Title

Taking LID to the Streets: A Case Study of Stormwater Management on Leland Avenue in San Francisco, California

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Abstract

Over the past decade, low impact design (LID) has emerged as a promising strategy for urban stormwater management. Yet despite the growing awareness and acceptance of LID techniques, it is still a relatively new field of practice, with institutional and technical challenges that are new to experienced planners, designers, engineers, construction crews and maintenance staff. In order to ensure that the proliferation of new LID installations will be successful, it is crucial to identify lessons learned from early demonstration projects. This report seeks to increase understanding of City-driven street-based LID projects through a case study of the Leland Avenue Streetscape Improvements in San Francisco. The project, which was completed in 2010, is notable as the first street redesign in San Francisco to incorporate sustainable stormwater management practices.

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Introduction

Urban stormwater management has begun to undergo a paradigm shift. Rather than focusing on infrastructure systems that rapidly convey stormwater offsite, cities are increasingly supporting small-scale, decentralized strategies that mimic the natural processes through which stormwater is slowed, stored and infiltrated into the ground. These techniques are referred to by various names, including low impact development or design (LID), green infrastructure, and best management practices (BMPs). Over the past decade, cities such as Portland, Seattle and New York have launched high profile programs to promote green infrastructure in urban streets (Portland Bureau of Environmental Services, 2011; Seattle Public Utilities, 2011; New York Department of Environmental Protection, 2010).

San Francisco's forays into sustainable stormwater management have also gained momentum in recent years. Since the mid-2000s, the Urban Watershed Management Program of the San Francisco Public Utilities Commission (SFPUC) has been promoting the use of LID through policies, guidelines, grants and demonstration projects. In 2006, Sunset Swales Parking lot became the first public LID project in San Francisco, using vegetated swales and infiltration basins to manage runoff and improve water quality in the Lake Merced area. At the time, no citywide guidelines for LID existed for either private developments or in public right-of-ways.

In 2010, the City adopted a Stormwater Management Ordinance (San Francisco Public Works Code, Article 4.2, Section 147) that requires development projects over 5000 square feet to manage stormwater onsite, in accordance with the SFPUC and Port of San Francisco's *Stormwater Design Guidelines.* These guidelines apply to private developments, not to public right-of-ways. San Francisco's guidelines for street-based LID are presented in the *Better Streets Plan*, which became effective on January 16, 2011. Section 6.2 of the *Plan* discusses placement, design, installation and maintenance considerations for a variety of BMPs including permeable paving, swales, vegetated gutters and infiltration trenches.

Despite the growing awareness and acceptance of LID techniques, it is important to recognize that it is still a relatively new field of practice, with institutional and technical challenges that are new even to experienced planners, designers, engineers, construction crews and maintenance staff. Therefore, it is crucial to learn from early projects in order to improve successive projects.

This report seeks to examine the benefits and challenges of street-based LID projects through a detailed case study of the Leland Avenue Streetscape Improvements, an early LID implementation in San Francisco. The project is notable as the first City-driven street redesign to incorporate sustainable stormwater management practices. It also constitutes the first LID design executed by the DPW Bureau of Engineering, and the first use of permeable pavement in a City project. The main sponsors of these improvements were the San Francisco Planning Department and Department of Public Works.

This case study is organized as follows:

- Part I provides a brief introduction to the site location and project timeline.
- Part II describes key aspects of the planning process, including institutional, social and financial factors such as community outreach and funding.
- Part III discusses the technical aspects design and implementation, such as soil characteristics, choice of materials and expected performance.
- Part IV addresses the post-construction issues of monitoring and maintenance.

Methods

This research for this case study is based upon the following sources:

- Review of manuals on low impact development from other cities and counties.
- Review of published reports from San Francisco agencies such as the Planning Department, Department of Public Works (DPW) and Public Utilities Commission (SFPUC).
- Review of internal memos and design documents provided by the DPW and SFPUC.
- In-person interviews with the following individuals:
    - Leslie Webster, SFPUC Urban Watershed Management Program
    - Rosey Jencks, SFPUC Urban Watershed Management Program
    - John Dennis, DPW Bureau of Engineering, Landscape Architect
    - Ken Kortkamp, consultant to SFPUC
- Phone interviews with the following individuals:
    - Beth Goldstein, Hydroconsult Engineers
    - Adam Varat, SF Planning Department
    - Sarah Minick, SFPUC Urban Watershed Management Program
    - Tomio Takeshita, SFPUC Field Operations Manager

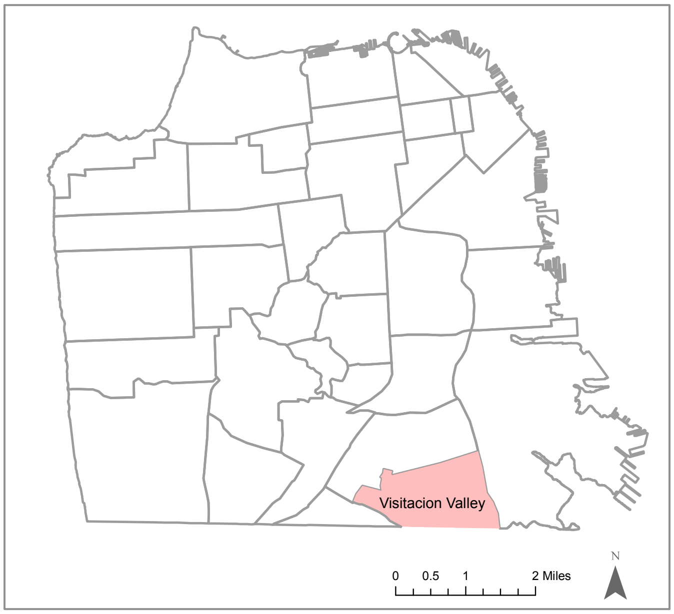
Throughout the report, the facts and circumstances of the Leland Avenue case study are supplemented by comparisons with the newly-developed guidelines set out in San Francisco's *Better Streets Plan* and *Stormwater Design Guidelines*.

Part I: Project overview

Site location

Leland Avenue serves as the "main street" for the Visitacion Valley neighborhood in the southeast of San Francisco (Figure 1). The commercial corridor stretches for four blocks from Bayshore Boulevard to Rutland Street, and includes neighborhood-serving businesses as well as a post office and library (Figure 2). The street has a gentle slope from west to east, which causes water to drain in the direction of Bayshore Boulevard (San Francisco Planning Department, 2006).

Figure 1. Map of San Francisco showing location of Visitacion Valley



Source: San Francisco Planning Department

Figure 2. Leland Avenue project area

Source: San Francisco Planning Department

Timeline

The stormwater management facilities on Leland Avenue were implemented as part of a larger streetscape redesign that took place between 2005 and 2010. The project included LED streetlights, accessible curb ramps, corner bulb-outs, street repaving, sidewalk furniture and public artwork. Permeable pavement and bioretention planters were implemented to decrease stormwater flows to the City's combined sewer system, support water conservation goals, and link the new streetscape to neighboring green spaces along the Visitacion Valley Greenway. Table 1 presents a timeline of events related to the project.

Table 1. Project timeline

Date	Event
1999	Schlage Lock factory at Bayshore Boulevard closes down
2004	Four community workshops are held to generate a Community Action Plan for the economic revitalization of Leland Avenue
July 2005	Planning Department receives funding to begin a streetscape design demonstration project on Leland Avenue
Oct 2005 – April 2006	Three community visioning workshops are held, with the results summarized in a report entitled “A New Leland Avenue”
Oct 2006	DPW receives capital grant funding to implement the design
April 2007	Hydraulic modeling completed by Hydroconsult Engineers
2008 - 2009	Detailed design engineering
Aug 2009 – Sept 2010	Construction of street improvements
September 23, 2010	Completion of project celebrated at 5th annual Leland Avenue Street Fair

Part II: Key factors in the Leland Avenue LID implementation

This section discusses key aspects of the planning process for the Leland Avenue project. The opportunity to install LID features on Leland Avenue would not have occurred without substantial institutional, community and financial support for the project.

Institutional factors: Inter-agency partnerships for "complete streets"

The Leland Avenue project provides an early example of the inter-agency partnerships that are necessary to realize the ideal of "complete streets" in San Francisco. A "complete street" is a street that is not merely a thoroughfare for vehicle traffic, but also a public space that serves social, recreational and ecological needs. At Leland Avenue, the desire to implement sustainable stormwater management facilities arose in conjunction with other objectives, including economic revitalization, street beautification and pedestrian safety enhancements.

Reflecting the complexity of redesigning a street to serve multiple purposes, the Leland Avenue Streetscape Improvements required collaboration between multiple agencies. The Planning Department led the planning process, hiring consulting firms to manage the community workshops and produce concept designs. After the visioning process was complete, and funding had been obtained, the Department of Public Works led the project through the design engineering and construction phases. Throughout, the PUC acted in a technical advisory role, hiring consultants to perform hydraulic modeling and providing input on matters such as soil testing and material specifications.

The ideal of the complete street is now entrenched in the *Better Streets Plan*, which itself was a multi-agency partnership to produce a comprehensive, unified set of guidelines and implementation strategies for streets in San Francisco. Although the *Plan* was not adopted until December 2010, after the completion of Leland Avenue, its development was concurrent with the Leland Avenue project. Indeed, the *Plan* carries out the intent of the Better Streets Policy, which was adopted on February 6, 2006, the same month that the community vision process for Leland Avenue completed. The Better Streets Policy states that streets shall be designed "in keeping with the Urban Design Element of the City's General Plan, the City's Transit-First Policy, best practices in environmental planning and pedestrian-oriented, multi-modal street design, and incorporation of sustainable water management techniques to ensure continued quality of life, economic well-being and environmental health in San Francisco" (San Francisco Administrative Code, section 98.1 a).

Social factors : Neighborhood revitalization and community involvement

The initial motivation for the Leland Avenue Streetscape Improvements was not environmental sustainability, but economic revitalization. The neighborhood in which Leland Avenue is located is an ethnically diverse, lower income neighborhood that has been the focus of numerous planning efforts since the closure of the Schlage Lock Factory in 1999. In 2004, three local organizations—Urban Solutions, Asian Neighborhood Design and Local Initiatives Support Corporation—led a community planning process under the Neighborhood Marketplace Initiative program of the Mayor's Office of Economic and Workforce Development. The report generated from this process notes that Leland Avenue has a number of vacant and boarded up storefronts (Urban Solutions, 2004). The outcome of the process was a Community Action Plan encompassing physical improvements, safety/cleanliness, promotion and economic development. Streetscape improvements and pedestrian safety were components of the plan for physical improvements.

The community was solicited for more focused input on streetscape improvements during three workshops held between October 2005 and February 2006. The Planning Department hired Van Meter Williams Pollack, Asian Neighborhood Design and Merrill Morris to run the workshops and come up with conceptual designs.

At the workshops, community members expressed their perception of the street as being uninviting and rundown, not a place where they would tend to linger, aside from fulfilling daily shopping needs (SF Planning Department, 2006, p.18). In terms of improving the street, participants “strongly encouraged the use of sustainable technology and public art as a way to promote a unique identity for the avenue” (SF Planning Department, 2006, p.19). Sidewalk bulbouts, native plants and trees were all identified as desirable elements of the plan. In the second workshop, participants were presented with three designs. The preferred approach combined both hardscape and greenscape elements, including sustainable stormwater facilities such as porous pavement. The third workshop provided an opportunity to refine the preferred design alternative through comments from the community.

Residents remained involved in certain aspects of the design as the project progressed, ensuring that the design elements were suitable for their community. This was exemplified by a controversy over tree selection. The original design concept presented by Van Meter Williams Pollack in the 2006 report calls for pear trees along the avenue. The problem is that the blossoms of a pear tree are white, and in Chinese culture, white flowers are considered a symbol of death and are used only at funerals. Once the implications of this decision had been recognized by the sizeable Asian community in the Visitacion Valley, community members organized a successful campaign to have the planned pear trees replaced by cherry trees, with pink blossoms (J.Dennis, personal communication, April 8, 2011). The need for cultural sensitivity when selecting trees is noted in the *Better Streets Plan*, which encourages outreach to cultural groups when formulating plans for tree plantings (City of San Francisco, 2010, p.175).

Investigations into community satisfaction with the completed street improvements and the degree to which these improvements will contribute to economic revitalization are outside the scope of this report, but these would be worthwhile topics for future studies.

Financial factors: Funding sources

The preferred design alternative that emerged from the Leland Avenue visioning process was estimated at approximately $5 million in construction costs (San Francisco Planning Department, 2006, p.45). Given the substantial costs of street construction, the ability to obtain funding is a prerequisite for successful implementation. In the case of Leland Avenue, the multi-agency partnerships, community engagement and economic revitalization components of the project seem to have been instrumental in qualifying for grants.

In 2006, the San Francisco Planning Department and the Department of Public Works put together an application for a capital grant from the Transportation for Livable Communities (TLC) federal program. The program designates funds for community-based transportation projects that bring vibrancy to commercial cores, including streetscape and pedestrian improvements identified through inclusive community planning efforts. Two grants of $2.05 million and $1.76 million were received, totaling $4.1 million with local matching funds. Table 2 summarizes the funding sources and amounts for the project.

Table 2. Project funding

Source	**Date**	**Details**	**Amount**
Evelyn and Walter Haas Jr Fund	2005	-	$75,000
San Francisco County Transportation Authority (SFCTA)	2005	Prop K funds	$50,000
Planning Total			$125,000
Metropolitan Transportation Commission (MTC)	2006	Regional Transportation for Livable Communities (TLC) program	$2,050,000
SFCTA	2007	TLC county share program	$1,762,000
SFCTA	2007	Prop K funds	$15,120
SFCTA	2008-2009	Prop K funds	$212,480
Implementation Total			$4,039,600

Part III: Design and Construction

This section describes the technical factors that are likely to influence the success of the stormwater features on Leland Avenue. A rigorous design process was required to turn the initial concept drawings into implementable LID facilities. This process included both empirical data collection and computer modeling, as well as some reliance on industry “best practices” to choose material specifications and feature configurations. The construction process was also an important process, with certain practices that had to be followed in order to ensure the design integrity of the installation.

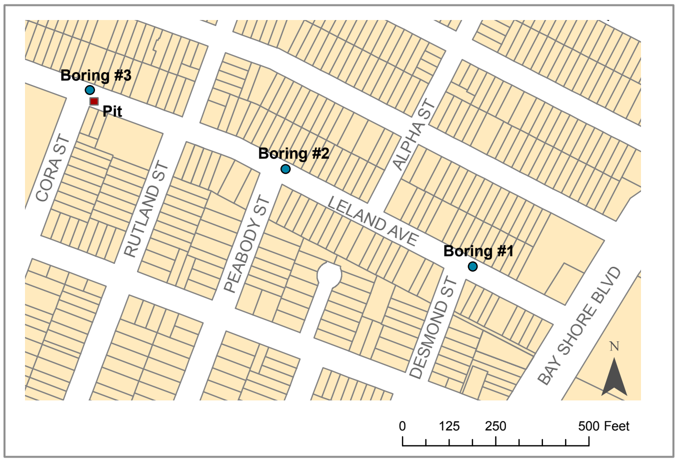
Infiltration testing

An “infiltration-based” LID feature is one in which stormwater is eventually absorbed into the soil below, thus recharging the groundwater table and diverting runoff from the municipal drainage system. Infiltration is not appropriate if native soils have low infiltration rates, the groundwater table is close to the surface, or if there is a high potential for pollutants to enter the LID facility. A high groundwater table not only increases the likelihood of saturating the soil during a rainfall event, but also lessens the distance that the water travels from the surface to the water table, thus reducing the opportunity for filtering out pollutants. In situations where the requirements for infiltration-based systems are not met, LID features are designed so that the stormwater drains back into the municipal system.

Preliminary information for Leland Avenue soil characteristics came from boring logs conducted near Leland Avenue at the Schlage Lock factory site. These tests showed infiltration rates between 0.1 and 10 inches per hour (Jonston, 2007). Based on these data, it was hoped that the permeable pavement could be infiltration-based, which would not only lead to the greatest stormwater benefits, but would also avoid the expense of installing underdrains.

Conducting site-specific geotechnical testing at Leland Avenue was one of the first steps taken in the detailed design phase. In order to proceed with infiltration-based features, the test results needed to show infiltration rates greater than 0.5 in/hr and a groundwater elevation at least 10 feet below the surface of the street (Baradaran, 2008, p.1). The test sites consisted of three 8-foot-deep borings and one 4-foot-deep test pit (Figure 3). The test was conducted in September 2008. Groundwater was not encountered in any of the three borings, which had depths of 8.3 to 8.5 feet. To measure the percolation rate, the test pit and borings were fifilled with water, and the time for water to percolate was observed and recorded. The infiltration rates were measured to be between 1 and 35 in/hr across the four testing locations, at depths ranging from 3 to 8 feet (Baradaran, 2008, p.1). The report notes that the variation in measured rates could be due to the soil being smeared with a thin layer of silt or clay. The conclusion of these tests was that the site was suitable for infiltration-based LID features.

Figure 3. Location of boring and pit tests



Source: Department of Public Works

Design feature: Permeable pavement

Permeable pavement is an attractive and convenient option for urban LID installations because the surface can continue to serve as a functional sidewalk, driveway or parking area while providing multiple stormwater benefits, including attenuation of peak flows, reduction of total runoff volume and filtration of pollutants. At Leland Avenue, permeable pavement was used to replace impervious material in a five-foot strip along the parking lane and in a three-foot strip on the sidewalk (Figure 4). In total, 9,600 square feet of permeable pavement were installed along the parking strip, and 3,600 square feet were installed on the sidewalk.

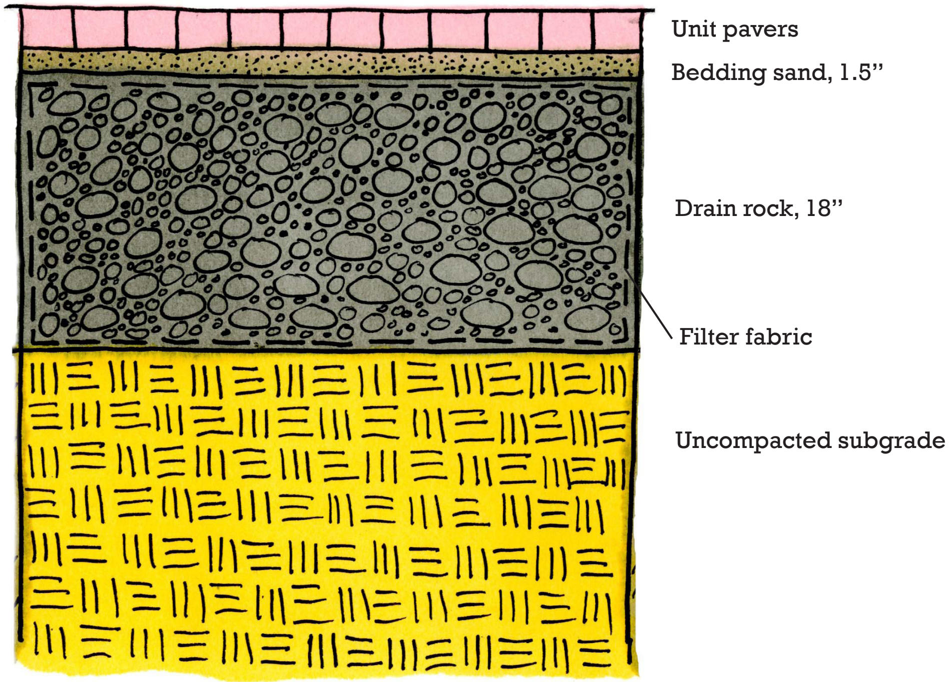
Figure 4. Permeable pavement on sidewalk and parking strip

Generally speaking, permeable pavement can be implemented with a variety of materials, including porous concrete, porous asphalt and concrete block pavers. For systems that use pavers, the water can percolate through the pavers themselves, if the pavers are porous, or the water can percolate through gravel or soil in the spaces between the pavers, if the pavers are not porous. In the Leland Avenue installation, the pavers are porous, meaning that water seeps into the paver material itself, and therefore, there is no need for gaps between the pavers (Figure 4). The brand of the paver is the "Ekopaver" manufactured by Airostone Corporation. It is made of a highly porous, ceramic-based material advertised to handle rainfall at an average rate of 2 inches per minute.

Based on accessibility, maintenance and performance concerns, the use of permeable pavers required the approval of multiple organizations, including the Mayor's Office of Accessibility, SFPUC and the DPW Operations team. As part of the process of introducing permeable pavement into the public right-of-way, the DPW issued a Director's Order approving the use of pervious paving systems and citing their benefits for treating stormwater runoff (Reiskin, 2010).

Although the pavers are the only visible component of the system, the LID installation actually consists of several layers of materials. The pavers are laid in bedding sand with a depth of 1.5 inches, below which is 18 inches of drain rock (Figure 5). The drain rock is surrounded by a filter fabric that screens out fine sediment. Below the drain rock is uncompacted native soil. The construction of the three-foot wide strip of permeable pavement on the sidewalk is similar to that on the road, but with an 8 inch drain rock base rather than an 18.5 inch drain rock base.

Figure 5. Cross section for unit pavers on parking strip



The cost of the permeable pavement, including the base, was $35 per square foot for the parking lane installation, and $30 per square foot for the sidewalk installation. The total cost of the permeable pavement installation was $442,800.

Design feature: Bioretention planters

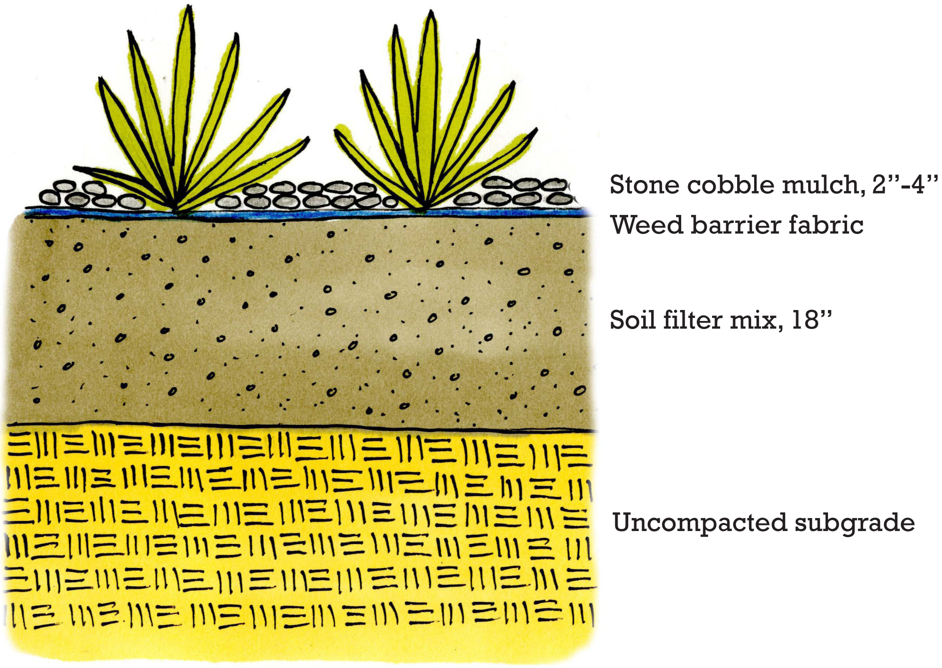
Bioretention planters provide attractive landscaping while collecting, filtering and infiltrating runoff. The Leland Avenue Streetscape Improvements included eighteen planters in total. Nine of the planters have 18 inch-wide stormwater inlets and outlets and nine planters do not. Figure 6 shows an example of a planter with a stormwater inlet and Figure 7 shows an example of a planter with no inlet.

Figure 6. Bioretention planter with stormwater inlet

Figure 7. Bioretention planter with no stormwater inlet

As can be seen in Figures 6 and 7, the visible surface of the planter is covered in stone cobble mulch. A weed barrier fabric is placed between the mulch and the 18-inch-deep growing medium below (Figure 8). The soil filter mix is stipulated to have a minimum infiltration rate of 5 in/hr and a maximum infiltration rate of 10 in/hr. (If the water infiltrates too quickly, the filtration benefits will not occur.) The DPW's specification document calls for the mix to be tested after installation to ensure that it satisfies these requirements.

Figure 8. Cross-section of bioretention planter



The choice of plants is crucial due to the very particular conditions of LID facilities. The plants must tolerate high volumes of water, yet they must also be able to survive with low amounts of water during the dry season. The plants chosen for Leland Avenue are listed in Table 3.

Table 3. List of plants

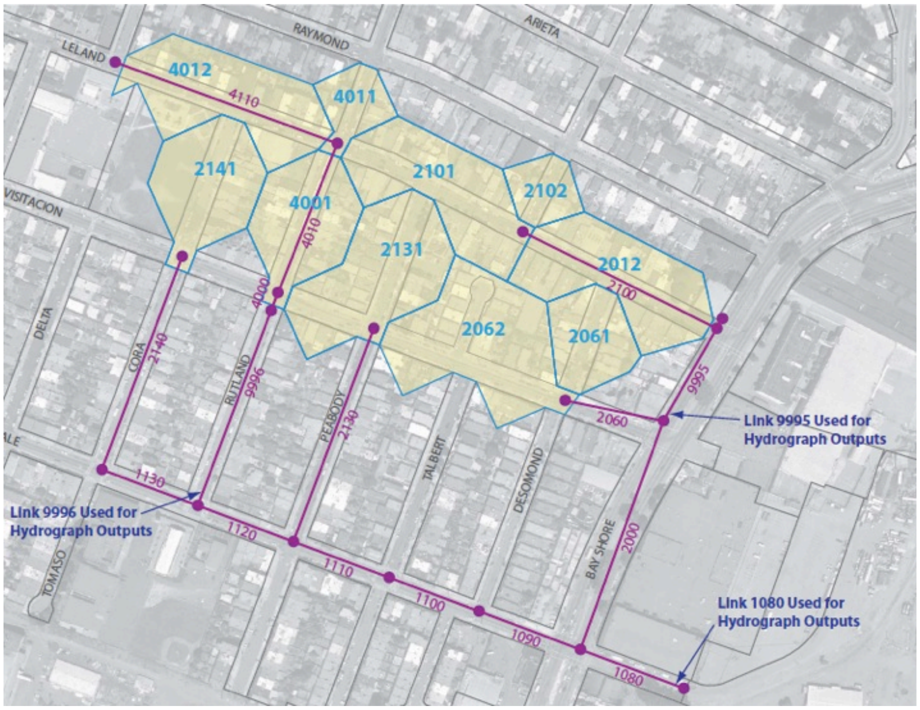
Botanical Name	**Common Name**	**Number planted**
Tristania Laurina	Elegant Brisbane Box	
Baumea Rubiginosa	Variegated Striped Rush	106
Juncus Patens	California Rush	106
Mimulus Cardinalis	Scarlet Monkey Flower	106

Performance estimates based on hydraulic modeling

In 2007, prior to the detailed design phase, the SFPUC hired consultants to perform hydraulic modeling of the proposed BMPs and estimate the drainage benefits. This effort used the InfoWorks Collection Systems dynamic sewerage and stormwater drainage modeling tool, an established model developed by Wallingford Software in the UK. The InfoWorks model is also being used as San Francisco's citywide stormwater and wastewater planning tool (Jonston, 2007).

Baseline conditions were established using a truncated drainage network for the existing stormwater infrastructure in the project area (Figure 9). The total area of this catchment area is 16.94 acres, with a pre-construction impervious surface area of 10.16 acres and a pervious surface area of 6.78 acres. Based on schematics available at the time, the permeable pavement was expected to replace 1.53 acres of impervious surface. The bioretention planters were assumed to drain back to the sewer system rather than rely on infiltration, and were expected to provide 5882 cubic feet of detention storage.

Figure 9. Local drainage network for Leland Avenue



Source: Hydroconsult Engineers

Model rainfall events

The rainfall events used for the assessment were 1-hour and 3-hour storms with 2-year and 5-year recurrence intervals. The 5-year storm event is the DPW drainage system design standard, so modeling of this recurrence interval enabled the benefits to be compared with the capacity of existing drainage infrastructure. The rationale for including 2-year storm events was that the benefits of these LID strategies were expected to be evident in shorter, less intense storms. The total rainfall corresponding to storms of these durations and recurrence intervals is indicated in Table 4.

Table 4. Storm events used in modeling

Storm event	**Total rainfall (in)**	**5-minute rainfall intensity (in/hr)**
2-year, 1-hour duration	0.627	2.239
2-year, 3-hour duration	1.042	2.239
5-year, 1-hour duration	0.751	2.751
5-year, 3-hour duration	1.082	2.961

Model parameters

Runoff parameters were chosen based on a combination of boring and aquifer testing logs for Schlage Lock, soil infiltration maps, and existing literature on LID. These parameters are summarized in Table 5.

Manning's 'n' is a coefficient in the Manning formula that represents the relative roughness of different surfaces over or through which water flows. The rougher the material, the larger the value of Manning's n. The values for impervious and pervious surfaces were based on what was previously used in the Infoworks model, while the value for permeable pavement was based on typical ranges found in engineering reference texts. Comparing the relative value of these coefficients, the roughness of permeable pavement is just over 3.5 times that of impervious pavement, and exactly 3 times smaller than that of pervious pavement.

The *depression storage* parameter represents the capacity of a surface to retain water in pits and depressions. Surface runoff occurs only after the depression storage capacity has been filled. This water is then subject to evaporation or infiltration. Smooth surfaces have lower depression storage than rough surfaces. Permeable pavement was modeled to have depression storage capacity 6 times greater than impervious surfaces, and 0.5 times greater than pervious surfaces.

The *Horton infiltration* parameter describes the capacity of a material to absorb rainfall before generating runoff. Impervious pavement has no infiltration capacity, whereas pervious pavement has an infiltration rate between 0.4 to 0.5 inches per hour. It was assumed that the infiltration rate in the permeable pavement installation would be limited by the infiltration rate of the native soil underneath, not by the permeable pavement. Thus, permeable pavement is modeled to have the same infiltration rate as a pervious surface, because the characteristics of the soil below are the same.

Table 5. Hydraulic modeling parameters

	Impervious	**Permeable pavement**	**Pervious**
Mannings 'n' for overland flow, roughness	0.014	0.05	0.15
Depression storage (in)	0.05	0.3	0.2
Horton infiltration minimum (in/hr)	n/a	0.4	0.4
Horton infiltration maximum (in/hr)	n/a	0.5	0.5

Model results

The model predicted a decrease of approximately 12% in total runoff volume for all modeled storm events, based on an expected 1.53 acres of permeable pavement replacing impervious surface. The model also predicted a decrease of approximately 12% in peak runoff flow rate for all modeled storm events.

Modified Rational Method Tool

The model results were used to calibrate coefficients for a simplified spreadsheet-based calculation tool, called the Modified Rational Method Tool. The values of the coefficients were adjusted until the calculated peak flows and runoff volumes across all storm events were within 20% of the values achieved from the more sophisticated InfoWorks model. The intent of this tool is to enable rough predictions of future drainage improvements without requiring a computer based hydraulic model.

In this tool, the rational method is used for peak flow calculations:
$Q = C*I*A$
Where:
Q = peak flow rate in cfs
C = runoff coefficient
I = rainfall intensity in inches/hr
A = area in acres

The runoff coefficient method is used to calculate runoff volume:
$V=C*R*A$
Where:
V = runoff volume in cubic feet
C = runoff coefficient
R = total rainfall in feet
A = area in square feet

Updated performance estimates based on the Modified Rational Method

In this section, performance estimates are calculated for baseline, expected and installed conditions at the site, using the Modified Rational Method Tool. Updated estimates of the drainage benefits are needed because there were significant changes to the LID features between the hydraulic modeling phase and actual construction.

The key change for the permeable pavement installation is that the surface area is much less than estimated during the modeling phase. The model assumed a total area of 1.53 acres, whereas the actual installation is approximately 0.23 acres. This reduction in area is at least partly due to the use of concrete at crosswalks and intersections (Figure 10) rather than permeable pavers as indicated in original concept drawings (SF Planning, 2006, p.29). The primary reason for the reduced scale of the permeable pavement installation is believed to be cost (J.Dennis, personal communication, April 8, 2011).

Figure 10. Concrete crosswalk imprinted to resemble permeable pavement

The key difference for the bioretention planters is that they were modeled as temporary storage measures that drain back to the sewer system, but ultimately they were implemented as infiltration-based systems.

In terms of the overall catchment area, the extent of the street improvements along Leland Avenue was reduced from five blocks (Bayshore Boulevard to Cora Street) to four blocks (Bayshore Boulevard to Rutland Street). To accurately reflect this change, one might reduce the area of the baseline drainage network, but for the purposes of continuity, these calculations use the same baseline drainage area as in the modeling effort. Table 6 presents a comparison of the baseline conditions, expected LID features and installed LID features.

Table 6. Comparison of baseline, expected and installed drainage area conditions

	Baseline Conditions	**Expected LID Conditions**	**Installed LID Conditions**
Existing impervious surface area (acres)	10.16	8.63	9.84
Existing pervious surface area (acres)	6.78	6.78	6.78
LID permeable surface area (acres)	0	1.53	0.32
Storage volume (ft^3)	0	5882	0

Runoff coefficients

The runoff coefficients are based on a calibration process conducted as part of the hydraulic modeling effort. Because the planters were initially assumed to be temporary storage, the runoff coefficient for the infiltration-based planter surface was not part of the original modeling effort. For these calculations, this value was chosen to be the same as the permeable pavement runoff coefficient, reasoning that the planters would create very little runoff due to the high infiltration rate of the growing medium and the raised concrete wall around the perimeter of each planter.

Table 7. Runoff coefficients

Surface type	**Runoff coefficient, C**
Impervious	0.8
Pervious	0.25
Permeable pavement	0.05
Infiltration-based planter	0.05

Results

The installed LID facilities are predicted to reduce runoff volume for the catchment area by 2.4% for all storm events, compared to 11.7% under the initially planned LID facilities. This difference is due to the substantial reduction in permeable pavement surface area. Table 8 presents both the actual runoff volumes and percentage reductions from the baseline for all storm events.

Table 8. Runoff volume in ft^3, under baseline, expected and installed conditions

Storm event	**Baseline Conditions**	**Expected LID Conditions**	**Reduction**	**Installed LID Conditions**	**Reduction**
2-year 1-hour (0.627 in)	22,362	19,751	11.7%	21,816	2.4%
2-year 3-hour (1.042 in)	37,174	32,832	11.7%	36,266	2.4%
5-year 1-hour (0.751 in)	26,767	23,641	11.7%	26,113	2.4%
5-year 3-hour (1.082 in)	38,579	34074	11.7%	37,637	2.4%

The installed permeable pavement and bioretention filters are calculated to reduce peak runoff flow by about 2.7 percent for the 2-year 5-minute storm, and by about 2.4 percent for the 5-year 5-minute storm. The reduction is significantly less than that calculated for the expected LID features used in the original modeling effort, for which the Modified Rational Method predicts a reduction of between 14.3 to 15.3%. These values are slightly greater than the reduction of 12% predicted by the Infoworks model. Table 9 summarizes the calculated peak flow for baseline, expected and installed conditions.

Table 9. Peak runoff in cfs, under baseline, expected and installed conditions

Storm intensity	**Baseline Conditions**	**Expected LID Conditions**	**Reduction**	**Installed LID Conditions**	**Reduction**
2-year 5-minute (2.239 in/hr)	22.2	18.8	15.3%	21.6	2.7%
5-year 5-minute (2.969 in/hr)	29.4	25.2	14.3%	28.7	2.4%

Discussion

While the calculated reductions in runoff volume and peak flow for the installed LID features may seem small in comparison with earlier estimates, it is important to note that the baseline drainage area is defined to be quite large, with a total area of about 17 acres. Given that the installed LID features take up only 0.32 acres, or 1.9% of the catchment area, it is reasonable that the reduction in runoff would be between 2.4% and 2.7%. Furthermore, as can be seen in Figure 6, the catchment area encompasses much more than Leland Avenue itself. For example, the drainage area includes private properties whose surfaces would never be modified in the context of a street redesign.

This discussion raises the question of what drainage benefits should be expected from a LID installation in the public-right-of-way to justify the expense and long-term maintenance. At present, the City of San Francisco does not have a standard for the percentage reduction in rate and quantity of stormwater runoff for a street-based LID installation, although it does have a standard for private developments, which is based on the requirements for achieving LEED Sustainable Sites Credits 6.1 and 6.2 (SFPUC, 2009). Given that street-based LID consists of small-scale, decentralized facilities, it is unlikely that any one installation would provide a huge reduction in stormwater; rather, the idea is that the cumulative effect of LID throughout the city would be significant. It may be the case that any replacement of impervious surface with pervious surface is positive, and that it would be undesirable to establish a standard of performance that might inhibit smaller-scale installations from taking place. LID also provides non-stormwater-related benefits such as street beautification and community education. On the other hand, assuming there are limited funds for streetscape improvements, it might be good to establish standards so that money can be applied towards projects with the greatest ecological impact. It is understandable that pilot projects, such as Leland Avenue, would not be developed with a specific performance target, but as these projects become more common, standards may help to promote best practices.

Construction

Because water is intended to percolate into LID features, LID construction represents a different paradigm from conventional street construction. The proper functioning of LID facilities is highly dependent on the careful treatment of the materials to preserve their infiltration capacity. The *Better Streets Plan* notes that "pervious pavement is most susceptible to failure during construction" (p.194), with compaction, sealing and sediment build-up being the key processes to avoid. Construction crews that are not already experienced with LID may find it difficult to understand and remember the need for LID-specific practices at the construction site.

For example, it is not unusual for litter to accumulate at a construction site. If conventional pavement were to be installed, it would even be possible for the debris to be sealed under the concrete. In the case of permeable pavement, however, this litter would potentially affect the infiltration rate and release pollutants into the water. During Leland Avenue construction, DPW staff requested on multiple occasions that the crew remove debris from permeable pavement excavations, as shown in Figure 11, before proceeding with construction (K. Kortkamp, personal communication, April 22, 2011).

Figure 11. Trash thrown on permeable pavement subgrade

Source: SFPUC

Preventing fine sediment from accumulating in porous materials is also critical in LID installation. One SFPUC staff member observed porous pavement being used as a staging area for sand and chipstone, without the use of filter fabric to protect the pavement. This practice is specifically addressed in the *Better Streets Plan*, which states: "do not allow construction stating, soil/mulch storage, etc. on unprotected pavement surfaces" (194).

For future projects, it may be useful for the DPW and SFPUC to produce a clear, concise "Guide to LID Construction" for construction teams. This guide could explain the need to avoid compaction, sealing and sediment build-up at the construction site while providing easily implementable strategies to achieve these conditions. The guide should be published in multiple languages. A pre-construction orientation session for LID components may also help to avoid problems later in the process.

Part IV: Post-construction topics

Performance monitoring

No formal post-construction evaluation of Leland Avenue LID performance has taken place. One option for measuring post-construction performance would be to install flowmeters at key stormdrain locations during the wet season. With detailed rainfall records, these measurements could be compared to the system performance predicted by the hydraulic model, which would also have to be updated to reflect the changes since the initial hydraulic modeling effort.

More recent projects to install LID features at Newcomb Avenue and Cesar Chavez Street have used flowmeters to measure pre-construction stormwater flow. The installation is managed by SFPUC crews, who insert the flowmeter into lateral pipes accessed from a drain cover (Figure 12). The major challenge associated with flowmeters is that they can be time-consuming to manage, requiring repeated visits, with traffic control measures needed in the vicinity of the drain (T. Takeshita, personal communication, April 25, 2011). Before a storm event, the crew must inspect the flowmeter to ensure that it is working and that it has a battery with enough charge. Because the flowmeters are not wireless, the crew returns to the flowmeter after a storm event to download data.

Figure 12. Flowmeter installed in lateral pipe at Cesar Chavez and Harrison

Source: SFPUC

Another challenge of successfully measuring pre-construction conditions is timing. Ideally, the flowmeter would be installed at the beginning of the rainy season (early fall) and left in place until the end of the rainy season (late spring). However, the pre-construction window for a project may not coincide with this timeframe. For example, the flowmeter at Cesar Chavez Street was installed in January, partway through the rainy season. It is also possible that the flowmeter may be inadvertently "de-installed" in the course of other streetwork, as happened on Cesar Chavez Street when the flowmeter popped out and was not put back in place for a week.

Regardless of the challenges, it is exciting that pre-construction conditions are being measured for upcoming LID installations. Performance evaluations would be useful in justifying the benefits of existing LID projects in order to gain funding for future projects. Performance data would also "close the loop" on the design process, allowing lessons to be learned and applied to future designs. It seems that the flowmeters and technical expertise necessary to install the flowmeters already exist at the SFPUC. What is needed are dedicated financial and human resources to work on monitoring. If possible, a specific source of funding for project monitoring would help these activities to continue in the post-construction phase, given that project grants seem to be focused on design and construction expenses.

Maintenance

LID facilities have special maintenance requirements that differentiate them from other streetscape and landscape elements. Lack of proper maintenance does not result in merely an aesthetic deterioration, but a functional deterioration or perhaps even complete failure, leading to flooding. For example, both permeable pavement and soil filter mix in planters can become clogged with fine sediment that reduces the infiltration rate of the material. Maintenance activities therefore consist primarily of inspection and removal of sediment and debris.

The SFPUC's *BMP Factsheet* for permeable pavement indicates that porous pavers, such as those used at Leland Avenue, should be inspected monthly for clogging with sediment, and should be vacuumed or pressure washed seasonally. Each year, the infiltration rate should be measured through simple methods using a sprinkler and stopwatch. Every 10 to 15 years, it is recommended to lift the surface paving units to clean the underlying drain rock and remove accumulated sediment.

The SFPUC's *BMP Factsheet* for bioretention BMPs recommends that debris should be removed semi-annually from planter inlets and outlets to avoid clogging. Over time, as sediment gets added to the system, the infiltration performance may degrade, so it may become necessary to till the soil, replace the soil or replant the whole system at intervals of every 3 to 5 years (SFPUC, 2010, p.78).

The project's budget allows for one year of landscape maintenance to be incorporated into the construction contract, at a cost of $25,000, but responsibility after the first year has yet to be determined. The street is officially maintained by the Department of Public Works, but there are limited numbers of staff to inspect and maintain landscaping (J.Dennis, personal communication, April 8, 2011). Given these constraints, DPW landscape architects focused on designing for zero maintenance, for example by choosing plants that would need as little maintenance as possible.

One proposal for what might happen after the initial year of maintenance was drafted by the SFPUC in April 2010. In this plan, the responsibility for the planters is shared by two community organizations, the Friends of Visitacion Valley Greenway and the Visitacion Valley Business Opportunities and Outreach to Merchants (VVBOOM). The annual maintenance cost for the planters was estimated to be $9336, and the Visitacion Valley Community Facilities & Infrastructure Fee & Fund was proposed as the funding source. The plan proposed that responsibility for the permeable pavement be shared by the Department of Public Works and VVBOOM. The anticipated annual maintenance cost for the pavement was $1448.

Based on inspection of the LID features in May 2011, it seems likely that some additional maintenance attention may be needed beyond typical street maintenance. In the course of use, the porous pavers have been stained by oil and chewing gum (Figure 13), which may reduce the ability of water to seep into the pavers.

Although the street is subject to regular street-sweeping, it is unclear whether this will be sufficient to clean the pavers of these stains and remove fine sediment which may accumulate.

Figure 13. Oil stains on permeable pavement parking strip

The main issue observed with the bioretention planters on a May 6 site visit was the accumulation of litter carried by stormwater into planters with stormwater inlets. Figure 14 shows an image of a planter that was located downslope relative to other planters in the vicinity and had a particularly bad trash accumulation problem.

Figure 14. Trash collecting at a planter stormwater inlet

The issue of maintenance responsibilities will only become more serious as the number of LID installations in San Francisco increases. The City has already explored partnerships with community groups, and given limited City funds for streetscape maintenance staff, this may be the most viable option. It seems that it would be advisable for some City staff to be have oversight over the maintenance of all LID features in the City, while recruiting and training community members to help with maintenance activities. This arrangement is currently being employed by the "Green Streets Stewards" Program of the City of Portland's Bureau of Environmental Services (Portland Bureau of Environmental Services, 2010).

Conclusion

The Leland Avenue Streetscape Improvements mark the first time that LID facilities were incorporated into the City's "complete streets" projects. The design embodies urban stormwater management principles and LID strategies that are now captured in the *Better Streets Plan* and the *Stormwater Design Guidelines.* In many ways, the Leland Avenue project is a success simply for being the first City-driven attempt to incorporate sustainable stormwater management facilities into a streetscape redesign.

The Leland Avenue Streetscape Improvements are also remarkable as an example of collaboration between city agencies to accomplish a project with benefits that encompass pedestrian safety, neighborhood revitalization, street beautification and sustainable stormwater management. In terms of technical accomplishments, the process of learning the soil characteristics, infiltration testing procedure and material specifications required of LID installations was likely very valuable for DPW landscape architects, engineers and project managers. This knowledge is now being applied to successive projects, and it is even being shared directly with the public, in the form of permeable pavement installation tips for residents who acquire sidewalk landscaping permits (DPW, 2011). The most major challenges for street-based LID projects such as Leland Avenue seem to be related to construction, performance monitoring and long-term maintenance.

There are currently two new San Francisco street redesigns in progress with plans to implement LID features. It will be interesting to see how City staff apply their experience with Leland Avenue towards improving the planning, design, implementation and maintenance of the LID installations at Newcomb Avenue and Cesar Chavez Street.

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Appendix A: Material Specifications

Permeable pavement

Material	**Description**	**Specifications**
Unit pavers	Porous block paver, known as the “Ekopaver,” manufactured by Airostone Corporation. Colors are Dark Brown and Sand.	• 3 ¾” wide, 7 ¾” long, 2 3/8” high. • Conforms with ASTM C 936 standard, for heavy vehicular traffic, 8000 psi minimum compressive strength • Conforms with ASTM C 1028 for slip resistance • Minimum absorption of 5 percent
Setting bed	Fine, sharp nonplastic aggregate.	• Conforms with ASTM C 33
Drain rock	This material is installed below permeable pavers.	• Conforms with requirements of Class 2 Permeable Material of Section 68-1.025 of Caltrans Standard Specifications (CTSS) • R-Value greater than 78
Filter fabric	This material is wrapped around the drain rock.	• Conforms with Section 88-1.03 of Caltrans Standard Specifications

Bioretention planters

Material	**Description**	**Specifications**
Soil filter mix	Growing medium, 18” deep.	• Composition must be 50% construction sand, 20 to 30% topsoil with no more than 5% maximum clay content and 20 to 30% organic leaf compost. • Minimum infiltration rate of 5 in/hr, maximum infiltration rate of 10 in/hr • Confirm to Contra Costa County Water Program, Stormwater C3 guidebook requirements
Rock cobble mulch	2 x 4 Lin Creek Cobbles in multiple colors of tan and beige.	None
Weed barrier and filter fabric	Nonwoven polypropylene, 4 oz. weight.	• Water flow rate of 14 • Permeability of 0.22