SUSTAINABLE STORMWATER MANAGEMENT: IMPLEMENTING BEST MANAGEMENT PRACTICES IN SAN FRANCISCO'S PANHANDLE AREA

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by

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CERTIFICATION OF APPROVAL

I certify that I have read *Sustainable Stormwater Management: Implementing Best Management Practices in San Francisco's Panhandle Area* by Alicia M. Omlid, and that in my opinion this work meets the criteria for approving a thesis submitted in partial fulfillment of the requirements for the degree: Master of Arts in Geography: Resource Management and Environmental Planning at San Francisco State University.

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Certain types of urbanization and the addition of hardscape prevent the infiltration of rainwater into the soil and increase surface runoff. When runoff quantity exceeds the capacity of the sewer system, combined sewer overflows (CSOs) occur, sending partially untreated water into the San Francisco Bay and/or Pacific Ocean. Low Impact Development Best Management Practices (LID BMPs) (i.e. flow-through planters and permeable paving) can help alleviate CSOs. The goals of this research was to use ArcGIS to determine optimum site suitability in the Panhandle area of San Francisco for implementing LID BMPs based on the environmental variables of slope, depth to bedrock, and soil type, and to address why LID BMPs have not been widely implemented in San Francisco. I found that there are no policy impediments preventing LID BMP implementation and I make recommendations for San Francisco based on case studies as the city moves towards implementing them on a wider scale.

I certify that the Abstract is a correct representation of the content of this thesis.

____________________________________ ____________
Chair, Thesis Committee Date

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CHAPTER 1: INTRODUCTION

The United States Environmental Protection Agency (USEPA) has indicated that a typical city block creates more than five times as much stormwater runoff than a woodlot of the same size (U.S. EPA 2003, in VanWoert 2005). Streets, roofs, sidewalks, and parking lots (greater than ½ acre in size) make up approximately fifty-seven percent of San Francisco's land area (Kennedy *et al*. 2007). On-street parking and parking lots smaller than ½ acre in size make up an additional undisclosed amount. The addition of hardscape (i.e. asphalt and concrete) and certain types of urbanization prevent the infiltration of rainwater into the soil and increase surface runoff (Dunne & Leopold 1978, Wong & Eadie 2000). As a result, the amount of stormwater entering the sewer system increases, causing sewer pipes to become overburdened. When sewer pipes are overburdened, combined sewer overflows (CSOs) can occur, which result in untreated sewage being discharged into the San Francisco Bay or Pacific Ocean.

Sewer systems in many large cities, including San Francisco, are very old and extremely expensive to enlarge. San Francisco is an anomaly among other California jurisdictions such as San Mateo County, Alameda County, and

Santa Clara County because it operates a combined sewer system rather than a separate sewer system. Combined sewers treat both stormwater and sewage, while separate sewers only treat sewage before discharging it into receiving waters. In a separate sewer system, stormwater is often allowed to run off into nearby creeks, rivers, and other water bodies.

However, a more sustainable form of urbanization and development that addresses the reduction of CSOs is possible. Many aspects of geography including resource management, hydrology, and urban/environmental planning/policy can play significant roles in developing these increasingly sustainable methods. An ecological approach to land-use planning has been recognized as a means to the long-term sustainability of ecosystem benefits, services, and resources (Zipperer *et al*. 2000).

An ecological approach to land-use planning encourages cities to live within their means in terms of resources and allows planners to address multiple policy goals concurrently (water conservation, regulatory compliance, and increasing green space). Additionally, an ecological approach to land-use planning typically involves adding vegetation to the grey, urban landscape to take small steps towards mimicking the landscape as it was pre-development. The additional vegetation can also assist with groundwater recharge in some locations, incorporate habitat into the urban landscape, and beautify the urban environment. However, the idea that urban watersheds can be restored to pre-development conditions is not realistic and will be discussed further in Chapter 2.2.

1.1 Combined Sewer System

Many large, older cities in the United States such as Washington DC, New York City, Philadelphia, Boston, Portland (Oregon), Seattle, and San Francisco operate on a combined sewer system (Figure 1). As previously mentioned, combined-sewer systems collect wastewater and stormwater in the same pipes.

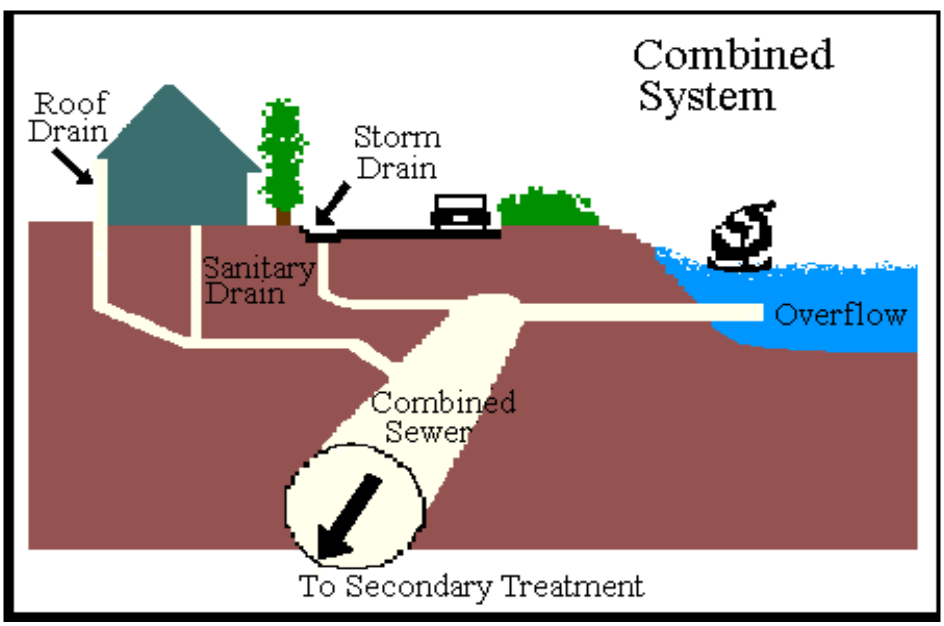

Figure 1: Diagram of a Combined Sewer System. Source: http://dnr.metrokc.gov

Combined sewers were introduced in 1855 and were a vast improvement over urban cesspool ditches that ran alongside city streets prior to implementation (Tibbetts 2005). A downfall of combined sewers is that during rainy weather, an excess of stormwater enters the system along with the raw sewage. The excess amount of stormwater and sewage combines to produce the aforementioned CSOs where raw sewage can travel via overland flow into nearby waters. In San Francisco, the untreated water can flow directly into the San Francisco Bay and the Pacific Ocean from 40+ locations around the city (San Francisco Department of Public Works 2006).

In 1989, the U.S. EPA adopted a CSO Control Strategy to direct states to develop an approach for the development and implementation of measures to reduce pollutant discharges from CSOs in order to comply with Clean Water Act requirements (U.S. EPA 1989). The three objectives of the strategy were to: ensure that if CSOs occur, they are only as a result of wet weather, to bring all wet weather CSO discharge points into compliance with the technology-based and water-quality based requirements of the CWA, and to minimize the impacts of CSOs on water quality, aquatic biota and human health (City of Portland 2007). The occurrence of CSOs is largely a function of sewer pipe sizes that have been outgrown by the populations they serve.

1.2 Objectives of this Research

Reducing combined sewer overflows into the San Francisco Bay by reducing stormwater flows entering the combined sewer system is part of the driving force behind the implementation of sustainable stormwater management techniques. These techniques are what I will refer to as Low Impact Development (LID) Best Management Practices (BMPs) or LID BMPs. Chapters 2 and 3 discuss LID BMPs in greater detail.

San Francisco city agencies are developing strategies for stormwater management using LID BMPs in the City's combined sewer areas that aim to reduce or slow the flow of stormwater runoff. The Panhandle of Golden Gate Park and surrounding neighborhoods (see Figure 2) have been determined by the San Francisco Department of Public Works (SFDPW) as an area for potential BMP implementation due to its capacity to infiltrate stormwater runoff diverted from the City sewer system (Braswell 2008). The Panhandle area also lies near the top of the Channel watershed (see Figure 3) (as delineated in the Stormwater Design Guidelines (2009) and in data used by the San Francisco Department of Public Works), which increases the potential of the probable LID BMPs to make a positive impact in reducing combined sewer overflows downstream. Leopold (1968) recognized that the volume of runoff is related to

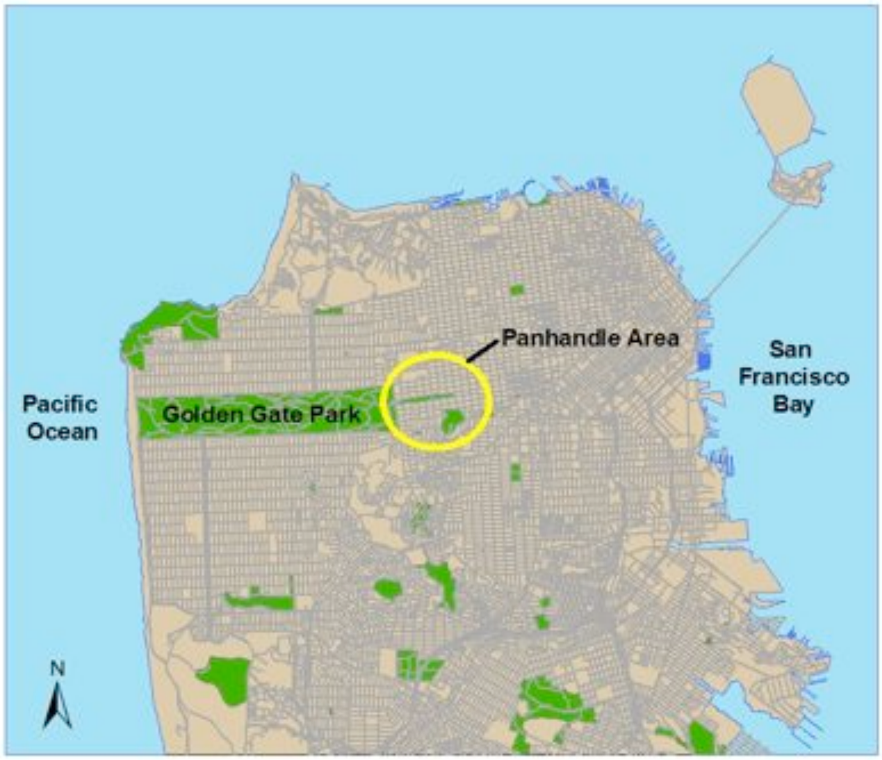

Figure 2: Context map of Panhandle project area within larger San Francisco study area. Source: San Francisco DPW.

land slope and soil type as well as to the type of vegetative cover. Because of the built-out nature of San Francisco, vegetative cover has largely been reduced. Slope and soil type, along with depth to bedrock and the amount of impervious surface cover, are essentially the determinants of runoff volume in San Francisco.

The goal of this study is twofold. First, I investigate where stormwater LID BMPs can be located in the public right-of-way within the Panhandle area of San Francisco given the current built-out conditions. I recommend a selection

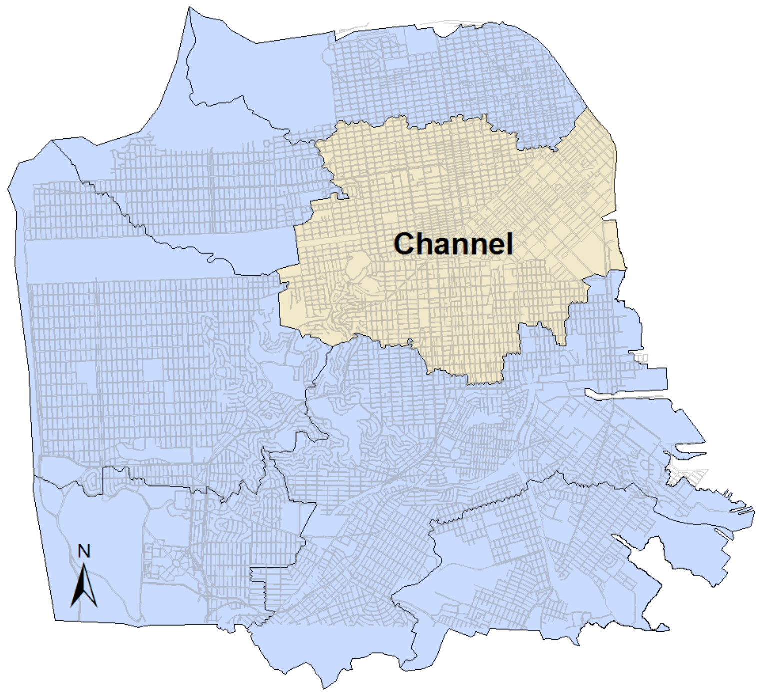

Figure 3: Channel watershed boundary. Source: San Francisco DPW.

of stormwater LID BMPs based on specific site conditions (i.e. slope, soil permeability, and depth to bedrock). My results provide a preliminary site suitability analysis for a selection of stormwater BMPs. Additional soil sampling to ensure proper infiltration rates and depth to bedrock would ideally be performed before the stormwater BMPs would be implemented. Current curb-cuts (i.e. driveways) were not spatially recognized in this study since this is a preliminary study and I did not have data. Actual implementation of LID BMPs would require this knowledge. LID BMPs that do not require a rigorous site suitability analysis (i.e. disconnected downspouts) will also be discussed.

Secondly, I address how sustainable stormwater management policy is put into practice. The implementation of BMPs is a simple way to alleviate capacity pressure on the City's sewer system, but I was interested in finding out why these technologies have not been widely implemented in such a progressive city as San Francisco. Was/is there a policy (i.e. parking, traffic engineering) in place that contradicts the goals of LID BMPs and prevents the implementation of sustainable stormwater management? What has to change in order to get BMPs into San Francisco's citywide policies and ultimately enacted?

1.3 Scope of the Study

My study focuses on two sites of different scales. The city of San Francisco is what I refer to as the study area and it is discussed in this Chapter. Chapter 4 will describe what I refer to as the "project area", which includes five small sub-catchments in the eastern basin (see Figure 4) near the top of the Channel watershed (Figure 3).

1.3.1 San Francisco’s Drainage & Sewer System

Ninety percent of San Francisco is served by a combined sewer system. The other ten percent of San Francisco is land largely under the jurisdiction of the Port of San Francisco on the east side of the city along the San Francisco Bay. San Francisco’s sewer system collects approximately 80 million gallons of

Figure 4: San Francisco's sewage treatment plant locations. Source: SFPUC. (Note the incorrect location of drainage divide where it crosses the Panhandle. Correct location shown in future maps.)

wastewater on a typical dry weather day (SFSewers 2009). This is enough to fill 120 Olympic-size swimming pools (Ramirez-Herrera *et al.* 2007). San Francisco's drainage is roughly divided into two main drainage basins: eastern and western (see Figure 4). There are two primary sewage treatment plants in the southwest and southeast portions of the city (see Figure 4). A third treatment plant exists in the northeast to help manage stormwater in heavy rain events.

1.3.2 San Francisco's Climate & Rainfall

San Francisco has a Mediterranean climate with dry summers and rainy winters. May through September typically supply less than an inch of rain (Stormwater Design Guidelines 2009). The first storms usually come in October and November (Brigham 2007) and 20 inches typically fall between November and March (San Francisco Public Utilities Commission & the Port of San Francisco 2009). Storms are less frequent in spring and less rain falls per storm (Golden Gate Weather 2006, in Brigham 2007). The occurrence of storms in early spring and fall is sporadic and storms occurring during these times usually produce light precipitation (Golden Gate Weather 2006 in Brigham

2007). However, polar and subtropical air masses can produce heavy rainfall events (Null 2002, in Brigham 2007).

Rainfall distribution throughout the city is uneven. The southern part of the city receives the most rainfall. The western and northeastern parts of the city receive slightly less and the extreme northeast receives the least amount (San Francisco Public Utilities Commission & the Port of San Francisco 2009). Within a distance of only a few miles there can be as much as a 20 percent difference in average annual rainfall in San Francisco (Golden Gate Weather Services 2002).

1.4 Significance of the Study

The topic of sustainable stormwater management (also known as integrative stormwater management) is significant because it incorporates many aspects of geography, namely resource management, hydrology and urban/environmental planning/policy. The implementation of stormwater BMPs not only reduces runoff volume of stormwater and improves the quality of the water, but reduces the urban heat island effect, creates habitat in the city, and improves upon the aesthetics of the cityscape.

Sustainable stormwater management is a relatively new area of study and will benefit by more research and application in different locations, taking into consideration the variability of soil permeability, slopes, and depth to bedrock. These variables are the environmental determinants for site suitability of the various LID BMP measures. Private property, parking (i.e. on-street) zoning, locations of curb-cuts (i.e. for driveways), and locations of underground utilities are the policy variables that also help determine where LID BMPs can be implemented.

In essence, sustainable stormwater management aims to recognize the changes in the landscape, most often due to forms of urbanization that do not seek to add vegetation to the landscape (Whipple *et al*. 1983). Sustainable stormwater management also aims to devise approaches to limiting certain undesirable effects, and take advantage of the newly offered opportunities (Whipple *et al*. 1983). These opportunities are specifically the aforementioned LID Best Management Practices (BMPs) and can bring vegetation and small green spaces to an otherwise concrete-filled cityscape with the larger goal of reducing combined sewer overflows into the San Francisco Bay by diverting stormwater away from sewer pipes.

CHAPTER 2: BACKGROUND: LOW IMPACT DEVELOPMENT STORMWATER MANAGEMENT IN PORTLAND & SEATTLE AND INTRODUCTION TO STORMWATER REGULATIONS

The dust bowl era of the 1930s brought watershed concerns to light, particularly potential water quality impacts and the associated management practices that could minimize these negative watershed effects (Ice 2004). The need for better land-management practices to maintain land and stream conditions to serve the present and future usable water needs was recognized (Ice 2004). This recognition led to the introduction of the predecessors of the stormwater BMPs that will be described in Chapter 3. Federal laws, and local ordinances and policies associated with stormwater will also be explained in this Chapter. This gives the study a regulatory framework and further stresses the importance of reducing CSOs from a regulatory standpoint.

2.1 Sustainable Stormwater Management & Low Impact Development (LID) BMPs

Typically, stormwater drainage is designed to collect, convey, and discharge runoff from urban areas as quickly as possible in order to prevent flooding (Delleur 2003). Sustainability calls for development to be carried out in a manner that limits impacts to the natural functions of landscapes, hydrologic systems, and habitats (Porter 2007). Sustainable stormwater management treats stormwater as a reusable resource rather than a waste product, and seeks to incorporate flood prevention, good drainage, and efficient conveyance into a site specific LID BMP, while simultaneously reducing pollution and providing other amenities such as landscaping and habitat. It also takes a watershed approach to managing stormwater, meaning that it looks at stormwater as part of the larger hydrologic system. This draws on McHarg's (1969) idea that "nature is a single interacting system and that changes to any part will affect the operation of the whole".

McHarg & Steiner (1998) suggested that planning and design should occur with nature in mind, and that ecology should be used to inform environmental design. Implementing LID BMPs follows McHarg's lead by looking to nature as the most effective manager of water and stormwater runoff (U.S. EPA 2006). The goal is to move in the direction of reproducing the pre-development hydrologic regime through the use of stormwater BMPs (U.S. EPA 2006) in order to reduce peak flows and improve stormwater quality. Clearly, the current level of development in San Francisco does not promote a complete return to the pre-development hydrologic regime as will be discussed in the following section. LID BMPs are small steps that urban areas can take to address and assess both water quality and quantity.

The use of LID Best Management Practices was pioneered in Prince George's County, Maryland in the early 1990s (U.S. EPA 2000b) as a way to mitigate the negative effects of increasing unsustainable forms of urbanization, and impervious surfaces (Dietz 2007). The EPA defines a BMP as a "technique, measure or structural control that is used for a given set of conditions to manage the quantity and improve the quality of stormwater runoff in the most cost-effective manner" (San Francisco Public Utilities Commission & the Port of San Francisco 2009). They are widely acknowledged as being the most effective method to control non-point sources of pollution (Ice 2004). There are two categories of BMPs that address reducing pollution. Source control BMPs aim to prevent pollution at its source. Treatment control BMPs seek to detain, bioinfiltrate, harvest, retain, or slow the conveyance of stormwater to the sewer.

Hydrologic functions of storage, infiltration, groundwater recharge, and maintenance of volume and frequency of discharges can be addressed with LID BMPs in addition to lengthening runoff time (Coffman 2000 in U.S. EPA 2000b). In stormwater management, lengthening runoff time is known as hydrograph modification. By modifying the hydrograph to avoid hydrographic peaks, flooding and erosion can be reduced since stormwater is released to the sewer system over a longer period of time.

LID BMPs may mitigate the expense of sewer pipe construction by augmenting inadequate sewer capacity in an innovative way that benefits both the human and the physical environment (e.g. reducing combined sewer overflows) and has largely been proven to be cost-effective. A selection of LID BMPs considered for use in the project area is described in Chapter 3. The LID BMPs discussed are those that appear to be the most widely used in the literature and case studies.

2.2 Sustainable Stormwater Management as Restoration

The idea that urban watersheds can be restored to pre-development conditions is not realistic. Ecological restoration is a widely interpreted term. Restoration is “a singular word offering myriad meanings and rich rhetorical resources” (Eden 2002 in Bauer 2008). The term is common language for developers, ecologists, academics, planners, environmentalists, and others. However, the term means different things to these different people in different professions and contexts.

Elliot (1997) posits that restoration assumes that environments that have been altered, degraded, or destroyed can in fact be completely restored. In a significantly built-out environment such as the city of San Francisco, complete restoration is out of the question. Others have used the terms environmental "rehabilitation" or "enhancement" (Rhoads et al 1999; Eden et al 2000 in Bauer 2008). These terms are more accurate and less misleading. However, Higgs (1997) states that good restoration will vary from site to site, but will always be "rooted by ecological fidelity: the combination of structural replication, functional success, and durability". In these words, restoration would be an appropriate term to use in association with the goals of sustainable stormwater management because it does not falsely lead people to believe that what they are supporting is restoration, but rather a structural replication of a selection of natural functions.

2.3 Stormwater Regulation Laws

Ecological information was not used for planning until 1969, when the National Environmental Policy Act (NEPA) was passed. NEPA required all federal government agencies to "initiate and utilize ecological information in the planning and development of resource oriented projects" (Steiner 2000). Many laws regarding water and water quality have helped increase the quality of water in the United States beginning with the Clean Water Act of 1972. This section will give an overview of the primary regulations related to stormwater that influence stormwater policy-making, from the federal to municipal levels.

2.3.1 The Federal Clean Water Act of 1972 & NPDES

The Federal Clean Water Act (CWA) was passed in 1972. It is the primary regulator of surface water quality protection in the United States. The CWA's main purpose is to reduce direct pollutant discharges into waterways, finance municipal wastewater treatment facilities, and manage polluted runoff (Clean Water Act 1972). It also made it illegal to discharge any pollutant into navigable waters unless a permit was issued by the Environmental Protection Agency (Clean Water Act 1972). Section 402 of the CWA created the National Pollutant Discharge Elimination System (NPDES) program. This was the first time that stormwater runoff, which is now known to be a major contributor to impaired waters, was regulated.

There are NPDES permits for wastewater and NPDES permits for stormwater. In California, the Regional Water Quality Control Board (RWQCB) issues NPDES permits. The San Francisco Bay Area lies within Region 2. The NPDES program was created to focus on eliminating point sources of pollution discharge. In 1987 the CWA identified stormwater as a point source of pollution (Clean Water Act 1972). A phased approach was proposed to regulate municipal storm sewer systems. Phase I permits began issuance in 1990 to medium (100,000 and 250,000 residents) and large (250,000+ residents) municipalities. These are often issued to a group of co-permittees encompassing an entire metropolitan area (California Environmental Protection Agency 2009).

Phase II permits require stormwater from small municipal separate storm sewer systems (MS4s) to reduce the discharge of pollutants to the "maximum extent practicable" (MEP) (U.S. EPA 2000a). MS4s include smaller cities as well as complexes such as campuses, prisons and hospitals. MEP is the performance standard specified in Section 402(p) of the Clean Water Act that refers to using a variety of best management practices and measurable goals (U.S. EPA 2000a). The EPA avoided giving an exact definition of MEP to give MS4s the necessary flexibility to optimize reductions in stormwater pollutants on a location-by-location basis (Debo and Reese 2003). Phase II also requires that stormwater management programs for MS4s be developed. These plans comprise six elements: Public Education & Outreach, Public Participation/Involvement, Illicit Discharge Detection and Elimination, Construction Site Runoff Control, Post-Construction Runoff Control, & Pollution Prevention/Good Housekeeping (U.S. EPA 2000a).

Additional federal requirements that need to be recognized include the Americans with Disabilities Act (ADA) and the CWA Total Maximum Daily Load (TMDL) Program. The San Francisco Department of Building Inspection (DBI) and the San Francisco Department of Public Works (SFDPW) locally enforce the ADA. The ADA is relevant to LID implementation because many of the BMPs can be located in the public right-of-way/sidewalks where sidewalk width permits (thereby avoiding on-street parking removal). A clearance of 48" is required for sidewalk width and permeable paving must comply with ADA standards if it is to be used in the public right of way.

Section 303(d) of the Clean Water Act declares that individual states are responsible for determining total maximum daily loads (TMDLs) of pollutants that are allowed to run into water bodies. The TMDL is then enforced by the Regional Water Quality Control Board (RWQCB).

2.3.2 The Federal Combined Sewer Overflow Policy

In 1994 the U.S. EPA issued the Combined Sewer Overflow Control Policy (the national control of CSOs) through the NPDES permitting program. This policy was built on the 1989 EPA CSO Control Strategy and directed communities to dramatically reduce or eliminate their CSOs. The EPA also began working with municipalities in order to achieve the standards set out in the Clean Water Act. Coordination among stakeholders and public involvement during the decision-making process were emphasized with this policy.

A short-term and a long-term plan for controlling the CSOs were mandated with this policy and municipalities with CSOs were left with two options. They could either build separate underground pipes for sewage and stormwater, or they could keep the existing combined pipes and somehow build capacity (Tibbetts 2005). Implementing LID BMPs is a way to build capacity (both above ground with LID BMPs like rain gardens or flow-through planters, or with underground storage devices like cisterns), which avoids the cost-prohibitive construction of new pipes.

Public health is also of great concern in regards to CSO management. The EPA contends that “because CSOs contain raw sewage and contribute pathogens, solids, debris, and toxic pollutants to receiving waters, CSOs can create serious public health and water quality concerns” (U.S. EPA 1994). Gaffield *et al.* (2003) investigated the scale of public health risk from urbanization spawned stormwater runoff. They concluded that stormwater management to minimize runoff and associated pollution makes the most sense for protecting public health at the least cost. Sewage infrastructure requires a large investment, while incorporating LID BMPs reduces stormwater volume and can improve the quality of stormwater simultaneously (Gaffield *et al.* 2003).

Using LID BMPs allows stormwater to be treated where it falls, rather than at the traditional end-of-pipe sewage treatment plants.

2.3.3 California Environmental Quality Act (CEQA)

The California Environmental Quality Act (CEQA) was enacted in 1970. It followed the National Environmental Policy Act (NEPA) of 1969, which requires federal agencies to assess the possible environmental consequences of projects that they plan to undertake, fund, or approve. An Environmental Impact Statement (EIS) is required that documents the potential environmental impact of the proposed action and alternatives. CEQA operates under the same premise by requiring state government agencies to consider the environmental consequences of projects while informing decision-makers and the public about the potential significant environmental effects of proposed City projects (San Francisco Public Utilities Commission & the Port of San Francisco 2009). Locally, the San Francisco Planning Department administers CEQA.

LID BMP construction projects are typically small in scale with the exception of large underground cisterns or detention basins. There are a few applicable issues on the CEQA Environmental Checklist Form (Appendix G of the CEQA Guidelines) that are applicable to the implementation of stormwater LID BMP projects. Section VII of the checklist addresses potential impacts of projects related to hydrology and water quality. Stormwater LID BMP projects aim to do just the opposite of the issues listed in this section, i.e. "Substantially alter the existing drainage pattern of the site or area…or substantially increase the rate or amount of surface runoff in a manner which would result in flooding on-or off-site" (State of California 2005). A large detention basin would alter the existing drainage pattern, but positively, rather than negatively as the checklist item suggests. Nevertheless, the change should be analyzed and documented for future reference.

Section XV of the checklist addresses potential impacts of projects related to transportation/traffic. One of the checklist items relates to whether a project will result in inadequate parking capacity. San Francisco does not need to consider parking as an environmental impact as is evidenced by the Emporium case (San Franciscans Upholding the Downtown Plan v. City & County of San Francisco 2002). Parking is considered a social matter rather than an environmental matter for CEQA review (San Francisco Bicycle Coalition 2008). The final applicable checklist item occurs in section XVI concerning utilities and service systems. A checklist item asks if the project would "Require or result in the construction of new storm water drainage facilities or expansion of existing facilities, the construction of which could cause significant environmental effects" (State of California 2005). Again, an LID BMP implementation project would do the opposite.

2.3.4 San Francisco Ordinances & Policies

There are a number of ordinances and policies that either have been adopted or are currently under public review that should assist in the realization of LID BMPs being implemented in the city of San Francisco.

San Francisco's Better Streets Plan is a document written to assist decision makers, street designers, managers, and stakeholders (i.e. community members, developers, and organizations) in planning for how streets are designed, built and maintained. The Better Streets Plan explicitly states: "if fully realized, the Better Streets Plan will…help to minimize sewer/stormwater overflows into the Bay" (City and County of San Francisco 2008). The policy also calls for reducing pollution by incorporating on-site stormwater management as a way to reduce combined sewer overflows. The Plan further encourages the incorporation of sustainable stormwater management techniques to ensure continued quality of life, economic well-being, and environmental health in San Francisco (City and County of San Francisco 2006).

The latest version of the San Francisco Sewer System Master Plan is currently under Environmental Review. The San Francisco Planning Department's Major Environmental Analysis division is identifying environmental impacts of proposed actions and identifying ways to reduce or avoid environmental damage. The Sewer System Master Plan's goals include developing a long-term strategy for managing the City's wastewater and stormwater and maximizing the system's reliability and flexibility. There is however, a lack of funding to maintain or expand the aging infrastructure. As a result, a more sustainable system is desired. Best Management Practices are cited as a major tool in accomplishing a more sustainable system (San Francisco Public Utilities Commission & the Port of San Francisco 2009).

The Green Building Ordinance is a third initiative that addresses stormwater management. The Green Building Ordinance was enacted in 2004. It required that city-owned buildings to be built to a Leadership in Energy and Environmental Design (LEED) Silver standard. LEED standards were developed by the US Green Building Council and evaluate building's environmental and energy efficiency.

Additionally, ordinance 137-05 amended the San Francisco plumbing code in 2005. This ordinance made it possible to direct rainwater to alternative storage places like rain barrels, cisterns, and rain gardens (City and County of San Francisco 2005).

2.3.5 San Francisco Stormwater Design Guidelines

The San Francisco Stormwater Design Guidelines (SDG) apply to areas with separate sewer systems in San Francisco. This final document was a recent (2009) joint effort between the San Francisco Public Utilities Commission and the Port of San Francisco. This document will likely be a template for a similar document that could be applied to the combined sewer system areas of the city of San Francisco. The SDG is the result of a two-year community planning effort that ultimately provides developers, engineers, and architects with a tool to assist them in incorporating LID BMPs into new development projects within the separate sewer system area of San Francisco.

2.4 Portland, Oregon & Seattle, Washington as Model Cities

Stormwater BMPs are generally known to be effective in places with a steady rainfall regime. Portland and Seattle both have a steady rainfall regime that lasts roughly from November through April and San Francisco experiences more drought-like conditions interrupted with shorter, more intense storms from November to April (USDA Soil Conservation Service 1991). Despite the differences in rainfall regimes, places with Mediterranean climates can also benefit from the use of LID BMPs because the underlying principles and goals of their implementation are the same in both climates. Local municipalities including Alameda and Contra Costa counties, as well as international municipalities such as Western Australia have similar Mediterranean climates to San Francisco's and have experienced success with LID BMPs.

Portland, Oregon and Seattle, Washington have been practicing sustainable stormwater management for over ten years. They are model cities for sustainable stormwater management. Granted, Portland and Seattle do not have the same density and parking pressure of San Francisco, which has likely made LID BMP implementation easier in those cities. Ways of incorporating LID BMPs into dense urban environments without sacrificing parking are now available and will be further discussed.

Close monitoring of LID BMPs has been an important tool to show the public that many of the stormwater BMPs have successfully been removing pollutants and reducing the amount of stormwater entering the sewer system. Both Portland and Seattle and their respective stormwater management programs will be discussed in greater detail in Chapter 3.

CHAPTER 3: LITERATURE REVIEW OF LOW IMPACT DEVELOPMENT BMPS AND CASE STUDIES

In this Chapter, I discuss a selection of Low Impact Development BMPs that could be employed in the project area. Additionally, details of Seattle, Washington's and Portland, Oregon's sustainable stormwater programs are discussed as they have been in place for over ten years and have proven to be successful. I investigate how these cities' programs have become model programs and attempt to shed light on what San Francisco can take from their successes in order to develop a successful program as well.

3.1 Description of Selection of LID BMPs

The descriptions of the selection of LID BMPs provide basic information on what LID BMPs aim to do and show what they look like when built into the landscape. The selection of LID BMPs is representative of what San Francisco's Better Streets Policy calls for in it's intention to incorporate sustainable water management techniques as part of its larger goal to create streets and publicly-accessible rights-of-way that "contain the characteristics and objectives of good street design and sound environmental planning" (City and County of San Francisco 2006). The first four LID BMPs that are described (vegetated swales, flow-through planters, rain gardens, and permeable paving) are the four that I carried out site suitability analyses for. The site suitability analysis is discussed in Chapter 4. The other three are discussed here in order to provide awareness of other, more easily adaptable LID BMPs that do not have as stringent of site requirements of the former four.

3.1.1 Vegetated Swales

Literature suggests that vegetated swales represent a practical and potentially effective technique for controlling urban runoff quality (California Stormwater BMP Handbook 2003). Vegetated swales are broad, shallow channels that utilize plants, engineered soils and a rock sub-base to slow, store,

Figure 5: Vegetated swale in Portland, OR. Photo: A. Omlid.

and remove pollutants from stormwater runoff before they enter a sewer drain (Figure 5). Additionally, pets (i.e. dogs) can use the vegetated area thus reducing the concentration of urine/feces in the few dog parks.

The slope requirement for this stormwater BMP varies in the literature. The slope refers to the longitudinal slope that is parallel to the street length. For example, the California Stormwater BMP Handbook (2003) recommends a longitudinal slope of 2.5% for vegetated swales. The city of Seattle recommends a slope of 2-6% (City of Seattle 2000, in San Francisco Public Utilities Commission & the Port of San Francisco 2009). Check dams are recommended for channel gradients over 4% (U.S. EPA 1999 in San Francisco Public Utilities Commission & the Port of San Francisco 2009). A channel gradient value of 2-2.5% was used for this site suitability analysis (Chapter 4) as the optimum value for vegetated swales (Mundy 2009). Exceeding the established maximum slope is technically possible, but my study is intended to provide direction in placing the LID BMPs where they would function optimally for pilot projects. A depth to bedrock value of >10’ and places where NRCS soil type A is present are the other two environmental parameters.

3.1.2 Flow-Through Planters (Bioretention Planter)

Flow-through planters or bioretention planters are closely related to vegetated swales (Figures 6 & 7). Bioretention refers to the infiltration, evaporation, and filtering of stormwater runoff. They are contained vegetated stormwater treatment systems that use soil infiltration to slow and store stormwater runoff, and remove pollutants from stormwater runoff. Portland has seen notable success in the reduction of peak flows by utilizing this LID BMP in its Green Streets Program (City of Portland 2004). A flow-test in the Siskiyou Curb Extension Project in northeast Portland, determined that the peak flow

Figure 6: Flow-through planter in Eugene, OR. Photo: A. Omlid.

from a 25-Year storm (an intense thunderstorm with 1.89 inches in 6 hours and a peak intensity of 3.32 inches/hour) would be reduced by 88%, which protects against basement sewer backup and CSOs (City of Portland 2004). Curb-side planters function to catch runoff from streets.

Figure 7: Curb-cut to direct stormwater into planter in Portland, OR. Photo: A.Omlid.

Flow-through planters are often built in a succession down a street so that when the most upstream one is full, the excess water can flow out, into the street and into the next one. The neighborhoods in Portland where the planters are built are different from those in San Francisco, however. Sidewalks must be at least 48” wide in San Francisco to comply with the American’s with Disabilities Act (ADA). Sidewalks along Haight Street in the study area cannot afford to lose any width due to high pedestrian levels. However, this neighborhood scores high on DeLeon’s Progressive Voting Index (DeLeon ca 2005), which provides some insight that businesses and residents might be progressive enough to realize the environmental/aesthetic benefits of LID BMP implementation. There are many wide sidewalks on less trafficked streets nearby that are suitable for flow-through planter implementation (Figure 8). Parking does not necessarily need to be removed for flow-through planters to be implemented. Figure 5 shows an example of parking removal, but Figure 9 shows how the two can coexist.

Figure 8: Wide & underused sidewalk on Clayton St. @ Haight St. 5% slope. Photo: A. Omlid.

**Figure 9: Flow-through planter and parking in Portland, OR.
Photo by Alicia Omlid**

The California Stormwater BMP Handbook (2003) recommends a channel gradient slope range of .5%-5% for flow-through planters, which I used. Again, exceeding the established maximum slope is technically possible, but my study is intended to locate optimum sites for the selected suite of LID BMPs for community and political support, the optimum values of .5-5% were used.

3.1.3 Permeable (Porous) Paving

Permeable paving refers to any porous, load-bearing surface that allows for temporary rainwater storage prior to infiltration or drainage to a controlled outlet. It can take the form of porous asphalt, porous concrete, turf blocks, un-grouted paving stones or bricks, or plastic grid systems (see Figure 10). Stormwater is retained in an underlying aggregate layer until it infiltrates into the

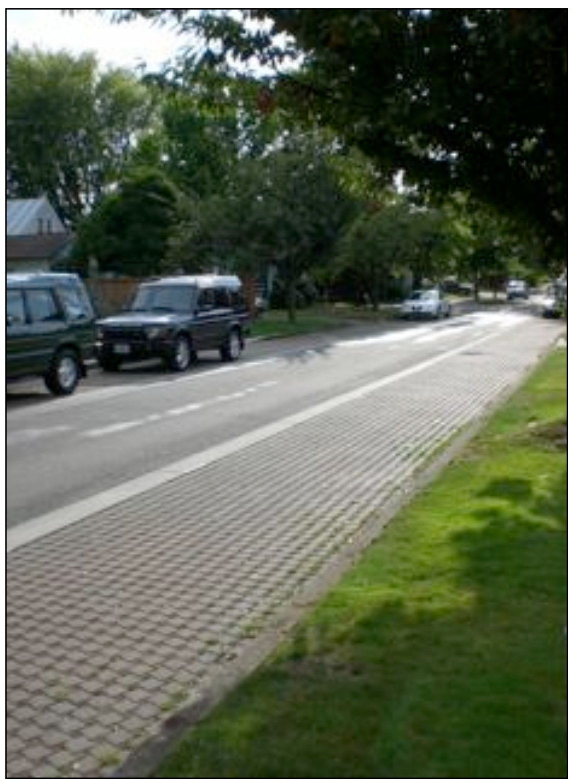

Figure 10: Permeable paving blocks in Portland, OR. Photo: A. Omlid.

soil in an infiltration-based system. As with many of the LID BMPs, maintenance can be a concern. Using conservative slope values helps to ensure proper functioning.

Streets with speeds less than 35 miles per hour, parking lots, driveways, sidewalks, and street-side parking areas are recommended sites for permeable paving (San Francisco Public Utilities Commission & the Port of San Francisco 2009). Chicago, with its nearly 2000 miles of back alleys, recently implemented a stormwater ordinance that mandates the use of pervious pavement in the reconstruction of alleyways (Buranen 2008). Permeable paving is restricted to relatively flat sites of less than 5% (U.S. EPA 1999 in Dreelin, Fowler, & Carroll 2006). This study used optimum street slope gradient values of 0-2% (Mundy 2009). Where stormwater is being allowed to infiltrate, there must be at least four feet between the paving and bedrock (San Francisco Public Utilities Commission & the Port of San Francisco 2009).

3.1.4 Rain Gardens

A rain garden is a depressed area in the landscape that collects rainwater (see Figure 11). Rain gardens reduce stormwater volumes by capturing, infiltrating, and transpiring rainwater. Plants that are tolerable of periodic inundation are planted in the depressions. These plants in combination with soil microorganisms, filter stormwater before it infiltrates into the soil or is conveyed to the sewer system.

Rain gardens require well-drained soil and a depth to bedrock of at least ten feet (San Francisco Public Utilities Commission & the Port of San Francisco 2009). Areas with a slope less than five percent are recommended. They are often used in conjunction with a curb cut to direct stormwater runoff into the rain garden, or in conjunction with disconnected downspouts as shown in Figure 11.

Figure 11: Rain garden catches runoff from roof via disconnected downspouts in Portland, OR. Photo by Alicia Omlid.

3.1.5 Cisterns and Rain Barrels

Modern cisterns are based on an ancient technology used in arid climates to capture and store rainwater (Koutsoyiannis *et al*. 2008; AbdelKhaleq and Ahmed 2007). They come in many sizes, can be above or below ground, and they can be used on their own or in conjunction with downspout disconnections as another resourceful way to use stormwater (Figure 12). Rain barrels are smaller containers used to capture rainwater runoff from roofs. This water can then be used for irrigation or other non-potable uses. In San

Figure 12: Disconnected downspout from building (yellow) connects to cistern (behind fence). Portland, OR. Photo: A. Omlid.

Francisco, a permit is not required to install a rain barrel that does not connect to an indoor plumbing system. Cisterns that collect water for potable uses require a permit from the Department of Building Inspection. Stable, flat areas are necessary to site rain barrels and above-ground cisterns.

3.1.6 Downspout Disconnection

Downspout disconnection refers to disconnecting the roof downspouts in order to prevent water from going directly into the sewer system. They have been very successful in Portland, Oregon in terms of volume reduction and community participation. 56,000 property owners disconnected their downspouts from 1995-2007. It is estimated that disconnected downspouts have helped to decrease stormwater runoff in Portland by one billion gallons annually (San Francisco Public Utilities Commission 2007), which is approximately ten percent of the total annual stormwater runoff. Rain barrels, cisterns, or rain gardens can be used in conjunction to capture roof runoff and subsequently use it as a resource. The collected water can then be used to wash cars or for irrigation purposes. If the water is not collected, a splash pad to dissipate the water or rain garden is needed where the water hits the ground.

Figure 13: Disconnected downspout with dissipator (can also lead to a rain garden or, alternatively be attached to rain barrel or cistern). Photo: A. Omlid.

3.1.7 Expanding the Urban Forest

Expanding the urban forest is one of the simplest means to reducing stormwater runoff. The urban forest refers to publicly and privately maintained street and park trees in an urban environment. Trees intercept rainfall before it hits the ground and uptake water that hits the ground, thereby reducing runoff volumes and peak flows. A 2005 study by San Francisco's Urban Forest Council found that on average, each street tree intercepts roughly 1000 gallons of rainfall each year (San Francisco Planning and Urban Research Association

2008). San Francisco's Better Streets Plan calls for the use of drought-tolerant species to be used because they are not as resource intensive as species that require frequent watering during dry periods. Native trees are typically looked to because of their ability to survive well in San Francisco's climate, but many of them grow too large and don't tolerate being planted in sidewalks (Sullivan 2004).

3.2 Sustainable Stormwater Programs in Seattle, WA & Portland, OR

Researching the process and history by which other sustainable stormwater programs have been implemented and funded has clarified how a citywide sustainable stormwater management policy could move forward in San Francisco.

In 1999, the City of Seattle implemented the Natural Drainage System (NDS) approach to stormwater management. Seattle Public Utilities has projected that the sustainable stormwater management projects that have been implemented in the city are at least 25 percent less expensive than traditional stormwater systems due to decreased building and infrastructure maintenance costs (WERF Seattle 2008). The Oregon Museum of Science & Industry (OMSI) in Portland is a well-known site of successful bioretention planters that treat runoff from the large parking lot. It has been documented that construction costs were reduced by approximately $78,000 through the reduction of pipes, manholes, and catch basins (Liptan and Murase 2000).

The Endangered Species Act's (ESA) listing of various salmon species in the 1990s provided an impetus for developing an effective stormwater program early on (Johnson 2008). Salmon has long been a cultural and commercial icon in the northwest. Overfishing reduced salmon numbers in the 1990s and federal action was needed to protect the species. San Francisco has never felt the cultural and economic pressure to reduce stormwater pollution to help save an endangered/threatened species as Portland and Seattle did regarding the ESA listing of selected salmonid species.

Portland's Sustainable Stormwater Management program was an outgrowth of both mandated requirements and City policy (Hauth 2008). In 1991, a court order was issued in Portland to stop CSOs from going into the Willamette River, which bisects the city. In 1996, the Stormwater Policy Advisory Committee (SPAC) was formed. This group was comprised of a variety of stakeholders from a variety of professional fields and advises the City on stormwater matters. Collaboration and education is heavily emphasized in Portland. The Bureau of Environmental Services offers workshops to the community on how to implement BMPs and developers are encouraged to build water quality protection into new construction (WERF Portland 2008). City agencies are required to incorporate stormwater BMPs into routine sewer and road projects under Portland's Watershed Management Plan, which was adopted in 2006.

3.3 Importance of Pilot Projects

Pilot projects have proven to citizens that LID BMPs can be effective in reducing the quantity of stormwater entering sewers as well being elements of beautification in neighborhoods. Portland has aggressively pursued EPA grants to fund pilot projects. $2.6 million was awarded to pay for 25+ BMP projects throughout the City of Portland between 2002 and 2005 (Center for Neighborhood Technology 2007). Continuous monitoring of pilot projects has further enforced the fact that BMPs are successful in reducing peak flows and treating stormwater on site. Portland has found that many of its projects reduce peak flows by at least 80-85% and retain 80-95% of stormwater on site (Center for Neighborhood Technology 2007).

A noteworthy example of a successful LID BMP pilot project outside of the northwest is Chicago's use of permeable paving in alleys. Chicago's Streetscape and Urban Design Program in the Department of Transportation (CDOT) developed the Green Alley Program as a response to flooding in basements and Chicago's Mayor Daley's desire for Chicago to be the "greenest city" (Buranen 2008). Project director Janet Attarian has expressed amazement in how quickly the program went from pilot to policy (Buranen 2008). The pilot projects' funding came from their regular construction program funds, not special sources.

The pilot projects gave residents an opportunity to witness the projects' effectiveness and get behind them, which is one reason why the Green Alley Program is so successful. Also aiding in public support was the well-designed graphic manual that describes green technologies and gives a cost-benefit analysis to the layman. This helped to gain support from city staff and the larger public (Buranen 2008). The Stormwater Design Guidelines document prepared for used in San Francisco's MS4 areas is similar in nature, which will help in teaching the community about LID BMPs.

Because city staff and Chicago's mayor were on board, the program was passed into policy with ease (Buranen 2008). Since San Francisco currently appears to have a similar political arena, now would be a great time to implement BMP pilot studies throughout the city. Assuming success of the pilot programs, citizens would become aware of green infrastructure and the environmental benefits associated with it.

A local example of a related small-scale pilot project that has gathered community support is San Francisco's PARK(ing) Day. This annual event brings awareness to parking space alternatives and the lack of public open space in cities by encouraging people to build makeshift mini-parks in parking spaces throughout the city on a specified date each year (REBAR 2009). This event has grown tremendously in San Francisco, highlighting city dwellers' desire for greenery and park space in urban cities instead of traditional parking spaces.

Mayor Newsom has supported a significant amount of environmental policies during his time in office. Recycling restaurant grease and the Mayor's Green Building Ordinance are some examples of environmentally conscious policies that he has supported. Newsom's website proclaims "Mayor Newsom believes that California needs to prioritize renewable and efficient energy, clean transportation, green buildings and above all else – a culture of sustainability" (Newsom 2008). With this view, it would appear that proposing a citywide sustainable stormwater policy is within reason and would receive support.

3.4 Stormwater/Drainage Fees/Incentives

In 1958 Seattle formed a Sewer Utility and adopted a stormwater drainage fee in 1988. The fee allowed the creation of the Drainage and Wastewater Utility, which eventually became part of Seattle Public Utilities (SPU) in 1997. The stormwater/drainage fee is based on each property's estimated impact, and is billed on the King County property tax statements. Seattle has historically funded stormwater and wastewater programs in a variety of ways including fees, bonds, and general fund sources (City of Seattle ca 2003). Drainage fees fund 99% of the drainage operating revenue requirement for SPU (City of Seattle 2006).

Similarly, in Portland, a stormwater utility fee was established in 1977 to help pay for the increasing cost of managing stormwater runoff (Portland Bureau of Environmental Services 2009). Portland's Clean River Rewards Program was developed to give property owners incentive to manage stormwater onsite (WERF Portland 2008). Residential and commercial ratepayers can receive a discount on their stormwater fee depending on the extent to which they can manage runoff. Residential customers have discount incentives for managing roof runoff only, while commercial customers have discount incentives for managing roof runoff as well as parking surface runoff. Giving incentives to commercial customers to manage parking surface runoff in addition to roof runoff helps avoid the construction of large swaths of hardscape that swiftly transports stormwater into the city's sewers, rather than into a stormwater LID BMP.

At this point in time, the SFPUC does not have an incentive program for managing stormwater on-site. As mentioned earlier, Portland's downspout disconnection program proved successful in eliminating approximately one billion gallons of stormwater (ten percent of the annual total) from the sewer system annually (SFPUC 2007, Portland Bureau of Environmental Services 2009). The City of Portland's Bureau of Environmental Services provides a $53 incentive to residents if they take their downspouts off the grid. Likewise, San Francisco's Department of Public Works lowers the permit fee as an incentive for sidewalk landscaping when more than one residence on a city block applies for a permit. A similar policy would need to be perpetuated in order to promote the creation of a stormwater program that provides incentives for residents or businesses that choose to capture stormwater on site.

CHAPTER 4: PHYSICAL SETTING & METHODOLOGY

4.1 Description of the Project Area

My study was conducted in the city of San Francisco in the area surrounding the Panhandle of Golden Gate Park in an area served by San Francisco's combined sewer system. This area lies within the Channel watershed (see Figure 1), one of San Francisco's eight major watersheds, or drainage basins (as delineated in the Stormwater Design Guidelines and in data used by the San Francisco Department of Public Works). These drainage basins represent the current drainage system, yet resemble historical

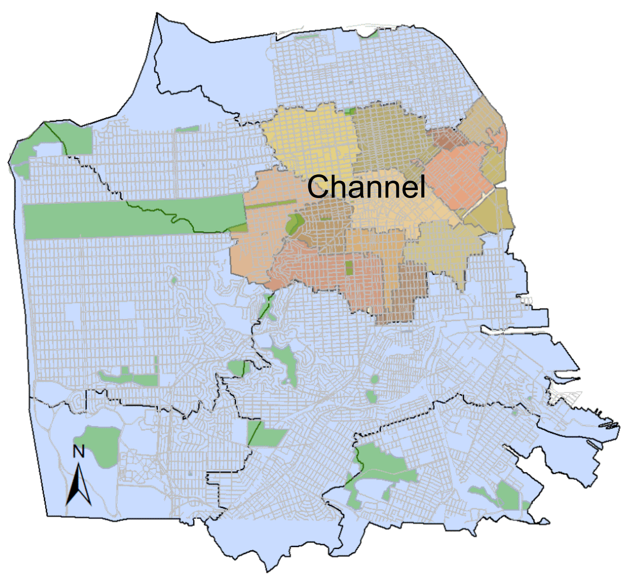

Figure 14: Sub-catchments in the Channel basin. Source: SF DPW.

watersheds (Ramirez-Herrera, Sowers, and Richard 2007). Each watershed represents land that drains to a common part of the bay or ocean during wet weather events (Ramirez-Herrera, Sowers, and Richard 2007).

The Channel watershed is composed of 15 sub-catchments. Sub-catchments are smaller basins within the larger watershed and ultimately drain to the same point within the larger watershed (see Figure 14). The built environment in San Francisco largely defines sub-catchments. These sub-catchments include yet smaller sub-catchments (see Figure 15). There are 22 smaller sub-catchments in the chosen sub-catchment. My study looks at five of the smallest of sub-catchments. These five sub-catchments are in the Haight-Ashbury and North of the Panhandle (NOPA) neighborhoods of San Francisco.

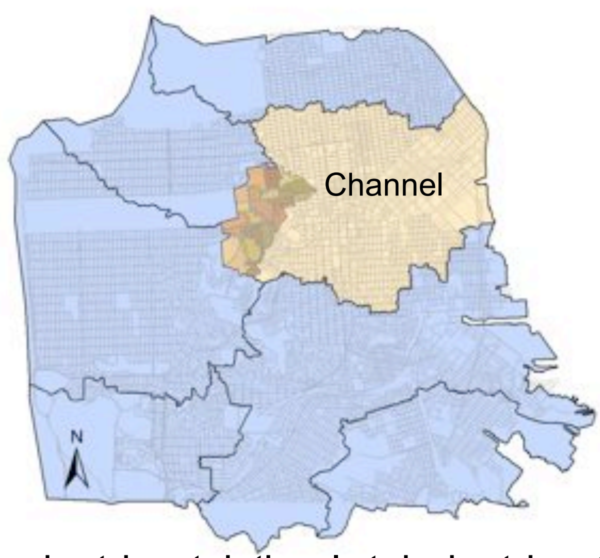

Figure 15: Smaller sub-catchments in the selected sub-catchment. Source: SF DPW.

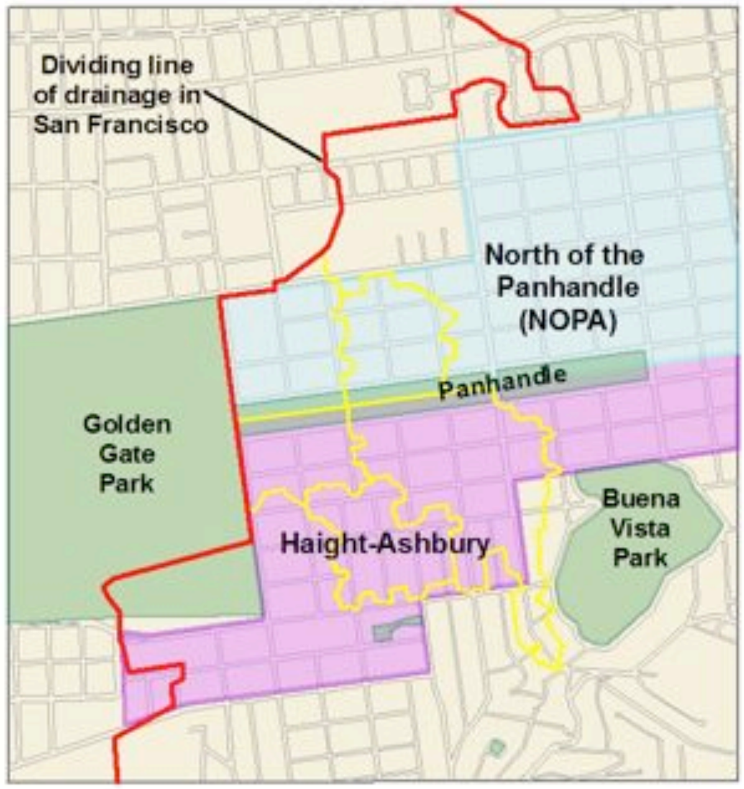

Figure 16: Selected sub-catchments are highlighted in yellow. Haight-Ashbury (purple) & NOPA (blue) neighborhoods are also delineated.

Two sub-catchbasins are in the North of Panhandle (NOPA) neighborhood and three are located in the Haight-Ashbury neighborhood (see Figure 16). The five sub-catchments have a total land area of 152.8 acres. For the purposes of BMP planning, analysis of smaller drainage areas is more effective, particularly for areas that are already built out (Mundy 2009). The use of smaller, site-specific BMPs reduces the need for large, mechanical systems to move stormwater. Additionally, bringing the study down to a more humanistic scale helps facilitate a better understanding among the resident public of the hydrologic functions occurring in the BMPs (Fox 2008).

The Haight-Ashbury and NOPA neighborhoods lie upstream from where combined sewer overflows (CSOs) occur (Braswell 2008). The upstream positioning of Haight-Ashbury and NOPA makes them vital to the reduction of CSOs because stormwater volumes can be reduced, slowed, and potentially stored in the Panhandle and surrounding streetscapes. In San Francisco, combined sewer overflows (CSOs) result in partially treated water being discharged ultimately into the San Francisco Bay and the Pacific Ocean. In San Francisco, there are typically eight CSOs per year discharging into the Pacific Ocean, four into the San Francisco Bay from the northern part of San Francisco, ten into the Bay from the northeast part of San Francisco, and one from the southeast (Braswell 2008). The Channel watershed’s runoff contributes to the ten CSOs entering the Bay from the northeast part of San Francisco (Braswell 2009).

Haight-Ashbury and NOPA are adjacent to one another; yet exhibit varying site conditions, including slope and soil permeability differences. The neighborhoods are largely built-out, which places constraints on which BMPs can be implemented. The variance in site conditions allows for a wider palette of BMPs to be implemented. LID BMPs are not limited to streetscapes.

Figure 17: Typical yard area in project area. Photo: A. Omlid.

Potential locations for stormwater BMPs include yard areas in the center of city blocks (Figure 17), off-street parking lots, and parks.

4.1.1 Geography of the Study Area

Just as variations in rainfall exist within the city and from sub-catchment to sub-catchment, so does permeability of soils and slopes. Many BMPs require little to no slope to function properly and a high to moderate soil infiltration rate. A high to moderate soil infiltration rate is especially necessary for BMPs that allow water to infiltrate on site.

The Natural Resources Conservation Service (NRCS, formerly the Soil Conservation Service) has identified and classified four hydrologic soil groups (HSGs): A, B, C, and D, according to their minimum infiltration rate. These rates vary greatly in the literature. The NRCS identifies the infiltration rates to be: greater than .30 in/hr for soil type A, .15-.30 in/hr for soil type B, .05-.15 in/hr for soil type C, and 0-.05 in/hr for soil type D (USDA Natural Resources Conservation Service 1986). The Ventura Countywide Stormwater Quality Management Program (2001) uses a range of infiltration rates covered by multiple sources including the Bay Area Stormwater Management Agencies Association (BASMAA), which accounts for their substantially higher values. This program identifies the respective infiltration rates to be: 1.00-8.3 in/hr, .5-1.00 in/hr, .17-.27 in/hr, and .02-.10 in/hr. The Stormwater Design Guidelines for San Francisco’s separate sewer areas use these figures and generally deems infiltration rates greater than .5 in/hr appropriate for infiltration based

BMPs (Mundy 2009). Using these figures, HSGs A and B are appropriate for infiltration-based BMPs assuming that the depth to groundwater is sufficient in order to prevent contaminants from entering groundwater.

Only HSG A and D are present in the five study basins (See Figure 20). HSG A soils have low runoff potential and are typically composed of sands and gravel. HSG D soils have a high runoff potential and typically include clay soils, soils in a permanent high water table, and shallow soils over nearly impervious material (Ventura County 2001). Haight-Ashbury contains HSGs A & D. NOPA contains only HSG A.

Slopes also vary between the two neighborhoods. The range in slopes in the Haight-Ashbury portion of the study area varies from 0 to 19%. NOPA is more flat, with slopes ranging from 0% to 7%. All of these variations in site conditions influence which BMPs can ultimately be employed.

Another important site consideration for BMP implementation is the depth to bedrock. A depth of 10'+ is commonly needed for infiltration based BMPs (i.e. vegetated swales, permeable paving). A very small portion of the southeastern-most sub-catchment has unsuitable bedrock depth for infiltration based BMPs (see Figure 18).

Figure 18: Sufficient (10'+) soil depth (depth to bedrock) for infiltration-based stormwater BMPs shown in dark brown.

4.2 Methods

4.2.1 GIS Site Suitability Analysis

Each LID BMP has optimum site conditions. To determine the best places within the project area for each LID BMP, each BMP's associated variables (i.e. slope, depth to bedrock and NRCS hydrologic soil classification) were overlaid using ArcMap. The resulting maps (shown and discussed in

Chapter 5) display where each BMP can perform optimally. Modifications to stormwater BMPs are possible to help broaden their spatial applicability (e.g. lining swales and attaching to an underdrain to prevent infiltration), but my study looks at the optimum locations for the selection of BMPs where there is no need for modification.

San Francisco Department of Public Works (DPW) provided all spatial data used in my study. A shapefile containing slope values for each street block in San Francisco is one dataset (see Figure 19). This dataset was

Datasets Used in Site Suitability Analysis

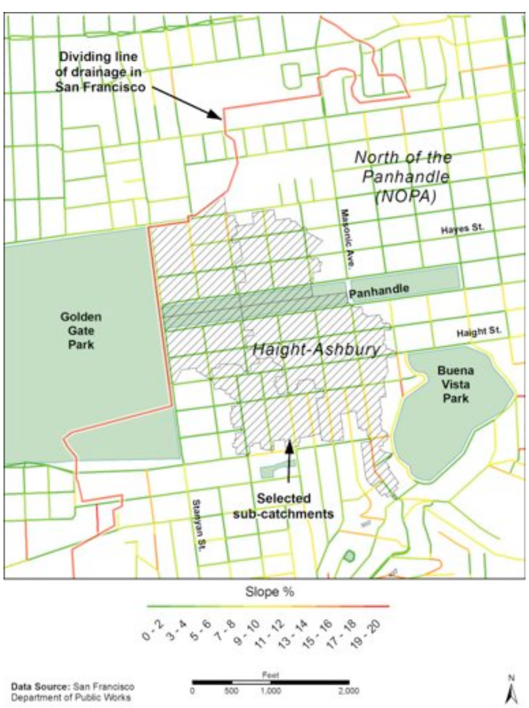

Figure 19: Street slopes in the project area.

Figure 20: NRCS Hydrologic soil groups. HSG A (dark brown) & HSG D (coral) are found in the project area.

created from contour elevation data, x- and y-coordinates of the start and endpoints of each street, and a point file containing the intersections of each street line segment (Seagrave 2009). The intersections were spatially joined to the elevation data to create a new file containing both the x- and y-coordinates of the intersections and their corresponding elevation attributes (Seagrave 2009). A tabular join then allowed the intersection nodes to be linked to the street line file, which created attributes called “start node elevation” and “end node elevation” (Seagrave 2009). A field for “elevation change” was added to the street line file and was populated by subtracting the starting and ending elevations (Seagrave 2009). Fields for square of elevation change and square root of elevation change were then added and calculated, yielding the inputs for the final slope values, which were determined using the Pythagorean theorem, which states that rise (change in y-value) over run (change in x-value) equals slope (Seagrave 2009). Hydrologic soil group (see Figure 20) and depth to bedrock (see Figure 18) for the city of San Francisco are the other two datasets.

To determine the optimum location for each stormwater LID BMP, each of these three data layers were overlaid. For example, a slope of 2-2.5% is optimal for vegetated swales. The ‘Select by Attributes’ function was used in ArcMap to determine where streets with slopes of 2-2.5%, NRCS hydrologic soil group A, and a depth to bedrock greater than ten feet coexist within the project area.

The optimum slope for flow-through planters is .5-5%. The same steps were followed using the same datasets to determine each LID BMP's optimum site suitability, but using different slope values for each BMP.

4.2.2 Limitations of the Data & Sources of Error

The soil data used is from the National Resources Conservation Service (NRCS) soil survey and is therefore coarse in nature. For the purposes of my study, precise spatial locations of soil types are not necessary. If upon further inspection, locations deemed appropriate for vegetated swales by this study actually have poorly drained soil (i.e. NRCS hydrologic types C or D), unsuitable soil could be excavated and replaced with well-drained soil and an underdrain to direct remaining water towards the sewer.

The slope data is in whole numbers. However, the optimum slope value range for some stormwater BMPs is .5%-5% for flow-through planters and 2-2.5% for vegetated swales. This resulted in more conservative site suitability analyses since the actual values of 1-5% and 2% were used respectively.

4.2.3 Policy Methodology

Determining how San Francisco can move towards adopting sustainable stormwater practices and policies, required an understanding of how other cities have achieved the goal. Seattle, Washington and Portland, Oregon are two cities that have been practicing sustainable stormwater management since the 1990s. Because their programs and policies have been successful in their aims, and appear to receive support from citizens, these two cities were examined in order to obtain information on what San Francisco can do to follow suit. Researching each respective city's policies online and speaking with people associated with the implementation of the city's respective sustainable stormwater management programs were the methods used. Questions like "what hindered the implementation of sustainable stormwater programs in the beginning of the planning process?", "what can be done to move the implementation process forward?" and "how important are pilot projects to getting public support of sustainable stormwater management?"

Online research included examining their respective Stormwater Management Manuals (or similarly titled documents), program websites, stormwater research organizations' websites, and technical reports concerning assessment of pilot projects. Interviews with professionals in the sustainable stormwater management field allowed questions to be asked that were not discernable through research alone.

CHAPTER 5: RESULTS AND CONCLUSION

The varying site conditions associated with the Haight-Ashbury and NOPA neighborhoods allowed for diversity in the LID best management practices that could be implemented. The resulting site suitability maps show where LID BMPs can be optimally sited within the project area based on slope, soil type, and depth to bedrock. Further soil sampling may be necessary to ensure that soils are suitable for infiltration due to the coarse nature of the available soil data. The site suitability analysis revealed the optimum locations for each selected LID BMP and therefore provided conservative results. A sensitivity analysis was done to show what the effects are when more liberal ranges, such as those recommended in other jurisdictions, are used. Collaboration of City agencies, building successful pilot projects, and the presence of an environmentally aware political arena are discussed as important components in the execution of a successful city-wide sustainable stormwater management program.

5.1 Site Suitability for the Stormwater BMPs

Vegetated swales are one of the more difficult BMPs to site in a built-out environment because they require a significant linear right-of-way (Mundy 2009).

Swales are generally best used to collect stormwater from parking lots (Mundy 2009). In the case of a vegetated swale pilot project, this site suitability analysis determined that vegetated swales could be implemented on a limited number of blocks (see Figure 21) due to the constrictive optimum slope values. Many of these blocks are also suitable to other potentially more appropriate infiltration based LID BMPs such as flow-through planters or rain gardens. Alternatively,

Figure 21: Site suitability for vegetated swales using a slope range of 2-2.5% is highlighted in blue.

cisterns and rain barrels could be looked to for retaining stormwater on-site.

Flow-through planters are suited to many streets in the study area (see Figure 22), including many north-south oriented blocks adjacent to the Panhandle. Stormwater could be captured in flow-through planters on these blocks and the excess could flow into planters on Oak and Fell streets, which parallel the Panhandle.

Rain gardens are suitable to many of the flatter, east-west oriented streets within the study area, including the entire lengths of Oak, Fell, and Hayes Streets

Figure 22: Site suitability analysis for flow-through planters using a slope range of .5-5% is highlighted in blue.

(see Figure 23). As with the flow-through planters, stormwater flowing downhill from the southern ends of the Haight-Ashbury neighborhood can be captured in street-side rain gardens on Oak Street.

Permeable paving site is most suitable to flat streets or streets with very low slopes of 0-2%. In the project area, these conditions correspond largely to the entire lengths of east-west running streets parallel to the Panhandle where NRCS hydrologic soil group A is also present (Figure 24).

Figure 23: Site suitability for rain gardens using a slope range of <5% is highlighted in blue.

Figure 24: Site suitability for permeable paving using a slope range of 0-2% is highlighted in blue.

The Panhandle itself provides an opportunity for infiltrating stormwater. My study did not look at the Panhandle in detail. However, it is feasible that stormwater that would exceed the capacity of the proposed LID BMPs could be conveyed to the Panhandle. The Panhandle contains NRCS soil type A, has a depth to bedrock greater than ten feet, and has spatial parameters that would allow for a variety of infiltration-based LID BMPs. Alternatively, a large underground detention basin could be built to store large amounts of stormwater, which could then be used for irrigation purposes. Using the Panhandle as a collection area is a practical example of using the current organization of the built environment to maximize stormwater collection and storage for future use. Its location in the landscape offers an ideal situation to take advantage of its physical and hydrologic characteristics from a stormwater management standpoint.

Disconnecting downspouts and connecting them to rain barrels or cisterns is something that is applicable to nearly every building that has a flat surface to place the collecting device on. Planting trees in empty planter boxes along city streets is another easy way to increase the stormwater capacity on a small level.

5.2 Analysis of Error & Sensitivity Analysis

The site suitability analysis determined the optimum locations for LID BMPs. However, the optimum slope values that I used for each LID BMP fall within a wider range of slope values recommended in different jurisdictions. For vegetated swales, if a more liberal street slope range of 2-6% was used instead of the optimum 2-2.5% slope, the resulting site suitability map would be represented as shown in Figure 25.

Figure 25: Sensitivity analysis showing the site suitability for vegetated swales when using slope values of 2-6% is highlighted in purple.

Some literature suggests that flow-through planters can be effective at up to 20% slopes. Using this range determines that all streets in the project area are suitable for flow-through planters based on this parameter alone. The resulting site suitability analysis is shown in Figure 26. Because San Francisco experiences intense storm events, washout and erosion would likely be issues with flow-through planters when using such high slope values. Citing the importance for LID BMPs to function optimally in order to remove stormwater from the sewers and gain community support, using such liberal slope values gives a false sense of how spatially applicable LID BMPs really are.

On the other hand, using a slightly more conservative slope range of

Figure 26: Sensitivity analysis showing site suitability for flow-through planters using slope range of 0-20% is highlighted in magenta.

1-3% than what was used in the actual site suitability analysis (2-6%) shows how constrictive a site suitability analysis can be (see Figure 27). A site suitability analysis is clearly suitable to many purposes and can be molded to fit the goals of the individual/agency in charge of producing it. It could misleadingly be used to show that BMPs can be placed nearly anywhere, or it can be used conservatively to show optimum locations for LID BMP implementation. I have attempted to arrive at the latter of these goals with my site suitability analyses.

When a more conservative 0-2% slope range is modeled (Figure 28), rain

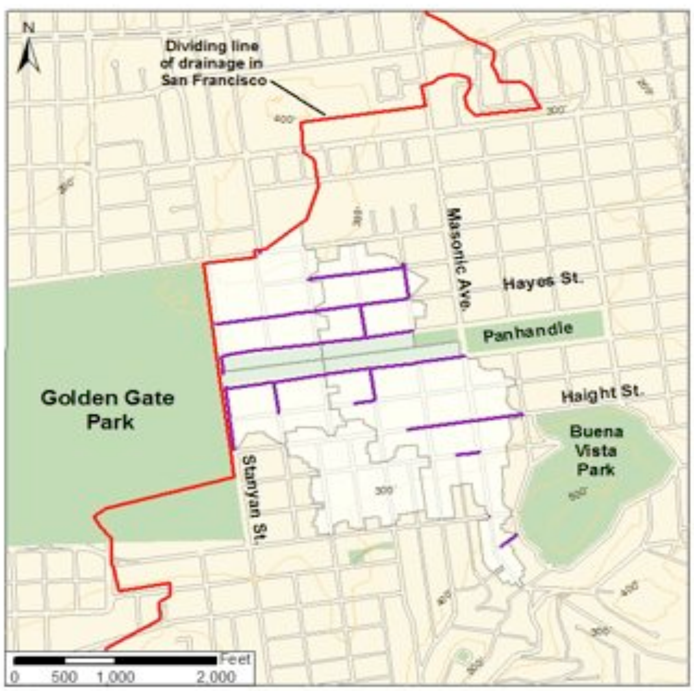

Figure 27 Sensitivity analysis showing site suitability for flow-through planters using a slope range of 1-3% is highlighted in purple.

gardens are shown to be largely only suitable to east-west oriented streets. This differs from my results which showed many of the north-south oriented blocks adjacent to the Panhandle to be suitable locations for rain gardens.

Figure 28: Sensitivity analysis showing site suitability for rain gardens using slope values of 0-2% is highlighted in purple.

Literature commonly suggests that permeable paving is appropriate for slopes of less than 5% (Dreelin *et al*. 2006). A slope range of <5% actually equates to using a slope range of 0-4% since my slope data contains only whole

Figure 29: Sensitivity analysis showing the site suitability for permeable paving when using slope values of <5% is highlighted in purple.

numbers and slopes with a value of 5% are left out (Figure 29). These values are more liberal than the ones used in the actual site suitability analysis. Again, my site suitability analysis was conservative in order to determine where permeable paving would work optimally. Flatter surfaces encourage percolation into the soil.

An additional source of error would be that the site suitability analysis does not take into consideration which streets have high pedestrian traffic and would therefore be unable to accommodate many infiltration-based LID BMPs. For example, the site suitability analysis shows that Haight Street, between Central and Ashbury Streets (yellow circle in Figure 30), is shown to be suitable

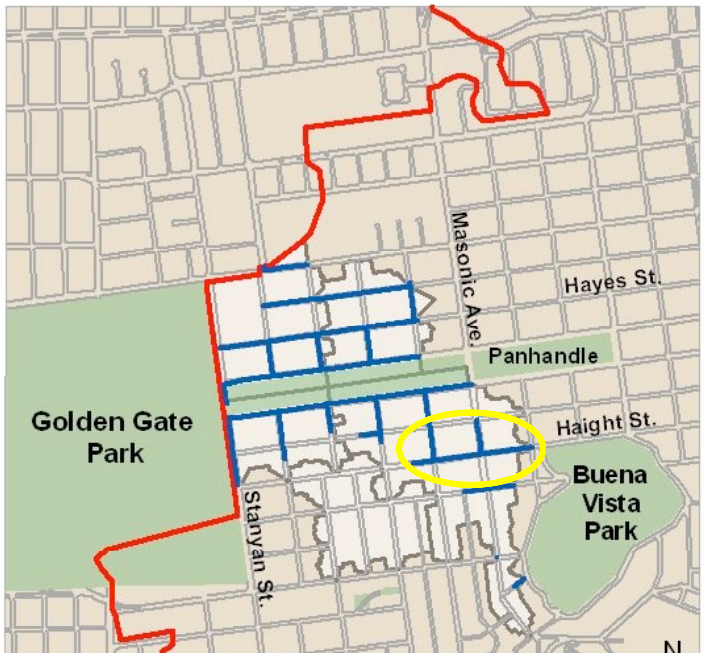

Figure 30: Example of where site suitability analysis does not take highly trafficked pedestrian streets into account.

for flow-through planters. However, this area is touristy and therefore has high pedestrian traffic volumes, which would likely prevent building flow-through planters in the existing narrow sidewalks. An alternative would be removing on-street parking, narrowing streets, or a combination of both. There is potential for controversy in the implementation of LID BMPs if on-street parking is to be removed. However, District 5 of which Haight-Ashbury and NOPA are a part of, is the second most progressive district in the city/county according to DeLeon's Progressive Voting Index. This may be reason to believe that residents/businesses might be apt to support an environmental project such as the implementation of LID BMPs (DeLeon ca 2005).

5.3 Policy Recommendations

The collaboration of city agencies is of utmost importance in getting stormwater BMPs implemented in a timely manner in San Francisco. Incentive programs have proven successful in both Portland and Seattle. SPUR recommends adopting a rate structure that reflects the contribution of stormwater to the system, which would involve a stormwater treatment charge proportional to the amount of impervious surface on the ratepayer's site (San Francisco Planning and Urban Research Association 2008). This would make property owners aware of ways that they could decrease their fees (i.e. implementing pervious pavement, a rain garden, or other LID BMP). Pilot projects and multi-agency cooperation are also key components to thriving sustainable stormwater management programs.

5.3.1 Collaboration of City Agencies

Collaboration of city agencies and the willingness of city employees to adopt a new view of project management and approach to construction projects are important to the success of sustainable stormwater projects (Johnson 2008). Seattle faced some difficulty initially in getting engineers from the Seattle Department of Transportation to adapt to building projects sustainably. Engineers commonly want to get their projects out into production in a timely manner while staying on budget, so encouraging everyone to buy into a new way of thinking is necessary.

In San Francisco, the PUC is likely to be the most influential agency in implementing BMPs (San Francisco Planning and Urban Research Association 2006). However, the Planning Department can allocate resources when designing sidewalks, parking lots, and streets, and the Department of Public Works can adapt by using permeable pavement where possible. The Municipal Transportation Agency is not solely responsible for public right-of-ways, but collaboration on their behalf is desirable. The Recreation and Parks Department, Department of the Environment, San Francisco Redevelopment Agency and the Department of Building Inspection are all stakeholders in sustainable stormwater management policy implementation on a citywide scale (San Francisco Planning and Urban Research Association 2006). Another point to make concerning the shift to sustainable development is that as more green developers enter the marketplace, sustainable development will become the norm and traditional development will be phased out (Johnson 2008).

5.2.2 Political Environment

Although San Francisco's Sewer System Master Plan (2006), Better Streets Plan (2006), and the Mayor's Green Building Ordinance (2008) all mention sustainable stormwater management, its importance to San Francisco's urban environment has not been fully realized. These initiatives can enjoy full realization once all stakeholder agencies play their part. City planning and city staff support are extremely important in getting sustainable stormwater management programs off the ground (Johnson 2008). An environmentally aware political arena is also an important (Johnson 2008).

An environmentally aware political arena appears to be present in San Francisco. Many environmentally conscious policies are initiated by the Board of Supervisors, who are responding to the needs and wants of their constituents. For example, environmental responsible policies such as collecting restaurant grease for use in producing biodiesel and requiring large grocery stores to cease using plastic bags have been enacted within the last couple of years. This is one reason why it is surprising that a sustainable stormwater program has not been fully implemented yet. In 1997, the Board of Supervisors adopted the Sustainability Plan for the City of San Francisco and signed the Precautionary Principle into city policy. In 2003, the Board of Supervisors developed the Environment Code for San Francisco. The Precautionary Principle “requires the selection of the alternative that presents the least potential threat to human health and the City's natural systems” (San Francisco Board of Supervisors 2003). These programs and policies provide a positive framework for sustainable stormwater management techniques to fit into.

5.4 Conclusion

The site suitability analysis based on environmental variables (slope, soil type, & depth to bedrock) in the Panhandle area of San Francisco showed where a selection of LID BMPs can optimally be implemented in order to reduce the amount of stormwater entering the city’s combined sewer system. Sensitivity analyses helped to reveal how using more conservative or liberal slope values can affect the resulting site suitability map. Using more liberal slope values could lead to the construction of LID BMPs in places where they would not necessarily perform optimally.

My study did not base site suitability on the location of current curb-cuts (i.e. driveways) or utilities. Further follow up in the field would be necessary to determine which portions of suitable blocks (suitable blocks determined by the site suitability analysis) could potentially house LID BMPs. A common thought regarding the implementation of LID BMPs is that street parking will be eliminated. The Better Streets Plan and the Stormwater Design Guidelines show that this can be avoided by either narrowing streets to make room for LID BMPs, or LID BMPs can be built into public rights-of-way where space permits.

Increased homeowner awareness of the opportunity to obtain a low-cost sidewalk landscaping permit could also help bring vegetation to San Francisco's streets, as well as the previously mentioned incentive-based sewer rate restructuring. Additionally, the interior of blocks (usually backyards), and existing park areas should also be looked at more closely as space to capture and retain stormwater. Downspouts can be disconnected and attached to rain gardens, rain barrels, or cisterns to store water for later use. Not only is water entering the sewer reduced, but the water is also able to be reused. Earlier this year, the San Francisco Public Utilities Commission provided a $50 discount when San

Francisco residents purchased rain barrels for $120. SFPUC is currently investigating the possibility of re-implementing the program this fall. The SFPUC also provides a do-it-yourself guide to making rain barrels on their website. More community outreach and education coupled with workshops that teach residents about the benefits of capturing rainwater would be beneficial.

There are no policies in place that are preventing BMPs from being implemented citywide. San Francisco has simply gotten a late start in adopting sustainable stormwater policies. San Francisco Public Utilities Commission and the Port of San Francisco did not take a serious look at including BMPs as a way to sustainably manage stormwater until 2006. In this respect, BMPs are a fairly new concept in San Francisco, even though their use has been well publicized in the northwestern US and elsewhere since the 1990s. With the extra push and pressure that Seattle and Portland received from the ESA listing of selected salmonid species, it is easy to see how their stormwater programs got such an early start.

The city planning process can be arduous, which helps to explain the lack of action in actually building BMPs into the existing city fabric. The San Francisco Planning and Urban Research Association (SPUR) suggests a fundamental change in the way citizens think about and respond to water (San

Francisco Planning and Urban Research Association 2006). The Stormwater Design Guidelines (2009) for managing stormwater in San Francisco's MS4 areas will hopefully do just that by shifting San Francisco's attention to sustainable ways of managing stormwater. SPUR believes that minimizing the number and volume of annual system overflows should be the highest priority for SFPUC's sewer master plan and hopes that LID BMPs will be "implemented at a large enough scale to serve as core elements of the Plan" (San Francisco Planning and Urban Research Association 2008).

The San Francisco Stormwater Design Guidelines mandate the use of BMPs in new development and redevelopment within the MS4 areas of San Francisco. They also make the investment costs of implementation the responsibility of the developers. Encouraging developers, landscape construction companies, and the like, to adapt to sustainable development practices will be a necessary step towards a greener direction.

Cooperation among City agencies cannot be stressed enough. It will be vital in implementing a successful sustainable stormwater program in the City of San Francisco. It would be wise for one City agency or another to take a stronger lead in putting BMP implementation policy in place citywide. Portland has received a large amount of funding for BMP projects by aggressively pursuing grants from the EPA. A similar approach to accumulating funds could be used in San Francisco. This would not require tax dollars or a fee to be imposed while citizens are still unsure about the benefits of BMPs. In conjunction with regular monitoring of pilot projects, I suspect that citizens would realize the value of sustainable stormwater management techniques as citizens in Portland and Seattle have over the lifespan of their respective programs.

Appendix 1

Stormwater LID BMP	Siting Constraints/Assumptions
Vegetated Swale	Optimum Slope 2-2.5% Hydrologic soil group A or B Depth to bedrock >10'
Rain Garden	Optimum Slope <5% Hydrologic soil group A or B Depth to bedrock >10'
Flow-Through Planter	Optimum Slope .5-5% Hydrologic soil group A or B Depth to bedrock >10'
Permeable Paving	Optimum Slope 0-2% Hydrologic soil group A or B Depth to bedrock >10'

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