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

Phase 2 LID
Summary Report

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Summary

As part of Phase 2 of the James V. Fitzgerald Pollution Reduction Program, the County of San Mateo Department of Public Works constructed 12 Low Impact Development (LID) practices to reduce pollutants in stormwater discharges to the protected James V. Fitzgerald Area of Special Biological Significance in Montara and Moss Beach, CA. The LIDs included two swale designs, a native grass sod swale and a vegetated swale with an underdrain system.

Two high priority sites and one low priority site were monitored during storm events to assess LID effectiveness. Composite samples collected during the entire storm length showed a small reduction in outflow concentrations. Suspended sediment was reduced by 6.8% at the vegetated swale site and 31% at the grassy swale site. Copper was reduced by approximately 5% while lead was reduced by 17 and 36%. Zinc concentrations increased at the vegetated swale site by 15% but were reduced at the grassy swale site by 22%. The pyrethroid pesticide permethrin was successfully reduced by 23 and 36%. Due to the small sample numbers per site the confidence in concentration reductions for contaminants is not very high. The higher reductions numbers, however, are very likely to confirm effective treatment. When flow data were combined with concentration data to analyze pollutant loading over an entire storm event, there was no observed load reduction when the range of error (20 to 25%) for laboratory and flow measurements was considered. The only exception was pyrethroid pesticide loads, which were reduced by approximately 50%. For some water quality constituents, such as PAHs, nitrate, and ammonium, the mean concentrations were higher in outflow composite samples.

At the two high priority sites, the majority of stormwater was able to percolate into the subsurface biosoils and underdrain system during low flow conditions. During high flow conditions, however, stormwater passed through the swales in a stream-like manner on the surface of the features without the chance to infiltrate through the swale system, due to the large drainage areas and high volume of runoff. The size of the treatment areas for the two high priority sites was not sufficient to efficiently treat the total volume of runoff during high flow conditions. Based on the composite sampling representing combined low flow and high flow conditions, the overall contaminant load reduction was minimal.

At the low priority site, sediment concentrations were reduced on average by approximately 31%. This grassy swale treated a small discharge area of 0.3 acres and with that had a much higher treatment area to discharge area ratio than the two high priority sites. Sediment reductions were observed at this site and it can be assumed that particle-associated pollutants (e.g., most metals, pyrethroid pesticides, and PAHs) were also reduced within the swale.

The study also found minimal reductions and, in some cases, input of vehicle-derived pollutants like PAHs and copper due to the close proximity of roadways and near-source pathways for loading (wind, input from roadway mid-way through swale). For other pollutants, such as permethrin, with sources often located farther upstream of the swales, reductions were greater. Even though the composite samples did not allow for individual reduction evaluation

during low flow periods, it was observed that greater amounts of runoff infiltrated during light rain, and it can be assumed that greater pollutant reduction occurred within the treatment area at these times.

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 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 non-stormwater runoff from discharges such as landscaping irrigation and car washing 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 transportation (engine combustion, diesel particulates, engine or transmission leaks), leaking supply lines, or leaching from road surfaces comprised of asphalt. Atmospheric deposition also plays a role in contributing contaminants, like mercury and polychlorinated biphenyls, travelling with dust particles from distant sources. Residential and urban land uses can also contribute pollutants. Common household and urban pollutants include pesticides, trash, animal/pet waste (bacteria), and contaminants from roof and gutter materials.

Impervious surfaces like roads, driveways, parking lots, and rooftops prevent water from soaking into the ground and greatly increase the runoff volume during storms. Higher volumes and rates of stormwater runoff can cause increased soil erosion, greater and more frequent flooding, and reshape surface waters through scour and deposition.

Rural land uses such as agriculture, ranching, equestrian facilities, and open space recreation also have the potential to introduce pollutants. These pollutants include nutrients and fertilizers, fecal contamination, pesticides, and increased sediment due to higher erosion rates. Changes to vegetation can also lead to increased runoff.

Various structural BMPs and green infrastructure or 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. LID infrastructure, such as rain gardens and vegetated swales, provides pollutant removal and runoff detention by filtration through porous areas in the engineered biofiltration soil, porous gravel layers, and through biological uptake and microbial breakdown processes by the plants and soil. In a previous study conducted by 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 Davis, 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.

The functionality of LIDs can be impacted by design, construction, and maintenance challenges, or a combination of these factors (Brown and Hunt 2010). However, rain gardens and bioswales have been recommended as measures to reduce pollutants in runoff from building roofs and transportation infrastructure (Dunnett and Clayden 2007) and are implemented in many locations to reduce pollutant runoff to receiving water bodies. Since the James V. Fitzgerald Marine Reserve (Reserve) is the receiving water body for runoff from Moss Beach and Montara and is designated as an ASBS, efforts to reduce pollutants in runoff were made to protect aquatic organisms and the marine environment.

During the Pilot Phase of the Project, a total of seven BMPs were installed, of which four were LIDs and three were structural BMPs. Two LID sites and two structural BMP sites were selected as priority water quality monitoring sites for which samples were tested for the entire suite of water quality parameters (sediment, trace metals, organic contaminants, nutrients, and fecal indicator bacteria). The remaining two LID sites were monitored for sediment concentrations only. All studied BMPs/LIDs 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. Overall the desirable reduction of concentrations to below Ocean Plan objectives was achieved, with the exception of copper concentrations at the two monitored structural BMP sites.

During Phase 2 of the Project, 12 vegetated swales were installed. Phase 2 vegetated swales were constructed by retrofitting existing roadside ditches and drainage features. Due to site limitations and because this project was not subject to Municipal Regional Permit C.3 LID requirements for new and redevelopment, the swales were not constructed per the San Mateo County C.3 Technical Guidance design guidelines i.e., depth of biofiltration soils, treatment area size relative to drainage area (SMCWPPP 2009).

A priority for the project was to address high threat discharges to the ASBS. Site selection was restricted due to multiple factors including:

- short distance of existing ditch segments,
- narrow right-of-way width,
- slope and existing culvert and driveway pipe inverts,

- lack of engineered storm drain system for underdrain system connection,
- permeability of existing soils,
- existing utilities,
- existing roadway drainage patterns (i.e., storm water inflow mid-way along existing ditch),
- construction cost,
- presence of environmentally sensitive habitat and special-status species (i.e., wetlands, California red-legged frog)

Per the San Mateo County Green Streets and Parking Lots Handbook (San Mateo County 2009) and the C.3 Stormwater Technical Guidance (San Mateo County Water Pollution Prevention Program (SMCWPPP) 2014) LID features should be designed to treat runoff from storms with a magnitude up to 0.2 inches of rain per hour and should be designed to make up 4% of the entire runoff area. As such, many of the Phase 2 sites were undersized.

Deviations from the C.3 design guidelines allowed for more widespread low cost implementation of BMPs/LIDs within 10 of the 11 direct ASBS storm drains and testing of a variety of BMP/LID types to help guide future implementation.

Construction of Phase 2 LIDs was phased in 2013 and 2014. The objective of this last season (the winter of 2013/14) of monitoring was to further evaluate the effectiveness of vegetated swales with and without an underdrain for the reduction of sediment and other pollutants (trace metals, trace organics, sediment, and nutrients) in stormwater runoff. In order to comply with grant requirements, monitoring needed to be conducted during the 2013 rainy season.

The 12 proposed vegetated swale sites were examined to determine which were most conducive to monitoring. Three sites were selected – two high priority sites and one low priority site. Two high priority sites were monitored during five storms for the entire suite of contaminants, and one low priority site was monitored for sediment concentrations only. Due to the site limitations described above, all sites presented challenges. The two high priority sites that were selected received runoff from relatively large drainage areas compared to the footprint of the treatment area. Rainfall above 0.02 inches per hour (very little and relatively low intensity for this region of CA) exceeded the infiltration capacity of the systems resulting in most water quickly passing through the system without filtration. Ideally, LID infrastructure is used to mitigate runoff velocity, runoff volume, and water quality across a range of flow rates (Dunnett and Clayden 2007). However, this could not be achieved at the monitored sites for Phase 2 of this Project because of the inadequate sizing ratio of the swales to drainage areas.

Most LID research has been focused on efficiency defined by % capture, but there is recognition that the evaluation of performance by % capture can be misleading in some circumstances. LIDs placed in very clean watersheds, with very low contaminant concentrations in runoff will often show poor performance if evaluated as percent reduction in contaminant concentration. This occurs because the design characteristics of the LID filter (adsorption rates of the engineered media, residence time, native soil infiltration rates, sizing ratio, number and dispersant qualities of the influent point(s) of entry, and other factors) limit any further contaminant concentration reduction. Under such circumstances, if further reduction is desirable, research groups across the US have been exploring augmentation of the engineered biosoil with resins, biochar, and other highly adsorptive substances, increased retention time, and enhancing infiltration. On the other hand, less well designed LIDs in highly contaminated watersheds (for example those with some near field industrial influences) may show greater performance based on percent reduction due to the high contaminant influent concentrations which are easily reduced by a standard or less well designed and maintained LID system.

In this Project, the sampling design and assessment of performance was challenged by both relatively non-contaminated sites with little industrial influence and budgetary constraints on sample numbers, and the number of pollutants being assessed. Since land use and sources are similar in all monitored watersheds for this Project, the comparison of different LIDs in percent reduction should be useful, especially since the attempt was made to point out large differences in inflow concentrations when they occurred. Additionally, effluent concentrations were compared to available water quality targets and load estimates were calculated to present a variety of measures of efficiency for the studied LIDs.

The challenge of low sample numbers is not unprecedented. Sample numbers of just 3-10 are a common facet of previous studies of bioretention (Davis et al. 2003; Diblasi et al. 2009; Hatt et al. 2009; Li and Davis 2009; Line and Hunt 2009) and are often discussed as a study limitation in relation to the strength of interpretations. With such low sample numbers, it is usually possible to state with some confidence if treatment is occurring (i.e. answer the question yes or no). It is often also possible to determine or at least hypothesize what the cause of low treatment performance might be (e.g. whether or not there is blow-through or a net release from the engineered media) but is it often less easy to state with certainty what the actually % effectiveness is.

Methods

Site Description

In addition to the Pilot Phase sampling sites, three monitoring sites for Phase 2 (Figure 1, Table 1) were selected in the unincorporated communities of Moss Beach and Montara, San Mateo County, in the San Francisco Bay Area with the goal of evaluating the effectiveness and success of the implemented LIDs.

The monitoring approach for Phase 2 involved monitoring at two high priority LID sites and one lower priority LID site that were representative types of bioswales installed during the Project. The two high priority sites were located on the east side of Main Street, between 8th and 9th Street, in Montara and the east side of Wienke Way, south of Juliana Avenue, in Moss Beach. The Main Street site consisted of a grassy swale with no underdrain, and the Wienke Way site consisted of a vegetated swale with an underdrain. No structural stability control, such as rock pavers or rock weirs, was needed since the sites were relatively protected from traffic and only slightly sloped. The third and lower priority site was a relatively short grassy swale located at the end of Juliana Avenue in Moss Beach.

Table 1. Sampling locations for Phase 2.

Name	Type	Latitude	Longitude	Elevation	Datum
Main Street	grassy swale, no underdrain	37°32'27.34''N	122°30'57.31''W	108 ft	WGS 84
Wienke Way	vegetated swale with underdrain	37°31'42.69''N	122°30'57.20''W	45 ft	WGS 84
Juliana Avenue	grassy swale, no underdrain	37°31'43.96''N	122°31'00.06''W	43 ft	WGS 84

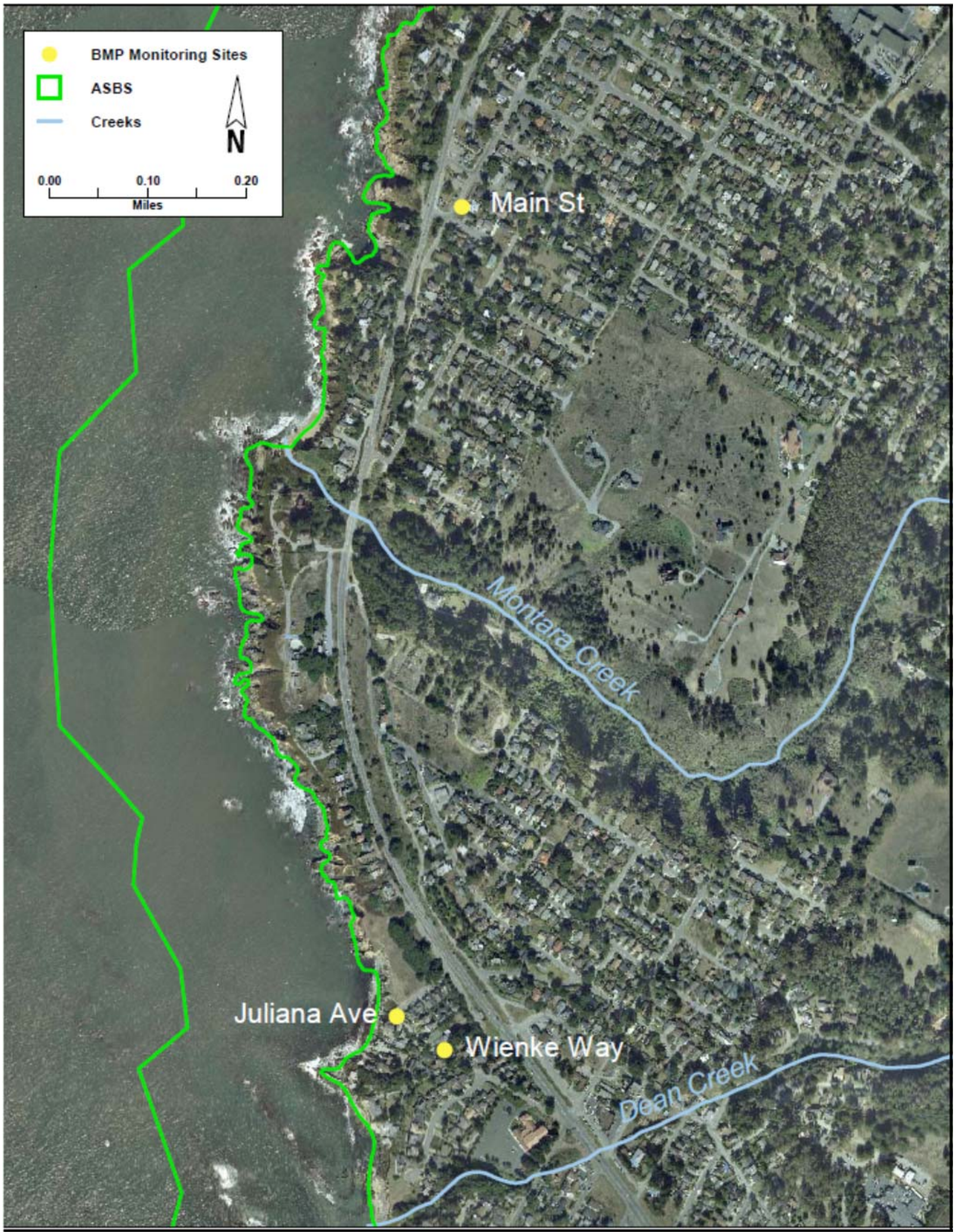


Figure 1. Map of the study area showing Phase 2 sample locations in Montara and Moss Beach.

The coastal communities of Montara and Moss Beach (Figure 1) 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). The winter season of 2013/14 was exceptionally dry with only 54% of the average precipitation between January and May (Figure 2).

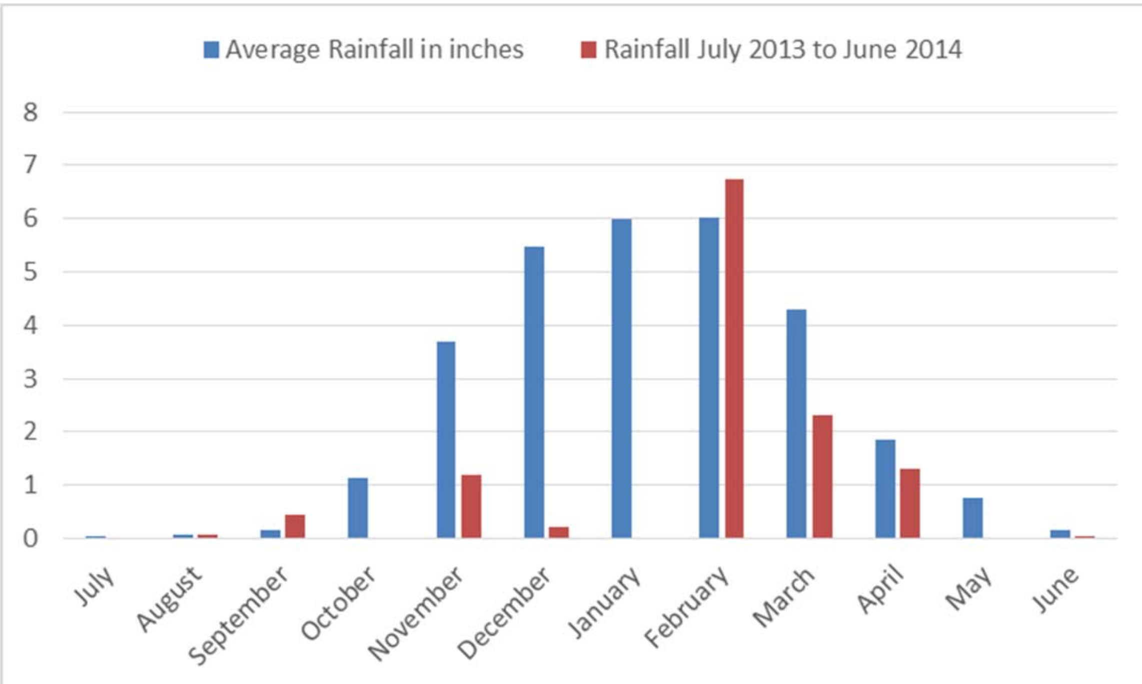


Figure 2. Average annual rainfall totals in inches in Half Moon Bay, CA compared to monthly totals (Climatic Year: July 2013 through June 2014). Latitude N37.4725, Longitude W122.4433, Elevation 36 feet. NOAA NCDC Station 43714.

Two types of LIDs were installed for Phase 2 of the project: 1) vegetated swale with a permeable gravel layer and underdrain system, and 2) grassy swale with native grass sod and biofiltration soil. Both LID types showed good results in reducing pollutant concentrations during the Pilot Phase.

The Main Street grassy swale was located on the east side of Main Street, between 8^{th} and 9^{th} Street, in Montara (Figure 3). It has no subdrain and was installed between a driveway culvert (inflow sampling site) and an intersection (outflow sampling site). The dimensions of the swale were approximately 80 feet (ft) long, 3 ft wide, 0.5 ft deep (below street level). Surface and subsurface filtration was achieved through native grass sod installation over approximately six inches of biosoil. The total surface treatment area was approximately 250 square feet. Erosion control fabric was added on the inboard side of the swale to minimize erosion of exposed soil from the edge of the residential property. Native *Mow Free* grass sod consisted of red fescue

(*Festuca rubra*), Idaho fescue (*Festuca idahoensis*), and Native Western Mokelumne fescue (*Festuca occidentalis*).

Figure 3. Grassy swale at Main Street, Montara. a) Removal of ice plant, b) installation of erosion control fabric and sod, looking south, c) completion of swale, and d) sampling during rain storm, looking north. Drainage area is approximately 10 acres.

The grassy swale at the corner of Juliana Ave and Wienke Way was the second smallest LID site of this Project. It was installed to capture a small drainage area that is not treated by the larger vegetated swale system that was installed along Juliana Avenue during the Pilot Phase. The Phase 2 grassy swale treats stormwater from the south side of Juliana Avenue and a short stretch of Wienke Way (Figure 4). The dimensions of this swale were approximately 60 ft long, 6 ft wide, 0.5 ft deep (below street level). Surface and subsurface filtration was achieved through native grass sod over biosoil. Total surface treatment area is approximately 360 square feet. Native *Mow Free* grass sod including the same previously listed species was used.

Figure 4. Grassy swale at Juliana Avenue and Wienke Way in Moss Beach. a) Removal of ice plant cover, and b) installation of sod, c) posts were installed to protect swale from tire damage, d) SSC sample collection at inflow. Drainage area is approximately 0.3 acres.

The vegetated swale located along the east side of Wienke Way extends from the driveway culvert at 178 and 184 Wienke Way (inflow sampling site) to the driveway culvert at 198 Wienke Way (outflow sampling site). The swale was built with a subdrain that discharged water into the existing culvert (Figure 5). The dimensions of the swale were approximately 100 ft long, 3 to 5 ft wide, 2 ft deep (below street level). A combination of native grass sod and biosoil (first

50 ft) and underdrain installation (last 50 ft) was used. A barrier/liner was installed beneath the underdrain to prevent lateral seepage and protect the adjacent roadway, wall, and residential utility area from undercutting and potential damage. The underdrain system consisted of two 4 inch perforated pipes, the water barrier, and permeable gravel, topped with biosoil and native grass sod. The total surface treatment area is approximately 650 square ft. Native *Biofiltration Sod* consisted of red fescue (*Festuca rubra*), purple needlegrass (*Nasella pulchra*), California barley (*Hordeum californica*), and wet meadow barley (*Hordeum brachyantherum*). The sod was supplemented with native plantings of *Juncus, Scirpus, Carex, Oenathe, Rosa, Potentilla, Mimulus*, and *Fragaria*.

Figure 5. Vegetated swale at Wienke Way in Moss Beach. a) Construction and installation of drain, b) Installation of barrier/liner, c) completed swale, looking south, d) sampling during rain storm at outflow collection site (looking north). Drainage area approximately 29.4 acres.

Field Methods

General Approach to BMP/LID Performance Assessment

To better characterize pollutant load reduction and to decrease the noise of variability and pulses during each storm, the monitoring design for Phase 2 was revised to incorporate composite sampling instead of discrete sample collection. This design was recommended by the Southern California Coastal Water Research Project staff and the Technical Advisory Committee.

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 the appropriate sample volume per aliquot for all parameters at the inflow (approximately 20 min) water would have passed through the treatment area. Ideally an outflow aliquot 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 pollutant concentration reduction is best considered as a component of weight of evidence (USEPA 2009).

Five flow-weighted composite samples were collected at the inlet and the outlet of the two priority BMP sites during the wet season of 2013/14. Each composite sample consisted of five aliquots, ideally collected over the full duration of the storm, but the collection time was limited to 10 hours to keep SFEI staff safe and alert during the sample collection.

The only exception to composite sampling was fecal indicator bacteria (FIB) sampling, for which composite samples could not be collected due to their short holding time (6 hr). FIB samples were collected as discrete samples and delivered to the analytical laboratory before 3 pm for analysis.

Two surrogates, suspended sediment concentration (SSC) and turbidity, were used to increase the confidence in the sampling results for all composite sample pollutants. Surrogate SSC samples were collected as five discrete samples at the Wienke Way vegetated swale, in addition to the composite sample for later comparison. Three to five discrete SSC samples per storm were also collected at the low priority grassy swale site at Juliana Avenue during the five monitored storm events. Surrogate turbidity was measured at the beginning and end of each composite sample collection at the two high priority sites.

Two Hach model #910 flow meters, rented from Oratech Control, Inc. (Brisbane, CA) were deployed, one at each of the priority sites to log the flow data in 1-minute intervals for the duration of the storm. Stored data were downloaded in a dry location after the field team returned to the SFEI office. The flow meters were installed immediately downstream of the outlet collection site. Geotechnical studies and soil surveys in the vicinity have shown that the upper 5 feet of the subsurface is generally very high in clay content with limited permeability and greater runoff potential (i.e., Hydrologic Soil Group D). It was assumed that flow at the outlet was approximately equal to flow at the inlet. Therefore, flow only had to be monitored at the outlet of the sites to describe effluent concentrations and load reductions.

Contaminant load reduction was the most important consideration of LID performance. In classifying LID efficiency based on composite sample pairs, four classes of performance; *Poor* (negative performance or apparent source within the treatment system), *Low* (0-30% reduction), *Moderate* (30-70% reduction), and *High* (70-100% reduction) were generated.

Targeted Storms and Storms Sampled

Water samples were collected during a variety of storm events, moderate intensity rainfall events (>0.1 inches of rain per hour) and low intensity rainfall events (<0.1 inches of rain per hour), and under saturated and unsaturated conditions of the swales to study the LID performance during a variety of flow conditions. High intensity rainfall events (>0.2 inches of rain per hour) were only captured once (February 2, 2014). During the February 2, 2014 storm and during peaks in the hydrograph for smaller storms it was also observed that in both the Main Street and Wienke Way swales, water was moving rapidly over the treatment area without much delay or percolation. Due to impervious surfaces within the swale drainage areas, the response time (time between the beginning of rainfall to the beginning of runoff) ranged from five minutes (at Wienke Way) to 15 minutes (at Main Street), so the SFEI sampling team had to be ready and on site when the rain started.

Two priority LID sites (one vegetated swale with underdrain and one grassy swale) and one low priority LID site (grassy swale) were monitored for contaminants during five storm events. At each of the two priority LID sites, 10 composite sample sets (including in- and outflow samples) of trace elements, PAH, pyrethroid, nutrients, and SSC were collected. FIB samples were also collected during each storm at these two priority sites, but not as part of the composite sample. Three additional sets (in- and outflow) of instantaneous SSC samples were collected at the low priority site during each of the five monitored storms as a surrogate for particle-bound contaminants.

Water Sample Collection

Water samples were collected at a depth of 1-4 inches 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 the composite sample containers, tubing was flushed with site water for at least one minute. Later, when water was transferred from the composite sample container, each individual sample bottle was triple rinsed with site water unless a preservative was used for the container. 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 and Hunt 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 <4ºC.

Swale water quality monitoring was conducted on February 2, February 5/6, February 7, March 5, and March 26, 2014. Five aliquots for a composite sample were collected at the inflow and outflow of each priority swales (Wienke Way and Main Street). The aliquots were collected at multiple stages of the hydrograph. Three additional SSC samples were collected at the low priority site (Juliana Avenue) during the same storms.

Ancillary Measurements

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

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^{o}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 SSC.

Trace Elements

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

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 the solvent was 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 HRGC equipped with a DB-5 capillary column and coupled to a HRMS. The HRMS was operated at a static (≥8000) mass resolution in the EI mode using voltage selected ion detection.

<u>Nutrients</u>

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. Nitrate samples 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

Dataset completeness

Results were reported for 20 field samples, field replicates, field blanks, method blanks, matrix spike/matrix spike replicates (MS/MSDs), laboratory control materials (LCMs), and lab replicate samples for 11 trace elements in two lab batches. Only total phase results were reported. Data were reported blank corrected. Field blanks were not used for the QA/QC evaluation.

Overall acceptability

Overall the data were acceptable. MDLs were sufficient with non-detects (NDs) being reported only for silver, although silver NDs (78%) were extensive (>=50% NDs). Field blanks were examined, but not used in the evaluation. Blank contamination was found in the field blank for aluminum and silver at levels four times the method detection limits, but this level is well below the average field sample concentration for aluminum (6.69 versus 827 µg/L). Silver, however, was found in the field blank at a level approximately equal to the average field sample results, excluding NDs (0.08 versus 0.076 µg/L), and results were flagged.

Lab replicates of field samples were used to evaluate precision, with all the average RSDs being less than the target MQOs (35% for arsenic and selenium, and 25% for the other trace elements). Average RSDs for replicates of the matrix spikes and LCMs were examined and were less than their target average RSD (all <16%). The average RSDs for field and lab duplicates were not used in the evaluation, but were examined and found to be less than the target MQOs (all <12%). No qualifiers were added.

The LCMs were used to assess the accuracy of the trace elements. Recoveries measured for the LCMs were good with recovery errors less than the target MQOs (35% for arsenic and selenium, and 25% for the other trace elements); all ≤12%. No additional qualifiers were needed. Matrix spikes were not used for the evaluation as several of them were not spiked at concentrations high enough to be detected above the ambient sample concentrations, but low enough to be within the range of the ambient samples. The matrix spike recovery error for cadmium was 28% above the target MQO of 25%, all the other available matrix spike recovery errors were less than their target MQOs (aluminum and manganese were not available).

Average trace element concentrations were generally between 1-3 times higher than the 2012 Pilot Phase water sample averages. Selenium was 5 times higher. Average MDLs between years were comparable.

Organic Compounds (PAHs)

Dataset completeness

Data were reported for 23 PAHs (no ALKYLATED PAHs were reported) for 20 water samples, and 1 field replicate. One field blank, method blanks, and laboratory control spike samples (LCSs) were also analyzed in four lab batches. Only total fraction was analyzed and data were reported not blank corrected. Data were reviewed based on the Regional Monitoring Program QAPP (Davis et al. 2001).

Overall acceptability

Overall the data were acceptable. MDLs were sufficient with four of the 23 PAH analytes having non-detects (ranging from 5 to 62% NDs), with 50% (2 out of the 4) having extensive non-detects (>=50% NDs; Benz(a)anthracene and Dibenz(a,h)anthracene).

About 56% (13 out of 23) of the PAHs had some contamination in at least one of the four method blanks. Benz(a)anthracene had 28.6% of sample results flagged with the censoring contamination qualifier of “VRIP”. Blank contamination was found in the single field blank for 11 out of 23 (48%) of the PAHs. Data were not blank corrected.

Precision was evaluated using the LCS replicates. Average RSDs for the LCS samples were well below the target MQO of 35% for all PAHs (all <10%). Average RSDs for the field replicate were examined, but not used for the evaluation, with all being less than the 35% MQO target (all <25%). No qualifiers were needed.

Accuracy was assessed using the LCSs as no CRMs or matrix spikes were reported. Recovery for all 23 PAH analytes was good, with recovery errors less than the target 35% MQO for all reported analytes (all less than 18%). No additional qualifiers were needed.

Average PAH concentrations ranged from 73 to 1328% of those measured in the 2012 Pilot Phase water samples, generally less than 600%, the exceptions Benzo(b)fluoranthene, Benzo(j/k)fluoranthene, and Indeno(1,2,3-c,d)pyrene, were 613%, 764%, and 1328%, respectively. Method detection limits (MDLs) were generally less in 2014 than in 2013, except for Benz(a)anthracene and Dibenz(a,h)anthracene where the MDLs in 2014 were two times higher.

<u>Organic Compounds (Pyrethroids)</u>

Dataset completeness

Results were reported for 20 water samples, one field replicate, one field blank, method blanks, and lab control samples for 14 pyrethroids (Deltamethrin/Tralomethrin as a coelution; Tetramethrin results were flagged as rejected by the laboratory). Only the total fraction was analyzed, and the results were not blank corrected.

Overall acceptability

Overall the data were acceptable. MDLs were sufficient (<50% NDs) for only Total Permethrin (19% NDs). Phenothrin had 66.7% NDs, and the remaining pyrethroids were 100% NDs. Four lab blanks were reported, one for each of the four lab batches, with no blank contamination observed. No contamination was found in the field blank.

Laboratory control samples were used to evaluate accuracy, as no CRMS or matrix spikes were provided, with the average % Error being below the target MQO of 35% for all pyrethroids, except Resmethrin (37.6% Error) which were flagged with the non-censoring qualifier of “VIU”. Replicates on the laboratory control samples were generally good with average RSDs below the target MQO of 35% for the majority of the pyrethroids. Fenpropathrin (49.17%), and Resmethrin (39.91%) had blank spike average RSDs above 35%, but below 70%, and were, therefore, flagged with the non-censoring qualifier VIL.

The average concentration of Total Permethrin in the 2014 Phase 2 samples was 57% of the 2012 Pilot Phase samples. Average Phenothrin concentration in the 2014 water samples was 12% of the concentration measured in one 2013 sample. Bifenthrin was detected in one 2013 sample, but was not detected in all 2014 samples.

<u>Nutrients/SSC</u>

Dataset completeness

Data were reported for three analytes, Ammonia as N and Nitrate as N for 20 composite water samples and SSC for 54 water samples (grab and integrated). Field replicates, lab replicates, field blanks, lab blanks, LCSs, matrix spikes, and certified reference materials (for SSC) were also analyzed in 15 batches (5 for each analyte). Total fraction results were analyzed for Nitrate as N. Dissolved fraction results were reported for Ammonia as N. SSC was measured for particulate fraction. Data were reported not blank corrected. Field blanks were examined, but not used in the evaluation.

Overall acceptability

Overall the data were acceptable. MDLs were sufficient with only Ammonia as N having non-detects (32% NDs). Data were not blank corrected. None of the nutrients were found in the lab blanks. Nitrate as N was measured in field blanks at a level approximately six times the MDL (average field blank concentration of 0.00575 mg/L as compared to the average MDL of 0.0009 mg/L), but this was only about 2% of the average concentration of Nitrate as N measured in the field samples (0.29 mg/L).

Precision was assessed using the lab replicates for Nitrate as N with the average RSD of 1.13% being less than the MQO of 15%. Certified reference materials were used to evaluate the precision of the SSC results with the average RSD of 8.85% being less than the MQO of 10%. Ammonia as N precision was examined using matrix spikes and the average RSD of 10.04% was below the 15% MQO. No qualifiers were needed.

The certified reference materials were used to evaluate accuracy of SSC. Ammonia as N and Nitrate as N were assessed using the matrix spike samples and laboratory control samples, respectively. Average recovery error for SSC was greater than the target MQO of 10% so results were flagged with the non-censoring qualifier of “VIU” (%Error 11.44%). Nitrate as N (23.6% average error) was greater than its MQO of 15% and results were also flagged with the non-censoring qualifier of “VIU”.

Average nutrient concentrations ranged from 23% (Ammonia as N) to 160% (Nitrate as N) of those measured in the 2012 Pilot Phase water samples. Average SSC was 51% of the average 2012 concentrations.

Results and Discussion

A primary goal for the Project was to install BMPs/LIDs to reduce contaminant concentrations and loading into the Fitzgerald ASBS and to provide information on BMP/LID effectiveness to better inform future decisions on BMP/LID implementation to comply with ASBS Special Protections. For many of the water quality constituents in this study, comparison to San Francisco Bay Basin Water Quality Control Plan (Basin Plan) water quality objectives is not possible because many of the Basin Plan objectives are narrative or they are yet to be established for certain parameters. In the results and discussion below, Criterion Maximum Concentration (CMC) for Water Quality recommended by EPA are included for comparison. These CMC criteria were published pursuant to Section 304(a) of the Clean Water Act (CWA).

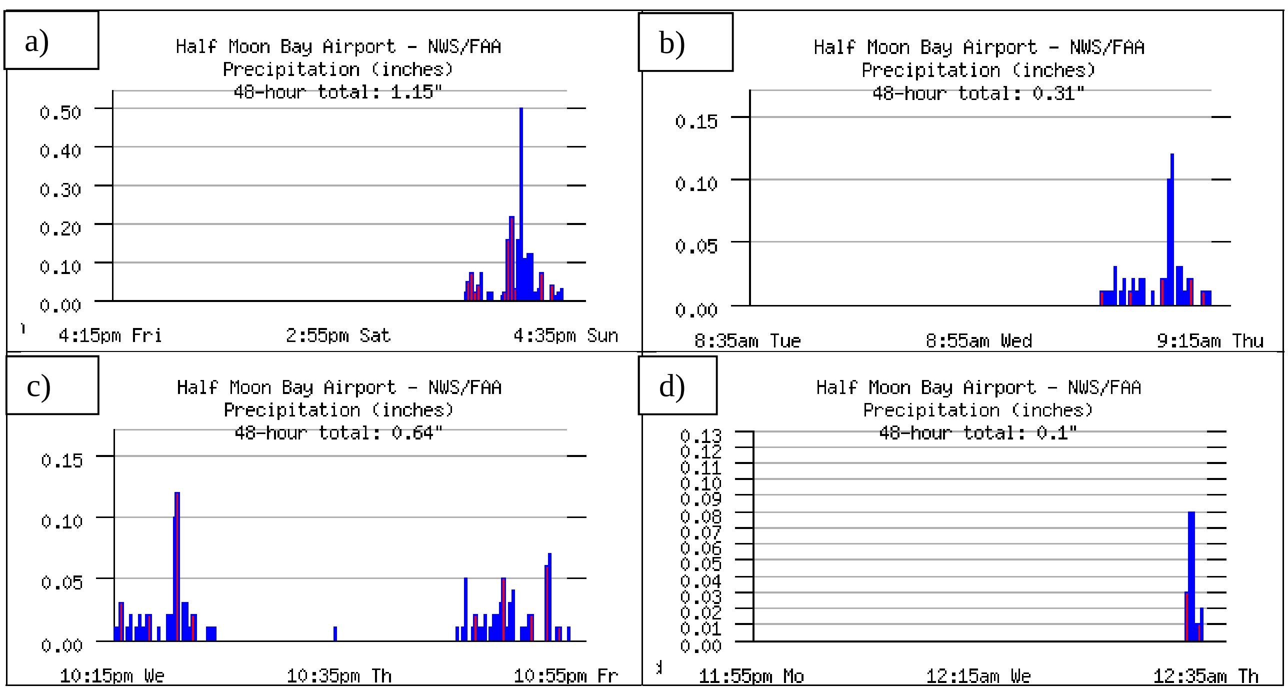
The point of compliance for the ASBS Special Protections is ocean receiving waters, and the target for compliance is below the 85% percentile threshold of water quality data from ocean receiving water reference sites. Monitoring to establish the 85% for reference sites is in progress by the Central Coast ASBS Regional Monitoring Program. The Special Protections require that BMPs be designed to meet Table B Instantaneous Maximum Water Quality Objectives in Chapter II of the Ocean Plan or contribute to an overall 90% reduction for core direct discharges in a given ASBS. For this study, the monitored stormwater at the outflow of the BMPs/LIDs is freshwater that has not been diluted or discharged to the ASBS. Because the

ASBS point of compliance is ocean receiving water, direct comparisons of stormwater data from this study to future ocean receiving water data cannot be made. Data from this study are also not directly comparable to Ocean Plan objectives as they are intended for ocean samples collected after initial dilution has occurred. However, Ocean Plan objectives have been included below for general comparison purposes.

The overall goal to reduce contaminant concentrations and loads was achieved for most contaminants with the exception of copper and PAHs at the vegetated swale site and copper, zinc, and PAHs at the grassy swale site that did not always meet Ocean Plan objectives. However, the Ocean Plan objectives are the most protective objectives that the collected data can be compared to since they apply to ocean water and are intended to be used after initial dilution. The monitored stormwater at the outflow of the BMPs/LIDs has not been diluted.

<u>Precipitation and Flow</u>

About 16 % of the total rainfall volume over the estimated drainage area for Main Street were measured as flow in the treatment area. For the Wienke Way watershed, approximately 36% of the total rainfall volume was measured as flow in the treatment area during the monitored storms. Since the monitored runoff areas have approximately 35% imperviousness (low density residential) much of the rainfall can still infiltrate into the ground in open space areas and between roads and houses. Not all of the rain water runs off into the Reserve through the stormdrains. For the five monitored storms the total rainfall amount varied from 0.1 to 1.2 inches over a 48-hour period (Figure 6) and lasted from three to over 10 hours.



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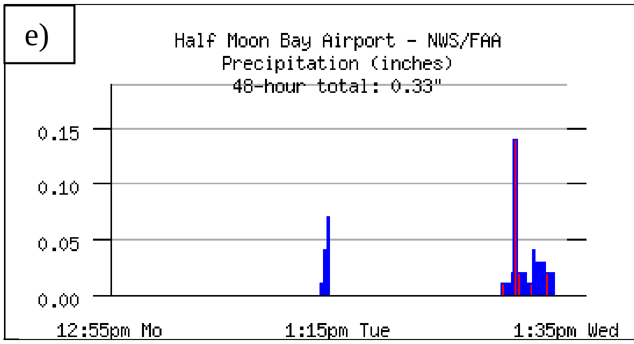


Figure 6. Total precipitation at the Half Moon Bay airport for five storm events. A) February 2, 2014, b) February 5/6, 2014, c) February 7, 2014, d) March 5, 2014, e) February 26, 2014. Data retrieved through the NOAA National Weather Service, Western Region Headquarters (http://www.wrh.noaa.gov/mesowest/getobext.php?wfo=&sid=KHAF&num=48)

During the monitored storms samples were collected when changes in the hydrograph became apparent to capture different flow scenarios and collect aliquots that represent the treatment capacity of the swales overall without variations that originate from fast changing systems and instantaneous occurrences (Figure 7). However, periods of low and high flow cannot be distinguished in the composite sampling results and thus higher treatment effectiveness during low flow conditions may have been muted in the overall sample. Through visual observations, it was apparent that infiltration was higher during low flow periods at both high priority sites, while during moderate and higher flows infiltration was much less relative to the volume flowing over the surface.

On average, measured flows at Wienke Way were approximately five times higher than average measured flows at the Main Street site. Average flows were 0.31 cubic feet per second (cfs) and 0.07 cfs, respectively. These relatively high flows from large drainage areas quickly led to creek-like conditions in both swales when rainfall intensity increased. Response times (time from first rainfall to measurable flow) were very fast and were observed within approximately 5 min at Wienke Way and 20 min at Main Street, depending on the intensity at the onset of the storm.

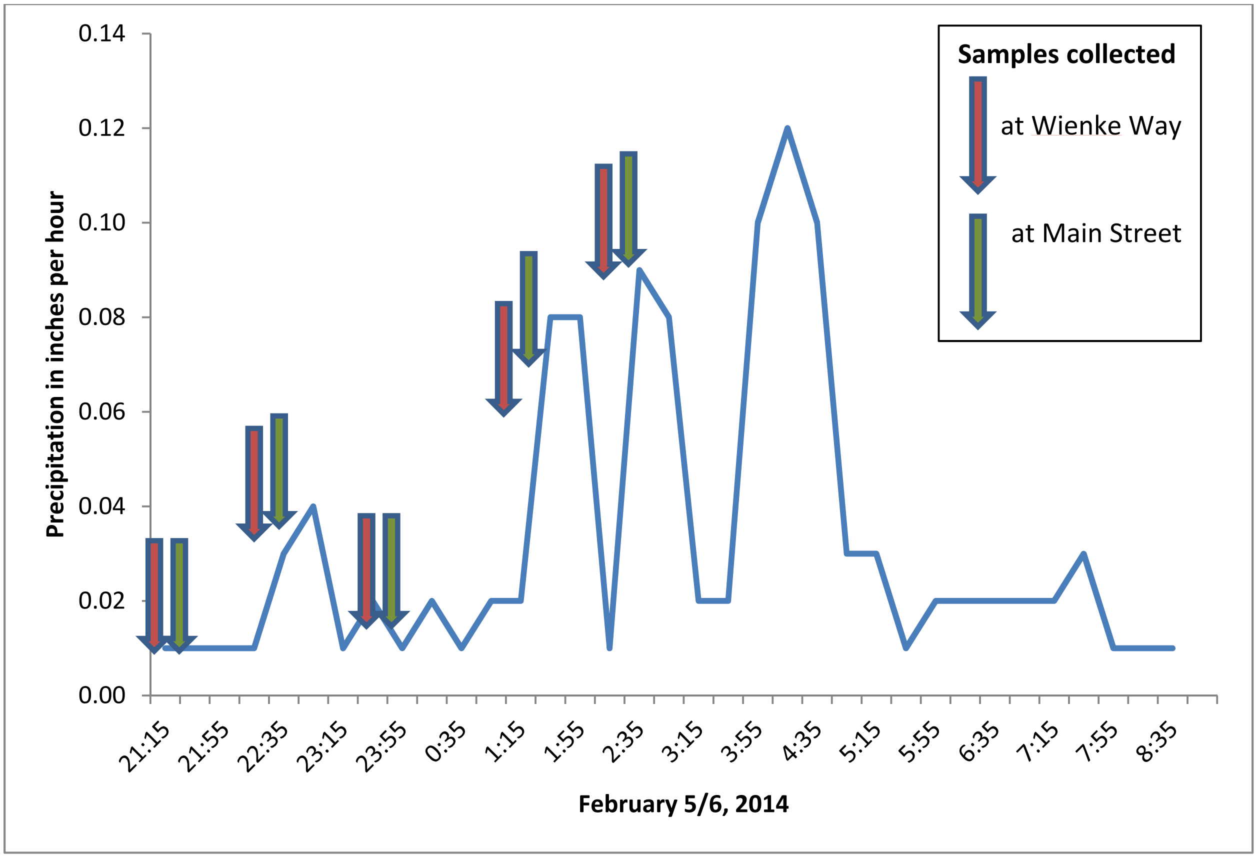


Figure 7. Precipitation in inches per hour at the Half Moon Bay airport on February 5 and 6, 2014, approximately 0.8 miles south of the monitored sites. Arrows indicate time of aliquots sample collection at Wienke Way (red) and Main Street (green) sites.

Suspended Sediment Concentrations and Loads

Benchmarks for sediment are not quantified in the Ocean Plan and objectives usually refer to turbidity rather than sediment concentrations. SSC ranged from 26 to 68 mg/L (mean 43) at the Wienke Way inflow and 95 to 1,100 mg/L (mean 360 mg/L) at the Main Street inflow. Outflow concentrations ranged from 21 to 86 mg/L (mean 41 mg/L) at Wienke Way and 84 to 240 mg/L (mean 140 mg/L) at Main Street. Sediment concentrations were reduced on average by 6.8% at Wienke Way and 27% at Main Street (Table 2). Out of all 11 monitored project sites, the Main Street and Wienke Way sites had the lowest SSC reductions. The Main Street site had the second highest sediment input maximum concentrations (1,100 mg/L) observed over the three years of monitoring. The highest concentration was observed at the Pilot Phase grassy swale site with 2,100 mg/L. Visual observations showed that gophers could have significantly contributed to the comparatively high sediment load at the Main Street site through direct sediment input from numerous large mounds within and directly upstream of the sampling site (Figure 8). Even though the Wienke Way site and the Pilot Phase vegetated swale site also had some gopher activities directly within the treatment areas, the Main Street site seemed to have the highest gopher presence.

Figure 8. Gopher activity within drainage just upstream of sample collection point on Main Street.

The small grassy swale at the end of Juliana Avenue reduced sediment concentrations on average by approximately 31%. Concentrations varied from 10 to 810 mg/L at the inflow (average 150 mg/L) and from 18 to 730 mg/L at the outflow (average 100 mg/L) for the 15 individually collected samples. No loads were calculated since no flow measurements were taken at this low priority site.

It is possible that small amounts of sediment in the effluent originated from the newly constructed swale, rather than coming from the upstream watershed. Both sites were finished only a few weeks before water samples were collected. This process has been a concern in previous studies (Deitz and Clausen 2005; Hunt et al. 2006) and can conceivably diminish LID treatment efficiency for both SSC and particle-bound pollutants. It is likely that sediment particles will be further reduced in the runoff in the coming years due to maturing of plants and their root systems. The establishing of deeper roots will aid the physical particulate filtering process.

Table 2. Suspended sediment concentrations and reductions at all Project sites. Grey rows show results from WY 2013/14.

		Inflow (mg/L)			Outflow (mg/L)			
LID/BMP	**Site**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**% Reduction**
Vegetaed Swale	Juliana Ave	4.3	1,000	118	3.5	580	74	37
Grassy Swale	Ocean Blvd	24	2100	650	7.1	480	72	89
Flume Filter	6th Street	72	760	340	41	190	88	74
Filter Cartridge	North Lake	27	240	100	36	110	76	28
Vegetaed Swale 2	Wienke Way	26	68	43	21	86	41	6.8
Grassy Swale 2	Main Street	95	1,100	360	84	240	140	27
Grassy Swale 3	Juliana Ave north	10	810	150	18	730	110	31

Sediment loads ranged from 0.4 to 22 kg at the Main Street inflow and from 0.1 to 15 kg per storm at the Main Street outflow (Figure 9). At Wienke Way, loads ranged from 0.5 to 29 kg at the inflow and from 0.5 to 36 kg at the outflow. Error bars, estimating a 20% laboratory and flow measurement error, indicating that there was not much change in the sediment load between inflow and outflow at the treatment areas located at Wienke Way and Main Street.

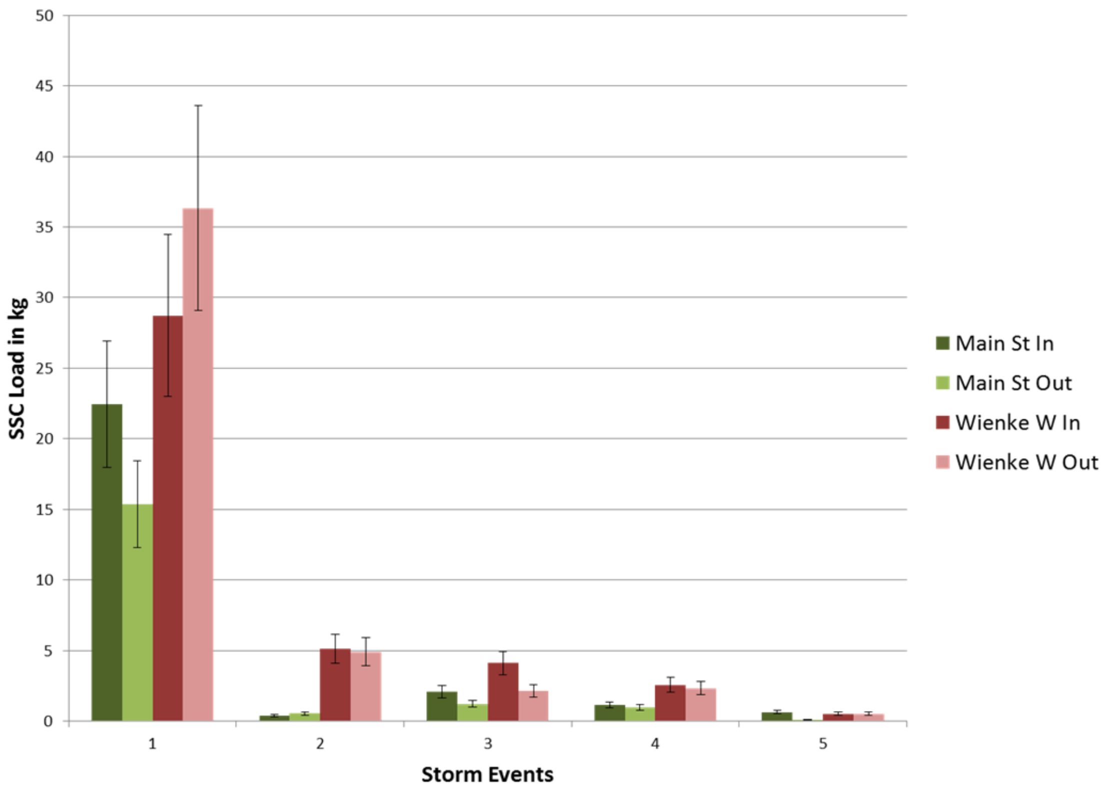


Figure 9. Total sediment load (kg) for each of the five storm events going into and out of the treatment areas at Wienke Way (red) and Main Street (green).

The first monitored storm in early February (Storm 1) after a long (7-week dry period) carried the highest sediment load into the treatment areas. A sediment load about 10 times higher compared to the following storms was measured at Wienke Way. At the Main Street site the sediment load during the first monitored storm was approximately 20 times higher than the average sediment load during the following storms (Figure 9). The first monitored storm also had the highest total rainfall amount over approximately 10 hours (1.2 inches total).

Storm 3 (February 7, 2014) showed the most efficient reduction in sediment load for the Main Street and Wienke Way sites, 41% and 48%, respectively. Storm 3 was a moderate intensity storm with a total rainfall amount of 0.33 inches over approximately six hours. It was preceded by a storm with similar intensity (0.31 inches) 24 hours earlier.

<u>Trace Element Concentrations and Loads</u>

Out of the suite of measured trace metals in this Project, copper and zinc are of most concern because they can be highly toxic to aquatic life. They are discussed in this report in more detail while Table 4 shows all metals monitored in this study. Concentrations for copper ranged from 17 to 39 µg/L at the inflow at Main Street (mean 23 µg/L) and from 15 to 34 µg/L (mean 22 µg/L) at the outflow. At Wienke Way, concentrations ranged from 5.3 to 13 µg/L at the inflow (mean 9.0 µg/L) and from 7.0 to 13 µg/L (mean 8.7 µg/L) at the outflow. The Ocean Plan objective (daily maximum) for copper is 12 µg/L, and the recommended Criterion Maximum Concentration (CMC) for aquatic life recommended by EPA for copper is 13 µg/L. The CMC was exceeded for all Main Street site samples (in- and outflow) but not at the Wienke Way site. Average copper concentrations were more than twice as high at Main Street compared to Wienke Way. Concentration reductions for copper were low (between 4 and 5%) and similar to copper loads within the margin of error. The copper reductions are therefore not considered significant. The same was observed for other mostly vehicle-derived metals (e.g., zinc, lead). However, only one inflow sample at the Main Street site (March 26, 2014) exceeded the CMC for aquatic life for Zn (120 µg/L). No samples were above the Zn CMC at the Wienke Way site. The Ocean Plan objective of 80 µg/L and the ambient water quality guidelines for marine life of 90 µg/L (USEPA 2005) were likely not exceeded considering the dilution that occurs when the swale effluent enters the ocean at the ASBS.

Given the average 25% error for analytical and flow measurements, total loads for all metals showed no distinguishable change between inflow and outflow during the five storms (Figure 10 and 11). Metal loads were approximately four times higher at Wienke Way compared to Main Street for almost all measured metals. However, the drainage area for the Wienke Way swale is much larger and on average receives about five times as much flow as the Main Street swale.

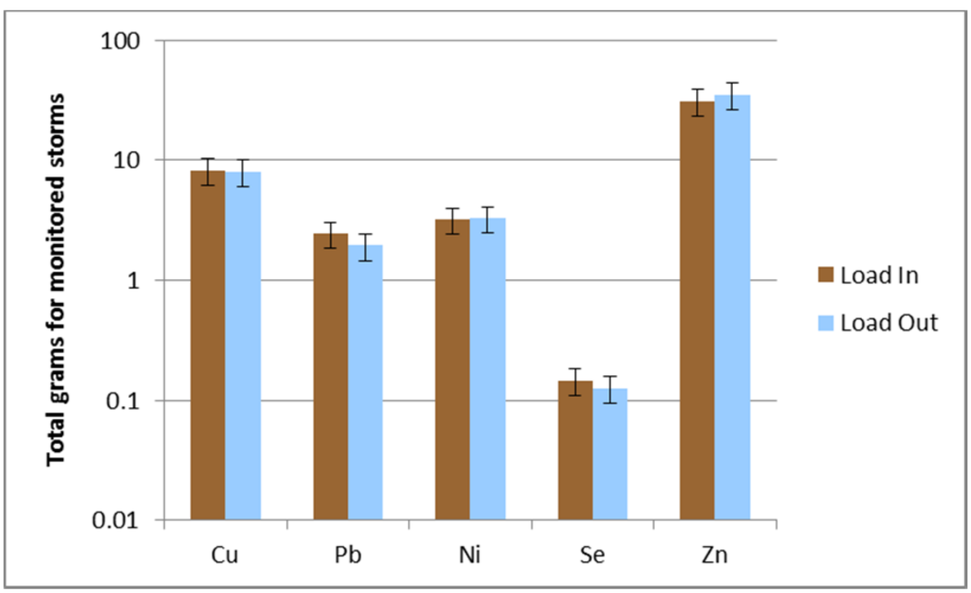


Figure 10. Total loads of trace metals (copper, lead, nickel, selenium, and zinc) in grams during five monitored storms at the Wienke Way vegetated swale. Note logarithmic scale.

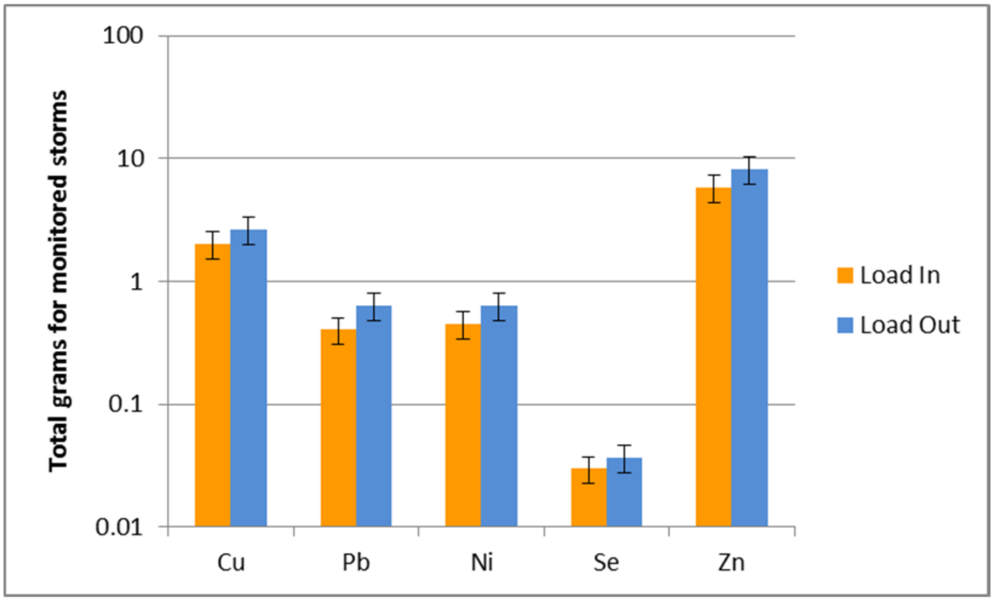
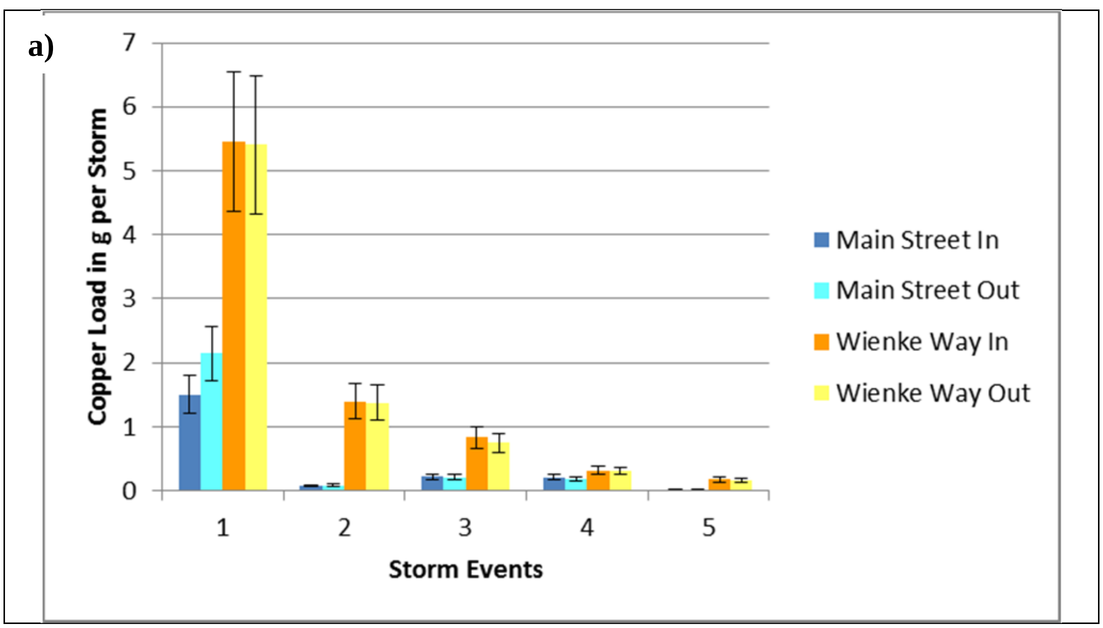


Figure 11. Total loads of trace metals (copper, lead, nickel, selenium, and zinc) in grams during five monitored storms at the Main Street grassy swale. Note logarithmic scale.

Individual metal loads separated for all five storm events (e.g., zinc, Figure 12b) did not show a distinguishable change either. Mostly changes were within the margin of error that represents a 25% error for the analytical method and for the accuracy of flow measurements.



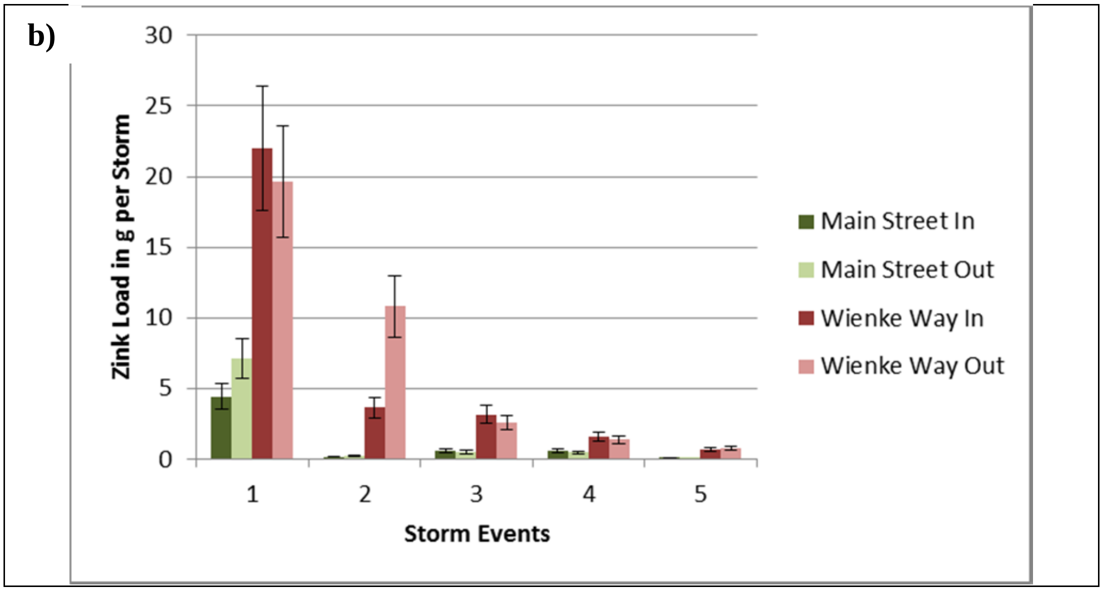


Figure 12. a) Copper and b) zinc loads in grams per storm broken up into the five different storm events.

Since the Main Street swale is located on the eastside of Highway 1 and Main Street it is likely that metals from road surfaces were transported with particles into the swale. In this area, the predominant wind pattern is from the northwest and sometimes southwest, so the wind is likely a pathway for contaminants into the swale areas during wet and dry periods.

<u>Organic Compounds</u>
Concentrations for PAH ranged from 116 to 526 ng/L (mean 214 ng/L) at the inflow of Wienke Way and from 98 to 500 ng/L (mean 335 ng/L) at the outflow of that treatment system. At the Main Street site, inflow concentrations ranged from 560 to 3,900 ng/L (mean 1,970 ng/L) and from 250 to 3,400 ng/L (mean 1,570 ng/L) at the outflow.

For both priority sites in this study PAH concentrations were above the objectives of the Ocean Plan. However, this objective applies to the ocean as a receiving water body and assumes dilution once the stormwater reaches the ocean. This objective should therefore be used as a reference rather than a strict guideline. Only the Main Street site accomplished a slight reduction in PAH concentrations of approximately 20%, while Wienke Way showed an approximate export of 60% of PAHs over the five monitored storms. Similar to concentrations, loads for PAHs were reduced at Main Street by approximately 40% while a PAH load export of about 10% was calculated for Wienke Way.

Very different results were observed for the pyrethroid pesticide permethrin, which is used for ant and termite control around homes and in yards. Permethrin was the only pyrethroid pesticide that had measurable concentrations out of the suite of pyrethroids tested. High non-detects for pyrethroids are common and in most samples observed in the Bay Area to-date, only deltamethrin, cypermethrin, cyhalothrin lambda, permethrin and bifenthrin have been observed. Permethrin and bifenthrin are the most commonly detected pyrethroids.

Fenpropathrin, esfenvalerate/ fenvalerate, cyfluthrin, allethrin, prallethrin, phenothrin, and resmethrin are rarely detected (Gilbreath et al. 2014).

Permethrin concentrations varied from below the 330 pg/L method detection limit (MDL) to 4,300 pg/L (mean 1,600 pg/L) at the Wienke Way inflow and from below the MDL to 1,800 pg/L (mean 1,000 pg/L) at the outflow. At the Main Street site permethrin concentrations varied from 880 to 11,000 pg/L (mean 5,300 ng/L) at the inflow and from 1,600 to 11,000 pg/L (mean 4,100 ng/L) at the outflow. Permethrin concentrations were reduced by 36% at the Wienke Way site and by 23% at the Main Street site. There are no guideline concentrations for permethrin or total pyrethroids listed in the Ocean Plan objectives.

Permethrin loads were highest during the first monitored rainfall event on February 2, 2014 after a longer period of dry weather. Loads were successfully reduced at the Wienke Way and the Main Street sites by 57% and 40%, respectively (Figure 13).

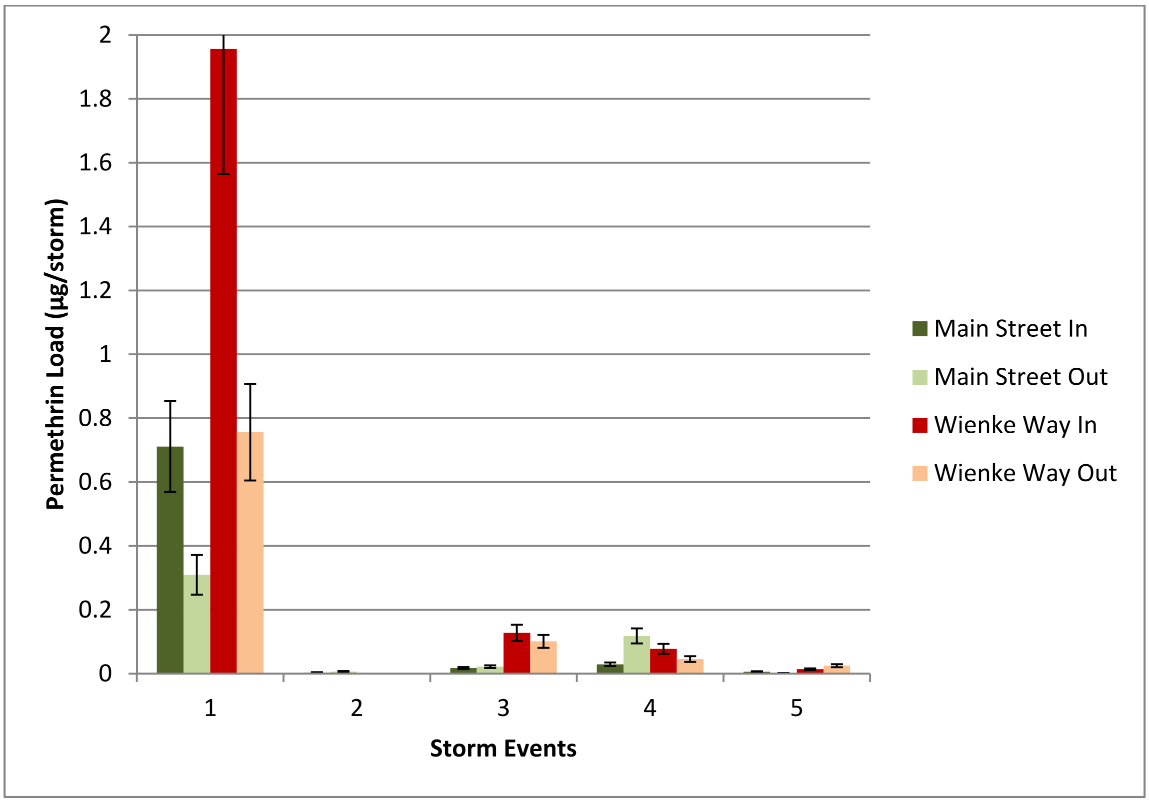


Figure 13. Permethrin loads in µg per storm for all five storm events.

Other studies have documented the efficiency of bioretention for treatment of PAHs (David et al. 2014, Diblasi et al. 2009). They observed reduced effluent concentrations and an efficiency of 87% load reduction and 90% concentration reduction. However, similar reductions were not observed during this study. This may be due to sizing and siting (i.e., near-source contaminants, LID location at roadway and parking lot terminus versus parallel).

Similar to the observation with trace metals, these results suggest that organic contaminant (e.g., PAHs) pathways into the swale exist from high traffic areas like Highway 1. The Main Street swale does not receive direct runoff from the Highway 1 but sediment and dust particle transport by wind and fog seems very likely. Therefore, it is not surprising that measureable treatment of near-source contaminants was not successful. Even during dry periods, contaminants are likely to be deposited within the swale making it difficult to evaluate the full treatment capacity of the swale. Additionally, the relatively small swale sizes compared to the drainage areas account for the *Low* performance for PAH removal.

The difference between vehicle-derived contaminants (like trace metals and PAHs) and permethrin is that sources of permethrin were more distant. There were not many adjacent residential parcels that could have been a direct source for pesticides. It is more likely that permethrin originated rather from the upper watersheds and were transported within the drainage ditch system into the treatment area. This allowed for permethrin to be filtered throughout the length of the swale and would explain the higher success in load reduction compared to near-source vehicle-derived pollutants.

<u>Nutrients</u>

Ammonium concentrations ranged from 0.02 to 0.12 mg/L (mean 0.03 mg/L) at the Wienke Way inflow site and from 0.01 to 0.13 mg/L (mean 0.03 mg/L) at the outflow. At the Main Street site, concentrations ranged from 0.02 to 0.05 mg/L (mean 0.02 mg/L) at the inflow and from 0.01 to 0.07 mg/L (mean 0.03 mg/L) at the outflow. While ammonium was not detected in the composite samples collected during the last two storms, ammonium was exported on average by -10% at the Wienke Way site and by -42% at the Main Street site.

Nitrate concentrations ranged from 0.1 to 0.6 mg/L (mean 0.3 mg/L) at the inflow of the Wienke Way site and from 0.1 to 0.6 mg/L (mean 0.2 mg/L) at the outflow. At the Main Street site, concentrations ranged from 0.1 to 0.7 mg/L (mean 0.3 mg/L) at the inflow and from 0.04 to 0.7 mg/L (mean 0.3 mg/L) at the outflow. Nitrate concentrations were slightly reduced at the Wienke Way site (20% reduction) and also reduced by 23% at the Main Street site. Nitrate loads were reduced by 3% at Main Street and by 14% at Wienke Way (Figure 14). There are no guidelines for ammonium or nitrate concentrations in the Ocean Plan.

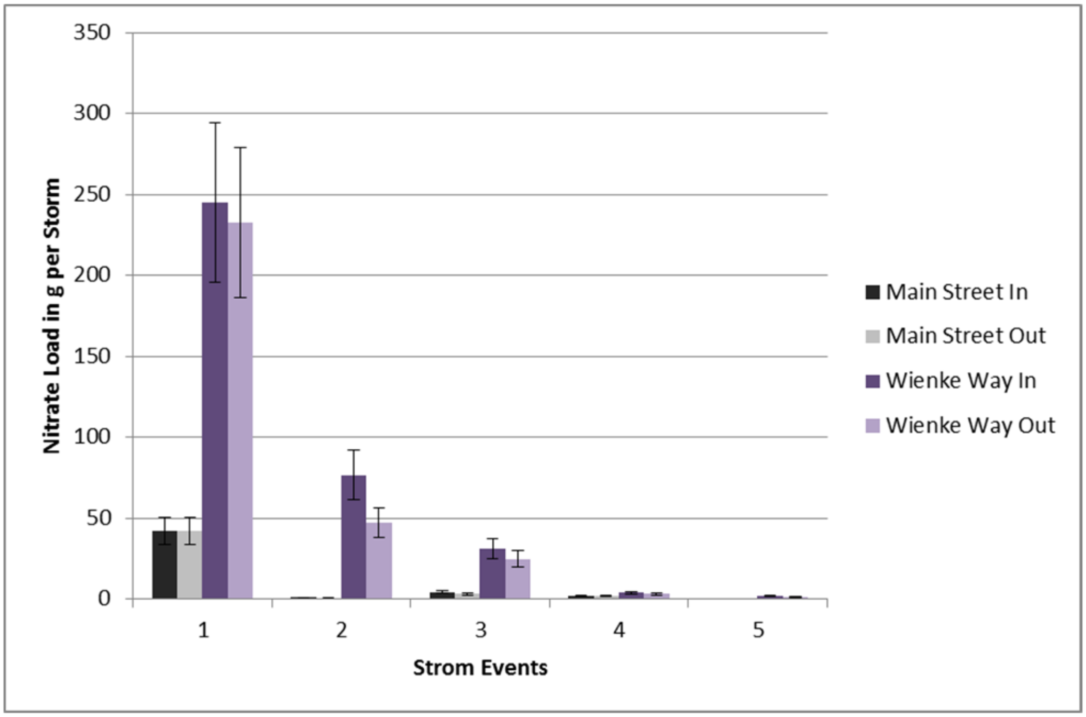


Figure 14. Nitrate loads in g per storm at Main Street and Wienke Way during all monitored storm events.

No fertilizer was used during or after the construction of the swales. Nevertheless, nutrient export was observed at both studied sites. The Main Street and Wienke Way retrofits likely enhanced the attractiveness to be used by dogs and cats, particularly at Main Street since the site was converted from a compacted dirt shoulder to a soft grassy swale between the sidewalk and the street.

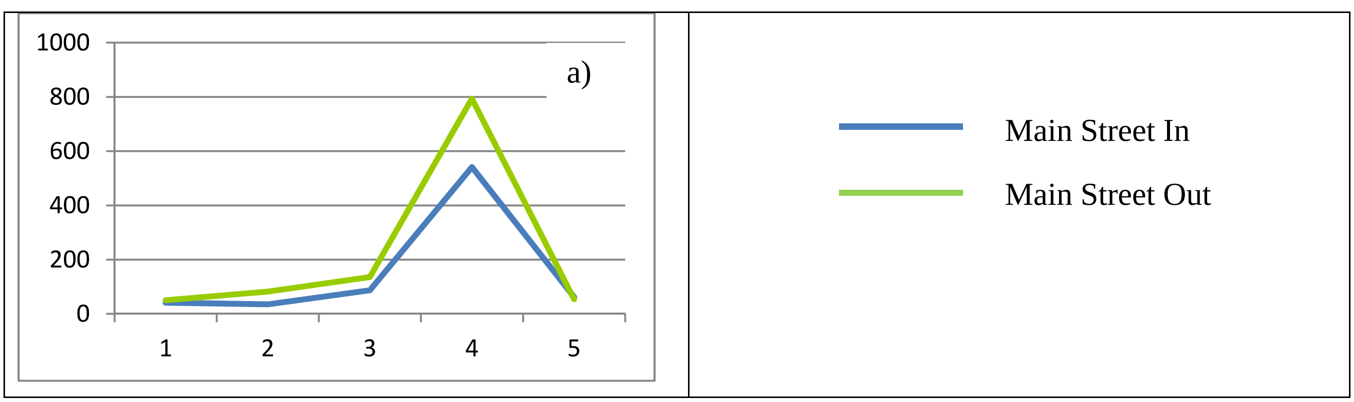
<u>Fecal Indicator Bacteria</u>

No concentration reduction was observed on average for *Enterococcus, E. coli*, or Total Coliform. While the Main Street swale mostly exported *Enterococcus* (on average -250%) the Wienke Way swale exported on average only -25% and showed slight *Enterococcus* reduction for the first three rainfall events. The Wienke Way swale is much lower than the street level compared to the Main Street swale and possibly less desirable for cats and dogs. For comparison, the average *E. coli* concentration observed at the swales (31,500 MPN) is approximately 100 times higher than the recommended freshwater criteria recommendation for contact recreation. *Enterococcus* concentration at Main Street ranged from 1,160 to the maximum count of 24,196 MPN. There are no objectives for bacteria listed in the Ocean Plan, but as a reference, beaches are considered unsafe for contact recreation when *Enterococcus* concentrations rise above 110 MPN.

<u>Ancillary Measurement</u>

A number of ancillary measurements were made to help understand the physiochemical characteristics of runoff as it passes through these bioswales. Dissolved oxygen ranged from 6.8 to 8.9 mg/L at the inflow and from 5.1 to 8.0 mg/L at the outflow. The average dissolved oxygen concentrations were 7.3 mg/L (inflow) and 7.2 mg/L (outflow). The difference in dissolved oxygen concentrations from inlet to outlet was on average less than 7%, which is statistically different ($p = 0.009$, t-test) with lower concentrations at the outlet. Compared to the cemented ditch from where the stormwater drained into the bioswale the swale contained more organic matter, which perhaps lead to decomposition and anaerobic conditions and lower DO on the outlet. Temperature varied from 9.2°C to 14.3°C at the inflow over the course of the five sampling events and from 9.3°C to 14.7°C at the outflow. Individual sampling events varied by less than 3% between inflow and outflow temperature, which is not statistically different ($p = 0.5$, t-test). Changes in salinity from inflow to outflow were below 15%, with salinity ranging from 0.04 to 0.26 at the inflow (average 0.12) and from 0.05 to 0.22 at the outflow (average 0.12). This is not a statistically significant difference ($p = 0.5$, t-test).

Numerous turbidity measurements were taken during each storm (Figure 15 and 16) since there is no analytical cost involved with this parameter. The Ocean Plan objectives recommend that the monthly average turbidity should not exceed 75 NTU and that at any time the maximum turbidity of 225 NTU should not be exceeded. But again, this applies to diluted ocean water and provides a reference only. Turbidity at Wienke Way ranged from 3 – 139 NTU (average 41) at the inflow and from 5 – 125 NTU (average 40) at the outflow. This difference is not statistically significant ($p = 0.1$, t-test). At Main Street turbidity was more variable and ranged from 19 – 875 NTU (average 104) at the inflow and from 17 – 1512 NTU (average 204) at the outflow, which is a statistically significant increase ($p = 0.02$, t-test). Turbidity varied greatly during storm events and from storm to storm but not so much between inflow and outflow. Turbidity at the inflow was generally similar to turbidity measured at the outflow but occasionally an increase in turbidity was observed at the outflow (Figure 14 and 15). Any kind of disturbance within the swale could have caused the increased turbidity at the outflow, e.g., gopher activity or erosion of the swale bank. With the exception of dissolved oxygen and turbidity, the other physiochemical parameters changed little if at all as stormwater passed through the bioswales.



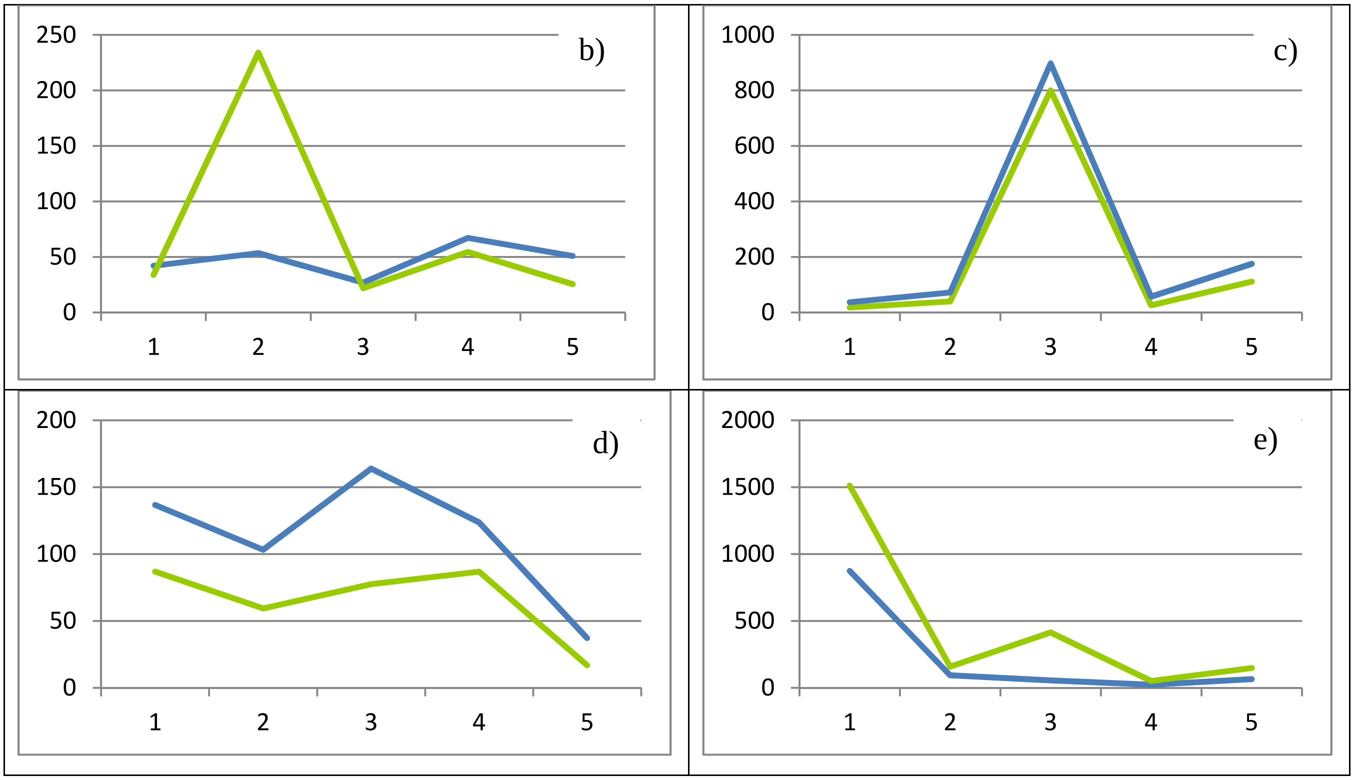
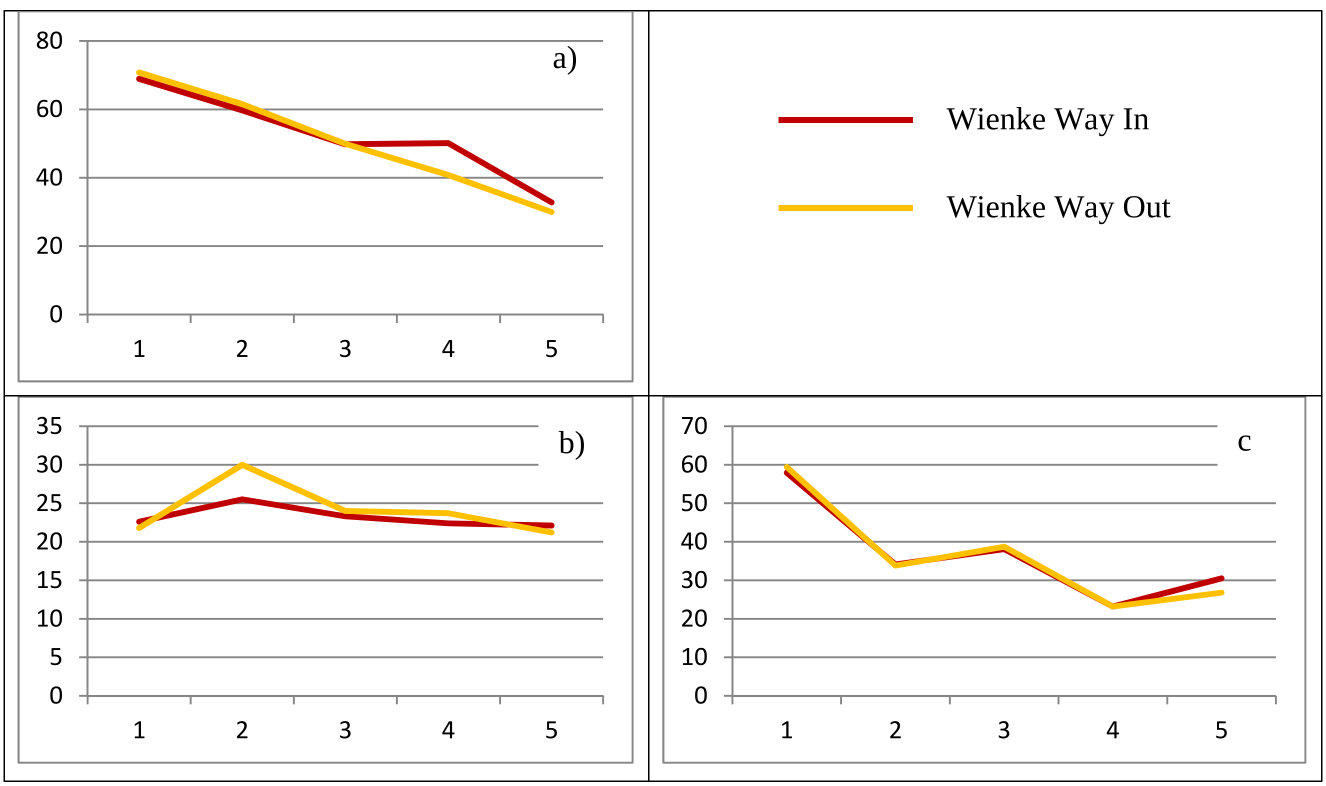


Figure 15. Turbidity at Main Street during the duration of five storm events. Storm event a) February 2, 2014, b) February 5, 2014, c) February 7, 2014, d) March 5, 2014, e) March 26, 2014. Please note different y-axis scales.



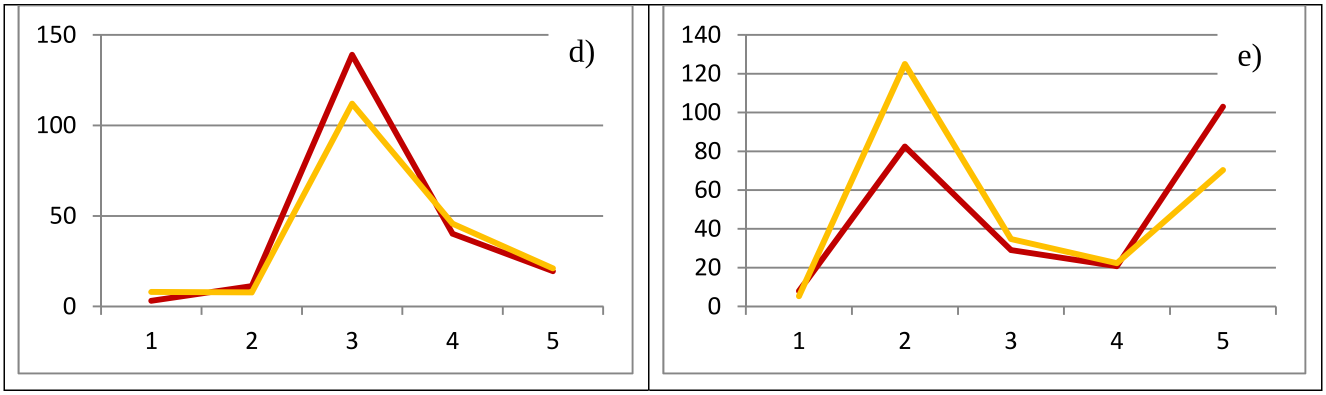


Figure 16. Turbidity at Wienke Way during the duration of five storm events. Storm event a) February 2, 2014, b) February 5, 2014, c) February 7, 2014, d) March 5, 2014, e) March 26, 2014. Please note different y-axis scales.

The discrete samples that were collected for SSC right after each aliquot at the outflow of Wienke Way during one storm event showed a 31% difference to the composite sample at the outflow of Wienke Way for the same storm. The average of the five discrete samples was 59 mg/L and the composite sample had a sediment concentration of 86 mg/L. This confirms that SSC varies greatly during short time periods (even within minutes) and the composite samples have likely provided the best results for the overall performance of the swales compared to the discrete samples that were collected during the first and second year of the Fitzgerald Project.

Conclusions

While sediment concentration reductions were characterized as *Low* effectiveness at the two priority sites, the third swale (a low priority site) showed *Moderate* effectiveness for sediment reduction (31%). This grassy swale treated a small discharge area of 0.3 acres and had a discharge to treatment area ratio of 2.8%, which is closer to the recommended 4%. Since sediment was effectively reduced in this swale one can assume that particle-associated pollutants (e.g., most metals, pyrethroid pesticides, and PAHs) were also moderately reduced within the swale.

While metal reductions at the monitored sites in Phase 2 were in the *Low* effectiveness category and showed no significant load reductions beyond the 25% standard error, a number of previous studies have reported rain garden and bioswale efficiency for the removal of copper, lead, and zinc ranging between 43-99% for copper, 31-100% for lead, and 64-99% for zinc (Davis et al. 2003; Hatt et al. 2009; Hunt et al. 2006; Hunt et al. 2008; Li and Davis 2009). Also, Pilot Phase sites showed promising results with *Moderate* to *High* effectiveness for the reduction of metal concentrations (34-66% for copper, 33-76% for lead, and 64-85% for zinc). The two priority Phase 2 sites had low drainage area to treatment area ratio (Wienke Way 0.05 and Main Street 0.06) (Table 3), which likely reduced pollutant reduction efficiency. Pilot Phase LIDs site ratios for the two high priority sites (vegetated swale and the grassy swale) were 1.4 and 0.5, respectively.

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

Sites / Characteristics	Grassy Swale 2 Main Street	Veg. Swale 2 Wienke Way	Grassy Swale 3 Juliana Ave.
Drainage Area (acres)	10.0	29.4	0.3
Drainage Area Imperviousness	35 %	35%	35%
Treatment Area	250 sq ft	650 sq ft	360 sq ft
Filter Media Depth	0.5 ft	2-4 ft	0.5 ft
Filter Type	Biosoil/sod	Biosoil/sod	Biosoil/sod
Filter Content	95.6% sand/4.4% clay	95.6% sand/4.4% clay	95.6% sand/4.4% clay
Infiltration rate	5.7"/hr	5.7"/hr	5.7"/hr
Subdrain	No	Yes	No
%SSC Reduction	27	6.8	31
% Cu Reduction	5.0	4.2	NA
% Zn Reduction	22	-15	NA
% PAH Reduction	20	-57	NA
% Permethrin Reduction	23	36	NA

PAH concentrations were high and far above Ocean Plan objectives at both priority sites (Table 4 and 5). However, the Ocean Plan objectives are intended for the ocean receiving waters upon completion of initial dilution. Using the objectives in this report is for comparison purposes only. Maximum copper concentrations were also above the Ocean Plan objectives at the in- and outflow of both swales and approximately three time as high at the Main Street site compared to Wienke Way.

At the Main Street site also lead maximum concentrations were above Ocean Plan objectives at the inflow but below this guideline at the outflow of the swale (20 µg/L). Lead and copper concentrations were also below the Ocean Plan objectives at Wienke Way. As discussed earlier, the overall performance of the two swales showed limited effectiveness, likely due to the drainage area to treatment area ratio and local pollutant loading from within and adjacent to the swale. This resulted in low pollution concentration reductions when compared to other LID sites in the Bay Area. Chromium was the only other metal that exceeded Ocean Plan objectives but does not cause great concern for aquatic life.

Nutrient removal showed *Poor* performance at both sites and could be related to increased cat and dog traffic in these improved LID areas.

The best performance results were achieved for pyrethroid pesticides that showed *Low* effectiveness at the Main Street site (23%) and *Moderate* effectiveness in removal of pyrethroids (36%) at the Wienke Way site.

Table 4. Summary of water quality monitoring results. A) Vegetated swale (Wienke Way) (n = 5), b) grassy swale (Main Street) (n = 5). Highlighted in yellow are exceedances of Ocean Plan Objectives.

a)		Inflow			Outflow			Ocean Plan	Vegetated Swale	Daly City**	El Cerrito***
Parameter	**Units**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Objectives**	**% Reduction**	**% Reduction**	**% Reduction**
Cadmium	µg/L	0.04	0.11	0.06	0.03	0.08	0.05	4	23	84	NS
Chromium	µg/L	1.1	3.2	2.2	1.1	2.2	1.8	8	18	NS	NS
Copper	µg/L	5.3	13	9.05	5.2	13	8.7	12	4.2	83	69
Manganese	µg/L	21	67	40	23	61	40	NA	0.9	NS	NS
Nickel	µg/L	2.6	5.9	4.1	2.8	5.4	4.0	8	2.6	20	NS
Lead	µg/L	1.7	4.1	2.5	1.5	3.2	2.0	20	17	51	NS
Selenium	µg/L	0.7	8.0	2.6	0.6	4.0	1.8	60	30	NS	NS
Zinc	µg/L	19	52	35	23	55	40	80	-15	93	NS
SSC	mg/L	26	86	43	21	86	41	NA	6.8	29	79
Nitrate	mg/L	0.077	0.58	0.29	0.05	0.55	0.24	NA	20	NS	NS
Ammonium	mg/L	ND	0.12	0.031	ND	0.13	0.034	NA	-10	NS	NS
PAHs (13 Ocean Plan compounds)	ng/L	120	560	210	98	500	340	8.8	-57	NA	NS
Permethrin	µg/L	ND	0.0046	0.0016	ND	0.0018	0.001	NA	36	NS	50

**David et al. 2011
*** Gilbreath et al. 2012b
NS not sampled

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	0.06	0.36	0.14	0.05	0.20	0.10	4	29	84	NS
Chromium	µg/L	1.8	8.7	3.9	1.8	6.6	3.2	8	17	NS	NS
Copper	µg/L	16	39	23	15	34	22	12	5.0	83	69
Manganese	µg/L	54	400	140	50	210	97	NA	30	NS	NS
Nickel	µg/L	2.9	12	5.5	2.8	8.5	4.7	8	14	20	NS
Lead	µg/L	2.4	23	7.3	2.7	8.5	4.7	20	36	51	NS
Selenium	µg/L	0.6	4.9	1.7	0.7	4.1	1.7	60	-1.4	NS	NS
Zinc	µg/L	40	160	72	35	110	56	80	22	93	NS
SSC	mg/L	95	1,100	360	84	240	140	NA	27	29	79
Nitrate	mg/L	0.14	1.0	0.33	0.038	0.66	1.3	NA	23	NS	NS
Ammonium	mg/L	ND	0.048	0.019	ND	0.065	0.026	NA	-42	NS	NS
PAHs (13 Ocean Plan compounds)	ng/L	564	3,900	2,000	250	3,400	1,600	8.8	20	NA	NS
Permethrin	µg/L	0.00088	0.011	0.0053	0.0016	0.0048	0.0041	NA	23	NS	50

**David et al. 2011

*** Gilbreath et al. 2012b

NS not sampled

The bioswales monitored during Phase 2 of the James V. Fitzgerald Area of Special Biological Significance Pollution Reduction Program located in Moss Beach and Montara showed *Low* efficiency in removing metals and organic pollutants from stormwater. There were likely inputs of pollutants originating from local sources (vehicle- and roadway-derived pollutants, sediment from gopher activity within and near the swales, pet waste and activity within swale) within the treatment areas.

Pollutants originating more from more distant sources, e.g., pyrethroid pesticides from upstream residential properties not located directly next to the swale, entered the swale with the stormwater influent and showed more successful treatment.

In general, both priority sites were undersized in relation to the drainage area and could not effectively treat larger flows. Rainfall amounts of as little as 0.02 inches per hour exceeded infiltration capacity. Sediment concentrations were more effectively reduced at the Main Street site compared to Wienke Way, although Main Street, on average, had more than twice the influent concentration of suspended sediment than the Wienke Way site.

Recommendations

The installation of larger treatment areas closer to the recommended ratio of 1:25 (4% of the catchment area) would likely provide more effective treatment and contaminant reduction and is recommended for future projects. For this Project however, there was not enough adequate right-of-way space for retrofitting existing ditches with vegetated swales of the appropriate treatment in the desired direct ASBS outfall drainages. To do so would have increased the cost drastically beyond the scope for this Project's budget.

Placement of multiple management cells in a series could be considered as a future option to increase treatment area for sites with larger drainage areas, however such site configurations have not been well studied. Such configurations could be given more attention and a thorough evaluation of their effectiveness should be completed since they may be an innovative, effective, and more feasible approach considering space and budgetary constraints of LID projects. Additional monitoring for these bioretention cell series would be recommended,

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 and the swale length can be maximized thereby reducing flow and velocity, then treatment effectiveness will likely be improved. Reducing velocities of stormwater within the swale will also help to avoid scouring and resuspension of filtered sediment and contaminants, as well as plant material.

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