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Restoration Potential of a Mining-Impacted Urban Stream: Horseshoe Branch of Lion Creek, Oakland, CA

Final Draft

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Abstract

Horseshoe Creek, located in the Oakland Hills of California, flows through a remnant oak and redwood forests in Horseshoe Canyon. From the 1880s through the 1930s, nearby Leona sulfur mine deposited massive tailings piles in the valleys east of Horseshoe Creek. During that time, clear-cut logging of redwoods denuded and destabilized the surrounding hillsides. Today, most of Horseshoe Creek's upper and middle reaches are either culverted or transformed into an engineered channel, and Merritt College sits on top of the filled valleys that once formed its headwaters. Drawing from Past studies that have assessed heavy metals distribution and transport, we investigate the restoration potential of this highly impacted urban stream. In doing so, we consider the causes and effects of ecological degradation, identify areas for future study, and propose restoration actions.

Introduction

The San Francisco Bay Area grew rapidly during the mid-1800s from sparsely populated ranching region during the Spanish era to a hub of immigration, manufacturing and trade. San Francisco was the financial and shipping hub of the Gold Rush, but drew on the rest of the Bay Area for the raw materials necessary to build the city and supply miners passing through to the gold fields. Oakland produced redwood timber, fruits and vegetables, rock, and minerals the Gold Rush. After the completion of the Southern Pacific Railway in 1869, Oakland grew into an important shipping and manufacturing center. Though largely forgotten by contemporary residents, legacy impacts of this early resource extraction remain in the hills and along the waterfront (Walker, 2008).[1]

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[1] Historical information drawn from Richard Walker's excellent environmental history of the Bay Area, *The Country in the City, The Greening of The San Francisco Bay Area* (Walker, 2008).

In the 1920s and '30s, Oakland grew into a sprawling, densely urban city. Developers filled in the floodplains of the thirteen creeks that flow from the hills, down the piedmont, and to the bay, eliminating most public access in the flatlands. Sewers and industries discharged directly into surface water until 1951. Starting with Frederick Law Olmsted in the 1860s, some planners advocated preservation of streams in the Bay Area (among other cities), as urban greenways, but their efforts failed; in San Francisco, Oakland, and Berkeley, most creeks disappeared into pipes underground (Schwartz, 2000). Urbanization increased runoff, creating characteristically "flashy" hydrographs, and increased the volume of contaminants flowing into streams and the bay.

The urban stream restoration movement that arose in the San Francisco Bay Area in the 1970s has tried to address ongoing impacts from urbanization while considering the lasting legacy of the resource extraction era (Schwartz, 2000). Early efforts focused on public access, channel reconstruction, and revegetation, usually on short stream reaches flowing through public lands (Schwartz, 2000). Such projects create great social value through public access and educational opportunities (Kondolf, 2008). In most urban systems hydrology and water quality limit ecological recovery, so channel reconstruction projects produce limited ecological value. Few stream restoration projects in the Bay Area have addressed the impacts of mining, although hundreds of abandoned hard-rock mines leach acidity and heavy metals into area stream (Walker, 2008). The hydro-ecological effects of stormwater pollution are well understood, and in California most new development and redevelopment projects must capture and treat site stormwater runoff and mitigate for any increases in stormwater runoff rates (City of Oakland, 2005). However, no regulations mandate upgrades of existing developments, so any reduction in stormwater runoff will likely be city-funded or voluntary. Some city and county governments (e.g. San Francisco, CA; Portland, OR; Puyallup Co., WA) have

developed pilot programs or incentives to encourage stormwater treatment retrofits to residential properties, schools, and commercial buildings (Woelfle-Erskine and Uncapher, in press).

This study investigates restoration potential in an urban stream that is highly impacted by acid mine drainage and urbanization. Past studies of the creek have assessed heavy metals distribution and transport (Ahumada et al., 2008; Butler, 2007), and documented historical conditions on and near Mills College. We consider the causes of ecological degradation and identify priority reaches and restoration actions.

Study Area

Lion Creek in Oakland, California flows from the Oakland Hills to San Leandro Bay. Its 1600-acre watershed has been highly altered by mining, logging, and urban development. From now urbanized headwaters, the Horseshoe Creek branch of Lion Creek flows through remnant oak and redwood forests in Horseshoe Canyon, then joins Lion Creek and flows through a culvert under Highway 13 (Figure 1). Lion Creek daylights and flows in a natural channel through Mills College. Below the college, Lion Creek picks up the Chimes Creek tributary, then flows via culvert through the densely urbanized flatlands to San Leandro Bay.

Few historical records document pre-development conditions and land use changes, but past logging and mining leave visible traces on the landscape. Large redwood trees were logged in the late 19th century and likely dragged down the channel with oxen (Woelfle-Erskine, 2004). The Leona Quarry, near Horseshoe Creek's headwaters, provided stone to Oakland developers during the early 20th century, and then was used for a housing development (Walker, 2008). The Leona Mine produced sulphur and small amounts of metals from the 1880s through the 1930s (RWQCB,

2006); large tailings piles are visible in the channel of an unnamed tributary of Lion Creek (east of Horseshoe Creek). Most of Horseshoe Creek's upper and middle reaches were culverted or transformed into an engineered channel, and the upper valleys were filled in for the construction of Merritt College in the late 1960s (Robin Freeman, personal communication, 10.26.10).

Increased runoff and erosion caused by logging and urbanization has led to flooding in the upper watershed and increased sediment deposition in Lake Aliso on the Mills College campus (Robin Freeman, personal communication)[2]. Concerns about increased runoff and erosion from new developments prompted neighborhood creek advocacy briefly during the 1990s (Robin Freeman, personal communication). An active stream-advocacy group at Mills College hosts regular creek cleanup and restoration workdays and has restored native vegetation to a small reach on the Mills College campus. In 2009, high school students from the East Bay Academy for Young Scientists (EBAYS) adopted Horseshoe Creek and have been investigation restoration and trail maintenance strategies. Environmental studies and Landscape horticulture classes from Merritt College frequently use the creek for field classes, and the York Trail is popular with hikers and dog walkers.

Study Reach and Objectives

This report focuses on the portion of Horseshoe Creek between Merritt College and Highway 13 (Figure 2). We selected this reach for the following reasons

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[2] Robin Freeman's archive at the Merritt College Self-Reliant House contains minutes and correspondence from the now-defunct "Friends of Two Creeks" group, in which residents document flooding and erosion problems and concerns about a large shopping mall proposed for the former Leona Quarry, which is located outside our study area.

- It is within a City of Oakland Park: thus it is accessible and sees significant public use

- The canyon's steep topography prevents development along this stretch

- This reach has significant erosion due to increased flows from urban runoff

- It is impacted by low pH groundwater infiltration

- The reach is being studied by other groups

- The channel is constrained within narrow, steep canyons, and – on a human time-scale – its route has not changed dramatically

The objective of this study is to develop baseline biologic, geomorphic, and hydrologic analyses of Horseshoe Creek with the intent that this information would be used as a foundation for future studies of the Creek. In addition, we will present framework for the long-term rehabilitation of the Creek and discuss restoration strategies to addressing issues that are negatively affecting it.

Methods

Survey and Geomorphology

We surveyed two sub-reaches of Horseshoe Creek (Figure 2). The survey data consists of longitudinal profiles for the two reaches and six cross-sections, four at Profile 1 and two at Profile 2 (Figures 5-12). Profile 1 is called the lower reach and Profile 2 the upper reach. We used a Topcon level and survey rod to establish elevations and a surveyor's tape to measure distance. Elevations were recorded to the nearest tenth of a foot and distances to the nearest foot.

To establish control for this survey and provide a reference for future surveys, we set two 18-inch iron stakes. We located the stakes using a hand-held GPS. The first

stake is set at the base of a redwood tree and corresponds to the right bank pin of

Cross-section 1. Since no vertical benchmark was available in the area, this stake was

given an arbitrary elevation of 100-feet. Elevations for Profile 1 and Cross-sections 1 – 4

are relative to this benchmark. The second pin was set at the base of a redwood stump

corresponding to cross-section 5 in the upper reach. This stake was given the arbitrary

elevation of 1000-feet. Elevations for Profile 2 and Cross-sections 5 and 6 are relative to

the second stake.

GIS Mapping and Runoff Calculations

The Oakland Museum of California provides various maps of Bay Area

Watersheds to the public via their online Creek and Watershed Information Source.

Using the Lion Creek watershed map as a basemap (Figure 1), we extrapolated the

Horseshoe Creek sub-watershed in ArcMap and drew sub-watershed polygons along

paths orthogonal to topographic contours and along the peaks between adjacent creeks

(Figure 2). All of Merritt College was included in the Horseshoe Creek sub-watershed

because the drainage culvert for this property forms the current headwaters of the

Creek.

We used the rational method to calculate peak stream flow rates:

$$Q = 1.008 CIA \quad (1)$$

where Q = peak flow rate in cubic-feet-per-second (cfs), C = runoff coefficient, I = rainfall

intensity inches-per-hour (in/hr), and A = watershed surface area (acres). The runoff

coefficient (C) is the percentage of rainfall that will run off the ground surface during a

storm event and show up as a flow in the stream. Where multiple land uses are found

within the watershed, it is customary to use an area-weighted runoff coefficient according to the following equation:

$$C = \frac{\sum_i C_i A_i}{A_{total}} \qquad (2)$$

We primarily used runoff coefficients from a table offered by Environmental Modeling Systems Inc. (EMS, 2010) with input from the City of Oakland Storm Drainage Design Guidelines (City of Oakland, 2010). Using satellite imagery, different land use types in the Horseshoe Creek watershed were circumscribed with GIS polygons (Figure 3). We used these polygons to calculate area-weighted average runoff coefficients (Table 1). We calculated a pre-development flow rate using a runoff coefficient for parks and undeveloped lands. This calculated flow rate was used as a baseline for comparison to post-development flows

   Ideally, the rational method is used to estimate a watershed's runoff from measured peak stream flows and storm event precipitation. However, Horseshoe Creek is not gauged, so we approached the problem in a different way. First, we calculated a theoretical peak stream flow using satellite imagery to estimate runoff coefficients coupled with measured storm precipitation intensity. We then back-calculated runoff coefficients for the nearby Strawberry Creek and Codornices Creek watersheds, which are similar in elevation and land cover to Horseshoe Creek. We used measured precipitation and flow rates from two storm events to calculate and refine the rational method predictions of peak flow for Horseshoe Creek (Table 2). The 2007 Strawberry Creek Hydrology Report documented a February 2004 storm with an intensity of 0.88

in/hr that filled a 426 cfs culvert to capacity (EH&S, 2007). From this, the rational model yielded a runoff coefficient of 0.24 for the Strawberry Creek watershed. Live stream gauge data is available for Codornices Creek (Balance Hydrologics, 2010). During the November 20, 2010 rain event, measured peak flow rate and precipitation resulted in a runoff coefficient of 0.44 for the Codornices Creek watershed. These calculated values indicate that our estimated runoff coefficient of 0.36 for Horseshoe Creek is reasonable.

Bioassessment and pH

We used an "upstream-downstream" study framework to identify the impacts of acid mine drainage on aquatic communities in the study reach. We identified study sights using visual assessment and pH measurements (Table 3). In the lower study reach, knickpoint migration exposed brightly colored, acidic springs within and next to the stream channel. The average pH was 8.43 (n=9, range= 8.36-8.54). In the upper reach we found no colored sediments, and the average pH was 8.65 (n=12, range = 8.58-8.69). We collected five invertebrate samples at both study transects and combined them into one composite sample per site. We also collected pH, water depth, and habitat data at each site. The water depth and habitat data are incorporated into the long profile and cross sectional plots.

We collected macroinvertebrates from large riffles using the Surface Water Ambient Monitoring Program (SWAMP) bioassessment protocol (Ode, 2007). Riffles are the "richest" habitat because flow rates and oxygen levels are highest there, and thus usually offer the highest diversity of benthic macroinvertebrates (Ode, 2007). At each transect, we placed a D-frame net with a mesh size of 0.5-micrometers just downstream from the riffle, and sampled a one-square-foot area upstream of the net. We removed organisms from the large rocks by agitating them in the current then disturbed the top layer of gravel for 60-seconds making sure that all organisms entered the net. We

preserved the organisms within one hour in 95-percent ethanol for lab analysis, and analyzed the samples two weeks after collection.

In the lab, we separated the organisms by taxa and identified them to the family level. Collecting habitat data (e.g. sediment grain size, organic matter, dissolved oxygen, etc.) and collecting the replicate macroinvertebrate samples necessary for statistical analysis was beyond the scope of this study. Instead, we used the Hilsenhoff Family Biotic Index (FBI) (Zimmerman, 1993), a rapid-bioassessment procedure, to characterize the biotic communities upstream and downstream of the acid springs region of our study reach.

Results and Discussion

Channel Characterization and Erosion

The average longitudinal slope of the two reaches is 11-percent and 18-percent respectively. However, these steep slopes are misleading as both reaches have developed a step pool channel form, with small waterfalls punctuating short riffle-pool sections. This is most evident in Profile 2 (Figure 7) where there is a 9.5-foot drop in the channel between stations 0+75 and 0+95. Similarly, Profile 1 (Figure 6) has a drop of 3-feet between stations 0+43 and 0+48 and a drop of 2-feet between stations 0+82 and 0+90. The increased water velocity and scour at the base of these falls tends to erode and undercut the falls, increasing their height and pushing the headcut farther upstream.

While profiles provide insight onto the longitudinal character of the channel, cross-sections provide information about channel's shape and bank structure. Notably, cross-sections illuminate the effects of erosion. The footings of concrete walls along the right bank provide an indication of the former channel location. Cross-sections 2 and 3 (Figure 9,10) show that the current right stream bank is lower than the base of the wall

by 3.5 and 5-feet respectively. Similarly, Cross-section 4, which was taken at the base of a large head cut, shows a difference in bank height of 8-feet (Figure 11).

Changes in Flow Regime Following Urbanization

Table 1 presents the GIS polygon acreage, runoff coefficient values by category, and the calculated weighted-average runoff coefficients for this site. Since the coefficients provide a range of possible values: low, average, and high weighted averages were determined. Table 2 presents the average predicted percent increase in peak flow rate from the baseline, undeveloped condition. The results suggest, on average, a 109-percent increase in peak flow rate to the stream, with a 37-percent increase in the value of the runoff coefficients from Merritt College alone. Assuming no significant change to the channel size, the increased flow rates result in higher in-stream velocities. When water velocity increases, the shear stress on the channel increases. Greater shear stress results in increased erosion of the channel bed and banks -- evidence of which is clearly evident today.

Geomorphology

While there is no visual evidence that the channel in the lower reach has shifted position in recent history, it has suffered serious erosion. Two events – one historical, one ongoing – have contributed greatly to this erosion. The historical event was the clear-cut logging of the redwoods in the second half of the 19th Century. This activity denuded and destabilized the hillsides. It is difficult to quantitatively measure the effects of logging since there are no pre-logging measurements of the stream. However, there are a number of old-growth redwood stumps along the Creek's channel where the creek side roots are exposed and the stumps undercut from erosion (Figure 14). The location of these stumps provides anecdotal evidence of historical channel elevations.

The second and on-going cause of excessive erosion in the channel is the increased peak flows from the construction of Merritt College and the hard piping of the Creek upstream. Evidence of the effects of this erosion is apparent in the channel (Figure 16,17,18). Concrete walls and bridges have been built along the channel to stabilize the banks and provide a trail. There has been significant erosion and undercutting of these structures.   The height of the base of these walls relative to the current bank height provides evidence of the location of the channel banks at the time of their construction.

As a result of this erosion much of the portion of the Creek we surveyed now appears to be under bedrock or large boulder control, which will slow future downcutting of the channel. However, during high flows the Creek will continue to experience excessive bank erosion. Evidence of this ongoing erosion can be seen most clearly in Cross-section 4, where the left bank is undercut by 2-feet creating a cave-like area (Figure 11). Since the canyon walls are earthen and extend almost vertically upward from this undercut for several hundred feet, the eventual collapse of this undercut may trigger a larger landslide. The left bank of the Creek though out the entire area we surveyed is very steep, often 1:1 slope to near vertical and extends upward for hundred feet or more (Figure 15). Further bank erosion in the Creek will likely precipitate larger geomorphic changes.

 Water Quality

Previous researchers have identified high levels of heavy metals (~50 micrograms/ Liter of lead) in nearby springs, and elevated levels (~10-15 micrograms/L of lead) in our lower study reach (Figure 20), suggesting that contaminants are diluted in the stream, but are present in levels high enough to affect aquatic life (Schmidt et al.,

2008).[3] We confirmed earlier researchers' findings that pH in in-channel and near-channel springs ranges from two to four. We found that pH in the study reach ranges from 8.36 to 8.64. We found that the bedrock step at the downstream limit of Study Reach 1 marked a slight but distinct change in water quality. Downstream of this step, we noticed several acidic, orange-colored springs in the area where previous research documented elevated levels of lead, zinc, and copper (upstream of this step, pH averaged 8.65 (n=12, range=8.58-8.69) (Figure 4). Downstream of this step, pH averaged 8.43 (n=9, range=8.36-8.54). Neither reach exhibited pH depression to an extent that would impact benthic macroinvertebrate populations.

Benthic macroinvertebrate communities differed markedly upstream and downstream of the bedrock step (Table 3, Figure 5,19). Total abundance, number of taxa, and number of sensitive taxa were significantly higher upstream of the bedrock step than in the downstream acidic-spring-influenced reach. This preliminary survey suggests that heavy metals impacts in Horseshoe Branch extend beyond the zone of pH depression.[4]

Discussion

Our results give rise to a guiding image of Lion Creek as a stream that is heavily impacted by urban runoff and legacy mining activity. Here we present the guiding image, identify several restoration opportunities, and identify key questions for future research.

Guiding Image

The Lion Creek watershed is completely urbanized except for the steep reach of

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[3] The US EPA is currently revising its aquatic life standard for lead in water, so no legally binding standard is available. The British Columbia Ministry of Environment standard is 3 micrograms/L, well below the levels found in every sample from Lion Creek and its tributaries.
[4] Schmidt et al., 2002 found a similar effect in their study of acid mine drainage impacts on the North Fork Powell River (Virginia, USA).

Horseshoe Creek that flows through Horseshoe Canyon and a short, modified reach of Lion Creek that flows through Mills College. Although Horseshoe Creek is highly modified from pre-settler conditions, it retains much of its native vegetation and character. Second-growth redwood and California bay forest shade the step-pool channel, and ferns and native grasses have begun to stabilize some eroded slopes. Bedrock ledges, boulder cascades, and large woody debris control grade and trap alluvium in many reaches. Any restoration goals in this tributary will be limited by the dense urban character of the Oakland flatlands and upper watershed and, perhaps most significantly, by the acid mine drainage that transports heavy metals into the stream. Acid mine drainage is difficult and expensive to remediate, and limits ecological restoration of aquatic ecosystems. Nonetheless, there is considerable opportunity here to enhance the ecosystem services provided by Horseshoe Creek.

Restoration Opportunities in Horseshoe Creek

1. Stormwater: The most pressing geomorphic issue at Horseshoe Creek is the channel and bank erosion. The bedrock and engineered grade controls will help to stabilize the channel vertically, but the extremely narrow and steep banks will likely continue to erode during storm events. Decreasing runoff in the upper watershed (a "passive" strategy) may reduce erosion to the point where natural vegetation recovery stabilizes stream banks. This can be achieved either through large stormwater detention basins or a combination of "low impact design" strategies, including living roofs, infiltration swales, and permeable pavement (BASMAA, 1999). Since Merritt College has the single largest impact on the watershed, looking for ways to reduce runoff rates from the College's hardscape – parking lots, buildings, etc – is an obvious solution. Retrofitting existing storm drain systems to include Best Management Practices (BMPs) such as directing parking lot runoff to vegetated swales and detention areas has been

shown to reduce runoff rates and pollutant loads substantially (Xiao, 2009). These BMPs can be installed with little impact to the College, and they are relatively inexpensive, simple projects compared to the cost and challenge of earthwork and structural restoration in the stream channel. Removal of the concrete trapezoidal channel just below Merritt College may also be possible under a reduced runoff regime.

2. Riparian Vegetation: Several volunteer groups in this area participate in annual creek cleanups, and could spearhead efforts to remove invasive English ivy and Himalayan blackberry from the slopes. Non-native species currently help stabilize the steep, erosive canyon slopes, and should be removed gradually to avoid mobilizing hillside sediments. As a precaution, native species should be planted, and perhaps identified with trailside plaques to provide an educational benefit for students and hikers.

3. Public Access: The near-vertical slopes of Horseshoe Creek are not stable in the long term. Most trails are located on the tops of actively eroding terraces (Figure 16), which creates a considerable public safety risk. Relocation of the impacted trails seems like the most viable option. In some locations along the creek, trails could be moved to a lower terrace on the opposite bank. Trail users we encountered during fieldwork identified trail maintenance as a top priority, and some expressed willingness to participate in maintenance activities.

4. Mine Cleanup: Remediation of the acid mine drainage is long overdue; source control is the most beneficial solution. Given the extent of the impact, and the extent of residential development atop tailings and waste rock, complete source control may not be practical. *In situ* water treatment could be a viable option, especially in the lower reach before the stream enters the culvert at Highway 13. The valley widens in this reach, and the creek becomes more alluvial. Treatment in this location would not benefit

Horseshoe Creek, but would decrease metals transport to Mills College and the San Francisco Bay.

Future Research

Long-term studies, further hydrological analysis, and historical research can help illuminate the links between legacy mining impacts, geomorphology, hydrology, and biological condition. We identified the following five research and monitoring priorities:

Future Monitoring/Research Priorities
Continuing surveys of cross-sections and grade to assess channel stability and evolution
Measure peak flow rate during a storm even to calculate runoff coefficient
Biomonitoring and pH to identify downstream extent of AMD impact
Locate sources of AMD to Horseshoe Creek
Assess volume of tailings in unnamed tributary

Several Lion Creek studies are currently in process. Mills College professor Kristina Faul and her students are studying water chemistry and hydrology in Lion Creek and Lake Aliso to inform on-campus lake and stream restoration activities. An active Mills College group holds regular "Creek Care" days and involves local K-12 students in monitoring and restoration. The East Bay Academy for Young Scientists (EBAYS) is also conducting water quality monitoring and bioassessment studies in the watershed.

Although many unanswered questions remain about the exact mechanisms of contaminant transport, the general scope of the hydrological, geomorphologic, and water quality impacts of legacy land use changes are clear. To reduce erosion and flashy flows, Merritt College should implement low-impact design strategies such as permeable pavement, living roofs, and stormwater detention basins to decrease peak flows to

Horseshoe Creek. Only after peak flows have decreased and the channel stabilized should structural erosion-control measures be considered in the riparian zone. To improve water quality, mine waste should be removed, or acid mine drainage should be treated. Cleanup responsibility ultimately lies with the property owner, Collin Mbanugo. Recent fines have apparently been too low to force his action. The RWQCB should assess fines that reflect the true human and ecological cost of ongoing acid mine drainage, and use those revenues to remediate mining impacts. State and regional agencies should target limited funds at mine reclamation and stormwater reduction using an adaptive management approach that builds on current educational research projects at Mills College and EBAYS. Agencies, in collaboration with Mills and Merritt colleges, can provide technical support to volunteers to improve trails and restore native riparian vegetation.

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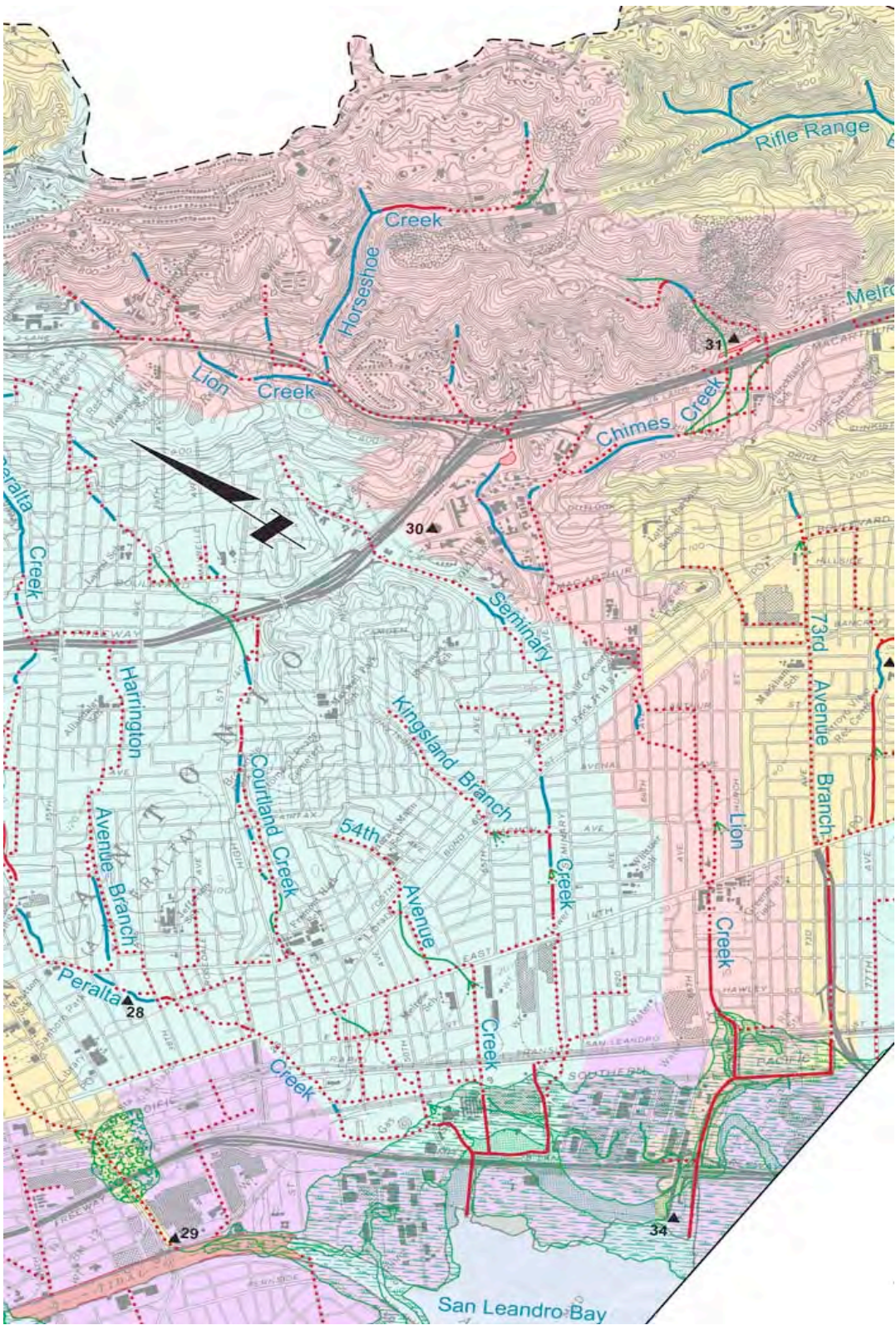
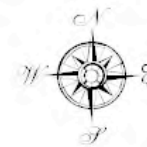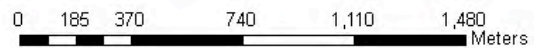**Figure 1: Lion Creek Watershed Delineated in Pink (Oakland Museum of California, 2010)**
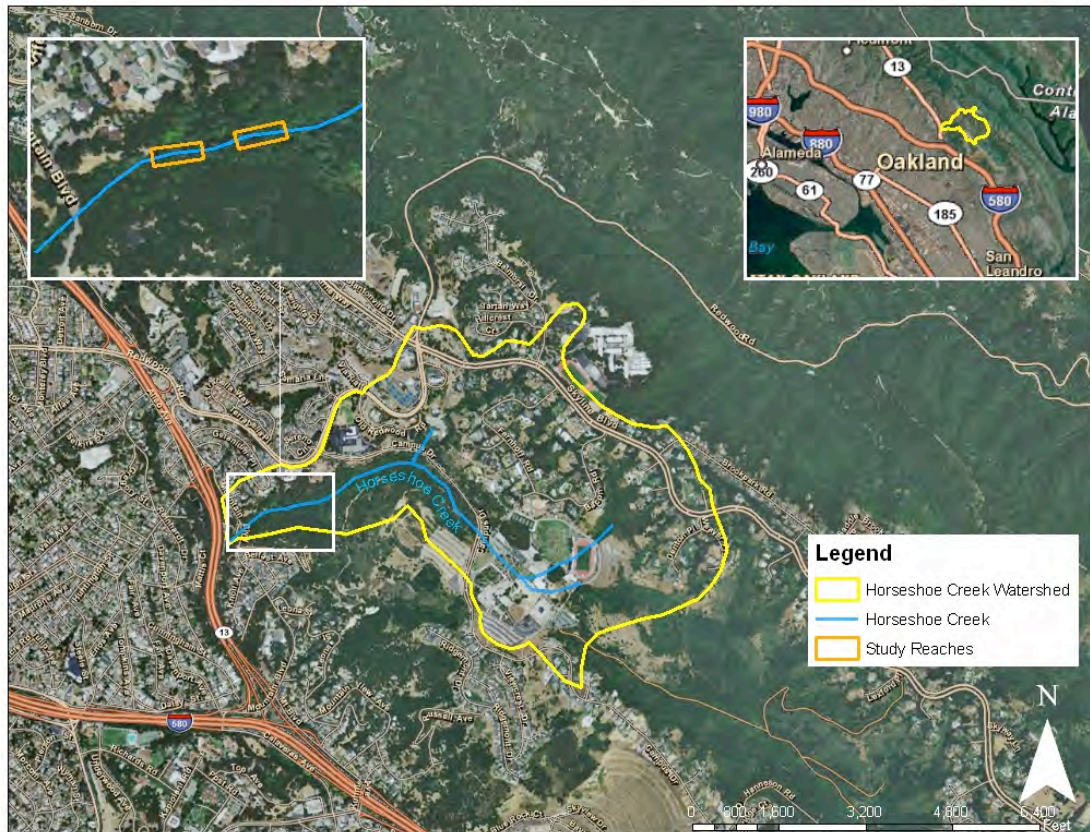
Figure 2: Study Reaches and Watershed of Horseshoe Branch, tributary of Lion Creek.
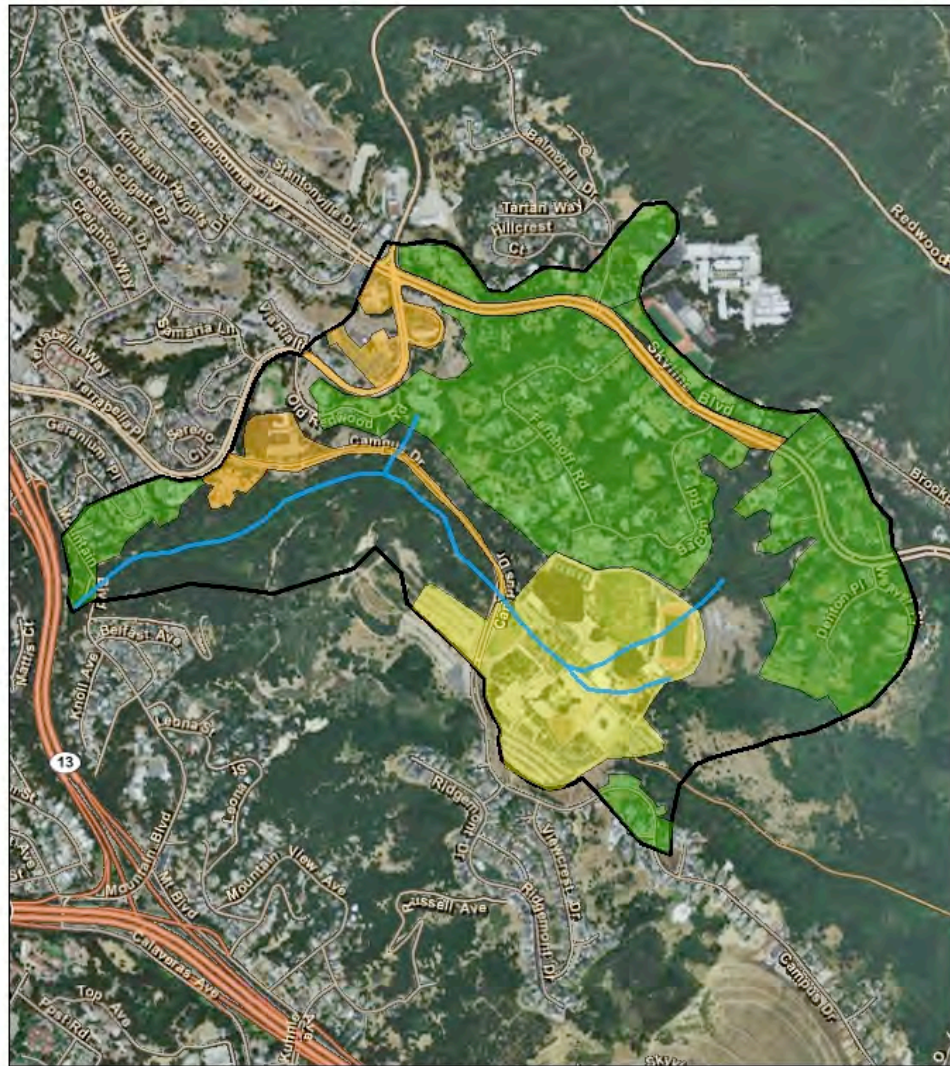
Figure 3: Developed areas in the watershed. These areas were weighted to assign the runoff coefficient for rational method calculations.
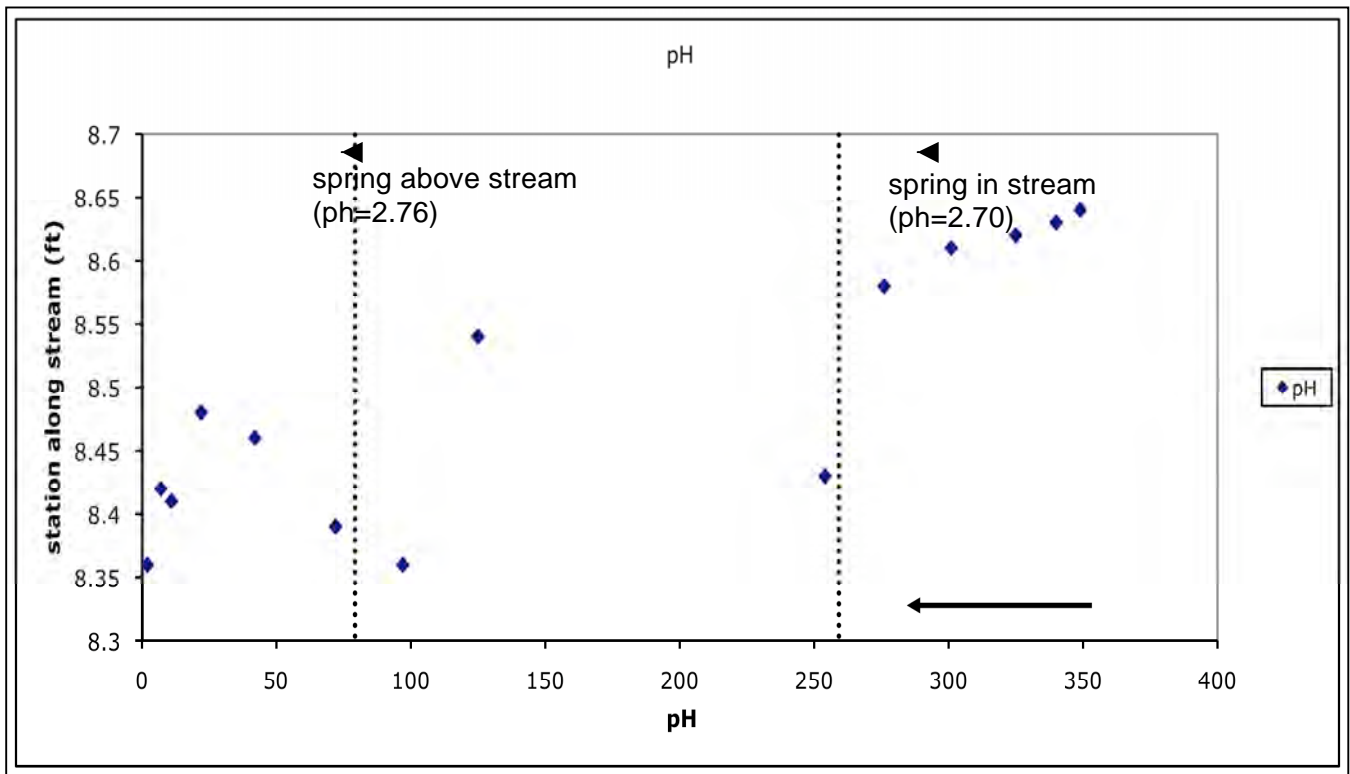
Figure 4: pH along both study reaches of Horseshoe Branch, 10/26/10

Figure 5: Benthic macroinvertebrates samples, 10/26/10. Note increase in sensitive taxa. Note: Ephemoptera not shown.

Figure 6: Longitudinal Profile 1

Figure 7: Longitudinal Profile 2

Figure 8: Cross Section 1

Figure 9: Cross Section 2

Figure 10: Cross Section 3

Figure 11: Cross Section 4

Figure 12: Cross Section 5

Figure 13: Cross Section 6

Figure 14: Tree Roots Exposed and bank failure
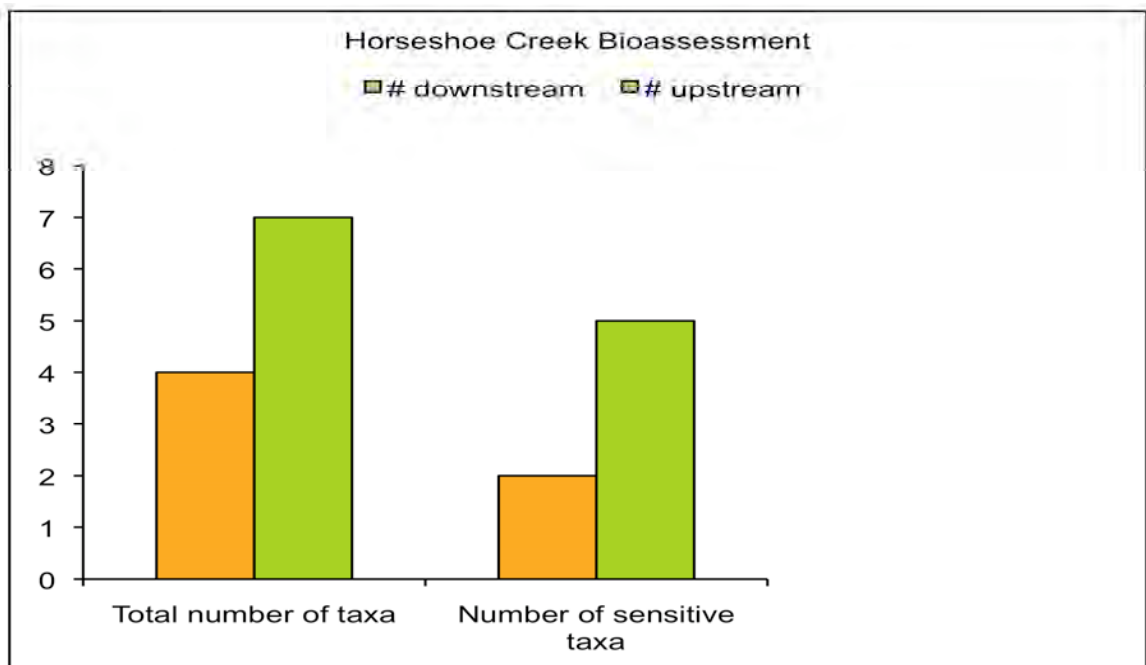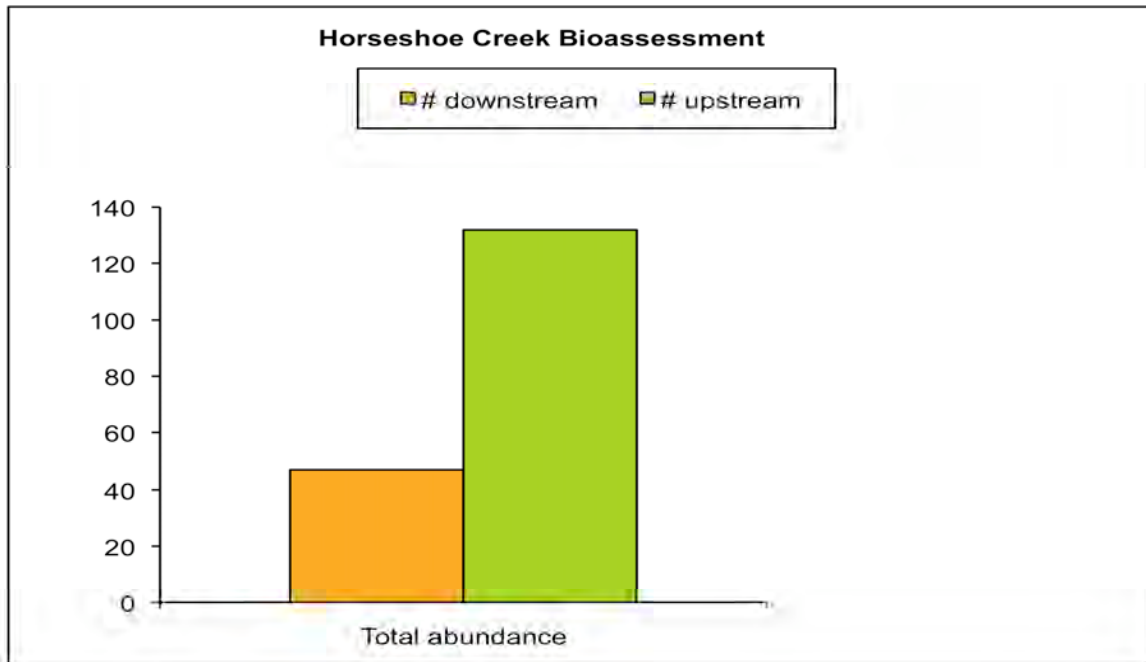
Figure 15: Survey at Cross Section 2

Figure 16: Bank Erosion and Trail Failure

Figure 17: Upstream View at Lower Profile (Profile 1)

Figure 18: Upstream View at Upper Profile (Profile 2)

Figure 19: Bioassessment survey results showing decreased abundance and taxonomic richness below the reach impacted by acid mine drainage.
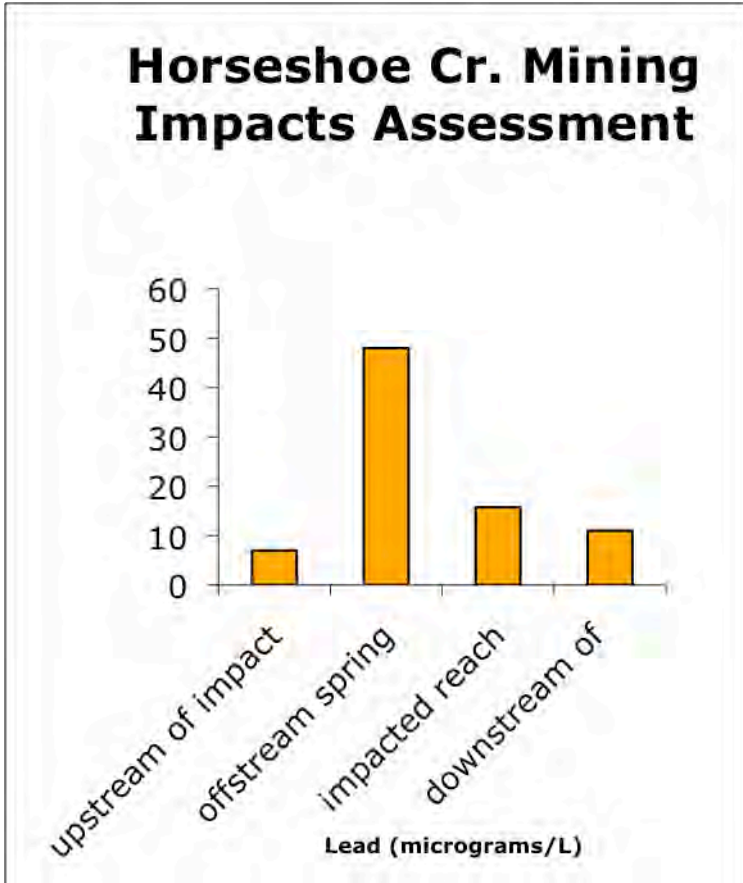
Figure 20: EBAYS lead study results (February and May 2009)

Table 1: Parameters for Calculation of Weighted Average Runoff Coefficient

Description	Area (acres)	High C	Avg C	Low C
Subwatershed	703			
Merritt College	108	0.70	0.60	0.50
Pavement	57	0.95	0.83	0.70
Residential	321	0.40	0.33	0.25
Parks/Forested	216	0.25	0.18	0.10
Watershed Weighted Average		0.44	0.36	0.28
Merritt College Weighted Average		0.32	0.24	0.16

Table 2: Parameters and Results from Rational Method

2/25/2004 Storm Event	Q [cfs]	I [in/hr]	A [acres]	C	Baseline Q	%Increase
Strawberry Creek	426	0.88	1977	0.24		
Horseshoe Creek	226	0.88	703	0.36	108	109
11/20/2010 Storm Event						
Codornices Creek	117	0.37	704	0.44		
Horseshoe Creek	95	0.37	703	0.36	46	109

Table 3: Bioassessment Data

Order	Family	Subfamily	Common name	# up-stream	# down-stream	Pollution tolerance*
Ephemoptera	Oligoneuridae		mayfly	2		2
Ephemoptera	Leptophlebidae		mayfly	1		2
Trichoptera	Psychomyiidae	Psychomyiinae	caddisfly	1		2
Trichoptera	Helicopsychidae		caddisfly	9	4	3
Plecoptera	Perlodidae	Perlodinae	stonefly	9	12	2
Odonata	Lestidae		damselfly	3	1	9
Diptera	Simuliidae		black fly	46	24	6
Total abundance				71	41	
Total number of taxa				7	4	
Number of sensitive taxa				5	2	

*Hilsenhoff Family-Level Biotic Index Score, 0= low, 10= high