Bioswales for stormwater remediation and infiltration: Assessing regulatory climate and quantifying filtration capacity of a Claremont bioswale

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Skyler Lewis, Boyu Liu, Paul Picciano, Liana Solis
Pomona College Environmental Analysis Senior Seminar
Spring 2016
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INTRODUCTION

Watershed management is critical in ensuring a sustainable water supply. This project is designed to assess the impact of bioswales in the context of Southern California’s climate. The patterns of droughts and floods make these green infrastructure appealing as they offer potential to boost water quality and regenerate local aquifers, while reducing the area of impermeable surfaces in our urban landscape. As bioswales have not been commonly incorporated into infrastructure development, our project focuses on a relatively new bioswale, added in 2012 and located on Pomona College’s campus, to serve as our case study in determining the viability of bioswales in the Pomona Valley. Through scientific, economic, and political analyses, and through collaboration among Pomona, Harvey Mudd, and Pitzer Colleges, we promote more sustainable watershed management and thinking in efforts to revitalize our local water supply and re-engage the Pomona Valley community.

LITERATURE REVIEW

This report’s literature review component outlines and synthesize relevant natural and social science information in order to communicate the benefits and potential of bioswales to stakeholders, and to place our findings in the context of our local watershed. First, we explore the physical geography and hydrogeology that influence the flow of overland and below-ground waters in Claremont, in conjunction with the history of local water management that has impacted these waters. Second, we expand upon the details of today’s regional and local water policy as it applies to water-sensitive drainage, stormwater management, and bioswale development in particular. Finally, we discuss the physical science of bioswales—for filtration of surface water and infiltration for recharge of groundwater—to explore their

Figure 1. Photograph of the Pomona College bioswale and parking garage soon after construction was finished. Photo from Watry Design Inc. (architect and engineer) retrieved from www.watrydesign.com

Cover image: Loyd Cooper, Postcard of Mt. Baldy and wash. Honnold Mudd Library, City of Claremont History Collection.
known properties, benefits, and limitations and to lead into our field experiment.

**Hydrologic context and local history**

The Pomona Valley is a broad alluvial fan (Figure 4 and 5), formed from the gradual deposition of sediments by the tributaries of the Santa Ana River as the flow from their source in the San Gabriel Mountains. One of these tributaries, San Antonio Creek, originates from snowmelt on Mount San Antonio (aka Mount Baldy), the 10,000-foot focal point of the San Gabriel Mountains.

Before the 20th century, the San Antonio Creek flowed freely out from the mountains during the wet seasons, spreading out in the rocky, sage scrub-laden San Antonio Wash (Figure 2) and infiltrating substantially into the groundwater of the Six Basins Aquifer (mapped in Figure 3). The creek is historically the primary source of water for this aquifer, which lies at the western edge of the Pomona Valley beneath Claremont, La Verne, Pomona, and northern Upland, and today accounts for 50% of the City of Claremont’s water supply. While San Antonio Creek’s surface waters are part of the Santa Ana River watershed to the east, the creek-fed Six Basins Aquifer is, below the ground, considered part of the San Gabriel River groundwater basin, draining to the west. (The surface watersheds are separated by the downhill slope of the ground, while underground the two basins are divided by the partial barriers of the San Jose and Chino faults) (DWR, 2003).

The Six Basin Aquifer’s groundwater was once plentiful enough that, nourished by San Antonio snowmelt, artesian springs bubbled to the surface in the City of Claremont, feeding perennial streams and swamplands. Since this time, the character of the watershed has undergone fundamental changes. Overdrafting of groundwater during the height of citrus cultivation in the Pomona Valley substantially lowered the water table, causing the springs to subside, re-emerging only in the heaviest of storms (Wright, 1999).

The Pomona Valley Protective Association (PVPA) formed in 1910 to address the overdraft of groundwater—to protect property owners’ rights in the Six Basins Aquifer area and ensure a sustainable supply of irrigation for the citrus growers—as well as to mitigate the threat of flash floods inundating the growing towns. Claremont’s Willis S. Jones pioneered a plan for the conservation and infiltration of San Antonio floodwaters, to be accomplished through a combination of an upstream dam at the canyon mouth, an overflow spillway, and a system of spreading ditches (Figure 2) that would mitigate floodwater by allowing infiltration back into the groundwater before excess water was channeled away (Hackenberger, 2015). The bicarbonate-rich alluvium underlying the region is highly permeable, and thus is ideal for infiltrating water quickly from the surface back into the aquifer.

After much conflict between Pomona, Ontario, and Chino stakeholders over the fate of the redirected water, PVPA members jointly purchased about 700 acres around the San Antonio Wash. Spurred on by heavy flooding in 1916-1917 and the growing demand for water in the valley, they soon completed an infiltration system on the western (Los Angeles County) side of the San Antonio Wash. The expansive region featured a spindling, tree-like network of spreading
ditches that conformed to the slope of the land. Later, in the 1930s, a second system was developed on the eastern (San Bernardino County) side, which involved a series of retention basins. The basins are separated by gabion check dams, slowing the water and allowing for more percolation through the porous beds into the alluvium and the water table below (Mitchelson, 1937). PVPA also constructed a smaller spreading grounds at Thompson Creek, a tributary of the San Gabriel River itself. The Thompson Creek Spreading Grounds remains a conserved area rich in native sage scrub.

The two spreading grounds in northern Claremont were crucial in ensuring a stable water supply for the growing region, and were in many ways the direct predecessors to, and inspirations for, today’s state-of-the-art bioswales. In his 1917 report to the PVPA, Jones highlighted the effectiveness of the native coastal sage scrub in infiltrating water, in stark contrast to the heavy flow off orchard lands. “The wisdom of keeping a large acreage of this sage brush covered land in its virgin state,” he asserted, “will become more and more apparent as time goes on and lands are cleared for cultivation” (Hackenberger, 2015).

Indeed, as time went on, the paradigm of water management in the Pomona Valley shifted to one of large-scale waterworks. With the New Deal came the Flood Control Act of 1936, through which the Army Corps Dam was built and completed in 1956. The dam all but eradicated the threat of serious flooding in the valley, yet it further insulated residents from the watershed context. Rain falling below the dam would increasingly flow across paved surfaces—or through the concrete channels of the San Antonio and Thompson washes—rather than feeding the Six Basins Aquifer and the cities’ water supply. In recent years, with new construction projects like the Claremont Graduate University’s infiltration basin (built in 2009) and Pomona College’s bioswales and drought program (built in 2012) comes the opportunity for residents to re-engage with the local watershed and aquifer.

**Local management and policy**

**Federal Regulatory Framework: the Clean Water Act**

The centerpiece of the Clean Water Act (CWA) is its mandate “that all discharges into the nation’s waters are unlawful, unless specifically authorized by a permit” [42 U.S.C. §1342(a)]. Discharges are narrowly defined as point sources. All point sources of pollutants are required to obtain a National Pollutant Discharge Elimination System (NPDES) permit and ensure that their pollutant discharges do not exceed specified effluent standards, which should first be based on the best available pollution technology or the equivalent.

By 1987, Congress became concerned about the significant role that stormwater played in contributing to water pollution, and it commanded EPA to regulate a number of enumerated stormwater discharges more rigorously. Specifically, Section 402(p), introduced in the 1987 Amendments to the CWA, directs EPA to regulate some of the largest stormwater discharges—those that

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**Figure 4.** Cross-sections through the Claremont area, showing the layout of the unconfined aquifer in the context of rock types and faults. Note that the aquifer transect shown runs relatively N-S between North Claremont and Pomona, while the geologic transect starts farther to the E near San Antonio Canyon, and runs SW across Claremont and Pomona towards Diamond Bar; this is why the latter map bypasses the Indian Hill Fault zone. Diagrams adapted from Hauksson and Jones (1991) and Bortungno and Spittler (1986).
Figure 5. Local hydrological context of the study site. Data from California Department of Transportation, California Department of Water Resources (Bulletin 118 groundwater basins; Adjudicated groundwater basins), Pomona Valley Protective Association, US Geological Survey (Mineral Resources Program; National Hydrography Dataset; Watershed Boundary Dataset).
occur at industrial facilities and municipal storm sewers from larger cities and other significant sources (e.g. large construction sites)—by requiring permits and promulgating discharge standards that require the equivalent of the best available technology [42 U.S.C. §1342(p)(3)].

Upon passage of Section 402(p), EPA divided the promulgation of its stormwater program into two phases that encompass increasingly smaller discharges. The second phase, finalized in 1995, includes smaller municipal storm sewer systems and smaller construction sites (down to one acre) [60 Fed. Reg. 40,230 (Aug. 7, 1995) (codified at 40 C.F.R. Parts 122, 124 (1995)]. If these covered sources fail to apply for a permit, they are in violation of the CWA. With a population of about 36,054 in 2014 (United States Census Bureau, 2014), the City of Claremont falls into the category of a small municipal storm sewer system.

Section 303(d) of the CWA requires that states compare existing water quality data with water quality standards and develop a Total Maximum Daily Load (TMDL) for those waters found to be in nonattainment status to ensure attainment in the future. The TMDL program provides a new opportunity for states to regulate stormwater sources more vigorously (National Research Council, 2008).

### NPDES Stormwater Program

The NPDES stormwater program regulates some stormwater discharges from three potential sources: municipal separate storm sewer systems (MS4s), construction activities, and industrial activities (EPA, 2015).

The most relevant category for green infrastructure is MS4s. Requirements of stormwater discharges from MS4s were issued in two phases. The first phase was issued in 1990 and requires medium and large cities with populations of 100,000 or more to obtain NPDES permit coverage for their stormwater discharges. The second phase was issued in 1999 and covers smaller cities and MS4s. NPDES permits for regulated MS4s require permittees to develop a stormwater management program (SWMP) (EPA, 2016).

### California State Water Resources Control Board (SWRCB)

The California SWRCB is the major regulatory entity of stormwater runoff in California. It regulates stormwater by encouraging Low Impact Development (LID) and requiring stormwater general permits from CalTrans, construction, industrial, and municipal programs (SWRCB, 2016). The permits are designed to have overlaps and redundancy (SWRCB, 2016). Relevant permits include but are not limited to the State of California Construction General Permit (CGP) and Stormwater Pollution Prevention Plan (SWPPP). They generally focus on Best Management Practices (BMPs) requirements.

### Claremont Municipal Code

The Claremont Municipal Code (City of Claremont, 2016) has requirements for construction activities, industrial and commercial facilities, municipal facilities, and development activities. In general, these requirements involve preparing appropriate permits and documents beforehand, adopting BMPs, and monitoring, information collection, and reporting. Required documents can include the General Construction Activities Stormwater Permit, the NPDES permit, the State Water Board 401 Water Quality Certification, and the SWPPP. The SWPPP is the most relevant to stormwater runoff from streets. The State Water Board 401 Water Quality Certification focuses more on fill or dredged materials, and has special responsibility for wetlands, riparian areas, and headwaters (SWRCB, 2016).

### Bioswale benefits

As green landscape elements consisting of vegetation and subsoils designed to channel surface water runoff, bioswales offer numerous beneficial services in support of stormwater management. Two such noteworthy services include groundwater recharge through surface water infiltration, and stormwater filtration of pollutants.

#### Groundwater infiltration

Grassed bioswales and dry bioswales are the most effective types of swales in allowing surface water to percolate through to groundwater. Grassed bioswales are designed to have nearly flat slopes to maximize the amount of time water travels through the system from top to bottom, ideally about ten minutes during the peak of a storm. Dry bioswales also support groundwater filtration, as they are designed with a sand and soil mix that allows for better water flow than the original soil would. Grassed and dry bioswales allow for better water transfer to the...
groundwater than wet bioswales that contain organic debris at the bottom, which block infiltration to the water table (CRD, 2013).

The United States Department of Agriculture (USDA) has recommended that bioswales should have a minimum infiltration rate of 0.5 in per hour. Evaluating the infiltration rate is important because bioswales capture the polluted water runoff from impervious areas. If the bioswale does not have a high enough infiltration rate, the water will escape untreated into a storm drain rather than percolate into the groundwater. To prevent this escape, the USDA has determined that any bioswale that is constructed must be able to weather a ten year storm. In other words, a bioswale must be able to handle 2.4 inches of water within 24 hours (USDA, 2007). Lastly, water percolation further prevents erosion in the area that would otherwise occur without such a stormwater management system (Green et al., 2013).

**Pollution filtration**

In addition to groundwater recharge, another beneficial service bioswales provide is the filtration of stormwater. During this process, bioswales naturally remove and absorb pollutants from the water before it reaches either the storm drain or infiltrates into the groundwater. Bioswales achieve this filtration through a variety of mechanisms, including sedimentation, absorption, and vegetative uptake, although the former is believed to be the most effective (Groves et al, 1999). The ability of a bioswale to filter and clean water has significant implications for stormwater and groundwater quality, but is highly dependent on the specific design of the bioswale, including soil composition and plant species.

Common pollutants in stormwater runoff include a myriad of both suspended and dissolved particles: heavy metals, such as copper, zinc, and lead; nutrients such as nitrate and nitrite, ammonia, and phosphate; and various hydrocarbons. These pollutants are filtered and retained differently through the various mechanisms and elements in the bioswale. Many heavy metals, with the notable exception of zinc, are suspended solids in the water and are physically filtered in the soil through a process called sedimentation, i.e. sediment filtration. In contrast, dissolved pollutants can be filtered through vegetative uptake of nutrients, or through various chemical and biological absorption processes that occur with ion reactions in the soil and plants, such as metal cations reacting with clay and organic matter (Jurries, 2003).

The specific elements in the bioswale, including soil and vegetation types, play significant roles in filtration. The bioswale must be designed such that it slows down the rate of water flow to allow nutrient uptake and the chemical and biological processes to occur. The compositions of different soils influence the rate of flow and filtration of different sized particles and can thus achieve differing levels of filtration. Soils typically consist of a sandy loamy composition with additional mulch and compost, and alkaline solids and subsoils can provide extra filtration capabilities. As for plants, the varying abilities of different species to filter pollutants are largely unknown, although studies in constructed wetlands have demonstrated the ability of some plant species to filter heavy metals (Schweizer, 2013).

A key consideration and concern in pollution filtration and retention is the accumulation of heavy metals over time, which could impact the health and effectiveness of the bioswale. High levels of accumulation can oversaturate soils, thereby reducing the ability of the bioswale to filter pollutants. Called leaching, this could result in the bioswale recharging the groundwater supply with contaminated stormwater. Furthermore, reaching dangerous levels of pollutants also poses significant threat for anything in contact. To date, the accumulation of heavy metals is a concern that has not been extensively studied.

**INTERVIEW FINDINGS**

To gain insight into local water-sensitive stormwater management efforts and regulatory perspectives, particularly in the City of Claremont, we interviewed several officials at the City of Claremont Town Hall. In particular, we met with Mr. Nikola Hlady, an Assistant Planner in the Community Development and Planning Departments; Ms. Loretta Mustafa, a City Engineer in the Engineering Department; and Mr. Christopher Veirs, the Principal Planner in the Community Development and Planning Departments. Throughout these interviews, we discussed city and county requirements for stormwater management, incentives for water-sensitive drainage systems, key obstacles and regulatory challenges, and the current state of projects in the area.
State of stormwater management in the City of Claremont

Mustafa and Veirs provided coherent insight regarding the current state and direction of stormwater management in Claremont and on challenges of funding and incorporating green infrastructure into a developed urban landscape. Current regulations in Claremont emphasize infiltration as a means of managing stormwater, in contrast to alternative policy measures such as requiring the capture and treatment of stormwater for particular matter to meet TMDL standards before it reaches bodies of water. Currently, the city prohibits dry-weather runoff (e.g. from watering a lawn) and requires infrastructure sufficient to infiltrate wet-weather runoff from an 85th-percentile storm. Claremont is not alone in this policy mentality, and in a collaborative watershed management plan submitted to the regional water quality control board, the cities of Claremont, La Verne, Pomona, and San Dimas aim to be able to infiltrate an 85.2 acre-feet per storm event by 2023 (Mustafa and Veirs, 2016).

While infiltration has been the policy direction pursued in the City of Claremont, Mustafa and Veirs raised several concerns that must be addressed regarding the viability of green infrastructure developments such as bioswales. One of the most pressing scientific questions regarding bioswales is the danger and extent of accumulation of metals and toxics in plants. "Do the plants become toxic themselves?" they ask. However, this question has been difficult to answer thus far as bioswales are a relatively new innovation for stormwater management, and such an investigation would require years of sampling and testing, especially for long-run implications. Another consideration Mustafa and Veirs expressed is maintenance, as silt and other materials can accumulate and block drainage, creating an impermeable barrier and requiring the bioswale to be cleared out. Even more, clogged surfaces designed for infiltration can introduce flood risks. However, they still prefer bioswales over other forms of stormwater management efforts such as permeable concrete, which would likewise require maintenance in terms of periodic pressure-washing to free lodged debris. Developers often attempt to maximize space by creating infiltration systems under permeable roads, they explained, but bioswales have an advantage as a green landscaping feature in that they reduce the "heat island effect" that occurs in otherwise urban landscapes (Mustafa and Veirs, 2016).

Mustafa and Veirs stressed additional obstacles integrating more sustainable practices into Claremont’s built environment. The City of Claremont is already largely developed, which means that requiring water-sensitive practices in new developments is not sufficient to meet infiltration standards. Thus, installing sufficient infrastructure requires retrofitting existing developments, a much more cumbersome task. As a result, Claremont has been fighting towards infiltration on rights-of-way such as green streets, parkland, and city facility land. Even so, challenges would still remain with green streets as, for example, most trees are above ground level and swales are depressed constructions (Mustafa and Veirs, 2016).

Hlady, who expressed concerns regarding codes and regulations on stormwater control and green infrastructure, that they are neither very systematic nor specific (Hlady, 2016). According to Hlady, the requirements are dispersed over different departments and codes, creating an unorganized and lackluster platform that obstructs forward progress even in the initial planning stages. Furthermore, Hlady’s Planning Department, he explains, lacks much needed discretion over installment of green infrastructures, which mostly depend on the property owners’ willingness to comply. In other words, these private property owners are the ones who decide whether or not to build a project. Lastly, Hlady expresses how there is little incentive to set up such sustainability programs, as grants are necessary to secure sufficient funding.

Mustafa and Veirs elaborated further on the funding difficulties facing Claremont. As projects depend on grants, and retrofitting Claremont’s streets with green infrastructure developments would cost the city millions of dollars, securing sufficient funds is certainly a requirement for any initiative to become a physical reality. However, Claremont’s relative location far up the watershed and small size compared to other cities in the region places it at an inherent disadvantage for receiving funding. In fact, South Bay cities such as Long Beach receive the majority of the funding because they are the largest source of pollutants and are located closer to the ocean, where runoff is directed. While Claremont is required to comply with the same infiltration standards as these other
cities, it does not receive as much funding because of it is perceived as a lower priority (Mustafa and Veirs, 2016).

**Existing and planned projects**

While Claremont certainly faces legitimate challenges in integrating water-sensitive drainage systems for infiltration of stormwater, the development of bioswales and other forms of watershed management infrastructure in Claremont is already underway or planned for the coming years. The primary and most comprehensive planned project is the City of Claremont Foothill Master Plan, which aims to incorporate many sustainable features along Foothill Boulevard, a major street in the area. This effort comes at an opportune time as the Claremont already plans to retrofit Foothill, and several sections of the boulevard have lost trees due to disease and old age, thus offering space to implement new projects without removing them (Mustafa and Veirs, 2016).

Claremont is additionally seeking to implement several other projects as well. One is pilot bioswale project on Indian Hill Boulevard, which would involve installing a large bioswale on the Claremont High School campus. As Mustafa and Veirs explained, streets that run North-South, such as Indian Hill, are ideal for stormwater projects as they experience the largest amount of runoff. However, while the City submitted a stormwater grant for funding for this project, the grant was unfortunately denied. Mustafa and Veirs plan to pursue this project further, but meanwhile efforts are underway to modify the irrigation system along the street median in front of the school, converting the system from spray to drip irrigation. This project serves as an alternative to a bioswale in the median because it’s not possible to depress the median (the landscape is “crowned”) (Mustafa and Veirs, 2016).

According to Mustafa and Veirs, Claremont also aims implement in the future is the Rooftop Runoff Reduction Plan, where individual property owners will install cis-

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Figure 6. The site for our field experiment: one of three bioswales at Pomona College in the city of Claremont. Photographs taken soon after a rainstorm in February 2016. Clockwise from top left: upper check dam; top-down view of upper check dam; upper and lower check dam with a bioretention basin (Basin II as defined in Figure 7) in between; water spilling out of the lower check dam; drain outlets into the lower portion of the bioswale (Basin IV); lower basin (Basin IV) with additional inlets.
terns, rain gardens, or bioswales to directly capture rainwater from rooftop runoff. This project would reduce the amount of water reaching the streets, and thus reduce the amount of runoff containing pollutants from lawns (e.g. animal feces) and the street (Mustafa and Veirs, 2016).

Lastly, Mustafa and Veris expressed interest in stormwater management efforts at the Claremont Colleges in hopes of collaboration at some point in the future. While the projects on the Claremont Colleges are managed separately from city infrastructure, these projects can benefit the City’s infiltration goals and improve watershed management in the area.

FIELD STUDY

As Schweizer (2013) emphasizes, “water filtration effectiveness of bioswales is not yet entirely understood.” This study aims to contribute to gaps in this uncertainty. By analyzing water intake and outtake samples from a bioswale on the Pomona College campus during rain events, we conduct water quality research and assess the ability for the bioswale to filter and retain various pollutants in stormwater runoff.

Study site

We conducted a field study at a bioswale located on the campus of Pomona College in East Claremont. The East Claremont area has particularly high infiltration rates when compared to the rest of the East San Gabriel River Watershed Management Program (which comprises the cities of Claremont, La Verne, San Dimas, and Pomona), reaching 0.8 to 0.9 inches per hour of infiltration (ESGVWMG, 2015, p. B-8).

Completed in 2012, the bioswale was constructed as part of a new water-sensitive athletic field and parking structure project, and is located directly west of the parking garage. (The same project also included a second bioswale on the east side of the parking garage, and a third across the street on the west, which we chose not to focus on due to their observed lower water flow.) The bioswale of interest consists of two major sections, as illustrated in Figure 7.

North of the garage’s driveway entrance is a series of three vegetated, gravel-filled bioretention ponds (Basins I, II, and III). The ponds are separated by two river-rock berms (check dams), which serve to slow down and retain the stormwater so that it can infiltrate, and allow the water to filter through additional gravel and vegetation before passing through the berm pipes into the subsequent pond. Water enters the upper pond through two storm drain outlets: one connected to a roadside drain on Columbia Avenue, the other connected to a roof drain to take runoff from the rooftop athletic field.

After passing under the entrance driveway through two drains, the water enters the southern portion of the bioswale, a single large bioretention pond (Basin IV). Here, it mixes with water from two other storm drain outlets: one connected to another roof drain and a driveway inlet; another connected to a series of grated concrete catch basins within nearby vegetated depressions, and to the opposite driveway’s stormwater inlet. Water that does not infiltrate into the groundwater exits the bioswale through a complex storm drain inlet, passing first through a gravel pile and then a fabric filter before entering the storm drain system (during intense floods, water may bypass this filter system to enter directly through the grate of a concrete catch basin just uphill).

The northern bioretention ponds are planted with white alder (Alnus rhombifolia) trees, whose root nodules contain nitrogen-fixing bacteria. The lower pond lacks tree plantings, but is buttressed by California Sycamore (Platanus racemosa) and Coast Live Oak (Quercus agrifolia). Planted vegetation within the ponds include Golden Currant (Ribes aureum var. gracillimum), Scarlet Monkeyflower (Mimulus cardinalis), and California Rush (Juncus patens ‘Elk Blue’). California Rush, also known as blue rush, grey rush, or spreading rush, is a native, drought-tolerant riparian plant that is frequently used in phytoremediation swales for the filtration of toxins, while monkeyflower is known to uptake copper from its environment.

In Claremont and at the Pomona College bioswale, there have been some worries that water may be prevented from infiltrating into the aquifer (Figure 4) due to the presence of impermeable clay lenses amidst the alluvial aquifer. In this case, the water would flow laterally and potentially reemerge at a surface spring downstream, or create localized flooding as has occurred in Pomona College basements in the past (Oldham, 2007). However, such natural clay lenses are understood to be sparse, barring an isolated example of an artificially-introduced impermeable layer from a past construction proj-
ect that brought in imported sediments after over-excavating (Mustafa & Veirs, 2016).

Using slope data and the locations of curbs and storm drains uphill from the bioswale, we estimated the drainage area of this bioswale at approximately 3 hectares (7.4 acres or about 30,000 ft²), made up of the roof of the parking structure, about 1 hectare, and an area of ground surface, about 2 hectares (Figure 8). This is likely to be a conservative estimate as it does not consider rainfall landing on roofs elsewhere that may make it onto the street, or the various small drainage spouts that deliver water onto the streets that drain into the swale. The Pomona College campus, for comparison, spans about 57 hectares (140 acres) in land area.

**Methods**

Our field experiment focuses on water inflow and outflow in basins I, II, and III. This design provides a semi-controlled “natural experiment,” as all storm water inputs to these basins occur in Basin I. Thus, they are functionally isolated from further external inflow, in contrast to additional stormwater inflow allowed Basin IV, and make an optimal site for an experiment. Aside from direct precipitation and whatever runoff enters from the walking path area, Basin II receives stormwater (roof and road runoff) solely from the nine pipes from Basin I. All surface water exiting Basin II flows through the eight pipes connecting it to Basin III, and finally flows through two pipes into Basin IV. Analyzing inflow and outflow of these basins allows evaluation of the effectiveness of bioswale in filtering pollutants throughout each of the first three basins.

The site was visited, and samples were taken, at two times during a set of cold storms that reached Claremont on 5-7 March 2016. (Figure 9). The first sampling time, at approximately 3:00 a.m. on 6 March 2016, was just before the peak of the first large storm, which totalled 1.28 inches of rain over 11 hours. The second sampling time, at approximately 7:00 a.m. on 7 March 2016, was immediately following a second, acute thunderstorm that dropped 0.29 inches of rain in just over one hour.

Water samples were taken at each of 21 sample locations (Figure 7), i.e.,
- at each of the two drain inlets in basin I (the northernmost basin);
- at each of the nine pipes in the upper check dam separating basins I and II;
- at each of the eight pipes in the lower check dam separating basins II and III; and
- at each of the two drain outlets connecting basins III and IV under the driveway.

For each visit to the site, a set of 150mL high-density polyethylene (HDPE) bottles were prepared by soaking for 30 minutes in dilute hydrochloric acid, rinsing with purified deionized water (Millipore), and air drying. 22 bottles were prepared: 21 for the sample locations, and one control filled with deionized water also brought to the site.

Samples were taken in a 400mL Pyrex beaker. At the drain outlets, samples were taken by dipping the beaker into the water directly...
in front of the outlet. At the check dam pipes, samples were taken by holding the beaker below the pipe and filling to the 300mL mark. Next, readings of temperature, pH, electrical conductivity (EC), and dissolved oxygen (DO) were taken from the beaker sample using a calibrated Eureka Manta2 sub3 multiparameter monitoring sonde, and recorded into a spreadsheet on the attached PDA, along with the sample location. Finally, 150mL of the sample was transferred into a marked 150mL HDPE bottle for storage. The DI control was poured into the beaker on site, tested for temperature, pH, EC, and DO, and returned to its HDPE bottle. The full batch of samples was immediately taken back to the laboratory, and nitric acid was added to preserve the sample at pH ≤ 2 for analysis.

Water samples were then analyzed for trace metal content using a PerkinElmer Optima 8300 ICP-OES, calibrated using multielement standards. Three replications were used for each sample, with the mean taken. Elements to test for were selected from lists of known stormwater contaminants (e.g., Grant, 2003) and past research projects (e.g., Schweitzer, 2012). Split by periodic table groups, and showing symbols and atomic numbers, these elements are:

- **Alkaline earth metals:**
  - Mg 12 Magnesium
  - Ca 20 Calcium
  - Ba 56 Barium

- **Transition metals:**
  - V 23 Vanadium
  - Cr 24 Chromium
  - Mn 25 Manganese

Figure 8. Estimated water flow patterns based on infrastructure and topography. Approximate watershed of the bioswale of interest is outlined, and covers about 2 hectares of land plus 1 hectare for the roof of the parking garage. Digital surface model extracted from Google Earth.
Figure 9. Hourly and cumulative precipitation data for Claremont, California, 5-7 March 2016. Sampling times are indicated with arrows. Data from California Department of Water Resources, Claremont (CMO) station.

Results
Observations were taken during a pair of El Niño storm systems on 6-8 March 2016 (Figure 9), and are presented separately:

First storm
The first set of samples was taken starting at 3:31am on 6 March 2016, around the start of the first system. A very light had fallen prior to 3:00am (0.24 inches spread over 6 hours), and the storm had just begun to pick up substantially. 0.23 inches fell between 3:00 and 4:00am, and the storm continued at this intensity for the next three hours with an additional 0.80 inches of rain. By 4:00am about 0.47 inches of rain had fallen, implying about 3.48 acre-inches (about 94,000 gallons) draining into the site per our estimate of drainage area from Figure 8.

Upon arrival at the site, water was flowing out of the Basin I inlet and just beginning to flow through the upper (Basin I-II) check dam. A set of samples were taken at 3:31am at the inlet and at this upper check dam. About an hour later, water began to flow through the lower (Basin II-III) check dam. A set of samples were taken starting at 4:33am at this lower check dam, and at the lower drain (Basin III-IV) shortly after. We consider these samples to capture the same confidence intervals assigned using bootstrapping with 1000 repetitions except for the inlet, for reasons mentioned in the sample size section of the discussion.

Most of these contaminants are known contaminants from roadways, including from corrosion of auto bodies (Fe, Cr), brake pad and lining wear (Cr, Cu, Ni), moving engine parts (Cr, Cu, Fe), asphalt paving (Ni), tire wear (Cd, Pb, Zn), and motor oil and grease (Ni, Zn) (Grant et al., 2003). Calcium (Ca) is included specifically to address the possibility of airborne calcium carbonate (CaCO₃) dust traveling from the nearby concrete quarry (Holliday Rock), settling on the ground, and running off during storm events.

For Ca and Mg, the spectrometer’s radial view was used, and results are analyzed in units of mg/L (approximately, parts per million). For the rest of the elements, which were expected to be observed in smaller trace concentrations, the axial view was used, with results analyzed in μg/L (approximately, parts per billion).

Results were analyzed using non-parametric statistics. For each storm, medians are taken at each of the four sampling locations in the upper bioswale (inlet, upper check dam, lower check dam, outlet), and
plume of water (the “first flush”) reasonably well, as they were taken just as water began to flow through each of the respective check dams. (For comparison, a second set of samples was also taken around this same time at the upper (Basin I-II check dam), representing a later plume of water.)

Electrical conductivity decreased from 157.85 μS/cm to 116.5 μS/cm over the course of the swale, a decline in the water’s capacity to conduct current that indicates a decline in the amount of ions dissolved in the water. pH neutralized from 6.41 to 7.08 (a change from slightly acidic to neutral) over the course of the swale, with the greatest difference occurring between inlet and first check dam. Water entered the swale from the northern inlet at a temperature of 16.13 °C (61.03 °F) and cooled to 14.92 °C (58.86 °F) by the time it exited.

The total concentration of all metals tested tended to decline between the first and second storm, with a significant decline between concentrations at the inlet and outlet, and between the first check dam and the outlet. Restricted to the alkaline earth metals (calcium, magnesium, barium), there was a significant decline between the first check dam and the outlet; restricted to the transition metals (all except the alkaline earth metals, lead, and thallium), a marked difference between high concentrations at the inlet and low concentrations at the other three locations. There was no significant trend in the post-transition metals (lead and thallium), though this group was rare to begin with.

**Second storm**

The second set of samples was taken starting at 7:55am on 7 March 2016. This time was immediately following a sudden thunderstorm downpour, in which 0.26 inches fell between 6:00 and 7:00am. Rain had stopped falling by the sampling time, as only 0.03 inches fell between 7:00am and 8:00am, concluding the storm until later in the day. We estimate the volume of water having entered the swale to be 2.15 acre-inches or about 58,000 gallons. The second storm differed from the first storm in that much less time had passed since the last time it rained.

Upon arrival at the site, water was flowing out of the Basin I inlet and the upper (Basin I-II) check dam, and just beginning to flow out of the lower (Basin II-III) check dam. Samples were taken in quick succession (to avoid time effects) at the upper inlet, upper check dam, lower check dam, and lower

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**Figure 10.** For each of the two storms, water quality indicator medians for location (inflow, check dam between basins I and II, check dam between basins II and III, and outflow). All values < 0 were rounded to 0 (i.e., Not Detected) for the sake of presentation. 95% confidence intervals shown for the latter three locations.
drain; over the course of the procedure, water had begin flowing steadier and faster at the lower parts of the swale. Compared to the first storm, temperature was consistently cooler, electrical conductivity (EC) lower, pH more neutral, and dissolved oxygen higher. EC did not show a downward trend over the course of the swale, but instead increased from 67.85 μS/cm at the inlet to 92.95 μS/cm at the outlet.

Concentrations for many elements were systematically lower in the second storm, and many of those with downward trends in the first storm showed neutral to upward trends in the second storm. Transition metals overall had noticeably higher concentration at the inlet, but otherwise there were no significant downward trends for any of the metal groups.

**Discussion**

**Comparing against water quality standards**

We found that there is a statistical change in the amount of metals as the storm water flows through the bioswale. To understand if these changes are significant to human health, we compared our data to the National Primary Drinking Water Regulations (NPDWRs) that is set by the EPA. The NPDWRs were created as part of the Safe Drinking Water Act in 1974 to protect public health (EPA 2016a). The Safe Water Drinking Act requires there to be standards set for microorganisms, disinfectants, disinfection byproducts, inorganic chemicals, organic chemicals, and radionuclides. Maximum contaminant levels (MCL) and maximum contaminant level goal (MCLG) are set for each contaminant. The MCL is an enforceable standard for the highest level of a contaminant that is allowed in drinking water whereas the MCLG is a non-enforceable public health goal. MCLG are created to be the maximum level at which there are no known adverse health effects. MCL are set to be as close to the MCLG as feasibly possible while taking into consideration the best available treatment technology and cost. Our project is focused on the maximum contaminant levels (MCL) of inorganic chemicals that were found in the bioswale.

Of the 15 inorganic chemicals tested for in the bioswale, seven (Ba, Cd, Cr, Cu, Hg, Pb, and Tl) are regulated under the NPDWRs and five (Cu, Fe, Mn, Ag, and Zn) are regulated under the NSDWRs, or the National Secondary Drinking Water Regulations. The NSDWRs are non-mandatory water quality standards set by the EPA. These standards only act as guidelines for aesthetic considerations, meaning that water within these limits will have the best taste, odor, and color (EPA 2016b).

Five of the seven contaminants included in both the bioswale samples and under the NPDWRs did not exceed the MCL at any point during either storm. Thallium was the only contaminant in this category that exceeded both the MCLG and MCL set by the NPDWRs. The MCL for the 0.5 μg/L and the MCL is 2 μg/L. During the March 6 storm, the MCL of 2 μg/L was exceeded once during the storm by the median value of 2.56 μg/L for the 1-2 dam with the lower standard error bound reaching below the 2 μg/L limit. The Thallium did not exceed the MCL at any other point of the March 6 Storm. During the March 8 storm, the median value exceeded the MCL for the inflow, 1-2 dam, and 2-3 dam. The inflow had a median value of 3.36 μg/L. The 1-2 dam and 2-3 dam both

<table>
<thead>
<tr>
<th>Trace Metal Indicator</th>
<th>Maximum Recommended Concentration</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver (Ag)</td>
<td>100 μg/L</td>
<td>μg/L</td>
</tr>
<tr>
<td>Barium (Ba)</td>
<td>1000 μg/L</td>
<td>μg/L</td>
</tr>
<tr>
<td>Calcium (Ca)*</td>
<td>17.1 mg/L</td>
<td>mg/L</td>
</tr>
<tr>
<td>Cadmium (Cd)</td>
<td>5 μg/L</td>
<td>μg/L</td>
</tr>
<tr>
<td>Cobalt (Co) †</td>
<td>6 μg/L</td>
<td>μg/L</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
<td>50 μg/L</td>
<td>μg/L</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>1300 μg/L</td>
<td>μg/L</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>300 μg/L</td>
<td>μg/L</td>
</tr>
<tr>
<td>Mercury (Hg)</td>
<td>2 μg/L</td>
<td>μg/L</td>
</tr>
<tr>
<td>Magnesium (Mg)*</td>
<td>17.1 mg/L</td>
<td>mg/L</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>50 μg/L</td>
<td>μg/L</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td>100 μg/L</td>
<td>μg/L</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>15 μg/L</td>
<td>μg/L</td>
</tr>
<tr>
<td>Thallium (Tl)</td>
<td>2 μg/L</td>
<td>μg/L</td>
</tr>
<tr>
<td>Vanadium (V)</td>
<td>50 μg/L</td>
<td>μg/L</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>5000 μg/L</td>
<td>μg/L</td>
</tr>
</tbody>
</table>

* Ca and Mg standards (measured in mg/L) are based on California State Water Resources Control Board (SWRCB) overall standards for water hardness, to which these elements contribute.
† SWRCB does not have a standard for Cobalt; listed value is the Environmental Screening Level reported by the San Francisco Bay Regional Water Quality Control Board.
had median values that exceeded the MCL, 2.10 µg/L and 2.36 µg/L respectively, with lower standard error bounds falling below 2 µg/L but above the MCLG of 0.5 µg/L. Thallium is an important contaminant to identify because long-term exposure above the MCL can potentially lead to health effects such as hair loss; changes in blood; kidney, intestine, or liver problems (EPA 2016a).

Thallium is more toxic to humans than mercury, cadmium, lead, copper, or zinc. Thallium is typically found as monovalent thallium (Tl⁺) in water. This monovalent state allows for thallium to be readily dissolved into water which allows for it to be transported easily (Twidwell and Williams-Beam 2002). Currently, the EPA has found that there are two effective methods of removing thallium to less than 2 µg/L from drinking water using activated alumina and ion exchange (EPA 2015).

Mercury has a MCL and MCLG of 2 µg/L. This MCL was only exceeded during the March 6 storm in the inflow and 1-2 dam with median values of 46.98 µg/L and 75.00 µg/L respectively. The minimum standard error boundary for the inflow samples go below the MCL. Long term exposure to mercury can lead to kidney damage (EPA 2016a). Fortunately there are several ways to remove mercury from water using coagulation or filtration, granular activated carbon, lime softening, and reverse osmosis (EPS 2015).

Of the five contaminants sampled and covered by the NSDWRs, Fe and Mn both exceed the secondary MCL (EPA 2016b). The secondary MCL for iron is 300 µg/L. During the March 6 storm, the secondary MCL was exceeded by the inflow, 2-3 dam, and outflow dam by the median values of 738.59 µg/L, 338.74 µg/L, and 334.90 respectively. The 1-2 dam and 2-3 dam samples had the lower standard error bound reach below the secondary MCL of 300 µg/L. During the March 8 storm, the MCL was exceeded by all of the samples at the bioswale. The median values were 346.50 µg/L for the inflow, 324.35 µg/L for dam 1-2, 526.62 µg/L for dam 2-3, and 697.47 µg/L for the outflow. Iron is considered a secondary contaminant because if it exceeds the secondary MCL, it only acts as a nuisance and may only cause the water to have a rusty color; sediment; metallic taste; reddish or orange staining (EPA 2016b). Iron can be removed through greensand filtration and oxidation, coagulation, or filtration (EPA 2007).

The secondary MCL of 50 µg/L for manganese was exceeded during both storms. The March 6 storm was only above the secondary MCL in the 2-3 dam with a median of 74.38 µg/L. During the March 8 storm, the 2-3 dam again exceeded the secondary MCL with a median value of 86.38 µg/L. The maximum standard error boundary of the outflow exceeded the secondary MCL, but the median value was below 50 µg/L. Manganese is monitored because it can cause the water to become black to brown in color; cause black staining; or have bitter metallic taste (EPA 2016b). Like iron, manganese can be removed through greensand filtra-
Table 3. Median water quality indicators at each point along the bioswale, for each of the two storms.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Units</th>
<th>Storm</th>
<th>Inflow*</th>
<th>1-2 Dam</th>
<th>2-3 Dam</th>
<th>Outflow</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>from street</td>
<td>from garage</td>
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<tr>
<td><strong>Temperature</strong></td>
<td>°C</td>
<td>1</td>
<td>15.88</td>
<td>16.38</td>
<td>15.29</td>
<td>14.93</td>
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<td></td>
<td>2</td>
<td>11.20</td>
<td>13.10</td>
<td>11.29</td>
<td>11.69</td>
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<tr>
<td><strong>pH</strong></td>
<td>units</td>
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<td>90.70</td>
<td>97.90</td>
<td>92.50</td>
<td>96.40</td>
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<td>2</td>
<td>97.40</td>
<td>102.60</td>
<td>98.20</td>
<td>97.90</td>
</tr>
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<td><strong>Dissolved Oxygen (DO)</strong></td>
<td>% Sat.</td>
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<td>6.16</td>
<td>6.49</td>
<td>6.67</td>
<td>6.65</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>6.37</td>
<td>6.45</td>
<td>6.85</td>
<td>7.04</td>
</tr>
<tr>
<td><strong>Electrical Conductivity (EC)</strong></td>
<td>μS/cm</td>
<td>1</td>
<td>148.20</td>
<td>167.50</td>
<td>157.75</td>
<td>130.30</td>
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<tr>
<td></td>
<td></td>
<td>2</td>
<td>56.40</td>
<td>79.30</td>
<td>79.10</td>
<td>84.35</td>
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<tr>
<td>(total metals)</td>
<td>mg/L</td>
<td>1</td>
<td>18.89</td>
<td>29.41</td>
<td>18.05</td>
<td>14.99</td>
</tr>
<tr>
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<td>2</td>
<td>6.74</td>
<td>15.22</td>
<td>8.21</td>
<td>9.51</td>
</tr>
<tr>
<td>(alkaline earth metals)</td>
<td>mg/L</td>
<td>1</td>
<td>16.11</td>
<td>24.88</td>
<td>16.97</td>
<td>13.95</td>
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<td>5.35</td>
<td>11.17</td>
<td>7.54</td>
<td>8.80</td>
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<tr>
<td>(transition metals)</td>
<td>mg/L</td>
<td>1</td>
<td>2.77</td>
<td>4.52</td>
<td>1128.27</td>
<td>737.69</td>
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<tr>
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<td>1.37</td>
<td>4.04</td>
<td>737.55</td>
<td>841.66</td>
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<tr>
<td>(post-transition metals)</td>
<td>μg/L</td>
<td>1</td>
<td>3.52</td>
<td>5.52</td>
<td>5.04</td>
<td>3.17</td>
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<td>11.23</td>
<td>4.43</td>
<td>3.24</td>
<td>5.85</td>
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<tr>
<td><strong>Silver (Ag)</strong></td>
<td>μg/L</td>
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<td>1262.70</td>
<td>214.48</td>
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<td>498.67</td>
<td>194.33</td>
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<td><strong>Barium (Ba)</strong></td>
<td>μg/L</td>
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<td>4.58</td>
<td>4.04</td>
<td>2.53</td>
<td>2.37</td>
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<td>1.52</td>
<td>1.34</td>
<td>1.51</td>
<td>1.91</td>
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<tr>
<td><strong>Calcium (Ca)</strong></td>
<td>mg/L</td>
<td>1</td>
<td>ND †</td>
<td>0.01</td>
<td>ND</td>
<td>ND</td>
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<tr>
<td></td>
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<td>ND</td>
<td>ND</td>
<td>ND</td>
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<tr>
<td><strong>Cadmium (Cd)</strong></td>
<td>μg/L</td>
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<td>2050.95</td>
<td>405.76</td>
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<td><strong>Cobalt (Co)</strong></td>
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<td>64.04</td>
<td>27.99</td>
<td>18.74</td>
<td>26.69</td>
</tr>
<tr>
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<td>30.33</td>
<td>19.58</td>
<td>16.88</td>
<td>37.01</td>
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<tr>
<td><strong>Chromium (Cr)</strong></td>
<td>μg/L</td>
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<td>1.31</td>
<td>0.47</td>
<td>0.81</td>
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<td>0.31</td>
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<tr>
<td><strong>Copper (Cu)</strong></td>
<td>μg/L</td>
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<td>7.03</td>
<td>47.49</td>
<td>1.92</td>
<td>1.55</td>
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<tr>
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<td>3.92</td>
<td>31.73</td>
<td>2.19</td>
<td>1.41</td>
</tr>
<tr>
<td><strong>Iron (Fe)</strong></td>
<td>μg/L</td>
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<td>61.60</td>
<td>30.29</td>
<td>32.97</td>
<td>27.43</td>
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<td>33.70</td>
<td>21.31</td>
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<td>17.50</td>
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<tr>
<td><strong>Mercury (Hg)</strong></td>
<td>μg/L</td>
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<td>0.20</td>
<td>0.22</td>
<td>0.13</td>
<td>0.18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>ND</td>
<td>ND</td>
<td>0.18</td>
<td>0.13</td>
</tr>
<tr>
<td><strong>Magnesium (Mg)</strong></td>
<td>mg/L</td>
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<td>7.60</td>
<td>7.14</td>
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<td>7.15</td>
<td>1.80</td>
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<td>3.61</td>
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<td><strong>Nickel (Ni)</strong></td>
<td>μg/L</td>
<td>1</td>
<td>ND</td>
<td>ND</td>
<td>1.48</td>
<td>ND</td>
</tr>
<tr>
<td></td>
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<td>2</td>
<td>4.08</td>
<td>2.63</td>
<td>1.06</td>
<td>2.29</td>
</tr>
<tr>
<td><strong>Lead (Pb)</strong></td>
<td>μg/L</td>
<td>1</td>
<td>2.70</td>
<td>3.26</td>
<td>3.07</td>
<td>2.61</td>
</tr>
<tr>
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<td>1.69</td>
<td>1.04</td>
<td>1.09</td>
<td>1.33</td>
</tr>
<tr>
<td><strong>Thallium (Tl)</strong></td>
<td>μg/L</td>
<td>1</td>
<td>13.75</td>
<td>22.95</td>
<td>14.55</td>
<td>11.94</td>
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<td>4.51</td>
<td>10.15</td>
<td>6.40</td>
<td>7.50</td>
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<tr>
<td><strong>Vanadium (V)</strong></td>
<td>μg/L</td>
<td>1</td>
<td>2.34</td>
<td>1.90</td>
<td>2.37</td>
<td>1.97</td>
</tr>
<tr>
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<td>0.83</td>
<td>1.01</td>
<td>1.12</td>
<td>1.29</td>
</tr>
<tr>
<td><strong>Zinc (Zn)</strong></td>
<td>μg/L</td>
<td>1</td>
<td>25.49</td>
<td>25.58</td>
<td>24.63</td>
<td>18.40</td>
</tr>
<tr>
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<td>14.73</td>
<td>11.60</td>
<td>13.32</td>
<td>15.27</td>
</tr>
</tbody>
</table>

* Inflow results are shown, not as medians as they are on the graphs, but as individual observations.
† ND = Not Detected. After medians were taken (if applicable), negative values were rounded to zero (ND) for reporting.
tion and oxidation, coagulation, or filtration (EPA 2007). All NPDWRs and NSDWRs are also regulated by the California Department of Public Health (CDPH). All MCL are the same with the exception of barium and chromium. The NPDWR for barium is 2000 µg/L while the CDPH limit is 1000 µg/L. The NPDWR for chromium is 100 µg/L and the CDPH MCL is 50 µg/L (CDPH 2013). No samples collected from the bioswales exceed either MCL for barium or chromium.

Out of the 15 inorganic contaminants tested from the bioswale Ca, Mg, Co, and Ni are the only inorganic chemicals not regulated under the Safe Drinking Water Act. However, Ca, Mg, and Ni are regulated under the Drinking Water-Related Regulations set by the State Water Resources Control Board for the state of California (SWRCB 2015). Calcium and Magnesium are regulated together as a factor of the hardness of the water and not individually as calcium and magnesium concentrations. If there is less than 17.1 mg/L of calcium and magnesium, then the water is considered soft, and above 17.1 mg/L is considered hard water (CDPH 2013). During the March 6 storm, the median value of calcium exceeded the 17.1 mg/L threshold at the inflow. There are no other times during either storm when calcium or magnesium cross the threshold between hard and soft water. Hardness does not have any known health impacts, but hard water can prevent soap from lathering and cause a whitish scale deposit in pipes and kitchen or laundry appliances (WQA 2016).

The only inorganic compound that was sampled for at the bioswale that is not covered under the NPDWRs, NSDWRs, or California Drinking Water-Related Regulations is cobalt. While cobalt does not have an enforceable limit in California, there is an environmental screening level (ESL) which is used to “expedite the identification and evaluation of potential environmental concerns at contaminated sites.” In this ESL, a MCL priority of 6.0 µg/L for cobalt has been determined as the minimum amount that will impact human health (Fry 2016). The median concentrations for cobalt in the bioswale exceeded the 6.0 µg/L MCL priority during both storms. The inflow for the March 6 storm had a median of 27.26 µg/L. The median value of the inflow for the March 8 was 17.83 µg/L with the minimum standard error boundary below the MCL priority. While cobalt is currently considered an unregulated contaminant, it has been identified as a possible human carcinogen and will continued to be monitored in drinking water. Currently ion exchange and reverse osmosis are the best technologies for removing cobalt from drinking water (EPA 2010).

Sample sizes and confidence intervals

During each storm event, there are two samples at the inlets, nine samples at the first check dam between the first and the second basin, eight samples at the second check dam between the second and the third basin, and two samples at the outlets (Figure 7). Samples at the two check dams and the outlets are approximately from the same water bodies (basin I, II, and III, respectively), which makes it possible to have confidence intervals, although that can be problematic when there are only two samples.

It does not make sense to have confidence intervals for water samples at the inlets. As shown in the map of the site (Figure 7), one of the inlets is connected to a storm drain on Columbia avenue, while the other one is connected to a drain on the garage roof. It is plausible that water from the street is more polluted than water from the roof because of traffic. Thus, the water samples taken at the two inlets are not from the same source, and it would not make sense to calculate confidence intervals for each of them as the sample size is one.

However, it still makes sense to calculate a mean from the two samples at the inlet because the water will be mixed in the first basin. Ideally, one would calculate a weighted average that is weighted by the flow rate at the two inlets. Unfortunately, without flow

![Graph](image)

Figure 11. Medians and confidence intervals (where applicable) for two primary contaminants that exceeded recommended levels at some point. Graphs for all contaminants are located in Figure 12 at the end of the report.
rate, the best we could do is to calculate the mean. This is the value presented in all graphs (Figures 10-12).

Therefore, any comparison involving the inlets is strictly only qualitative. But it is still of our interest to compare the metal concentrations at the inlets with those downstream because the first basin seems to filtrate the water a lot more than the other basins (Figure 7).

In the future, a research group interested in studying the Pomona bioswale should prepare to take substantially more samples than we did to avoid this problem. Ideally, flow rate would also be measured.

**Explaining unexpected increases in metal concentrations**

Table 2 summarizes the overall observed trend in each of the categories, while Table 3 presents all medians.

Among the fifteen kinds of metals tested, twelve showed significant downward trend during the first storm, three were insignificant, and none showed an upward trend (Table 2). During the second storm, however, six showed increases in concentration (Ba, Ca, Cr, Fe, Mg, Ni), five showed no significant trend (Ag, Cd, Hg, Mn, Pb), and only four of them showed significant decrease in concentration (Co, Cu, Tl, Zn). This is a concerning observation because it shows that bioswales can cause increase in heavy metal concentration in some cases, and even to a level higher than the MCL for the case of Thallium (Figure 11).

There are several factors that can contribute to the increase in metal concentration. Since the surface area of the bioswale is much smaller compared to the drainage area that it treats, the change in metal concentration in the water body should mainly be a result of interaction with the bioswale instead of due to precipitation. Plus, the intensity of precipitation when we did sampling for the second storm has already dropped significantly. Thus, for the purpose of this study we suppose the increase in metal contents came from the bioswale.

There exists a two-way exchange of metal contents between the bioswale and water. Metal ions can deposit and adhere to the surface of rocks or get absorbed by soil and plants. On the other hand, metal can also be washed off from the surface of rocks or dissolve from soil and enter the water again.

Physical and chemical indicators are significantly different between the two storms. The temperatures of water samples taken during the first storm are generally in the range of 15-16 °C, while the temperatures of water samples from the second storm are between 11 and 12 °C. With regard to pH level, water samples from the second storm are in general more alkaline than water samples from the first storm. Water samples from the second storm also have significantly higher level of dissolved oxygen. These factors can affect the direction and rate of ion exchange between soil and water as well as the direction and rate of precipitation and dissolution of the metals. It is possible that the combination of the temperature, pH, and level of dissolved oxygen during the second storm is more conducive to the dissolution of metals into water.

Moreover, the overall metal concentration during the second storm is significantly lower. Since there should be equilibrium metal concentrations in physical and chemical processes involved, the metal concentration can more easily increase when its level is low. This might be part of the reason why the metal concentration decreased in the first storm and increased in the second storm.

It is also possible that the increase in concentration mainly came from wash off instead of chemical reaction. Since flow speed was not measured, this hypothesis cannot be verified with data.

Since the increase in metal contents is likely from the soil, it would be immensely helpful to bring insights from studies that focus on the change in metal contents in soil. A team at Harvey Mudd College is doing a study of this kind. In the future, such cooperation is crucial in providing the whole picture and drawing meaningful policy implications.

A potential concern that follows from our study is: If water indeed infiltrates in Basin II, then the “after” measurements are only capturing contaminant levels in the water that did not infiltrate, which may introduce bias. This is a valid question that should be addressed by combining our results with studies on metal accumulation in the soil. But on the other hand, it is unlikely that water with a certain concentration of metal contents infiltrates more easily. The only reason for concern is that there might be suspended solids that got captured by the soil and plants. This is indeed one of the mechanisms bioswales work and should be counted towards the effectiveness of bioswales. Therefore, the partial infiltration of water
Figure 12. For each of the two storms, trace metal medians for location (inflow, check dam between basins I and II, check dam between basins II and III, and outflow). All values < 0 were rounded to 0 (i.e., Not Detected) for the sake of presentation. 95% confidence intervals shown for the latter three locations.
should not have introduced a significant bias to our results. However, the accumulation of suspended solids in the bioswale is a cause of concern that should be studied along with other forms of metal accumulation in soil.

Fortunately, the only element whose mean concentration at the outlet exceed the MCL is Iron. The mean concentrations for most of the elements that showed upward trend are far below the MCL. As mentioned in the above section, Iron only acts as a nuisance and may only cause the water to have a rusty color; sediment; metallic taste; reddish or orange staining (EPA 2016b). Thus, although the accumulation of metals in soil warrant future research, there is no sign that the bioswale on Pomona’s south campus has affected water quality in a way that can negatively impact human health.

However, there is a sign for concern. During the first storm, the concentration of Thallium is zero in all water samples taken at the inlet, but increased to a level significantly higher than 1 ug/L at the checker dam between the first and the second basin. The mean concentration is 2.56 ug/L and the median is 1.48 ug/L. Meanwhile, the MCL for Thallium is 2 ug/L and the MCLG is 0.5 ug/L. Thus, it appears that the concentration of Thallium increased from zero to a level high enough to cause health concern after passing the first basin of the bioswale. Although its concentration dropped back to zero at the outlet thanks to the other basins, this incidence showed that the Thallium sitting in the first basin can significantly pollute the water. As more Thallium accumulates in the other basins, it is possible that one day the entire bioswale will become a source of pollution for Thallium. Due to limited number of samples, this needs to be verified with further investigation.

Limitations

In addition to the sample size issues previously mentioned, time and weather constraints limited the number of experimental trials we could conduct. We recommend that this trial be replicated in a future rainy season, across many storms, including the first storms of the rainy season in late autumn and early winter. With careful measurement of the same plume of water as it passes through the bioswale, across many replications, these findings could be interpreted with enough confidence as to inform local water management policy on the subject of water sensitive drainage systems.

CONCLUSION

Our data have revealed some possible trends, but this study is only the beginning of understanding how this bioswale works. As the bioswale was only built in 2012, its infiltration capacity may change throughout the years and metals may accumulate over a longer time frame. Additionally, Pomona Valley has a diverse landscape and results from a similar study conducted elsewhere in the Valley would likely reflect factors such as roads with more traffic, nearby industries, bioswale vegetation, and the geomorphology of the swale. Ideally, policies that encourage green infrastructure should be implemented, and bioswales should be incorporated into future planning to incorporate water-sensitive drainage systems.