Appendix 4 Bioretention Cell and Bioretention Swale Research: Flow Control and Pollutant Removal Capability

REFERENCE	STUDY SETTING	SUMMARY	FINDINGS	COMMENTS
Davis, A.P., Shokouhian, M., Sharma, H., & Minami, C. (2001 January/February). Laboratory study of biological retention for urban stormwater management. *Water Environment Research, 73,* 5-14.	Laboratory	Two laboratory-scale bioretention boxes were constructed with perforated pipes at 2 different depths to collect effluent. Synthetic stormwater runoff was applied at specific flow rates and durations, and pollutant removal assessed. Soil composition: sandy loam (pH 6.4, CEC 2.9 meq/100 g soil, organic matter content 0.6%) with shredded hardwood bark mulch topcoat. Boxes included creeping juniper plantings.	Pollutant removal: • Copper: 89 to 98%. • Lead and Zinc: > 97 to 98% (lower ports below detectable limits). • Ammonium: -8 to 54% upper ports, 60 to 79% lower ports. • Nitrate: -96% upper port, 24% lower port, (large box only). • Phosphorous: 16 to 73% upper and mid ports, 71 to 81% lower ports.	• High metal removal in upper layers of large and small box. Removal did not increase much with depth. • Significant metal accumulation found in mulch layer samples. • Nutrient removal more variable than metals. Removal increased with depth. • 98 effluent samples taken from upper and lower pipes in the small box and 80 samples from the large box.
Davis, A..P., Shokouhian, M., Sharma, H., Minami, C., & Winogradoff, D. (2003 January/February). Water quality improvement through bioretention: Lead, copper, and zinc removal. *Water Environment Research, 75,* 73-82.	Laboratory and field	Two laboratory-scale bioretention boxes were constructed with perforated pipes at 2 different depths to collect effluent. Synthetic stormwater runoff was applied at varying flow rates, flow durations, metal concentrations, and pH to assess pollutant removal. Soil composition: sandy loam topped with 2.5 cm of mulch. Boxes included creeping juniper plantings. Additionally, synthetic stormwater runoff was applied and effluent measured at 2 field sites with bioretention facilities.	Pollutant removal: Lab • Copper: 87% to 98%. • Lead: 92% to 98%. • Zinc: 85% to 98%. Field Greenbelt facility: • Copper: 97%, lead: 95%, zinc: 95%. Largo facility: • Copper: 43%, lead: 70%, zinc: 64% cadmium: 27%, total phosphorous: 87%, TKN: 67%, nitrate: 15%.	Lab: • Removal for metals was excellent and similar to initial study (see above). • Removal at upper ports was affected slightly by flow rate and duration. • Removal at lower ports was not affected by flow rate and duration. • Removal at upper ports was affected slightly by pH and concentration. • Removal at lower ports was not affected by flow, pH and concentration (soil likely buffering pH changes). Field: • Greenbelt facility showed good agreement with lab analysis. • Largo removal was significantly lower and speculatively attributed to Greenbelt being an older facility with mature groundcover and having a higher fraction of fines in the soil.

REFERENCE	STUDY SETTING	SUMMARY	FINDINGS	COMMENTS
Kim, H., Seagren, E.A., & Davis, A.P. (2003, July/August). Engineered bioretention for removal of nitrate from stormwater runoff. *Water Environment Research, 75*, pp. 355-367.	Laboratory	A laboratory pilot-scale bioretention cell engineered with an anoxic zone at bottom of cell was constructed to assess nitrate removal potential (this phase was part of a larger nitrate removal study). A sand layer mixed with newspaper (electron donor for denitrification process) was placed at bottom of cell and used as a saturated anoxic zone. Synthetic stormwater was applied to the cell and effluent collected after passing through sand layer.	Pollutant removal: • First 2-3 hours no nitrate or nitrite observed in effluent during applications at 7 and 42 days after system inoculation. • After 2-3 hours removal for nitrate and nitrite were 70% to 80% for the 7 to 8-hour stormwater applications.	• No nitrate or nitrate in the effluent for the first 2 to 3 hours likely attributed to the following: The amount of effluent released during that period was water stored in system from previous application; accordingly, that water had a longer period exposed to the anoxic zone favorable to denitrification. • Pilot-scale bioretention cell performance suggests that incorporating an anoxic zone in the bottom of bioretention area can be effective for removing nitrate.
Horner, R., Lim, H., & Burges, S.J. (2002, November). *Hydrologic monitoring of the Seattle Ultra-Urban stormwater management projects* (Water Resources Series Technical Report No. 170). Seattle, WA: University of Washington.	Field	660 feet of residential road was narrowed and linear bioretention/ bioswales were installed within the right-of-way. A v-notch weir installed at the ultimate outfall of the project measured surface flow volumes and timing. Flows for the conventional pre-construction street were compared to the retrofit design.	Pre-construction (March-July 2000): • Rainfall: 7.96 inches. • Runoff: 4979 cubic feet. Post construction (March-July 2001): • Rainfall: 9.00 inches. • Runoff: 132 cubic feet. Oct 20 2003 record storm event: • Rainfall: 4.22 inches (32.5 hour storm duration). • Runoff: none.	• Approximately 97% reduction in surface flow volume was recorded from pre- to post-construction conditions. • Contributing area is approximately 2.3 acres and total impervious area is approximately 35%. Total rooftop contribution reaching the streets, swales and monitoring station is not known.

REFERENCE	STUDY SETTING	SUMMARY	FINDINGS	COMMENTS
Hon G, E., Seagren, E., Davis, A. P. (2002, June). Sustainable Oil and Grease Removal from Stormwater Runoff Hotspots using Bioretention. Paper for the *74th Annual Conference and Exhibition of the Pennsylvania Water Environment Association.* State College, PA.	Laboratory	The research examined the capacity of a mulch layer to capture oil and grease (O&G) via sorption and filtration. Simulated stormwater runoff carrying selected hydrocarbons was applied to a bench-scale "reactor" with a 3-cm thick leaf compost layer. Stormwater was applied at a rate of 4 cm/hr for 6 hours resulting in a naphthalene concentration of 1.7-2.4 mg/L. To distinguish biodegradation and other removal pathways, experiments with and without microbe populations were conducted. Mulch samples were analyzed for contaminants, volatilized hydrocarbons captured, and microbial population counts conducted to correlate with biodegradation rates.	During simulated storm event: • Approximately 90% removal of dissolved naphthalene from aqueous phase via sorption. After storm event (37 and 40 hours): • Abiotic experiment: approximately 32% removal via biodegradation in the mulch layer. • Biotic experiment: approximately 72% removal via biodegradation in the mulch layer. After storm event (74 hours): • Biotic experiment: approximately 95% removal via biodegradation in the mulch layer. Losses due to volatilization were negligible.	• Naphthalene, in dissolved and particulate-associated phases, was selected because of its toxicity and common presence in stormwater. • Research was designed to test bioretention in automotive-intensive hotspots such as gas stations. • The native microbial population in the mulch was capable of biodegradation and inoculation with specific microorganisms to degrade O&G was not necessary. • The change in microbial numbers corresponded to the loss of naphthalene (i.e., microbial numbers were highest when the most naphthalene was degraded).