Daylighting Islais Creek:
A Feasibility Study

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Abstract

San Francisco's Islais Creek (Figure 1) has been buried in culverts for more than 70 years. It currently conveys the combined sanitary and storm sewer that drains the Southeast corner of the city. This combined sewer overflows into San Francisco Bay several times a year, and into the city streets approximately once every five years. We propose separating the sewer and storm drains, and explore re-opening Islais Creek to carry stormwater runoff to the bay. We delineated the watershed and channel using Arc/Info and GIS. We chose study reaches at the outlets of three subwatersheds, representing different flow conditions, elevations, urban development constraints, and opportunities for restoration. These variations necessitate different channel forms for each reach; we present experimental designs as cross-sections and plan view reaches overlaid onto an aerial photo of the city. We discuss project viability and opportunities.

Problem Statement/Introduction

The City and County of San Francisco is unique in California because it has a combined sewer system. The city collects both the sanitary and stormwater into the same pipes, which convey it to wastewater treatment plants where it is treated to primary and secondary levels. In the United States, combined sewer systems were constructed prior to the 1950s and are common primarily in older, urban communities. About 90% of the systems are found in eastern and midwestern communities of fewer then 100,000 people and about 60% serve communities with fewer then 10,000 people (EPA 2002).

San Francisco's system was designed in the 1850s to operate under dry weather and rain events with return periods shorter than five years. For those rain events that are in excess of a five-year event, the system discharges partially treated wastewater into the San Francisco Bay and the Pacific Ocean through a series of 36 outfalls (Figure 2). These discharges, called combined sewer overflows (CSOs), degrade the quality of the receiving waters and periodically pose a significant public relations problem for the city. Prior to upgrades initiated in 1972, the city experienced up to 80 CSOs per rainy season. National projections of annual CSO discharges are estimated at 1,260 billion gallons per year (EPA 2002). Current numbers for San Francisco hover at approximately ten per year (Brown and Caldwell 2004).

When constructing its combined system, the city culverted most of its creeks to convey wastewater and to permit development on the floodplains. These creeks now run in pipes under the streets. This results in flooding and property damage during large storms, particularly in areas where the sewer lines are hydraulically undersized or in need of cleaning. In a combined sewer system, when the system exceeds capacity, it also backs up and surcharges into the street. The impacts can be dramatic:

> "Walker is describing this appetizing scenario: When it rains, the sewer pipes under Third Street back up. But they don't just back up. Runoff creates enough pressure in the undersized line that water blows up through the manhole in the intersection in front of Onnie's Cafe. It's a real-life version of a classic cartoon scene: Look—it's a manhole cover, suspended on a 4-foot fountain of water surging up from the sewer! Every now and again, a wayward rat comes surfing out with the water and scurries past, as watery sewage flows down the street, right past the cafe and other businesses on this stretch of Third".
>
> "Things were moving down the street, OK," Walker explains in a gingerly way that makes clear the things he's discussing are not pleasant. "And, kids play in the water. They just do.
> "People know what's going on, and they stay away. We will never be a viable neighborhood until they clean up the sewer and waste-water plant." (Davis and Gao 1998)

The community of Bayview Hunters Point is home to city's Southeast Water Treatment Plant, which has a maximum wet weather treatment capacity of 250 million gallons (MG) or 10.5 MG/hr and treats the largest volumes of the city's wastewater. (Brown and Caldwell 2004) It is also located in the lower points of the Islais Valley Watershed (Figure 2), which generates the largest stormwater volumes for the city. Along with other low-lying neighborhoods unfortunate enough to be built on top of buried streams, the Bayview is the location of sewer surcharges in stormy weather.

Not surprisingly, communities are not happy with the flooding problems and like many other cities; San Francisco is embarking on a plan to rebuild the water infrastructure. This process, called the Clean Water Master Plan (CWMP), will develop a multi-billion dollar capital improvement plan to upgrade and resize the pipes drains of the city. The project intent is to rebuild and increase the capacity of the combined system and fix the problem flooding areas. Additionally, the city is reviewing a $60-300 million proposal to increase the capacity of the sewer system through a pinch point in the watershed. The project, called the Cross-Town Tunnel, would pipe excess water to the eastern side of the city for treatment (Williams 2003). Until the recent development of a community advisory committee, there was little discussion of using the CWMP to rethink the appropriateness of rebuilding the combined sewer or the traditional pipe and gutter conveyance system. To date, the city has not publicly discussed separating the combined system, but intends to include research into the innovations using Low Impact Design (LID) or "green" infrastructure such as detention basins or swales to absorb runoff. Cities around the country are increasingly realizing the multiple benefits of daylighting culverted streams for flood protection, neighborhood enhancement and wildlife and recreational amenities. Ecological benefits of exposing the water to sunlight, air, and soil can include improved water quality through removal of organic and inorganic pollutants by new vegetation growth (Forester 2004). Additionally, daylighted and open waterways often have greater hydraulic capacity than culverts. With increased space and the establishment of flood plains, stream flow can be slowed down and total runoff can be reduced through infiltration, reducing flooding. However, the debate in San Francisco has not considered the benefits reported by other municipalities such as Boston, Detroit or Portland, that are separating portions of their combined sewer system or alternative methods of stormwater conveyance during the planning phase of the CWMP (CDPW 2003) (Rouge River 2003) (PBES 2004a).

Study Objectives

The goal of this term project is to investigate the feasibility of daylighting portions of the stormwater sewer along Islais Creek, the largest creek in San Francisco, assuming that the city will separate portions of the combined sewer. Our objectives were to identify reaches representative of different conditions within the watershed, where the creek could potentially be opened and sewer capacity increased. We investigated the volume control benefits associated with daylighting and explored the potential opportunities and barriers within the current landscape.

Methods

This project combined elements of landscape design with traditional and modern hydrological analysis. Because the landscape and water conveyance of San Francisco have been heavily altered through urban development, we could not assume that the streamflow or shape of a re-opened Islais Creek would bear much in common with the creek that is visible in historical photos. Instead, it was necessary to re-map the watershed and flow-path with the current topography and estimate hypothetical flow and creek size based on a mostly-impermeable watershed.

Watershed and Channel Delineation

To estimate the flood flows that would need to be conveyed by the daylighted stream (in its storm sewer function), we first estimated the drainage areas for each reach. We delineated the major channels and watersheds using ArcMap and Arc/Info (Figure 3). ArcMap is a Geographical Information Systems (GIS) software package that allows one to use to gather, analyze and manipulate spatial data. The data comes in *shape files*, visual representations of data, such as watershed boundaries, that are spatially related to a database. The San Francisco Department of Public Works (DPW) provided the major and minor drainage basins in ArcMap GIS shape files along with hand-drawn historical creek polylines (Figure 4). We used the GRID sub-module of ARC/Info to delineate a watershed boundary with a ten Meter Digital Elevation Model (DEM) USGS dataset (Figure 3) (USGS 2003). A DEM is a computer data file that gives land surface elevation; we used a raster-based DEM with 10-meter grid cells. The flow accumulation function in GRID generated the flow direction map (Figure 5). We overlaid this onto the minor drainage basin layer in ArcMap to identify reaches and tributaries within the watershed that were representative of the variety of flows and volumes (Figures 6, 7, 11, and 15).

Additionally, the DPW provided a GIS shape file of the combined sewer system that showed pipe locations and diameters.

Study reach Identification and Description

It was not possible, in the scope of this project, to predict flow volumes and channel size for the entire length of Islais Creek. Instead, we identified study reaches at *Glen Park*, *Cayuga*, and *Islais Creek Mouth* to be representative of the spectrum of watershed conditions (Figure 1). Each is at the mouth of a subwatershed, situated at high (350 feet (ft)), medium (100 ft), and low (0 ft) elevations, respectively. The elevations were determined using 25 ft contour lines (GIS shape file) obtained from DPW.

The Glen Park study reach sits in the neighborhood of the same name, downstream of Glen Canyon Park (Figure 8). It is the headwaters for the northern reaches of Islais Creek. Our study reach is located within the park, west of where the creek goes into a 5-ft diameter pipe under Chenery St., Paradise St., and Bosworth Avenues.

The second study reach, Cayuga, is downstream of the confluence of the two main branches of Islais Creek (Figure 12). Cayuga, Lyell, Alamany, and Rotteck Streets bound the reach. At this point, the channel would carry about half of the watershed's runoff. Pipes carrying runoff at this convergence range from 6-8 ft in diameter. This site experiences significant flooding problems due to nearby development, the surrounding "pinched" topography, and relatively large flow volumes.

The mouth of the watershed lies at what used to be San Francisco's shoreline (Figure 24). Landfill has widened the city out into the Bay, but the hydraulic connection between Islais Creek and the Bay has remained as an inlet (Figure 19). The Islais Creek Mouth study reach is located just upstream of the tip of this inlet. It is located just east of the Route 280 on-ramp, north of Islais and Napoleon Streets (Figure 16). At this outlet, three, 8.5 ft x 10.5 ft rectangular pipes converge to discharge water.

Runoff Calculations

The San Francisco Public Utilities Commission (SFPUC) provided much of the necessary data to calculate runoff for the three watersheds in this study, including rainfall intensities for a variety of recurrence intervals (0.25- to 100-year) and over a range of time discretizations (**Table 1**).

Time of concentration, the time at which all rainfall hitting the remotest portions of a basin begins contributing to flow ("peak discharge"), is affected by watershed length, slope, and runoff characteristics. Peak flow and time of concentration can be measured easily for different rainfall events on open creeks, using a flow gage. Since Islais Creek is covered and ungaged, we estimated the time of concentration *(t_c)* for each watershed using the FAA method, which estimates t_c for airports, and the Hathaway and Kirpich functions, methods generally used for less developed watersheds (Columbia 1998) (Dingman 2002) (Reitsma 2004). Additional error could be introduced by our rough estimate of runoff coefficient (see below). However, estimated times of concentration were relatively consistent between methods (**Table 2**). These times of concentration were used to choose the most appropriate time discretizations of rainfall event to calculate runoff volumes. Shorter discretization is associated with higher rainfall intensity and thus bigger peak flow; we want to capture the highest intensity possible to avoid underestimating peak flow and risking flood damage. On the other hand, using a discretization shorter than the time of concentrations could lead to overestimation of peak flow, unnecessarily increasing costs. We chose the discretization most closely matching time of concentration: a half-hour for the upper two control reaches, while the hour discretization was more appropriate for the mouth.

To calculate peak discharge, we also needed to estimate the runoff coefficient, the fraction of rainfall that runs off, directly becoming streamflow. The SFPUC has calculated a runoff coefficient of 0.61 for the Islais Creek Watershed (Brown and Caldwell 2004). However, this number is based only on the percent of impermeable surfaces in the watershed; it probably approximates the average runoff for all precipitation falling on the city. Actual runoff varies between rainfall events, with larger rainfall events producing a runoff coefficient of up to 1.00. The California Department of Transportation uses a runoff coefficient of 0.95 for impervious areas (CADOT 2003). Because the primary motivation for this project is to reduce flooding effects during larger storm events, we used 0.95 to estimate runoff curves from precipitation records. A lower runoff coefficient may be appropriate for the uppermost watershed, and for events with shorter recurrence intervals (see discussion.)

Using the Rational Method presented in Dingman (2002), peak discharge is calculated as:

$$q_{pk} = u_R \times C_R \times i_{eff} \times A_D$$

where i_{eff} is rainfall intensity in inches per hour, C_R is the runoff coefficient, A_D is the watershed area in acres, and u_R is a unit conversion factor equal to 1.008. This formula directly yields peak runoff for the 0.25-year to 100-year storm events (**Table 3**). Values for Glen Park were then used to build a flow exceedence diagram to obtain the 1.5-year flow (Figure 20). An Extreme Value III distribution gave the best fit to the higher-frequency data, although no common probability distribution offered a good fit for all data points. Bankfull flow, assumed to be a 1.5-year recurrence event, was calculated from the flow exceedence relationship:

$$ln(flow) = .4113(\Phi) + 5.2702$$

where $\Phi = -ln(-ln(F))$ and F is the probability factor, which is equal to $1-(0.5\ years/1.5\ years)$ here.

Cross-section Design

The channel of Islais Creek is constrained by different runoff intensities, slopes, neighboring uses, and downstream uses at each control point. **(Table 4)** With the peak runoff calculated above (**Table 3**), we use Manning's equation to determine channel size and shape (Crowe et al. 2001). Width and depth are dependent variables in Manning's equation, allowing the design to accommodate considerable width constraints. For instance, the middle cross-section discussed below is designed to be quite deep in order to limit width. Flows and cross-sections were designed for single points in these reaches. It is assumed that the cross-section dimensions would be valid throughout the reach, the length of which would be determined by available funding and physical and political obstacles. See Table 4 and Figure 21 for results.

Glen Park: The tributary of Islais Creek that flows through the Glen Park neighborhood is open through much of the park, but it receives only a portion of the subwatershed's natural runoff, since most is redirected into sewers. We calculated subwatershed slope to be 3%, $Q_{1.5}$ (the flow of a storm event that has a 1.5-year recurrence interval) at 247 cubic feet per second (cfs), Q_{25} at 443 cfs, and Q_{100} at 548 cfs. These flows are less than six percent of the watershed's total runoff, allowing for a "natural" cross-section design: a channel with a bank-to-bank width of 32.1 (ft.) and 30° bank slope would carry $Q_{1.5}$, which is assumed to be bankfull flow (Figures: 21, 22, and 23). The 100-year flow event would be contained in this channel and the floodplain, which adds an extra 68 ft. on each side, bringing the total width to 169 ft.

Cayuga: This reach is located at the confluence of the two major tributaries; it currently experiences chronic flooding problems. Nearby land uses include highway 280, other major roads, and housing for significant population density. The channel here is the most constrained of the three study areas. Local slope is 1.3%, and Q_2, Q_5, and Q_{25} are 2661, 3225, and 4240 cfs, respectively. To reduce flooding, we designed the channel to convey Q_5: 141 ft. bank-to-bank width and 30° bank slope. The channel banks should be protected against erosion with rip-rap up to the two-year water mark, but small plants would line the upper bank and floodplain (Figures: 21, 22, and 23). Due to the shorter time of concentration, peak flow at Cayuga is almost as high as that at the mouth, and a floodplain capable of conveying Q_{25} would be very wide. To reduce this width and the resulting encroachment into nearby land-uses, small concrete channels capable of carrying 250 cubic feet per second (8.5 ft. across, bank slope 60°) would border both edges of the floodplain, now reduced to 182 ft. on each side. These side-channels are designed to direct water onto the floodplain or back into the main channel except in exceptional flow events. Total width is 522 ft.

Islais Creek Mouth: Sewage outfalls into the remnant inlet channel mark the current mouth of Islais Creek (Figure 16). Nearby development is mostly industrial, with some publicservice facilities, artists' studios, and a park. Historical photos and writings suggest that the area was formerly a wide wetland, ranging to 500 acres in area and extending fully 2 miles inland (Figure 24), some of which could potentially be restored (Grunsky 1909). We calculated total watershed slope to be 0.7%, and Q_1, Q_5, and Q_{25} to be 1504, 3250, and 5162 cfs, respectively. The channel is designed in tiers to 1) carry various sizes of flow, 2) encourage regular over-bank flow for wetland functionality, 3) provide space and material for the river to rearrange itself as befits hydrological conditions, and 4) hydraulically connect lower Islais Creek to the tidal, saltwater bay system. The smallest channel would need to be 140 ft. bank to bank to convey Q_1, with a bank slope of 15^o. The next channel tier would be 294 ft. across with a bank slope of 15^o, and carry Q_5. The wide top floodplain (394 ft. on each side) would carry a 25-year flood, with similar cement side-channels to the Cayuga cross-section design (each 15 ft. across, 60^o bank slope), for a total width of 1112 ft. The top floodplain should receive some water during each winter from direct precipitation and runoff (Figures: 21, 22, and 23).

Aerial Photo Analysis

We illustrated plan views of the creek cross-sections using AutoCAD and overlaid them onto aerial photos of the city to identify the impacts of daylighting on the existing neighborhoods (Figures: 10, 14, 18). The Glen Park study reach is set slightly downstream of the "flow accumulation" point that was identified in ArcInfo, as that point is actually in a park, where daylighting would not affect neighborhood infrastructure. It is also worth noting that the floodplain at Glen Park would carry a 100-yr flow, whereas the floodplains at the other two reaches were designed to accommodate the 25-year flow. At each reach we outlined the buildings in the floodplains and counted the numbers of buildings that would be impacted and targeted for removal. It appears that we'd need to remove 19 houses, 61 houses, and 25 buildings from Glen Park, Cayuga, and mouth, respectively (Figures: 9, 13, and 17).

Discussion

The study site cross sections were drawn to illustrate the design of the daylit portions of the creek (Figures 10, 14, and 18). At Glen Park, several proposals have been developed by the San Francisco Planning Department for reopening the channel along with a "Green Street" design.

Green streets are curb-less and engineered with vegetated swales and medians to capture and infiltrate the runoff, which would have traditionally been routed to the sewer for treatment. This water then enters the rivers through base flow, slower and cleaner than if it had been allowed to travel over the streets accumulating pollution from the streets. Due to the large volumes of water and frequent flooding at the Cayuga site, we propose to purchase and remove housing at the confluence of the major tributaries in the watershed. Opening this area would provide some relief to flood events by providing a place for the excess water to flow, and possibly reduce the width of the designed floodplain. This is in addition to the significant reduction in floodplain width that would be required to convey a 25-year flow instead of a 100-year flow, should the city choose that as a sufficient level of flood protection at Glen Park.

The Cayuga space could also serve as a public park during the dry season and provide a detention basin in the wet season. There is a precedent for this in the Sun Valley Watershed in Los Angeles where the LA County Department of Public Works has converted a park to double as a flood detention basin in the rainy season (LADPW 2002). Additionally, vegetated corridors and access to water could support urban wildlife.

Separating the sewer from the stormwater and allowing the creek to periodically overflow its banks would reduce the pressure on the sewer system. We would also recommend removing the houses in the worst flooding areas. By looking at the long-term costs associated with lawsuits associated with flooding incidents and the ongoing maintenance costs, the cost of purchasing and removing the block of houses could be justified.

At the base of the Islais Creek's flow path, we propose a larger design for a multi purpose wetland park. Successful precedents for such a project are available within the city, at Crissy Field on the Presidio and Heron's Head Park. The mouth of Islais Creek could be designed as a multipurpose wetland, with a detention pond and the natural water purifying benefits of wetland processes. . Additionally, this would keep water out of the sanitary sewer, reducing the likelihood of a CSO.

Daylighting vs. Restoration

Many experts agree that urban creek projects cannot be considered "restorations" due to the highly developed catchment basins and altered hydrologic systems. Nonetheless, daylighting urban streams may yield benefits, such as those we aimed for with this project: reduced flooding, reduced property damage, increased access to green space for recreation and aesthetic enjoyment, and the less tangible benefits of access to natural processes and systems that vary with exposure with seasonal rainfall patterns.

Climate change / flood frequency

While there is substantial dispute about the long-term effects of climate change, there is a general consensus among modelers and scientists that California will receive more rain, and that the number of extreme events will increase (Vanrheenen et al. 2004). This will put even more pressure on San Francisco's aging combined sewer system, resulting in increasing threats to sanitation and property damage. Separating the combined sewer and opening Islais Creek will both increase the threshold for flood emergencies and decrease sewage overflows.

Watershed vs. Sewershed

Some of the calculations for overland flow may be inconsistent due to discrepancies in the data. Runoff was calculated for the topographic watershed of Islais Creek, as delineated in ArcInfo. However, flow direction and accumulation are currently controlled through sewersheds, where sewer pipes often re-direct runoff in or out of natural watersheds. The sewersheds surrounding Islais Creek are generally larger (Figure 4) than the local watersheds. If San Francisco were to continue importing stormwater to the Islais Creek watershed, or if portions of the stormwater were to remain combined with the sanitary sewers, flow volumes and cross-sectional areas would need to be re-calculated.

Relationship of runoff coefficient to rainfall intensity

Given the degree of urbanization in San Francisco, we used a runoff coefficient of 0.95 as a reasonable estimate for larger storms, as used by the California Department of Transportation and other planning agencies for streets and other impermeable spaces. However, 0.95 is over 50% larger than 0.61, the value provided by SFPUC. A value near 0.61 may be appropriate for Islais Creek storm events as large or larger than as the 1-year event. Such a change would result in different peak flows for small storm events, flood/frequency relationship, and cross-sectional area necessary to convey smaller events. More research could be undertaken to correlate runoff vs. rainfall intensity in the Islais Creek basin, but it would require monitoring flow in storm sewers. Alternatively, a channel daylighting project could proceed in multiple phases, with the runoff coefficient refined for each successive phase. If this project were undertaken in conjunction with a Green Streets approach, the runoff coefficient would decrease.

Culverts

Given the degree of development in the watershed, it seems unreasonable to assume that the entire main stem of Islais Creek would be daylighted. At the very least, portions of the creek such as those under the freeway or historical buildings, would remain in culverts while other portions were being restored. To minimize flooding, some method of ensuring that stream flow in open portions was routed into downstream culverts would be necessary. This would probably require some combination of sloping the nearby landscape towards the culvert, lining the downhill banks to prevent incision and meandering, and storm drains at the downhill end to be hydraulically connected to the channel.

Water Quality

Because a combined sewer is effective in providing a high quality of stormwater treatment, it is important not to lose these benefits. Other cities like Boston, Portland and Detroit are separating their sewers at strategic locations in the watershed and adding non-structural or "green" best management practices to provide an adequate level of water treatment. Portland has instituted a Green Streets program in the watersheds feeding their rivers (PBES 2004b). If the city were to daylight portions of the creek, a Green Streets program along the main channel of the Islais Creek Watershed would slow and purify the water entering the channel, thereby improving water quality.

Channel Maintenance

As with any urban waterway, a daylighted Islais Creek would require monitoring and maintenance. The channel may require dredging of sediment to maintain conveyance capacity. Of more concern to the community is probably bank stability. Banks would need some level of protection to prevent meandering and avulsion, and the bed may need lining to prevent incision. We foresee the highest level of vigilance required to prevent flooding at the Cayuga study reach, due to the nearby topography, the significant adjacent and downstream development, and because peak flow at Cayuga would be nearly as high as at Islais Creek Mouth. To put maintenance costs in perspective, current flooding issues are most severe near Cayuga for the same reasons.

Conclusions

San Francisco's frequent combined sewer overflows and in-street flooding problems demand a permanent infrastructure solution. The current proposal, to redirect the combined sewer eastward in a larger pipe, will mostly address these problems. However, it ignores the opportunity to re-create open-water habitat within the city, continues the unnecessary treatment of storm runoff, and will remain prone to combined sewer overflows in large events. If, instead, the city were to strategically separate the sewer and stormwater systems, a reopened Islais Creek could convey the storm runoff directly to San Francisco Bay.

Creek design would necessarily vary throughout the mainstem according to local runoff patterns, development levels, and natural conditions. Upstream reaches could function with a relatively natural shape and hydrology, in coordination with other multipurpose green design to mitigate urban impermeability effects. Significant development constrains the middle reach necessitating typical urban creek features such as lined banks and overflow channels. Daylighting the mouth of Islais Creek will restore historical wetland functionality through overbank flow and natural channel braiding processes. Overtime, houses and other infrastructure would need to be removed from the creek corridor to prevent flood damage and increase hydrologic functionality. This would be true in all reaches, but most prominently in middle stretches.

To adequately analyze this proposal, the city would have to conduct long-term cost analysis to justify removing housing to daylight the creek. If the projects could reduce the pressure on the combined system, or the costs of flood damage, liability and maintenance, there could be a good case made for daylighting the creek and other green infrastructure.

Removing housing and reintroducing open water into an urban community would require community outreach and education to help people appreciate the stream and visualize the potential for neighborhood improvement.

Daylighting Islais Creek for stormwater conveyance would reduce combined sewer overflows into San Francisco Bay and the city streets, reduce the threat of flooding, reduce the inflow to wastewater treatment plants, create aquatic habitat, create public recreational space, and advance understanding of urban water management.

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Appendices

Return Period	Duration							
(Yrs)	5 min	10 min	15 min	30 min	1 hr	2 hrs	3 hrs	6hrs
100	4.8	3.42	2.8	1.88	1.28	0.88	0.6933	0.48
50	4.32	3.12	2.52	1.7	1.15	0.795	0.627	0.433
25	3.84	2.76	2.28	1.52	1.03	0.71	0.557	0.387
10	3.36	2.4	1.96	1.31	0.9	0.62	0.49	0.33
5	2.904	2.07	1.712	1.156	0.79	0.555	0.44	0.297
2	2.364	1.74	1.4	0.954	0.66	0.4575	0.373	0.245
1	1.968	1.428	1.176	0.8	0.562	0.39	0.323	0.21
0.5	1.56	1.152	0.96	0.66	0.47	0.325	0.27	0.177
0.25	1.164	0.864	0.736	0.516	0.372	0.26	0.213	0.14

Table 1: San Francisco rainfall events (intensity in/hr.) (Lee 2004)
Reproduced from the San Francisco Public Utilities Commission.

	Runoff coeff.	Elev. Change	Slope (%)	Area (acres)	Flowpath (m)	t_c (min) (FAA)	k (Kirp)	t_c (min) (Kirpich)	r (Hath)	t_c (min) (Hathaway)
Glen Park	0.61	475	7.0	304	2064	**21**	2	**38**	0.4	**35**
Cayuga	0.95	200	1.3	2913	4736	**17**	0.4	**28**	0.05	**21**
Islais Creek	0.95	300	0.9	5223	10385	**29**	0.4	**59**	0.05	**30**

Table 2: Subwatershed characteristics and Time of Concentration

Return Period (Yrs)	30 min (Glen. P.)	30 min (Cay.)	1 hr (Is. Cr.)
100	547.71	5244.08	6414.38
50	495.27	4741.99	5762.92
25	442.83	4239.89	5161.57
10	381.65	3654.12	4510.11
5	336.78	3224.55	3250.45
2	277.93	2661.09	2327.62
1	233.07	2231.52	1504.44
0.5	192.28	1841.01	983.95
0.25	150.33	1439.33	574.32

Table 3: Flood flow events at control points (in cubic feet per second)

	DA	Local slope	Low-Flow Channel capacity								Floodplain capacity (total)				Concrete Side Channels (each)						Total Width
			Q (cfs)	RI	bw (ft)	d (ft)	R_h	BS	*n*	Mat'l	Q	RI	ftw (ft)	Mat'l	Q	RI	bw	d	BS	*n*	(ft)
Glen Park	304	3%	247	1.5	16	5	3.4	30^{o}	0.3	gravel	150	100	136	weedy							169
Cayuga	2913	1%	2661	2	104	9.1	7.8	30^{o}	0.25	rip-rap	515	25	364	weedy	250	25	4.7	2	60^{o}	0.012	522
			3225	5	104	11.3	9.4	30^{o}	0.3	grass											
Islais Cr.	5223	0.7%	1504	1	80	8	6.2	15^{o}	0.25	soft	911	25	788	weedy	500	25	12	2	60^{o}	0.012	1155
			3250	5	273	5.6	6.72	15^{o}	0.35	wetland											

Table 4: Channel specifications: DA- Drainage Area (acres); Q - flow volume (cubic feet/second); RI - Recurrence Interval (years); n – Manning's n; bw – bed width (feet); d – depth; Rh - hydraulic radius; BS – Bank Slope; Mat'l – Bed and bank material; ftw – total width of floodplain