INTRODUCTION

Urban streams and watercourses require comprehensive management strategies to meet the needs of multiple goals, including but not limited to flood control, riparian and aquatic habitat, and public and private property rights. Balancing these goals is a difficult task that requires balancing the needs of people and the need to have a natural, healthy, and self-sustaining creek system. As urbanization and industrialization areas press people closer to watercourses, conflicts arise between natural erosion cycles and residential structures and infrastructure. Stream bank erosion is a natural phenomenon associated with low-gradient (i.e., slopes less than 2%) alluvial creeks by which material is transported from high-energy areas to low-energy areas. Often this natural cycle is exacerbated in the urban context, as sediment and hydrologic supply regimes are altered such that the sediment input is reduced and the hydrologic response (i.e., runoff) is increased.

The following study examines the baseline conditions of the watershed, the current conditions of the Chimes Creek channel in the study reach, assesses long-term erosion potential, and provides options for reducing erosion impacts.

SECTION 1. SETTING

This section of the Bank Stabilization Feasibility study presents information on the regional setting of the project site, including a discussion of watershed characteristics, design flows, and general urban watershed sediment transport patterns. It is important that bank stabilization and channel restoration plans consider the watershed's regional and historical hydrologic and geomorphic processes because each determines overall creek morphology and response to potential stabilization projects. For example, regional geomorphic trends in a creek such as channel bed incision, downstream migration of channel bends, knickpoint migration, and other channel adjustments to altered watershed hydrology and sediment inputs are all key considerations in developing a bank stabilization plan that is not susceptible to upstream problems, and that does not merely move site problems downstream. Specific geomorphic processes at the watershed and reach scale are discussed in Section 2 "Geomorphic Analysis".

Location

The Chimes Creek watershed is located in northwestern Alameda County and is within the Oakland City Limits (**Figure 1**). Chimes Creek originates in the Oakland Hills and flows southeast for ~0.5 mi. before entering the Leona Quarry development. The creek flows through a constructed detention basin after exiting the Leona Quarry development and outlets to a 48" culvert at I-580. The creek flows underground from I-580 through the Sunnymere, Altamont, and Edgemore neighborhoods and outfalls into the unculverted section of Chimes Creek near the intersection of Hillmont Dr. and Delmont Ave. This feasibility report targets the unculverted section of Chimes Creek between Hillmont Dr. and Delmont Ave. and the Alameda County Flood Control District (ACFCD) culvert near Nairobi Place (~1150 lineal feet). Despite a City of Oakland Right-of-Way (ROW) at Nairobi Place (STA 2+20) and a 10 ft path right-of-way perpendicular to STA 7+85, the entire the project reach is privately owned (**Sheets 1 and 2**). Public access to Chimes Creek is extremely limited with private property lines and fences extending across the channel in numerous locations. After exiting the project reach, Chimes Creek continues westward for approximately 1.5 miles before joining Horseshoe Creek.

Climate

The climate of northwestern Alameda County is strongly influenced by the Pacific Ocean and is typical of conditions throughout the San Francisco Bay Area; winters are mild and summers are moderately warm. Minimum and maximum daily temperatures vary by approximately 30 degrees in the summer months and by about 15 to 20 degrees in the cooler months. Average summer temperatures range from 52º F to 78º F, and average winter temperatures range from 41º F to 55º F (NOAA, 2008). Rainfall in the San Francisco Bay region is greatly influenced by topographic features and varies significantly by elevation and by location within the region but averages between 20 and 30 inches per year. Over 90 percent of the annual precipitation occurs in the six-month period from November through April when the prevailing westerly winds drive storms off the Pacific Ocean.

Hydrology

The portion of the Chimes Creek watershed relevant to this study extends from the highest point in above Leona Quarry (~1085 ft) to the Alameda County Flood Control District (ACFCD) culvert near Nairobi Place (~ 210 ft). Arc Hydro, a water resources extension available in ArcGIS 9.3, was used to delineate the entire Chimes Creek watershed above the ACFCD culvert based on a USGS 10 meter digital elevation model. At approximately 387 acres, the majority of the watershed is composed of variable clay loams, silty clay loams, and clay soil types of the Xerorthents group (BH, 2003). The upper Chimes Creek watershed is dominated by the Leona Quarry (est. 1900s) and contains steep (>30%) shallow soils that can produce high run-off to urban channels below. The lower Chimes Creek watershed consists of dense residential neighborhoods and highly impervious surface cover on gradual slopes (<30%).

Hydrology of urban watersheds can be extremely complex. City drain systems, detention basins, and culverts are juxtaposed on top of natural drainage patterns and a mélange of soil types, vegetation, and land uses. Previous hydrologic reports in the Chimes Creek watershed focused on the development impacts associated with the Leona Quarry project (BH, 2005 and PWA, 2003) and did not explicitly predict flows into the Chimes Creek project reach. To generate design flows for this feasibility report, Questa reviewed the BH report, city storm drain plans, local topography, and as-builts for the Leona Quarry development and selected a worst case flow scenario. **Table 1** provides a summary of post development flows reported in previous hydrologic studies and the following discussion explains the selection of flows for this feasibility report.

Table 1. Summary of Hydrologic Flows

Date	*Source*	*2-yr*	*10-yr*	*25-yr*	*100-yr*
2003	Balance Hydrologics[1]	70	137	163	227
2005	Balance Hydrologics[1]	59	104.7	124.3	131.4
2005	Balance Hydrologics[2]	104.7	173.7	176.2	179.3

[1] Flows predicted at I-580 Culvert.
[2] Flows predicted at Chimes Creek outfall, which assume downstream drainage capacity limits

Two general methods exist for determining design flows for channel bank stabilization and channel restoration. Statistical methods can be used if an adequate flow record exists or rainfall run-off models can be used to predict flows based on a typical design storm (i.e. the 2-yr, 10-yr, 25-yr, or 100-yr storm). Unfortunately, flow records near Chimes Creek are insufficient for a statistical analysis. Reverification of exact peak discharges would entail field verification of detention basin volumes and operation protocols, ground truthing storm networks and elevations with GPS equipment or as-builts, and extensive rainfall run-off and storm drain system modeling similar to the BH, 2005 report. These tasks were not performed as part of this Bank Stabilization and Channel Restoration Feasibility Report. Therefore, design flows were selected based on a review of hydrologic modeling studies for the Leona Quarry development and the assumptions of the contributory downstream watershed shown in Table 1 and described below.

Review of the BH, 2005 report suggests flow conditions downstream of the I-580 culvert entrance are exceptionally complex. The 2005 BH model accounted for the watershed area below I-580 that drains to Chimes Creek and additional downstream boundary constraints imposed by the existing City storm drain system. For example, during the 10-yr, 25-yr, and 100-yr flow events, the drain system upstream of the project reach is operating at its capacity, approximately 180 cfs (**Table 1**). During infrequent (10-yr, 25-yr, and 100-yr) events, ponding begins upstream of Delmont Ave as the Chimes outfall culvert reaches capacity and the City drain pipes throughout the Sunnymere, Altamont, and Edgemore neighborhoods exhibit pressure flow (BH, 2005). Under these conditions water can be expected to pond in the topographic depression between Altamont Ave. and Gardenia Place and overflow into adjacent streets to the northwest and towards Chimes Creek to the Southeast. Reports of basement flooding at 6509 Hillmont Ave. may be explained by ponding water as it enters the Chimes Creek channel from the North. Overall, the Chimes Creek outfall constrains flows originating in the upper watershed and explains why there is little difference between the 10-yr and 100 year events: excess storm water is being temporarily stored in the overbank areas while the pipe system is at capacity. However, the extent of the downstream drainage system modeling is unclear and may not have been analyzed too vigorously. Given the complexity of flow patterns between the I-580 culvert and the project reach, we selected the design flows from the BH 2005 report for the corresponding 2-

yr, 10-yr, 25-yr and 100-yr flow events and then scaled the values up by 10% as a factor of safety. Values were scaled up to account for uncertainty in the overall storm drainage system performance and localized detention effects. This ensures that concept designs would be feasible under conservative discharge assumptions.

Peak flows used in Restoration Alternative Analysis

Profile Name	Recurrence Interval (yr)	%Exceedance Probability	Discharge (cfs)
Q2	2	50	120
Q10	10	10	191
Q25	25	4	194
Q100	100	1	198

By conservatively estimating the flow numbers, it ensures that the any quantities or design details presented in feasibility analysis will apply to detailed design as the project moves towards construction readiness.

Extensive examination and modeling of offsite, privately owned stormwater management systems was not included in this report. Also, it should be noted that alternatives that remedy upstream hydro-modification, considering the current downstream drainage system capacities, would not address the significant erosion that has occurred in the reach and would have limited impact on feasibility design. We believe a more effective approach in this case is to focus on the specific project reach and stabilize it under conservative flow numbers.

Land Use and Drainage

The Chimes Creek watershed experienced rapid development during the pre and post-war period due to its proximity to San Francisco, Oakland, and California's fertile inland valleys. A historical USGS topographic map from 1897 depicts the Chimes Creek watershed as mostly undeveloped land with no permanent structures located in the vicinity of what are now the Leona Quarry, Seminary Drive, and the Hillsmont neighborhood (**Figure 3**). An aerial image dated to 1946 (HA, 2009) and a 1947 USGG topographic map (**Figure 3**) show that the area is moderately developed with approximately 70% of the watershed already converted into residential neighborhoods and asphalt surface roads. A 1958 aerial image suggests development continued steadily into the late 1950s and raised developed land area to well over 80% of the watershed. Initial development was focused in the flat alluvial fan at the base of the Chimes Creek watershed; however, as development pressure increased and available land decreased, residential neighborhoods were constructed on adjacent hillsides and hilltops near the current locations of Campus, Ridgemont, and Viewcrest Drives.

As urban development proceeded, streams like Arroyo Viejo, Peralta, and Chimes Creek were straightened, channelized, and conformed to meet drainage and engineering goals. The lower portion of Chimes Creek from I-580 to Delmont Ave. was converted to an underground culvert system that varies in diameter between 48 and 57 inches. Surface run-off from paved streets and the city drainage system enter the Chimes Creek culvert in numerous locations and eventually empty into the project reach. While a majority of Chimes Creek is culverted, a short (1150 ft) section surfaces between Hillmont Dr. at Delmont Ave. and the ACFCD culvert 200 ft downstream of Nairobi Place. This region of Chimes Creek has undergone considerable erosion most notably in the 1981-1982 El Nino event and during a January 2006 storm event that wreaked havoc on many undersized culvert and stream systems throughout California.

Aside from the general residential development and corresponding increase in impervious surface cover described above, three other large scale projects dominate Land Use and Drainage alterations in the Chimes Creek watershed. The first occurred with the opening of the Leona Quarry in 1904, which operated as a coarse aggregate mine for construction projects throughout the Bay Area. Run-off volume likely increased significantly after the Quarry opened due to a reduction in vegetation and stripping of native soils. Development of the Ridgemont neighborhood in 1982 above the Leona Quarry also modified the hydrology of Chimes Creek through the addition of increased surface run-off that was eventually mitigated as part of the 2005 Leona Quarry project. The third and most recent development occurred in 2005 after Leona Quarry was reclaimed and converted to a 427 unit residential neighborhood. Extensive site grading and re-vegetation, including an expanded stormwater detention basin, were completed in an effort to reduce downstream development impacts. A final hydrologic study by Balance Hydrologics (BH, 2005) and review by Phillip Williams and Associates (PWA, 2006) found that as-built flow peaks at the I-580 culvert had decreased by 17.5, 22.4, 4.9 and 0.9 for the 2, 5, 10, 25, and 100 year flow events, respectively.

Hydrology and Geomorphology of Urban Streams

Urban development across the Bay Area drastically altered the hydrologic and geomorphic regimes of coastal streams draining into San Francisco Bay. Urban development results in increased impervious surface areas that reduce infiltration and time lags between rainfall and flood peaks, and increase sheet flow velocity and flood magnitudes. Overall, urbanization has created streams that have a higher relative erosive power and respond more rapidly than in their pre-developed state. Additionally, in the long term, urban development tends to reduce the amount of sediment entering a stream as banks are stabilized and buildings, roadways, and other structures decrease sediment inputs.

Unfortunately, discharge and sediment transport data, morphologic surveys, and high resolution aerial imagery spanning the undeveloped and developed periods for the project site are unavailable, so determining the timing and magnitude of urban development effects on Chimes Creek is not easily accomplished. Despite these uncertainties, the link between hydrology and geomorphology is well established.

Streams respond to changes in discharge and sediment inputs by adjusting their shape (profile and planform) or roughness over varying timescales in what Lane, 1955 called a dynamic equilibrium (**Figure 4A**). Prior to major urban development Chimes Creek was likely in such a state, adjusting its slope, sediment size, and planform shape to channel inputs such as precipitation, mass wasting, and bank erosion. As the equilibrium shifted concurrent with urban development; sediment sources were removed and discharge was increased. This initiated a sequence of geomorphic change that can be predicted with the conceptual model of stream response shown in **Figure 4B**. Increased discharge and reduced sediment supply in Chimes Creek will cause a decrease in channel slope as the increased erosive power of the stream removes sediment in the channel.

Anecdotal evidence can be useful in determining geomorphic response in urban watersheds. For example, during a community meeting on March 25th 2009, residents provided a rough timeline of major erosion events along Chimes Creek. These observations verify the predictions of channel response of Figure 4A and 4B. For example, residents reported that in the early 1980s, it was possible to walk down a gradually sloped bank and across Chimes Creek at approximately STA 6+80. Currently, the average top of bank width is 20 feet and a near vertical 8 foot tall slope prohibits easy access across the channel. To quantify the direction, magnitude, and processes of ongoing channel profile and planform changes for feasibility level design, a contemporary geomorphic analysis is warranted (See Section 2 "Geomorphic Analysis").

Figure 4A. Lane's Scale of Dynamic Equilibrium
(Rosgen, 1996)

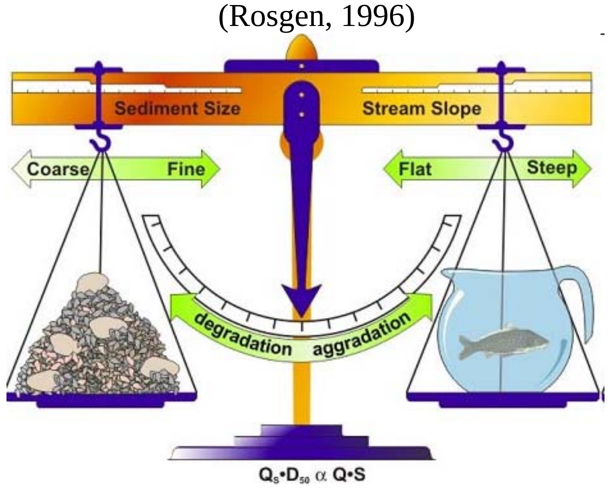
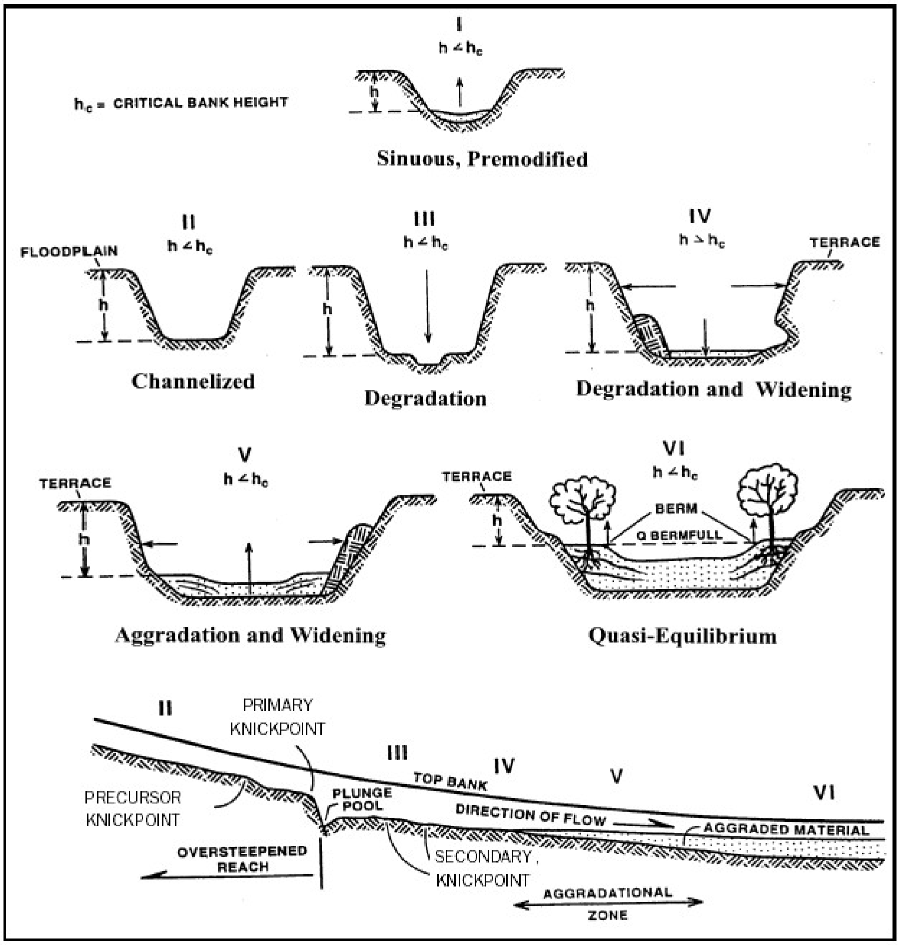


Figure 4B. Conceptual Channel Evolution Model
(Schumm, 1984)



SECTION 2. GEOMORPHIC ANALYSIS

This section of the Bank Stabilization Feasibility report presents (1) a review of watershed scale geomorphic processes and (2) a reach scale geomorphic analysis of Chimes Creek. The former describes large scale processes and patterns that may affect channel morphology in the Chimes Creek project reach, while the latter presents key reach scale processes illuminated through a topographic survey, geomorphic inventory, bankfull channel dimension, and plan and profile analysis of the entire project reach (STA 0+00 – 11+50). A geomorphic analysis investigates the relationship between hydrologic components of a watershed such as precipitation and slope and their effect on stream shape (profile, planform). Typical procedures of a geomorphic analysis include quantifying physical features of the watershed (slope, curvature) and reach scale characteristics such width, bank height, erosion sites, channel knickpoints, slope, bars, pools, and riffles. The main goal is to identify the key ongoing