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Authors
Goodman, Judd
Lunde, Kevin B
Zaro, Theresa

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BAXTER CREEK GATEWAY PARK:
ASSESSMENT OF AN URBAN STREAM RESTORATION PROJECT

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Prepared for:
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Instructor: Dr. Mark Tompkins
University of California, Berkeley

Prepared by:
Judd Goodman
Kevin B Lunde
Theresa Zaro

ABSTRACT

This study describes a post-project evaluation of the Baxter Creek Gateway Restoration Project located in a small, urbanized section of creek in the City of El Cerrito, Contra Costa County, California. The project was conducted to restore sinuosity, provide aquatic and riparian habitat, and enhance public access to a 700-foot section of channelized stream. Our assessment of this project's performance (completed less than a year after the project was constructed) evaluated the restoration effort's progress and provides a baseline for future assessments of the project as it matures. Assessment approaches and techniques included physical surveys of the creek's longitudinal (long) profile and several cross sections, facies mapping of the creek's bed structure, estimation of a sediment budget for the site's drainage basin, observations of site users, interviews with community stakeholders, visual evaluation of vegetation success rates, and photo documentation of current site conditions.

Although the restoration project is new and some intended features will take years to develop, we evaluated the project based on the proposed goals that we could measure and interpret with only two to three days of field work. We found that the creek's planform was similar to the plans but detected some bank erosion as well as bed material transport from the upstream to downstream end of the project. The current sediment yield for the urban catchment is much less than during historical conditions. Based on bed structure measurements, sediments will need to be managed at the site as common flows were predicted to move gravels and cobbles in the restored reach. The quality of potential vegetative and aquatic habitat within the project site had increased as a result of the restoration, but the site's surrounding culverted creek and urbanized landscape limit the feasibility of fish and amphibian colonization. Exotic riparian vegetation grew prolifically despite the fact that crews removed all vegetation during construction, planted only natives, and a citizen group frequently removed invasives. The multi-use trail and interpretive signs contributed to a successful recreational community space, but the trail will need improvements in connectivity beyond the project site before it can serve as a viable segment of the inter-city Ohlone Greenway trail system. The current monitoring plan for the restoration is well written and includes important abiotic and biotic factors, but we also recommend installing a permanent stream gauge at the site, monitoring flood overflow conveyance in adjacent streets, conducting physical surveys of the long profile and established cross sections, and regular facies mapping.

INTRODUCTION

River restoration is a rapidly growing field of study and has developed into a billion dollar business. Nationwide more than $7.5 billion dollars were spent from 1990 to 2003 to enhance the structure, function, biota, and water quality in streams and rivers, yet we know very little about outcomes from these projects (Bernhart et al., 2005). Since more money will be spent on restoration in the future it is imperative that restoration ecologists, planners, and engineers learn as much as possible about the successful components of these projects. Many restoration projects have been implemented in urban areas where there is a need to meet many project objectives (e.g., flood control and ecological restoration) with many project constraints (e.g., narrow right of way and nonpoint source pollutants). To understand the outcomes of a recent urban restoration project, we conducted a post-project appraisal of the Baxter Creek Gateway Restoration Project in El Cerrito, California. This paper will serve as an evaluation of the project and also contains data that can be used as a baseline for future evaluations at the Gateway site.

Site Location and History

The Baxter Creek Gateway Restoration project is located in the City of El Cerrito in the East San Francisco Bay Area (Figure 1). The site is located on a 1.6 acre property 700 feet long and contains a reach of one of three tributaries of Baxter Creek (Figures 2 & 3). The stream is culverted just above the project and drains a mostly urban landscape. The stream is again culverted immediately below the project site so water can pass under San Pablo Avenue before joining the other two tributaries.

Baxter Creek once supported substantial red-legged frog (*Rana draytonii*) populations, and was even a source of frogs for a frog farming operation in the late 19th century (Owens-Viani, 2004). It is probable that this coastal stream also supported a number of native fish species in the past, such as three-spined stickleback (*Gasterosteus aculeatus*), Sacramento sucker (*Catostomus occidentalis*), and California roach (*Lavinia symmetricus*) (Robert Leidy, *pers comm.*). However, as railways, roads, and housing were added to the landscape, most of Baxter Creek and its tributaries were channelized or diverted into underground culverts, reducing a dynamic system to a water conveyance pipe (Figure 3).

The Friends of Baxter Creek, a local non-profit environmental organization, spearheaded a movement to restore this portion of the creek, which was valuable since it was an earthen channelized section that had not been culverted like most other portions of the creek (Figure 3). The City of El Cerrito undertook the restoration project as the lead agency, donated $50,000 for the project, and solicited funds from the State Water Resources Control Board for $492,000 and the California Coastal Conservancy for $450,000. Monies purchased the land, covered construction costs of the creek and pedestrian path, and paid for monitoring and management of the site post construction conducted by The Watershed Project. Construction began in summer 2005 and was officially completed in September 2006. To date, most post-project surveys as mentioned in the monitoring plan (e.g., water chemistry, benthic macroinvertebrates, and vegetation) have been conducted by various agencies and the Watershed Project is currently analyzing these indicators.

Restoration Project Objectives and Description

The restoration project's goals varied between documents and over time, but the overall restoration aims were as follows:

1) Restore the channel including water quality, habitat quality, aquatic biota & native vegetation
2) Build community capacity for watershed management and stewardship by developing watershed-wide programs for education and outreach monitoring; and
3) Integrate amenities into the Gateway restoration site that facilitate on-going education, participation, and training related to watershed stewardship and restoration.

In order to reach these goals, the restoration project included the following activities: reconfiguration of the creek channel planform to introduce sinuosity; importation of gravel and cobble to recreate processes of deposition and erosion; grading outside the channel to create an active floodplain to enhance seasonal flooding; planting of native riparian vegetation to promote habitat and control erosion; extension of a multi-use pedestrian trail to allow public access to the creek; and creation of educational signage and programs to encourage stewardship and raise community awareness (EOA, 2005; 2006).

Post-Project Appraisal Aims

Our post-project appraisal seeks to evaluate how Baxter Creek Gateway Project is meeting its stated objectives. We evaluated quantitative and qualitative indicators of these aims. In addition, we evaluated other potential outcomes, such as geomorphic analyses, which are very important to the project's long-term success and will supplement data collected by The Watershed Project. In sum, we assessed the current status of the Gateway project in relation to: 1) flood control; 2) geomorphology: 3) habitat; and 4) social and educational outcomes.

METHODS

We spent a total of four days at the site, characterizing the physical features of the stream reach, quantifying public use of the site, and observing the system and its ecology first hand. For our post-project appraisal we reviewed the engineering plans, Project Assessment and Evaluation Plan (EOA, 2005), Maintenance & Management Guide (El Cerrito, 2006), Quality Assurance Project Plan (EOA, 2006), flow memorandum by FarWest Restoration Engineering (Leventhal, 2006), and website documents (Friends of Baxter Creek, 2006).

Flood Control

We assessed flood protection and hydraulic behavior of the Gateway project by analyzing the following:

- Hydrology
- Hydraulics
- Interviews of local businesses

Hydrology: In order to assess the magnitude of flows anticipated in the reach, we analyzed the hydrology of the project's drainage basin. Though stream gauge data is not available for Baxter Creek, the City of El Cerrito Department of Public Works has modeled the flow rates at the outlet of the pipe off Key Boulevard (Leventhal, 2006). We compared the 10-year and 100-year flows with estimates based on the Rantz flood frequency analysis for the San Francisco Bay Area and the Rational Method (Rantz, 1971). We determined parameters for both of these methods from a conceptual map (Figure 4) created from the USGS Richmond Quadrangle Map, land use maps of the area, and El Cerrito's Storm Drain Atlas.

Hydraulics: We reviewed the HEC-RAS model summary memo written by the design engineer (Leventhal, 2006). Three physical scenarios, each with the 10-year and 100-year flow events, were modeled. The scenarios included the pre-restoration condition, the restored design channel, and the restored design channel without a downstream hydraulic restriction. Because the original scope did not specify flood control as an objective, the design engineer did not hydraulically analyze the overbank flooding down Ohio and Conlon Streets. Therefore, to address this shortcoming, we used typical cross-sectional street geometry, measured slope, and Manning's equation, to estimate the discharge conveyed at curb level of Ohio and Conlon Streets. Manning's equation is expressed as $v = (1.49/ n) * R^{2/3} * S^{1/2}$ where: v is channel velocity; n is the roughness coefficient; R is hydraulic radius; and S is mean slope.

Interviews: The project team interviewed business owners adjacent to the Baxter Creek Gateway Restoration. We asked them how long their business has been located there and what flood problems they have encountered prior to and after the restoration construction. We also interviewed the design engineer of the project, who had observed the site during one of last winter's heavy storms.

Geomorphology

We identified morphologic processes acting on the project site by observing the system at a basin and reach scale. From the basin perspective we:

- Reviewed background documents.
- Prepared a Baxter Creek watershed profile.
- Approximated sediment yield of the basin for pre and post development conditions.

At the reach scale, we:

- Surveyed a longitudinal profile and eight cross-sections.
- Performed pebble counts at five gravel patches.
- Calculated critical bed shear stresses and the bankfull bed shear stress for each facie.

Background documents: In order to better understand the channel forming processes and anthropogenic changes of the basin, we reviewed: El Cerrito's Storm Drain Atlas; geologic and faulting maps (Figure 5); aerial photographs from 1939 and 2002 (Figures 6 and 7); a zoning map from 1937 (Figure 8); an artistic rendering of the Bay Area from 1911 (Figure 9); and a historical creek map from 1897 (Figure 10). We also walked the basin to identify open areas which might be sources of sediment. From the documents, geologic characteristics and changes to the basin land use were ascertained.

Baxter Creek Watershed Profile: We created a longitudinal profile of the Baxter Creek watershed from the headwaters of the Gateway Project basin to the San Francisco Bay outlet based on the USGS Richmond Quadrangle map. The profile shows where the project reach is in relation to the rest of watershed and in what geomorphic zone (production, transport, or deposition) it is in.

Basin Sediment Yield: As a first approximation, we estimated sediment yield by assuming that with steady state conditions (i.e. over a long time frame), the rate of uplift is equal to the rate of erosion in areas where erosion is free to occur. Thus, the sediment yield is expressed as $q_{sed} = \rho_r * (dz/dt) * A$ where: q_{sed} is sediment yield; ρ_r is density of rock; dz/dt is uplift rate; and A is undeveloped area. We assumed that developed areas with underground storm drains do not contribute sediment to the channel.

Physical Survey: One way to measure morphologic changes of a channel is to routinely survey established cross sections and longitudinal profiles after high flow events and compare conditions through time. We surveyed eight cross sections and one longitudinal profile at the Gateway site using a level, stadia rod, and tape measure. We marked the cross-section locations with pins and tags so that they could be easily identified for future surveys (Figure 11). The benchmark used was in Conlon Street, underneath a monument cover, as shown on the project drawings (Figure 12). Our survey acts as baseline since no as-built survey was performed, though we did compare the longitudinal profile to the designed profile.

Facies Mapping, Pebble Counts, and Bed Shear Stress Calculations: We conducted facies mapping and pebble counts to catalogue the baseline status of the restoration, determine the location of the added gravels and cobble, and to predict flows required to move this bed material.

We identified facies based on a visual survey. Aquatic vegetation was recorded on the facies map since the substrate underneath the emergent vegetation could not be evaluated. Then, we conducted pebble counts along five individual facies of stream beds and gravel bars to determine the median pebble size (Wolman, 1954). We randomly sampled between 50 and 80 sediment clasts within each facie instead of the recommended 100 to avoid double counting clasts as the facies were relatively small. We then determined the median particle size (D_{50}) for each facie.

We computed the critical bed shear stress -- the stress needed to mobilize sediment -- for two of the gravel patches in which pebble counts were performed. Critical bed shear stress is computed by using the empirical equation ($\tau_c = \tau_c^* (\rho_s - \rho)\ g\ D_{50}$) where: τ_c is the critical bed shear stress (dynes/cm^2); τ_c^* is the Shield's number (0.047 for gravel); ρ_s is grain density (g/cm^3); ρ is water density (g/cm^3); g is acceleration due to gravity (cm/s^2); and D_{50} is the median grain size of the deposit (cm). We compared the critical stresses with the bed shear stress at the designed bankfull, which is computed as: ($\tau = \rho gRS$) where: τ is the bed shear stress (Pa/m of length); ρ is the density of water (kg/m^3); R is the hydraulic radius (m); and S is the overall channel slope (m/m). In general, in natural rivers, the bankfull shear stress is greater than the critical since sediment is expected to be transported during bankfull conditions. In theory the bankfull flow is approximately the channel forming discharge, which can be found by multiplying the sediment rating curve by the flow frequency curve. Though we did not construct a flow frequency curve or a sediment rating curve, we did estimate the mean velocity and discharge under bankfull conditions using Manning's equation ($n = 0.037$) and then approximated a recurrence interval to see whether it is similar to a 1 to 2 year event, as is typical of natural channels.

Wildlife and Vegetation Assessment

We investigated the historical presence of fish and amphibian species in the Baxter Creek watershed by looking at on-line museum records at the Museum of Vertebrate Zoology at UC Berkeley (MZV, 2006) and the California Academy of Sciences at San Francisco (CAS, 2006) to determine the pre-urban impact status of the creek. We also surveyed individuals knowledgeable of the current species in the watershed and at the Gateway site to determine whether populations at other reaches on Baxter

Creek could colonize the Gateway site. During visits to the Gateway site, we documented wildlife encountered (e.g., fish, amphibians) as an indicator of the value of the restoration project to aquatic and semi-aquatic species. We qualitatively evaluated the success of this goal because November is not the optimal time to survey amphibian breeding and multiple samples would need to be conducted throughout a season to determine if breeding of fish or amphibians is successful and document juvenile survival rates. In particular, we listened for amphibian mating calls and looked for adults at the site. We conducted sweeps with an aquarium net of two schools of small fish and visually identified a number of individuals from each school.

We also completed a photo survey to document the overall success of site vegetation, and referred to results from detailed 50-square-meter transects The Watershed Project conducted in July 2005 and July 2006 by (The Watershed Project, 2006)

Social and Educational Factors

The social aspects of the Baxter Creek Gateway Project are important components of the project's stated objectives, but as is often the case in creek restoration projects, there are few guidelines for evaluating these components (some are addressed in Purcell 2002). We assessed site visitation frequencies by tallying site visitors during three visits. We noted how each site user was traveling and whether or not each person interacted with the site (e.g., sat on a bench, read the signs). When appropriate, visitors to and neighbors of the site were asked their opinion of the project. We also assessed, albeit subjectively, the interpretive signage and usability of design elements throughout the site.

RESULTS

Flood Control

Hydrology: According to the El Cerrito Department of Public Works, the discharge associated with the 10-year and 100-year recurrence intervals is 90.5 and 130.5 cfs, respectively (Leventhal, 2006). For the Rantz Method we calculated Q_{10} = 54 cfs and Q_{100} = 220 cfs and for the Rational Method we calculated Q_{10} = 77 cfs and Q_{100} = 163 cfs (Table 1). These results assume 22 in/yr mean precipitation

(EOA Inc, 2005) and 113 acres of drainage area. The peak urbanized flows are approximately double what they were before the natural watershed was developed.

Hydraulics: The HEC-RAS model shows that the 30-inch downstream culvert is the controlling hydraulic condition as it is unable to convey the 10-year and 100-year flows. Using Manning's equation, the culvert is only able to convey 63 cfs, assuming a 2% slope and a full pipe. Both the pre-restoration and post-restoration models show a backwater condition in which Ohio Street and Conlon Street would divert water from the site onto San Pablo Avenue, though the post-restoration condition shows that flooding is reduced with additional flood plain capacity incorporated into the design. The conveyance capacities through the overflow streets was not assessed in the modeling report, but with a Manning's calculation assuming a 30-foot street width and a 2.4% slope, we estimate the conveyance at curb height as 45.5 cfs for each street. According to the flood modeling report, breakout flows may also be diverted to San Pablo Avenue at a location just upstream from the 30-inch storm drain outlet. The conveyance capacity of San Pablo Avenue was not determined. Velocities are low at the downstream end due to backwater, but they do increase in the upstream areas. The post-restoration scenario with no hydraulic restriction downstream predicts that a 100-year event could be conveyed without overflow onto side streets, though velocities would increase in the channel.

Interviews: Interviews of the businesses most susceptible to flooding are summarized in Table 2. Of note is J and R Transmission, which has been at its current location since 1953. One employee estimated that, prior to restoration, the channel would overtop onto their lot two to three times a year. Since restoration, they have had no flooding problems despite the wet winter last year. The design engineer observed the channel last winter during a heavy rain event and said that water flowed over the sidewalk and onto San Pablo Avenue due to a backwater pool at the northern end of the project.

Geomorphology

Background Documents: The historical documents indicate that the original stream had been moved into the Santa Fe Railroad right of way prior to 1897 (Figure 10). Below the location of the railroad a permanent stream channel is not apparent, indicating that the natural channel may have changed location several times within the floodplain. The aerial photos and zoning map indicate that the basin was developed to nearly the same extent in the late 1930's as it is presently. Undeveloped areas draining to the Baxter channel include the Mira Vista Golf Course, Canyon Trail, and the Gateway site itself (Figure 3). Geology of the basin includes shallow serpentine matrix mélange bedrock at the highest elevations, sandstone bedrock farther down slope with colluvial deposits to the north, and alluvial deposits in the vicinity of the Gateway site. The entire basin is within a mile of the Hayward Fault (Figure 5).

Baxter Creek Profile: The Baxter Creek watershed profile has a concave up curvature, typical of fluvial channels (Figure 13). The project site is located below the foothills shown by the grade break and is at the upstream end of the alluvial fan, a zone of deposition.

Basin Sediment Yield: We estimated the pre-developed sediment yield per unit area to be 1000 tonnes/km^2-yr (2854 tons/mi^2-yr) based on an uplift rate of 0.5 mm/yr for the Hayward Fault (Williams, 2004). This result is consistent with the documented sediment yield of Wildcat Creek, which has the same uplift rate as the study basin. The overall pre-development sediment yield is 494 tonnes/yr, assuming that all 122 acres of the natural drainage basin were being eroded. For post-development the area available for erosion is 28 acres, resulting in a long-term sediment yield of approximately 113 tonnes/yr. This rate is considered a maximum considering that maintenance crews dispose of accumulated sediment in catch basins and on travel ways. In fact, it would not be surprising if almost no sediment is supplied to the reach due to the urban setting of the basin and lack of open space. Thus the post-development long-term sediment yield is likely between 0 and 113 tonnes/yr.

Physical Survey: The longitudinal profile and eight cross sections are plotted and a plan map is provided showing the cross section locations (Figures 14-16H). Compared to the designed longitudinal profile, upper portions of the current Gateway Channel bed have eroded to form small step pools. It appears the channel banks have eroded from their original shape since the surveyed cross-sections deviate from the rectangular 8-foot by 1-foot design geometry.

Facies Mapping, Pebble Counts, and Bed Shear Stress Calculations: Locations selected for facies mapping are noted in Figure 14, and a detailed facies map of the upper half of the reach is shown in

Figure 17. Abundant in-channel aquatic emergent vegetation and algae appeared to occupy more than half of the overall reach (Figure 18), particularly in the lower section of the project. See Table 3 for results of the pebble counts, estimated critical bed shear stresses, and estimated recurrence interval of bed movement. It is important to note that the critical bed shear stress was less than the bankfull shear stress of the designed channel, 340 dyne/cm^2 (0.71 lb/ft^2), for all but (D_{50} = 47mm) facie #1. The designed bankfull geometry assumes a 1 ft depth, 8 ft channel width, and a 1.4% channel slope. The mean bankfull velocity is 4.1 ft/s and bankfull discharge is 31 cfs for the design condition. According to the Rantz method, this bankfull discharge corresponds with approximately a 4-year recurrence interval. Because the channel has changed since design, alternative bankfull shear stresses, velocity, and discharge are provided in the Appendix.

Wildlife and Vegetation Assessment

While many species were or were likely to be present historically, few were observed during our visits (Table 4). We heard mating calls from two male Pacific treefrogs (*Pseudacris regilla*) on Oct 17, 2006. Of the two fish schools sampled, all individuals were mosquitofish (*Gambusia affinis*). Based on visual observations of other schools in the reach, the total population of mosquitofish in the restored reach was between 500 to 1,000, and nearly all were juveniles. We also observed raccoon prints along the channel.

According to transect vegetation studies conducted by The Watershed Project, native grass and forb cover on the site had increased, but is still less than the cover of non-native grasses and forbs (The Watershed Project, 2006). The cover of native trees, mostly arroyo willows (*Salix lasiolepis*), has increased slightly, but the cover of native shrubs within the transects was negligible.

Social and Educational Outcomes

We observed and recorded levels of site use during four site visits. It should be noted that three out of the four observations were done on Tuesdays during the middle of the day and would most likely vary if we observed use on weekends or during typical commute hours. The average number of visitors to the site varied on the days during which we were observing (Table 5). The total numbers of visitors to the site varied by day as did their mode of transportation (Table 5, Figure 19). We also observed that several northbound cyclists traveling along the existing multi-use trail turn off onto Key Boulevard before reaching the project site. This was presumably because the project site's trail currently ends on San Pablo Avenue, a busy vehicular thoroughfare that cyclists would rather avoid, and so it can be concluded that better connectivity to downstream trails would encourage higher levels of site usage.

The interpretative signs at the site explained the restoration rational, process, and goals. The signage allowed visitors to better understand the restoration goals and why urban creeks are important amenities. The signs themselves were well written, durably constructed, easy to understand, and free of graffiti and markings.

DISCUSSION

Flood Control

Hydrology: Ideally, the hydrologic analysis would be performed with historical stream gauge records. Because Baxter Creek has not been gauged, we relied on empirical models to predict flow. These different models can produce varied results, as seen by the comparison of El Cerrito's estimated flows with the Rantz and Rational Methods. A reliable stream gauge record would eliminate uncertainty in hydrological analysis and would thus improve hydraulic analyses used to determine flood protection by better predicting the expected flow conditions. It is stated in the Monitoring and Assessment Plan that volunteers are to measure stream discharge once a month for nine months. This low frequency of monitoring will not provide statistically significant information about the basin's hydrology. We believe that it is worthwhile to install stream gages in Baxter Creek so that future hydrologic studies of the watershed can be more accurately and scientifically defined.

Hydraulics: Considering that the scenario with no hydraulic restriction downstream predicts that a 100-year event could be conveyed without overflow onto streets, it makes sense to look into enlarging the 30-inch storm drain. Daylighting this section of storm drain is not likely feasible because it is routed under San Pablo Avenue. According to Manning's equation, enlarging the pipe to 48-inches would allow the highest predicted flow of 220 cfs to be conveyed, assuming the same 2% slope. If the storm drain outlet were upsized, however, then higher velocities and bed shear stresses would result since the back water pool would likely no longer exist at high flows. These high velocities could cause undesired erosion if the channel bed and banks are not protected to limit sediment movement. Also, if the storm drain is upsized, then desired seasonal flooding over the banks will likely occur less frequently, thus compromising that habitat related goal. An alternative approach to upsizing the storm drain outlet is to perform a detailed flood analysis of the site in which the overflow capacity through Ohio Street, Conlon Street, and San Pablo Avenue would be assessed. This type of study would help address flood protection concerns for the properties located west and adjacent to the Baxter Creek Gateway Project, something which has not yet been done.

Interviews: Thus far, no property damage has occurred from flooding of the restoration site, despite a wet winter last year. Though this is certainly a good result, it does not mean that flooding will not occur in the future. As vegetation in and around the channel establishes itself, the corresponding increase in roughness may cause higher flow depths for a given flow.

Geomorphology

Background Documents: Based on geologic maps and field visits, we identified the geomorphic processes governing erosion of three undeveloped areas. We believe that the golf course is governed by diffusive soil creep as indicated by its lack of colluvial deposits and convex hilltop curvature (Figure 20). Canyon Trail is eroded by advective shallow landsliding and overland flow erosion, supported by the fact that it is located on a colluvial deposit and there are slide scars and rills visible (Figure 21). The Gateway site is formed by fluvial processes and is situated on alluvial deposits.

Baxter Creek Profile: The Gateway restoration site is located at the upstream end of an alluvial fan, where in natural conditions, sediment deposition would take place. However, the morphologic processes have changed as a result of development and a cessation of sediment being supplied from the basin above. The result is a channel that tends to incise.

Basin Sediment Yield: Looking at geomorphic processes at the basin scale shed light on how the channel form responded at the reach scale. Because the sediment supply has been greatly reduced (from ~494 tonnes/yr to 0-113 tonnes/yr) and peak storm flows have been magnified, due to greater impermeability of the basin, the water that flows into Baxter Creek Gateway channel is likely sediment starved. Thus, when the "hungry water" flows through the project reach, it tends to carry the sediment in the channel with it. In performing the pebble counts we found that the upper portion of the Gateway reach had a significant amount of clay at the bed surface, which was presumably covered by imported "washed, round drain rock aggregate, 1" to 6" in diameter" as mentioned in the bid specifications. Considering that the site is hydraulically controlled by the undersized 30-inch storm drain downstream, thus creating a backwater pool where velocities and shear stresses are negligible in the 10 and 100-year events (Leventhal, 2006), we anticipated channel erosion at the upper end and deposition at the lower end of the project. This was confirmed by our longitudinal profile survey (Figure 15), which shows that the upper end of the channel has cut down in the year since construction. The infilling at the lower end may exacerbate flooding onto adjacent property if it blocks the already undersized outlet. We anticipate that excavation of deposited sediment at the north end of the Gateway project will likely need to occur in the future.

Physical Survey: In comparing the surveyed cross sections with the designed channel shape, it appears that the initially steep bank walls (Figures 22 and 23) have eroded throughout the project reach. Tracking morphologic processes, such as these eroded banks, is essential to understanding how the creek physically changes over time and is also critical to carrying out an adaptive management approach. We recommend that surveying of the eight established cross sections and long profile, after significant storm flows, be included in the Baxter Creek Maintenance and Management Guide and that our survey be used as a baseline.

Facies Mapping, Pebble Counts, and Bed Shear Stress Calculations: According to the bed shear stress results, bed sediments become mobile at a critical shear stress lower than the bankfull bed shear stress. This is the normal condition in natural channels, but the question should be asked whether in an urban environment, the bed material ought to be moved. In an urban stream like the one at Gateway, the sediment supply has been cutoff upstream by urbanization, so there is no way of replacing bed material other than depositing it manually. From a managerial standpoint, the City must assess whether it is worth the maintenance cost to re-supply bed material in order to allow the channel to convey sediment. One key factor in this decision-making process might be determining how often the sediment needs to be re-supplied. This would be best determined by on-site monitoring through facies mapping.

Wildlife and Vegetation Assessment

The two species noted before the project was conducted, Pacific treefrog and mosquitofish, have either recolonized the site or survived the de-watering of the creek and grading that occurred during construction. Since we observed treefrogs attempting to mate, and others have observed successful larval recruitment from the site before restoration, we infer that the Gateway site will continue to support the complete life history of treefrogs and the population will remain viable. This could be confirmed with observation of egg laying in Jan/Feb and observation of larval emergence in May/June. Treefrogs are a robust amphibian species (Stebbins, 2003); this population may increase with a larger instream food supply (algae) or terrestrial juvenile/adult food supply (insects). Treefrogs will be a distinct biological amenity to the Gateway site as they are notable, charismatic, and will attract the attention of the public.

The presence of mosquitofish at the site indicates that the water quality, food availability, and overall habitat are suitable to support fish. However, mosquitofish is an invasive fish species that is tolerant of moderate to poor conditions and was brought to the West for mosquito control (Moyle, 2002). While not generally considered a wildlife amenity in streams, mosquitofish presence indicates that other native fish might survive in the reach if intentionally reintroduced. Also the abundant mosquitofish population serves as a food source to wading birds such as egrets and herons. The mosquitofish population at present appears to be benefiting from the protection of the instream vegetation (watercress and ludwigia) and if that were removed manually or during a storm event this population may decrease.

The absence of historical fish and amphibian species at Baxter Creek indicates a degraded status of the entire stream system and watershed in general. While the current restoration project was not designed to address problems in the larger watershed or other tributaries, we wanted to bring the current restoration project into a larger spatial and temporal context to discuss some limitations of urban restoration projects. Based on anecdotal reports, no other fish or amphibian species besides mosquitofish or treefrogs are present at other restored areas of Baxter Creek and thus we should not expect any of these other species to naturally recolonize the Gateway project. If, however, other populations existed elsewhere in the watershed, fish could probably not move instream between these sites, and amphibians could not reach the Gateway project over the urban landscape. If restoration managers were considering reintroducing fish or amphibian species from neighboring watersheds at the Gateway site, two important factors should be considered. First, the Gateway site has approximately 750 feet of potential instream habitat; native fish might require more habitat for foraging, avoiding predators, and reducing intraspecific competition to form a sustainable population. While the present reach lacks deep pools, which are places of refuge for fish during the summer, such features may develop in future years as the weirs continue to force water to scour the stream bed. Second, water quality in the stream is most certainly reduced due to nonpoint pollutants from herbicide use, lawn fertilizers, automobiles. The results from physio-chemical and chemical water testing of dissolved oxygen, temperature, and toxins that are currently being examined as part of the restoration project monitoring plan will help determine if water quality would be a limitation to the survival of native fish or amphibians.

The vegetation transects conducted by The Watershed Project show that the site is dominated by non-native plants but that some native species are surviving. Even maintaining a minority of native riparian species required constant weeding by Friends of Baxter Creek as well as a thorough watering scheme. However, the vegetation community will change as the willows mature and shade the creek and riparian areas; thus, a judgment on the success of the vegetation probably should not occur until the plant material has a many seasons to become established.

Social and Educational Outcomes

While the monitoring plans detail biological, vegetation, and water chemistry monitoring, we could find little information on efforts to monitor the success of the social aspect of the project's objectives. For example, a document entitled *Baxter Creek Restoration Project Monitoring and Assessment Plan* was prepared to fulfill the requirements of the project's funding grant and to ensure monitoring of water quality, habitat, benthic macroinvertebrate assemblage, and photodocumentation monitoring (EOA, 2006). While this monitoring process does involve the public and members of Friends of Baxter Creek and thus has a community stewardship aspect, it does not prescribe any monitoring or assessment of social and educational functions of the project site. Another document contained extensive adaptive management guidelines specifically for the Gateway Project (City of El Cerrito, 2006), complete with a calendar to guide maintenance and assessment, but also did not address community access, education, and stewardship.

The project site is currently being visited by a variety of users (recreation, commuting, pedestrian, cyclist, dog walkers, rollerbladers, etc.) and is designed appropriately to accommodate different intensities of usage. It was observed that most people are using the trail as a throughway and are not stopping in the site, possibly because the site's surrounding land uses and nearby BART track are not conducive to a sit-and-relax situation.

Restoration Plan Analysis

The gateway Restoration project was designed to meet multiple objectives, which can result in conflicts between various goals; however, we did not see a conflict between restoration goals for this project. Public access should not alter the water quality at the site as long as debris is maintained by the citizen groups (e.g., Friends of Baxter Creek) and dog waste is picked up by pet owners. To this end, we observed little dog feces or trash at the site. Also, since flood control was not a driver for this restoration project, which is often not the case in urban restoration, there was space to grade the site in order to hydrologically reconnect the floodplain and the stream. Restoring this lateral connectivity can restore stream function of silt and nutrient deposition on the floodplain and enhance both riparian vegetation and wildlife habitat (Tompkins, 2006).

Restoring sinuosity (meanders) to the channel form improved upon the straightened channel, but it is unclear how the meander amplitude and wavelength were determined from the available planning documents. If such information was not considered, then we recommend creating the restored structure based on the historical creek form, should such a form fit within the project bounds and goals, and be appropriate within the current geomorpholocial setting.

Supplementation of the streambed sediments with gravels, cobble, and large boulders provides habitat heterogeneity for insects and small organisms living on the creek bed. This habitat structure should help provide an adequate food base for fish, amphibians, and birds. The weirs and even the solitary boulders appear to be creating scour pools, which also create a diversity of aquatic habitats, thereby favoring a diverse aquatic community. The riffle-pool sequence mentioned in the plans has not yet developed at this site, though this may take time to form. While scour pools are developing, riffles were nonexistent. Riffles might be apparent in spring when flow is higher. However, areas that appear suitable for riffle formation are semi-covered in silt, which will limit the macroinvertebrate diversity at the site.

CONCLUSIONS

The Gateway Restoration Project at Baxter Creek in El Cerrito is likely to achieve many of its prescribed goals as the site continues to develop. We recommend that flood protection be added as an objective of the Gateway Project considering it is in the best interest of the community to prevent loss of property due to flooding. Another project objective, we recommend adding, is the understanding of geomorphologic processes and monitoring of erosion and deposition characteristics of the reach. In order to help meet these flood control and geomorphologic objectives of the Baxter Creek Gateway Restoration, we recommend the following: installation of a stream gauge at the site; analysis of flood overflow conveyance in Conlon Street, Ohio Street, and San Pablo Avenue to determine flood risk of adjacent properties; surveying of the eight established cross sections and long profile after peak storm events; and facies mapping of the project site after peak storm events.

In terms of social outcomes, because many northbound cyclists turn off the Ohlone Greenway trail before the project site we recommend that trail connectivity be made a priority in future planning efforts by the City. Also, future assessments of the project should include a survey of surrounding residents and workers, site users, and stakeholders in order better assess the achievement of the project's stated goals and what could foster greater use of the trail and interaction with the creek. Wildlife and water quality goals may be hard to attain because these results are largely determined by factors outside the project boundaries. Perhaps the City could consider reintroducing local populations of native fish or amphibians to see if a resident population can be established.

This restoration project was constructed with aspects of stream form, function, and ecology at its core. The monitoring plan for the water chemistry, macroinvertebrates, and vegetation will allow for adaptive management and quantitative success measurements of the many goals of the restoration project. Also, El Cerrito was wise to leave money for evaluation so important lessons can be learned from this project and applied to future restoration activities.

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TABLES

Table 1. Flow estimates for the restoration project

Flow (cfs)	FarWest documents*	Rantz method	Rational method
Q_{10}	90.5	54	77
Q_{100}	130.5	220	163

*** Leventhal, 2006**

Table 2. Interview results with local businesses

BUSINESS	TIME ON PROPERTY	FLOOD PROBLEMS
Red Onion Restaurant	7 years	None
J & R Transmission	53 years	Prior to restoration, banks overtop 2-3 times per year. Post-restoration, no problems.
N-max Furniture & Gifts	1 year	None

Table 3. List of facies attributes based on geomorphic analyses.

Facie	Area (ft^2)	D_{50} (mm)	% clasts Embedded	Critical shear stress (dynes/cm)*	Flow to produce critical shear stress (cfs)	RI of flow (yrs)**
#1 Cobble bar	27	47	9.8	373	47	6-8
#2 Instream bed	55	14	12.3	111	6	1-2
#3 Instream bed	67.5	20	6.2	159	11	1-2
#4 Gravel bar	45	22	9.1	167	13	1-2
#5 Gravel bar	33	16	3.9	122	8	1-2

*Bankfull bed shear stress estimated to be 340 dynes/cm.

**Recurrence interval (RI) estimated from Rantz method based on flow to produce listed critical shear stress (see Appendix)

Table 4. Records of wildlife in Baxter Creek watershed and at the Gateway site.

	In watershed historically*	In watershed pre-construction*	At site pre-construction**	At site post-construction
Amphibians				
Red-legged frog	Yes	No	No	No
Pacific treefrog	Yes	Yes	Yes	Yes
Western toad	Yes	No	No	No
Fish				
Three-spined stickleback	Probably	No	No	No
Sacramento sucker	Probably	No	No	No
California roach	Probably	No	No	No
Mosquitofish (invasive)	No	Yes	Yes	Yes

***records from MVZ 2006, CAS 2006, and interviews with Baxter Creek volunteers and Robert Leidy.**
****records from The Watershed Project documents and Baxter Creek volunteers.**

Table 5. Observations of visitors using the pedestrian trail.

Date	**Sampling window**	**Total number of visitors**		**Interaction with site**		**Rate (visitors/hr)**
		Cyclist	*Pedestrian*	*Sat or Ate*	*Read Sign*	
10/17/2006	12 pm- 2 pm	0	3	0	0	1.5
10/24/2006	9 am-1 pm	12	10	2	2	5.5
10/31/2006	11 am- 4 pm	8	11	1	2	3.8
12/04/2006	4 pm- 6 pm	4	3	0	0	3.5

APPENDIX

CALCULATION SHEET

AKM Consulting Engineers

Sheet 1 of ___

Project Name: Baxter Creek Gateway Project.

Project No.: ______ Computed by: ______ Checked by: ______ Date: 11/27/06

DATA ANALYSIS

(1) Slope ≈ 0.014 = 1.4%

(2) @ XS 4 → D_{50} ≈ 22 mm, D_{84} ≈ 45 mm
@ XS 1 → D_{50} ≈ 16 mm, D_{84} ≈ 30 mm

(3) cross-sections & longitudinal profile provided in figures 10-14?

(4) XS1 → bankfull depth ≈ 1.0 ft
bankfull width ≈ 8.2 ft
bankfull cross-sectional area ≈ 4.6 ft²

XS4 → bankfull depth ≈ 1.1 ft
bankfull width ≈ 7.5 ft
bankfull cross-sectional area ≈ 5.6 ft²

DESIGN (typical) → bankfull depth ≈ 1 ft
bank full width ≈ 8 ft
bank full cross-sectional area ≈ 7.5 ft²

LEOPOLD REGIONAL CURVE (0.18 mi² drainage area) → bankfull depth ≈ 1 ft
bankfull width ≈ 8 ft
bankfull cross-sectional area ≈ 8 ft²

- Differences btwn. 10/31/06 cross sections & design may be due to bank erosion and/or construction variation from plans.

- Design is based on Leopold regional curve for SF Bay Area.

(5) 1.5-year Q from plot (Rantz Method) ≈ **17 cfs**

$Q_{bankfull}$ from regional trend ≈ **13 cfs**

$Q_{bankfull}$ from channel hydraulics:

XS 1 → $u_{bankfull} = \frac{1.49}{n}(R)^{2/3} S^{1/2} = \frac{1.49}{0.037}\left(\frac{4.6ft^2}{8.4ft}\right)^{2/3}(0.014)^{1/2} = 3.19\ \frac{ft}{s}$

$Q_{bankfull} = 4.6ft^2 \times 3.19\ \frac{ft}{s} = $ **14.7 cfs**

XS 4 → $u_{bankfull} = \frac{1.49}{n}(R)^{2/3} S^{1/2} = \frac{1.49}{0.037}\left(\frac{5.6ft^2}{8.4ft}\right)^{2/3}(0.014)^{1/2} = 3.64\ \frac{ft}{s}$

$Q_{bankfull} = 5.6ft^2 \times 3.64\ \frac{ft}{s} = $ **20.4 cfs**

$Q_{bankfull}$ from design channel hydraulics:

$u_{bankfull} = \frac{1.49}{0.037}\left(\frac{7.5ft^2}{9.24ft}\right)^{2/3}(0.014)^{1/2} = 4.15\ \frac{ft}{s}$

$Q_{bankfull} = (7.5ft^2)(4.15\ \frac{ft}{s}) = $ **31.1 cfs** ← too high, why design this way?

T ≈ 4 yrs

(6)(a) Q required to move bed material:

XS 1 → $\tau_c = \tau_{*c}(\rho_s - \rho)\, g\, D_{50} = 0.047(2.65-1\ \frac{g}{cm^3})(981\ \frac{cm}{s^2})(1.6cm)$
$=$ **121.7 dyne/cm²**

flow depth @ movement: $h_c = \frac{\tau_c}{\rho g S} = \frac{121.7\ \frac{dyne}{cm^2}}{(1\frac{g}{cm^3})(981\frac{cm}{s^2})(0.014)} = $ **8.86 cm** $= 3.49\text{ in} = $ **0.29 ft**

$A_c \approx 1.2$ sq units × $\left(\frac{1ft \times 0.25ft}{sq\ unit}\right) = $ **0.3 ft²** OR $8ft \times 0.29ft = 2.32ft^2$ ⟸ DESIGN

$u_{manning} = \frac{1.49}{0.037} \times (0.29ft)^{2/3}(0.014)^{1/2} = $ **2.09 ft/s**

$Q_{manning} = 0.3ft^2 \times 2.09\ \frac{ft}{s} = $ **0.63 ft³/s** OR $2.32ft^2 \times 2.09\ \frac{ft}{s} = 4.85\ cfs$

(6)(b) T ≈ 0.0067 yr 2.44 day OR $T \approx \left(\frac{Q}{13.244}\right)^{1.64} = 0.19$ yrs.

CALCULATION SHEET

AKM Consulting Engineers

Sheet 3 of ___

Project Name: ___

Project No.: ___ Computed by: ___ Checked by: ___ Date: 11/27/06

(6)(a) Q required to move bed material

XS 4 → $\tau_c = (0.047)(2.65 - 1\frac{g}{cm^3})(981\frac{cm}{s^2})(2.2cm) = 167.4 \frac{dyne}{cm^2}$

$h_c = \frac{\tau_c}{\rho g S} = \frac{167.4 \frac{dyne}{cm^2}}{(1\frac{g}{cm^3})(981\frac{cm}{s^2})(0.014)} = 12.2cm = 4.80in = 0.40ft$

$A_c = 35 \text{ sq units} \times \left(\frac{1ft \times 0.25ft}{\text{sq units}}\right) = 0.88ft^2$ OR $8ft \times 0.40ft = 3.2ft^2$

$u_{manning} = \frac{1.49}{0.037} \times (0.40ft)^{2/3}(0.014)^{1/2} = 2.59 \frac{ft}{s}$

$Q_{manning} = 0.88ft^2 \times 2.59\frac{ft}{s} = 2.15 \frac{ft^3}{s}$ OR $3.2ft^2 \times 2.59\frac{ft}{s} = 8.29\frac{ft^3}{s}$

(6)(b) $T \approx \left(\frac{Q}{13.284}\right)^{1.64} = 0.05yr = 18.4 day$ OR $T \approx 0.46 yrs$

XS4 likely more representative than XS 1 since XS 1 acts as a pool in storm events.

(6c) suspension threshold

$\tau_b = \rho g R S = (1\frac{g}{cm^3})(981\frac{cm}{s^2})\left(\frac{5.6ft^2}{8.4ft}\right)\left(\frac{12in}{1ft}\right)\left(\frac{2.54cm}{1in}\right)(0.014) = 279.1 \frac{dyne}{cm^2}$

$u_* = \sqrt{\frac{\tau_b}{\rho}} = \sqrt{\frac{279.1 \frac{dyne}{cm^2}}{1\frac{g}{cm^3}}} = 16.7\frac{cm}{s}$ $u_* \approx w_s$ for max grain size in suspension.

$W_* = \frac{\rho w_s^3}{(\rho_s - \rho) g \nu} = \frac{(1\frac{g}{cm^3})(16.7\frac{cm}{s})^3}{(2.65\frac{g}{cm^3} - 1\frac{g}{cm^3})(981\frac{cm}{s^2})(0.01\frac{cm^2}{s})} = 288$

from empirical curve : $D_*' = 7 \times 10^4 = \frac{(\rho_s - \rho) g D_n^3}{\rho \nu^2}$

$D_n = \left(\frac{D_* \rho \nu^2}{(\rho_s - \rho) g}\right)^{1/3} = \left(\frac{(7\times10^4)(1\frac{g}{cm^3})(0.01\frac{cm^2}{s})^2}{(2.65 - 1\frac{g}{cm^3})(981\frac{cm}{s^2})}\right)^{1/3} = 0.163cm = 1.63mm$ coarse sand.

CALCULATION SHEET Sheet 4 of ___

AKM Consulting Engineers

Project Name: ___

Project No.: ___ Computed by: ___ Checked by: ___ Date: ___

(6)(e) Bedload transport rate for bankfull discharge.

$$\tau_* = \frac{\rho g R S}{(\rho_s - \rho) g D_{50}} = \frac{(1\,g/cm^3)(981\,\frac{cm}{s^2})(\frac{5.6\,ft^2}{8.4\,ft})(\frac{12\,in}{1\,ft})(\frac{2.54\,cm}{1\,in})(0.014)}{(1.65\,\frac{g}{cm^3})(981\,\frac{cm}{s^2})(22\,cm)} = \boxed{0.0784}$$

$$\Phi = 8(\tau_* - 0.047)^{1.5} = 8(0.0784 - 0.047)^{1.5} = \boxed{0.0444}$$

$$q_b = \left[\left(\frac{\rho_s}{\rho} - 1\right) g D_{50}^3\right]^{1/2} \Phi = \left[\left(\frac{2.65}{1} - 1\right)(981\,\frac{cm}{s^2})(22\,cm)^3\right]^{1/2} 0.0444$$

$$= \boxed{5.83\,\frac{cm^2}{s}}$$

$$\Rightarrow Q_b = (8\,ft)\left(\frac{1\,m}{3.28\,ft}\right)\left(5.83\,\frac{cm^2}{s}\right)\left(\frac{1\,m}{10^2\,cm}\right) = 0.142\,\frac{m^3}{s} \times \frac{2.65\times10^3\,kg}{m^3}$$

$$= 377\,\frac{kg}{s}$$

How does this relate to yearly sed. transport?

Leopold (Katalyn) 1994?

$$\text{Sinuosity: } \frac{\text{meander length}}{\text{straight length}} = \frac{750'}{625'} = 1.2$$

$$\frac{\lambda_{ave}}{\text{width}} = \frac{82.6\,ft}{8\,ft} = 10.3$$

Sediment yield $= (\rho)\left(\frac{\partial z}{\partial t}\right)(A)$

$$q_{sed,\,natural} = \left(\frac{2.0\,g}{cm^3}\right)\left(0.5\,\frac{mm}{yr}\right)(122\text{ acres}) = \left(\frac{2000\,kg}{m^3} \times \left(\frac{10^3\,m}{1\,km}\right)^3 \times \left(\frac{1\text{ tonne}}{10^3\,kg}\right)\right)\left(\frac{0.5\,mm}{yr} \times \frac{1\,km}{10^6\,mm}\right) * \left(122\text{ acres} \times \frac{1\,mi^2}{640\text{ acres}} \times \left(\frac{1.609\,km}{1\,mi}\right)^2\right)$$

$$= 494\ \frac{\text{tonne}}{yr}$$

$$q_{sed,\,developed} = \left[\frac{2000\,kg}{m^3} \times \left(\frac{10^3\,m}{1\,km}\right)^3 \times \left(\frac{1\text{ tonne}}{10^3\,kg}\right)\right] * \left[\frac{0.5\,mm}{yr} \times \frac{1\,km}{10^6\,mm}\right] * \left[28\text{ acres} \times \frac{1\,mi^2}{640\text{ acres}} \times \left(\frac{1.609\,km}{1\,mi}\right)^2\right]$$

$$= 113\ \frac{\text{tonne}}{yr}$$

$$\frac{q_{sed}}{A} = (\rho_{bedrock})\left(\frac{\partial z}{\partial t}\right) = \left(\frac{2000\,kg}{m^3} \times \left(\frac{10^3\,m}{1\,km}\right)^3 \times \left(\frac{1\text{ tonne}}{10^3\,kg}\right)\right) * \left(\frac{0.5\,mm}{yr} \times \frac{1\,km}{10^6\,mm}\right)$$

$$= 1000\ \frac{\text{tonne}}{km^2\text{-}yr}$$

Hydrology - Rantz Method $Q = K A^a P^b$

Drainage Area = 0.18 mi²

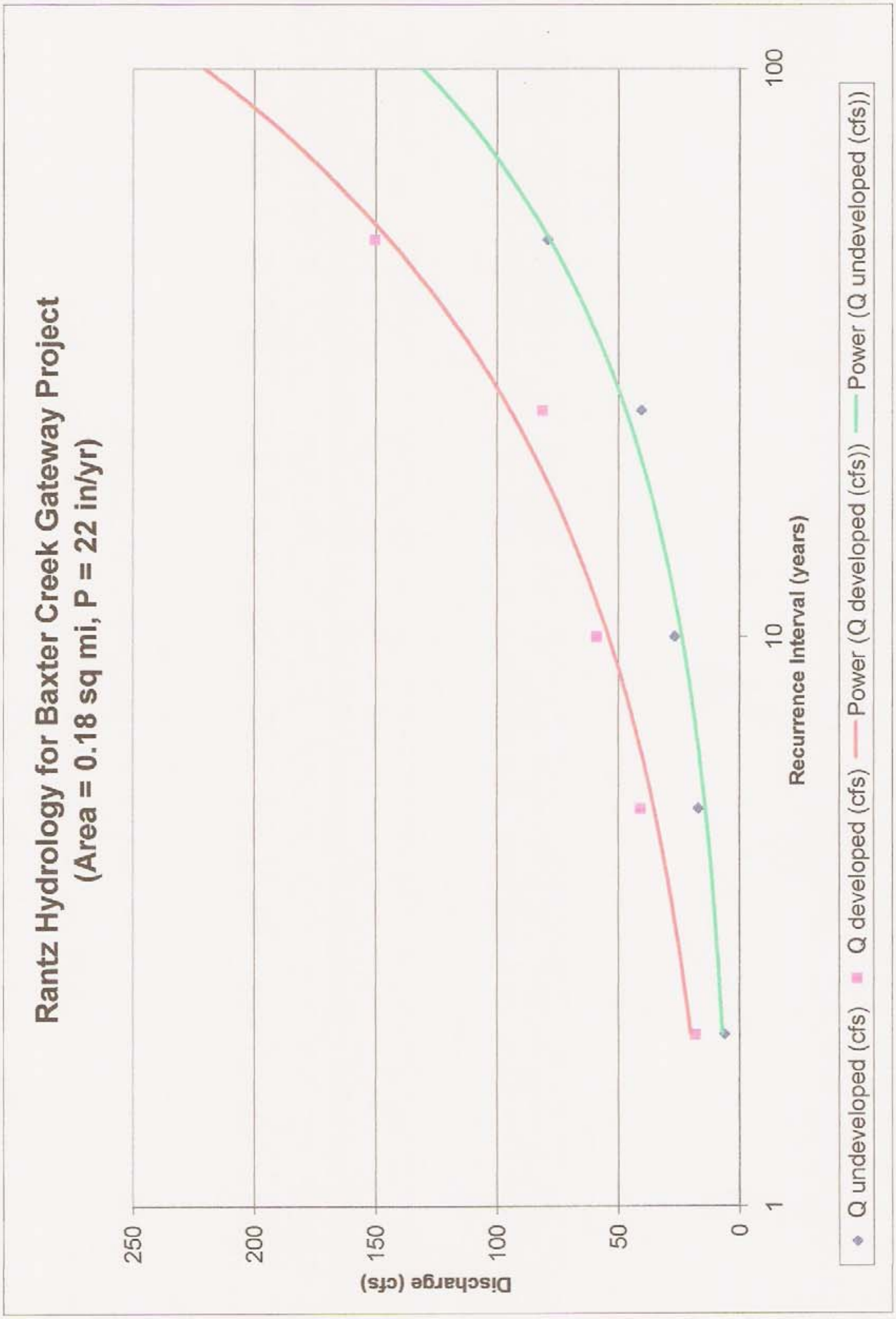
Mean annual precip. = 22 $\frac{in}{yr}$

Degree of Development = 77% urbanized

70% of channels sewered

		urban Coeff.
$Q_2 = 0.069 \times A^{0.913} \times P^{1.965}$	= 6.3 cfs	2.9
$Q_5 = 2 \times A^{0.925} \times P^{1.206}$	= 17.0 cfs	2.4
$Q_{10} = 7.38 \times A^{0.922} \times P^{0.928}$	= 26.7 cfs	2.2
$Q_{25} = 16.5 \times A^{0.912} \times P^{0.797}$	= 40.6 cfs	2
$Q_{50} = 69.6 \times A^{0.847} \times P^{0.511}$	= 79.0 cfs	1.9

Best fit is shown on plot!


Rantz Hydrology for Baxter Creek Gateway Project
(Area = 0.18 sq mi, P = 22 in/yr)
Discharge (cfs)
250
200
150
100
50
0
1
10
100
Recurrence Interval (years)
Q undeveloped (cfs)
Q developed (cfs)
Power (Q developed (cfs))
Power (Q undeveloped (cfs))

Hydrology - Rational Method $Q = Cia$

Given: Drainage Area = 113 acres

mean precip. = 22 in/yr

degree of development = 77%, single family residential.

Ave. channel characteristics → $L = 6400 ft$, $S \approx 9.2\%$, $n \approx 0.013$

cross-sectional area = 4.91 ft^2, $P \approx 7.85 ft$.

100yr event

overland travel time: $C = 0.4$, $t_{overland} = 12 min$

channel travel time: $v = \frac{1.49}{n}\left(\frac{A}{P}\right)^{2/3} S^{1/2} = \frac{1.49}{0.013}\left(\frac{4.91}{7.85}\right)^{2/3} 0.09^{1/2} = 25 \frac{ft}{s}$

$t_{channel} = \frac{6400 ft}{60 min \times 25 \frac{ft}{s}} = 4.3 min$

(Rantz, 1971)

$t_c \approx 16.3 min$

*Fig. 5 (impervious area) → 42% impervious, 100yr recurrence, $C = 0.77$

weighted C value = $(0.7 \times 0.77) + (0.3 \times 0.23) = .66$

*Table 4. $\frac{0.58 in}{16 min} \times \frac{60 min}{hr} = 2.18 \frac{in}{hr}$

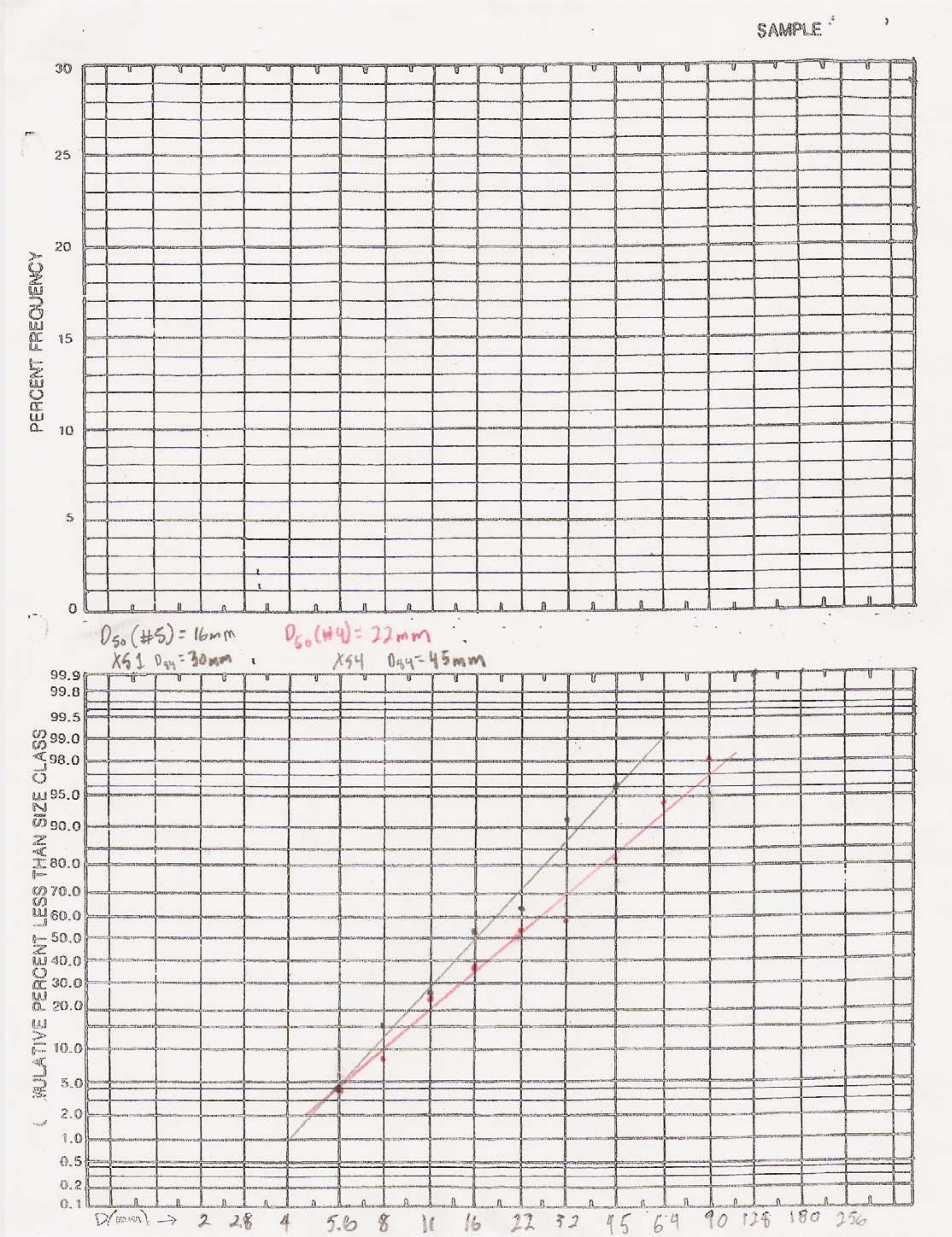
$Q_{100} = (0.66)(2.18 \frac{in}{hr})(113 acres) =$ **163 cfs = Q_{100}**

10 yr event

$t_c = 22 min$ $\quad i = 0.48 \frac{in}{hr} \times \frac{60 min}{22 min} = 1.31 \frac{in}{hr}$

$C = 0.52$

$Q_{10} = (0.52)(1.31 \frac{in}{hr})(113 acres) =$ **77 cfs = Q_{10}**


SAMPLE
PERCENT FREQUENCY
30
25
20
15
10
5
0
D_{50} (#5) = 16mm
X51 D_{84} = 30mm
D_{50} (#4) = 22mm
X54 D_{84} = 45mm
CUMULATIVE PERCENT LESS THAN SIZE CLASS
99.9
99.8
99.5
99.0
98.0
95.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
5.0
2.0
1.0
0.5
0.2
0.1
D(mm) → 2 2.8 4 5.6 8 11 16 22 32 45 64 90 128 180 256

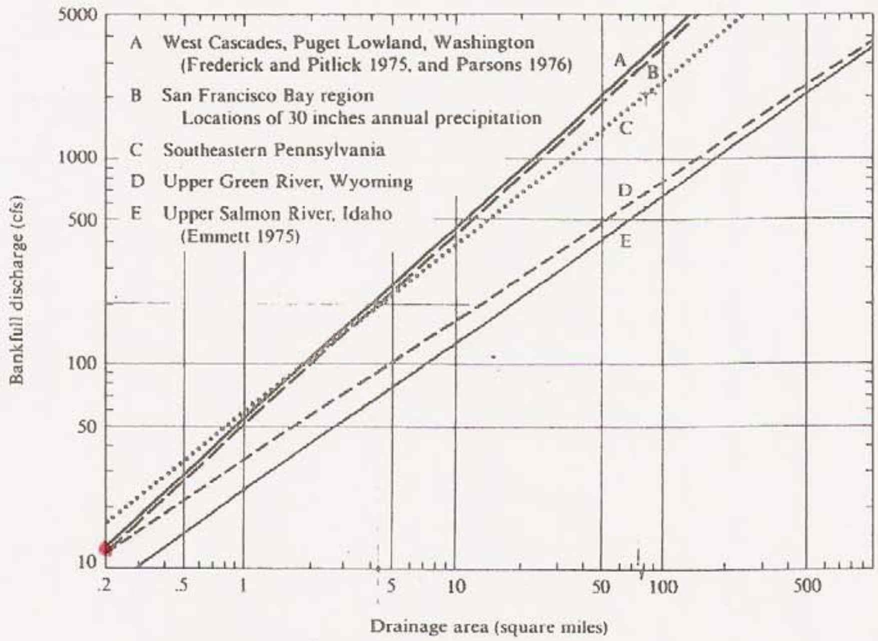


Figure 16-18 Bankfull discharge as a function of drainage area in the form of average relations for five regions.

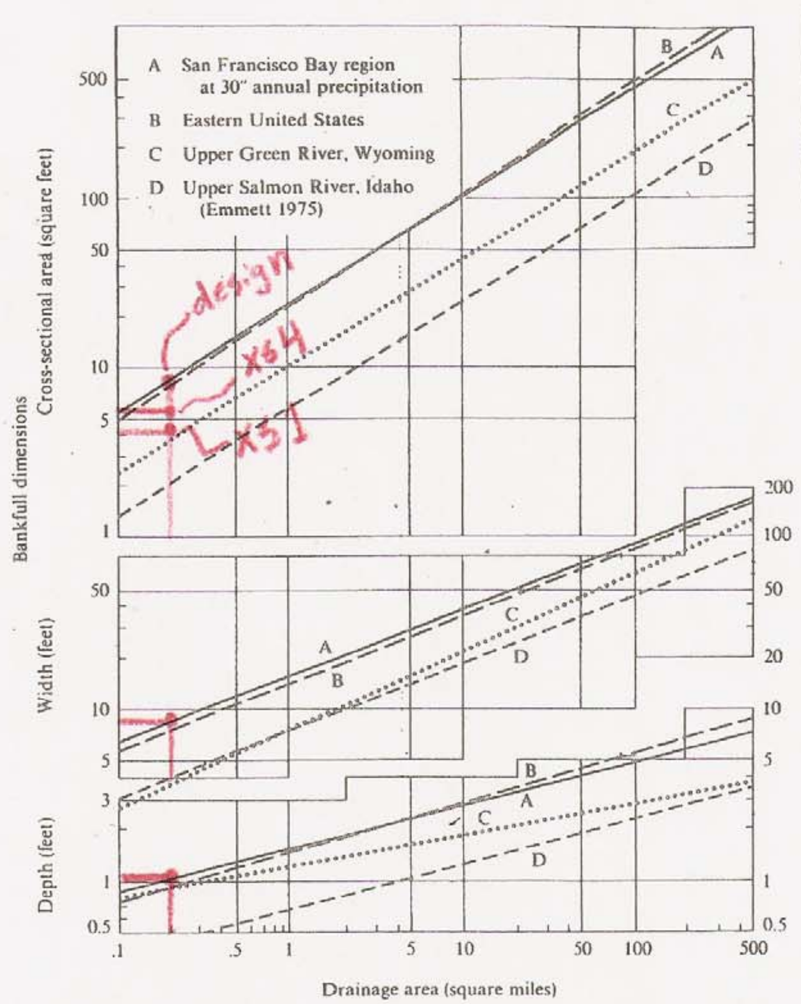


Figure 16-16 Average values of bankfull channel dimensions as functions of drainage area for four regions.