Title

Term project for Landscape Architecture 222, Prof. G. Mathias Kondolf, University of California, Berkeley, Spring 2009. Hard copy available at the Water Resources Center Archives, UC Berkeley.

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Educative Waterscapes: Stormwater Management Design in San Francisco's Public Schools

by Hayley Diamond and Andrea Gaffney

Abstract: How can stormwater management design be incorporated into public school campuses to provide ecological and educational benefits while reducing the impacts on San Francisco's combined sanitary/storm sewer system?

Schools in San Francisco have a large percentage of impervious surfaces on their campuses, and the City's combined sanitary storm sewer system has aged to a point of necessary upgrade. These two issues converge on the subject of stormwater management, where a potential synergy exists. Schools are landscapes for education, so why not provide an educative landscape for the school that addresses the City's infrastructure issue? Demonstration projects for innovative stormwater management can address not only flooding issues but also educate students and communities about water pollution, water conservation, habitat value, micro-climate value, and benefit the overall aesthetics of a community.

This paper specifically discusses green stormwater infrastructure retrofits at two existing public schools in San Francisco, with the purpose of developing a decision-making process for the choice and locations of green infrastructure components in school facilities for environmental and educational benefits. A case study matrix evolved from research on green stormwater infrastructure retrofit projects at several educational campuses located throughout the country. Results from the case study matrix, along with information gathered through interviews with the San Francisco Public Utility staff and a literature review of stormwater design documents, informed the development of an educative waterscape plan for one of the school campuses, McKinley Elementary School.

Introduction Schools in San Francisco have a large percentage of impervious surfaces on their campuses, and the city's combined sanitary storm sewer system has aged to a point of necessary upgrade (SFPUC 2009). These two issues converge on the subject of stormwater management, where a potential synergy exists. Schools are landscapes for education, so why not provide an educative landscape for the school that addresses the city's infrastructure issue? Demonstration projects for innovative stormwater management can address not only flooding issues but also educate students and communities about water pollution, water conservation, habitat value, micro-climate value, and benefit the overall aesthetics of a community. Demonstration stormwater management projects at schools can be used as test projects for other sites in the community. Schools are distributed throughout the city so the school demonstration program could be an effective way to widely distribute exposure to concepts of green infrastructure.

Low Impact Design-Overview Low Impact Design (LID) addresses both the quantity and quality of stormwater runoff through a decentralized approach to stormwater facility sizing and siting. Green stormwater infrastructure facilities, such as rain gardens, swales, and permeable pavers, slow down the flow of stormwater over a site, lessening its impact on the City's combined storm sewer system. In addition, green stormwater infrastructure facilities can treat urban pollutants, such as metals, sediment, oils and grease that are often transported by stormwater runoff in a storm (SFPUC 2009).

LID mimics natural hydrologic cycles of stormwater through the detention, retention, and infiltration of stormwater runoff at its source. Vegetated stormwater facilities can provide significant habitat for wildlife, open space and recreation areas, and environmental education opportunities. Rainwater harvesting, while delaying the peak flow, can also effectively reduce demand on potable water sources for non-potable uses such as irrigation and toilet flushing.

San Francisco Context San Francisco has a Mediterranean Climate with dry summers and rainy winters. The irrigation demand occurs in the summers, when there is no rainfall, which increases pressure on the potable water supply. Therefore LID solutions such as rainwater harvesting and storage can reduce the demand on the potable water supply for non-potable irrigation needs.

In early 2009, the San Francisco Public Utilities Commission (SFPUC) published the draft *San Francisco Stormwater Design Guidelines* (*Guidelines*) that outlined requirements for treating stormwater runoff in the City's separate storm sewer areas, approximately 10% of the city. The *Guidelines* also specify requirements for developers in the combined storm sewer areas in response to the recently adopted Green Building Ordinance. The *Guidelines* apply to projects in the combined storm sewer area until the city develops separate performance measures for these areas. Performance measures, once written, may vary between the separate and combined storm sewer areas. In the separate storm sewer areas, water quality issues are more significant because stormwater runoff discharges directly into the Bay and Pacific Ocean without being treated. In the combined storm sewer areas, a reduction in stormwater runoff quantity and flow can reduce the demand on the city's aging storm sewer infrastructure and prevent combined sewer discharges in the event of a large storm. The *Guidelines* set goals for stormwater management that include treating stormwater at its source, minimizing and disconnecting impervious surfaces, and using stormwater as a resource as opposed to a waste product.

METHODS

This study applied the following methods: case studies, expert interviews, existing regulatory stormwater calculations, site analysis and design.

Case Studies The case studies are presented in a matrix, which analyzes nine schools and other educational facilities retrofitted with green stormwater infrastructure projects. The list would be more extensive if it included new-construction school projects with green infrastructure, but we chose to limit this study to retrofit projects. This limitation provides a realistic framework for what existing schools can accomplish with relatively limited budgets and schedules. The treatment types, sizes, and costs presented in this matrix represent a variety of possibilities for the school stormwater management retrofit demonstration projects. The SFPUC's Urban Watershed Planning Charrette and the *Guidelines* informed this list of possible green infrastructure projects. The list of educational components represents a compilation of benefits mentioned in both the case studies and in the various SFPUC publications on the benefits of stormwater management.

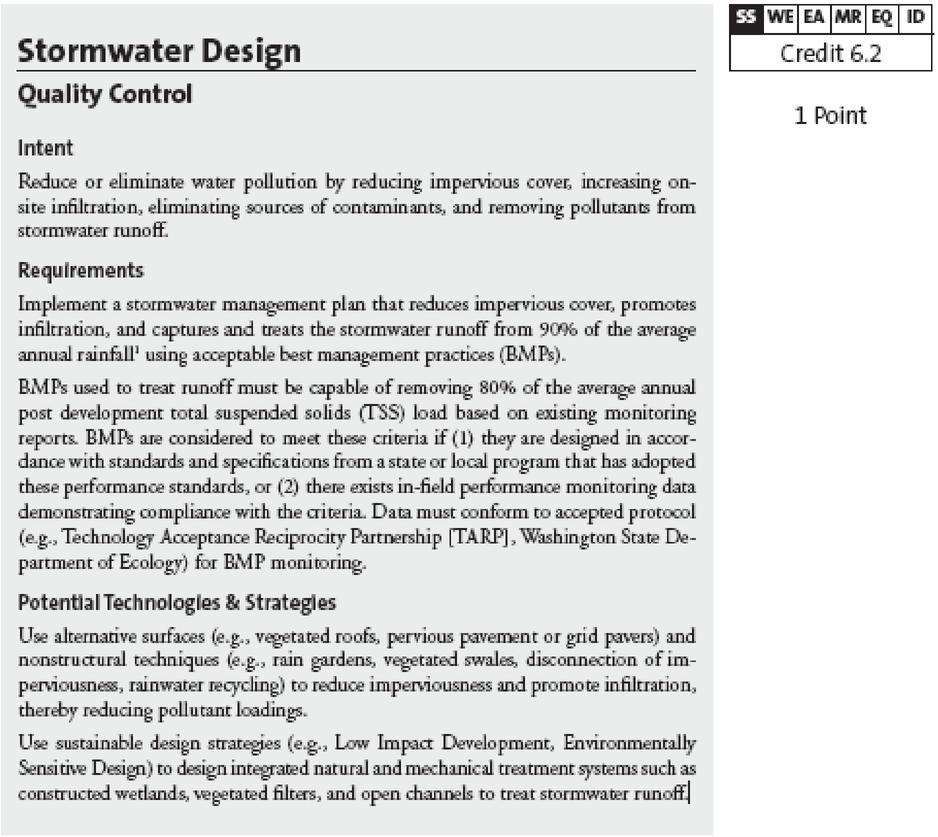
Interviews We spoke with Rosey Jencks and Sarah Minick of the SFPUC to understand their program's goals for stormwater management in public schools. Their specific comments are presented in the results section. They suggested we follow the *Guidelines* methods for preparing a Stormwater Control Plan for LID, which are outlined by the following steps:

1. Characterize existing site conditions
2. Identify design and development goals
3. Develop a site plan
4. Develop a site design (design the flow path of stormwater on a site from point of first contact to the discharge point)
5. Select and locate source controls
6. Select and locate green infrastructure technologies
7. Size treatment green infrastructure technologies
8. Check against design goals and modify as necessary
9. Develop an operations and maintenance plan
10. Compile the Stormwater Control Plan

The Stormwater Control Plan specifies these measures for new development in non-combined sewer areas of the city; however, this paper will apply them to the school retrofit process for demonstration purposes. The goals for school projects should also include educational components that address any or all of the following issues: watershed awareness, water quality awareness, water conservation awareness, and indirect benefits such as habitat value, food security (near home food production), heat island reduction/micro-climate protection (through the reduction in impervious surfaces), ecosystem awareness, and neighborhood beautification. Therefore, we added the evaluation of educational components to the Stormwater Control Plan method.

San Francisco Stormwater Management Performance Measures To follow the steps outlined in the Stormwater Control Plan, which includes stormwater treatment calculations, we used the equations listed in the *Guidelines*. The City of San Francisco has adopted a performance measure equivalent to Leadership in Energy and Environmental Design (LEED) Sustainable Sites Credit 6.2 entitled "Stormwater Design: Quality Control," for its separate storm sewer areas, outside of the Port-operated properties **(Figure 1)**. The performance measure requires the use of a volume-based 0.75 inch design storm (R_d) to capture 90% of the average annual rainfall for semi-arid watersheds (San Francisco Stormwater Design Guidelines 2009). Controlling the flow of stormwater runoff generated in the five-year storm at a five-minute concentration time works towards the goal of reducing impacts on the City's combined storm sewer system. The Rational Method, where rainfall intensity (I) is 2.97 inches per hour can yield a calculation for this flow (S. Durbin, Sustainable Watershed Designs, Personal Communication, March 2009).

Figure 1. LEED Credit 6.2



Stormwater Design

Quality Control

SS WE EA MR EQ ID

Credit 6.2

1 Point

Intent

Reduce or eliminate water pollution by reducing impervious cover, increasing on-site infiltration, eliminating sources of contaminants, and removing pollutants from stormwater runoff.

Requirements

Implement a stormwater management plan that reduces impervious cover, promotes infiltration, and captures and treats the stormwater runoff from 90% of the average annual rainfall[1] using acceptable best management practices (BMPs).

BMPs used to treat runoff must be capable of removing 80% of the average annual post development total suspended solids (TSS) load based on existing monitoring reports. BMPs are considered to meet these criteria if (1) they are designed in accordance with standards and specifications from a state or local program that has adopted these performance standards, or (2) there exists in-field performance monitoring data demonstrating compliance with the criteria. Data must conform to accepted protocol (e.g., Technology Acceptance Reciprocity Partnership [TARP], Washington State Department of Ecology) for BMP monitoring.

Potential Technologies & Strategies

Use alternative surfaces (e.g., vegetated roofs, pervious pavement or grid pavers) and nonstructural techniques (e.g., rain gardens, vegetated swales, disconnection of imperviousness, rainwater recycling) to reduce imperviousness and promote infiltration, thereby reducing pollutant loadings.

Use sustainable design strategies (e.g., Low Impact Development, Environmentally Sensitive Design) to design integrated natural and mechanical treatment systems such as constructed wetlands, vegetated filters, and open channels to treat stormwater runoff.

Site Analysis We visited both schools with Kat Sawyer of Rebuilding Together San Francisco, who provided an overview of the campus layouts, and her organization's plans for landscape refurbishments. We combined this information with other sources to generate existing conditions documents from which we calculated the stormwater runoff.

Stormwater Runoff Calculations To calculate both the stormwater runoff treatment requirements for the sites per the *Guidelines* and the stormwater runoff generated in a five-year storm with a five-minute concentration time, we began by delineating the site boundary for the school campuses **(Figures 2 and 3)**. We drafted initial plans based on Google Earth imagery and then verified with site measurements. Nik Kaestner, the sustainability director of the San Francisco Unified School District also provided us with a set of as-built construction drawings. From these documents, we determined the area (in square feet) of all of the existing hardscaping, building, and landscaping at the school sites and the respective runoff coefficients of the various landscape surfaces to calculate the composite runoff coefficients and required stormwater runoff treatment volumes **(Tables 1 and 2)**. We calculated runoff treatment volume using the equation: $V = CAR_d$, where R_d is 0.75 inch. For the five year storm, at a five minute time of concentration we used the Rational Method to determine flow: $Q = CIA$, where I is 2.97 inches (S. Durbin, Sustainable Watershed Designs, Personal Communication, March 2009). Next, we divided the site into drainage management areas (DMA #), in which all of the surfaces are draining to one location, based on the existing grading and drainage of the sites **(Figures 4 and 5)**. We repeated the calculations of surface areas, composite runoff coefficients, and the required stormwater runoff treatment volumes and flowrates **(Tables 3 to 15)**.

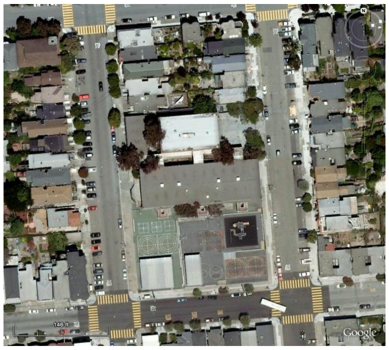


Figure 2. Daniel Webster Elementary School (left)
Figure 3. McKinley Elementary School (right).

Figure 4. Daniel Webster Elementary School Drainage Management Areas

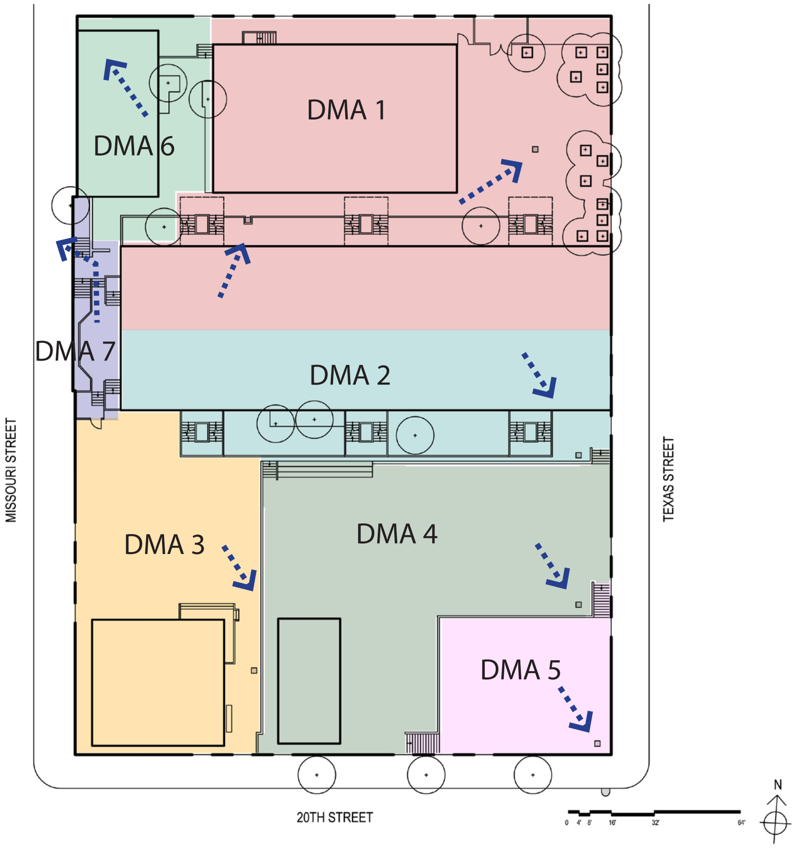


Figure 5. McKinley Elementary School Drainage Management Areas

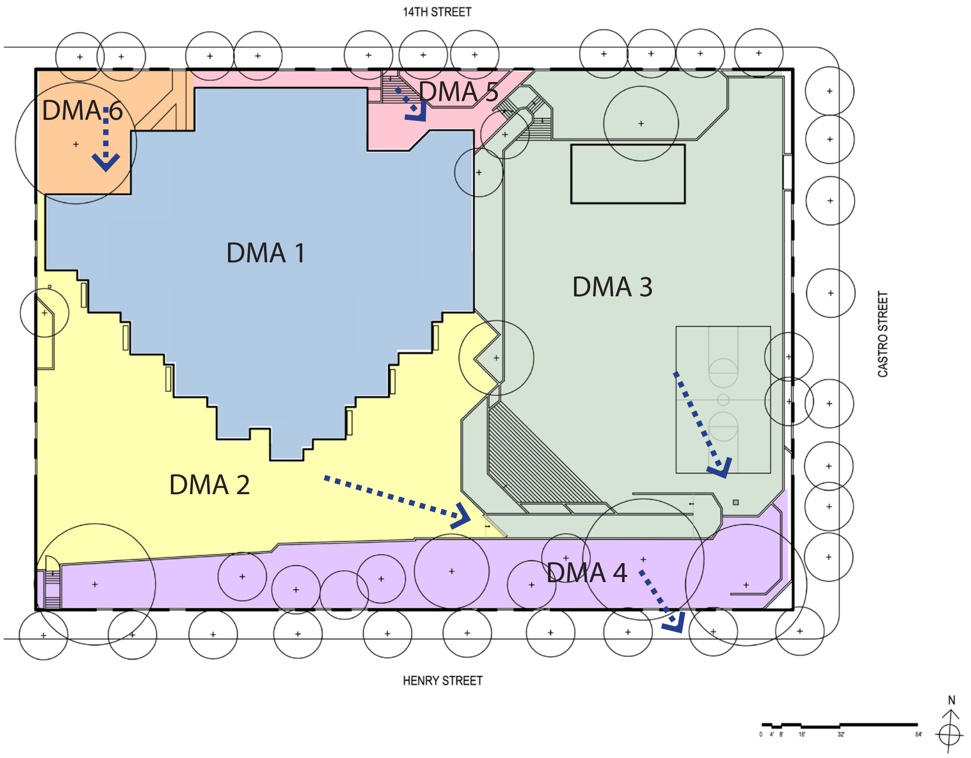


Table 1. Daniel Webster Elementary School Surface Calculations

Daniel Webster Elementary School Total Site: 54,769.5 ft^2			
Surface	**Area (ft^2)**	**c_i**	**Area (ft^2) x c_i**
Impervious Roof			
Main Building	11165		
Auditorium	5013		
North Classroom	1869		
Portable Classroom (Preschool)	2311		
Portable Office (Preschool)	1075		
Impervious Roof Total	21433	0.85	18218.05
Asphalt Play Surface	25430	0.8	20344
Concrete Paths, Walls and Stairs	5825.5	0.9	5242.95
Planting Area	2081	0.2	416.2
Total	54769.5		44221.2
C (∑(Area x c_i) / Total Site Area)			0.805486
V (ft^3) = $CA_{tot}R_d$, where R_d is 0.75" =			2763.825
Q (cfs) = CIA_{tot}, where I is 2.97" = (area converted to acres)			3.007915

Table 2. McKinley Elementary School Surface Calculations

McKinley Elementary School Total Site: 69544 ft^2			
Surface	**Area (ft^2)**	**c_i**	**Area (ft^2) x c_i**
Impervious Roof			
Main Building	17920		
Portable Classroom	1133		
Impervious Roof Total	19053	0.85	16195.05
Asphalt Play Surface/Parking	28924	0.8	23139.2
Concrete Paths, Walls and Stairs	4329	0.9	3896.1
Planting Area	16048	0.2	3209.6
Total	68354		46439.95
C (∑(Area x c_i) / Total Site Area)			0.679404
V (ft^3) = $CA_{tot}R_d$, where R_d is 0.75" =			2902.497
Q (cfs) = CIA_{tot}, where I is 2.97" = (area converted to acres)			3.16636

McKinley Elementary School Drainage Management Areas

Table 3. McKinley Elementary School Drainage Management Area 1 Runoff Calculations

DMA 1			***McKinley Elementary School***
Total Size: 17920 ft^2			
Surface	**Area (ft^2)**	**c_i**	**Area (ft^2) x c_i**
Impervious Roof			
Main Building	17920		
Impervious Roof Total	17920	0.85	15232
Total	17920		15232
C (∑(Area x c_i) / Total Site Area)			0.85
V (ft^3) = $CA_{tot}R_{d}$, where R_d is 0.75" =			952
Q (cfs) = CIA_{tot}, where I is 2.97" = (area converted to acres)			1.038545

Table 4. McKinley Elementary School Drainage Management Area 2 Runoff Calculations

DMA 2			***McKinley Elementary School***
Total Size: 13225 ft^2			
Surface	**Area (ft^2)**	**c_i**	**Area (ft^2) x c_i**
Asphalt Play Surface/Parking	13065	0.8	10452
Planting Area	160	0.2	32
Total	13225		10484
C (∑(Area x c_i) / Total Site Area)			0.792741
V (ft^3) = $CA_{tot}R_{d}$, where R_d is 0.75" =			655.25
Q (cfs) = CIA_{tot}, where I is 2.97" = (area converted to acres)			0.714818

Table 5. McKinley Elementary School Drainage Management Area 3 Runoff Calculations

DMA 3			***McKinley Elementary School***
Total Size: 23357 ft^2			
Surface	**Area (ft^2)**	**c_i**	**Area (ft^2) x c_i**
Impervious Roof			
Portable Classroom	1133		
Impervious Roof Total	1133	0.85	963.05
Asphalt Play Surface	15859	0.8	12687.2
Concrete Paths, Walls and Stairs	3256	0.9	2930.4
Planting Area	3839	0.2	767.8
Total	24087		17348.45
C (∑(Area x c_i) / Total Site Area)			0.720241
V (ft^3) = $CA_{tot}R_{d}$, where R_d is 0.75" =			1084.278
Q (cfs) = CIA_{tot}, where I is 2.97" = (area converted to acres)			1.182849

DMA 4			***McKinley Elementary School***
Total Size: 8652 ft^2			
Surface	**Area (ft^2)**	**c_i**	**Area (ft^2) x c_i**
Concrete Paths, Walls and Stairs	940	0.9	846
Planting Area	8512	0.2	1702.4
Total	9452		2548.4
C (∑(Area x c_i) / Total Site Area)			0.269615
V (ft^3) = $CA_{tot}R_d$, where R_d is 0.75" =			159.275
Q (cfs) = CIA_{tot}, where I is 2.97" = (area converted to acres)			0.173755

Table 6. McKinley Elementary School Drainage Management Area 4 Runoff Calculations

DMA 5			***McKinley Elementary School***
Total Size: 2135 ft^2			
Surface	**Area (ft^2)**	**c_i**	**Area (ft^2) x c_i**
Concrete Paths, Walls and Stairs	1097	0.9	987.3
Planting Area	1038	0.2	207.6
Total	2135		1194.9
C (∑(Area x c_i) / Total Site Area)			0.559672
V (ft^3) = $CA_{tot}R_d$, where R_d is 0.75" =			74.68125
Q (cfs) = CIA_{tot}, where I is 2.97" = (area converted to acres)			0.08147

Table 7. McKinley Elementary School Drainage Management Area 5 Runoff Calculations

DMA 6			***McKinley Elementary School***
Total Size: 2725 ft^2			
Surface	**Area (ft^2)**	**c_i**	**Area (ft^2) x c_i**
Concrete Paths, Walls and Stairs	230	0.9	207
Planting Area	2495	0.2	499
Total	2725		706
C (∑(Area x c_i) / Total Site Area)			0.259083
V (ft^3) = $CA_{tot}R_d$, where R_d is 0.75" =			44.125
Q (cfs) = CIA_{tot}, where I is 2.97" = (area converted to acres)			0.048136

Table 8. McKinley Elementary School Drainage Management Area 6 Runoff Calculations

Daniel Webster Elementary School Drainage Management Areas

Table 9. Daniel Webster Elementary School Drainage Management Area 1 Runoff Calculations

DMA 1 ***Daniel Webster Elementary School***

Total Size: 19008.5 ft^2

Surface	**Area (ft^2)**	**c_i**	**Area (ft^2) x c_i**
Impervious Roof			
Main Building	6474		
Auditorium	5013		
Impervious Roof Total	11487	0.85	9763.95
Asphalt Play Surface	4116	0.8	3292.8
Concrete Paths, Walls and Stairs	2015.5	0.9	1813.95
Planting Area	1390	0.2	278
Total	19008.5		15148.7
C (∑(Area x c_i) / Total Site Area)			0.796943
V (ft^3) = $CA_{tot}R_{d}$, where R_d is 0.75" =			946.7938
Q (cfs) = CIA_{tot}, where I is 2.97" = (area converted to acres)			1.032866

Table 10. Daniel Webster Elementary School Drainage Management Area 2 Runoff Calculations

DMA 2 ***Daniel Webster Elementary School***

Total Size: 6409 ft^2

Surface	**Area (ft^2)**	**c_i**	**Area (ft^2) x c_i**
Impervious Roof			
Main Building	3988		
Impervious Roof Total	3988	0.85	3389.8
Asphalt Play Surface	1661	0.8	1328.8
Concrete Paths, Walls and Stairs	594	0.9	534.6
Planting Area	166	0.2	33.2
Total	6409		5286.4
C (∑(Area x c_i) / Total Site Area)			0.82484
V (ft^3) = $CA_{tot}R_{d}$, where R_d is 0.75" =			330.4
Q (cfs) = CIA_{tot}, where I is 2.97" = (area converted to acres)			0.360436

Table 11. Daniel Webster Elementary School Drainage Management Area 3 Runoff Calculations

DMA 3 **Daniel Webster Elementary School**

Total Size: 10382 ft^2

Surface	**Area (ft^2)**	**c_i**	**Area (ft^2) x c_i**
Impervious Roof			
Main Building	1595		
Portable Classroom (Preschool)	2311		
Impervious Roof Total	3906	0.85	3320.1
Asphalt Play Surface	5816	0.8	4652.8
Concrete Paths, Walls and Stairs	494	0.9	444.6
Planting Area	166	0.2	33.2
Total	10382		8450.7
C (∑(Area x c_i) / Total Site Area)			0.813976
$V (ft^3) = CA_{tot}R_d$, where R_d is 0.75" =			528.1688
$Q (cfs) = CIA_{tot}$, where I is 2.97" = (area converted to acres)			0.576184

Table 12. Daniel Webster Elementary School Drainage Management Area 4 Runoff Calculations

DMA 4 **Daniel Webster Elementary School**

Total Size: 10697 ft^2

Surface	**Area (ft^2)**	**c_i**	**Area (ft^2) x c_i**
Impervious Roof			
Portable Office (Preschool)	1075		
Impervious Roof Total	1075	0.85	913.75
Asphalt Play Surface	9220	0.8	7376
Concrete Paths, Walls and Stairs	402	0.9	361.8
Total	10697		8651.55
C (∑(Area x c_i) / Total Site Area)			0.808783
$V (ft^3) = CA_{tot}R_d$, where R_d is 0.75" =			540.7219
$Q (cfs) = CIA_{tot}$, where I is 2.97" = (area converted to acres)			0.589878

Table 13. Daniel Webster Elementary School Drainage Management Area 5 Runoff Calculations

DMA 5			***Daniel Webster Elementary School***
Total Size: 3422 ft^2			
Surface	**Area (ft^2)**	**c_i**	**Area (ft^2) x c_i**
Asphalt Play Surface	3187	0.8	2549.6
Concrete Paths, Walls and Stairs	235	0.9	211.5
Total	3422		2761.1
C (∑(Area x c_i) / Total Site Area)			0.806867
V (ft^3) = CA$_{tot}$R$_d$, where R$_d$ is 0.75" =			172.5688
Q (cfs) = CIA$_{tot}$, where I is 2.97" = (area converted to acres)			0.188257

Table 14. Daniel Webster Elementary School Drainage Management Area 6 Runoff Calculations

DMA 6			***Daniel Webster Elementary School***
Total Size: 3404 ft^2			
Surface	**Area (ft^2)**	**c_i**	**Area (ft^2) x c_i**
Impervious Roof			
North Classroom	1869		
Impervious Roof Total	1869	0.85	1588.65
Concrete Paths, Walls and Stairs	1321	0.9	1188.9
Planting Area	214	0.2	42.8
Total	3404		2820.35
C (∑(Area x c_i) / Total Site Area)			0.82854
V (ft^3) = CA$_{tot}$R$_d$, where R$_d$ is 0.75" =			176.2719
Q (cfs) = CIA$_{tot}$, where I is 2.97" = (area converted to acres)			0.192297

Table 15. Daniel Webster Elementary School Drainage Management Area 7 Runoff Calculations

DMA 7			***Daniel Webster Elementary School***
Total Size: 1447 ft^2			
Surface	**Area (ft^2)**	**c_i**	**Area (ft^2) x c_i**
Concrete Paths, Walls and Stairs	1141	0.9	1026.9
Planting Area	306	0.2	61.2
Total	1447		1088.1
C (∑(Area x c_i) / Total Site Area)			0.75197
V (ft^3) = CA$_{tot}$R$_d$, where R$_d$ is 0.75" =			68.00625
Q (cfs) = CIA$_{tot}$, where I is 2.97" = (area converted to acres)			0.074189

RESULTS

The results section discusses the case studies, site analysis for Daniel Webster and McKinley Elementary Schools, and site design for McKinley Elementary School.

Case Studies The following matrix presents a series of LID stormwater retrofit projects at schools and other educational facilities **(Table 16)**. Most of the case study projects are located in Portland, Oregon, a city that practices innovative stormwater management, but also has a comprehensive knowledge-sharing program that has produced these in-depth case study reports. The matrix does not include a school rain garden in Seattle, which is sponsored by the Sierra Club and remains under construction as of May 4th, 2009 (Sierra Club Cascade Chapter Website 2009). The case study matrix also excludes, due to a lack of available information, seven additional projects in Philadelphia schools. The Portland case studies exemplify a knowledge-sharing capacity that can inform the work of other schools and water management agencies. The EPA could support this effort through its existing LID case study web page. The projects in the matrix include several commonalities:

- All projects contain educational components that occurred during the design and construction process and/or as part of the school's curriculum.
- Most projects were partially funded through grants or volunteer efforts.
- There is a direct location/hydrologic nexus between treatment site and applied LID technology. This makes processes accessible for educational purposes and may reduce infrastructure costs.
- All projects contribute to a reduction in peak flow and mitigate combined storm sewer system capacity issues, which makes them excellent demonstration cases for commercial applications for other neighborhood combined storm sewer system capacity reduction projects. (The Texas school may or may not be a combined storm sewer system improvement project.) The cost-benefit analysis for the most expensive case study, indicated that the on-site control cost one-third as much as the combined storm sewer system upgrade estimate. This resulted in decreased costs for the city and for the school district.

- In certain cases, extensive information on adjacent project sites exempted projects from site-specific drainage/infiltration testing. This significantly reduced costs for projects with infiltration components.
- Atkinson Elementary School lesson: a school official, in addition to a parent, should be in charge of the project to coordinate with the school calendar and staffing issues.
- None of the projects involved eco-roof technologies for stormwater management. The increased structural load needed to support the water live load can be cost prohibitive for retrofit projects. However, if roof repairs are already scheduled for the school, a cost-benefit analysis could indicate the feasibility of adding an extensive eco-roof construction. Extensive eco-roofs—the lighter weight construction of the two main types of eco-roofs—can provide water quality filtering, urban heat island reduction, habitat, and garden beautification, if not educational facilities. (The authors recognize the fear that may strike school officials by the thought of students on rooftops. However, if the rooftops are designed to be inhabited, then they can function no differently than terraces.)
- Most of the Portland school case studies discuss operations and maintenance, which typically consists of a contract between the school district and another party. The other partner is either the city, the parks department, the public works department, a neighborhood organization or a combination therein.

In an interview, Rosey Jencks and Sarah Minick of the SFPUC expressed concern with the decision-making process for LID, as well as the importance of locating green stormwater infrastructure facilities at the sites (e.g. rainwater harvesting systems should be located near to where the water will be used). We directly addressed their concern by sizing and locating rainwater harvesting facilities adjacent to where the water would be used for both gardening and educational purposes. In addition, we sited a series of treatment faciltities (swales and permeable paving) in potentially higher pollutant areas, such as the campus parking lot.

Table 16. Case Study Matrix

Case Study Matrix for School Stormwater Management Retrofit Projects

School	Astor Elementary School Stormwater Garden Portland, Oregon	Glencoe Elementary School Parking Lot Retrofit Portland, Oregon	DaVinci Arts Middle School Living Water Garden Project Portland, Oregon	Atkinson Elementary School Portland, Oregon	Mt.Tabor Middle School Portland, Oregon	Wattles Boys and Girls Club Portland, Oregon	Glencoe Elementary School Rain Garden Portland, Oregon	Carver Center School Midland, Texas	Penn Alexander Partnership School Philadelphia, PA
Cost	$130,384	$93,585	$78,729	$17,854	$523,000	$56,581	$98,000	$2,500	n/a
% Volunteer/Grant Money	45%	n/a	50%	100%	n/a	53%	n/a	100%	100%
Year Constructed	2005	2002	2002	2006	2007	2001	2003	2008	2006
Total SF Conversion	n/a	4400sf	7200sf	512sf/9000sf roof	4245sf/17,000sf roof	4800sf/ 21,000 sf roof	2000sf	4100sf roof	6400sf
Amount of Stormwater Treated Annually (gallons) (*cistern capacity)	289000 gal	n/a	314000 gal	n/a	n/a	314000 gal	n/a	4100*	n/a
Technology									
ecoroof									
cistern	x		x					x	
permeable pavement									x
vegetated swale/rain garden/ bio-filtration	x		x	x	x	x	x		x
vegetated infiltration basin/bio-retention	x	x	x	x	x	x	x		
detention basin or drywells			x		x	x			x
constructed wetlands			x						
urban forest	x			x					x
stream daylighting									x
Educative Component									
Watershed Awareness	x		x						x
Water Quality Awareness	x		x		x				x
Water Conservation Awareness	x		x					x	
Flood Awareness/CSO Reduction/ Demonstration Project	x	x	x	x	x	x	x		x
Habitat Value	x			x	x		x	x	x
Food Security	x							x	x
Heat Island Reduction	x			x	x				
Ecosystem Awareness	x		x	x	x	x		x	x
Beautification	x		x	x	x	x	x		x
Type of Area Treated									
Impervious Surface Play Area	x		x	x	x				x
Parking Lot		x			x		x		
Other				roof	roof	roof	back lot area	roof	side yard
Case Study Source	1	1	1	1	1	1	1	2	3

1 (http://www.portlandonline.com/Bes/index.cfm?c=44463)
2 (http://www.twdb.state.tx.us/iwt/rainwater/award0803.html#nogo)
3 (http://cfpub.epa.gov/npdes/greeninfrastructure/gicasestudies_specific.cfm?case_id=69)

Site Analysis Daniel Webster Elementary School, constructed in 1936 and refurbished in 1975, sits on the northern edge of the Islais Creek Watershed, adjacent to the Channel Basin. McKinley Elementary School, constructed in 1977, is located at the historic headwaters of Mission Creek in the Channel Basin Watershed **(Figure 6)**. Daniel Webster Elementary School has 174 enrolled students, and McKinley Elementary School has 255 enrolled students (SFUSD 2008).

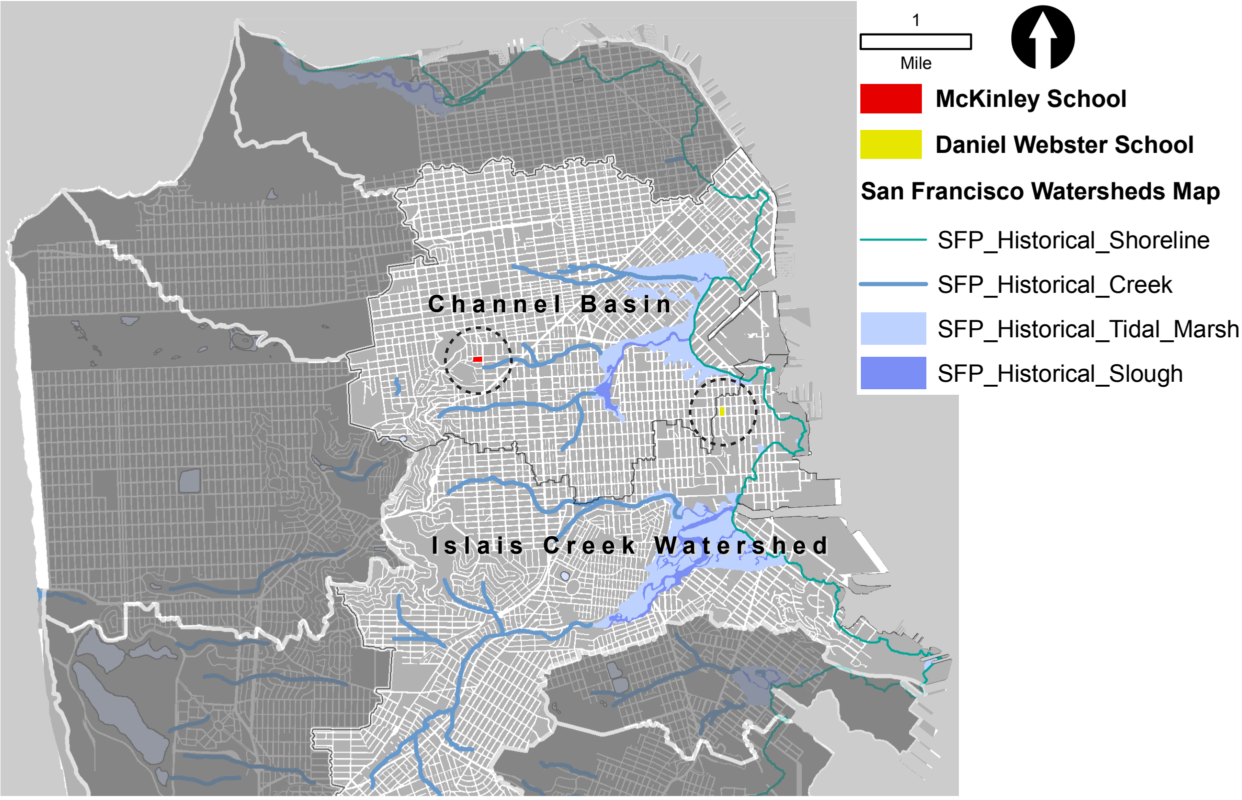


Figure 6. Watersheds map

Daniel Webster Elementary School is bounded by Missouri Street to the west, Texas Street to the east and 20th Street to the south, and single-family detached housing to the north in the Potrero Hill neighborhood. The site slopes from the north to the south. The campus navigates the slope with four terraces that culminate in a high retaining wall along 20th Street. The main entrance to the school is at Missouri Street. There is a large, central classroom building, a detached cafeteria building, an asphalt parking lot, several asphalt playgrounds, two portable classroom buildings for the preschool and some small garden spaces that include a few mature tree species, including Eucalyptus. The sidewalks along both Missouri Street and Texas Street were refurbished, with the assistance of Rebuilding Together San Francisco, to include planting areas with trees, vines, rock mulch and drought-tolerant plants. The drainage for the large, central classroom building appears to flow through downspouts that follow the stairwells that flank the north and south sides of the building. These areas adjacent to the stairwells may provide useful locations for the placement of future rainwater harvesting systems. The catch basins and asphalt play surface adjacent to the upper portable building of the preschool need refurbishment. The retaining wall along Texas Street and 20th Street also appears compromised, presumably due to site drainage issues **(Figure 7)**.

Figure 7. Daniel Webster Elementary School

McKinley Elementary School is bounded by 14th Street to the north, Henry Street to the south, Castro Street to the east and single-family detached residences to the west. The site slopes from the north to the southeast. The main entrance to the school is at 14th Street. The school building is large and multi-storied. Several classrooms have doors that open onto an asphalt playground, which includes a play structure, small, raised planter along the west edge of the playground and several raised planting beds against the south-side of the classroom building. A ramp (with a channel that drains the upper asphalt playground area) leads to a lower asphalt playground that has a large, stepped amphitheater, sloped planting areas to the west and north (the north planting area has a

California native garden), and a portable classroom to the north. The planting areas include mature Redwood trees. The playground also serves as a small parking lot. The area drains to a catch basin at the southwest corner that flows unto a hillside plating area. The slope at the south-side of the site is bordered by a retaining wall at Henry Street and is not accessible from the schoolyard but borders the ramp that connects the upper and lower playground. The vegetated slope is largely overgrown and not maintained. The adjacent sidewalks to the north, south and east have tree-planting areas, and the sidewalk to the east along Castro Street includes a raised planter adjacent to the school fence **(Figure 8)**.

Figure 8. McKinley Elementary School

McKinley School Design This design exercise aims to reduce impacts on the combined storm sewer system through a series of demonstration projects that either retain and infiltrate stormwater runoff at its source or slow the flow of stormwater runoff to the storm drain, as well as educate students about watershed awareness, water conservation, water pollution awareness, habitat value, food security, and reduction in heat island. McKinley Elementary School is located virtually at the headwaters of Mission Creek, an historic creek that was culverted and buried in the early development of the city. As an over-arching educational concept, this demonstration project should illustrate the different processes and sections of the watershed on the school campus: “School as Watershed,” **(Figures 9 and 10)**. [This is an alternative proposal to the Rebuilding Together San Francisco project that wants to demonstrate the “journey of San Francisco’s (drinking) water from the Sierra Mountains to the city through the Hetch Hetchy Valley,” which would employ a mural and vegetation from the Sierra’s ecosystems, (McKinley Greening Plan Community Challenge Grant Project Description).] In this paper’s “School as Watershed” proposal, the roof of the main building (DMA 1) and the playground (DMA 2), represent the upper watershed production zone. The water transfer across DMA 2 and down the stair runnel to DMA 3 symbolizes the middle watershed transfer condition. The rain garden surrounding the storm drain in DMA 3 demonstrates the deposition processes of the lower watershed. DMA 5 and the northern half of DMA 3 exemplify a tributary that settles into a “marsh” landscape parking lot. The rainwater collected from the roof of the portable building will be stored in a cistern that will irrigate the adjacent vegetable plots, creating a nexus between clean water, water conservation awareness, and food security. Soil conditions at the campus could not be assessed, and we did not have access to any prior soil reports.

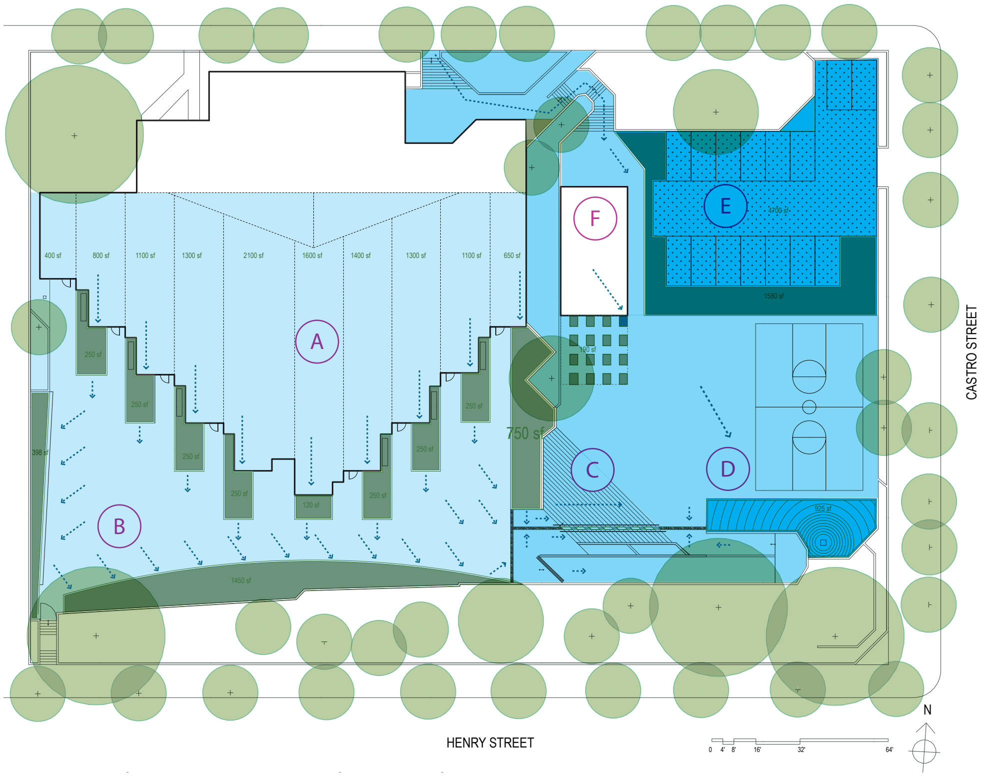
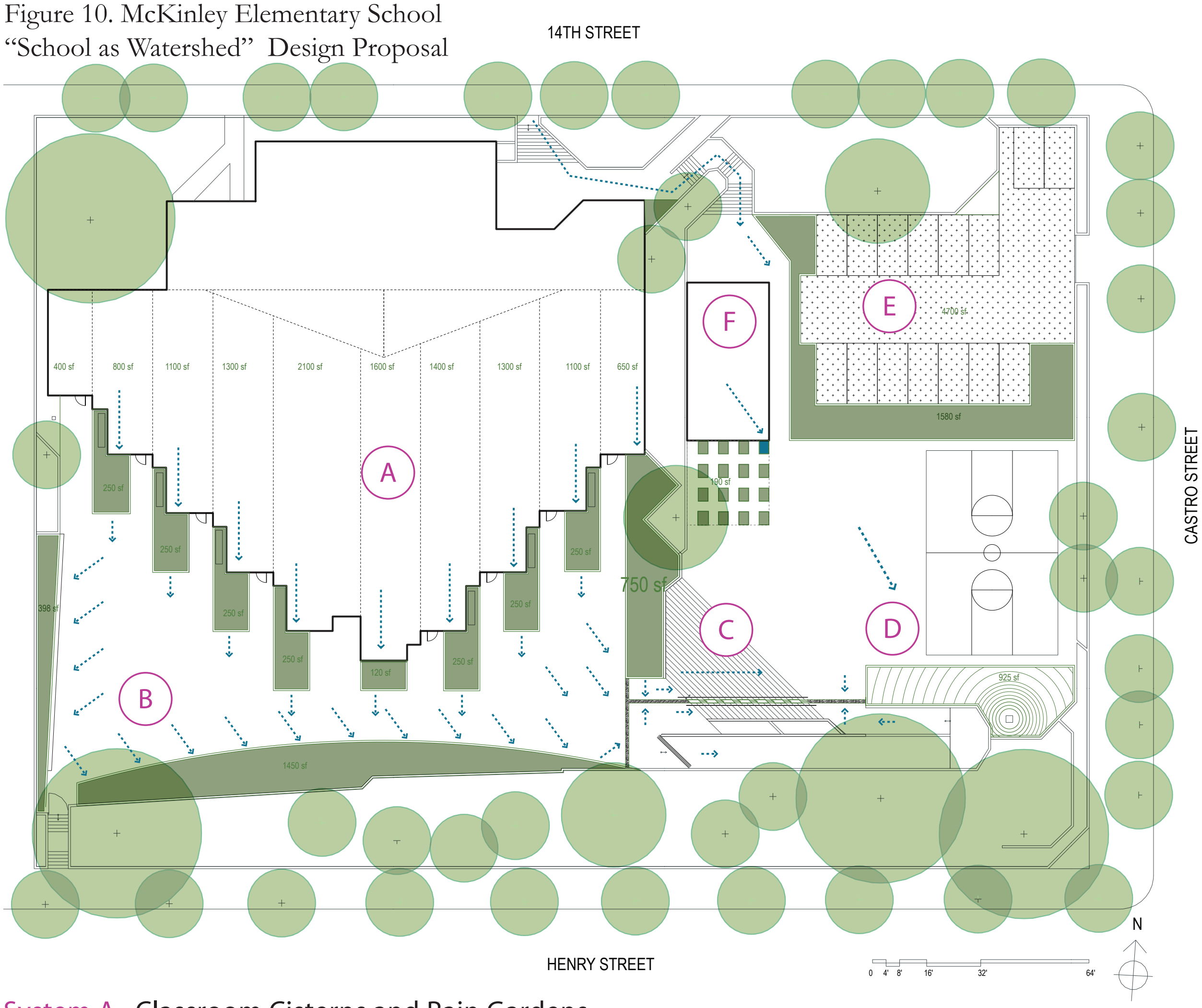


Figure 9. McKinley Elementary School “School as Watershed” Design Proposal

Figure 10. McKinley Elementary School
“School as Watershed” Design Proposal

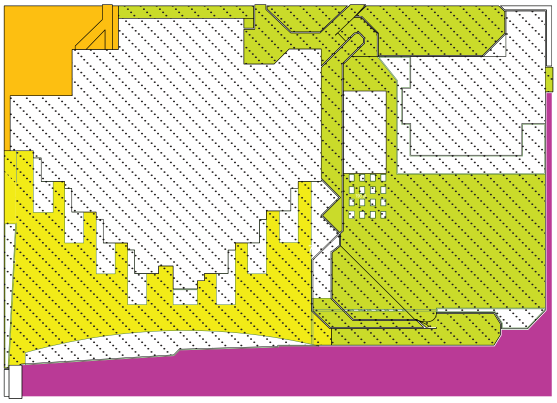


System A	Classroom Cisterns and Rain Gardens
System B	Vegetated Swale Flow-through Planter-Benches
System C	Stair Runnel/Folly
System D	Storm Drain Rain Garden
System E	The Tributary Parking Lot
System F	Vegetable Garden Cistern

☐ Impervious Surface removed from runoff load

▨ Areas treated on-site

Existing Drainage Management Areas



Designed Drainage Management Areas

SYSTEM A: Classroom Cisterns & Rain Gardens (DMA 1 to DMA 2)

Purpose Each classroom on the south side has its own rain barrel cistern and rain garden for classroom educational purposes. These can be planted thematically for different purposes, but should, according to the concept and the stormwater control sizing, include a drought tolerant plant palette that can withstand a wet period during the winter. The cistern contains minimal irrigation storage, but is sufficient for educational purposes. Since the rain barrels only hold 50 gallons, overflow is expected as part of the educational process, demonstrating the combined storm sewer overflow process. The overflow can be an artistic scupper at the top of the rain barrel.

Technologies Disconnected downspouts from the main roof fill eight 50-gallon cisterns. The roof will need to be re-plumbed for these downspout locations and crickets will need to be installed on the roof to redirect the water flow. The downspouts present an educative design opportunity for transporting the runoff from the roof to the cisterns **(Figures 11 to 13)**. Once the cisterns are full, the water overflows into the surrounding rain garden planters. If designed with infiltration into the soil below, assuming an infiltration rate of 0.5 inch per hour, this area will be sufficient with twelve inches of soil to accommodate the volume of water from its portion of the roof (SFPUC Draft Rain Garden Calculator). The largest area of the roof draining to a single cistern/garden is 1,600 square feet (sf) and is accommodated by a 222 sf rain garden. The planter's designed size is 250 sf for architectural alignment and will accommodate the flow. If the rain garden planters are built on top of the existing asphalt, then they will need to be able to overflow to the playground in DMA 2, where the water can flow towards vegetated swales, down the stair runnel, or into the existing storm drain as a last option.

Benefits

- Onsite treatment for 11,750 sf of the main roof-65% of roof area
- 2,620 sf of additional planting
- 400 gallon cistern capacity for irrigation

Figures 11, 12, 13. Examples of creative and educative solutions for disconnected downspouts in Portland, Oregon. (photos by Andrea Gaffney)

SYSTEM B: Vegetated Swale Flow-through Planter-Benches (DMA 2)

Purpose Two vegetated swales (or flow-through planters) will accept sheet flow from the playground area and infiltrate small volumes of stormwater runoff into the soil and vegetation, assuming a soil infiltration rate of 0.5 inches per hour. These areas will provide habitat and shade as well as seating space. Currently, the edges of the playground are lined with benches. These benches can be integrated into the swale design and contain educational elements about the habitat and species in the area and placed in the swales through painted, imbedded art or signage.

Technologies Two vegetated swales exceed the flow capacity requirements for the five-year storm at a five-minute concentration time. (Calculations are in the appendix). Assuming 0.15 for the *n* coefficient, we applied Manning's equation to calculate the design flow in the vegetated swale at 2.14 cubic feet per second (cfs). This flow exceeds the calculated storm flow of 0.715 cfs.

Benefits

- Habitat, improved water quality, reduced urban heat island, reduced peak flow.

SYSTEM C: Stair Runnel/Folly (DMA 2 to DMA 3)

Purpose/Technologies/Benefits This educative runnel conveys playground sheet flow, overflow from the vegetated swales and overflow from the classroom rain gardens down to the lower rain garden surrounding the storm drain. Cutting open a passageway between the upper playground and the top of the amphitheatre creates a new pedestrian and hydrologic connection. It also provides an opportunity for evincing watershed processes. The artistic runnel signifies the transport section of the watershed and functions by filling a series of stepped buckets that visibly overflow water in a stair-stepped manner. The bucket-scuppers, filled with rocks and vegetation, sit between the railings on the staircase so students can follow the water. The water feature connects to trench drains at the top and bottom of the stairs, to facilitate pedestrian mobility across the surfaces. The trench drains also provide an educational opportunity to display information **(Figures 14 and 15).**

Figures 14 and 15 Left: A trench drain and runnel along a staircase in Portland, Oregon. Right: an energy dissipation bucket that overflows to a runnel. (photos by Andrea Gaffney)

SYSTEM D: Storm Drain Rain Garden (DMA 3)

Purpose/Technologies/Benefits This system is a 925 sf rain garden that surrounds the storm drain. It can accommodate the runoff from the 8,800 sf of asphalt and concrete from DMA 3 that is not controlled by System E. The performance measure rainfall depth of 0.75 inch, produces 440 cf of water, which the rain garden can accommodate with less than six inches of standing water. After reaching this depth, it overflows into the storm drain. The additional volume from the upper playground exceeds the capacity of the rain garden, but the stair runnel should retain some of the water from DMA 2 so as not to scour the rain garden. The rain garden should infiltrate the water into the soil, so testing needs to establish feasibility **(Figure 16**).

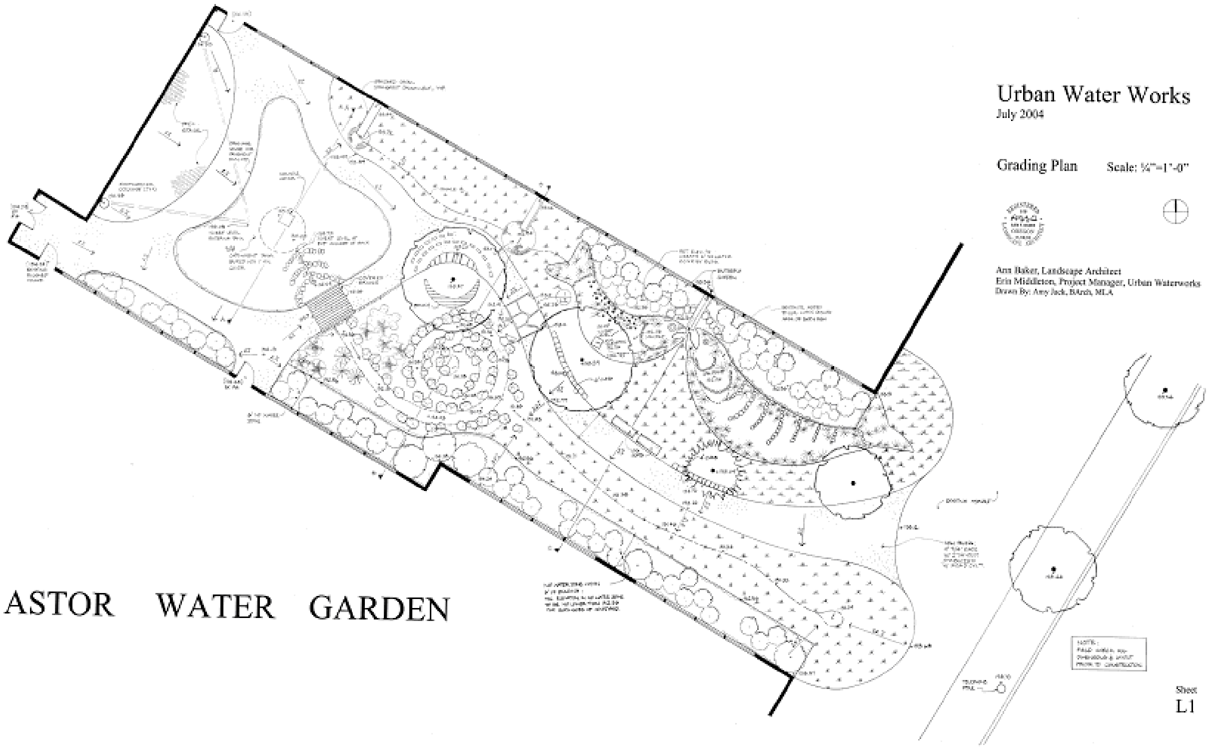


Figure 16. "Infiltration basins: The three infiltration basins are shallow depressions (typically 6 inches deep) that capture and infiltrate runoff. The two fish-shaped basins contain check dams to slow flow, and small areas are lightly lined with bentonite to temporarily retain some water. Channels provide for overflow between the two fish-shaped basins" (Astor Elementary School Water Garden).

SYSTEM E: The Tributary/Marsh Parking Lot (Northern Half of DMA 3 and DMA 5)

Purpose/Technologies/Benefits We relocated the portable classroom along the retaining wall adjacent to the main building, which allows for the parking to be reconfigured into a more compact design. The driving surface is permeable asphalt that infiltrates at a rate, which is self-treating for the design storm. The vegetated bio-infiltration swales around the parking lot retain and infiltrate the runoff from the adjacent areas of DMA 3 and the entirety of DMA 5. The swales contain check-dam berms planted with trees that provide shading for the parking and playground throughout the day. The trees can also be selected for habitat characteristics. The portable classroom relocation also reinforces a visual connection between the playground and the native plant garden along 14th Street. The native garden plant palette can be extended into the bio-filtration areas to expand the perceptual space of the garden.

SYSTEM F: Vegetable Garden Cistern (Portable Building in DMA 3)

Purpose/Technologies/Benefits Sixteen 3'x4' raised-bed vegetable plots are located adjacent to the portable classroom. Rainwater collected from the roof of the classroom is stored in a 1,500-gallon cistern. Assuming a crop coefficient of 0.8, this cistern provides enough irrigation for crops year-round. Ideally, the parents and the community would maintain the beds during the summer in exchange for free water and growing space. The Penn Alexander School in Philadelphia employs this model.

CONCLUSIONS

The stormwater runoff analysis and "School as Watershed" design for McKinley Elementary School follows the SFPUC's Stormwater Control Plan Steps up to step nine, "Develop an operations and maintenance plan," (Refer to Stormwater Control Plan steps in the Methods section). In step two, "Identify design and development goals" the goals need to meet both stormwater performance measures as well as educational objectives so that the design steps can incorporate the educational components. For steps five and six, "Select and locate green infrastructure technologies" and "Size treatment green infrastructure technologies," the decision about where to locate the projects should take the educational components into consideration. For example, the eight classrooms on the south side of the school all have direct access to the playground, so we located the downspout disconnection rain gardens in a distribution related to the classrooms. The classes can be responsible for these spaces and use them for different learning opportunities. When deciding what type of green infrastructure technologies to apply to school retrofit projects, consider the following comments: infiltration requires soil testing and groundwater location, which add costs unless this knowledge is available elsewhere; detention requires space and reuse of water; retention requires space and time for infiltration and/or drainage. Consider developing the educational goals into a parallel curriculum.

LID effectively minimizes and disconnects impervious surfaces, providing for both water quality and quantity control. In addition, LID often enhances environmental quality through increased habitat and open space. Stormwater management design, incorporating LID technology and sensitive siting practices, provides an opportunity to incorporate environmental education and watershed stewardship into the public school campus, resulting in educative and regenerative landscapes.

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Figure 17. California Irrigation Management Information System Reference Evapotranspiration Zones (WUCOLS).

APPENDIX A

Coefficient Calculations (WUCOLS) California Irrigation Management Information System (CIMIS) Reference Evapotranspiration Zone 2: Coastal Mixed Fog Area higher ET_0 than Zone 1. **(Figure 17)** map of CIMIS zones (California Department of Water Resources 2009).

Landscape Coefficient Factors determine irrigation demand based on species. The Landscape Coefficient (K_l) is equal to the multiplication of Species water demand (Ks) by Planting Density (K_d) by Microclimate (K_{mc}) and is written as $K_L = K_s \times K_d \times K_{mc}$. The drought tolerant plants were chosen from a list of Native Plants that the California Native Plant Society compiled for LID projects in San Francisco. The Mission Blue Butterfly habitat is adjacent to this site, so planting for this species would provide a potential habitat educational component. In order to promote water conservation, the plants selected for this stormwater project have a low water demand. Planting Density and Microclimate are assumed to be average. Therefore $K_L = 0.2 \times 1.0 \times 1.0 = 0.2$. A Crop Coefficient is substituted for the Landscape Coefficient where crops are used instead of vegetation plantings. The crop coefficient of 0.8 was used to calculate the vegetable garden irrigation demand. Once the crop choices are selected, the crop coefficient can be refined.

Vegetated Swale Calculations The vegetated swales are irregular in cross-section, so for the purposes of this calculation, a normalized cross-section was used. The entire swale is 120 feet long, but only 106 feet was used to calculate the flow because this is the portion that is eight feet wide. The swale is eight feet wide, with a 3-feet wide base and 3:1 sloping sides for an overall depth of ten inches. The cross-sectional surface area A is 4.583 sf. The wetted perimeter wp is 8.27 feet. We then calculated the hydraulic radius R to be 0.55 feet. The longitudinal slope s is 0.5%. Manning's n is assumed to be very rough at 0.15. Therefore flow is calculated as $Q=VA$ where $V=(1.49)\ (s^{0.5})(R^{0.67})/n$, so $Q=2.14$ cfs.

APPENDIX B

Applicability to the European Union Water Framework Directive (WFD)

Low Impact Design (LID) retrofit stormwater projects at schools can function in the European Union in a similar capacity as they might function in San Francisco, and have shown to function in Portland, Oregon. They can provide a venue for demonstration projects that lead to reduced combined sewer overflows and increased water quality, while also educating students and the surrounding communities, as well as providing other environmental and aesthetic benefits. LID provides a toolkit of solutions for different issues and sites. This flexibility lends itself to the decentralized nature of the WFD by providing choices without prescribing solutions. The WFD could support the development of LID or green infrastructure case studies, as suggested by the authors for the US EPA, to facilitate knowledge building amongst the member states.

California Irrigation Management Information System (CIMIS)
REFERENCE EVAPOTRANSPIRATION ZONES

Figure 17. California Irrigation Management Information System Reference Evapotranspiration Zones (WUCOLS).