Benthic Biomonitoring of Suspended Sediment Input into Strawberry Creek

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Introduction

Urbanization and development have historically gone hand-in-hand with environmental degradation. Strawberry Creek, running from the East Bay hills through the University of California, Berkeley campus and the City of Berkeley (Fig. 1), was representative of the fate of many urban streams. Most of the creek was funneled through concrete channels for flood and erosion prevention or underground culverts to function as a storm sewer system. Fish had long since disappeared, and most pollution-intolerant flora and fauna had retreated into the undeveloped Berkeley Hills. High concentrations of biological and chemical pollutants, including fecal matter and heavy metals, entered Strawberry Creek through misconnected or broken sanitary sewers. Channelization of parts of Strawberry Creek increased stream velocities, exacerbating streambank erosion in unchannelized sections (Charbonneau, 1987). These pollution and erosion problems spurred the campus Environmental Health and Safety office in 1987 to initiate a study of water quality, resulting in the publication of the Strawberry Creek Management Plan, a comprehensive examination of stream quality and recommendations for its improvement (Charbonneau and Resh, 1992). Then-Chancellor Heyman formed the Chancellor's Advisory Committee on Strawberry Creek Environmental Quality, whose goal was the restoration of Strawberry Creek to a level that can again support diverse populations of both terrestrial and aquatic life.

Ecological restoration efforts since then have sought to return Strawberry Creek and its riparian areas as fully as possible to their original state in order to provide habitats for wildlife, as well as open space for human population of Berkeley. These efforts have included: elimination of most point sources of pollution; mitigation of bank erosion through the installation of check dams and natural stream bank retention walls; and the reintroduction of native fish into the creek (Owen, 1992).

However, Strawberry Creek is by no means fully restored. It still receives pollution from non point sources (Charbonneau, 1987). The Creek's urban environment and channelization combine to produce an extremely 'flashy' (high wet flows and low dry flows) hydrologic regime that increases erosion compared to naturally less variable flows (Charbonneau and Resh, 1992). Accidental pollution inputs, such as a broken sewer line that released untreated sewage into the North Fork of Strawberry Creek for over a week in 1993, continue to be a problem. Finally, beginning in 1992 construction activity on campus has introduced concrete residue into the lower

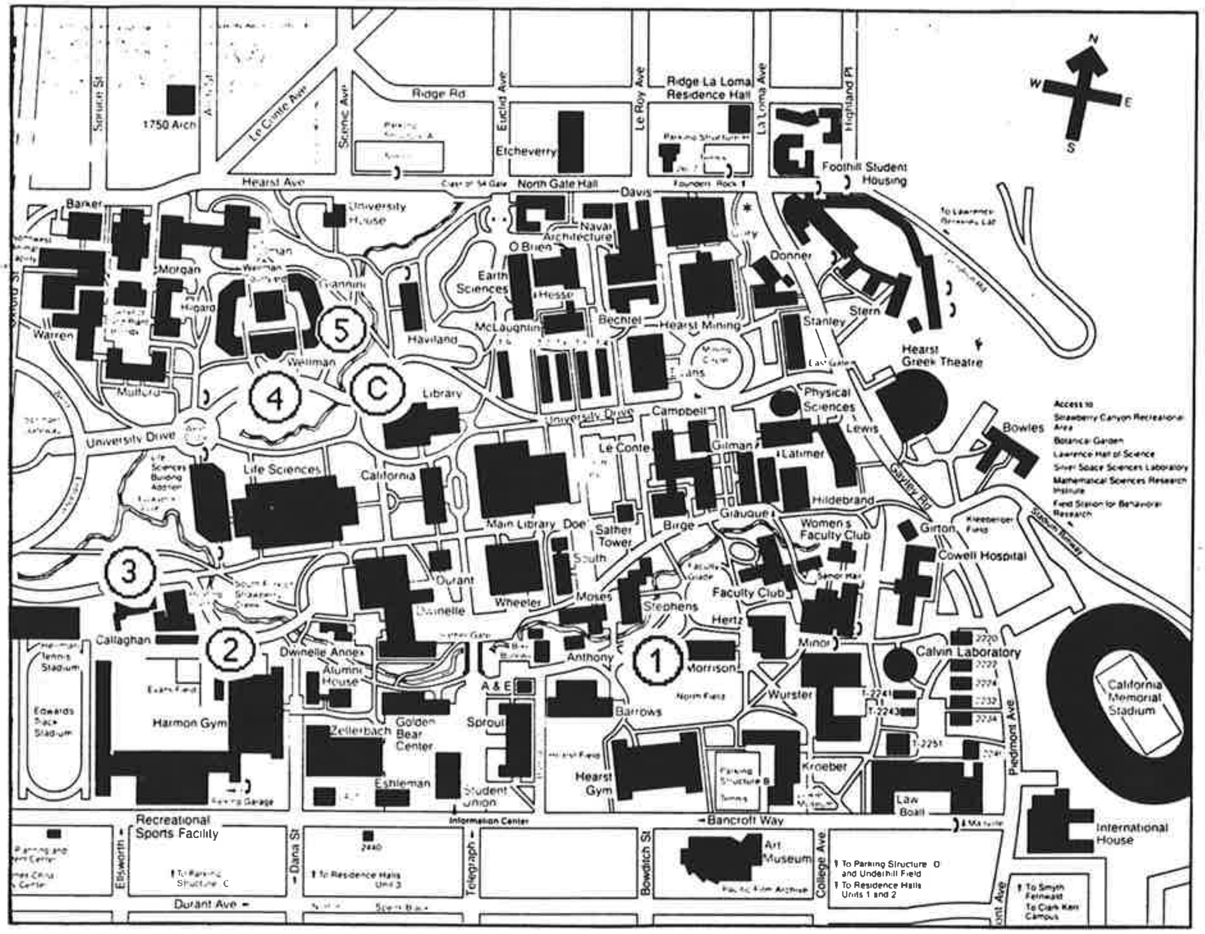

Fig. 1. Map of UC Berkeley campus, circles mark sample sites.
Source: UC Berkeley General Catalog, 1992

portion of the North Fork, raising suspended sediment (SS) levels to a point where the input was visually obvious, turning the affected stretch milky white, and detracting from the aesthetic value of Strawberry Creek (Hans, 1992, pers. comm.). Although SS and sediment in general are natural components of the stream, their input is usually highest during peak storm flows and not a nuisance during dry periods.

The purpose of this project was to determine if the introduced sediment is merely impacting Strawberry Creek's aesthetic value or if it is more seriously impacting the creek ecosystem. The benthic macroinvertebrate community in both forks of Strawberry Creek was examined for alterations in species diversity and abundance along several sections of the creek, above and below the sediment discharge from the cross-campus culvert and also on the unaffected South Fork. Macroinvertebrate data was converted into a Family-level Biotic Index (FBI) to evaluate present water quality.

Past Studies

Strawberry Creek has been the subject of numerous studies, many performed by students. None of the studies that I examined has tried to observe macroinvertebrate response to localized sediment input. Studies of this type have been performed at other locations, with varying sediment inputs and stream discharges.

Owen (1992) made the last study of macroinvertebrate populations in both forks of Strawberry Creek, both on campus and upstream in undeveloped Strawberry Canyon. He found campus sampling sites, especially on the North Fork, to have much lower diversity and abundance than Strawberry Canyon South Fork sites, speculating that the most likely cause of differences between the North and South Forks was polluted surface runoff into the North Fork.

Bjornn (1977) found that riffles with a slight to moderate level of silt imbedding a cobble and gravel substrate supported larger benthic insect populations than unsilted or heavily silted riffles.

In a related study, Gammon (1970) studied the effects of inorganic sediment from a rock quarry on a stream in Indiana, concluding that small amounts of SS (~40 mg/liter) had a measurable, negative impact on aquatic macroinvertebrates.

Background

This section presents information on the history of Strawberry Creek, the point-of-input of the SS, the potential effects of elevated SS input on benthic macroinvertebrates, and the family-level biotic index.

Strawberry Creek drains a 470 ha watershed, 40% of which is urbanized, into San Francisco Bay. Unlike most of the other creeks in Berkeley, a large part of Strawberry Creek is unculverted in an urban area and possesses a riparian zone for wildlife. The Creek is also unique because of the remediation efforts of the last six years.

As stated earlier, Strawberry Creek has been regularly abused by the growth of UC Berkeley and the surrounding city. Parts of the Creek were diverted and channelized, destroying habitats, and water quality was degraded by sewage and chemical contamination (Charbonneau, 1987). Native fish, including silver salmon, disappeared in the 1930s, and by 1986 water quality had deteriorated to the point where City of Berkeley health officials issued warnings against direct contact with Creek water (Charbonneau and Resh, 1992).

Restoration efforts began in 1987 with the production of the Strawberry Creek Management Plan and the establishment of the Chancellor's Advisory Committee on Strawberry Creek Environmental Quality (Owen, 1992). Sanitary sewers in the city and campus were diverted from the Creek; erosion of stream banks were controlled by construction of check dams; and native fish (three-spined stickleback, roach, hitch) reintroduced (Charbonneau and Resh, 1992). Water quality has steadily improved to this day, although non-point source pollution continues.

Runoff from impervious surfaces (roofs, parking lots, lawns) continues to transfer pollutants such as pesticides, fertilizers, oil and soil into the storm drain system, which is connected directly into Strawberry Creek on campus and in North Berkeley (Charbonneau and Resh, 1992). Washdowns, discharges and storm runoff from construction at the Doe/Moffitt Library Addition and Soda Hall on Hearst Avenue have contributed to the introduction of solids into the Creek since late 1992 (Hans, 1992, pers. comm.). The cross campus culvert (CCC), which empties into the North Fork just upstream of University Drive (Fig. 1), consolidates drainage from the northeastern portion of the campus, which includes the Library Addition Project. The section of the North Fork downstream of the CCC is visibly more turbid.

SS pollutants can have a detrimental effect on a river ecosystem, particularly riffle communities. Riffles, which are characterized by shallow water flowing turbulently over a rocky substrate, are the most productive part of a stream (Goldman and Horne, 1983). The turbulent flow provides better aeration, providing a highly oxygenated environment for aerobic benthos. Sedimentation is highest in pools, the slower and deeper counterpart of riffles, so the interstices between substrate particles in riffles can provide suitable shelter for non-burrowing macroinvertebrates and solid surfaces for clinging macroinvertebrates.

The diversity of riffle macroinvertebrates declines when siltation occurs. Light silting has a variable effect on macroinvertebrates, depending on the species under consideration (Minshall, 1984). Burrowing macroinvertebrates can thrive in silty, muddy substrates (e.g. *Oligochaeta*, aquatic earthworms and *Chironomidae*, midges) and replace the more numerous, less tolerant species (e.g. filter feeding *Hydropsychidae* and *Simuliidae*) when siltation occurs (Wiederholm, 1984; Roback, 1974; Hynes, 1960). While organic matter is a food resource and beneficial to stream biota in many cases, overloading of organic silt can actually deoxygenate the water by increasing the biological oxygen demand if not consumed or removed by high flows. Inorganic solids can blanket the substrate and smother invertebrates, even those tolerant of siltation, in the interstices or deprive them of their daytime refuges (Hynes, 1960).

When current velocity is high or particles small, the solids do not silt out but remain in suspension. High levels of SS can block sunlight and disrupt photosynthesis, indirectly affecting invertebrates by reducing their food supply (Hynes, 1960). Low levels of SS increase the drift rate of some invertebrates from affected riffles, decreasing species abundance (Gammon, 1970; Wiederholm, 1984).

The family-level biotic index is a semiquantitative method of evaluating water quality utilizing invertebrate samples (Table 1). The FBI is calculated as $\sum n_f t_f / N$: n_f is the individuals of a family in the sample; t_f is the tolerance value of organic pollution of a family; N is the total individuals in the sample (Hilsenhoff, 1988). Water quality ranges from very poor to excellent on a 10-point scale. An FBI provides an easy and rapid assessment of the health of a stream, necessitating

	Family Biotic Index	Water Quality	Degree of Organic Pollution
	0.00-3.75	Excellent	Organic pollution unlikely
	3.76-4.25	Very good	Possible slight organic pollution
1992	4.26-5.00	Good	Some organic pollution probable
1995	5.01-5.75	Fair	Fairly substantial pollution likely
	5.76-6.50	Fairly poor	Substantial pollution likely
	6.51-7.25	Poor	Very substantial pollution likely
1987	7.26-10.00	Very poor	Severe organic pollution likely

Table 1. Evaluation of water quality using the family-level biotic index (FBI).
Source: Hilsenhoff, 1988

identification of invertebrates to the family level, rather than the genus or species level required for the more accurate Biotic Index (Hilsenhoff, 1988). The FBI does not take into account the diversity of pollution tolerances within a family. Although Hilsenhoff (1988) himself showed that the FBI tended to overestimate pollution in clean streams and underestimate pollution in polluted waters, Resh (1992) demonstrated its ability to discriminate between an impact and the absence of one.

Methodology

Three separate analyses comprised this project: a physical characterization of sampling sites; a suspended sediment analysis; and a macroinvertebrate standing crop survey.

Sampling Sites: Five sections of Strawberry Creek and the CCC (SS samples only) were selected as sampling locations (Fig. 1). A transect was made across each sampling section and depth measurements made every 3 inches. This data was combined with stream velocity measurements to determine discharge at each sampling location. A rubber bob was sent down 20-foot sections of each site five times and the times averaged to produce an average stream velocity at each site. Substrate composition was characterized visually and examined for substrate imbeddedness by silt.

Site 1: South Fork, 13.5 m section between brick bridge and wooden bridge at southeast corner of Stephens Hall.
Site 2: South Fork, 16.5 m section along Cross Campus Road between Heating Plant and Harmon Gym, near the Grounds Maintenance shacks.
Site 3: Main Branch, 18 m reach just downstream of the confluence of the North Fork and the South Fork.
Site 4: North Fork, 7 m section paralleling Life Sciences Building downstream of University Drive auto bridge.
Cross campus culvert: North Fork, approximately 5 m upstream of University Drive auto bridge.
Site 5: North Fork, 7.2 m section near Giannini Hall between pedestrian bridge and auto bridge.

Sample sites 3 and 4 received sediment from the CCC, while sites 1, 2 and 5 served as controls.

Suspended sediments: A 500-ml water sample containing SS was taken from each site and the CCC at approximately 4 day intervals between 9 AM and 5 PM February 9-March 30 with a DH-48 water sampler provided by the Landscape Architecture Department. Turbidity measurements were made using a Hach model 2100A turbidimeter. Turbidity was measured in nephelometric turbidity units (NTU). Each water sample was analyzed volumetrically to determine the settleability of SS entering each riffle, and the total solids content of each sample determined gravimetrically to obtain weight/sample volume data (AHPA, 1985).

Benthic macroinvertebrates: Macroinvertebrates were sampled March 15 and April 2-3, with at least 12 replicates at each location, using a modified Hess sampler. It consisted of a 10-inch diameter, open cylinder with two side opposite-facing openings 2 inches above the bottom. The upstream opening was flush-covered with 1 mm mesh, while the downstream opening terminated in a nylon mesh. The 78 in^2 of substrate within the sampler area was disturbed to a depth of 2-3 inches for 30 seconds to dislodge invertebrates which were carried by the current into the net. The contents of the net were then emptied into storage containers and refrigerated until they could be preserved in 70% ethanol. Laboratory identification was facilitated by using a binocular microscope and family identification keys in Lehmkuhl (1979) and Merritt and Cummins (1984). Insects were identified to the family level and other invertebrates to order.

Samples were randomly taken from each site by placing a numbered grid over a sketch of each site and generating random numbers with dice. Each square in the grid represented an area about 1 m^2. Within these squares I chose suitable sampling spots (i.e. no bedrock or densely packed cobble).

Data

Stream data: Stream velocities were higher in the South Fork and Main Branch locations examined, causing dry weather discharges at these locations to be much higher than North Fork locations (Table 2). The discharge at site 2 is greater than the discharge at site 1, a result of higher stream velocity at site 2. Green plants were not found at sites 4 and 5. Algae was present at all other sites.

Substrates at sites 3, 4 and 5 were generally heterogeneous, with particle sizes ranging from silt (<.063 mm) to large cobble (128-256 mm) spread randomly across the whole site. Substrates at sites 4 and 5 also consisted of the full range particle sizes, but the larger particles were primarily confined to in the parts of the stream with highest discharge. The substrates at sites 1, 2 and 3 contained higher proportions of large particles and were less imbedded in silt than North Fork sites. Particles at sites 4 and 5 were about 50% imbedded.

	site 1	site 2	site 3	site 4	site 5
discharge (cfs)	25.4	82.4	49.2	10.8	3

Table 2. Discharge of Strawberry Creek at sample sites.

sediment sample	1	2	3	4	5	6	7	8	9	10
date	2/9, Tu	2/12, F	2/16, Tu	2/21, Su	2/27, Sa	3/2, Tu	3/8, M	3/17, W	3/19, F	3/30, Tu
conditions	wet	dry	dry	wet	dry	dry	dry	wet	dry	dry
site 1: turbidity	n/a	2	20	17	8	3	4	39	11	n/a
ss (mg/L)	n/a	2.4	17.4	18	7.6	6	4	51.4	10.5	n/a
site 2: turbidity	n/a	2	18	23	8	4	4	37	10	3
ss (mg/L)	9.4	3	17	20	6.4	5.2	4.8	38.8	11.4	4.3
site 3: turbidity	n/a	3	5.2	32	6	5	11	33	20	42
ss (mg/L)	41.4	4.6	4.8	34.6	7.2	6.8	13.4	40.6	22.9	224.8
site 4: turbidity	n/a	11	4	47	2	3	64	42	33	145
ss (mg/L)	23.4	16.6	3	55.2	4	4	72.6	52.4	45.5	189.6
culvert: turbidity	n/a	25	10	82	2	9	110	39	89	280
ss (mg/L)	25.6	38.2	10.4	101.2	3	11.6	344	113.4	147	1229.8
site 5: turbidity	n/a	2	2	3	2	2	1.2	39	2	1
ss (mg/L)	2.6	1.6	1.6	3.4	2.8	2.2	3.6	38.2	0.9	0.7

Table 3. Suspended sediment concentrations and turbidity at each sample site, by sample round.

Sediment data: While sampling in impacted areas of Strawberry Creek, I noticed a strong limestone scent, much like that of wet concrete or the dust generated by sandblasting. SS discharge generally began before 9 AM and ceased by 6 PM. SS concentrations and turbidity measurements are presented in Table 3. Levels of SS visually similar to that gathered in sediment samples 8-10 were observed on weekdays from 3/17-4/9. Site 3 showed elevated levels of SS during high SS discharge from the CCC, but lower than at site 4.

The SS discharged by the CCC consisted of very fine particles that formed a colloidal suspension in the Imhoff cone. On only two occasions did a measurable amount of SS settle, sample round 1 (site 4) and round 10 (site 3 and culvert). The first sample contained untreated sewage from the broken sewer line, and .1 ml/L of sediment settled out. The site 3 and culvert samples from sample round 10 settled out .2 ml/L and .4 ml/L respectively. The rest of the samples showed less than .1 ml/L settling out.

Wet weather samples contained about 10 times the SS of dry weather samples. SS input from the CCC increased dramatically in March, as evidenced by the data gathered in sampling rounds 7-10. For example, data from round 7 (March 8) showed 344.0 mg/L SS in the CCC discharge. This input raised the North Fork's SS level from 3.6 mg/L at site 5 to 72.6 mg/L at site 4, and raised turbidity over 60 NTU.

Macroinvertebrate data: Site 1 showed the highest levels of diversity, with representation by 21 families or orders of macroinvertebrates, while site 3 had the highest total population of macroinvertebrates (Table 4). The North Fork sampling locations were very similar, although site

Group	Family	site 1	site 2	site 3	site 4	site 5
Ephemeroptera	Baetidae	11	88	292	2	1
	Siphlonuridae	0	1	1	0	0
	Leptophlebiidae	3	8	0	0	0
Odonata	Coenagrionidae	1	6	3	0	1
Plecoptera	Nemouridae	2	1	1	0	0
	Chloroperlidae	23	8	0	0	0
	Perlodidae	3	0	0	0	0
	Taeniopterygidae	1	0	1	0	0
Trichoptera	Hydropsychidae	3	0	0	0	0
	Rhyacophilidae	4	0	0	0	0
	Phryganeidae	1	0	0	0	0
	Hydroptilidae	1	0	0	0	0
Coleoptera	Elmidae	6	1	0	0	0
	Dytiscidae	2	0	0	0	0
Diptera	Chironomidae	60	89	210	205	25
	Empididae	0	2	0	0	0
	Simuliidae	9	6	0	1	0
	Ceratopogonidae	2	2	0	0	0
	Stratiomyidae	0	0	3	0	1
Copepoda	Cyclapoida	6	8	5	20	1
Oligochaeta		30	22	69	229	240
Nematoda		2	0	25	38	65
Amphipoda		1	0	1	0	0
Hydracarina		2	1	1	0	0
Mollusca	Gastropoda	0	0	0	0	1
	Bivalvia	0	1	0	0	0
total invertebrates		173	244	612	495	335
samples		14	24	26	14	12
invertebrates/sample		12.35714	10.16667	23.53846	35.35714	27.91667
total families		21	15	12	6	8
Family Biotic Index		3.58			5.99	

Table 4. Results of macroinvertebrate survey and FBI for the North Fork and the South Fork.

5 had slightly higher diversity (eight families compared to six families). Site 4 supported extremely high numbers of *Chironomidae*. Both site 4 and site 5 were inhabited by large numbers of *Oligochaetes*, comprising over 70% of the standing crop of macroinvertebrates at site 5. No stoneflies (*Plecoptera*) were found at either site. The South Fork sites (1 and 2), had the highest diversity of all the sampled sections of Strawberry Creek, although in several cases entire families were represented by an individual insect. Site 3 had an intermediate level of diversity.

FBI calculations indicate that the water quality of Strawberry Creek is fair (5.04). Separating the South Fork from the North Fork revealed a startling dichotomy. South Fork water quality evaluates as excellent (3.58), whereas North Fork water quality was fairly poor (5.99).

Analysis

Discharge data showed that the South Fork of Strawberry Creek has a more 'natural' hydrologic regime, maintaining relatively high flows even during dry conditions, compared to the trickle that the North Fork conveys. The low discharge in the North Fork contributed to sedimentation, helping to explain the higher imbeddedness of the substrate at sites 4 and 5. Lower SS levels were found at site 3 than at site 4, reflecting dilution by the South Fork.

The variation in stream conditions could have introduced bias into the macroinvertebrate data, as the sites with the lowest discharge and stream velocity (4 and 5) also had the lowest diversity. These sites received the poorest aeration, and the low flow inhibited sampling at some spots. The weak current was less able to carry macroinvertebrates into the collection mesh, possibly biasing samples from these sites toward small, light macroinvertebrates.

Sediment sample rounds 1 and 10 produced the only volumetric data on SS. Fecal contamination accounted for the bulk of the settled sediment at site 4, round 1. Sediment from site 3, round 10 consisted of particles larger than silt and probably did not originate from the CCC, given the lack of sediment settling in the sample from site 4. The general lack of volumetric data is traceable to the spatial separation of sample sites 3 and 4 from the CCC. The discharge from the CCC entered into a pool and passed through two check dams before reaching site 4. Most settling of SS occurred in the slow pools upstream of site 4.

Comparing the North Fork sites, site 5 had slightly higher family diversity (8 vs. 6) than site 4, while site 4 had a higher number of insects per square area. Eight families of macroinvertebrates were found at site 5 with four of them represented by just one individual, making any assertions based on diversity about the SS input from the CCC tenuous at best. Site 4 showed eight times the number of *Chironomidae* as site 5. *Chironomidae* was one of the families I expected to benefit from elevated SS input, and their elevated presence at site 4 appeared to confirm this theory. Bjornn (1977) found about three times as many *Chironomidae* in riffles experiencing SS addition versus the control riffles. However, when the imbeddedness of substrate particles increased beyond 33%, numbers of *Chironomidae* were negatively correlated with SS addition.

The data from calculation of the FBI agrees with the most current studies performed on Strawberry Creek water quality. Gade (1993) found that the water quality in the North Fork was poorer than that of the South Fork. North Fork samples by Owen (1992) contained no stoneflies, indicating that organic pollution is likeley. The SS data revealed that virtually none of the SS discharged from the CCC was being deposited on the streambed at site 4. Also, macroinvertebrate samples from site 5 showed poor diversity, making it unlikely that site 4 would show higher diversity. Stoneflies, which are intolerant of organic pollution as a family, were absent from North Fork samples. Finally, both *Oligochaeta*, which were found in extremely high numbers in the North Fork, and *Chironomidae* are are tolerant of fairly high levels of organic pollution (Hynes, 1960). It is apparent that the rupture of the sewer line along with a history of poor water quality have had far more deleterious effects on the ecology of Strawberry Creek than the input of inorganic sediment from the CCC.

Conclusion

The question posed at the start of this paper remains unanswered. Because the water quality of the North Fork of Strawberry Creek was so poor, a clear assessment of the effects of elevated SS on benthic macroinvertebrates in Strawberry Creek was impossible. The SS discharge could have been responsible for the elevated numbers of *Chironomidae* at site 4, but the absence of pollution-intolerant organisms is of overriding concern. I recommend that a similar study be performed next year on the South Fork if discharge practices at the new Haas School of Business now under construction also result in addition of SS to Strawberry Creek. The South Fork is far healthier and could be adversely affected.

I also recommend a closer examination of the North Fork. Owen's (1992) data also showed very poor macroinvertebrate diversity and population counts in the North Fork, so the spill from the sewer line was not as significant as it first appeared. Non point source pollution controls need to be reconsidered if it is in fact organic pollution that is ailing the North Fork. Finally, the North Fork is more physically homogenous, possessing very few riffle habitats, than the South Fork. A macroinvertebrate habitat restoration project may have to be undertaken.

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