Title

Natural Treatment Systems for Stormwater Cleanup in Southern California: A biofilter coastal case study

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Natural Treatment Systems for Stormwater Cleanup in Southern California:
A biofilter coastal case study

A thesis submitted in partial satisfaction of the requirements
for the degree Master of Science

in

Engineering Sciences (Applied Ocean Science)

by

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The Thesis of Kathleen Elaine Galloway is approved, and is acceptable in quality and form for publication on microfilm and electronically:

Chair

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List of Abbreviations

BEF	Biodiversity-Ecosystem Function
BMP	Best Management Practice
LID	Low Impact Development
N	Nitrogen
ND	No Data
P	Phosphorus
SIO	Scripps Institution of Oceanography
TN	Total Nitrogen
TP	Total Phosphorus
UCSD	University of California, San Diego

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Abstract of the Thesis

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by

Kathleen Elaine Galloway

Master of Science in Engineering Sciences (Applied Ocean Science)

University of California, San Diego, 2016

Professor Lisa A. Levin, Chair

Biofiltration systems use a variety of biological, chemical, and physical processes to capture and improve the water quality of stormwater runoff. Biofilters are frequently specified for design in construction projects in southern California, but are rarely monitored for long-term success. Typically, the engineering design criteria are focused on the hydrologic aspects, soil type, and vegetation, but rarely consider the benefits of ecological services or the presence of fauna. By improving our understanding of biofilters, we can introduce a scientific component to an engineered design that does not typically consider the benefits of a man-made ecosystem. Four biofilters constructed in 2010 at the Scripps Institution of Oceanography were selected as a model to examine existing biofilter function based on biofilter pollutant removal capabilities and ecosystem structure. Historic and current analysis of the biofilters show that concentrations of total copper, total zinc, and total suspended solids were reduced by the biofilter, though the percent pollutant removed has decreased over time. Nutrient and bacteria removal is more complicated, with input rather than removal during some periods; improvements could be made to optimize this. Recommendations to improve the sustainability and longevity of biofilters based on the data and literature include a) the incorporation of a saturated zone, b) the use of rain barrels, c) outreach and education, and d) further local experimentation on the relationship between biofilter flora and fauna.

Section 1: Introduction

As San Diego continues to grow and develop, so does the importance of effective stormwater management (SANDAG 2013). Stormwater best management practices (BMPs) are used to mitigate the impacts of human development on the quality and quantity of stormwater in the form of urban runoff (Roy-Poirier, Champagne and Filion 2010). Biofiltration systems are a kind of natural treatment systems (NTS) that use a variety of biological, chemical, and physical processes to capture and improve the water quality of stormwater runoff (Grant et al. 2012), (Askarizadeh et al. 2015). Typically, the engineering design criteria are focused on the hydrologic aspects, soil type, and vegetation to a degree, but pay little attention to fauna (City of San Diego 2016). Additionally, there is very little assessment of biofilter success in southern California, and comparing the performance of biofilters installed in different geographic locations (with different pollutants) can be complicated (Roy-Poirier, Champagne and Filion 2010). Although biofilters are specified for design all over San Diego County, their functionality is rarely measured, with the exception of routine maintenance to prevent clogging (removing trash, debris, and sediment accumulation). This presents a unique opportunity to better understand how biofilters function long after implementation.

Four biofilters located on the bluffs of the Scripps Institution of Oceanography (SIO) campus in La Jolla, CA, USA (Figure 2) were selected as a model system to address a set of themes and questions that can be applied to coastal biofilters in southern California.

1.1 Research Objectives

The objective of this study is to better understand the function of coastal biofilters over time. This thesis explores two major themes related to biofilters with associated quantities, as follows:

A) **Ecosystem Structure:** Exploration of the role of soil, plants, and animals in the biofilters:
   a. What is the ecosystem structure with respect to (a) flora and (b) fauna?
   b. What is the composition of the soil in each biofilter with respect to metals and salinity?
   c. Is there a link between the present flora and fauna in the biofilters?
   d. Do the different configurations and design of each biofilter affect their efficiency?

B) **Biofilter Performance:** Analysis of the pollutant removal efficiency of different constituents, and how biofilter functionality changes with age:
   a. How have the existing biofilters historically performed since establishment in 2010?
   b. How did the biofilters perform during El Niño winter 2015-2016?
   c. What role do the biofilters play in copper, zinc, and TSS removal?
   d. What role do the biofilters filters play in bacteria and nutrient removal?
   e. Is the pollutant removal efficiency changing with age?

A protocol was developed to monitor the effectiveness of the SIO biofilters, based on the quality of the stormwater entering and leaving each biofilter and the ecosystem structure of each, including the soil, fauna, and flora.

The SIO biofilters sit directly adjacent to the beach and receive salt and aerosols from the ocean. Thus, this thesis will consider the challenges associated with biofilters in saline, coastal environments and will explore the advantages to creating an ecosystem within the biofilter. This includes the benefits that may come with the presence of soil invertebrates and the application of ecological theories. Based on the data, I will make design recommendations that can be implemented when the Scripps biofilters are replaced in 2017. By improving our understanding of biofilters, a scientific component can be introduced to an engineered design that does not typically consider the benefits of a man-made ecosystem. Using this knowledge, we can create an environment more similar to the pre-development conditions, while providing long-term solutions to the water quality problems that have been intensified by human development.

Section 2: Biofilters and Urban Runoff in San Diego County

Rapid urbanization of southern California is a huge risk to the coastal ecology through loss of habitat and the increase of contaminants to aquatic ecosystems (Schiff et al. 2000). Surface runoff is one of the largest sources of pollutants to the Southern California Bight, and since stormwater sewers and sanitary sewers in the region are not combined, the water receives no treatment prior to discharging into coastal bays, estuaries, and oceans (Schiff et al. 2000). In addition, San Diego County is prized for its beaches, and poor water quality is a major concern because of the threat it poses to beach recreation. Stormwater runoff is a major contributor to poor beach water quality, and pollution can lead to beach closures and beach visitors becoming ill, potentially harming San Diego’s economy (Lew and Larson 2005).

Land development increases the amount of impermeable surfaces, which prevents water from infiltrating into the ground like it would naturally. This leads to an increase in the volume of urban runoff, which often carries contaminants that pollute coastal waters. Low Impact Development (LID) is a planning strategy that aims to protect water quality by preserving and mimicking natural hydraulic functions (Grant et al. 2012), (County of San Diego 2014). The use of natural treatment systems such as biofilters achieve two major water quality objectives at once; they reduce the amount of urban runoff by allowing stormwater to infiltrate into the ground, and reduce the amount of pollutants through natural treatment processes. Biofiltration systems can thus provide small-scale treatment to a greater problem that begins far from the coast.

2.1. Pollutants of Concern

There are many pollutants found in urban runoff that can have detrimental effects to coastal water bodies (Table 1). Metals such as copper, lead and zinc are of particular concern because of their prevalence, toxicity to aquatic organisms, and persistence in the environment (Brown and Peake 2006). Heavy metals from cars can have detrimental ecological and biological impacts; car tires contribute zinc and brake pads contribute copper often found in stormwater (TDC Environmental, LLC 2015), (TDC Environmental, LLC 2016).

Excessive sedimentation from erosion and scour can blanket estuarine systems and prevent infaunal organisms from receiving sufficient oxygen. Sedimentation in particular is worse in San Diego because the soils tend to be water repellent and do not allow infiltration, increasing the volume of runoff and susceptibility to erosion. High levels of nutrients (such as phosphorus and nitrate) can increase eutrophication (Correll 1998), which can lead to excessive algal blooms and the depletion of dissolved oxygen in the receiving waters, a primary concern for aquatic ecosystems (Roy-Poirier, Champagne and Filion 2010).

Pollutants of concern from urban runoff, summarized in Table 1 below, show the sources and consequences of ineffective stormwater management.

Table 1 – Primary Pollutants of Concern in Stormwater Runoff in Southern California

Pollutant	**Source**	**Environmental Impacts**
Nitrogen and Phosphorus	Fertilizers, yard/pet waste, cleaning supplies	Eutrophication (dead zones, hypoxia)
Heavy Metals (Cu, Pb, Zn)	Car emissions, oil drips, tire wear, asphalt roads, brake pads	Toxic to aquatic organisms, persistent in environment
Sediment	Erosion, scour, construction sites, unprotected dirt	-Can blanket estuarine systems, prevent organisms from getting oxygen -Worse in SD because of clayey soils
Bacteria	Animal feces, sewage	Harmful to humans (beach closures) and aquatic organisms
PAHs	Parking lots, cars	Human carcinogens, toxic to aquatic life

2.2 Biofilter Design

The engineering criteria for designing and constructing biofilters is largely structural (City of San Diego 2016). Water quality calculations are performed to achieve a certain spatial area, surface storage volume, and subsurface storage volume based on the contributing impervious area. The depths of various media including engineered soil, filter course, and aggregate are based on these calculations. A typical biofiltration section from the San Diego Storm Water BMP Manual is shown in Figure 1.

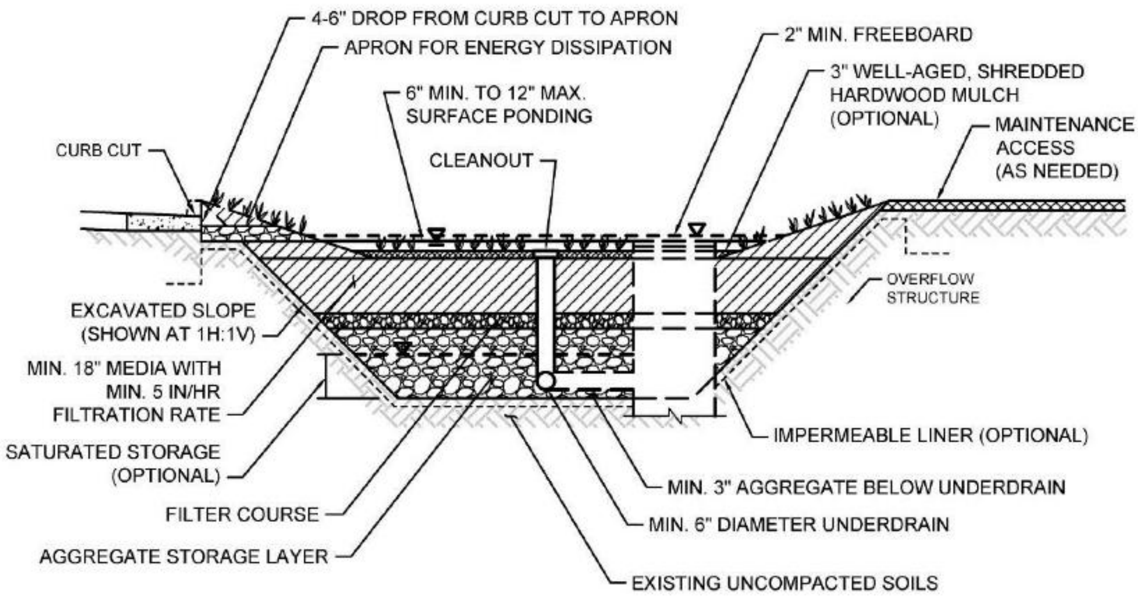


Figure 1 - Typical Biofiltration Section (City of San Diego 2016)

The manual does not specify plants or animals or any sort of ecosystem services in the design criteria. The potential benefits of considering these factors are discussed in Section 3: Existing Biofilter Research. The design manual has recommendations for biofilter design that accommodates rain events with excess precipitation- but very few guidelines address the opposite- like the drought conditions that San Diego County has been experiencing for the past five years (San Diego County Water Authority 2016). There exists a need to analyze biofilter performance under low rainfall conditions, which are much more common, to understand the realistic performance of biofilters in southern California.

2.3 Study Sites - Scripps Biofilters as a model

Four biofilters on the SIO campus at the University of California, San Diego (UCSD) were selected as a model for this study (Figure 1). One of the biofilters (TC-01) has been analyzed by UCSD since 2010 for stormwater metal and total suspended solid concentrations, while the other three biofilters (TC-02, TC-03, and TC-04) were analyzed from May 2015 to May 2016.

Figure 2 - Biofilter Locations on Scripps Institution of Oceanography Campus in La Jolla, CA, USA

The four biofilters of study are all located along the coast at SIO (Figure 2) and each have a slightly different size and shape (Figure 3).

Figure 3- Pictures of the SIO biofilters. From top left: 1) TC-02, 2) TC-02, 3) TC-03, 4) TC-04 and 5) outfall onto the beach.

These biofilters are important because they outfall directly onto the beach (lower bottom right of Figure 3) of a protected area of ocean, which is designated as the San Diego-Scripps Area of Special Biological Significance (ASBS). There are 34 ASBS in California, which are monitored and maintained by the State Water Resources Control Board. These ASBS support unique aquatic life and are the “basic building blocks for a sustainable, resilient coastal environment and economy” (Faick 2015). The ASBS at Scripps (Figure 4) encompasses the San Diego-Scripps State Marine Conservation Area, and is adjacent to the San Diego-La Jolla ASBS. In addition to hosting a variety of aquatic species, SIO and the Birch Aquarium draw seawater from this area for research purposes (Faick 2015).

Figure 4 - The San Diego-Scripps ASBS (La Jolla Shores Watershed Management Group 2008)

Key pollution threats to this ASBS include stormwater runoff, thus, the area is heavily regulated (La Jolla Shores Watershed Management Group 2008). Because of the permit requirements, no “dry weather flows” are allowed to discharge into the ocean; meaning only rainwater is allowed to leave through the effluent pipe connected to the biofilter. This presents challenges to the vegetation present in the biofilter; not only must the vegetation be able to survive the harsh salinity from the ocean and air, they must be able to survive with minimal irrigation.

The design of these biofilters was based on an “ecology embankment” developed by the Washington State Department of Transportation. The biofilters receive discharge from the underground storm drain system, which collects stormwater runoff from the surrounding streets, parking lots, and landscaped areas. A portion of this runoff is diverted into the four biofilters by a 3-inch diversion wall that is located inside the manhole, which is located upstream of the biofilter. The diverted stormwater is called the “first flush” and typically contains most of the pollutants that have been collecting on the roadway since the last storm event. Stormwater is distributed over the entire top width of the biofilter through a perforated pipe or a drainage cell. This allows the water to be evenly distributed across the length of the biofilter as it flows through the soil media, which is 18 inches (46 cm) thick. All other flows (such as from a larger rain storm) bypass the biofilter and flow directly to the discharge point at the beach.

2.4 Previous system modifications

The design of the SIO biofilters has evolved since their installation in 2010. UCSD noted decreased hydraulic performance in the monitoring data for TC-01; the biofilter became clogged in February 2013 when no effluent flow was recorded. Modifications were made in attempt to reduce the amount of biofilter clogging (University of California 2015). Firstly, the mechanism by which the biofilter receives influent flow was modified. Originally, all four biofilters received flow from a perforated pipe and gravel bed that was intended to disperse flow along the entire width of the biofilter. In 2013, this dispersion method was revised in TC-01; the perforated pipe was replaced with a strong plastic structure with 95% void space. The 3” diversion wall was raised to a 5” diversion curb to allow for more diversion to the biofilter. A small section of screen was also added to the diversion vault in TC-01 to prevent debris from entering the biofilter (Figure 5).

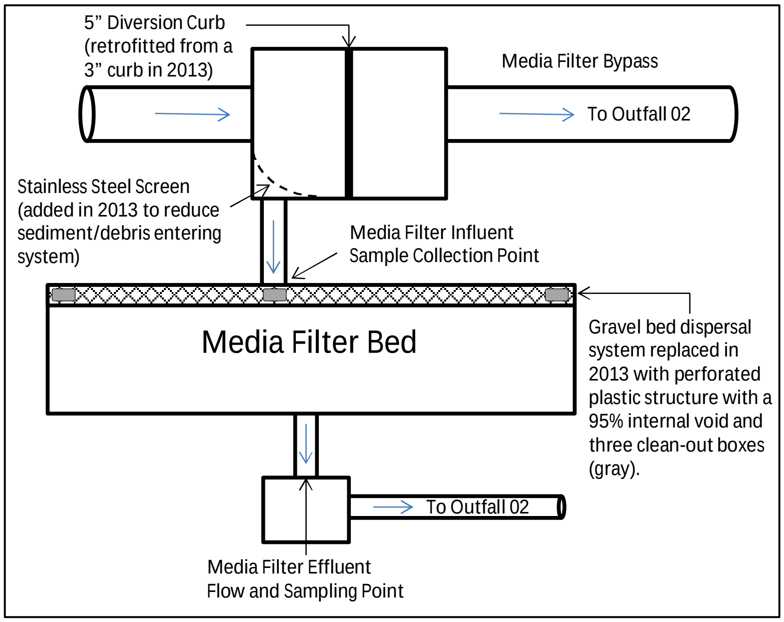


Figure 5 - 2013 Retrofit to biofilter influent dispersal system (University of California 2015)

The other three biofilters, TC-02 through TC-04, still have the original dispersion mechanism and need to be vacuumed continuously, which hinders their pollutant removal abilities. When the biofilters are retrofitted in 2017, all biofilters will use the drainage cell design technology (Personal Communication, K. O’Connell 2015).

2.5 Pollutant Removal Process

The soil media mix used in the SIO biofilters is the primary facilitator for stormwater pollutant removal. It is comprised of dolomite, gypsum, gravel, and perlite (Herrera Environmental Consultants, Inc. 2006). Dolomite and gypsum add alkalinity and ion exchange capacity which promotes the removal of metals and phosphorus. The carbonite contained in dolomite increases the alkalinity of the runoff, which allows metal carbonates and hydroxides to form. Calcium from dolomite and gypsum, and magnesium from gypsum, combine with phosphate to form insoluble metal-phosphate particles that are filtered out in the gravel. Copper and zinc are removed from the stormwater runoff by adsorption to gypsum and dolomite. Perlite improves moisture retention, which is critical in order for a biofilm to form in the media mix. Perlite also increases retention for chemical reactions, which aids in the treatment process. The biofilm has the capability to remove phosphorus and metals, as well as metabolize petroleum hydrocarbons (Herrera Environmental Consultants, Inc. 2006).

Pollutants such as sediments are removed through physical filtration; as water percolates through the gravel, larger particles are naturally strained out. The media removes pollutants such as suspended solids and soluble metals, which are typically contained in highway runoff. The pollutants are removed through the processes of physical straining, ion exchange, carbon precipitation and biofiltration. Additionally, the topsoil of each biofilter was planted with local native vegetation to reduce sediment runoff (Herrera Environmental Consultants, Inc. 2006).

Section 3: Existing Biofilter Research on Structure and Function

Many different features of biofilters have been studied by scientists. A part of this research that may be applicable to future design is described herein, as there often exists a gap between engineering design criteria and scientific research. Existing research on biofilters includes examination of hydrology and the contaminant removal abilities of biofilters, filter media composition and depth, biofilter vegetation, and the incorporation of saturated zones (Davis et al 2009). Studies are now beginning to examine the potential role of soil invertebrates in biofilter function (Mehring and Levin 2015).

Stormwater management is becoming even more important as built environments will need to function under climactic conditions different from the recent past to reduce the risk of harmful environmental impacts (Pyke et al. 2011). Detailed studies are needed to better understand the implications of climate change at a local level, so adaptation strategies that ensure long-term sustainability of stormwater management can be developed (Pyke et al. 2011). The incorporation of ecological aspects such as flora, fauna, and ecological theories into biofilter design may improve the longevity and sustainability of the biofilters.

3.1 The Role of Vegetation

Urban ecosystems have complexities from anthropogenic influences that must be considered when studying urban ecology (Breuste and Snep 2008). Though filter media is considered the primary pollutant removal mechanism, vegetation is a common feature of biofilters and improves their aesthetics and arguably their function. Common biofilter plants in southern California include shrubs, rushes, sedges, grasses and trees

(City of San Diego 2016). Past research has shown significant differences in nutrient retention abilities in vegetated versus non-vegetated systems, and deep-seeded roots have been shown to have a strong ability to remove pollutants and contribute to nutrient uptake (Davis et al. 2006), (Read et al. 2009). Specifically, vegetation has been shown to have a significant effect in biofilter removal capabilities of total nitrogen (TN) and total phosphorus (TP) (Davis et al. 2009). The research suggested that the combination of both media type and vegetation affect nutrient retention in biofilters; differences were recorded between the pollutant removal abilities of vegetated versus barren systems with varying filter media (Davis et al. 2006). The vegetated systems removed more pollutants than the barren systems, and notably, systems void of vegetation eventually became exhausted of their TP retention abilities (Davis et al. 2009). In Australia, as high as 90% retention of pollutants were found in systems planted with sedge *Carex apressa* (Ellerton, Hatt and Fletcher 2011). From a physical standpoint, the presence of vegetation increases retention and infiltration into soils. In addition, the soil rhizosphere that exists in well-established plant communities provides a rapid sorption capability that does not exist in non-vegetated systems (Davis et al. 2009).

In summary, research has shown that the presence of vegetation can have a multitude of benefits to biofilters; it can increase nitrogen and phosphorus retention, increase infiltration, and generally provide a more stable environment.

3.2 The Role of Soil Invertebrates

Recent research has examined the potential role of soil invertebrates, which can facilitate infiltration (Mehring and Levin 2015) and potentially improve southern California soils, where clayey soils with poor infiltration rates are often present. A number of different species may benefit biofilters. Soil invertebrates significantly impact the dynamics of soil organic matter, structure, and plant growth potential, which can have a dramatic impact on the soil function (Lavelle 1996).

Research has shown that soil invertebrates impact soil nutrient storage, removal, and processing. For example, earthworms are well-documented ecosystem engineers that can enhance denitrification, plant growth, and nutrient uptake; bioturbation by earthworms may allow for enhanced plant root density and expansion through soils. Springtails can impact plant growth and nutrient uptake by feeding on fungi. Isopods enhance organic matter breakdown and carbon mineralization by feeding on particulate organic matter, and millipedes also consume particulate organic matter (Mehring and Levin 2015). Additionally, soil invertebrate biomass can store substantial amounts of carbon, nitrogen, and phosphorus, which temporarily immobilizes nutrients and prevents them from being leached (Mehring and Levin 2015). Indirectly, this can also increase nutrient uptake by plants; some invertebrate species were reported to enhance uptake by more than 200% in vertical-flow wetlands, while others such as springtails, millipedes, isopods can enhance plant uptake of nitrogen (Mehring and Levin 2015), (Mehring et al. submitted 2015).

Biofilter faunal communities can be diverse, are stable over short timeframes, and likely impact important biofilter functions such as pollutant removal ability (Mehring, et al. submitted 2015). There are generally better outcomes for systems with a higher abundance of ecosystem engineers, such as earthworms. However, soil invertebrate communities are intensely linked to human activities; in many cases the invertebrate communities tend to disappear as a result of anthropogenic activities (Lavelle 1996). Some research has been done on the fauna of biofilters in Australia, which face similar climactic conditions and challenges to southern California, but significantly different rainfall (Ambrose and Winfrey 2105). Recent research showed that soil faunal communities did in fact develop after biofilter construction, which suggests that biofilters might attract a variety of taxa and their potential benefits (Mehring and Levin 2015).

The full pollutant removal capabilities of biofilters as a built ecosystem are not well understood, which presents a need to look at the biofilter as a whole to understand the ecosystem and the potential benefits of considering ecosystem services.

3.3 Application of the Biodiversity-Ecosystem Function Theory to Biofilters

By incorporating ecological theories such as biodiversity-ecosystem function into biofilter design, a more efficient and self-sustaining biofilter can be created. Biodiversity-ecosystem function (BEF) is a complicated theory that may be applicable to future biofiltration research, as a higher biodiversity may result in better functioning biofilters. Human domination of ecosystems has had significant effects on the presence and diversity of species present (Loreau et al. 2001). In general, human impacts reduce biodiversity, which is significant because as land becomes more developed, a large number of species are needed to maintain ecosystem functionality (Loreau et al. 2001).

There are a few mechanisms that may contribute to the improvement of biofilters through application of this theory (Levin and Mehring 2015):

1. **Niche differentiation:** Different species perform different desired functions (infiltration, nutrient removal, metal uptake). More species increases likelihood of facilitation.
2. **Complementarity:** Different species may complement each other, and perform better than an individual species alone. It is possible to maximize the performance of desired functions with the introduction of many species.

3. **Sampling Effect**: Introducing multiple species increases the probability that the best performing or surviving species will be present. Determining which species affect certain processes is still an open question.
4. **Insurance:** Higher biodiversity may be important for maintaining ecosystem processes under changing climate conditions. Different species may respond to different environmental changes. San Diego experiences a wet and dry season, the incorporation of multiple species will increase the chances of having species that perform better at different times of the year.

Research has shown some examples where more diverse grasslands create more productive ecosystems; a higher diversity of species led to less nitrogen leaching (Tilman, Wedin and Knops 1996). This may be because a higher number of species takes greater advantage of niche opportunities, as diverse systems have been shown to capture more nitrogen (Tilman, Wedin and Knops 1996), (Cardinale 2011). Research has shown that maximum nutrient removal is achieved by planting a suite of species with complementary effects. In Australia, the combination of a sedge (*Carex appressa*) and a rush (*Lomandra longifolia*) showed higher nutrient removal when the plants were grown together as opposed to independently (Ellerton, Hatt and Fletcher 2011). In coastal environments that are exposed to more saline conditions, the incorporation of "nurse plants" can decrease evaporation which may prevent the hypersalinity of soil (Levin and Mehring 2015).

In summary, thinking about BEF in the context of biofilter design can impact the success and sustainability of the biofilter. Biodiversity is extremely complicated and human impacted ecosystems present different challenges; a higher biodiversity may be important for maintaining processes under changing ecosystem conditions. Since different species likely perform best during different stages of the biofilter lifecycle, a high biodiversity could improve the lifespan of the system and potentially protect from invasive species. However, the full value of applying ecological theories to biofilters specifically is not yet well tested, and presents a need for further research.

Section 4: Biofilter Sampling Methods

4.1 Research Needs

Only biofilter TC-01 has historically been monitored, even though all four biofilters have monitoring capabilities and are equipped with influent and effluent sampling boxes. The three previously unmonitored biofilters (TC-02, TC-03, and TC-04) were analyzed in 2016 for the same constituents as TC-01 (copper, zinc, total suspended solids), as well as for bacteria and nutrients. The Scripps biofilters located at approximately 32.8681° N, 117.2503° were sampled as described in Table 2.

In addition to stormwater samples, soil samples were taken at multiple times throughout the year to understand the ecosystem structure of each biofilter and how it changes throughout the year. This included gaining an understanding of the soil composition (presence of soil invertebrates, metal concentrations, and salinity) and the vegetation present in each biofilter (Table 2).

Table 2- Stormwater and soil sampling dates and locations

	TC-01	**TC-02**	**TC-03**	**TC-04**	**NOTES**
2011-2015 Stormwater	Stormwater (Cu, Zn, TSS)				UCSD Monitoring Data
5/20/2015 Soil	Invertebrates (13 samples)				
8/25/2015 Soil	Invertebrates (2 samples)	Invertebrates (2 samples)	Invertebrates (2 samples)	Invertebrates (2 samples)	Samples under plant
2/16/2016 Soil	Invertebrates (1 sample)	Invertebrates (1 sample)	Invertebrates (1 sample)	Invertebrates (1 sample)	Sample under plant
3/7/2016 Stormwater		Cu, Zn, TSS, bacteria, nutrients	Cu, Zn, TSS, bacteria, nutrients	Cu, Zn, TSS, bacteria, nutrients	
3/16/2016	Salinity (4 samples)	Salinity (4 samples)	Salinity (4 samples)	Salinity (4 samples)	Samples along transect from inlet to outlet. 2 near inlet, 2 near outlet
4/10/2016 Soil	Cu, Zn, Pb, Salinity (3 samples)	Cu, Zn, Pb, Salinity (3 samples)	Cu, Zn, Pb, Salinity (3 samples)	Cu, Zn, Pb, Salinity (3 samples)	Shallow sample near inlet, sample near outlet, deep sample near outlet
5/6/2016 Stormwater		Cu, Zn, TSS, bacteria, nutrients	Cu, Zn, TSS, bacteria, nutrients	Cu, Zn, TSS, bacteria, nutrients	

4.2 Soil Sampling Protocol

4.2.1 Field Sampling Methods

To sample invertebrates in the soil, filter media samples (top 5 cm of soil media) were collected from each biofilter using a plexiglass corer 5 cm in diameter. The filter media cores were fixed in 10% buffered formalin within 12 hours of collection. For each sample, vegetation percent cover of the entire biofilter at the time of sampling was noted and a picture was taken. If the core sample was taken underneath a plant, the plant species was recorded. Soil samples to determine invertebrate populations occurred on three different occasions. The first sampling on May 20th, 2015 involved the collection of 13 samples, but only 1/13 samples were collected under vegetation, and that particular sample was the only sample with any taxa present. The methodology was consequently modified, the rest of the samples to determine invertebrate populations were collected under vegetation. On August 25th, 2016, 8/8 samples were collected under plants, and on February 16th, 2016, 4/4 samples were collected under plants.

4.2.2. Laboratory Methods

To analyze the invertebrate community structure, the filter media from soil cores was rinsed over nested sieves (ASTM sieve sizes No. 18, No. 50, and No. 325) to separate the invertebrates and organic matter for sampling events A, B, and C. Filter media larger than 300 µm was sorted under a Wild M5A stereomicroscope at 12x magnification in order to remove all invertebrates, which were then classified according to order, suborder, and enumerated.

Soil salinity was measured by using a handheld seawater refractometer. To determine the range of salinity in each biofilter, samples were taken along a transect from the inlet to the outlet for each biofilter. Near the inlet and outlet two samples were taken, one slightly to the north, one slightly to the south, for a total of 4 samples per biofilter. The soil samples were introduced into a 10 mL syringe. They were saturated with DI water and filtered through double GEF filter paper discs at the base of the syringe.

Soil samples taken on April 10th, 2016 were analyzed for soil content, including salinity, total copper, and total zinc. Three samples were taken; one near the inlet, one near the outlet, and one “deep” sample towards the bottom of the biofilter (12-18 inches deep) near the outlet to see if the metal content or salinity varied with depth. Salinity was measured using the same process described previously. Samples were sent to EnviroMatrix for metal contaminant analysis.

4.3 Stormwater Sampling Protocol

4.3.1. Field Sampling Methods

A pole sampler was used to collect six grab samples in the influent and effluent boxes at the inlet and outlet of each biofilter. The sampling protocol was developed based on San Diego Coastkeeper’s standard operating procedure for water quality sampling in San Diego. A “clean hands/dirty hands” technique was used to minimize contamination of the sample (See Appendix 1 – SIO Biofilter Sampling Standard Operating Procedure Manual for more detail). Since the pollutant load varies throughout the duration of the rain event, a “composite” stormwater sample was analyzed; the six samples were combined and then analyzed, allowing for a better picture of the quality of stormwater entering and exiting each biofilter.

4.3.2. Laboratory Sampling Methods

After the composite stormwater samples were combined, they were analyzed two different ways. Samples for metals (copper and zinc) and total suspended solids were sent to EnviroMatrix for analysis. Stormwater samples for nutrients (nitrate, ammonia, phosphate) and were analyzed by San Diego Coastkeeper using Hach TNT plus vial tests for nutrients. Stormwater samples for bacteria (*Enterococcus*, total coliform, *E. coli)* were also analyzed by San Diego Coastkeeper using Idexx tests.

Section 5: Ecosystem Structure

To better understand the SIO biofilters, various components of the biofilter ecosystem were observed and analyzed, including the soil composition (metal content and salinity), vegetation, and soil invertebrates present.

5.1 Soil Metal Content and Salinity

Measurements were taken on March 16th to determine the salinity of the soil in all four of the SIO biofilters (Table 3). Average salinity ranged from 4.75 ± 1.25 to 9 ± 2.97 ppt.

Table 3 - Soil Salinity in TC-01, TC-02, TC-03, TC-04 on March 16, 2016

		Salinity [0/00]	Average Salinity	Standard Error
TC-01	IN - North	9	8.75	1.31
	IN - South	11		
	OUT - North	10		
	OUT - South	5		
TC-02	IN - North	8	4.75	1.25
	IN - South	5		
	OUT - North	4		
	OUT - South	2		
TC-03	IN - North	5	5.25	1.31
	IN - South	9		
	OUT - North	4		
	OUT - South	3		
TC-04	IN - North	10	9	2.97
	IN - South	4		
	OUT - North	17		
	OUT - South	5		

The four biofilters did not have significantly different salinity levels (P=0.275). There was no correlation between the salinity of the inlet and outlet among the four biofilters (P=0.4986).

The purpose of the samples taken on April 10, 2016 was to analyze the metal composition of the soil in each biofilter for copper, lead, and zinc and salinity (Table 4).

Table 4 - Soil Composition (Cu, Pb, Zn, S) on April 10, 2016

	Copper (mg/kg)	Average Copper	Lead (mg/kg)	Average Lead	Zinc (mg/kg)	Average Zinc	Salinity 0/00	Average Salinity
TC-01-IN	10.2	10.40 ± 0.12	7.27	7.53 ±0.19	45.9	44.07 ±1.41	10	9.17 ±0.83
TC-01-OUT	10.6		7.89		45		7.5	
TC-01-DEEP	10.4		7.42		41.3		10	
TC-02-IN	13.4	12.90 ±0.29	9.25	11.38 ±1.64	54.1	55.17 ±1.81	6.5	4.83 ±1.01
TC-02-OUT	12.9		10.3		52.7		3	
TC-02-DEEP	12.4		14.6		58.7		5	
TC-03-IN	13.4	11.32 ±1.14	12.9	12.43 ±1.01	51.5	45.53 ±3.30	7	4.83 ±1.09
TC-03-OUT	11.1		13.9		45		3.5	
TC-03-DEEP	9.47		10.5		40.1		4	
TC-04-IN	14.8	15.97 ±0.69	12.4	12.00 ±0.23	71.5	70.40 ±2.40	7	7.33 ±2.03
TC-04-OUT	15.9		11.6		73.9		11	
TC-04-DEEP	17.2		12		65.8		4	

Average copper levels ranged from 10.40 ± 0.12 (mg/kg) to 15.97 ±0.69 (mg/kg). Average lead levels ranged from 7.53 ±0.19 (mg/kg) to 12.43 ±1.01 (mg/kg). Average zinc values ranged from 44.07 ±1.41 (mg/kg) to 70.40 ±2.40 (mg/kg). Average salinity ranged from 4.83 ±1.01 to 9.17 ±0.83 ppt. These results were plotted and analyzed to see if the constituents varied among the four biofilters (Figure 6).

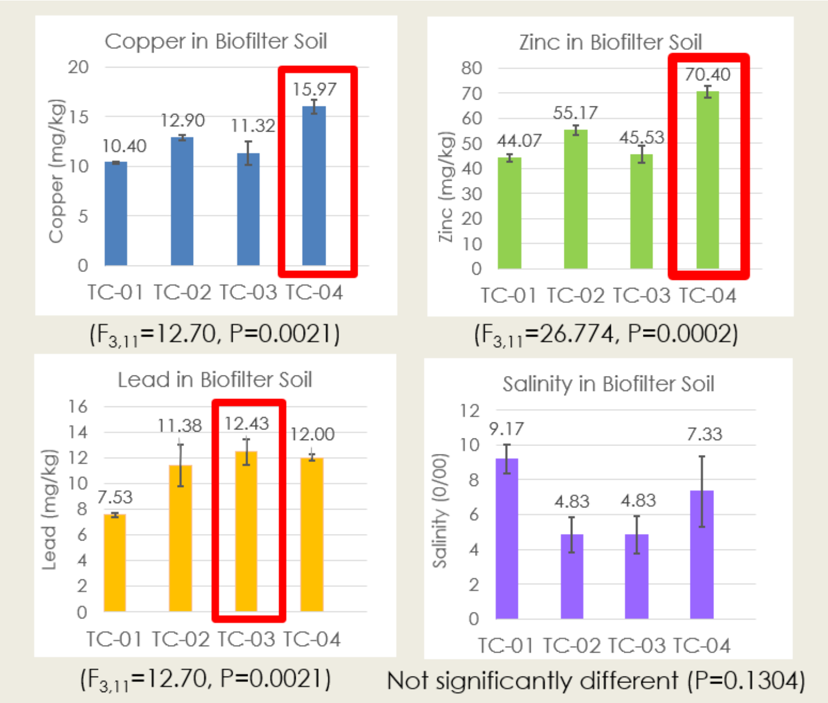


Figure 6 - Average levels of Copper, Zinc, Lead, and Salinity in biofilters TC-01, TC-02, TC-03, and TC-04 measured on April 10, 2016. Red box indicates significantly higher average value.

TC-04 had a higher concentration of copper than the other four biofilters ($F_{3,11}$=12.70, P=0.0021), with a mean of 15.97 mg/kg (±0.69). TC-02 and TC-04 were similar, and TC-01 through TC-03 were similar to each other. TC-03 had a higher concentration of lead than the other three biofilters ($F_{3,11}$=5.3401, P=0.0259), with a mean of 12.43 mg/kg (±1.01). TC-04 had a significantly higher concentration of zinc than the other three biofilters ($F_{3,11}$=26.774, P=0.0002), with a mean of 70.40 mg/kg (±2.40). None of the other three biofilters were similar to TC-04. TC-03 was similar to TC-02 and TC-01.

There was a significant positive relationship between the amount of zinc and copper in soil of each biofilter (R^2=0.8175, P<0.0001). Both pollutants are typically associated with vehicle use; copper from brake pads and zinc from tires (State of Oregon Department of Environmental Quality 2014). The elevated level of both metals in

TC-04 is expected, as it receives runoff from the adjacent parking lot. There was no significant difference in salinity among the four biofilters ($F_{3,11}$=2.5336, P=.1304, and there was no correlation between percent vegetation cover and salinity (P=0.1485).

5.3 Vegetation in Biofilters

Most of the vegetation from the original plantings in 2010 has not survived, likely because of the persistent drought conditions and the permit restrictions on irrigation. TC-02, the biofilter located immediately north of the Scripps administration building, has consistently had the highest percent cover of vegetation out of all four biofilters since this study began in May 2015.

Table 5 - Percent vegetation cover in SIO biofilters

Vegetation Cover in Biofilters				
	TC-01	TC-02	TC-03	TC-04
August 2015	20%	30%	7%	25%
December 2015	7%	25%	10%	2%

Vegetation cover has varied throughout the year (Table 5), and generally decreased between August and December 2015 as shown in images in Figure 7 and Figure 8. This could be a result of seasonal temperature variance, length of day, or the angle of the sun; some biofilters experience shade more than others because of their design. For example, TC-04 is a few feet below the sidewalk and is shaded more frequently than the other three biofilters. The biofilters have also experienced different structural changes; the gravel that is supposed to be only around the perimeter has migrated inward, which may hinder plant growth and soil invertebrate presence. TC-03 is also almost completely covered in sand, which may be a result of heavy rains (Figure 8).

Figure 7 - Vegetation Cover in SIO Biofilters - August 2015. Clockwise from top left: A) TC-01, B) TC-02, C) TC-04, and D) TC-04.

Figure 8 - Vegetation Cover in SIO Biofilters - December 2015. Clockwise from top left: A) TC-01, B) TC-02, C) TC-04, and D) TC-04.

A photo from December 2013 (Figure 9) shows the contrast in the vegetation between 2013 and 2015; TC-01 was once heavily vegetated.

Figure 9 - TC-01 in December 2013 showing denser vegetation than observations in 2015-2016. Photo credit: Kimberly O'Connell.

Multiple species were present during the 2015-2016 sampling of the four biofilters. These species include *Erigeron glaucus* (seaside daisy), *Portulaca oleracea* (purslane), A*chillea millefolium (yarrow)*, *Isocoma menziesii* (Menzies' goldenbush), *Chamaesyce maculata* (spurge) and more recently, *Mesembryanthemum nodiflorum* (Slenderleaf Iceplant) as shown in Figure 10. Unidentified weeds were also found in the biofilters. *Erigeron glaucus* was planted when the biofilters were initially constructed, but the other species all appear to have colonized the biofilters.

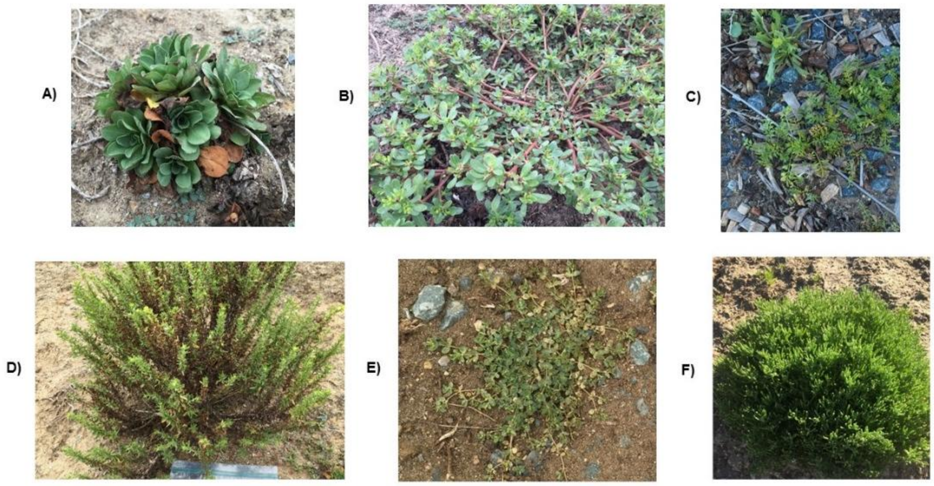
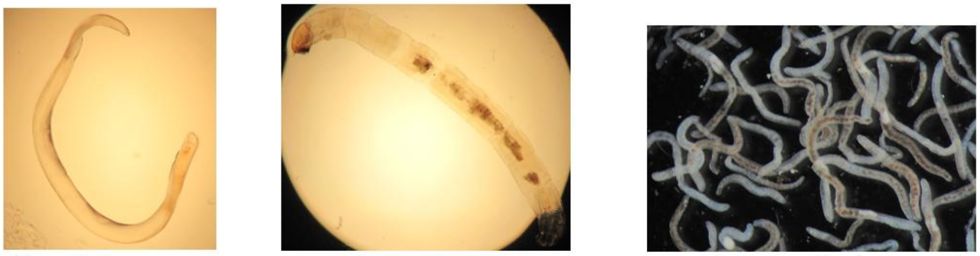


Figure 10 - Flora found in SIO Biofilters.
Clockwise from top left: A) Erigeron glaucus (seaside daisy), B) Portulaca oleracea (purslane), C) Achillea millefolium (yarrow), D) Isocoma menziesii (Menzies' goldenbush), E) Chamaesyce maculata (spurge) and F) Mesembryanthemum nodiflorum (Slenderleaf Iceplant).

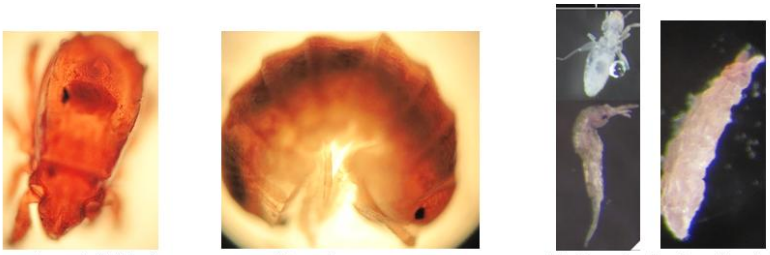
Although there was no significant correlation between salinity and percent vegetation cover in these biofilters (P=0.1485), it still might be something to consider. Vegetation can provide shade for the soil, decreasing the amount of evaporation, which would result in less saline soil. There may have been a correlation between vegetation and salinity a few years ago, but most the original vegetation has not survived, and was not present when this study began. For comparison, the salinity in the Scripps biofilter soil (4.83 ±1.01 to 9.17 ±0.83 ppt) is slightly higher than the soil in a bioswale slightly further inland on Scripps campus (0 to 7 ppt). This bioswale, which is adjacent to Sverdrup Hall, has a much higher percentage of vegetation.

5.2 Soil Invertebrates in Biofilters

The soil media was analyzed to determine the presence of soil invertebrates in each biofilter. Taxa included nematodes, mites. Springtails, and potworms, as shown in microscope images in Figure 11.



Nematoda Insect larva Enchytraeids (potworm)

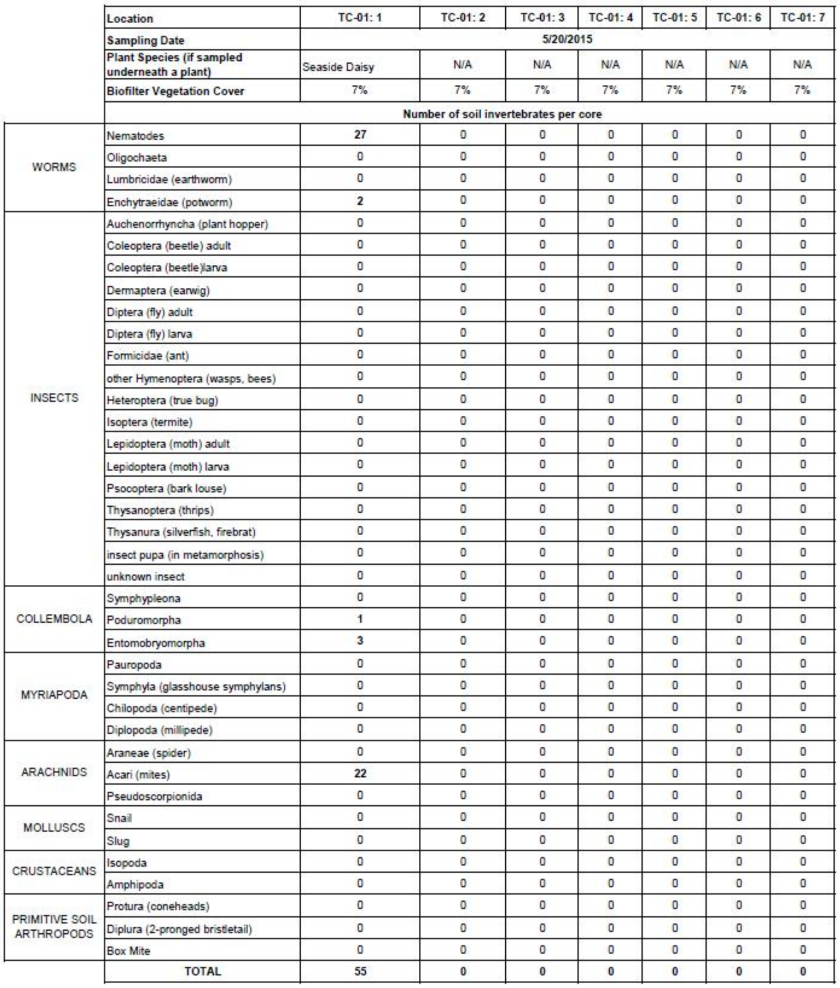


Acari (Mite) Crustacean Collembola (springtail)

Figure 11 - Soil invertebrates found in the SIO biofilters. Photo Credit: Jennifer Gonzalez

The first soil sampling event in May 2015 involved sampling across the entire spatial area of TC-01. Sorting results showed that soil invertebrates were only present under a plant in Sample 1 (Table 6); results are expressed in number of invertebrates per soil core. Samples 2-13 (8-13 not shown in table) were devoid of soil invertebrates. Nematodes were the most prevalent taxom in TC-01 Sample 1, with 27 per core, followed by Acari (mites) (22 per core), Entomobryomorpha (springtail) (3 per core), Enchytraeidae (potworm) (2 per core) and Poduromorpha (springtail) (1 per core). No other taxa were detected (Table 6).

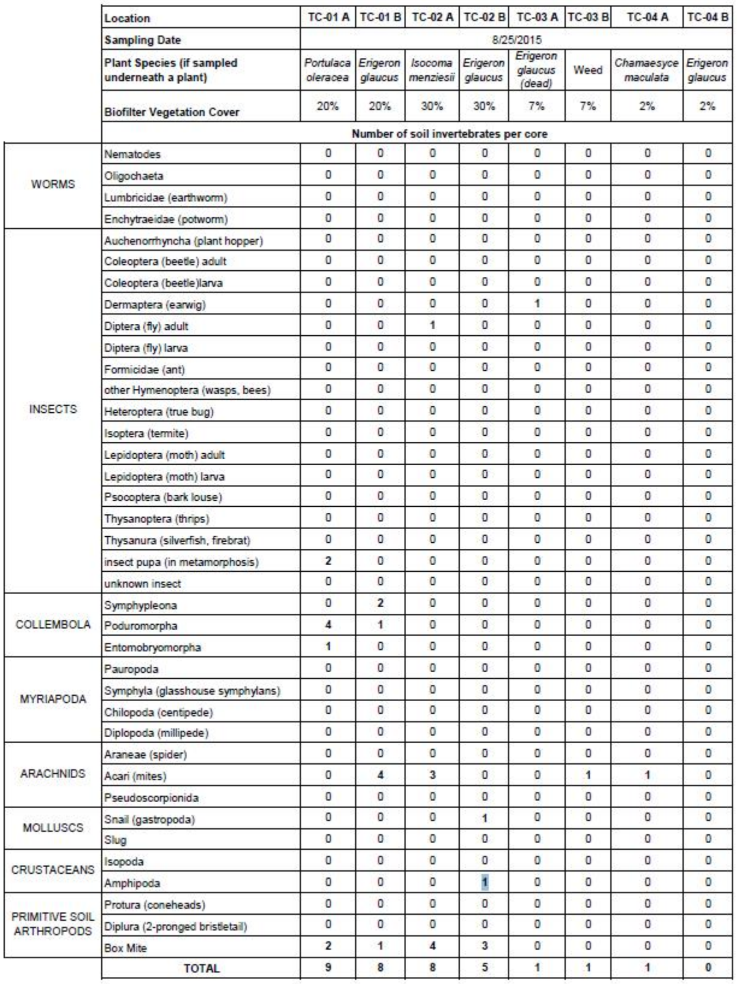
Table 6 - Fauna present in TC-01 Samples 1-7 on May 20, 2015.
Results expressed in number of invertebrates per core. Samples 8 through 13 (not shown) had no invertebrates present, similarly to samples 2 through 7 (shown).



	Location	**TC-01: 1**	**TC-01: 2**	**TC-01: 3**	**TC-01: 4**	**TC-01: 5**	**TC-01: 6**	**TC-01: 7**
	Sampling Date	**5/20/2015**						
	Plant Species (if sampled underneath a plant)	Seaside Daisy	N/A	N/A	N/A	N/A	N/A	N/A
	Biofilter Vegetation Cover	7%	7%	7%	7%	7%	7%	7%
		Number of soil invertebrates per core						
WORMS	Nematodes	**27**	0	0	0	0	0	0
	Oligochaeta	0	0	0	0	0	0	0
	Lumbricidae (earthworm)	0	0	0	0	0	0	0
	Enchytraeidae (potworm)	**2**	0	0	0	0	0	0
INSECTS	Auchenorrhyncha (plant hopper)	0	0	0	0	0	0	0
	Coleoptera (beetle) adult	0	0	0	0	0	0	0
	Coleoptera (beetle)larva	0	0	0	0	0	0	0
	Dermaptera (earwig)	0	0	0	0	0	0	0
	Diptera (fly) adult	0	0	0	0	0	0	0
	Diptera (fly) larva	0	0	0	0	0	0	0
	Formicidae (ant)	0	0	0	0	0	0	0
	other Hymenoptera (wasps, bees)	0	0	0	0	0	0	0
	Heteroptera (true bug)	0	0	0	0	0	0	0
	Isoptera (termite)	0	0	0	0	0	0	0
	Lepidoptera (moth) adult	0	0	0	0	0	0	0
	Lepidoptera (moth) larva	0	0	0	0	0	0	0
	Psocoptera (bark louse)	0	0	0	0	0	0	0
	Thysanoptera (thrips)	0	0	0	0	0	0	0
	Thysanura (silverfish, firebrat)	0	0	0	0	0	0	0
	insect pupa (in metamorphosis)	0	0	0	0	0	0	0
	unknown insect	0	0	0	0	0	0	0
COLLEMBOLA	Symphypleona	0	0	0	0	0	0	0
	Poduromorpha	**1**	0	0	0	0	0	0
	Entomobryomorpha	**3**	0	0	0	0	0	0
MYRIAPODA	Pauropoda	0	0	0	0	0	0	0
	Symphyla (glasshouse symphylans)	0	0	0	0	0	0	0
	Chilopoda (centipede)	0	0	0	0	0	0	0
	Diplopoda (millipede)	0	0	0	0	0	0	0
ARACHNIDS	Araneae (spider)	0	0	0	0	0	0	0
	Acari (mites)	**22**	0	0	0	0	0	0
	Pseudoscorpionida	0	0	0	0	0	0	0
MOLLUSCS	Snail	0	0	0	0	0	0	0
	Slug	0	0	0	0	0	0	0
CRUSTACEANS	Isopoda	0	0	0	0	0	0	0
	Amphipoda	0	0	0	0	0	0	0
PRIMITIVE SOIL ARTHROPODS	Protura (coneheads)	0	0	0	0	0	0	0
	Diplura (2-pronged bristletail)	0	0	0	0	0	0	0
	Box Mite	0	0	0	0	0	0	0
	TOTAL	**55**	**0**	**0**	**0**	**0**	**0**	**0**

Based on the results from the May 2015 sampling, the methodology was modified for future sampling. Since invertebrates were only found near vegetation, samples taken in August 2015 were always collected under plants. The highest abundance of soil invertebrates was found in sample TC-01 A (Table 7). Sample TC-01 A had Poduromorpha (4 per core), Entomobryomorpha (1 per core) and insect pupae (2 per core) as well as box mites (2 per core) (Table 7). Sample TC-01 B was collected under an *Erigeron glaucus* (seaside daisy), the same species as Sample 1 from the May 2015 sampling. These results showed that slightly different invertebrates were present compared to the May 2015 sampling; there were fewer Acari (4 per core compared to 22), the same amount of Poduromorpha (springtail) (1 per core), no Entomobryomorpha (springtail), but Symphypleona (springtail) (2 per core) and box mites (1 per core). TC-02, which had the most vegetation of all four biofilters had Acari (3 per core), Dipetera (1 per core) and box mites (4 per core) in sample TC-02 A. Sample TC-02 B had Gastropoda (snail) (1 per core), Amphipoda 1 per core) and box mites (3 per core) (Table 7). TC-03 was sparse, showing Dermaptera (1 per core) in TC-03 A and Acari (1 per core) in TC-03 B (Table 7). TC-04 only had Acari (1 per core) in TC-04 A; no taxa were found in TC-04 B (Table 7).

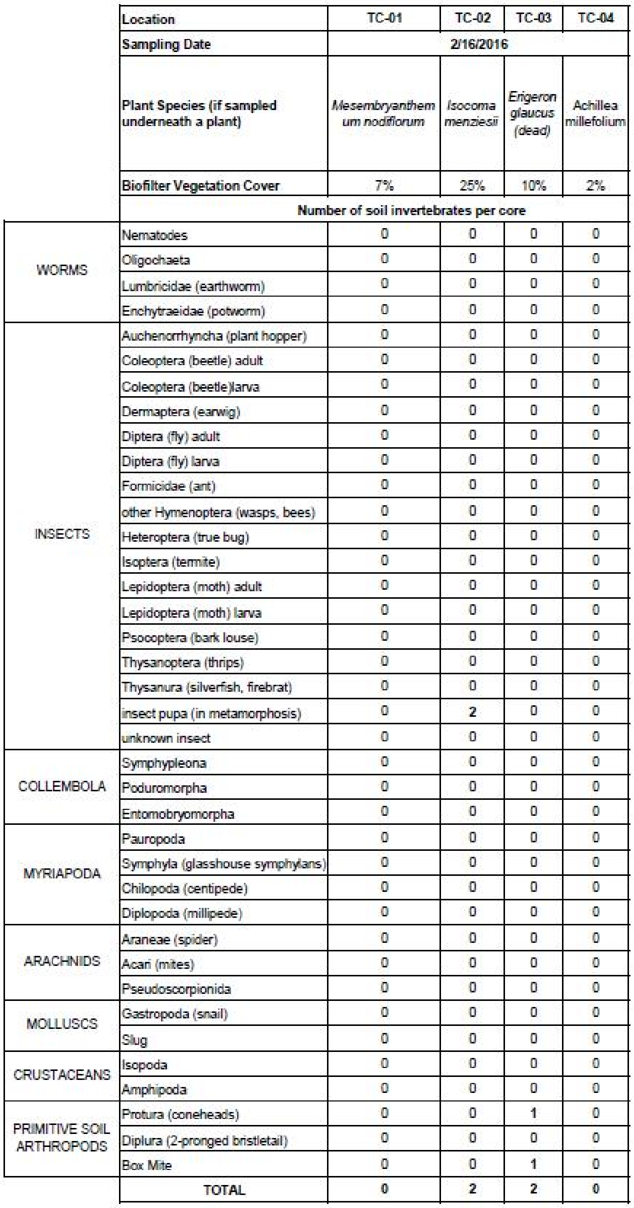
Table 7 - Fauna present in TC-01, TC-02, TC-03, and TC-04 on Aug 25, 2015



	Location	**TC-01 A**	**TC-01 B**	**TC-02 A**	**TC-02 B**	**TC-03 A**	**TC-03 B**	**TC-04 A**	**TC-04 B**
	Sampling Date	8/25/2015							
	Plant Species (if sampled underneath a plant)	*Portulaca oleracea*	*Erigeron glaucus*	*Isocoma menziesii*	*Erigeron glaucus*	*Erigeron glaucus (dead)*	Weed	*Chamaesyce maculata*	*Erigeron glaucus*
	Biofilter Vegetation Cover	20%	20%	30%	30%	7%	7%	2%	2%
	Number of soil invertebrates per core								
WORMS	Nematodes	0	0	0	0	0	0	0	0
	Oligochaeta	0	0	0	0	0	0	0	0
	Lumbricidae (earthworm)	0	0	0	0	0	0	0	0
	Enchytraeidae (potworm)	0	0	0	0	0	0	0	0
INSECTS	Auchenorrhyncha (plant hopper)	0	0	0	0	0	0	0	0
	Coleoptera (beetle) adult	0	0	0	0	0	0	0	0
	Coleoptera (beetle)larva	0	0	0	0	0	0	0	0
	Dermaptera (earwig)	0	0	0	0	1	0	0	0
	Diptera (fly) adult	0	0	1	0	0	0	0	0
	Diptera (fly) larva	0	0	0	0	0	0	0	0
	Formicidae (ant)	0	0	0	0	0	0	0	0
	other Hymenoptera (wasps, bees)	0	0	0	0	0	0	0	0
	Heteroptera (true bug)	0	0	0	0	0	0	0	0
	Isoptera (termite)	0	0	0	0	0	0	0	0
	Lepidoptera (moth) adult	0	0	0	0	0	0	0	0
	Lepidoptera (moth) larva	0	0	0	0	0	0	0	0
	Psocoptera (bark louse)	0	0	0	0	0	0	0	0
	Thysanoptera (thrips)	0	0	0	0	0	0	0	0
	Thysanura (silverfish, firebrat)	0	0	0	0	0	0	0	0
	insect pupa (in metamorphosis)	2	0	0	0	0	0	0	0
	unknown insect	0	0	0	0	0	0	0	0
COLLEMBOLA	Symphypleona	0	2	0	0	0	0	0	0
	Poduromorpha	4	1	0	0	0	0	0	0
	Entomobryomorpha	1	0	0	0	0	0	0	0
MYRIAPODA	Pauropoda	0	0	0	0	0	0	0	0
	Symphyla (glasshouse symphylans)	0	0	0	0	0	0	0	0
	Chilopoda (centipede)	0	0	0	0	0	0	0	0
	Diplopoda (millipede)	0	0	0	0	0	0	0	0
ARACHNIDS	Araneae (spider)	0	0	0	0	0	0	0	0
	Acari (mites)	0	4	3	0	0	1	1	0
	Pseudoscorpionida	0	0	0	0	0	0	0	0
MOLLUSCS	Snail (gastropoda)	0	0	0	1	0	0	0	0
	Slug	0	0	0	0	0	0	0	0
CRUSTACEANS	Isopoda	0	0	0	0	0	0	0	0
	Amphipoda	0	0	0	1	0	0	0	0
PRIMITIVE SOIL ARTHROPODS	Protura (coneheads)	0	0	0	0	0	0	0	0
	Diplura (2-pronged bristletail)	0	0	0	0	0	0	0	0
	Box Mite	2	1	4	3	0	0	0	0
	TOTAL	9	8	8	5	1	1	1	0

A few weeks after extremely heavy rain in early January 2016, a soil sample was taken from each biofilter to assess if the invertebrate structure had changed as a result of heavy rainfall. Biofilters TC-01 and TC-04 did not have any soil invertebrates present (Table 8). TC-02 had insect pupa (2 per core) and TC-03 had Protura (1 per core) as well as box mites (1 per core).

Table 8 - Fauna present in TC-01, TC-02, TC-03 and TC-04 on February 16, 2016



	Location	**TC-01**	**TC-02**	**TC-03**	**TC-04**
	Sampling Date	**2/16/2016**			
	Plant Species (if sampled underneath a plant)	*Mesembryanthemum nodiflorum*	*Isocoma menziesii*	*Erigeron glaucus (dead)*	Achillea millefolium
	Biofilter Vegetation Cover	7%	25%	10%	2%
		Number of soil invertebrates per core			
WORMS	Nematodes	0	0	0	0
	Oligochaeta	0	0	0	0
	Lumbricidae (earthworm)	0	0	0	0
	Enchytraeidae (potworm)	0	0	0	0
INSECTS	Auchenorrhyncha (plant hopper)	0	0	0	0
	Coleoptera (beetle) adult	0	0	0	0
	Coleoptera (beetle)larva	0	0	0	0
	Dermaptera (earwig)	0	0	0	0
	Diptera (fly) adult	0	0	0	0
	Diptera (fly) larva	0	0	0	0
	Formicidae (ant)	0	0	0	0
	other Hymenoptera (wasps, bees)	0	0	0	0
	Heteroptera (true bug)	0	0	0	0
	Isoptera (termite)	0	0	0	0
	Lepidoptera (moth) adult	0	0	0	0
	Lepidoptera (moth) larva	0	0	0	0
	Psocoptera (bark louse)	0	0	0	0
	Thysanoptera (thrips)	0	0	0	0
	Thysanura (silverfish, firebrat)	0	0	0	0
	insect pupa (in metamorphosis)	0	**2**	0	0
	unknown insect	0	0	0	0
COLLEMBOLA	Symphypleona	0	0	0	0
	Poduromorpha	0	0	0	0
	Entomobryomorpha	0	0	0	0
MYRIAPODA	Pauropoda	0	0	0	0
	Symphyla (glasshouse symphylans)	0	0	0	0
	Chilopoda (centipede)	0	0	0	0
	Diplopoda (millipede)	0	0	0	0
ARACHNIDS	Araneae (spider)	0	0	0	0
	Acari (mites)	0	0	0	0
	Pseudoscorpionida	0	0	0	0
MOLLUSCS	Gastropoda (snail)	0	0	0	0
	Slug	0	0	0	0
CRUSTACEANS	Isopoda	0	0	0	0
	Amphipoda	0	0	0	0
PRIMITIVE SOIL ARTHROPODS	Protura (coneheads)	0	0	**1**	0
	Diplura (2-pronged bristletail)	0	0	0	0
	Box Mite	0	0	**1**	0
	TOTAL	**0**	**2**	**2**	**0**

Results from the soil invertebrate analysis suggest that invertebrates primarily exist where vegetation is present. There was no significant correlation between percent vegetation and invertebrate density (P>0.05) but this is likely a result of the methods. More random samples are needed to test for correlations between the presence of soil invertebrates and vegetation. Samples should also be taken along a transect in a direction away from a plant for correlation.

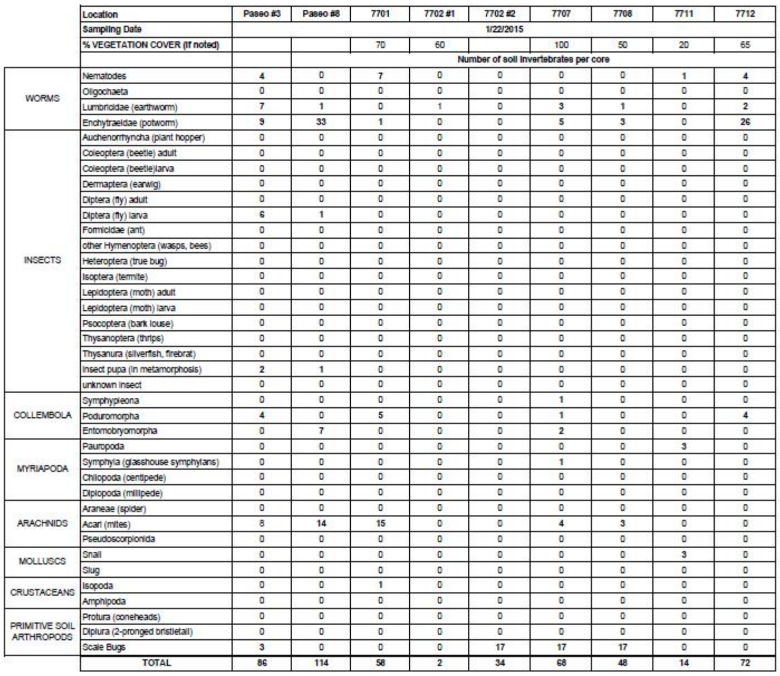
The presence of invertebrates in the SIO biofilters varied significantly throughout the year. The very low density of soil invertebrates present in February 2016 may be attributed to significant rainfall in early 2016. Between January 4 2016 and January 6 2016, 2.99” of rainfall were recorded in San Diego (Weather Underground 2016). Perhaps this flushed a lot of the invertebrates out when the biofilters became flooded and were unable to drain (Figure 12).

Figure 12 - TC-01 Flooded on January 7, 2016

There seems to be a correlation between the presence of soil invertebrates and certain plants, but a better sampling methodology is needed to accurately determine the significance (P=0.5867). Seaside daisy appears to support the most taxa; purselane and Menzies' goldenbush also support some soil invertebrate life (Table 6 and Table 7). No taxa were found near the unidentified weed or iceplant (Table 8).

As discussed in Section 3, "ecosystem engineers" may have positive effects on the function of biofilters. Though potworms were present in May 2015 in TC-01, the only other "ecosystem engineers" found in the samples were springtails, whose presence was detected in TC-01 in August 2015 (Table 7). Here I draw comparisons with fauna of Elmer Avenue Green Street, a biofilter site in inland Los Angeles County which was analyzed for soil invertebrates (Table 9). This biofilter site had more soil invertebrates present, with generally similar taxa. The most notable difference is the presence of Lumbricidae (earthworm) in the Elmer Ave sites. Because of the presence of ecosystem engineers, the Elmer Avenue biofilters are likely receiving some of the ecosystem benefits that the SIO biofilters are not.

Table 9 - Fauna present in Elmer Ave Biofilters on January 22, 2015



	Location	Paseo #3	Paseo #8	7701	7702 #1	7702 #2	7707	7708	7711	7712
	Sampling Date	1/22/2015								
	% VEGETATION COVER (if noted)			70	60		100	50	20	65
			Number of soil invertebrates per core							
WORMS	Nematodes	4	0	7	0	0	0	0	1	4
	Oligochaeta	0	0	0	0	0	0	0	0	0
	Lumbricidae (earthworm)	7	1	0	1	0	3	1	0	2
	Enchytraeidae (potworm)	9	33	1	0	0	5	3	0	26
INSECTS	Auchenorrhyncha (plant hopper)	0	0	0	0	0	0	0	0	0
	Coleoptera (beetle) adult	0	0	0	0	0	0	0	0	0
	Coleoptera (beetle)larva	0	0	0	0	0	0	0	0	0
	Dermaptera (earwig)	0	0	0	0	0	0	0	0	0
	Diptera (fly) adult	0	0	0	0	0	0	0	0	0
	Diptera (fly) larva	6	1	0	0	0	0	0	0	0
	Formicidae (ant)	0	0	0	0	0	0	0	0	0
	other Hymenoptera (wasps, bees)	0	0	0	0	0	0	0	0	0
	Heteroptera (true bug)	0	0	0	0	0	0	0	0	0
	Isoptera (termite)	0	0	0	0	0	0	0	0	0
	Lepidoptera (moth) adult	0	0	0	0	0	0	0	0	0
	Lepidoptera (moth) larva	0	0	0	0	0	0	0	0	0
	Psocoptera (bark louse)	0	0	0	0	0	0	0	0	0
	Thysanoptera (thrips)	0	0	0	0	0	0	0	0	0
	Thysanura (silverfish, firebrat)	0	0	0	0	0	0	0	0	0
	Insect pupa (in metamorphosis)	2	1	0	0	0	0	0	0	0
	unknown insect	0	0	0	0	0	0	0	0	0
COLLEMBOLA	Symphypleona	0	0	0	0	0	1	0	0	0
	Poduromorpha	4	0	5	0	0	1	0	0	4
	Entomobryomorpha	0	7	0	0	0	2	0	0	0
MYRIAPODA	Pauropoda	0	0	0	0	0	0	0	3	0
	Symphyla (glasshouse symphylans)	0	0	0	0	0	1	0	0	0
	Chilopoda (centipede)	0	0	0	0	0	0	0	0	0
	Diplopoda (millipede)	0	0	0	0	0	0	0	0	0
ARACHNIDS	Araneae (spider)	0	0	0	0	0	0	0	0	0
	Acari (mites)	8	14	15	0	0	4	3	0	0
	Pseudoscorpionida	0	0	0	0	0	0	0	0	0
MOLLUSCS	Snail	0	0	0	0	0	0	0	3	0
	Slug	0	0	0	0	0	0	0	0	0
CRUSTACEANS	Isopoda	0	0	1	0	0	0	0	0	0
	Amphipoda	0	0	0	0	0	0	0	0	0
PRIMITIVE SOIL ARTHROPODS	Protura (coneheads)	0	0	0	0	0	0	0	0	0
	Diplura (2-pronged bristletail)	0	0	0	0	0	0	0	0	0
	Scale Bugs	3	0	0	0	17	17	17	0	0
	TOTAL	86	114	58	2	34	68	48	14	72

Section 6: Biofilter Metal, Nutrient, and Bacteria Removal Performance

The historic performance of biofilter TC-01 was analyzed using the influent and effluent concentrations of stormwater. This information was gathered between November 2010 and March 2016; samples were collected on 11 different occasions. The sampling frequency was dictated by funding and occurred 2-3 times per year; therefore samples were not collected every time a rain event occurred. New data gathered on two different occasions in March and May 2016 were analyzed to evaluate the performance of TC-02, TC-03, and TC-04 based on influent and effluent concentrations. Since stormwater from the Scripps biofilters discharges directly in the ocean, I will compare the effluent concentrations to the concentration of pollutants that have been determined to affect marine life.

In 2012, a California Ocean Plan was adopted by the State Water Resources Control Board (SWRCB) to prevent degradation of marine communities and exceedances of water quality objectives due to waste discharges (State Water Resources Control Board 2012). Since a TMDL does not exist for the ocean at Scripps, the values from this document will be used as a basis of comparison for the biofilter performance (State Water Resources Control Board 2012). For the purposes of this experiment, I will use the instantaneous maximum values, which are applicable to the grab sampling methodology that was used to gather the data (Table 10).

Table 10 - Water Quality Objectives for Marine Life Protection

Water Quality Objectives for Protection of Marine Aquatic Life	
Water Parameter	*Instantaneous Maximum*
Copper	30 µg/L
Zinc	200 µg/L

To measure other constituents of concern, I will use the criteria established in the San Diego Region Basin Plan (Table 11), where bacteria are measured according to the most probable number (MPN) of organisms present in 100 mL; a common method to determine bacterial densities (San Diego Water Board 2012).

Table 11 - Basin Plan Water Quality Guidelines

San Diego Basin Plan Water Quality Objectives	
Water Parameter	Basin Plan Guideline Value
Nitrate	>1 mg/L
Ammonia	>0.025 mg/L
Total Phosphorus	>0.1 mg/L
E. coli	>406 MPN/100 mL
Enterococcus	>108 MPN/100 mL

Analyses using these criteria are consistent with the watershed-specific pollutants of concern described in the La Jolla Shores Coastal Watershed Management Plan, which is used to protect and improve water quality for the receiving waters (La Jolla Shores Watershed Management Group 2008).

6.1 Copper and Zinc Removal

Copper and zinc are essential elements for all living organisms, but elevated levels can be harmful to all biological species (EPA 2002). These metals in dissolved form can be taken up directly by bacteria, algae, plants, and aquatic organisms, or they can adsorb to particulate matter and enter organisms through various routes (EPA 2002). The biofilter performance was measured for both “total” metals and “dissolved” metals, where “total” represents the sum of all size fractions, and “dissolved” samples yield metals in solution.

Copper and Zinc Historic Performance in TC-01

The performance of TC-01 was analyzed using data gathered between November 2010 and April 2016 for copper and zinc by looking at the influent and effluent concentrations (Figure 13, Figure 15). Since 2010, biofilter TC-01 has been reducing the amount of total copper and total zinc from the influent to the effluent discharge (Figure 13). Total copper effluent concentrations are generally below the basin plan guidelines of 30 µg/L, while total zinc effluent concentrations are consistently below the basin plan guideline of 200 µg/L (Figure 13).

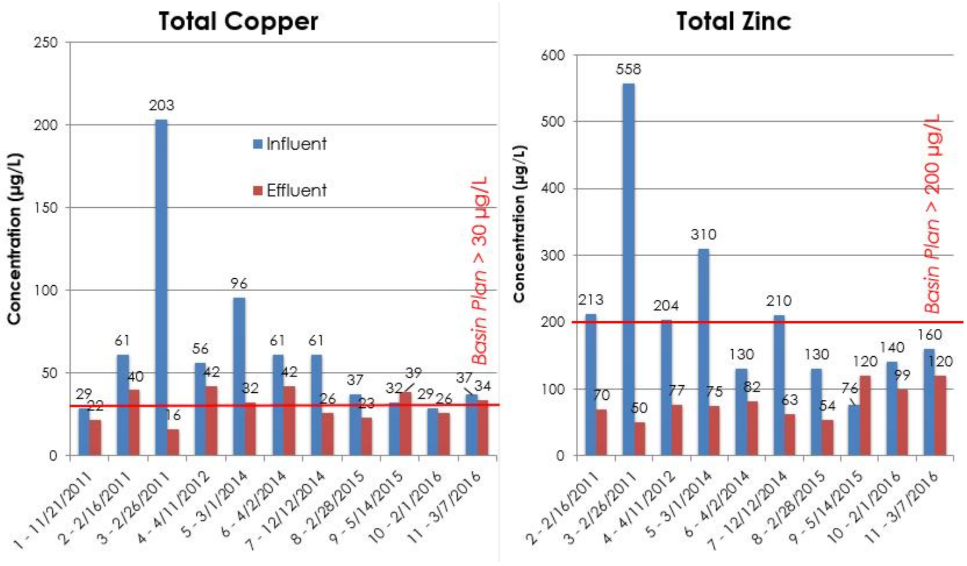


Figure 13 -Total Copper and Zinc Historical Removal in TC-01. Influent concentrations are shown in blue and effluent concentrations shown in red, values given above each bar. (University of California 2015). The basin plan standards for both pollutants are shown as a red horizontal line.

Though the effluent concentration of total copper was above the basin plan goal on four separate occasions, the dilution of these discharges within the mixing zone likely results in lower concentrations of copper and zinc in the ocean water within the ASBS (La Jolla Shores Watershed Management Group 2008).

These data were also analyzed regarding the percent removal of total copper and total zinc (Figure 14). The percent removal was generally positive, but began declining after February 2011. The percent removal of total copper was at a high of 92.1% in February 2011; compared to the most recent sampling event in March 2016 which only had a percent total copper removal of 8.1%. The percent removal of total zinc was also at a high in February 2011 with 91.0% removed, compared to only 25.0% removed in March 2016.

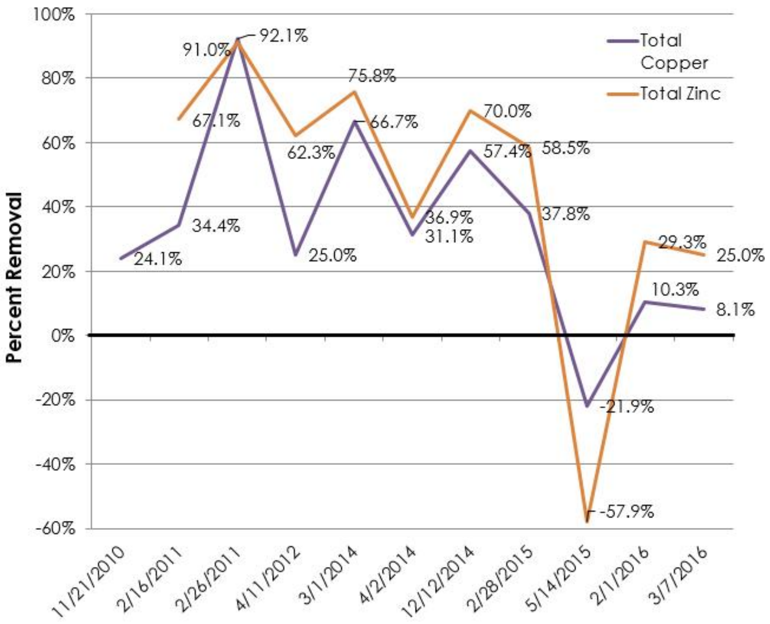


Figure 14 - Total Copper and Total Zinc percent removal in TC-01.

Since the biofilters were not sampled for every single rain event, I analyzed the data to see if there was a relationship between the number of days since the last rain event and the removal ability of the biofilter. However, there was no relationship between the number of days since the last rain event or the amount of rainfall and the influent concentration, effluent concentration, or percent pollutant removed of total copper or total zinc (P>0.05).

The biofilters were not as capable at reducing the concentration of dissolved copper or dissolved zinc as they were for total copper and total zinc. For dissolved copper, the effluent concentration was often higher than the influent concentration for rain events occurring after 2011. In contrast, the concentration of dissolved zinc was often reduced by the biofilter (Figure 15).

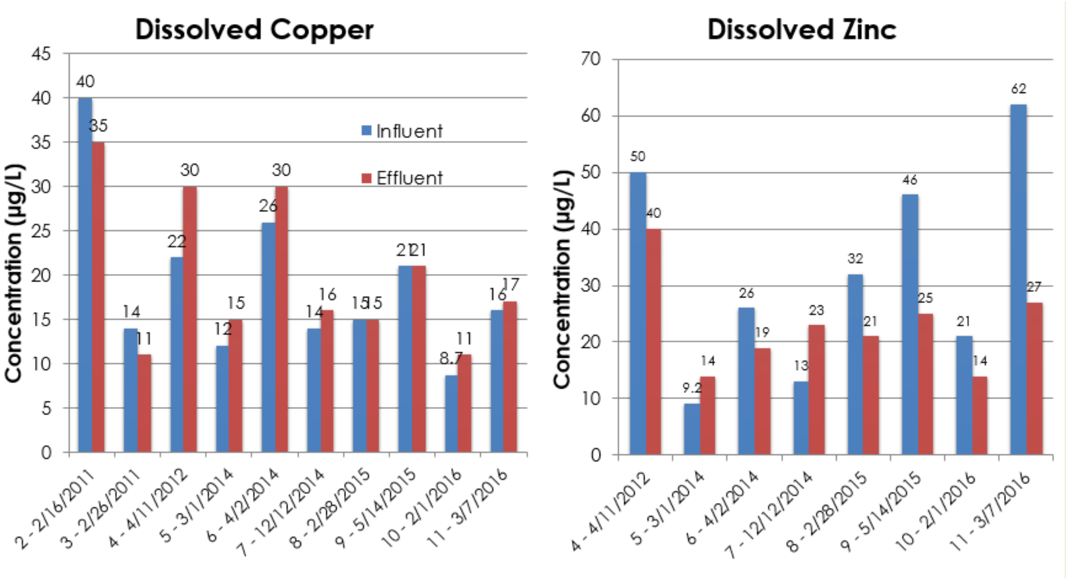


Figure 15 - Dissolved Copper and Zinc Historical Removal in TC-01. Influent concentrations are shown in blue and effluent concentrations shown in red, values given above each bar. (University of California 2015).

This may be a result of metals binding to particulates that are being removed and stored within media, and stormwater flushing may be adsorbing an additional dissolved fraction of metals, which has been observed in previous studies (Brown and Bay 2006). Looking at the bigger picture, the differences in concentrations of dissolved metals are relatively minor due to the low concentrations measured.

The pollutant percent removal of dissolved metals in TC-01 fluctuated significantly (Figure 16). The concentration of effluent dissolved copper was higher than the influent concentration except for in in February 2011. There was a maximum increase of 36.4% dissolved copper between the influent and effluent concentrations. Dissolved zinc had better results, and since 2015 the percent removal has ranged from 34.4% to a high in March 2016 of 56.5% (Figure 16).

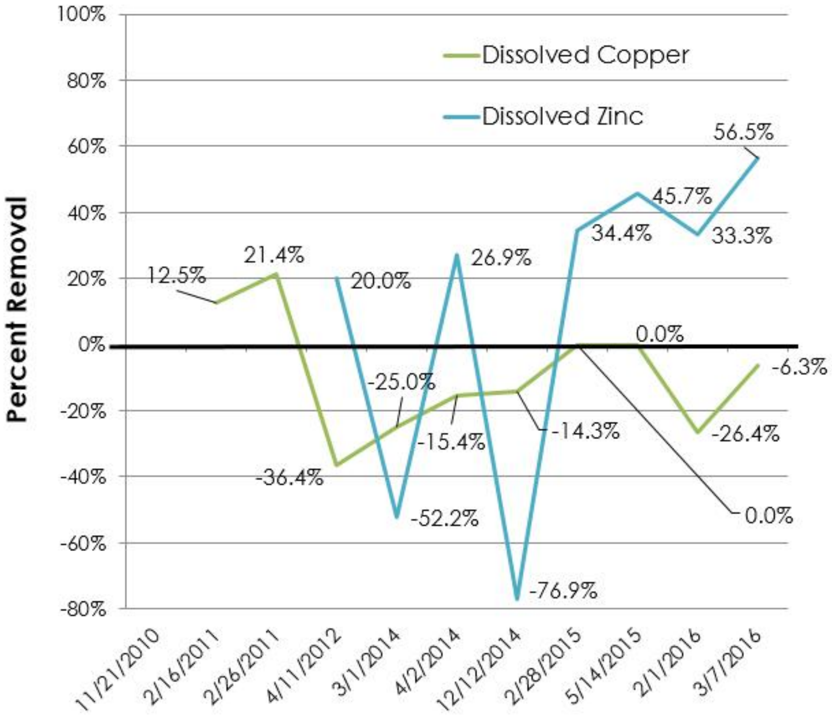


Figure 16 - Dissolved Copper and Dissolved Zinc percent removal in TC-01.

Similar analysis was completed to see if there was a relationship between rainfall and dissolved copper and zinc removal abilities. However, there was no relationship between the number of days since the last rain event or the amount of rainfall and the influent concentration, effluent concentration, or percent pollutant removed for dissolved copper and dissolved zinc (P>0.05).

Copper and Zinc 2016 Performance

Total metal data collected during March and May 2016 for TC-01, TC-02 and TC-04 produced similar results to the historic performance of TC-01; the biofilters reduced the amount of total copper and total zinc leaving the biofilter (Figure 17). No effluent discharge was observed leaving TC-03, which implies that the biofilter was clogged at either the inlet or the outlet. TC-03 is significantly smaller than the other three biofilters, so perhaps this particular biofilter became too full of sediment to accept any more flow.

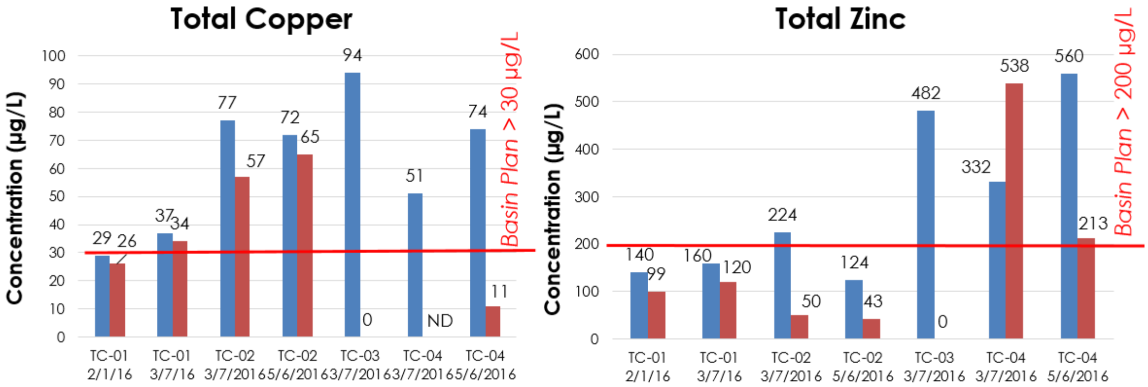


Figure 17 - 2016 Total Copper and Total Zinc Removal. Influent concentrations are shown in blue and effluent concentrations shown in red, values given above each bar.. The basin plan standards for both pollutants are shown as a red horizontal line.

Similar to the historic results of TC-01, the total copper concentrations leaving TC-01, TC-02 and TC-04 were above the basin plan goal (Figure 17), but again these discharges are diluted in the mixing zone.

An analysis was performed to see if the percent vegetation cover or rainfall impacted the biofilter removal ability of copper and zinc. However, there was no correlation between percent vegetation, rainfall total, or number of days since last rain event, and the influent concentration, effluent concentration, or percent pollutant removed of total copper and total zinc ($P>0.05$).

6.2 Total Suspended Solids Removal Efficiency

Total suspended solids (TSS) are an important water quality parameter as they can alter physical, chemical, and biological properties of aquatic ecosystems (Dahlgren, Van Nieuwenhuyse and Litton 2004). These modifications can include changes in temperature, nutrient levels, turbidity, and habitat of aquatic organisms. Through particle binding, they can carry trace metals (such as copper, lead and zinc), nutrients (such as phosphorus and nitrogen), and microorganisms (such as *E.coli* and *Enterococcus*) (Cordone and Kelley 1961) . These particles provide a mechanism for eventual incorporation into the food web (Cordone and Kelley 1961).

TSS Historic Performance in TC-01

Historically, the concentration of TSS leaving TC-01 has been significantly lower than the concentration of TSS entering TC-01 (Figure 18). TSS percent removal has always been positive, but since December 2014 has been rapidly declining, with a high of 93.1% removed in December 2014, compared to only 7.1% removed in March 2016 (Figure 18).

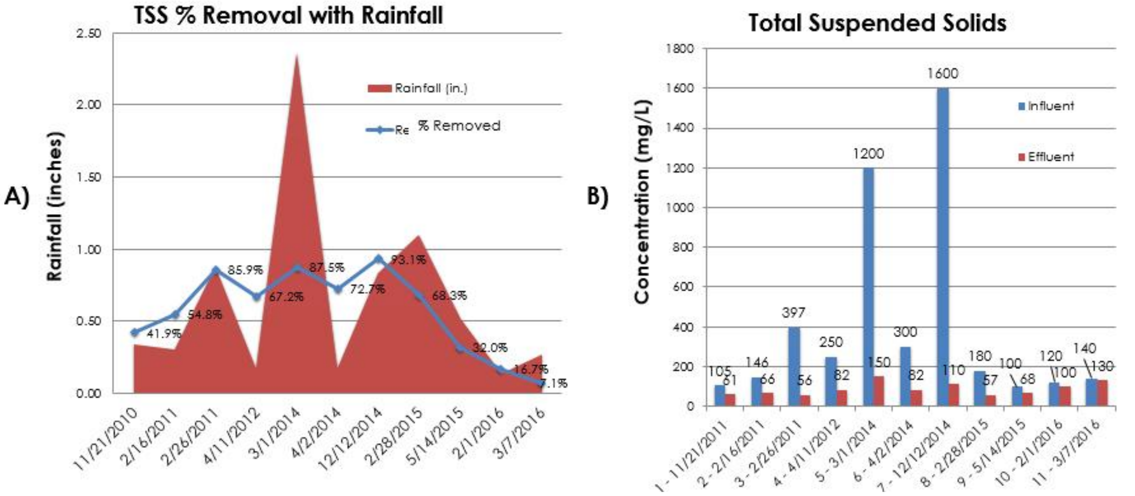


Figure 18 – Historic Total Suspended Solids Removal in TC-01. (A) Rainfall (inches) in red, percent TSS removal shown as blue line. (B) Influent concentrations are shown in blue and effluent concentrations shown in red, values given above each bar.

There is a correlation between the amount of rainfall and the TSS influent concentration ($R^2=0.4238$, $P=0.03$); more rainfall results in a higher influent TSS. This suggests that more rainfall likely results in more erosion and sediment entering the stormwater. There was no correlation between number of days since last rain and influent concentration, effluent concentration, or percent of TSS removed.

TSS 2016 Performance

TSS data collected during 2016 for TC-01, TC-02 and TC-04 produced similar results to the historic performance of TC-01; the biofilters always significantly reduced the concentration of TSS leaving each biofilter. Biofilter TC-03 was clogged and produced no effluent discharge (Figure 19).

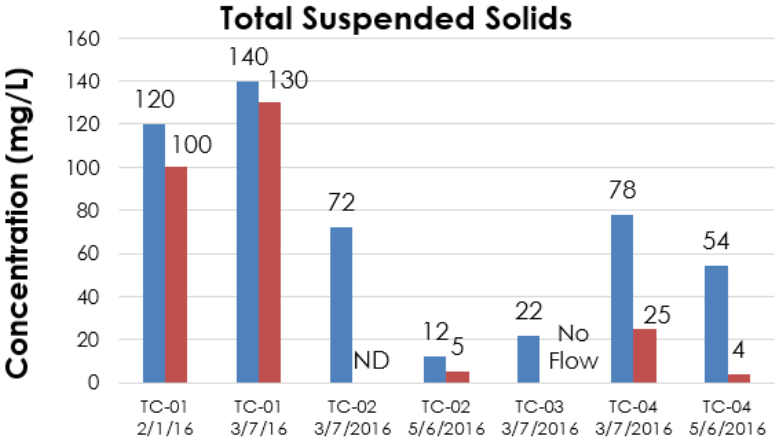


Figure 19 - 2016 Total Suspended Solids Removal. Influent concentrations are shown in blue and effluent concentrations shown in red, values given above each bar.

There was no correlation between percent vegetation, rainfall total, or number of days since last rain event, and the influent concentration, effluent concentration, or percent TSS removed ($P>0.05$).

6.3 Bacteria and Nutrient Removal Performance

Bacteria and nutrient analyses were not performed on the biofilters until 2016, but these are important indicators of water quality. *E. coli* and *Enterococcus* bacteria are indicators of water contamination by fecal material (i.e. animal fees or human sewage), which indicate the presence of pathogens that can cause illness (U.S. EPA 2012). Nutrients such as nitrogen and phosphorus are also important water quality indicators. Both are natural parts of aquatic ecosystems, but high levels can cause eutrophication, produce pollutants such as ammonia, and can seriously harm our waterways (U.S. EPA 2015).

Bacteria 2016 Performance

Biofilter performance for TC-02 and TC-04 was measured regarding three different types of bacteria; *E. coli*, *Enterococcus*, and total coliform (Figure 20). *E. coli* and *Enterococcus* are indicator bacteria that are typically associated with pathogens, and are important for human health as higher than normal levels typically indicate the presence of pathogens and can be harmful to humans. It was not possible to analyze the bacteria concentrations in TC-01 because the auto sampling equipment was mounted in the influent and effluent boxes; grab sampling could have disturbed the sampling process and was therefore forbidden by UCSD. It was also not possible to analyze TC-03 because no effluent discharge was recorded.

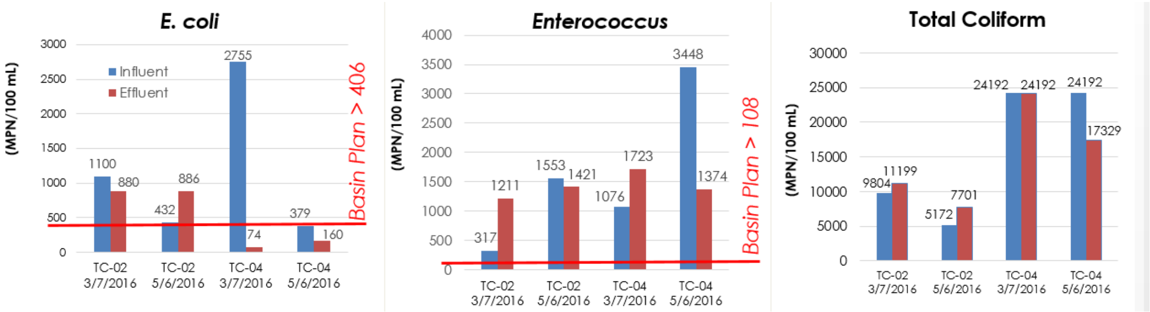


Figure 20 - 2016 Bacteria Removal. Influent concentrations are shown in blue and effluent concentrations shown in red, values given above each bar. The basin plan standards for both pollutants are shown as a red horizontal line.

The amount of *E. coli* was reduced during both rain events in TC-04, and for the March 2016 rain event in TC-03 (Figure 20). However, the amount of *E. coli* leaving TC-02 was above the basin plan guideline of 406 MPN/100 mL. The *Enterococcus* removal varied; it increased in both TC-02 and TC-04 for the March 2016 rain event, and was reduced in both biofilters during the May 2016 rain event (Figure 20). *Enterococcus* was significantly above the basin plan guideline of 108 MPN/100 mL in all biofilters. Total

Coliform levels were increased in the effluent discharge in TC-02 in both rain events, and the concentration was reduced in the May 2016 rain event for TC-04.

There was no correlation between percent vegetation, rainfall total, or number of days since last rain event, and the influent concentration, effluent concentration, or percent bacteria removed (P>0.05) for *E.coli*, *Enterococcus*, or Total Coliform. Biofilters TC-02 and TC-04 are not reducing the bacteria levels in the influent stormwater, and are often discharging higher levels of bacteria in the effluent stormwater. This data can likely be extrapolated to the other two biofilters, which means there is much room for improvement in the design of the SIO biofilters to specifically target bacterial reduction.

Nutrients 2016 Performance

Biofilter performance for TC-02 and TC-04 was measured for three different nutrients: nitrate, ammonia, and phosphorus (Figure 21).

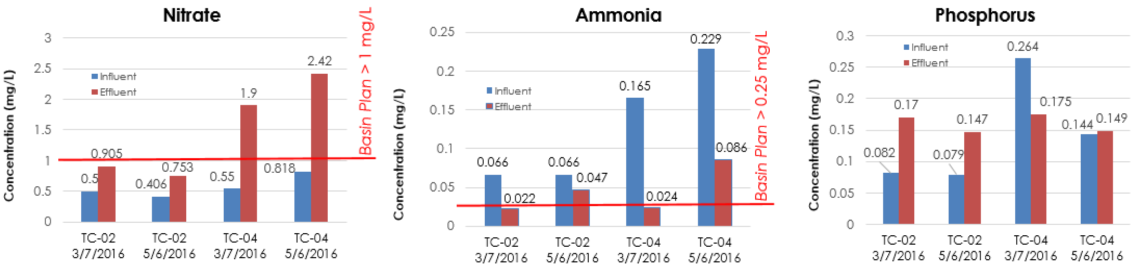


Figure 21- 2016 Nutrient Removal. Influent concentrations are shown in blue and effluent concentrations shown in red, values given above each bar. The basin plan standards are shown as a red horizontal line.

The effluent nitrate concentration is above the basin plan guideline of 1 mg/L exiting TC-04 in both sampling events, and the effluent concentration exiting TC-02 is under the basin plan guideline for both events. Effluent ammonia was reduced by the biofilters to below the basin plan guideline of 0.25 mg/L in TC-02 and TC-04 on March 7, 2016, but exceeded the basin plan guideline on May 6, 2016 for both biofilters.

A few significant correlations were found in these results. While ammonia concentrations were reduced by both biofilters in both rain events, nitrate levels were increased exiting both biofilters in both events. There is a relationship between rainfall and ammonia; the more days since the last rain event, the less effluent ammonia (R^2=0.9588 P=0.0208). This suggests that nitrification, which converts ammonium to nitrate, may be occurring in between rain events when the biofilter is drained and aerobic conditions exist. This may have resulted in the accumulation of nitrate in unsaturated soils, which may have been flushed out during the next rain event (Davis et al. 2001). These results agree with past research on biofilters in Maryland that showed poor nitrate reduction and occasionally nitrate production when comparing the influent and effluent concentrations (Davis et al. 2009).

More rainfall also resulted in a higher effluent ammonia concentration (R^2=0.9588 P=0.0208). This also agrees with past research, which showed that increasing the intensity and duration of rain result in an increase of infiltration into the soil, and a reduction in pollutant removal rate (Davis et al. 2006).

There is a correlation between vegetation and nitrate levels; more vegetation cover resulted in less effluent nitrate (R^2=0.9235, P=0.039). More vegetation cover also resulted in a higher percent removal of nitrate (R^2=0.9384, P=0.0313). This is consistent with past research regarding the ability of plants to remove TN found in stormwater runoff (Davis et al. 2009).

There is a correlation between rainfall and phosphorus; the more days since the last rain event, the higher effluent phosphorus concentration (R^2=0.9767, P=0.0119). The more rainfall, the lower effluent concentration of phosphorus (R^2=0.9764, P=0.0119). This suggests that more phosphorus is released during dry conditions.

There is also a relationship between phosphorus and vegetation; more vegetation results in less percent phosphorus removed. This does not agree with literature and the removal ability of plants, but perhaps the small sample size is to blame for this inconsistency. More research is needed to examine the relationship between nutrient removal and vegetation in the SIO biofilters.

6.4 Discussion

The biofilters have historically removed total copper, total zinc, and TSS from the influent stormwater (Figure 13, Figure 16, and Figure 18). The design retrofit in 2013 did not appear to significantly change the percent pollutant removals in TC-01; though the removal efficiency initially spiked (Figure 22).

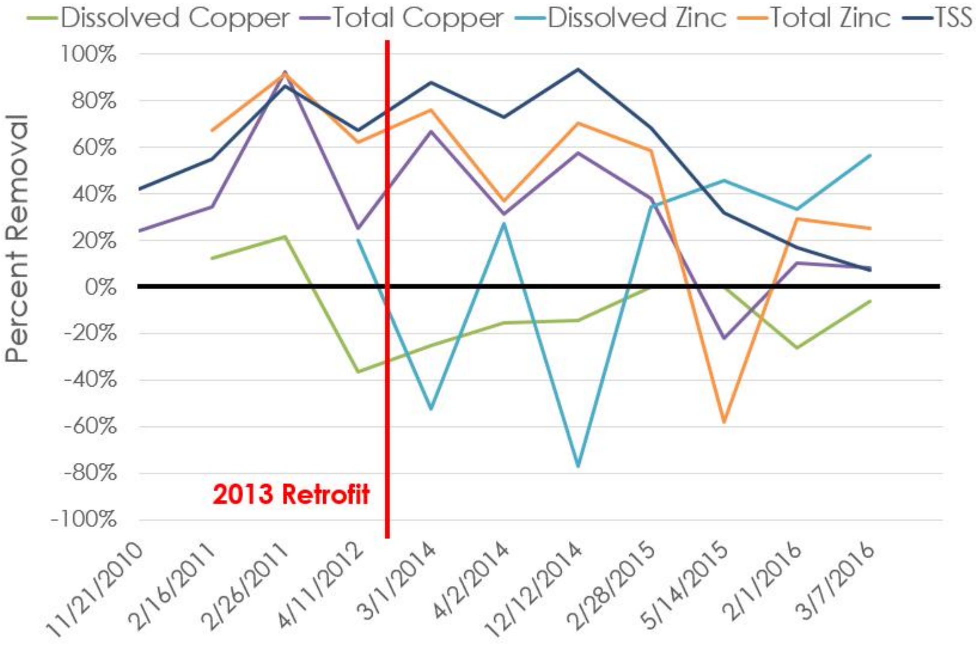


Figure 22 - TC-01 Historic Performance of dissolved copper and zinc, total copper and zinc, and total suspended solids removal. Red line indicates design retrofit in 2010.

It seems that percent removal of all pollutants in TC-01 has been declining since December 2014, which is coincidentally when the TSS percent removal also significantly declined. Perhaps this is a result of the biofilters becoming clogged with sediment. A calculation was performed to see approximately how much volume is in each of the four biofilters, assuming the soil has 40% void space (Table 12). Considering this explanation, it would make sense that TC-03 is completely clogged; it has approximately 10% of the capacity of TC-01 or TC-02. It is likely that once a certain volume of sediment enters the biofilter, the voids fill up and pollutant removal abilities decline. In standard biofilter design where runoff enters the top of the biofilter, routine maintenance includes removing the top few inches where TSS have accumulated. Since stormwater is piped into the SIO biofilters this method would not be as effective. Perhaps there is a way to ensure the soil towards the upstream end of the biofilter is replaced, by routinely cleaning out the soil surrounding the perforated pipe or drainage cell.

Table 12 - Area, volume, and void space of TC-01, TC-02, TC-03 and TC-04

	Area (m^2)	Depth (m)	Volume (m^3)	Void space (m^3)
TC-01	144	0.4572	65.84	26.33
TC-02	152	0.4572	69.49	27.80
TC-03	15	0.4572	6.86	2.74
TC-04	20	0.4572	9.14	3.66

6.5 Biofilter Design Differences

The historic data from TC-01 regarding copper, zinc, and TSS were relatively consistent with the data from 2016 for TC-02 and TC-04. TC-03 produced no effluent flow during any of the monitoring events, leading to the conclusion that it is completely clogged. The spatial area of TC-03 is also significantly smaller (Table 12) than two of the other biofilters, which means the perforated pipe has less area to distribute over and might clog more easily.

The influent total metal concentrations may be correlated with the land use of the catchment area draining to each of the biofilters. Copper levels of influent stormwater entering TC-02 (72 µg/L to 77 µg/L) are slightly higher than the stormwater going into TC-04 (51 µg/L to 74 µg/L). This may be attributed to the use of brake pads; TC-02 receives stormwater runoff from Discovery Way on SIO campus, a steep road, which requires cars to use their brakes. The parking lot adjacent to TC-04 is flat, which does not require as much brake use. Zinc levels of influent stormwater are higher entering TC-04 (332 µg/L to 560 µg/L) compared to TC-02 (124 µg/L to 224 µg/L). This may be attributed to tire use, as the parking lot is frequently used by visitors to SIO and cars idling to look at the surf conditions.

Section 7: Conclusion and Design Recommendations

Much can be learned from the analysis of the stormwater data from the Scripps biofilters, as the performance of a biofilter is rarely monitored at all, let alone years after implementation. In general, the biofilters on SIO campus are still functioning six years after their construction. They are still reducing the concentration of the specific pollutants (copper, zinc, and TSS) for which they were intended, but percent removal is seriously declining, and the biofilters may stop working if they are not replaced. The data from 2016 has shown that while the biofilters reduce the amount of ammonia and *E. coli,* the biofilters are not removing nitrogen, phosphorous, or *Enterococcus* from the stormwater. The design can be improved to target these specific pollutants and to make the biofilters more effective.

An increase in vegetation in the biofilters will improve their function, based on the data that showed a positive relationship between percent vegetation and nitrate removal. In addition, previous biofilter research suggests that vegetation has the ability to significantly improve the function of the biofilters; especially regarding N and P removal (Read et al. 2009). An increase in vegetation will likely result in an increase in soil invertebrates; an increase in soil invertebrates may result in less maintenance as invertebrates may improve the utility of the system (through increased bioturbation, plant growth, nutrient uptake, and organic matter breakdown). Here I present some ideas for the improvement of the SIO biofilter design.

7.1 Design Recommendations

One of the greatest obstacles to successful SIO biofilter vegetation is the irrigation restrictions due to the ASBS discharge designation. There needs to be a solution for providing irrigation to the biofilters during periods of drought without violating the dry-weather flow restriction. This would allow plants to establish themselves, develop soil fauna, and potentially receive ecosystem benefits. Some suggestions to this problem are as follows:

1. **Saturated Zone:**

   A saturated zone could be incorporated below the gravel layer which allows for water storage and can provide irrigation for the vegetation. Plant roots would have access to water during extended dry periods, and the biofilter would be able to retain moisture between storms. This option would ensure no dry weather flows exit the biofilter; excess water from irrigation would remain in the saturated zone. Saturated zones have also been shown to significantly enhance the removal of fecal indicator bacteria (Rippy 2015). This option is relatively inexpensive, as the biofilters would need to be deeper but could have a similar design mechanism.
2. **Rain Barrels:**

   Roofs from the adjacent buildings could be equipped with rain barrels; specifically the Administration Building, Scripps Seaside Forum, Surfside and Caroline's Café. The use of rain barrels would reduce the reliance on potable water. A specific watering plan (including calculation of watering volumes for each biofilter) could be implemented to ensure no dry weather flows could leave the biofilters.
3. **Deeper Soil Layer:**

   A deeper biofilter would result in a larger volume of soil media. This would allow for more heavy metal and TSS removal, as the soil media is the primary removal mechanism. The incorporation of organic matter into the design might improve the dissolved metal removal abilities, as metals tend to stick to organic matter. The current biofilters are only 18” deep, which is very shallow considering their large spatial area. Deeper biofilters can also store more water and allow for deeper plant roots.

4. **Portable water tank:**

   The effluent sampling box could be closed or connected to a portable water storage container. If excess water were to leave the biofilter, it could be captured and recycled for future irritation needs.

5. **Greywater harvesting:**

   Greywater could be recycled from the adjacent buildings and used for irrigation; though this would require prior testing to ensure the greywater would not contribute more pollutants to the biofilter. This option would be better for biofilters on other parts of campus that do not discharge into the storm drain system or an ASBS.

All four biofilters should be retrofitted with the drainage cell technology that was installed on TC-01 in 2013. This will reduce the likelihood of clogging and allow for easier maintenance.

7.2 Outreach and Education

The incorporation of better educational signage might increase the public’s understanding of biofilter and raise interest in this approach to stormwater cleanup. The current signage for the SIO biofilters is minimal and has room for improvement (Figure 23).

Figure 23 - Signage at SIO regarding biofilter design (left) and the potential of biofilter signage, image from Coronado Cay (right)

Pedestrians visiting the campus may be less likely to litter; while conducting this research I found many cigarettes and beer cans in the biofilters. Giving the public a better understanding of the importance of biofilters may help prevent littering and may make them more likely to care.

The Levin Lab has been involved in a series of public workshops at Ocean View Growing Grounds in City Heights, San Diego CA, which is a neighborhood-run urban community project which involved the conversion of a vacant lot into a community garden (Figure 24). The workshops were intended to increase local community awareness of the environmental problems of the future and ideas for mitigation, such as biofiltration. By teaching the children environmental stewardship at a young age, they are more likely to protect and improve the environment. By involving the community in such public spaces, the implementation and stewardship of entities like biofilters improves, and they often have a longer lifespan.

Figure 24 - Local community members harvesting vegetables in Ocean View Growing Grounds, February 2016

7.3 Future Research

Looking ahead, there needs to be continued biofilter research specific to southern California. Ideally, the SIO biofilters would be continuously monitored to see if the soil reaches a maximum pollutant contamination. It would also be beneficial to monitor the biofilters after they are replaced in 2017, and to replace them in such a way to test the removal abilities of different vegetation combinations. A series of experimental biofilters and testing wells could provide great input for the future of biofiltration in southern California. The incorporation of the biodiversity-ecosystem function could be used in the design of these experimental biofilters. Since a relationship between the flora and fauna is likely, but was not documented in this study, further research could help illustrate this correlation. Ideally, soil samples would be taken along a transect moving away from various plant species to determine if a spatial relationship exists between invertebrates and plants. Random samples should be taken to see how the invertebrates continue to migrate and to determine if invertebrates prefer certain local species.

Biofilter ecology is complicated, and more scientific research will lead to better design. By improving the function of biofilters, we can provide long-term solutions to the water quality problems that have been intensified by human development.

Appendix 1 – SIO Biofilter Sampling Standard Operating Procedure Manual

SUMMARY OF METHOD

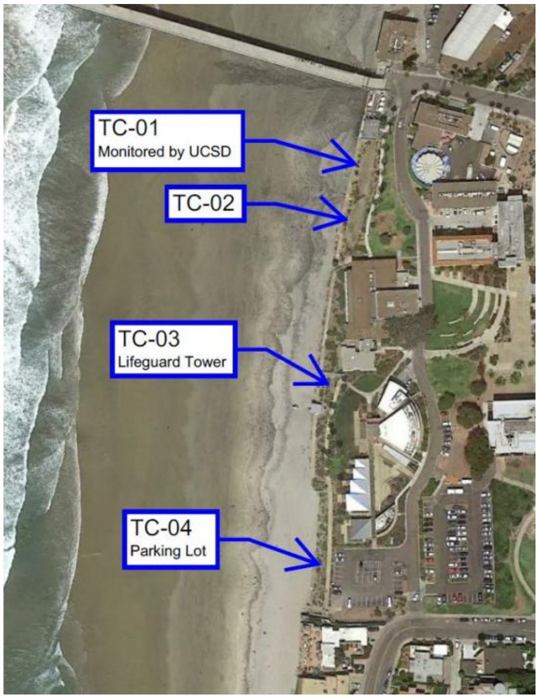
The following Standard Operating Procedure (SOP) will serve as a guidance document for all stormwater monitoring to occur at the SIO Biofilters.

Before each sampling event, we will meet in **Room 2229** in Sverdrup Hall.

Sampling Checklist:
- Sampling Bags
- Pole Sampler
- Sample Log
- Sharpie
- Manhole Opener
- Clean Nalgene bottles to combine samples (leave in lab)

If we need to print more sample logs, use printer svh2 (log-in:levinprint pw: worms)

We will be sampling TC-02, TC-03 and TC-04 as TC-01 is already monitored by UCSD, and we cannot disturb the equipment.



Appendix Figure A1 - Sampling Locations

CLEAN HANDS/DIRTY HANDS TECHNIQUE

Clean hands/dirty hands technique require two or more people working together. While sampling, one person is designated as clean hands (CH) and a second person as Dirty Hands (DH). Although specific tasks are assigned at the start, some tasks overlap and can be handled by either, as long as prescribed care is taken to prevent contaminating the sample.

- Both CH and DH wear appropriate disposable, powderless gloves during the entire sampling operation and change gloves frequently, usually with each change in task (wearing multiple layers of gloves allows rapid glove changes).
- Both CH and DH should start with a fresh pair of gloves when beginning the next site.

CLEAN HANDS (CH) gives and receives sampling containers, but otherwise minimizes contact with sampling equipment to reduce risk of cross-contamination. In general, roles of CH are:

- Retrieves sample bag
- Holds sample bag while DH closes the sampling pole clasps
- Receives full sample container from DH sampler and transfers sample to inner storage bag
- Records field data after samples have been collected

DIRTY HANDS (DH) operates all sampling equipment and is involved with all operations involving contact with potential sources of contamination. In general, tasks of DH are:

- handling of outer bottle storage bag
- opening of manhole/boxes
- collects sample with pole
- places sample in cooler, after CH places containers in inner storage bags
- handles water-flow equipment
- clasps sample bag onto pole
- cleans field equipment

UNIVERSAL GUIDELINES AND PRECAUTIONS

- Safety first- no water sample is worth risking your health/safety. When in doubt GET OUT!
- Wear gloves at all times
- Verify samples are being taken in exact location as indicated by field notebook
- Only collect a sample if the site has adequate water flow.
- Water samples are to be collected before any other activity is performed at the site
- Sampler should be positioned downstream from sample collection point
- Collect WQ samples from center of manhole
- Avoid touching bottom of manhole/box, avoid any residue from water surface
- Collect sample 3-5" below water surface (if possible)
- When using sampling pole and bottle: plunge upside down container into the water and rotate 90 degrees upstream and sweep through water to collect sample
- Take care when sealing sample bag to remove most of the air from the bag so that the sample bottle is not insulated from the ice by excessive air being trapped inside the bag

SEQUENCE OF SAMPLE COLLECTION AND ANALYSES:

Refer to "COLLECTING SAMPLES" for detailed procedures

1. Collect first 100 mL bag using sampling pole. Place into Ziploc bag with corresponding TC-#. Store in cooler immediately

2. Collect second 100 mL bottle as above. Place into Ziploc bag with corresponding TC-#. Store in cooler immediately

SAMPLE CONTAINER LABELING

Label each storage bag with:

- Media Filter ID
- In/Out
- Date and Time

In most cases, containers will be pre-labeled with site ID and site name. Clean hands is responsible for labelling the sample bottle with waterproof sharpie prior to sampling. These labels need to correlate with the similar fields on the site data collection sheet.

COLLECTING SAMPLES

We will be collecting two (2) 100 mL sample bags from each sampling location (6 total). The first will be used for lab analyses of bacteria/nutrients, the second will be sent away for metals/suspended solids analyses.

1. Prepare to sample. Clean hands labels sampling bag, and holds sampling bag while DH secures clamp around it. DH collects sample.
2. Collection.
   Sample bag in cuff is placed into water opening down, push down until you can rotate 90 degrees towards flow and push into flow until sampling bag is full. Avoid letting surface water enter the bag Scoop out of water column and bring towards self without spilling. CH will close sampling bag while DH removes the cuff. This is repeated for second sampling bag.
3. Storage
   The sampling bag is put into the inner clean bag and sealed by clean hands. DH seals the outer bag and places sample in cooler. Make sure to carefully remove most air when sealing bags (both CH inner bag and DH outer bag) so sample makes contact with ice and is not insulated by excessive air trapped in bags.

SAMPLING LOCATIONS

We will have 6 sampling locations in total. There are 3 media filters and we will sample the inlet and outlet of each media filter. We will work North→South, In→Out. The reason we will not be sampling the outlet right after the inlet for each media filter is to create a time lag and give the water some time to percolate throughout the media filter.

Location 1: TC-02 Inlet

- Remove MH Lid (marked Media Filter 2 Diversion)
- Take sample

Location 2: TC-03 Inlet

- Remove MH Lid (marked Media Filter 3 Diversion)
- Take sample

Location 3: TC-04 Inlet

- Attempt to remove grate (marked Media Filter 4 Diversion)
- Take sample
- **If grate is too heavy to move, create a ponded area and take sample directly on top of inlet
-

Location 4: TC-02 Outlet

- Remove Sampling Box Lid, take sample

Location 5: TC-03 Outlet

- Remove Sampling Box Lid, take sample

Location 6: TC-04 Outlet

- Remove Sampling Box Lid, take sample
- **If sampling box is too dangerous to reach, take sample of outlet pipe onto beach

SAMPLE SHORT TERM STORAGE AND PRESERVATION

Properly store and preserve samples as soon as possible. This is done immediately after collection by placing the containers on ice in the cooler (make sure samples are surrounded in ice, not just sitting on top of). Sufficient ice will be needed to lower the temperature to at least 4º C within 45 minutes after time of collection. Sample temperature will be maintained at 4ºC until delivered to the laboratory. Care is taken at all times during sample collection, handling, and transport to prevent exposure of sample to direct sunlight.

Once back in lab, samples will be combined for analysis. Refer to

FIELD SAFETY ISSUES

Proper gloves must be worn to prevent contamination of the sample and to protect the sampler from environmental hazards (disposable polyethylene, nitrile, or non-talc latex gloves are recommended). Never do anything to jeopardize your own or others safety.

BIOFILTER SITE DATA SHEETS

Each visited biofilter requires a completed Field Data Sheet.

- Refer to data sheet to monitor progress throughout field procedure
- Make sure to check all appropriate boxes and fill all blank fields paying special attention to measurement units
- Record any and all results when processing and reading make note of any change from procedure or results that seem unusual.
- Clean all equipment after use and between sites
- Remember to process one sub-watershed batch at a time as they come in from field with priority to keep under holding time.

CHAIN OF CUSTODY FORMS (COC)

Every sample bottle that will be returned to the lab must have a completed chain of custody form that correlates with it.
Samples should be traceable from collection or receipt in the laboratory through preparation and analysis to final archival or disposal. This process ensures the integrity of the samples from time of collection through sample disposal. Custody is defined as having control of the sample in one or more of the following manners: physical possession, in persons view after taking possession, secured by a person in a manner that prevents tampering of sample, and/or secured by a person in an area restricted to authorized personnel. The sample custodian is the person assigned the responsibility for custody of the sample at a given field site, laboratory, or testing facility. Include region and trip information as well as any special instructions to the laboratory.

TRANSFERRING CUSTODY

Record is in permanent ink on chain-of-custody form for receiving samples from the field and/or sediment preparation laboratory to a biological laboratory. The chain-of-custody forms travel with samples during the transfer, and are filed in the laboratory project files. Upon arrival at the laboratory, the sample custodian examines the sample containers to ensure the sample seals are intact and sample containers have not been damaged. If any containers have been damaged or mislabeled, the sample custodian takes custody of the samples by signing, dating, and noting the time in the on the chain-of-custody form. When you pass your samples along to another team for delivery to the SDCK lab, this constitutes as a transfer and the samples must be relinquished and received as stated above.

SUBDIVIDING SAMPLES

Once at the laboratory, if samples have to be subdivided and submitted to another laboratory, this information should be noted on the chain-of-custody form. With each transaction, the sample custodian relinquishes custody to the sample recipient who then becomes the next sample custodian.

COMBINING SAMPLES FOR ANALYSIS

600 mL is needed for each sample to be analyzed (500 mL to EnviroMatrix, 50 mL for Coastkeeper, extra 50 mL just in case). To combine samples, divide 600 mL by the number of samples. Let’s assume 4 samples are collected- so 150 mL would be used from each sample bag.

1. Pour sample bag into beaker up to 150 mL.
2. Pour beaker into the appropriately labeled 1000 mL Nalgene bottle.
3. Rinse beaker with DI water.
4. Repeat until all samples have been combined.
5. Invert Nalgene bottle a few times to mix sample.
6. Pour 500 mL of combined sample into the two EnviroMatrix bottles.
7. Place all 3 sample bottles on ice- deliver to EnviroMatrix and SDCK for analysis.

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