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Project Summary

Sources of Urban Runoff Pollution and Its Effects on an Urban Creek

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Sources and impacts of urban runoff were studied for the Coyote Creek near San Jose, California. The 3-year monitoring study included three tasks: (1) identifying and describing important sources of urban runoff pollutants; (2) describing the effects of those pollutants on water and sediment quality, aquatic organisms, and associated beneficial uses of the creek; and (3) assessing potential measures for controlling the problem pollutants in urban runoff.

Results indicated that various urban runoff constituents (especially organics and heavy metals) may be responsible for many of the adverse biological conditions observed in Coyote Creek. But adequate control of pollutants would require extremely high removals that would be difficult as well as costly to achieve.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

A 3-year monitoring study was conducted to evaluate the sources and impacts of urban runoff on water quality and biological conditions in Coyote Creek near San Jose, California. The three major elements of this study included: (1) identifying and describing important sources of urban runoff pollutants; (2) describing the effects of those pollutants on water and sediment quality, aquatic organisms, and associated beneficial uses of the creek; and (3) assessing potential measures for controlling the problem pollutants in urban runoff. In many cases, very pronounced gradients of water and biological quality indicators were observed. Though cause-and-effect relationships cannot be conclusively proved in a study such as this, the degraded conditions in Coyote Creek may be the results of several factors, including urban runoff, stream flows, (associated or not with urban runoff), and natural conditions such as drought, stream gradient, groundwater infiltration, etc. Information developed during this study implies that various urban runoff constituents (especially organics and heavy metals in the water and polluted sediment) may be responsible for many of the adverse biological conditions observed.

Site Description

The Coyote Creek watershed (Figure 1) is near San Jose, California. Coyote Creek is a small stream, about 130 km (80 mi) long, originating in a wilderness area that is virtually free of pollutant sources. The upper reaches and headwaters of Coyote Creek have extremely rugged, chaparral-covered terrain with slopes commonly exceeding 30 percent. Much of this land is within the Henry Coe State Park; nonpark land

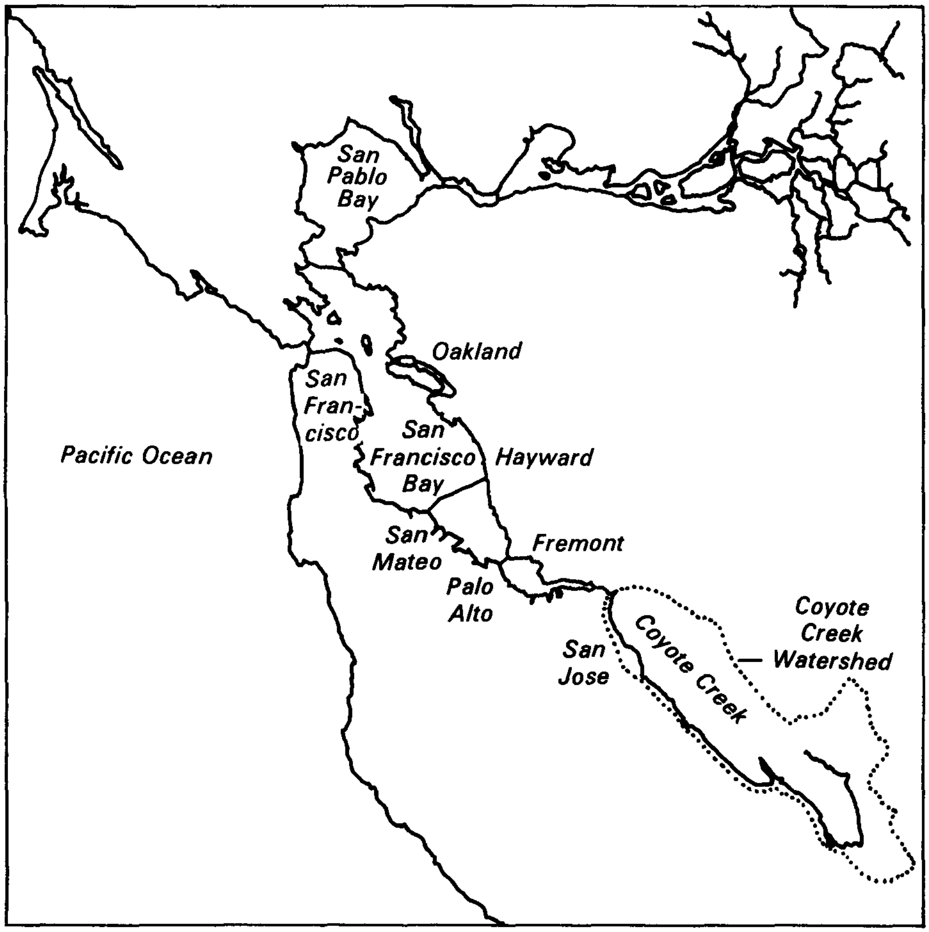

Figure 1. *Location of the Coyote Creek watershed in relation to the San Francisco Bay Area.*

is used primarily for low-intensity cattle grazing. The Coyote Creek watershed is about 70 km (45 mi) long and 15 km (10 mi) wide, and it contains about 80,000 ha (200,000 acres). About 15 percent of the watershed (all in the downstream reach) consists of parts of the San Jose urban area. The upstream waters pass through two manmade flood control reservoirs (Coyote Lake and Lake Anderson) that control the creek flow during most of the year. The lower reaches of the watershed are in broad plain. Most of the 24-mile-long study area was located between Lake Anderson in the nonurban area and the first major creek confluence within the city of San Jose (where Coyote Creek meets Silver Creek).

Field Program

In this study, water quality, sediment, and biological characteristics of the creek were measured in the urban and nonurban reaches of Coyote Creek. Differences in these characteristics were evaluated to quantify any degradation and to identify the pollutant sources. Early in the study (spring of 1977), a pilot water quality survey was conducted along Coyote Creek from Anderson Dam to San Francisco Bay. Water quality samples were obtained at 10 sites and analyzed for major constituents. The full-scale sampling program was designed and carried out after this pilot survey was completed.

The beginning of the 3-year monitoring project followed 2 years of severe drought, during which precipitation was only about half its normal average. Normal rains are about 33 cm/yr (13 in./yr) in the area below Lake Anderson and 50 to 70 cm (20 to 28 in.) in the watershed above Lake Anderson. The first major rains ending the drought occurred in November 1977, and rains during the study period were close to normal. Typical summer flows in the urbanized creek sections were less than 1.5 m^3/s (53 ft^3/s).

During the field program, 41 stations were sampled in both urban and nonurban perennial flow stretches of the creek. Short- and long-term sampling techniques were used to evaluate the effects of urban runoff on water quality, sediment properties, fish, macroinvertebrates, attached algae, and rooted aquatic vegetation. The program was designed to define receiving water conditions in the urban and nonurban areas during dry weather conditions.

Sampling Methods

Creek flow rates were either measured by the field personnel using a digital current meter, or they were estimated with floats. All stream sampling on this project was conducted manually with submerged, plastic, wide-mouthed bottles. The samples were preserved and analyzed according to the requirements of the U.S. Environmental Protection Agency (EPA).

Sediment samples were obtained by scooping bottom material into glass jars and sealing the containers underwater. The samples were then frozen and delivered to the laboratory for EPA-approved analyses. Sediment core samples (for examining stratification) were obtained with a liquid carbon dioxide freezing core sampler.

Biological samples (mosquitofish, filamentous algae, crayfish, and cattail plant segment) were obtained at selected sampling stations and were chemically digested and analyzed for total lead and zinc concentrations.

Fish were collected by seining and electroshocking representative pool and riffle habitats. Captured fish were identified and counted. The total length and weight were recorded for each specimen. Where numerous individuals of a particular species were encountered, only length range and aggregate weight were recorded.

Replicate benthic macroinvertebrate samples were collected from natural substrates (e.g., cobbles, gravel, sand) in both pool and riffle habitats by means of an Ekman dredge or a Surber sampler. Also used were replicate pairs of artificial substrate samplers (Hester-Dendy) constructed of multiple, parallel plates of Masonite.* These samplers were left in the stream for 8 weeks and then removed and examined in the laboratory.

Qualitative benthic collections were also made with the use of a D-frame sweep net. The benthic samples were washed through a sieve with a mesh size of 500 μm. Organisms retained on the screen were removed, preserved, identified to the lowest possible taxon, and enumerated.

Attached algae samples were obtained from both natural and artificial substrates throughout the various reaches of Coyote Creek. Qualitative samples of attached algae were collected by scraping uniform areas of natural substrates such as logs and rocks. Qualitative collections of attached algae were made with the use of artificial substrates consisting of diatometers equipped with glass slides. These were suspended in the water column for 8 weeks and then removed and examined in the laboratory. The qualitative samples were preserved and identified. The quantitative samples were prepared, identified, and enumerated using the proportional count method.

Rooted aquatic plants were sampled qualitatively whenever they were encountered in the study area. Plant specimens were collected, pressed or preserved, and identified.

Sources of Runoff Pollutants

Urban runoff studies must determine how much of the total pollutant yield observed at the watershed outfall is attributable to each source. Sources far from the inlet to the storm sewerage system require overland flow. Accordingly, they contribute relatively small amounts of pollutants (based on observations at the outfall). Conversely, parking lots or street surfaces are impervious to water and are typically located adjacent to the storm sewer inlets. Hence the pollutants from these areas contribute most to the outfall yield.

One important project phase examined potential sources of pollutants. Runoff samples and dry particulate samples were collected from various source areas in San Jose, including roofs, parking areas, and gutters. Rainfall samples and outfall samples were also analyzed. Rain was found to have the lowest pollutant concentrations, whereas the parking lot and gutter flows had the highest levels (for most of the constituents studied). Puddles in a city park were found to have much greater specific conductance and concentrations of total solids and nitrates than any other samples. The observed lead concentrations ranged widely, from less than 0.01 for the rain to more than 1.0 mg/L for gutter flows.

Particulate samples from the San Jose area had typically greater pollutant concentrations than the corresponding levels in local soils. Most constituent levels increased with the degree of urbanization. Rooftops are thought to contribute the least pollutants. Parking lots, street surfaces, and sidewalks are expected to contribute most of the heavy metals and bacteria, and some nutrients to the total runoff yield. Landscaped areas and vacant lots contribute most of the solids, oxygen-demanding materials, and other nutrients.

The amount and character of runoff-borne pollutants from a given site depend on factors such as the volume of the storm event and the length of the antecedent dry period (i.e., the period of pollutant accumulation). Large storms (those with high intensities and/or large rainfall volumes) result in contributions from impervious areas (street surfaces and other paved areas) that are small relative to the total runoff particulate yield. This pattern is more pronounced when the antecedent dry periods are short. During such conditions, the paved surfaces stay relatively clean because of the frequent rains. A large rainfall will result in significant erosion from the surrounding saturated pervious areas, however. Thus areas with moderate rainfall intensities and long periods of accumulation (i.e., dirty paved surfaces and dry surrounding soil conditions) would have most of their urban runoff output associated with pavement washoff.

Of the total solids deposited in an urban area, only about a third would ever reach the outfall. And only about 10 percent of the nutrients and oxygen-demanding materials deposited might affect the receiving water quality. But most of the heavy metals deposited in the area would affect the receiving waters. The remaining deposited pollutants that are washed off the source areas but do not reach the outfall would accumulate in other areas of the urban environment. The most significant of such pollutant sinks in the urban area are probably soils, groundwater, plants, and animals.

Coyote Creek Water Quality

The purpose of the water quality monitoring program on Coyote Creek was to define receiving water conditions in the urban and nonurban areas during dry weather. Dry weather conditions were studied because they reflect long-term water quality characteristics in the creek and are less influenced by any specific urban runoff event. Data on wet-weather water quality conditions were obtained from previous studies.

Dry-weather concentrations of many constituents exceeded the expected wet-weather concentrations by factors of 2 to 5. For example, during dry weather, concentrations of many of the major constituents (e.g., major ions, total solids, etc.) were significantly greater in both the urban and nonurban reaches. These constituents were all found in substantially lower concentrations in the urban runoff and in the rain. The rain and the resulting runoff apparently diluted the concentrations off these constituents in the creek during wet weather. Within the urban area, many constituents were found in greater concentrations during wet weather than during dry weather—COD, organic nitrogen, and especially heavy metals such as lead, zinc, copper, cadmium, mercury, iron, and nickel. Similar differences between wet and dry weather were also noted for the nonurban areas, but the wet weather concentrations were typically much higher in the urban than in the nonurban area.

Values for dry-weather samples obtained from the urban and nonurban reaches of Coyote Creek were summarized in Table 1. Lead concentra-

*Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

tions were more than seven times greater in the urban reach than in the nonurban reach during dry weather, with a confidence level of 75 percent. Other significant increases in urban area concentrations occurred for nitrogen, chloride, orthophosphate, COD, specific conductance, sulfate, and zinc. The dissolved oxygen measurements were about 20 percent less in the urban reach than in the nonurban reach of the creek.

Lead concentrations exceeded the water quality criteria for both livestock and aquatic life. During dry weather, the water was also hard to very hard (typical of Santa Clara County surface and ground waters). Chloride concentrations at the furthest downstream station (Dixon) were high because of tidal influences that caused mixing with San Francisco Bay water. About half of the observed ammonia values were equal to or greater than the established criteria for aquatic life (0.02 mg/L). Total coliform bacteria populations were also high at most of the sampling sites. Water quality upstream of the urbanized area was fairly consistent from site to site, but the quality changed markedly as the creek passed through the urbanized area.

Selected wet-weather samples were also analyzed for priority pollutants as a special part of this study.

Coyote Creek Sediment Quality

Coyote Creek sediment quality is summarized in Table 2. Lead concentrations in the urban area sediments were greater than those from the nonurban area by a factor of about 6, which is the widest margin for any constituent monitoring. Large differences were also found between the urban and nonurban area data for both sulfate and phosphate. Average zinc concentrations in the urban sediments were about 1.5 times those of nonurban sediments, but with a high degree of confidence.

During the first survey, the differences between urban and nonurban sediment concentrations were much greater: sulfur, lead, and arsenic levels were 4 to 60 times greater in urban area sediments. Seasonal and yearly changes in relative sediment concentrations can therefore be significant.

Selected sediment samples were also analyzed for many elements using mass spectrographic procedures. Other sediment samples were also analyzed for priority pollutants.

The ratio of sediment concentrations (mg/kg) to water concentrations (mg/L) was also calculated. This sediment-to-water ratio (S/W) would be low for readily soluble constituents. and it would be high for relatively insoluble constituents. The S/W ratios

Table 1. *Summary of Coyote Creek Water Quality Conditions in Dry Weather*

	Nonurban Area Stations Below Anderson Dam (mg/l)			*Urban Area Stations Above Silver Creek (mg/l)*			*Urban/Nonurban Differences*	
Parameter	*Mean*	*Min*	*Max*	*Mean*	*Min*	*Max*	*Ratio**	*% Confidence †*
Total solids	270	244	299	590	280	1200	2.2	98
Chloride	<20	<20	<20	43	30	60	>2.2	98
Dissolved oxygen	8.6	6.5	10.6	6.8	1.5	11.0	0.8	>99
COD	17	12	23	30	19	53	1.8	98
Total phosphate	<0.2	<0.02	0.59	0.25	<0.02	0.54	>1.3	65
Total Kjedahl nitrogen	<0.3	<0.05	0.50	0.45	<0.05	0.78	>1.7	85
Lead	<0.005	0.001	0.002	0.036	0.003	0.10	>7	75
Zinc	0.019	0.019	0.019	0.033	0.010	0.075	1.7	80

** Ratio of urban to nonurban mean values.*
† Percent confidence that urban does not equal nonurban values.

Table 2. *Summary of Coyote Creek Sediment Quality Conditions*

	*Nonurban Area Stations Below Anderson Dam (mg/kg)**			*Urban Area Stations Above Silver Creek (mg/kg)*			*Urban/Nonurban Differences*	
Parameter	*Mean*	*Min*	*Max*	*Mean*	*Min*	*Max*	*Ratio†*	*% Confidence‡*
COD	35,500	7,400	98,000	39,300	4,600	131,000	1.1	<60
Total phosphate	148	7.5	344	168	14	406	1.1	<60
Total Kjeldahl nitrogen	6,500	138	29,000	2,490	146	14,000	0.4	85
Lead	18.8	6.7	37	114	20	400	6.1	96
Zinc	64	14	90	96	30	170	1.5	97
Median particle size (μ)	4,350	210	8,760	4,480	70	8,600	1.0	<60

** Units are in milligrams of constituent per kilogram of total solids, except for the median particle size, which is measured in microns.*
† Ratio of urban to nonurban mean values.
‡ Percent confidence that urban does not equal nonurban mean values..

were found to be very high for most of the constituents monitored. The largest difference between urban and nonurban S/W ratios was for lead, where the S/W ratio was more than 3,000 for the urban area and only about 400 for the nonurban area. The total Kjeldahl nitrogen S/W ratio was about 5,500 for the urban area, but it exceeded 22,000 for the nonurban area. For the other constituents studied, the S/W ratios for urban and nonurban areas were much closer. Urban runoff constituents could be present in the creek water column at acceptable concentrations even when interstitial waters in the sediments were polluted. Unfortunately, little information is available concerning the effects of polluted sediments on benthic organisms.

Effects of Pollutants on Aquatic Organisms in Coyote Creek

Bioaccumulation of Lead and Zinc in Selected Coyote Creek Organisms

Some evidence of bioaccumulation of lead and zinc was found in many of the samples of algae, crayfish, and cattails. The measured metal concentrations in the organisms exceeded those in the sediments by a maximum factor of about six. Concentrations of lead and zinc in the organisms exceeded water column concentrations by factors of 100 to 500. Lead concentrations in urban area samples of algae, crayfish, and cattails were two to three times as high as those in nonurban samples, and zinc levels in urban algae and cattails were about three times as high as those of nonurban samples. Lead and zinc concentrations in fish tissues were not noticeably different in urban and nonurban samples.

Species of Fish Found in Coyote Creek

The relative abundance of fish species observed in the urban and nonurban reaches of Coyote Creek is shown in Table 3. Introduced fish often cause radical changes in the nature of the fish fauna present in a given water body. Often they become the dominant fish because of a superior ability to compete with the native species for food or space, or because of a greater tolerance to environmental stress. Introduced species are generally most abundant in aquatic habitats modified by man, whereas native fish tend to persist mostly in undisturbed areas. Such is apparently the case within Coyote Creek.

Samples from the nonurban portion of the study area were dominated by an assemblage of native fish species such as hitch, threespine stickleback, Sacramento sucker, and prickly sculpin. Rainbow trout, riffle sculpin, and Sacramento squawfish were captured only in the headwater reaches and tributary streams of Coyote Creek. Collectively, native species constituted 89 percent of the number and 79 percent of the biomass of the 2,379 fish collected from the upper reaches of the study area. By contrast, native species accounted for only 7 percent of the number and 31 percent of the biomass of the 2,899 fish collected from the urban reach of the study area.

Hitch was the most numerous native fish species present. Hitch generally exhibit a preference for quiet water habitat and are characteristic of warm, low elevation lakes, sloughs, sluggish rivers, and ponds. Mosquitofish dominated the collections from the urbanized section of the creek and accounted for more than two-thirds of the total number of fish collected from that area. This fish is particularly well adapted to withstand extreme environmental conditions, including those imposed by stagnant waters with low dissolved oxygen concentrations and elevated temperatures. The second most abundant fish species in the urbanized reach of Coyote Creek, the fathead minnow, is equally well suited to tolerating extreme environmental conditions. The species can withstand low dissolved oxygen, high temperature, high organic pollution, and high alkalinities. Often thriving in unstable environments such as intermittent streams, the fathead minnow can survive in a wide variety of habitats.

Table 3. *Relative Abundance of Fish Species Collected from Coyote Creek Between Anderson Dam and Silver Creek*

Species	*Nonurbanized Reach (%)*	*Urbanized Reach (%)*
Native fish:		
Hitch	*34.8*	*4.9*
Threespine stickleback	*27.3*	*0.8*
Sacramento sucker	*12.6*	*0.1*
Prickly sculpin	*8.2*	*<0.1*
Sacramento blackfish	*4.3*	*1.0*
California roach	*1.8*	*0.3*
Introduced fish:		
Mosquitofish	*5.6*	*66.9*
Fathead minnow	*0.6*	*20.6*
Threadfin shad	-----	*2.4*
Green sunfish	*<0.1*	*1.2*
Bluegill	*0.2*	*1.0*
Largemouth bass	*<0.1*	*0.4*
White crappie	*0.1*	-----
Black crappie	*0.1*	-----
Goldfish	*3.5*	*0.3*
Carp	*0.9*	*0.1*
Golden shiner	-----	*<0.1*
Total number of fish collected	*2,379*	*2,899*

Benthic Macroinvertebrates Observed in Coyote Creek

The abundance and diversity of taxa generally appear to be greatest in nonurbanized sections of the stream (Figure 2). The overall increase in number and diversity of benthic organisms encountered in the 1979 samples as compared with the 1978 samples may be attributed to further recovery from the drought conditions that preceded this study. The benthos in the upper reaches of the creek consisted primarily of amphipods and a diverse

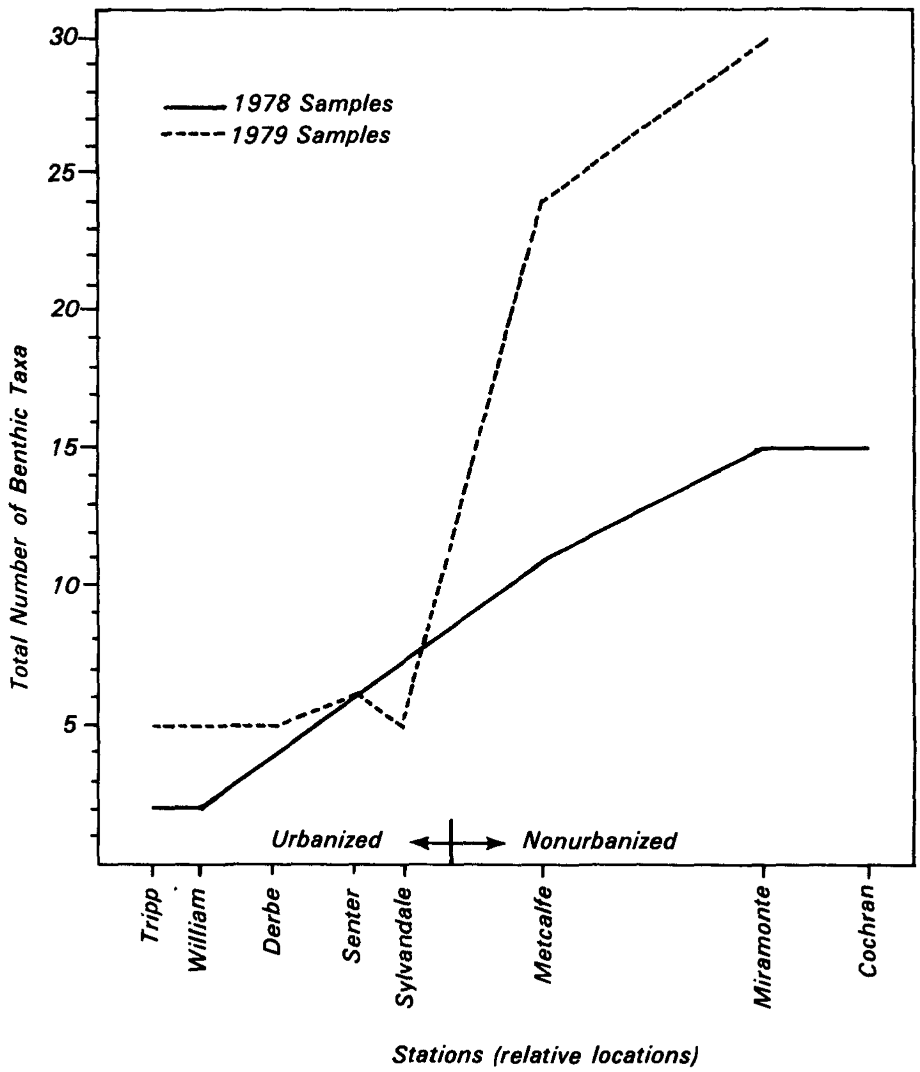

Figure 2. *Abundance of benthic taxa collected from natural and artificial substrates in Coyote Creek during 1978 and 1979.*

assemblage of aquatic insects. Together, those groups made up two-thirds of the benthos collected from the nonurban portion of the creek. Clean water forms were abundant and included amphipods (*Hyaella azteca*) and various genera of mayflies, caddisflies, black flies, crane flies, alderflies, and riffle beetles. In contrast, the benthos of the urban reaches of the creek consisted almost exclusively of pollution-tolerant oligochaete worms (tubificids). Tubificids accounted for 97 percent of the benthos collected from the lower portion of Coyote Creek.

Conclusions

The biological investigations in Coyote Creek indicated distinct differences in the taxonomic composition and relative abundance of the aquatic biota present in Coyote Creek. The nonurban sections of the creek support a comparatively diverse assemblage of aquatic organisms, including an abundance of native fish and numerous benthic macroinvertebrate taxa. In contrast, the urban portions of the creek comprise an aquatic community that generally lacks diversity and is dominated by pollution-tolerant organisms such as mosquitofish and tubificid worms.

Although certain differences in physical habitat occur in the downstream reaches of the study area (e.g., a decrease in stream gradient, shorter riffles, and wider, deeper pools), such differences are not thought to be responsible for the magnitude of change noted in the aquatic biota of the urban reach of Coyote Creek. Urban runoff, which has been shown to increase significantly the levels of many toxic materials in the receiving water and sediments of the stream, is more likely to be at fault.

No single pollutant appears to be responsible for the significant decrease in the abundance and diversity of aquatic life observed in Coyote Creek as it passes through San Jose. Very large concentrations of several toxic pollutants in the sediments were observed, but they cannot be conveniently related to water quality criteria or published test results on water quality effects. The reported water quality effects on aquatic organisms present in Coyote Creek do not consider antagonisms or synergisms that are likely to occur, except for the antagonistic effect of hardness on heavy metal toxicity. The combined effects of various heavy metals can often be greater than the effects of any single element. Some of the constituents most likely to create water quality problems do occur in potentially harmful concentrations in both the nonurban and urban reaches of Coyote Creek (temperature, ammonia, nitrates, phosphorus, and mercury). The most important constituents that exceeded water quality criteria in the urban area and not in the nonurban area include dissolved oxygen, copper, and lead. Though zinc concentrations exceeded the water quality criteria both in nonurban and urban areas, the excess was much greater in the latter.

Changes in the nature of the stream substrate also occur as a result of silt and debris deposits from urban runoff. Such changes are likely to be a primary reason for the decline in species abundance and diversity in the urban reaches of Coyote Creek.

Water quality criteria for various beneficial uses could conceivably be met in all reaches of Coyote Creek, but it would require vigorous control of urban runoff pollutants. In this study, needed control levels were estimated by comparing observed pollutant concentrations with (a) levels that were needed to support various beneficial uses, (b) concentrations typical of secondary wastewater effluent, and (c) concentrations typical of the nonurban control areas.

The degree of pollutant control required for urban runoff may be as follows: lead, 75 to 98 percent; zinc, 35 to 50 percent; suspended and settleable solids, 40 to 90 percent; and oxygen-demanding materials (e.g.,COD, BOD, total organic carbon) and phosphate, about 85 percent. Depending on the location of acceptable biological conditions, total urban runoff control would have to be more than 80 percent effective. These removal goals are all very high and would be difficult to meet.

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***Richard Field** is the EPA Project Officer (see below).*
The complete report, entitled "Sources of Urban Runoff Pollution and Its Effects on an Urban Creek," (Order No. PB 83-111 021; Cost: $16.00, subject to change) will be available only from:
National Technical Information Service
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Springfield, VA 22161
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