

Strawberry Creek on the University of California, Berkeley Campus: A case history of urban stream restoration

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ABSTRACT

1. Strawberry Creek (37°52' N; 122°15' W) is the major focus of open space on the University of California, Berkeley (Alameda County, California, USA) campus; it provides visual amenity and variety, riparian and wildlife habitat, and educational and recreational opportunities.

2. Since the beginning of this century, urbanization of the catchment, channel alteration and water quality degradation combined to cause deterioration of the creek's habitat and overall environmental quality; this was manifested by a marked absence of flora and fauna, obvious water pollution and severe erosion.

3. In 1987 a restoration project was undertaken that focused on water-pollution and erosion-control measures. In 1989, native three-spined sticklebacks (*Gasterosteus aculeatus*) were successfully reintroduced. Family Biotic Index scores for the macroinvertebrate community indicated a change from the 'poor' water quality conditions in 1986 to 'good' water quality in 1991.

4. Environmental education programmes now involve over 1500 students who use the creek each year in laboratory exercises; a popular natural history and conservation walking-tour guidebook has also been prepared.

5. On-going restoration efforts include additional reintroductions of other native species, further environmental education efforts and monitoring.

6. Obstacles and key factors that led to the successful implementation of this project are presented to assist in implementing similar ecological restoration projects of urban streams.

INTRODUCTION

Degradation of aquatic habits in urban areas is pervasive throughout much of the world; unfortunately, examples of successful restoration of urban aquatic habitats are rare (Gore, 1985). Moreover, many urban stream restoration projects in North America are designed to create 'river malls' or 'creek walks' — aesthetic improvements and artificially managed systems designed primarily to enhance economic development or passive recreation. In contrast to these projects, Strawberry Creek (an urban stream that flows through the University of California, Berkeley, campus) has undergone an extensive ecological restoration over the past 5 years. In this paper, we present a case history of the restoration of Strawberry Creek and highlight some of the methods that made it successful in the hope of providing a model to assist in implementing similar urban stream restoration projects.

GEOGRAPHIC AND HISTORICAL SETTING

The headwaters of Strawberry Creek ($37^{\circ}52'30''$ N; $122^{\circ}15'30''$ W) are located in Strawberry and Blackberry Canyons above the University of California, Berkeley, campus (Alameda County, California, Figure 1). The catchment covers 470 ha and is drained by two branches—the North and South Forks—which converge on the central campus grounds to form the main branch of the creek.

As it leaves the central campus, Strawberry Creek enters a culvert which flows beneath the City of Berkeley to central San Francisco Bay. The creek flows almost entirely underground with few limited exceptions, notably Strawberry Creek Park where the City of Berkeley unearthed the culvert and used the creek as the park's centrepiece.

HABITAT DEGRADATION

Strawberry Creek has always been a central element of the University campus. In 1860, when the College of California moved to its present site in Berkeley from Oakland, the creek played a major role: the founders stated that 'all the other striking advantages of this location could not make it a place fit to be chosen as the College Home without this water. With it every excellence is of double value' (Willey, 1887). However, within a few years, the subjugation and degradation of Strawberry Creek had begun.

As land was cleared for grazing in Strawberry Canyon in the late 1800s, runoff from the hills increased, causing severe erosion downstream. As early as the 1880s, check dams were built on the central campus reaches of the creek to prevent further stream-bed incision and subsequent bank erosion. In 1883, the first section of the creek was culverted just downstream of the campus. The installation of culverts continued



Figure 1. Strawberry Canyon, the University of California, Berkeley campus, and San Francisco Bay. The South Fork of Strawberry Creek originates in this canyon and flows through the campus to central San Francisco Bay.

through the 1930s when the federal government's Depression-era Works Progress Administration enclosed almost all of the remaining open reaches of the creek in Berkeley because of public health and flooding concerns.

Channelization and habitat alteration of Strawberry Creek on the campus began in the early 1900s and continued until the 1960s. The stream bed and stream banks were covered with concrete in some reaches as an attempt to stabilize channel downcutting and eroding banks caused by increased runoff from urban development in the catchment. Retaining walls were installed in many unstable areas, and other reaches of the creek were channelized or diverted for flood control purposes. Following serious flooding in 1958 and 1963, major storm-drain improvements were undertaken, including extending a bypass culvert further up into Strawberry Canyon, which resulted in the loss of another 0.5 km of natural stream channel.

The course of Strawberry Creek through the Berkeley campus was also altered. The construction of a large football stadium (78 000-spectator capacity) at the base of Strawberry Canyon in 1923 necessitated a major diversion of the creek on campus lands. Where the creek once cascaded over waterfalls at the bottom of the Berkeley hills, it was re-routed underground into a storm-water bypass-culvert that flowed under the stadium and eventually discharged back into the natural channel on the central campus grounds.

The first documented report of water quality degradation of the creek appeared in a local newspaper article in 1895 that complained of the 'unsightly appearance of sewer-begrimed water and filthily discoloured banks' (*Berkeleyan*, Sept. 1895, p. 2). A variety of newspaper articles and student reports in the 1970s and 1980s related the continuing water quality problems in Strawberry Creek. Campus health officials conducted an 'anti-pollution survey' in 1970 in an attempt to identify and correct sources of pollution. At that time it was thought that all building discharges into the creek had been eliminated. However, in the early 1980s, City of Berkeley health officials advised against direct contact with the creek because of sewage and chemical contamination, and degradation by urban runoff. Campus officials attributed the high bacteria counts in the creek to pollution from dogs roaming freely on the campus; in response, their recommendation for solving this problem was that a 'leash law' for dogs should be established.

STRAWBERRY CREEK MANAGEMENT PLAN

By the mid-1980s, Strawberry Creek looked like many other urban streams: its waters often appeared turbid, foamy, discoloured, or oily. Stream-bank erosion along both forks continued to worsen, threatening trees and structures such as bridges and retaining walls. Studies by faculty and students documented marked lack of flora and fauna compared with other less affected streams flowing into San Francisco Bay. As a result of these studies, a group of faculty members teaching courses in the environmental sciences became increasingly concerned about the deterioration of the creek. These concerns were raised, and potential educational uses of a restored creek were listed. In 1987, the campus Environmental Health and Safety (EH&S) office, recognizing the deteriorating quality of the creek, the lack of any resource management strategies, and the potential importance of the creek to the campus and community at large, commissioned a water quality study of Strawberry Creek that was initially funded by a \$15 000 grant from the campus Chancellor.

The original objectives of the water quality study were to evaluate the creek's water quality and identify both point and non-point sources of pollution, develop creek and catchment management strategies, and produce a document upon which future evaluation and management decisions could be based. However, it soon became apparent that for the study to be comprehensive, it would have to be expanded to address all aspects of urban creek restoration and encompass broader ecological issues such as habitat and biological community enhancement.

The outcome of the initial 6 month study was the Strawberry Creek Management Plan (Charbonneau, 1987). The report included a detailed description of the creek and its catchment, soils and geology; land use; the storm drainage system; and a characterization of the creek's hydrologic regime. The study found

that urban storm-water runoff from the entire catchment was routed into the creek. In effect, the creek served as the storm drain system. Urbanization also had a profound impact on the creek and catchment; about 40% of the 470 ha catchment was urban, and characterized by extensive areas of impermeable surfaces (parking lots, buildings, roads and irrigated lawns). These factors combined with culverting and channelization to create a very 'flashy' hydrologic regime where peak storm flows were higher, and dry weather baseflows were lower, than they would be under natural conditions. The lag time (time interval between peak rainfall and peak runoff) was only about 15–20 minutes on the central campus.

These altered hydrologic conditions dramatically influenced the creek's morphology. The result was accelerated channel downcutting and stream-bank erosion as well as destruction of the natural pool-riffle sequence. This altered channel morphology is typical of streams that have been channelized (e.g. Brookes, 1988). Scouring storm flows during the wet season, lowered baseflow during the dry season, and sedimentation ultimately combined to degrade aquatic habitat.

The study also included an extensive environmental assessment of the creek's water quality and existing biological communities. Ambient baseline water quality was assessed by setting up a systematic monitoring programme that involved periodic sampling at strategic locations along both forks of the creek. Assessment of biological communities was made through student research projects.

WATER QUALITY

The monitoring programme found that water quality in the upstream canyon areas was typical of unaffected streams in north coastal California, but water quality was degraded in downstream urban reaches by eutrophic nutrient concentrations and bacterial contamination. For example, downstream nitrate concentrations averaged almost 3 mg l^{-1} , whereas average total phosphorus concentrations were nearly 0.3 mg l^{-1} . Sediment sampling carried out in conjunction with water sampling also found elevated concentrations of lead, zinc and mercury in silty bottom sediments. It appeared that sewage contamination was a major problem, shown by elevated faecal coliform bacteria concentrations (Table 1).

Water quality impacts of non-point source urban runoff were also investigated by conducting wet-weather sampling (this area has a Mediterranean climate) and comparing the results to dry-weather baseline data. Significant increases in chemical oxygen demand, suspended solids, nutrients, bacteria and heavy metals concentrations were observed compared to baseline levels (Charbonneau, 1987). It was surmised that the creek was significantly affected by the short-term 'shock loading' effect of toxic urban runoff contaminants, especially trace heavy metals. This could explain the elevated metals concentrations found in the finer creek sediments.

An extensive sanitary engineering investigation, focusing on point source pollution, was undertaken by campus EH&S and facilities personnel. Over 100 pipes were located along the banks of the creek on the central campus. The sources of these pipes were then identified by physical inspection, checking utility maps and building plans when available, dye tracer testing with non-toxic fluorescein dye, and even using a miniature cable-operated TV camera that allowed visual inspection of critical drain-lines. Most of the pipes were found to be storm drain lines, but some cross-connections between sanitary sewer lines and storm drains were discovered.

Ten pipes that flowed continuously were targeted for water quality sampling. Composite samples were taken from each pipe over a 24-hour period and analysed for a range of constituents including pH, trace metals and chemical oxygen demand. The results showed that most of the effluent was cooling water, but a few of the pipes had elevated metals and organic concentrations; these were targeted for further investigation. On a cumulative basis, these point-source effluents—even though they discharged mainly domestic water—were altering the natural water chemistry of the creek through their sheer volume. Direct discharges from some old campus buildings were also discovered. These buildings were constructed in the 1920s and 1930s before modern building and health codes were in effect (which also illustrated how the creek had served as an all-purpose sewer system) (Figure 2).

Table 1. Strawberry Creek water quality data.

	South Fork		North Fork	
	Pre-restoration Upstream	Post-restoration Downstream	Pre-restoration Upstream	Post-restoration Downstream
pH (std. units)	8.1	8.0	8.1	8.0
Biochemical oxygen demand	<2.6	<2.6	<3.0	<3.0
Chemical oxygen demand	<8	13	20	10
Total alkalinity ($\text{mg l}^{-1} \text{CaCO}_3$)	140	106	108	85
Hardness	144	100	111	92
Spec. conductivity (umhos cm^{-1})	382	326	263	230
Dissolved solids	252	198	200	170
Suspended solids	4.0	2.9	10	2.0
Turbidity (NTU)	2.7	1.9	4.2	1.6
Colour (c.u.)	15	13	20	15
Chloride	16.3	23.5	15.0	14.0
Oil and grease	<1.0	<1.7	—	—
Total Kjeldahl-nitrogen	0.28	0.34	<1.0	4.9
Ammonia-nitrogen ($\text{NH}_3\text{-N}$)	0.04	0.13	<0.10	0.10
Nitrate (NO_3)	1.7	2.0	2.7	1.7
Total phosphorus	0.21	0.24	0.41	0.14
Total coliform (MPN/100 ml)	2375	11000	16000	16000
Faecal coliform (MPN/100 ml)	260	11000	350	5000
Faecal streptococci (MPN/100 ml)	1275	11025	1600	16000

All analytical results in mg l^{-1} unless otherwise specified.

All concentrations are mean values based on varying numbers of discrete grab samples.

Pre-restoration sampling performed in 1987, post-restoration sampling in 1992.

Upstream stations in Blackberry Cyn (North Fork) and Strawberry Cyn (South Fork); downstream stations located at confluence (central campus).

Analyses performed by California Department of Health Services Sanitation and Radiation Laboratory, Berkeley, California.



Figure 2. Strawberry Creek on the University of California, Berkeley campus, *circa* 1906 (from the University of California, Berkeley archives).

The investigations also found deteriorating sanitary sewer lines that were infiltrating into parallel or adjacent storm sewer lines that emptied into the creek. The most dramatic example was found at the football stadium, which overlies the Hayward fault zone. The sanitary sewer line beneath the stadium had crumbled from shear stress, and during periods of high use large volumes of raw sewage were finding their way into a nearby storm drain line. Sampling of the creek during several Saturday football games (when attendance was 40 000–60 000) showed huge peaks of faecal coliform during halftime and the post-game period (up to 500 000/100 ml).

BIOLOGICAL COMMUNITIES

The initial creek study also documented biological communities. Occurrence of Steelhead salmon (*Oncorhynchus kisutch*), which made migratory spawning excursions from San Francisco Bay into the creek, were last reported on the campus in the early 1930s and no species of fish had been found in any of the student studies. The disappearance of the salmon fisheries in the creek was probably caused by a combination of factors: physical habitat destruction, barriers to migration caused by installation of culverts downstream of the campus, and water quality degradation (Figure 2).

Aquatic macroinvertebrates are the group of organisms most widely used in water quality monitoring programmes (Rosenberg and Resh, 1992), and these organisms have been surveyed regularly in Strawberry Creek for over 20 years. Upstream of the campus, 15–20 families of macroinvertebrates have typically been found compared with five or fewer on the campus. The most sampling-intensive and site-extensive survey in Strawberry Creek was conducted in 1986; 11 families were found on the campus (Table 2) whereas 27 families were collected above the campus. Moreover, upstream sites were characterized by high richness of animals that typically occur in unstressed environments (caddisflies, mayflies and stoneflies). Conversely, downstream creek sites were characterized by animals that frequently tolerate moderate to high levels of organic pollution (e.g. various Diptera and monocultures of tubificid worms); these taxa are often common in perturbed urban streams (Resh and Grodhaus, 1983). The results of these macroinvertebrate surveys substantiated the findings of the water quality investigations.

Periphyton, or the community of algae, fungi and bacteria that are attached to or live upon submerged surfaces, was also surveyed. The most abundant taxon found in the catchment was the alga *Cladophora glomerata*, which usually grows well in waters that have a relatively high nutrient content.

In general, the diversity of wildlife in the catchment was found to have consistently diminished with the increasing urbanization and consequent degradation of riparian areas over the years. Some species that

Table 2. Strawberry Creek macroinvertebrate survey data.

Group	Family	Pre-restoration (1986)	Post-restoration (1991)
Ephemeroptera	Baetidae	x	xxx
	Heptageniidae		xx
	Leptophlebiidae		x
Odonata	Coenagrionidae	xxx	xxx
Plecoptera	Nemouridae		x
Hemiptera	Corixidae		x
	Gerridae		x
	Veliidae	x	
Megaloptera	Sialidae	x	x
Trichoptera	Hydropsychidae	xx	xxx
	Hydroptilidae		xxx
	Lepidostomatidae		xxx
	Odontoceridae		x
	Sericostomatidae		x
	Dryoptidae		x
Coleoptera	Dytiscidae	x	
	Elmidae		x
	Chironomidae	xxx	xxx
Diptera	Empididae		x
	Simuliidae		xxx
Acarina			x
Gastropoda	Physidae	x	xx
Pelecypoda	Sphaeriidae		xxx
Oligochaeta	Lumbricidae	xxx	xxx
	Tubificidae	xxx	xxx
Turbellaria	Planariidae	x	
Number of families		11	23
Family Biotic Index		7.4 (poor)	4.9 (good)
(water quality category)			

Survey based on macroinvertebrates collected from South Fork on central campus. Number of 'x' refer to frequency of occurrence: x, found in a single sample; xx, found in more than one but in less than the majority of samples; xxx, found in the majority of samples. Family Biotic Index scores are calculated using Hilsenhoff's (1988) formula.

are tolerant of urban conditions (e.g. raccoons (*Procyon lotor*), opossums (*Didelphis virginiana*), and various rodents (*Microtus*, *Rattus*)) were still found on the central campus. However, many other mammal and bird species were found in the relatively undeveloped upper canyon catchment that the campus had designated as an Ecological Study Area (Figure 1, Strawberry Canyon).

IMPLEMENTATION OF THE RESTORATION PROJECT

The results and recommendations of the Strawberry Creek study were presented to the campus Chancellor's office in the Fall of 1987. The EH&S Director convinced the Chancellor's office that a faculty-staff advisory committee was needed to oversee the restoration project if it were to succeed. Subsequently, the Chancellor's Advisory Committee on Strawberry Creek Environmental Quality (referred to hereafter as the 'Creek Committee') was formed.

Based on faculty recommendations, a professor with tenure and long-standing involvement with campus environmental issues was chosen as Committee Chair. Other faculty members from academic departments ranging from Entomology to Landscape Architecture were also recruited based on their interest and expertise. In addition to the faculty, critical campus staff representing EH&S and the campus facilities and planning departments were also placed on the Committee. Because the creek's catchment included lands in the City of Berkeley as well as the US Department of Energy's Lawrence Berkeley Laboratory, representatives from both entities were also invited to serve on the Creek Committee. In effect, representatives of all the appropriate units were brought together to discuss the problems, formulate strategies and tactics, and to coordinate their actions toward creek restoration.

The Creek Committee agreed on a common goal for the restoration project: to restore the ecological integrity of the creek. Moreover, the Committee wanted to promote the teaching and research values of the creek. As a final objective, the group hoped that the restoration project would provide an innovative example of urban creek restoration. EH&S staff were charged with the responsibility of coordinating implementation efforts; individual committee members concentrated on issues relating to their expertise.

The first priority was to correct the deficiencies that were identified in the sanitary engineering investigations. Extensive sanitary sewer rehabilitation projects were undertaken by the campus engineering staff in several critical areas, including the football stadium. Cross-connections were eliminated and the direct discharges were re-routed to the sanitary sewer system. Campus deferred-maintenance funds (nearly US\$500 000) were used for these sanitary engineering projects, which began in the Fall of 1987 and continued throughout 1988. Further investigations were also conducted during this time period, and the list of needed repairs grew. However, by the Spring of 1989 the worst problems had been corrected.

A wide variety of smaller and less costly sanitary engineering projects were also performed during this time: garbage bin wash-down areas were modified to prevent direct runoff into the creek; abandoned pipes and associated structures along the creek were sealed or removed; and back-flushing practices at a large campus swimming pool complex were modified to prevent chlorinated water from entering the storm drain system.

EH&S personnel responded to reports of spills and pollution incidents in the creek caused by improper disposal or accidental releases of a wide range of materials into the storm drain system; most often these included motor oil and painting materials. The source of this pollution was often difficult to locate because of the lag time between the drain disposal and subsequent signs of pollution in the creek, but prompt reporting, immediate response and detailed storm-drain maps made it possible to track down responsible parties in some cases. Offenders were held responsible for any clean up that was necessary and threatened with criminal prosecution if it recurred. As a preventive measure, floating oil-spill control booms were installed by EH&S where the creek entered the central campus grounds from the urban Northside district of the City of Berkeley (see below). These absorbent booms also trapped floating debris and trash.

Accelerated stream-bank erosion on the central campus was also a major concern. An environmental consulting/hydrology firm identified priority problem areas and developed a plan of action that

complemented the restoration goals. A top priority site was a 5 m high vertical-eroding bank that was beginning to undercut an adjacent automobile bridge. Instead of a conventional concrete retaining wall, a redwood cribwall was designed and installed at the site (Figure 3). This innovative 'biotechnical' erosion control method stands out as the most highly visible demonstration project that was undertaken. The cribwall was planted with a variety of native plant species by student volunteers. By the time the redwood logs rot away (in about 75 years), the plant materials will have taken over the structural function of bank stabilization.

In addition to the cribwall, a number of grouted rock or wood check dams were designed and placed in the creek to prevent further downcutting of the stream bed and subsequent bank undercutting and erosion (Figure 4). The dams were designed to be as low as possible (maximum 45 cm from spillway to plunge pool) so that if migratory salmonids were ever reintroduced into the creek, they could overcome these obstacles. Low check dams were also found to be much more stable over time. The dams were usually installed in a series, stairstep-fashion, in areas of steep channel gradient in order to achieve desired channel aggradation and stability while still maintaining a low profile. In addition to stabilizing the channel and dissipating storm-flow energy, the check dams also provide varied habitat for fish and aquatic insects in the downstream plunge pools. Most of the dams were built by California Conservation Corps (CCC) crews under the supervision of campus staff. Old check dams were also repaired and stabilized with riprap.

The check dams have now been in place through several wet seasons. To examine the performance of these channel bed modifications, creek channel profiles were compared for 1988 (before the check dams were installed) and 1990. Although the total rainfall during these years was comparatively low, the check dams were subjected to a moderately severe storm in 1989, which would represent a 1 in 5- to 10-year event. At the majority of the sites examined, the addition of check dams resulted in bed aggradation (Figure 5); sediments deposited behind the check dam mitigate stream-bank undercutting and have stabilized short reaches upstream of the dams.

It should be noted that in some locations in Strawberry Creek the check dams were inadequately tied into the banks and the dams were either not wide enough to provide stability or they were too tall (which

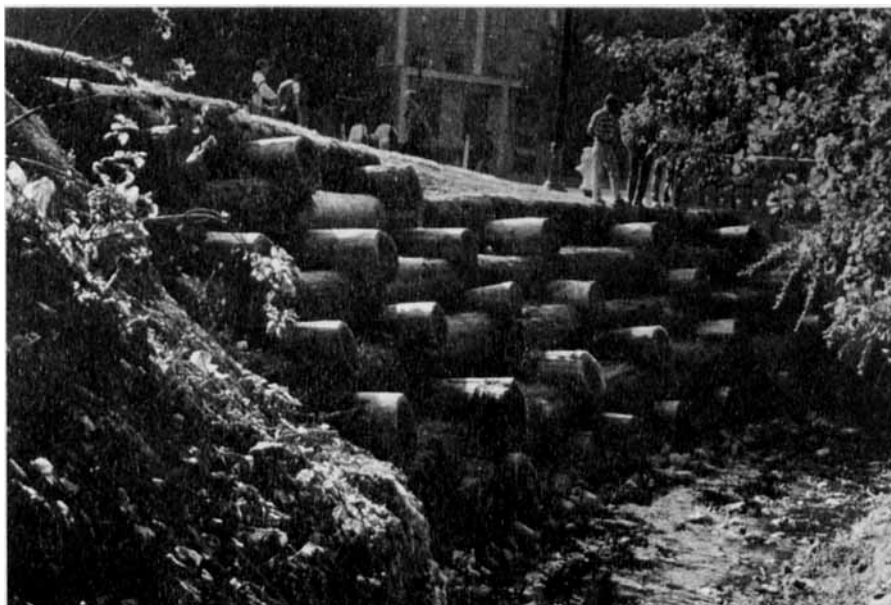


Figure 3. Redwood cribwall for erosion control soon after installation; vegetation has now covered the logs.



Figure 4. Notched redwood-log check dam in the creek.

concentrated energy loss). Most likely these check dams will fail within a few years. A successful check dam must be protected from toe scour, endcutting and seepage-induced washout, and be strong enough to withstand the impact of large, floating debris; unfortunately, universally applicable engineering designs for these structures have not been developed (Sklar and Haltiner, 1991). Finnigan *et al.* (1980), Wesche (1985) and Swales (1989) provide information on stream channel enhancement techniques; upon request, we will provide information on features of stable check dams and other modifications that have been successfully used on Strawberry Creek.

The CCC also assisted in erosion control activities in the headwater canyons of both the North and South Forks. Several gullies (i.e. incised channels formed by running water) were repaired using a variety of regrading, slope stabilization, and revegetation techniques. Improved grading and maintenance of canyon fire roads, berms and drainage systems was also implemented. During heavy winter rain-storms, emergency erosion control measures such as diversion of downslope runoff in sensitive areas of Strawberry Canyon was accomplished by creating dykes and berms. These, and other sound catchment management practices, helped to reduce erosion and subsequent downstream sedimentation in the creek.

RESULTS OF THE RESTORATION PROJECT

Water quality in the urban downstream reaches of both the North and South Forks appeared to improve compared with pre-restoration conditions (Table 1). Water clarity and aesthetic value noticeably improved on the central campus, indicated by decreases in downstream suspended solids and turbidity. Downstream nutrient and faecal bacterial concentrations both decreased since sewage contamination was eliminated.

Through the cooperation of the state Regional Water Quality Control Board, bioassays were conducted using water from the campus portion of the South Fork of Strawberry Creek. 7-day static renewal bioassays were performed using fathead minnows (*Pimephales promelas*) and *Ceriodaphnia* sp., a pollution-sensitive crustacean. No acute (mortality) or chronic (growth or reproductive impairment) effects were observed in either species. These results encouraged the Creek Committee to begin discussions about restocking the

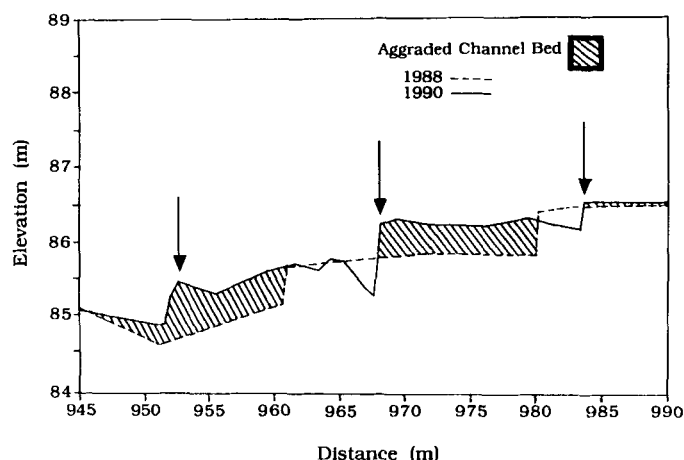


Figure 5. Example of Strawberry Creek channel-profile change, 1988–1990, following the installation of check dams; arrows represent location of check dams; distance represents that from culvert at the western campus border (based on Sklar and Haltiner, 1991).

creek with native fish. All agreed it was feasible, and research was conducted on which species to reintroduce first. A list was drawn up of native fish thought likely to occur in this stream, along with their habitat and water quality requirements. It was decided that the three-spined stickleback (*Gasterosteus aculeatus*) was the best choice because of its tolerance for frequently disturbed habitats and its relatively hardy nature. It appeared that the water quality required for its growth and reproduction could be met. With the assistance of local parks officials, sticklebacks were collected from a nearby catchment and released into Strawberry Creek in May 1989. Publicity emphasizing the occurrence of fish for the first time in over 50 years (since salmon were last reported) resulted in extensive and favourable television and newspaper coverage.

Since 1989, several generations of native fish have successfully spawned in Strawberry Creek. Fears over the fish being flushed downstream by flashy winter storm flows have thus far been unfounded. Apparently, there is enough pool and undercut bank habitat in the stream for the fish to find cover from the heavy flows; in addition, plunge pools resulting from check-dam installation provide habitat refuge. Other native fish species such as roach (*Hesperoleucus symmetricus*) and hitch (*Lavinia exilicauda*), and *Turricia* salamanders have also been reintroduced into the creek. Crayfish have migrated from upstream reaches, and large numbers of stoneflies, mayflies and caddisflies now occur in the creek. Unfortunately, within the last year, other exotic species such as goldfish (*Carassius auratus*) and mosquitofish (*Gambusia affinis*) have also found their way into the creek from well-intentioned ‘conservationists’; but so far they have not become established due to high winter flows. Early in 1991, snowy egrets (*Leucophylax thula*) were observed foraging for fish in the creek for the first time in decades.

Macroinvertebrate surveys already show increased family richness in the on-campus portion of the creek (Table 2), and values now approach family richness levels found in reaches above the campus. While survey results in 1986 (expressed in terms of the Family Biotic Index, (Hilsenhoff, 1988)) indicated that Strawberry Creek water quality was ‘poor’, the 1991 survey indicated that water quality was ‘good’ (Table 2). Over time, other native animals may be naturally attracted back to the newly restored ecosystem.

ENVIRONMENTAL EDUCATION

Educational activities have always been a crucial element of the restoration project. Guest lectures were regularly given on various aspects of the project, as well as on the ecology of the creek and its catchment,

to a number of different classes in a range of academic departments such as Landscape Architecture, Conservation and Resource Studies, Forestry, City and Regional Planning, Biology, and Environmental Sciences; currently, well over 1500 students use the creek annually as part of their laboratory exercises in 50 different classes. A teaching videotape that illustrates sampling procedures was made using the creek as a focus (Resh *et al.*, 1990); this is currently being used in over 200 university and regulatory agency classes in North America.

Presentations were also given to San Francisco Bay Area conservation groups and at various events and conferences, and group walking tours of the creek and catchment were given to organizations or classes that requested it. These informal walking tours led to the development of a written, walking tour of campus natural history (Charbonneau *et al.*, 1989). About 3000 of these illustrated booklets were initially printed but they proved to be so popular that the supply was nearly exhausted in one year; an additional 10 000 copies have been printed. The tour includes six stops and emphasizes conservation and natural history (copies are available from VHR upon request).

The campus Botanical Garden in upper Strawberry Canyon was also interested in the restoration project because the South Fork of the creek bisects the Garden. The Creek Committee assisted with the planning and design of an interpretive creekside trail within the Garden. The trail was installed complete with two wooden observation decks overlooking the canyon catchment and creek. In the Fall of 1990, the Garden sponsored a public symposium on Strawberry Creek that highlighted the restoration project, the ecology of the creek and its catchment, and other topics related to urban stream restoration. The symposium ended with a release of three-spined sticklebacks in the Garden's reach of the creek.

Efforts were also made to educate catchment residents living in the City of Berkeley's Northside district. This densely populated area had been a constant source of pollution in the North Fork of the creek caused by improper dumping of oil and other materials into the storm drain system. In close cooperation with the City of Berkeley, an informational mailing to all Northside residents within the catchment was conducted. Each resident received a cover letter signed by both the City Manager and Vice-Chancellor of the University explaining the pollution problems caused by storm-drain disposal, information on where to dispose of used motor oil, as well as tips on erosion control for homeowners. Included in the mailing packet was a map showing where the creek passed both above and underground through the neighbourhood, and a local parks district brochure on erosion control. The campus organized all of these materials and the City mailed out about 1000 packets of information to individual Northside residents.

Further efforts to combat improper storm-drain disposal were tried. A logo was designed and stencilled onto curbs where storm-drain grates were located, serving both to heighten people's awareness of the creek as well as to discourage casual dumping. The logo read 'Dump No Waste—Drains to Creek' along with an outline of a fish. This logo was painted in bright blue on all campus storm drains, and permission was also given by the City of Berkeley to paint the curbs in the Northside district. Additional stencilling was also occurring throughout Berkeley as a local urban creeks restoration group painted logos on curbs at the approximate locations of numerous creeks that were now culverted underground. Each urban creek was identified by its own particular logo; appropriately, a stickleback-like fish was selected as the logo for Strawberry Creek and stencilled periodically on the sidewalks as the creek made its way underground towards San Francisco Bay.

Apparently, efforts at raising people's awareness of the creek were successful. A tremendous increase in the reporting of pollution incidents occurred. In one case, the day after a campus newspaper reported the fish introductions, over 50 calls were received when (non-toxic) green dye from plumbers checking sewer lines was observed in the creek.

Finally, resource materials on Strawberry Creek were collected and deposited into a master file at the Water Resources Center Archives on campus. Academic departments contributed scores of past student reports on the creek (some going back to the 1920s) and as additional information is collected, copies are given to the Archives to file. A centralized repository of information on Strawberry Creek has been an

essential step in realizing the goal of enhancing the creek's value as a teaching and research resource for the campus, and this collection has become a valuable reference centre for urban creek restoration projects in the San Francisco Bay area.

OBSTACLES TO RESTORATION

A number of impediments will always inhibit the complete restoration of Strawberry Creek. Not surprisingly, the most imposing obstacle is the urban environment of the creek's catchment. Extensive development in the catchment has permanently altered the hydrologic regime of the creek, creating flashy flow conditions. Scouring storm flows accelerate erosion and degrade the aquatic habitat. Urban storm-water runoff causes short-term shock-loading of various pollutants, but the physical effects of the runoff volume itself are probably more significant. Retrofitting of storm-water detention facilities is not feasible because of the existing dense pattern of development, and its prohibitively high cost. The creek's function as the storm drain system for the catchment also subjects it to pollution from improper hazardous materials disposed in catch basins and from accidental spills. It has been recommended that storm-water mitigation efforts should concentrate on non-structural Best Management Practices, including source controls such as improved street sweeping, regular cleaning of storm drains and erosion control.

The hydrologic characteristics of Strawberry Creek directly affect its morphology. Culverts and, to a lesser extent, check dams will always pose physical barriers to migration of fish from San Francisco Bay. These obstacles also prevent recolonization following acute upstream disturbances. The flashy flows and channel alterations have produced predominantly shallow riffle habitats in the creek, as many natural pools have been filled in by sediment. This lack of a natural pool-riffle sequence limits the diversity of aquatic habitats. Scouring storm flows also produce erosion leading to stream-bank failure and sedimentation. The limitations on Strawberry Creek's physical habitat characteristics prove to be the single most significant factor limiting its complete restoration. Because there are no practical measures available for us to use to decrease peak flows, mitigating measures such as structural habitat enhancement (e.g. deflectors, boulder placement) are the only feasible alternatives for improving the creek's physical habitat.

Finally, Strawberry Creek represents an analogy of the problem facing freshwater conservation efforts throughout the world because the natural catchment crosses jurisdictional lines of the campus, the Lawrence Berkeley Laboratory, and the Northside district of the City of Berkeley. Control of spills has generally been achieved on the South Fork of the campus, but pollution still enters the stream from outside the campus boundaries. For example, storm drains enter the culverted North Fork as it flows underneath the Northside district; this water then flows onto the campus. In fact, the North Fork on the campus remains somewhat degraded and has a less diverse flora and fauna than the South Fork. Essentially, this jurisdictional boundary problem in Strawberry Creek is a microcosm of the boundary problems that plague almost all river systems worldwide.

KEYS TO SUCCESS

Many factors contributed to the success of the creek restoration project up to this time. First, campus administrative support was provided. Second, funding was available in both the EH&S and facilities deferred-maintenance budgets, and cooperative agreements with state agencies allowed water quality monitoring analyses to be done at a fraction of the usual costs. Third, the faculty-based Creek Committee cut through many of the bureaucratic entanglements facing administrative committees: all members were committed to making the project work; representatives from all jurisdictions within the catchment were involved in the decision-making process; and a planner with a technical background was placed in a project management role with coordination and implementation responsibilities backed by the authority vested in the Creek Committee. Close cooperation between campus EH&S and facilities personnel was essential for all phases

of the project, especially the sanitary engineering and erosion control aspects. This point has been underscored by contributors to the chapters in Gardiner (1991).

The greatest challenge for the Strawberry Creek restoration project was not technical in nature, but institutional. We found that creating changes in a complex institutional setting, such as a 31 000-student public university, was difficult but not impossible. The conservation goal of the project seemed to change long-standing attitudes and practices; likewise, education and heightened public awareness helped win administrative support despite objections raised such as the possibility of negative publicity caused by potential fish kills. In any event, progress in the restoration of Strawberry Creek was made in very short time. For example, the period from the inception of the initial creek study to the day that native fish were first restocked in the creek covered almost exactly 2 years.

ON-GOING RESTORATION EFFORTS

The recommendations made in the initial creek study have now been institutionalized. The Chancellor's advisory committee continues to oversee restoration efforts, concentrating on native biological communities and advising campus academic departments on how to include the creek in their teaching programmes. The campus facilities staff continue to work on stream-bank erosion control and re-routing minor discharges, but new, major projects have been limited by reductions in the deferred-maintenance budgets. EH&S still responds to pollution calls, monitors the general water quality of the creek, and periodically changes the oil-spill control booms that have been installed on the creek. Recently, a professor in the Department of Landscape Architecture established multiple stream-channel cross sections to provide baseline conditions against which future changes in channel geometry and sedimentation can be calculated.

It is apparent from our experiences in Strawberry Creek that ecological restoration projects in urban settings must consider several essential elements. Initially, an inventory and diagnostic survey must be performed; existing conditions must be documented and evaluated so that restoration opportunities and constraints can be identified. Goals should be well defined for the entire project, as well as for specific locations. Roles and responsibilities of participating entities should be clearly defined, and a project coordinator should be appointed to oversee implementation efforts. As repeatedly emphasized in the chapters in Boon *et al.* (1992) and Gardiner (1991), it is essential that entire catchments be considered in developing management strategies rather than focusing attention only on the water body of interest. Finally, planning activities should concentrate on implementation, and in this regard both short-term and long-term goals should be periodically re-examined.

ACKNOWLEDGEMENTS

Elaine Bild, Sonja Biorn-Hansen and Ben Gonzales were instrumental in securing funding for these projects and for providing administrative leadership and support for the restoration programme. Dozens of students helped in this project; we especially thank R. Hufbauer, J. Pan, J. Phillips and L. Stevens for their efforts.

REFERENCES

- Boon, P. J., Calow, P. and Petts, G. E. (Eds) 1992. *River Conservation and Management*, John Wiley, Chichester.
- Brookes, A. 1988. *Channelized Rivers: Perspectives for Environmental Management*. John Wiley, Chichester.
- Charbonneau, R. 1987. *Strawberry Creek Management Plan*, Office of Environmental Health and Safety, University of California, Berkeley, California.
- Charbonneau, R., Kaza, S. and Resh, V. H. 1989. *Strawberry Creek. A Walking Tour of Campus Natural History*, University of California, Berkeley, California.
- Finnigan, R. J., Marshall, D. E., Mundie, J. H., Slaney, P. A. and Taylor, G. D. 1980. *Stream Enhancement Guide*, Government of Canada, Fisheries & Oceans, Province of British Columbia, Ministry of Environment, Vancouver, BC.

- Gardiner J. L. (Ed.) 1991. *River Projects and Conservation. A Manual for Holistic Appraisal*, John Wiley, Chichester.
- Gore, J. A. (Ed.) 1985. *The Restoration of Rivers and Streams: Theories and Experience*, Butterworth, Boston.
- Hilsenhoff, W. L. 1988. 'Rapid field assessment of organic pollution with a family-level biotic index,' *Journal of the North American Benthological Society*, 7, 65–68.
- Resh, V. H., Feminella, J. W. and McElravy E. P. 1990. *Sampling Aquatic Insects*, Office of Media Services, University of California, Berkeley.
- Resh, V. H. and Grodhaus, G. 1983. 'Aquatic insects in urban environments', in Frankie, G. and Koehler, C. (Eds), *Urban Entomology*, Praeger Publishers, New York, 247–276.
- Rosenberg, D. M. and Resh, V. H. 1992. *Freshwater Biomonitoring and Benthic Macroinvertebrates*, Chapman and Hall, New York.
- Sklar, L. and Haltiner, J. 1991. *Strawberry Creek Bank Stabilization Monitoring and Follow-up Report*, University of California, Berkeley; Philip Williams & Associates, San Francisco, California. 30.
- Swales, S. 1989. 'The use of instream habitat improvement methodology in mitigating the adverse effects of river regulation on fisheries', in Gore, J. A. and Petts, G. E. (Eds) *Alternatives in Regulated River Management*, CRC Press, Boca Raton, Florida, 185–208.
- Wesche, T.A. 1985. 'Stream channel modifications and reclamation structures to enhance fish habitat', in Gore, J. A. (Ed.), *The Restoration of Rivers and Streams: Theories and Experiences*, Butterworth, Boston, 103–164.
- Willey, S. H. 1887. *History of the College of California*, published by the author, San Francisco.