Introduction

Shallow groundwater is vulnerable to contamination from varied pollution sources due to its close proximity to urban surfaces and built water infrastructure (Lerner, 2002; Schirmer et al., 2013). During dry weather, shallow groundwater may receive pollutant inputs from sanitary sewer exfiltration (Wolf et al., 2006; Wolf et al., 2013) and irrigation with reclaimed water. In wet weather, stormwater infiltration may introduce contaminants into groundwater if these do not attenuate in the soil subsurface. Shallow groundwater may also be an important water resource in the future, in particular in urban areas facing water stress, such as Southern California. As such, it is important to understand the extent and potential for shallow groundwater contamination from different pollution sources.

Previous work I have performed in the Holden lab has been mostly related to dry weather infiltration, focusing on leaking sewers and reclaimed water irrigation and their potential to contaminate shallow groundwater. However, my current dissertation emphasis is on wet weather infiltration, i.e. stormwater infiltration, and in particular on low impact development (LID) approaches to stormwater management.

Stormwater runoff frequently causes water quality impairment in aquatic ecosystems, and is one of the leading causes for surface waters not attaining their designated uses (NRC, 2009). LID has emerged as an economic and flexible approach to address stormwater pollution. Its principles are rooted in the promotion of on-site capture and treatment of stormwater and minimization of the changes with respect to the pre-development hydrology. This approach leads to mitigation of peak flows and impacts from polluted runoff (Dietz et al., 2007). Treatment is provided as stormwater infiltrates and travels through the soil subsurface; pollutants are eliminated via filtering, adsorption onto soil particles, biological transformations and biological uptake. Although LID systems can effectively reduce nutrient loads, sediments and other pollutants, open questions remain regarding their long-term performance and potential to contaminate shallow groundwater.

My goals for the summer where to develop a working knowledge on low impact development systems by reading and synthesizing across LID literature, and focusing on open questions regarding LID performance and management. This work led to the development of a study plan to evaluate LID systems at the UC Santa Barbara campus. Additionally, I collaborated on several Holden Lab projects gaining valuable field and lab experience in support of my own research. These collaborations included work performed for the Source Identification Protocol Project (SIPP) project and the Urban Water Environment project (UWE).
Progress

1) Wet weather infiltration – stormwater and low impact development (LID)

During the summer I reviewed a draft proposal for a larger LID UC collaborative research regarding biofilter systems, and provided input to my advisor. This project aims to address the biophysical and social barriers that limit use of natural treatment systems such as biofilters to capture, treat and reuse urban stormwater runoff in Southern California.

I also completed a literature research on different LID systems including permeable pavement, bioretention, wetlands, and bioswales (vegetated open channels). This research revealed that one question that remains to be answered regarding wetlands and bioswales is how sustainable these systems are, primarily if long-term performance may be hampered by pollutant buildup in sediments, inhibiting sensitive microbes performing important biogeochemical processes. This has implications both for urban runoff and shallow groundwater quality.

Since microbes in the sediments of wetlands and bioswales play an essential role in pollutant removal and nutrient cycling in wetland environments, it is important to understand how the pollutants that are sequestered in these systems might affect them. Studies relating microbial community diversity and function, environmental factors and nutrients in stormwater wetlands will be helpful to assess wetland biological integrity, and inform better design and management.

During the summer and fall I developed a study plan to assess sediment conditions in LID systems on campus, focusing on wetlands and bioswales. I plan to perform a field-scale investigation on the effects of stormwater pollutants on sediment microbial communities via baseline sediment sampling and two sampling campaigns; one at the end of the wet season and one at the end of the dry season. Specifically, I have chosen to focus on ammonia oxidizers, which catalyze the oxidation of ammonia to nitrate and are pivotal to nitrogen cycling. These microorganisms are sensitive to environmental conditions and are slow-growers, which makes them susceptible to inhibition. They are also typically more sensitive to environmental stressors than other microorganisms, and may therefore be used as indicators of wetland biological integrity (Sims et al., 2013).

Sediment sampling will occur on three Cheadle Center for Biodiversity and Ecological Restoration (CCBER) management areas on campus. Final selection of the LID systems will be based on analysis of the design plans and site visits to record any relevant physical features. At each location, three sampling points will be chosen along the transect joining the inlet and outlet of the LID system. At each sampling point, three samples will be collected to ensure sufficient replication. Each sample will be composited from ten individual 10-cm cores, which will be obtained using a piston-corer constructed from a sterile 60-mL polypropylene syringe. Samples will be chilled in the field and processed in the lab within 6 hours. The samples will be homogenized by removing visible litter and sieving through a 2 mm screen. Sub-samples for soil moisture analysis, nitrification potential assay, determination of microbial biomass via substrate-induced respiration, and sediment characterization will be obtained. The remaining sample will be stored at -80°C until further microbial community analysis.
This research is part of a proposal that was submitted to the Coastal Fund for funding, and was performed in consultation with CCBER. Expected benefits include new insights into the microbial communities that catalyze nitrogen transformations in sediments of LID systems, in particular regarding potential impairment due to accumulation of pollutants that these systems are intended to sequester. This information can inform future design and management of LID projects, by helping to answer questions regarding how long the stormwater management system can be used without maintenance, what the expected nutrient removal is over the long term, and how this function can be sustained. This would ultimately support LID implementation at UCSB and beyond.

2) Pathogen Culturing – Source Identification Protocol Project (SIPP)

The SIPP project involves the discovery and testing of new methods to detect fecal contamination in California beaches. The work I contributed to involved a sewage aging study performed on a coastal lagoon to determine how DNA-based fecal markers change under ambient conditions, and how this knowledge might be used to improve microbial source tracking and aid in management decisions regarding remediation of contaminated surface waters and determination of potential health risks to swimmers.

My collaboration to this project included culturing of two sewage-associated pathogens: *Campylobacter* and *Salmonella* spp. This work involved enriching and then isolating the target microorganisms through several sequential steps using selective media and appropriate growth conditions. Confirmation tests were performed and colony growth was visually inspected for positive or negative identification. Presumptive isolates were picked for molecular confirmation.

This work provided me with valuable experience in culture-based techniques, which will be useful for evaluation of pathogens in LID systems for my own research.

3) Dry weather infiltration – Urban Water Environment Project (UWE)

The goal of the UWE research is to evaluate the potential for shallow groundwater contamination from sanitary sewer exfiltration, reclaimed water irrigation and stormwater. The study area is downtown Santa Barbara. Sewage exfiltration has been confirmed in our study area as shown by previous studies in the Holden Lab group regarding contamination of stormwater drains and surface waters due to leaking sewers (Sercu et al., 2009; Sercu et al., 2011). The research in which I collaborated in the summer is guided by the following questions: How do emerging contaminant and bacterial concentrations in sewage and reclaimed water compare with those in shallow groundwater? Do the data suggest contamination from leaking sewers and/or irrigation with reclaimed water?

**Previous Work**

In August 2013, as part of a pilot study, we sampled shallow groundwater from five existing monitoring wells in Santa Barbara (Figure 1) and compared water quality in these wells to deep groundwater (negative control) and to untreated sewage and reclaimed water (positive controls). A broad list of contaminants including pharmaceuticals and personal care products, volatile organic
compounds, trace metals and pathogens were analyzed. We developed a Geographic Information Systems (GIS) model based on Santa Barbara sewer infrastructure attributes to predict the locations where sewage and groundwater interactions are more likely to occur. Locations in our pilot study comprised low to medium exfiltration probability scores. Results indicated that groundwater in the sampled wells was impacted by less than 1% sewage equivalent concentrations and that the GIS-based model shows promise as a tool to identify locations where sewer exfiltration followed by groundwater contamination is likely to occur (Gyun Lee et al., 2014, in review).

![Figure 1](image-url)  

**Figure 1:** Sampling locations for pilot study (monitoring wells and positive and negative controls). The map is shaded according to the probability of exfiltration score: red represents high probability, followed by orange, yellow, green and blue. Image kindly provided by Patrick Roerhdanz.

Based on the results from the pilot study, a targeted list of analytes was selected by taking into account three criteria: their detection in the positive controls, conservative behavior, and ability to differentiate between groundwater, untreated sewage and reclaimed water samples. These analytes include priority organics that are suitable sewage or reclaimed water indicators; volatile organic compounds (VOCs) associated with industrial pollution; microbial pollutants linked to fecal contamination; trace metals; and nutrients. Our analysis thus provides a comprehensive picture of the extent of shallow groundwater contamination in downtown Santa Barbara (Gyun Lee et al., 2014, in review).

**Dry weather sampling and GIS-model validation**

In order to further test the GIS-based model of exfiltration and evaluate the extent of groundwater contamination due to leaking sewer lines in downtown Santa Barbara, we developed a study plan which involved analysis of the targeted analytes identified during the pilot study, over a broader spatial area. Our study included the five wells originally sampled for the pilot study, installation
of new wells and sampling of groundwater monitoring wells included in the GeoTracker database. GeoTracker is an online database system accessible via the State Water Resources Control Board, which tracks regulatory data for diverse cleanup sites, including leaking underground fuel tanks (LUFT) sites and permitted underground storage tank (UST) facilities.

I contributed to the selection of GeoTracker wells by screening all available monitoring data from 2006 to present date and choosing the wells that were screened at shallow groundwater depth and showed little evidence of contamination or were fully remediated. High industrial contamination, in particular from volatile organic compounds, may mask detection of trace organics, and interfere with our analysis. The GeoTracker wells covered a range of low to medium sewer exfiltration probability. The proposed drilling locations were mostly located in areas presumed to be “hot spots” for sewer exfiltration. Our sampling locations accordingly include a gradient of high to low sewer exfiltration probabilities.

Six shallow groundwater wells were installed during the fall, using an outside contractor. Installation was performed using a Geoprobe®, which allowed retrieval of intact soil cores. I participated in the processing of soil cores in the lab by sectioning the cores and homogenizing by sieving through a 2 mm screen, or manually homogenizing when sieving was not possible. I also determined microbial biomass via substrate-induced respiration.

During the fall, six of the selected GeoTracker wells, and the five wells included in the pilot study were sampled. In the lab, I collaborated with sample processing by filtering groundwater for PPCP analysis, performing DNA extraction and analysis of fecal indicator bacteria.

We only have preliminary results from the groundwater wells that were sampled during the fall, which cannot be used on their own to infer the extent of contamination due to sewer exfiltration or other sources. As such, they are not presented in this report.

The field and lab experience obtained through this collaboration will be helpful when I perform my own field-scale investigation of LID systems on campus.

Acknowledgements

I am thankful for the generous support provided by the Earth Research Institute at UC Santa Barbara through the Summer Fellowship, which helped me to complete this research. The work described in this report regarding the extent of sewage exfiltration and likelihood for shallow groundwater contamination is a collaborative effort of the Urban Water Environment team in the Holden Lab, comprised of Do Gyun Lee, Patrick Roehrdanz and myself. We also receive guidance and support from other members in the Holden Lab and outside collaborators. Additionally, I would like to thank Lisa Stratton and Jodi Woods for providing information on low impact development projects on campus. Finally, I thank my advisor Patricia Holden for her guidance and financial support.
References


