Heavy Metal Contamination of Soils in an Ecologically Enhanced Urban Stormwater Retention Basin

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1. Introduction

Pollutants in stormwater runoff, including heavy metals, can dramatically affect the quality of receiving water bodies, connected ecosystems, and groundwater.

Constructed wetlands have become a popular tool for the removal of contaminants from stormwater, providing benefits such as wildlife habitat and plant species diversity in addition to water storage and flood prevention.

Vegetation in constructed wetland systems is able to adsorb and amass metals, accumulating high metal concentrations in the soil as plants die and are not completely decomposed. Whether from natural or anthropogenic sources, high heavy metal concentrations in soils pose a hazard to humans, wildlife, aquatic organisms and the environment.

There are currently no direct regulatory requirements or guidelines to assess whether stormwater basin soils are contaminated with heavy metals.

2. Objectives

i. Determine the present level of heavy metal contamination in the soils of a wetlands-enhanced stormwater retention basin
ii. Map the spatial distribution of Cd, Cr, Cu, Pb, Ni and Zn in the basin
iii. Compare current heavy metal concentrations in the basin to the year 2000 (Lander, 2003)

3. Site Description

- 1.2 ha enhanced retention basin in a 16 ha watershed on the University of Florida (UF) Campus (Figure 1a)
- Constructed in 1988 as a typical wet retention basin and redesigned beginning in 1995 to incorporate a wetlands component and multiple treatment cells (Figure 1b)
- Majority of the basin consists of a shallow organic horizon underlain by clay deposits

4. Methods

Sampling Design

- Sample locations assigned randomly within cell 1 (25 sites) and cell 2 (15 sites) (Figure 1c)
- Samples collected with stainless steel equipment and acrylic tubing (Figure 1c)
- 0-5 cm and 5-10 cm depths (however, O and C horizons were kept separate)

Analytical Methods

- Soil samples tested for Cd, Cr, Cu, Ni, Pb and Zn
- Digestion – EPA 3050B
- Analysis – AAS (atomic absorption spectrometry)

Spatial Analysis Methods

- Spatial Analyst in ArcMap 9.1
- Cell 1 and cell 2 interpolated independently using ordinary kriging

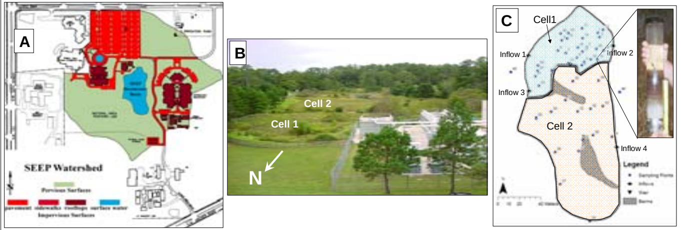

Figure 1. The Storm Water Ecological Enhancement Project (SEEP) at the University of Florida, Gainesville, FL. The SEEP is located within a small urban watershed (a). It is comprised of two cells, with Cell 1 being the primary holding cell where a majority of treatment is designed to take place (b). The resultant landscape (c) is more diverse than a typical stormwater retention area.

5. Results

Metal concentrations in the upper 5 cm of the O horizon are given in Table 1 and interpolated values for the basin are depicted in Figures 2 and 3. In certain circumstances where the O horizon did not extend to 5 cm, the entire O horizon was used.

Comparisons to Reference Values

All metals were detected above Florida baseline concentrations[1] in both cells, with the exception of Cr. For the most part, cell 1 samples were higher than Florida baseline concentrations more often than samples in cell 2, especially Cd, Cu, and Pb. Because the soils in the SEEP were higher than the maximum range for natural Florida soils, they were affected by anthropogenic inputs.

The majority of sites exceeded SQAG TECs[2] for most metals in cell 1, as well as many sites in cell 2. A few metals had concentrations exceeding SQAG PECs in both cells, most notably Cu and Ni. The only metal to exceed residential SCTLs[3] was Cu. No sites exceeded commercial SCTLs.

Spatial Distribution of Heavy Metals

Spatial distributions of the six heavy metals in the upper 5 cm of the O horizon are shown in Fig. 2. In general, the highest levels of heavy metals were located in cell 1 (the forebay). Only Cr had low levels in cell 1, near inflow 1. Large areas with low levels of Cd, Cu, Pb, Ni, and Zn were located in cell 2. Most metals were highest near inflows and in cell 1, where the majority of the stormwater enters and is detained. The center of cell 1 as well as cell 2 had lower metal concentrations for many metals.

Inflows 2 and 3 supply Cd, Cr, Zn, Pb and Ni. Inflow 1 supplies Ni, Pb and Cu.

Soil metal Concentrations in 2007 versus 2000

Using interpolated values, Cd, Cu, Pb and Ni increased between 2000 and 2007 in the 0-5 cm and 5-10 cm zones. Chromium decreased in concentration. Copper had the largest increase. Some variation may be due to differing sampling points and a larger sample set in 2007 (35 sites) compared to 2000 (20 sites).

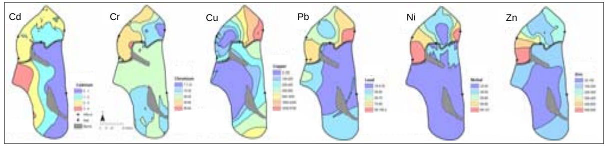

Figure 2. Spatial distribution levels of the six heavy metals studied in the SEEP. Only the 0-5 cm depths were used. All units are mg/kg.

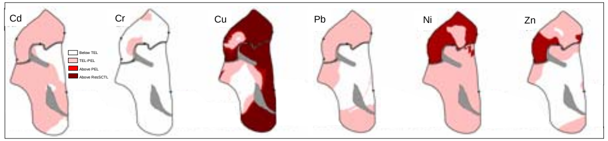

Figure 3. SQAG TELs[4], SQAG PELs[4], and SCTLs[3] in the SEEP are spatially shown.

Table 1. Comparison of SEEP soil metal concentrations in the upper 5 cm of the O horizon to guideline concentrations.

<table>
<tr><th colspan="3"></th><th colspan="3">Percentage of Sites Exceeding Reference Values (Cell 1 | Cell 2)</th></tr>
<tr><th>Metal</th><th>Cell 1 range (mg/kg)</th><th>Cell 2 range (mg/kg)</th><th>Florida baseline range[1] (mg/kg)</th><th>Freshwater SQAGs: TEC/PEC[2] (mg/kg)</th><th>SCTLs: Residential/ Commercial[3] (mg/kg)</th></tr>
<tr><td>Cd</td><td>0.0-5.4</td><td>0.0-3.7</td><td>0.0-0.33
96% | 66.7%</td><td>0.99/4.98
76%/ 4 % | 53.3%/ 0%</td><td>82/1,700
0%/ 0 % | 0%/ 0 %</td></tr>
<tr><td>Cr</td><td>6.2-64.5</td><td>21.6-59.1</td><td>0.89-80.7
0% | 0%</td><td>43.4/111
36%/ 0% | 13.3%/ 0%</td><td>210/470
0%/ 0 % | 0%/ 0 %</td></tr>
<tr><td>Cu</td><td>26.3-7118</td><td>5.0-1125</td><td>0.22-21.9
100% | 73.3%</td><td>31.6/149
96%/76% | 66.7%/ 40%</td><td>150/89,000
72%/ 0% | 40%/ 0%</td></tr>
<tr><td>Pb</td><td>7.4-132</td><td>6.0-88.8</td><td>0.69-42.0
72% | 6.7%</td><td>35.8/128
80%/8% | 13.3%/ 0%</td><td>400/1,400
0%/ 0 % | 0%/ 0%</td></tr>
<tr><td>Ni</td><td>19.4-161</td><td>19.6-81.9</td><td>1.70-48.5
32% | 26.7%</td><td>22.7/48.6
96%/ 32% | 86.7%/ 26.7%</td><td>340/35,000
0%/ 0 % | 0%/ 0%</td></tr>
<tr><td>Zn</td><td>88.4-809</td><td>13.1-236</td><td>0.89-29.6
100% | 86.7%</td><td>121/459
88%/ 12% | 26.7%/ 0%</td><td>26,000/630,000
0%/ 0% | 0%/ 0%</td></tr>
</table>

1 Chen et al. (1999). Baseline concentrations for surface soils in Florida.

2 MacDonald et al. (2000). Soil Quality Assessment Guidelines (SQAGs) developed for freshwater sediments in Florida specify Threshold and Probable Effect Concentrations for aquatic organisms. Below the Threshold Effect Concentration (TEC), adverse biological effects on sediment-dwelling organisms are rarely observed. Above the Probable Effect Concentration (PEC), adverse biological effects on sediment-dwelling organisms are frequently observed.

3 Direct exposure Soil Cleanup Target Levels (SCTLs) identified in Florida Administrative Code (F.A.C.) 62-777 to protect humans at both residential and commercial levels who may contact contaminated soil via ingestion, inhalation of dust, and direct contact. Developed for application to sites pursuant to certain chapters of the F.A.C. (i.e. Brownfields, hazardous waste sites).

4 Threshold Effect Levels (TELs) and Probable Effect Levels (PELs) developed for coastal sediments in Florida. These levels are similar to TECs and PECs.

6. Discussion

The SEEP was effective at preventing the migration of most metals; Cr, Cu, Ni, Pb, Zn, had their largest concentrations contained in cell 1 (the forebay). The berms in cell 2 also seemed to provide an effective barrier to the migration of a number of metals, most notably Cd and Cu. Soil metal concentrations decreased rapidly with depth. Most metals were highest near inflows and in cell 1. The center of cell 1 as well as cell 2 had lower metal concentrations for many metals.

By design, the majority of stormwater enters from the western portion of cell 1, where it is impounded by the berms and weir separating it from cell 2. Water enters cell 2 after most particulates have settled out of solution. This aided in the containment of some metals to cell 1. Soil metal concentrations exceeded Florida baseline concentrations and toxicity comparison values for a number of metals, but for the most part did not exceed SQAG PECs[2] or SCTLs[3] (with the exception of Cu).

Strong spatial patterns were present and discernable at the sampling density selected for the project.

Compared to 2000, the metal concentrations in 2007 were increased in the 0-5 cm and 5-10 cm zones for all but Cr. Naturally, an increase in soil metal concentrations is expected if the system is functioning properly. 000

7. Conclusions

Overall, stormwater managers should be aware that high levels of heavy metals may accumulate in stormwater basin soils over time. The effects of these metals on humans, wildlife and the environment should be considered in the design and management of stormwater basins, especially those with ecologically enhanced designs that serve multiple purposes.

Although monitoring of basin soil quality is not required at the current time, stormwater managers should be aware of the benefits and risks involved in trapping contaminants from stormwater and storing them in the soil.

8. Literature Cited

Chen, M., L. Ma, and W. Harris. 1999. Baseline concentrations of 15 trace elements in Florida surface soils. Journal of Environmental Quality 28:1173-1181.

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Lander, M. 2003. Evaluation of selected heavy metal concentrations in soils of an urban stormwater retention basin. M.S. thesis. University of Florida, Gainesville, FL.

MacDonald, D.D., C.G. Ingersoll, and T.A. Berger. 2000. Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems. Archives of Environmental Contamination and Toxicology 39:20-31.