Urban Storm-Induced Discharge Impacts
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DISCHARGE IMPACTS

U.S. Environmental Protection
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by

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URBAN STORM-INDUCED DISCHARGE IMPACTS: US ENVIRONMENTAL PROTECTION AGENCY RESEARCH PROGRAM REVIEW

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ABSTRACT

Fecal coliform bacteria (and pathogens), high flow rates, sediment, toxic heavy metals and organic pollutants are most commonly associated with urban receiving water problems. Most beneficial uses have been shown to be adversely effected by urban runoff, including shell fish harvesting, fish and aquatic life propagation, drinking water supplies, aesthetics and recreation. Most of the problems occur over long periods of time and are not associated with individual runoff events, making cause and effect relationships difficult to study.

The Storm and Combined Sewer Program of the U.S. Environmental Protection Agency has sponsored several long-term research projects to investigate these problems, along with data reviews to identify urban runoff problems from available information. Current research efforts are stressing sources and controls for toxicants in urban runoff.

KEYWORDS

Urban receiving water impacts; urban runoff; urban stormwater.

INTRODUCTION

Many urban area receiving water problems have been identified. However, the seriousness of the issue is highly dependent on the definition of what constitutes a problem. Most governmental agencies are most concerned with water quality concentrations that exceed standards or other criteria. Unfortunately, urban runoff behaves in different manners than typical municipal wastewater discharges for which many standards were developed and proven. As an example, urban runoff occurs for relatively short periods of time. Toxicant concentrations developed for continuous exposures would therefore have to be modified for the much shorter exposure durations. Short-term bioassay tests using urban runoff have typically indicated low toxicity (Pitt, 1979). However, monitored mass loadings indicate substantial discharges and potentially greater toxicities for storm-induced discharges than shown with the short-term bioassay tests. In contrast, long-term receiving water studies have found aquatic organism stresses indicating significant toxicity problems with urban runoff (Pitt and Bozeman, 1982; Perkins, 1982 as examples). In general, urban runoff problems, as identified in these long-term monitoring studies, appear to be more related to habitat destruction (due to high flow rates), sediment accumulation and chemical transformations of materials in the sediments. Very few short-term problems (such as fish kills) have been associated with specific urban runoff events.

In another example, fecal coliform concentrations in urban runoff are very high (US EPA, 1983) and have been shown to cause excessive concentrations that exceed water contact criteria at downstream swimming beaches (Yousef et al., 1980; Field and Turkeltaub, 1981). A number of studies have directly monitored bacterial pathogens in urban runoff (Field, et al., 1976; Olivieri, et al., 1977; Davis, et al., 1979). These studies have shown that the assumed relationships between fecal coliforms and pathogenic bacteria (typically Salmonella) may not be valid for urban runoff. Unfortunately, other pathogens (especially

Pseudomonas aeruginosa) are present in urban runoff in very high concentrations (Pitt and McLean, 1986; Bannerman, 1988) and are usually not monitored in sanitary surveys.

It has been difficult to directly link many of the observed urban receiving water problems to urban runoff sources. It has taken special research projects that have involved long-term monitoring of the beneficial uses directly (such as aquatic life) to support the more conventional water quality analyses used to identify the cause and effect relationships.

This paper presents a review of some of the studies that have examined available data to indicate urban runoff problems, plus summaries of two long-term urban receiving water impact studies sponsored by the Storm and Combined Sewer Program of the U.S. Environmental Protection Agency (EPA). A brief outline of current EPA Storm and Combined Sewer Program studies concerning runoff toxicant sources and their control is also provided.

BACKGROUND

Heaney, et al. (1980), in an evaluation of the literature pertaining to urban runoff effects on receiving waters, found that well-documented cases of receiving water detrimental effects were scarce. Urban runoff impacts are sometimes difficult to observe in urban areas because of the poor water quality conditions that have already existed for long periods of time. Fish kills are the most obvious indication of urban runoff problems in many situations. However, because urban receiving water quality is so poor, the amount of aquatic life in typical urban receiving waters is very stressed and limited in abundance and diversity. Ray and White (1979) stated that one of the complicating factors in determining fish kills related to heavy metals is that the fish mortality may lag behind the first toxic exposure by several days, and is usually detected many miles downstream from the discharge location. The actual concentrations of the water quality constituents that may have caused the kill could then be diluted beyond detection limits, making probable sources of the toxic materials impossible to determine in many cases.

Dissolved Oxygen

The most studied urban runoff effect has been dissolved oxygen in the receiving waters. Heaney, et al. (1980) found that worst case conditions do not always occur during the low flow periods following storms. Urban runoff effects on dissolved oxygen, especially associated with runoff sediments, may occur at times substantially different from the actual storm period.

Keefer, et al. (1979) examined the data from 104 water quality monitoring sites near urban areas throughout the US for dissolved oxygen conditions. About one half of the monitoring stations examined showed higher than average dissolved oxygen deficits occurring at times of higher than average streamflow, or on days with rainfall. They found that for periods of steady low flows, the DO fluctuated widely on a daily cycle, ranging from 1 to 7 mg/l. During rain periods, however, the flow increased, of course, but the diurnal cycle of this dissolved oxygen fluctuation disappeared. The minimum DO dropped from 1 to 1.5 mg/l below the minimum values observed during steady flows, and remained constant for periods ranging from 1 to 5 days. They also reported that as the high flow conditions ended, the DO levels resumed diurnal cyclic behavior. About 50 percent of the stations examined in detail would not meet a 5 mg/l DO standard, and about 25 percent of these stations would not meet the suggested 2.0 mg/l standard for 4-hour averages.

Another study that examined dissolved oxygen depletion on a regional basis was conducted by Ketchum (1978) at nine Indiana cities. The results of this study w: hat wet-weather DO levels generally appeared to be similar or higher than those observed during dry-weather conditions in the same streams. Significant wet-weather DO depletions were not observed.

The investigation of dissolved oxygen depletions due to storm-induced discharges is complicated by many factors. As an example, resuspension of contaminated sediments during high flows worsened and delayed the dissolved oxygen depletions directly associated with storm related discharges in Milwaukee (Meinholz, et al., 1979). Downstream processes (deposition and resuspension, dilution from tributaries, changes in BOD degradation rate, etc.) all mask the direct connections of observed dissolved oxygen conditions with storm-induced discharges. Mass discharges of pollutants may therefore be a more appropriate indicator of the magnitudes of oxygen depletion problems, instead of observed oxygen depletions.

The EPA Storm and Combined Sewer Program has found that mass discharges of BOD_5 and COD from wet-weather runoff is about the same as the dry-weather discharges of these pollutants from municipal wastewater treatment plants (Field and Turkeltaub, 1981). During storm periods, the wet-weather discharges increase to about 10 times as great as the dry-weather discharges. Because a large fraction of these oxygen depleting materials are associated with floatable and settleable solids, physical processes play an important role in actual oxygen depletion conditions. Also, the BOD in urban runoff is exerted over a much longer period of time than many other wastewaters, making the BOD_5 values a much smaller portion of the ultimate BOD than in other wastes (Pitt, 1979). Therefore, the actual portion of the ultimate BOD from storm-induced discharges may actually be even greater than indicated, based on BOD_5 mass balances.

Sediment Problems

Examples of heavy metal and nutrient accumulations in urban sediments are numerous. The most common mechanism of polluted sediments effecting the water column in urban streams is the resuspension of previously deposited material. Resuspension of sediments in urban streams occur under conditions of highly variable flow. Many urban streams experience major flow variations. Large quantities of sediment can be transported in the creek system by deposition, and resuspension, and subsequent redeposition. This repetitive process can result in polluted solids taking a long time to pass through an urban creek. The transport of the pollutants is, therefore, difficult to relate to specific runoff events. Much of the suspended pollutant material in an urban creek during a high storm flow may actually be resuspended sediment material that had been deposited during previous storms.

A number of mechanisms are available to allow the transport of pollutants from sediments into the water column. DePinto, et al. (1980) investigated the effects of oxygen levels, aquatic organisms, detergents, and the chemical forms of nutrients in the sediment, on the desorption of phosphorus from sediments. Nalepa and Quigley (1980) also examined the increased rate of sediment pollutant releases for many conditions caused by aquatic organisms (including chrionomids, tubificid worms, and fresh water clams).

Due to the nature of urban runoff, long-term effects can be very important. The characteristics of urban runoff that create long-term sediment effects are the large quantities of polluted solids that originate in various urbanized areas. These sediments can contribute to water quality problems at later dates when they are washed into the receiving water. Pitt (1979), in his study in San Jose, found that urban runoff oxygen demand affecting Coyote Creek can exert much greater biochemical oxygen demands 10 to 20 days after a rain event than during the first few days after a rain event. This increase in oxygen demand may be as much as tenfold. Therefore, sediments having high oxygen demands can substantially affect overlaying dissolved oxygen concentrations many days after they are deposited by a specific storm event. As mentioned previously, Meinholz, et al. (1979) found more critical oxygen deficits that were located much further downstream than predicted in Milwaukee due to the resuspension of contaminated sediments during high flows.

Wilber and Hunter (1980), in their studies on the Saddle River near Lodi, New Jersey, found that significant sediment enrichments of heavy metals in the lower Saddle River were affected by urbanization, as compared to the more rural upper Saddle River. The increase in heavy metal sediment concentrations due to urbanization ranged from about three for zinc and copper to more than five for lead, chromium, and cadmium.

Rolfe and Reinbold (1977) in their study near Champaign-Urbana, Illinois, also found that lead concentrations were much higher in an urban stream (almost 400 mg/l) compared to rural streams in the same area. They also found a greater diversity of plants and animals in the rural streams than in the urban streams.

Effects of Urban Runoff on Aquatic Organisms

Coyote Creek Study. This three-year monitoring study was conducted by Pitt and Bozeman (1982), under sponsorship and direction of the Storm and Combined Sewer Program of the EPA. The objective of this study was to evaluate the sources and impacts of urban runoff on water quality and biological conditions in Coyote Creek as it passed through San Jose, California. Coyote Creek is a small stream, only being a few meters wide and less than a meter in depth during dry weather. However, it drains a large watershed of about 80,000 ha which contains two reservoirs in the nonurban upstream reaches. The upstream area is a wilderness area that is free of almost all pollutant sources. The flows coming from the upstream areas are therefore regulated and quite clean, but the downstream urban flow contributions are highly variable and polluted.

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. In many cases, very pronounced gradients of water and biological quality indicators were observed. Information collected during this study indicated that the effects of organics and heavy metals in the water and in the polluted sediment, were probably most responsible for much of the adverse biological conditions observed.

Within the urban area, many constituents were found in significantly greater concentrations during wet-weather than during dry-weather (chemical oxygen demand, organic nitrogen, and especially heavy metals - lead, zinc, copper, cadmium, mercury, iron, and nickel). Lead concentrations were found to be more than seven times as great in the urban reach than in the nonurban reach. Lead concentrations exceeded the water quality criteria for both livestock and aquatic life uses. Water quality for most constituents 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. Urban reach dissolved oxygen concentrations were about 20 percent less than in the rural reach.

Lead concentrations in the urban area sediments were greater than those from the nonurban area by a factor of about six. Large differences were also found between the urban and nonurban area concentrations for both sulfate and phosphate. During the first survey, the differences between urban and nonurban sediment concentrations were much greater than later surveys; sulfur, lead, and arsenic were found to have substantially greater concentrations (4 to 60 times greater) in the urban area sediments than in the nonurban sediments. Seasonal and yearly changes in sediment concentration differences between the urban and nonurban creek reaches were therefore important. Both variable stream flows and urban runoff discharges from year to year were probably responsible for these sediment quality variations with time.

Some evidence of bioaccumulation of lead and zinc was found in many of the samples of algae, crayfish, and cattails analyzed. The measured concentrations of the metals in the organisms exceeded concentrations in the sediments by about six times. Concentrations of lead and zinc in the organisms exceeded water column concentrations by factors of about 100 to 500 times. Lead concentrations in urban area samples of algae, crayfish, and cattails were found to be two to three times as high as in nonurban area samples, whereas zinc concentrations in urban area algae and cattail samples were about three times as high as the concentrations in the samples from the nonurban areas. Lead and zinc concentrations in fish tissue were not noticeably different between the urban and nonurban area samples.

Introduced fishes often cause radical changes in the nature of the fish fauna present in a given waterbody. In many cases, they become the dominant fishes because they are able to out-compete the native fishes for food or space, or they may possess greater tolerance to environmental stresses. In general, introduced species are most abundant in aquatic habitats modified by man while native fishes tend to persist mostly in undisturbed areas. Such is apparently the case within Coyote Creek.

The nonurban portion of the study area was dominated by native fish species, such as hitch, three spine stickleback, Sacramento sucker, and prickly sculpin. Collectively, native species comprised 89 percent of the number and 79 percent of the biomass of the 2379 fishes examined from the nonurban reaches of the study area. In contrast, native species accounted for only seven percent of the number and 31 percent of the biomass of the 2899 fishes examined from the urban reach of the study area.

Mosquitofish dominated the collections from the urbanized section of the creek and accounted for over two-thirds of the total number of fish collected from the 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 specie in the urbanized reach of Coyote Creek, the fathead minnow, is equally well suited to tolerate extreme environmental conditions. This specie can withstand low dissolved oxygen, high temperature, high organic pollution and high alkalinity. Often thriving in unstable environments such as intermittent streams, the fathead minnow can survive in a wide variety of habitats.

In general, the abundance and diversity of taxa were greatest in the nonurbanized section of the stream. The benthos in the upper (nonurban) reaches of the creek consisted of 14 different specie, primarily of amphipods and a diverse collection of aquatic insects. Clean water forms were abundant in the nonurban sections of the creek 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 of only two specie, the most common being pollution tolerant oligochaete worms (tubificids). Tubificids accounted for 97 percent of the benthos collected from the lower (urban) portion of Coyote Creek.

Bellevue Urban Runoff Study. Pitt and Bissonnette (1984) summarized the many aspects of urban runoff in Bellevue, Washington that were studied during a four-year program sponsored and directed by the EPA (Corvallis Lab, Storm and Combined Sewer Program, and the Water Planning Division - NURP). The University of Washington (Pederson, 1981; Richey et al., 1981; Perkins, 1982; Scott et al., 1982; Sloane, 1982) conducted a series of studies to compare the biological and chemical conditions in urban Kelsey Creek with rural Bear Creek. Conveyance of stormwater, open space and resource preservation, recreational, and aesthetics beneficial uses were all degraded to varying extents in the urban creek, compared to the rural creek.

The urban creek was significantly degraded when compared to the rural creek, but still supported a productive, but limited and unhealthy salmonid fishery. Many of the fish in the urban creek, however, had respiratory anomalies. The urban creek was not grossly polluted, but flooding from urban developments had increased dramatically in recent years. These increased flows have dramatically changed the urban stream's channel, by causing unstable conditions with increased stream bed movement, and by altering the availability of food for the aquatic organisms. The aquatic organisms are very dependent on the few relatively undisturbed reaches. Dissolved oxygen concentrations in the sediments depressed salmon embryo survival in the urban creek. Various organic and metallic priority pollutants were discharged to the urban creek, but most of them were apparently carried through the creek system by the high storm flows to Lake Washington.

The fish population in Kelsey Creek had adapted to its degrading environment by shifting the species composition from coho salmon to less sensitive cutthroat trout and by making extensive use of less disturbed refuge areas. Studies of damaged gills found that up to three-fourths of the fish in Kelsey Creek were affected with respiratory anomalies, while no cutthroat trout and only two of the coho salmon of the many sampled in Bear Creek had damaged gills. Massive fish kills in Kelsey Creek and its tributaries were observed on several occasions during the project due to the dumping of toxic materials down the storm drains: Instream embryo bioassays indicated that coho embryo salmon survival was significantly greater in Bear Creek than in Kelsey Creek, but no difference was found when using rainbow trout embryos. Kelsey Creek also had higher water tempera ures (probably due to reduced shading) than Bear Creek. This probably caused the faster fish growt observed in Kelsey Creek.

There were significant differences in the numbers and types of benthic organisms found. Mayflies, stoneflies, caddisflies, and bettles were rarely observed in Kelsey Creek, but were quite abundant in Bear Creek. These organisms are commonly regarded as sensitive indicators to environmental degradation. The benthic organism composition in Kelsey Creek varied radically with time and place while the organisms were much more stable in Bear Creek.

These aquatic organism differences were probably most associated with the increased peak flows in Kelsey Creek caused by urbanization and the resultant increase in sediment carrying capacity and channel instability of the creek. There was also the potential for accumulation of toxic materials in the stream system affecting aquatic organisms; but only low concentrations of toxic materials were found in the receiving waters.

Kelsey Creek had much lower flows than Bear Creek during periods between storms, especially during the summers. Urbanization in the Kelsey Creek watershed caused much greater flows during rains, but reduced flows during dry weather. These low flows may also have significantly affected the aquatic habitat and the ability of the urban creek to flush toxic spills or other dry-weather pollutants from the creek system.

CURRENT STUDIES

Current EPA Storm and Combined Sewer Program sponsored and directed research projects are examining the sources and control of toxicants found in urban runoff and storm-induced discharges. The above discussion indicates the variety of receiving water effects that may occur from storm-induced discharges. In many cases, the discharge and sedimentation of toxicants may be responsible for many of the beneficial use degradations found. These new projects therefore emphasize the identity of the source area locations responsible for discharges of these compounds and their most efficient control methods.

Toxicity and chemical tests, in conjunction with literature information, are being used to investigate the effectiveness of several general control practices (such as sedimentation, flotation, filtration, basic liquid/solid partitioning, photo-degradation, and aeration). These tests will examine the benefits of typical treatment processes to reduce toxicity and potential toxic pollutant components of storm-induced discharges (also including combined sewer overflows).

Preliminary toxicity results have found that source area runoff samples vary widely in their relative toxicities. As an example, a residential roof runoff sample has been found to be the most toxic of all samples examined to date, possibly because of the relatively high concentrations of soluble heavy metals (especially zinc) that may have leached from galvanized metal roof gutters and downspouts. This sample also contained the highest concentrations of DDT observed so far. Other samples that had relatively high toxicities were from automobile service facilities (oil change stores, automobile repair facilities, etc.), unpaved industrial parking and storage areas, and paved industrial streets.

Many of the toxicants being examined have been found in the samples analyzed to date. Heavy metals are the most commonly detected toxicants. Pyrene, fluoranthene, and 1,3-dichlorobenzene are the most commonly detected organic toxicants.

CONCLUSIONS

The effects of storm-induced discharges on receiving water aquatic organisms or other beneficial uses is very site specific. Different land development practices may create substantially different runoff flows. Different rain patterns cause different particulate washoff, transport and dilution conditions. Local attitudes also define specific beneficial uses and desired controls. There is also a wide variety of water types receiving urban runoff, and these waters all have watersheds that are urbanized to various degrees. Therefore, it is not surprising that urban runoff effects are also quite variable and site specific.

Attempts to identify urban runoff problems using available data have not been conclusive because of differences in sampling procedures and the common practice of pooling data from various sites, or conditions. It is therefore necessary to carefully design comprehensive, long-term studies to investigate urban runoff problems on a site specific basis. Sediment transport, deposition, and chemistry play key roles in urban receiving waters and need additional research. Receiving water aquatic biological conditions, especially compared to unaffected receiving waters, should be studied to support laboratory bioassays and literature information.

Receiving water effect studies need to examine beneficial uses directly, and not rely on published water quality criteria and water column measurements alone. Published criteria are usually not applicable to urban runoff because of the intermittent discharge nature of urban runoff, the unique chemical speciation of its components, and interferences with runoff solids.

The two West Coast studies summarized in this paper both found significant aquatic life beneficial use impairments in urban creeks, but the possible causes were quite different. The Coyote Creek study found major accumulations of toxic sediments in the urban reaches of the creek, while the Bellevue study found very little toxic material in the sediments. The Bellevue urban creek had a very large carrying capacity for sediment and high flow rates which apparently flushed the toxic sediments through the creek and into Lake Washington. Fish kills were observed in Bellevue, but they were associated with illegal storm drain discharges during dry-weather.

The long-term aquatic life effects of urban runoff are probably more important than short-term effects associated with specific events. The long-term effects are probably related to the deposition and resuspension of toxic sediments, or the inability of the aquatic organisms to adjust to repeated exposures to high concentrations of toxic materials or high flow rates. Long-term effects may only be expressed at great distances downstream from discharge locations, or in accumulating areas (such as lakes).

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