

# UC Berkeley

## Hydrology

### Title

Landscape-based stormwater management for industrial lands Piers 94-96

### Permalink

<https://escholarship.org/uc/item/89112146>

### Author

Jencks, Rosey

### Publication Date

2005-07-13

### Supplemental Material

<https://escholarship.org/uc/item/89112146#supplemental>



**Landscape-based Stormwater Management for Industrial Lands Piers 94-96**  
**LA 222- Hydrology for Planners**  
**Rosey Jencks**

Abstract: .....	3
Introduction.....	4
Site Context.....	4
Project Description.....	5
Results.....	17
Discussion.....	18
Conclusion .....	19
References .....	20
Figures .....	21

**Abstract:**

I propose a conceptual design for nonstructural stormwater treatment using vegetated swales for a contaminated industrial site informally called Piers 92, 94 and the Backlands, on the southern waterfront in San Francisco. The site was created from landfill and remains in active industrial uses. The Port of San Francisco plans to redevelop the site with an access road and several more industrial lots, and needs to provide treatment for the ensuing contaminated runoff. To design the appropriate dimensions of the swales, I determined drainage areas, assigned runoff coefficients, calculated runoff volumes, and proposed sizing and planting pallet for vegetated swales. I also discuss the maintenance needs and suggest methods for monitoring the treatment performance.

## **Introduction**

The Port of San Francisco, working with the Bayview Hunters Point Community and environmental advocates, has examined the potential use of non-structural based storm water management methods to treat and convey storm water in a part of the Port's Southern Waterfront (an area extending from Pier 70 south to Pier 96) (Fig. 1). The study was endorsed by the community and outlines alternative options for managing storm water with the redevelopment of this area.<sup>1</sup> Today, most stormwater collected in San Francisco drains to a combined stormwater and sewage system, and is conveyed to the City's Southeast wastewater treatment facility in the Bayview (Fig. 2). At this site the Port is not connected to the combined sewer and aims to not increase stormwater discharge to the southeast treatment facility by managing it on site. This practice would reduce contribution to the treatment plant during wet weather, when peak demands affect the treatment facility's capacity. The installation of the non-structural stormwater treatment controls would be a step towards meeting several goals expressed by the community, the Port and state requirements. For this term project, I developed a conceptual design for vegetated swales to assist the Port to develop the preliminary plans to implement these naturalized stormwater treatment systems along a proposed extension to Amador Street in the Port's Piers 92-94 and the Backlands.

## **Site Context**

### ***Climate, elevation, precipitation and soils***

The City and County of San Francisco is located on the western edge of the San Francisco Bay, the largest estuary on the U.S. Pacific Coast and one of the world's largest natural harbors. The city's elevation ranges from two feet below sea level to 938 feet, at Mount Davidson.<sup>2</sup> San Francisco is blessed with a temperate Mediterranean climate, with dry summers (less than an inch of rainfall falling from May through September), and cool wet winters (over 80 percent of the rain falls between November and March, occurring over about 10 days each month) (Fig. 3).<sup>3</sup> Figure three shows the mean monthly annual precipitation chart for the city. Rainfall is characterized by fast or "flashy" storm events that contribute large volumes of rain in short amounts of time. San Francisco's rainfall ranges from 22" over south central portion of San Francisco, to 20" along the western edge and the northeastern quadrant, to 18" along the northwestern waterfront.

---

<sup>1</sup> Treadwell and Rollo and the Watershed Resources Collaboration Group. Stormwater Management Study for the Southern Waterfront Pier 70-96. Prepared for the Port of San Francisco. December 2001.

<sup>2</sup> [http://www.wrh.noaa.gov/mtr/sfd\\_sjc\\_climate/sfd/SFD\\_CLIMATE3.php](http://www.wrh.noaa.gov/mtr/sfd_sjc_climate/sfd/SFD_CLIMATE3.php)

<sup>3</sup> <http://ggweather.com/sf/narrative.html> (Accessed August 5, 2004.)

## **Project Description**

In a planning area known as Piers 90-96 and the Backlands, the Port intends to install a pilot natural stormwater treatment system for stormwater management. The Port is currently developing a new roadway, the Amador Street Extension, (Fig. 4) within the Backlands area. Once the roadway is completed, a vegetated swale stormwater treatment system will be installed to capture the increased runoff generated by this new road. If the stormwater treatment proves to be successful, it will help the Port determine if a more expansive area wide system could be employed in the future development of the area.

## **Project Goals**

The Port's goals for site include stormwater management using designed, vegetated landscape features to reduce water pollution, erosion impacts, and offer aesthetic benefits to the area. They would like the conceptual design to include vegetated treatment swales that convey and treat stormwater up to the 25-year storm, and a proposal for vegetation types to beautify the area. Other goals include vegetation elements that will provide windbreaks and mitigate the generation of windblown dust from surrounding unpaved, un-vegetated parcels.

## **Site visit**

A visit to the project site shows that the area is highly industrial with large trucks moving large volumes of concrete and aggregate materials (Figures 5a,b, c, & d). The area is predominantly bare soil. It is quite dusty and muddy, but has wide-open views across the Bay. A series of natural wetlands, considered important bird habitat by the local Audubon society, will eventually become part of a larger constructed wetland system for treating more runoff.

## **Best Management Practices**

Best management practices (BMPs) is an umbrella term used to describe methods, activities and maintenance procedures or other management practices for reducing the amount of pollution entering a water body. The term originated from the rules and regulations developed pursuant to the federal Clean Water Act.<sup>4</sup> Landscape-based stormwater management methods include engineered, landscaped drainage systems such as swales or infiltration basins that collect storm water from paved surfaces and rooftops, and filter the storm water through vegetation and infiltration. This method of treating storm water has multiple benefits that include limiting volume to the nearby aging Southeast Treatment Facility, visually

---

<sup>4</sup> US Environmental Protection Agency. Polluted Runoff (Nonpoint Source Pollution) Glossary. <http://www.epa.gov/owow/nps/Ecology/chap8.html>

enhancing the area with more landscaping, providing passive recreation areas and walking trails, and providing habitat for plant and animal life.

### **Soils and Infiltration Potential**

Opportunities for infiltration, a typical method for natural stormwater management, are somewhat limited in large areas of the city that are very steep or have shallow depths to bedrock, baymud and bayfill.<sup>5</sup> (Fig. 6) Large sections of the eastern side of the city, including the Port's jurisdiction, are built on reclaimed wetlands that were filled with landfill. Piers 92 and 94 were constructed from filling San Francisco Bay in the mid 60s and 70s.<sup>6</sup> Where infiltration is difficult, there are other appropriate measures for natural treatment. Consultant's reports indicate that there are significant concentrations of heavy metals, petroleum hydrocarbons, lead and the remnants of arsenic and diesel based herbicides in the soils.<sup>7</sup> Test borings conducted by the aforementioned assessment found that the underlying soils consist of sandy clay and sand interspersed with varying amounts of gravel, concrete, brick and wood debris (fig. 7). In areas with potential contamination, infiltration based BMPs are not recommended. Soils for plants should be imported and placed over an impermeable seal to prevent contamination of runoff from contact with underlying soils.<sup>8</sup>

### **Adjacent Land Uses**

The Port is an enterprise agency that is responsible for generating its own funds for operations and maintenance. To generate funds, the Port leases their land along the Southern Waterfront and is required to maintain certain maritime land uses on various properties. Based on the Port's maritime and industrial past and this legislated mandate, the existing land uses along the Southern Waterfront remains highly industrial. A review of existing facilities within the vicinity of the project site reveals a mixture of activities ranging from municipal repair shops, recycling, and storage facilities to concrete mixing, dry docks, ship repair, auto wrecking and transfer stations. Each of these facilities is located along the waterfront and generates a variety of air and waterborne contaminants. In developing its stormwater management plan, the Port has identified potential contaminants generated within their jurisdiction that will have to be addressed through their stormwater management plan.<sup>9</sup> Existing land uses, sizes, operating conditions and potential contaminants are listed below:

---

<sup>5</sup> San Francisco Public Utilities Commission. Screening of Feasible Technologies Report. 2/27/04. P. 5-1.

<sup>6</sup> Treadwell and Rollo. Site Mitigation Plan. Proposed Berkeley Asphalt/Bode Gravel Batch Plants, Pier 92. Prepared for the San Francisco Department of Public Health. March 29, 2001. P.1.

<sup>7</sup> Treadwell and Rollo. Site Mitigation Plan. Proposed Berkeley Asphalt/Bode Gravel Batch Plants, Pier 92. Prepared for the San Francisco Department of Public Health. March 29, 2001. P.3.

<sup>8</sup> Personal Communication with Port of San Francisco, Keith H. Lichten, San Francisco Bay Regional Water Quality Control Board. 4/26/2005.

<sup>9</sup> Partial table reproduced from the Treadwell and Rollo and Watershed Resources Collaboration Group's Stormwater Management Plan for Port of San Francisco Southern Waterfront Pier 70 to Pier 96

Table 1				
Adjacent Land Uses				
Area	Name	Area Size	General Operations	Potential Contaminants
Pier 90-96 & Backlands	Port of San Francisco	Unknown	Pier 90: Storage and Maintenance yard	Solvents, metals, hydrocarbons
	Bodemix Concrete (Bedrock Concrete)	.7 acres	Pier 90: Storage and distribution of sand, gravel products to the construction industry (wet concrete mix)	Sediment, hydrocarbons
	San Francisco Community Recycling Center	Unknown	Pier 90: Recycling of household items for resale	Unknown
	Three D's Trucking	Unknown	Piers 90-92: Trailer and container storage next to grain silos	Sediment, hydrocarbons
	American Storage Unlimited, Inc.	Unknown	Pier 90: Public Storage Facility	Unknown
	Specialty Crushing	2.2 acres	Pier 92: Concrete recycling from public and private demolition projects.	Sediment, hydrocarbons
	Mission Valley Rock	1.5 acres	Pier 92: Bulk aggregates/sand and gravel with approximately 6,000-8,000 short tons of static storage capacity. Includes barge-offloading operation using conveyer system. Materials are cleaned, separated and stored for truck distribution to construction industry.	Sediment, hydrocarbons
	Darling International	4.5 acres	Pier 92: Transports products such as tallow, fats, greases, and cooking oils through pipelines for import to tankers. Rendering and storage of products in 10 steel storage tanks.	Hydrocarbons
	Pacific Cement	Unknown	Pier 92: Cement batch plant	Sediment, hydrocarbons

Source: Treadwell and Rollo and the Watershed Resources Collaboration Group. Stormwater Management Study for the Southern Waterfront Pier 70-96. Prepared for the Port of San Francisco. December 2001.

## **Vegetated Swales for Stormwater Management**

### *Description*

The California Stormwater Best Management Handbook describes vegetated swales as “shallow channels with vegetation covering the side slopes and bottom that collect and slowly convey runoff flow to down stream discharge points.”<sup>10</sup> Swales provide treatment by filtering the runoff through the vegetation planted in the swale and underlying subsoils. They slow runoff and trap and remove low to medium levels of particulate pollutants that include trace metals and suspended solids, sediment, nutrients, trash, metals, bacteria, oil, grease and organics.

<sup>10</sup> California Stormwater BMP Handbook – New Development and Redevelopment. January 2003. TC-30 p.1

## ***Site Design***

I took the following steps (Fig. 8) while developing the conceptual design: Determine drainage areas, assign runoff coefficients, calculate peak flows, calculate flow velocity, calculate cross sectional areas, calculate required widths and depths, calculate required widths and depths, calculate culvert dimensions, and select vegetation.

### **1) Determine major drainage areas**

To size swales it is necessary to know how much water will be draining from the surrounding areas. The Port staff indicated roughly which areas on the site that they wanted to tie into the swales. Several of the tenants on the site have already designed their lots to be hydraulically isolated, and they capture and reuse all of the rainfall that falls on their sites. The remaining drainage area consists of approximately 221,550 square feet (5.08 acres) along the new proposed Amador extension. When complete, the site will have a 28-foot wide road with 6 feet of gravel on either side. The road is 1,013 feet long with a total square footage of 28,300 square feet of asphalt. The rest of the site will be dirt, vegetation and swales. There are a few areas crossed by driveways that need culverts, so I divided the area into separate sub-drainages when divided by the culverts in order to determine the necessary size of the pipes. (Fig. 9)

### **2) Assign site runoff coefficients**

The rational method is a method for calculating runoff and treatment volumes for stormwater management among other things. The rational method is calculated using:

$$q = CiA$$

Whereas:

q = peak runoff rate (ft<sup>3</sup>/sec)

C = dimensionless runoff coefficient (between 0 and 1)

i = rainfall intensity (in/hr)

A = area of the drainage area (acres)<sup>11</sup>

The drainage areas currently consist of gravel, dirt and vegetation. The Bode parking lot (drainage area K) is decomposed granite and I assigned it a value of 0.5.<sup>12</sup> The new asphalt road will have a 6-foot gravel shoulder. I gave asphalt a runoff coefficient of 0.95, and the gravel 0.7.



<sup>11</sup> Strom, Steven and Kurt Nathan. Site Engineering for Landscape Architects. 1993. P. 101

<sup>12</sup> Strom, Steven and Kurt Nathan. Site Engineering for Landscape Architects. 1993. Table 8.1P. 106

C                      0.95                      0.7

To simplify things, I assigned the areas consisting of asphalt and gravel a weighted average runoff coefficient that is calculated where C is the total weighted average runoff coefficient, given by

$$C = (c_i A_i) / A_{tot}$$

Where  $c_i$  = runoff coefficient for the *ith* are of contributing drainage

$A_i$  = *ith* area.

See table for the calculations.

Areas consisting of asphalt and gravel were given the weighted average runoff coefficient of 0.88. For the most part, the drainage areas consisted of uniform surface. However, drainage areas A, B, B1, C, D, E and F, consisted of a mixture of asphalt, gravel, vegetation and dirt.

<i>Initial weighted coefficients</i>		
	Asphalt and gravel	Dirt and vegetation
C	0.88	0.3

For these areas I used the weighted average again using the above formula and calculated weighted average runoff coefficients of .59 for each area that consisted of the road, shoulder, dirt and vegetation. Fig. 10 shows for more details on the calculations.

### 3) Determine peak flows

To calculate the capacity of the vegetated swales, I needed to know how much water will be generated during the peak flows and how much water needs to be treated. For the Port site, the water quality volume (WQV) is 80 to 90% of the annual rainfall. This translates to approximately 0.5-1.25 inches of rain or a 2-year recurrence interval storm.<sup>13</sup> Since there will be no other treatment for the runoff from this site, these swales will be sized to accommodate a very large storm. The staff from the Port requested that the swales be sized to convey and treat a rainfall intensity of 1.24 inches per hour. The San Francisco Public Utilities Commission<sup>14</sup> considered this rain event is to be approximately the 100-year storm, while the Rantz formula suggests that this event is larger than the 100-year storm.<sup>15</sup> This would typically be seen as creating oversized swales, but the swale dimensions produced by smaller events would not provide adequate treatment according to the Department of Transportation's and the California Stormwater Quality Association's (CASQA's) design guidelines. Therefore, in consultation with Port

<sup>13</sup> Treadwell and Rollo and the Watershed Resources Collaboration Group. Stormwater Management Study for the Southern Waterfront Pier 70-96. Prepared for the Port of San Francisco. December 2001.

<sup>14</sup> San Francisco Public Utilities Commission Bureau of Engineering. SF Rainfall Table.

<sup>15</sup> Rantz, \_\_\_\_\_. Table 4: Precipitation depth duration-frequency data for the San Francisco Bay Region. 1971.

staff, I continued to use the 1.24 inches per hour for sizing. I proceeded to use the rational method to determine to various flows (q) for each drainage area.

**Table: 2 Rational Method for calculating Runoff (Q)**

Sub drainage areas	Area (ft <sup>2</sup> )	ft <sup>2</sup> /acre	Acres	I (in/hr)	C	Q (cfs)
A	3,040.00	43,560.00	0.07	1.24	0.59	0.05
B1	1,160.00	43,560.00	0.03	1.24	0.59	0.02
B (gate/culvert)	800.00	43,560.00	0.02	1.24	0.59	0.01
C	5,680.00	43,560.00	0.13	1.24	0.59	0.10
D (gate/culvert)	800.00	43,560.00	0.02	1.24	0.59	0.01
E	15,000.00	43,560.00	0.34	1.24	0.59	0.25
F	10,400.00	43,560.00	0.24	1.24	0.59	0.17
G	2,500.00	43,560.00	0.06	1.24	0.88	0.06
H	10,240.00	43,560.00	0.24	1.24	0.88	0.26
I	5,700.00	43,560.00	0.13	1.24	0.88	0.14
J	23,655.00	43,560.00	0.54	1.24	0.30	0.20
K (Bode Parking lot)	47,025.00	43,560.00	1.08	1.24	0.50	0.67
L	76,800.00	43,560.00	1.76	1.24	0.30	0.66
M	18,750.00	43,560.00	0.43	1.24	0.30	0.16
<b>Total Area</b>	<b>221,550.00</b>		5.086			<b>2.77</b>

#### 4) Calculate flow velocity and Dimensions of Swales

To find the minimum dimensions of the swale based on the parameters from developed by the Low Impact Design Center; I added the flow (Q) derived from the rational equation, to the equation for calculating the area of a trapezoid to determine the other needed dimensions to accommodate the peak flow.

Since the design guidelines recommend that the bottom width not exceed two feet, I began by plugging the two-foot, base<sub>1</sub> dimension into the equation for the area of a trapezoid. The maximum height of the flow (0.25 ft. plus an additional .25 feet for overflow protection) and the 4:1 (W:V) side slope ratio were kept constant.

$$Q = ((2 + \text{base}_2) / 2) * 0.50$$

For the smaller drainage areas, the calculation of the bottom and top widths as a function of the flow produced dimensions smaller than the recommend minimum widths, so I increased their widths to the minimum dimensions as recommended by the design guidelines of two feet on the bottom and six feet on the top. (Table 3) I also calculated the cross sectional area using the  $Q = \text{Velocity} * \text{Area}$  equation to cross check the velocity created by the swale dimensions to ensure that they did not exceed the one foot per second as recommend by the design guidelines. Where it exceeded the recommended velocity, I increased the widths until it fell into the acceptable parameter.

Table 3: Calculating dimensions												
Drainage Areas (B1,B and A)	Q	Q	V feet/sec	A	Min. x- sectiona l area	2 b1	b2	h	A	WP	R	
A - Swale section 1	0.05											
B (culvert)	0.02											
B1 Swale section 2	0.01											
Swale 1 (A,B and C)	0.08	0.08	0.04	2	1 ft^2	2	2	6	0.5	2	6.12 0.33	
<b>Drainage Areas (C,D,E)</b>												
C - Swale 3	0.10											
D (culvert)	0.01											
E - Swale 4	0.25											
Swale 2 (C,D, and E)	0.36	0.361	0.18	2	1 ft^2	2	2	6	0.5	2	6.12 0.327	
<b>Drainage Areas (F)</b>												
F - Swale 5	0.17											
Swale 3 (F)	0.17	0.175	0.09	2	1 ft^2	2	2	6	0.5	2	6.12 0.327	
<b>Drainage Areas (G,H, L, and M)</b>												
GM - Swale 6	0.22											
HL - Swale 7	0.91											
Swale 4 (G,H, L, and M)	1.14	1.135	0.45	2.50	1 ft^2	2	4	8	0.5	2.5	7.12 0.351	
<b>Drainage Areas (C,D,E,G, M H, L, J)</b>												
Drainage Areas (C,D,E)	0.36											
Drainage Areas (G,H, L, and M)	1.14											
Drainage Areas I, J	0.34											
Swale 5 (C,D,E,G, M H, L, I, J)	1.84	1.841	0.61	3.00	1 ft^2	2	4	8	0.5	3	8.12 0.369	
<b>Drainage Areas (K, J, F)</b>												
K	0.67											
Drainage Areas (C,D,E,G, M H, L, I, J) Swale 8	1.84											
F - Swale 5	0.17											
Swale 6 (All)	2.68	2.68	0.89	3	1 ft^2	2	4	8	0.5	3	8.12 0.369	

To crosscheck my calculations, I plugged the values into the Manning equation; an empirical equation to determine open channel flow, to determine if they roughness values calculated area reasonable based on the site conditions

The Manning equation is represented by:

$$V = (1.49 R^{2/3} S^{1/2}) / n$$

Where:

V = velocity in feet/second

1.49 = a conversion factor for unitd

Hydraulic Radius (R) = Area/ Wetted perimeter

S = slope

N = roughness factor.

To calculate the values for the Hydraulic radius (R), I the bottom dimension and side slopes to determine the wetted perimeter. When divided by the area ((R) = Area/ Wetted perimeter), the wetted perimeter gives you the hydraulic radius (R).

Then plugging these values into the Manning equation allowed me to determine the roughness (n) values.

The roughness (n) values were all relatively high, ranging from 0.26 to 0.29, so since I designed the swales to be densely vegetated, it means that the dimensions will accommodate both the runoff and the additional swale plants.

<b>Table 4: Cross checking with the Manning Eq.</b>		Manning Eq. $V = 1.49 R^{.67} S^{.5} / n$						
<b>Drainage Areas (B1,B and A)</b>	<b>Q</b>	<b>V f/s</b>	<b>S</b>	<b>n</b>	<b>0.67</b>	<b>0.5</b>	<b>1.49</b>	
A - Swale section 1	0.05							
B (culvert)	0.02							
B1 Swale section 2	0.01							
Swale 1 (A,B and C)	<b>0.08</b>	0.04	0.15	0.27	0.67	0.50	1.49	
<b>Drainage Areas (C,D,E)</b>								
C - Swale 3	0.10							
D (culvert)	0.01							
E - Swale 4	0.25							
Swale 2 (C,D, and E)	<b>0.36</b>	0.18	0.145	0.268	0.67	0.500	1.490	
<b>Drainage Areas (F)</b>								
F - Swale 5	0.17							
Swale 3 (F)	<b>0.17</b>	0.09	0.145	0.268	0.67	0.500	1.490	
<b>Drainage Areas (G,H, L, and M)</b>								
GM - Swale 6	0.22							
HL - Swale 7	0.91							
Swale 4 (G,H, L, and M)	<b>1.14</b>	0.45	0.145	0.281	0.67	0.500	1.490	

**Drainage Areas (C,D,E,G, M H, L, J)**

Drainage Areas (C,D,E) 0.36

Drainage Areas (G,H, L, and M) 1.14

Drainage Areas I, J 0.34

Swale 5 (C,D,E,G, M H, L, I, J)	1.84	0.61	0.145	0.291	0.67	0.500	1.490
---------------------------------	------	------	-------	-------	------	-------	-------

**Drainage Areas (K, J, F)**

**K** 0.67

Drainage Areas (C,D,E,G, M H, L, I, J) Swale 8 1.84

F - Swale 5 0.17

Swale 6 (All)	2.68	0.89	0.145	0.291	0.67	0.500	1.490
---------------	------	------	-------	-------	------	-------	-------

## 5) Calculating Culvert dimensions

The drainage areas are also connected at five points by culverts. To size the proper dimensions of a pipe or culvert one must know the surface slopes, the required peak flow (Q) to convey, and add the cumulative flows as the pipes are connected. Pipes should be buried at a minimum of 3 feet to protect them from being crushed by traffic.<sup>16</sup>

Calculations can be determined knowing that the cross sectional area of a circular pipe flowing full is  $\pi r^2$ , the area of a circle. The wetted perimeter is equal to the circumference ( $2\pi r$ ), therefore the hydraulic radius is represented by:

$$R = \frac{\pi r^2}{2\pi r} = r/2$$

Whereas:

R = hydraulic radius, ft, and

r = inside radius of the pipe section.

This combined with the Manning equation ( $V = (1.486/n)(R^{.67})(S^{.05})$ ) and the continuity equation,  $q = AV$ , can be combined as follows:

$$q = A * (1.486/n) * R^{.67} * S^{.05}$$

This is then applied to the known values from the site:

Drainage areas B1 and B (QB1 = .02 cfs, QB = .01 cfs, n = .02417, 4% slope,)

$$V = (1.486/n)(R^{.67})(S^{.05})$$

$$Q = A * (1.486/n) * R^{.67} * S^{.05}$$

$$.03 = \pi r^2 * (1.486/.024) (r/2)^{.67} * .4^{.05}$$

$$r^2 * r^{.67} = (.03 * .024 * 2^{.67}) / \pi * 1.486 * .4^{.05}$$

$$r^{2.67} = .0011 / 4.457$$

$$r^{2.67} = .00024$$

$$r = .00024^{1/2.67}$$

---

<sup>16</sup> Strom, Steven, and Kurt Nathan. Site Engineering For Landscape Architects, Second Edition. P. 144 1993.

<sup>17</sup> Strom, Steven, and Kurt Nathan. Site Engineering For Landscape Architects, Second Edition. Table 9.2 Roughness Coefficients (n) for Pipes and Channels. P. 122 1993.

$$r = .00024^{.374}$$

$$r = .1047 \text{ ft, } 1.25 \text{ inches (2.5 inch diameter)}$$

Drainage areas C and D ( $Q_c = .10$  cfs,  $Q_d = .01$  cfs,  $n = .02418$ , 1.58% slope, )

$$V = (1.486/n) * (R^{.67})(S^{.05})$$

$$Q = A * (1.486/n) * R^{.67} * S^{.05}$$

$$.11 = \pi r^2 * (1.486/.024) (r/2)^{.67} * .158^{.05}$$

$$r^2 * r^{.67} = (.11 * .024 * 2^{.67}) / \pi * 1.486 * .158^{.05}$$

$$r^{2.67} = .0042 / 4.25$$

$$r^{2.67} = .0009$$

$$r = .0009^{1/2.67}$$

$$r = .0009^{.374}$$

$$r = .0725 \text{ ft, } .871 \text{ inches (1.74 inches diameter)}$$

Drainage areas C and D ( $Q_{CD} = .11$  cfs,  $Q_E = .25$  cfs,  $n = .02419$ , 1.3% average slope)

$$V = (1.486/n) * (R^{.67})(S^{.05})$$

$$Q = A * (1.486/n) * R^{.67} * S^{.05}$$

$$.36 = \pi r^2 * (1.486/.024) (r/2)^{.67} * .13^{.05}$$

$$r^2 * r^{.67} = (.36 * .024 * 2^{.67}) / \pi * 1.486 * .13^{.05}$$

$$r^{2.67} = .0137 / 4.21$$

$$r^{2.67} = .0003$$

$$r = .0003^{1/2.67}$$

$$r = .0003^{.374}$$

$$r = .1136 \text{ ft, } 1.3 \text{ inches (2.7 inch diameter)}$$

---

<sup>18</sup> Strom, Steven, and Kurt Nathan. Site Engineering For Landscape Architects, Second Edition. Table 9.2 Roughness Coefficients (n) for Pipes and Channels. P. 122 1993.

<sup>19</sup> Strom, Steven, and Kurt Nathan. Site Engineering For Landscape Architects, Second Edition. Table 9.2 Roughness Coefficients (n) for Pipes and Channels. P. 122 1993.

These calculations yielded very small pipe diameters, but the staff at the Port suggested that the minimum pipe size be eight-inches in diameter to prevent clogging which is significantly larger and should accommodate the flow under various storm events.

## 6) Vegetation

### *Proposed planting pallet for swale design - A native pallet versus turf grasses*

There are several different varieties of swales; grass swales are planted with turf grass whereas vegetated swales are planted with bunch grasses, shrubs or trees. Grass swales convey water more quickly than vegetated swales.<sup>20</sup> If planted with turf grass, site managers may need to provide supplemental irrigation to keep the turf green year-round. Port staff indicates that there is a plan for providing a source of recycled irrigation water, but the presence of nearby wetlands suggests that increasing the habitat value of the site should be considered. I suggest using native plants because they are adapted to San Francisco's winter rains and summer droughts, and can provide food and forage for urban wildlife. Because I am substantially over sizing the swales, it is also possible to increase the roughness by adding taller or non-turf vegetation types. If grasses are planted, there are varying heights for grasses recommended, but the CA BMP handbook suggests that grasses should not exceed six inches.

For swales draining either side of the road, I chose a pallet consisting of *Carex tumulicoa* (Berkeley Sedge), *Juncus oxymoris* (Pointed Rush), and *Mimulus bifidus*, (Sticky Monkey Flower). For the swale located at the end of the connected swale system, I added *Typha domingensis* (Cattail) because there will be more water accumulating at this end of the system. I chose *Bromus carinatus* (California brome). (Fig. 13) Each of these choices is a native plant that has a high amount of surface area to provide maximum contact with the runoff.<sup>21</sup>

### *Seeding versus sod*

If the Port decided to install a grassy swale with sod, design manuals suggest that sod tiles should be placed so that there are no gaps between them with the ends staggered to prevent channel formation, and a sod roller should be used to prevent air pockets between the sod and soil. If seeding, erosion control measures should be used until the grass is established for at least 75 days after the first rainfall of the season.<sup>22</sup>

---

<sup>20</sup> Bay Area Stormwater Management Agencies Associations. Start at the Source 1999. p. 139

<sup>21</sup> California Stormwater BMP Handbook – New Development and Redevelopment. January 2003. TC-30 p.4

<sup>22</sup> Bay Area Stormwater Management Agencies Associations. Start at the Source 1999. p. 139

### *Soil characteristics for swale installation*

Swales should not be constructed from fill. Because the underlying soil is contaminated, soils should be imported and an impermeable seal should be applied to prevent contamination.<sup>23</sup> In my proposed swale cross-section design, I added eight inches of imported sandy loam to ensure adequate flow through treatment and an impermeable swale.

### *Maintenance*

A swale's performance is only as good as long as it is maintained properly. The California BMP Handbook recommends inspection twice annually, repairing any damage to the swale as quickly as possible, and reseeded bare patches as soon as detected to prevent erosion. If vegetated swales are chosen maintenance needs include: mowing, periodic trash and sediment removal once it accumulates past three inches, weed control and irrigation to maintain green appearances during drought conditions. Irrigation may be needed during the dry seasons, but some studies show that vegetated controls are effective at pollutant removal even when dormant.<sup>24</sup> Vegetative cuttings should not be left in the swale.

## **Results**

### *Swales Dimensions*

The final sizes of the swales are substantially larger than needed for the various drainage areas. Initial calculations keeping the depth of the water, 4:1 side slopes and velocity constant, resulted in some impossible dimensions. In consultation with Port staff, I chose the smallest dimensions that did not result in negative numbers for the bottom widths, and ended up with two final cross section dimensions for swales with the B1: B1 = 2 ft., B2 = 6 ft. and B1 = 4 ft., and B2 8 ft. (Figures 11, 13, 14, 15, and 16) Table 3 shows the calculations for the initial volumes and sizes from the sub-drainage areas and the final dimensions I chose for the swales.

### *Culvert Dimensions*

The resulting sizes for the culverts were too small to prevent clogging. In consultation with the Port Staff, we estimated that an 8-inch diameter pipes made from corrugated steel would be large enough to convey the runoff. Culverts need to be at least three feet below the surface to prevent damage from vehicular traffic.<sup>25</sup>

---

<sup>23</sup> Personal Communication with Port of San Francisco, Keith H. Lichten, San Francisco Bay Regional Water Quality Control Board. 4/26/2005.

<sup>24</sup> California Stormwater BMP Handbook – New Development and Redevelopment. January 2003. TC-30 p.4

<sup>25</sup> Wilson, Bradley. Port of San Francisco. Person communication, April 2005.

### *Swale design*

This property is mainly a working industrial site and the purpose of the swales is primarily to function for treatment. Choosing native vegetation will enhance existing habitat provided by the nearby wetland plant communities. The southern drainage areas will tie into a culvert that discharge into the nearby wetlands after a short residence time in the swales. The northern drainage swales will collect runoff from the new road and adjacent edges for the parcels. Midway through, the eastern swales, Swale no. 1 will cross under the road and join the western swales no. 4 and 5 where it will combine for final treatment in the final swale on the northern edge of the Bode Parking lot (drainage area K). See Figure 9 for a plan view of the flow direction of the runoff. The final drain is located at the end of the swale on the northern edge of the Bode Parking lot.

Where water enters and exits at concentrated points from the culverts, erosion control fabric and cobbles should be included to dissipate energy.<sup>26</sup> To ensure adequate pollutant removal, it is also necessary to ensure a thick layer of vegetation. The design handbooks recommend that swales should not be used in areas with steep topography, where slopes exceed 4%. A trapezoidal or parabolic shape provides maximum surface area contact, treatment effectiveness and ease for maintenance.

I chose trapezoidal shapes, the addition of permeable soils, an impermeable sheet, and dense vegetative cover to decrease flow velocities and settle particulates. (Figure 12).

### **Discussion**

The assignment of runoff coefficients for use in the Rational Method can have a significant impact on the runoff volumes, and there is a great deal of uncertainty associated with the choices. I chose higher parameters to err on the conservative side. This is justifiable because the treatment swales are the only source of treatment for this industrial runoff. This conservative choice, added with substantially over sizing swale dimensions, will ensure adequate residence time to drop out pollutants. I recommend vegetated swales over grassy swales because they provide more opportunities for enhancing habitat values and aesthetically more interesting than mowed turf. If the Port decided that they wanted the grassy swales, they would have to increase the maintenance regimes and mow periodically. Since the site is contaminated, the potential for infiltration is limited. The application of an impermeable seal will prevent infiltration and the vegetated swales will function more like a flow-through planter.

---

<sup>26</sup> S Bay Area Stormwater Management Agencies Associations. Start at the Source 1999. p. 41

## **Conclusion**

There are large amounts of uncertainty in assigning runoff coefficients to the various surfaces and the assumptions that are folded into the design storm and rain events. I hope by over sizing the swales I addressed the margin of uncertainty associated with these assumptions. As the Port of San Francisco continues to redevelop the Southern Waterfront, the application of natural drainage systems such as swales could potentially reduce additional loads on the City of San Francisco's combined sewer system, which in theory will improve the treatment capacity of the combined sewer by reducing the volumes entering the sewer. This sounds like good news for water quality, but it could be argued that no matter how many vegetated swales are added to convey runoff, adding more industrial uses such as cement plants and gravel processing to this bay front property will degrade the water quality simply by the additional airborne particulate matter. Addressing this question is a larger land use question, which is beyond the scope of this project, but should be considered when analyzing citywide water treatment and pollutant loads into the Bay.

## References

- Bay Area Stormwater Management Agencies Associations. Start at the Source 1999.
- California Stormwater Quality Association. California Stormwater BMP Handbook – New Development and Redevelopment. January 2003.
- Golden Gate Weather Services. <http://ggweather.com/sf/narrative.html> (Accessed August 5, 2004.)
- Low Impact Development (LID) Center.  
[www.lowimpactdevelopment.org/epa03/LIDtrans/L07\\_Swales.pdf](http://www.lowimpactdevelopment.org/epa03/LIDtrans/L07_Swales.pdf). Accessed 5/1/05.
- NOAA, National Weather Forecast Office website.  
[http://www.wrh.noaa.gov/mtr/sfd\\_sjc\\_climate/sfd/SFD\\_CLIMATE3.php](http://www.wrh.noaa.gov/mtr/sfd_sjc_climate/sfd/SFD_CLIMATE3.php). Accessed April 14, 2005.
- Keith H. Lichten, San Francisco Bay Regional Water Quality Control Board. Personal Communication with Port of San Francisco, 4/26/2005.
- Rantz, \_\_\_\_\_. Table 4: Precipitation depth duration-frequency data for the San Francisco Bay Region. 1971.
- San Francisco Public Utilities Commission Bureau of Engineering. SF Rainfall Table.
- San Francisco Public Utilities Commission. Screening of Feasible Technologies Report. 2/27/04. P. 5-1.
- Strom, Steven and Kurt Nathan. Site Engineering for Landscape Architects. 1993. P. 101
- Treadwell and Rollo and the Watershed Resources Collaboration Group. Stormwater Management Study for the Southern Waterfront Pier 70-96. Prepared for the Port of San Francisco. December 2001.
- US Environmental Protection Agency. Polluted Runoff (Nonpoint Source Pollution) Glossary. <http://www.epa.gov/owow/nps/Ecology/chap8.html>
- Wilson, Bradley. Port of San Francisco. Person communication, April 2005.
- USDA-NRCS. 2005. The PLANTS Database (<http://plants.usda.gov>). National Plant Data Center, Baton Rouge, LA 70874-4490 USA.

## Figures