low impact development technical workshop series

Water Quality Treatment in Bioretention

Topics

Mechanisms

Performance

Special considerations

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All primary pathways for removing pollutants from storm flows are active in bioretention

Stormwater volume reduction.

Sedimentation.

Filtration.

Phytoremediation.

Thermal attenuation.

Adsorption.

Volatilization.

water quality treatment

Some characteristics of our urban pollutants

- **Little known about mixtures of pollutants, but strong synergism indicated for some pollutants (e.g. pesticides).**
- **Many pollutants associated with fines (particularly metals), many <0.45 microns (dissolved).**
- **Structural stormwater controls alone limited for WQ protection.**

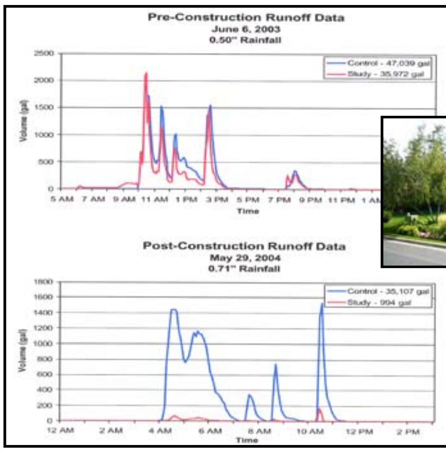
introduction

Flow volume reductions in bioretention

	Completed	Infiltration	Sizing	Volume Reduction (%)
Siskiyou Green Street	Oct 2003	1.5 -2.0 in/hr	6%	*(1/04 – 12/05) 83%
Glencoe Rain Garden	Oct 2003	1.8 - 3.0 in/hr	6%	(1/04 – 12/05) 94%
Greensboro NC	2001	0.2 – 0.6 in/hr	5%	(2002) 78%
Sea Street	2001	variable		(2001 – present) 98%
110th Cascade	2003			(10/04 – 06) 74%
Meadow on the Hylebos	2006	0.0 – 0.8 in/hr	15%	(10/07 – 5/08) 99.99%



water quality treatment



Burnsville, MN

Soil sampling in bioretention facilities

	e. Coli (mpn/g)	Cu (mg/kg)	Pb (mg/kg)	Hg (mg/kg)	Zn (mg/kg)
Siskiyou Green Street					
0-6"	280	34.4	56.8	0.103	170
6-12'	--	17.0	12.2	0.032	100
12-18"	--	17.6	10.9	0.054	96
SW 12th & Montgomery					
0-6"	7	30.1	29.9	0.043	120
12-18"	--	22.2	18.9	0.082	92

MTCA
Pb: 250 mg/kg
Hg: 2 mg/kg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Percent removal of metals and TSS in bioretention and grass bioswales

	TSS mgL^{-1}	P/TP mgL^{-1}	P/diss mgL^{-1}	NO3+2-N mgL^{-1}	NH4-N* mgL^{-1}	TKN mgL^{-1}	Total Cu ugL^{-1}	Total Pb ugL^{-1}	Total Zn ugL^{-1}	FC
Grass Swales (dry)										
25th percentile										
In	8.00	0.06	0.03	0.11	--	0.31	5.02	1.65	19.1	1400
Out	5.12	0.12	0.05	0.13	--	0.29	3.57	1.08	15.5	1900
Median										
In	21.70	0.11	0.06	0.30	--	0.72	10.86	3.93	36.2	4720
Out	13.60	0.19	0.07	0.25	--	0.62	6.54	2.02	22.9	5000
75th percentile										
In	56.00	0.24	0.09	0.62	--	1.48	27.00	18.20	136.0	20300
Out	33.00	0.32	0.26	0.47	--	1.10	13.20	6.27	50.0	18500
Bioretention Facilities										
25th percentile										
In	18.30	0.06	--	0.16	--	0.54	8.35	2.06	46.3	--
Out	3.80	0.05	--	0.11	--	0.32	3.98	2.50	4.8	--
Median										
In	37.50	0.11	--	0.26	--	0.94	17.00	3.76	73.8	--
Out	8.30	0.09	--	0.22	--	0.60	7.67	2.53	18.3	--
75th percentile										
In	87.80	0.22	--	0.41	--	1.58	38.50	7.00	153.8	--
Out	16.00	0.20	--	0.39	--	1.25	12.00	5.00	36.0	--

water quality treatment

Percent removal of metals and TSS in bioretention and grass bioswales

	TSS (mg/L)	Cu (μg/L)	Pb (μg/L)	Zn (μg/L)
Davis etal 2001*		89% (u) 92% (l)	>98% (u) >98 (l)	>98% (u) >98 (l)
Davis etal 2003**		>99%	>99%	>99%
Greenbelt		97%	>95%	>95%
Largo		43%	70%	64%
Hunt etal 2006				
Greensboro	-180%	99%	81%	98%
Chapel Hill	--	--	--	--
Hsieh, Davis 2005	91%			
Multhanna etal 2007		63%	93%	87%
PNW Bioswales (Herrera 2006)	64%			47%
National Bioswales (Herrera from Barrett)	43%			53%

Event mean concentrations

* Percent reduction at 18 cm (upper) and 61 cm (lower) depths (lab)

** Percent mass removal (lab)

water quality treatment

Percent removal of nutrients in bioretention and grass bioswales

	TKN (mg/L)	NO_3 (mg/L)	TP (mg/L)	Hydrocarbons (μg/L)
Davis etal 2006*	38% (u) 68% (l)	-96% (u) 24% (l)	1% (u) 81% (l)	
Greenbelt	57%	16%	65%	
Largo	67%	15%	87%	
Mass removal	97%	97%	99%	
Hunt etal 2006				
Greensboro	-4.9%	75%	-240%	
Chapel Hill	45%	13%	65%	
Hsieh 2005				>97%
PNW Bioswales (Herrera 2006)			18%	-10%
Nat'l Bioswales**				-88%

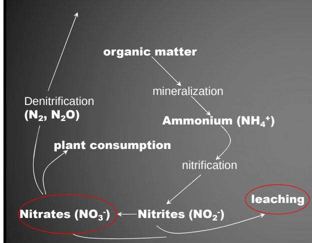
Event mean concentrations

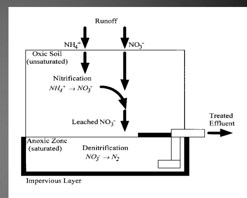
* Percent reduction at 18 cm (upper) and 61 cm (lower) depths (lab)

**Herrera from Barrett

water quality treatment

Methods for managing nitrate

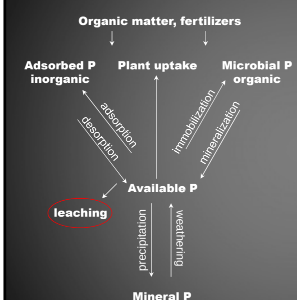


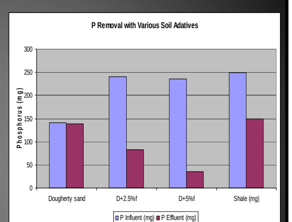


NO_3^- electron acceptor not O_2 in anaerobic conditions
$2NO_3^- + 10e^- + 12H^+ \rightarrow N_2 + 6H_2O$
Electron donor may be sugar, hydrocarbon (simple) or complex (mulch).

water quality treatment

Methods for retaining phosphate

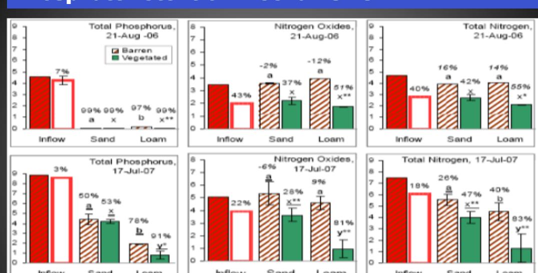




Fly ash significantly improves P retention, but significantly reduces K. (Zhang 2000)

water quality treatment

Phosphate retention mechanisms



P-sorption increased significantly in vegetated vs non-vegetated plots. Increased O_2 from roots→oxidizes Fe (ferric form has high P sorption capacity) and arbuscular mycorrhizal fungi associated with roots (luxury uptake) possible mechanisms. (Lucas, Greenway 2007)

water quality treatment

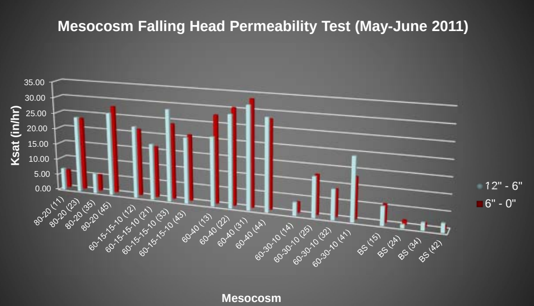
WSU LID Research Program: Bioretention Soils

bioretention: mesocosms

Soil treatments

- 60% sand--40% compost.
- 80% sand--20% compost.
- 60% sand--30% compost--10% WTRs.
- 60%sand--15% compost--15% shredded bark--10% WTRs.
- Compost and biochar media.

WSU LID Research Program: Bioretention Soils



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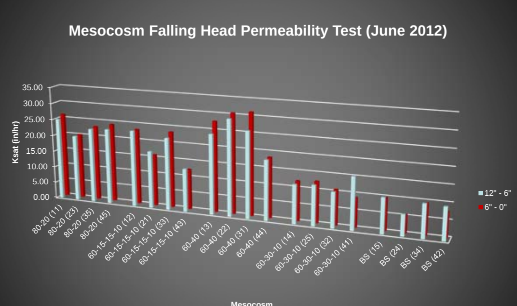
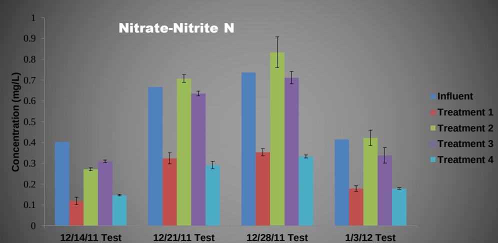


Bioretention Water Quality Treatment

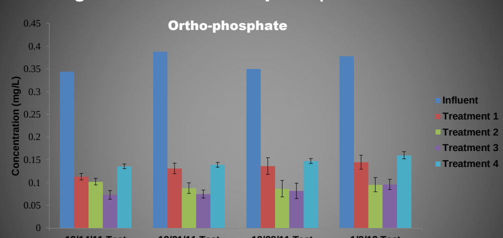
Balancing N removal and P capture (60-15-15-10 columns)



Date	Influent	Median Effluent	% Change	n
12/14/2011	0.403	0.209	48.14	12
12/21/2011	0.667	0.48	28.04	12
12/28/2011	0.737	0.532	27.82	12
1/3/2012	0.415	0.2585	37.71	12

Bioretention Water Quality Treatment

Balancing N removal and P capture (60-15-15-10 columns)



Date	Influent	Median Effluent	% Change	n
12/14/2011	0.344	0.1075	68.75	12
12/21/2011	0.388	0.1095	71.78	12
12/28/2011	0.35	0.111	68.29	12
1/3/2012	0.378	0.1205	68.12	12

Bioretention Water Quality Treatment

All mesocosms (Phase 1 leaching regime)

Analyte	Units	Median Influent	Min	Median Effluent	Max	n
TSS	mg/L	4.9	1	5.3	22.5	36
Diss Zn	µg/L	71	4	4	10	40
Diss Cu	µg/L	3	1.7	8.6	15.9	40
PO4	mg/L	0.016	0.086	0.236	0.461	40
NO3-NO2	mg/L	0.361	0.05	0.145	1.03	32
Fecal coliform	CFU/100mL	229	5	22.5	65	32

Bioretention Water Quality Treatment

Water quality treatment mechanisms

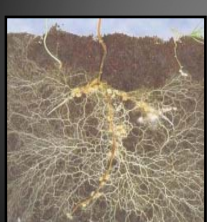
Is the following statement true:

If 0.5 µg/L influent concentration of dissolved Cu results in 2 µg/L effluent concentration, then

100 µg/L influent concentration dissolved Cu will result in 400 µg/L effluent concentration

Plants play a critical role in bioretention flow and water quality treatment performance

- Plant roots penetrate soil creating flow paths, exude saccharides and dead material that feed soil organisms and create soil aggregates.



- Treatment mechanisms:
  - Nutrient uptake.
  - Metal uptake.
  - Uptake, volatilization, transformation of organics.
- Plants influence water quality directly (e.g. uptake) and indirectly through physical an chemical changes to rhizosphere.

bioretention plants

Summary and recommendations

- Bioretention areas provide excellent Zn, hydrocarbon, bacteria and TSS removal.
- Metal, hydrocarbon and TSS removal primarily in upper few centimeters. Hydrocarbons transformed within a few days. Mulch layer most important for metal and hydrocarbon removal.
- Phosphorus, nitrogen and Cu removal is variable. Nitrate, phosphate and Cu export is possible.
- Phosphate management: 1) sorption capacity (short and long term); 2) plants likely necessary for improved and adequate P management; 3) precipitation (longer-term and likely between events process; 4) HRT and BSM depth (likely due to increased contact time).

water quality treatment

Summary and recommendations

- Nitrate removal dependent on O_2 levels. Use raised under-drain to create an anaerobic zone and improve NOx for effluent release to marine water.
- More research needed for optimizing for phosphate and Cu removal. Research in progress at WSU.
- Discussion focused on percent removal and concentrations. When considering volume reduction in rain gardens, loads dramatically reduced for all constituents.
- Need to be careful with selection of materials and suppliers (particularly with compost).

water quality treatment