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Understanding Stormwater Management Options Using a Water Balance Framework

Fall 2013

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Disclaimer:

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Executive Summary

This study was conducted as part of a class project by students in the Advanced Watershed Science and Policy (ENVS660) course at California State University at Monterey Bay. The primary objectives of this study were to 1) Develop an annual water balance examining the effects of different components of the water cycle in the small, medium, and large storm seasons, as well as in the dry season, 2) Estimate the percentage of stormwater that could be diverted or treated before reaching the ASBS during small, medium and large storms under three potential management scenarios, and 3) Estimate the percentage of stormwater that could be retained or treated using low impact development (LID) based on land use type and stormwater runoff during small, medium, and large storms.

The City of Pacific Grove's coastline supports a wide variety of aquatic life and is part of the Monterey Bay National Marine Sanctuary (MBNMS). It is also the destination for a large portion of the City's stormwater runoff, which drains into the Pacific Grove Area of Special Biological Significance (ASBS) within the MBNMS. Special protections prohibit dry weather flows into the ASBS, and mandate a number of requirements for continued discharge of wet weather flows. Regulations from the State Water Resources Control Board require the City to monitor receiving waters. If natural water quality is degraded, the City must either treat stormwater flows to remove pollutants or divert it for non-potable uses. However, successful capture of stormwater runoff requires that the City first gain an estimate of its water balance in order to gage the volume of runoff that must be managed.

We developed a comprehensive seasonal and annual water balance of the ASBS watershed to give the City an analytical framework with which to address stormwater issues. The water balance can be used by the City to evaluate appropriate management scenarios. We found that the most effective management scenario incorporated both LID implementation and diversion infrastructure. This management scenario reduced runoff reaching the ASBS by 77%. The water balance showed that LID strategies did not reduce as much runoff as the stormwater diversions with reductions of 24% and 55%, respectively. While these modeled reductions are approximations, the results of this study indicate that the City would come close to complying with regulatory mandates by adopting both of these strategies.

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List of Definitions and Acronyms

- ASBS – Areas of Special Biological Significance
- BMPs – Best Management Practices
- BS – Bioswales are landscape elements with gently sloped sides designed to remove silt and pollution from surface runoff water.
- CalAm – California American Water Company
- CCRWQCB – Central Coast Regional Water Quality Control Board
- CWC – California Water Code
- EPA – Environmental Protection Agency
- GIS – Geographic Information Systems
- GR – Green roof is a roof of a building that is partially or completely covered with vegetation and a growing medium, planted over a waterproofing membrane. LID – Low Impact Development/Design
- MBNMS – Monterey Bay National Marine Sanctuary
- MRSWMP – Monterey Regional Storm Water Management Program
- MRWPCA – Monterey Regional Water Pollution Control Agency
- NPDES – National Pollutant Discharge Elimination System
- PC – Permeable concrete a special type of concrete with a high porosity used for concrete flatwork applications that allows water from precipitation and other sources to pass directly through
- PP – Pervious pavers have a base and sub-base that allow the movement of stormwater through the surface.
- RB – Rain barrel is a water tank used to collect and store rainwater runoff, typically from rooftops via rain gutters
- SCS – Soil Conservation Service
- SWRCB – State Water Resources Control Board
- USDA – United States Department of Agriculture Forest Service
- USGS – United States Geologic Survey

1 Introduction

1.1 Regulatory Issues and water supply in the City of Pacific Grove

In an effort to preserve biologically unique and sensitive marine ecosystems for future generations, California designated thirty-four Areas of Special Biological Significance (ASBS) along its coast in the 1970s; one of which is located off the coast of Pacific Grove on the Monterey Peninsula. An ASBS is a marine area monitored and maintained for water quality by the State Water Resources Control Board (SWRCB). The Pacific Grove ASBS extends for 3.2 miles along the shoreline from the Monterey Bay Aquarium to Asilomar Boulevard just before Point Pinos. It encompasses 500 acres within the Monterey Bay National Marine Sanctuary (MBNMS) (Figure 1).

Currently, the Pacific Grove ASBS receives runoff from approximately 103 acres in Monterey and 848 acres in Pacific Grove. ASBSs are afforded special protections under the Marine Managed Areas Improvement Act (Public Resources Code section 36600) to maintain water quality, thus runoff needs to be minimized and diverted away from the City of Pacific Grove (City) existing coastal stormwater outfalls. The special protections prohibit dry weather flows into the ASBS, and mandate a number of requirements for continued discharge of wet weather flows. Regulations from the SWRCB require the city to monitor receiving waters and, if natural water quality is degraded, treat stormwater flows to remove 90% of pollutants or divert it for non-potable uses (SWRCB 2012). Stormwater runoff into the ASBS is regulated this way for all storms up to the 85th percentile of wet days. In order to comply with these requirements, the City may develop infrastructure to divert runoff for storage and treatment before it enters the ASBS through coastal outfall pipes. The City is also considering the implementation of low impact development (LID) strategies in the watersheds draining to the ASBS.

The City relies on surface and groundwater sources to meet its water needs, but there is a shortage of potable water for domestic and commercial uses due to limitations on existing water supplies (City of Pacific Grove Small Water Supply Projects 2012). Some of the physical limitations include: inadequate surface water and groundwater storage capacity in the Carmel River Basin, consecutive dry years, and the threat of seawater intrusion in the Carmel River and Seaside Groundwater Basins (MPWMD 2013). The possible stormwater diversions introduced above could serve the additional function of helping the City of Pacific Grove (City) meet shortfalls in water supply.

California American Water (CalAm), the City's supplier, is currently under SWRCB Cease and Desist Orders, which require withdrawals from the Seaside Groundwater Basin and the Carmel River Aquifer to be reduced to 4,150 ac-ft per year (AFY) in a dry year by 2017 (SWRCB CDO, 2003 & 2009). CalAm's production in the 2013 water year was 11,600 AFY (MPWMD 2013). A failure to meet this reduction goal could result in enforced mandatory water conservation for peninsula cities, which would affect the local tourism-based economy. While CalAm is working with several local agencies to develop alternative supplies via large-scale projects, the City is looking for ways to conserve, store, and recycle rainfall and other sources of runoff occurring within its city limits. If the City can retain rainfall runoff through the implementation of LIDs and diversion projects that incorporate new storage facilities it could gain some independence from the constraints of this undersupplied region.

1.2 Goals

To aid the City of Pacific Grove in their efforts to minimize runoff to the ASBS we conducted a study to examine potential stormwater runoff mitigation measures. We developed an analytical framework within which to complete the following goals:

Overall Goal:	Develop an annual water balance examining the effects of different components of the water cycle in the small, medium, and large storm seasons, as well as in the dry season.
Supporting Goal:	Estimate the percentage of stormwater that could be diverted or treated before reaching the ASBS during small, medium and large storms under three potential management scenarios.
Supporting Goal:	Estimate the percentage of stormwater that could be retained or treated before reaching the ASBS during small, medium and large storms using LIDs based on land use type.

1.3 Study Area

Pacific Grove is located approximately 100 miles south of San Francisco, on the northwestern tip of the Monterey Peninsula, between the cities of Pebble Beach and Monterey (Figure 1). It is an urbanized community covering only 2.87 mi^2, but supporting a population of over 15,000 people, giving a density comparable to San Jose, CA (US Census Bureau 2010).

In this study, we only considered runoff from sub-basins emptying into the ASBS, which comprise an area of 979.5 acres out of the total 1213.3 acre watershed. Of the total watershed area, 1106.5 acres lie within the Pacific Grove boundaries, and the rest are in the City of Monterey. The watersheds that drain into the ASBS were determined based on drainage points to each of four parts of stormwater transport and treatment infrastructure: the David Ave Reservoir, the proposed Pine Avenue Diversion Pipeline, a proposed treatment plant at Point Pinos, and the dry weather diversion system to Monterey Regional Water Pollution Control Agency (MRWPCA). Single-family residential land use comprises 40 % of the study area, while medium and high density residential / commercial land use is 15 %, open space is 13 %, and streets are 22 % of the total land area. Average annual rainfall in Pacific Grove is 19.7 inches, and runoff patterns are influenced by the city's steeply sloped topography, shallow soils, storm drain infrastructure, and urban development, such as buildings and other impervious surface coverage. The drainage area ranges in elevation from sea level to 562 feet above mean sea level, consists primarily of sandy loam soils, and it overlays sandstone and granodiorite bedrock layers. The eastern half of the city is heavily paved, with a network of streets extending from upper elevations down to the ocean. The majority of the western half of the city lacks curbside drains and sidewalks, with considerably fewer paved surfaces extending to the ocean. Over 44 % of the areas draining into the ASBS are impervious surfaces, with a large amount of runoff conveyed by the City's aging stormwater infrastructure. Paved surfaces, curbside drains, gutters, catch basins, and subsurface stormwater pipe networks collect stormwater and direct it downslope towards the Pacific Ocean. These impervious drainage networks nearly eliminate infiltration opportunities, thereby increasing stormwater load and velocity (excerpt from CSUMB ENVS660 2011).

1.4 Overview of Project

We developed a framework to analyze stormwater management using a seasonal and annual water balance of the ASBS watershed for the City of Pacific Grove. We estimated the percentage of untreated runoff reaching the ASBS for multiple management scenarios and then scaled the percentage of untreated runoff from a single storm to total seasonal and annual estimates of untreated runoff volume. This approach allowed a comparison of potential stormwater management proposals and can be adjusted if additional or more specific data becomes available.

The water balance included inputs from stormwater runoff diversion modeling and LID implementation modeling. The water balance incorporated the following potential management scenarios proposed by the City:

- Scenario A: ASBS watershed current management: dry flow runoff pumped to MRWPCA.
- Scenario B: Proposed diversion infrastructure improvements including David Avenue Reservoir, Pine Avenue diversion, Point Pinos Treatment Plant and the MRWPCA diversion.
- Scenario C: LID implementation on different land use types across the entire watershed.
- Scenario D: Both infrastructure improvements and LID implementation effects combined.

Generally, a water balance sums inputs and outputs of the system, which for a system in equilibrium, will equal zero. Looking at several years of data, the ASBS water balance was calculated using the conceptual model in Figure 2 for a set of wet season management scenarios, the dry season and an overall annual total. We calculated the total change in storage by adding precipitation and irrigation inputs and subtracting surface runoff, baseflow and evapotranspiration.

More specifically, we used precipitation data from rain gages and irrigation data from the City as inputs and then calculated changes in the water balance by modeling predicted runoff (discussed in Chapter 2), LID efficacy (discussed in Chapter 3), and applied these results to the water balance (Chapter 4) based on three types of storms: small, medium, and large. We categorized small storms as 0–80 % of wet days, medium storms as 80–90 % of wet days, and large storms as 90–100 % of wet days. These corresponded to the 40th percentile, 85th percentile, and 95th percentile storms based on a cumulative frequency curve created by Fall Creek Engineering, Inc. (FCE, 2013) for the City in an earlier study. Precipitation data was obtained from a gage located at Lover's Point in Pacific Grove (Weather Underground, 2013). These data spanned from November 2010 to November 2012.

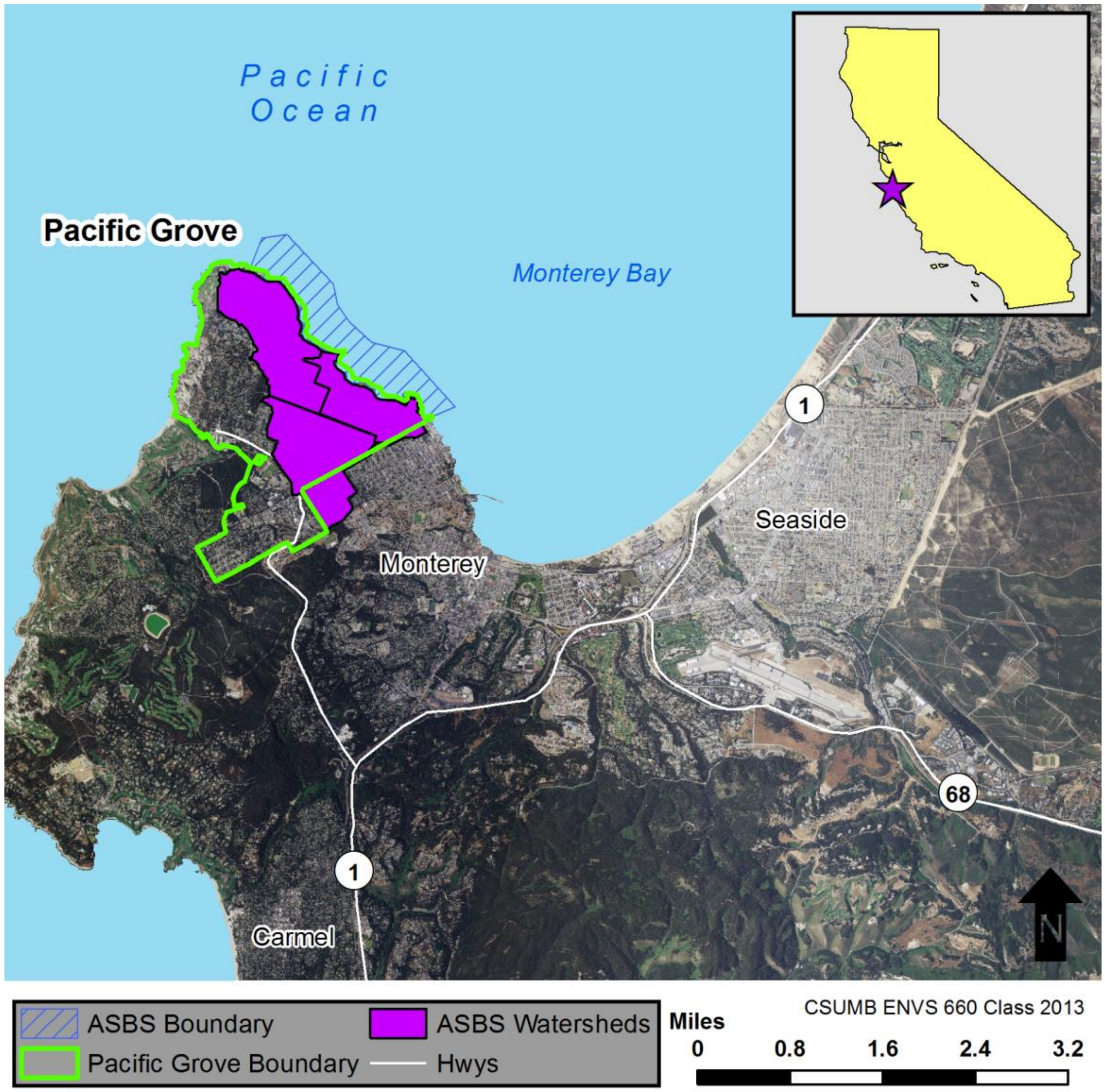


Figure 1. Location of watersheds within Pacific Grove, California that drain into the Area of Special Biological Significance.

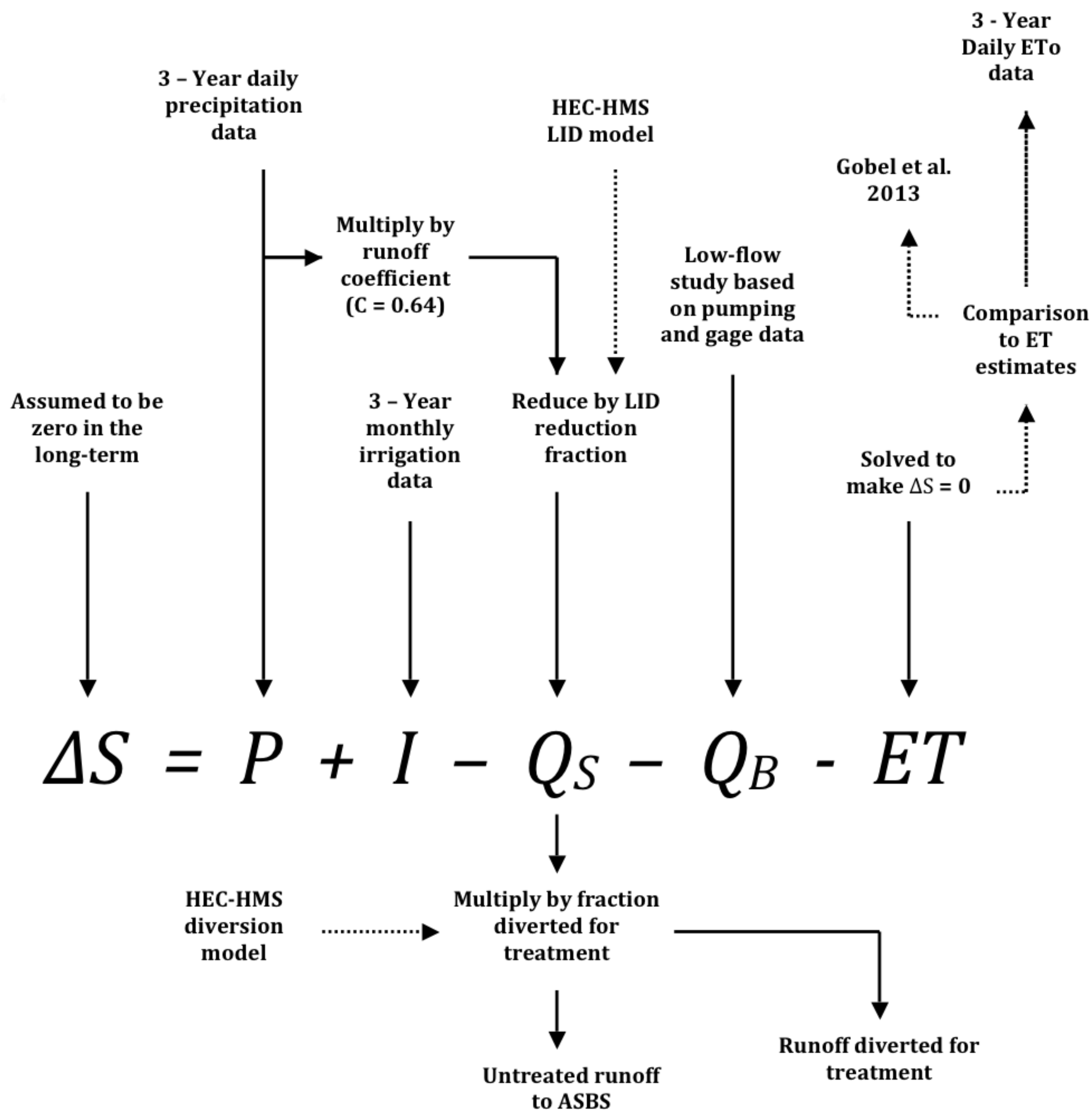


Figure 2. Water balance formula where ΔS represents change in storage, P represents Precipitation, I represents Irrigation, Q_S represents surface flow, Q_B represents base flow, and ET represents Evapotranspiration.

2 Stormwater Diversion Modeling

2.1 Introduction

One component of developing a water balance for the City of Pacific Grove was to evaluate potential runoff diversion and treatment projects and how they might affect overall runoff into the ASBS. This chapter describes model-based estimation of the fraction of stormwater treated by a proposed diversion and treatment project. Estimates were produced for single storms, for subsequent use in the overall seasonal and annual water balance model (Chapter 4). This is especially relevant, because of a 2005 change to the California Water Code (CWC) that has put pressure on the City to develop local water projects. Some projects, like the Marina Dry Weather Diversion, have already been implemented, and others, like the Point Pinos Treatment Plant, are being considered by the City. The Marina diversion functions during the dry weather season to

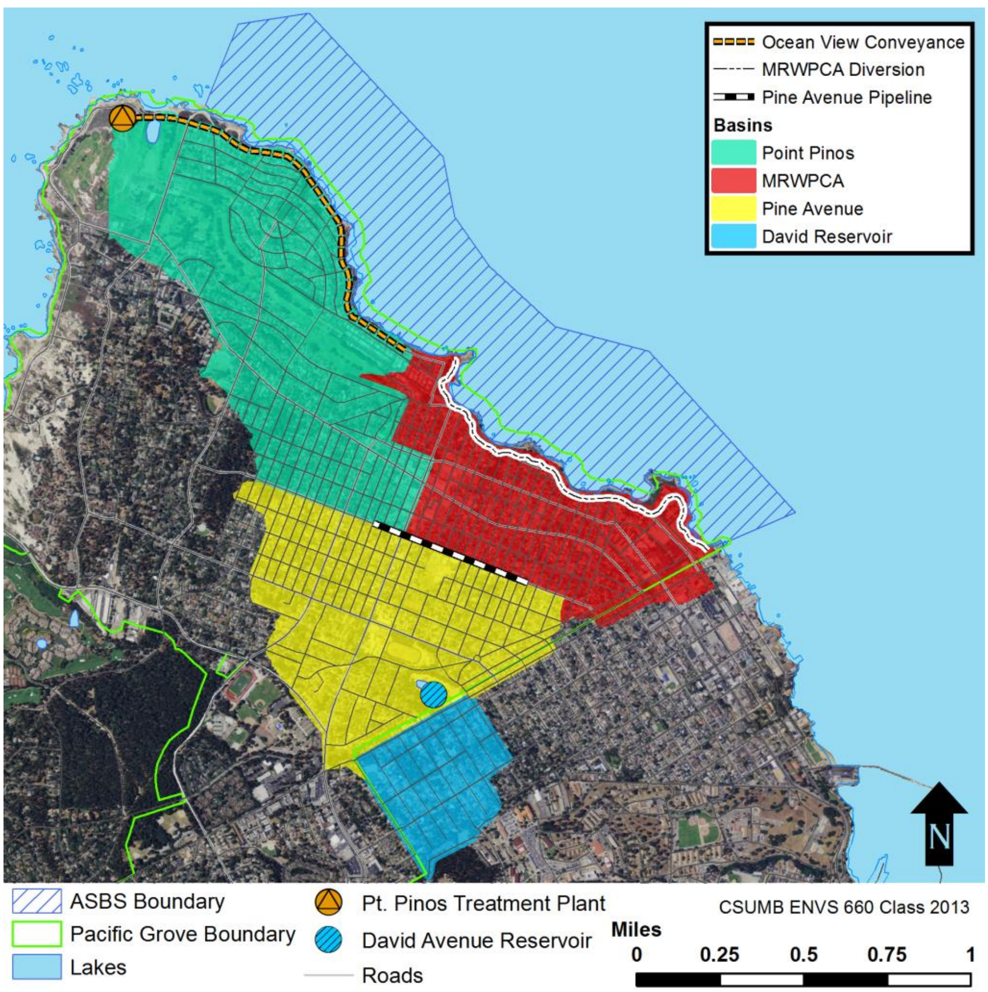


Figure 3. Location of potential diversions to David Reservoir, Point Pinos Treatment, Marina Regional Treatment Center

divert runoff using a system that captures flow from most outfalls located between Lovers Point and 1st street (Figure 3). Two sewer pump stations pump the water north along Ocean View Blvd. to the City of Marina for processing at the regional wastewater treatment plant operated by MRWPCA. It is proposed that the Dry Weather Diversion be modified to transfer wet weather flows to the Marina treatment plant. In addition, runoff could be transferred through a proposed pipeline under Pine Avenue and retrofitted pipes running south along Ocean View Blvd to a new stormwater treatment facility (Figure 3). The David Avenue Reservoir would also be restored which would provide a catchment for runoff from the upper watershed.

The proposed stormwater treatment facility would be constructed at the former Point Pinos treatment plant (PPTP) site and the treatment system would be designed to reduce pollutants by 90% before discharge. Some water from the PPTP would be available for irrigation, with a planned storage capacity equivalent to the 3-day irrigation water requirement of the municipal golf course. Treated water from the Marina diversion could also potentially be used for the MRWPCA Groundwater Replenishment Project (Fall Creek Engineering 2013).

2.2 Methods

We modeled the effects of the David Avenue Reservoir (DAR), PPTP, and MRWPCA's wastewater facility on runoff. Specifically, we estimated the ratio of stormwater runoff that would be treated, and the amount that would flow untreated into the ASBS. We created coarse watershed models using HEC-HMS hydrologic modeling software (USACE 2000) with the following four sub-basins (Figure 4):

- The David Avenue Basin represented the watershed area above DAR.
- The Pine Avenue Basin included the watershed area between DAR and Pine Avenue. Pine Avenue was selected as a dividing point between watersheds because the city has proposed to build a diversion pipe at that location.
- The Point Pinos Basin encompassed the region between Pine Avenue and the PPTP, reaching down to the ocean. Runoff in this watershed was directed into the PPTP Diversion pipe.
- Just east of the Point Pinos Basin, the MRWPCA Basin represented the watershed below Pine Avenue to the ocean, which included the current dry-weather diversion system that leads to the MRWPCA treatment facility.

The models simulated flows for 1 small, 3 medium, and 3 large storms using 24-hour precipitation data with a 5-minute time-step for storms occurring between 2010-2013 (Wunderground 2013). We ran the models with synthetic storms of each type (small, medium, large) for comparison.

We determined the ratio of treated to untreated runoff for each storm, which was then used to calculate annual treated and untreated runoff totals for the Pacific Grove water balance (addressed in Chapter 4). The following three diversion scenarios (DS) were evaluated:

DS1: runoff from all basins, except the MRWPCA Basin, was diverted toward the PPTP, and runoff from the MRWPCA Basin was diverted toward Marina.

DS2: runoff from all basins except the MRWPCA Basin was diverted toward the PPTP, with excess runoff from those basins diverted toward Marina along with runoff from the MRWPCA Basin.

DS3: runoff from all basins was diverted toward the PPTP. All flow constraints except for the treatment plant processing rate were removed in this scenario. The purpose was to give a comparison against the other two scenarios showing how much water the PPTP could treat if pipes were retrofitted to convey all runoff to the treatment plant.

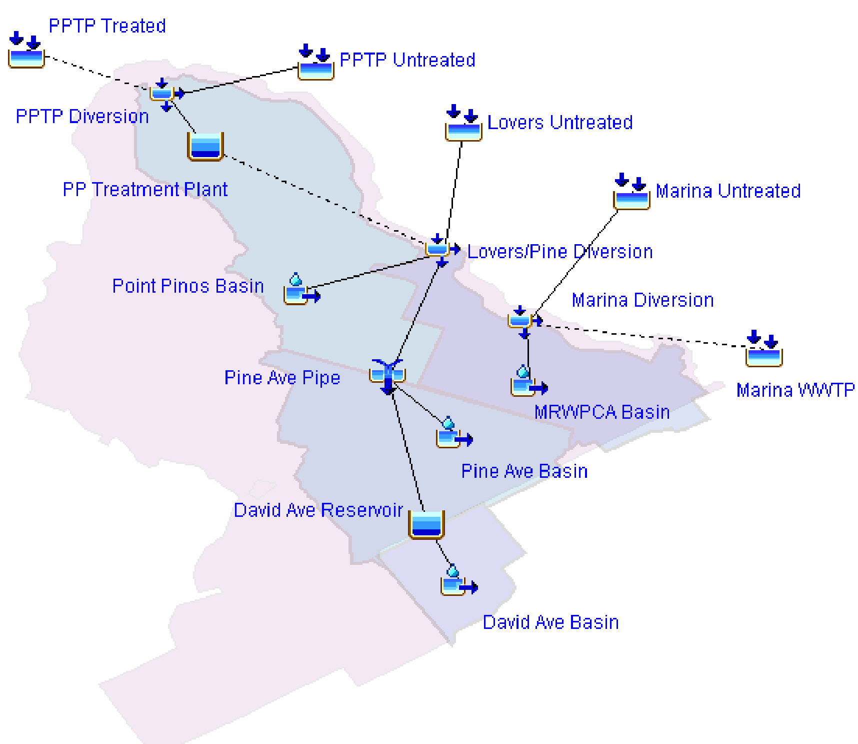


Figure 4. Diversion Scenario 1 (DS1) modeled the MRWPCA basin separately from the remainder of the ASBS watersheds.

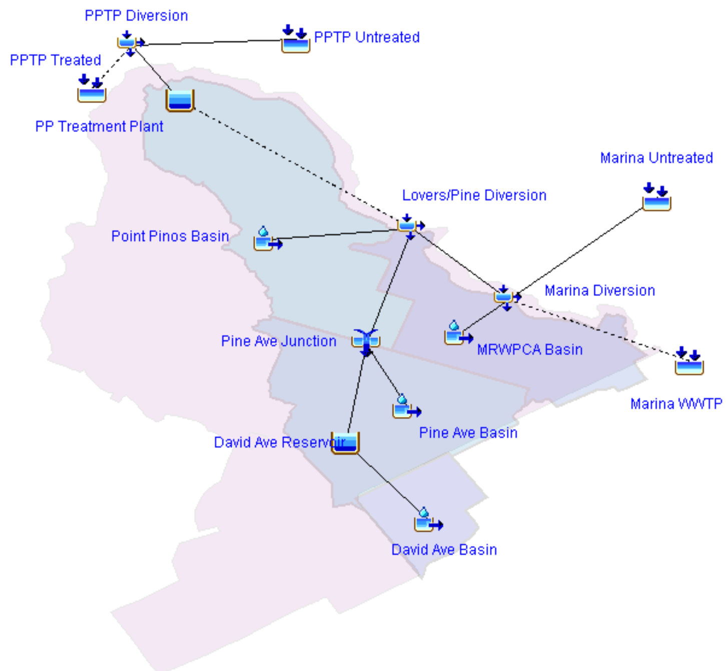


Figure 5. Design Scenario (DS2) was a hybrid approach that allowed diversion from the Lovers/Pine Diversion to the Point Pinos Treatment plant (PPTP) or alternatively to the Marina Diversion if the PPTP had reached capacity.

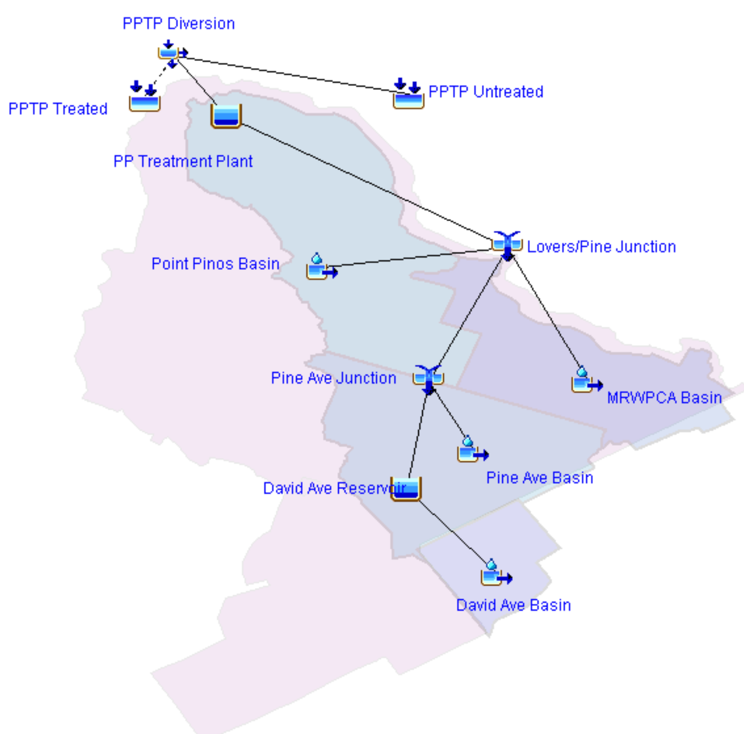


Figure 6. Design Scenario 3 (DS3) assumes that all runoff is directed to the Point Pinos Treatment plant using a higher capacity conveyance than is planned

Table 1. Parameters for the Pacific Grove HEC-HMS watershed model.

Element	Parameters	David Ave Basin	Pine Ave Basin	Point Pinos Basin	MRWPCA Basin
Subbasin	*Area (mi^2)*	0.14	0.45	0.60	0.35
Subbasin	*Area (acres)*	89	286	381	222
Loss	*Runoff Coefficient (%)*	64	64	64	64
Transform	*Time of Concentration (HR)*	0.1	0.1	0.1	0.1
	Storage Coefficient (HR)	1.5	1.5	1.5	1.5

2.2.1 Model Parameters

Models of each diversion scenario were given constant parameters across all sub-basins (Table 1). The purpose of this simple approach was to produce a rough estimate of the rainfall to runoff relationship of the entire study area. Model parameters mimicked watershed runoff as described by the rational method (Pilgrim and Cordery 1993), which estimates peak discharge as the product of the runoff coefficient (ratio of runoff to rainfall), rainfall intensity, and drainage basin area. We adopted a conservative approach and set the runoff coefficient (Table 1) to a relatively high value (64%) based on rainfall and runoff data from Greenwood Gulch, a sub-basin of the Pacific Grove watershed (FCE 2013). This choice of runoff coefficient may have resulted in an overestimation of runoff. Further analysis of runoff coefficients could provide a more accurate estimate of runoff.

2.2.2 Model Calibration

We calibrated the models using data from a CSUMB flow gage installed in the lower Greenwood Gulch area during 2012. Using flow measurements from January 19 and 20, 2012 (Watson et al. 2012) and the corresponding rainfall data from a 95% storm, we compared a hydrograph of actual to modeled predicted runoff (Figure 7). We adjusted transform parameters, which include time of concentration (hr) and storage coefficient (hr), until a good visual match between the predicted and observed storm peaks and flow dispersion was obtained.

The model over-predicted total runoff (5.3 ac-ft predicted, 4.1 ac-ft observed) for smaller precipitation peaks within the 95% storm, but there was a good fit between modeled and observed peak flow and timing. The goal of the model was to estimate a ratio of treated to untreated water for the specific storms, therefore fit between peak flow and timing was prioritized over total amount of discharge.

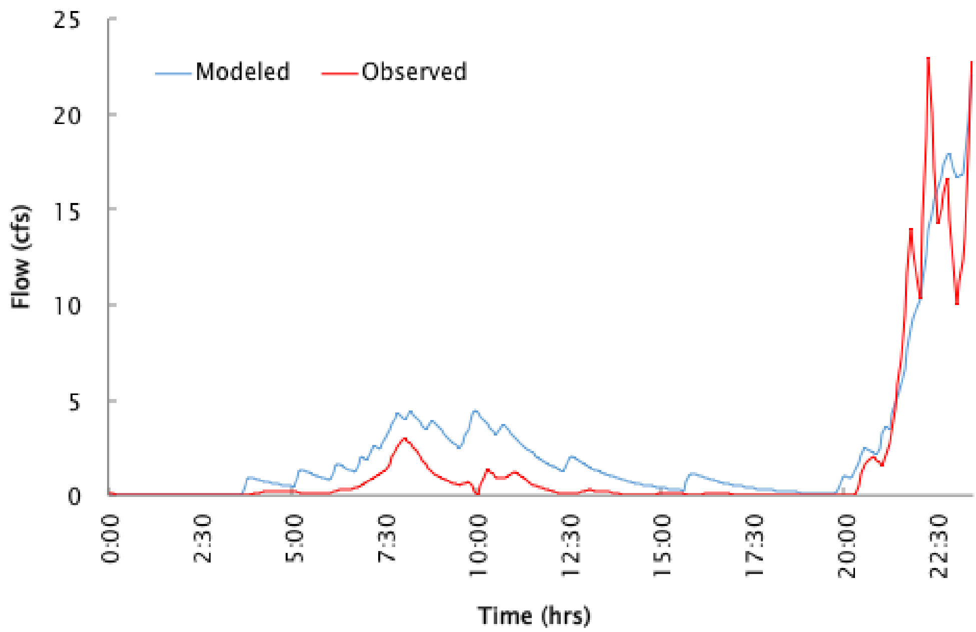


Figure 7. Hydrograph showing model calibration using CSUMB Greenwood Gulch flow gage from 95th percentile storm in 2012. The model shows an overestimation of flow during less intense precipitation events, but good timing on peak of hydrograph. A close fit was seen in both flow and timing during intense precipitation events.

2.2.3 David Avenue Reservoir

The David Avenue Reservoir (DAR) was assumed to have 45 total ac-ft of available storage (City of Pacific Grove 2013). In our modeling efforts we assumed any release valves would be closed in the event of a storm in order to capture the maximum amount of stormwater runoff. We modeled the amount of runoff captured by DAR in the three flow scenarios (small, medium, and large storms). We assumed that the city would maintain a continuous 15 ac-ft volume of water for aesthetic reasons and to foster a wetland habitat.

2.2.4 Point Pinos Treatment Plant

We modeled the treatment plant based on design information shared by Fall Creek Engineering, Inc, the consulting firm hired by the Cities of Monterey and Pacific Grove to develop a concept design for the Monterey-Pacific Grove Area of Biological Significance Stormwater Management Project (E. Corwin Oct. 2013-Pers Comm). To represent the current design, we modeled the flow of untreated stormwater from the David Avenue Basin, Pine Avenue Basin, and Point Pinos Basin toward the treatment plant at a constrained rate of 3,000 gal/min based on the proposed pipe size and capacity. Runoff was treated at a rate of 1,500 gal/min, with excess untreated runoff stored up to a capacity of 430,000 gal. Once the treatment storage was full, excess untreated runoff was assumed to go into the ocean for all scenarios. For each of the three flow scenarios

(40% storm, 85% storm, 95% storm), we estimated the percentage of total runoff that would be treated at the PPTP, and the percentage that would flow directly into the ocean.

2.2.5 MRWPCA Diversion

The MRWPCA diversion pipeline connects the MRWPCA Basin to the Marina wastewater treatment plant (Marina WWTP). Though it is currently a dry season diversion only, we modeled the diversion as though it was capable of conveying wet season flows with a maximum flow rate of 1100 gal/min (typical for a 6 in. pipe)(Flex PVC 2013). We assumed there was no limit to the amount of water that MRWPCA could treat; however in reality there is likely a maximum capacity at the facility. The MRWPCA diversion was modeled in two ways: 1) in DS1 we assumed the diversion pipe was not accepting runoff from any basin except for the MRWPCA Basin and 2) in DS2 we connected all basins to the MRWPCA diversion so that runoff exceeding the 3,000 gal/min of the PPTP diversion pipe could be sent to Marina for treatment. DS3 did not incorporate the MRWPCA diversion. The total amount of runoff treated by MRWPCA was calculated for all storm events. Overflow was assumed to flow untreated into the ASBS.

2.3 Results

The modeled effects of the proposed diversion and treatment projects on runoff showed implementation of DS2 would result in the highest amount of captured and treated water, and thus the least amount of untreated runoff to the ASBS (Table 2)(Figure 8). DS2, which simulated the diversion of water to the PPTP and Marina WWTP, with a connection between the diversion pipelines, treated 100% of water in the average 40% storm, 32% of water in the average 85% storm, and 21% of water in the average 95% storm. DS1 lacked the connection between the two diversion systems, but performed nearly as well as DS2, producing the same average fraction of treated water in each storm type except for the 85% storm (DS2 treated 32%, DS1 treated 31%). This suggests a connection between the PPTP and Marina WWTP diversion systems may not have a significant effect on total treated runoff. In DS3, where all runoff was directed toward the PPTP, the average amount of water treated was 6-12% less than in the other scenarios for the 85% and 95% storms. The limiting factor in DS3 was the PPTP treatment rate. However, DS3 was able to treat 100 % of runoff in the 40% storm.

Table 2: Comparison of water treatment efficacy under three diversion scenarios (DS) using real and synthetic storms.

	40% Storms (Runoff Treated %)	85% Storms (Runoff Treated %)					95% Storms (Runoff Treated %)				
	Storm 1	Storm1	Storm 2	Storm 3	**Average**	Synthetic	Storm1	Storm 2	Storm 3	**Average**	Synthetic
DS1	100	34	16	40	**31**	50	38	13	21	**21**	31
DS2	100	35	16	40	**32**	50	38	13	21	**21**	31
DS3	100	21	9	28	**20**	33	27	8	14	**15**	18

Evaluation of Diversion Scenario efficacy was based on averaged storm results, however different precipitation patterns of storms within the same percentile (40, 85, 95) produced varying runoff results. For example, we simulated 3 different 95% storms under the DS1 scenario and the percent of treated water from each storm varied from 13-38%. Pulses of rain varied between storms and runoff treatment was limited by rates of treatment. This variation in precipitation dispersion throughout the 24-hour period resulted in some 95% storms having higher treatment ratios than 85 % storms. In light of the irregular results with the real storms, we did a preliminary analysis with synthetic storms (Table 2), and initial results showed the expected inverse relationship between storm magnitude and fraction of treated water. It should be noted that precipitation in the synthetic storms was more evenly distributed, allowing for steady treatment and optimistic treatment results.

The percentages of runoff treated by DS1 and DS2 were similar, suggesting that the implementation of DS2, which requires additional infrastructure, would not create a significant reduction in untreated runoff to the ASBS unless treatment rates at PPTP or conveyance capacity to Marina WWTP were increased. The performance of PPTP in DS3, where the entire watershed drained to only this treatment facility, was consistent with DS1 and DS2 with the exception of the 40% storm. The total ratio of treated water was less in the DS3 scenario due to the absence of the Marina WWTP. In the 40% storm the PPTP was able to treat 100% of the runoff without the assistance of Marina WWTP.

Table 3. Comparison of treatment facility productivity in three diversion scenarios (DS).

		Point Pinos TP	**Marina WWTP**	**Total**
Scenario	Storm Percentile	Runoff Treated (%)	Runoff Treated (%)	Total Treated
DS1	40	73	27	100
	85	20	11	31
	95	14	7	21
DS2	40	73	27	100
	85	20	12	32
	95	14	7	21
DS3	40	100	-	100
	85	20	-	20
	95	15	-	15

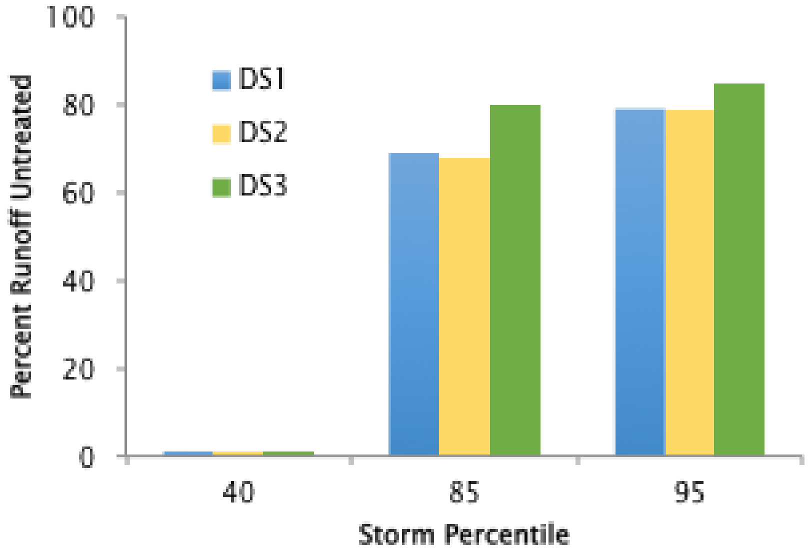


Figure 8. Percentages of untreated runoff within the ASBS watershed for small, medium, and large storms under the three diversion scenarios.

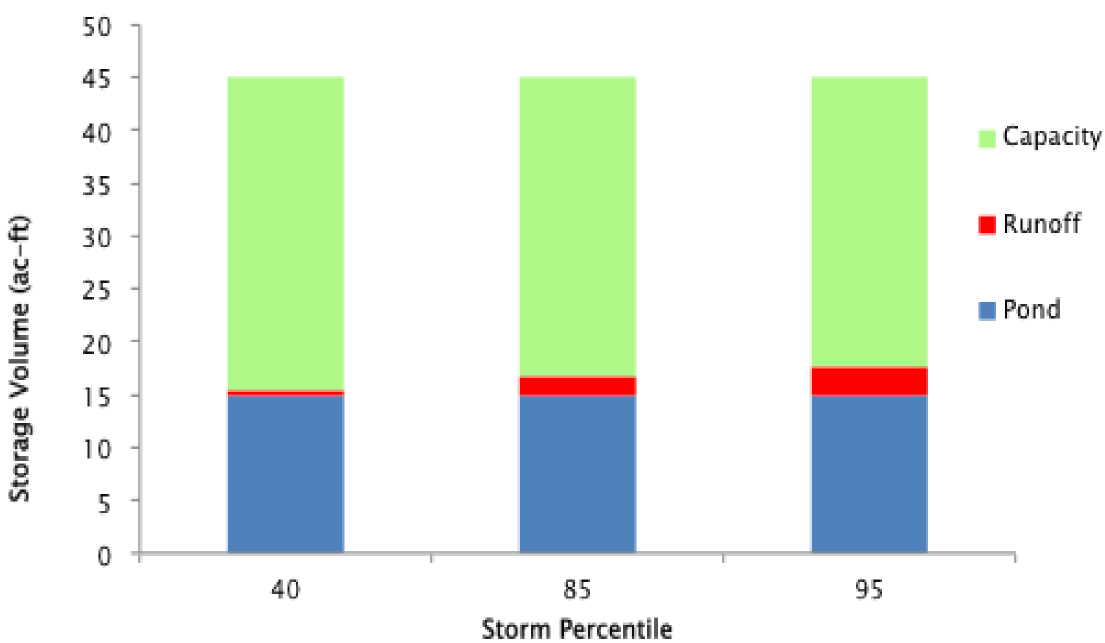


Figure 9. Water level changes in the DAR storage during modeled small, medium, and large storms. The reservoir never reaches its 45-ac-ft capacity.

Modeled estimation of the David Avenue Reservoir (DAR) revealed it could detain 100% of the runoff coming from the upper-most basin (David Avenue Basin). Starting with the assumed 15 ac-ft of base storage, the model predicted the storage would increase from 15 ac-ft to 15.3 ac-ft during the small storm and up to 17.2 ac-ft during the medium and large storms across all Diversion Scenarios (Figure 9). None of the storms filled half of the reservior's 45 ac-ft capacity. Further study could investigate the possibility of pumping stormwater from the lower watersheds to utilize the DAR's excess capacity.

2.4 Limitations

This HEC-HMS modeling was simplified to treat the entire study area as one watershed with coarse parameters in order to generate approximate ratios of treated and untreated runoff and inform the annual water balance. Further investigation of sub-basin characteristics could lead to more accurate model predictions. The values used to model the pipe size, transport rate and treatment rate of the Point Pinos Treatment Plant are based on preliminary draft design specifications that may change in the future. Results based on these specifications may not be applicable if the design changes. Also, the model was calibrated using limited flow data and one storm, the 95th percentile storm on January 20, 2012.

3 Stormwater Runoff Mitigation Using Low Impact Developments

3.1 Introduction

Another goal in developing the Pacific Grove water balance was to show the potential effects of LID implementation within the watersheds draining into the ASBS. The City of Pacific Grove identified preferred LIDs to be modeled in this assessment. We estimated the effectiveness of each LID to reduce stormwater runoff when implemented on four land use types (Figure 9). The model produced a watershed-wide percent reduction of runoff for each LID type for the three storm sizes. These values were used as inputs in the overall City water balance (see Chapter 4).

3.2 Methods

3.2.1 Methods Overview

HEC-HMS hydrologic modeling software (USACE 2000) was employed to predict and evaluate the ability of LID strategies to reduce runoff from four case study sites across three different storm scenarios: small storm, medium storm, and large storm (see Chapter 1.2: Project Overview). Seven different LID types were modeled: bioswales (BS), green roofs (GR), rain gardens (RG), rain barrels (RB), permeable concrete (PC), and pervious pavers (PP). For each modeling scenario, a specific LID type was paired with an appropriate land use category. Figure 10 shows the distribution of land use categories spanning the watersheds that drain into the Pacific Grove ASBS. Single-Family Residences (SFR) with rain barrels, rain gardens, and permeable pavers; Medium-High Density Residential/Commercial (MHRC) with green roofs and permeable concrete; Pine Avenue with bioswales, rain gardens, and permeable concrete; and streets and sidewalks (S/S) with permeable concrete (Figure 11a-11c).

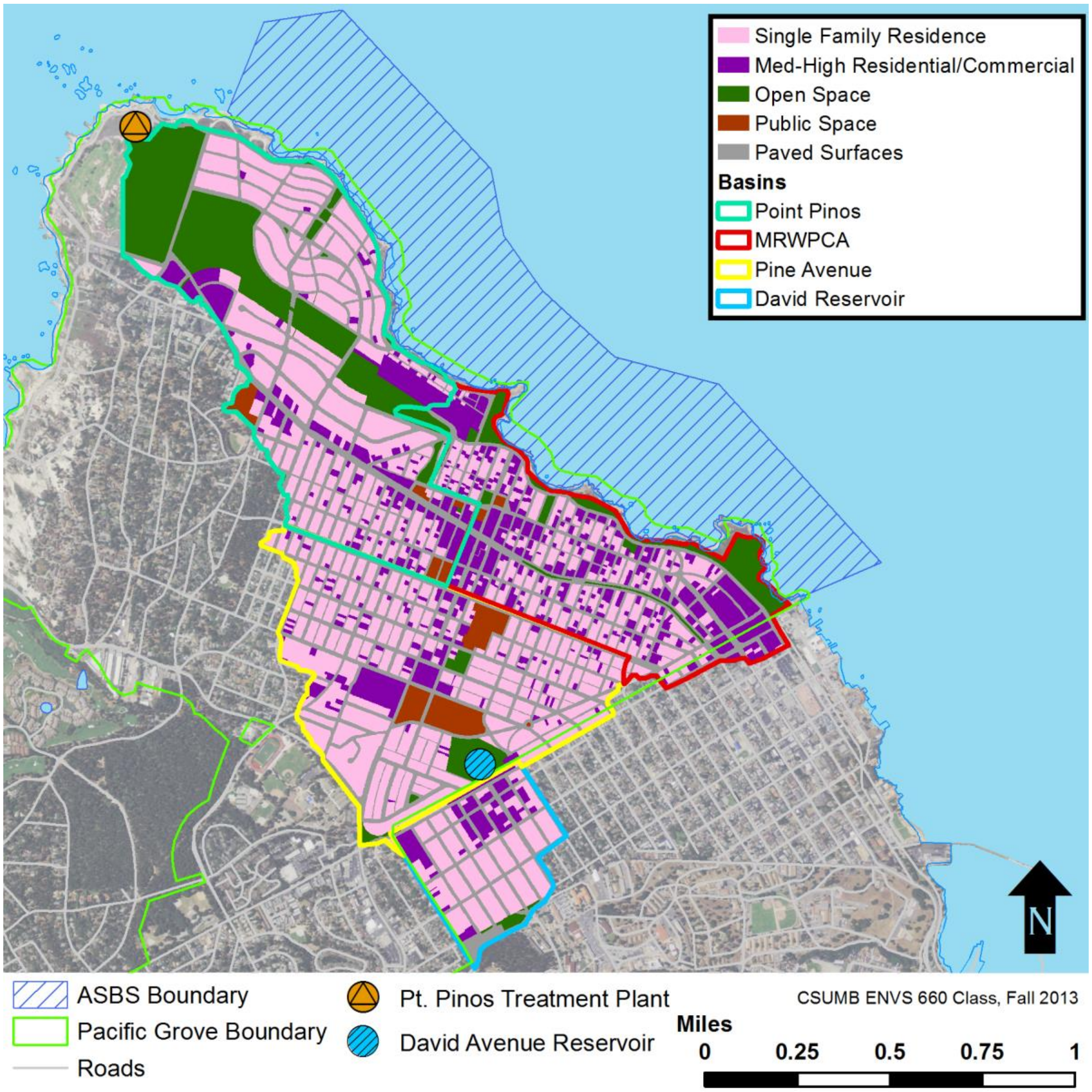
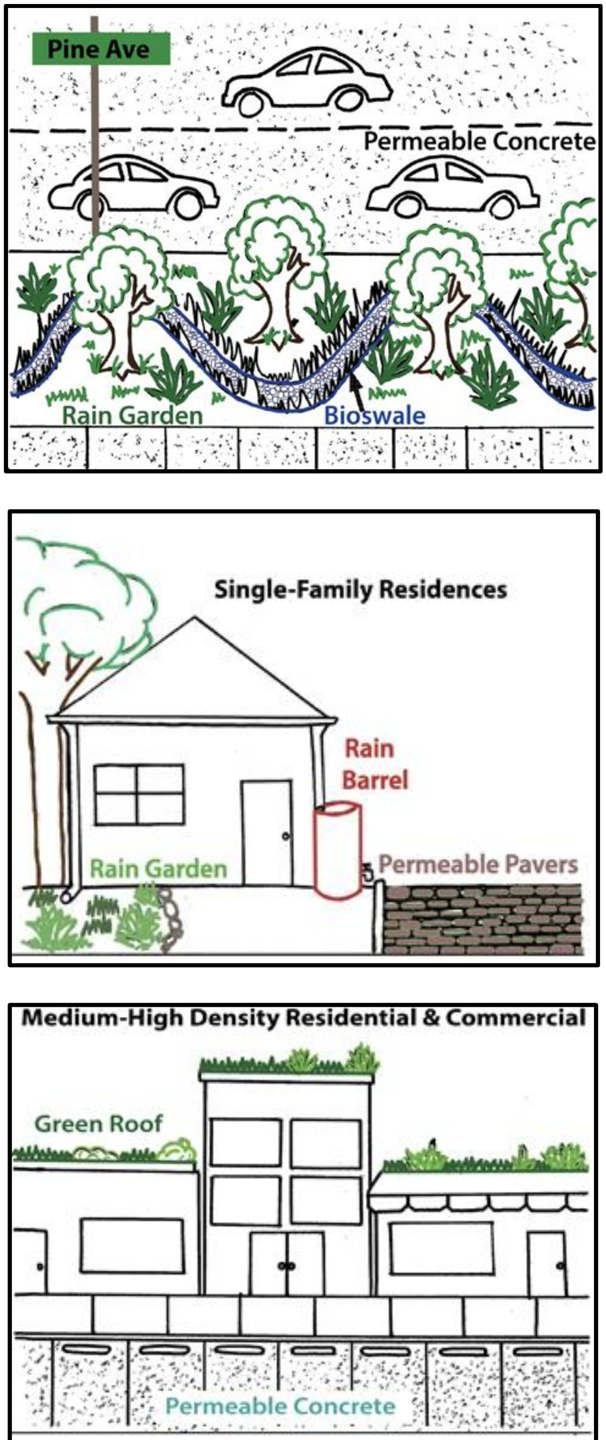


Figure 10. Distribution of land use categories in the watersheds draining to the Pacific Grove ASBS.



a)

b)

c)

Figure 11 a-c. Graphic representations of selected Low Impact Development methods along Pine Avenue, for a single-family residence, and for a medium-high density residential and commercial parcel.

3.2.2 Model Elements

We developed a separate model for each of the four land use categories. The models considered the effectiveness of LIDs at the site scale, with each site treated as its own sub-basin within the larger model. The elements of each sub-basin within the model included:

- Total area of study site
- Simple Canopy Method: initial storage and maximum capacity values
- Soil Conservation Service (SCS) Loss Method: simulates precipitation that would be removed from the system under these conditions. It requires values of Percent of Impervious Surface, Initial Abstraction (loss that occurs before runoff begins), and a runoff Curve Number (CN) from the Soil Conservation Service (SCS) (Table 4). Canopy values, area, and percent impervious surface were calculated using ArcGIS (ESRI 2013) (Table 5)

In order to convert rainfall volume to runoff volume under the SCS Loss Method, each sub-basin used a CN which accounts for Hydrologic Soil Group (HSG), plant cover, interception factors, and surface storage capacity (Table 4). A composite CN for the SCS Loss Method was determined by using the CN values from a table developed by the U.S. Department of Agriculture (USDA 1986). CNs for permeable concrete and green roofs were chosen based on previous studies designed to determine CNs for LID strategies (Ballestro et al, 2012; Carter and Rasmussen, 2007). The CN for the modeled rain barrel was based on a volume conversion of a 60-gallon barrel to a percent area with high permeability (CN of 40). The soil and cover condition was calculated in order to obtain the "S" portion of the initial abstraction (I_a) parameter using the following equation (USDA 1986):

$$S = (1000/CN) - 10$$

Initial abstraction (I_a) accounts for precipitation that disappears before it becomes runoff, and was calculated as follows (Schwartz 2010):

$$I_a = 0.05 * S$$

The response of the four land use types to each storm was simulated with a 5-minute time-step from 2010-2013 (Wunderground 2013) under scenarios that represented sites with and without the implementation of LID strategies.

Table 4. Composite Curve Number calculations for each of the modeled LIDs per land use type (SFR - Single Family Residence; MHRC - Med/High Residential/Commercial; S/S - Streets and Sidewalks) based on the cover description and Hydrologic Soil Group A (USDA 1986). "Yard" was calculated as a type of open space in "fair condition", where the grass cover > 50-75%. "Existing vegetation" was calculated as open space in "poor condition", where the grass cover < 50%. Calculations for Rain Gardens were made through a composite process based on cover types "Meadow" and impervious area ("Gravel").

Land Use	Sub-model	Cover Description	CN	Area (%)	CN x Area	Composite CN?	Final CN
Single Family Residence	Null	House		55.2		No	49
		Yard	49	37.6	1842		
		Driveway		7.2			
	Null + RB	House		55.2		Yes	49
		Yard	49	36.3	1779		
		Driveway		7.2			
		Rain barrel	43	1.3	56		
	Null + RG	House		55.2		Yes	42
		Driveway		7.2			
		Rain garden (composite)	42	37.6	1579		
	Null + PP	House		55.2		Yes	48
		Yard	49	37.6	1842		
		Permeable pavers	40	7.2	288		
	Null + RB + RG + PP	House		55.2		Yes	42
		Rain barrel	43	1.3	56		
		Rain garden	42	36.3	1525		
		Permeable pavers	40	7.2	288		
Medium-High Residential/Commercial	Null	Existing vegetation	68	46.0	3128	No	68
		Impervious		54.0			
	Null + GR	Existing vegetation	68	44.0	2992	Yes	77
		Impervious		12.0			
		Green Roof	86	44.0	3784		
	Null + PC	Existing vegetation	68	44.0	2992	Yes	69
		Impervious		44.0			
		Permeable concrete	74	12.0	888		
	Null + GR + PC	Existing vegetation	68	44.0	2992	Yes	77
		Green Roof	86	44.0	3784		
		Permeable concrete	74	12.0	888		
Pine Avenue Pipeline	Null	Existing vegetation	68	5.0	340	No	68
		Street		95.0			
	Null + RG	Rain garden (composite)	46	9.4	433	Yes	46
		Street		90.6			
	Null + BS	Bioswale	41	20.6	845	No	41
		Street		79.4			
	Null + PC	Existing vegetation	68	9.4	639	Yes	73
		Permeable concrete	74	90.6	6704		
	Null + RG + BS + PC	Rain garden (composite)	46	9.4	433	Yes	65
		Bioswale	41	20.6	845		
		Permeable concrete	74	70	5180		

Table 5. HEC-HMS parameters used for each land use type (SFR - Single Family Residence; MHRC - Medium-High-density Residential/Commercial; PAP - Pine Avenue Pipeline: S/S -Streets/Sidewalks.

	Method	Canopy		Loss		
	Parameter	Initial Storage (%)	Max Storage (in)	Initial Abstraction (in)	Curve Number	Impervious (%)
Land use	*Sub-model*					
SFR	Null	0	0.04	0.52	49	62
	Null + RB	0	0.04	0.66	42	61
	Null + RG	0	0.04	0.69	43	62
	Null + PP	0	0.04	0.75	40	55
	Max LID	0	0.04	0.69	42	54
MHRC	Null	0	0.00	0.24	68	56
	Null + GR	0	0.00	0.15	72	12
	Null + PC	0	0.00	0.22	71	44
	Max LID	0	0.00	0.15	73	0
PAP	Null	0	0.00	0.24	68	91
	Null + RG	0	0.00	0.58	46	91
	Null + BS	0	0.04	0.72	41	79
	Null + PC	0	0.00	0.18	73	0
	Max LID	0	0.04	0.27	65	0
S/S	Null	0	0.00	0.01	98	100
	PC	0	0.00	0.18	74	0

3.3 Results

During small storms, 100% of rainfall was retained under the maximum LID implementation scenario on all four, land use types. For SFRs, the percentage was 71%, likely because the study area was so small that LID implementation made the difference in retention difficult to detect, (Table 6) (Figure 11a).

Maximum LID implemented on Pap, MHRC, and S/S land uses retained greater than 90% of rainfall during medium storms while those implemented on SFRs retained only 50% of rainfall (Table 6) (Figure 11b).

During large storms, 100% of rainfall was detained on PAP, 85% by MHRC, and 89% by S/S modeled with maximum LID implementation, while maximum LIDs implemented SFRs on retained 49% runoff, (Table 6) (Figure 11c). A comparison between no LID and maximum LID implementation versus the percentage of rainfall retained for the four land use categories is shown in Figure 12.

Table 6. HEC-HMS modeled results for each land use (SFR - Single Family Residence; MHRC - Med-High Residence/Commercial; PAP - Pine Avenue Pipeline; S/S - Streets/sidewalks) during small, medium and large storm events. Sub-models include: status quo (Null), rain barrels (RB), rain gardens (RG), permeable pavers (PP), green roofs (GR), bioswale (BS) and pervious concrete (PC). "Max LID" represents the implementation of all LIDs combined that were modeled on each land use per case study. S/S's sub-model PC represents the maximum LID.

		Small Storm					Medium Storm					Large Storm				
Land use	Sub-model	Precipitation (in)	Runoff (in)	Loss (in)	Retai-ned (%)	Retention Increase (%)	Precipitation (in)	Runoff (in)	Loss (in)	Retai-ned (%)	Retention Increase (%)	Precipitation (in)	Runoff (in)	Loss (in)	Retai-ned (%)	Retention Increase (%)
SFR	Null		0.02	0.05	71	-		0.25	0.19	44	-		0.48	0.32	40	-
	RB		0.02	0.05	71	0		0.25	0.20	44	0		0.47	0.33	42	1
	RG		0.02	0.05	71	0		0.25	0.19	44	0		0.48	0.32	40	0
	PP		0.02	0.05	71	0		0.22	0.22	50	7		0.42	0.38	47	7
	Max LID		0.02	0.05	71	0		0.22	0.23	50	7		0.41	0.39	49	8
MHRC	Null		0.04	0.03	43	-		0.26	0.19	43	-		0.47	0.32	41	-
	GR		0.01	0.06	86	43		0.08	0.37	83	40		0.20	0.60	75	35
	PC		0.03	0.04	57	14		0.20	0.25	55	12		0.39	0.41	52	11
	Max LID	0.07	0.00	0.07	100	57	0.45	0.03	0.42	94	51	0.80	0.12	0.68	85	45
PAP	Null		0.06	0.01	14	-		0.40	0.04	10	-		0.72	0.08	10	-
	RG		0.03	0.04	57	43		0.37	0.08	19	8		0.69	0.11	14	5
	BS		0.03	0.04	57	43		0.36	0.09	21	10		0.64	0.16	20	10
	PC		0.00	0.07	100	86		0.02	0.43	96	85		0.09	0.71	89	80
	Max LID		0.00	0.07	100	86		0.00	0.45	100	90		0.00	0.80	100	90
S/S	Null		0.01	0.06	86	-		0.44	0.00	1	-		0.80	0.00	0	-
	PC		0.00	0.07	100	14		0.02	0.43	96	94		0.10	0.70	88	88

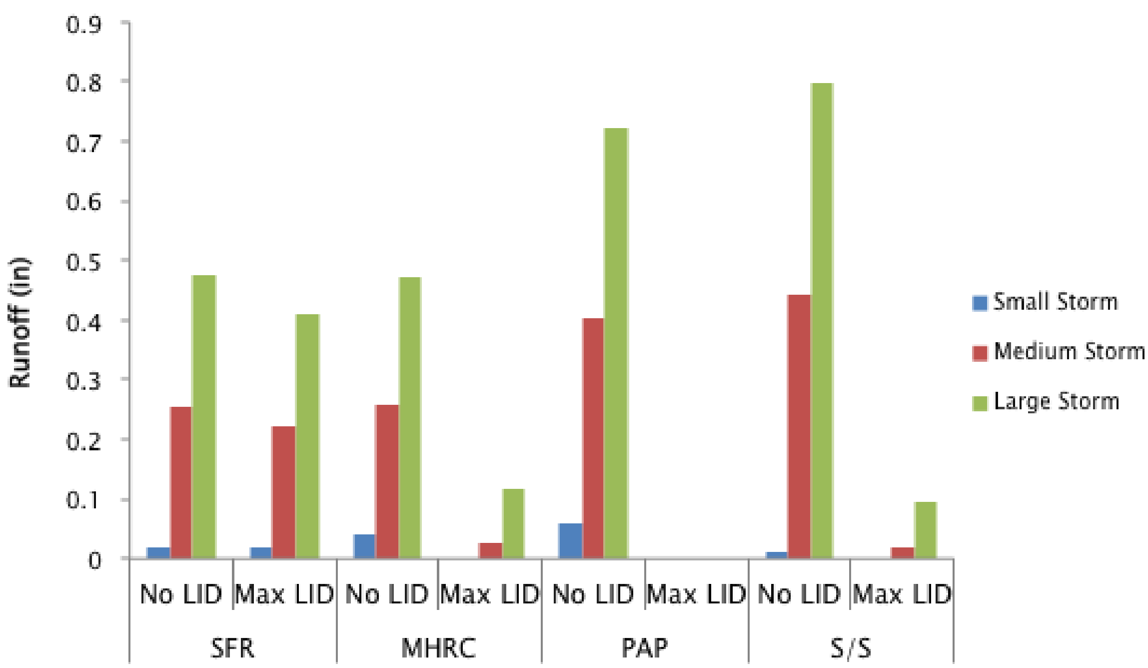


Figure 12. Comparison of percent of reduced runoff for the four land use categories between no LID measures (Null) and all (Max) LID measures for each land use for a) small, b) medium and c) large storms.

3.4 Limitations

In this analysis, the loss method used to determine the efficacy of various LID strategies during different storm scenarios was limited by the fact that only one highly permeable soil type was considered (HSG A) because, although it was the dominant type throughout the ASBS watersheds, the lower watersheds are characterized by highly impermeable soils (HSG D). The manual used to reference appropriate CN values defined that a CN below 40 should not be modeled using the SCS Loss Method. Additionally, although the CNs used were from established sources, CNs are derived from a specific location that may have greater groundwater storage capacity than Pacific Grove, which has little to no storage capacity. The level of granularity is also an issue when it comes to modeling LID technologies. For example, the model's composite curve is not capable of taking into account features of individual parcels, for example a storm drain that siphons runoff away from a nearby bioswale. LID retention values reflect how much rainfall each LID method would retain for a particular land use category rather than how that LID would handle rainfall and runoff within the modeled watershed. In the case of Pine Avenue LIDs, this meant that because the model only accounted for its own surface area and not surface runoff coming from streets above it, its 100% efficacy overestimates how it would actually perform. This also means that the model underestimates the net benefits of Pine Avenue LID strategies.

4 Water Balance

4.1 Introduction

This chapter incorporates the results of Chapter 2 and Chapter 3 into an overall water balance for the ASBS watershed. The water balance, which was the main goal of this study, examined the effects of different components of the water cycle in the dry season and the large, medium, and small storm seasons.

4.2 Methods

We estimated watershed component inputs and outputs to assess the relative impacts of the several stormwater management scenarios. The water balance was calculated using the formula in Figure 13. The formula conceptualizes the hydrologic system in equilibrium, with a long-term change in storage of 0. By generalizing the analysis, we were able to model the system according to the physical processes in a highly simplified form, which also allowed us to compare the output (untreated Qs) across changed circumstances.

We generalized our analysis by using average values for water balance components and scaling them to seasonal and annual levels. For example, the single storms described in the overview (Chapter 1.4) were used as a measure of the typical amount of precipitation in a given storm event within the season. The number of events falling within each percentile range was multiplied by the selected event for that range to generate a coarse estimate of the total precipitation for that season. We incorporated the results of the LID and Diversion Scenario 1 (DS1) models to determine their effect on annual runoff (Q_S) for the watershed.

We evaluated the water balance of the entire ASBS watershed and how it was affected by existing and proposed stormwater treatment diversion systems. The water balance incorporated the following management scenarios:

- Scenario A: Status quo, with current ASBS watershed management, including the MRWPCA Dry Weather Diversion.
- Scenario B: Proposed DS1 infrastructure improvements including the David Avenue Reservoir, Pine Avenue diversion, Point Pinos Treatment Plant and the MRWPCA wet weather diversion.
- Scenario C: LID implementation on different land use types across the entire watershed.
- Scenario D: Both infrastructure improvements and LID implementation effects combined.

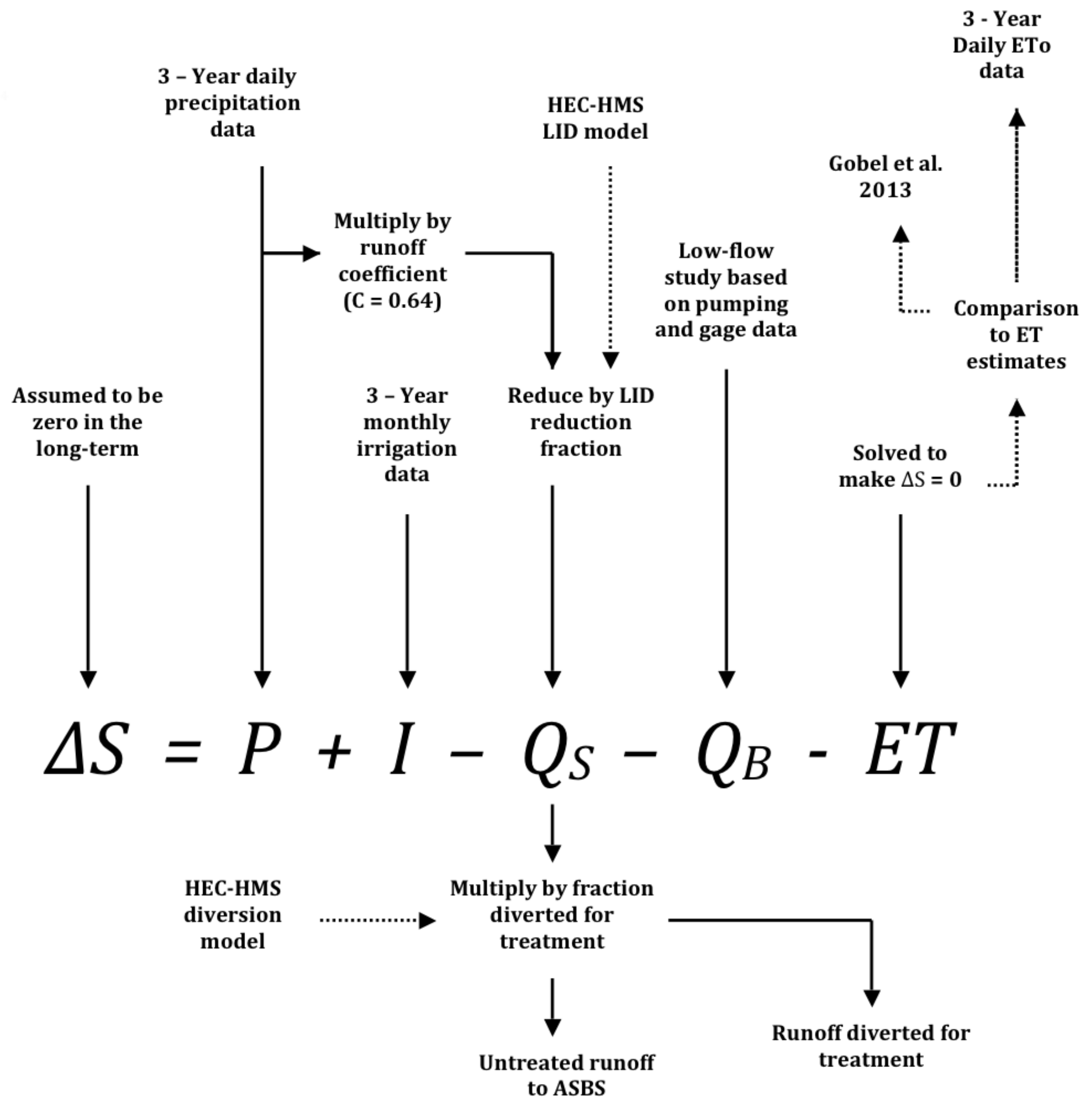


Figure 13. Water balance formula where ΔS represents change in storage, *P represents* Precipitation, I represents Irrigation, Q_S represents surface flow, Q_B represents base flow, and ET represents Evapotranspiration.

The overall change in untreated runoff delivered to the ASBS was estimated for each of these scenarios. Percentages of treated/retained and untreated/unretained runoff calculated during the treatment plant and LID modeling analyses, respectively, were used to estimate seasonal and annual untreated runoff reaching the ASBS and were then incorporated into the water balance calculations.

4.2.1 Precipitation

Daily precipitation data for WY 2010 – 2012 were used to determine average number of storm counts for each storm season. The break values for each storm season were chosen from the FCE cumulative frequency curve.

4.2.2 Irrigation

Irrigation was estimated from three and a half years of monthly California American Water residential customer data provided by the City of Pacific Grove staff. We used the minimum month method, where the month with the lowest average water use was assumed to be a baseline of indoor water use, and any amount above this was assumed to be outdoor water use (Gleick et al, 2003). The water use data was based on the entire city, so to scale to the ASBS watershed we multiplied this value by the proportion of the ASBS watershed area to the area of the entire City of Pacific Grove.

4.2.3 Surface Runoff

Surface runoff was estimated using the chosen precipitation event for each season multiplied by the number of storm events in that category, the total watershed area, and the runoff coefficient of 0.64 used by FCE in a previous study of Pacific Grove runoff (FCE 2013). An annual volume of surface runoff was estimated, as well as a volume for each storm category. The surface runoff and untreated runoff reaching the ASBS under the different scenarios were calculated using the following formulas:

$Qs = P * area * RC$, untreated $Qs = Qs - (Qs * area/total\ area * percent\ treated\ or\ retained)$,

where Q_S represents surface flow, P represents Precipitation, and RC runoff coefficient. The diversion model was incorporated into the water balance by multiplying the surface runoff by the percentages of runoff reduced by the diversions and the fractional area contributing to the diversions. The LID model was incorporated into the water balance by multiplying the surface runoff by the percentage of runoff reduced on each land use by maximum LID implementation and the fractional area of that land use. The effect of the LID on the treatment plant and diversion was modeled by subtracting the runoff reduced by LID for the watershed area contributing to the treatment plant and diversion from the total amount of untreated runoff reaching the ASBS.

4.2.4 Baseflow

Baseflow was estimated according to a low flow analysis for the Greenwood Gulch subwatershed within the ASBS watershed (Watson 2013). The low flow estimated was between 2.5 and 3.2 gallons/minute (gpm) of dry weather flow in Greenwood Park. We selected 3 gpm for a coarse estimate of the amount of baseflow for the contributing area of the watershed and extrapolated this to the entire ASBS watershed. We assumed this flow is constant throughout the year and is unrelated to precipitation events. In reality, baseflow probably increases during the wet season, and future work should account for precipitation-baseflow relationships.

4.2.5 Evapotranspiration

Since evapotranspiration (ET) is difficult to quantify accurately, we defined ET as the residual of the water balance equation. Specifically, given the estimated values for each of the other water balance components and the assumption that long-term change in storage (ΔS) equals 0, we were able to compute ET as the value that allows the change in storage to equal 0. We checked the resulting ET's proportion of the total water balance against an estimate from the literature (Gobel et al, 2013).

4.3 Results

The water balance was produced as a table in Excel (Table 7). Compared to the status quo, the combined use of diversion infrastructure improvements and watershed-wide implementation of LID strategies (Scenario D) yielded the greatest reduction in runoff into the ASBS at approximately 77%. The proposed diversion and treatment infrastructure improvements alone (Scenario B) estimated a reduction of 55%, while maximum LID implementation (Scenario C) showed a 24% reduction in the total compared to the status quo.

Table 8. The water balance for the ASBS water shed is shown by storm category and management plan. The amounts of runoff treated and untreated at Point Pinos and Marina, as described in MS 1 are also shown.

Units in acre feet (ac-ft)	Inputs		Outputs							
	Precipitation	Irrigation	ET	Surface Runoff	Baseflow	Change in Storage	Management Scenario	Total Runoff to ASBS	Runoff Diverted to Point Pinos	Runoff Diverted to Marina
Annual Total	866	67	359	554	20	0	Status quo	554		
							Max LID	422		
							Diversion	249	184	75
							Diversion + Max LID	125	147	61
Large storm days (6) >90%	342	0	6	219	0.31	117	Status quo	219		
							Max LID	155		
							Diversion	156	28	14
							Diversion + Max LID	79	19	10
Medium storm days (6) 80-90%	231	0	6	148	0.31	77	Status quo	148		
							Max LID	102		
							Diversion	92	27	15
							Diversion + Max LID	46	18	10
Small storm days (52) (<80%)	293	0	51	188	2.80	52	Status quo	188		
							Max LID	165		
							Diversion	0	128	43
							Diversion + Max LID	0	110	37
Dry days (302)	0	67	297	0	16.48	-247	Status quo	0		
							Max LID	0		
							Diversion	0	0	4
							Diversion + Max LID	0	0	4

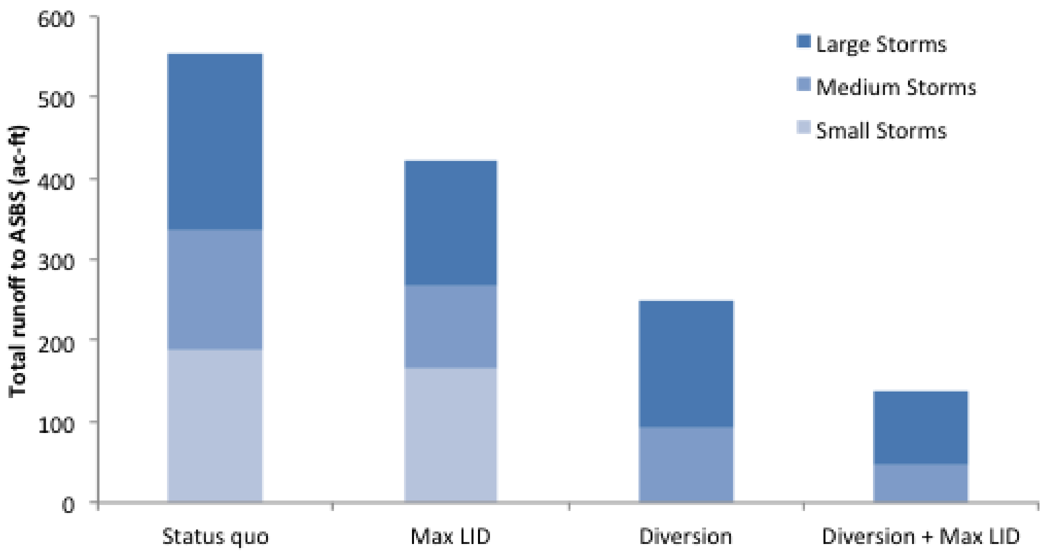


Figure 14. Annual water balance components for each modeled scenario within the ASBS watershed. Each bar is divided by the runoff contribution of the storm category.

4.4 Limitations

We made several assumptions for the entire watershed that may be inaccurate for discrete areas within the ASBS watershed but were not considered due to the broad nature of the model and time constraints.

One aspect not considered in the model was that small drainages within the Point Pinos basin drain directly into the ocean. These areas were relatively small in comparison to the entire watershed and the outputs were deemed negligible for this study. In the future, these areas could be designated as separate basins to create more accurate predictions. Gage data from the Greenwood Gulch sub-watershed provided a short period of record with which to estimate baseflow over the entire watershed. Additional flow data for the entire watershed would allow for the creation of a more accurate model. Additionally, the dry season baseflow was assumed to be sourced from shallow groundwater, irrigation waste, or sewage inflow to stormwater systems. Further field studies about sources of dry season baseflow would be valuable to both the water balance and the runoff model.

The ET estimate may contain a wide margin of error due to the lack of a simple method to measure basin-wide ET. The measurement of ET is typically used for agricultural crops of a single species and is not easily transferable to an entire watershed. The high runoff coefficient and surface runoff estimates used in this study may have resulted in an underestimate of ET.

The use of a single, very high runoff coefficient for the entire watershed in all storm sizes was a rough approximation of the total volume of runoff. In reality, runoff volume may change with land cover, slope, and precipitation intensity. A more precise estimate of the relationship between precipitation and runoff volume would require additional stream gages on outflows through the city. In addition, the short record length of precipitation data may have underestimated the actual average number of storms within each category for an average year due to the occurrence of two dry years within the three-year period. A slightly more accurate method of scaling precipitation by storm seasons could have been to scale by total rainfall in each storm season and divide by the amount of rainfall in the single storm.

In order to incorporate the lot-sized LID models into the water balance, the maximum LID implementation for each land use was chosen and applied to that land use area for the entire watershed. In reality implementation of LID may depend on the design feasibility, cost, or landowner preferences. However, this broad approach allowed for a coarse prediction of potential LID effects on the water balance.

5 Discussion and Recommendations

We generated a comprehensive seasonal and annual water balance of the ASBS watershed to give the City a framework with which to evaluate appropriate management scenarios. This analysis included coarse models of the effects of proposed stormwater diversion projects and LIDs on volume of runoff. Outputs from these models were incorporated into the overall water balance to demonstrate possible annual reduction of the City's stormwater runoff. The models were simple and made broad assumptions for the entire watershed with the goal of predicting ratios and general values rather than specific runoff volumes. A water balance did not previously exist for the City, so producing a coarse estimate for annual and seasonal runoff in this form is a new tool, which could prove useful to water resource managers tasked with prioritizing water management projects. The water balance framework can be used to incorporate more accurate models using updated or more specific data and new or updated water management scenarios.

Based on the water balance runoff predictions both diversion/treatment and LID were predicted to have substantial impact on runoff, and should continue to be pursued by the City:

- As expected, the combination of Max LID implementation and Diversion Scenario 1 (DS1) would yield the largest reduction in runoff, decreasing volume reaching the ASBS by estimated 77%.
- Modeling the effects of the proposed DS1 alone reduced the annual runoff by an estimated 55%.
- The LID implementation model had the smallest effect, reducing runoff into the ASBS by estimated 24%.

Although LID strategies did not reduce as much runoff as the stormwater diversions, they are generally more cost effective and lower in maintenance than conventional, structural stormwater controls (EPA 2000). Ideally, the City would implement both, however, not all sites are suitable for LID. Site constraints often dictate design specifications, which may limit the ability to scale LID modeling across an entire watershed. Within City property, it is prudent to implement LIDs in an area that already has a maintenance plan. This will help ensure that the facilities receive the maintenance necessary to continue functioning well without potentially incurring additional cost to the City (EPA 2000).

In addition to costs, other considerations such as soil permeability, depth of water table and slope must be considered when implementing LID strategies. Knowledge of site-specific baseflow rates and groundwater levels is key to successful design. For example, shallow soils atop impermeable rock, as exist in the Greenwood Gulch watershed, will interfere with the subsurface storage capacity and infiltration rate of permeable pavement or bioswales (Machusick 2011).

The City is considering the various diversion and treatment projects that were modeled in this study. Modeled efficacy of DS1 and DS2 were very similar. It should be noted that DS2 would require additional infrastructure. The additional costs associated with implementation of DS2 may be worthwhile if designs are adjusted to transport and treat flow at higher rates.

The State Water Resources Control Board ASBS Special Protections obligate the City of Pacific Grove to eliminate dry weather runoff and ensure that wet weather runoff does not alter natural water quality in the ASBS. One means of complying with this requirement is to divert runoff for storage and treatment before it enters the ASBS through outfall pipes leading to the ocean. Based on the results of our analysis, a combination of the proposed management scenarios and the implementation of LID strategies would help the City to meet the ASBS protection requirement by diverting or retaining an estimated 77% of stormwater runoff. Additionally, such diversions could help the City meet shortfalls in water supply.

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[USACE] United States Army Corps of Engineers. 2000. Hydrologic Modeling System. Hydrologic Engineering Center. Technical Reference Manual.

[USCB] United States Census Bureau 2010 Census Urban Area List http://www2.census.gov/geo/ua/ua_list_ua.xls 2010 Census Urban Area

[USDA] United States Department of Agriculture. June 1986. Urban Hydrology for Small Watersheds. National Resource Conservation Service. Conservation Engineering Division. Technical Release 55.

[USEPA] United States Environmental Protection Agency Office of Water. 2000. Bioretention Applications - Inglewood Demonstration Project, Largo, Maryland, and Florida Aquarium, Tampa, Florida. EPA-841-B-00-005A.

[USEPA] United States Environmental Protection Agency, Office of Water and Low Impact Development Center, Low Impact Development (LID); A Literature Review , EPA-841-B-00-005, Washington, DC, October, 2000.

[UDT] Urban Design Tools. 2007. Low Impact Development. Bioretention. Watershed Benefits - Pollutant Filtering. Accessed on 10/09/2013. Available from: http://www.lid-stormwater.net/bio_benefits.htm

Appendix A: Hydrographs

Model graphs were smoothed using 20 minute moving averages.

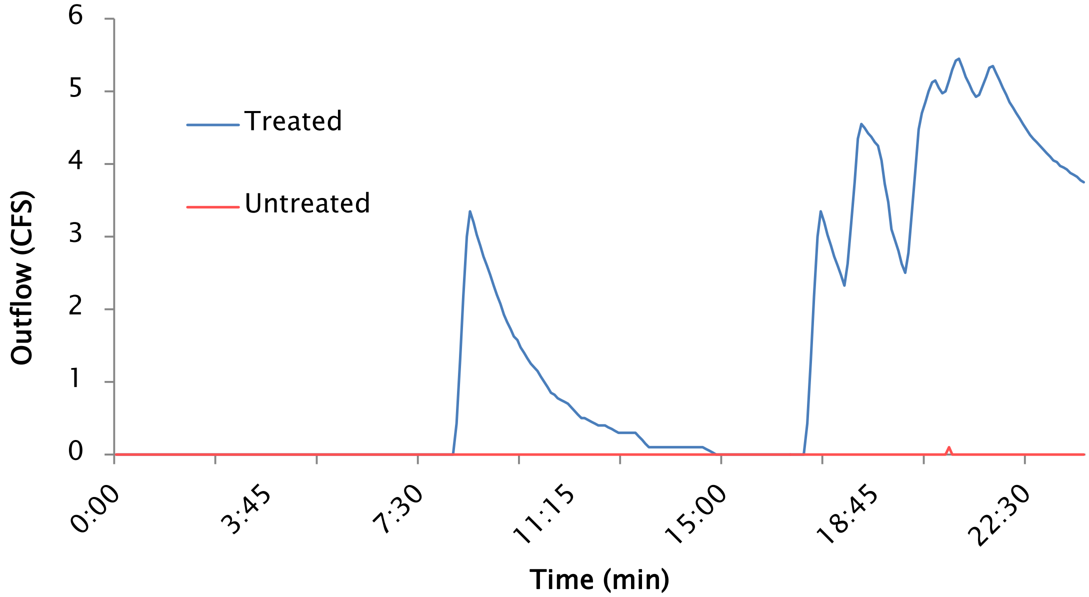

Figure 15. Hydrograph of total treated and untreated runoff under Diversion Scenario 1 during a 40th percentile storm.

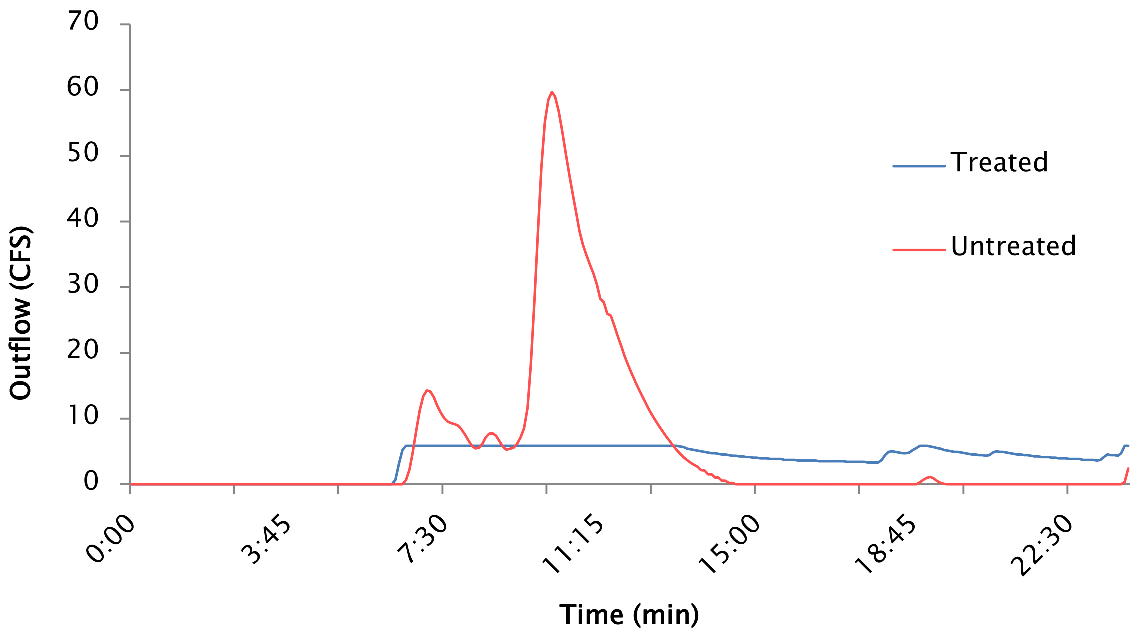

Figure 16. Hydrograph of total treated and untreated runoff under Diversion Scenario 1 during an 85th precentile storm.

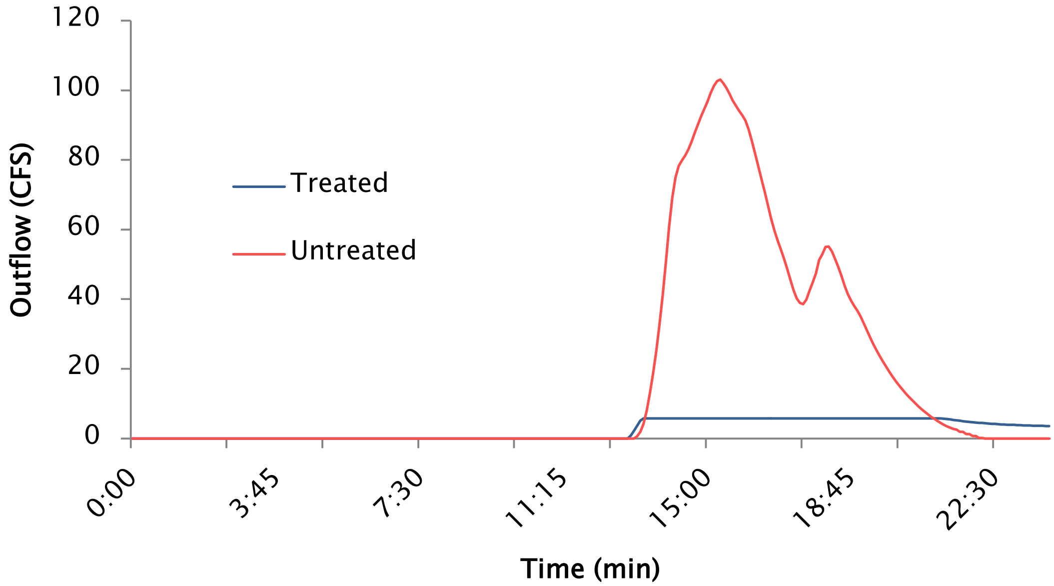

Figure 17. Hydrograph of total treated and untreated runoff under Diversion Scenario 1 during a 95th percentile storm. Model graphs were smoothed using 20 minute moving averages.

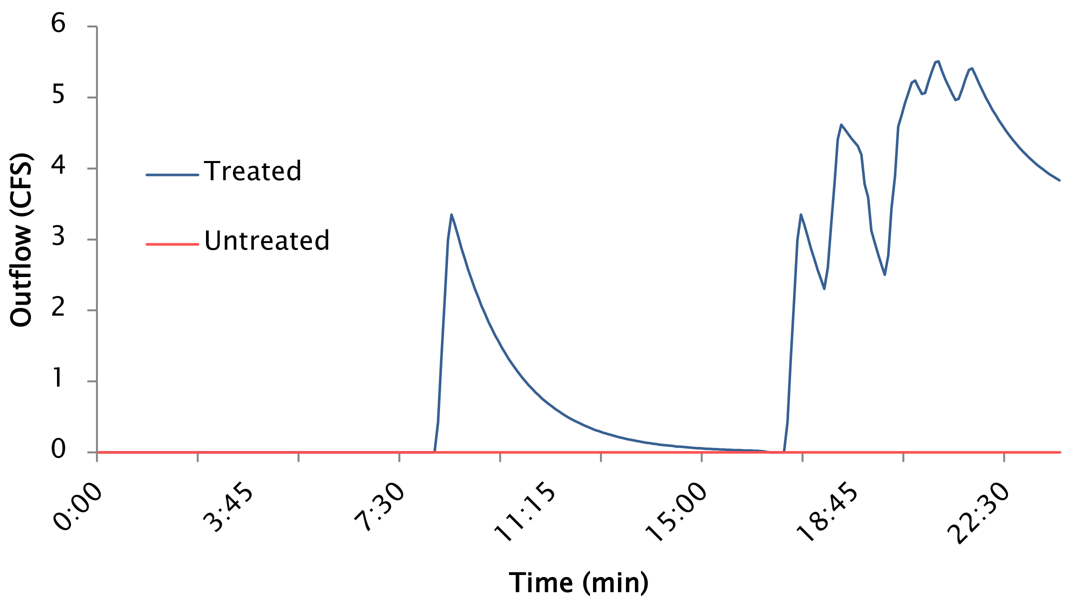

Figure 18. Hydrograph of total treated and untreated runoff under Diversion Scenario 2 during a 40th percentile storm.

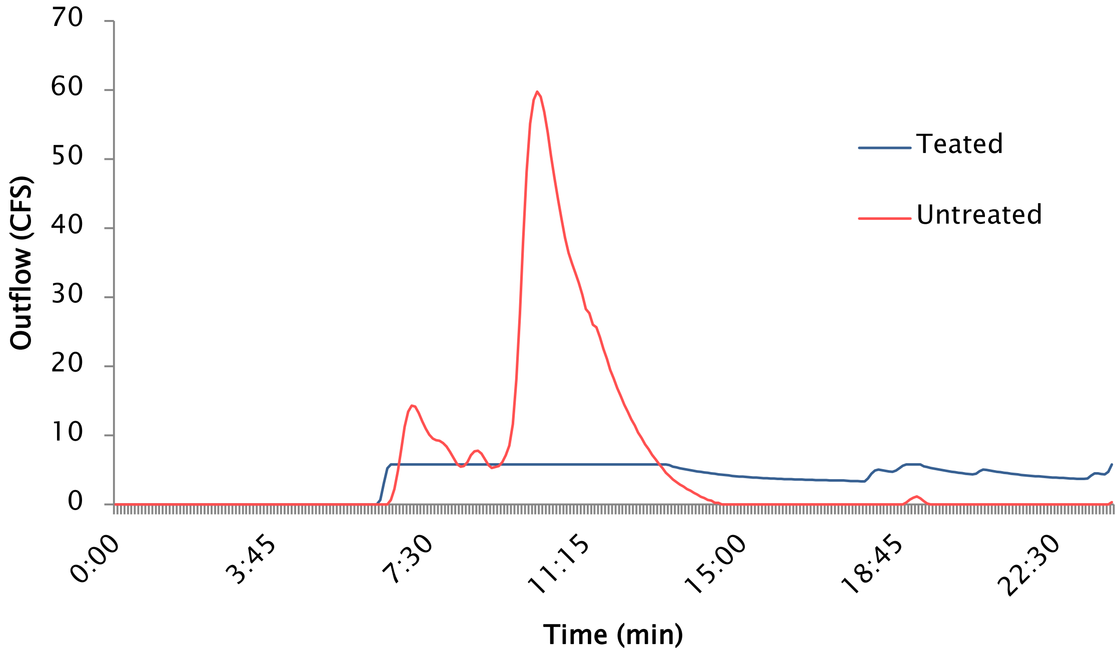

Figure 19. Hydrograph of total treated and untreated runoff under Diversion Scenario 2 during a 85th percentile storm.

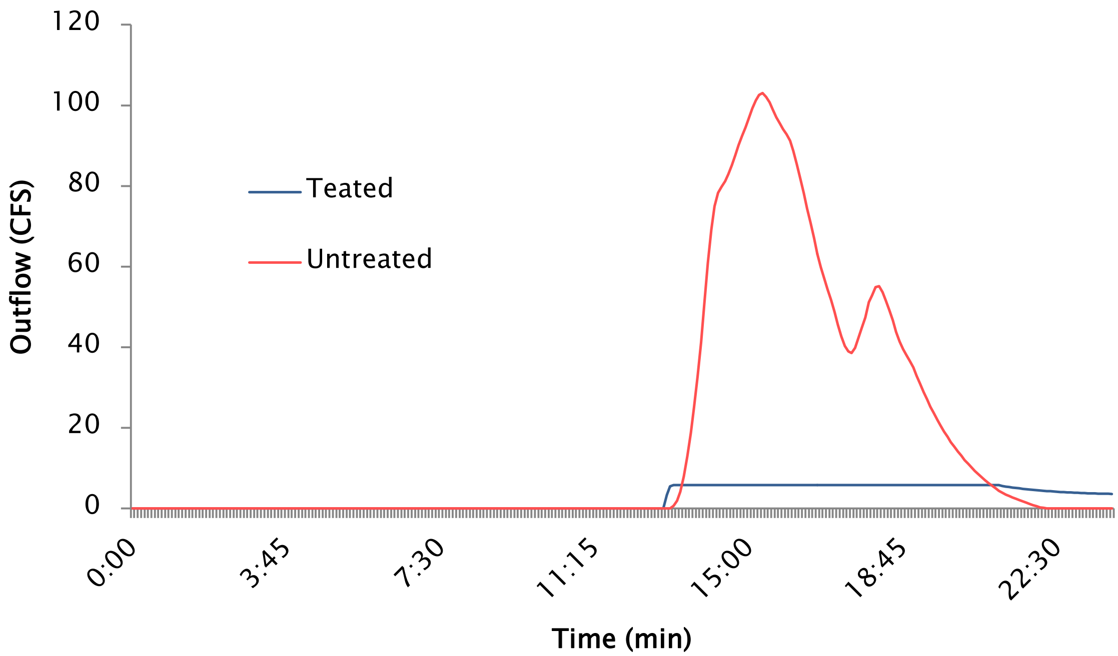

Figure 20. Hydrograph of total treated and untreated runoff under Diversion Scenario 2 during a 95th percentile storm.

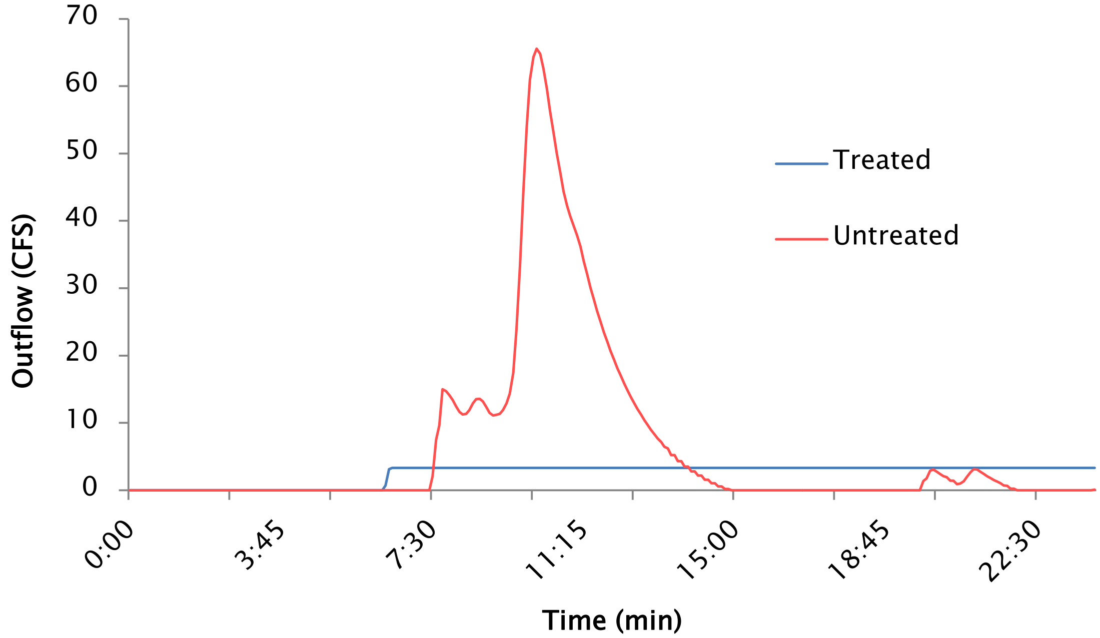

Figure 21. Hydrograph of total treated and untreated runoff under Diversion Scenario 3 during a 40th percentile storm.

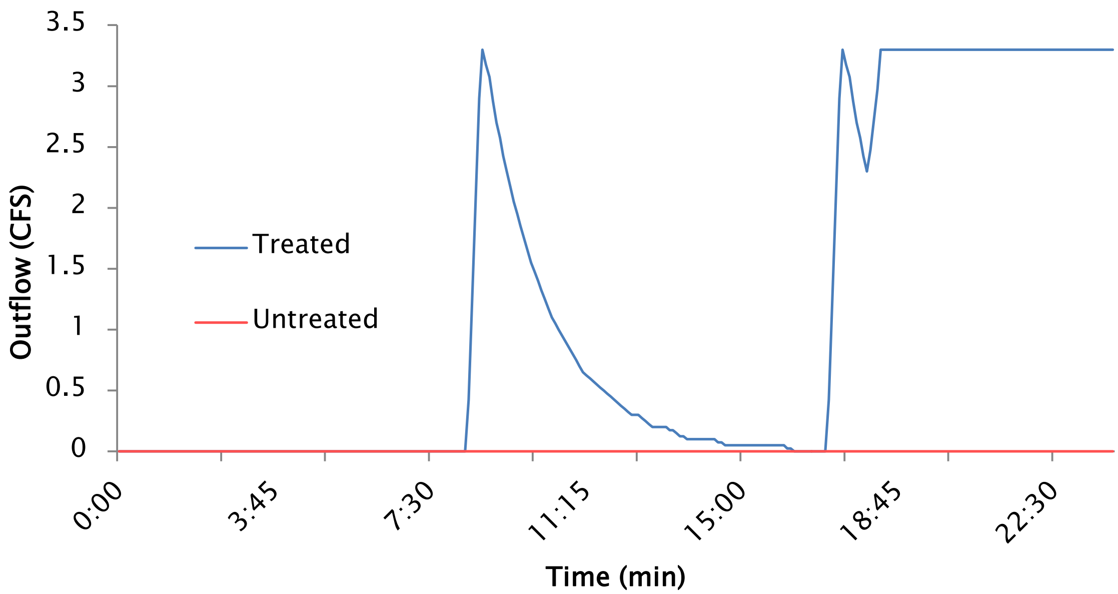

Figure 22. Hydrograph of total treated and untreated runoff under Diversion Scenario 3 during an 85th percentile storm.

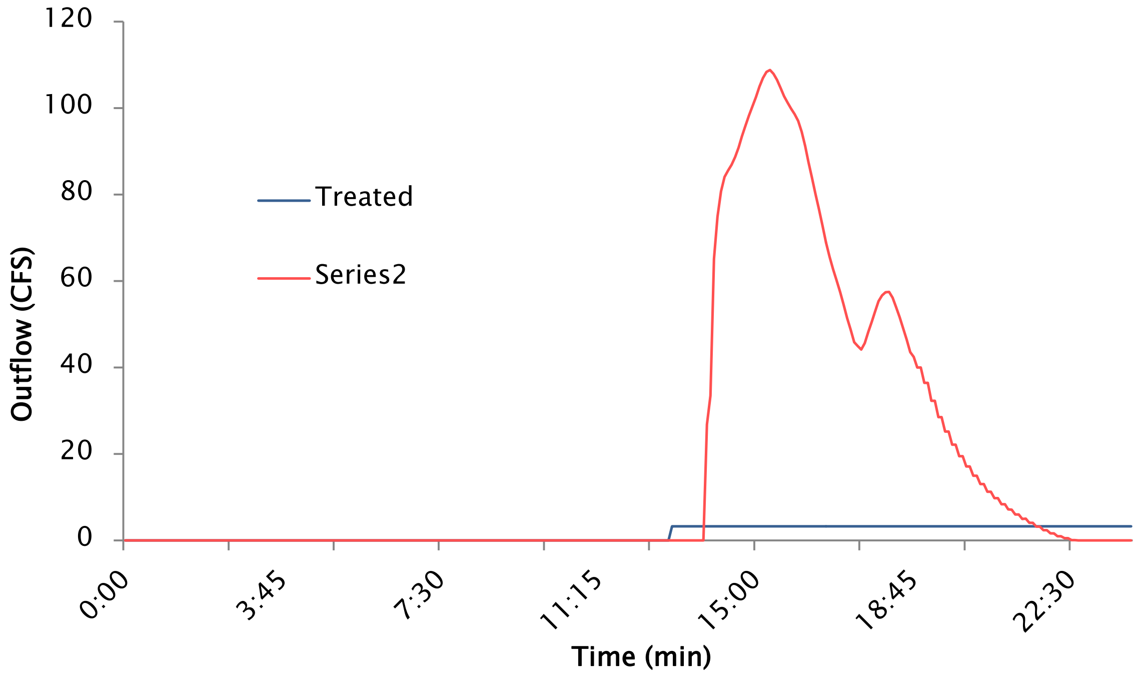

Figure 23. Hydrograph of total treated and untreated runoff under Diversion Scenario 3 during an 95th percentile storm.

Appendix B: LID Area Parameters

	LID	Area (ft^2)	Area (%)
SFR	Rain barrel	327	1
	Rain garden	2,004	37
	Pervious pavers	392	7
	House (roof)	3,006	55
	Total	**5,728**	**100**
MHRC	Pre-existing veg	2,038	52
	Green roof	548	14
	Pervious concrete	1,359	34
	Total	**3,945**	**100**
Streets	Rain garden	21,240	9
	Bioswale	46,620	21
	Pervious concrete	158,340	70
	Total	**226,200**	**100**

Appendix C: Water Measurement Conversion Table

CFS	GPM	AFY
1.00	448.83	724.45
0.00	1.00	1.61
0.00	0.62	1.00

CF	Gallons	AF
1.00	7.48	0.00
0.13	1.00	0.00
43560.00	325851.43	1.00

Appendix D: Archived Spatial Data

Printable maps and ArcGIS shapefiles used in this report can be accessed from the Central Coast Watershed Studies website at http://ccows.csumb.edu/pubs/ (2011 Class Reports).

Appendix E: Water Balance Summary Poster

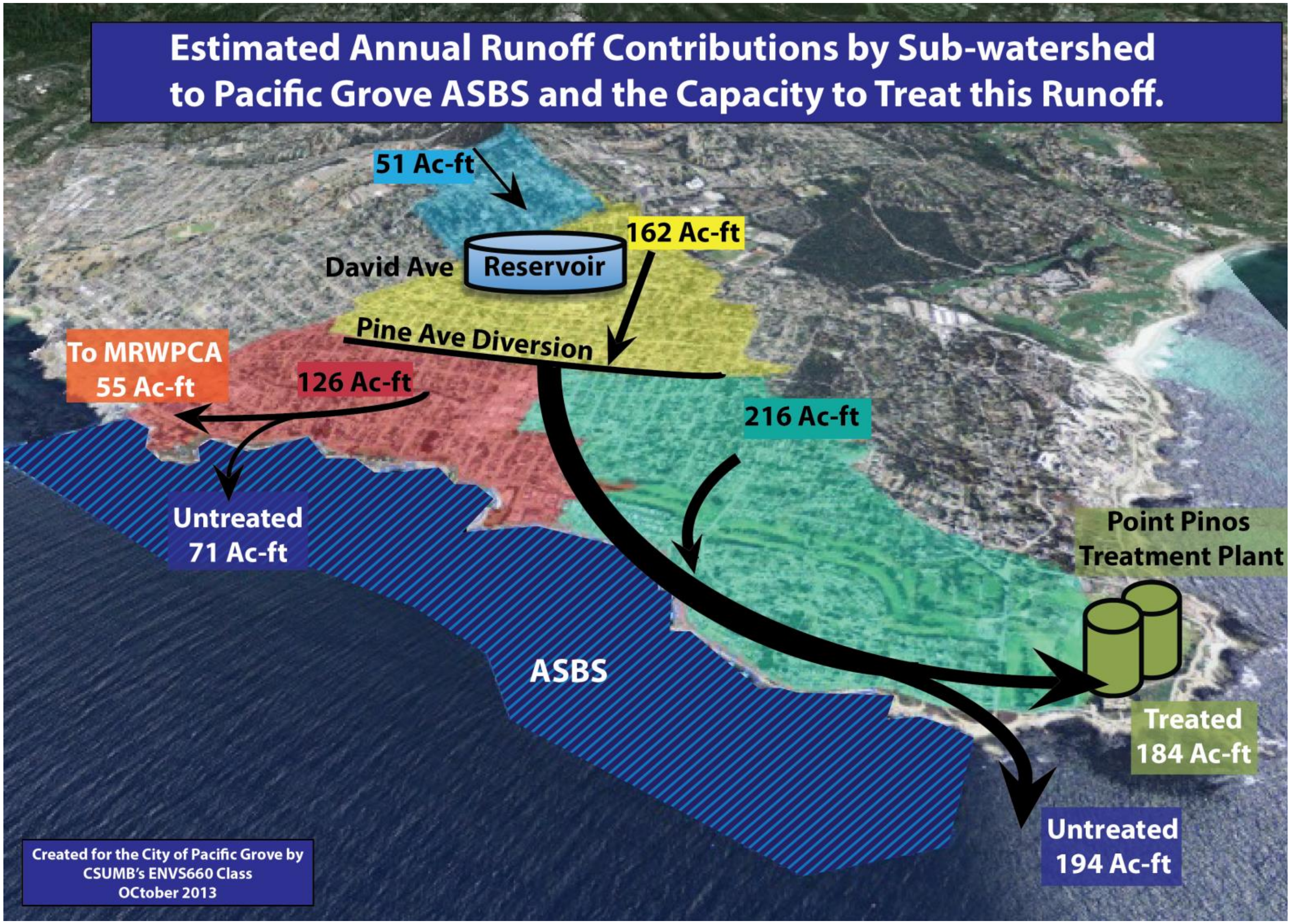

Figure 17. Estimated annual runoff contributions by sub-watershed to Pacific Grove ASBS with the size of arrows representing the capacity to treat runoff.