A Sustainable Stormwater Management Proposal for a Bayfront Military Brownfield

Doyle, John

2011-05-12

A Sustainable Stormwater Management Proposal for a Bayfront Military Brownfield

John Doyle

Hydrology for Planners LA 222 - Term Project
May 12, 2011
FINAL DRAFT

ABSTRACT

Stormwater management has become a key issue related to our built environment. This research project focuses on tailoring on-site stormwater management to Alameda Point, a decommissioned military brownfield redevelopment site south of the Port of Oakland and part of the City of Alameda. Since its closure in 1997, several redevelopment master plans have been created, but due to the land remediation process and shifting development markets, no plan has been implemented and the site remains largely vacant.

In this study, stormwater runoff peak volumes are estimated to understand how much required retention would be needed for approximately 150 acres of the redevelopment site. Various features such as rain gardens, bioretention planters, green roofs, and permeable pavement serve as a kit-of-parts. These elements are schematically positioned to shape the site's new sustainable framework plan.

INTRODUCTION

Sustainable strategies for on-site stormwater management proposed here can be incrementally implemented and specifically tailored throughout the ongoing redevelopment of the Bay Area's abundant former military sites.

Today stormwater management has become a key issue related to our built environment. We are faced with ever-expanding urbanization that reduces land permeability and increases stormwater runoff. Most often this runoff flows untreated over streets, through storm sewers, and eventually into our rivers, lakes, and oceans. Along the way this water becomes contaminated with motor oil, garbage, and sediment. The impermeable surfaces of urbanized areas also prevent stormwater from recharging the groundwater, which can lead to land subsidence and eventually flooding. The major change in runoff processes results from covering parts of the catchment with impervious roofs, sidewalks, roadways, and parking lots, effectively reducing infiltration capacity of these areas to zero *(Dunne and Leopold 1978, 275)*. The increased stormwater runoff leads to difficulties of storm drainage control, groundwater recharge, and stream-water quality *(Dunne and Leopold 1978, 275).*

In San Francisco and other cities around the country like Portland, Oregon these problems are actively being addressed through sustainable on-site stormwater management techniques. Although not enforced like building codes, design guidelines have been created by government agencies to aid developers, architects, and urban designers in retrofitting existing infrastructure and building new sustainable infrastructure. These guidelines introduce methods for storing, cleaning, conveying, and recycling stormwater on-site. An underlying goal of on-site stormwater management is to reduce demand for municipal freshwater supply, a critical issue especially relevant in California where long-term water supply sources are being depleted.

This research project focuses on tailoring on-site stormwater management to Alameda Point, a decommissioned military brownfield redevelopment site south of the Port of Oakland and part of the

City of Alameda. Since its closure in 1997, several redevelopment master plans have been created, but due to the land remediation process and shifting development markets, no plan has been implemented and the site remains largely vacant. Prior proposals have introduced stormwater management strategies, but have not directly located them on plans nor made runoff or capacity measurements.

There are currently no on-site stormwater management systems at Alameda Point, rather, all the untreated runoff drains through storm sewers directly into the Oakland Inner Harbor, the Seaplane Lagoon, and the San Francisco Bay. Future redevelopment planned for Alameda Point will present a chance to develop a range of solutions to reduce pollution of the bay. Further, on-site stormwater could be treated and recycled to reduce the site's demand on fresh water supply for irrigation, toilet flushing, and other non-potable water needs.

In this study, stormwater runoff peak volumes will be estimated to understand how much required retention would be needed for approximately 150 acres of the redevelopment site. Various features such as rain gardens, bioretention planters, green roofs, and permeable pavement will serve as a kit-of-parts. These elements will be schematically positioned to shape the site's new sustainable framework plan.

This study is one component of a larger thesis project for the Master of Urban Design program where Alameda Point is considered as a new bayfront redevelopment site *(Figure 1).* The thesis aims to transform the former Naval Air Station and campus into a publicly-accessible waterfront that includes new and retrofitted mixed-use development, a comprehensive transit network, and measures to protect the low-lying site from future flooding due to sea level rise and tidal surges. Stormwater management is integral in developing a comprehensive sustainable development approach.

METHODS

The San Francisco Public Utilities Commission's (SFPUC) recent San Francisco Stormwater Design Guidelines (SFSDG) report lists a variety of best management practices (BMP's), which will be used as a basis for proposed design features. All measurements and calculations have been made from an AutoCAD survey base map. Shoreline and site observations were obtained from a site visit conducted on April 2, 2011.

To calculate existing site runoff, the context area was divided into two drainage management areas (DMAs) - the north, designated DMA One, and the south, designated DMA Two *(Figure 3).* This report analyzes and provides stormwater management strategies for DMA One. Surfaces within DMA One were then categorized into types of cover - impervious areas (paving, roofs) and pervious areas (grass, landscaping). After using the corresponding runoff coefficients and adding, the overall site runoff coefficient was used to estimate existing on-site runoff *(Table 1).*

Next, total on-site rainfall was determined. The SFSDG lists two methods for using design rainfall depths. The first method follows the California Stormwater BMP Handbook for volume-based sizing of BMP's and is used by the Port of San Francisco to grant building permits. This method uses design rainfall capture curves to identify 80 percent capture of annual stormwater volume within a 48-hour draw-down period. 80 percent was determined to be the optimal balance between cost and incremental treatment volume by BMP's *(San Francisco Stormwater Design Guidelines (SFSDG), 95).* Based on the composite runoff coefficient for the study drainage management area *(Table 2)*, the design rainfall capture for Alameda Point, is approximately 0.5 inches *(Figure 2).* This estimate uses the nearest rain gauge, located at Oakland Airport.

The second method, required by the SFPUC for design in San Francisco uses a design rainfall depth of 0.75 inches *(SFSDG, 96).* Despite being located across the Bay, for the purposes of this study the higher of the two design rainfall depths (0.75 inches) will be used to determine runoff capture and treatment volumes. Finally, both the Port and SFPUC require the CSBMP Handbook's method for flow-based sizing of applicable BMP's, which uses a design rainfall intensity of 0.2 inches per hour *(SFSDG, 93).*

To understand the total volume of stormwater treated on-site, calculations were done for each proposed treatment element. These calculations are general estimates as DMA One is such a large site. Several redevelopment assumptions were also made, but for the purposes of this project, it is valuable to see the comparisons between existing runoff and proposed treatment volumes.

Equations and variables used:

$V = CA_{tot}R_d$ $C = (\Sigma c_i A_i)/A_{tot}$ $C = [(c_1A_1) + (c_2A_2) + (c_3A_3) + (c_4A_4)]/A_{tot}$ *(LA 222 Ex. 4)*
V = existing runoff volume (ft^3)
R_d = design rainfall (in) = (0.75in)
A_{tot} = total site area (ft^2)
C = the weighted average runoff coefficient, $C = (\Sigma c_i A_i)/A_{tot}$
c_i = runoff coefficient for ith area of contributing drainage
A_i = ith area (ft^2)
Rational Method: $Q = CiA$ *(Dunne and Leopold 1978, 299)*
Q = design flow rate (ft^3/sec)
C = composite runoff coefficient
i = design rainfall intensity (in/hr)
A = total drainage area (acres)
$Q = VA_x$ *(LA 222 Ex. 6)*
Q = discharge (ft^3/sec)
V = velocity (ft/sec)
A_x = cross-sectional area (ft^2)

RESULTS AND DISCUSSION

The following contents represent calculations and descriptions for proposed stormwater management features in DMA One based on those in the SF Stormwater Design Guidelines. The calculations and descriptions are followed by a discussion of how certain features can be sited to mitigate flooding from sea level rise and tidal surges, although the flood capacities of these features were not sized based on calculations in this study.

Table 1, Determining a Composite Runoff Coefficient

Surface Type	c	Area (ac)	Area (ft^2)				
Pervious Surfaces	0.15	47 acres	$2.04 \times 10^6 ft^2$				
Impervious Surfaces	0.80*	103 acres	$4.49 \times 10^6 ft^2$	Roof	0.80	19 acres	$830{,}877 ft^2$
Total	0.60	150 acres	$6.53 \times 10^6 ft^2$	Pavement	0.80	84 acres	$3.66 \times 10^6 ft^2$

*0.80 recommended *c* for asphalt *(SFSDG, 93)*

Table 2, Existing Runoff for DMA One

Total volume of rain	V = (0.063ft)(6.53x10^6ft^2) = 411,642ft^2 = 9.5ac-ft
Composite runoff coefficient	C = [(0.15 x 2.04x10^6ft^2) + (0.80 x 4.49x10^6ft^2)] / (6.53x10^6ft^2) = 0.60
Existing runoff	V = (0.60)(6.53x10^6ft^2)(0.063ft) = 246,985ft^3 (or 5.7ac-ft)

The overall existing stormwater runoff for DMA One is approximately 5.7 acre-feet*.* This represents approximately two-thirds of the total rainfall as untreated runoff, a significant volume entering the bay for a given storm. In other words, a 0.75-inch storm produces 9.5 acre-feet of rain over the 150 acres of DMA One. 40 percent of the rain is absorbed by existing surfaces, leaving 60 percent as runoff. What are ways to reduce this 60% by slowing, storing, and recycling this stormwater? How can the site act more naturally to absorb the stormwater?

In order to answer these questions, a basic design strategy was created to progressively treat runoff from small-scale to large-scale, or from individual building sites to streets to overall neighborhood districts. This strategy consists of a series of on-site stormwater best management practices, including green roofs, bioretention rain gardens, permeable pavement, bioretention flow-through planters, vegetated swales, canals, and constructed wetlands *(Figure 4).* The basic sequence follows:

- Stormwater is locally treated on-site by green roofs and rain gardens, which handle roof runoff.
- Permeable pavement parking areas, along with landscaping and lawn areas capture and treat on-site stormwater. Excess runoff from these areas is directed to and treated by bioretention flow-through planters sited along internal parking areas.
- Flow-through planters are sited along streets to capture and treat runoff from building sites, streets, and permeable pavement on-street parking areas. Excess stormwater from these planters is directed into overflow pipes that flow into storm drains.

- Remaining site runoff (and potentially storm drain flow) is directed into perimeter vegetated swales for treatment and conveyance. Partially-treated water from swales travels into either constructed wetlands or a canal along the perimeter of the DMA.
- After this progression of incremental treatment, clean stormwater either enters the bay or is recycled and used for irrigation or toilet flushing.

These low-impact development (LID) stormwater best management practices are described in more detail below, with a series of sizing and development assumptions to aid in runoff calculations.

Extensive Vegetated Roofs (Green Roofs): *(Figure 6a)*

- Extensive vegetated green roofs consist of small plants, are lightweight, and require less than six inches of soil depth. Retrofitted green roofs are common, but require enough structural integrity to support the added roof load. A green roof uses drought-tolerant plants to serve as a filtering sponge to absorb, slow, and treat stormwater *(Figure 5a)*. Other benefits include building insulation, noise reduction, roof longevity, and a reduction of the heat island effect. Excess stormwater runoff from the green roof can be directed into on-site rain gardens, underground detention cisterns, or basement graywater recycling cisterns. Some drawbacks to green roofs include potential seismic hazards due to top-heavy roof loads, higher up-front investment, and maintenance. Costs vary widely, but are usually 30-50% higher than regular roofs *(San Francisco Stormwater Design Guidelines - Appendix A (SFSDG-A), 107)*. The smaller existing buildings at Alameda Point would be the best candidates for a retrofitted green roof, while the larger hangar buildings would be better suited for photovoltaic arrays, or solar water heating systems.
- Assume 30% existing roofs retrofitted to be green.
- Assume new building footprint have 30% new green roofs.

Table 3, Green Roof Areas

30% retrofit green roofs	249,263ft^2
30% new green roofs	310,000ft^2
Total	559,263ft^2

Table 4, Green Roof Treatment and Runoff

Retrofit green roof treatment capacity	7,852ft^3 =	(1 - 0.5)(249,263ft^2)(0.063ft)
New green roof treatment capacity	2,930ft^3 =	(1 - 0.5)(93,000ft^2)(0.063ft)
Total treated by green roofs	10,782ft^3	
Runoff from green roofs	10,782ft^3 =	(0.5)(342,263ft^2)(0.063ft)

The preceding calculations show green roofs capturing 50% of the overall rainfall, with 50% as runoff to be directed into rain gardens.

Bioretention Rain Gardens: *(Figure 6b)*

- Bioretention rain gardens utilize native vegetation to capture, infiltrate, and remediate polluted stormwater runoff, thereby reducing overall runoff into storm drains. Rain gardens include a top layer of vegetation above mulch, which rests on planting soil. Water percolates through this system, then ideally infiltrates into the soil. If infiltration cannot be achieved, a perforated pipe or an overflow drain pipe can carry excess water. A rain garden with these elements can handle six inches of ponding in a large rain event *(SFSDG-A, 72)*. In the context of Alameda Point, rain gardens will be used adjacent to building roofs to capture and treat excess runoff on-site. Size and design flexibility are advantages of using rain gardens around buildings. Rain gardens can be aesthetically rustic or refined depending on context and are relatively cheap to build and maintain.
- Assume rain gardens have six-inch treatment depth, or five-inch ponding depth in a 0.75-inch storm.

Table 5, Rain Garden Treatment for Green Roofs

Volume to be treated	10,782ft^3 =	
Rain garden area required	25,671ft^2 =	10,782ft^3 / (0.42ft^3 / ft^2) *

*rain garden 5"ponding depth (0.42ft); 0.42ft x 1ft^2 = 0.42ft^3 capacity

Table 6, Non-Green Roof Runoff

Non-green roof area to be treated	488,614ft^2	
Runoff from non-green roofs	24,626ft^3 =	(0.8)(488,614ft^2)(0.063ft)

Table 7, Rain Garden Treatment for Non-Green Roofs

Volume to be treated	24,626ft^3	
Rain garden area required	58,633ft^2 =	24,626ft^3 / (0.42ft^3 / ft^2)

The preceding calculations show rain gardens capturing and treating 100% of all runoff from both green roofs and non-green roofs.

Permeable Pavement: *(Figure 6c)*

- Permeable pavement offers on-site stormwater treatment and infiltration through use of either porous asphalt or spaced pavers with grass, gravel, or sand in between. Layers of increasingly-sized gravel slow stormwater and eventually allow ground infiltration. Permeable pavement has been used typically in parking areas, where vehicular movement and frequent heavy live loads are less. Pavers can be multifunctional and serve as patios or plazas as well. These types of pavement can be cheaper than regular pavement when life-cycle costs, such as site drainage and longevity are considered. At Alameda Point, the majority of on-street parking areas, some parking stall areas, and pedestrian plazas will be permeably-paved.
- Assume 20,000 linear feet of total new and existing streets.
- Assume 75% of streets have on-street parking with permeable pavement, total of 15,000 linear feet.
- Typical width of on-street parking is eight feet on each side of street.
- Assume average remaining street width of 30 feet (travel and turning lanes).

Table 9, Street Areas

On-street parking permeable pavement area	240,000ft^2	(15,000ft)(8ft)(2)
Street impermeable area	600,000ft^2 =	(20,000ft)(30ft)

Table 10, Street Area Treatment and Runoff

On-street parking permeable pavement area capacity	6,048ft^3 =	(1-0.6)(240,000ft^2)(0.063ft)
Runoff from on-street permeable pavement area	9,072ft^3 =	(0.6)(240,000ft^2)(0.063ft)
Runoff from street impermeable area	30,240ft^3 =	(0.8)(600,000ft^2)(0.063ft)
Total runoff from street areas	39,312ft^3	

The preceding calculations show permeable pavement along streets capturing 40% of rainfall, leaving 60% as runoff to be directed into bioretention flow-through planters.

Bioretention Flow-Through Planters: *(Figure 6b)*

- Bioretention flow-through planters utilize native vegetation to capture, infiltrate, and remediate polluted localized stormwater runoff, thereby reducing overall runoff into storm drains. Planters include a top layer of vegetation above mulch, which rests on planting soil. Water percolates through this system, then ideally infiltrates into the soil. If infiltration cannot be achieved, a perforated pipe or an overflow drain pipe can carry excess water. A planter with these elements can handle six inches of ponding in a large rain event *(SFSDG-A, 72)*. In the context of Alameda Point, planters will be placed along streets between sidewalks and parking strips, in boulevard medians, and at some intersection bulb-outs. This configuration of on-street stormwater management is often referred to as a "green street". Like rain gardens, flow-through planters are flexible in size and aesthetics. They can exhibit rustic, garden-like character in residential or park areas and become streamlined, urban fixtures in denser areas similar to downtown Portland, Oregon *(Figure 5b-d).*
- Assume five-foot typical planter width, with six-inch treatment depth, or five-inch ponding depth in a 0.75-inch storm.

Table 11, On-Street Bioretention Flow-Through Planter Treatment

Volume to be treated	39,312ft^3	
Bioretention flow-through planter area required	93,600ft^2 =	39,312ft^3 / (0.42ft^3 / ft^2) *
Length of street provided with planters	9,360ft =	(93,600ft^2) / (5ft)(2)
Planter area provided	9,3600ft^2 =	(9,360ft)(5ft)(2)

*planter 5"ponding depth (0.42ft); 0.42ft x 1ft^2 = 0.42ft^3 capacity

Table 12, Parking Lot Areas

Permeable pavement parking lots	200,000ft^2 *
Impermeable parking lots	300,000ft^2 *
Total	500,000ft^2

*assumed new and retrofitted parking areas

Table 13, Parking Lot Area Treatment and Runoff

Permeable pavement parking lot capacity	5,040ft^3 =	(1-0.6)(200,000ft^2)(0.063ft)
Runoff from permeable pavement parking lots	7,560ft^3 =	(0.6)(200,000ft^2)(0.063ft)
Runoff from impermeable parking lots	7,560ft^3 =	(0.8)(150,000ft^2)(0.063ft)
Total runoff from parking lot areas	15,120ft^3	

Table 14, Parking Lot Bioretention Flow-Through Planter Treatment

Volume to be treated	15,120ft^3	
Bioretention flow-through planter area required	36,000ft^2 =	15,120ft^3 / (0.42ft^3 / ft^2)
Perimeter/median length of parking lots available for planters	10,000ft *	
Planter area provided	40,000ft^2 =	(8,000ft)(5ft)

*estimated based on 500,000ft^2 of total parking lot area

The preceding calculations show bioretention flow-through planters able to treat 100% of runoff from streets and parking lots. The following table tallies the preceding areas that have been fully treated on-site:

Table 15, Areas Treated On-Site

Roofs	830,877ft^2	19 acres
Rain Gardens	111,067ft^2	2.5 acres
Streets	840,000ft^2	19 acres
Parking Lots	500,000ft^2	11.5 acres
Bioretention Planters	173,314ft^2	4 acres
Total		56 acres

Table 16, Remaining Areas to be Treated with Runoff Volumes

Surface Type	Area (ac)	Runoff (ft^3)	Runoff Calculation
Pervious Surfaces (lawns, landscaping)	47 acres	19,278ft^3	(0.15)(2.04x10^{6}ft^2)(0.063)
Impervious Surfaces (sidewalks, paths, courts)	47 acres	102,816ft^3	(0.8)(2.04x10^{6}ft^2)(0.063)
Total	94 acres	122,094ft^3	

Vegetated Swales: *(Figure 6d)*

- Vegetated swales work similarly to rain gardens, except swales are gently sloped for stormwater runoff conveyance in addition to retention and treatment. Swales are composed of native vegetation planted in a channel cross-section shape to direct water as a small stream.

Calculations for swale sizing must account for the additional factor of flow (*Q*) in order to manage stormwater velocity in large rain events. For the case of Alameda Point, swales will be used along peripheral site areas to directly capture excess runoff in larger events from streets, parking lots, and parks. Swales will also be connected to overflow storm drains. Swales will be used as pretreatment before water moves into a wetland or canal system.

- Assume 15-foot width, with six-inch grass (provides four-inch treatment depth minus one-inch rain equals three-inch additional capacity) *(SFSDG-A, 48)*.

Table 17, Vegetated Swale Treatment and Overflow

Volume to be treated	122,094ft^3	
Swale area required	488,376ft^2 =	122,094ft^3 / (0.25ft^3 / ft^2) *
Perimeter length available for swales	6,500ft	
Swale area provided	97,500ft^2	(6,500ft)(15ft)
Volume treated by swales	24,375ft^3	(97,500ft^2)(0.25ft^3 / ft^2)
Overflow from swales	97,719ft^3	122,094ft^3 - 24,375ft^3

*swale 3"ponding depth (0.25ft); 0.25ft x 1ft^2 = 0.25ft^3 capacity

Table 18, Flow-Based Swale Treatment

Flow	Q =	CiA =	(0.48)(0.2in/hr*)(94ac) =	9ft^3/sec
Swale cross section area	A_x =		[(15ft)(0.33ft)] - [(0.5)(0.33ft)(3.5ft)(2)] =	3.8ft^2
Flow velocity	V =	Q/A_x =	9ft^3/sec / (3.8ft^2) =	2.4ft/sec**

*recommended design rainfall intensity = 0.2in/hr *(SFSDG, 95)*.
**recommended high flow condition maximum flow velocity = 3ft/sec *(SFSDG-A, 51)*.

The preceding calculations show vegetated swales treating approximately 20% of runoff from site areas, with 80% to be conveyed into constructed wetlands.

Constructed Wetlands: *(Figure 6e)*

- Constructed wetlands are typically sited and sized to capture and treat stormwater runoff from a neighborhood, or district-wide DMA. They serve ecologically like natural wetlands by offering flood control, habitat, and abundant vegetation. Treated wetlands stormwater also has the potential for reuse in a recycled water system. Constructed wetlands should be part of a larger runoff treatment system that includes pretreatment elements to filter trash and sediment prior to entering the wetlands *(SFSDG-A, 58)*. At Alameda Point, one wetlands area will be the last step in capturing and treating excess runoff from DMA One. It will be sited along the shoreline of the Oakland Inner Harbor and have the capability to release treated stormwater into the harbor, or to recycle the water for nearby building and park use. The wetlands will be "surface flow", meaning that they will have water all year round. During the dry season, the wetlands water source may need to be supplemented with excess water from other sources. The wetlands will further serve as a neighborhood park amenity and might include recreational boardwalk trails and bridges. The wetland will also represent the historic nature of the former San Antonio Creek estuary marshes that were here in the 1800s before the harbor channel was dredged.

- Assume wetland occupies three to five percent of the DMA, so a minimum five-acre wetland required *(SFSDG-A, 60)*.
- Assume two-foot depth (24 inches minus one inch of rain equals 11-inch additional capacity).

Table 19, Constructed Wetland Treatment

Overflow from swales to be treated	97,719ft^3	
On-site rainfall to be treated	13,721ft^3	(5 acres)(43,560ft^2)(0.063ft)
Total volume to be treated	111,440ft^3	
Total wetland area required	58,042ft^2	111,440ft^3 / (1.92ft^3 / ft^2) *
Total wetland area provided	217,800ft^2	(5 acres)(43,560ft^2)

*wetlands 23"ponding depth (1.92ft); 1.92ft x 1ft^2 = 1.92ft^3 capacity

The preceding calculations show constructed wetlands treating 100% of swale conveyance, with additional 75% capacity for flood mitigation.

Flood and Sea Level Rise Mitigation

As a federally-operated military station, this site was never mapped by FEMA so the 100-year flood plain and Base Flood Elevation (BFE) areas have been approximated. The BFE is determined by inland wave run-up elevation, which typically exceeds wave crest elevations at the shoreline. Previous studies have estimated one-foot wave run-up elevations above 100-year flood elevations. Generally, flooding at the Point during a 100-year event would occur around the Seaplane Lagoon, along the

Oakland Inner Harbor, and over a large portion of the runway areas. The latest BFE has been set at +6.1' in relation to the City of Alameda datum *(SunCal, 144).* This is approximately three feet above most of the site areas at Alameda Point *(Figure 7a).*

Tidal analysis at Alameda shows an observed fluctuation of up to 11 feet with typical annual fluctuations ranging from nine to ten feet. The lowest observed water level (LOWL) was approximately 11 feet below typical land elevations, while the highest observed water level (HOWL) was approximately level with typical land elevations. A combination of high tide along with storm surge waves would most likely cause the most extensive flooding at the Point. Although offshore breakwaters reduce wave impacts along the south shore of the Point, the west shore remains exposed. Today most of the shoreline consists of boulder riprap revetments that are sparsely vegetated for further wave energy dissipation. Several storm sewer outfalls also occur around the Point's shoreline, which would be restructured in conjunction with future stormwater management efforts.

Although not critical for stormwater treatment in the system at Alameda Point, canals could be introduced to aid in flood mitigation. The majority of the site lies approximately six feet above today's mean sea level. This means that during some high tides and storm events, portions of the Alameda Point shoreline flood. According to the Bay Conservation and Development Commission, sea levels are estimated to rise 55 inches by the year 2100, and would significantly affect Alameda Point *(Figure 7b)*. Canals could be a valuable asset in directing floodwaters from developed site areas. The overall canal strategy for the site includes introducing a canal loop along the low-lying site perimeter to capture flood waters from higher elevations. The excess runoff, or floodwater, would be directed first into pretreatment basins or swales prior to entering the canal. The canal cross-section might include a low bank to handle normal water flow, then a wider, floodable high bank to handle high flows during flooding. The treated water could then be directed either into the wetlands systems or directly into the Oakland Inner Harbor or Seaplane Lagoon. This canal system would serve as a unique community park amenity for recreation and leisure, similar to the Gowanus Canal "Sponge Park" in Brooklyn, New York *(Figure 8).*

CONCLUSIONS

Without these elements in place, it was calculated that 5.7 acre-feet, almost two million gallons, of stormwater runoff was produced in DMA One. From the calculations, it is shown that the proposed stormwater management elements are able to handle 100% of stormwater runoff from a 0.75-inch design storm, and they only occupy approximately one quarter of the entire 150-acre DMA *(Figure 9).* Further, almost all of these elements serve multi-functionally as park amenities, habitat, building roofs, or vehicular areas. Larger features, such as constructed wetlands and canals, can handle excess capacity from flooding, although a separate study should be conducted to determine adequate sizing of these features.

Table 22, Stormwater Management Summary (for 0.75-inch storm)

Extensive green roof	Fully-treated on-site and by rain gardens
Non-green roof	Fully-treated on-site by rain gardens
Bioretention rain garden	Fully-treated on-site
Streets (permeable and impermeable)	Fully-treated on-site and by bioretention planters
Parking lots (permeable and impermeable)	Fully-treated on-site and by bioretention planters
Bioretention flow-through planters	Fully-treated on-site
Remaining site areas	Partially treated by swales, overflow into wetlands
Vegetated swales	Directed flow into constructed wetlands
Constructed wetlands	Fully-treated on-site, recycle or flow into bay

Although all stormwater management solutions should be designed on a site-specific basis, some general conclusions can be made from the preceding study. Assuming the same 0.75-inch design storm event, the following basic estimates for BMP-sizing may aid urban designers, architects, landscape architects, civil engineers, and planners during schematic site design:

- Rain gardens adjacent to extensive green roofs that are sized to be approximately 5% of roof area can be expected to handle on-site treatment.

- Rain gardens adjacent to non-green roofs that are sized to be approximately 12% of roof area can be expected to handle on-site treatment.
- Bioretention flow-through planters that occupy approximately 50% of total street length, in conjunction with permeable pavement on-street parking, can be expected to handle on-site treatment.
- Bioretention flow-through planters that are sized to be approximately 8% of the total parking lot area can be expected to handle on-site treatment. This assumes 40% permeable pavement and 60% impermeable pavement parking lots.
- Constructed wetlands that area sized to be approximately 3% of the total DMA, in conjunction with all other stormwater pretreatment elements, can be expected to handle on-site treatment with excess capacity for flood mitigation. This conclusion also follows the recommendation from the San Francisco Public Utilities Commission *(SFSDG-A, 60)*.

These conclusions are helpful to understand when making the case for including low-impact development stormwater management into a retrofitted or new development project.

Stormwater management is an increasingly pressing issue in cities today and should be addressed at all development scales from single building sites to neighborhoods, districts, and entire cities. Strategies for stormwater treatment and recycling especially need to be implemented here in California and other regions experiencing serious water supply shortages. The preceding kit-of-parts and comprehensive strategy show relatively low-impact methods to capture, treat, and reuse stormwater. If eventually implemented, this redevelopment of Alameda Point could serve as a regional Bay Area model project for retrofitted development plans as well as increase public awareness of long-term sea level rise mitigation measures.

REFERENCES CITED

California Stormwater Quality Association. "Stormwater Best Management Practice Handbook - New Development and Redevelopment." 2003. http://www.cabmphandbooks.com/Development.asp.

dlandstudio. "Gowanus Canal Sponge Park." Accessed April 2011. www.spongepark.org.

Dunne, Thomas, and Luna B. Leopold. *Water in Environmental Planning*. New York: W.H. Freeman and Company, 1978.

LA 222 - Hydrology for Planners course. *Exercise 4 - On-Site Stormwater Design*. 2011.

LA 222 - Hydrology for Planners course. *Exercise 6 - Flow Measurement and Open Channel Flow*. 2011.

San Francisco Bay Conservation and Development Commission (BCDC). "55-Inch Sea Level Rise by End of Century." 2008. http://www.bcdc.ca.gov/planning/climate_change/index_map.shtml.

San Francisco Public Utilities Commission. "San Francisco Stormwater Design Guidelines" (SFSDG). November 2009. http://sfwater.org/mto_main.cfm/MC_ID/14/MSC_ID/361/MTO_ID/543.

San Francisco Public Utilities Commission. "San Francisco Stormwater Design Guidelines - Appendix A: BMP Fact Sheets" (SFSDG-BMP). November 2009. http://sfwater.org/mto_main.cfm/MC_ID/14/MSC_ID/361/MTO_ID/543.

SunCal Companies. "Alameda Point: Draft Redevelopment Master Plan." December 2008.

United States Environmental Protection Agency. "Using Smart Growth Techniques as Stormwater Best Management Practices." 2005. http://www.epa.gov/smartgrowth/publications.htm.

FIGURES

Figure 1, Map of Study Area (author's diagram).

Figure 2, Runoff Coefficient Curves (California Stormwater BMP Handbook - Appendix D).

Figure 3, Drainage Management Areas and Existing Surface Types (author's diagram).

Figure 4, Schematic Stormwater Management Strategy (author's photographs and diagram).

Figure 5, Green Roof and Bioretention Flow-Through Planters in Portland, Oregon (author's photographs).

Figure 6, Stormwater Best Management Practices (San Francisco Stormwater Design Guidelines - Appendix A: BMP Fact Sheets).

Figure 7, Flooding and Sea Level Rise Effects on Alameda Point (7a - SunCal's Alameda Point: Draft Redevelopment Master Plan report; 7b - BCDC's 55-Inch Sea Level Rise by End of Century diagram).

Figure 8, Gowanus Canal "Sponge Park" in Brooklyn, New York (dlandstudio. www.spongepark.org).

Figure 9, Schematic Siting of Stormwater Management Features (author's diagram).

Figure 1, Map of Study Area

- Alameda Point, Alameda, California
- study area (red boundary) approximately 320 acres
- existing buildings (gray)

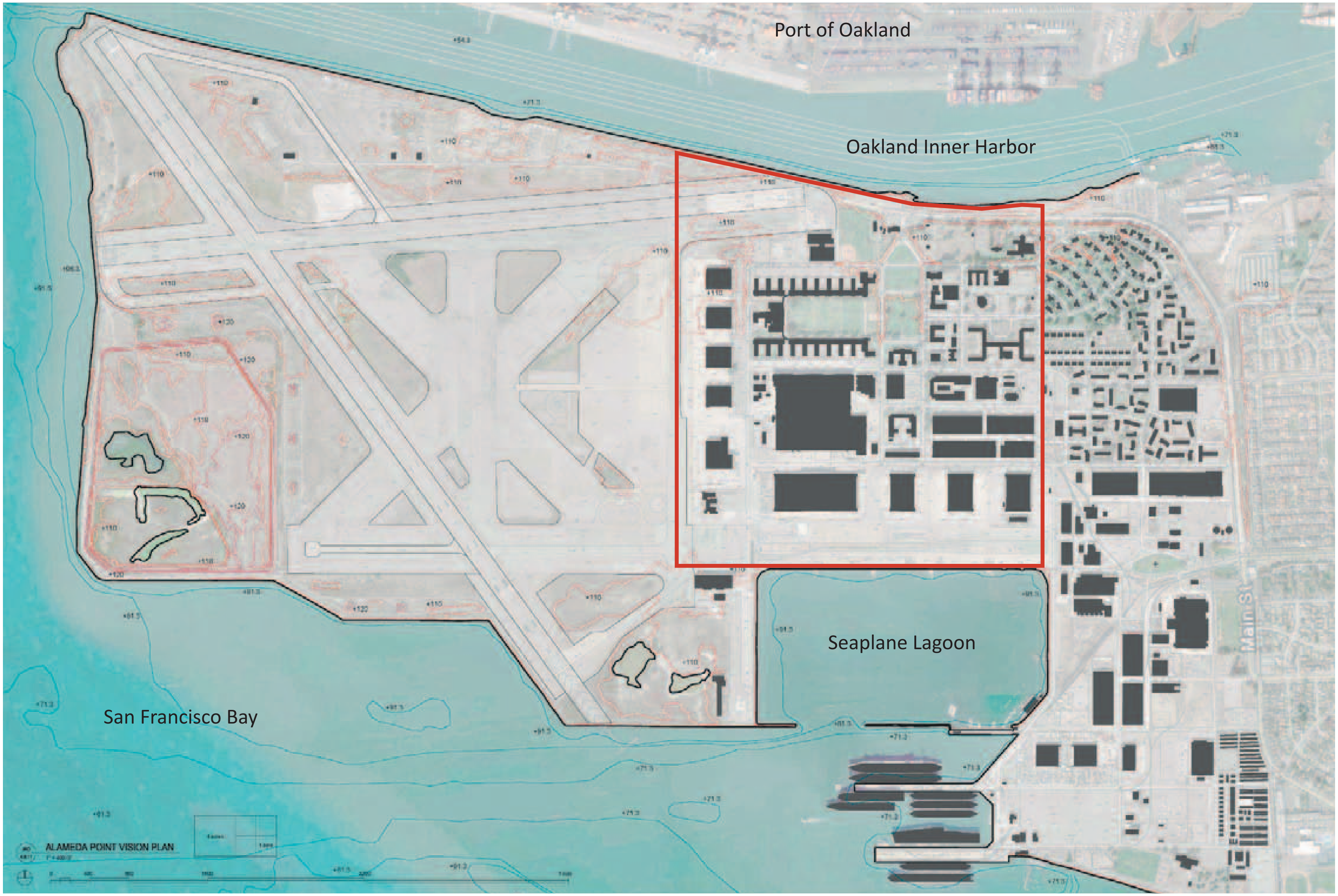


Figure 2, Runoff Coefficient Curves *(California Stormwater BMP Handbook - Appendix D)*

- black dashed curve shows interpolated curve based on 0.60 composite runoff coefficient
- black dot shows interpolated data point representing approximately 80% runoff capture
- black vertical arrow shows an approximate 0.5 inch unit basin storage volume/design rainfall depth

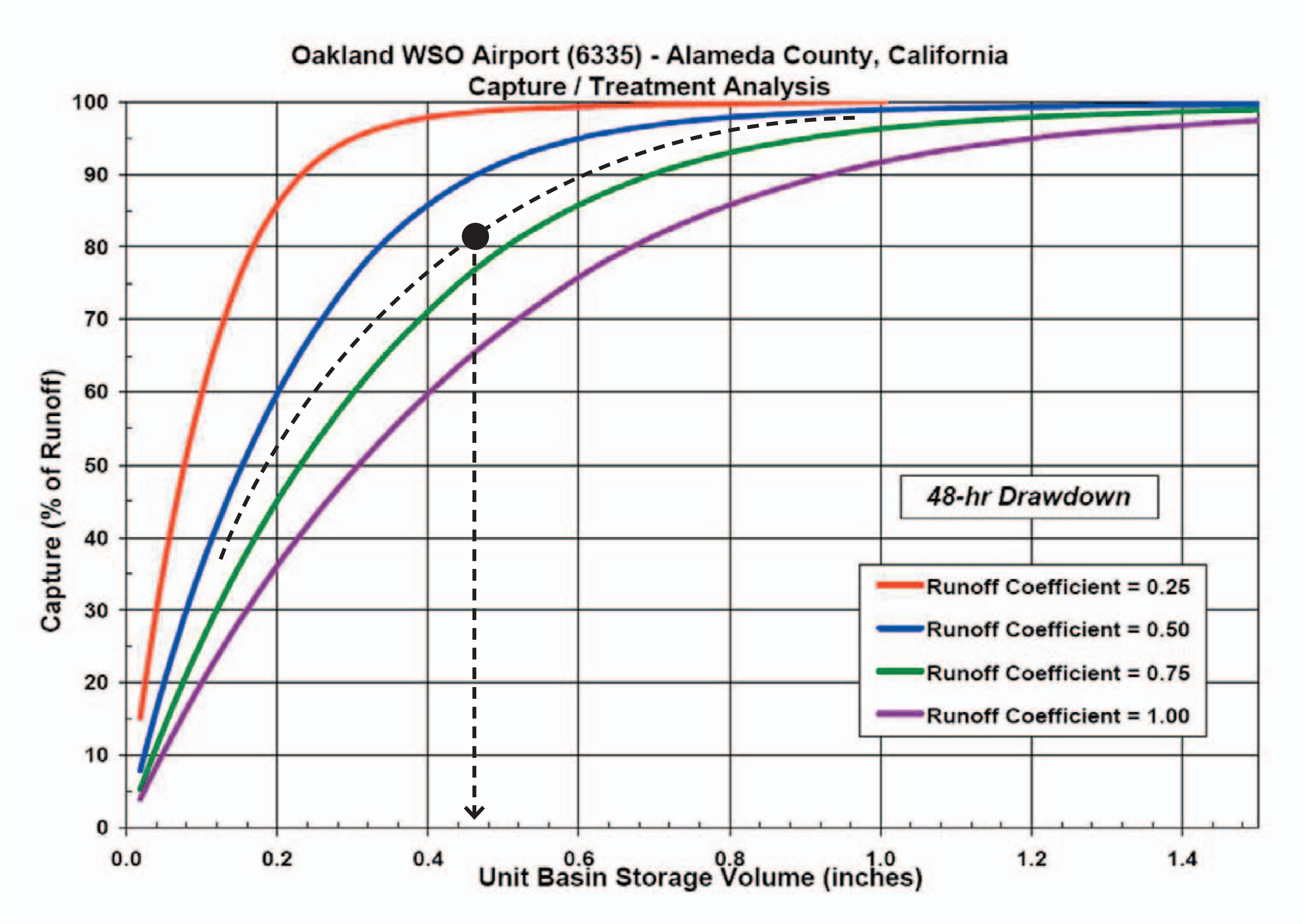


Figure 3, Drainage Management Areas and Existing Surface Types

- Drainage Management Area 1 (DMA One) = 150 acres
- Drainage Management Area 2 (DMA Two) = 170 acres
- DMA One - 31% pervious surfaces (47 acres)
- DMA One - 69% impervious surfaces (103 acres) [18% impervious surface as roof (19 acres); 82% impervious surface as paving (84 acres)]

🟩 Pervious Surfaces
■ Existing Roofs
← Storm Sewers

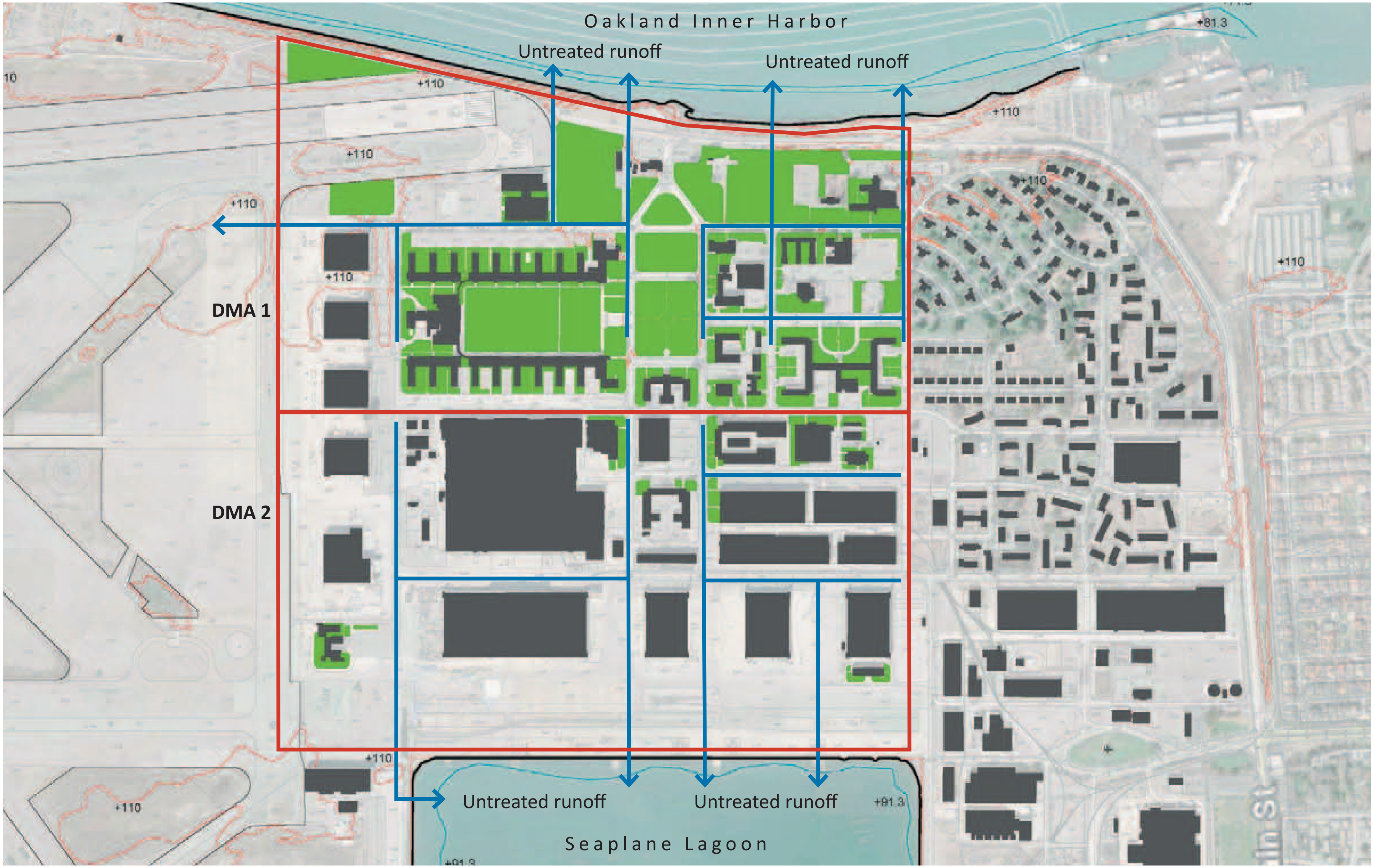


Figure 4, Schematic Stormwater Management Strategy

1: stormwater treated by on-site green roofs
2: stormwater runoff from green roofs and non-green roofs treated by on-site rain gardens
3: stormwater treated by permeable pavement on-street parking areas and parking lots
4: stormwater runoff from permeable and impermeable pavement treated by adjacent bioretention flow-through planters
5: additional stormwater runoff and overflow in larger events treated and conveyed by vegetated swales
6: canals treat and convey runoff from swales into constructed wetlands; canals have excess capacity for large flood events
7: constructed wetlands treat runoff from canals and/or swales; constructed wetlands have excess capacity for large flood events
8: treated stormwater is recycled for landscape irrigation, toilet flushing, and other non-potable uses
9: treated runoff from constructed wetlands is released into bay

Figure 5, Green Roof and Bioretention Flow-Through Planters in Portland, Oregon

Figure 5a, New green roof at South Waterfront high-density building

Figure 5b, Flow-through planters at South Waterfront

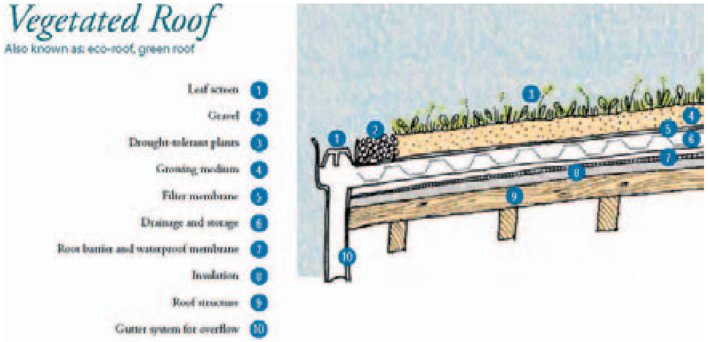
Figure 5c, Flow-through planter at New Columbia low-income neighborhood

Figure 5d, Flow-through planters at new Director Park plaza street

Figure 6, Stormwater Best Management Practices *(San Francisco Stormwater Design Guidelines - Appendix A: BMP Fact Sheets)*

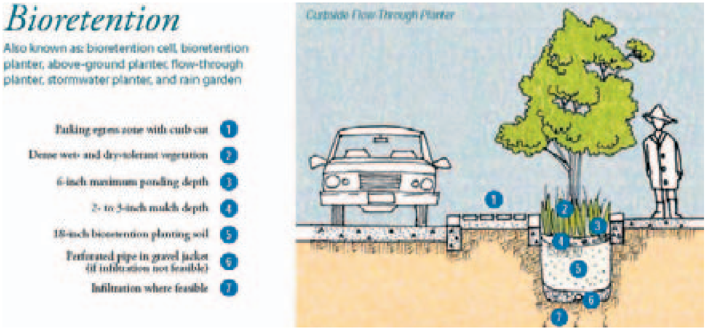
- 0.75-inch design storm event
- rough cost estimates include construction and maintenance

Figure 6a *(SFSDG-A, 104)*



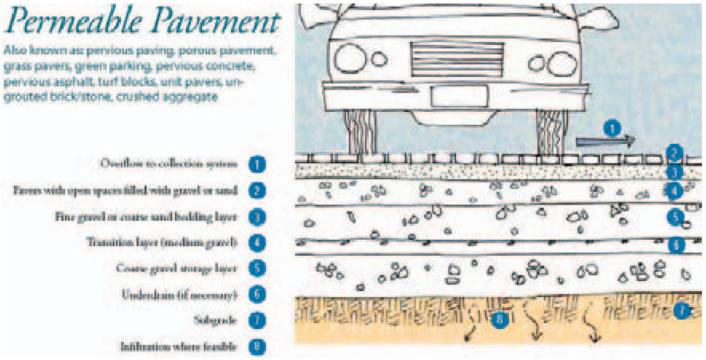
50% absorption
50% runoff
0.5 runoff coefficient
0ft^3 excess capacity per ft^2
\$11-25 per ft^2 (new)
\$7-45 per ft^2 (reroof)

Figure 6b *(SFSDG-A, 72)*



100% absorption
0% runoff
0 runoff coefficient
0.42ft^3 excess capacity per ft^2
\$9 per ft^2
Size: 5-10% of adjacent impervious drain area

Figure 6c *(SFSDG-A, 24)*

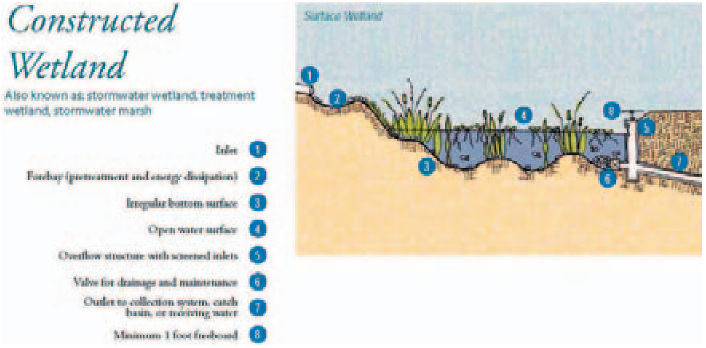


40% absorption
60% runoff
0.6 runoff coefficient
0ft^3 excess capacity per ft^2
\$2-10 per ft^2 (25% cheaper than typical pavement including drainage costs)

Figure 6d *(SFSDG-A, 48)*

100% absorption
0% runoff
0 runoff coefficient
0.25ft^3 excess capacity per ft^2
\$5-10 per linear ft (assume 15’ width, 6” grass, 4” treatment depth)
Size: drains up to 5 acres adjacent drain area

Figure 6e *(SFSDG-A, 58)*



100% absorption
0% runoff
0 runoff coefficient
1.92ft^3 excess capacity per ft^2
\$3 per ft^2 (assume 2ft depth)
Size: 3-5% of adjacent impervious drain area (typical minimum 5 acres)

Figure 7, Flooding and Sea Level Rise Effects on Alameda Point

Figure 7a, Map from SunCal master plan report showing existing areas of inundation based upon Base Flood Elevation (100-year tide plus 18" of sea level rise)

Source: SunCal Companies. "Alameda Point: Draft Redevelopment Master Plan." December 2008.

Figure 7b, Map from Bay Conservation and Development Commission showing areas of inundation during a 100-year tide plus 55" of sea level rise predicted for the year 2100.

Source: San Francisco Bay Conservation and Development Commission (BCDC). "55-Inch Sea Level Rise By End of Century." 2008. http://www.bcdc.ca.gov/planning/climate_change/index_map.shtml.

Figure 8, Gowanus Canal “Sponge Park” in Brooklyn, New York (*dlandstudio. www.spongepark.org.)*

- retrofitted urban canal pretreats stormwater runoff in basins before entering canal
- basins serve as floodable area during large events
- basins and canal serve as community park amenity

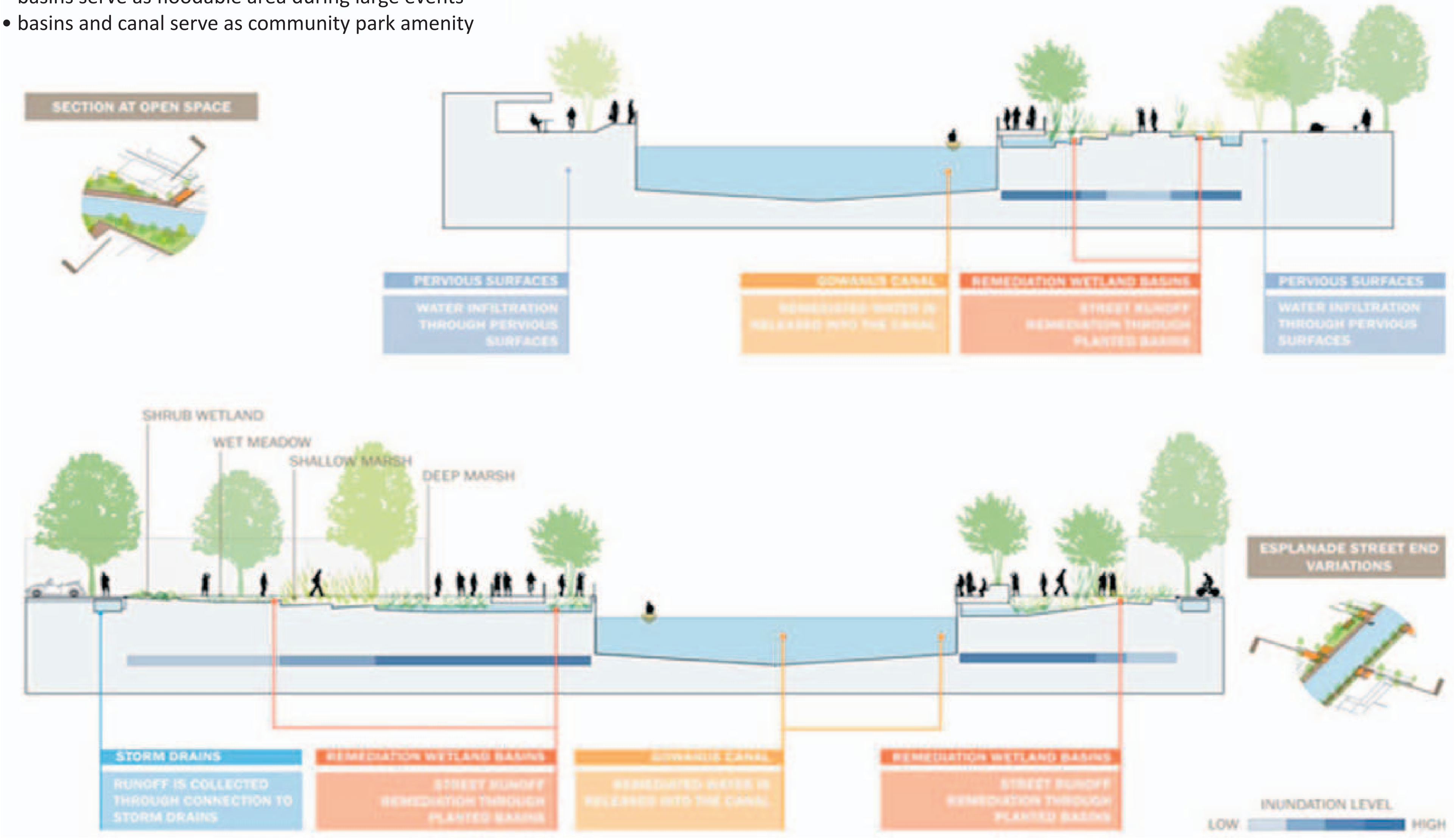


Figure 9, Schematic Siting of Stormwater Management Features