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Central Coast Watershed Studies

CCoWS

Stormwater characterization for reduction and reuse: Presidio of Monterey, California

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Disclaimer:

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Executive Summary

This study was conducted by students at California State University, Monterey Bay as part of a class project in Advanced Watershed Science and Policy (ENVS660). The objectives of this study included:

1. Describe the regulatory environment for stormwater management in the Presidio of Monterey (POM)
2. Identify potential Low Impact Development sites
3. Estimate of stormwater runoff volume and peak flow rate using a HEC-HMS model
4. Estimate effect of LID on stormwater runoff using a HEC-HMS model
5. Summarize geologic data to assess LID feasibility

POM is located on the central coast of California, in the city of Monterey. Stormwater from POM drains indirectly into the Pacific Grove Area of Special Biological Significance (ASBS) within the Monterey Bay National Marine Sanctuary (MBNMS). POM is tasked with implementing best management practices to reduce pollutant load delivered through their storm water system. To accomplish this goal, POM is exploring the use of low impact development (LID) techniques, such as bioswales, sub-surface irrigation, pervious pavement, and cisterns.

We conducted a watershed delineation to determine what areas drained into neighboring municipalities and to determine the areas that would drain into potential LID sites. We analyzed the physical characteristics, such as geology, slope, hydrologic soil groups, and land cover of POM to determine the best sites for potential LIDs, as well as LID feasibility. To assess the potential effectiveness of LID techniques, we modeled the current conditions on POM and compared them to modeled LID scenarios for the 85th percentile storm using HEC-HMS.

We estimated that bioswales, sub-surface irrigation and the reuse of a storage tank as a cistern were the most effective at preventing runoff from the 85th percentile storm. The effectiveness of these features was inversely related to the watershed area that was drained into them. The effectiveness of the bioswales may be limited by the capacity for groundwater storage within POM. The results indicate that there is the potential to implement effective LIDs on POM. However, further research is needed to fully understand the capacity for infiltration, the volume of bioswales, regulatory constraints, and to properly validate the model against existing conditions.

List of Definitions and Acronyms

AMBAG – Association of Monterey Bay Area Governments

ASBS – Areas of Special Biological Significance

BMPs – Best Management Practices

CalAm – California American Water Company

CCRWQCB – Central Coast Regional Quality Control Board

DEM - Digital elevation model

EPA – Environmental Protection Agency

GIS – Geographic Information Systems

HSG - Hydrologic Soils Group

LID - Low impact development

LiDAR - Light detection and ranging

MBNMS – Monterey Bay National Marine Sanctuary

MRSWMP - Monterey Regional Stormwater Management Program

MRWPCA – Monterey Regional Water Pollution Control Agency

NPDES – National Pollutant Discharge Elimination System

POM - Presidio of Monterey

SCS – Soil Conservation Service

SWRCB – State Water Resources Control Board

USDA – United States Department of Agriculture Forest Service

USGS – United States Geologic Survey

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1 Introduction

The Monterey peninsula is working to implement best management practices for managing storm water. As part of this effort, and in conjunction with new federal guidelines, the Presidio of Monterey (POM) is developing an Integrated Water Management Plan to reduce potable water consumption, to manage stormwater runoff and to optimize water usage. In accordance with POM's Command Policy Memorandum #15, Environmental Management System (2012), POM's goals are to:

- Quantify and reduce stormwater discharge to receiving waters
- Reduce potable water consumption
- Act as a community leader in water conservation and stormwater management
- Comply with local, state and federal regulatory requirements

Important regional factors to be considered are the increasing urbanization, regional water scarcity, impaired waterways, regulatory requirements, and proximity to protected marine habitats. Opportunities exist to address these issues and the above goals through stormwater capture, storage, and re-use.

Some of the unknowns for storm water characterization on POM include the stormwater runoff volume, peak flow rate, and the detention and percolation capacity. Low Impact Development (LID) is one approach to minimizing stormwater runoff that can mitigate the effects of new development and the adverse impacts of stormwater runoff. POM is assessing the potential of LID to reduce and improve the quality and quantity of stormwater runoff into neighboring municipalities, the Monterey Bay National Marine Sanctuary (MBNMS), and the Pacific Grove Area of Special Biological Significance (ASBS).

1.1 Adverse Impacts of Stormwater Runoff

Stormwater runoff can adversely impact terrestrial and aquatic habitats and natural hydrological processes. Stormwater runoff can erode local waterways; increase the pollutant load into sensitive habitats; flood urban and natural areas; reduce rates of groundwater recharge; and reduce baseflow in river systems (Mazer et al. 2001; Qin et al. 2013). These issues occur when stormwater volume and peak flow rate is greater than what would naturally occur given a natural landscape. Perhaps most importantly, higher intensity stormwater runoff occurs when there is an increase in urbanization, which reduces the ability of the land to infiltrate precipitation. High intensity stormwater runoff can mobilize and concentrate urban pollutants into aquatic habitats, thereby impairing water quality and disrupting biological and ecological function (Hsieh and Davis 2005). According to the State Water Resources Control Board (SWRCB) (2013b) pollutants of concern that are found in urban stormwater runoff include car emissions, car maintenance wastes, municipal sewage, pesticides, household hazardous wastes, pet wastes, trash and more. Furthermore, stormwater runoff also poses challenges for urban environments. Concentrated stormwater can damage building foundations, accelerate damage to paved roads, and flood homes and buildings.

1.2 Stormwater Management Techniques

Traditional approaches to stormwater runoff management usually involves a network of storm drains with many inlets to expediently collect stormwater runoff from urban zones and to convey that water into natural waterways (Montalto et. al. 2007). Traditional stormwater infrastructure often does not utilize the landscape to treat, store or slow down stormwater runoff. Instead traditional stormwater systems convey and concentrate stormwater runoff, negatively impacting natural systems (Hsieh and Davis 2005).

LID is one technique that is increasingly implemented in urban landscapes to address stormwater management (Gilroy and McCuen 2009). Unlike traditional stormwater infrastructure, LID strives to maintain an areas' pre-development hydrology (Dietz 2007; EPA 2000). LID can reduce runoff in two ways; it can prevent runoff by capturing water as it contacts the ground, or it can intercept and treat runoff before it leaves the target area.

1.3 Overview of Project

To address the lack of understanding of stormwater characteristics on POM we:

1. Described the regulatory environment for stormwater management in POM
2. Identified potential LID sites
3. Estimated the stormwater runoff volume and peak flow rate using a HEC-HMS model
4. Estimated the effect of LID on stormwater runoff using a HEC-HMS model
5. Summarized geologic data to assess LID feasibility

1.4 Study Area

POM is located on the central coast of California in the City of Monterey on the northwestern tip of the Monterey Peninsula (Fig. 1). POM is bounded by the cities of Pacific Grove and Monterey, and the community of Pebble Beach. It is approximately 400 acres and stretches approximately 1.5 miles inland from the coast. POM is the current site of the Defense Language Institute Foreign Language Center (DLI-FLC) - a school for members of the U.S. Military. At any given time the school accommodates a community of approximately 3,500 people (POM 2014).

POM has a mixture of highly urbanized and open space areas. POM is primarily undeveloped in the southwest portion of the property and developed in the lower northeast portion. The undeveloped areas are composed of open space and contain parts of the Huckleberry Hill Nature Preserve, along with some water tanks and minor tracks. The developed areas are characterized by roads, buildings, recreational fields, and parking lots. The most heavily developed area within POM is known as the historic district and is located in the central portion of the property (POM 2008).

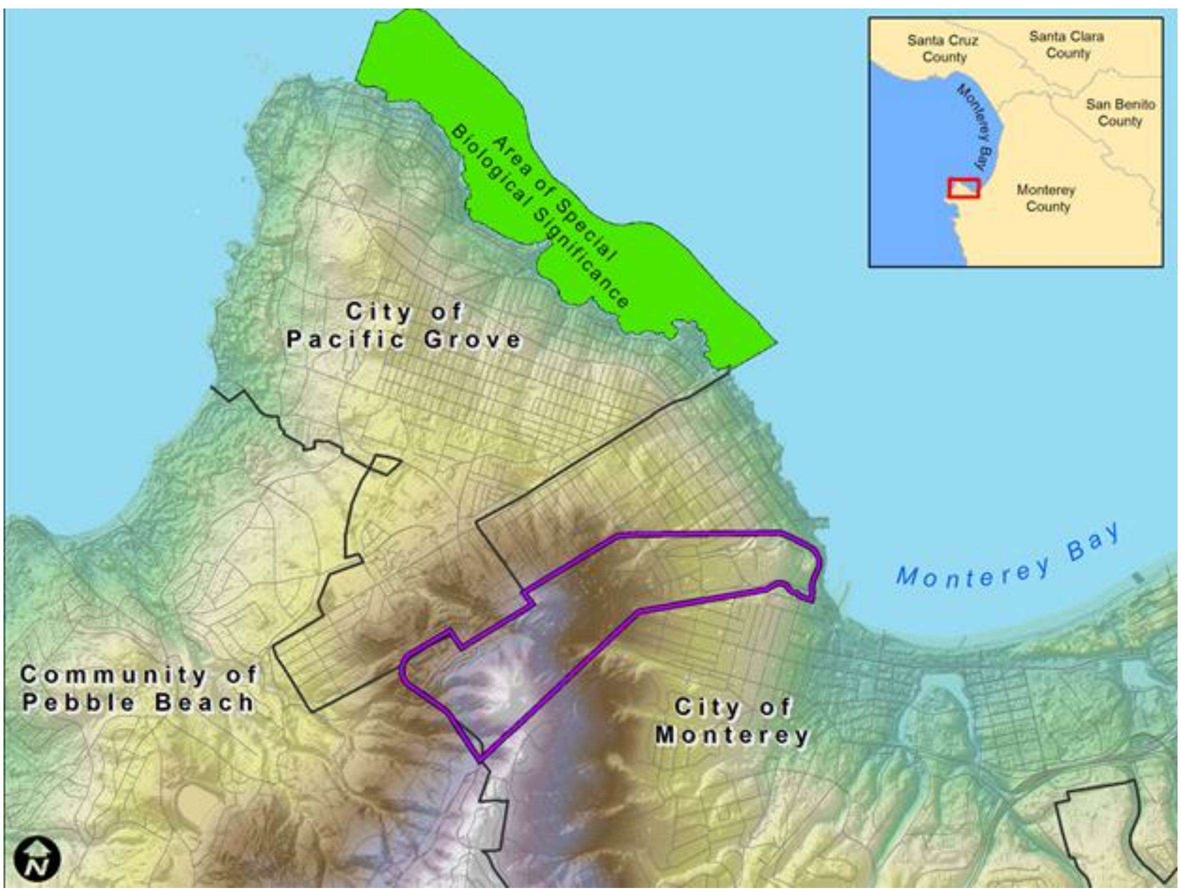


Figure 1: Location of the Presidio of Monterey and nearby municipalities that drain into Monterey Bay and the Pacific Grove Area of Special Biological Significance (ASBS)

1.5 Stakeholders

Stakeholders in POM's stormwater management may include the following:

City of Pacific Grove

City of Monterey

Pebble Beach Community

State Water Resources Control Board

Monterey Bay Sanctuary Citizen Watershed Monitoring Network

California Department of Fish and Wildlife

California Coastal Commission

Monterey County Water Resources Agency

Monterey Peninsula Water Management District

Cal-Am

U.S. Army

Monterey Regional Stormwater Management Program

2 Regional Constraints and Regulatory Environment

2.1 Introduction

The central coast is characterized by several water-related constraints that motivate improved water resources management on the Central Coast. These constraints include limitations on existing water supplies, water quality impairment, special protections for aquatic habitats, and many federal, state and local regulatory requirements. The following section reviews regional constraints the most relevant regulations that motivate the usage of Low Impact Development at the time the document was written (2014).

2.2 Water Supply Deficit

According to the Monterey Peninsula Water Management District, the region will experience a water supply deficit starting in 2017 unless supplementary water supplies are found (MPWMD 2013). This is due in part to an Order issued to Cal-Am, the primary water purveyor for the region, to stop drawing water from the Carmel River and a requirement from the State Board to reduce groundwater extraction from the Seaside Groundwater Basin (MPWMD 2013). Water lost from these sources amount to about 75% of water supply, and as a result, water demand is projected to exceed water supply by over 6,000 acre-feet. The area's water scarcity has several implications for the customers of Cal-Am; most importantly, the order issued by the state board placed a temporary moratorium on new water connections for building projects unless water credits are obtained from the Monterey Peninsula Water Management District. Additionally, the Order asserts that any new water sources developed by Cal-Am must first result in an equal reduction in extraction from the Carmel River, such that 75% of water extraction from the Carmel River is reduced before any additional water can be allocated for new users (SWRCB 1995).

2.3 National Pollutant Discharge Elimination System (NPDES)

In 1973 the Federal Water Pollution Control Act (Clean Water Act) created the National Pollutant Discharge Elimination System (NPDES) permit program to regulate any facility that discharges pollutants into U.S. waterways. Compliance with NPDES is enforced by the Environmental Protection Agency (EPA). In California the EPA has given responsibility to the State Water Resources Control Board (SWRCB) and the nine Regional Water Quality Control Boards to issue NPDES permits and to enforce compliance (SWRCB 2014). POM is a stormwater discharger regulated by the Central Coast Regional Water Quality Control Board (CCRWQCB).

In 2013 POM applied for a new MS4 Phase II permit for Non-Traditional Systems. The permit requires the reduction of pollutants from the sewer system to U.S. waterways to the maximum extent possible. The reduction in pollutants is achieved through the development of a stormwater management plan (SWMP) that implements Best Management Practices (BMPs). The permit includes post-construction requirements to improve water quality after projects are built. POM is required to develop, implement and enforce a program to minimize the discharge of pollutants to the MS4 system from any construction activity that disturbs greater than one acre of land. The permit promotes and prioritizes LID as a cost-effective way to comply with regulations (SWRCB 2013a).

During 2013 each Regional Water Quality Control Board began an effort to delineate Watershed Management Zones (WMZs) to categorize dominant watershed processes, so that during the next permit term, permittees would be required to identify WMZs within their jurisdiction and to implement the post-construction stormwater capture techniques appropriate to those WMZs. The CCRWQCB has already delineated WMZs for the region and given local MS4s the option to participate in the Central Coast Joint Effort to fulfil the post-construction requirements for the 2013 permit. POM did not participate in the Joint Effort for the 2013 permit.

The permit also includes special requirements for Areas of Special Biological Significance (ASBS) dischargers and requires stormwater management plans to align with the Total Maximum Daily Loads (TMDLs) of receiving water bodies. Other requirements include: illicit discharge detection and elimination, pollution prevention, monitoring of receiving water bodies, public outreach and education, public involvement and participation, program effectiveness and assessment, and mapping of outfalls and associated drainage areas.

2.3 Areas of Special Biological Significance (ASBS)

Thirty-four Areas of Special Biological Significance (ASBS) were established in the 1970s to protect and support biologically significant and diverse marine habitats. These areas generally have more stringent water quality standards and they are maintained for water quality as enforced by the State Water Resources Control Board. Specifically, discharge from point sources of waste are prohibited and discharge from non-point sources are to be controlled to the maximum extent possible.

Most of POMs stormwater drains into the Monterey Bay and some of the water enters the Pacific Grove Area of Special Biological Significance (ASBS). Although POM does not directly discharge into the ASBS, some of the water it discharges into neighboring municipalities does end up in the ASBS (Fig. 2). According to the permit, POM does not have to comply with the special protections for discharges to ASBS (SWRCB 2013b). In 2005 the state board issued a CDO (Cease and Desist Order) to the City of Monterey and PG to stop all discharge into the ASBS, but the cities were able to apply for an authorization to discharge into the ASBS if a water quality monitoring protocol was put in place. Since then a collaboration of agencies formed the Central Coast ASBS Regional Monitoring Program, a project to monitor compliance through water sampling and analysis for various pollutants of concern. Any way that the presidio can reduce its pollutant load is beneficial not only to the ASBS, but to neighboring cities, who must ensure water quality meets the state board's standards.

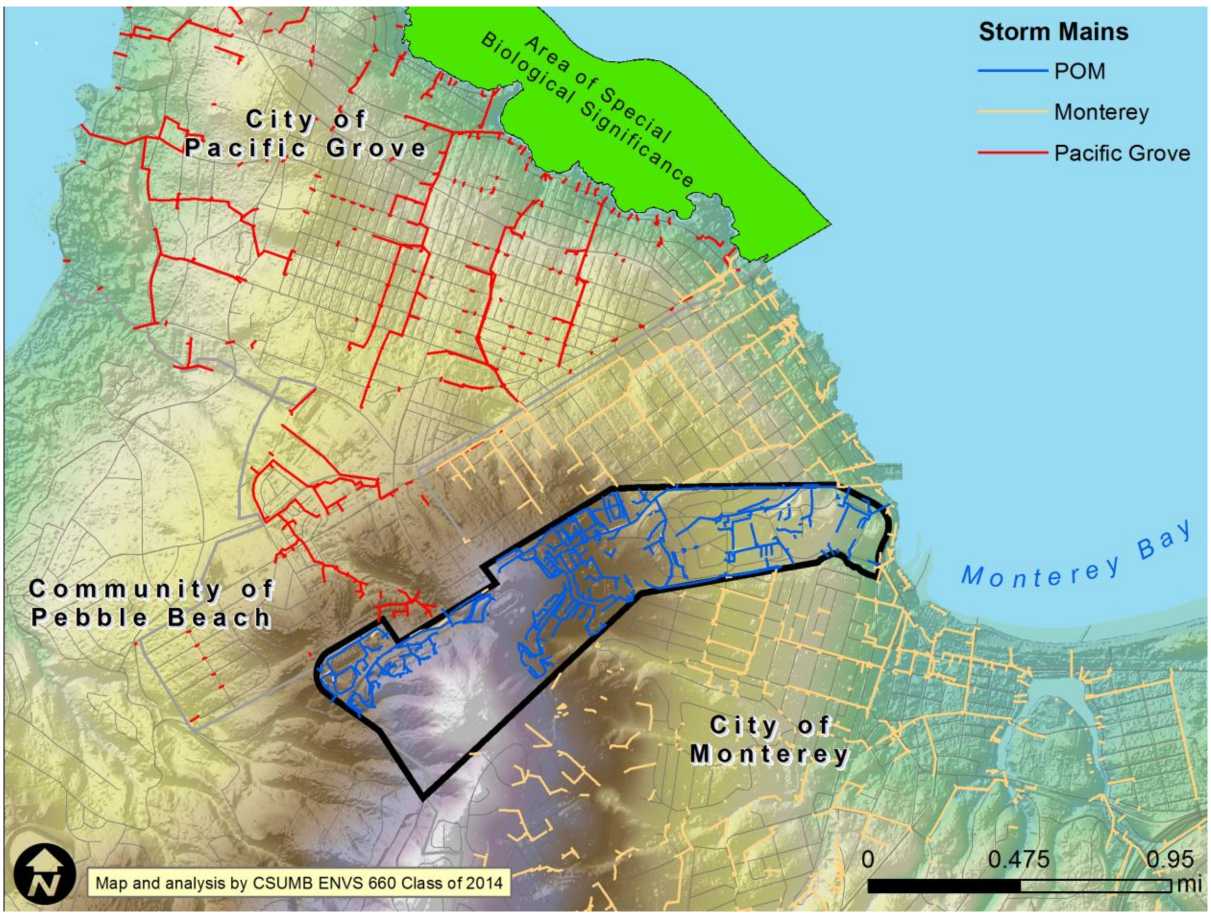


Figure 2: Location of the Presidio of Monterey's storm drain network (blue), the City of Monterey's storm drain network (tan) and the City of Pacific Grove's storm drain network (red). POM's stormwater drains into the Monterey Bay through the City of Monterey's storm drain network and to the Pacific Grove Area of Special Biological Significance (ASBS) through Pacific Grove's storm drain network

2.4 Executive Orders

In 2009 Barack Obama signed Executive Order No. 13514, The Federal Leadership in Environmental, Energy and Economic Performance. The Order states that the policy of all federal agencies will be to, "...conserve and protect water resources through efficiency, reuse, and stormwater management…". To achieve this policy all federal agencies are required to improve water usage by reducing overall water usage and to implement stormwater runoff management guidelines in Section 438 of the Energy Independence and Security Act of 2007 (EISA). Specifically, Executive Order No. 13514 (2009) requires federal agencies to reduce potable and landscaping water consumption by 26% and 20% respectively by 2020, and EISA requires federal agencies to maintain or improve stormwater runoff to pre-development conditions to the maximum extent technically feasible. EISA requires the implementation of green infrastructure or low impact development to protect receiving waters from changes in runoff temperature, volumes, durations and rates, in association with any development or re-development project greater than 5,000 square feet (EISA 2007). According to EISA, stormwater management compliance is performance based and therefore a prescriptive requirement is not given for selecting and sizing stormwater control technologies. EISA suggests two options to meet the pre-development hydrology requirement: (1) stormwater capture technologies can be designed to retain the 95th percentile rainfall event, or (2) a site-specific hydrologic analysis can be conducted pre-development to determine stormwater runoff volume and peak flow, and stormwater capture technologies should be designed such that post-construction hydrology does not exceed the pre-construction hydrology. A description of percentile-based rainfall events can be found in Section 6.2.7.

3 Physical Characteristics

3.1 Introduction

The physical characteristics of the watersheds in POM can inform an understanding of the landscape's propensity to generate stormwater runoff and the capacity of the landscape to store, slow and treat stormwater runoff. Physical characteristics that facilitate the implementation of LID generally have the following characteristics: low slope, hydrologic soil groups with low runoff potential, and a geology characterized by sedimentary deposits.

We used spatial data from various sources to analyze, quantify and discuss the following physical characteristics: geology, slope, hydrologic soil groups, land cover type, percent impervious cover, watershed management zones, and infiltration potential. Most of the spatial data are representative of the landscape at a large scale and may not accurately represent the small-scale nuances in those physical characteristics. We supplemented our understanding of the geology using bore-hole logs provided by POM and the City of Monterey. To our knowledge the data provided by the City of Monterey for sidewalks, roads, parking lots and buildings are up to date, and we assume that they accurately represent all impervious surfaces on POM.

We created maps and tabulated statistics using data obtained from the following sources using ArcGIS 10 (ESRI 2014):

- DEM (elevation, hillshade, contours): 3 meter National Elevation Data (NED). Downloaded from the USDA Geospatial Data Gateway on 10/2/2014.
- Land Cover: NLCD 2011 Land Cover Map. Downloaded from the USGS National Map Viewer on 10/10/2014.
- National Agricultural Imagery Program (NAIP) 2012. Bands: 1-3. Downloaded from the USGS National Map Viewer on 10/10/2014.
- GIS data on streets, sidewalks, parking lots, storm mains and storm main locations were provided by the City of Monterey and the Presidio of Monterey on 10/5/2014.
- Hydrologic Soils Group, Watershed Management Zones, Geologic Unit, and Physical Landscape Unit shapefiles. Downloaded from Central Coast Regional Water Quality Control Board on 10/20/2014.

3.2 Geology

Knowledge of the geologic substrate can give insight into the capacity of the landscape to infiltrate and store stormwater runoff. The geologic unit spatial data provided by SWRCB predominately characterizes the geology of POM as crystalline bedrock, such as granite or granodiorite, with overlying Quaternary sedimentary deposits on marine terraces (Fig. 4). This is supported by the regional geologic history of the Peninsula which is characterized by tectonic uplift and wave-cut marine terraces.

To analyze the subsurface geology we used the geologic unit map and created two cross sections and plotted the bore-hole log data on those cross-sections. Specifically, we analyzed 31 bore-hole logs from four sites (Mason Street, Building 610, Parking Lot, Building 418) that were drilled under construction sites. Each bore-hole log recorded whether groundwater was encountered. For each bore-hole we mapped the depth at which water was encountered. We also mapped the point of auger refusal, if it occurred. The point of auger refusal was assumed to be the transition from regolith to bedrock - where overlying weathered bedrock transitioned to intact bedrock. Similarly, we mapped the first point of penetrometer refusal - where the drilling machinery was changed from a penetrometer to an auger.

Depth to groundwater varied substantially over short distances within POM (Fig. 4). In total, groundwater was encountered in 5 of the 31 bore logs. Of the four bore-hole logs drilled near Mason Street, three had perched groundwater ranging from 0 - 4 ft below the surface, and were typically underlain by clay. These four bore logs were all within crystalline bedrock. The other two bore-hole logs that water were near building 610 (Fig. 4). These two logs were located within Quaternary sedimentary deposits. Groundwater was encountered at 3 feet. The finding of water within Quaternary sedimentary deposits is expected because infiltration is more likely to occur within sedimentary deposits rather than crystalline bedrock. Lastly, the bore-holes at Building 418 encountered no water.

Depth to bedrock also varied substantially throughout POM. Auger refusal depths (an approximate transition between regolith and bedrock) ranged from 7 ft to 45 ft. At the parking lot site the three logs stop around 9 - 9.5 ft depth, and do not state that this was the point of auger refusal. Areas mapped as Quaternary sedimentary deposits would be expected to have a greater depth to bedrock, as opposed to areas mapped as crystalline bedrock. However, there was minimal correlation between the mapped surface geology and the sub-surface geology described by the boring logs. This could be because geologic maps do not necessarily take the depth of overlying soils into consideration.

Furthermore, the regional geologic map likely does not account for small-scale variations in sub-surface geology.

While the bore-hole data denotes areas in which groundwater was encountered, further geotechnical surveys are necessary to understand the extent and volume of availability capacity temporary additional groundwater storage. Furthermore, the bore-holes were drilled prior to construction projects in small areas. The 31 bore logs we analyzed were from four different sites within POM and the bore-holes were drilled within close proximity to each other at these locations. For this reason it is difficult to characterize the sub-surface geology and groundwater depths throughout the entire POM. Further analysis of the bore logs is necessary to fully characterize the sub-surface geology of the POM.

3.3 Slope

Steeper slopes primarily characterize the eastern portion of POM, whereas the western portion is primarily characterized by medium to shallow slopes (Fig. 3). Each watershed is summarized by slope classifications in Table 1. It is generally accepted that for LID to be most effective the landscape most have a low gradient. According to the CCRWQCB (2011) a favorable gradient for groundwater recharge is less than 10%, and according to the City of Los Angeles (2011) an infeasible gradient for LID is 20%.

3.4 Hydrologic Soil Groups

According to the Natural Resources Conservation Service (NRCS) data, POM exhibits an approximately equal mix of type B and type D soils (Fig.3). The type B soils (medium-low runoff potential) are typically located in the western portion of POM, as well as the far eastern portion near Monterey Bay. The type D soils (high run-off potential) are typically located in the middle to eastern portion of POM. We also tabulated the area of hydrologic soils for each watershed, as displayed in Table 1.

The three bore logs located on Mason Street with perched groundwater were within type B hydrologic soil. The fourth log at this site did not encounter groundwater and was within type D hydrologic soil. This finding was consistent with the fact that type B soil has a larger infiltration rate than type D, which has the greatest amount of runoff. The other two bore logs located near building 610 that encountered water were located within type D hydrologic soil.

3.5 Land Cover

The eastern portion of POM is primarily developed, while the western portion of POM is characterized by open space according to the NLCD data (Fig. 3). While the NLCD is at a fairly coarse resolution of 30 m, it accurately depicts the land cover on POM. Additionally, we tabulated the percent impervious area by watershed using the shapefiles provided by POM (Table 1). Of the six watersheds, Coast Guard and Twins had the highest percent impervious area, greater than 40%, while Pebble Beach and Pacific Grove watersheds had a lower amount of impervious area, less than 20%. Both Library and Lighthouse Curve watershed had 23% impervious area.

Table 1: Area of cover of slope, hydrologic soils group, and impervious cover by watershed within POM (tabulated using ArcGIS 10, ESRI 2014).

	Area	Slope (% cover)			Hydrologic soil group (% cover)			Impervious
Watershed	(acres)	0 - 10 %	10 - 40 %	> 40 %	B	D	n/a	(% cover)
Coast Guard	108	55	45	0	20	80	0	42
Twins	73	61	38	1	27	73	0	43
Library	67	33	58	9	68	25	7	23
PB	58	30	61	9	40	60	0	15
PG	46	20	64	16	60	35	5	17
LHC	8	59	40	1	100	0	0	23

3.6 Watershed Management Zones

Of the ten WMZs of the central coast, as defined by the CCRWQCB, five are present within POM, including zones 1, 3, 4, 9, and 10 (Fig. 3). The eastern portion of POM is composed of WMZ 4 and 10 and the western portion of POM is composed of WMZ 1 and 9.

WMZs were delineated by the SWQCB to inform post-construction stormwater management requirements. WMZs were determined by categorizing the landscape into unique combinations of the geologic unit, classified slope, and direct receiving water body type (Table 2). These three attributes combined created 90 WMZs (CCRWQCB 2013). The WMZs were further simplified into 54 WMZs with similar watershed processes. Of the 54 WMZs, ten are identified in the Central Coast region (CCRWQCB 2013). Each WMZ is aligned with a specific post-construction stormwater management design requirement to reflect the idea that stormwater mitigation measures should appropriately align with the landscape and key watershed processes at play (CCRWQCB 2013).

Table 2: Watershed Management Zones in POM and their key attributes as delineated by the CCRWQCB (2013).

WMZ	Drains to	Underlain by
1	stream or wetland	Quaternary and Late Tertiary deposits, 0-40%; Early to Mid-Tertiary sediments, 0-10%
3	stream or wetland	Underlain by Franciscan mélange and Pre-Quaternary crystalline, 0-10%
4	lake, large river, or marine nearshore	Underlain by all geologic types, 0–10%, and Quaternary and Late Tertiary deposits, 10-40%
9	wetland	Underlain by Franciscan mélange and Pre-Quaternary crystalline, >10%; or drains to stream or wetland, and underlain by Franciscan mélange and Pre-Quaternary crystalline, 10–40%
10	lake, large river, or marine nearshore	Underlain by Franciscan mélange, Pre-Quaternary crystalline, Early to Mid-Tertiary sediments, 10-40%; or, drains to lake and underlain by all geologic types >40%

3.7 Infiltration Potential

The infiltration potential is based upon the CCRWQCB's designation of areas into physical landscape zones (PLZ). The PLZ is a unique combination of the area's geology and slope. For each PLZ CCRWQCB (2011) has designated an infiltration potential of high, medium, and low (Table 3). We reclassified the PLZ shapefile from the CCRWQCB and mapped the infiltration potential using CCRWQCB's rating table (CCRWQCB 2011). Areas of low infiltration potential dominate the western portion of POM, whereas the eastern portion of POM has areas of high, medium and low infiltration potential (Fig. 3).

Table 3: Infiltration potential based on the geologic unit and the slope class with POM. This table was adapted from the CCRWQCB (2011).

Slope Class	Geologic Unit	Infiltration Potential
0-10%	Pre-Quaternary crystalline	Medium
	Early to Mid-Tertiary sed.	High
	Quaternary deposits	High
10-40%	Pre-Quaternary crystalline	Low
	Early to Mid-Tertiary sed.	Medium
	Quaternary deposits	High
>40%	Pre-Quaternary crystalline	Low
	Early to Mid-Tertiary sed.	Medium
	Quaternary deposits	Medium

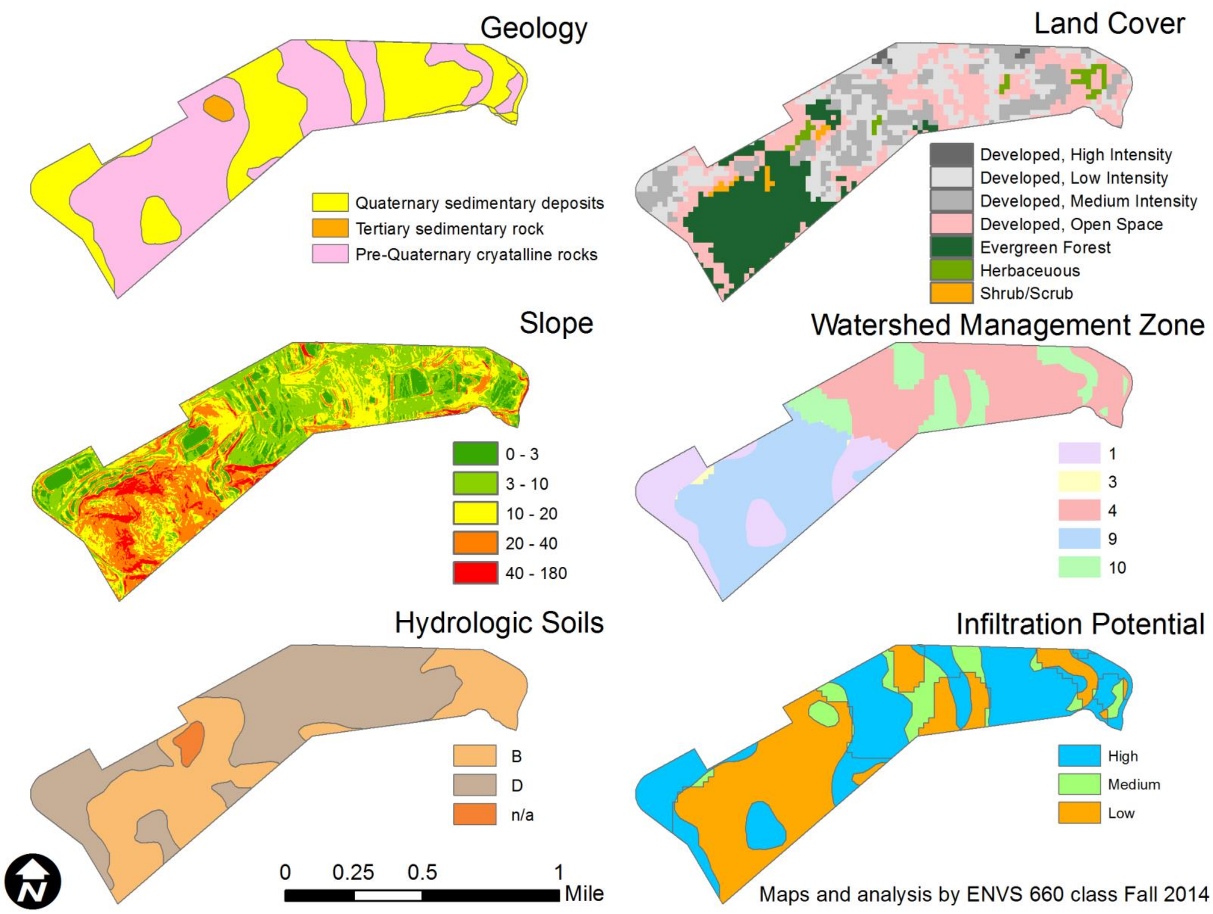


Figure 3: Maps of the geology, slope, hydrologic soils groups, land cover, watershed management zones, and infiltration potential on POM. The watershed management zones and infiltration potential are developed by the CCRWQCB based upon specific attributes. Table 2 describes the attributes for each WMZ, as well as the associated infiltration potential.

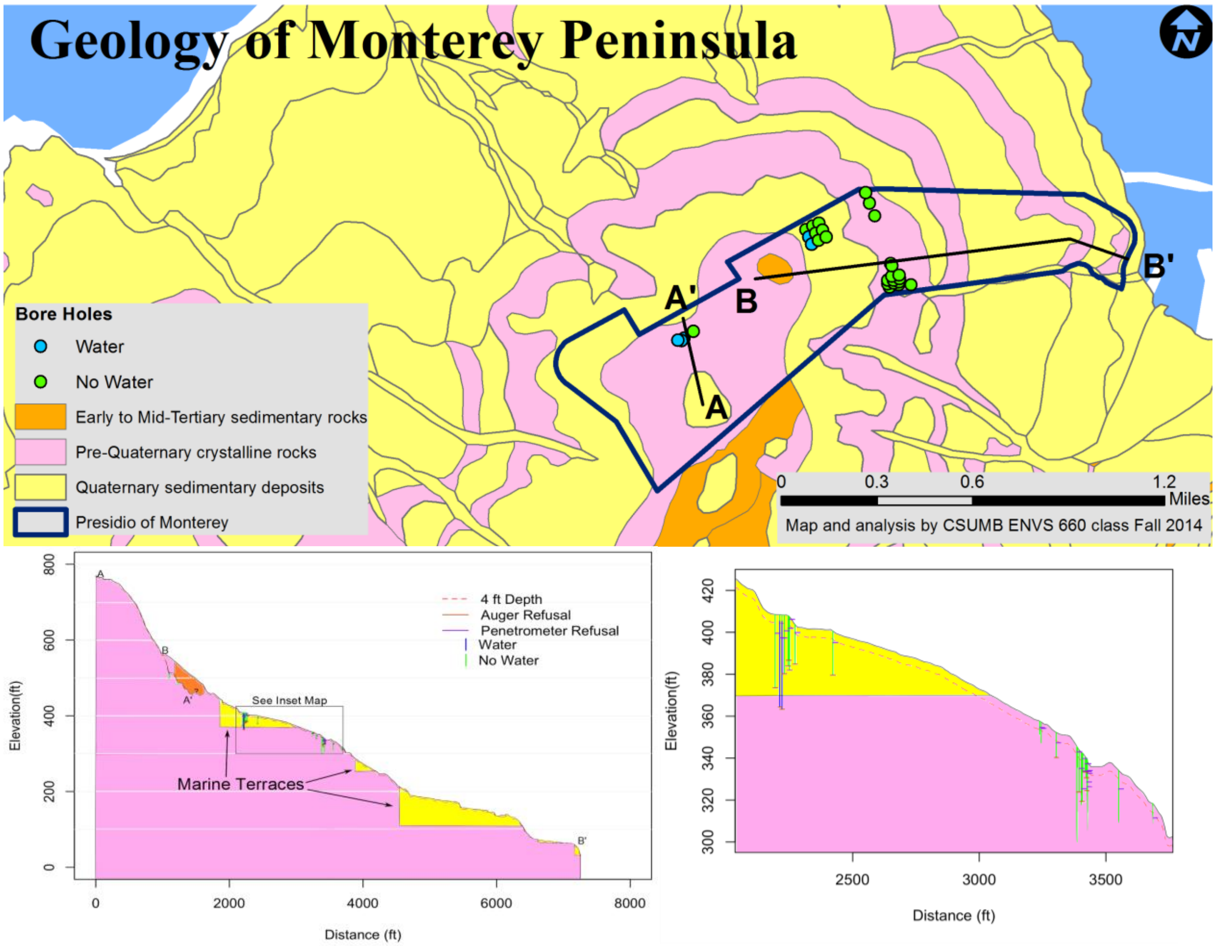


Figure 4: Geologic map and cross sections along POM. Bore log locations were approximated along the cross sections. The location of marine terraces are inferred and approximated. The depth and extent of groundwater is colored accordingly in cross-sectional view. The depth of auger refusal was approximated to be the transition from overlying weathered rock to intact bedrock. Larger versions of the cross section and inset are located in Appendix J.

4 Potential Low Impact Development (LID) Sites

4.1 Summary of relevant LID techniques

LID techniques can be classified into two broad groups: stormwater prevention techniques, and stormwater treatment techniques. Prevention techniques prevent runoff by intercepting rainfall at potential runoff sources before it becomes concentrated flow in channels and drains. Treatment techniques operate on runoff that has already become concentrated in channels and drains, by detaining it, delaying it, facilitating residence time within biological or mechanical pollutant reduction systems, and facilitating percolation and evaporation. Relevant examples of these broad groups are summarized as follows.

4.1.2 Pervious pavements

Pervious pavement is a prevention type LID that allows stormwater to infiltrate through a variety of permeable replacements to traditional paving surfaces (Dietz 2007). Water flows through the pavement and is retained sub-surface in a reservoir with stone aggregate where it continues to percolate into natural soils beneath. Pervious pavements provide several benefits including:

- Stormwater runoff reduction
- Groundwater recharge
- Prevention of splashing and glare off roads, and improvement in safety and comfort (Yang and Jiang 2002).

Percolation near buildings can have adverse structural effects. Pervious pavement should have a buffer of 100 feet if up-stream from a building foundation or 10 feet if down-stream, with slope less than 5% (DOT 2003). The depth of water table can also be a restricting factor in areas where the water table is high. Furthermore, soil groups can limit where pervious pavement might be the most effective.

4.1.2 Roof Rainwater Collection

Stormwater can be collected from rooftops by the use of rain barrels and other collection systems. Simulations have predicted that average household irrigation is enough to use the complete capacity of the roof collection storage during most rain events (Jones and Hunt 2010)

4.1.4 Vegetated Rooftops

Vegetated rooftops give previously impervious surfaces the capacity to store water. Vegetated rooftops effectively retain stormwater when compared to non-vegetated rooftops (Carter and Rasmussen 2007).

4.1.3 Detention/Retention Ponds

Detention/retention ponds are engineered reservoirs that act to store runoff. Detention ponds are effective at reducing runoff, but their depth limits vegetation growth to the perimeter of the pond. This has implications for the pond's ability to filter pollutants in the water (Wong et al. 1999).

4.1.3 Diversion and Storage

Storage tanks serve as reservoirs to capture stormwater runoff. They promote water conservation through re-use of stormwater for non-potable uses such as irrigation and toilet-flushing. The capacity of storage tanks is essential in predicting their effectiveness in managing stormwater for a given watershed.

4.1.5 Sub-surface irrigation

Sub-surface irrigation systems such as EPIC (Environmental Passive Integrated Chambers) can store stormwater runoff directly beneath the areas in need of irrigation. These systems act as a reservoir that allows for passive water flow between subsurface interconnected chambers. The chambers are filled with sand and contain a perforated pipe through the center. As water flows through the pipes, it leaks into surrounding sand where it can serve to irrigate above-ground vegetation. This allows for more efficient irrigation as compared with overhead sprinkler irrigation.

4.1.6 Bioswales

Bioswales are natural or engineered vegetated drainage elements that incorporate detention and infiltration of stormwater (Xiao and McPherson 2011). Both physical and biological processes help to reduce pollutant load in bioswales. They are composed of a combination of vegetation, soil amendments, and rocky berms that slow stormwater runoff flow, facilitate infiltration, and filter out pollution (Fig. 4-2). Additionally, bioswales moderate peak flow and increase stormwater residence time, important factors in pollutant reduction and removal.

Figure 4-2: An example of a bioswale configuration that could be implemented at POM. This bioswale is adjacent to Pajaro Valley High School .

4.2 Potential LID Sites at POM

In conjunction with POM staff, we identified several sites with potential for LID installation. Two field surveys were conducted to inventory potential LID sites, flow direction and topography. Based on communication with staff from POM and City of Monterey and the site characteristics (i.e. slope, soil type, archeological concerns, etc.) we developed a list of suitable LID techniques. We enumerated the following LID opportunities for implementation on POM (see Fig. 4-3): pervious pavement (LID P), diversion and storage (LID 1, LID 6), bioswales (LID 2, LID 4, LID 5), and sub-surface irrigation (EPIC) (LID 3). For each LID site considered, we assessed its potential to store, intercept and reduce stormwater runoff (Table 4).

For one of the diversion and storage LIDs (LID6), we used an existing 220,000 gallon reservoir with infrastructure in place for non-potable water reuse. For pervious pavement (LID P), all parking lots were considered a potential LID site. GIS analysis showed that there are approximately 35 acres of parking lots on the Presidio (Figure 6). When limitations relative to slope, proximity to building foundation, and water table depth for pervious pavement were accounted for, this acreage shrank significantly to 5 acres (Figure 6). For bioswales and the EPIC system (LIDs 2,3,4,5), we created concept maps to illustrate where these LIDs could be implemented on the Presidio. The bioswale concept design (Fig. 7) was created on a site where an above ground culvert system currently exists and could be converted to a bioswale. For the EPIC system (LID 3), we selected a site where efficient irrigation would be most beneficial and effective with respect to water conservation (Fig. 8).

Table 4: Summary of common LID techniques and their incorporation into the present study.

LID	Type	Modeled	LID #
Roof rainwater collection	Prevention	No	
Pervious pavement	Prevention	Yes	LID P
Vegetated rooftops	Prevention	No	
Detention/retention ponds	Treatment	No	
Bioswales	Treatment	Yes	LIDs 2, 4, 5
Diversion and storage	Treatment	Yes	LIDs 1, 6
Sub-surface irrigation	Treatment	Yes	LID 3

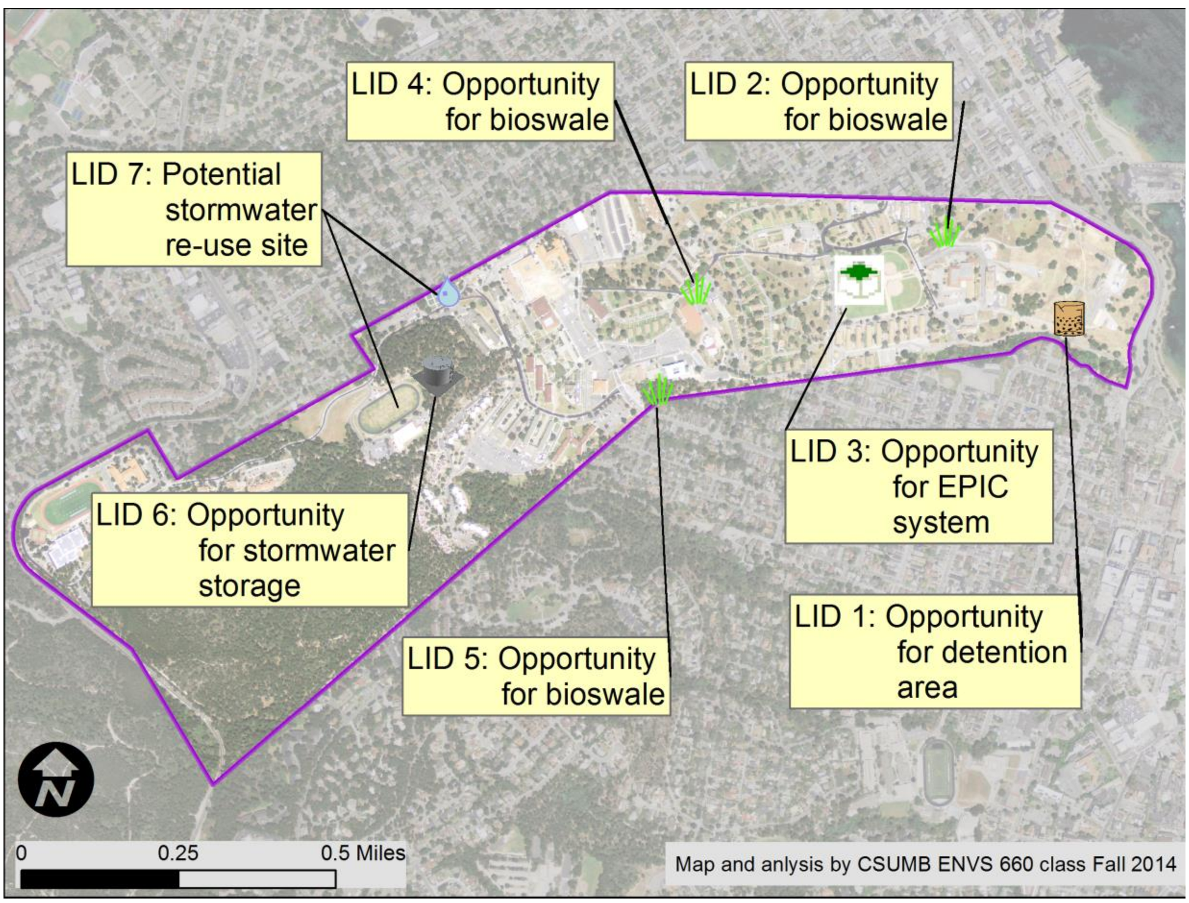
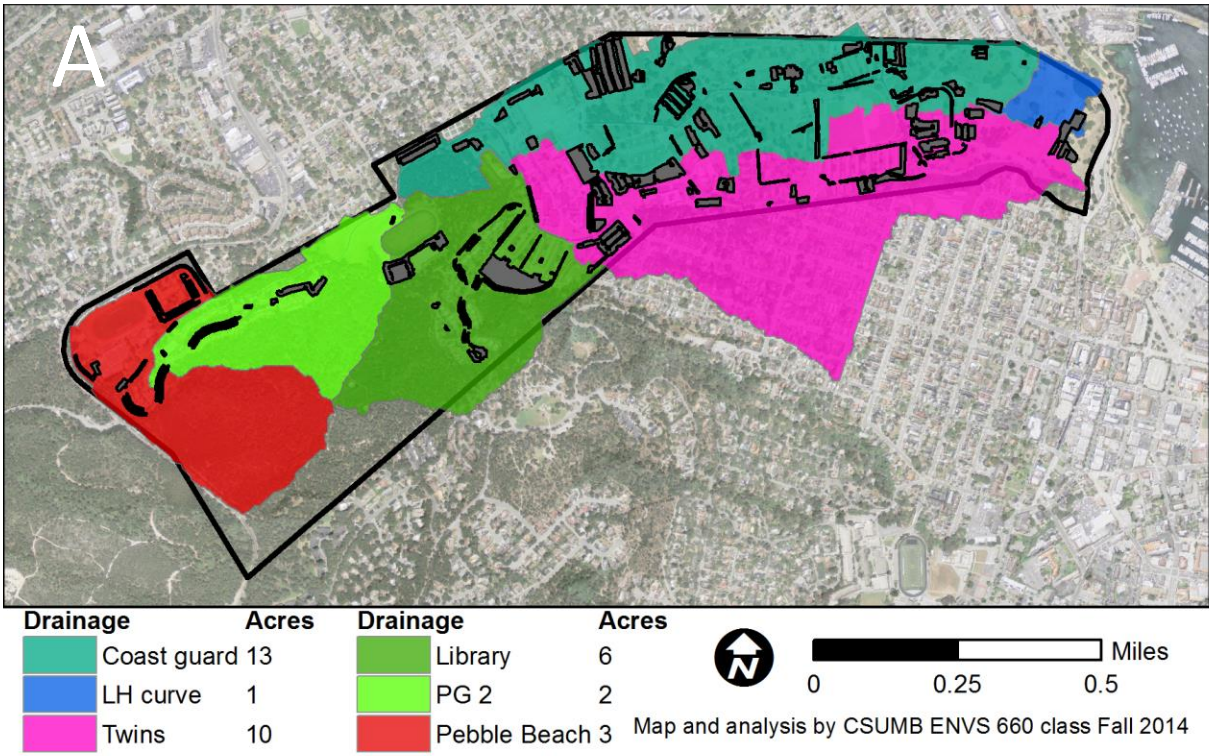


Figure 4-3: Map of potential LID sites. LIDs are denoted by various symbols. Purple line outlines the POM boundary.



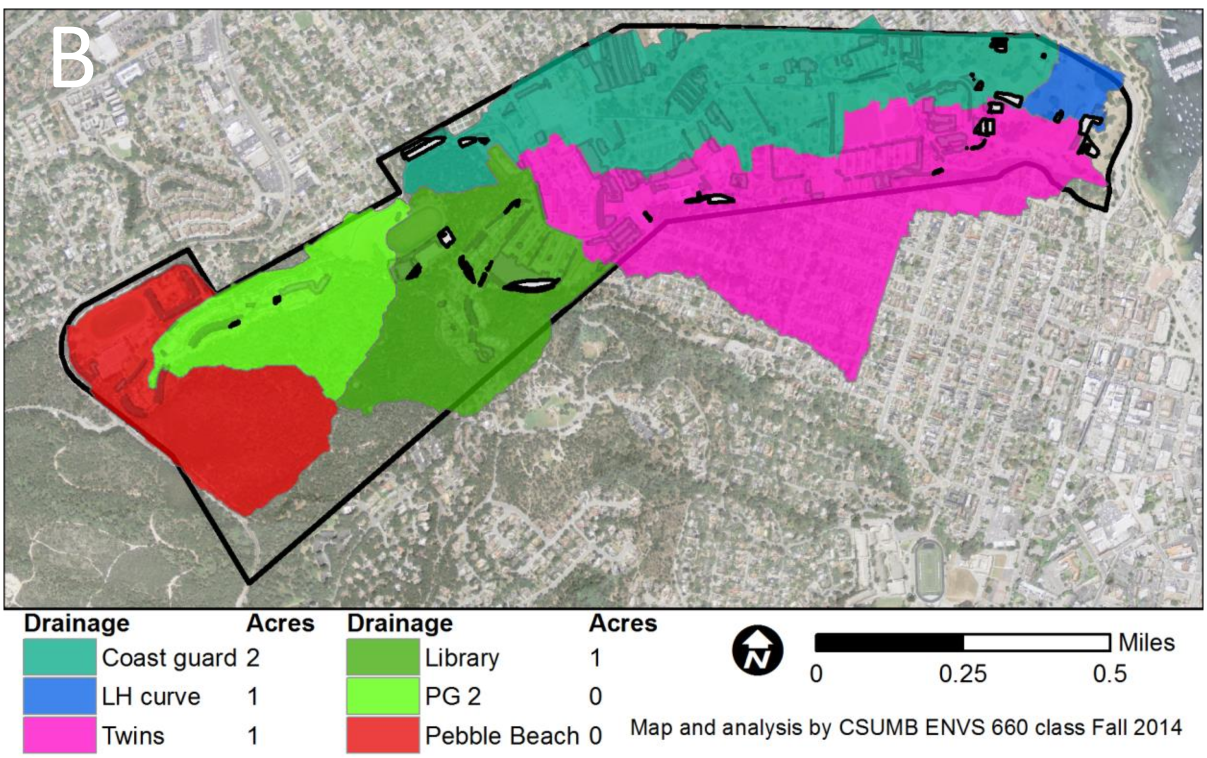


Figure 6: Comparison of potential pervious pavement sites: (A) LID P sites as modelled, and (B) parking lots that meet the criteria for ideal pervious pavement placement according to Caltrans (2010).

Figure 7: Concept map for bioswale located at LID 4. Bioswale design is illustrated over existing above ground stromwatyer drainage. Vegetation is represented by green grass.

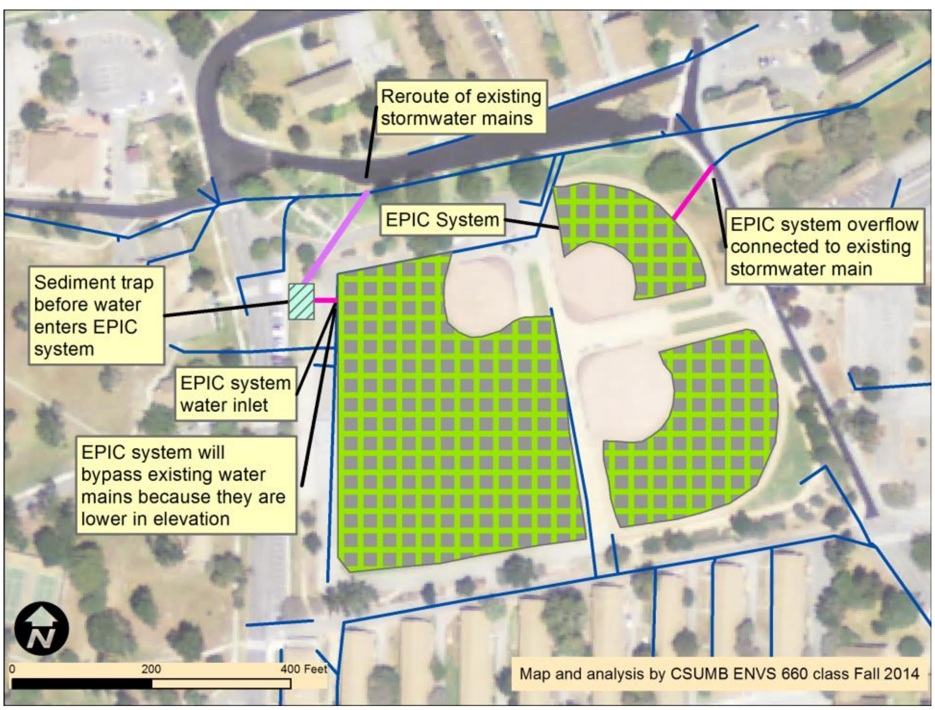


Figure 8: Concept map for EPIC system at LID 3. Reroute option from existing drain system, inlet and overflow structures are outlined in pink and purple lines respectively.

5 Watershed Delineation

5.1 Introduction

To understand the area that drains into each of POM's neighboring municipalities and into each potential LID site we conducted a watershed delineation. We used existing maps, ground verification, and LiDAR data to delineate watersheds for the stormwater systems and potential LID sites. Given POM's urban landscape, the watershed delineation does not necessarily honor the topography of the natural landscape. In areas that were predominantly undeveloped, the watersheds were dictated by the topography. Conversely, in areas that were predominantly urban, the watersheds were dictated by the storm drain system.

POM's stormwater system is composed of open concrete culverts and subterranean storm drains. The primary function of the current storm drain system is to quickly capture and divert water off of the property. The storm system on POM is categorized into six sub-systems based on the storm main system's exit point from the property. These sub-systems are named Coast Guard, Lighthouse Curve (LHC), Twins, Pebble Beach (PB), Library, and Pacific Grove (PG). Five of them drain indirectly into Monterey Bay through outfalls in the City of Monterey and Pacific Grove, and two of them drain directly into natural stream channels (POM 2008). The City of Monterey receives stormwater from the Coast Guard and LHC sub-systems; The Twins sub-system drains into the natural stream channel along the south side of the lower POM; The Library drainage empties into a natural stream channel; and The Pebble Beach and PG drainages connect to the City of Pebble Beach and Pacific Grove storm main systems respectively.

5.2 Storm drain outfall watersheds

To determine the overall direction of stormwater flow and the boundaries between the storm main subsystems, we conducted a watershed delineation using a Geographic Information System (GIS). We delineated watershed boundaries for all six storm main sub-systems by analyzing the topography of POM as described by a LiDAR-based Digital Elevation Model (DEM). We analyzed the DEM using the watershed delineation tools in ESRI's ArcGIS 10 (ESRI 2014). We obtained shapefiles for the storm main system and road areas from POM and the city on Monterey, and 'burned' the storm mains into our DEM by subtracting 5 feet from the original DEM, where storm mains existed, to account for the underground and aboveground movement of stormwater runoff within the storm drain system. Through interviews with POM and City of Monterey personnel we determined that there is a storm drain that runs the length of Clay St. in Monterey whose outfall is in the Twins natural stream channel. We created a polyline to represent this drain and burned it into the DEM as well. We used the following 'Hydrology' tools in the Spatial Analyst extension to delineate sub-watersheds: Fill Analysis, Flow Direction, Flow Accumulation and Watershed. Following the watershed delineation, we ground-truthed locations that showed a discrepancy between the storm main system map provided by POM and the watershed boundaries produced by ArcGIS (Fig 9).

With the assistance of POM and City of Monterey personnel, we visited each storm drain cover for the storm drains that were inconstant with the POM map and the GIS based watersheds. At each location we took into account the slope of the ground, slope of the drain pipes, and the direction of outflow, to identify storm drains with the appropriate outflow location. We updated the watershed delineation to more accurately reflect the direction of stormwater flow. We performed the following key steps in ArcGIS Model Builder to delineate the watersheds:

- Created a DEM that included buildings and removed tree canopy from LAS LiDAR data (AMBAG 2010). We included buildings because they obstruct surface water flow and tree canopy does not. LiDAR points from trees were removed by conducting a supervised classification of 4-band NAIP imagery (2010) to create a tree coverage map buffered by 15 ft., to cover for errors in the classification.
- Burned a paved road polygon 1 ft. into the DEM.
- Burned the storm mains polyline into the DEM as 5 ft. deep and 3 foot wide trenches.
- Flow points for watershed determination were placed at locations of significant flow out of the Presidio. These points primarily corresponded with the storm drains that were burned into the DEM.
- The watersheds were labeled with the name of the appropriate outflow location as determined by the updated storm drain map.
- Individual sub-watershed polygons were 'dissolved' to create single polygons for all the area draining to each outflow.

The largest inconsistencies between the original POM storm main map and field verification were located on the East side of the Coast Guard drainage. The watershed delineation revealed that the Twins and Coast guard were the largest of the watersheds on POM (Fig. 10). Because the storm main under

Clay St. ends at the same natural stream channel as the Twins drainage, a large area of Monterey was included in the Twins watershed (Fig. 11). The updated watershed delineation map is in Appendix C.

5.3 LID sub-watersheds

Sub-watershed delineation for the LID sites was conducted through similar methods as the Drainage system delineation. Because the bioswale locations were selected to be in natural channels they were already at locations of flow accumulation. We used the existing DEM with burned storm drain and roads to delineate the sub-watersheds using watershed delineation tools in ArcGIS.

Determination of the sub-watersheds for the Soldier Field EPIC system and the water tank near hilltop field required further DEM manipulation and storm drain analysis. We burned a trench into the DEM along the lower edge of Soldier Field so that we could use a single flow point in ArcGIS for all of the areas that were modeled to ‘flow’ into the field. In order to connect to the EPIC system a storm drain could not be too low. Specifically the storm drains west of the field are likely located too far below the ground to be connected to the potential EPIC system (Fig 12). To accommodate for this, we placed a flow point at that storm drain where it reaches to Soldier Field. The sub-watershed generated from that point was excluded from the sub-watershed for the EPIC site.

The water tank near hilltop field is near the top of the hill and therefore has a very small sub-watershed. Water would have to be pumped up to the tank to take advantage of its capacity. Because of this we did not delineate a specific sub-watershed for the water tank.

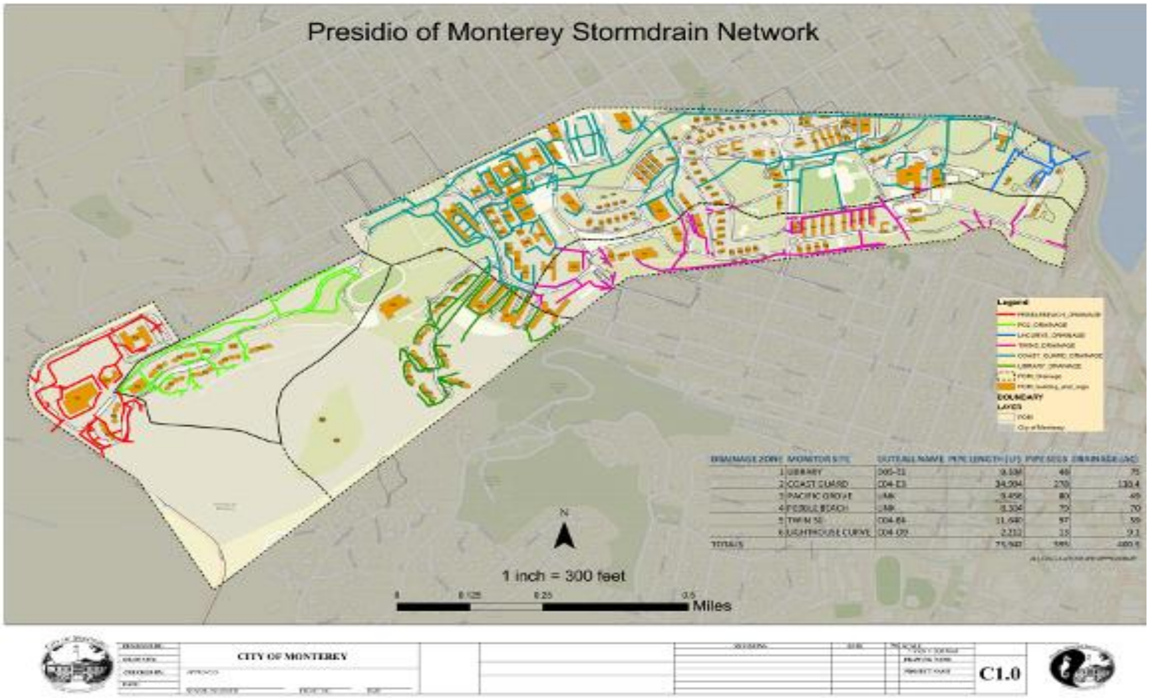


Figure 9: Storm drain network delineation map provided by POM. The delineation of storm drains was based on existing watershed delineations, visual assessment of the network and backtracking bacterial loads during flow events (Information obtained through interviews with POM personnel).

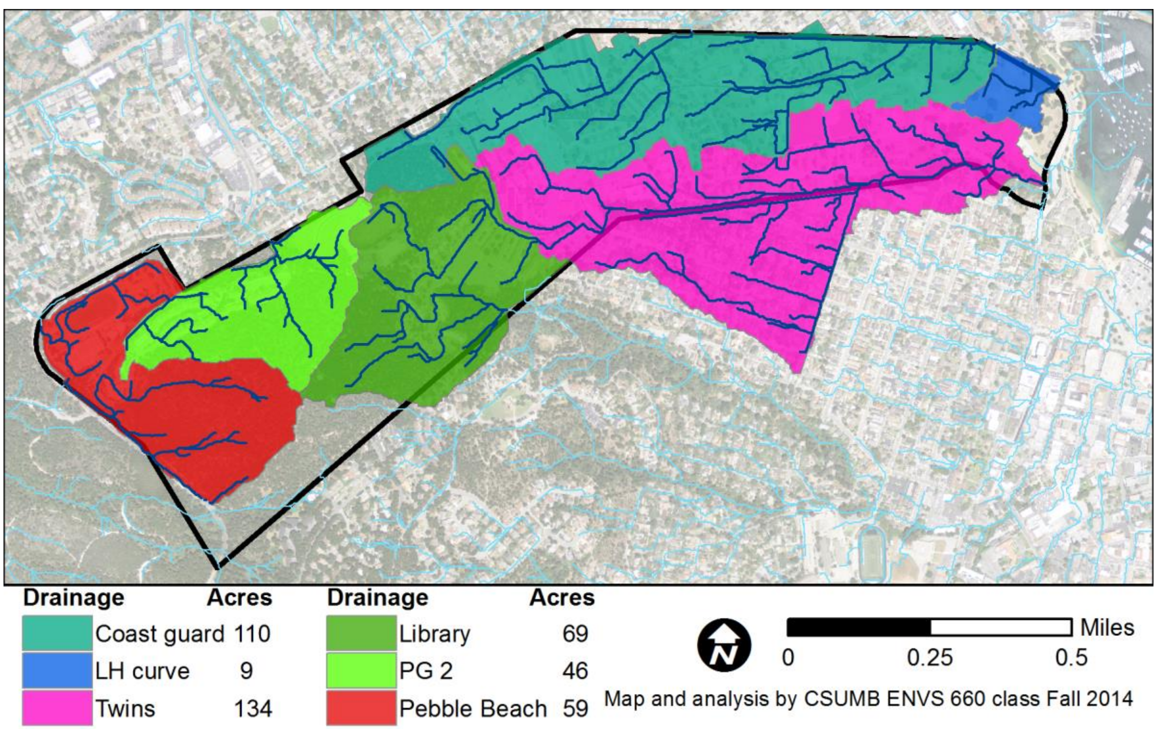


Figure 10: Drainage watersheds based off the updated storm drain network.

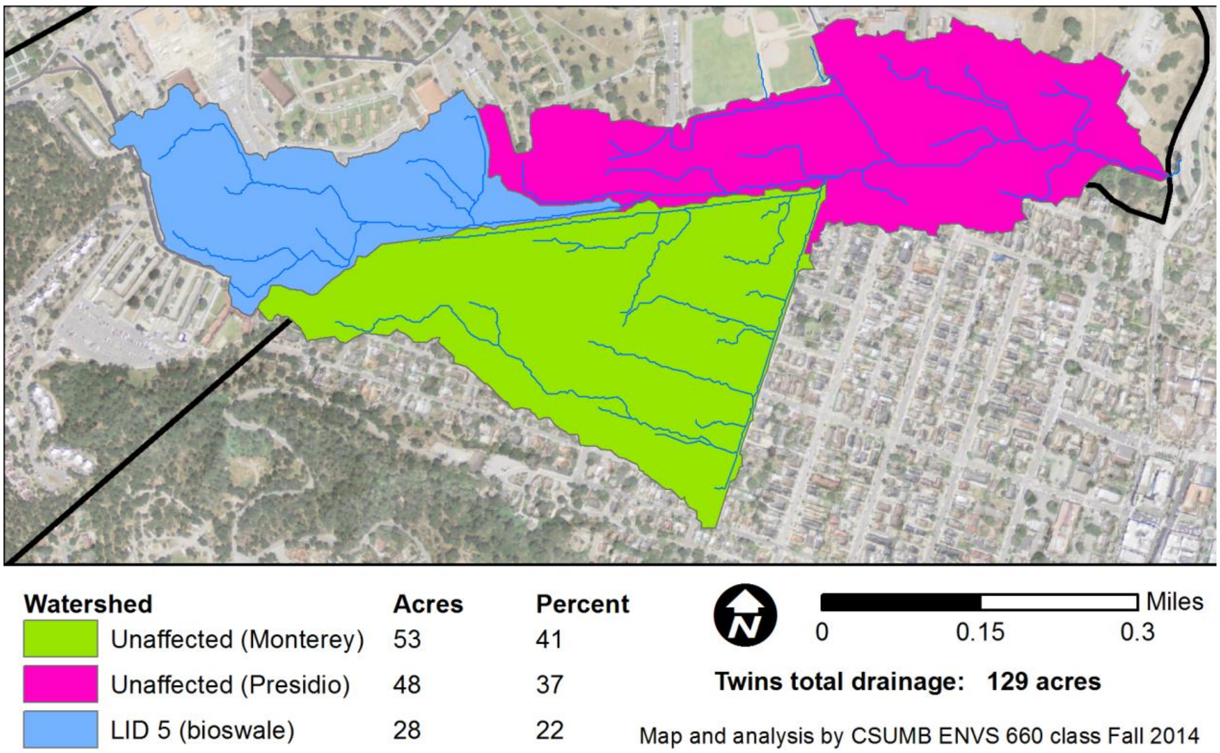


Figure 11: Sub-watersheds LID 5 (bioswale) and the Clay St. storm drain in Monterey.

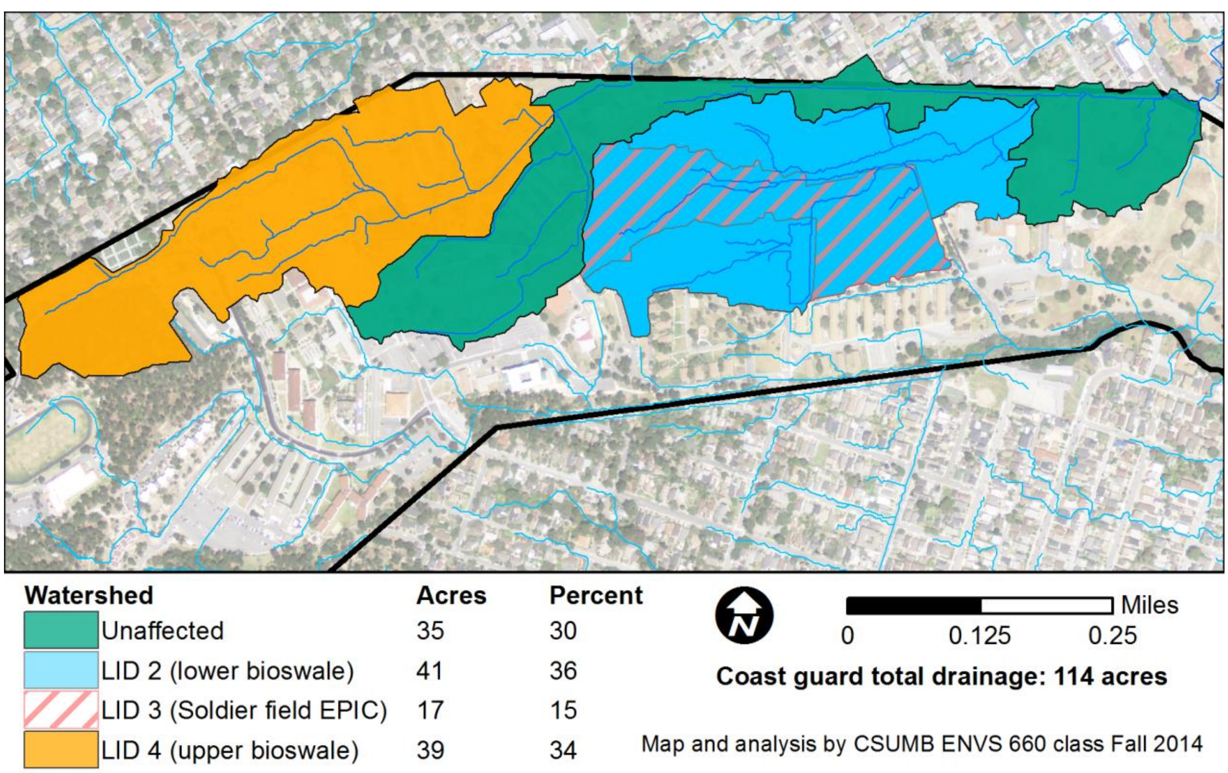


Figure 12: Sub-watersheds for the LID's in the Coast Guard watershed. The sub-watershed for LID 3 is a subsection of the sub-watershed for LID 2.

6 Estimation of Stormwater Runoff

6.1 Introduction

To estimate stormwater runoff from POM and how this would change under future LID implementation, we modeled stormwater hydrology using Hydrologic Engineering Center Hydrologic Modeling Software (HEC-HMS). This system allows a watershed's surface hydrology to be represented as a set of runoff-producing 'sub-basins', runoff-retarding 'reaches', and runoff-storing 'reservoirs', that are connected together to allow estimation of runoff at the outlet of various sub-watersheds.

6.2 Modeling methods

The function of specific LIDs can be represented through addition of new model structural elements and manipulation of model parameters controlling hydrological processes such as percolation, runoff detention, and storage volume. We compared three scenarios, respectively reflecting: (1) existing watershed conditions represented using a simple model structure; (2) existing watershed conditions represented using a more complex model structure including LID elements, but with the parameters of those elements set to reflect existing watershed conditions; (3) watershed conditions under future LID implementation, structured as for the second scenario, but with parameters set to represent anticipated LID function. The first and second scenarios were expected to lead to identical results, but were included separately to confirm that any differences between the results of the second and third scenarios were due to actual LID implementation and not merely undesired artefacts of model structural change. Our discussion of results focusses primarily on comparison between the second and third scenarios.

Watershed features and LID sites are modeled within HMS using hydrologic elements. Each watershed was divided into smaller sub-watersheds that were represented by sub-basin elements. Each sub-watershed represented either an area that drains into an LID site or an area that does not drain into an LID site (i.e. all area of a sub-watershed other than the area that drains into an LID site). Bioswales (LID 2, LID 4, and LID 5) were modeled using paired reach/reservoir elements. The EPIC irrigation system (LID 3) and stormwater catchment tank (LID 6) were modeled using reservoir elements. These elements and their parameters are catalogued in Table 5.

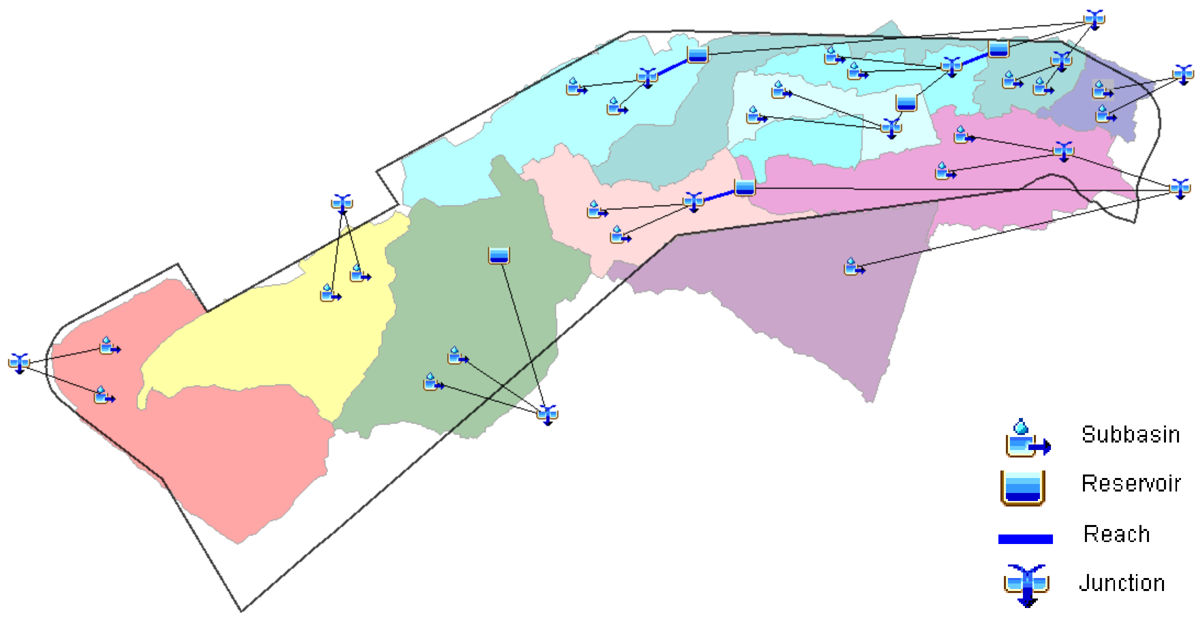


Figure 13: Model structure used in both current and future conditions models. The six POM drainages were divided into sub-watersheds, each flowing into LID sites or a POM outflow. Parking lot surfaces for each sub-watershed were represented by a separate sub-basin element (which is why most of the sub-basins elements appear in pairs). This allowed the runoff generating parameters (curve numbers) for parking lots to be changed independently as required by the LID P scenario.

6.2.1 Sub-basins

We modelled sub-basin elements using the Soil Conservation Service (SCS) loss method and Clark unit hydrograph (CUH) transformation. As modelled, sub-basin elements required five parameters: area (acres), curve number (CN), initial abstraction (*Ia*, inches), time of concentration (TOC, hours), and storage coefficient (hours).

We developed composite CNs for each sub-watershed based on land cover, which we classified as impervious, open, or woods. USDA Technical Release 55 (TR-55) (USDA 1986) defines the CN of these land cover types, which we weighted according to area. We represented the parking lot area of each sub-watershed with separate sub-basin elements so that the pervious pavement LID could be modeled by changing the curve numbers of those sub-basins.

Initial abstraction (*Ia*) represents the amount of precipitation that is lost before runoff begins to be generated. It was calculated using this equation (Schwartz 2010):

$$Ia = 0.05 \times S$$

where *S* is the maximum runoff possible once runoff begins. To calculate *S* we used an equation from TR-55 (1986):

$$S = \frac{1000}{CN} - 10$$

We calculated *Ia* values by combining these equations as described by CSUMB Class ENVS 660 (2013):

$$Ia = 0.05 \times \left(\left(\frac{1000}{CN}\right) - 10\right).$$

The Clark Unit Hydrograph describes the transformation between the hyetograph (precipitation time-series) and the hydrograph (discharge time-series). The two parameters that determine this transformation are Time of Concentration (hours) and the Storage Coefficient (hours). We used values for these parameters provided by CSUMB Class ENVS 660 (2013), which were calibrated to reproduce the measured hydrograph at Greenwood Park in Pacific Grove. Future work should consider using smaller values; the values we used are probably over-estimates that lead to more dissipation of hydrograph peaks than is realistic, because the Greenwood Park watershed is larger than the sub-watersheds modeled within POM.

6.2.2 Reaches

Several reach parameters describe the kinematic wave function, channel geometry, and slope. The kinematic wave function describes the degree to which a channel, symbolized by the reach element, slows down the flow of water. The main parameter is Manning's n; it represents the roughness of the surface over which the water flows. We set Manning's n to the maximum value allowed by the software since reach elements were being used to represent bioswales, which can be designed to maximize roughness. For example, dense shrubs have a manning's n value that is similar to the one used in the model (Arcement et al., [date unknown])

We based parameter values representing channel geometry on field estimates of what each LID site could accommodate. Slope was determined in ArcGIS using a LiDAR-based DEM of the area.

6.2.3 Reservoirs

The capacity of bioswales to temporarily store water was modeled using reservoir elements in HMS. The size of the storage was specified from simple geometric assumptions based on site topography. Outflow rates for each reservoir were specified to allow the reservoirs to drain within a few days following each storm. Reservoir outflow was routed back into to the storm drain and channel system. No percolation was modeled beneath bioswales. This omission led to over-estimation of the stormflow volume downstream of bioswales. Future work should consider a more sophisticated and complete means of estimate the hydrologic effect of bioswales on storm runoff.

6.2.4 Precipitation

We estimated runoff based on the 85th percentile 24-hour storm event (CCRWQCB [date unknown]). The value of this event for the POM area is (coincidentally) 0.85 inches. A design storm was then synthesized by distributing this depth over a 24 hour period using the regionally appropriate Type I curve developed by NOAA (2014) (Fig. 14).

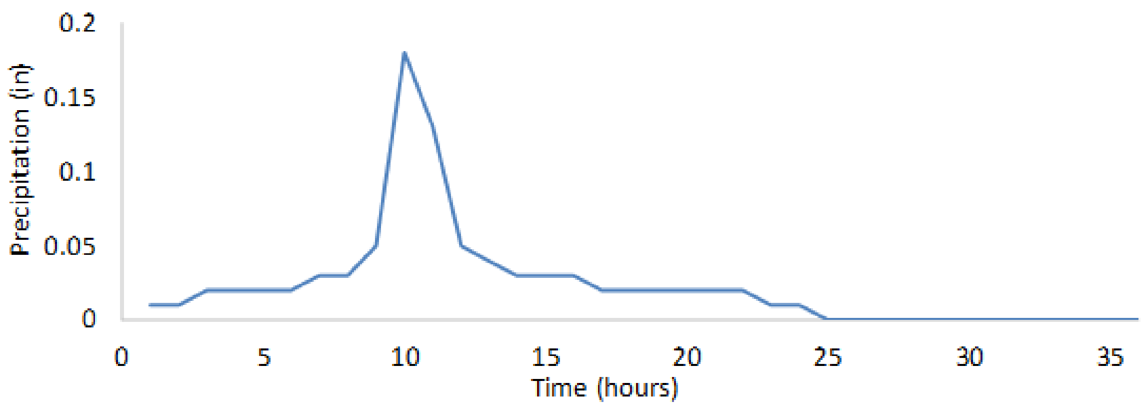


Figure 14: Twenty-four hour time series of a synthetic storm. Total precipitation for the storm based off /of data from the CCRWQCB. Total precipitation is 0.85 inches.

Table 5: HEC-HMS parameters. We compared a current conditions model (cur.) to a future conditions model (fur.). LIDs 2, 4, and 5 were bioswales and were modeled with paired reservoir/reach elements. LID 4, an EPIC system, and 5, a storage tank, were modeled with reservoir elements. Area, initial abstraction (I_a), and reservoir volume are reported in hundredths of their respective units.

Watershed:	**Coast Guard**									**Twins**						**Library**				
LID name:	LID 2		LID 3		LID 4		LID P		Non-LID	LID 5		LID P		Non-LID		LID 6		LID P		Non-LID
LID type:	Bioswale		EPIC		Bioswale		Perv. Pave.			Bioswale		Perv. Pave.		**Pres.**	**Mont.**	Rain. Catch.		Perv. Pave.		
Parameters	*(cur.)*	*(fut.)*	*(cur.)*	*(fut.)*	*(cur.)*	*(fut.)*	*(cur.)*	*(fut.)*		*(cur.)*	*(fut.)*	*(cur.)*	*(fut.)*			*(cur.)*	*(fut.)*	*(cur.)*	*(fut.)*	*(cur.)*
Subbasin																				
Area (mi^2):	21.9	21.9	16.4	16.4	32.5	32.5	13.1	13.1	30.9	23.3	23.3	9.8	9.8	43.1	52.7	0.0	63.3	5.5	5.5	63.3
CN	83	83	84	84	80	80	98	74	81	83	83	98	74	76	89	0	63	98	74	63
I_a (in)	0.10	0.10	0.10	0.10	0.13	0.13	0.04	0.04	0.12	0.10	0.10	0.02	0.02	0.15	0.06	0.00	0.29	0.01	0.01	0.29
TOC (hr)	0.10	0.10	0.10	0.10	0.10	0.10	0.40	0.40	0.10	0.10	0.10	0.20	0.20	0.10	0.10	0.00	0.10	0.10	0.10	0.10
Stor. Coef. (hr)	1.50	1.50	1.50	1.50	1.50	1.50	6.00	6.00	1.50	1.50	1.50	3.00	3.00	1.50	1.50	0.00	1.50	1.50	1.50	1.50
Reservoir																				
Volume (ac-ft)	0.00	0.66	0.00	2.31	0.00	0.30				0.00	0.54					0.00	0.61			
Discharge (cfs)	50	0.50	100	0.00	50	0.50				50	0.50					100	0.00			
Reach																				
Manning's n	0.01	0.15			0.01	0.15				0.01	0.15									
Length (ft)	1	492			1	1089				1.0	1200									
Slope (ft/ft)	0.03	0.03			0.09	0.09				0.10	0.10									
Width (ft)	5.0	5.0			5.0	5.0				5.0	5.0									
Side slope (ft/ft)	2.0	2.0			2.0	2.0				2.0	2.0									

Wshed (cont.):	**Pacific Grove**			**Pebble Beach**			**Light House Curve**		
LID name:	LID P		Non-LID	LID P		Non-LID	LID P		Non-LID
LID type:	Perv. Pave.			Perv. Pave.			Perv. Pave.		
Parameters	*(cur.)*	*(fut.)*		*(cur.)*	*(fut.)*		*(cur.)*	*(fut.)*	
Subbasin									
Area (mi^2):	1.5	1.5	44.5	2.1	2.1	57.0	1.3	1.3	7.8
CN	98	74	66	98	74	72	98	74	63
I_a (in)	0.01	0.01	0.26	0.01	0.01	0.20	0.01	0.01	0.30
TOC (hr)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Stor. Coef. (hr)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50

6.3 Results

6.3.1 Estimated runoff under current conditions

As expected, the estimated outflow was the same for the two different model configurations designed to represent current conditions.

Comparing estimated outflow between watersheds, Figure 15 illustrates that all of the watersheds reached peak flow conditions at approximately the same time. As expected, the magnitude of runoff from each watershed correlates primarily with the area of the watershed, with the exception of the Twins Total watershed (Fig. 16), which had a higher proportion of impervious area (mostly within the Monterey sub-watershed, which accounts for 49% the Twins watershed outflow).

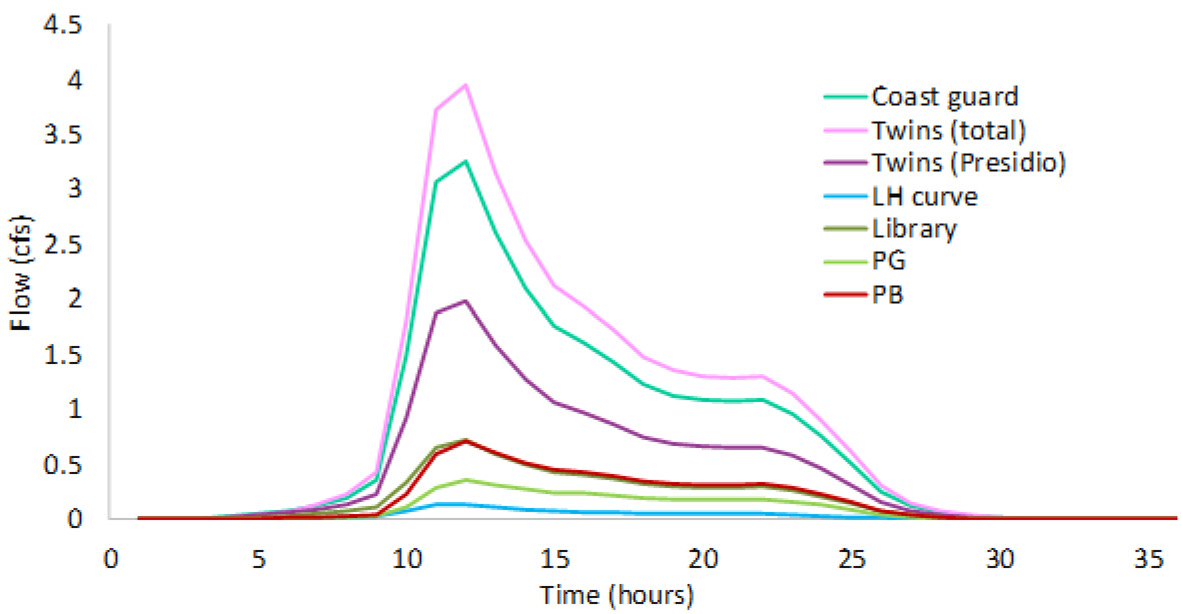


Figure 15: Hydrograph of each of the watersheds under the current conditions scenario over a 36 hour period starting at the beginning of the modeled storm.

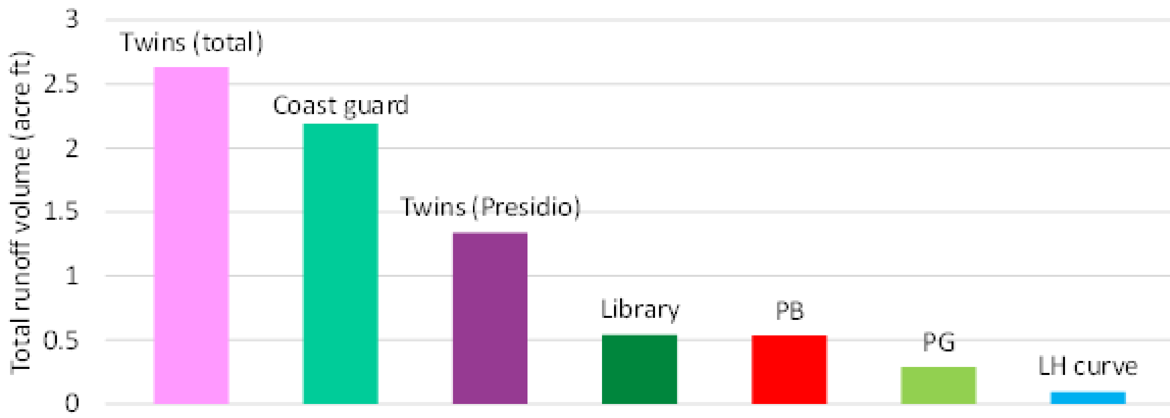


Figure 16: Estimated total runoff volume from each watershed within the 36 hours following the start of the synthetic storm. Volumes are from the current conditions scenario. Delayed flow beyond the first 36 hours was not modeled.

6.3.2 Estimated runoff under future LID scenarios

The extreme pervious pavement model was estimated to be moderately effective at reducing runoff (Fig 17). Because there were parking lots in all of the drainages, the pervious pavement was the only LID that reduced outflow in all six of the drainages.

The treatment LIDs were estimated to be more effective than the pervious pavement LIDs at reducing total outflow and peak flow (Figs 17 & 18). The effectiveness of the treatment LIDs that acted to intercept runoff appeared to be impacted primarily by the LID's modeled capacity to store water and the size of their sub-watersheds. Because the modeled water tank in the Library drainage did not discharge water until after its capacity was surpassed, the Library drainage had no discharge with the LID in effect. The bioswales substantially reduced peak flows, and delayed the majority of flow beyond the 36-hour modeling period (Fig 19). With the exception of LID 4, the bioswales approached, but did not reach full capacity during the modeled 85th-percentile storm.

These results demonstrate the twofold effect of treatment LIDs. First, by spreading the flow out through time they reduce the peak flow (Fig. 18; Fig. 19). Second, by slowing down the flow of water, they allow more time for the water to infiltrate into the ground (a process that we did not model), reducing total outflow volume.

The EPIC system at LID 3 prevented close to 100% of the outflow from its sub-watershed and only filled to 13% of its capacity during a single 85th-percentile storm (Fig 20).

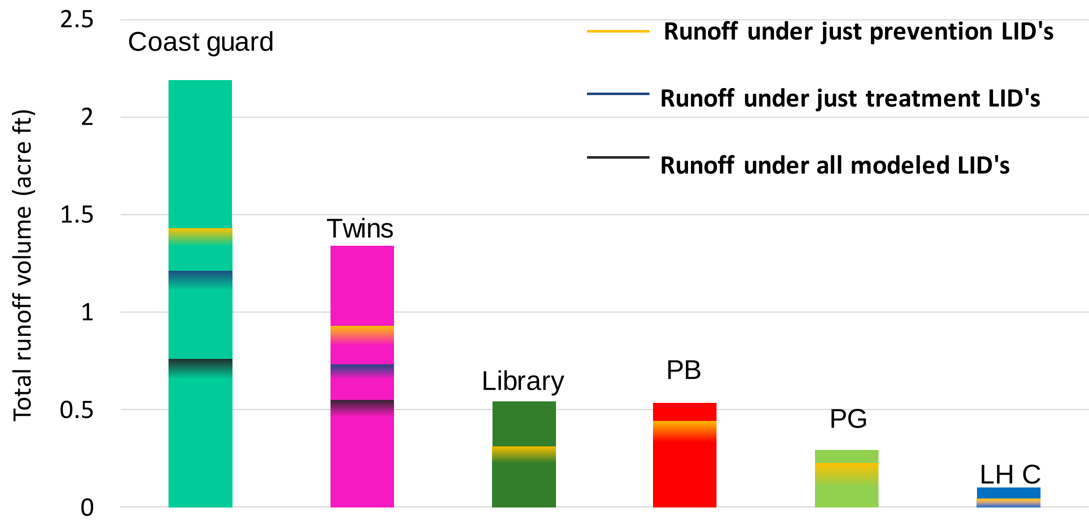


Figure 17: Total volume of runoff from each drainage within the first 36 hours following the start of the synthetic storm. Four modeled scenarios are graphed: current conditions scenario, the extreme pervious pavement scenario (labelled "just prevention"), a scenario that combines all of the treatment LID's, and an all LID scenario.

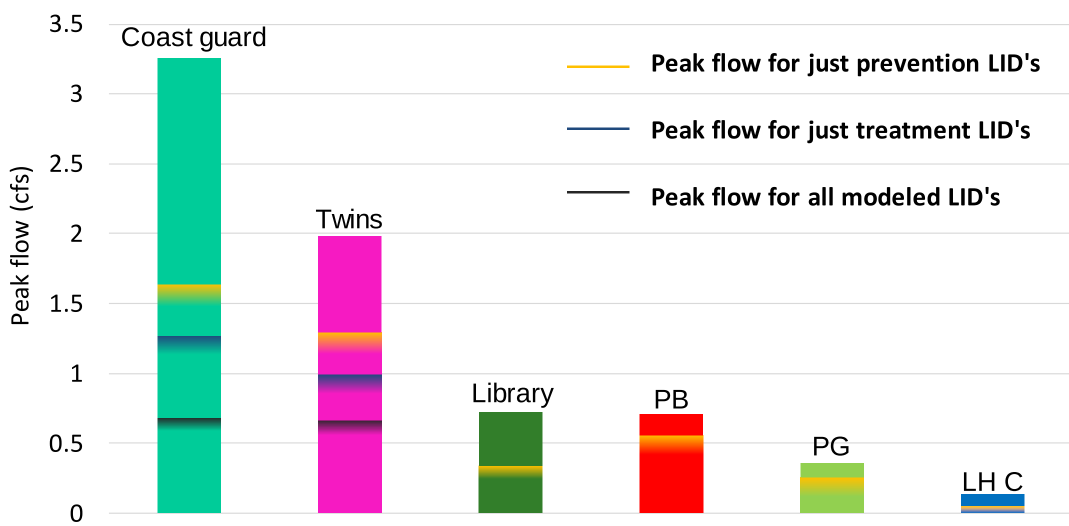


Figure 18: As for Figure 17, but showing peak flow rates.

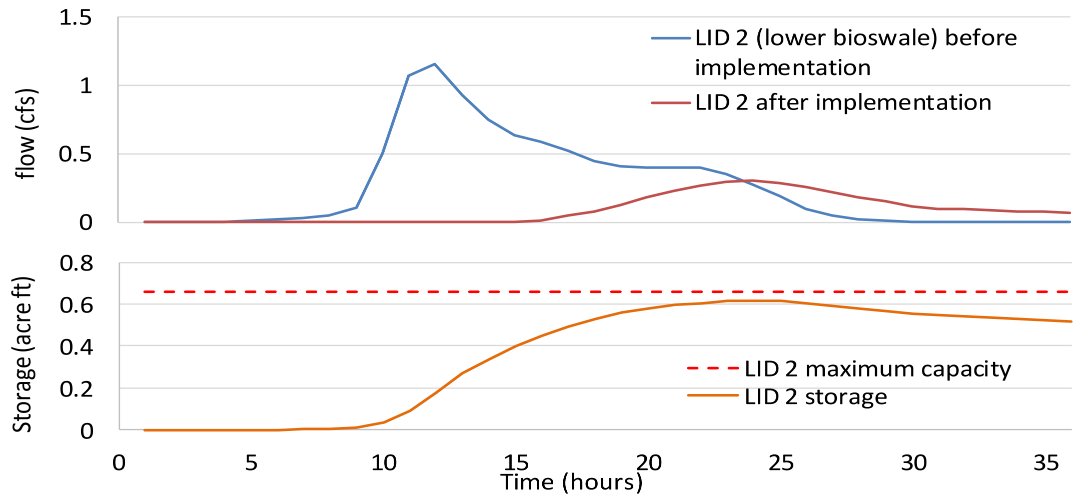


Figure 19: Top: Hydrograph comparing outflow for the current condition and with LID 2 implemented .ID 2 sub-watershed. Bottom: Water storage of the LID 2 bioswale over time. The modeled bioswale 5 had similar results as LID 2 (see appendix).

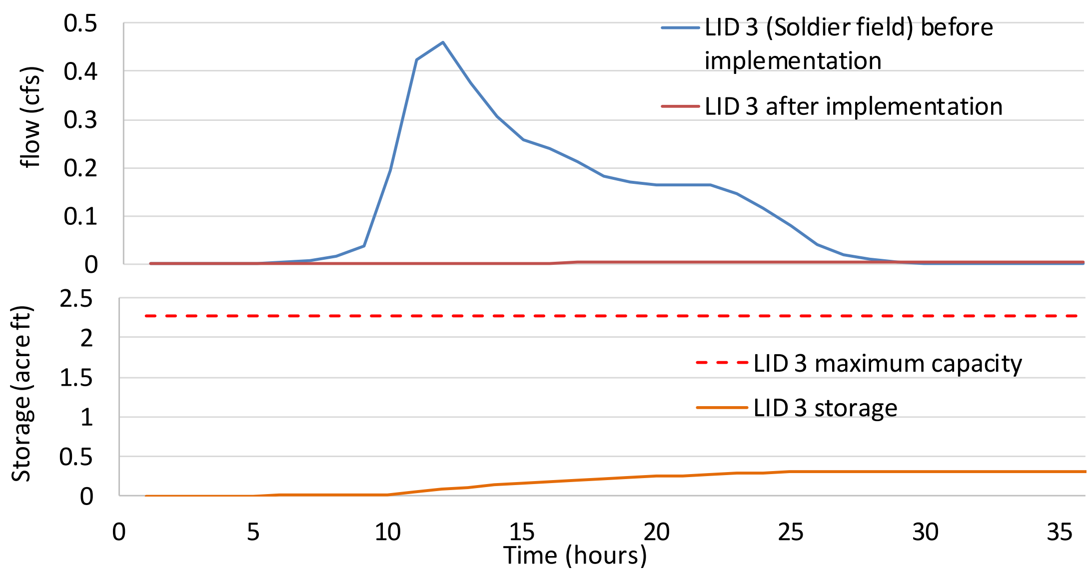


Figure 20: Top: Hydrograph comparing outflow for the current condition and with LID 3 implemented in the LID 3 sub-watershed. Bottom: Water storage of the LID 3 EPIC over time.

6.4 Hydrogeological constraints

Percolation beneath bioswales requires available groundwater capacity (depth to water table) in order to be viable. We briefly considered this as follows. An upper bound for increase in water table elevation (ΔH) given a certain depth of percolated water (I) from a spatially isolated source like a bioswale is given by:

$$\Delta H = \frac{I}{S}$$

where S is the estimated storativity of the regolith (the subsurface, above bedrock). The total water to be percolated beneath a bioswale after an 85th-percentile storm was estimated to be approximately 2 ft of water, based on the residual water depth in the modeled reservoirs after 36 hours since the start of the storm. The storativity of regolith was estimated to be 0.08 based upon Woyshner et al. (2002), which reported the storativity of marine terraces within the Mid- California Coast. This leads to an upper bound for water table increase of 25 ft. The actual value would be smaller, to the extent that percolated water could dissipate laterally away from its source. Thus, the actual expected water table rise might be as low as ten times less than the value predicted by the equation, i.e. 2.5 ft.

The range of depth of auger refusal, an approximation of bedrock depth, was 6.5-45 ft. The average depth of auger refusal for the 15 bore-hole logs 22 ft, which is less than the maximum possible water table rise (25 ft) but greater than the expected water table rise assuming substantial lateral subsurface flow.

Clearly, this comparison is very approximate. But the fact that the values have similar orders of magnitude provides a very general indication that percolation-based mitigation of stormwater runoff could be viable in some parts of POM.

6.5 Limitations

Some limitations of our analysis are summarized as follows:

- The model was not calibrated to observed flow data. We were therefore unable to quantify its accuracy. However, some degree of confidence can be attached to the estimation of *relative* effects, i.e. POM watersheds with LID vs those without LID.

Models that may not necessarily be known to be accurate in an absolute sense can provide valuable insight in a relative sense.

- Some under-estimation of peak flows would have resulted from our use of hydrograph transform parameter values taken from a model calibrated to the Greenwood Park watershed in Pacific Grove by the CSUMB ENVS 660 class of 2013. The Greenwood Park watershed is larger than the POM watersheds, and runoff from larger watersheds has more time for peak flow rates to dissipate.
- We did not model percolation beneath bioswales. This omission would have led to over-estimation of peak flow and total flow.

7 Discussion and Conclusion

We described the regulatory impetus for LID and analyzed the feasibility of LID on POM in four major steps. First, we studied physical characteristics of POM watersheds. Second, we identified LID opportunity sites suggested to us by POM and City of Monterey personnel. Third, we delineated POM watersheds based on the above steps and field verification. Finally, we developed a software model to estimate the effect that LID would have on POM runoff from the 85th percentile storm.

The physical characteristics of POM watersheds can be used to inform LID placement in at least two ways. Firstly, LIDs should be placed in areas that will promote the greatest amount of infiltration. Geology, slope, hydrologic soils, and land are all determinants if infiltration rates. The infiltration potential map can be used at a broad scale to identify potential LID sites. Past and future bore-hole logs can be used to supplement knowledge about sub-surface characteristics in specific locations.

Secondly, treatment LIDs should be placed in locations that match the capacity for the LID to accommodate runoff against the watershed area above the LIDs and the expected runoff volumes from that area. Our model was based on the current delineations of watersheds and sub-watersheds on POM. It would be possible to make substantial alterations to the sizes of the watershed by altering the storm main system infrastructure. Watersheds may be changed in order to balance the sub-watershed area with the capacity of the receiving LID. An analysis on potential changes to the storm main system and resulting watersheds may reveal new effective LID sites and allow for improved modeled LID performance.

While physical characteristics should inform LID placement, the environment can also be engineered to allow flexibility in LID placement and capacity. For example, the capacity of the stormwater catchment LID varies according to the rate at which the water is used for non-potable purposes. Furthermore, the library watershed was modeled to divert all water into the tank. This amount may be adapted to the amount of energy available for pumping water uphill. Further studies are necessary to determine the most cost and energy effective ways to divert water to the tank and the resulting watershed area that would be used to fill the tank.

The pervious pavement LID can also be implemented on widely varying scales. As modeled, every parking lot on the Presidio was given a curve number representing pervious pavement. This is an extremely aggressive scenario, intended to determine the maximum possible runoff prevention. There are a number of site criteria associated with pervious pavement that would temper the extent of this scenario; criteria include depth to water-table, slope, hydrologic soil type, and distance from buildings. These, and factors such as the cost of implementation and maintenance, would need to be taken into consideration prior to installing pervious pavement. Pervious pavement may be most appropriate for new parking lots if sites meet the necessary criteria. There may also be opportunity to install bioswale type infiltration features in parking lots that have been shown to be effective at reducing runoff (Xiao and McPerson 2011).

We were able to model the hydrologic effects of various LIDs and estimate that many of them are promising. This should be viewed as a proof-of-concept exercise, given the limited time frame in which the model was developed. Model accuracy is limited, for example, by lack of runoff measurements for model validation, use of excessively dispersive hydrograph transform parameters, and omission of percolation beneath bioswales.

We also did not model the cumulative behavior of POM hydrology under an entire storm season. We modeled one 24-hour 85th-percentile storm event. There are historically 12 storms each year that are as wet or wetter (ENVS 660 2013, Table 8). Performance of some LIDs may not be assured beyond a certain number of consecutive storms. For example, the EPIC system would likely be able to capture all stormwater runoff from 85th percentile storms throughout the entire year. However, the tank and the bioswales reach capacity after a single 85th percentile storm. Therefore, immediately after an 85th percentile storm, there may not be remaining capacity to hold more runoff. The capacity of the bioswales to reduce runoff during a series of consecutive storms would depend on the rate of infiltration of the captured water.

The regulatory environment is just as important as the physical one with regards to LID implementation, and there are several domains to be aware of. Under the next NPDES permit, LID techniques will be required for certain construction projects and will be based upon the watershed management zone. It is important to know these regulations and plan the appropriate LID technique. Any construction that occurs on POM will also change the land cover and the amount of generated stormwater runoff. The existing model would need to be adjusted to account for these land cover changes and make the most accurate predictions about capturing the 85th percentile storm.

There are also archaeological constraints present throughout POM. Prior to any construction an archaeologist should be consulted to select areas that do not impact cultural resources. A few of the LID sites analyzed within this project, including LID 3 and LID 4, the EPIC system and bioswales respectively, may be in locations of archaeological significance. There are a number of different ways bioswales can be constructed. The type of bioswale selected for any given location should consider physical characteristics that minimize impacts to cultural resources.

Rare plants are another potential regulatory hazard. Four special status plant species can be found on POM (POM 2008). A number of regulations protect these plants, and LID site selection should consider the presence of these plants and minimize disturbance to the maximum extent possible.

In conclusion, upon analyzing the physical characteristics of POM watersheds and modelling the effects of LID on stormwater runoff, we found strong evidence that LID will be an important part of POMs success in meeting its commitment to the environment and the Monterey Peninsula community.

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9. Appendices

Appendix A: Scope of Work

ENVS 660 (Advanced Watershed Science & Policy) class. Module B, 2014. CSUMB

Stormwater characterization for reduction & reuse – Presidio of Monterey

Scope of Work

08-Oct-2014

F. Watson (instructor, CSUMB)
with class mentors: J. Tully (Presidio), A. Baer (City of Monterey), T. Leisten (Presidio)

1. Caveat
   1.1. This Scope of Work is provided as a comprehensive list of all that **might** be achievable by the students in the 5-week time frame allowed. The students may elect to address a **subset** of the SOW. It would be better do a good job with a subset, than an incomplete job with the full SOW.
2. Background
   2.1. The Presidio of Monterey would like to:
      2.1.1. Quantify and reduce stormwater discharge to receiving waters (e.g. Sanctuary, nearby SMCA and ASBS), in the context of stormwater regulations applied by SWRCB.
      2.1.2. Improve quality of stormwater that does go to the bay
      2.1.3. Reduce potable water consumption.
   2.2. Opportunity exists to combine above two goals through stormwater capture, storage, and re-use e.g. for irrigation.
   2.3. Unknowns include:
      2.3.1. Stormwater volume & frequency distribution, both overall and from specific sub-watersheds and land-uses
      2.3.2. Available capacity for detention (slowing down flow, without necessarily reducing volume) and percolation (through infiltration into sub-surface, subject to available capacity).
3. Scope of work
   3.1. Describe problems being addressed
      3.1.1. Describe adverse impacts of stormwater discharge, and describe regulatory environment
      3.1.2. Describe need to reduce use of potable water in relation to state-wide drought, Peninsula-wide constraints (e.g. cease & desist order), total Presidio consumption & dollar cost, etc.
      3.1.3. Describe site constraints, e.g. steep and impervious, with shallow bedrock.
   3.2. Describe the existing storm drain system, including topology, elevation, flow direction etc. (This may include reference to city of Monterey storm drain analysis if available.)
   3.3. Perform watershed delineation, both for major stormwater sub-systems, and for key points of interest (e.g. watershed upstream of specific detention or percolation opportunity sites) (probably based on LIDAR)
   3.4. List sites where opportunity exists for detention/percolation/infiltration/storage/diversion treatments etc. Describe the hydrological/hydraulic characteristics of treatments that could potentially be installed at these sites.

3.4.1. Treatments might include pervious pavement, swales, detention ponds, percolation ponds, diversion and storage systems, sub-surface irrigation (EPIC), raised gravel beds beneath parking lots, sub-surface "capacitance" pipes and bottomless catch-basins in storm drain system, etc,

3.4.2. Hydrologic/hydraulic characteristics would include maximum acceptable rates of inflow/percolation, total storage, residence time, etc.

3.4.3. List constraints:

3.4.3.1. Describe geological constraints by creating map and cross-section of depth to bedrock and depth to groundwater, based on existing geological map/s and bore-hole logs

3.4.3.2. Summarize archaeological constraints

3.5. Tabulate areas of specific land uses and land cover types by sub-watershed. Land cover type should be broken down to the level of types like parking lots, pervious pavement, sidewalks, lawns, rooftops, etc.

3.6. Estimate stormwater volume & frequency distribution using HEC-HMS watershed modeling approach, both overall and from specific sub-watersheds and land-uses

3.7. Estimate capacity for reduction of stormwater generation by changing land cover characteristics (i.e. before entering the stormwater system)

3.8. Estimate available capacity for detention and/or percolation (infiltration & storage) (i.e. after entering the stormwater system, perhaps temporarily) at selected opportunity sites

3.9. Estimate utility of treatments (see 2.3 above) given frequency distribution of stormwater

3.10. Present graphical comparison of current & treated stormwater volumes & frequency distribution

4. References

4.1. PG stormwater diversion project – See EIR and associated docs from Fall Creek Engineering etc.

4.2. Pristel – recent CSUMB MS thesis on stormwater management/policy

4.3. CCRWQCB web site – various docs that clarify the regulatory environment

4.4. Past ENVS 660 reports on PG stormwater – include quantification of water balance, use of HEC-HMS watershed model, calibrated against actual streamflow data

4.5. Scopes of work relating to collaboration between Presidio and City of Monterey in relation to stormwater management

4.6. Presidio's Non-Potable Water Concept Plan

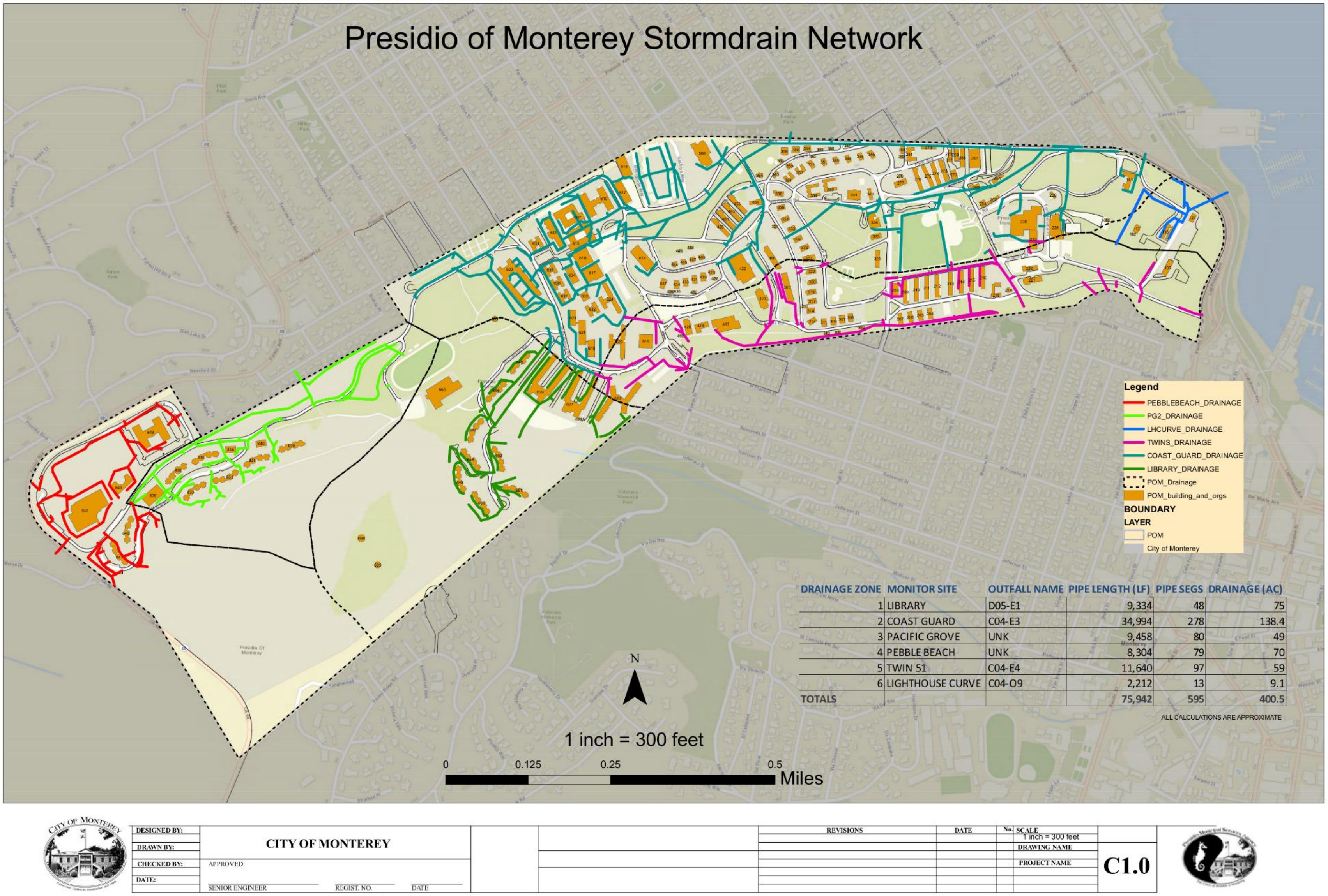
4.7. Reports on Peninsula stormwater quality impacts, e.g. First Flush reports

4.8. Geological map

4.9. Bore-hole logs provided by City

4.10. GIS data sets & PDF maps provided by Presidio & City

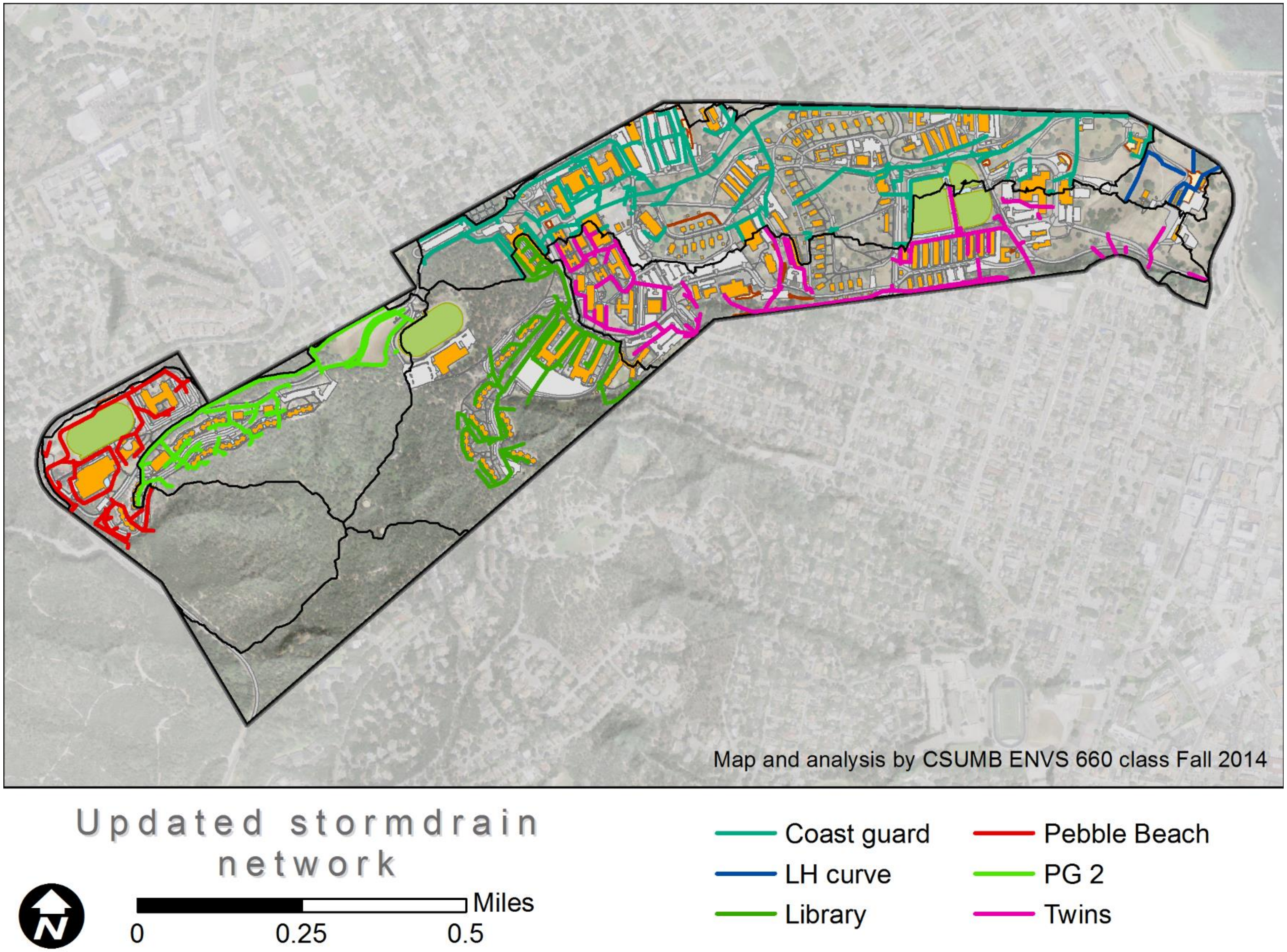
Appendix B: Existing Stormwater Drain Map from Presidio of Monterey



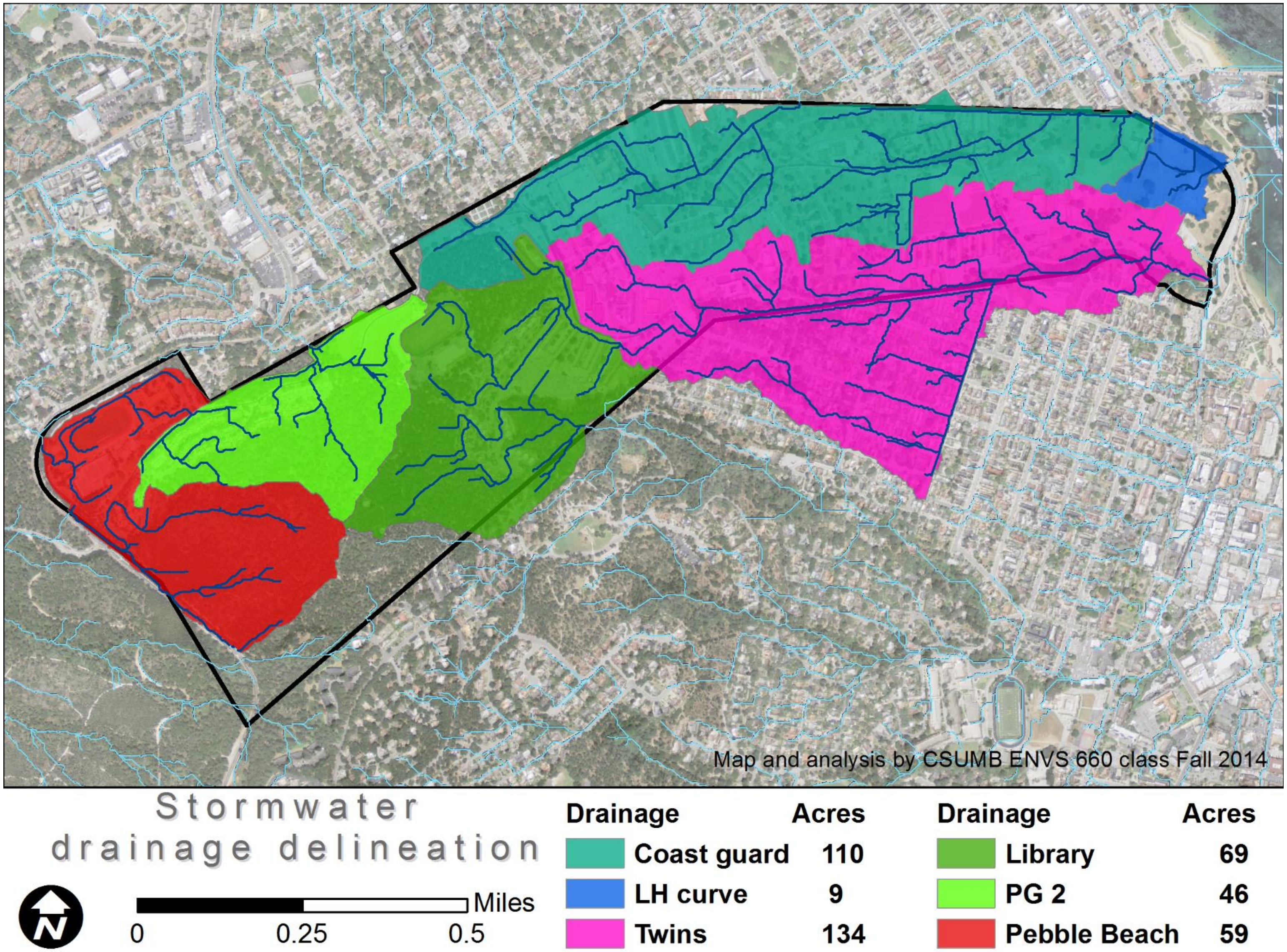
DRAINAGE ZONE	MONITOR SITE	OUTFALL NAME	PIPE LENGTH (LF)	PIPE SEGS	DRAINAGE (AC)
1	LIBRARY	D05-E1	9,334	48	75
2	COAST GUARD	C04-E3	34,994	278	138.4
3	PACIFIC GROVE	UNK	9,458	80	49
4	PEBBLE BEACH	UNK	8,304	79	70
5	TWIN 51	C04-E4	11,640	97	59
6	LIGHTHOUSE CURVE	C04-O9	2,212	13	9.1
TOTALS			75,942	595	400.5

ALL CALCULATIONS ARE APPROXIMATE

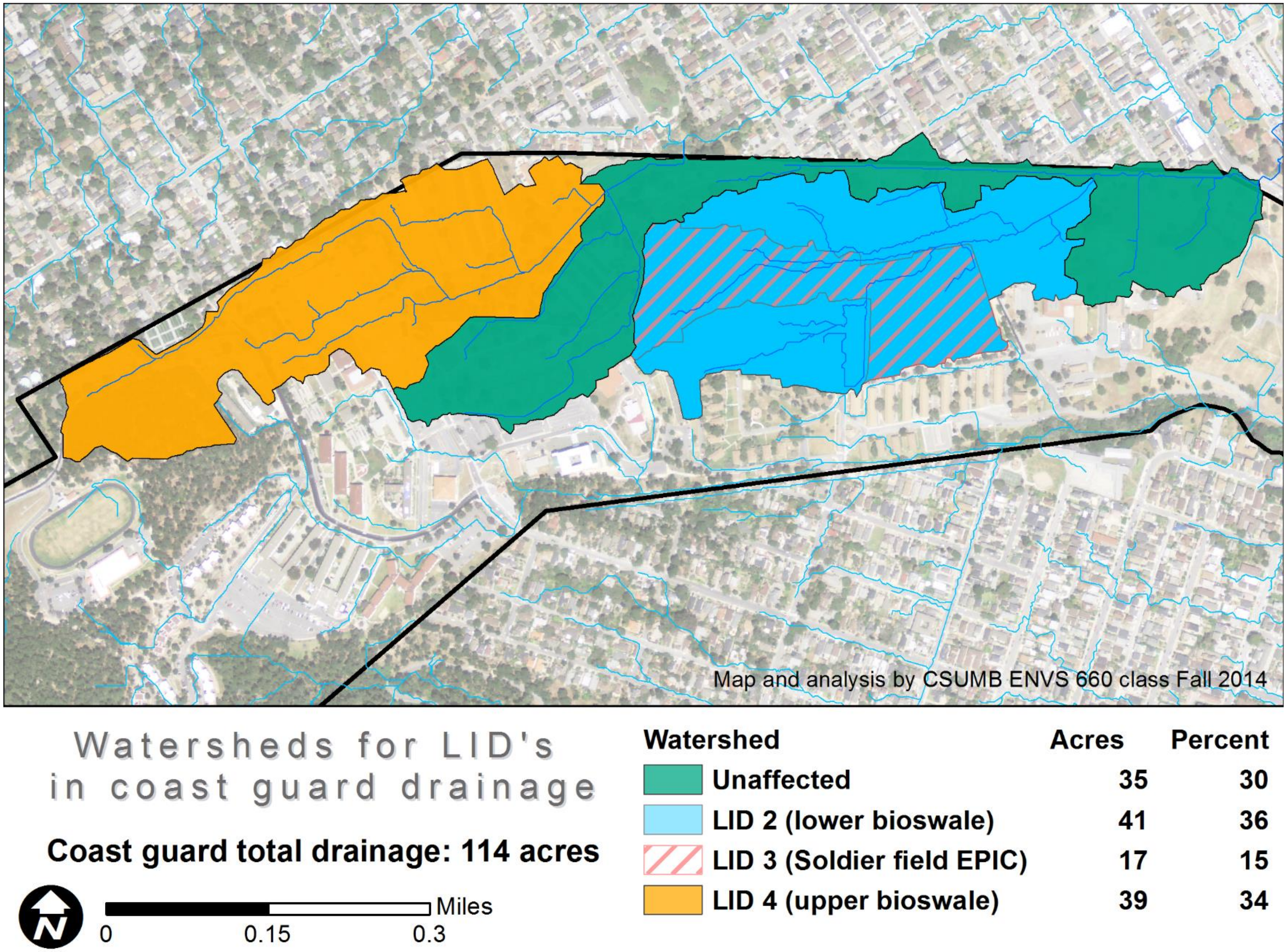
Appendix C: Updated Storm drain Network for POM



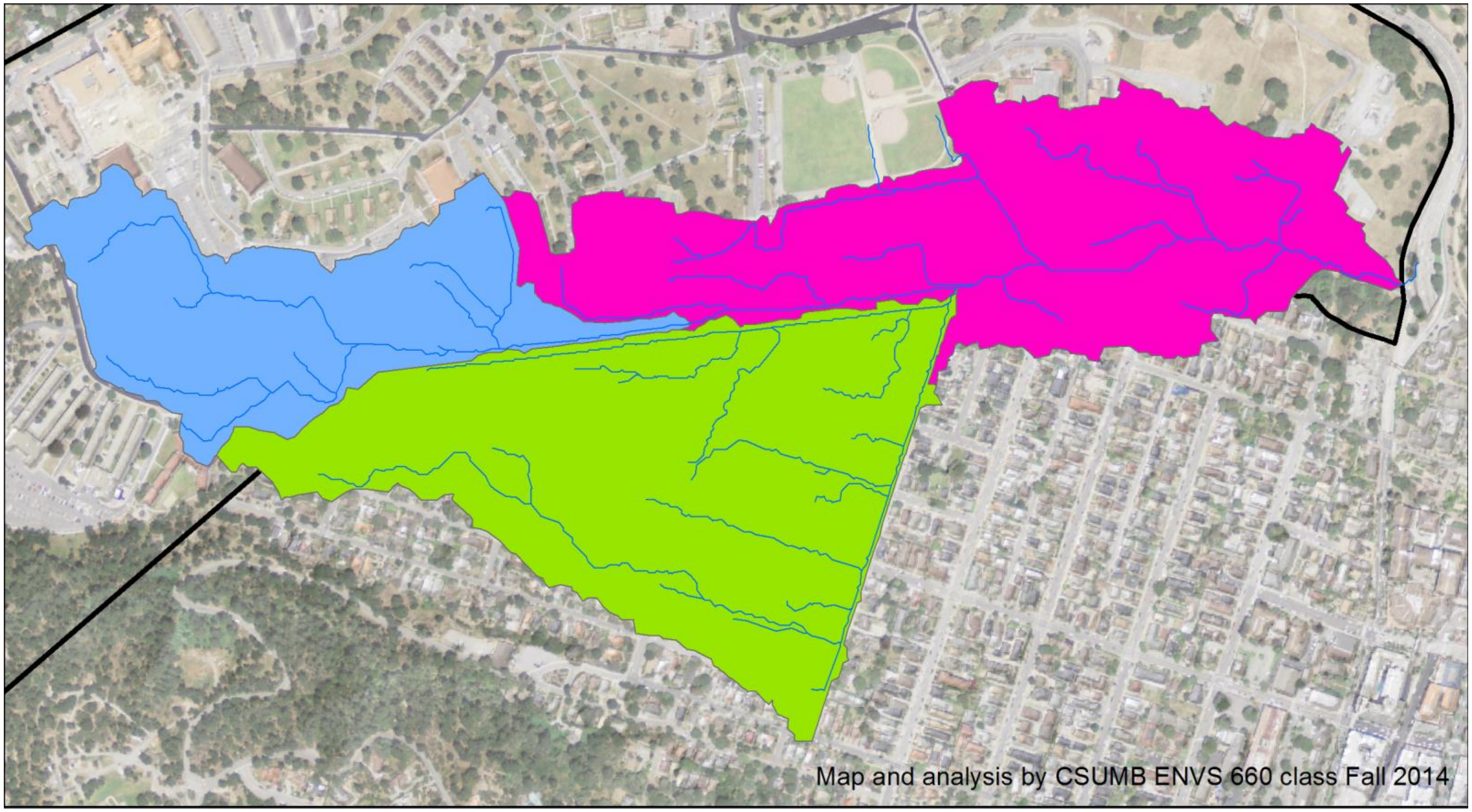
Appendix D: Stormwater Delineation for POM



Appendix E: Sub-Watershed Delineations



Watershed	Acres	Percent
Unaffected	35	30
LID 2 (lower bioswale)	41	36
LID 3 (Soldier field EPIC)	17	15
LID 4 (upper bioswale)	39	34



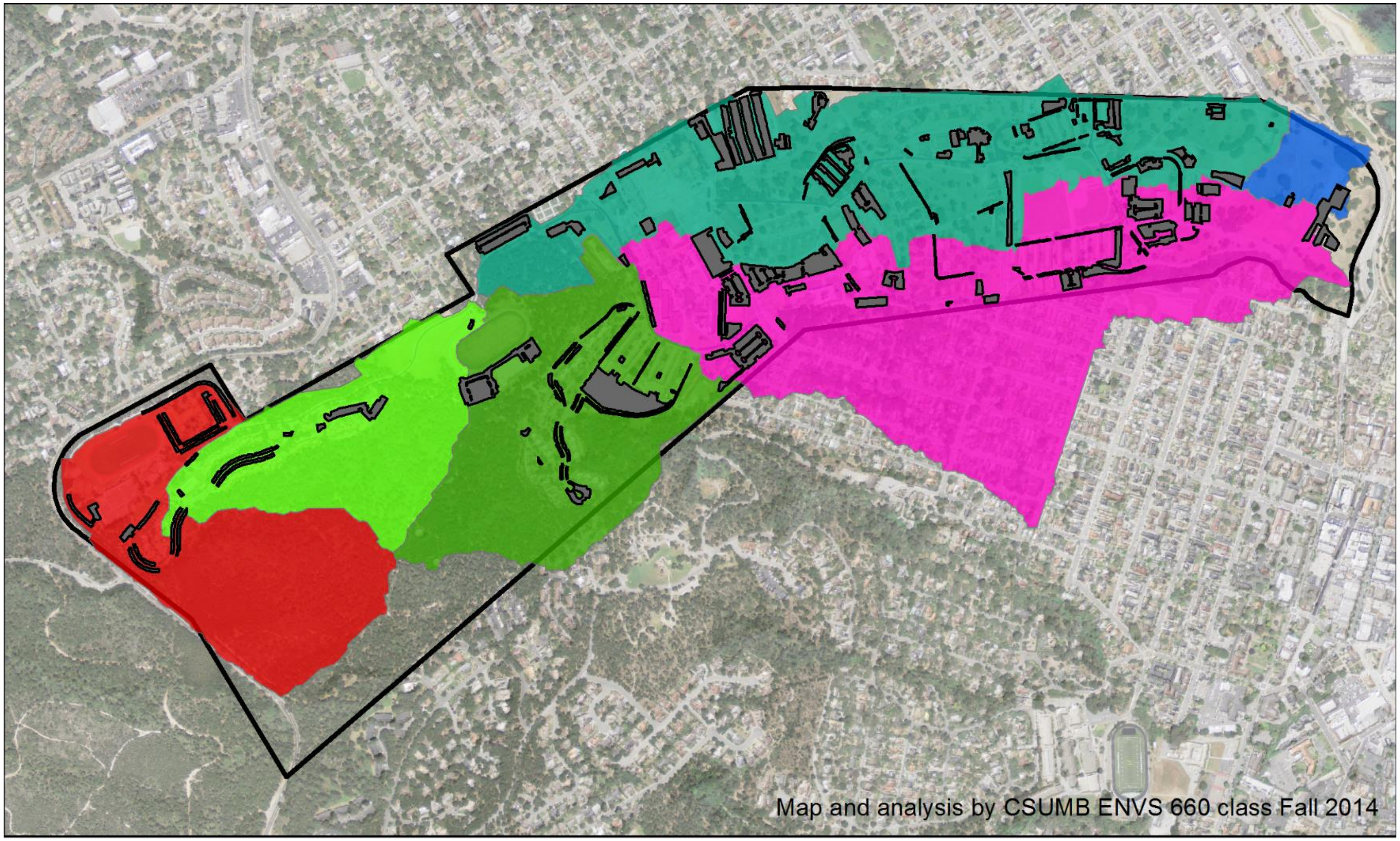
Watersheds for LID's in Twins drainage

Twins total drainage: 129 acres

0 0.15 0.3 Miles

Watershed	Acres	Percent
Unaffected (Monterey)	53	41
Unaffected (Presidio)	48	37
LID 5 (bioswale)	28	22

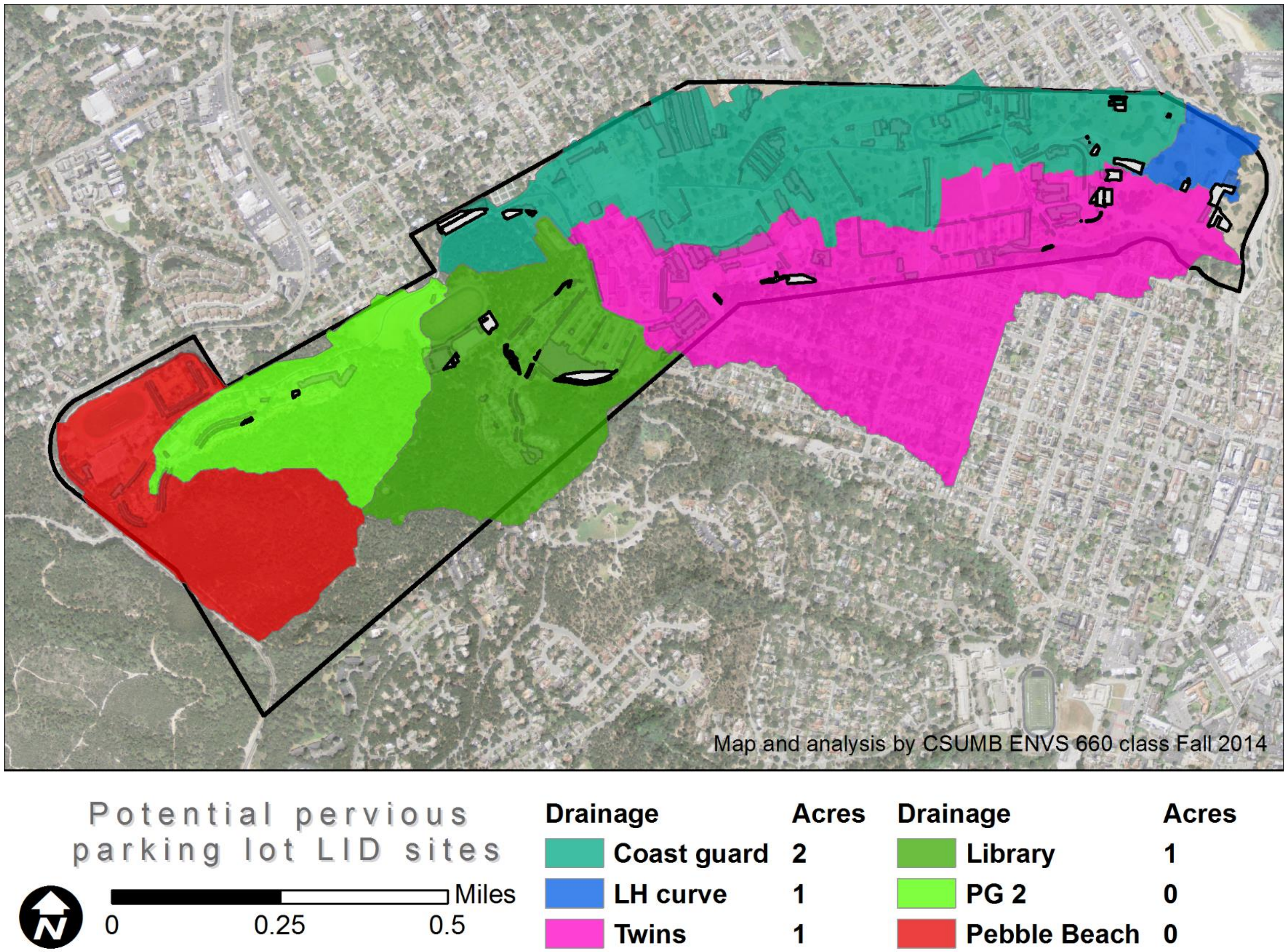
Appendix F: Parking Lots on POM



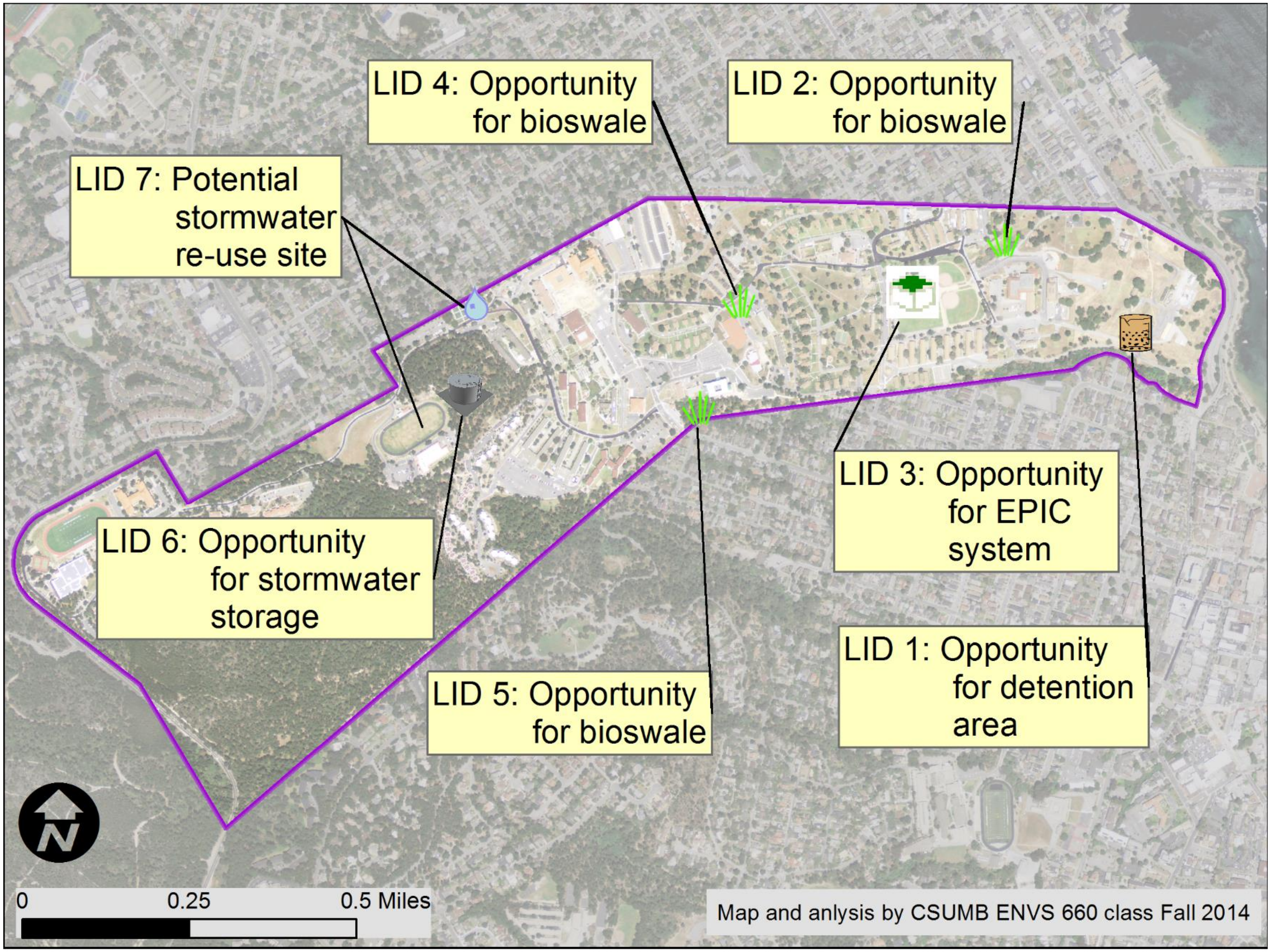
Parking lot area by watershed

0 0.25 0.5 Miles

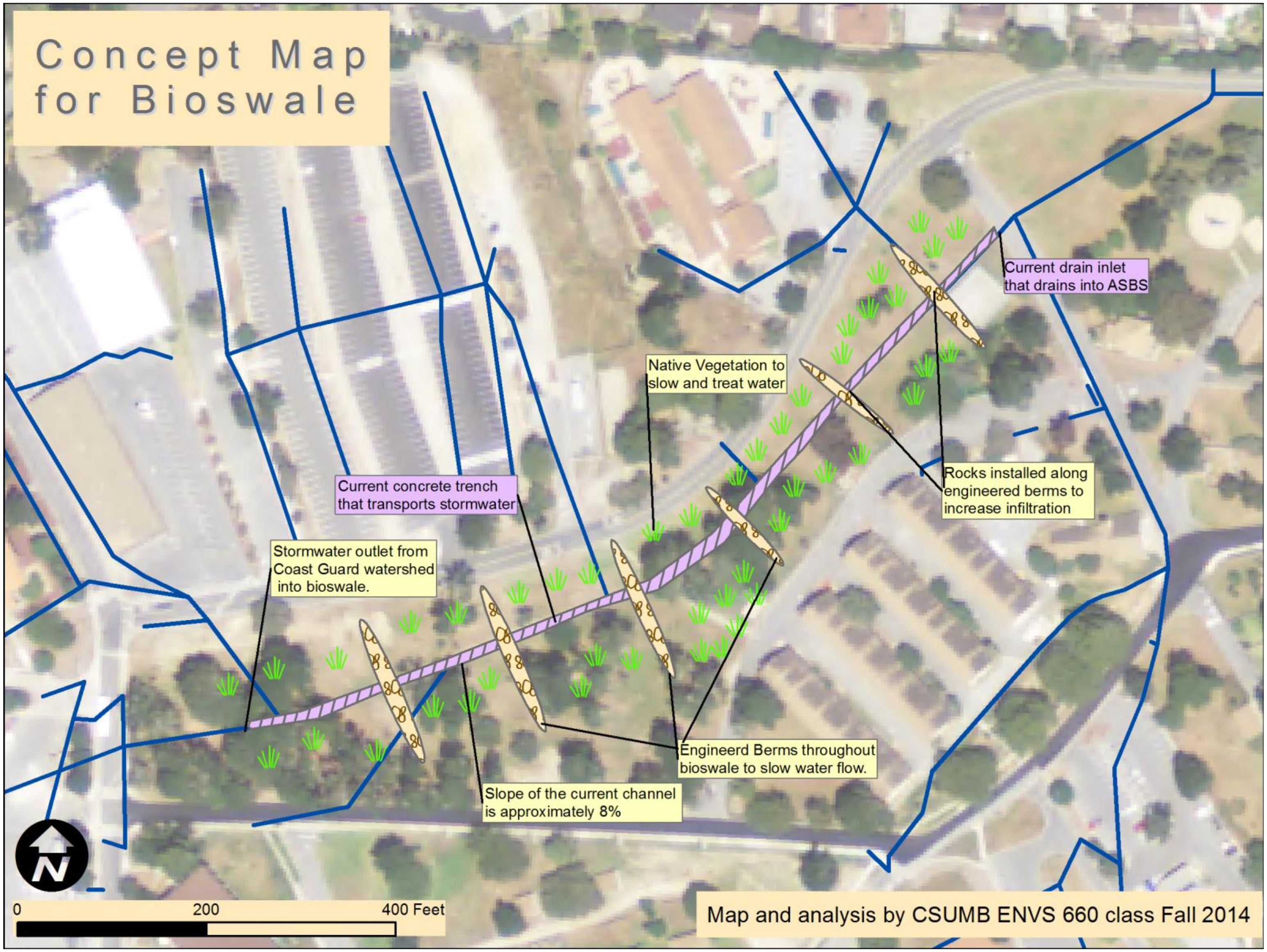
Drainage	Area	Drainage	Area
Coast guard	13	Library	6
LH curve	1	PG 2	2
Twins	10	Pebble Beach	3

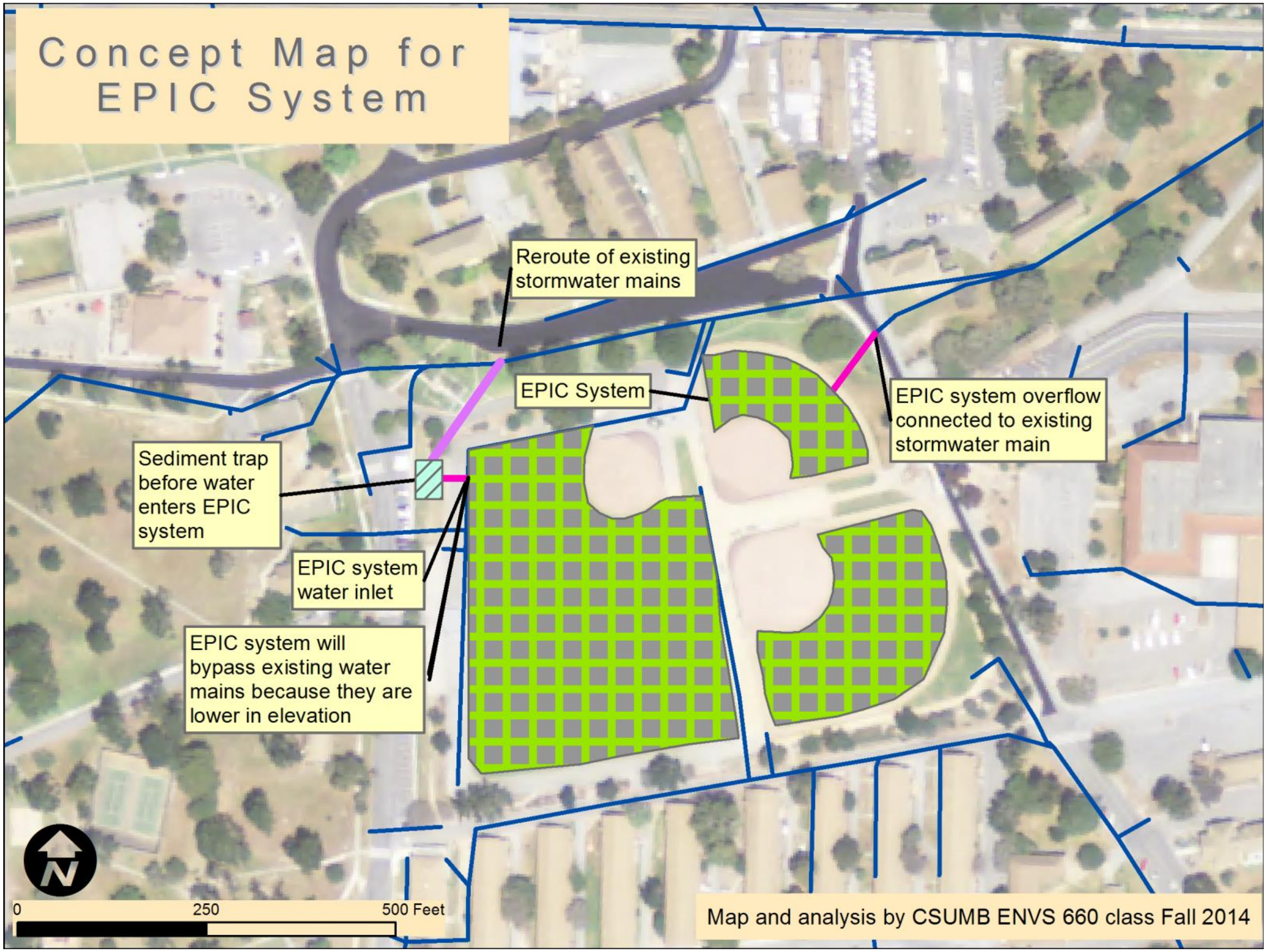

Map and analysis by CSUMB ENVS 660 class Fall 2014
Potential pervious parking lot LID sites
Miles
0
0.25
0.5
N
Drainage
Acres
Coast guard 2
LH curve 1
Twins 1
Drainage
Acres
Library 1
PG 2 0
Pebble Beach 0

Appendix G: Potential LID Sites and Techniques

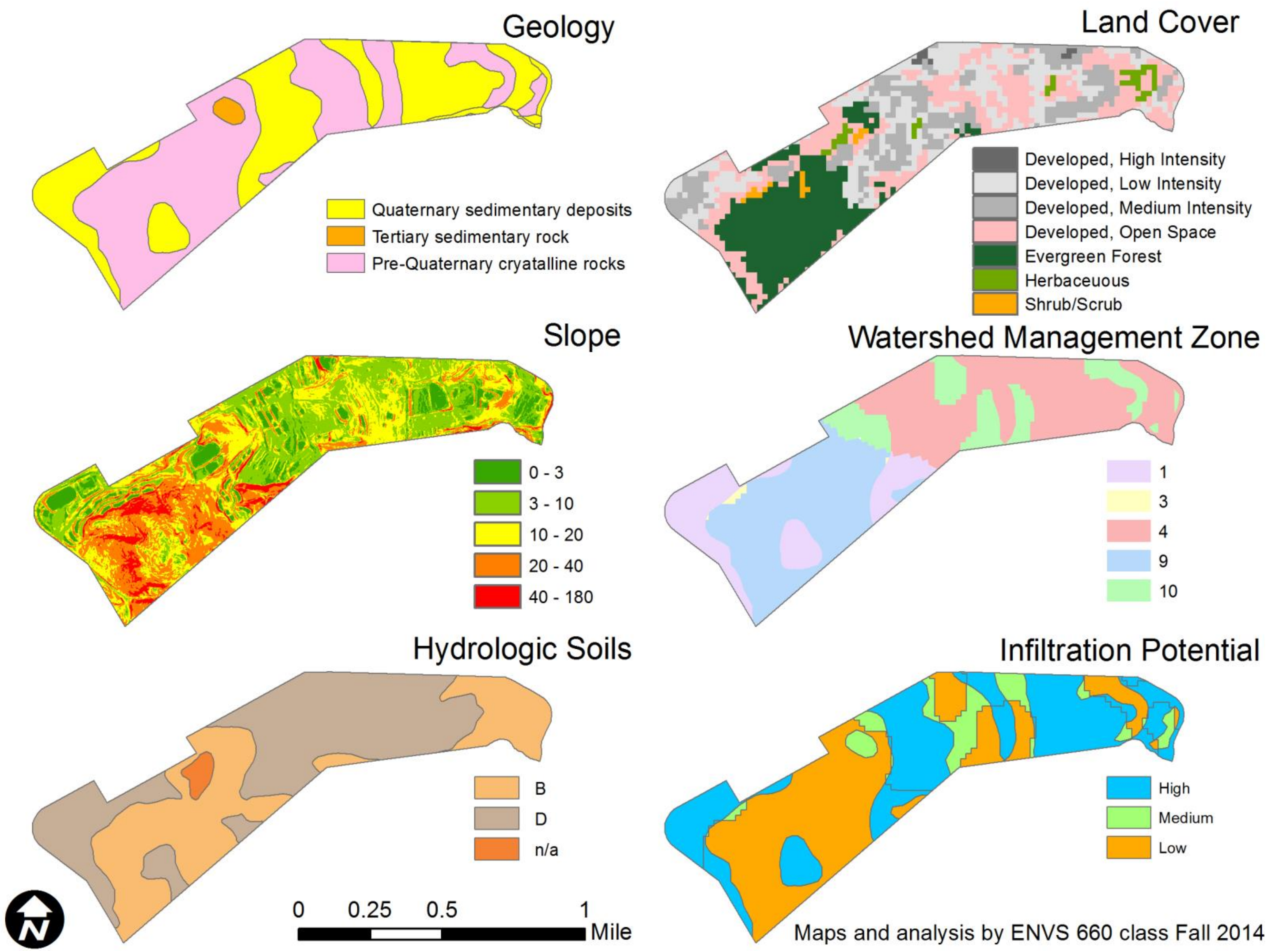


Appendix H: Concept Maps for Potential LID Sites

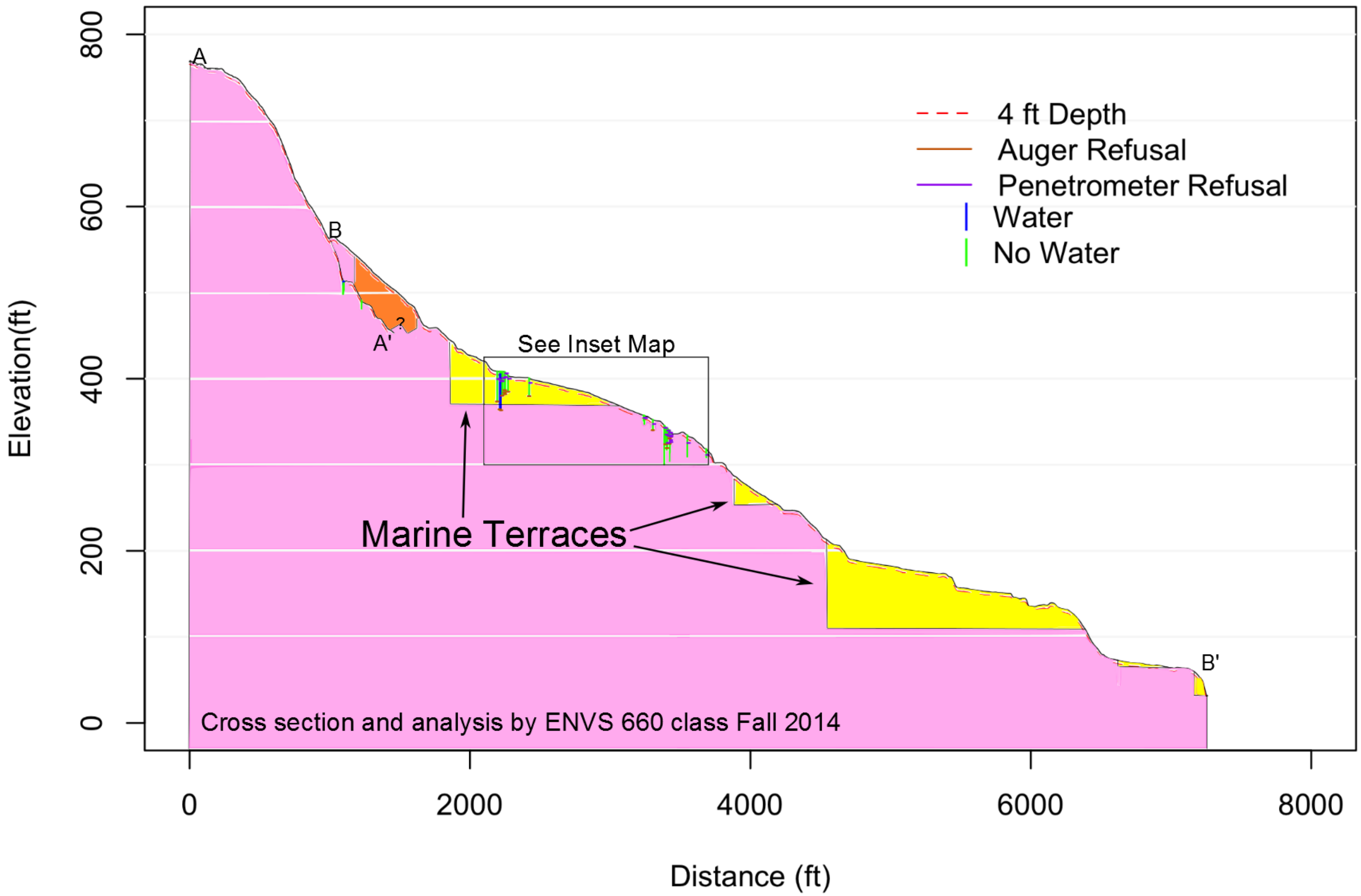


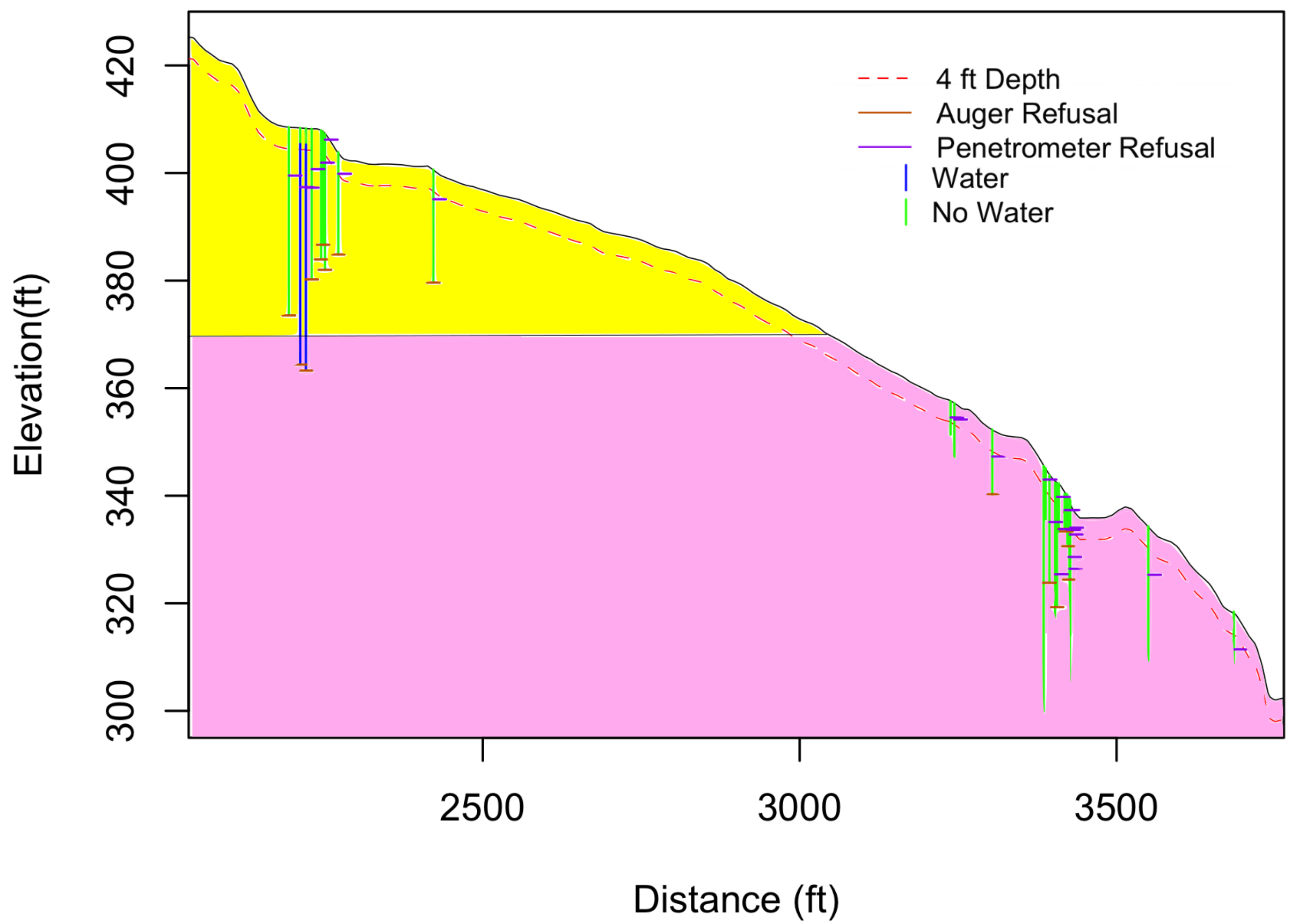

Concept Map for EPIC System
Reroute of existing stormwater mains
EPIC System
EPIC system overflow connected to existing stormwater main
Sediment trap before water enters EPIC system
EPIC system water inlet
EPIC system will bypass existing water mains because they are lower in elevation
0
250
500 Feet
Map and analysis by CSUMB ENVS 660 class Fall 2014

Appendix I: Physical Characteristics of POM



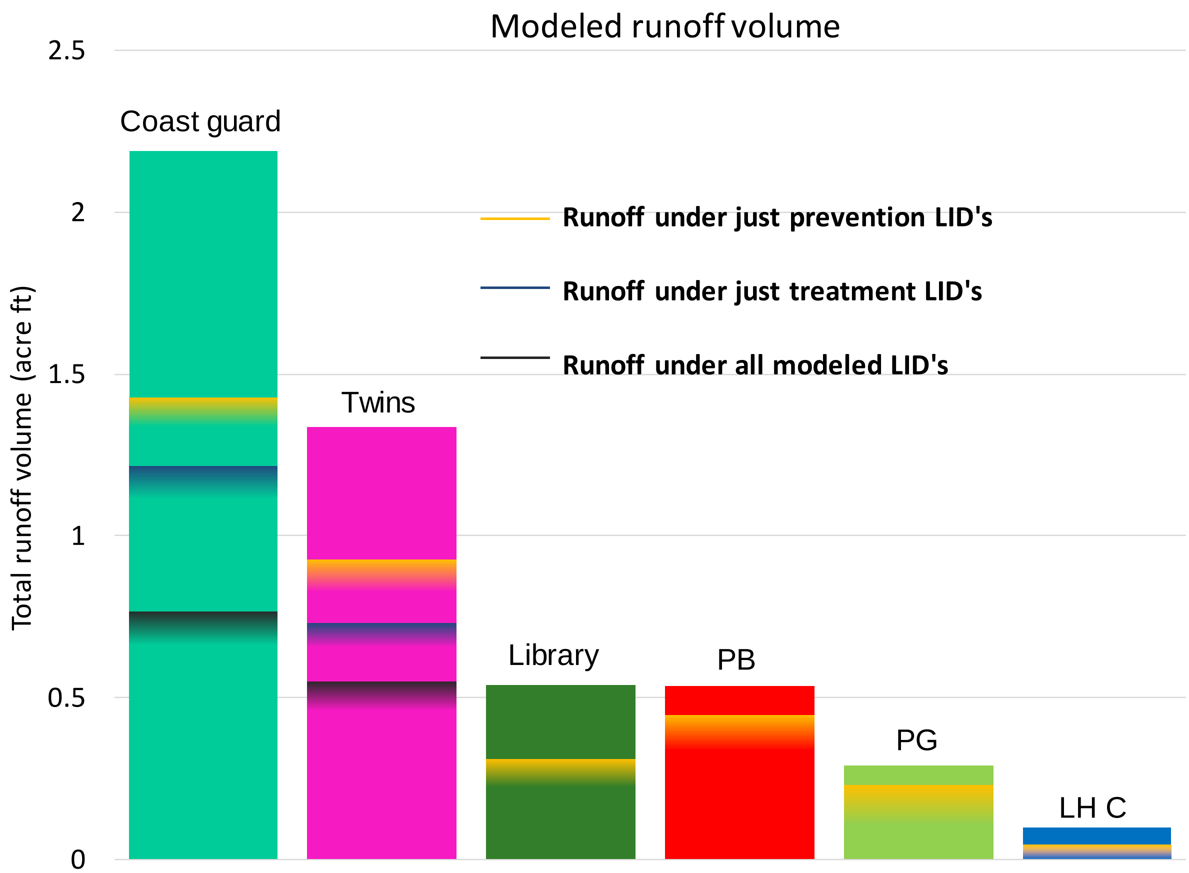
Appendix J: Geologic Cross Sections on POM

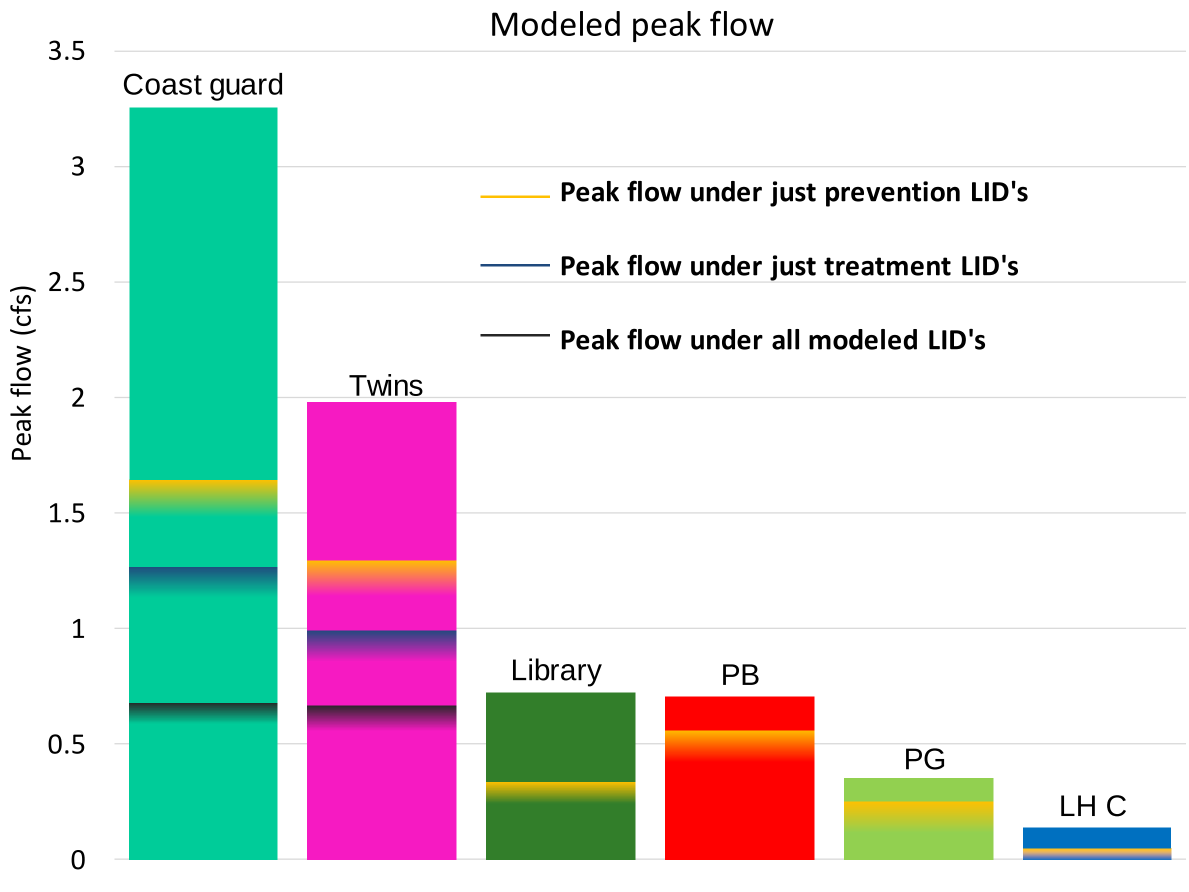




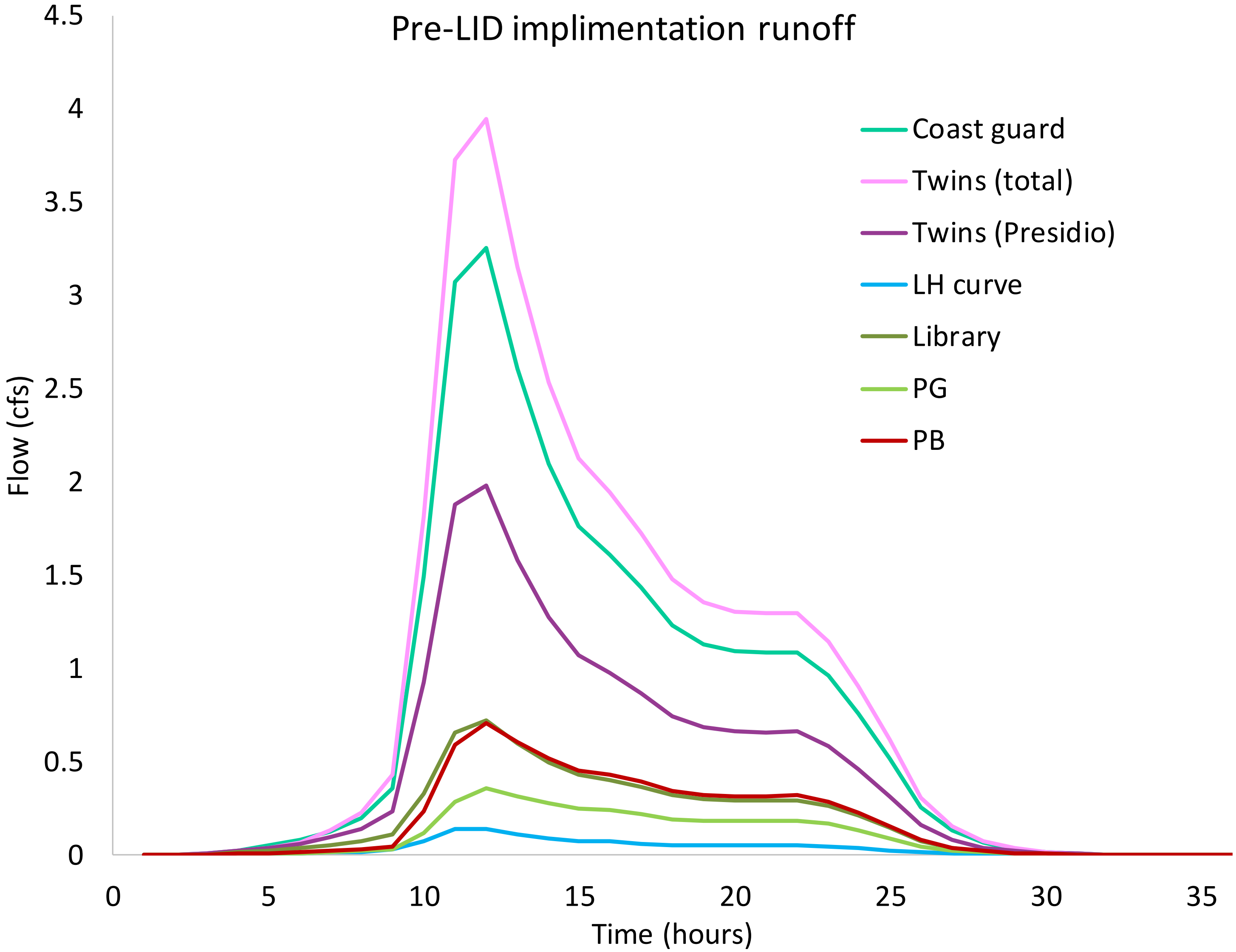
4 ft Depth
Auger Refusal
Penetrometer Refusal
Water
No Water
Elevation(ft)
420
400
380
360
340
320
300
2500
3000
3500
Distance (ft)

Appendix K: Modeled Results

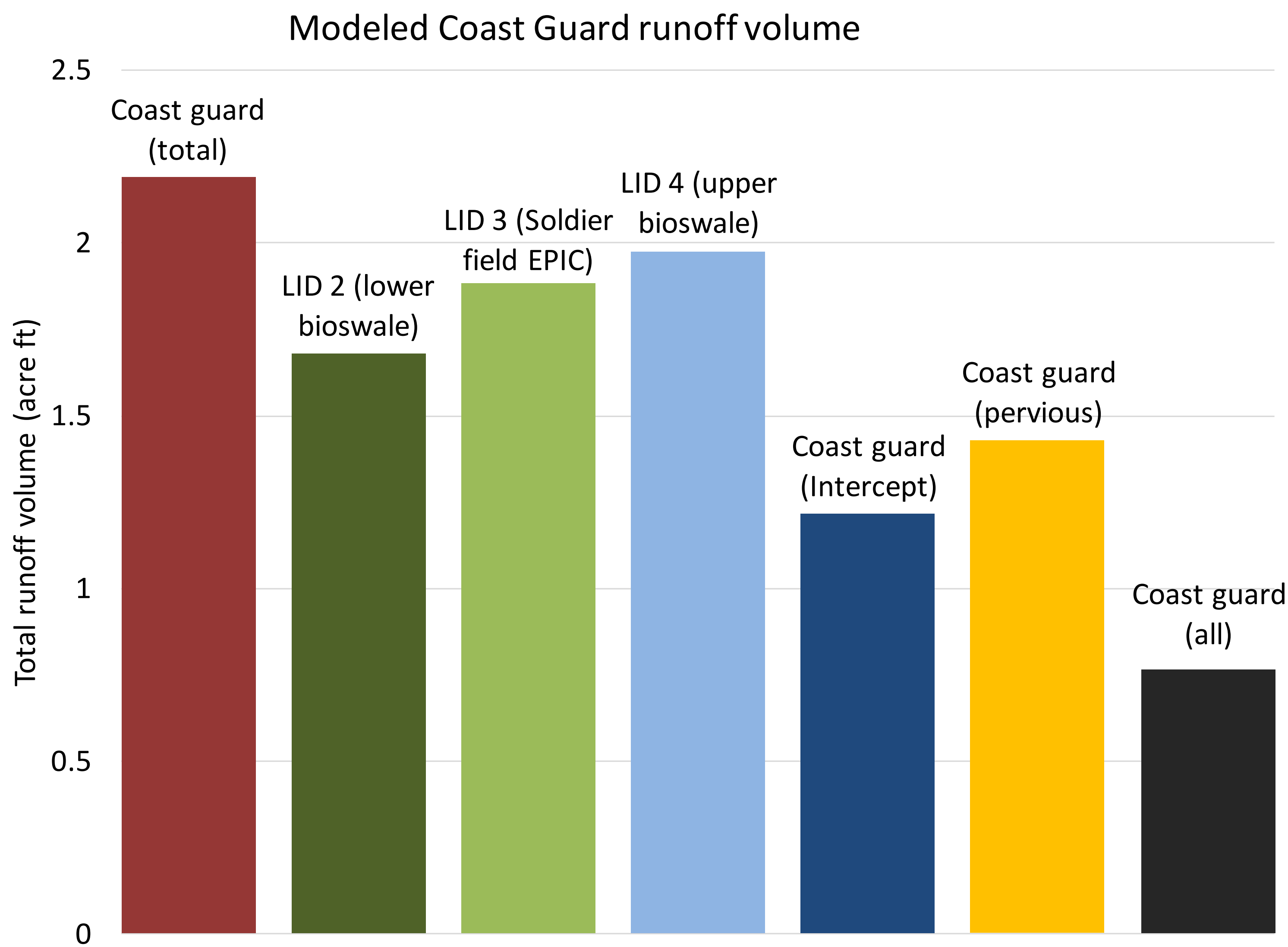


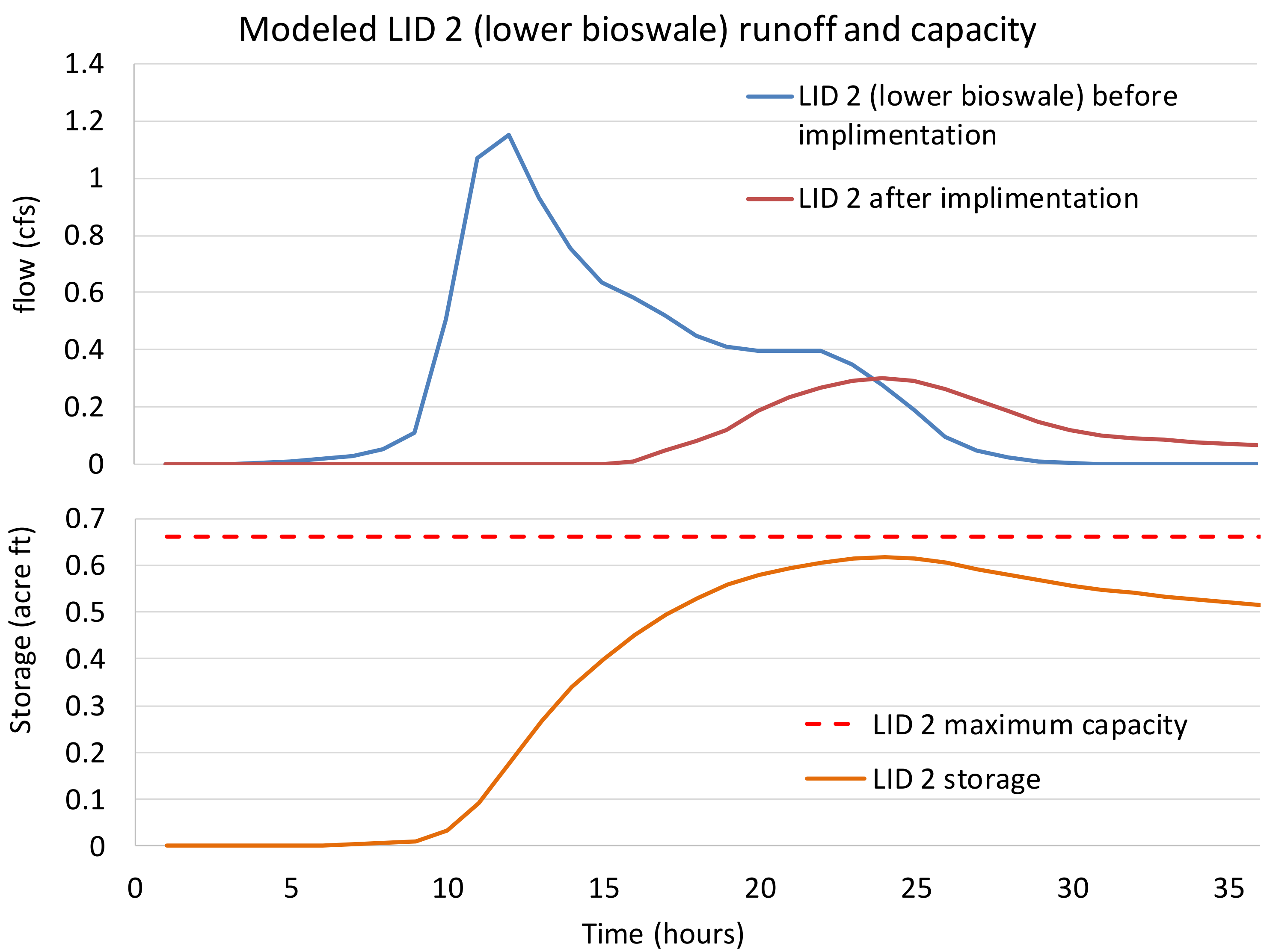


Modeled peak flow
Peak flow (cfs)
3.5
3
2.5
2
1.5
1
0.5
0
Coast guard
Twins
Library
PB
PG
LH C
Peak flow under just prevention LID's
Peak flow under just treatment LID's
Peak flow under all modeled LID's

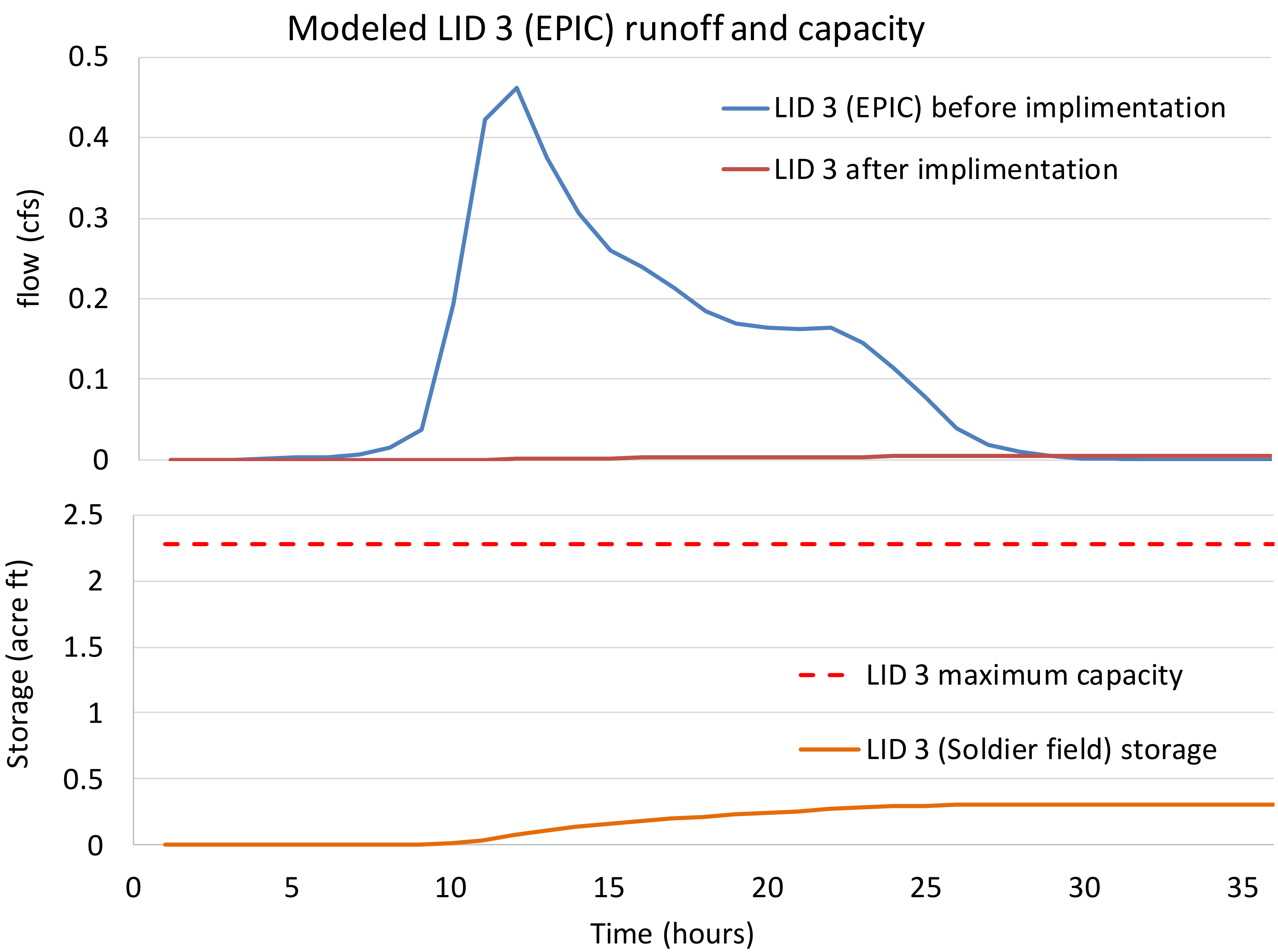


Pre-LID implimentation runoff
Flow (cfs)
Time (hours)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
30
35
Coast guard
Twins (total)
Twins (Presidio)
LH curve
Library
PG
PB

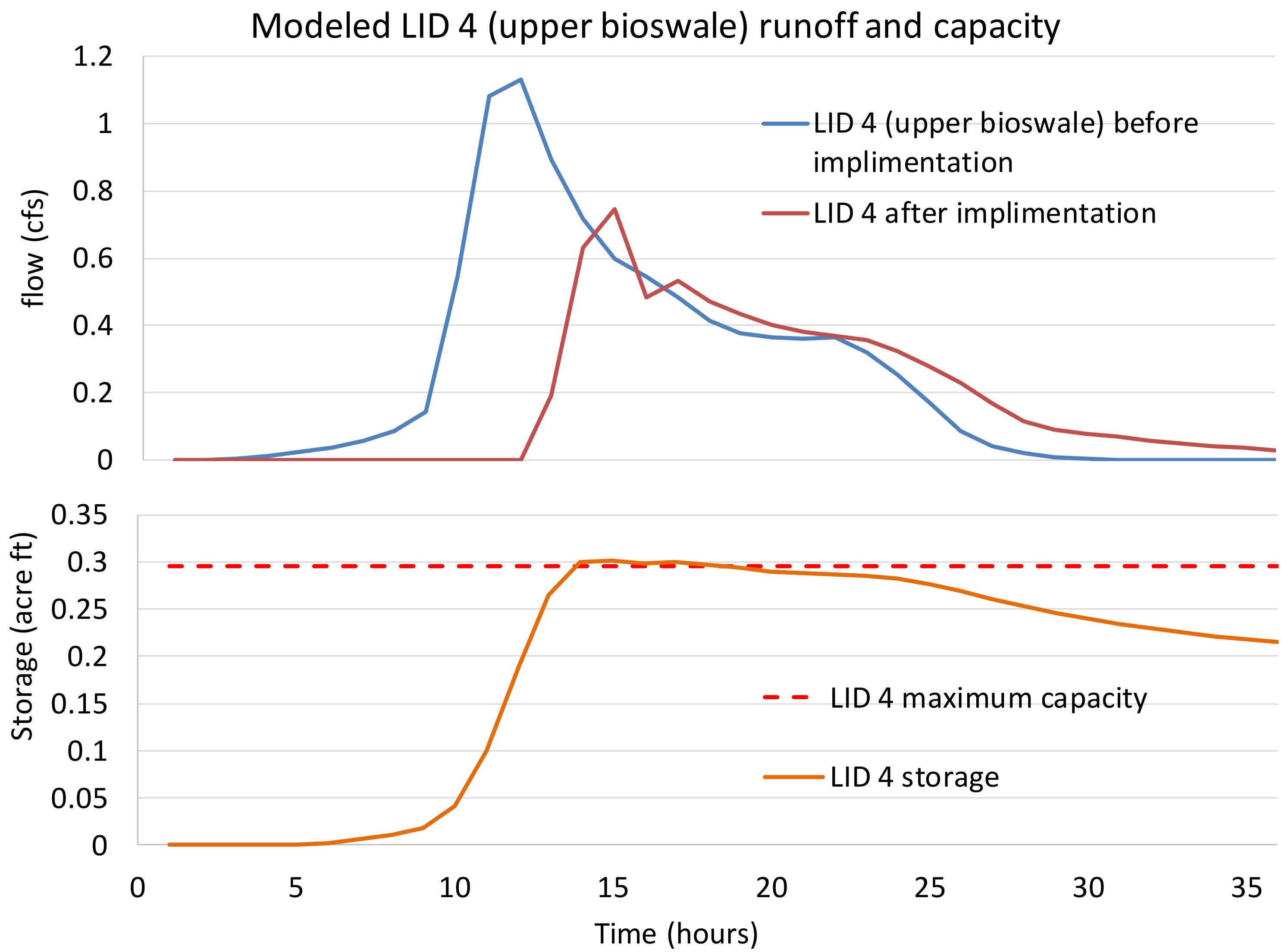

Modeled Coast Guard runoff volume
Total runoff volume (acre ft)
2.5
2
1.5
1
0.5
0
Coast guard (total)
LID 2 (lower bioswale)
LID 3 (Soldier field EPIC)
LID 4 (upper bioswale)
Coast guard (Intercept)
Coast guard (pervious)
Coast guard (all)

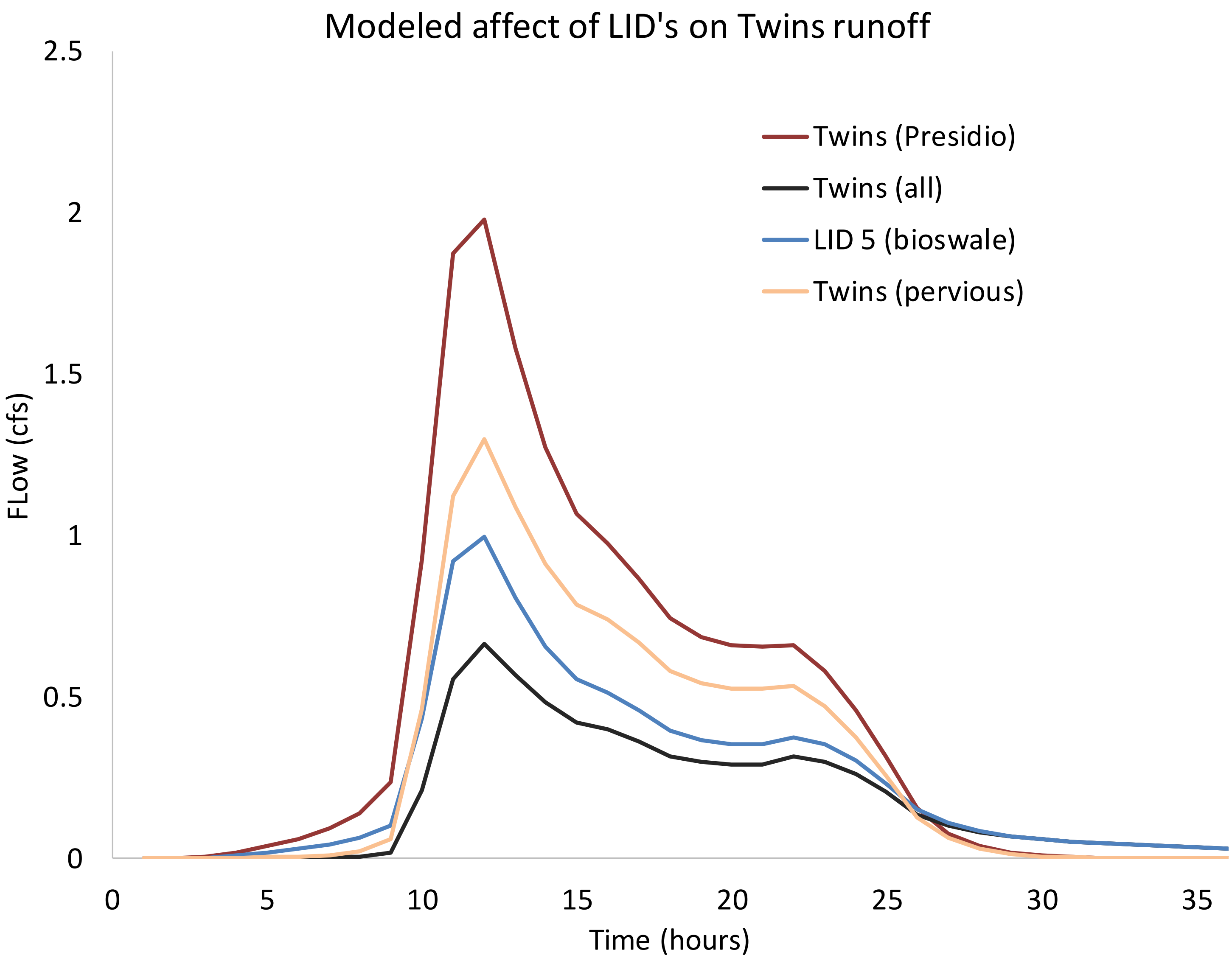


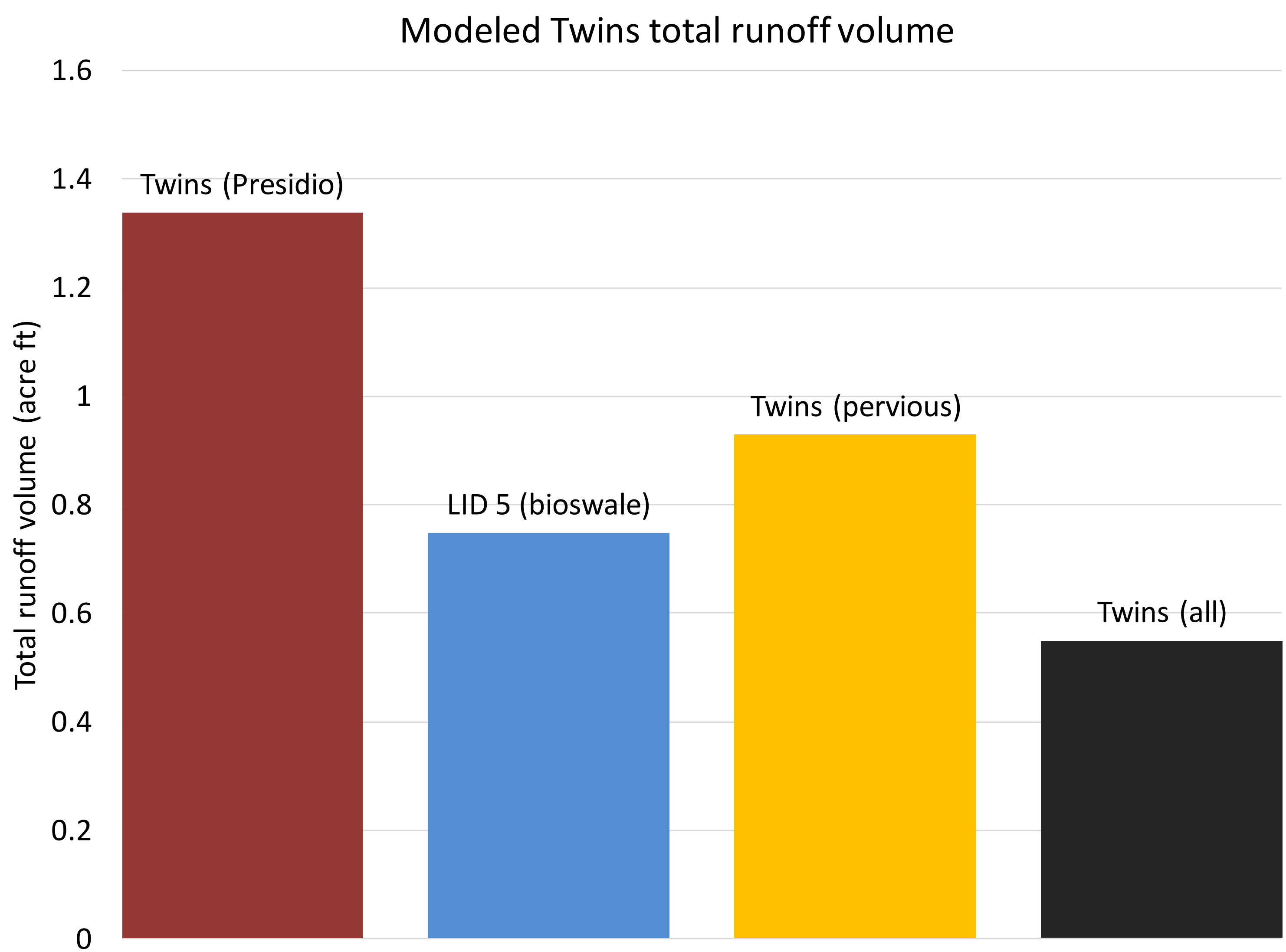
Modeled LID 2 (lower bioswale) runoff and capacity
1.4
1.2
1
0.8
0.6
0.4
0.2
0
flow (cfs)
LID 2 (lower bioswale) before implimentation
LID 2 after implimentation
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Storage (acre ft)
LID 2 maximum capacity
LID 2 storage
0
5
10
15
20
25
30
35
Time (hours)

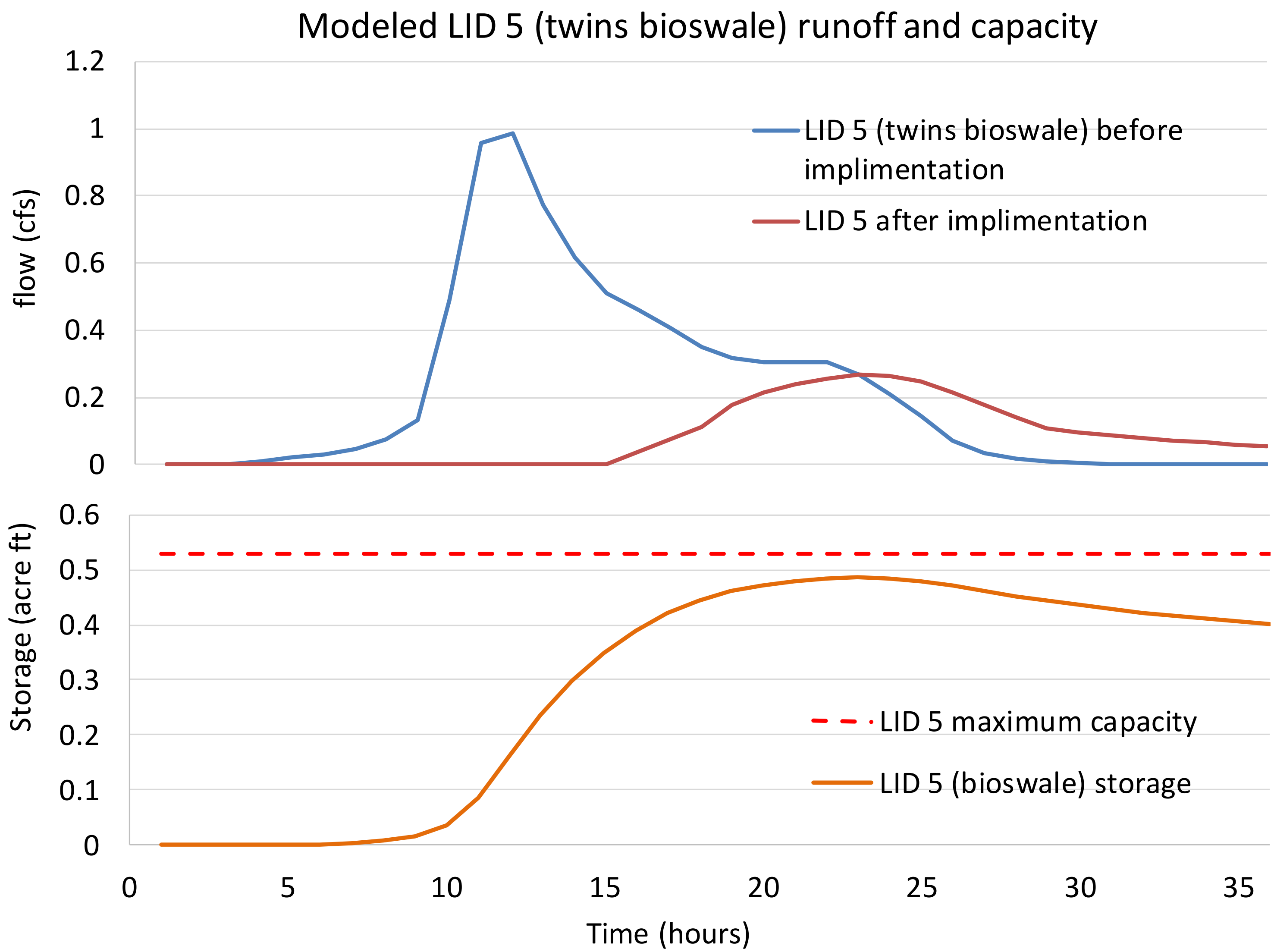


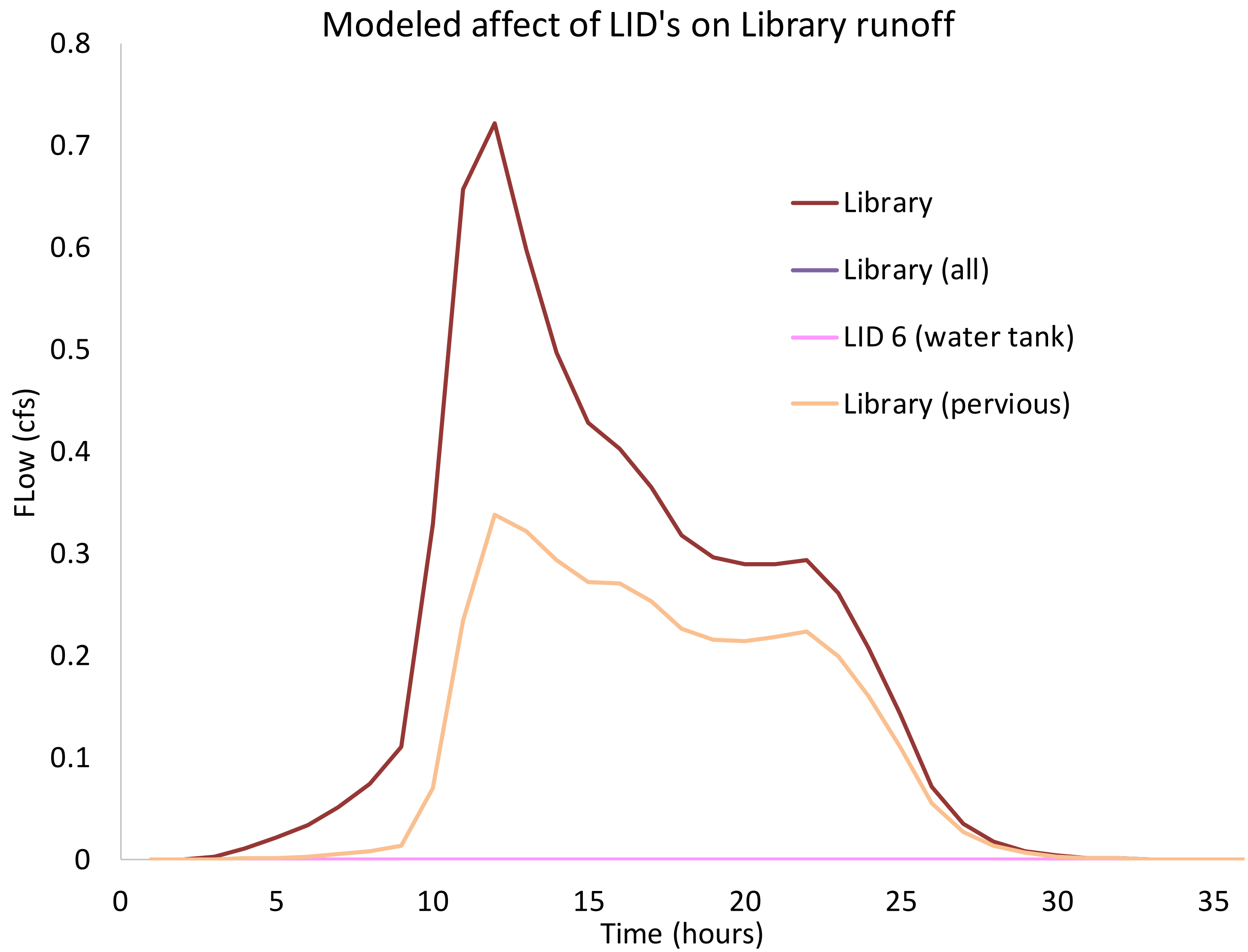
Modeled LID 3 (EPIC) runoff and capacity
LID 3 (EPIC) before implimentation
LID 3 after implimentation
flow (cfs)
0.5
0.4
0.3
0.2
0.1
0
2.5
2
1.5
1
0.5
0
Storage (acre ft)
LID 3 maximum capacity
LID 3 (Soldier field) storage
0
5
10
15
20
25
30
35
Time (hours)

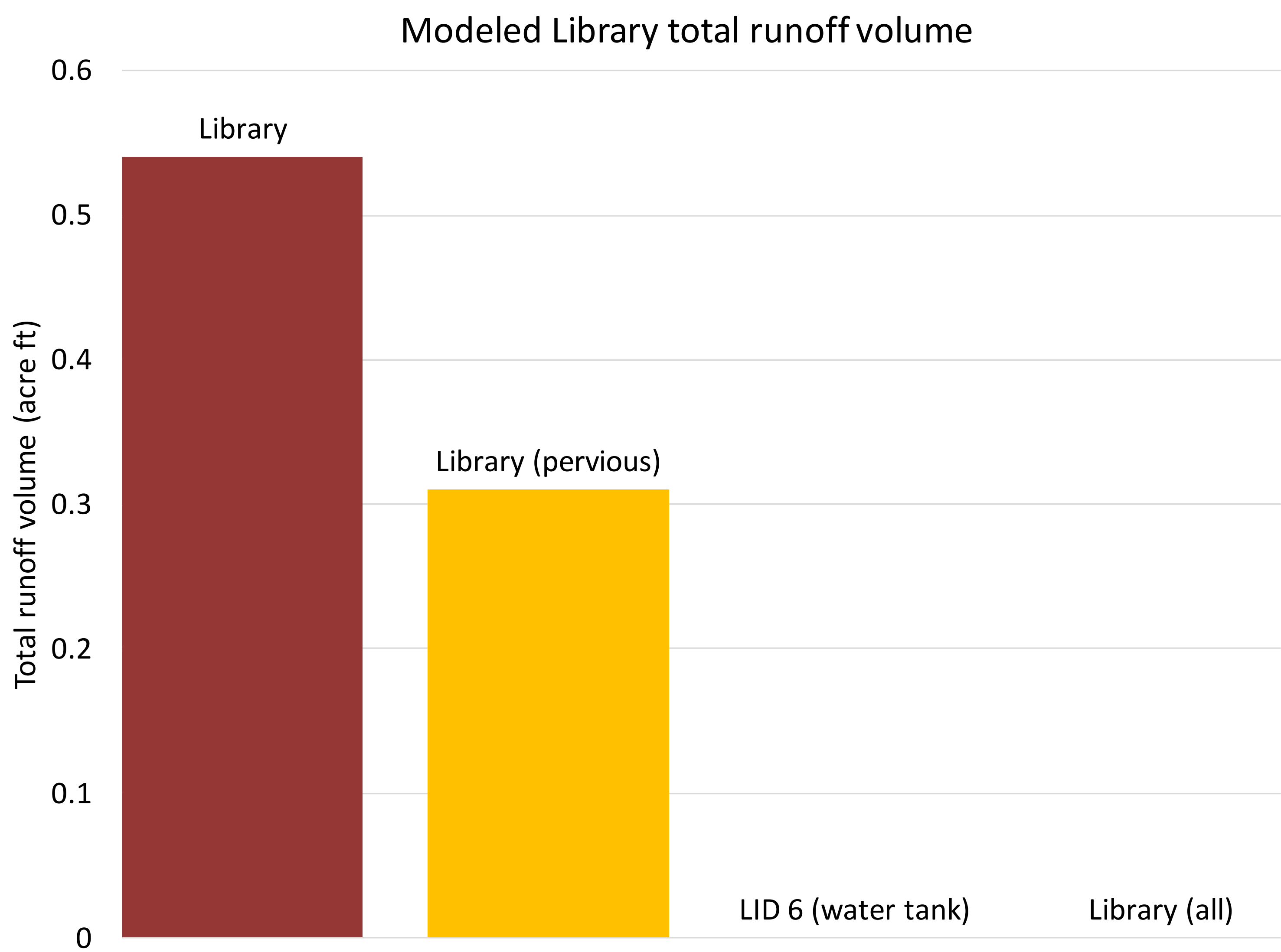

Modeled LID 4 (upper bioswale) runoff and capacity
1.2
1
0.8
0.6
0.4
0.2
0
flow (cfs)
LID 4 (upper bioswale) before implimentation
LID 4 after implimentation
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Storage (acre ft)
LID 4 maximum capacity
LID 4 storage
0
5
10
15
20
25
30
35
Time (hours)

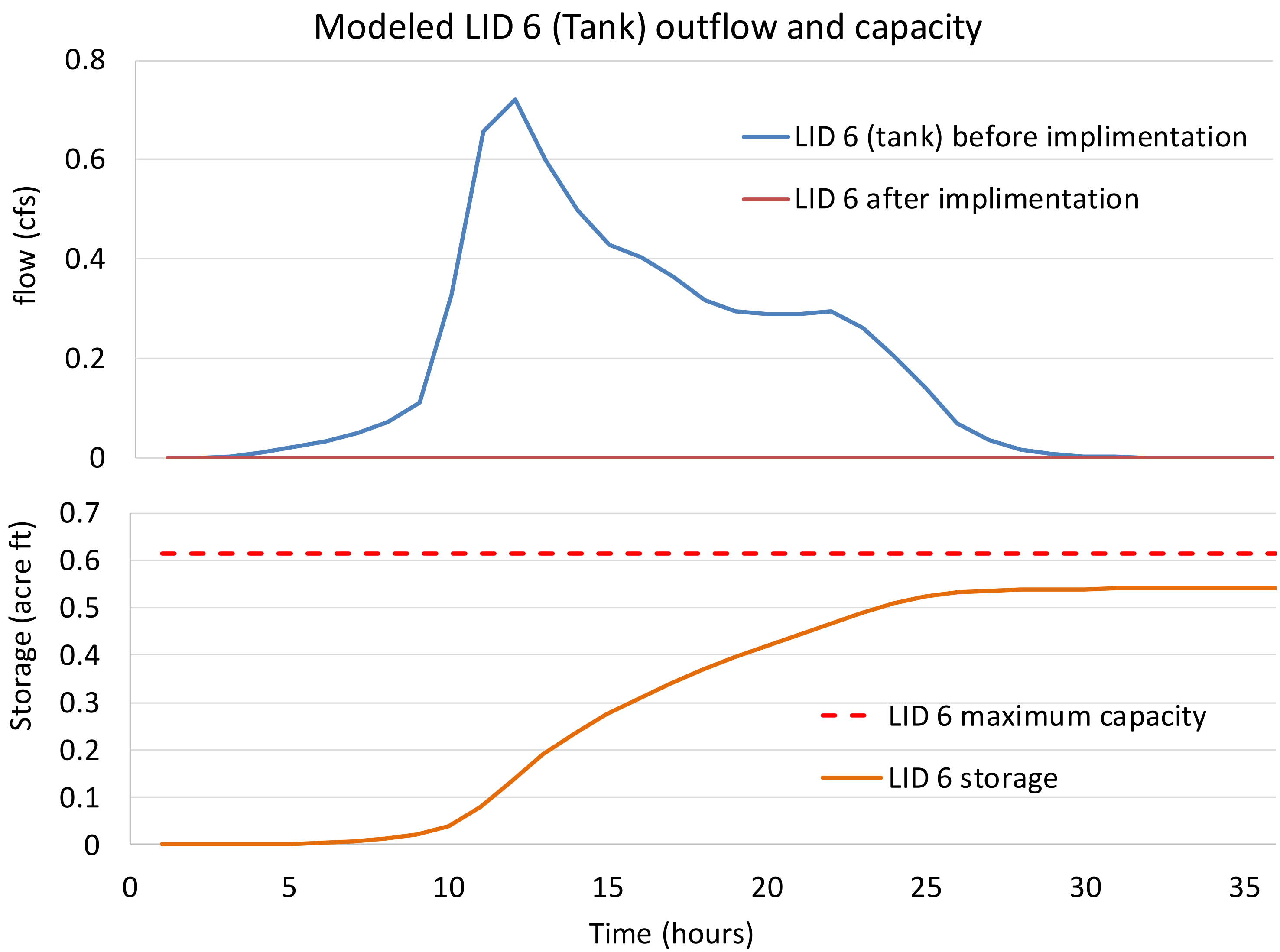

Modeled affect of LID's on Twins runoff
FLow (cfs)
Time (hours)
Twins (Presidio)
Twins (all)
LID 5 (bioswale)
Twins (pervious)
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
30
35


Modeled Twins total runoff volume
Total runoff volume (acre ft)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Twins (Presidio)
LID 5 (bioswale)
Twins (pervious)
Twins (all)

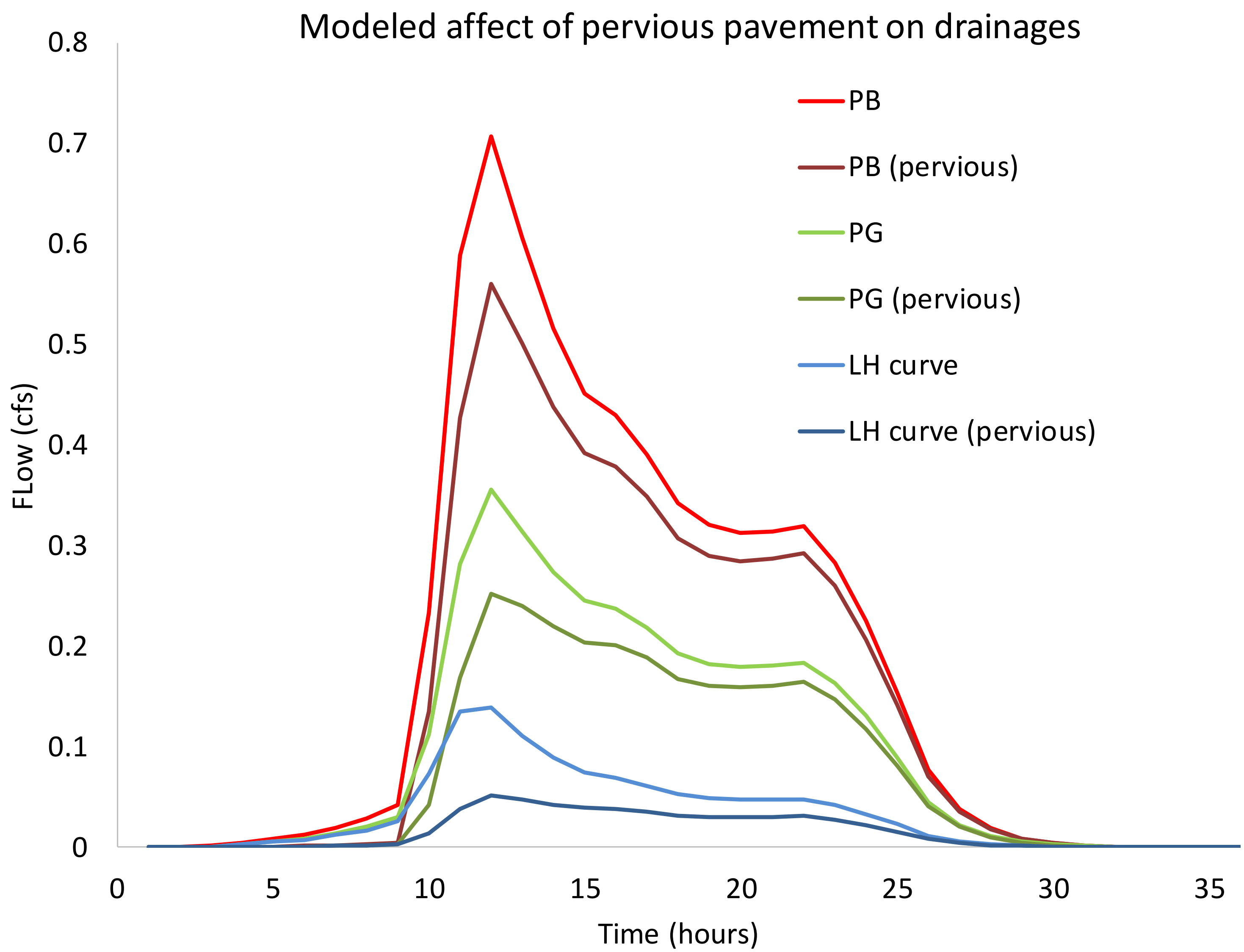

Modeled LID 5 (twins bioswale) runoff and capacity
flow (cfs)
1.2
1
0.8
0.6
0.4
0.2
0
LID 5 (twins bioswale) before implimentation
LID 5 after implimentation
Storage (acre ft)
0.6
0.5
0.4
0.3
0.2
0.1
0
LID 5 maximum capacity
LID 5 (bioswale) storage
0
5
10
15
20
25
30
35
Time (hours)


Modeled affect of LID's on Library runoff
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
FLow (cfs)
0
5
10
15
20
25
30
35
Time (hours)
Library
Library (all)
LID 6 (water tank)
Library (pervious)

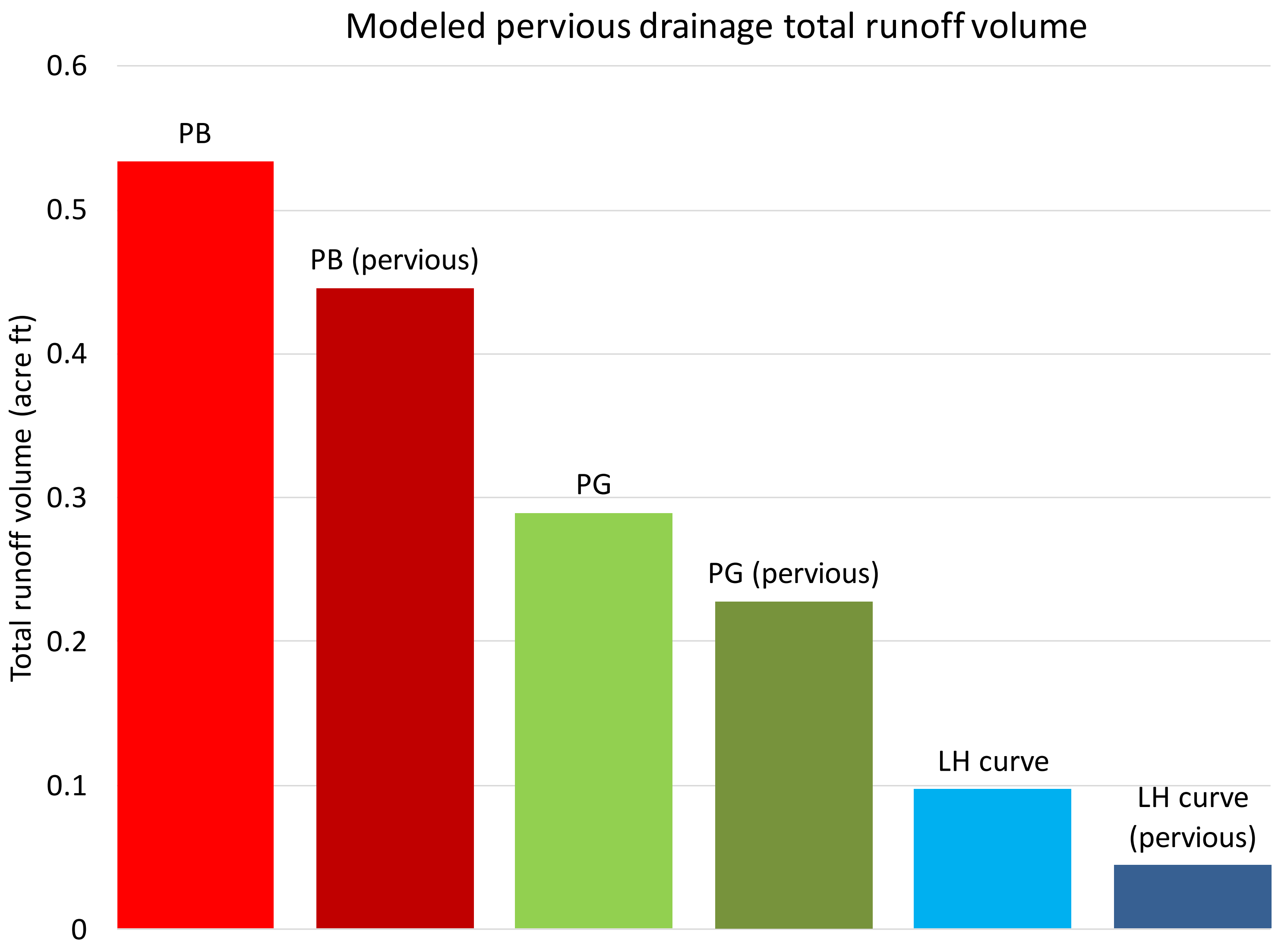

Modeled Library total runoff volume
Total runoff volume (acre ft)
0.6
0.5
0.4
0.3
0.2
0.1
0
Library
Library (pervious)
LID 6 (water tank)
Library (all)



Modeled LID 6 (Tank) outflow and capacity
flow (cfs)
0.8
0.6
0.4
0.2
0
LID 6 (tank) before implimentation
LID 6 after implimentation
Storage (acre ft)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
LID 6 maximum capacity
LID 6 storage
0
5
10
15
20
25
30
35
Time (hours)



Modeled affect of pervious pavement on drainages
PB
PB (pervious)
PG
PG (pervious)
LH curve
LH curve (pervious)
FLow (cfs)
Time (hours)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
5
10
15
20
25
30
35


Modeled pervious drainage total runoff volume
Total runoff volume (acre ft)
0.6
0.5
0.4
0.3
0.2
0.1
0
PB
PB (pervious)
PG
PG (pervious)
LH curve
LH curve (pervious)