Comparison of Gray versus Green Infrastructure Solutions for the Vulcan Avenue\Union Street\Orpheus Street\Encinitas Boulevard Drainage Improvements

Submitted to:

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1. Introduction

Localized urban flooding can create nuisance conditions, threaten the safety of drivers, and cause property damage. Traditionally, urban flooding has been alleviated by increasing the capacity of the drainage system (namely gutters and storm drains) to convey runoff and prevent flooding during storms that produce excessive runoff rates. A tradeoff of this strategy is that pollutants in stormwater are piped directly to the receiving waters, which can cause serious water quality impairments. It has often been assumed that traditional practices for stormwater management (gray infrastructure) are better suited for flood mitigation and flood control than green infrastructure and that green infrastructure solutions will cost more to implement than typical gray infrastructure for stormwater management. However, recent research has indicated that green infrastructure practices can, when implemented and maintained properly, not only improve water quality but also provide retention at the runoff source, decreasing the runoff volume entering the drainage network and the demand on a drainage system. Developed watersheds can benefit from the added storage from areas retrofitted with bioretention, permeable pavement, and/or other green infrastructure practices.

The Vulcan Avenue neighborhood, located between Leucadia Boulevard and Encinitas Boulevard in the City of Encinitas, is drained by several lateral connections that convey stormwater runoff to an undersized storm drain system under Coast Highway 101 at a constant rate regulated by an orifice plate in the laterals. Because the drainage network is undersized and flows through the laterals are restricted, Vulcan Avenue and surrounding areas experience flooding even during small and frequent storm events less than the 85th percentile. Therefore, implementation of green infrastructure along Vulcan Avenue and in sump areas can effectively reduce the extent of flooding.

This report describes the investigation of the potential for green infrastructure, including permeable pavement and bioretention, to address urban flooding while simultaneously protecting surface waters from pollution. A cost-effective solution that provides flood control and flood mitigation while addressing water quality requirements will be recommended. These solutions will also provide multiple other benefits to the surrounding community, such as enhanced aesthetics, drainage, safety, and sense of well-being. They also will promote a healthier, greener and more sustainable urban landscape.

2. Background

The neighborhood surrounding Vulcan Avenue, east of Interstate 5 between Leucadia Boulevard and Encinitas Boulevard, has experienced substantial localized flooding in recent years. Flooding has historically occurred in this area along and adjacent to Vulcan Avenue, between Union Street and Orpheus Avenue. This area contains several sump areas that historically were not connected to an underground storm drain system. Therefore, during storm events, stormwater runoff ponded along Puebla Street, Union Street, Vulcan Avenue, and within the North County Transit District (NCTD) right-of-way until it eventually infiltrated into the ground, evaporated, or was otherwise removed from the sump area.

2.1. Existing Flooding Problems

In 2001 and 2003, the City of Encinitas enhanced the storm drain system to reduce the extent of flooding produced during small and frequent storm events. The enhancement included the installation of several laterals (2001) and orifice plates in the laterals (2003) to convey the stormwater runoff along Vulcan Avenue and sump areas to a 24-inch storm drain under Coast Highway 101 (main line). The main line begins near Union Street, flows in the northerly direction, and outlets into the two detention basins located in series just north of La Costa Avenue. Although the improvements result in lower ponded water elevations and reduced flooding in detention areas, the area is still suffering from flooding (Rick Engineering, 2003).

Rick Engineering Company conducted a detailed hydrologic and hydraulic analysis for Coast Highway 101 (between Encinitas Boulevard and La Costa Avenue), dated November 18, 2003 and January 28, 2005, to analyze inundation of City streets and private properties during frequent storm events. According to the study, approximately 320 acres drain to a 24-inch RCP pipe under Highway 101 via lateral connections. The drain is significantly undersized as storm events exceeding a 1-year storm overtax the system and cause flooding. Therefore, the City installed orifice plates in storm drain laterals to regulate the flow rate entering the storm drain. 128.7 acres of that respective area are located east of Highway 101 between Leucadia Boulevard and Encinitas Boulevard. This area is drained to the main line via an 18-inch storm drain line under Vulcan Avenue (Vulcan Avenue line) and a lateral connection under Cereus Street with a total constant rate of 1 cfs (Figure 1). The study concluded that during any storm event that produces a runoff flow rate greater than 1 cfs, stormwater runoff from that 128.7 acres will pond along Vulcan Avenue within the NCTD right-of-way and flood the area, particularly the intersection of Vulcan Avenue and Union Street. There is also a sump area in the vicinity of the intersection of Orpheus Avenue and Hymettus Avenue that is not connected to any storm drain. During a storm event, runoff from the surrounding area ponds in that sump area and causes flooding on the property of multiple residents. Figure 2 indicates the flooding areas.

Figure 1. Study area

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS

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Figure 2. Flooding areas

Table 1 reports flooding events that have been documented by the City in the last 15 years, although additional undocumented events may have occurred during this period.

Table 1. Historical rainfall events resulting in flooding

Event Date	Observed 24-Hour Storm Depth (approximate)	Average 24-Hour Storm Recurrence Interval (Annual Probability)[1]	Runoff Peak Flow Rate from Long-Term Modeling Data
October 20, 2004	2.7 inches	≈ 5-year Storm (20% Annual Probability)	9 cfs
December 18, 2010	2.0 inches	≈ 2-year Storm (50% Annual Probability)	*N/A – Outside Period of Available Data*

[1] Per County of San Diego Department of Public Works Flood Control Division (2003), the 2-year, 24-hour and 5-year, 24-hour storms in coastal areas of Encinitas are 1.8 inches and 2.5 inches, respectively.

2.2. Existing Water Quality Impairments

Multiple pollutants currently impair the beneficial uses of the Pacific Ocean Shoreline at Moonlight Beach. To address these impairments, the San Diego Regional Water Quality Control Board (Regional Board) adopted Order R9-2013-0001—National Pollutants Discharge Elimination System (NPDES) Permit and Waste Discharge Requirements for Discharges from the Municipal Separate Storm Sewer Systems (MS4) Draining the Watersheds within the San Diego Region (Municipal Permit). The Municipal Permit requires the owners of storm drain systems to implement management programs to limit discharges of non-stormwater runoff and pollutants from the storm drain systems. Recently prepared water quality improvement plans (WQIPs) prescribe collaborative and adaptive strategies for the Responsible Agencies to attain compliance with the requirements of the Municipal Permit.

The study area addressed in this report, the Vulcan Avenue neighborhood, falls within the Lower San Marcos Hydrologic Area (HA), which is located in the Carlsbad Watershed Management Area (WMA). A WQIP was created for Carlsbad WMA, and the Pacific Ocean Shoreline segment at Moonlight Beach was one of the main focus areas identified in the Lower San Marcos HA. The shoreline at Moonlight Beach is identified as impaired with the Regional Board's Resolution No. R9-2010-0001—*Revised Total Maximum Daily Loads (TMDL) for Indicator Bacteria, Project I – Twenty Beaches and Creeks in the San Diego Region (Including Tecolote Creek)* (Bacteria TMDL). Therefore, the City of Encinitas has begun to implement programmatic strategies throughout its jurisdiction to control pollutants and non-stormwater discharges from its MS4 system. Thus, implementing green infrastructure in this area will not only reduce the peak flow rate of stormwater discharges and provide flood mitigation cobenefits, but will also improve quality of the runoff from the area in a cost-effective manner.

3. Gray Infrastructure Evaluation

A preliminary drainage study and hydraulic analysis were performed for the Vulcan Avenue neighborhood to determine the size and capacity of the storm drains that could alleviate flooding during the 5-year, 10-year, 50-year, and 100-year, 24-hour design storm events. Per the County of San Diego Hydrology Manual isohyetal map (2003), the 50-year and 100-year rainfall depths in coastal areas of Encinitas are the same (50/100-year, 6-hour and 50/100-year, 24-hour rainfall depths are 2.5 inches and 4 inches, respectively); therefore, the analysis for these two storm events was performed together.

3.1. Hydrology

The U.S. Army Corps of Engineers HEC-HMS (Hydrologic Engineering Center-Hydrologic Modeling System) computer program was used to determine peak flow rates of the tributary areas to the main line located at Cereus Street. The HEC-HMS analyses were based on the Natural Resources Conservation Service (NRCS) hydrologic method (formerly known as the soil conservation service [SCS]) and performed for the existing conditions. As mentioned earlier, 128.7 acres drain through four subbasins (SB 1b, SB 1a, SB1, and SB 2) to the main line via the Vulcan Avenue line and line A. A 23.8-acre area that is not connected to any storm drain system drains through one subbasin (SB7) (Figure 3). Hydrologic parameters and drainage boundaries of the subbasins were obtained from the report prepared by Rick Engineering Company, dated November, 18, 2003, and summarized in Table 2 below.

Table 2. Hydrologic parameters

Subbasin ID	Subbasin Area (acre)	CN	Lag Time (min)
SB 1a	8.4	60	8.33
SB 1b	22.3	65	9.76
SB 1	59	61	16.94
SB 2	39	67	8.68
SB 7	23.8	67	9.60

The 5-year, 10-year, and 50/100-year rainfall depths were derived from the County of San Diego Hydrology Manual isohyetal map to generate the nested rainfall distribution for each design storm event. The nested storm pattern is a synthetic storm with the maximum rainfall intensities for a given storm frequency nested for duration between 5 minutes and 24 hours and shall be used for the flood flow computations (County of San Diego Hydrology Manual, 2003).

The subbasin parameters were then entered into the HEC-HMS hydrologic model along with the generated nested rainfall distributions to determine the peak of the runoff rates. The results of the HEC-HMS hydrologic model are summarized in Table 3.

Table 3. HEC-HMS peak flowrate summary

Subbasin ID	Design Storm Event/Peak Flowrate (cfs)		
	5-Year	10-Year	50/100-Year
SB 1a	1.4	2.9	7.4
SB 1b	7.0	11.5	24.7
SB 1	7.8	15.8	40.2
SB 2	15.8	24.2	49.4
SB 7	8.2	13.2	28.2
Junction 1 (SB 7 and SB 1b combined)	15.2	24.7	52.8
Junction 3 (all subbasins combined)	37.5	63.9	142.5

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community, Esri, HERE, DeLorme, TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

Figure 3. Target drainage area (Rick Engineering, 2003)

3.2. Hydraulic

The Federal Highway Administration (FHWA) Hydraulic Toolbox was used to determine the required pipe sizes to convey the peak flow rate produced by the design storm events. The HEC-HMS flow rates were entered into the Hydraulic Toolbox, and the pipe sizes required to convey the runoff produced by the 5-year, 10-year, and 50/100-year, 24-hour events, without causing flooding, were calculated.

3.2.1. Existing Hydraulic Condition

Under existing condition, SB 1a, 1b and 1 drain to the headwall of the 18-inch Vulcan Avenue line located along the western side of Vulcan Avenue between El Portal Street and Basil Street. Stormwater runoff from SB 1b is directed to Orpheus Avenue via a storm drain at Union Street and Orpheus Avenue where it then combines with runoff from SB 1a and SB 1 and ultimately drains to the headwall entrance of the main line (Rick Engineering, 2003). There is also a storm drain at the intersection of Cereus Street and Hermes Avenue (line A) that extends westerly to Vulcan Avenue. Stormwater runoff from SB 2 drains to line A, which joins the Vulcan Avenue line approximately east of the intersection of Basil Street and Highway 101. These two lines then join the main line under Highway 101. An orifice plate is installed at the junction of the Vulcan Avenue line and line A to regulate flow into the main storm drain to 1 cfs. As previously mentioned, SB 7 is not connected to any storm drain.

3.2.2. Proposed Hydraulic Condition

Under proposed conditions, a new storm drain system would be installed under Orpheus Avenue (south of Puebla Street) and Vulcan Avenue (between Cereus Street and Encinitas Boulevard) to convey stormwater runoff from SB 1a, 1b, 1, 2, and 7 southerly to an existing 96-inch storm drain under Encinitas Boulevard, which eventually discharges to Cottonwood Creek. The existing Vulcan Avenue line would have to be disconnected from the main line and regraded to convey the water counter grade to the south rather than to the north. The storm drain at Union Street and Orpheus Avenue would also need to be upsized. Table 4 and Figure 4 show the proposed pipe sizes and locations required to eliminate flooding caused by the 5-year, 10-year, and 50/100-year, 24-hour event from the study area. In addition to the evaluating the design storm, a long term simulation was performed, utilizing rainfall and runoff data from 2000 to 2010. The Long Term Simulation Column shows the pipe sizes required to reduce flooding for the typical event that occurred between 2000 and 2010. This configuration will be compared to proposed green infrastructure solutions in the following sections. The configurations of the pipes are the same for all storm events.

Table 4. Proposed pipe sizes and locations

Pipe Location	Pipe Size (inch)			
	Long Term Simulation	Design Storm Event		
		5-Year	10-Year	50/100-Year
Orpheus Avenue (from Puebla Street to the intersection of Union Street and Orpheus Avenue)	24	18	24	30
Orpheus Avenue (from Union Street to Vulcan Avenue)	24	24	30	36
Vulcan Avenue (from Cereus Street to Encinitas Boulevard)	24	36	42	54
Cost	**$1,874,939**	**$1,961,592**	**$2,087,301**	**$2,328,126**

The total construction cost for the 5-year, 10-year and 50/100-year improvements will be $1,961,592, $2,087,301 and $2,328,126, respectively.

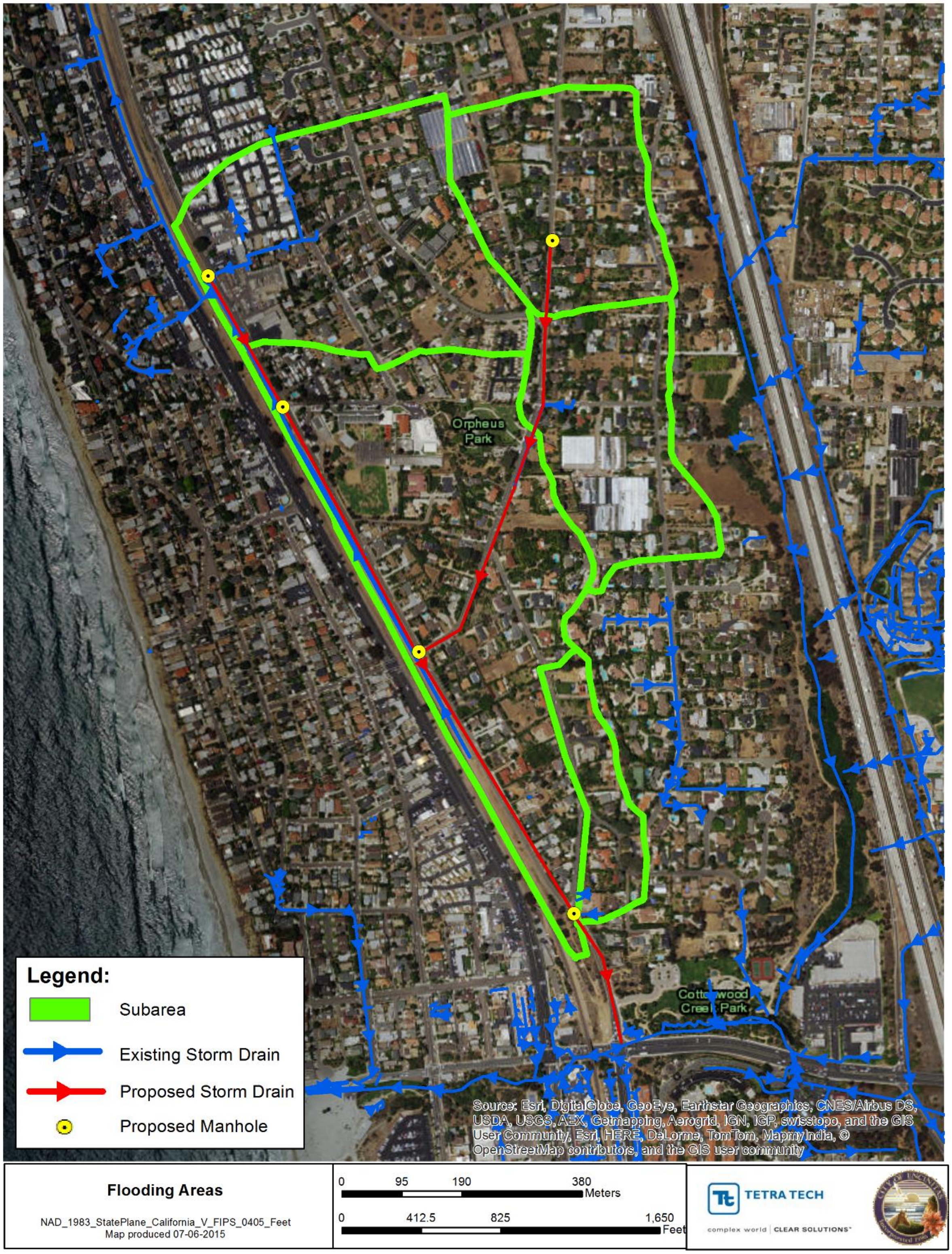

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Figure 4. Proposed gray infrastructure solution

4. Green Infrastructure Design and Evaluation

Integrating green infrastructure with gray infrastructure within the Vulcan Avenue neighborhood between Leucadia Boulevard and Encinitas Boulevard, which currently utilizes significantly undersized traditional stormwater management practices, can expand the benefit of the system beyond its original function. Incorporating treatment through green infrastructure not only improves water quality but also reduces the peak flow rate of stormwater discharges and provides flood mitigation in a cost-effective manner. The green infrastructure will also provide numerous advantages to the City, such as improvement to the community's overall well-being, increased property values, enhanced aesthetics, and recreational opportunities. This section outlines the general methodology and metrics that were used to assess the green infrastructure performance.

4.1. Site Location and Description

The drainage area, located in a coastal community, is highly developed with mixed land uses and high-to-moderate relief terrain. Table 5 presents the different types of land uses and their allocation percentages within the Vulcan Avenue drainage area. Single and multi-family residential comprise 67 percent of the area, followed by transportation (17 percent), open space (5 percent), institutional (5 percent), agricultural (3 percent), and commercial (3 percent).

Table 5. Distribution of land uses

Land Use type	Acres	Percent
Commercial	3.9	2.6
Agriculture	5.0	3.3
Institutional	7.2	4.7
Open Space	8.4	5.5
Transportation	26.1	17.1
Residential	101.9	66.8
Total	**152.5**	**100%**

4.2. Geotechnical Investigation

The soil type information was obtained from the 2003 Rick Engineering hydrologic report. The soil type is based on the United States Department of Agricultural Soil Survey for San Diego County and consists mainly of Type A soil.

4.3. Modeling Methodology

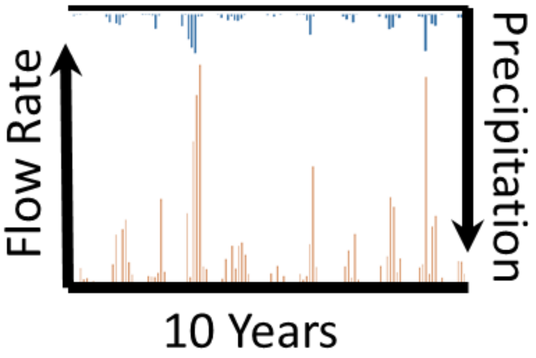
The most cost-effective hydrologic and water quality benefits can only be realized by evaluating a range of possible alternative green infrastructure designs and sizes to determine the optimum configuration. Such an approach maximizes the City's return per dollar spent. To evaluate the potential green infrastructure opportunities within the Vulcan Avenue neighborhood, the U.S. Environmental Protection Agency's (EPA) System for Urban Stormwater Treatment and Analysis Integration (SUSTAIN) model was configured for the site to simulate the hydrology of the contributing drainage area and the hydraulics of the green infrastructure.

4.3.1. Green Infrastructure Modeling (SUSTAIN)

SUSTAIN was developed by the EPA Office of Research and Development to facilitate selection and placement of BMPs and green infrastructure techniques at strategic locations in urban watersheds. It assists to develop, evaluate, and select optimal green infrastructure combinations at various watershed scales on the basis of cost and effectiveness. In this study, the green infrastructure effectiveness was measured based on the runoff volume reduction, decreasing flooding days per year, and the reduction of bacteria counts.

To optimize the impacts of the green infrastructures, SUSTAIN simulates thousands of implementation scenarios by varying design dimensions of multiple green infrastructure combinations, resulting in a cost and benefit (in this case, reduction in frequency of flooding events and bacteria counts) for each scenario. When all resulting scenarios are plotted, a threshold curve of cost versus effectiveness is generated and assists in selecting the cost-optimal green infrastructure size. Bioretention and permeable pavement were selected for evaluation.

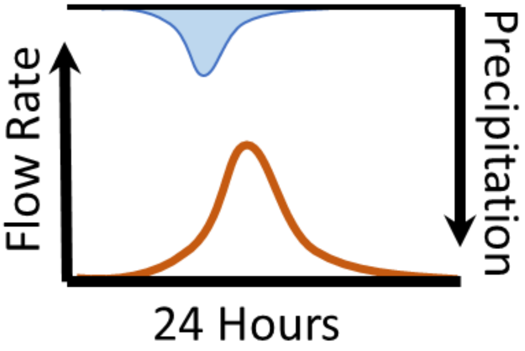
For this study, the cost-effectiveness curve was generated for daily flow exceedance and annual bacteria removal using 10 years of rainfall and runoff data from 2000 to 2010. Results were also generated for the 85th percentile, 5-year, 10-year, and 50/100-year, 24-hour design storms to determine the optimal green infrastructure combinations required for eliminating flooding during each design storm event. It is important to realize the differences between the design storm and long-term modeling scenarios; Figure 5 illustrates the key differences. Long-term simulations are generally preferred for green infrastructure optimization because the dynamic effects of actual antecedent conditions and subsequent storm events are represented.



Long-Term Simulation

Continuous simulation from year 2000 through 2010 using hourly input data.

Median Annual Runoff = 47 ac-ft
Min. Annual Runoff = 26 ac-ft (2002)
Max. Annual Runoff = 104 ac-ft (2005)
Average Annual Peak Flow = 50 cfs
Max. Peak Flow = 128.8 cfs (2004)



85th percentile

Hypothetical 24-hour storm pattern whose precipitation total is greater than or equal to 85 percent of all 24-hour storms on an annual basis.

Total Rainfall Depth = 0.6 inches
Peak Flow Rate = 4.6 cfs
Runoff Volume = 3.6 ac-ft

5-year, 24-hour

Hypothetical 24-hour storm pattern and intensity based on the storm depth that has a 20 percent probability of occurring in any given year.

Total Rainfall Depth = 2.5 inches
Peak Flow Rate = 37.5 cfs
Runoff Volume = 3.3 ac-ft

10-year, 24-hour

Hypothetical 24-hour storm pattern and intensity based on the storm depth that has a 10 percent probability of occurring in any given year.

Total Rainfall Depth = 3.0 inches
Peak Flow Rate = 63.9 cfs
Runoff Volume = 5.6 ac-ft

50/100-year, 24-hour

Hypothetical 50-year and 100-year, 24-hour storm pattern and intensity based on the storm depth that has a 2 percent and 1 percent probability of occurring in any given year, respectively.

Total Rainfall Depth = 4.0 inches
Peak Flow Rate = 142.5 cfs
Runoff Volume = 12.6 ac-ft

Figure 5. Conceptual comparison of design storm and long-term simulation scenarios

The simulated green infrastructure configurations are generally consistent with those in the Cottonwood Creek Watershed LID Retrofit Plan, although a sensitivity analysis was performed to optimize green infrastructure practice depths, and surface ponding depth was increased to 12 inches (consistent with the City of Encinitas Engineering Design Manual 2013). Figure 6 illustrates the general bioretention and permeable pavement configurations that were modeled.

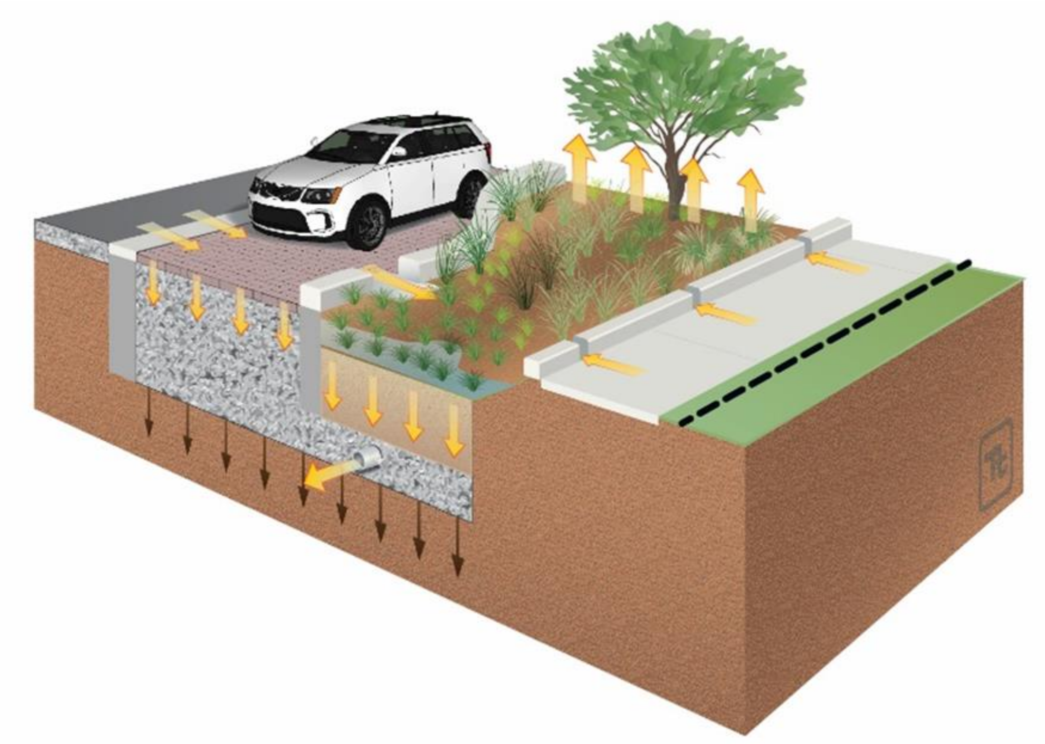


Figure 6. Conceptual schematic of modeled green infrastructure with bioretention and permeable pavement (left). Arrows indicate potential water flow paths.

4.4. Performance Metrics

Measureable performance targets were established to evaluate the benefits of green infrastructure using the model output. The metrics, tabulated in Table 6, are directly related to the existing flooding problems described in Section 2.1 and provide a range of potential design goals.

Table 6. Performance evaluation metrics

Goal	Model Scenario	Target	Threshold Value
Reduce Flooding	Long-Term Simulation (2000-2010)	Attenuate Flow to Thresholds	*1 cfs (regulated flow rate that drains the study area)*
	Design Storm Simulation	Attenuate Flow to Thresholds	*1 cfs (regulated flow rate that drains the study area)*
		Capture the Runoff Volume	100% removal

5. Green Infrastructure Modeling Results and Discussion

This section presents the potential green infrastructure solutions for addressing the flooding problems described in Section 2.1 per the performance metrics introduced in Section 4.4.

5.1. Solutions for Flooding

Green infrastructure is best suited to treat small, frequent storm events. Nevertheless, results indicate that mitigation of nuisance flooding can be achieved by green infrastructure. Figure 7 shows the long-term model results comparing dollars invested in green infrastructure versus the average annual flooding frequency. Each point along the curve represents a unique configuration and capacity of green infrastructure within the drainage area.

Figure 7 presents a “sliding scale” that can be used as a decision support tool when planning the extent of green infrastructure. Using a regression analysis, the point of diminishing returns (PDR) was identified as the most cost effective solution. However, to eliminate flooding as much as possible, the maximum available green infrastructure sizes were selected as the target design size for implementation. The selected green infrastructure sizes resulted in the combination of bioretention and permeable pavement sizes of 45,000 and 7,350 square feet with retention volumes of 76,500 and 2,940 cubic feet, respectively. In order to treat stormwater runoff, standard asphalt within the parking lanes along the Hymettus Avenue right-of-way should be replaced with permeable pavement. Overflow from permeable pavement or other runoff should be treated in bioretention, implemented within the right-of-way of Vulcan Avenue and Hymettus Avenue (Figure 8). The recommended green infrastructure combination is estimated to provide a 56 percent reduction in the long-term annual flood frequency with a total cost of $1,595,600.

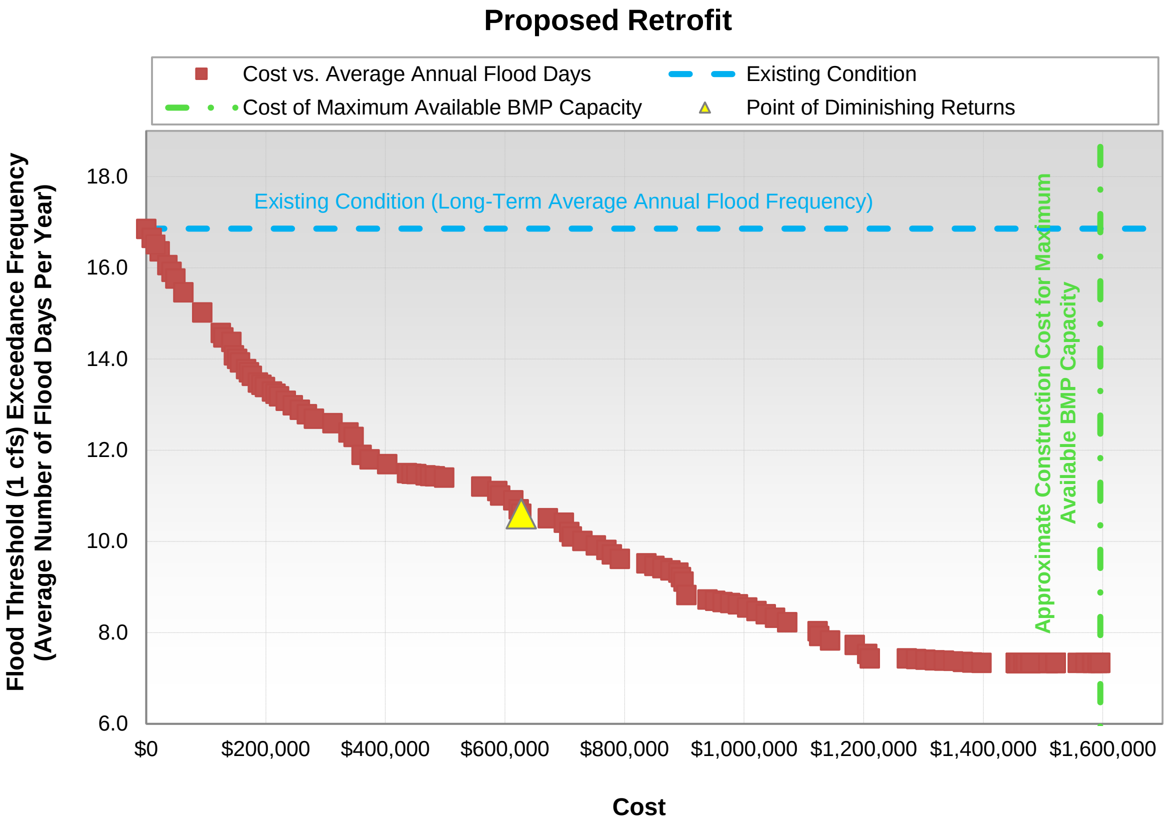


Figure 7. Flood exceedance frequency plot comparing green infrastructure investment to flood control benefits during long-term simulation. The cost of the traditional storm drain improvements exceeds the cost of the maximum available green infrastructure capacity; therefore the maximum cost is only shown.

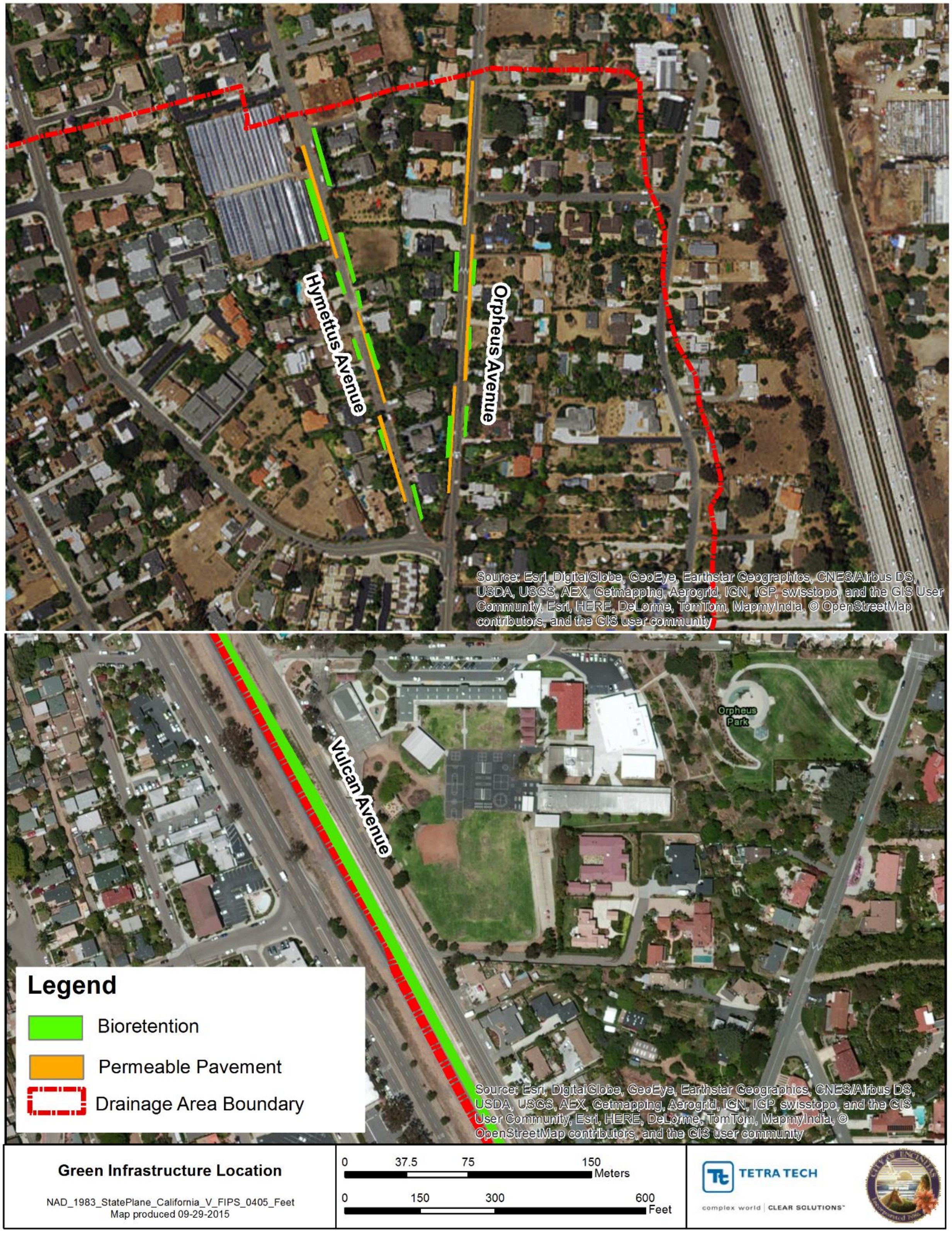


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Figure 8. Recommended areas for green infrastructure implementation

Additional analyses were performed to identify the size of the green infrastructure practice required to limit the discharge to 1 cfs for the 5-year, 10-year, and 50/100-year, 24-hour design storm events. Furthermore, the design storm events were modeled through the identified green infrastructure size to measure the percent runoff volume removal for each of them. Table 7, Table 8 and Figure 9 indicate the results of the analyses. The results show that green infrastructure could provide a cost-effective mechanism for simultaneously managing runoff quantity and quality during infrequent events.

Table 7. Design storm control results

Design Storm Event	Threshold: 100 percent Volume Removal		Threshold: 1 cfs bypass	
	Green Infrastructure Capacity (ac-ft)	Cost	Green Infrastructure Capacity (ac-ft)	Cost
85th Percentile	2.4	$3,790,320	2.0	$1,553,080
5-Year, 24-Hour	3.2	$4,951,640	2.8	$3,997,730
10-Year, 24-Hour	5.1	$7,221,500	4.9	$7,744,470
50/100-Year, 24-Hour	11.5	$16,683,660	10.5	$15,751,030

The costs shown in Table 7 are relative planning estimates and are not necessarily reflective of the actual design and construction costs. Table 8 includes a more detailed cost estimate presented in Section 7. An evaluation of the available area for green infrastructure practice retrofits indicated that there is area available to provide 1.82 acre feet of capacity. Any comparison of the gray versus green infrastructure, including the cost, in the following sections is based on the determination of available space for green infrastructure retrofits.

Table 8. Results for maximum available green infrastructure capacity in the study area

Proposed Retrofit	Design Storm Event			
	85th Percentile	5-Year, 24-Hour	10-Year, 24-Hour	50/100-Year, 24-Hour
Maximum Available Green Infrastructure Capacity	1.82	1.82	1.82	1.82
Percent Runoff Volume Removal	77%	60%	36%	17%
Approximate Total Cost	**$1,595,600**			

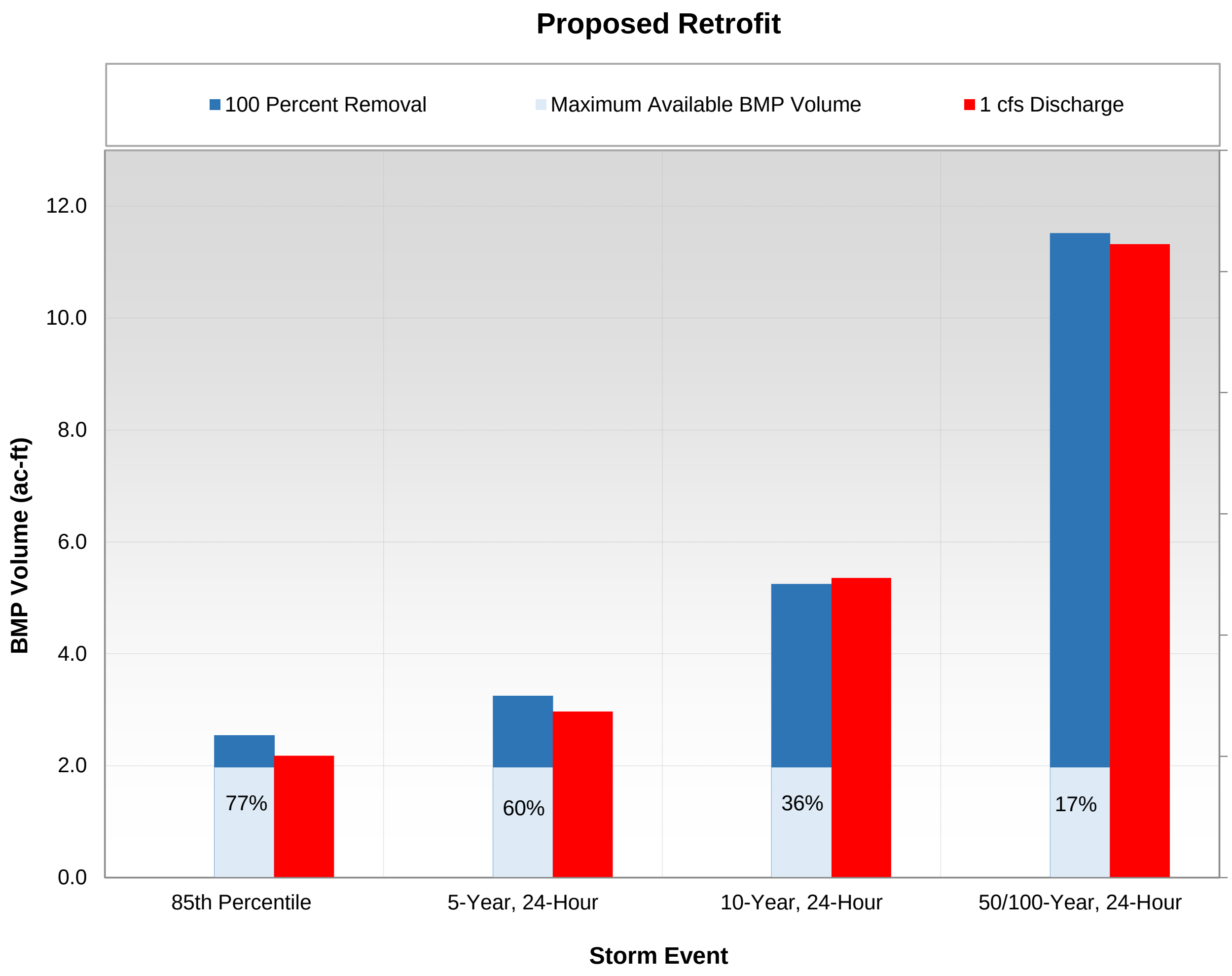

Figure 9. Results for design storm events analyses

6. Comparison of Gray vs Green Infrastructure

To compare the gray and green infrastructure scenarios, additional analyses were performed to evaluate the annual frequency of flooding utilizing the recommended sizes of gray and green infrastructure. Table 9 presents the results of these analyses.

Another comparison to note is that the current gray infrastructure configuration discharges into the watershed north of Cottonwood Creek. Implementing the proposed changes to the gray infrastructure would divert the drainage south into the Cottonwood Creek Watershed. Diverting this flow would increase the volume and could increase the bacteria concentrations and loads discharged at Moonlight Beach. Implementing the green infrastructure solutions would provide treatment near the source of the runoff reducing the volume and bacteria concentrations in the runoff.

Table 9. Comparison of gray and green infrastructure

Proposed Retrofit	Existing Conditions		Gray Infrastructure		Green Infrastructure	
	Cost	Annual Flooding Frequency (day)	Cost	Annual Flooding Frequency (day)	Cost	Annual Flooding Frequency (day)
Recommended Size for Long Term Simulation	$0	17	$1,874,939	8	$1,595,600	8
Recommended Size for 5-Year, 24 Hour	$0	17	$1,961,592	1	$4,951,640	1
Recommended Size for 10-Year, 24 Hour	$0	17	$2,087,301	1	$7,221,500	1
Recommended Size for 50/100-Year, 24 Hour	$0	17	$2,328,126	0	$16,683,660	0

7. Cost Estimate

Table 10 and Table 11 provide the costs for implementation of gray infrastructure and green infrastructure, respectively. Table 10 includes the breakdown of pipe costs, and costs for construction contingency, design, construction staking, construction inspection, and soil/material testing. Table 11 includes the breakdown of permeable pavement and bioretention costs, and costs for planning, mobilization, construction contingency, design, construction staking, construction inspection, and soil/material testing.

Table 10. Costs for gray infrastructure implementation for 5-Year, 10-Year, and 50/100-year design storms

Item No.	Description	Long Term Simulation	5-Year	10-Year	50/100-Year
1	**18-inch RCP (D-2000)**				
	Quantity	-	880	--	--
	Unit Price	-	$195.00	--	--
	Total	-	$171,600	--	--
2	**24-inch RCP (D-2000)**				
	Quantity	$6920	1,490	880	--
	Unit Price	$203.33	$203.33	$203.33	--
	Total	$1,407,066.67	$302,967	$178,933	--
3	**30-inch RCP (D-2000)**				
	Quantity	--	--	1,490	880
	Unit Price	--	--	$211.67	$211.67
	Total	--	--	$315,383	$186,267
4	**36-inch RCP (D-2000)**				
	Quantity	--	4,550	--	1,490
	Unit Price	--	$220.00	--	$220.00
	Total	--	$1,001,000	--	$327,800
5	**42-inch RCP (D-2000)**				
	Quantity	--	--	4,550	--
	Unit Price	--	--	$237.50	--
	Total	--	--	$1,080,625	--
6	**54-inch RCP (D-2000)**				
	Quantity	--	--	--	4,550
	Unit Price	--	--	--	$275.00
	Total	--	--	--	$1,251,250
Subtotal Cost		$1,407,066.67	$1,475,567	$1,574,942	$1,765,317
7	Construction Contingency	$211,060.00	$211,335	$236,241	$264,798
8	Design	$161,812.67	$169,690	$181,118	$203,011
9	Construction Staking	$40,000.00	$40,000	$40,000	$40,000
10	Construction Inspection	$45,000.00	$45,000	$45,000	$45,000
11	Soil/Materials Testing	$10,000.00	$10,000	$10,000	$10,000
Total Cost		**$1,874,939**	**$1,961,592**	**$2,087,301**	**$2,328,126**

Table 11. Costs for green infrastructure (permeable pavement and bioretention) implementation

Item No.	Description	Estimated Qty	Unit	Unit Cost	Total
	Preparation				
1	Traffic Control	20	Day	$1,000.00	$20,000.00
2	Temporary Construction Fence	10,544	LF	$2.50	$26,360.00
3	Silt Fence	10,544	LF	$3.00	$31,632.00
	Site Preparation				
4	Saw Cut Existing Asphalt	1,050	LF	$5.12	$5,376.00
5	Asphalt Removal	7,350	SF	$3.36	$24,696.00
6	Sidewalk Removal	42,000	SF	$2.01	$84,420.00
7	Excavation and Removal	5,272	CY	$45.00	$237,250.00
	Structures				
8	Permeable Pavement	7,350	SF	$12.00	$88,200.00
9	Structural Layer (washed no. 57 or no. 2 stone)	45	CY	$50.00	$2,268.52
10	Concrete Transition Strip	1,050	LF	$4.00	$4,200.00
	Bioretention				
11	Fine Grading	45,000	SF	$0.72	$32,400.00
12	Hydraulic Restriction Layer (30 mil liner)	7,140	SY	$0.60	$4,284.00
13	Soil Media Barrier (washed sand)	277.78	CY	$40.00	$11,111.00
14	Soil Media Barrier (choking stone, washed no. 8)	277.78	CY	$45.00	$12,500.00
15	Mortared Cobble Energy Dissipater	277	SF	$2.25	$623.00
16	Curb Opening with Grate	7	LS	$350.00	$2,585.00
	Landscaping				
17	Soil Media	3,333	CY	$45.00	$150,000.00
18	Vegetation	45,000	SF	$4.00	$180,000.00
19	Mulch	417	CY	$55.00	$22,917.00
Construction Subtotal					$940,820
20	Planning (20% of subtotal)				$188,160
21	Mobilization (10% of subtotal)				$94,080
22	Construction Contingency (15% of subtotal)				$141,120
Construction Total					$1,364,180
23	Design (10% of Construction Total)				$136,420
24	Construction Staking				$40,000
25	Construction Inspection				$45,000
26	Soil/Material Testing				$10,000
Total Cost					**$1,595,600**

8. Water Quality Assessment

As mentioned earlier, Moonlight Beach needs to comply with the Bacteria TMDL. Therefore, for this study area, fecal coliform was used as the basis for removal comparison. The amount of fecal coliform entering the storm drain varies depending on the size of the storm and the number of dry days between storms. A 10-year continuous simulation period from 2000 to 2010 was used to analyze the percent annual fecal coliform removal and water quality improvement. Figure 10 presents an annual fecal coliform removal cost-effectiveness curve for a 10-year simulation period. According to Figure 10, the recommended green infrastructure combination (bioretention and permeable pavement with retention volumes of 76,500 and 2,940 cubic feet, respectively) reduces bacteria by 932,259 million counts/year (81 percent) in the long-term analysis.

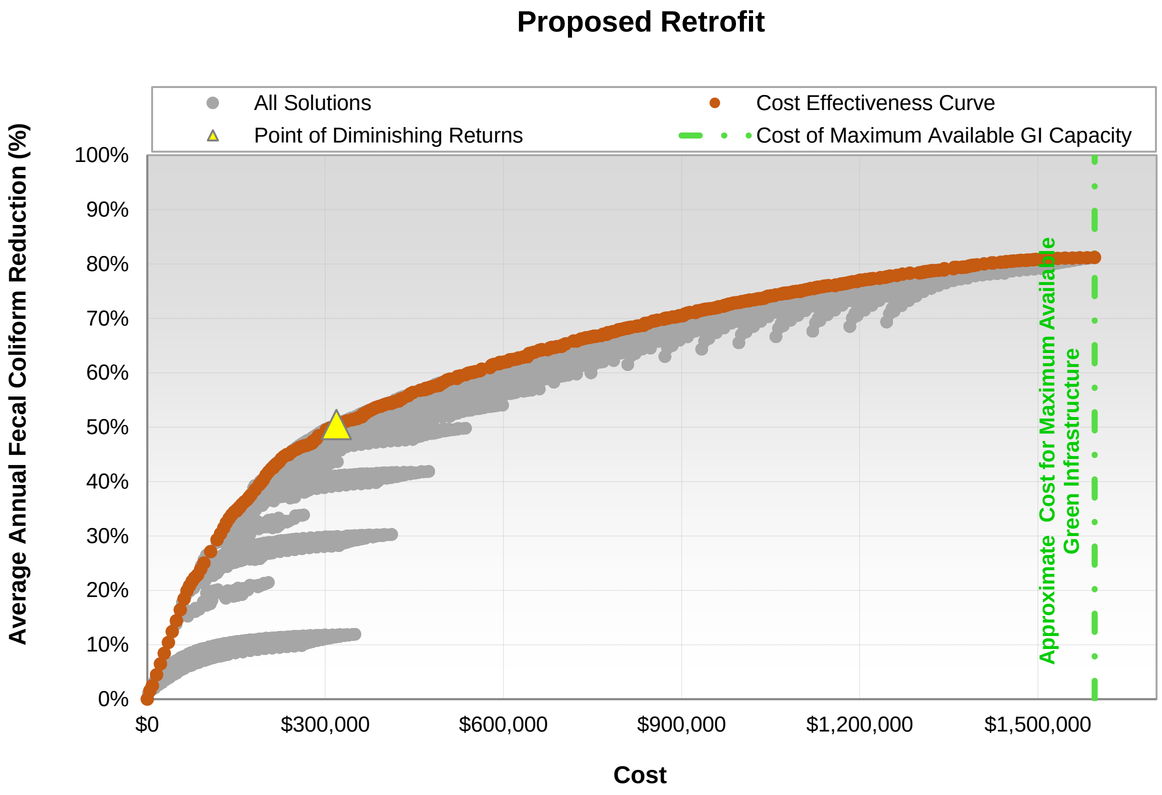

Figure 10. Cost vs. annual bacteria reduction

9. Conclusions and Considerations

This section summarizes the key results and provides further considerations.

9.1. Summary of Findings

A planning-level modeling exercise was performed to quantify the potential for green infrastructure to mitigate localized urban flooding in the City of Encinitas. Results of the analysis showed that the combination of bioretention and permeable pavement with total size of 52,350 square feet (maximum available green infrastructure footprint) and retention volume of 79,440 cubic feet provides the capacity to treat 77 percent, 60 percent, 36 percent, and 17 percent of the flow volume produced by 85th percentile 5-year, 10-year, and 50/100-year, 24-hour design storm events, respectively. In addition, results suggest that nuisance flooding in particular could be reduced, and the recommended green infrastructure configuration could decrease the frequency of flooding by up to 56 percent and bacteria counts by 81 percent. Comparison of the cost of the recommended green infrastructure size ($1,595,600) with the cost of gray infrastructure ($1,874,939) shows that implementing green infrastructure concepts can not only improve water quality but also have an impact on flooding with 14% less cost. When the added value of water quality improvement is considered (among other “green” community benefits discussed in Section 4), green infrastructure could provide a cost-effective mechanism for managing higher probability residential flooding events.

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