Title

A Watershed Approach to Urban River Restoration: A Conceptual Restoration Plan for Sausal Creek

Authors

Ippolito, Teresa
Podolak, Kristen

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A WATERSHED APPROACH TO URBAN RIVER RESTORATION:

A CONCEPTUAL RESTORATION PLAN FOR SAUSAL CREEK

by Teresa Ippolito and Kristen Podolak

with contributions from Katie Jagt, Tiago Teixeira, Eike Flebbe

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ABSTRACT

There are many sources of urban river degradation from channel straightening and culverting for flood control and development, to point and non-point source pollution, and altered flow regimes due to urbanization and increased impervious surfaces. In this study, we focus on the hydrologic impact of impervious surfaces in an urban watershed in the East Bay area. We used the Water Framework Directive (WFD), recent legislation in Europe, to understand how a watershed approach and systematic waterbody characterization can guide restoration efforts. Specifically, we applied the WFD to Sausal Creek Watershed and developed a conceptual restoration plan that incorporates watershed-scale low impact designs (LID) to restore a natural flow regime and in-stream restoration to enhance the physical habitat. We modeled the change in runoff due to urbanization, and calculated the total area required to mitigate for stormwater. Our results show a nearly two-fold increase in peak flow from pre-development to today. To mitigate for increased impervious surfaces 38-57% of the basin would need to drain to LID sites. We compared the cost of LID with the cost of in-stream restoration and found in-stream restoration of the entire three mile channel would be equivalent to treating one-sixth of the watershed with LID. Finally, we developed a short-term and long-term program of measures to restore Sausal Creek.

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I. INTRODUCTION

PROBLEM STATEMENT

River restoration is often limited to reach-scale restoration projects that mitigate for symptoms rather than tackling the sources of degradation. Dominant methods to address river degradation include bank stabilization to prevent erosion, native plantings and gravel imports for fish spawning. (Bernhardt et al. 2005, Kondolf and Micheli 1995). While these projects may provide benefits, they are very expensive, and, constructed individually, often create segments of higher quality creek within an overall degraded system. In addition, these projects may or may not be sustainable considering the hydrologic processes remain degraded. While we recognize there are many sources of urban river degradation, in this study we focus on one source, the hydrologic impact of increased impervious surfaces in a watershed in the East Bay.

Considering the importance of watershed processes, restoration efforts should adopt a watershed-scale approach, in conjunction with reach-scale projects where necessary. The European Union recently introduced legislation, the Water Framework Directive (WFD), requiring countries to assess the status of their water bodies, prevent further deterioration, and enhance water quality wherever possible on a watershed-scale. The WFD provides guidelines for restoration through administrative reorganization, systematic data collection, economic valuation, and establishment of a program of measures. As compared to the US approach, the goals and structure of the WFD can promote a new paradigm in river restoration, one that prioritizes restoration efforts and funding (Table 1, WFD 2000).

Using the WFD process, we developed a conceptual restoration plan for the Sausal Creek Watershed using low impact designs (LID) across the watershed to decrease stormwater runoff. In conjunction, we also proposed in-stream projects necessary to enhance the physical habitat.

We modeled the change in watershed runoff volume due to urbanization and calculated the cost of treating the additional volume. Our conceptual restoration proposal for Sausal Creek provides a framework for restoring other creeks in the East Bay facing similar pressures.

URBANIZATION AND RIVER DEGRADATION

The effect of urbanization on river flow is well documented (Leopold, 1994; Ferguson and Suckling, 1990; Dunne and Leopold, 1978). Impervious surfaces such as rooftops, roads, and parking lots cause higher peak runoff during storms, and prevent precipitation from infiltrating into the soil resulting in lower baseflows during non-storm periods (Figure 1,2). Flow regimes shape physical conditions such as landform and connectivity in rivers by altering erosion, transportation, and deposition rates (Gurnell et al. 2007). Non-natural flow regimes alter physical conditions and adversely affect ecology in rivers and streams. Numerous studies highlight the relationship between urbanization, hydrologic processes, morphology and ecology (Gurnell 2007, Mitchell 2006, Walsh et al. 2005, Ladson 2004). It is also notable that runoff quantities affect water quality, as urban runoff is often untreated prior to entering rivers and streams (Mitchell 2006, Walsh et al. 2005). Increasing treatment through infiltration reduces the amount of un-treated runoff and plays a role in improving water quality.

LOW IMPACT DEVELOPMENT (LID)/SUSTAINABLE URBAN DESIGNS (SUDS): MITIGATING THE EFFECTS OF URBANIZATION

Low impact designs (LID), called Sustainable Urban Designs (SUDs) in Europe, may provide an option to address the hydrologic pressures imposed by urbanization. LID attempts to model nature and match predevelopment hydrology through infiltrating, evaporating, and detaining runoff (Hager 2006). Examples of LID technology include green roofs, infiltration swales, rain gardens, and permeable pavements (Figure 3). Rain gardens and bioretention basins are usually planted with native species that are wet- and dry- tolerant and generally range from about one-tenth to one-third the size of the total roof, yard, or driveway (Cramer 2006). Using these techniques across a watershed reduce diffuse source pollution and reduce the impact of increased peak flows (Walsh et al. 2005). Studies show that LID can improve water quality and has a positive effect on groundwater flows by increasing low flows in adjacent streams during dry periods (Kays 2006). There are several examples of cities adopting LID as a way to restore rivers. Specifically, in the United States, Portland, Seattle, Maryland and Massachusetts lead the way in retrofitting urban areas and requiring LID in new developments.

II. METHODS

LEARNING FROM THE WFD

We reviewed the WFD to understand its watershed approach to management and potential to guide restoration. We reviewed how the directive covers land-use effects on water quantity and river ecological health. We also searched for links in the WFD between water quantity and water quality in terms of diffuse water pollution.

APPLYING THE WFD TO SAUSAL CREEK

We used the WFD as a tool to design a conceptual restoration plan for Sausal Creek Watershed. We selected Sausal Creek because it is characteristic of creeks in the East Bay area—the headwaters are the least developed and urbanization increases downstream. Stream flow is characterized by high seasonal and annual variability typical of the Mediterranean-climate. The majority of rainfall occurs in the winter in a few large storms; and, over the summer, the base flow in the stream is low. Sausal Creek drains a 4.15 mi^2 basin in Oakland, California (Figure 4). The watershed is smaller than the 400-20,000 square mile basin scale used in the WFD (Grantham et al. 2008). We used this smaller scale because it is useful for the 'Friends of Sausal Creek' group working to restore the creek. It was also a manageable scale for the short timeframe of this project, and the approach can serve as a guideline for prioritizing restoration efforts in other East Bay creeks.

The first step in applying the WFD to Sausal Creek was to establish a competent administrative entity at the basin scale and identify water bodies within the basin. We established a hypothetical administrative entity at the basin scale, "East Bay Water District", to include all of the creeks in the East Bay region.

We then characterized the creek, assessed current environmental conditions in the creek and identified areas at risk of not meeting 'good ecological status'. Good ecological status is defined in the WFD as a condition in which "the values of the biological quality elements for the surface water body type show low levels of distortion resulting from human activity, but deviate only slightly from those normally associated with the surface water body type under undisturbed conditions" (Annex V WFD, 2000). Strictly following the WFD approach would require an in depth characterization and status analysis based on sufficient monitoring data. However, due to a lack of a unified ecological classification system and monitoring data, we performed a risk assessment instead of determining the status of the creek. We relied on our observations and past studies to determine whether each of the three watersheds was "at risk" of not meeting a good ecological status and assigned a projected status and goal for each watershed.

Finally, we analyzed the pressures and impacts throughout the watershed and, particularly, focused our program of measures on how to mitigate the impact of urban areas on the natural flow regime.

MODELING THE HYDROMORPHOLOGIC IMPACT OF URBANIZATION

To quantify the hydromorphologic impact of urban areas, we calculated the pre-development and current hydrologic conditions of the Sausal Creek Watershed using the Rational Method (Q=CIA). Gilbreath et al. used this method in their study of best management plans for urban runoff in the Upper Laje, Portugal (Gilbraeth et al., 2005).

To calculate the peak flow (Q) we used GIS layers from the City of Oakland and digitized soil maps to determine the cover factor (C). We first divided the basin into individual areas (Ai), on the scale of 5 -170 acres. We defined each area by its unique combination of soil, existing land use, and percent impervious cover, which we estimated from satellite images (Table 4 and 5)(Welch, 1981; Google Earth). We compared these estimates of impervious cover to values from past studies (Lowe 1998, Lacan 1999). The pre-developed condition was assumed to be 100 percent-undeveloped land. From these values and the average slopes in each parcel we assigned a runoff coefficient to each parcel and calculated a weighted C value ($\sum$CiAi/Atot).

We calculated the time of concentration ($Tc = L^{1.15} / 7700H^{0.38}$) to get the rainfall intensity (I). We averaged the mean annual precipitation for the basin from the isohyetal map (Figure 10). Next, we calculated H, the difference in elevation between the basin outlet and the most distant ridge (ft). Based on the Tc and mean annual precipitation we looked up the rainfall intensity (I) using Table 4 from Rantz 1971. We calculated peak flow for the 2, 5, 10, 25, 50, and 100-year storms. We multiplied the peak flow by the duration of the storm to go from flow to flow volume (cubic feet per second to cubic feet). We calculated the difference in flow volume, or the amount of water that has been taken out of the subsurface and shallow groundwater table.

RESTORATION REQUIRES LID AND IN-STREAM PROJECTS

Based on the difference in flow volume between current and pre-development, or the treatment volume, we calculated the amount of land in the watershed that would need to be treated with LID to restore the natural flow regime. We use the equation $\Delta V=CA_{tot}R_d$,where ΔV is the change in runoff volume from pre-development to existing condition, C is the cover factor chosen for LID, A_{tot} is the area of LID providing treatment, and R_d is the design storm event for which treatment is provided. We used the 10-year, 2-hour storm event, with a depth of 1 inch, as the R_d, and a cover factor of 1 for proposed LID. We solved the equation for area, the area to treat, and calculated the percent of the drainage basin this treatment area represents. To fully appreciate the difference this volume of water has on creek base flows, further calculations would be necessary to model the evapotranspiration and subsurface flow to the creek. We did not have the time or resources to complete this analysis.

We used data from four LID projects in Washington to get a cost estimate and treatment effectiveness (Craig Doberstein personal communication). Our economic analysis, a requirement of the WFD, compared the cost of LID with the cost of in-stream restoration. The main objective of the economic analysis, a requirement of the WFD, was to calculate and compare the cost of LID with the cost of in-stream restoration and to give an idea of what it would take to completely restore Sausal Creek's hydromorphology using both in–channel modifications to restore channel morphology and LID stormwater management strategies to restore the creek's hydrology. From this analysis and guided by the WFD, we also developed a short-term and long-term program of measures to restore Sausal Creek that incorporates both LID and in-stream restoration.

III. RESULTS AND DISCUSSION

LEARNING FROM THE WFD

The WFD encourages watershed-scale river management and restoration. The goal is for most of Europe's water to achieve good "ecological status" by 2015 (WFD 2000). The focus is on the ecological and chemical quality of surface waters, but it also covers groundwater. The successful achievement of the WFD's goals will depend on the effective integration of land and water management and planning practices. The WFD adopts a watershed management approach to promote long-term river health by addressing the causes of degradation (WFD 2000).

The problem of urbanization and its effects on flow regime is an issue of land use and water quantity. Goals expressed within the language of the WFD do provide room for water quantity to be addressed. For example, Item 25 in the WFD states, "where relevant for the purpose of the environmental protection, quantity should be established." In addition, Item 34 states that "there is a need for a greater integration of qualitative and quantitative aspects of both surface waters and groundwaters, taking into account the natural flow conditions of water within the hydrological cycle." This language is broad; however, it does promote the inclusion of water quantity into the analysis of river and stream status.

Water quality, as it relates to water quantity, is also addressed in Item 19, "Control of quantity is an ancillary element in securing good water quality, and therefore measures on quantity, serving the objective of ensuring good quality should be established." This language provides clear direction in terms of diffuse pollution reduction, which could be mitigated by increased use of LID across the watershed. In addition, the following articles in the WFD provide further direction in terms of diffuse pollution:

Article II: Specifies the need to identify and quantify diffuse pollution sources.
Article IV and V: Require estimates and a program of measures for monitoring and control of diffuse sources within future Regional Basin Management Plans.
Article XI: Program of measures to address nonpoint source pollution

APPLYING THE WFD TO SAUSAL CREEK

In characterizing Sausal Creek, we identified two water body types: surface stream and a reservoir (Appendix B). We only addressed the surface water due to the timeframe of the project. We further characterized the surface water by separating it into three sections with similar environmental conditions based on past studies: the Palo Seco Reach, the Middle Reach, and the Lower Reach (Figure 5).

In assessing the current conditions of the creek, the Palo Seco Reach, located within Joaquin Miller Park is the highest quality segment of the creek, having the lowest amount of surrounding urbanization and the least amount of pressures and impacts (Figure 6 and Appendix A). The Middle Reach, from Shepard Creek Canyon through Dimond Park, is moderate in quality, with a mix of pressures and impacts including culverts and drop structures and an 825 ft restored portion of the creek (Eagon and Largent 2005)(Figure 6). We observed rainbow trout in pools below drop structures in this reach. The Lower Reach is the lowest quality portion of the creek and sustains the greatest impacts; it exists either as a rectangular stabilized channel or as a culverted underground channel. General pressures are listed in Table 2.

Based on our risk assessment and pressures and impacts analysis, we projected that the Palo Seco and middle reaches are likely in moderate ecological status and have the potential to meet a ‘good ecological status’. In contrast, we projected the conditions and pressures on the Lower Reach are likely sufficient to characterize the reach as a ‘heavily modified water body’ with moderate ecological potential, the objective being to reach good ecological potential as opposed to good ecological status (WFD 2000). The characterization, pressures and impacts, and projected status of each segment is included in Table 3.

MODELING THE HYDROMORPHOLOGIC IMPACT OF URBANIZATION

The increase in peak flow from pre-development to current conditions was nearly two-fold (Figure 12). The weighted cover factor was 0.35 for pre-development and 0.69 for current conditions (Appendix C). The difference between pre-development and current peak flow ranged from approximately 300-700 cubic feet per second. We recognize that this hydrologic analysis is incomplete for the purposes of restoring Sausal Creek as it does not consider the timing of flows in the creek or subsurface flow.

RESTORATION REQUIRES LID AND IN-STREAM PROJECTS

The percent of the basin required to treat a ten-year peak flow difference in volume between current and pre-development is 30% (Appendix C). We assumed that the primary LID technology would be rain gardens and bioswales and that these facilities had the ability to retain nearly 100 percent of the runoff from the contributing areas like was seen at the SEA-Streets project in Seattle, WA (Horner et al. 2002). In making this assumption, we must consider this paper's conclusion that states these high retention abilities can only be correlated with LID technologies that are installed as on-site treatment for one or more lots and not as an end-of-pipe solution that treats many blocks in one location.

The cost of LID for 30% of the basin ranged from $16 to $166 million dollars for the low and mid cost estimates (Table 6). In comparison the cost of in-stream restoration for the entire creek was less expensive, roughly $11 million.

We pinpointed areas in the watershed to utilize LID and created a phased restoration plan (Figure 12). Initially, designs should include LID in areas with highly permeable soils in the middle and upper watershed, focused on detaining runoff where stormdrains meet the creek and cause erosion problems. Eventually, designs should include LID throughout the entire watershed along with in-stream restoration measures. Once LID mitigates for increased peak flows, in-stream projects will be more successful in terms of long-term ecological restoration. These in-stream measures could include (Figure 13):

- Removing point source pollution such as the sewer pipe in the stream
- Isolating erosion control measures
- Removing concrete structures in the middle reach to improve fish habitat
- Realigning the channelized sections of the Shepherd Canyon tributary
- Creating parkland adjacent to the creek in the middle and upper reaches where current parks are not connected
- Building support to daylight the lower reaches of the creek, which would require huge costs and a long timeframe.

IV. CONCLUSION

In the process of applying the WFD to Sausal Creek, we identified opportunities to improve the sustainable management of creeks in the East Bay. As in Europe, one of the main pressures facing surface water bodies in the East Bay is hydrologic alteration, or changes to the natural flow regime and channel morphology. We focused on the impact of urbanization and showed how increased impervious surfaces alter the flow, especially in the winter months. To restore Sausal Creek requires a watershed approach that incorporates both low impact development and in-stream restoration.

Currently, there is no administrative entity responsible for overseeing this East Bay region as an integrated whole. River restoration is ad-hoc with efforts driven by local 'Friends of' groups. Even the largest scale group 'Friends of Five Creeks' does not adopt a coherent basin-scale management approach. Requirements to meet non-point source Total Maximum Daily Loads (tmdl) levels under the Clean Water Act fall to individual cities, which respond by using Best Management Practices. This approach also fails to address water pollution at a basin scale and results in individual reactionary responses as opposed to a prioritized land use and water planning response. The task of rearranging administrative jurisdictions and responsibilities may seem daunting, but the long-term result could be better stream health.

Another opportunity to improve restoration efforts in East Bay creeks would be to create a systematic water body characterization and status scheme similar to the WFD. This data would help prioritize restoration efforts within Sausal Creek Watershed and on the broader scale within the East Bay Water District. In which case, Sausal Creek would be compared with other East Bay Creeks and would compete for restoration funds. We struggled with a lack of systematic data on Sausal Creek and would face a similar problem when addressing other creeks in the East Bay. However, the EU countries have also struggled with insufficient data: about 30% of surface water bodies and 45% of ground water resources lack sufficient data (Grantham et al. 2008). The transparency of the economic valuation in the WFD would probably force river restoration in the East Bay to be more systematic. Finally, the WFD requirement to establish a program of measures leaves the design of the measures up to the individual countries. Although the cost of LID was more expensive than in-stream restoration, it addresses the source of degradation while in-stream measures improve the physical habitat but do not mitigate for the effect of urbanization in the long term.

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Table 1: Differences between the WFD and US Approaches to River Restoration

Differences	WFD	US
Approach	Watershed and reach	Mostly reach
Focus	Hydromorphology, Ecology, Cost Benefit Analysis	Reach and riparian corridor, fish passage and habitat
Timing	Advanced planning and reactionary	Mostly reactionary
Incentive to start	Required by government	Agency funding or grass roots, Cities and Clean Water Act
Incentive to finish	Fines	Clean Water Act requirements
Methods	systematic data collection and review process, reference condition based on exisiting high quality rivers within specific basin	no defined process and no clear reference condition
Monitoring	Required	Not always required or completed due to funding/resources
Community involvement	Required by methods	Often the incentive for restoration
Goals	To reach ‘good ecological status’ or ‘good ecological potential’ by 2015	No single defined goal

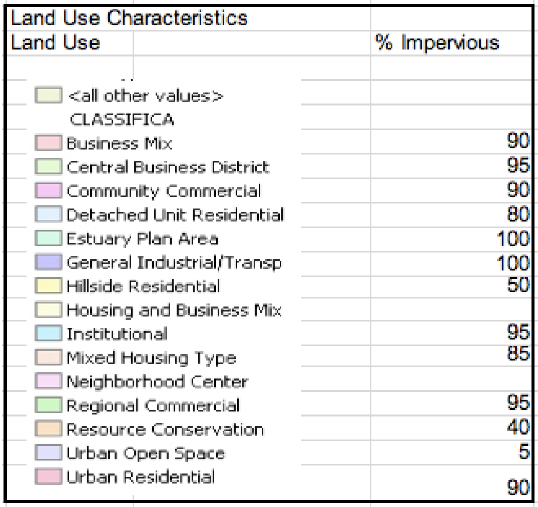
Table 2: Pressures Table

Pressures	
Water Quality	Diffuse and Point Source Pollution
Biology	Physical Barriers (Checkdams) and Invasive Species
Hydromorphology	Impervious Surfaces, Hillslope Erosion, and Physical Barriers to water flow (Checkdams)

Table 3: WFD Characterization and Projected Status Table

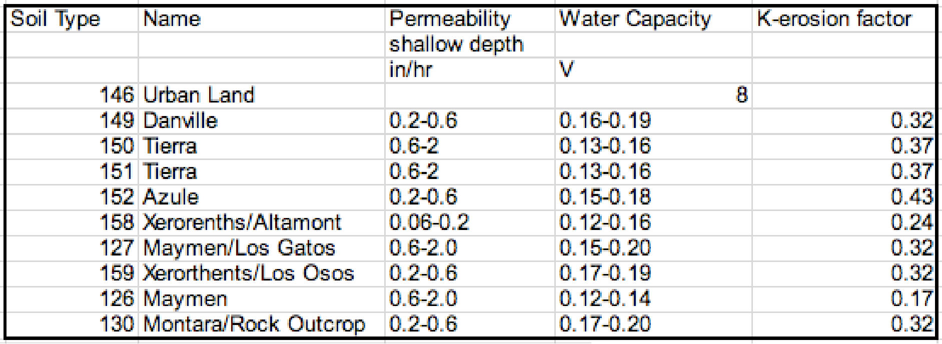
Watershed	General Description of Pressures/Impacts and Existing Condition	Projected Status	Projected Goal
Palo Seco	Highest quality, lowest amount of urbanization, some natural bank erosion, incision, and some invasives **Within Joaquin Miller Park:** Park land cover **Outside the park:** Single-family residences are dominant land cover	Moderate Ecological Condition	Good Ecologic Potential
Middle	Single-family residences are dominant land cover for this entire section **Shepard Creek Canyon through Dimond Park:** Moderate Quality, Some degradation- culverted, bank erosion, incision, remnant Works Progress Administration concrete drop structures from the 1930s, point source impacts from sewer line, high invasive species **In-Stream Restoration Area:** $400,000, 825 linear ft of channel modifications and planting (2002 by the Restoration Design Group), less erosion and fewer invasive species	Moderate Ecological Condition	Good Ecologic Potential
Lower	Sustains the greatest pressures and is heavily urbanized with industrial, commercial, and residential land cover. The underground culvert, or mouth of the creek, flows into a dredged tidal canal.	Heavily Modified Water Body - Moderate Ecologic Potential	Good Ecologic Potential

Table 4: Land Use Characteristics and % Impervious Cover



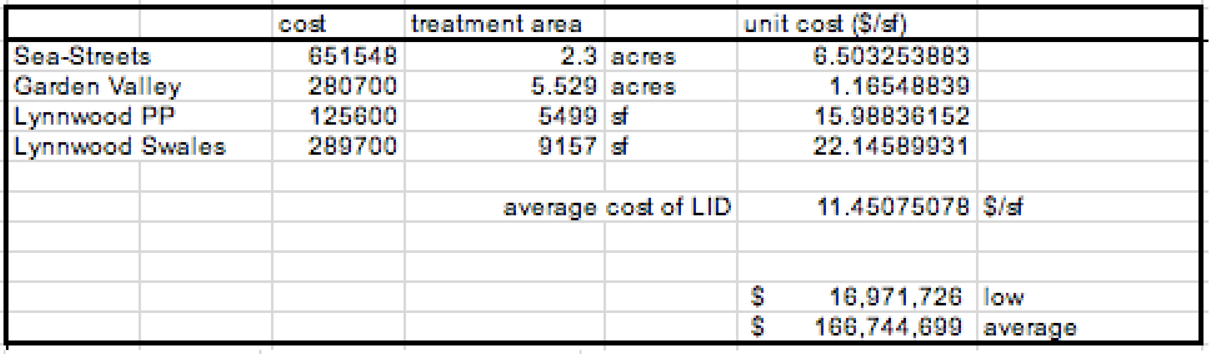
Land Use Characteristics	
Land Use	% Impervious
▭ <all other values>	
CLASSIFICA	
▭ Business Mix	90
▭ Central Business District	95
▭ Community Commercial	90
▭ Detached Unit Residential	80
▭ Estuary Plan Area	100
▭ General Industrial/Transp	100
▭ Hillside Residential	50
▭ Housing and Business Mix	
▭ Institutional	95
▭ Mixed Housing Type	85
▭ Neighborhood Center	
▭ Regional Commercial	95
▭ Resource Conservation	40
▭ Urban Open Space	5
▭ Urban Residential	90

Table 5: Soil Type and Permeability

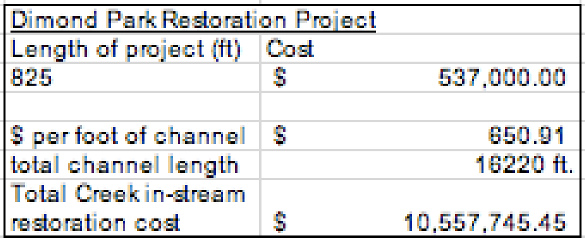


Soil Type	Name	Permeability shallow depth in/hr	Water Capacity V	K-erosion factor
146	Urban Land		8	
149	Danville	0.2-0.6	0.16-0.19	0.32
150	Tierra	0.6-2	0.13-0.16	0.37
151	Tierra	0.6-2	0.13-0.16	0.37
152	Azule	0.2-0.6	0.15-0.18	0.43
158	Xerorenths/Altamont	0.06-0.2	0.12-0.16	0.24
127	Maymen/Los Gatos	0.6-2.0	0.15-0.20	0.32
159	Xerorthents/Los Osos	0.2-0.6	0.17-0.19	0.32
126	Maymen	0.6-2.0	0.12-0.14	0.17
130	Montara/Rock Outcrop	0.2-0.6	0.17-0.20	0.32

Table 6. Economic Analysis: Economics of LID Compared to In-Stream Restoration.



	cost	treatment area		unit cost ($/sf)	
Sea-Streets	651548	2.3	acres	6.503253883	
Garden Valley	280700	5.529	acres	1.16548839	
Lynnwood PP	125600	5499	sf	15.98836152	
Lynnwood Swales	289700	9157	sf	22.14589931	
		average cost of LID		11.45075078	$/sf
				$ 16,971,726	low
				$ 166,744,699	average



Dimond Park Restoration Project	
Length of project (ft)	Cost
825	$ 537,000.00
$ per foot of channel	$ 650.91
total channel length	16220 ft.
Total Creek in-stream restoration cost	$ 10,557,745.45

Figure 1. Urbanizations impact on runoff (Lake Superior Duluth Streams).

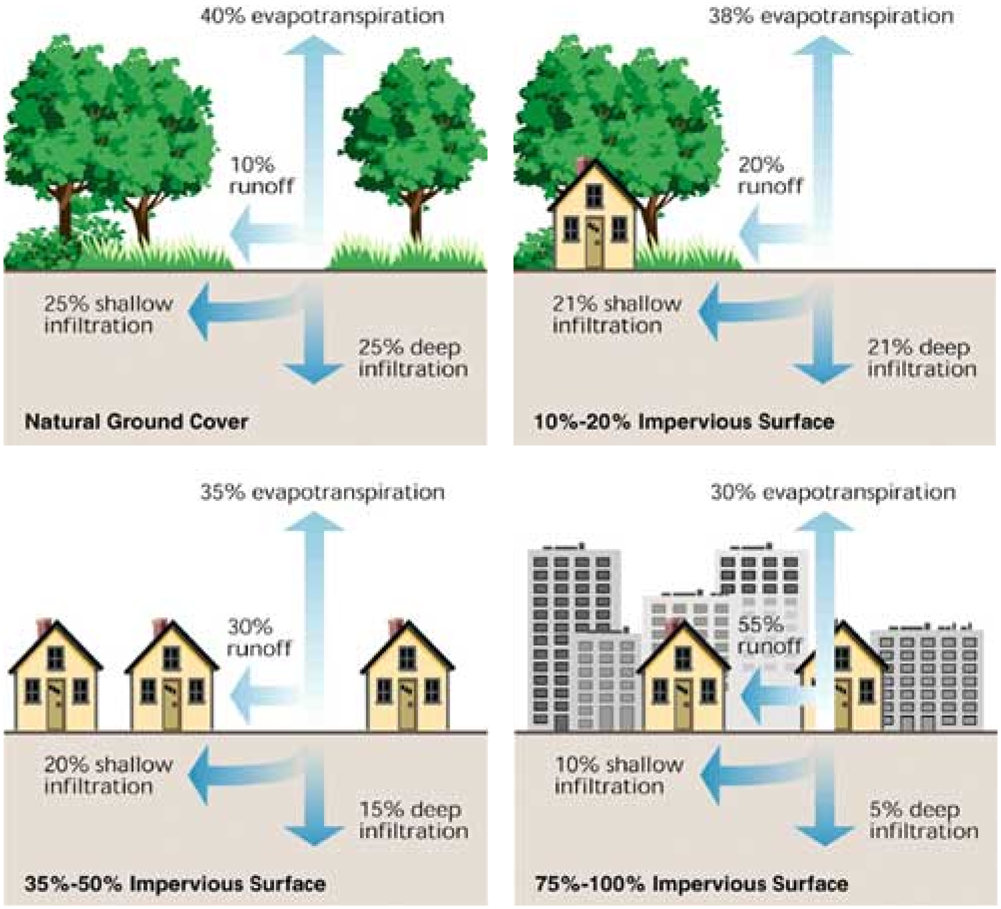


Figure 2. Pre- and post- urbanization hydrograph (Ritter 2006).

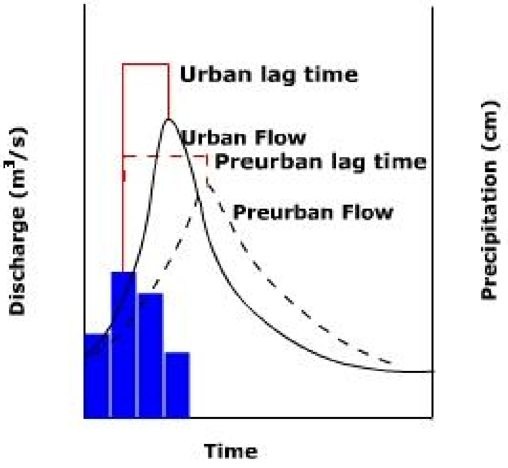


Figure 3. These photos show examples of LID and SUDS (Arlington County Virginia Government 2006, Rain Gardens New Approaches to Old Challenge, Water Sensitive Urban Design in the Sydney Region 2002-2006)

Green Roof Rain Garden

Bioretention

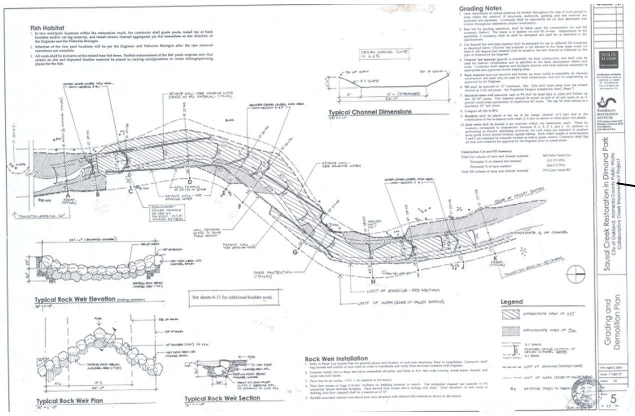
Figure 4. Location Map (Sausal Creek Watershed in bold).

Figure 5. Sausal Creek Watershed (Jane Wardani)

Figure 6. Sausal Creek Characterization

Sausal Creek Middle Reach

Sausal Creek Middle Reach Restoration



Sausal Creek Lower Reach

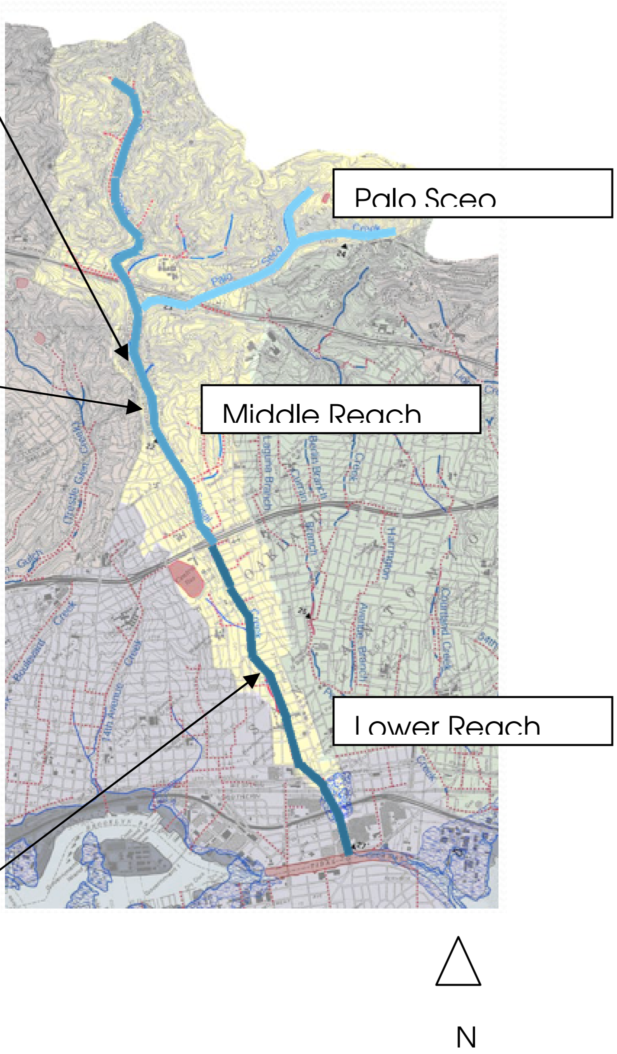
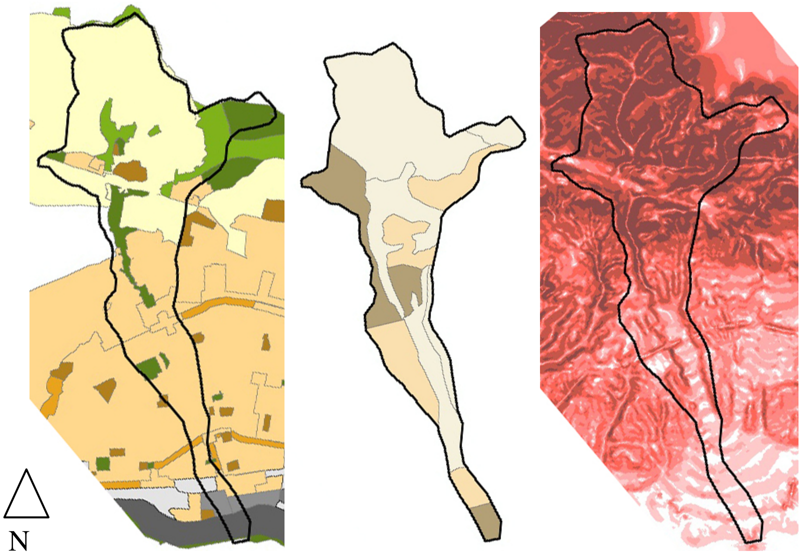


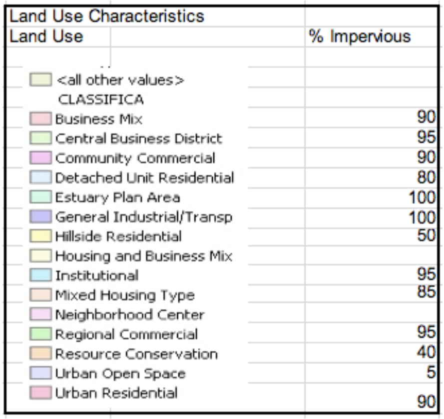
Figure 7. Pressures Map

Figure 8. Pressures Photos (sewer lines within the creek, bank erosion, and drop structures blocking fish passage)

Figure 9. Model Variables



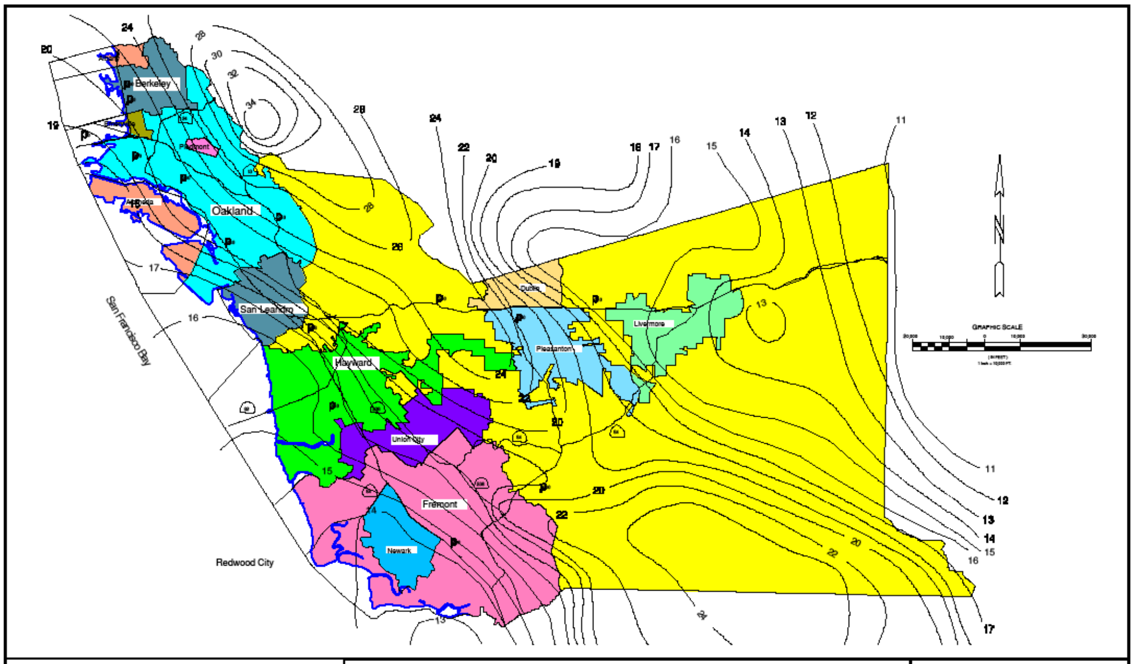
Land Use Soil Slope



Land Use Characteristics Land Use	% Impervious
⬜ <all other values> CLASSIFICA	
🟥 Business Mix	90
🟩 Central Business District	95
🟪 Community Commercial	90
🟦 Detached Unit Residential	80
🟩 Estuary Plan Area	100
🟪 General Industrial/Transp	100
🟨 Hillside Residential	50
🟨 Housing and Business Mix	
🟦 Institutional	95
🟧 Mixed Housing Type	85
🟪 Neighborhood Center	
🟩 Regional Commercial	95
🟧 Resource Conservation	40
🟪 Urban Open Space	5
🟥 Urban Residential	90

Impervious Cover

Figure 10. Mean Annual Precipitation



ALAMEDA COUNTY FLOOD CONTROL AND WATER CONSERVATION DISTRICT	MEAN ANNUAL PRECIPITATION (VALUES IN INCHES)	DATE: MAY 2003 **ATTACHMENT-6**

Figure 11. Model Results, Peak flow pre and post development comparison

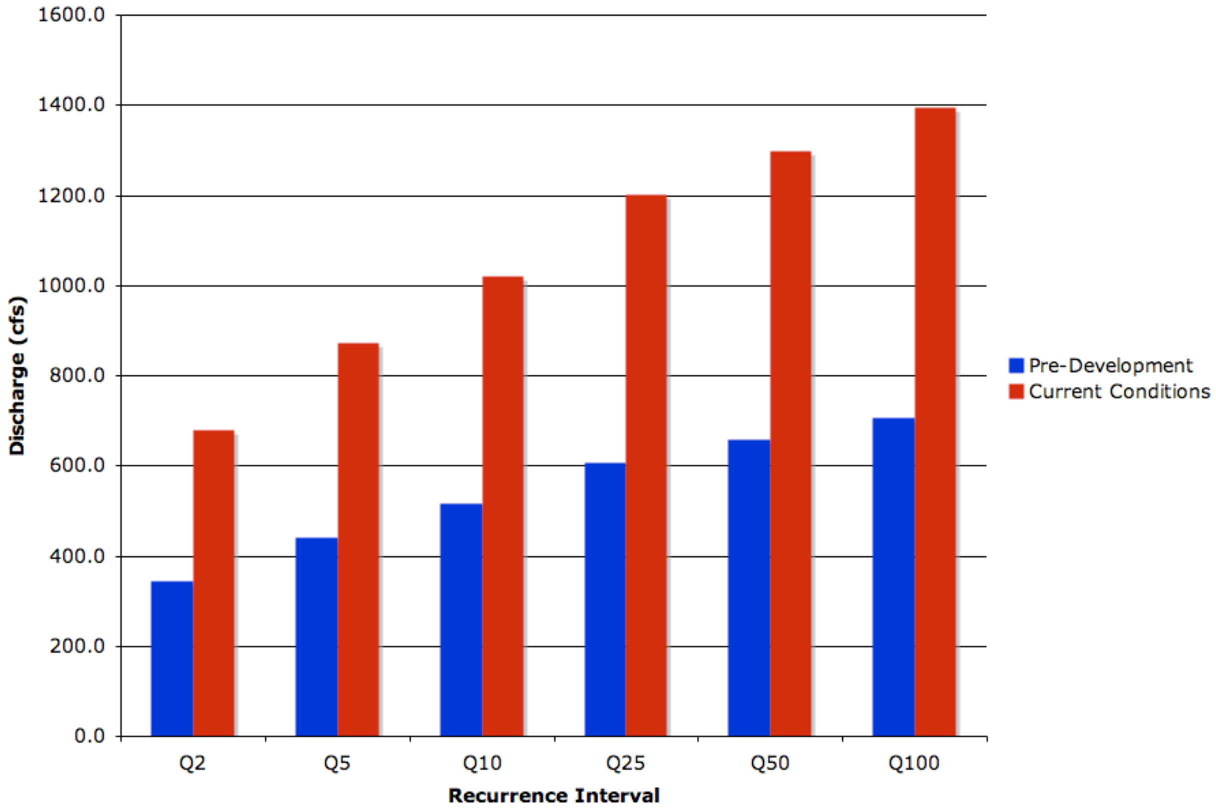
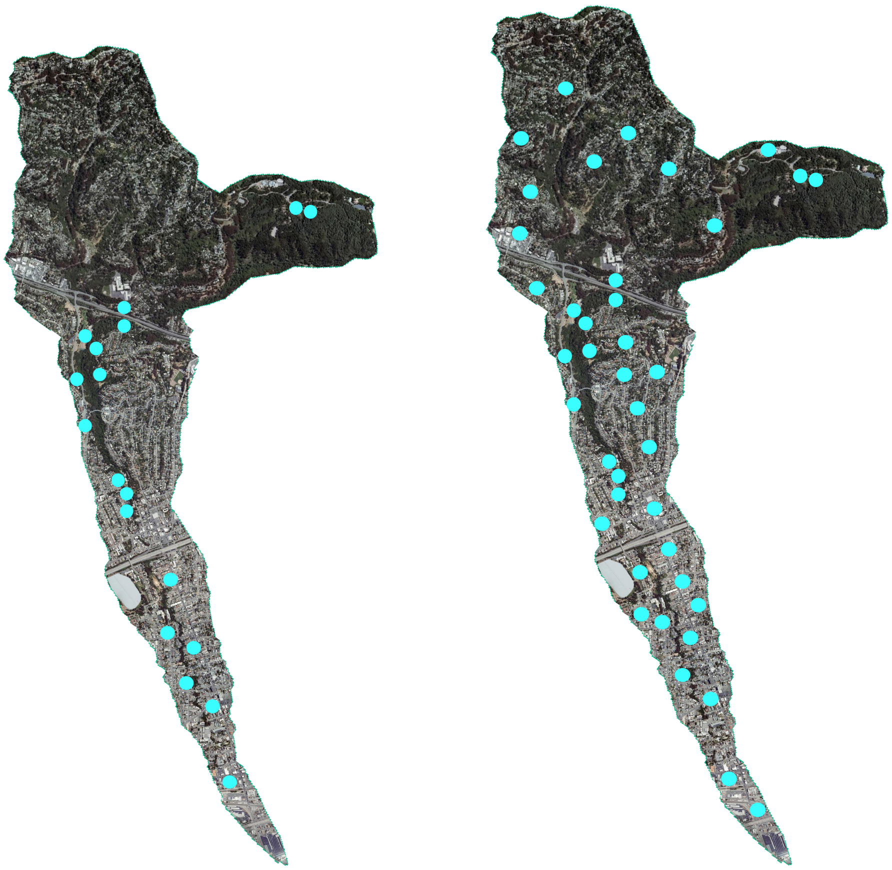


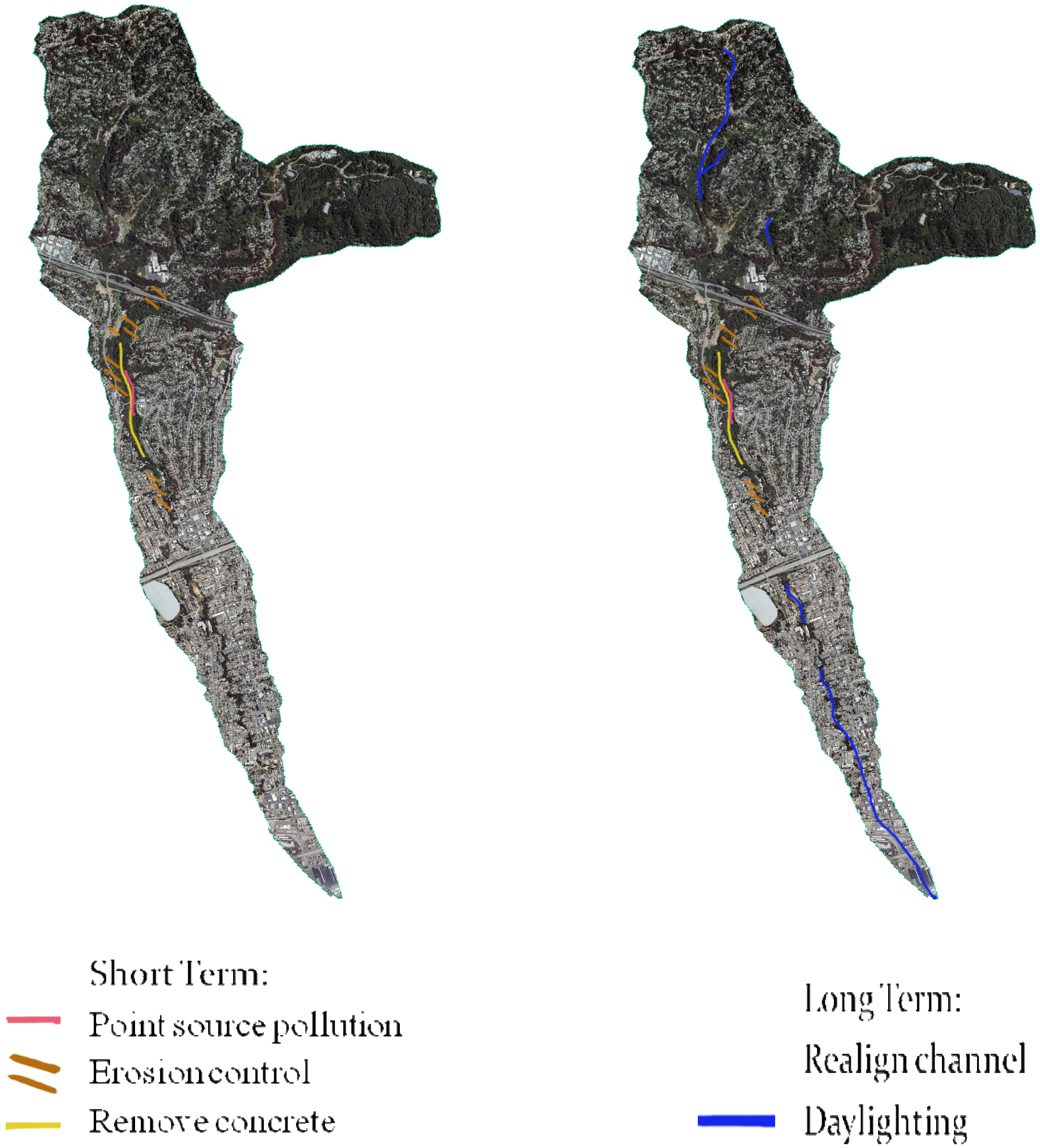
Figure 12. Program of Measures: Watershed-Scale Implementation of LID



Short Term:
Stormwater Drains
Downtown areas

Long Term:
LID throughout
watershed

Figure 13. Program of Measures: In-stream Projects



APPENDIX A

PRESSURES SPREADSHEET

1.1.1 Rivers	**Palo Seco Creek**	**Shepard Creek and Dimond Canyon**	**Lower Sausal Creek**
General	Minimal urbanization adjacent to creek, Impermeable no more than 50%, Primarily public park land – Joaquin Miller Park (second growth redwood grove), Virtually entire drainage is undeveloped and located within park, No culvert or erosion control within this portion	Culverted through Shepard Creek, Undeveloped land in canyon bottom of Dimond Canyon, Heavily urbanized along rims, Erosion control, checkdams and concrete embankments (1930's and 1940's)	Heavily urbanized, Creek concrete retaining walls and sandbags lining the banks, Heavily culverted
Biological Factors			
Composition and Abundance of Aquatic flora		Considerable Algae present	
Composition and abundance of benthic invertebrate fauna	Taxa Richness (14), Shannon Diversity (7.66), % Dominant Taxa (31.7), HBI (3.49), Jaccard Coeff (1), Stoneflies present (disturbance sensitive)	Taxa Richness (7), Shannon Diversity (3.38), % Dominant Taxa (46.4), HBI (2.52), Jaccard Coeff (0.3125), Stoneflies nearly absent (disturbance sensitive)	Taxa Richness (8), Shannon Diversity (2.61), % Dominant Taxa (72.1), HBI (3.18), Jaccard Coeff (0.2222), Stoneflies nearly absent (disturbance sensitive)
Composition, abundance, and age structure of fish Fauna		Rainbow trout in pool formed by concrete debris and checkdams	
Hydromorphological elements supporting the biological elements			
Hydrologic			
Quantity and dynamic of flow	Current Meter $7x10^{-3}$ m^3/sec	Current Meter 0.055 m^3/sec, flowing water, some pools deep enough to support rainbow trout, check dams pooling water and creating scour pools	Current Meter 0.0496 m^3/sec, flowing water through essentially a box channel or culvert
Connection to groundwater flow			
River Continuity			
-			
Morphological Conditions			
River depth and width variation	pool riffle sequence pronounced, deeper pools are largely absent, notable depth variation	Pool riffle sequence is not well defined, well defined in restoration area, minimal depth variation, depth variation observed in restoration area and in areas where pools were created by checkdams	channelized, incision and bank erosion, pool riffle sequence absent, some depth variation
Structure and substrate of river bed	Small cobbles and dark, loamy soil form in-stream substrate, large woody debris is present in channel, human-induced modifications include culvert downstream, trash rack and foorbridge joining public walkway, Pebble Count (Median Size 9.5, Mean Size 20.36)	largely mineral material with less plant litter, Pebble Count (Median Size 19.3, Mean Size 26.88), area contained concrete debris, many banks reinforced concrete and sandbags and stormdrain outlets	Instream substrate is entirely mineral, large woody debris present, but suspended above water (not servicing as habitat as warm and dry), , Pebble Count (Median Size 27.3, Mean Size 39.02), most banks reinforced concrete/sandbags
Structure of the riparian zone	second-growth redwood forests providing excellent canopy cover (>95%), great bank diversity, entirely shades, leaf litter covers the bank and stream bed, largely native plant species, 20% English Ivy in study area, to little light to support brambles	Canopy cover ~ 40% in study area,minimal bank diversity, stream is well lit, native riparian vegetation is minimal (higher in restoration area), leaf litter input likely minimal (higher in restoration area)	Canopy cover less than 20%, some woody debris, less than 1/10 water surface shaded, less than 1/3 bank supports riparian vegetation, minimal bank diversity
Chemical and Physico-chemical elements supporting the biological elements			
	Water Temp ^{o}C 10.7, PH 6.9, DO mg/L 10.5, % Oxygen Saturation 99, Conductivity mS 1.50 no green algae, cyanobacteria or submerged macrophytes observed in study area	Water Temp ^{o}C 12.3, PH 7.8, DO mg/L 10.4, % Oxygen Saturation 100, Conductivity mS 0.90	Water Temp ^{o}C 11.5, PH 8.0, DO mg/L 11.1, % Oxygen Saturation 105, Conductivity mS 0.7
References	**Igor Lacan et al 1999, Additional notes from site visit observations, Bathelder**		

APPENDIX B

WFD CHARACTERIZATION AND PROJECTED STATUS OF SAUSAL CREEK WATERSHED

PALO SECO WATERSHED

1.1 Characterization

(i) Rivers
(ii) System A used
(iii)NA
(iv)NA
(v) Artificial/HMWB Designation (Use Flow Chart from EU WFD to the Russian River)
  a. Water body ID → River
  b. Artificial WB → No
  c. Changes in hydromorpohology → Yes
  d. Description of significant changes in hydromorphology → See Pressures List
  e. Likely will fail good ecological status due to d. → No → Insufficient Monitoring Information →Risk Assessment: Project MES

Relevant environmental objectives: obtain GES

MIDDLE WATERSHED

1.1 Characterization

(i)Rivers
(ii)System B used
(iii)NA
(iv)NA
(v)Artificial/HMWB Designation (Use Flow Chart from EU WFD to the Russian River)
  f. Water body ID → River
  g. Artificial WB → No
  h. Changes in hydromorpohology → Yes
  i. Description of significant changes in hydromorphology → See Pressures List
  j. Likely will fail good ecological status due to d. → No → Insufficient Monitoring Information →Risk Assessment: Project MES

Relevant environmental objectives: Projected GES

LOWER WATERSHED

1.1 Characterization

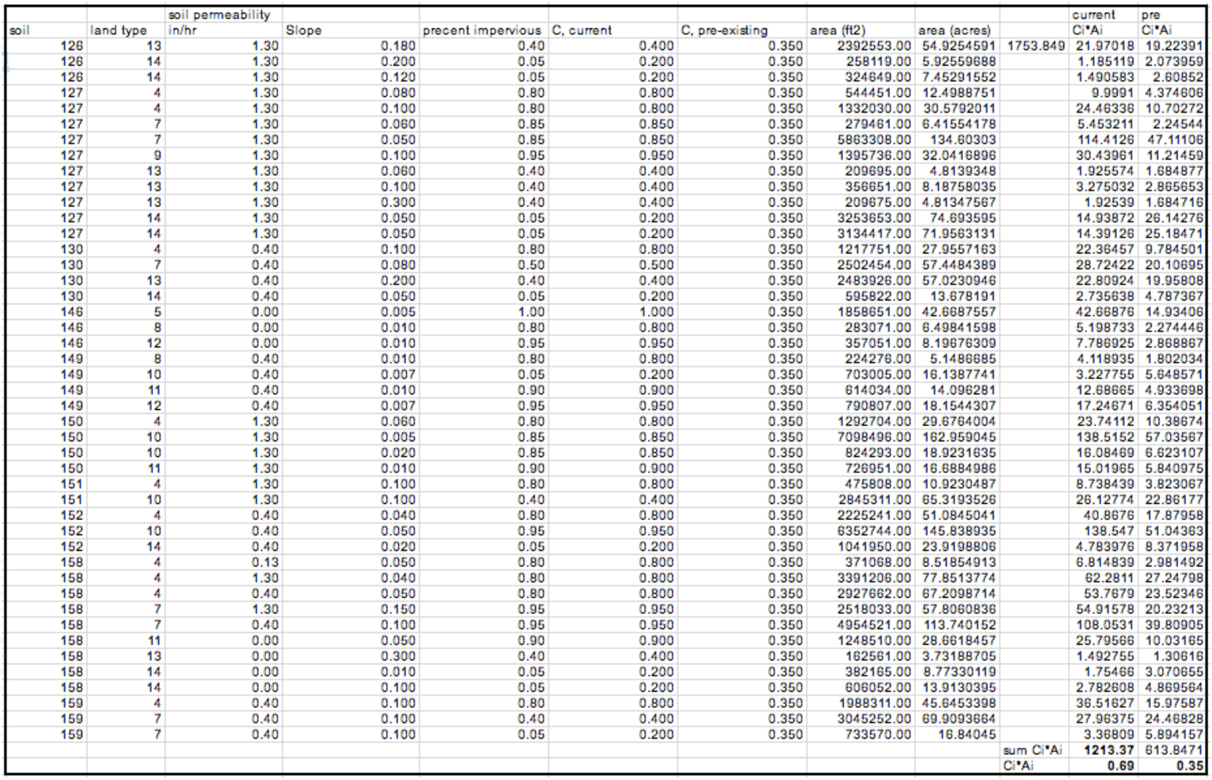
(i) Rivers
(ii) System B used
(iii)NA
(iv)NA
(v) Artificial/HMWB Designation (Use Flow Chart from EU WFD to the Russian River)
  a. Water body ID → River
  b. Artificial WB → No
  c. Changes in hydromorpohology → Yes
  d. Description of significant changes in hydromorphology → See Pressures List

e. Likely will fail good ecological status due to d. → Yes
f. Substantially changed in character due to d. → Yes
g. Identified provisionally as HMWB → Yes
h. Designation Test 4(3)(a): Measures necessary to achieve GES significant adverse social effects→ Insufficient Information →Projected Yes
i. Designation Test 4(3)(b): Significantly better environmental option technically feasible and not disproportionately costly → Insufficient Information →Projected No
j. Designate as HMWB: Projected Yes→ Projected MEP

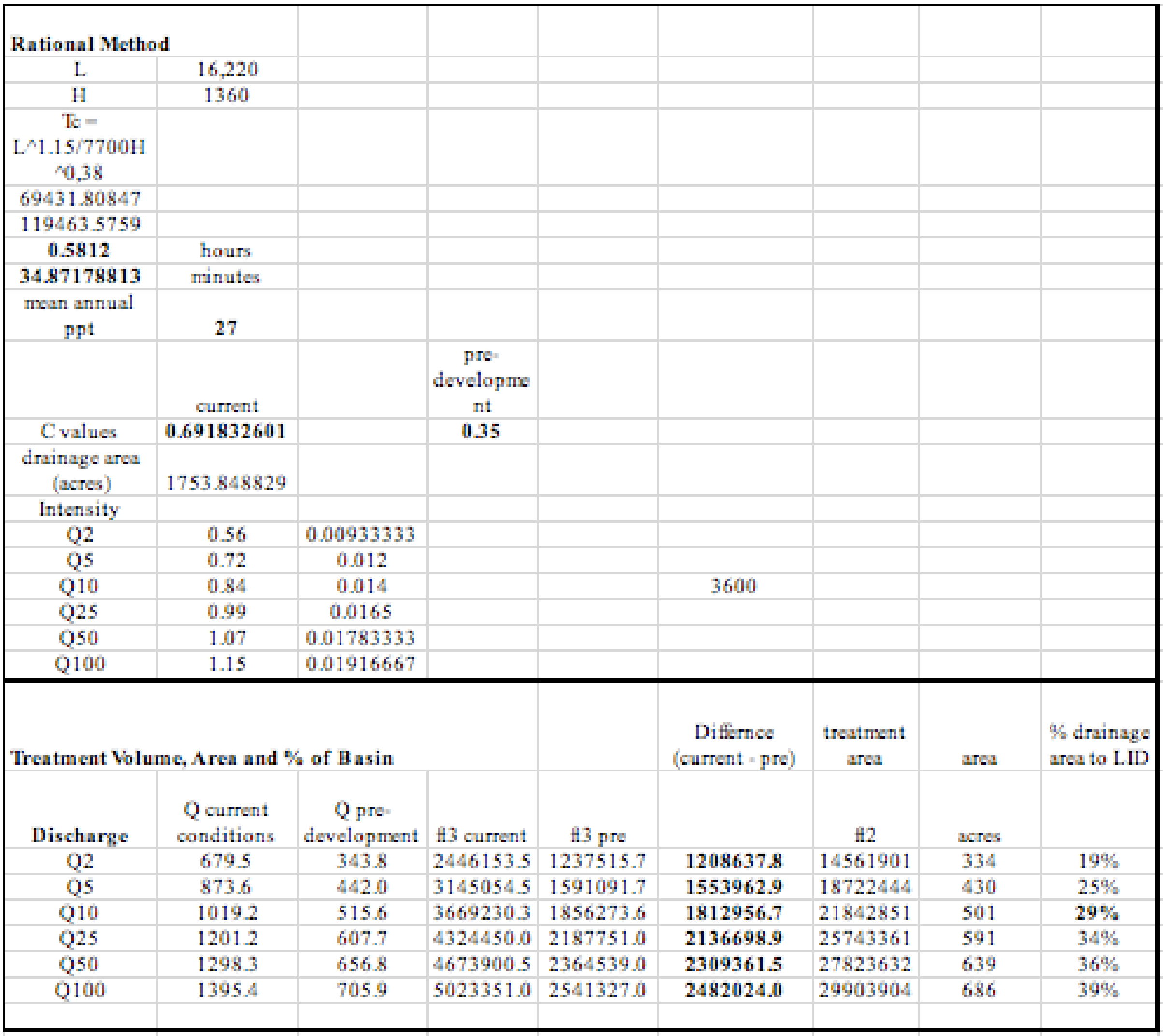
Relevant environmental objectives: Projected GEP

APPENDIX C

MODEL CALCULATIONS (RATIONAL METHOD)



		soil permeability								current	pre
soil	land type	in/hr	Slope	precent impervious	C, current	C, pre-existing	area (ft2)	area (acres)		Ci*Ai	Ci*Ai
126	13	1.30	0.180	0.40	0.400	0.350	2392553.00	54.9254591	1753.849	21.97018	19.22391
126	14	1.30	0.200	0.05	0.200	0.350	258119.00	5.92559688		1.185119	2.073959
126	14	1.30	0.120	0.05	0.200	0.350	324649.00	7.45291552		1.490583	2.60852
127	4	1.30	0.080	0.80	0.800	0.350	544451.00	12.4988751		9.9991	4.374606
127	4	1.30	0.100	0.80	0.800	0.350	1332030.00	30.5792011		24.46336	10.70272
127	7	1.30	0.060	0.85	0.850	0.350	279461.00	6.41554178		5.453211	2.24544
127	7	1.30	0.050	0.85	0.850	0.350	5863308.00	134.60303		114.4126	47.11106
127	9	1.30	0.100	0.95	0.950	0.350	1395736.00	32.0416896		30.43961	11.21459
127	13	1.30	0.060	0.40	0.400	0.350	209695.00	4.8139348		1.925574	1.684877
127	13	1.30	0.100	0.40	0.400	0.350	356651.00	8.18758035		3.275032	2.865653
127	13	1.30	0.300	0.40	0.400	0.350	209675.00	4.81347567		1.92539	1.684716
127	14	1.30	0.050	0.05	0.200	0.350	3253653.00	74.693595		14.93872	26.14276
127	14	1.30	0.050	0.05	0.200	0.350	3134417.00	71.9563131		14.39126	25.18471
130	4	0.40	0.100	0.80	0.800	0.350	1217751.00	27.9557163		22.36457	9.784501
130	7	0.40	0.080	0.50	0.500	0.350	2502454.00	57.4484389		28.72422	20.10695
130	13	0.40	0.200	0.40	0.400	0.350	2483926.00	57.0230946		22.80924	19.95808
130	14	0.40	0.050	0.05	0.200	0.350	595822.00	13.678191		2.735638	4.787367
146	5	0.00	0.005	1.00	1.000	0.350	1858651.00	42.6687557		42.66876	14.93406
146	8	0.00	0.010	0.80	0.800	0.350	283071.00	6.49841598		5.198733	2.274446
146	12	0.00	0.010	0.95	0.950	0.350	357051.00	8.19676309		7.786925	2.868867
149	8	0.40	0.010	0.80	0.800	0.350	224276.00	5.1486685		4.118935	1.802034
149	10	0.40	0.007	0.05	0.200	0.350	703005.00	16.1387741		3.227755	5.648571
149	11	0.40	0.010	0.90	0.900	0.350	614034.00	14.096281		12.68665	4.933698
149	12	0.40	0.007	0.95	0.950	0.350	790807.00	18.1544307		17.24671	6.354051
150	4	1.30	0.060	0.80	0.800	0.350	1292704.00	29.6764004		23.74112	10.38674
150	10	1.30	0.005	0.85	0.850	0.350	7098496.00	162.959045		138.5152	57.03567
150	10	1.30	0.020	0.85	0.850	0.350	824293.00	18.9231635		16.08469	6.623107
150	11	1.30	0.010	0.90	0.900	0.350	726951.00	16.6884986		15.01965	5.840975
151	4	1.30	0.100	0.80	0.800	0.350	475808.00	10.9230487		8.738439	3.823067
151	10	1.30	0.100	0.40	0.400	0.350	2845311.00	65.3193526		26.12774	22.86177
152	4	0.40	0.040	0.80	0.800	0.350	2225241.00	51.0845041		40.8676	17.87958
152	10	0.40	0.050	0.95	0.950	0.350	6352744.00	145.838935		138.547	51.04363
152	14	0.40	0.020	0.05	0.200	0.350	1041950.00	23.9198806		4.783976	8.371958
158	4	0.13	0.050	0.80	0.800	0.350	371068.00	8.51854913		6.814839	2.981492
158	4	1.30	0.040	0.80	0.800	0.350	3391206.00	77.8513774		62.2811	27.24798
158	4	0.40	0.050	0.80	0.800	0.350	2927662.00	67.2098714		53.7679	23.52346
158	7	1.30	0.150	0.95	0.950	0.350	2518033.00	57.8060836		54.91578	20.23213
158	7	0.40	0.100	0.95	0.950	0.350	4954521.00	113.740152		108.0531	39.80905
158	11	0.00	0.050	0.90	0.900	0.350	1248510.00	28.6618457		25.79566	10.03165
158	13	0.00	0.300	0.40	0.400	0.350	162561.00	3.73188705		1.492755	1.30616
158	14	0.00	0.010	0.05	0.200	0.350	382165.00	8.77330119		1.75466	3.070655
158	14	0.00	0.100	0.05	0.200	0.350	606052.00	13.9130395		2.782608	4.869564
159	4	0.40	0.100	0.80	0.800	0.350	1988311.00	45.6453398		36.51627	15.97587
159	7	0.40	0.100	0.40	0.400	0.350	3045252.00	69.9093664		27.96375	24.46828
159	7	0.40	0.100	0.05	0.200	0.350	733570.00	16.84045		3.36809	5.894157
									sum Ci*Ai	**1213.37**	613.8471
									Ci*Ai	**0.69**	**0.35**



Rational Method								
L	16,220							
H	1360							
Tc = L^1.15/7700H ^0.38								
69431.80847								
119463.5759								
0.5812	hours							
34.87178813	minutes							
mean annual ppt	**27**							
	current		pre-development					
C values	**0.691832601**		**0.35**					
drainage area (acres)	1753.848829							
Intensity								
Q2	0.56	0.00933333						
Q5	0.72	0.012						
Q10	0.84	0.014			3600			
Q25	0.99	0.0165						
Q50	1.07	0.01783333						
Q100	1.15	0.01916667						

Treatment Volume, Area and % of Basin					Differnce (current - pre)	treatment area	area	% drainage area to LID
Discharge	Q current conditions	Q pre-development	ft3 current	ft3 pre		ft2	acres	
Q2	679.5	343.8	2446153.5	1237515.7	**1208637.8**	14561901	334	19%
Q5	873.6	442.0	3145054.5	1591091.7	**1553962.9**	18722444	430	25%
Q10	1019.2	515.6	3669230.3	1856273.6	**1812956.7**	21842851	501	**29%**
Q25	1201.2	607.7	4324450.0	2187751.0	**2136698.9**	25743361	591	34%
Q50	1298.3	656.8	4673900.5	2364539.0	**2309361.5**	27823632	639	36%
Q100	1395.4	705.9	5023351.0	2541327.0	**2482024.0**	29903904	686	39%