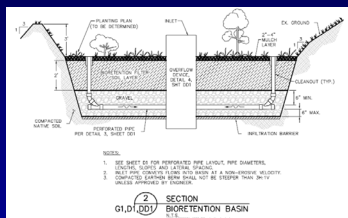
Treatability of Stormwater Toxicants using Bioretention Media



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Stormwater Control Performance Optimization

- Study site is a large RCRA (*Resource Conservation Recovery Act*) regulated field lab located in Southern California with low NPDES numeric effluent limits for stormwater (all outfalls and all events are monitored for compliance). Some permit limits include:
  - Cadmium: 4 µg/L
  - Copper: 14 µg/L
  - Lead: 5.2 µg/L
  - Mercury: 0.13 µg/L
  - TCDD (dioxin): 2.8 X 10^{-8} µg/L
- Many of the permit limits would likely be exceeded for most untreated stormwater discharges, including from residential and open space areas.

Stormwater Control Performance Optimization (cont.)

- With such restrictive limits, site requires designs refined to a much higher degree than in typical practice and guidance
- Need to optimize stormwater control performance through various design factors:
  - Treatment trains using combinations of sedimentation and media filtration
  - Long sedimentation pre-treatment drainage time
  - Sufficient media contact time to increase control of critical constituents
  - Specially-selected filtration media
- Bench-scale laboratory media testing was therefore conducted to provide needed performance and design information.

Media Testing Goals

- To provide information for design (e.g., optimal media components, depths, and contact times).
- To maximize the likelihood that filtration-based treatment controls will achieve performance objectives.
- To optimize design considering the large investment ($0.10 to $1.00 per lb of media and many tons needed) and to ensure long life before clogging or break-through.

- Bench-scale lab experiments performed by Penn State – Harrisburg and the University of Alabama

Media (from left to right): GAC, Rhyolite Sand, Site Zeolite, Surface Modified Zeolite, Sphagnum Peat Moss

Testing Protocol

- Thorough evaluation conducted to predict removal ability as a function of time, effects of clogging and maintenance, optimization of contact time, and changes in pore water chemistry in the filters between storms.
- The testing protocol had four phases:
  - Long-term column testing – pollutant removal as a function of water and pollutant loading; highlights breakthrough/pollutant saturation, and maintenance (including recovery of media functionality and length of maintenance periods)
  - Media depth testing – pollutant removal as a function of media depth (function of contact time of the runoff water with the media
  - Batch kinetics testing – pollutant removal as a function of contact time; highlights optimal contact time, trade-offs with ion-exchange
  - Aerobic/anaerobic testing – retention of pollutants by the media as it relates to pore-water chemistry

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Constituents Evaluated during Laboratory Media Tests

- Critical site constituents (possible periodic permit exceedences if untreated based on historic site sampling data): cadmium, copper, lead, zinc, oil and grease, mercury, and TCDD (2,3,7,8-Tetrachlorodibenzo-p-Dioxin).
- Other constituents listed on permit (rarely, if ever, expected to exceed permit limits if untreated): pH, TDS, sulfate, chloride, nitrates plus nitrites, fluoride, ammonia, nickel, antimony, boron, thallium, perchlorate, tritium, uranium, gross alpha, grass beta, radium, and strontium-90.

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Constituents Evaluated during Laboratory Media Tests (Cont.)

- Other constituents that affect media performance for constituent removal: flow rate, suspended solids, suspended sediment, particle size distribution, turbidity, sodium, calcium, magnesium, potassium, conductivity, oxidation-reduction potential, filtered aluminum, and filtered iron.
- Other constituents that help in understanding removal mechanisms of media: COD, UV-254, phosphate, nitrate, *E. coli* bacteria, alkalinity, hardness, and other filtered metals (Cd, Cr, Cu, Pb, Zn).

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Long-Term Column Tests: Flow Rate and Maintenance

- Infiltration rates typically decrease over a device's life due to solids capture on the surface of and in the media.
- Most media typically fail when the total solids loading is about 10 to 25 kg/m^2 of media surface (flow rate < 1 m/d, generally).

Tried potential maintenance options when the flow rate decreased to 5 m/d (effects of disturbing media vs. removing media from filter).

Media removal generally more effective, but must remove at least 4 – 6" because clogging solids are captured deep in the media (deeper than visible solids buildup).

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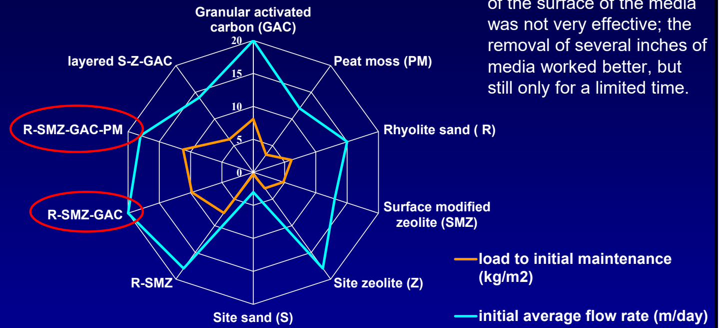
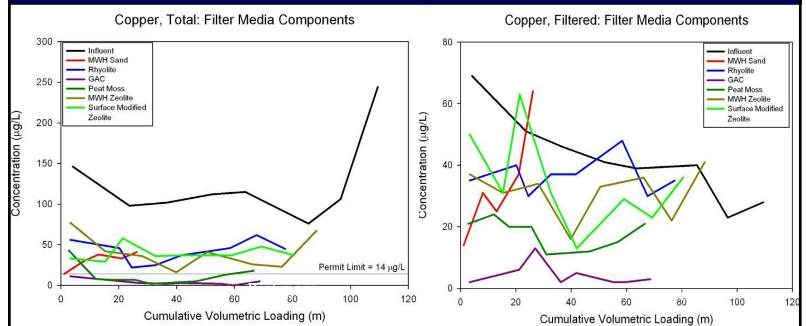
Column test results: Hydraulics and Clogging



Maintenance with scraping of the surface of the media was not very effective; the removal of several inches of media worked better, but still only for a limited time.

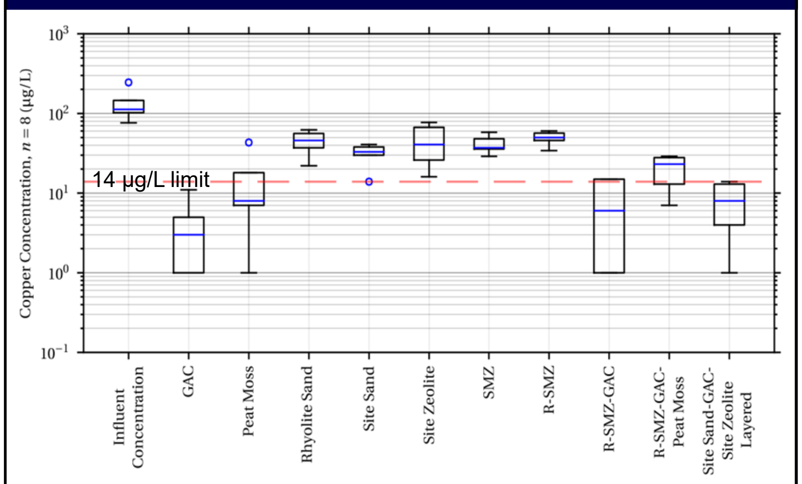
1. Site sand clogged first and had the lowest flow rate
2. Site zeolite and peat alone were next to clog
3. Mixing media and taking advantage of mixed pore spaces performed better than current site layered media combination; better depth filtration

Long-Term Column Test Results: Pollutant Removal



- Of individual media types studied, peat and GAC demonstrated best removal for total and dissolved copper (although note the relatively high influent concentrations)
- Primary copper removal mechanism appears to be physical straining (of particulate-associated phase) and sorption onto GAC along with organic complexation with peat components, rather than cation exchange

Media Performance Plots for Copper, Full-Depth Long-Term Column Tests



Column Test Results: Pollutant Removal

(paired sign test of influent vs. effluent)

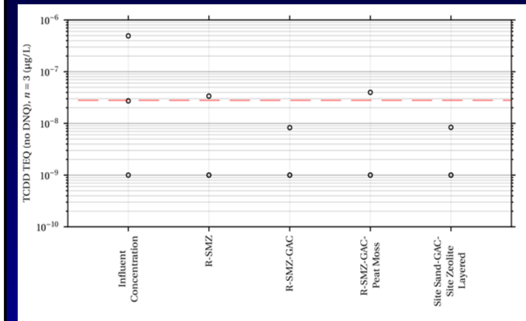
Media Type	Cr, Cu, Sb, Al	Pb	Zn	Cd, Ni, Tl, Fe	Hg	NO_3	TCDD	
R-SMZ-GAC	**T**, F	**T**	T	**T**, F	T	T	**T**	**Recommended biofiltration mixed media combination**
S-Z-GAC (layered)	**T**, F		T	**T**, F	T	T	**T**	**Layered filter media combination currently in use**

R = rhyolite; SMZ = surface modified zeolite; GAC = granular activated carbon; PM = peat moss; S = site sand; Z = site zeolite
T = removal for total form (unfiltered); F = removal for filtered form (passed through 0.45-µm membrane filter)

Other findings (data not shown here):

- Extensive modification of zeolite unneeded; simple ion exchange not primary removal mechanisms even for filtered metals.
- Mixed media combination met all current site permit limits, except Cu & Hg during peak conditions (not expected to occur); significant removals for all constituents measured, except for phosphorus and gross beta radioactivity.
- Current layered media also met current site permit limits, except for slightly elevated pH, when maximum site runoff conditions were considered.

Dioxin Control Observations

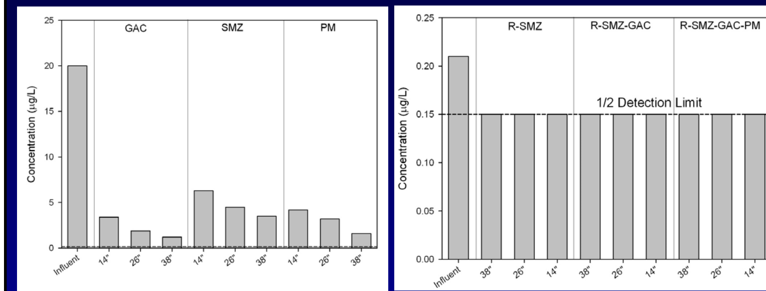


2.8 X 10^{-8} µg/L permit limit

These samples were less than the detection limit

- Dioxin results indicate good control; however, cannot be definitive since few data available (complexities and costs of the analyses limited samples).
- Two of the three effluent observations for each media were below the detection limit. The R-SMZ-GAC and layered media column each had a single detected effluent dioxin value at about 1/3 of the permit limit.
- The detected effluent concentrations were at least an order of magnitude less than the observed influent concentrations for these two media mixtures, showing good removals to close to, or below, the extremely low site permit limit.

Mercury Control Observations



- Best removals seen in deeper columns. Not able to meet permit limits at high influent concentrations.
- Mixed media results showed removal potentially possible at low concentrations but cannot confirm since all samples below detection limit.
- Mercury removal problematic at high flows and high concentrations for all media

Breakthrough Capacity Compared to Clogging Period

Ratios of Media Capacity to Clogging Period	R-SMZ	R-SMZ-GAC	R-SMZ-GAC-PM	Site Sand-GAC-Site Zeolite Layered
Cadmium, Total	>230	>170	>130	>150
Copper, Total	>2.2	>3.4	>1.7	>2.2
Gross Alpha radioactivity	>0.3	>0.3	>0.2	>0.2
Lead, Total	>2.1	>1.6	>0.9	>0.9
Mercury	>250	>230	>130	>140
Oil and Grease	0.1	>0.1	>0.1	<0.1
TCDD	>3.1	>2.5	>1.3	>1.5

Green: will clog before breakthrough
Red: breakthrough before clogging

Cumulative Particulate Loading to Failure and Expected Years of Operation for Largest Sedimentation-Biofiltration Treatment Trains on Project Site

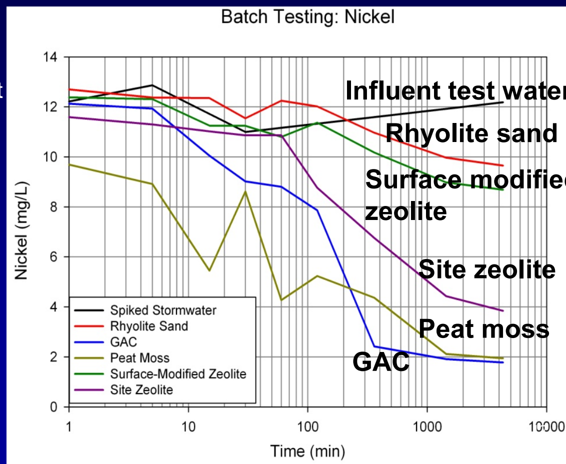
	R-SMZ	R-SMZ-GAC	R-SMZ-GAC-PM	Site Sand-GAC-Site Zeolite Layered
Load to clogging (kg/m^2)	7.5 - 38	11 - 53	11 - 55	6.5 - 33
Years to replacement	12 - 58	16 - 81	17 - 84	10 - 50

- Seven of the site biofilters were evaluated for clogging potential and chemical removal capacity. The biofilters were from about 1 to 10% of the drainage areas in size and had sedimentation pre-treatment.
- All of the media combinations would likely have an operational life of at least 10 years for the constituents of greatest concern, with the exception of oil and grease for the layered media.

Batch Testing Results: Contact Time

Minimal filtered metal removal observed for all media except peat when contact time <10 minutes.

The optimal contact times for filtered metals removal ranged from 10 to 1,000 minutes, depending on the metal and the media type.



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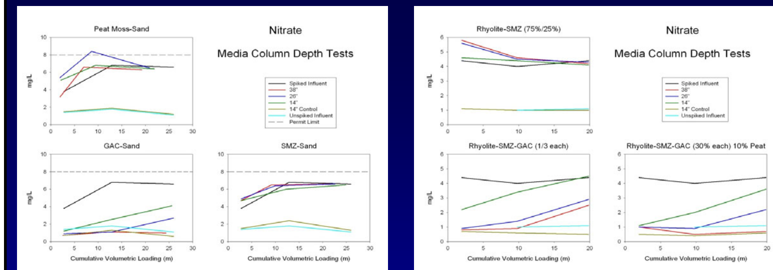
Varying Depth Column Test Results



- These tests determined the effect of contact time on pollutant removal. Longer contact times should enhance pollutant removals because the likelihood of making a favorable contact with the media increases.
- Only the GAC showed good removals of nitrate, with the removal ability being best with the deepest column. GAC therefore has a limited capacity for nitrate and increasing the amount of GAC in contact with the passing influent water increases the length of time that excellent removals occur.

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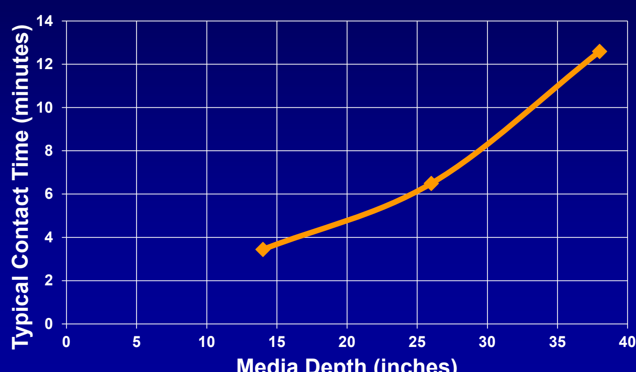
Example Relationship between Media Depth and Contact Time

Rhyolite Sand, Surface Modified Zeolite, and Granular Activated Carbon



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Site Recommendations

- Replace the current layered media mixtures with rhyolite sand-surface modified zeolite-granular activated carbon (and possibly with peat) mixture due to cost savings, less maintenance, and improved effectiveness.
- Recommended contact time of stormwater with the treatment media is 10 to 40 min, corresponding to slow to moderate treatment flow rates of about 5 to 60 m/day (1 to 15 gal/min/ft^2). Outlet control for the flows is likely to be more consistent and reliable than gravity drainage of the media at these flow rates.
- Media thickness should be 2 to 3 ft to provide sufficient contact time with the media and to have sufficient treatment capacity before the system fails due to clogging.

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Preparing Recommended Media for Large Biofilters

1. Filling individual media bags prior to mixing

2. Loading Rhyolite sand media bags into mixer

3. Loading surface modified zeolite media bags into mixer

4. Loading granular activated carbon media bags into mixer

5. Finished mixed media loaded into final bags

6. Mixed media ready for placement into biofilters

Large biofilters being re-built in preparation for new media placement

Conclusions

- Media combinations most robust.
  - Three (R-SMZ-GAC or S-GAC-Z) or four (R-SMZ-GAC-PM) media combinations most robust.
  - This provides redundancy of treatment techniques and addresses the wide variety of pollutants in stormwater runoff and the varying conditions that cause variations in influent quality.
- Mixing media more effective than layering.
  - Minimizes variations in flow rate throughout entire depth of media.
  - Provides similar contact time throughout media depth.
- Well-designed media generally able to meet low permit limits under normal flow conditions, but this requires better removal information than commonly found in guidance documents.