobile, gas spills, and vehicle exhaust. Polycyclic Aromatic Hydrocarbons (PAHs) are also toxic to aquatic life. PAHs can be discharged into the environment using coal tar asphalt sealants, commonly used by homeowners on residential driveways. The movement of vehicles or people walking over the sealed driveway can release dust particles containing PAH, which can then be washed off with the next rainfall into the stormwater management system. PAHs are also generated by the burning of fossil fuels and the airborne particles are then deposited by atmospheric deposition on an impervious surface, especially large flat roof areas. When it rains, the accumulations of PAHs due to atmospheric deposition are carried off in the stormwater.

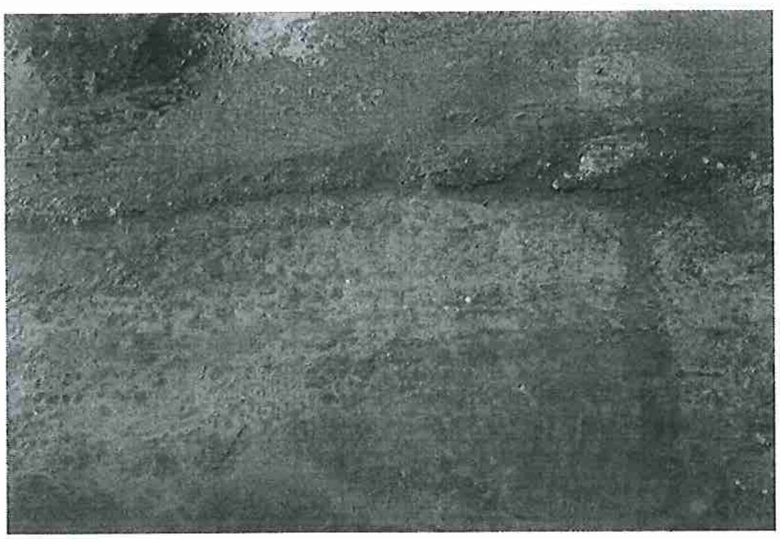

Figure 4 - Petroleum Hydrocarbons in Stormwater

Thermal Impacts

Impervious surfaces, such as roofs and moderately sized paved areas, such as residential driveways can heat up during sunny days and hold onto this heat. When rainfall occurs on these heated surfaces, the resulting runoff will have a highly elevated temperature as a result of the heat transference from the impervious surface to the runoff. As this heated runoff is discharged into receiving waters, the temperature of the receiving water is raised to a level which can exceed the temperature tolerance limits for fish and invertebrates, thus lowering their survival rates. Elevated water temperatures will also contribute to reduced oxygen levels in the water.

Figure 5 - Fish kills due to increased thermal levels

Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)

Biochemical oxygen demand (BOD) is the amount of dissolved oxygen needed by aerobic biological organisms to break down organic material present in a given water sample at certain temperature over a specific time period. The BOD value is most commonly expressed in milligrams of oxygen consumed per liter of sample during 5 days of incubation at 20 °C and is often used as a surrogate of the degree of organic pollution of water. Dissolved oxygen depletion is most likely to become evident during the initial aquatic microbial population explosion in response to a large amount of organic material. If the microbial population deoxygenates the water, however, that lack of oxygen imposes a limit on population growth of aerobic aquatic microbial organisms resulting in a long-term food surplus and oxygen deficit.

Chemical oxygen demand (COD) is the total measurement of all chemicals in the water that can be oxidized. Total Organic Carbon (TOC) is the measurement of organic carbons. The chemical oxygen demand test procedure is based on the chemical decomposition of organic and inorganic contaminants, dissolved or suspended in water. The result of a chemical oxygen demand test indicates the amount of water-dissolved oxygen (expressed as parts per million or milligrams per liter of water) consumed by the contaminants, during two hours of decomposition from a solution of boiling potassium dichromate. The higher the chemical oxygen demand, the higher the amount of pollution in the test sample.

Both BOD and COD are surrogates for the direct measures of specific pollutants found in non-point source runoff.

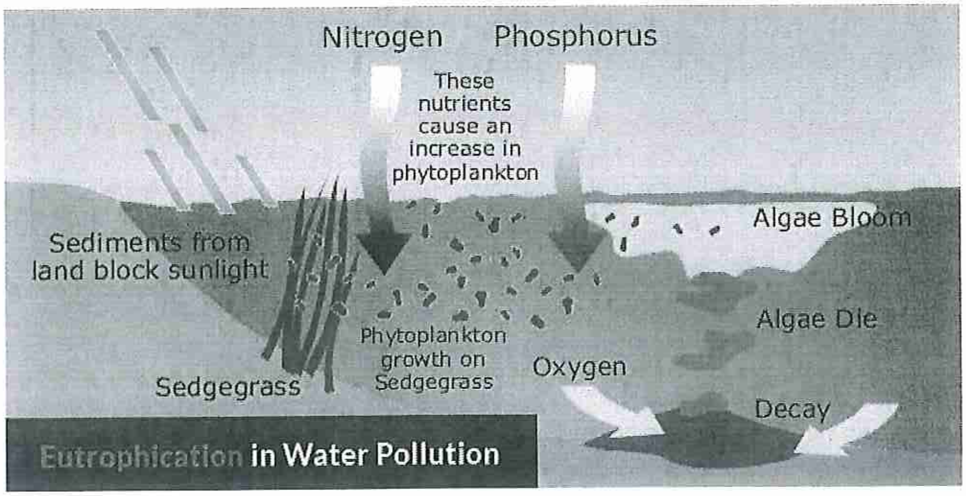

Figure 6 - Impacts of Nitrogen and phosphorus on aquatic systems

Pathogens

Pathogens are bacteria and viruses, which can cause disease in humans. Most pathogens are found in discharges from overflowing sanitary sewers or in combined sanitary/stormwater systems which is not applicable to the Town of Morris. In communities such as Morris, the primary source of pathogens in stormwater is pet waste which is not picked up along roadways. Dog poop which washes into a storm drain are the common source of both fecal coliform and enterococci bacteria which are used as indicators for the presence of pathogenic organisms, yet their presence does not mean a pathogen is present, just that there is a higher risk of being present.

Figure 7 - Primary source of pathogens in stormwater

Water Quality Volume Calculations:

Clark Hill Road

A = 0.0466 acres, I = 100%, Rv = 0.05+0.009(I) = 0.95

WQV = (1")*(0.95)*(0.0466)/12 = 0.0037 acre-feet (161 cubic feet)

Boulder Lane

A = 1.56 acres, I = 15.1%, Rv = 0.05+0.009(I) = 0.186

WQV = (1")*(0.186)*(1.56)/12 = 0.0242 acre-feet (1,053 cubic feet)

Mott Hill Road

A = 0.145 acres, I = 100%, Rv = 0.05+0.009(100) = 0.95

WQV = (1")*(0.95)*(0.145)/12 = 0.0115 acre-feet (500 cubic feet)

Mohican Trail

A = 0.02 acres, I = 100%, Rv = 0.05+0.009(100) = 0.95

WQV = (1")*(0.95)*(0.02)/12 = 0.0016 acre-feet (69 cubic feet)

Groundwater Recharge Volume Calculations:

Soil Group A, D = 0.4"

Soil Group B, D = 0.25"

Soil Group C, D = 0.10"

Clark Hill Road – Soil Group A

A = 0.0466 acres, I = 1.0, D = 0.4"

GRV = (0.4)*(1.0)*(0.0466)/12 = 0.0016 acre-feet (68 cubic feet)

Boulder Lane – Soil Group B

A = 1.56 acres, I = 0.151, D = 0.25"

GRV = (0.25)*(0.151)*(1.56)/12 = 0.0049 acre-feet (214 cubic feet)

Mott Hill Road – Soil Group C

A = 0.145 acres, I = 1.0, D = 0.10"

GRV = (0.10)*(1.0)*(0.145)/12 = 0.0012 acre-feet (53 cubic feet)

Mohican Trail – Soil Group B

A = 0.02 acres, I = 1.0, D = 0.25"

GRV = (0.25)*(1.0)*(0.02)/12 = 0.0004 acre-feet (18 cubic feet)

Peak Rate Calculations for 2-year, 10-year and 25-year rainfall events:

Boulder Lane:

2-year peak rate = 1.07 cfs

10-year peak rate = 2.98 cfs

25-year peak rate = 3.90 cfs

Wet swale must contain flow rate from 10-year rainfall event:

Bottom Width = 4.0'
Centerline Depth = 1.0'
Channel Slope = 2.7%
Roughness Coefficient: n = 0.175
Side Slopes = 2:1
Flow Rate = 2.98 cfs
Calculated Depth of Flow = 0.17'
Calculated Flow Velocity = 4.16 fps

Mott Hill Road:

2-year peak rate = 0.46 cfs
10-year peak rate = 0.69 cfs
25-year peak rate = 0.79 cfs

Wet swale must contain flow rate from 10-year rainfall event:
Bottom Width = 3.0'
Centerline Depth = 0.5'
Channel Slope = 4.55%
Roughness Coefficient: n = 0.175
Side Slopes = 2:1
Flow Rate = 0.69 cfs
Calculated Depth of Flow = 0.07'
Calculated Flow Velocity = 3.00 fps

Water Quality Analysis for Low Impact Sustainable Development Stormwater Retrofits at various locations around Lake Pocotopaug in East Hampton.

Annual Rainfall: 51"

Pollutant Loads calculated using Schueler's Equation for Annual Rainfall for following pollutants:

- Total Suspended Solids (TSS)
- Total Phosphorous (TP)
- Total Nitrogen (TN)
- Zinc (Zn)
- Copper (Cu)
- Total Petroleum Hydrocarbons (TPH)
- Dissolved Inorganic Nitrogen (DIN)

Clark Hill Road: Bioretention Cell

Pollutant	Annual Load (pounds)	Load Removed (pounds)	Percent Removed
TSS	45.5	39.6	87
TP	0.115	0.069	60
TN	1.10	0.187	17
Zn	0.072	0.0554	77
Cu	0.017	0.0131	77
TPH	1.40	1.39	99
DIN	0.172	0.076	44

Boulder Lane: Wet Swale with crushed stone check dams

Pollutant	Annual Load (pounds)	Load Removed (pounds)	Percent Removed
TSS	185.1	138.5	75
TP	0.925	0.370	40
TN	6.50	2.60	40
Zn	0.543	0.179	33
Cu	0.145	0.048	33
TPH	3.90	2.92	75
DIN	1.10	0.451	41

Mott Hill Road: Wet Swale with crushed stone check dams

Pollutant	Annual Load (pounds)	Load Removed (pounds)	Percent Removed
TSS	141.5	106.1	75
TP	0.357	0.143	46
TN	3.30	1.32	40
Zn	0.223	0.074	33
Cu	0.053	0.018	33
TPH	4.30	3.22	75
DIN	0.536	0.22	41

Mohican Trail: Open Cell Concrete Pavers with Pea Gravel with filter course

Pollutant	Annual Load (pounds)	Load Removed (pounds)	Percent Removed
TSS	20.5	203	99
TP	0.052	0.031	60
TN	0.476	0.0	0
Zn	0.032	0.024	75
Cu	0.008	0.006	75
TPH	0.621	0.615	99
DIN	0.078	0	0

The LISD retrofits which are to be constructed on Clark Hill Road, Boulder Lane, Mott Hill Road and Mohican Trail will reduce the pollutant loads associated with non-point source runoff. The systems on Clark Hill Road and Mohican Trail will also reduce runoff volumes by infiltration into the native soils. Thermal impacts of runoff from paved areas will also be reduced by either infiltration into the native soils or flow through dense, vegetated Wet Swales.

Hydrologic Modeling of Clark Hill Road Bioretention Cell and Mohican Trail Open Cell Paver system

Bioretention Cell:

Water Quality Storm

Summary for Subcatchment 1S: Clark Hill Road (existing)

Runoff = 0.04 cfs @ 12.09 hrs, Volume= 0.003 af, Depth> 0.79"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 0.00-24.00 hrs, dt= 0.05 hrs
Type III 24-hr WQ Storm Rainfall=1.00"

Area (sf)	CN	Description
2,030	98	Paved roads w/curbs & sewers, HSG B
2,030		100.00% Impervious Area

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

Summary for Pond 2P: Bioretention Cell

Inflow Area =	0.047 ac,100.00% Impervious, Inflow Depth > 0.79"	for WQ Storm event
Inflow =	0.04 cfs @ 12.09 hrs, Volume=	0.003 af
Outflow =	0.02 cfs @ 12.25 hrs, Volume=	0.003 af, Atten= 51%, Lag= 9.8 min
Discarded =	0.02 cfs @ 12.25 hrs, Volume=	0.003 af
Primary =	0.00 cfs @ 0.00 hrs, Volume=	0.000 af

Routing by Stor-Ind method, Time Span= 0.00-24.00 hrs, dt= 0.05 hrs
Peak Elev= 103.03' @ 12.25 hrs Surf.Area= 425 sf Storage= 15 cf

Plug-Flow detention time= 5.4 min calculated for 0.003 af (100% of inflow)
Center-of-Mass det. time= 5.0 min (792.4 - 787.4)

Volume	Invert	Avail.Storage	Storage Description
#1	103.00'	590 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc)

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
103.00	413	0	0
104.00	767	590	590

Device	Routing	Invert	Outlet Devices
#1	Discarded	103.00'	**2.000 in/hr Exfiltration over Surface area**
#2	Primary	103.75'	**6.0" Horiz. Orifice/Grate** X 2 rows C= 0.600 Limited to weir flow at low heads

Discarded OutFlow Max=0.02 cfs @ 12.25 hrs HW=103.03' (Free Discharge)
↳**1=Exfiltration** (Exfiltration Controls 0.02 cfs)

Primary OutFlow Max=0.00 cfs @ 0.00 hrs HW=103.00' (Free Discharge)
↳**2=Orifice/Grate** (Controls 0.00 cfs)

2-year rainfall event

Summary for Pond 2P: Bioretention Cell

Inflow Area =	0.047 ac,100.00% Impervious, Inflow Depth > 3.10" for 2-year event		
Inflow =	0.15 cfs @ 12.09 hrs, Volume=	0.012 af	
Outflow =	0.02 cfs @ 12.56 hrs, Volume=	0.012 af, Atten= 83%, Lag= 28.3 min	
Discarded =	0.02 cfs @ 12.56 hrs, Volume=	0.012 af	
Primary =	0.00 cfs @ 0.00 hrs, Volume=	0.000 af	

Routing by Stor-Ind method, Time Span= 0.00-24.00 hrs, dt= 0.05 hrs
Peak Elev= 103.32' @ 12.56 hrs Surf.Area= 525 sf Storage= 149 cf

Plug-Flow detention time= 38.7 min calculated for 0.012 af (100% of inflow)
Center-of-Mass det. time= 38.3 min (793.4 - 755.1)

Volume	Invert	Avail.Storage	Storage Description
#1	103.00'	590 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc)

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
103.00	413	0	0
104.00	767	590	590

Device	Routing	Invert	Outlet Devices
#1	Discarded	103.00'	**2.000 in/hr Exfiltration over Surface area**
#2	Primary	103.75'	**6.0" Horiz. Orifice/Grate** X 2 rows C= 0.600 Limited to weir flow at low heads

Discarded OutFlow Max=0.02 cfs @ 12.56 hrs HW=103.32' (Free Discharge)
↑1=**Exfiltration** (Exfiltration Controls 0.02 cfs)

Primary OutFlow Max=0.00 cfs @ 0.00 hrs HW=103.00' (Free Discharge)
↑2=**Orifice/Grate** (Controls 0.00 cfs)

10-year rainfall event

Summary for Pond 2P: Bioretention Cell

Inflow Area =	0.047 ac,100.00% Impervious, Inflow Depth > 4.76" for 10-year event		
Inflow =	0.22 cfs @ 12.09 hrs, Volume=	0.018 af	
Outflow =	0.03 cfs @ 12.65 hrs, Volume=	0.018 af, Atten= 88%, Lag= 34.0 min	
Discarded =	0.03 cfs @ 12.65 hrs, Volume=	0.018 af	
Primary =	0.00 cfs @ 0.00 hrs, Volume=	0.000 af	

Routing by Stor-Ind method, Time Span= 0.00-24.00 hrs, dt= 0.05 hrs
Peak Elev= 103.52' @ 12.65 hrs Surf.Area= 597 sf Storage= 263 cf

Plug-Flow detention time= 67.7 min calculated for 0.018 af (100% of inflow)
Center-of-Mass det. time= 67.2 min (814.8 - 747.6)

Volume	Invert	Avail.Storage	Storage Description
#1	103.00'	590 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc)

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
103.00	413	0	0
104.00	767	590	590

Device	Routing	Invert	Outlet Devices
#1	Discarded	103.00'	**2.000 in/hr Exfiltration over Surface area**
#2	Primary	103.75'	**6.0" Horiz. Orifice/Grate** X 2 rows C= 0.600 Limited to weir flow at low heads

Discarded OutFlow Max=0.03 cfs @ 12.65 hrs HW=103.52' (Free Discharge)
↑1=**Exfiltration** (Exfiltration Controls 0.03 cfs)

Primary OutFlow Max=0.00 cfs @ 0.00 hrs HW=103.00' (Free Discharge)
↑2=**Orifice/Grate** (Controls 0.00 cfs)

25-year rainfall event

Summary for Pond 2P: Bioretention Cell

Inflow Area =	0.047 ac,100.00% Impervious,	Inflow Depth > 5.46"	for 25-year event	
Inflow =	0.25 cfs @ 12.09 hrs,	Volume=	0.021 af	
Outflow =	0.03 cfs @ 12.72 hrs,	Volume=	0.021 af,	Atten= 89%, Lag= 37.7 min
Discarded =	0.03 cfs @ 12.72 hrs,	Volume=	0.021 af	
Primary =	0.00 cfs @ 0.00 hrs,	Volume=	0.000 af	

Routing by Stor-Ind method, Time Span= 0.00-24.00 hrs, dt= 0.05 hrs
Peak Elev= 103.60' @ 12.72 hrs Surf.Area= 627 sf Storage= 314 cf

Plug-Flow detention time= 80.1 min calculated for 0.021 af (100% of inflow)
Center-of-Mass det. time= 79.5 min (825.0 - 745.5)

Volume	Invert	Avail.Storage	Storage Description
#1	103.00'	590 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc)

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
103.00	413	0	0
104.00	767	590	590

Device	Routing	Invert	Outlet Devices
#1	Discarded	103.00'	**2.000 in/hr Exfiltration over Surface area**
#2	Primary	103.75'	**6.0" Horiz. Orifice/Grate** X 2 rows C= 0.600 Limited to weir flow at low heads

Discarded OutFlow Max=0.03 cfs @ 12.72 hrs HW=103.60' (Free Discharge)
↑—**1=Exfiltration** (Exfiltration Controls 0.03 cfs)

Primary OutFlow Max=0.00 cfs @ 0.00 hrs HW=103.00' (Free Discharge)
↑—**2=Orifice/Grate** (Controls 0.00 cfs)

Open Cell Paver System:

Water Quality Storm

Summary for Subcatchment 3S: Mohican Trail (existing)

Runoff = 0.01 cfs @ 12.12 hrs, Volume= 0.001 af, Depth> 0.17"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 0.00-24.00 hrs, dt= 0.05 hrs
Type III 24-hr WQ Storm Rainfall=1.00"

Area (sf)	CN	Description
2,000	85	Gravel roads, HSG B
2,000		100.00% Pervious Area

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

Summary for Pond 4P: Open Cell Paver System

Inflow Area = 0.046 ac, 0.00% Impervious, Inflow Depth > 0.17" for WQ Storm event
Inflow = 0.01 cfs @ 12.12 hrs, Volume= 0.001 af
Outflow = 0.01 cfs @ 12.17 hrs, Volume= 0.001 af, Atten= 10%, Lag= 3.0 min
Discarded = 0.01 cfs @ 12.17 hrs, Volume= 0.001 af

Routing by Stor-Ind method, Time Span= 0.00-24.00 hrs, dt= 0.05 hrs
Peak Elev= 98.16' @ 12.17 hrs Surf.Area= 40,510,800 sf Storage= 1 cf

Plug-Flow detention time= 2.6 min calculated for 0.001 af (100% of inflow)
Center-of-Mass det. time= 2.1 min (901.5 - 899.4)

Volume	Invert	Avail.Storage	Storage Description
#1	98.16'	16,204,320 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc) 40,510,800 cf Overall x 40.0% Voids
#2	99.16'	63 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc) 158 cf Overall x 40.0% Voids
#3	99.33'	93 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc) 465 cf Overall x 20.0% Voids
#4	99.83'	63 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc) 158 cf Overall x 40.0% Voids
		16,204,539 cf	Total Available Storage

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
98.16	40,510,800	0	0
99.16	40,510,800	40,510,800	40,510,800

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
99.16	930	0	0
99.33	930	158	158

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
99.33	930	0	0
99.83	930	465	465

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
99.83	930	0	0
100.00	930	158	158

Device	Routing	Invert	Outlet Devices
#1	Discarded	98.16'	**2.000 in/hr Exfiltration over Surface area**

Discarded OutFlow Max=1,875.50 cfs @ 12.17 hrs HW=98.16' (Free Discharge)
↑1=**Exfiltration** (Exfiltration Controls 1,875.50 cfs)

2-year rainfall event

Summary for Pond 4P: Open Cell Paver System

Inflow Area =	0.046 ac,	0.00% Impervious, Inflow Depth > 1.87"	for 2-year event
Inflow =	0.10 cfs @	12.09 hrs, Volume=	0.007 af
Outflow =	0.09 cfs @	12.13 hrs, Volume=	0.007 af, Atten= 10%, Lag= 2.4 min
Discarded =	0.09 cfs @	12.13 hrs, Volume=	0.007 af

Routing by Stor-Ind method, Time Span= 0.00-24.00 hrs, dt= 0.05 hrs
Peak Elev= 98.16' @ 12.13 hrs Surf.Area= 40,510,800 sf Storage= 14 cf

Plug-Flow detention time= 2.6 min calculated for 0.007 af (100% of inflow)
Center-of-Mass det. time= 2.3 min (826.1 - 823.8)

Volume	Invert	Avail.Storage	Storage Description
#1	98.16'	16,204,320 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc) 40,510,800 cf Overall x 40.0% Voids
#2	99.16'	63 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc) 158 cf Overall x 40.0% Voids
#3	99.33'	93 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc) 465 cf Overall x 20.0% Voids
#4	99.83'	63 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc) 158 cf Overall x 40.0% Voids
		16,204,539 cf	Total Available Storage

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
98.16	40,510,800	0	0
99.16	40,510,800	40,510,800	40,510,800

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
99.16	930	0	0
99.33	930	158	158

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
99.33	930	0	0
99.83	930	465	465

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
99.83	930	0	0
100.00	930	158	158

Device	Routing	Invert	Outlet Devices
#1	Discarded	98.16'	**2.000 in/hr Exfiltration over Surface area**

Discarded OutFlow Max=1,875.50 cfs @ 12.13 hrs HW=98.16' (Free Discharge)
↑—1=**Exfiltration** (Exfiltration Controls 1,875.50 cfs)

10-year rainfall event

Summary for Pond 4P: Open Cell Paver System

Inflow Area =	0.046 ac,	0.00% Impervious, Inflow Depth > 3.37"	for 10-year event
Inflow =	0.18 cfs @	12.09 hrs, Volume=	0.013 af
Outflow =	0.16 cfs @	12.13 hrs, Volume=	0.013 af, Atten= 10%, Lag= 2.3 min
Discarded =	0.16 cfs @	12.13 hrs, Volume=	0.013 af

Routing by Stor-Ind method, Time Span= 0.00-24.00 hrs, dt= 0.05 hrs
Peak Elev= 98.16' @ 12.13 hrs Surf.Area= 40,510,800 sf Storage= 25 cf

Plug-Flow detention time= 2.6 min calculated for 0.013 af (100% of inflow)
Center-of-Mass det. time= 2.3 min (809.3 - 807.0)

Volume	Invert	Avail.Storage	Storage Description
#1	98.16'	16,204,320 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc) 40,510,800 cf Overall x 40.0% Voids
#2	99.16'	63 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc) 158 cf Overall x 40.0% Voids
#3	99.33'	93 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc) 465 cf Overall x 20.0% Voids
#4	99.83'	63 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc) 158 cf Overall x 40.0% Voids
		16,204,539 cf	Total Available Storage

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
98.16	40,510,800	0	0
99.16	40,510,800	40,510,800	40,510,800

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
99.16	930	0	0
99.33	930	158	158

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
99.33	930	0	0
99.83	930	465	465

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
99.83	930	0	0
100.00	930	158	158

Device	Routing	Invert	Outlet Devices
#1	Discarded	98.16'	**2.000 in/hr Exfiltration over Surface area**

Discarded OutFlow Max=1,875.50 cfs @ 12.13 hrs HW=98.16' (Free Discharge)
↑1=**Exfiltration** (Exfiltration Controls 1,875.50 cfs)

25-year rainfall event

Summary for Pond 4P: Open Cell Paver System

Inflow Area =	0.046 ac,	0.00% Impervious, Inflow Depth > 4.02"	for 25-year event
Inflow =	0.21 cfs @	12.09 hrs, Volume=	0.015 af
Outflow =	0.19 cfs @	12.13 hrs, Volume=	0.015 af, Atten= 10%, Lag= 2.3 min
Discarded =	0.19 cfs @	12.13 hrs, Volume=	0.015 af

Routing by Stor-Ind method, Time Span= 0.00-24.00 hrs, dt= 0.05 hrs
Peak Elev= 98.16' @ 12.13 hrs Surf.Area= 40,510,800 sf Storage= 30 cf

Plug-Flow detention time= 2.6 min calculated for 0.015 af (100% of inflow)
Center-of-Mass det. time= 2.3 min (804.4 - 802.0)

Volume	Invert	Avail.Storage	Storage Description
#1	98.16'	16,204,320 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc) 40,510,800 cf Overall x 40.0% Voids
#2	99.16'	63 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc) 158 cf Overall x 40.0% Voids
#3	99.33'	93 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc) 465 cf Overall x 20.0% Voids
#4	99.83'	63 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc) 158 cf Overall x 40.0% Voids
		16,204,539 cf	Total Available Storage

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
98.16	40,510,800	0	0
99.16	40,510,800	40,510,800	40,510,800

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
99.16	930	0	0
99.33	930	158	158

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
99.33	930	0	0
99.83	930	465	465

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
99.83	930	0	0
100.00	930	158	158

Device	Routing	Invert	Outlet Devices
#1	Discarded	98.16'	**2.000 in/hr Exfiltration over Surface area**

Discarded OutFlow Max=1,875.50 cfs @ 12.13 hrs HW=98.16' (Free Discharge)
↑**1=Exfiltration** (Exfiltration Controls 1,875.50 cfs)

The HydroCAD modeling results show that both the Bioretention system and Open Cell Paver system will fully infiltrate the runoff from storm events up to and including the 25-year event from the contributing drainage area.

Respectfully Submitted:
Trinkaus Engineering, LLC

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