Title

Planning for Climate Change in Low-Impact Development Projects: A Case Study of the Sunset Swales Parking Lot Retrofit in San Francisco

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ABSTRACT

Climate change is anticipated to increase the frequency and intensity of precipitation extremes, with potentially significant implications for urban stormwater management. As an approach that can reduce stormwater quantity and improve runoff quality, low-impact development (LID) has been recognized as a strategy to manage potential impacts of climate change. However, the question of how LID programs and projects should themselves account for climate change has not yet been deeply explored. This study uses the case of the Sunset Swales Parking Lot Retrofit project in San Francisco to examine whether and how LID project design could account for climate change, particularly with respect to water quality concerns in municipal separate sewer systems (MS4). This paper uses a vulnerability-based approach, in which decision-makers begin by examining the potential impacts of climate-related events in a specific context, and then use climate change projections to assess the likelihood of experiencing those impacts.

LID projects are typically not intended to control runoff from very extreme events, but increased extremes could still affect functioning if overflow capacity is exceeded. In addition, a pattern of less frequent but more intense rainfall would require water quality flow sizing to be increased. Current research indicates that increased extremes are anticipated on average globally, although downscaled climate models do not produce conclusive results for California. Given this uncertainty, LID managers should seek out "robust" approaches to account for climate change – strategies that will perform well under many future scenarios. These might include promoting LID technologies in areas with greatest vulnerability to climate-related impacts, and instituting an on-going process for assessing risks and trends. At the site level, options include introducing additional capacity when flexibility exists (as in the case of Sunset Swales), ensuring effective maintenance programs, and adjusting vegetation given potential changes in rainfall and temperature.

PROBLEM STATEMENT

Climate change presents a significant challenge to water managers, who have long based their planning decisions upon the assumption that future weather and climate patterns will be similar to those of the past (Milly et al., 2008). In California, state and local agencies are increasingly encouraged to incorporate climate change in planning decisions (CA Natural Resources Agency, 2009). However, this can be a challenging for several reasons. Future climate change impacts are uncertain, especially at smaller spatial and temporal scales that are important for decision contexts, such as stormwater management. Further, the effects of climate change are intermingled with other factors, such as change in land cover, that also affect stormwater runoff (Hirschman et al., 2011).

Climate change is anticipated to increase the frequency and intensity of precipitation extremes, with potentially significant implications for urban stormwater management (Rosenberg et al., 2010). Stormwater infrastructure has been designed based on rainfall frequency analyses and intensity-duration-frequency curves, drawing upon past rainfall records (Goldstein, 2007). If precipitation patterns change such that the design capacity of infrastructure is no longer sufficient, existing flooding and pollution problems could be exacerbated.

Low impact development (LID) is an approach that integrates stormwater management into urban design so as to mimic pre-development runoff patterns and treat stormwater at its source (EPA, 2007). In combined sewer areas, LID strategies can be used to reduce the likelihood of localized flooding and combined sewer overflows (CSOs), and in municipal separate sewer systems (MS4s), LID is primarily targeted toward improving the quality of runoff. Since they are normally small-scale, LID projects normally target smaller storms than traditional stormwater management infrastructure, particularly since pollutants are associated with the "first flush" of rainfall (Prince George County, 1999). LID's benefits have been recognized as important stormwater management strategies in the context of preparing for climate change (Hewes and Pitts, 2009). However, the question of whether and how LID programs themselves should account for climate change in planning and site design has not yet been deeply explored.

In this study, I examine whether and how LID projects could account for climate change in the San Francisco area, with particular reference to the Sunset Swales Parking Lot, an LID project undertaken by the San Francisco Public Utilities Commission (SFPUC) in a MS4 area. Specifically, I investigate the following questions:

- What are current approaches to assessing risks related to climate change and options for adaptation?
- How might LID projects, in particular Sunset Swales near Lake Merced, be affected by climate change, and what risks does this pose?
- Based on current climate modeling studies, how likely is it that these changes will occur in the San Francisco area?
- How can LID program and project managers account for climate change in their decisions?

STUDY APPROACH

This study uses the case of the Sunset Swales Parking Lot project in San Francisco to assess the potential effects of climate change and identify options to incorporate climate change into planning LID projects, particularly with respect to water quality concerns in MS4 areas. This study broadly follows a vulnerability-based approach to assessing climate risks, which is described below. Research involved the following steps:

1. Review of literature regarding approaches to assessing climate change risks and current knowledge about climate change trends related to precipitation extremes
2. Review of guidelines, memos and project documents for SFPUC's LID work and the Sunset Swales project
3. Site visit to Sunset Swales near Lake Merced to understand the layout and observe site conditions following several days of intense rain (visit conducted on March 25, 2011)
4. Meeting with SFPUC staff regarding low-impact design practices, and the Sunset Swales design and maintenance (March 25, 2011):
   - Leslie Webster, SFPUC Urban Watershed Management Program
   - Rosey Jencks, SFPUC Urban Watershed Management Program Manager
   - Koa Pickering, Dept of Public Works (landscape architect for Sunset Swales)
5. Phone conversations, email exchanges and in-person discussions, including with Leslie Webster (SFPUC), Mike Mastrandrea (Stanford University), and Curt Baranowski (EPA Climate-Ready Water Utilities Program).

RESULTS AND DISCUSSION

This section describes and discusses key findings, organized into the following sections:

1. Overview of approaches to assessing climate risks
2. Background on LID efforts in San Francisco and the Sunset Swales site
3. Examination of how increased frequency and intensity of rainfall events might affect LID design, particularly in the case of Sunset Swales
4. Review of current climate change projections to assess the likelihood of impacts on LID projects in San Francisco
5. Review of possible approaches for the San Francisco Public Utilities Commission's Urban Watershed Management Program to account for climate change in LID projects.

1. Approaches to Integrating Climate Change into Decision-Making

Two broad approaches have emerged for assessing and managing the risks posed by climate change: hazard and vulnerability-based. These are described in a recent California Climate Change Research Center report (Moser et al., 2009). In the context of water management, these approaches are described as "top-down" and "bottom-up" (Brown, 2011, EPA, 2010, Miller and Yates, 2006).

- Hazards-based approach ("top-down"): this approach examines specific projections of climate change impacts and identifies decision options based on the anticipated magnitude of these impacts. Since it relies heavily on climate change model projections, this approach is most useful in when there is a reasonable degree of certainty about anticipated changes.

- Vulnerability-based approach (“bottom-up”): this approach first seeks to understand the kinds of risks that might result from changes in climate variables, and identify the system’s ability to cope beyond particular thresholds. To the degree possible, climate change projections are then used to assess the likelihood of crossing these thresholds (Moser et al., 2009, 67-8). This approach draws upon knowledge about experiences with past climate extremes to assess risks, and is less reliant on climate model projections.

Both approaches are currently being used in water management contexts. For example, Seattle Public Utilities is using downscaled climate models in a “top-down” approach to assess climate change risks to their water supply, while the East Bay Municipal Utility District (EMBUD) has employed a “bottom-up” approach, beginning by examining potentially vulnerable elements of their system (WUCA, 2010).

A critical challenge in both approaches is the significant uncertainty associated with climate change model projections, particularly at smaller spatial scales. While climate modeling is improving, this uncertainty is unlikely to diminish substantially anytime soon (Dettinger, 2005). However, uncertainty does not mean the risks do not exist, and decisions with long-term implications still need to be made. Rather than seeking to reduce uncertainty, adaptation literature suggests that a focus on managing risks is more useful and realistic (Moser et al., 2009, 66). Risk is usually defined as the product of the likelihood of a particular hazard and its consequences. For example, even if uncertainty is high about future rainfall patterns, action may still be needed if the consequences of these changes would be significant (Hultman, et al., 2010). Literature on developing adaptation strategies in the face of uncertainty suggests that decision-makers seek “robust” or “resilient” strategies, which would perform well under a range of possible future scenarios (CCSP 2009, 59-60).

From the perspective of stormwater management, low-impact development (LID) projects may be a “robust” strategy for coping with climate change impacts in urban areas that may experience increased frequency and intensity of rainfall. LID projects are usually small-scale, and additional projects can be added over time as needed. LID also brings additional benefits, such as increased greenery, improved aesthetics, and temperature-reducing effects (Hewes and Pitts, 2009). Thus, LID is likely to be beneficial under a range of future climate scenarios.

If LID programs are to be expanded to improve capacity to cope with climate change, the question arises as to whether and how climate change needs to be incorporated into the design and management of LID projects themselves. This paper focuses on this question, using the vulnerability-based (“bottom-up”) approach described above. This seems most appropriate given the context-specific nature of LID projects, and the limitations of climate model projections at small spatial scales.

2. Low-impact development (LID) in San Francisco and Sunset Swales

LID in San Francisco

The San Francisco Public Utilities Commission (SFPUC), in partnership with the Department of Public Works (DPW) and other city agencies, began efforts to support LID in the mid-2000s, spurred by increasing awareness of LID’s benefits for stormwater management as well as new regulation of municipal separate storm sewer systems (MS4s) under the Clean Water Act. SFPUC's Urban Watershed Management Program has funded pilot projects, provided small grants to communities, and led the development of Stormwater Design Guidelines for implementing Clean Water Act requirements in San Francisco (SFPUC, 2010). These Guidelines came into effect in January 2010, and apply primarily to new developments that disturb 5,000 square feet or more of ground surface. Although originally developed for MS4 areas (about 10% of the city), they are now applicable to combined sewers as well (SFPUC, 2010, L. Webster, SFPUC, personal communication, April 5, 2011).

As part of an effort to coordinate requirements with a new Green Building Ordinance in San Francisco, SFPUC decided to use U.S. Green Building Council LEED certification credits 6.1 and 6.2 on stormwater management. The LEED 6.2 credit for quality control entails capturing and treating 90% of the average annual runoff using best management practices, which LEED guidelines indicate is equivalent to treating 0.75 inches of rainfall in a semi-arid environment, such as San Francisco (USGBC, 2005). SFPUC conducted an analysis to determine that the LEED standards met or exceeded the requirements of the Regional Water Quality Control Board (Minick, 2008). So far, approximately 30 development projects have been reviewed or are currently under review following these Guidelines, including MS4 areas and combined sewer areas (L. Webster, SFPUC, personal communication, April 5, 2011).

Sunset Swales

Initiated by SFPUC and the Department of Public Works (DPW) in 2006, Sunset Swales parking lot was the first public LID project in San Francisco. It is located at the corner of Sunset and Lake Merced Boulevards on the eastern shore of Lake Merced, and covers approximately 3.5 acres or 152,000 square feet (see **Figure 1**). Since it is in a MS4 area, prior to this project all of the runoff from this site flowed directly into Lake Merced, contributing to water quality problems. The impetus for the project was not regulation (this was prior to San Francisco's Guidelines), but rather to test LID ideas and to aesthetically enhance the area surrounding Lake Merced (Webster, 2007). A large parking lot had just been paved in advance of a major golf tournament to be held nearby, and a new statue was to be placed at the site. This location was ideal in many ways for LID; the land was already gently sloped, and there was sufficient space at the site to easily accommodate swales and infiltration basins while still meeting parking needs. There were constraints as well. Installing swales and infiltration basins meant ripping out the new pavement, adding costs. In addition, some of the parking lot was allocated as a training area for CalTrans bus drivers, so a swale could not be added in this area (K. Pickering, personal communication, March 25, 2011).

When planning was underway, the San Francisco Stormwater Design Guidelines did not yet exist. SFPUC and DPW staff drew upon examples from successful projects in Portland, and reference publications from the Bay Area Stormwater Management Agencies Association, and an online sizing tool from CalTrans (Webster, 2007, R. Jencks, SFPUC, personal communication, March 25, 2011, K. Pickering, personal communication, March 25, 2011). Three infiltration basins were designed within a series of swales around the edges, as well as two islands within the lot. The overall cost of the project was $288,300, the largest portion attributed to labor and the purchase of treatment soils in the swales. See **Table 1** for a summary of project data and calculations and **Figure 2** for the site layout.

The site was designed to manage runoff of 1.03 inches/hour, which is a 25-year event according to San Francisco's intensity/duration/frequency (IDF) curve (Webster, 2007, Goldstein, 2007). Water quality features of the swales and basins were designed for the 0.25 year event, or 0.372 inches/hour (since the majority of pollutants are associated with small rainfall events). A flow-based sizing approach (the Rational Method) was used to determine the peak flow that the design should accommodate. This is a different sizing and method than is currently required by the new Stormwater Design Guidelines, which specify a volume-based sizing approach in MS4 areas using 0.75 inches as a rainfall depth, as per LEED credit 6.2 for semi-arid environments (SFPUC, 2010). The sizing calculator provided by SFPUC for separate sewer areas additionally specifies 0.2 in/hr as the performance indicator for water quality flow, which is less than the 0.372 in/hr used for water quality flow in Sunset Swales. Thus, both in terms of volume and flow, the design capacity of Sunset Swales significantly exceeds the capacity now required in the 2010 Guidelines. See **Table 2** for a comparison of methods and results.

3. Potential Impacts of Climate Change on LID design, with reference to Sunset Swales
Climate change may already be affecting precipitation patterns in two ways that are important for stormwater management: 1) increased frequency of extreme events; and 2) increased intensity of rainfall events. These changes would affect LID design and management in different ways depending upon whether a project is located in a combined sewer area (where reducing runoff quantity is the focus) or a MS4 area (where runoff quality is the primary concern). Since Sunset Swales is in a MS4 area, water quality implications are emphasized here.

1. <u>Increased frequency of extreme precipitation events</u>. This would mean that relatively infrequent extreme events would occur more frequently, with direct implications for stormwater management infrastructure that is designed to cope with very heavy storms. LID projects, however, are not usually designed for the heaviest storms. Analysis of rainfall events in California indicates that the majority of rainfall comes in smaller events, and these events also matter more for water quality (CASQA, 2003, 5-12 to 5-14). If smaller events are more important and these don't change, then water quality design features might not be affected.

   However, this depends upon how climate change affects the overall distribution of rainfall across storms. The water quality treatment volume is often determined as the average rainfall depth of 90% of rainstorms (this is the basis for the LEED 6.2 credit used in current San Francisco Guidelines). If climate change leads to fewer but more intense storms, then there could be implications for water quality, since this would raise the average rainfall depth of the 90th percentile event (Hirschman, 2011, 13). In addition, overflow features such as emergency outlets for infiltration basins would need to be designed to account for a greater frequency of overflow.

   As already noted above, Sunset Swales was designed beyond the new San Francisco Guidelines, and therefore beyond the equivalent of the 90th percentile storm, the basis for the LEED 6.2 credit (see Table 2). Climate change was not the reason for this; it appears that the sizing decision for Sunset Swales was primarily dictated by the fact that there was sufficient space at the site to permit this level of treatment, and costs were relatively low (K. Pickering, personal communication, March 25, 2011, R. Jencks, SFPUC, personal communication, March 25, 2011). Regardless of the reason, Sunset Swales may be better equipped to withstand an increased frequency of extreme events.

An increased frequency of extreme events on LID may also increase the need for site maintenance, as severe storms and high flows may cause greater damage to swale and basin vegetation, and cause greater erosion and sediment build-up and clogging. At Sunset Swales, site maintenance has been undertaken, but has involved some management challenges, primarily due to funding constraints and contracting requirements (R. Jencks, SFPUC, personal communication, March 25, 2011, 2011).

2. <u>Increased intensity of rainfall events.</u> Here, we assume rainfall occurs with greater intensity during storms of all frequencies. This would alter the intensity/duration/frequency (IDF) curve, such that a greater amount of rainfall would occur for a storm of a given frequency and duration. This could well have implications for water quality. When the design intensity of a swale or basin is exceeded, water may spill over and not receive treatment even during smaller, more common storms that are now more intense (Hirschman, 2011, 13). Again, site maintenance will also be more critical.

   As noted above, Sunset Swales is already planned for a greater rainfall intensity than required by the new San Francisco Guidelines. The water quality aspects of the site – the size of the bottom of the swales and the amount of treatment soil used – were designed to a 0.25-year storm, or 0.372 inches/hour, exceeding the requirements of the new Guidelines. By designing overall volume capacity for a 25-year storm, the site is probably better equipped to hold onto larger amounts of water even when the treatment soil media is already saturated.

Following a vulnerability-based approach, it is important to assess the nature and magnitude of the <u>consequences</u> of these effects of climate change. Ideally, <u>thresholds</u> would be identified, beyond which the consequences would be unacceptably high. However, given limited data, a qualitative analysis is offered here. Overall, we would expect that the primary consequence of such changes in rainfall patterns would be increased pollution in Lake Merced. Given the slope of the site, all untreated excess runoff is carried in the direction of the lake. Additional consequences might include increased maintenance costs (replacing plants, clearing debris, etc) and possibly temporary closures if damages are significant.

The vulnerability approach often uses observations of past impacts of heavy rainfall events to assess potential climate change impacts. Data is limited in the case of Sunset Swales. Presumably, less pollution is flowing into Lake Merced from the site than prior to the project. However, there have not yet been water quality tests at the site; SFPUC would like to conduct these, but resources are limited (R. Jencks, SFPUC, personal communication, March 25, 2011, 2011). The swales have discharged water three times since construction (but before plants were installed). Although this could be due to sizing of the swales and basins, it could also be due to crusting of the soil surface (which has been observed in similar projects elsewhere), or to the type of soil fill that was used (Webster, 2007). During a site visit on March 25, 2011, following several days of heavy rain, no significant overflows were observed, although the main infiltration basin was holding a significant amount of water (sufficient to make it habitable for a pair of ducks; see **Figures 3 and 4**). Since the site was built for a 25-year storm to begin with, we might expect the site to be fairly resilient in this respect. Other problems at the site so far, which maintenance efforts have sought to address, include plant damage and death (particularly the first set of oak trees, which did not survive), caking of the soil, and the collection of debris and sediment in inlets and check dams (Webster, 2007). All of these issues could be affected by increased amount or intensity of rainfall, potentially leading to more significant site impacts and greater need for maintenance.

Other LID sites in San Francisco may be subject to different risks. For example, in a combined sewer area, increased extremes in rainfall might increase risk of discharges, resulting in greater pollution and fines under the Clean Water Act. In heavily populated areas, extremes and greater intensity might lead to flooding, causing property damage and disruption of business. In low-income areas, these impacts might be even greater if residents lack resources to respond.

4. Current knowledge about future trends in precipitation extremes

Following the vulnerability-based approach, we now ask how likely it is that increased extremes or rainfall intensity will occur in San Francisco. As noted earlier, this is a challenging question, since climate modeling has primarily been conducted at a global scale, and "downscaling" climate projections to regional and local scales is a complicated process introducing many additional sources of uncertainty (CCSP 2008b, 3).

It is useful to begin with recent patterns that can already be observed. Studies show a clear increase in the frequency and intensity of heavy precipitation events over the last century, both globally and over North America (Tebaldi et al., 2006, CCSP 2008). This could well be due to climate change; increased heavy precipitation is associated with increased water vapor in the atmosphere, which has been occurring as the atmosphere warms due to greenhouse gases (CCSP 2008a). In the United States, changes have been most pronounced in the past 50 years over the Northeast, where the number of heavy precipitation days has increased by 58% between 1958 and 2007. In the southwestern region of the US (including California), this increase has been lower, at 16% (USGCRP, 2009). Analysis of historical data over San Francisco itself does not indicate a strong pattern of increased rainfall intensity over the past century, although part of the difficulty lies in data limitations (Goldstein, 2007).

Future projections at a global scale indicate that increased greenhouse gas emissions will continue to lead to more intense precipitation (Tebaldi et al., 2006). The Fourth Assessment Report of the Intergovernmental Panel on Climate Change indicates that globally, it is "very likely" (greater than 90% probability) that extreme precipitation events will become more frequent (IPCC 2007). Modeling studies further indicate that globally, climate change may have a greater effect on the frequency of extremes rather than on the full spectrum of rainfall events, and that overall, precipitation may become more intense, but less frequent (CCSP 2008a). Over North America, studies from multiple climate models show that the recurrence period for a current 20-year rainfall event will become a 12-15 year event by 2050, assuming current greenhouse gas emissions patterns continue (CCSP 2008b). It is important to note that these results are averaged over large areas, and do not account for high geographic variability in actual precipitation patterns.

So far, these trends have been difficult to pick up in downscaled modeling studies over California. The most recent study focusing on current and future extreme events in California Mastrandrea et al. (2009) was supported by California Climate Change Research Center at the California Energy Commission. This study found that for precipitation-related indicators, such as precipitation intensity, number of days with precipitation greater than 10mm, and percent of precipitation in very wet days, the two downscaled models used did not agree on either the direction or magnitude of change. On the other hand, the models do agree on changes in indicators of temperature extremes (fewer frost days, longer heat wave durations, more frequent heat waves, and warmer nighttime temperatures). In a study focused on projecting climate change impacts for stormwater infrastructure, findings on future precipitation extremes were also uncertain (Rosenberg et al., 2010). It should be kept in mind that climate modeling studies involve many choices about which models and statistical methods to use, and these choices heavily influence the results. For example, Dettinger (2005) shows that by using a re-sampling method to focus on the more common rather than extreme projections, the range of possible future temperatures is actually greater than that of possible future precipitation patterns.

Thus, it is possible to use downscaled climate models to develop quantitative projections of changes in precipitation extremes and/or intensity, or other climate variables important for stormwater management. However, the results of such a study would still be associated with significant uncertainty.

5. Decision Options for LID in San Francisco at the site and program level

As the above analysis suggests, the potential exists for climate change to affect the performance of LID projects. However, the nature and magnitude of these impacts are difficult to determine, given uncertainties in climate models as well as the complexities of specific contexts. The following are several possible "robust" strategies at program and site levels for SFPUC to consider in the face of this uncertainty.

Program level

- <u>Promote LID in a manner targeted toward areas with greatest vulnerability</u>. As observed earlier, LID itself can be seen as a "robust" adaptation strategy for stormwater management, since it is associated with other benefits and allows for the expansion to more sites over time. A vulnerability-based assessment for stormwater management in San Francisco would identify areas at highest risk of flooding and/or pollution damage. LID programs could be targeted toward these areas. They could also be targeted toward locations and technologies that take advantage of other benefits of LID besides stormwater management, thereby maximizing the additional benefits of these technologies. Some of these co-benefits, such as local temperature reductions from green roofs, are also relevant for coping with climate change. Of course, targeting LID interventions in either of these ways may be challenging given institutional and funding constraints. For example, although SFPUC would like to see more green roofs and green space incorporated into LID designs, these tend to be more costly and sometimes logistically difficult for developers to incorporate (L. Webster, SFPUC, personal communication, April 5, 2011). In addition, current Guidelines relate to new development and renovations, and this may limit SFPUC's ability to promote LID in specific locations in the city where new development is not taking place. However, SFPUC might target high-risk locations in some of its own demonstration projects and small grant funding.

- On-going evaluation of climate risks and trends. Given on-going change in factors affecting vulnerability to flooding and pollution impacts, it may be useful to establish a system of on-going evaluation of climate risks and trends. In doing so, SFPUC may wish to pay particular attention to how its Guidelines for LID design depend upon current assumptions about rainfall patterns. For example, the LEED 6.2 credit for water quality volume (0.75 inches) was derived by LEED from rainfall frequency distributions for semi-arid areas. If San Francisco's rainfall patterns shift significantly and the LEED credit is not adjusted, then the Guidelines may be inadequate.

  There is a growing set of resources available to support this, such as:
  1. *Tools for climate risk assessment.* A growing number of tools now exist, but one that may be particularly relevant is the EPA's Climate Ready Water Utilities Program is rolling out the Climate Resilience Evaluation and Awareness Tool (CREAT), a free software to enable water utilities to use climate model outputs to assess potential risks (see: http://water.epa.gov/infrastructure/watersecurity/climate/creat.cfm). The tool covers wastewater treatment, and includes projections of precipitation extremes (C. Baranowski, EPA, personal communication, April 20, 2011). Although not specific to LID itself, such a tool could provide further information regarding current knowledge about trends in precipitation extremes.
  2. *Climate research and monitoring in California.* The California Climate Change Research Center (http://www.climatechange.ca.gov/research/index.html) may continue to support studies on patterns of extreme events and monitor historical trends in precipitation extremes.
  3. *Water Utility Climate Alliance.* SFPUC is the host this network of climate utilities that are exploring and testing approaches to incorporating climate change into decision-making (http://www.wucaonline.org/html/). So far, their work has primarily focused on projecting water supply and demand (WUCA, 2010). However, engaging with this group may stimulate further thinking about how to address these issues in the context of wastewater management and the role of LID.

Site level

- When flexibility exists, consider introducing extra capacity. From the experience of Sunset Swales, we see that there are instances in which site conditions and finances do permit developing LID strategies at a capacity beyond that required by the current guidelines. In many situations, the immediate reason for this extra capacity may relate more to other benefits from LID – such as aesthetic value, in the case of Sunset Swales. However, extra capacity may also generate benefits in terms of resilience to greater extremes. One important component for MS4 areas might be incorporation of additional space for ponding in a swale so that water treatment can continue even under more intense rainfall conditions (Hirschman, 2011). However, it is also possible for excess capacity to decrease the effectiveness of a water quality-oriented LID project; if water flows through a treatment soil too fast, fewer pollutants might be removed (CASQA, 2003, 5-15). Thus, the value of extra capacity needs to be assessed for each context. In addition, there may be physical or budgetary constraints in a given site.

- Ensure that maintenance programs are well-supported. Based on Sunset Swales and other projects, maintenance efforts are extremely important for an LID project's overall performance. A greater frequency of extreme events and/or greater intensity of smaller events could exacerbate problems such as erosion and debris collection, and damage to plants. Maintenance programs are often difficult to sustain in terms of funding and personnel, but they may become even more important for LID projects as precipitation patterns change.

CONCLUSION

Changes in the frequency of precipitation extremes and the intensity of rainfall could have important implications for the design and maintenance of LID sites. Global climate research suggests that such changes are possible, and on average, are even likely. Downscaled climate model projections cannot yet provide specific estimates of the magnitude and likelihood of these changes at the scale of the San Francisco area. However, this uncertainty does not mean the risks do not exist. The vulnerability-based approach to assessing adaptation options suggests that decision-makers begin by examining the potential impacts of climate-related events in a specific context. If there is significant uncertainty about the likelihood of these impacts based on current climate knowledge (as in this case), decision-makers should seek to identify options that are "robust" to possible future scenarios. Strategies also need to be developed to continually monitor change, and update strategies as knowledge grows.

Increased precipitation extremes and intensity could lead to patterns that exceed the design criteria for some LID structures. Specifically, if storms are less frequent but more intense as global climate research suggests, rainfall frequency analysis might yield a greater water quality treatment volume. If rainfall intensities increase overall, IDF curves might shift so that smaller storms are associated with a larger amount of rainfall/hour, which would affect flow-based BMPs. If not accommodated in design, specific impacts of these increases might pose risk of increased pollution, and additional costs for repair and maintenance of the site. In the case of Sunset Swales, its location and the fact that it is already built with a larger capacity to treat runoff than is required by current San Francisco guidelines, suggests that its vulnerability to significant impacts from climate change may be limited. "Robust" approaches to accounting for climate change might include promoting LID technologies in areas with greatest vulnerability to climate-related impacts, instituting an on-going process for assessing risks and trends, and at the site level, introducing additional capacity when flexibility exists (as in the case of Sunset Swales), and ensuring effective maintenance programs.

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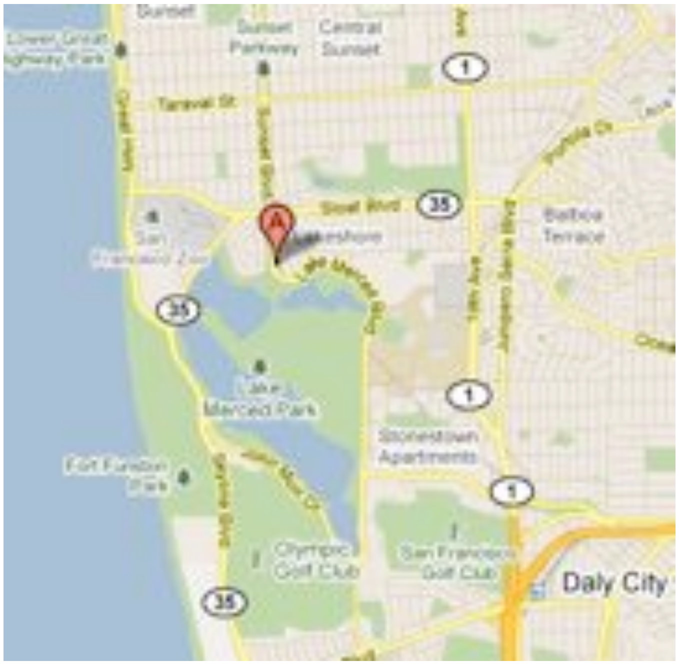
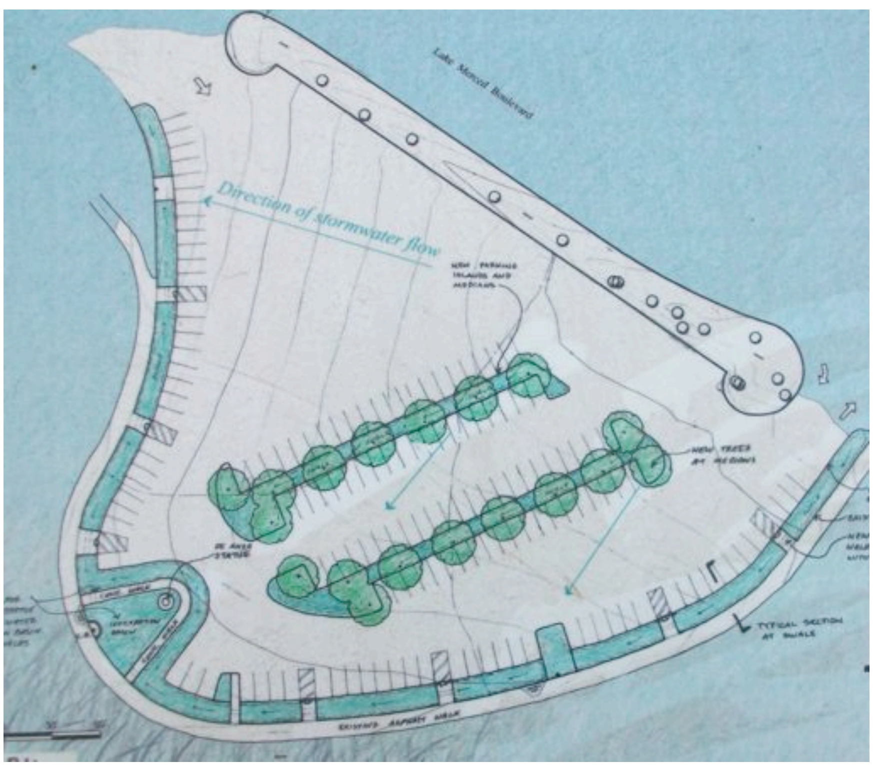
Figure 1. Sunset Swales Location Map



Source: Googlemaps

Figure 2. Sunset Swales Design Layout.



Source: SFPUC sign at the Sunset Swales site.

Table 1. Sunset Swales Summary Data

Location	Eastern shore of Lake Merced, separate sewer area
LID design type	Infiltration basins and vegetated swales
Date of construction	January 2006 – March 2007
Drainage area of site	3.56 acres (154,147 ft^2)
Area covered by swales/basins	8,500 ft^2 (6% of total area)
Design flow capacity	25-year storm event (1.03 in/hr)
Design capacity for water quality features	0.25-year storm event (0.372 in/hr)
Project cost	$288,300 (excluding on-going maintenance)

Source: Webster 2007

Table 2. Comparison of Actual Sunset Swales Design Calculations to Current Guidelines

	Actual capacity*	**Required under 2010 Stormwater Guidelines****	
Calculation method	Water Quality Flow Q = CIA	Water Quality Volume V = CAd	Water Quality Flow Q = CIA
Assumptions	C = 0.98 A = 3.54 acres (154,147 ft^2) I (25 yr) = 1.03 in/hr (volume) I (0.25 yr) = 0.372 in/hr (quality)	C = 0.80 (asphalt) A = 3.54 acres (154,147 ft^2) d = 0.75 in (LEED 6.2, equivalent to 90% of annual rainfall events)	C = 0.80 (asphalt) A = 3.54 acres (154,147 ft^2) I = 0.2 in/hr (as per Water Quality Calculator provided by SFPUC)
Results	**Q (25) = 3.57 ft^3/sec** **Q (0.25) = 1.29 ft^3/sec**	**V = 9,310 ft^3**	**Q = 0.57 ft^3/sec**

Source: Webster 2007, SFPUC 2009; calculations based on 2010 Guidelines are my own

*This follows the calculations in Webster 2007. A runoff coefficient of 0.98 was assumed in those calculations.
**This follows the calculation methods in the "Separate Sewer Area BMP Sizing Calculator – Water Quality" provided on the SFPUC website (http://sfwater.org/mto_main.cfm/MC_ID/14/MSC_ID/361/MTO_ID/543). See sheet labeled "Water Quality Volume and Water Quality Flow Rate Calculator". This sheet recommends the use of 0.8 as the runoff coefficient for asphalt (the type of cover found at Sunset Swales). It follows the SFPUC guidelines for water quality volume (0.75 in) and the water quality flow performance indicator is 0.2 in/hr (less than 0.372 in/hr, the water quality flow used in Sunset Swales).

Figure 3. Swale in Sunset Swales Parking Lot, with ponding water. March 25, 2011.

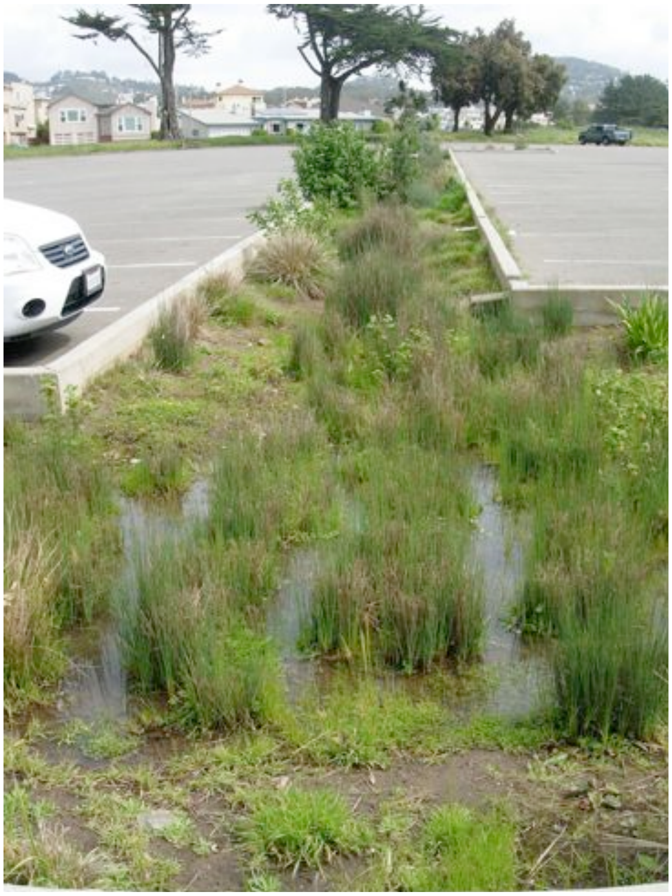


Figure 4. Large detention basin at Sunset Swales, with ducks. March 25, 2011.