INTRODUCTION

Stormwater runoff from developed areas contains a number of pollutants including nutrients from lawns and landscaped areas, metals from road surface materials, roofs, brake wear and tire wear, and organic pollutants (Pitt 1995, Davis et al. 2001, Councell et al. 2004, Eriksson et al. 2007). In order to mitigate the potential environmental impacts to receiving water bodies, several stormwater control measures can be used to slow down runoff, store pollutants and provide water quality improvements.

Infiltration and detention based stormwater control measures such as bioswales are increasingly being used to address stormwater pollution. Bioswales are vegetated open channels that treat and convey stormwater. Treatment is achieved via several processes including adsorption to soil particles, filtration by plants, biological assimilation, chemical and biological transformations and volatilization (Walker and Hurl 2002), but sedimentation is the most relevant (Stagge et al. 2012). When sediments deposit in bioswales, particle-associated pollutants such as metals are retained in the soil media and to a lesser extent may be taken up by vegetation (Sun and Davis 2007). Accumulation of metals in bioswales soil media is a cause of concern in the long-term due to potential for toxicity to biota (Davis et al. 2001, 2003), trophic transfer due to plant uptake and consumption by biota, and inhibition of microbial functions relevant to pollutant attenuation processes. These potential effects would likely manifest themselves in the long term, undermining the sustainability of bioswales.

The initial plans for this summer included completing a field-scale investigation to evaluate trace metal distribution in bioswales on the UCSB campus, and using these results to inform future study designs and plans. During the course of the summer, the scope of this project was modified to evaluate the influence of land cover on pollutant accumulation in sediments. Increasing our understanding of how metals accumulate and are distributed in bioswale sediments and how different land use cover in the catchment area contributes to this accumulation can inform bioswale management and help evaluate their long-term sustainability.

Although numerous studies have linked urban non-point pollution sources and differences in watershed land use to stormwater runoff quality (Davis et al. 2001, Heijerick et al. 2002, Van Metre and Mahler 2003, Browne and Peake 2006, Jartun et al. 2008, Lye 2009), studies evaluating the relationship between land cover and stormwater-derived heavy metal accumulation in sediments of bioswales are lacking. One study performed in roadside swales showed that heavy metals accumulated to higher concentrations than background levels, but that there were no significant differences between commercial and agricultural swales, except for copper, lead and zinc (Liebens 2001). Overall, there is a paucity of studies examining metal accumulation in bioswales in relation to watershed use.

The goal of this study is to evaluate the extent of heavy metal accumulation in bioswales that have been operational for over a decade, in a semi-developed area with Mediterranean type climate. Further, I will assess how differences in pervious and impervious land cover relate to heavy metal content in sediments. Future work will involve determining the potential impact on normal biogeochemical function of bioswales, by assessing microbial communities responsible for nitrogen cycling.
Specifically, this study is guided by the following questions:

(i) What is the evidence for heavy metal accumulation in stormwater bioswale sediments at the rooting zone depth after more than a decade of operation?

(ii) To what extent are differences in pervious or impervious land cover in areas draining to stormwater bioswales linked to differences in heavy metal and nutrient accumulation in the bioswale sediments?

(iii) To what extent does travel along the transect joining the inlet and outlet of the bioswale system attenuate nutrient and pollutant concentrations?

(iv) How do differences in vegetation establishment affect sediment deposition and heavy metal accumulation in bioswales?

(v) What is the relative bioavailability of metals that are deposited in bioswale sediments?

(vi) How are heavy metal and nutrient concentrations in bioswale sediments linked to total microbial biomass?

BACKGROUND DATA AND SITE SELECTION

To establish reference values for trace metal and nutrient levels in stormwater runoff, urban creeks and urban sediments, I performed a literature review and compiled results from existing studies on wetlands and bioswales, drawing from work performed by the Cheadle Center for Biodiversity and Ecological Restoration (CCBER) on the UCSB campus, the long term ecological research (LTER) program in coastal Santa Barbara and stormwater runoff data from low impact development projects overseen by the Santa Barbara Creeks Division.

Different bioswales on campus were visited and the Manzanita Village residential housing complex was selected as a study site. This site provides an ideal setting to explore land cover influence on metal accumulation in sediments in residential areas because it has a suitable gradient of land surfaces with varying degrees of imperviousness.

MANZANITA VILLAGE SITE DESCRIPTION

The restoration projects in Manzanita village, which resulted in the creation of several stormwater management features, were constructed in 2001-2002. The total project area comprises 12 acres, of which approximately 75% flows into at least one stormwater control feature, including four upper bioswales, a large infiltration marsh and a main bioswale that discharges into a coastal lagoon (Figure 1).

The soils are covered by shrubs or low input lawn that is irrigated with reclaimed water. No fertilizers are added to the vegetated soils, but occasionally glyphosate-based herbicides are applied for weed control. There vehicular traffic, is mostly limited to electric powered vehicles that circulate on service roads. The pitched roofs consist of single ply membrane roofing. Ocean aerosols rich in phosphate may deposit on the roofs, which also receive droppings from seagulls and pigeons that use them as a perching area (CCBER 2015).

The upper bioswales consist of a series of shallow basins separated by rock check dams with an average 2% slope and total lengths ranging 200-400 ft. The basins are 15-20 ft long and 8 ft wide; they have a trapezoidal cross section with a basin bed of 4 ft and a side slope ratio of 1:1. When full, the basins have a depth of approximately 6 inches. The main bioswale has similar characteristics as described above, but
it has an average slope of 6.5%. The bioswales are planted with native sedges and rushes that are well suited to the high clay subsoil. The bioswales are lined with coconut netting and straw wattles to limit erosion losses (CCBER 2015).

**Fig. 1:** Locations of stormwater control features on Manzanita Village (*Manzanita Village Storm Water and Urban Runoff Biofiltration System PowerPoint presentation by Lisa Stratton, CCBER*)

**SUBWATERSHEDS STUDY**

To determine differences in land cover for the subwatersheds draining to individual bioswales, an existing subwatershed map provided by CCBER was analyzed (Figure 2) to delineate different land cover areas using ArcMap 10.1. The following surfaces were distinguished: paved areas, rooftops, lawns, shrubs (natural vegetation) and gravel. Once the surfaces were marked, their areas were calculated. The total drainage area was obtained by summing the different land surface areas. The individual contribution from each type of land surface is expressed as a percent of this total area (Table 1).
The differences in pervious and impervious land cover amongst the bioswales allow for analyzing differences in sediment deposits, with bioswale 1 being having a mostly pervious watershed and bioswale 3 receiving runoff mostly from impervious surfaces. Bioswales 2 and 4 have a relatively even split between impervious and pervious land cover in their sub-watershed. The main bioswale is slightly different from the rest, because it has a much larger catchment area and also has a steeper slope, so that residence times are shorter and less treatment capability is expected. As such, it is excluded from the analysis.

Figure 2: Watershed and sub-watershed map for Manzanita Village (Manzanita Village Storm Water and Urban Runoff Biofiltration System PowerPoint presentation by Lisa Stratton, CCBER).
### Table 1: Drainage area for each bioswale, with detail regarding the percent pervious and impervious cover, and types of surfaces that contribute runoff.

<table>
<thead>
<tr>
<th>Bioswale ID</th>
<th>Drainage Area (m²)</th>
<th>% Impervious</th>
<th>% Roofs (impervious)</th>
<th>% Paved (impervious)</th>
<th>% Lawns (pervious)</th>
<th>% shrubs or gravel (pervious)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (Rattlesnake)</td>
<td>6356</td>
<td>31</td>
<td>17</td>
<td>14</td>
<td>25</td>
<td>44</td>
</tr>
<tr>
<td>2 (San Jose)</td>
<td>5348</td>
<td>55</td>
<td>23</td>
<td>32</td>
<td>38</td>
<td>7</td>
</tr>
<tr>
<td>3 (Cold Springs)</td>
<td>3120</td>
<td>77</td>
<td>34</td>
<td>43</td>
<td>23</td>
<td>0</td>
</tr>
<tr>
<td>4 (Sycamore)</td>
<td>2295</td>
<td>59</td>
<td>15</td>
<td>44</td>
<td>21</td>
<td>19</td>
</tr>
<tr>
<td>Main</td>
<td>27,720</td>
<td>48</td>
<td>26</td>
<td>22</td>
<td>32</td>
<td>20</td>
</tr>
</tbody>
</table>

**SAMPLING LOGISTICS**

For planning and logistic purposes I performed several site visits to estimate the sampling time contingent on the number of samples to be taken. Different coring devices were tried out in the field to determine the most suitable given the soil characteristics. Soil from four bioswales was sampled and sieved in the lab (4mm) to determine the initial sample mass required to obtain sufficient sieved soil for the planned analyses. A brief outline of the study design, still in development process, is presented.

**STUDY DESIGN**

*Number of bioswales*

Samples will be collected from bioswales 1, 2, 3 and 4, as identified in Table 2.

*Number of samples per bioswale*

To assess potential metal accumulation as runoff flows through each bioswale, six sediment samples will be collected at the inlet and outlet of the bioswales, following the direction of flow. Three of these samples will correspond to the basin bed, and three to the upper bank of the bioswale. This will allow assessing differences in sedimentation as the runoff flows through the bioswale as well as differences due to vegetation presence in the upper bank and basin bed. In bioswales with multiple roof downspouts an additional set of six samples will be collected at the midpoint of the bioswale. This results in a total of 72 samples, 18 for each bioswale.

*Negative Control*

A sample will be collected from a location not influenced by runoff from the residential area, which will capture natural metal levels in the background, as a result of parent rock material and atmospheric deposition.
Analysis to be performed

The following soil analyses will be performed, using the methods and storage conditions indicated in Table 3.

- Soil characteristics that may influence metal bioavailability and/or are relevant to microbial growth: soil moisture (gravimetric), organic matter (by loss on ignition), total organic carbon (TOC) and dissolved organic carbon (DOC), cation exchange capacity, pH, and temperature.
- Substrate induced respiration (SIR) and DNA extraction, to determine microbial biomass.
- Soil nutrient analysis: including total nitrogen and nitrogenous compounds such as ammonium and nitrate, total phosphorus and phosphate to assess nutrient loads to the bioswale.
- Total and dissolved metals (appropriate extraction procedures) by inductively coupled plasma-atomic emission spectroscopy (ICP-AES) to determine 1) total metals accumulated over time and 2) the fraction which may be bioavailable and cause toxicity (metals in dissolved form).

<table>
<thead>
<tr>
<th>Assay</th>
<th>Method</th>
<th>Immediate Y/N</th>
<th>Storage/handling conditions</th>
<th>Required sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>Gravimetric (standard soil methods)</td>
<td>Y</td>
<td>Sieve 2mm and homogenize.</td>
<td>1.5 g (x3)</td>
</tr>
<tr>
<td>Organic matter</td>
<td>Loss on ignition (standard soil methods)</td>
<td>Y</td>
<td>Sieve 2mm and homogenize. Dry prior to determination.</td>
<td>3.0 g (x3)</td>
</tr>
<tr>
<td>pH</td>
<td>Soil/water slurry (standard soil methods)</td>
<td>Y</td>
<td>Sieve 2mm and homogenize.</td>
<td>10.0 g</td>
</tr>
<tr>
<td>Trace metals (bioavailable)</td>
<td>Eluate extraction ICP-AES (EPA 6020)</td>
<td>N (1 month)</td>
<td>Sieve 2mm and homogenize. Store at -20°C. Thaw prior to extraction.</td>
<td>15.0 g</td>
</tr>
<tr>
<td>Metals (total)</td>
<td>Thermally-assisted acid digestion with aqua regia</td>
<td>N (1 month)</td>
<td>Sieve 2mm and homogenize. Store at -20°C. Thaw prior to extraction.</td>
<td>10.0 g</td>
</tr>
<tr>
<td>Substrate induced respiration</td>
<td>CO2 respiration over time, following Holden Lab procedures</td>
<td>Y</td>
<td>Sieve 2mm and homogenize. Dispense in amber, stoppered Mininert bottles.</td>
<td>10.0 g</td>
</tr>
<tr>
<td>DNA extraction (microbial biomass)</td>
<td>Extraction using MoBio Power soil kit</td>
<td>N (1 month)</td>
<td>Sieve 2mm and homogenize. Store 2g in empty bead tube at -20°C. Thaw prior to extraction.</td>
<td>5 g</td>
</tr>
<tr>
<td>Sediment characterization (includes nutrient analysis)</td>
<td>Performed by UC Davis Analytical Lab</td>
<td>N</td>
<td>Sieve 2mm and homogenize. Store at 4°C. Send within 24 hr</td>
<td>500 g</td>
</tr>
</tbody>
</table>

Table 3: Summary of soil analysis methods and storage conditions
**Required sampling volume**

Based on analysis, roughly 60 grams of sieved soil are required for all samples, plus an additional 500 g per sample that will be used to characterize the soils in the bioswales. In order to keep sampling times down and to reduce expense, soil characterization for each bioswale will include 3 composite samples per bioswale at the inlet, mid-point and outlet.

Based on previous analysis, and because the soil below the bioswales has dense rooting systems (rhizomatous vegetation), the mass of unsieved soil should approximately double the final mass of required soil.

A plastic corer 1.75 inch in diameter will be used to obtain samples to a depth of 10 cm, representing the active rooting zone depth. The soil will be sieved through a 2mm mesh and homogenized in the lab, prior to dispensing into appropriate containers. Based on previous work, the approximate soil mass from this corer is 162 grams, prior to sieving. This requires 1 core per sample. To obtain the additional 500 grams for soil characterization, 2 more cores are needed per sample (1 core when sample does not include soil characterization, and 3 cores when sample includes this characterization).

**FUTURE WORK**

Future work will involve finalizing the study design and sampling bioswales on campus to determine if metals are accumulating at levels of concern. Based on the results of this study, future work might include determining the potential impact on normal biogeochemical function of bioswales, by assessing microbial communities responsible for nitrogen cycling.

**ACKNOWLEDGEMENTS**

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