Final

James V. Fitzgerald Area of Special Biological Significance Pollution Reduction Program

Pilot BMP
Summary Report

Grant Identification Number 10-402-550

March 2013

Nicole David and David Gluchowski
San Francisco Estuary Institute

Summary

The County of San Mateo Department of Public Works and Parks implemented several types of structural stormwater treatment best management practices and low impact development practices concurrently at six locations where stormwater discharges into the protected James V. Fitzgerald Area of Special Biological Significance in Montara and Moss Beach, CA. The practices included two swale designs, a native grass sod swale and a vegetated swale with an under-drain system, and a flume filter device. The data for this pilot project showed that the monitored best management practices and low impact development practices reduced contaminant concentrations but also showed spatial and temporal variability due to individual system and watershed variations. Most particle-associated contaminant concentrations (polycyclic aromatic hydrocarbons, pyrethroids, chromium, copper, lead, nickel, and zinc) were reduced from the inflow of the best management practices and low impact development compared to the outflow. Moderately (30 – 70% reduction) to highly effective (70 – 100% reduction) treatment was measured at the vegetated swale and grassy swale sites, respectively. In general, longer residence times in both swale types seemed to be reducing contaminant concentrations more effectively than the very short residence times of stormwater in the flume filter best management practice. However, the different site characteristics (e.g., slope of road surface and additional entry points for untreated water between the inlet and the outlet) seemed to result in higher contaminant reduction rates at the grassy swale sites compared to the vegetated swale sites.

Introduction

Areas of Special Biological Significance (ASBS) are State of California designated coastal areas that support a diversity of aquatic habitat and life, often including unique species. These areas are granted special protection to promote resilient and healthy coastal ecosystems. As part of this protection, the State Water Resources Control Board aims to foster ASBSs by requiring that stormwater discharges do not alter natural water quality and meet Ocean Plan water quality objectives. The James V. Fitzgerald ASBS is one of the 34 ASBSs along the California coast. Its abundance in species habitat and species diversity attracts thousands of visitors every year for the educational experience of the tide pools and the scenic coastline.

Unfortunately, many ASBSs are under pressure from coastal development and urban encroachment. Stormwater runoff and runoff from landscaping irrigation, car washing, etc. especially in urban areas can deteriorate water quality and these fragile ecosystems because of contaminants that are washed off developed coastal landscapes during these runoff processes. Contaminants are often vehicle and road related, e.g., copper (Cu) from brake pads, zinc (Zn) and other metals from tire-wear particles and auto body debris, as well as trace organic contaminants like polycyclic aromatic hydrocarbons (PAH) that are introduced to the environment through combustion of fossil fuels for heating (oil, coal, wood, or gas) or transport (engine combustion, diesel particulates, engine or transmission leaks), leaking supply lines, or leaching from road surfaces comprised of asphalt. Additionally, contaminants can be introduced through roof and gutter materials or, in the case of public or private pesticide use, through homeowner or contractor application.

Rural land uses such as agriculture, ranching, equestrian facilities, and open space recreation also have the potential to introduce pollutants including nutrients and fertilizers, fecal contamination, pesticides, increased erosion rates related to trail and dirt roads, and changes to vegetation that can lead to increased runoff. Atmospheric deposition also plays a role in contributing contaminants from distant sources.

Various structural best management practices (BMPs) and green infrastructure or low impact development practices (LIDs), as it is often referred to, are known to help with the reduction of contaminant loads as well as with the improvement of the quality of discharged water in relation to contaminant concentrations. In Li and Davis (2009), bioretention cells showed reductions of contaminant concentrations and loads for sediment and metals. Additionally, a grassed filter strip installed along a highway in North Carolina reduced the concentrations of sediment and metals (Line and Hunt, 2009), and Boving and Neary (2007) showed that PAH concentrations can also be reduced using different filter materials for BMPs and LIDs. Nutrient reductions have been met with mixed results, possibly due to more complicated biological processes occurring in the treatment systems (Li and David, 2009; Line and Hunt 2009). In general, BMPs and LIDs have been successfully implemented and have effectively reduced contaminant loads and improved water quality draining to receiving water bodies.

To reduce contaminant concentrations draining into the Fitzgerald ASBS, a variety of BMPs and LIDs were installed in Montara and Moss Beach in the fall and winter of 2011. The pilot phase of this project intended to evaluate several types of BMPs/LIDs in order to guide decisions about a more wide-spread BMP/LID installation effort in upper watersheds in 2013 and 2014.The treatment types (either structural (BMP) or green infrastructure (LID)) reduce contaminant concentrations through adsorption, settling, decomposition, volatilization, and ion exchange (Dietz and Clausen 2006). This project integrated BMPs/LIDs into existing storm drains with the goal to reduce contaminant concentrations at the outflow of the treatment areas to below Ocean Plan objectives and to better understand contaminant sources from the ASBS drainages.

The Pacific Ocean at the James V. Fitzgerald Marine Reserve (within the ASBS boundary) and San Vicente Creek (also within the ASBS boundary) are listed on the 303 (d) List for impaired water bodies due to elevated coliform bacteria counts. Additionally, located immediately south of the Fitzgerald ASBS, Pillar Point Beach is listed on the 303 (d) List for high mercury concentrations and coliform bacteria. Reducing contaminant concentrations through BMPs/LIDs is essential for protecting beneficial uses and natural resources in the Fitzgerald ASBS. This pilot phase report, together with the Fecal Indicator Bacteria (FIB) report (David 2012) for creeks draining into the Reserve, aims to inform the County of San Mateo about the most effective BMPs/LIDs for water quality improvements and to help guide decisions for the second phase of the project. Beginning in the summer of 2013, the second phase of the project will involve installation of additional BMPs/LIDs in the Moss Beach and Montara area to reduce contaminant loading into the ASBS.

Methods
Site Description
Sampling sites (Figure 1, Table 1) were selected in the unincorporated communities of Moss Beach and Montara, San Mateo County, in the San Francisco Bay Area.The coastal communities of Montara and Moss Beach border the Reserve and ASBS. Their population in the 2010 census was 2,909 and 3,103, respectively. The communities are situated approximately 20 miles (32 km) south of San Francisco and 50 miles (80 km) north of Santa Cruz. Montara and Moss Beach cover an area of 3.9 square miles (10.0 km²) and 2.3 square miles (5.8 km²), respectively. Montara and Moss Beach have mild weather throughout the year. January average maximum temperature (56.9°F or 13.8°C) and September average maximum temperature (73.1°F or 22.8°C) span a narrow range based on the long-term record (NOAA National Climatic Data Center, Station 43714). Typical of central California, most of the rainfall occurs from November through April, normally totaling more than 27 inches (69 cm) (Figure 2).

Table 1. Sampling locations for pilot phase.

| Name	Type	Latitude	Longitude
Juliana Ave.	outfalls	37.52904	-122.51669
Seacliff Ct.	outfalls	37.54331	-122.51645
7th Street	outfalls	37.54270	-122.51687
FMR Parking Lot	outfalls	37.52409	-122.51677
North Lake	outfalls	37.52332	-122.51175
14th Street N	outfalls	37.53758	-122.51812
14th Street S	outfalls	37.53754	-122.51816
Cypress Ave.	outfalls	37.51988	-122.51336
Ocean Blvd.	outfalls	37.51289	-122.51038
Vallemar St.	outfalls	37.53126	-122.51709
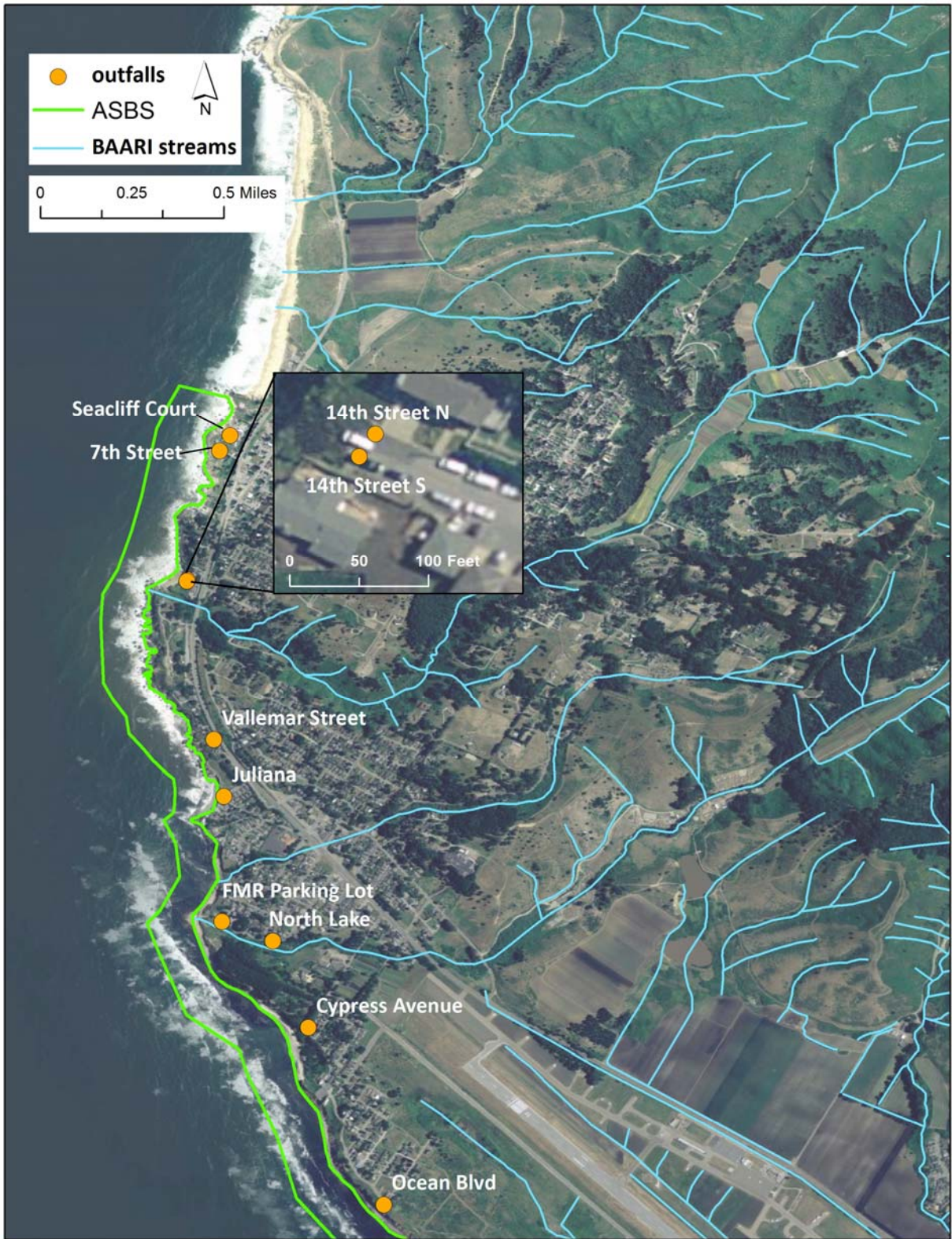
Figure 1. Map of the study area showing the sampling locations for pilot phase.
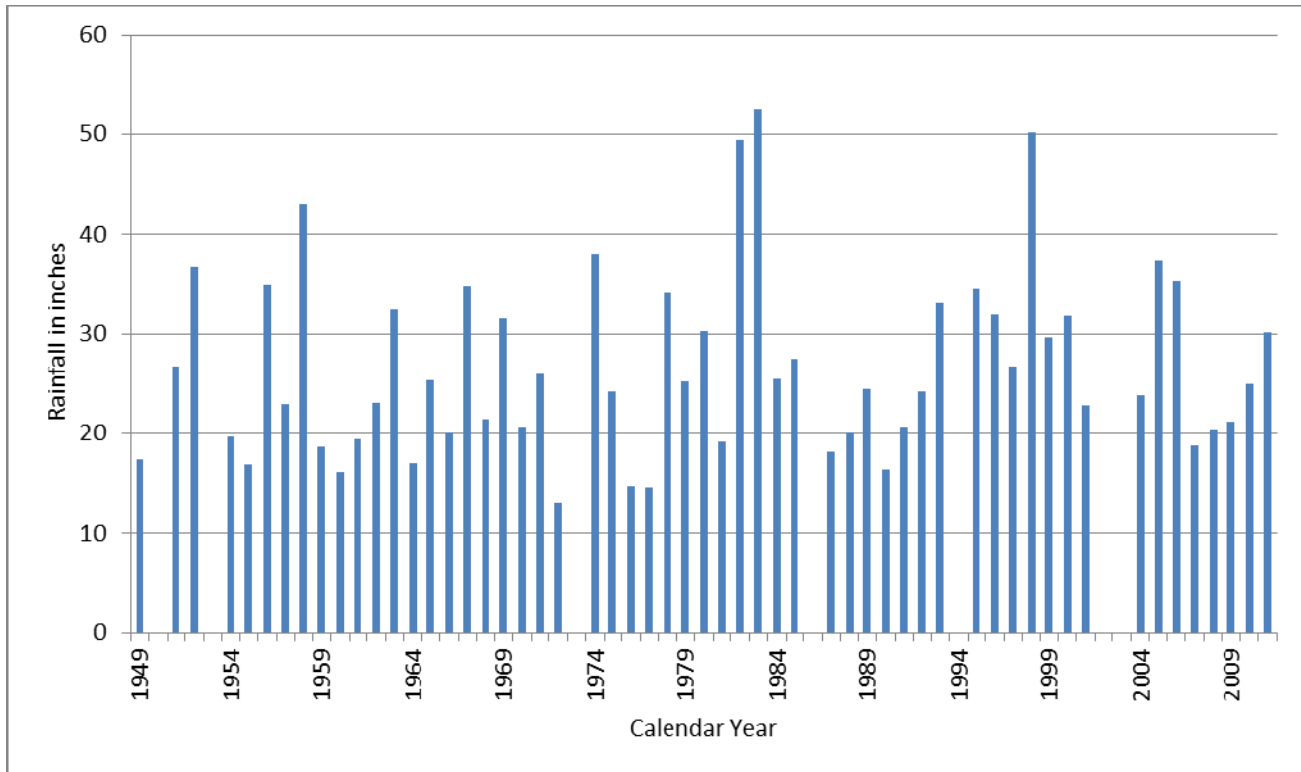
Figure 2. Annual rainfall totals in inches in Half Moon Bay, CA. Data gaps mark years with incomplete records**.** Latitude N37.4725, Longitude W122.4433, Elevation 36 feet. NOAA NCDC Station 43714.

Three types of BMPs/LIDs were monitored during the first year of the pilot phase. The first type was a vegetated swale, an open, shallow channel alongside the street with native vegetation covering the slopes and bottom of the channel. Runoff was collected from the naturally sloping drainage area and slowly conveyed to a downstream discharge point. The swale was designed to filter runoff through the vegetation and through the subsoil matrix, as well as to reduce runoff velocity. Similarly, the second type, a grassed filter strip/swale, was installed to treat runoff from adjacent areas. This swale type was covered by native grass sod, which also slowed down the runoff and allowed sediment and contaminants to settle and infiltrate into underlying soils. Both of these swale types are linear treatment types. Additionally, one point treatment type (the third type) was a flume filter storm drain insert, treating the stormwater runoff through a surface filter.

Vegetated swales with filter fabric, a sub-drain, and drain rock beneath a 15-inch layer of biosoil were constructed at Juliana Avenue and Cypress Avenue, Moss Beach (Figure 3). Within these systems permeable pavers and erosion control materials were used for better durability and to stabilize the edges to avoid soil erosion. Additionally, rock weirs were installed to slow down runoff where slope roughly exceeded 2%. Native plants, e.g., *Carex* and *Juncus*, were planted in between the pavers.

Figure 3. Vegetated swale at Juliana Ave., Moss Beach. Drainage area approximately 2.5 acres. A) Installation of filter fabric, drain rock and sub-drain. B) Installation of rock weirs and pavers. C) Finished swale looking west. D) Finished swale looking east. Stormwater enters swale at inlet on east end and from street surface between inlet and outlet.

Materials used for the swales were commercial-grade landscape components, designed to have minimal or no water contamination. Rock for the drain base and weir construction was locally quarried and washed before installation. PVC drain pipe used was ASTM D1785 standard for use with potable water, and joints were press fit together. Bio-soil fill in the swale was locally quarried sand mixed with sterile compost, and pavers were constructed of non-painted concrete.

Swale areas were seeded with a mix of native grass and barley in addition to the young grasses being planted. The seeds were not treated with any sort of pesticide (herbicide, fungicide or insecticide). Locally sourced and grown native plants were planted, using sterile nursery soil mix. Plants were lightly treated with an organic (16% N, 16% P, 16% K) fertilizer approximately six weeks before installation of the swales, that had likely absorbed into the plants by the time of planting. No pesticides (herbicide, fungicide or insecticide) were used in the growing process of the plants.

The second type of LID monitored were grassy swales (Figure 4). These systems were slightly less complex than the vegetated swales. After excavation, biosoil was used in combination with a soil conditioner, which is a blend of garden compost, chicken manure, rice hulls, redwood compost, and sand to break up the heavy clay soil. Sod was placed on top of the biosoil. A slightly different pre-plant fertilizer (17% N, 17% P, 17% K) was used for growing the sod. Additionally, a fungicide that contained zinc was used in the sod growing process and could potentially confound the results during the first year and perhaps other years of this study. A bromine-based herbicide that should not interfere with the results of the collected water samples was also used. Grassy swales were installed at Ocean Boulevard, Moss Beach, and 7th Street, Montara.

Figure 4. Grassy swale at Ocean Blvd., Moss Beach. Drainage area approximately 5 acres. A) Compacted area before beginning of construction. B) Installation of soil/compost mix after excavation. C) Installation of sod at the end of construction. D) Working swale during rainstorm.

The third BMP type that was studied was a BioClean flume filter storm drain insert (BioClean, Oceanside, CA, USA) (Figure 5). The flume filter boxes hold a series of BioMediaGREEN booms that remove contaminants from the passing runoff. They were installed at 6th Street and 14th Street in Montara. The flume filter was initially packed too densely with the booms, which caused overflow on both sides of the filter and led to water entering the discharge pipe untreated during the first storm, during which effectiveness was monitored. County of San Mateo staff corrected the installation of the flume filter, which seemed to work well with the correct amount of filter material. Since the flume filter was a lower priority site with three monitored storms, only the results of the last two storms are shown in the results section. The bypass/overflow results were not reported.

Figure 5. Flume filter at 6th Street, Montara. Drainage area approximately 1 acre. A) Street runoff is channeled through flume filter before it enters the pipe discharging the water to the Reserve. B) Slope of street surface directs stormwater toward treatment spot (red circle). C) Oil and sediment are visible in stormwater before water flows through the BioMedia GREEN booms. D) After storms, sediment, leaves, and detritus need to be cleaned out of the filter box.

A fourth type, also a drain insert unit, containing four filter cartridges was installed at North Lake Street in Moss Beach and samples were collected during storms in February and March 2013. The results from the North Lake drain insert will be submitted as an addendum to this report in August 2013.

Field Methods
General Approach to BMP/LID Performance Assessment
A paired sampling approach was used with one water sample being collected at the inflow of the treatment area and compared to another sample collected at the outflow. The assumption was made that during the collection time for a set of samples including all parameters at the inflow (approximately 20-30 min) water would have passed through the treatment area. Ideally an outflow sample could then be collected at the exit point of the treatment area that originated from the same water that was collected at the inflow. Of course, this assumption is limited by potentially different water residence times in each of the treatment areas, which may vary with storm intensity, and which, at this point, can only be estimated. As such, performance based on comparisons between influent and effluent sample pairs to derive contaminant concentration reduction is best considered as a component of weight of evidence (USEPA 2009).

The emphasis was on effluent water quality as the most important consideration of performance classifying the performance based on sample pairs more generally as poor (negative performance or apparent source within the treatment system), as little effective treatment performance (0-30%), as moderately effective performance (30-70%), and highly effective performance (70-100%). The paired sampling approach afforded by the pilot phase effort described here cannot be 100% accurate unless some kind of dye could be used to trace the runoff through the treatment system or flow could be monitored accurately. Since this type of monitoring was not financially and technically feasible (i.e., not sufficient depth for flow measurements), the value was practically improved by placing the data collected here in the context of other previous studies to provide the argument that the water quality performance observed for this study is reasonable and expected based on the broader wealth of studies of BMP and LID performance.

Targeted Storms and Storms Sampled
Water samples were collected during a variety of storm events (early and later in the season, moderate intensity storms (>0.1 inches of rain per hour) and smaller rainfall events (<0.1 inches of rain per hour), saturated and unsaturated conditions of the swales) to study the sites and their performance during a variety of flow conditions. High intensity storm periods (>0.2 inches of rain per hour) were only captured once (April 12, 2012, at 4 am) but an additional observation was made on March 14, 2012, at 9am that the swales were overflowing when rainfall exceeded approximately 0.2 inches per hour. This is consistent with the San Mateo County Green Streets and Parking Lots Handbook (San Mateo County 2009) that requires LID features to treat runoff from storms with a magnitude up to 0.2 inches of rain per hour. Due to high imperviousness of the sites, the response time (time between the beginning of rainfall to the beginning of runoff) ranged

from five minutes to 15 minutes, so the SFEI sampling team had to be ready and on site when the rain started.

One round of characterization or screening monitoring was conducted in January 2012 to narrow down the list of parameters for subsequent monitoring events. This was done to both reduce costs but also to reduce the time it would take to collect a full set of samples; time is a major challenge when dealing with such flashy rainfall and runoff processes. Only inflow into the treatment areas (two samples per site) was measured during this storm. After the final list of analytes was determined based on the initial two samples, two more storms (one in April 2012 and one in March 2012) were monitored with six and five samples collected, respectively. A total of 13 samples were collected over three storms between January and April 2012.

Three priority sites, including two LID sites (one vegetated swale and one grassy swale) and one BMP site (flume filter), were monitored for contaminants during two storm events. At each of the two LID sites, 11 sample sets (including in- and outflow samples) of trace elements, PAH, pyrethroid, nutrients, and suspended sediment concentration (SSC) were collected. FIB samples were also collected during each storm at these three priority sites (two samples at each site). At the BMP site, three sample sets were collected during two storms, of which the first sample was not reported due to densely packed filter material that resulted in water bypassing the treatment unit. Three additional low priority sites (one vegetated swale, one grassy swale, one flume filter) were monitored for SSC as a surrogate for particle-bound contaminants only, with three samples collected during one storm.

Water Sample Collection

Water samples were collected at a depth of 1-4 inches (0.025-0.1 m) at the inlet and outlet of the treatment units. A portable peristaltic pump was used to transfer water, using trace-metal clean tubing, into the sample containers. To avoid aerosol and contact contamination prior to sampling, the sample tubing and all containers for collection of trace elements were double bagged. Before filling sample containers, tubing was flushed with site water for at least one minute. Each sample container was triple rinsed with site water unless the container contained a preservative. The containers were filled completely to eliminate any headspace, and care was taken to minimize exposure of samples to sunlight. Immediately after collection, the containers were closed and placed on ice in a cooler (David et al. 2011). Samples were shipped to and received at the laboratories in good condition (defined in the Quality Assurance Project Plan) (David and Hunt 2011). All of the coolers containing water samples for trace element, trace organic, nutrient, or FIB analysis were received at the lab at the recommended temperature of <4°C.

Full sets of samples were collected at all priority sites with the exception of FIB and pyrethroids. FIB samples have a holding time of six hours and could only be collected during hours when delivery to the laboratory was possible. During the first effectiveness sampling, two FIB samples were collected at the vegetated and grassy swales. During the

second effectiveness sampling another two samples were collected at the priority swales and an additional sample was collected at the flume filter site. Pyrethroid analysis is extremely costly and the sample number was reduced to the rising stage and peak of the storm due to budget constraints. A total of four pyrethroid samples were collected at the vegetated swale and four at the grassy swale (two in March 2012 and two in April 2012).

Ancillary Measurements
Dissolved oxygen, pH, temperature, specific conductance, and salinity were measured with a multiparameter water quality meter (e.g., WTW Multi 340, Weilheim, Germany). At a minimum, surface readings were taken at the 1-4 inches (0.025-0.1 m) sampling depth once during each sample collection. Turbidity was measured in the field with a HACH® 2100p Turbidimeter (Loveland, CO) at the beginning and at the end of each sample collection.

Water Sampling for Screening

The first samples collected for this project were for screening purposes of contaminants only and not used to determine effectiveness of the different practices. These samples were only collected at the inflow of BMPs/LIDs to narrow down the list of contaminants analyzed for the remaining rainy season to the ones that often exceed Ocean Plan Objectives. Based on contaminant concentrations found in these initial samples the Technical Advisory Committee (TAC) recommended analysis of water samples for trace elements (silver (Ag), aluminum (Al), arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), manganese (Mn), nickel (Ni), lead (Pb), selenium (Se), and zinc (Zn)), pyrethroids, PAHs, ammonium, nitrate, SSC, and FIB. Mercury (Hg) and oil and grease analysis were discontinued because trace elements with similar physical characteristics and PAH were already included in the analysis and could serve as good surrogates for Hg and oil and grease. With fewer analytes per sampling event, the more general TAC recommendation of a higher sampling frequency could be realized within the existing budget and logistical constraints.

Water Sampling for Effectiveness
The first effectiveness sampling was conducted on March 13 and 14, 2012, when six samples were collected at the inflow and outflow of the vegetated swale, and six samples were collected at the inflow and outflow of the grassy swale. One sample was collected at the flume filter box, but since the box appeared to have too much filter material stuffed into the filter slot, water was bypassing this BMP, and no further samples were collected at this site during the March event. Only one additional SSC sample was collected at the flume filter later during the same storm. Three SSC samples were also collected at a smaller vegetated swale and a smaller grassy swale site during the same storm.

The second effectiveness sampling was conducted on April 10 through 12, 2012, when another five samples were collected at the inflow and outflow of each of the priority vegetated and grassy swale sites. Two samples were also collected at the inflow and outflow of the flume filter box that was functioning properly due to less filter material and better permeability.

Analytical Methods

Sediment

The concentration of suspended sediment was determined by East Bay Municipal Utility District's Laboratory utilizing ASTM D 3977. Samples were filtered through tared Gooch crucibles containing glass fiber filters, with a deionized water rinse of the sample container to remove adsorbed particles, and three 10 mL rinses of the filter to remove entrapped dissolved solids. Crucibles were dried overnight at $103^{\circ}C$. The increase in the weight of the crucible represented the suspended sediment in the sample, which was divided by the initial sample volume to obtain the suspended sediment concentration.

Trace Elements

Total mercury (Hg) was analyzed by Moss Landing Marine Laboratory using a modification of USEPA Method 1631e. The sample was preserved by adding either pretested 12N hydrochloric acid (HCl) or bromine monochloride (BrCl) solution. Prior to analysis, all Hg in a 100 mL sample aliquot was oxidized to Hg(II) with BrCl. After oxidation, the sample was sequentially reduced with $NH_2OH \cdot HCl$ to destroy the free halogens, then reduced with stannous chloride ($SnCl_2$) to convert Hg(II) to volatile Hg(0). The Hg(0) was separated from solution either by purging with nitrogen, helium, or argon, or by vapor/liquid separation. The Hg(0) was collected onto a gold trap and then thermally desorbed from the gold trap into an inert gas stream that carried the released Hg(0) to a second gold (analytical) trap. The Hg was desorbed from the analytical trap into a gas stream that carried the Hg into the cell of a cold-vapor atomic fluorescence spectrometer (CVAFS) for detection

The other trace elements (Ag, Al, As, Cd, Cr, Cu, Mn, Ni, Pb, Se, and Zn) were analyzed by Moss Landing Marine Laboratory using a modification of USEPA Method 1638. Samples were first solubilized by gentle refluxing with nitric and hydrochloric acids. After cooling, the sample was made to volume, mixed, and centrifuged or allowed to settle overnight prior to analysis. The digested sample was transferred into plasma generated by the radiofrequency excitation of argon gas where energy transfer processes caused desolvation, atomization, and ionization. The ions were extracted from the plasma through a differentially pumped vacuum interface and separated on the basis of their mass-to-charge ratio (m/z) by a mass spectrometer having a minimum resolution capability of 1 amu peak width at 5% peak height at m/z 300. Ions transmitted through the mass analyzer were detected by an electron multiplier or Faraday detector and the resulting current was processed by a data handling system.

Organic Compounds

Both, oil and grease and oil and grease (hydrocarbon), are EPA 1664 method defined analytes. Oil and grease is the conventional term used by the EPA for any material that can be extracted by n-hexane (HEM = n-hexane extractable material). It can include a variety of materials, including relatively non-volatile hydrocarbons, vegetable oils, animal fats, waxes, soaps, greases, and related materials. Oil and grease (hydrocarbon) refers to the petroleum hydrocarbon fraction of the total oil and grease. Another name for

this is non-polar material (NPM). The concentration of oil and grease in a water sample is defined as the n-hexane extractable material that does not adsorb to silica gel (HEM-SGT = n-hexane extractable material, silica gel treated).

Oil and grease analyses were carried out by East Bay Municipal Utility District's Laboratory using EPA method 1664A. A 1 L sample was acidified to pH <2 and extracted with n-hexane in a Horizon4790 extraction unit. The extract was dried over sodium sulfate. The extract was then concentrated in aluminum dishes and the residue was weighed. For SGT-HEM determination, an amount of silica gel proportional to the amount of HEM was added to the solution containing the re-dissolved HEM to remove polar materials. The solution was filtered to remove the silica gel, the SGT-HEM extract was then desiccated, concentrated in an aluminum dish, and weighed.

PAHs were analyzed using high resolution gas chromatography/ low resolution mass spectrometry (HRGC/ LRMS) by AXYS Analytical Laboratories (Sidney, BC, Canada). The method MLA-021, a variant of EPA Methods 1624 and 8270, was utilized for PAH analysis. Samples were spiked with a suite of deuterated surrogate standards and solvent extracted. Extracts were reduced in volume, solvent-exchanged to hexane, treated for sulphur and columned on deactivated silica gel. The extracts were spiked with a labeled recovery (internal) standard prior to instrumental analysis. PAH concentrations were analyzed in extracts using HRGC/LRMS performed on an Agilent 6890N GC/5973 MS/7683 autosampler. A Restek Rtx-5 chromatography column (30 m, 0.25 mm internal diameter (i.d.), 0.25 mm film) was coupled directly to the MS source. The MS was operated at a unit mass resolution in electron ionization (EI) multiple ion detection (MID) mode, acquiring two characteristic ions for each target analyte and surrogate standard. A splitless/split injection sequence was used.

Pyrethroids were analyzed by AXYS Analytical Laboratories using Method MLA-046 by HRGC (DB-5 capillary) and using voltage selected ion detection. Samples were first liquid-liquid extracted with dichloromethane and the extract was dried with anhydrous sodium sulfate. The extract was reduced to 1 mL and solvent exchanged to hexane. Cleanup was then performed on a florisil column. The first eluate (in 15:85 dichloromethane:hexane) was discarded, the second eluate (in 1:1 dichloromethane:ethyl acetate) was collected, evaporated and solvent changed to acetonitrile. A second cleanup was performed on an amino type SPE (solid phase extraction) cartridge. The extract was solvent changed to hexane, an isotopically labeled recovery (internal) standard (13C12-PCB 138) was added, and the extract was analyzed by high resolution gas chromatography/high resolution mass spectrometry (HRGC/HRMS). Instrumental analysis of the final extract was performed by split/splitless injection on a high resolution gas chromatograph (HRGC) equipped with a DB-5 capillary column and coupled to a high-resolution (HRMS) mass spectrometer. The HRMS was operated at a static (≥8000) mass resolution in the EI mode using voltage selected ion detection.

Nutrients
Analysis of nitrate was conducted by East Bay Municipal Utility District's Laboratory using USEPA Method 300.1, revision 1.0. The sample was collected in a 125 mL plastic

bottle and cooled to ≤6°C and had a holding time of 48 hours. A 50 μL volume of sample was introduced into an ion chromatograph (Metrohm 850 Professional IC system) and the anions of interest were separated and measured using a system comprised of an analytical column (Metrohm A Supp 7 250 x 4 mm 5μm), a suppressor (Metrohm chemical), and a conductivity detector.

Analysis of ammonium was also conducted by East Bay Municipal Utility District's Laboratory. Turbid samples were filtered through glass fiber filters before 50 mL of sample water was added to a mixing cylinder. An additional 2 mL of a phenol solution (10 g phenol in 100 mL reagent alcohol) was added, then 0.5 mL sodium nitroferricyanide solution (0.5 g sodium nitroferricyanide in 100 mL DI water), and then 5 mL of an oxidizing solution (80 mL alkaline sodium citrate solution and 20 mL sodium hypochlorite per 100 mL needed). The solution sat for 2-24 hours before it was read on a spectrophotometer at 640 nm.

Fecal Indicator Bacteria (FIB)
For the analysis of *Enterococcus*, 10 mL of the sample was pipetted to a sterile container of 90 mL de-ionized water. A packet of the Enterolert™ test kit (IDEXX Laboratories, Westbrook, Maine, USA) was mixed into the dilution. The sample was poured into an Idexx Quanti-Tray and then into a 41°C incubator. Results were read after 24 hours. Reported counts were obtained from the Idexx Quanti-Tray 2000 MPN Table. The test method employed to detect *Enterococcus* is called Enterolert from Idexx. It uses the defined substrate technology (DST). When B-glucosidase enzyme from the *Enterococcus* is mixed with 4-methyl umbellifery B-D-glucoside from the Enterolert test kit, the sample fluoresces. It can detect *Enterococcus* at 10 colony-forming units (cfu) per 100 mL. The reporting limit is 24,196 most probable number (MPN) per 100 mL.

For the analysis of total coliform and *E. coli*, a pouch of the Colilert® 18 test kit (IDEXX Laboratories, Westbrook, Maine, USA) was mixed into a 10 to 1 dilution sample. The sample was poured into a Quanti-Tray and was incubated at 35°C. Results were read between 18 to 22 hours after incubation. Reported counts were obtained from the Idexx Quanti-Tray 2000 MPN Table. Colilert® 18 test kit uses the DST to detect total coliform and *E. coli*. Ortho-nitrophenyl-B-D-galactopyranoside (ONPG) from the Colilert® 18 test kit detects B-D-galactosidase enzyme from the total coliform bacteria by turning the sample to yellow. 4-methylumbelliferyl-B-D-glucuronide (MUG) from the test kit detects the enzyme B-glucuronidase produced by *E. coli* when the sample fluoresces. It can detect total coliform and *E. coli* at 10 cfu per 100 mL. The reporting limit is 24,196 MPN per 100 mL.

QA Summary
Trace Elements
Data were reported for 12 trace elements for 58 water samples; mercury was analyzed in 34 samples. Field replicates, lab replicates, field blank, lab blanks, matrix spike/matrix spike replicates, a CRM and LCM, and other project samples were also reported. Only the total fraction was analyzed and data were blank corrected.

Overall, the data were acceptable. Method Detection Limits (MDLs) were sufficient, consistent with the QAPP (David and Hunt 2011), with 3 (Ag, Cd, and Se) of the 12 trace elements having non-detects (NDs) (ranging from 6 to 60% NDs), with only silver having more than 50% NDs. Data were not blank corrected because none of the trace elements were found to have contamination in the method blanks.

Matrix spikes and the laboratory control material (LCM) were used to assess accuracy of the trace elements, except for aluminum and mercury. Mercury was evaluated using the CRM and matrix spikes, while aluminum was evaluated using only the LCM. Recoveries were good, with recovery errors being less than 16% for all reported analytes, no additional qualifiers were needed. Lab replicates from field samples were used to evaluate precision, except for silver, which was evaluated using replicates of the matrix spikes and laboratory control material. Average precision was good being less than 15% for all the analytes. Relative standard deviation (RSDs) for the field replicate were also examined and were less than 9%, consistent with QAPP requirements (David and Hunt 2011). No additional qualifiers were added.

Average trace element concentrations from the Fitzgerald study ranged from 26 to 233% of those from other SFEI studies (2006-2011) (Gilbreath et al. 2012a) and were generally less than 100%, except for aluminum, copper, and selenium, which were respectively 106%, 112%, and 233% of the average concentration of other SFEI studies. This internal study comparison serves as an additional acceptability QA tool at SFEI.

Organic Compounds
Data were reported for 24 PAH analytes for 57 water samples. Field replicates, field blanks, lab blanks, and blank spike samples were also reported. Field blanks were not used for the QA/QC review. Only total fractions were analyzed and data were not blank corrected.

Overall, the data were acceptable. MDLs were sufficient with 22 of the 24 PAH analytes having non-detects (ranging from 4 to 97% NDs), with 32% (7 out of the 22) having >=50% NDs. About 30% (7 out of 24) of the PAHs had some contamination in one method blank. Naphthalene, 2-methylnaphthalene, dibenzothiophene, phenanthrene, and fluoranthene had respectively 45%, 41%, 21%, 14%, and 9% of sample results flagged with the censoring contamination qualifier of "VRIP" (results with reported concentrations <3x the blank results (by batch) are censored for contamination) according to the QAPP (David and Hunt 2011).

Replicates from blank spikes were used to evaluate precision. Average precision was less than the 35% target for all the analytes. RSDs for the field replicate were also examined and were generally good, less than 35% for all analytes, except for 2,6-dimethylnaphthalene, which had an RSD of 117%. No additional qualifiers were added. Blank spikes were used to assess accuracy of PAHs as no CRMs or matrix spikes were reported. Recovery for the majority of PAH analytes was good; with recoveries less than the target 35% for all reported analytes, no qualifiers were needed.

Average PAH concentrations from the Fitzgerald study ranged from 0.2 to 45% of those from other SFEI studies (2008-2010), and were generally less than 20%, except for 2-methylnaphthalene and 1-methylphenanthrene, which were respectively, 27% and 45% of the average concentration in other SFEI studies. The Sum of PAHs was calculated using the 22 PAH SFEI/RMP target list with the exception of biphenyl and 1-methylnaphthalene that have both historically contributed approximately only 1% to the "Sum of PAHs (SFEI)" for RMP status and trends water samples (total fraction).

Results were reported for pyrethroids for 26 water samples (25 field samples and one field replicate), field blank, method blanks, and blank spike samples for 14 pyrethroids (delta/tralomethrin as a coelution, and tetramethrin for information only). Only the total fraction was analyzed, and data were not blank corrected.

Overall, the data were acceptable. MDLs were sufficient (<50% NDs) for only one of the 13 pyrethroids, total permethrin (46% NDs), the rest were 100% NDs; including lab replicates, except for delta/tralomethrin and total cypermethrin, which had 96% NDs. Three lab blanks were reported with no blank contamination observed. Data were not blank corrected.

Blank spike samples were used to evaluate accuracy, as no CRMs or matrix spikes were provided, with the average percent error generally below the target measurement quality objectives (MQO) of 35%. Only two pyrethroids required flagging, phenothrin (45%) and resmethrin (57%), which were above 35%, but below 70% error, and were flagged with the non-censoring qualifier "VIU" (percent recovery exceeds laboratory control limit).

Replicates on blank spikes were generally good having average RSDs below the target MQO of 35%. Allethrin (36%), bifenthrin (43%), phenothrin (48%), and resmethrin (50%) had blank spike average RSDs above 35%, but below 70%, and were, therefore, flagged with the non-censoring qualifier "VIL" (RPD exceeds control limit).

The average total permethrin concentration in this study was 63% and delta/tralomethrin 1.6% of the average reported in water samples from other SFEI studies for 2008-2010 (Gilbreath et al. 2012a). Total cypermethrin results were NDs for other SFEI studies, compared to the average concentration of the Fitzgerald study of 1465 pg/L.

Oil and Grease/Nutrients/SSC
Data were reported for 33 oil and grease (hydrocarbon) samples, 75 SSC samples, 63 ammonium samples, and 70 nitrate samples. Blanks and one or more of CRM/LCS/MS were reported for all analytes to evaluate recovery, and duplicates of either grabs or one of the recovery sample types to evaluate precision.

Overall, the data were acceptable. MDLs were sufficient for <50% NDs except the oil and grease (hydrocarbon) (~80% NDs). MDLs for oil and grease (hydrocarbon) were ~2.5-3.5 mg/L. As an estimate, one half of that (1-2 mg/L) would be needed to get <50% NDs. No target analytes were found in blanks above MDL, so no blank flags were necessary. Precision was acceptable, <5% RSD on ammonium and nitrate laboratory

replicates, <5% average on SSC CRM replicates, and <25% average on oil and grease (hydrocarbon) matrix spike replicates. Recoveries were acceptable too, within the Fitzgerald QAPP limit of ±50% (<32%) of target on matrix spikes for oil and grease (hydrocarbon), and within 5% of target for SSC, ammonium, and nitrate, also well within their target of within 20%.

Precision was evaluated on lab replicates of field samples, or on CRMs or MSs where the former was not available. Precision was acceptable, <5% RSD on ammonium and nitrate laboratory replicates (within the target of <25%), <5% average on SSC CRM replicates, and <25% average on oil and grease (hydrocarbon) matrix spike replicates. Compared to 2012 SFEI pollutants of concern study sites (Lewicki and McKee 2009; Gilbreath et al. 2012a), the average SSC at Fitzgerald was higher than averages at most other study sites, but nitrate and ammonium were lower than most. The averages and ranges seemed reasonable.

Data Interpretation

For the calculation of averages, non-detects were included using 0.5 times the MDL for the specific analyte. Results from the screening effort (samples 1 and 2) were not included in the calculation of averages and were not displayed in graphs since these samples were collected early in the season and only at the inflow of the treatment areas. This made the screening results incomparable to the treatment effectiveness results collected in March and April 2012.

For the interpretation of treatment effectiveness four categories were used to describe the concentration reduction potential of a BMP/LID: 1) ineffective treatment (-30 – 0%), 2) little effective treatment (0 – 30%), 3) moderate treatment (30 – 70%), 4) highly effective treatment (70 -100%).

For the estimation of runoff, land use categories were assigned a land use specific runoff coefficient. Runoff coefficients describe the estimated percentage of rainfall onto a surface that becomes runoff, and vary between land use types based on a number of surface properties including soil characteristics, slope, vegetation, soil saturation, temperature, and the presence of impervious or fractured layers. Although these characteristics may be quite variable on temporal and spatial bases within a land use category, in this study we used the simplest approach of assigning a single coefficient for each land use category. We used the same coefficients Davis et al. (2000) and Lent et al. (2011) selected as the "best estimates" for their modeling of contaminant loads from stormwater in the San Francisco Bay Region. The runoff coefficient assumed for residential land use equals 0.35, which was used for estimating runoff in the lower parts of the watershed during the pilot phase. For the upland phase of the study, a mixed land use coefficient (0.30) for residential use and open space will likely be applied in 2013/14.

Total runoff volume was estimated using the simple equation for each watershed. It assumed a linear correlation between runoff and storm precipitation and similar land uses within each watershed.

$$V = P * \sum_{j=1}^{n} (C_j * A_j)$$

V = Total storm volume
P = Total rainfall for the specific watershed
C = Runoff coefficient for land use j
A = Area of land use j in the watershed

Results and discussion

<u>Precipitation</u>
Precipitation in the vicinity of the Moss Beach and Montara sites ranged from 0 to 0.26 in/hr during the time when samples were collected in March and April 2012. Samples were collected during different stages of the storms to describe the effectiveness of the LIDs/BMPs during the rising/falling stages and peaks of the storms (Figure 6).
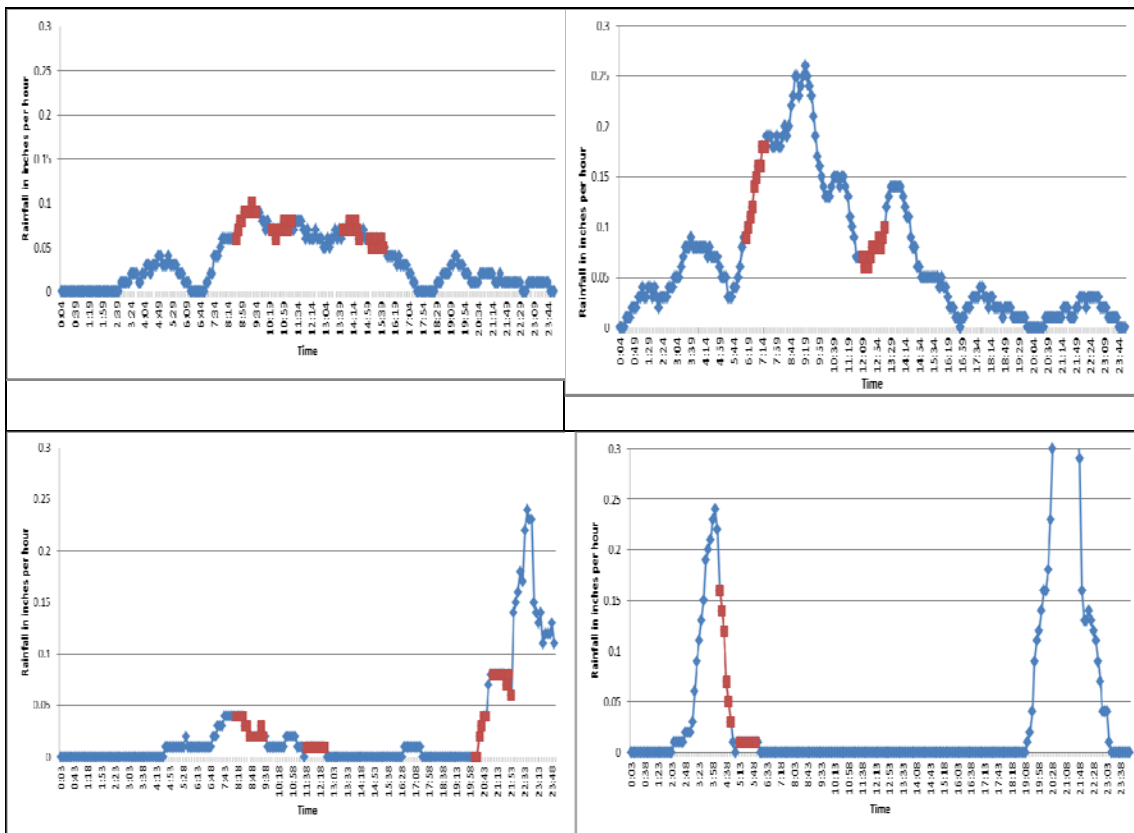

Figure 6. Precipitation during sampling events on March 13 and 14, 2012 (upper row) and April 10 and 12, 2012 (lower row). Y-axis displays rainfall in inches per hour, x-axis displays time of day. Red squares indicate the time of sample collection.

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Water Year (WY) 2012 began as one of the driest years on record and by New Year's Day only 9.43 inches (36% of the average annual rainfall for the study area) had fallen. More precipitation occurred in March and April but with long dry periods between rainfall events. The 2012 WY remained classified as "dry" with rainfall staying below 60% of the average annual precipitation.

For all estimations of flow volume, a rational runoff coefficient for urban areas of 0.35 was used (American Society of Civil Engineers 1969). The estimated runoff volume from the 6th Street drainage area at the flume filter site ranged from 0.25 to 5.0 m^3/h during sample collection (an average of 2.1 m^3/h of runoff during monitored storms). The flume filter did not store any runoff and it is assumed that the same amount of water drained into the Reserve from this drainage pipe. Runoff at the vegetated swale site was estimated to range from 0.63 to 12 m^3/h, with an average of 5.3 m^3/h for all sampling events. At this site, water can be stored initially in the filter material layer of the swale until the material is saturated. After that (approximately 10-15 min), water reaches the subdrain and is transported out of the swale. No volume reduction has been observed after the initial delay in the outflow. Similarly, the grassy swale site absorbed some runoff at the beginning of each storm, but since the natural subgrade in this area is clay, groundwater recharge from the swales is unlikely and negligible for the runoff calculation. Due to the larger drainage area, estimated flow volumes for the grassy swale ranged between 1.2 and 25 m^3/h and averaged at 11 m^3/h for all sampling events.

<u>Contaminant Loads</u>
Average contaminant loads at the inflow of all three treatment types were estimated by multiplying the contaminant concentration by the estimated flow volume and by a unit conversion factor (Table 2). These estimates are based on instantaneous samples and therefore only represent a snapshot in time. They are not representative of the duration of a storm. When compared to the Daly City library parking lot, an almost 100% imperviousness catchment area (David et al. 2011), the first order load estimates for water draining into the BMPs/LIDs were comparatively low.

Table 2. Average load estimates in mg/min for all three treatment types.

Parameter	Vegetated Swale	Grassy Swale	Flume Filter	Daly City*
SSC	3200	78,000	7900	
Copper	1.1	1.5	0.37	11
Lead	0.31	0.41	0.47	0.90
Zinc	3.2	4.50	1.8	170
PAHs	7.5×10^{-6}	9.8×10^{-5}	5.4×10^{-6}	0.9
Pyrethroids	2.3×10^{-5}	3.5×10^{-3}	1.8×10^{-4}	NA

*David et al. 2011. Note only x significant figures are reported for these calculations reflecting the relatively high uncertainty.

Suspended Sediment Concentrations
SSC varied from the 3.5 mg/L MDL to 2,100 mg/L during the peak of the April storm at the grassy swale site inflow. This high concentration was reduced to 7.1 mg/L (99% reduction) at the outflow of the swale after treatment. At the grassy swale site, where the treatment area received only very small amounts of additional runoff between inlet and outlet, reduction rates were on average 89% (ranging from 5% to 99%) based on pair samples. The only exception was the first sample of the April storm that showed high sediment export. At the beginning of a storm the occurrence of sediment export is not surprising, since the grassy swale experienced high foot traffic (people and dogs), and cars often parked on the swale before barriers were erected after April 2012. An accumulation of sediment within the swale area from wear and tear on the swale can explain the higher sediment outflow concentration after a longer dry period.

Suspended sediment at the vegetated swale site was reduced between 31% and 100% based on pair samples. However, five out of the 11 samples collected showed higher sediment effluent concentrations compared to the inflow concentrations, which indicates contribution of sediment from within the swale or additional input of sediment between the inflow and outflow originating from street runoff alongside the swale during moderate intensity storms (0.1 to 0.2 inches of rain per hour). Since other contaminant concentrations were also occasionally elevated at the outflow and the filter media of the swale being wrapped by filter fabric to minimize loss of sediment, the more likely explanation for the higher outflow concentrations would be the additional runoff that this swale received from the street toward the outflow point. The water entering the treatment system this way has a shorter residence time in the system and could cause the higher export concentrations.

The flume filter treated all samples successfully; reducing the sediment concentration by an average of 74% (32% and 90%) based on pair samples. However, at this site a reduced sampling effort was implemented and these results were based on a small sampling number (n = 2).

The low priority sites for each BMP/LID type that were only monitored for SSC showed very similar results to the same type of BMP/LID that was monitored more frequently. The vegetated swale at Cypress Avenue (Moss Beach) showed good results during low flow periods (on average 85% concentration reduction based on pair samples below 0.1 inches of rain per hour) but had increased sediment concentrations in the effluent during more intense rainfall when it received runoff from the street parallel to the swale. The grassy swale on 7th Street (Montara) reduced sediment concentrations by an average of 86%. The additional flume filter site at 14th Street (Montara) did not have measurable outflow during the monitored storms since a longer stretch of ice plants absorbed the majority of runoff.

Trace Elements
Total Hg results varied from the 0.2 ng/L MDL to 39.3 ng/L. Treatment of mercury during the first storm resembled trace elements with similar physical properties (e.g., Cr, Cu, Ni, Pb, and Zn). Reduction in Hg concentrations ranged from 18 to 90% for the

grassy swale and between 33 to 44% for the vegetated swale and the flume filter based on pair samples. Since Hg has to be analyzed separately by the analytical laboratory, using a different method to achieve high quality results, the TAC decided to discontinue monitoring Hg and evaluate the treatment capacity of BMPs/LIDs through the suite of trace elements that can all be analyzed with the same method. This decision freed up money that could be invested in a greater overall number of samples and, by extension, provided for increased interpretability of the resulting data.

Metal concentrations (Ag, Al, As, Cd, Cr, Cu, Mg, Ni, Pb, Se, and Zn) were generally reduced at all sites. For example for Cu, the metal of highest concern for aquatic life, concentrations were reduced on average by 34% at the vegetated swale site, by 26% at the flume filter site, and by 66% at the grassy swale site (Figure 7). However, during higher intensity storms (> 1 inch of rain per hour) there was an observable amount of sheet flow coming off the street entering the vegetated swale between inflow and outflow point and resulting in greater concentrations in effluent than in influent. The higher effluent concentrations likely occurred because the lateral runoff had very little or no treatment through the swale.
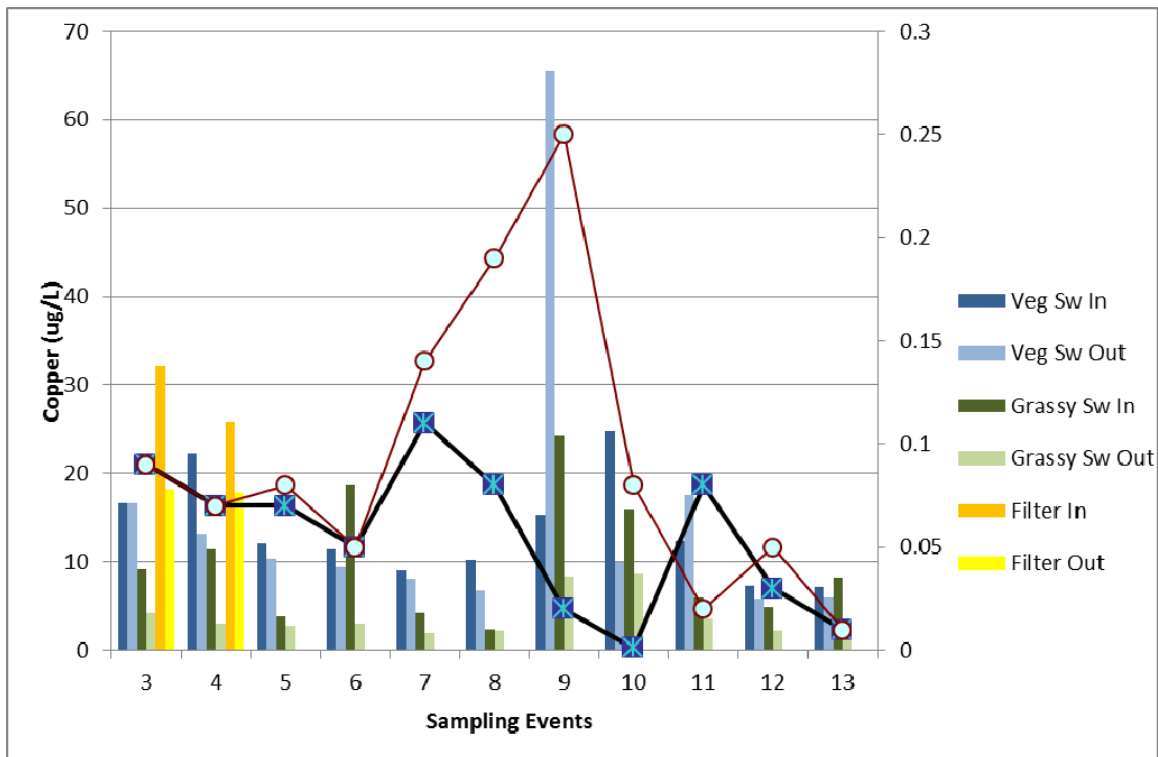

Figure 7. Copper concentrations at three different LID/BMP sites. The darker colors indicate concentrations entering the LID/BMP, the lighter hues of the same color indicate concentrations exiting the LID/BMP. Precipitation is characterized in inches per hour by the line graph with asterisks for inflow samples and line graph with circles for outflow samples (scale on right axis).

Concentrations for Cu were lowest in the inflow of the grassy swale site at Ocean Blvd. (average of 9.89 µg/L), followed by the vegetated swale site at Juliana Ave. (13.5 µg/L) and the flume filter site at 6th Street with 23.9 µg/L. The higher concentrations at 6th Street may have been caused by proximity to Highway 1, with high vehicle use and deposition of particles, even though the site does not receive direct highway runoff. Ocean Blvd. has lower vehicle traffic, especially since a section of this street is closed off due to earth movements.

A simlar trend was observed for lead concentrations (Figure 8), which were reduced on average by 33% at the vegetated swale, by 48% at the flume filter site, and by 76% at the grassy swale site. Again, it was apparent that during periods of higher intensity rainfall, runoff entered the vegetated swale site not just at the inlet but also between inlet and outlet and close to the outlet, at which point treatment was very limited and higher metal concentrations were measured in the effluent water compared to the influent on occasions.
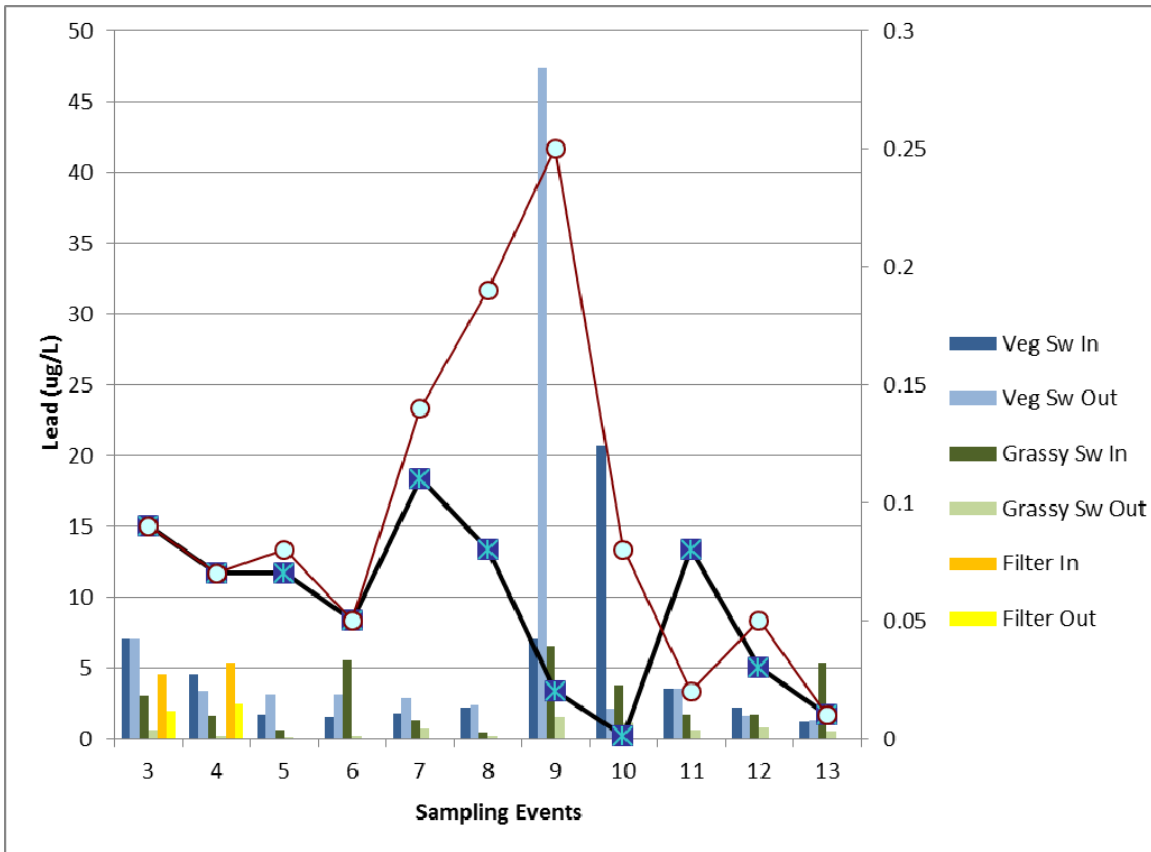

Figure 8. Lead concentrations at three different LID/BMP sites. The darker colors indicate concentrations entering the LID/BMP, the lighter hues of the same color indicate concentrations exiting the LID/BMP. Precipitation is characterized in inches per hour by the line graph with asterisks for inflow samples and line graph with circles for outflow samples (scale on right axis).

The differences in drainage area characterisitcs between the two swale sites were also apparent when turbidity data were displayed (Figure 9). At the grassy swale site, the majority of effluent turbidity measurements were greatly reduced from the influent measurements, indicating good treatment of stormwater runoff for fine particulates. Only two samples at the grassy swale site had higher turbidity in the effluent. Those two samples were both collected at the beginning of the third monitored storm after a longer dry period. It is possible that loose sediment from parked vehicles, human and dog, traffic had accumulated on top of the swale and washed out at the beginning of the storm. But after initial flushing the system seemed to work effectively and reduced turbidity in all remaining samples.

In comparision, the vegetated swale site did not show the same results. Seven out of the 22 paired samples showed reduced turbidy at the outflow, these samples were all collected during relatively short, but higher intensity rainfall periods, when rainfall was above 0.2 inches per hour during the inflow sample but much lower (<0.05 inches per hour) during the collection of the outflow sample (Figure 9b, sample event #9). The outflow sample was collected approximately 20 min after the inflow sample. During the collection of the outflow samples, runoff had slowed down enough for water to infiltrate and be treated. However, the majority of the samples showed an increase in turbidity at the outflow when compared to the inflow results.
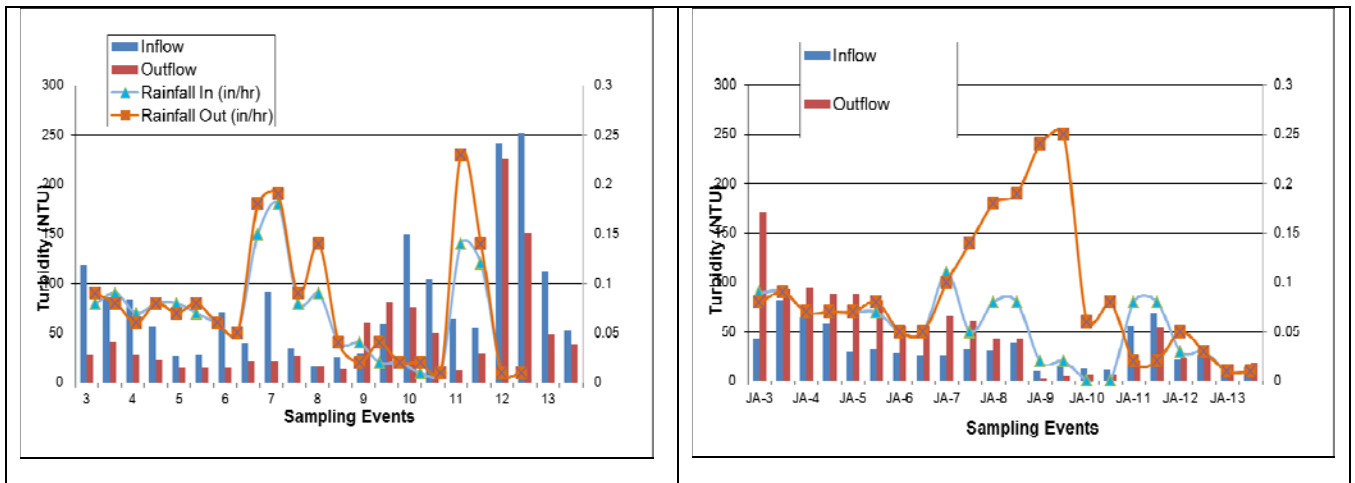

Figure 9. Turbidity measurement in NTU for the LID sites, a) grassy swale, b) vegetated swale.

Organic Compounds
Both, oil and grease and oil and grease (hydrocarbon), were only detected in ten out of 66 samples. Nine out of these ten samples with measurable concentrations were collected at the grassy swale site. Concentrations ranged from the 2.4 mg/L MDL to 7.9 mg/L and treatment was mostly 100% (or reduction to the MDL). Since the 15 individual congeners of PAHs that were also measured in all samples have a lower detection limit, PAHs were used to evaluate the effectiveness of the BMPs/LIDs and oil and grease analyses were discontinued after one storm.

PAH concentrations ranged from 4.2 ng/L at the outflow of the vegetated swale to 2,200 ng/L at the inflow of the grassy swale (Figure 10). Concentrations were reduced on average by 38% at the vegetated swale site, by 86% at the grassy swale site, and by 69% at the flume filter site based on pair samples. PAH concentrations were approximately seven times higher in road runoff at the grassy swale site compared to the vegetated swale site. However, the outflow concentrations at those two sites were in the same order of magnitude (between 72 and 44 ng/L on average).
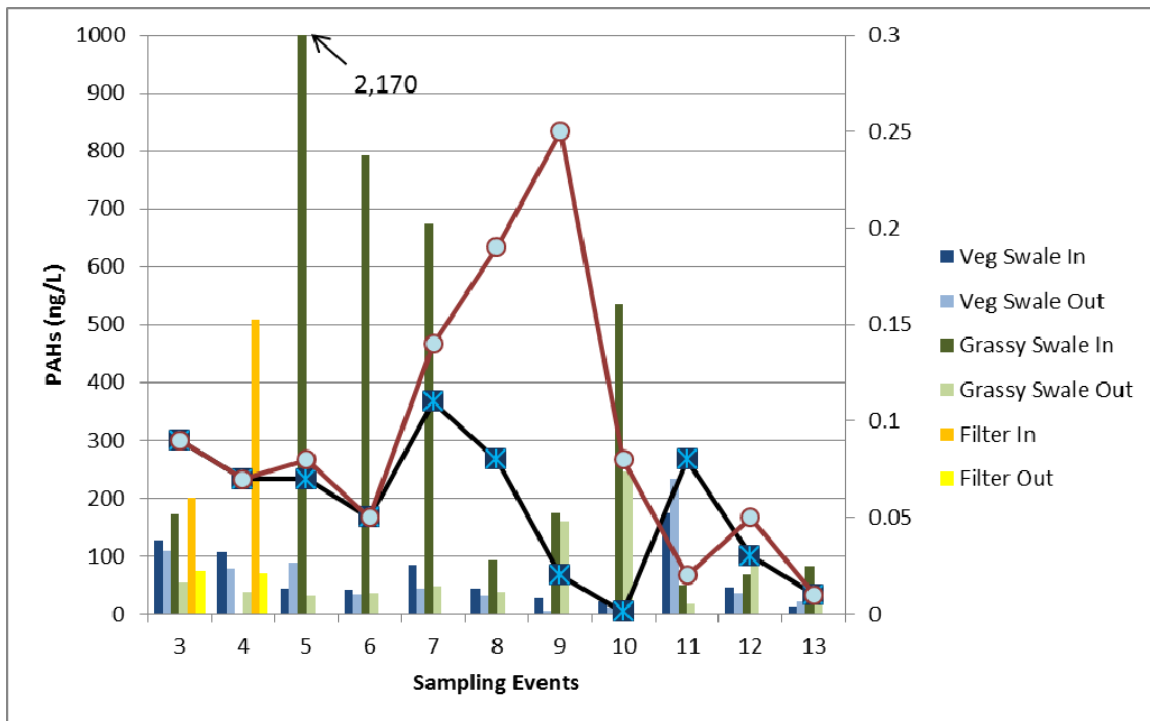

Figure 10. PAH concentrations at three different LID/BMP sites. The darker colors indicate concentrations entering the LID/BMP, the lighter hues of the same color indicate concentrations exiting the LID/BMP. Precipitation is characterized in inches per hour by line graph with asterisks for inflow samples and line graph with circles for outflow samples (scale on right). The fourth inflow sample for the grassy swale site broke during transport to the laboratory and could not be analyzed.

The only pyrethroid detected in measurable concentrations was permethrin. Permethrin is a general use pesticide for residential applications and is used to control insect, mainly ants and termites on the outside of homes and in yards. Permethrin is highly toxic to some fish and aquatic arthropods (Coats and Bradbury 1989). Observed concentrations in stormwater runoff in Moss Beach and Montara exceeded the acute toxicity thresholds for aquatic invertebrates (LC$_{50}$ 0.075 µg/L) in two samples collected in January at the grassy swale inflow at Ocean Blvd. (0.23 and 0.13 µg/L). Treated water at the outflow was below the toxicity threshold in all collected samples.

Permethrin concentrations ranged from the 0.0002 µg/L MDL to 0.23 µg/L collected early in the wet season during the contaminant screening sample collection in January. For higher permethrin concentrations (> 0.03 µg/L), the reduction through the

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BMPs/LIDs was generally very successful and near 100% (or below the MDL 0.0002 µg/L of xx µg/L). Lower concentrations (< 0.03 µg/L) that were observed during the April storm were reduced by approximately 38% based on the paired sampling. The smaller reduction could have been the result of approaching irreducible contaminant concentrations in the influent. The concept of irreducible contaminant concentrations is based on the likelihood that there is a practical limit of water quality in treatment unit effluent. Such a limit can be defined by the physical and chemical properties of the contaminant, the processes within the LID/BMP, and the sensitivity of the analytical method (USEPA 2004). Given the small sample size and the lack of observations for a much wider variety of storms, at this time, we cannot be sure what the limit of treatment may be but our observations do suggest treatment does occur at least at higher concentrations.

Nutrients
Concentrations for nitrate ranged from the 0.002 mg/L MDL to 0.68 mg/L at the flume filter site in April (Figure 11c). This high concentration was reduced to 0.33 mg/L at the outflow of the flume filter (55% reduction). In general, the flume filter reduced nitrate by an average of 42%. The flume filter is likely the only BMP for which inflow and outflow samples are directly comparable because of the very small treatment distance. For the swales, the residence time for the stormwater can only be estimated and water collected in the inflow may not be directly comparable to the sample water at the outflow. There is a risk that the outflow sample originated from runoff with a slightly different contaminant concentration at the inflow compared to what was actually captured with the inflow sample.

The vegetated swale reduced nitrate concentrations by approximately 72% on average but again showed nitrate export during higher flow periods, similar to SCC (Figure 11a). Five out of the 11 collected samples indicated an export of nitrate out of the treatment system, likely due to additional street runoff entering the swale close to the outflow point. Nitrate concentrations were relatively low at all sites but were lowest at the vegetated swale site. As concentrations drop below a certain concentration (0.2 mg/L) they become increasingly hard to remove from the stormwater. This limit is possibly related to the physical and chemical properties of the contaminant and the specific mechanisms of removal within the BMP/LID (USEPA 2004). Similar to the permethrin concentrations, the concept of irreducible concentrations is coming into effect again, in this example at nitrate concentrations below 0.7 mg/L (USEPA 2004).

The grassy swale reduced the nitrate concentrations on average by 76% with only two out of the 11 samples showing increased nitrate concentrations at the outflow (export) (Figure 11c). The average nitrate concentrations at the inflow of the grassy swale (0.24 mg/L) were two and a half times higher compared to the inflow samples at the vegetated swale site (0.10 mg/L) which may also result in the slightly better performance in nitrate reduction at the grassy swale site. The highest average concentrations were measured at the inflow of the flume filter site at 0.33 mg/L.
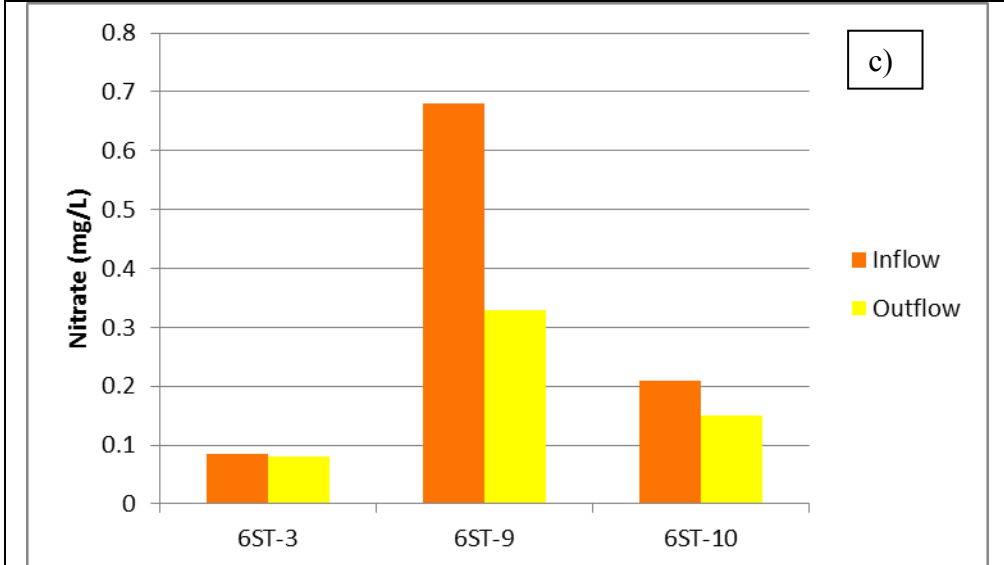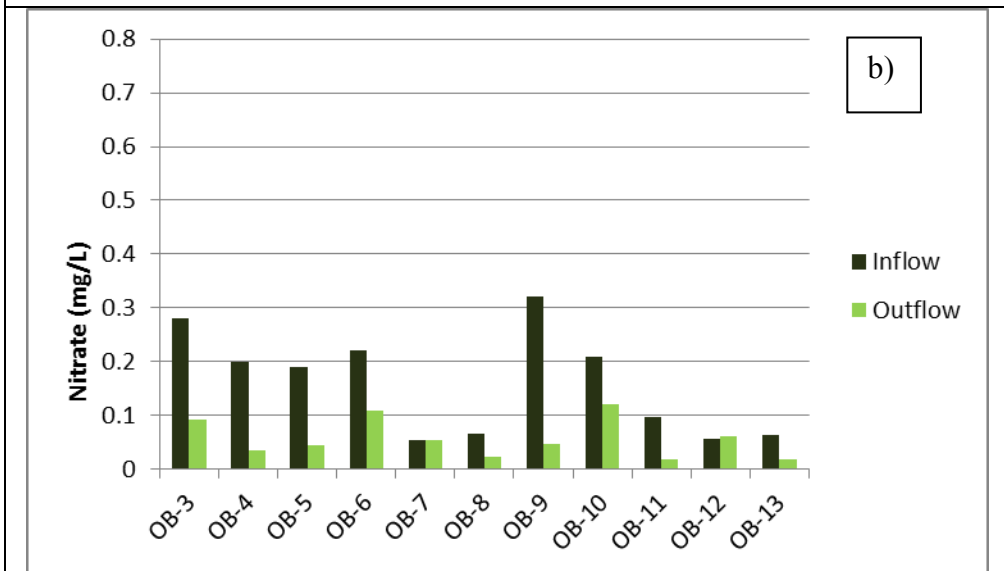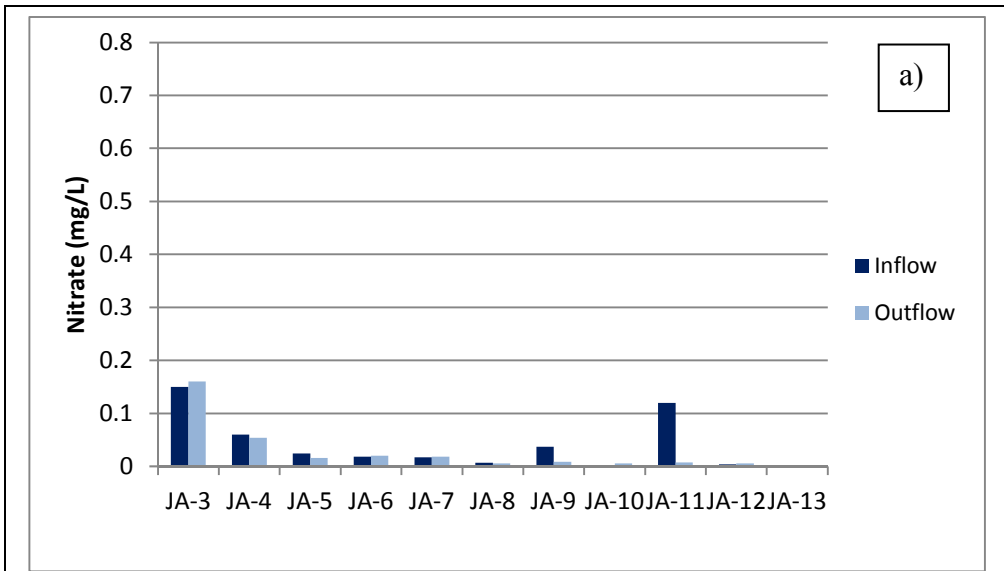
Figure 11. Nitrate concentrations at three treatment sites. A) Vegetated swale at Juliana Ave. (JA), b) grassy swale at Ocean Blvd. (OB), and c) 6th Street (6ST).

Ammonium concentrations ranged from 0.01 mg/L MDL to 0.31 mg/L at the inflow of the grassy swale at the beginning of the April storm. This concentration was reduced by 77% to 0.07 mg/L at the outflow of the swale. On average the grassy swale reduced ammonium concentrations by 75%, with only a couple of samples showing ammonium export.

The vegetated swale had, similar to nitrate, much lower ammonium concentrations in the street runoff than the other two sites. The average inflow concentration at this site was 0.008 mg/L while the concentrations at the grassy swale and the flume filter site were 19 and four times higher, respectively (0.15 mg/L and 0.02 mg/L, respectively). The average treatment effectiveness for ammonium was estimated at 16%, however the majority of the samples at this site were below the detection limit (0.01 mg/L) at the inflow sampling point.

The flume filter site did not show a reduction in ammonium concentrations. Out of the three samples collected at this site, one was below the MDL and two samples showed ammonium export. Since the flume filter does not receive additional runoff between the inlet and outlet, the ammonium increase must originate from the filter material used for this BMP. Possibly, nutrients were stored in the filter material during very low runoff periods (heavy fog or light drizzle) and were washed out during a monitored rainfall event. This could also be the case at the swale sites, where contaminant deposition could happen during dry weather or periods with high humidity and are washed out during high intensity rain.

Even though fertilizer, fungicides, herbicides, and a soil conditioner were used in the growing process of the sod and the installation of the grassy swales, it does not seem that the swale was a source of contamination, and hence we did not flag the results for nitrogen, phosphorus or zinc. The soil conditioner used was a blend of garden compost, chicken manure, rice hulls, redwood compost, and sand to break up the heavy clay soil. Chicken manure is high in N and P and the fertilizer used for growing the sod was high in N (17%) too. However, none of these pre-sampling applications seemed to have biased the nutrient sampling results.

The applied fungicide used in the sod growing process contained zinc but there was no evidence in the collected samples that suggested that zinc was elevated in the outflow of the swales. Additionally, the herbicide used on the sod before it was installed was a bromine-based herbicide and should not have influenced our analysis. The sampling for evaluating the effectiveness of the practices only started in March 2012 and all LID sites had, at that point, been flushed by several rainfall events after their fall installation.

Fecal Indicator Bacteria
FIB concentrations were not considerably reduced when water flowed through the LIDs/BMPs. Total coliform concentrations in most samples were above 24,196 MPN per

100 mL, which is the maximum count for the analytical method used. *E.coli* and *Enterococcus* concentrations increased at the outflow of the grassy swale compared to the inflow samples but that is not surprising as evidenced by the amount of dog fecal matter observed at the site. The vegetated swale and the flume filter reduced *E. coli* concentrations on average by 55% and 34%, respectively. The same sites reduced *Enterococcus* concentrations on average by 61% and 60%, respectively. Since the holding time for FIB samples is six hours, only a sample subset of collected samples was analyzed. Late afternoon and evening samples were not analyzed for FIB since next day laboratory drop-off would have exceeded the holding time. Therefore, the average percent reduction for FIB was based on a small sample size (n = 2 - 5), which is not necessarily representative of the treatment effectiveness of the LID/BMP.

Ancillary Measurement
Dissolved oxygen concentrations dropped from the inflow to the outflow of both swale types from an average of 15.7 mg/L to 14.9 mg/L, while the average temperature remained similar (12.0°C at inflow and 12.4°C at outflow). The dissolved oxygen concentration at the flume filter remained the same. These results suggest that there may be some oxygen consumption in the treatment systems, probably due to slower flow allowing some consumption by bacteria.

The partition of metals in dissolved and particle associated form depends on pH, temperature, and other factors. Measurements of pH ranged from 7.4 to 9.5 with an average of 8.3 at the inflow of the treatment system and 8.2 at the outflow. Temperature ranged from 11.1°C to 14.1°C, with an average of 12.0°C at the inflow and 12.0°C at the outflow of the treatment system. These slight changes in pH and temperature were not expected to cause remobilization or increased bioavailability of metals since the pH never dropped below 7.0 (Filgueiras 2002).

Conclusions
All studied BMPs/LIDs effectively reduced contaminant concentrations in stormwater before it drained into the Reserve. However, site specific and drainage area specific characteristics resulted in effectiveness variations at the monitored sites (Table 3). Overall the desirable reduction of concentrations to below Ocean Plan objectives has been achieved, with the exception of Cu concentrations at the flume filter site (Table 4). This site will be improved during the upland phase with the construction of an additional swale, which will filter runoff before it enters the flume filter for more treatment.

Table 3. Comparison of site characteristics and treatment effectiveness of studied sites.

Sites / Characteristics	Veg. Swale JA	Veg Swale CA	Grassy Swale OB	Grassy Swale 7ST	Flume Filter 6ST
Drainage Area (acres)	2.5	0.5	5	0.5	1
Drainage Area Imperviousness	35 %	35 %	35%	35%	35%
Treatment Area	1,500 sq ft	450 sq ft	1,000 sq ft	350 sq ft	1 sqft
Filter Media Depth	15 inches	15 inches	NA	NA	NA
Filter Type	Sandy/loam	Sandy/loam	Sod	Sod	Hydrocarbon boom
Filter Content	95.6% sand/4.4% clay	95.6% sand/4.4% clay	Soil/Grass	Soil/Grass	NA
Infiltration rate	5.7"/hr	5.7"/hr	NA	NA	NA
Subdrain	Yes	Yes	No	No	No
Maintenance	Low	Low	Low	Low	High
%SSC Reduction	37	60	89	85	74
% Cu Reduction	34	NA	66	NA	26
% PAH Reduction	38	NA	86	NA	69

In order to compare the performance of each of the units as determined so far by this pilot scale study, the results were summarized for all three treatment types (Table 4) and compared to previously studied LID study sites, a rain garden in Daly City (David et al. 2011) and a rain garden in El Cerrito (Gilbreath et al. 2012b). Some site characteristics (e.g., slope of adjacent areas that allows for runoff alongside the BMP/LID) may confound the results since the outflow at the discharge point of the treatment area was likely not treated in its entirety. For example, reduction of contaminants at the vegetated swale site was moderately effective but even during periods of moderate and smaller rainfall events, when the swale was not overflowing, higher outflow than inflow concentrations were occasionally observed. At rainfall below 0.05 inches per hour this site showed more consistent treatment but due to lateral runoff from the adjacent street the reduction rate was biased low during higher intensity storms.

Table 4. Summary of water quality monitoring results. A) Vegetated swale (n = 5*), b) grassy swale (n = 11), and c) flume filter (n = 2). Highlighted in yellow are exceedances of Ocean Plan Objectives.

a)*		Inflow			Outflow			Ocean Plan Objectives	Vegetated Swale % Reduction	Daly City** % Reduction	El Cerrito*** % Reduction
Parameter	**Units**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**				
Cadmium	µg/L	0.031	0.423	0.096	0.020	0.070	0.039	4	59	84	NS
Chromium	µg/L	0.81	4.89	2.51	1.2	4.94	2.52	8	-0.4	NS	NS
Copper	µg/L	7.10	24.8	14.4	5.79	16.6	9.57	12	34	83	69
Manganese	µg/L	11.0	449	73.1	10.3	57.6	31.2	NA	57	NS	NS
Nickel	µg/L	1.54	8.09	3.13	1.93	3.94	2.94	8	6.1	20	NS
Lead	µg/L	1.18	20.7	4.56	1.28	7.04	3.05	20	33	51	NS
Selenium	µg/L	0.83	2.92	1.71	0.62	2.92	1.32	60	23	NS	NS
Zinc	µg/L	10.6	126	32.1	3.01	28.3	11.6	80	64	93	NS
SSC	mg/L	4.3	1,000	118	3.5	580	74	NA	37	29	79
Nitrate	mg/L	0.002 (MDL)	0.15	0.095	0.002 (MDL)	0.16	0.027	NA	72	NS	NS
Ammonium	mg/L	0.005 (MDL)	0.018	0.0077	0.005 (MDL)	0.011	0.0065	NA	16	NS	NS
PAHs (22 RMP congeners)	ng/L	13.8	175	70.5	4.24	234	43.5	NA	38	90	NS
PAHs (13 Ocean Plan congeners)	ng/L	8.42	119	43.2	1.87	159	43.6	8.80	-1.1	NA	NS
Permethrin	µg/L	0.000236	0.004655	0.000457	0.000243	0.000608	0.00038	NA	17	NS	50

*The Fitzgerald ASBS results used for this table were low rainfall intensity (<0.05 inches per hour) samples only because higher rainfall intensity caused lateral runoff that biased the outflow results high. Both comparison studies had curbs and controlled inlet and outlet points.

**David et al. 2011

*** Gilbreath et al. 2012b

NS – Not sample

b)		Inflow			Outflow			Ocean Plan	Grassy Swale	Daly City	El Cerrito
Parameter	**Units**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Objectives**	**% Reduction**	**% Reduction**	**% Reduction**
Cadmium	µg/L	0.01	0.33	0.12	0.02	0.06	0.04	4	67	84	NS
Chromium	µg/L	0.35	5.53	2.41	0.34	2.96	0.96	8	60	NS	NS
Copper	µg/L	2.29	29.7	11.4	1.97	8.56	3.92	12	66	83	69
Manganese	µg/L	11	447	151	4.75	46.3	20.5	NA	86	NS	NS
Nickel	µg/L	1.15	19.3	6.99	1.09	5.8	2.71	8	61	20	NS
Lead	µg/L	0.436	6.57	2.65	0.163	1.53	0.62	20	76	51	NS
Selenium	µg/L	0.3 (MDL)	3.1	0.75	0.3 (MDL)	1.03	0.49	60	35	NS	NS
Zinc	µg/L	6.52	282	61.3	4.38	24	9.46	80	85	93	NS
SSC	mg/L	24	2100	650	7.1	480	71.9	NA	89	29	79
Nitrate	mg/L	0.054	0.32	0.24	0.019	0.12	0.058	NA	76	NS	NS
Ammonium	mg/L	0.022	0.31	0.15	0.010	0.10	0.037	NA	75	NS	NS
PAHs (22 RMP congeners)	ng/L	50.0	2,170	517	16.7	246	72.0	NA	86	90	NS
PAHs (13 Ocean Plan congeners)	ng/L	30.2	1,490	307	11.3	176	53.5	8.80	83	NA	NS
Permethrin	µg/L	0.00451	0.225	0.0772	0.00194	0.0139	0.00583	NA	92	NS	50

c)		Inflow			Outflow			Ocean Plan	Flume Filter	Daly City	El Cerrito
Parameter	**Units**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Objectives**	**% Reduction**	**% Reduction**	**% Reduction**
Cadmium	µg/L	0.06	0.20	0.14	0.07	0.08	0.08	4	46	84	NS
Chromium	µg/L	2.29	4.18	3.45	1.70	2.65	2.32	8	33	NS	NS
Copper	µg/L	13.7	32.1	23.9	16.4	18.4	17.6	12	26	83	69
Manganese	µg/L	48.0	117	89.3	55.2	69.1	63.6	NA	29	NS	NS
Nickel	µg/L	4.96	12.3	9.22	5.73	6.19	6.03	8	35	20	NS
Lead	µg/L	2.76	5.39	4.22	1.86	2.47	2.20	20	48	51	NS
Selenium	µg/L	2.62	4.84	3.47	2.02	4.81	3.48	60	-0.3	NS	NS
Zinc	µg/L	46.5	134	95.2	61.3	69.7	66.6	80	30	93	NS
SSC	mg/L	72	760	340	41	190	88	NA	74	29	79
Nitrate	mg/L	0.09	0.68	0.33	0.08	0.33	0.19	NA	42	NS	NS
Ammonium	mg/L	0.005 (MDL)	0.027	0.018	0.005 (MDL)	0.11	0.049	NA	-172	NS	NS
PAHs (22 RMP congeners)	ng/L	190	509	300	70.8	130	91.7	NA	69	90	NS
PAHs (13 Ocean Plan congeners)	ng/L	140	335	209	50.0	97.2	61.7	8.80	71	NA	NS
Permethrin	µg/L	0.00358	0.00358	0.00358	0.000895 (MDL)	0.000895 (MDL)	0.000895 (MDL)	NA	75	NS	50

In Moss Beach and Montara where no curbs define the streets and help engineers to modify flow pattern, the potential exists that lateral runoff, as observed at the vegetated swale site, may bias the results. This may likely be the case for the upland phase sites as well. If so, concentration monitoring for the winter 2013/14 could show similar runoff effects that may confound the treatment effectiveness of the installed LIDs.

Recommendations
In general, prolonged residence times for stormwater within a treatment system seemed to aid reduction in contaminant concentrations. If site characteristics allow for greater infiltration or the swale length can be maximized and flow can be significantly slowed down, treatment effectiveness will likely be improved. Additionally, velocities of stormwater within the swale should be kept low to avoid scouring of collected contaminants and plant material.

Maintenance
Due to the extremely small treatment area in the flume filters, maintenance efforts of those sites were high. Leaf litter, sediment, and other debris clogged the filters quickly (Figure 5d), resulting in water bypassing the BMP and not getting treated. These BMPs did not seem ideal for street ditches even though their performance, when functioning properly, was respectable compared to their size.

Limited data exist on the long term maintenance of the swales and the subdrains. It would be valuable to find out how leaf litter, other organic matter, and potentially trash keep these LIDs from working properly. How much maintenance is needed in the longer term to keep subdrains from clogging? If possible, follow-up monitoring should be conducted at the vegetated swale sites in a couple of years to ensure long-term treatment of runoff.

Sediment data would also provide important information to understand how these systems function over time as they mature. Will contaminants build up in the soils to a point where removal through filtration is not effective anymore? Is it necessary to remove filter media and replace it with clean soil/compost, and after how many years? This information would be highly valuable to maintain good contaminant reduction efforts from these LIDs for many years.

Budget
Since the data showed that pyrethroids are very effectively reduced through both swales types, resulting in concentrations that are not expected to cause harm to aquatic life based on the aquatic invertebrate LC_{50} of 0.075 µ/L for permethrin (Tomlin 2006), it could be recommended to not analyze water samples collected during the upland phase of this project for pyrethroids. Instead the budget for this costly analyte could be used to obtain a higher number of samples for all other analytes or possibly collect sediment cores at the vegetated swale sites and analyze those for trace element build up when they are three years old.

Additionally, sample frequency could be increased by sampling inflow/outflow pairs only a couple of times during each storm and emphasizing the collection of outflow only

samples for the remaining samples. This way, outflow results can be compared to ocean plan objectives to assure that contaminant concentrations stay below the thresholds for aquatic life, which is essentially the desired outcome of the BMP/LID implementation.

Acknowledgements

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Addendum to Final Report

James V. Fitzgerald Area of Special Biological Significance Pollution Reduction Program

Pilot BMP
Summary Report

Grant Identification Number 10-402-550

August 2013

Nicole David
San Francisco Estuary Institute

Summary

One additional BMP site was monitored in February and March 2013. This site was located at North Lake Street between Virginia Avenue and Vermont Avenue in Moss Beach, CA and included a four cartridge steel catchbasin (Contech Engineered Solutions, West Chester, OH) (Figure 1). This Stormwater Management StormFilter® was designed to remove pollutants like fine solids, soluble heavy metals, oil, and total nutrients with ZPG (zeolite, perlite, and Granular Activated Carbon) filter media. The drainage area for this treatment type was 1.4 acres.

Figure 1. Cartridge catch basin at North Lake Street, Moss Beach.

The drainage area imperviousness was estimated at 35%, similar to the previously studied sites in Montara and Moss Beach (see Table 3 in Pilot Phase report). The unit size or size of the treatment area is approximately 39 square feet and the maximum treatment capacity of the filter is 15 gallons per minute. A moderate level of maintenance will be required to clean the filter from debris and trash and to replace the cartridges every one to two years.

The filter cartridge showed the least effective treatment out of all monitored treatment types ranging from -26% (manganese) to 60% reduction (permethrin) (Table 1). The system had been installed shortly (approximately four weeks) prior to the sample collection, which may have caused the concentrations of some contaminants to be higher than expected on the inflow (e.g., PAH due to new asphalt around the installation site). Additionally, the cement outlet pipe leading treated runoff away from the cartridge and to the outflow point contained some sediment deposits and plant debris (Figure 2), which potentially caused an increase in contaminant concentrations at the outflow during high flow periods due to mobilization of sediment.

Figure 2. Outlet pipe discharging runoff after it has run through the cartridges. Sediment, seen here inside the pipe, from previous storms (before BMP installation) has likely accumulated contaminants.

Methods
Field methods and analytical methods were the same as described in the final report for all other sites. Please see James V. Fitzgerald Area of Special Biological Significance Pollution Reduction Program Pilot BMP Summary Report, March 2013 for details.

QA Summary
Trace Elements

Data were reported for 11 trace metals for six water samples. Mercury was not analyzed in 2013. A field replicate, lab replicate, lab blank, matrix spike (MS)/matrix spike replicate, a laboratory control material (LCM), and other project samples were also reported. Only the total fraction was analyzed, and data were blank corrected.

Overall, the data were acceptable. The choice of method and the Method Detection Limits (MDLs) were sufficient for providing information about trace metals. Only five of the 11 trace metals returned non-detects (ranging from 11 to 89% NDs), with selenium and silver having ≥50% NDs. In the case of silver, this is common in urban monitoring programs (Gilbreath et al. 2012a). None of the trace metals were found to have contamination in the method blanks.

Lab replicates from field samples were used to evaluate precision, except for selenium and silver, which were evaluated using replicates of the matrix spikes. Average precision was good being less than 7% for all the analytes. Field relative standard deviations (RSDs) were also examined and were less than 18%. No additional qualifiers were added. The MSs and the LCMs were used to assess accuracy of the trace metals, except for aluminum, arsenic, and manganese, which were evaluated using only the LCM. Recoveries were good, with recovery errors being less than 25% for all reported analytes, except silver (MS error equaled 32.6%) which was flagged with the non-censoring qualifier "VIU".

Organic Compounds
PAH data were reported for 23 PAH analytes for six water samples. Lab blanks and laboratory control spike samples were also reported. Only the total fraction of water samples was analyzed, and data were not blank corrected. Overall the data were of acceptable quality. MDLs were sufficient to provide useful data and information. Only 11 of the 23 PAH analytes returned non-detects (ranging from 17 to 100% NDs), with 64% (7 out of the 11) having ≥50% NDs. About 39% (9 out of 23) of the PAHs had some contamination in one method blank. Naphthalene, 2-methylnaphthalene, fluorene, and 2,3,5-trimethylnaphthalene had respectively 67%, 50%, 50%, and 17% of sample results flagged with the censoring contamination qualifier of "VRIP" (results with reported concentrations <3x the blank results (by batch) are censored for contamination) according to the QAPP (David and Hunt 2011).

Replicates from the laboratory control spike samples (LCSs) were used to evaluate precision. Average precision was less than the 35% target for all the analytes. No additional qualifiers were added. LCSs were used to assess accuracy of PAHs, as no certified reference materials (CRMs) or MSs were reported. Recovery for the majority of PAH analytes was good with recovery errors less than the target 35% for all reported analytes, and no qualifiers were needed.

Pyrethroid results were reported for six water samples, method blanks, and lab control samples for 14 pyrethroids (deltamethrin/tralomethrin as a coelution; tetramethrin results were flagged as not recorded). Only the total fraction of water samples was analyzed, and the results were not blank corrected.

Overall the data were acceptable. MDLs were only sufficient (<50% NDs) for three pyrethroids, with total permethrin (50% NDs), bifenthrin (83% NDs), and phenothrin (83% NDs) having any detectable concentrations, the rest were 100% NDs. Again, this level of non-detects is quite

common in Bay Area monitoring locations (e.g., Gilbreath et al. 2012b, McKee et al. 2013). Two lab blanks were reported, one for each of the two lab batches, with no blank contamination observed. Data were not blank corrected.

LCSs were used to evaluate accuracy, as no CRMS or MSs were provided, with the average percentage error being below the target measurement quality objectives (MQO) of 35% for all pyrethroids. No additional qualifiers were needed.

Replicates of the LCSs were generally good with average RSDs below the target MQO of 35% for the majority of the pyrethroids. Bifenthrin (35.19%), total permethrin, (35.86%), and prallethrin (39.44%) had blank spike average RSDs above 35%, but below 70%, and were, therefore, flagged with the non-censoring qualifier VIL. The exceedance of the 35% objective was likely a result of generally low concentrations (near MDL) rather than the choice of laboratory methods.

Nutrients/SSC
This dataset included 13 samples reported for SSC (including replicates), and nine for ammonia and nitrate. Blanks, LCSs, and MSs, and one CRM (for SSC) were also reported.

Overall the data were acceptable. The choice of laboratory methods and MDLs were sufficient to provide useful information; no analytes were below the MDL in any samples. Target analytes were not detected in blank samples. Precision on replicates (lab, MS, or LCS) was good (all RSD <5%, with targets of 5% for SSC, 10% for nutrients), with no added flags needed. Recovery sample average errors (<5% for SSC, 10% for nutrients) were good, with no added flags needed. Concentration ranges appeared reasonable. Nitrate and ammonia at Fitzgerald were always <0.5 mg/L.

Two samples (analyzed after a 2.5-day hold) were slightly over the method hold time for nitrate (48 hours), H flagged by the lab, and given a Qual ComplianceCode. These samples were received by EBMUD 37 hours after sample collection, at 10:20 am on March 7, 2013.

Results and Discussion
Precipitation
The three samples at the North Lake site were collected during small to moderate rainfall periods at the end of the rainy season with short total rainfall periods (less than one hour). The total amount of rainfall during the sample collection period was 0.58 inches. The first and the last sample were collected during small rainfall periods (0.10 and 0.08 inches per hour, respectively) and the second sample was collected during a moderate rainfall period (0.14 inches per hour).

Contaminant Loads
Average contaminant loads at the inflow of this storm filter treatment type were estimated by multiplying the contaminant concentration by the estimated flow volume and by a unit conversion factor (Table 1). These estimates are based on instantaneous samples and therefore only represent a snapshot in time. They are not representative of the duration of a storm.

Table 1. Average load estimates in mg/min for the storm filter treatment system. Compare to Table 2 in Pilot Report.

Parameter	Storm Filter
SSC	9,300
Copper	5.2
Lead	0.16
Zinc	4.2
PAH	0.012
Pyrethroids	0.0003

SSC

Concentrations of suspended sediment ranged from 36 to 240 mg/L, with an average of 105 mg/L at the inflow and 76 mg/L at the outflow (n = 3), resulting in an average reduction of 28% for SSC. Outflow samples showed less variable results compared to inflow samples, improving confidence in treatment, but the low sample number does not allow for the rejection of the null hypothesis (the null hypothesis refers to a default position that a potential treatment has no effect). The second sample was collected during higher rainfall intensity (0.14 inches per hour) and a larger amount of sediment export out of the treatment system was observed (SSC increased by over 300% from inflow to outflow.

This can be explained by the installation of the treatment system. The new filter cartridge was installed on the street side and replaced an existing drainage inlet, from which an existing concrete pipe outlets and transports the treated water underneath the sidewalk to the riparian area of San Vicente Creek. Samples were collected at the end of the outlet pipe. The existing concrete pipe contained sediment deposits and plant debris (Figure 2) that probably trapped and accumulated contaminants. During the higher rainfall period, it is likely that a portion of the deposited sediment may have been flushed from the outlet pipe, resulting in high outflow concentrations for sediment and other contaminants. It is also possible that sediment moved through the system in waves, but this would need to be confirmed with additional monitoring.

Trace Elements

Average trace element concentrations at the inflow were very similar to Juliana Avenue and Ocean Boulevard concentrations during the previous winter, with the exception of Al, As, Cr, and Mn, which were lower by about 50%. Copper concentrations were approximately six times higher at North Lake Street compared to the other sites. Copper concentrations exceeded Ocean Plan Objectives (12 µg/L) at the inflow and the outflow of the treatment system. Copper concentrations at North Lake Street ranged from 18.2 to 128 µg/L, with an average of 57.9 µg/L (n = 3) (Figure 3). Similar to all other trace elements, concentrations were reduced during the first sampling event with smaller rainfall amounts (0.1 inches per hour) and showed an increase in concentration at the outflow when rainfall increased to a moderate rainfall event (0.14 inches per hour). During the last sampling event with very little rainfall (0.08 inches per hour), concentrations were again reduced by the filter cartridge. Concentrations of Cu were reduced on average by 14%. Overall, the reduction of metals through the filter cartridge was far less than those observed at the other three treatment types (vegetated swale, grassy swale, and flume filter)

(Table 1). The pipe with the accumulated sediment and plant debris is likely the cause for this little effective treatment performance.
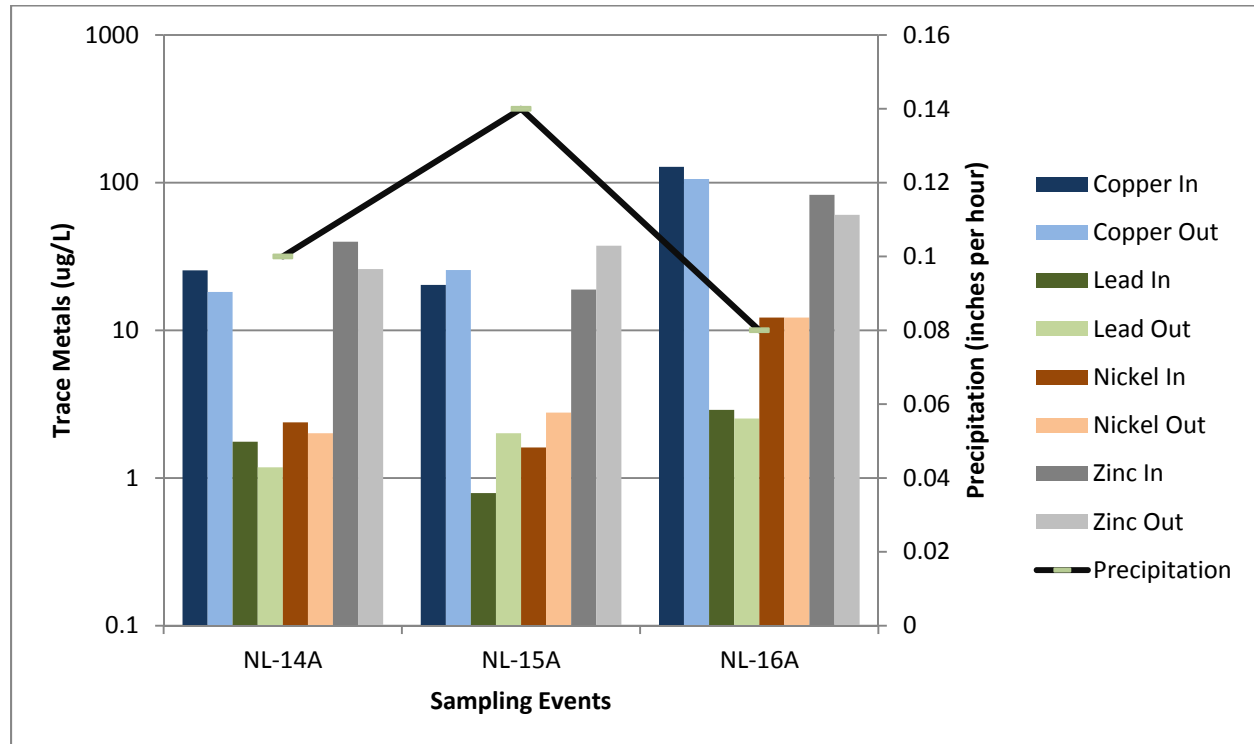

Figure 3. Trace element concentrations during three different sampling events at North Lake filter cartridge.

Organic Compounds

PAH concentrations ranged from 95 ng/L at the inflow to 620 ng/L also measured at the inflow of the treatment system. Concentrations were reduced on average by 4% by the filter cartridge. Concentrations at the inflow were about four times higher than PAH concentrations at the vegetated swale site at Juliana Avenue. One reason for the higher PAH concentrations could have been the recent installation of the filter cartridge, which included repaving of the street surface around the inlet. Since the installation was completed approximately four weeks prior to the first sampling event it is very likely that PAH contamination originated from the freshly paved surface area.

As for trace elements, the low average percent reduction from inflow to outflow could have been caused by the accumulation of sediment in the outlet pipe. Organic contaminants, like PAH and pyrethroids, are strongly associated with sediment particles and could have been mobilized from the outlet pipe during higher flows and measured in the outflow samples, biasing the results high.

Similar to the three other sites, sampled in the previous winter, the most common pyrethroid detected in stormwater runoff samples was permethrin. Permethrin concentrations ranged from 0.00226 µg/L to 0.00626 µg/L, but only three out of six samples had measurable concentrations. The first and the last sample showed relatively low concentrations at the inflow during the low intensity rainfall periods. Concentrations were reduced to non-detectable levels at the outflow.

However, the second sample showed low concentrations at the outflow while no permethrin was measured going into the treatment system. During the more intense rain, when the second sample was collected, permethrin could have been washed out of the pipe with older sediment deposits and measured at the outflow even though it was not detected at the inflow.

If only two samples (first and last) were considered, the treatment system would have been 83% effective in contaminant reduction on average. However, the second sample showed permethrin export without any permethrin flowing into the system, which is likely due to flushing of accumulated sediment and sediment-associated contaminants from the outlet pipe. This reduced the average treatment effectiveness to 60%.

Nutrients
Nitrate concentrations ranged 0.06 to 0.40 mg/L at the inflow of the filter cartridge site (highest and lowest concentrations both measured at the inflow point). These concentrations were higher than at the vegetated swale site at Juliana Avenue but lower than Ocean Blvd. and 6th Street watersheds. Treatment of nitrate through the filter cartridge was ineffective due to a large amount of export (concentration increase of 103%) during the second sample when rainfall was more intense.

Ammonia concentrations ranged from 0.07 to 0.2 mg/L (highest and lowest concentration measured at the outflow point). Ammonia was the only parameter that was reduced during the higher rainfall intensity sample (second sample) and showed an overall reduction in concentration of 20% with treatment through the filter cartridge. The reduction of ammonia being different from the other parameters could be a random result due to the very low sample number.

Fecal Indicator Bacteria
Concentrations of total coliform were above 24,196 MPN/100 mL at all inflow and outflow samples. This is the maximum concentration that the laboratory can identify without further dilution. Total coliform may not be a good indicator for urban stormwater samples since counts are usually at the maximum of the detection limit. SFEI will request dilution of total coliform samples for all samples collected in 2013/2014.

E.coli and *Enterococcus* concentrations both increased from inflow to outflow at the two monitored storm events (Figure 4). The third storm sample was not analyzed for fecal indicator bacteria because it was collected after 21:00 and would have exceeded the holding time by the time it could have been delivered to the laboratory. The increase in fecal indicator bacteria may be attributed to FIB accumulation within sediment deposits in the outlet pipe or due to fecal matter from animals taking shelter in the outlet pipe during the dry summer months.
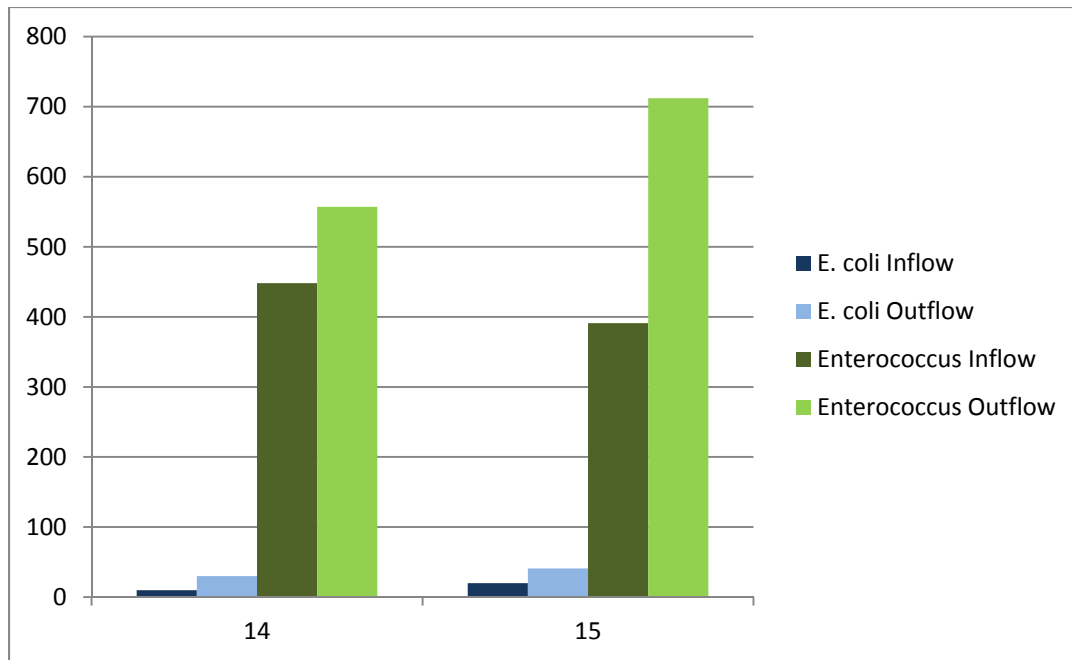
Figure 4. Fecal indicator bacteria concentrations during three different sampling events at North Lake filter cartridge.

Conclusion

The timing for monitoring this newly installed site was not ideal but since the rainy season was near the end, samples had to be collected during the February and March 2013 storms. Unfortunately, samples collected shortly after completed installation of BMPs/LIDs likely showed signals of the device installation and were not representative of the watershed. In this case, PAH concentrations were higher than expected for a small watershed area of 1.4 acres. New pavement around the filter cartridge catch basin could have resulted in elevated PAH concentration measured.

Additional bias of the data could have been introduced by accumulated sediment and plant debris within the outlet pipe that directs treated runoff to the outflow point (Figure 2). Sediment and associated contaminants within the outlet pipe were likely mobilized during higher flow runoff and could have been introduced into the samples, resulting in a "little effective treatment performance (0-30%)" performance of the system (Table 2), using the same rating system that was developed for the other pilot sites.

In general, stormwater flowed well through the system and overflow never occurred, but the storm sizes observed were very small compared to more typical operating conditions. If the outlet pipe were to be cleaned occasionally and accumulated sediments removed, increased treatment efficiency may be possible. Compared to the flume filter and the swales, this treatment system handled larger amounts of runoff without filling up and could potentially treat stormwater during higher intensity storms but based on the small data set collected so far, there is no certainty of any level of treatment performance.

Table 2. Summary of water quality monitoring results. Filter Cartridge (n = 3). Highlighted in yellow are exceedances of Ocean Plan Objectives.

Parameter	Units	Inflow			Outflow			Ocean Plan Objectives	Filter Cartridge % Reduction	Daly City % Reduction	El Cerrito % Reduction
		Min	Max	Mean	Min	Max	Mean				
Cadmium	µg/L	0.05	0.16	0.11	0.04	0.11	0.07	4	33	84	NS
Chromium	µg/L	0.64	2.79	1.61	1.08	2.22	1.62	8.	0	NS	NS
Copper	µg/L	20.3	128	57.9	18.2	106	49.9	12	14	83	69
Manganese	µg/L	14.9	79.8	42.7	25.2	94.9	53.8	NA	-26	NS	NS
Nickel	µg/L	1.61	12.2	5.40	2.01	12.2	5.66	8	-5	20	NS
Lead	µg/L	0.79	2.89	1.81	1.18	2.53	1.91	20	-5	51	NS
Selenium	µg/L	NS	NS	NS	NS	NS	NS	60	NS	NS	NS
Zinc	µg/L	18.9	82.8	47.2	26	60.5	41.3	80	12	93	NS
SSC	mg/L	27	240	100	36	110	76	NA	28	29	79
Nitrate	mg/L	0.06	0.4	0.2	0.1	0.2	0.2	NA	-12	NS	NS
Ammonium	mg/L	0.1	0.2	0.1	0.07	0.2	0.1	NA	20	NS	NS
PAHs (22 RMP congeners)	ng/L	95.0	620	300	160	520	280	NA	4	90	NS
PAHs (13 Ocean Plan congeners)	ng/L	66.4	420	204	105	352	191	8.8	7	NA	NS
Permethrin	µg/L	0.00343	0.00626	0.00485	0.00226	0.00226	0.00226	NA	60	NS	50

Note: The Daly City and El Cerrito studies provide data from other urban LID projects for comparison.
NS – not sampled
NA – not available

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