Attached
2009 AND 2012
University Of New Hampshire Reports
Bioretention Systems

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2009 UNH Report
Bioretention Systems

UNHSC research is showing that bioretention systems are most effective when they serve as local source control devices, intercepting and managing relatively small areas of impervious cover, in a well-distributed network of runoff control measures.

About Bioretention Systems

Bioretention systems, also known as "rain gardens," are among the most common LID stormwater approaches in use today. In general, runoff flows into landscaped depressions, where it ponds, filters through a soil mix, and infiltrates into the ground, or is connected to storm drains. The engineered soil mix and vegetation mimic the water quality treatment and infiltration similar to undeveloped areas. Soil mix design is essential to the performance and longevity of these systems. While the mix must contain enough fines and organic matter to sustain vegetation and slow down infiltration rates, too much of these components may cause systems to clog prematurely eliminating any water quality benefits. There are soil mix specifications available to support designers in successfully implementing bioretention systems in a wide range of site conditions. UNHSC has evaluated many such systems; this report looks at a design we call "Bio II."

Implementation

Bioretention systems can be used throughout the United States, and their acceptance and implementation varies regionally. However, an increasing number of states require a level of water quality treatment and volume reduction that only can be achieved through the incorporation of LID designs like bioretention. In some regions, local acceptance is hindered by lack of performance data, unfamiliarity with the design, and suspicions about seasonal functionality.

To achieve maximum volume reduction, bioretention systems should be located in soils that accommodate infiltration, such as those in group "A" (sand, loamy sand, or sandy loam with high infiltration rates) and "B" (silt loam or loam with moderate infiltration rates). Careful site analysis is required to design an effective, integrated network of these systems that allows infiltration throughout a site. Bioretention systems can also be used to great effect in areas with poor soils, where pre-development infiltration would have been minimal. These systems in poor soils will require underdrains to ensure proper drainage and treatment.

UNHSC research is showing that bioretention systems are most effective when they serve as local source control devices, intercepting and managing relatively small areas of impervious cover in a well-distributed network of runoff control measures. They can be used as an end-of-pipe system; however, such usage requires a more sophisticated design for the system to function properly, particularly when

Fast Facts

CATEGORY / BMP TYPE

Infiltration, Low Impact Development Design

UNIT OPERATIONS & PROCESSES

Hydrologic (Flow Alteration)

Water Quality: Physical (Sedimentation, Filtration), Biological (Vegetative Uptake), & Chemical (Some Sorption possible with proper design)

DESIGN SOURCE

Low Impact Development Center, Maryland

BASIC DIMENSIONS

Filtration Basin: 8 ft wide X 34 ft long X 2.5 ft deep

Forebay: 14 ft long X 8 ft wide

Total Area: 272 sf

SPECIFICATIONS

Catchment Area: 1 acre

Water Quality Flow: 1 cfs

Water Quality Volume: 3,300 cf

INSTALLATION COST

$18,000 per acre

MAINTENANCE

Maintenance Sensitivity: Low

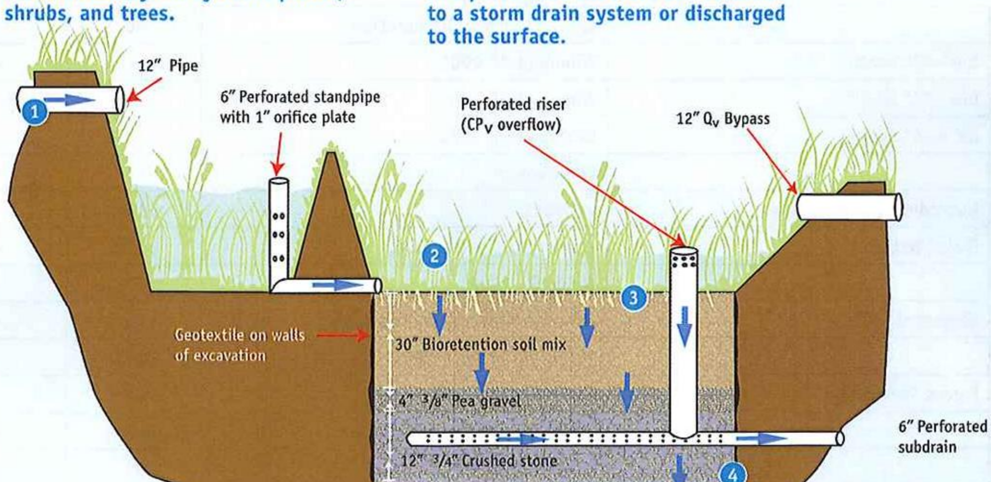
Inspections: Low

Sediment Removal: High

How the System Works

WATER QUALITY TREATMENT PROCESS

1. **Runoff flows into a sedimentation forebay or other pretreatment chamber. From there, it is slowly released into the filter basin through a perforated standpipe. When forebay capacity is reached, the overflow spills across a weir into the bioretention basin.**
2. **Biological treatment occurs through the uptake of pollutants by vegetation and soil microorganisms. Physical and chemical unit operations and processes that occur within the soil media include sedimentation, filtration, and sorption with organic matter and mineral complexes.**
3. **Nutrients like nitrogen are taken up by the roots of the vegetation and metabolized by the system's plants, shrubs, and trees.**
4. **The treated runoff can be allowed to infiltrate the native soils, or collected in a perforated subdrain and returned to a storm drain system or discharged to the surface.**



Not drawn to scale, vertical exaggeration

ATT. B2: 2009 UNH Report

UNHSC Pollutant Removal Efficiencies

Treatment Unit Description	Reference	TSS Total Suspended Solids (% Removal)	TPH-D Total Petroleum Hydrocarbons in the Diesel Range (% Removal)	NO3-N (DIN) Dissolved Inorganic Nitrogen (% Removal)	TZn Total Zinc (% Removal)	TP Total Phosphorus (% Removal)	Average Annual Peak Flow Reduction (% Removal)	Average Annual Lag Time (Minutes)
Conventional Treatment Devices								
Retention Pond	UNH	68	82	33	68	NT	86	455
Stone (rip-rap) Swale	UNH	50	33	NT	64	–	6	7
Vegetated Swale	UNH	58	82	NT	88	NT	52	38
Berm Swale	UNH	50	81	NT	50	8	24	58
Deep Sump Catch Basin	UNH	9	14	NT	NT	NT	NT	NT
Manufactured Treatment Devices (MTDs)								
ADS Infiltration Unit	UNH	99	99	NT	99	81	87	228
StormTech	UNH	80	93	NT	56	49	76	274
Aquafilter	UNH	62	26	NT	52	59	NT	NT
Hydrodynamic Separators	UNH	27	1	NT	24	42	NT	NT
Low Impact Development (LID)								
Surface Sand Filter	UNH	51	98	NT	77	33	69	187
Bioretention								
Bio I - 48" depth	UNH	97	99	44	99	–	75	266
Bio II - 30" depth	UNH	87	99	NT	68	34	79	309
Gravel Wetland	UNH	99	99	98	99	56	87	251
Porous Asphalt	UNH	99	99	NT	75	60	82	1,275
Pervious Concrete	UNH	97	99	NT	99	NT	93	1,144
Tree Filter	UNH	93	99	3	78	NT	NT	62

Reference Published Pollutant Removal Efficiencies

Treatment Unit Description	Reference	TSS Total Suspended Solids (% Removal)	TPH-D Total Petroleum Hydrocarbons in the Diesel Range (% Removal)	NO3-N (DIN) Dissolved Inorganic Nitrogen (% Removal)	TZn Total Zinc (% Removal)	TP Total Phosphorus (% Removal)
Sub Surface Detention/Infiltration	EPA Fact Sheet: Infiltration Trenches	–	–	–	–	60
Sand Filter	EPA Fact Sheet: Sand Filters	70	–	NT	45	33
	Claytor & Schueler, 1996	85	–	–	71	50
	Bell, W., et al, 1995	61-70	–	–	>82	–
	Winer, R., 2000	87	–	NT	80	59
Retention Pond	EPA Fact Sheet: Wet Detention Ponds	50-90	–	–	40-50	30-90
	EPA Fact Sheet: Wet Detention Ponds	80-90	–	–	–	–
Bioretention	Winer, R., 2000	79	–	36	65	49
	EPA Fact Sheet: Bioretention	90	–	–	–	70-83
Bio - 12" depth	Winogradoff, 2001	–	–	-97	87	NT
Bio - 24" depth	Winogradoff, 2001	–	–	-194	98	73
Bio - 36" depth	Winogradoff, 2001	–	–	23	99	81
	EPA website	84	–	–	–	–
Hydrodynamic Separators	various	52-84	–	–	–	30
Gravel Wetland	Claytor & Schueler, 1996	80-93	–	75	55-90	80-89
	Winer, R., 2000	83	–	81	55	64
Vegetated Swale	EPA Fact Sheet: Vegetated Swales	81	–	38	71	9
	Claytor & Schueler, 1996	30-90	–	0-80	71	10-65
Porous Pavement	NAPA, undated	89-95	–	–	62-99	65-71
	EPA Fact Sheet: Porous Pavement	82-95	–	–	–	65
	Winer, R., 2000	95	–	–	99	65

treating one or more acres of impervious cover. As with any infiltration or filtration system, when used in pollution hotspots or poor soils, they should be lined and outfitted with subdrains that discharge to the surface.

System Performance

Cost & Maintenance

The cost to install Bio II to treat runoff from a one-acre parking lot was $18,000. However, UNHSC expects this cost to come down as installers and designers gain familiarity with the systems. The Center installed a third bioretention system in 2007 at $14,000 per acre for the total cost; labor and installation were calculated to be $8,500 per acre, and materials and plantings cost $5,500 per acre. This indicates that for a municipality that has both equipment and personnel, the cost for retrofits is nearly $5,500 per acre of drainage.

Bioretention systems are designed to minimize maintenance. Generally, the highest maintenance burden is in the first three to four months, as the vegetation grows and the system begins to stabilize. Once vegetation is established, the maintenance decreases and becomes similar to that required for standard landscaping, such as seasonal mowing, raking, and pruning of vegetation. Systems with fine media may require more frequent attention due to clogging. However, since most clogging occurs on the surface, servicing these systems is simple. Long-term maintenance may involve routine inspection and occasional scraping and removal of surface fines.

Cold Climate

Bio II's ability to treat water quality and control water quantity remained relatively consistent in all seasons. UNHSC researchers have observed that most LID stormwater systems, when properly designed and installed, are not negatively impacted by cold climate. In fact, these systems showed fewer seasonal variation than many conventional approaches that depend on sedimentation as the primary unit operation. While some seasonal variation did occur in Bio II, significant design alterations do not appear to be necessary for cold weather applications of this system.

Water Quality Treatment

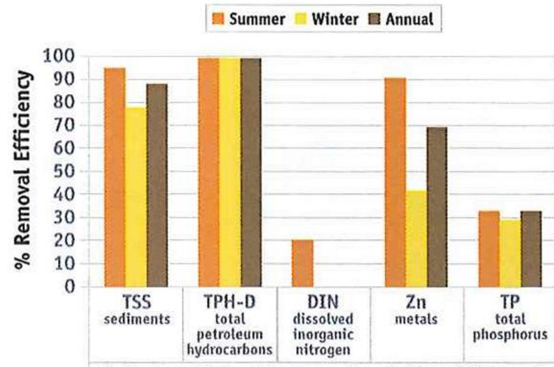
Bio II has proven effective at removing nearly all of the pollutants commonly associated with stormwater treatment performance assessment. It consistently exceeded EPA's recommended level of removal for total suspended solids and meets regional ambient water quality criteria for petroleum hydrocarbons. This system had lower removal of nitrogen and phosphorous than the previous bioretention system tested at the UNHSC. This may be due to reduced contact time and/or less dense root mat. These design variations are being examined in Bio III and Bio IV presently. Like the other systems monitored at UNHSC, Bio II does not provide chloride removal, although it does exhibit an ability to dampen chloride peaks.

The chart at top right reflects the bioretention performance in removing total suspended solids, total petroleum hydrocarbons, dissolved inorganic nitrogen, total phosphorus, and zinc.

Water Quantity Control

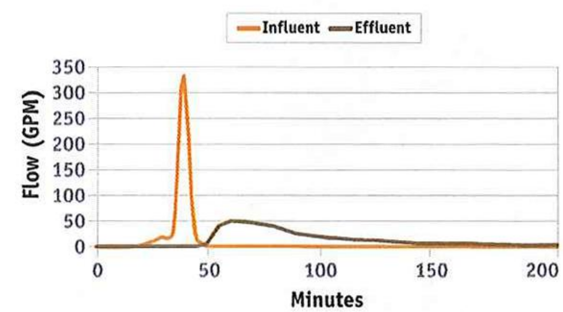
Like other infiltration and filtration systems, Bio II has a tremendous capacity to reduce peak flows and runoff volume in appropriate soils, i.e., those belonging to groups A and B. In the figure at bottom right, Bio II demonstrates effective peak flow reduction and large lag times regardless of season. Vegetation contributes to stormwater volume reduction through the process of evapotranspiration.

POLLUTANT REMOVAL: 2006–2008



Median Annual Influent Event Mean Concentrations (EMC) in mg/L				
48	754 ug/L	.21	.043	.09

HYDRAULIC PERFORMANCE



	Winter	Summer	Annual Average
Average Peak Flow Reduction	76%	82%	79%
Average Lag Time (minutes)	376	254	309

SYSTEM DESIGN

Bio II is comprised of a sedimentation forebay and a bioretention filtration basin. The basin is filled with a 30 inch bioretention soil mix (BSM), consisting of 60 percent sand, 20 percent woodchips, 10 percent compost, and 10 percent native soil. The filtration basin is well vegetated. Researchers selected vegetation for flood and drought tolerance, the capacity for maximum ground cover, and aesthetics.

The forebay holds 25 percent of the water quality volume (WQ_v), and drains through a stone level spreader into the bioretention basin, which holds 75 percent of the WQ_v. The basin allows eight inches of ponding, and the BSM has an infiltration rate of eight feet per day. Overflow contingencies exist for channel protection volume (CP_v) and conveyance protection volume (Q10) events. Typically Q2 events are conveyed over 24 to 48 hours, and Q10 events bypass to the surface.

The appropriate BSM design is important to ensure adequate drainage, support plant growth, and achieve water quality treatment objectives. It is important for soils to slowly percolate enough to achieve high quality treatment, yet fast enough to filter sufficient volumes of water such that the filter area not be inordinately large. Bio II's BSM specifications were developed with input from the Low Impact Development Center. The resulting BSM had reduced silts and clays of about 6 percent maintains an infiltration rate of approximately 8 feet per day, and had about 3 percent organic matter. Results indicate that this BSM had reduced removal performance for nitrogen and phosphorus, in comparison to Bio I that had an infiltration rate of 0.5 feet per day.

UNHSC is currently studying BSM for two other designs with high infiltration rates that use outlet controls to slowly release the WQ_v. One with 8 percent fines and 10 percent organic matter, and infiltration rate of 100 feet per day, and another with 10 percent fines, 7 percent organic matter, and an infiltration rate of 40 feet per day. Soil chemistry is important, especially when targeting phosphorus reduction. BSMs must contain relatively low levels of phosphorus to maintain a sorption capacity that can remove phosphorous from runoff. Studies from North Carolina State University recommend BSMs with a Phosphorus Index (P-Index) of 25 to 40.

UNHSC Measured Median Pollutant Removal Efficiencies

Treatment Unit Description	TSS Total Suspended Solids (mg/l)			TPH-D Total Petroleum Hydrocarbons in the Diesel Range (ug/l)			NO3-N (DIN) Dissolved Inorganic Nitrogen (mg/l)			TZn Total Zinc (mg/l)			TP Total Phosphorus (mg/l)			Average Annual Peak Flow Reduction	Average Annual Lag Time
	Influent	Effluent	% Removal	Influent	Effluent	% Removal	Influent	Effluent	% Removal	Influent	Effluent	% Removal	Influent	Effluent	% Removal	% Reduction	Minutes
Conventional Treatment Technologies																	
Retention Pond	55	30	68%	710	100	82%	0.3	0.2	33%	0.05	0.01	68%	0.09	0.11	NT	86	455
Detention Pond	77	16	79%	490	165	74%	0.3	0.2	25%	0.03	0.02	50%	0.05	0.05	NT	93	639
Stone (rip-rap) Swale	30	15	50%	580	380	33%	0.4	0.7	NT	0.07	0.02	64%	-	-	-	6	7
Vegetated Swale	48	16	56%	710	207	82%	0.3	0.3	NT	0.04	0.02	40%	0.08	0.10	NT	52	38
Berm Swale	51	23	50%	637	61	81%	0.2	0.3	NT	0.03	0.02	50%	0.07	0.09	NT	16	58
Deep Sump Catch Basin	48	34	9%	510	440	14%	0.2	0.3	NT	0.04	0.04	NT	0.08	0.07	NT	NT	NT
Manufactured Treatment Devices																	
ADS Infiltration Unit	49	BDL	99%	766	BDL	99%	0.3	0.9	NT	0.05	BDL	99%	0.12	0.02	81%	87	228
StormTech	87	13	83%	750	45	91%	0.3	0.5	NT	0.03	0.01	67%	0.07	0.03	52%	78	235
Aquifilter	28	11	62%	573	156	66%	0.3	0.3	NT	0.04	0.02	43%	0.07	0.05	24%	NT	NT
Online Hydrodynamic Separators	41	29	29%	774	442	42%	0.4	0.4	NT	0.05	0.04	26%	0.09	0.11	NT	NT	NT
Offline Hydrodynamic Separators (HDS)	120	21	75%	570	180	64%	0.2	0.3	NT	0.03	0.02	21%	0.05	0.05	NT	NT	NT
Low Impact Development (LID)																	
Surface Sand Filter	45	19	51%	788	17	98%	0.3	0.4	NT	0.06	0.01	77%	0.12	0.06	33%	69	187
Bio I - 48" depth (42" filter depth)	37	1	97%	798	BDL	99%	0.4	0.1	44%	0.07	BDL	99%	-	-	-	75	266
Bio II - 30" depth (24" filter depth)	48	6	87%	750	BDL	99%	0.2	0.2	NT	0.04	0.02	73%	0.08	0.05	34%	79	309
Bio III - 30" depth (24" filter depth)	120	8	91%	450	163	64%	0.4	0.3	44%	0.03	0.01	75%	0.03	0.05	NT	84	216
Bio IV - 37" depth (24" filter depth)	80	11	83%	495	165	65%	0.3	0.2	42%	0.03	0.01	67%	0.07	0.06	NT	95	61
Subsurface Gravel Wetlands	61	4	96%	644	BDL	99%	0.3	0.1	75%	0.04	0.01	84%	0.06	0.02	58%	92	391
Porous Asphalt	32	BDL	99%	631	BDL	99%	0.2	0.5	NT	0.04	0.01	75%	0.08	0.04	57%	82	1,275
Pervious Concrete	101	11	85%	310	BDL	99%	0.3	0.5	NT	0.03	0.01	75%	0.06	0.65	NT	93	1,011
Permeable Interlocking Concrete Pavement	51	BDL	99%	610	BDL	99%	0.4	BDL	99%	0.05	BDL	99%	0.13	BDL	99%	99	see pg 16
Tree Filter	31	2	91%	631	BDL	99%	0.2	0.2	1%	0.04	0.01	75%	0.07	0.06	NT	31	204

*BDL indicates a value that is Below Detection Limit of the test method.
NT indicates no treatment.

2012 UNH REPORT
Bioretention Systems

Bioretention systems are the workhorse of LID approaches and offer flexible, adaptive and reliable treatment of stormwater runoff.

About Bioretention Systems

Bioretention systems, also known as "rain gardens," are among the most common Low Impact Development (LID) stormwater approaches in use today. These systems consist of landscaped depressions which collect runoff that subsequently ponds, filters through a soil mix, and infiltrates into the ground, or discharges to the surface. The UNHSC has evaluated many different bioretention systems; this report specifically examines four bioretention designs (Bio 1, Bio 2, Bio 3, and Bio 4), two of which are new, and two of which have been studied and reported on previously. While structural variations exist, the main differences between these systems relate to the composition of bioretention soil mix (BSM) – namely sand, compost, wood chips, and loam.

Implementation

Bioretention systems are used throughout all areas of the U.S., but their acceptance and implementation varies regionally. An increasing number of states are requiring higher levels of water quality treatment and volume reduction that only can be achieved through the incorporation of filtration and infiltration designs like bioretention systems. In some regions, local acceptance is hindered by lack of performance data, unfamiliarity with the design, concerns over maintenance, and suspicions in regards to seasonal functionality. To maximize volume reduction of stormwater runoff with bioretention systems, they should be located in soils that accommodate infiltration, such as those classified as hydrologic soils group "A" (sand, loamy sand, or sandy loam with high infiltration rates) and group "B" (silt loam or loam with moderate infiltration rates).

System Performance

Cost

The installation costs associated with the bioretention systems implemented by UNHSC ranged from \$14,000 to \$25,000 per acre of impervious cover "IC" treated. These costs will moderate as installers and designers gain familiarity with the systems. In 2007, UNHSC installed Bio 4 in a vegetated parking lot median strip as a retrofit at a total cost of \$14,000 per acre, including \$8,500 per acre for labor and installation, and \$5,500 per acre for materials and plantings. These findings indicate that for municipalities with equipment and personnel, the retrofit costs are nearly \$5,500 per acre of drainage. These costs do not include design, permitting, or construction supervision costs.

Maintenance

Bioretention systems are designed for minimal maintenance. As indicated by the graph in the bottom right, the highest maintenance burden occurs during the first two years of operation as the vegetation grows and the system begins to stabilize. Once vegetation is established, maintenance decreases and becomes very predictable, similar to what is required for standard landscaping. Common maintenance tasks include seasonal mowing, raking, and pruning of vegetation. Beyond two years, long-term maintenance tends to level off and involve more routine and schedulable maintenance activities. The average of all maintenance costs and personnel hours required for the bioretention systems studied at UNHSC were \$1,820 and 21 hours of labor per year per acre of IC treated, respectively.

Infiltration rates (IR) are easily measured in bioretention systems using standard methods (ASTM D3385 – 09) or even more simply with instruments like the Turf-Tec Infiltrometer. At the UNHSC, IR was measured for all bioreten-

Issues in Focus

BIORETENTION SOIL MIX COMPOSITION

		Soil Mix					Hydraulic Loading Ration	PSD		
System	Date Installed	Sand	Compost	Soil	Woodchips	Vegetation Cover	Drainage Area : Filter Area	Date	Organic Content	% passing 200 um sieve
Bio-1	2004	45%	10%	45%	0%	Trees and Wetland Plants	18:1	2004	4.2	2%
Bio-2	2005	60%	10%	10%	20%	Wooded Vegetation	160:1	2005	2.9	7%
Bio-3	2009	60%	10%	10%	20%	Eco-Lawn	160:1	2009	6.6	10%
Bio-4	2008	70%	30%	0%	0%	Prairie Meadow Perennial	32:1	2008	9.9	8%

The soil mix used in the bioretention systems is central for determining flow control and water quality treatment performance. Hydraulic conductivity of bioretention soil mixes is variable and usually trends toward higher infiltration rates than originally designed for. Infiltration rates of BSM mixes are strongly correlated to the percent that passes the 200 sieve and guidance largely suggests that the fines should ideally be between 2-5%. Current research shows variable nitrogen and phosphorus removals and that additional research is needed to optimize bioretention systems for nutrient treatment.

tion systems studied. The figure below compares IR over the range of bioretention systems. Of particular interest is the decline of IR over time for 3 out of the 4 bioretention systems. This can be predicted and is likely due to the accumulation of fine materials on the surface of the filter. The IR reduction rate can be used to schedule cleanings and maintenance of the filter.

In contrast to the other systems vegetated with native perennial plants, the Bio 3 system was different in that the basin was vegetated with a conservation mix often used for detention basins), and contained a continuous dense vegetative cover. Previous studies have indicated that plant roots generally experience a 30% die back each year which aids in the development of macropores that keep soil surface IC high over time. The data from this study seems to suggest that dense vegetative cover is more important than plant type for maintaining IR in vegetative systems. If aesthetics are not a concern, then it is conceivable that grassed bioretention systems could reduce overall maintenance burdens in bioretetnion systems.

Cold Climate

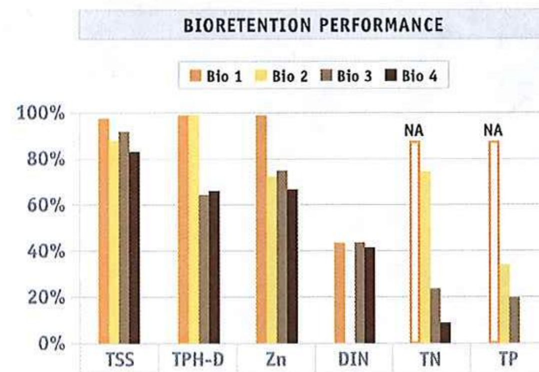
The ability for bioretention systems to treat water quality and control water quantity remained relatively consistent in all seasons over the range of systems monitored. UNHSC researchers have observed that most LID stormwater systems, when properly designed and installed, are not negatively impacted by cold climate.

Water Quality Treatment

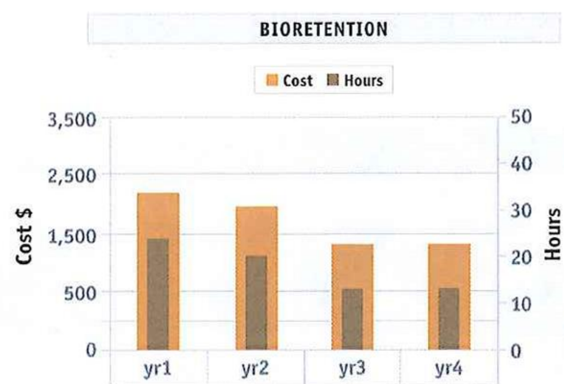
All bioretention systems have proven effective at removing sediment-bound pollutants commonly associated with stormwater treatment performance assessments. Additionally, the systems consistently exceed EPA's recommended level of removal for total suspended solids and achieved requisite removal for petroleum hydrocarbons and metals (TZn). However, the performance for nutrients is more variable. With the exception of Bio 2, the range of systems consistently removed dissolved inorganic nitrogen (DIN). A consistent trend with respect to percent removals was apparent in that a definite seasonality and a virtual ceiling at 40 – 45% removal were observed. Exceptions include Bio 2 which had no real DIN removal. This may be due to a less dense root mat and a reduced filter area caused by shading and pedestalling from woody vegetation. Over time woody vegetation can crowd and shade out bioretention areas and may not be suitable for this application. Total Phosphorus (TP) treatment performance was variable but trended toward efficiencies of roughly 20-30%, and may be maximized by limiting phosphorus levels in the design BSM. The chart at the right reflects bioretention performance in removing total suspended solids, total petroleum hydrocarbons, total zinc, dissolved inorganic nitrogen, total nitrogen, and total phosphorus.

WATER QUANTITY CONTROL

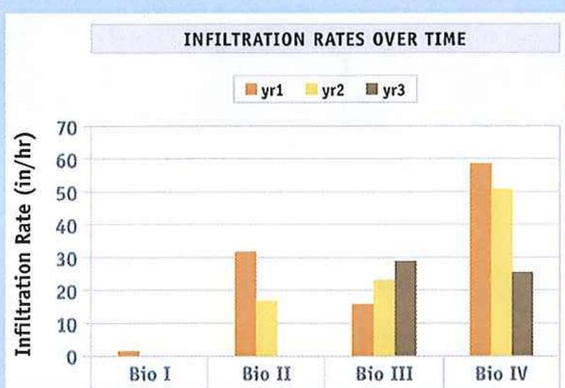
Systems	Winter	Summer	Average
Bioretention 1			
Average Peak Flow Reduction	77%	74%	75%
Average Lag Time (minutes)	408	108	266
Bioretention 2			
Average Peak Flow Reduction	74%	85%	79%
Average Lag Time (minutes)	346	265	309
Bioretention 3			
Average Peak Flow Reduction	84%	85%	84%
Average Lag Time (minutes)	215	217	216
Bioretention 4			
Average Peak Flow Reduction	94%	95%	95%
Average Lag Time (minutes)	52	67	61



NA = pollutant not monitored



BSM INFILTRATION RATES



The accepted optimum infiltration rate for bioretention soil mixes ranges between 0.5 to 12 inches per hour. Sandy bioretention soil mixes should provide excellent water quality performance with respect to most sediment associated pollutants. Designs with safety factors >3 should consider orifice control in bioretention underdrains in N and P sensitive watersheds. UNHSC research indicates that more robust vegetative cover is higher in importance as compared to plant selection or placement in maintaining long term surface infiltration rates.