FACTORS INFLUENCING THE QUALITY OF URBAN STREAMS IN GEORGIA AND THE IMPLICATIONS FOR STREAM MANAGEMENT

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INTRODUCTION

A statewide assessment of nonpoint sources of water pollution (EPD, 1985a) revealed that the beneficial use of urban streams not influenced by wastewater discharges had been severely impaired in four of five cases and that the impacts were much greater than in streams influenced by agriculture and silviculture. A subsequent study of four streams in Augusta, Columbus, Dalton, and LaGrange confirmed that the beneficial use of urban streams, especially those draining concentrations of aged commercial and industrial development, could be severely impaired by nonpoint sources (EPD, 1986). Restoration of degraded urban streams and protection of urban recreational waters and water supplies will require the cooperative management efforts of State and local government and public support. This paper describes typical degraded urban stream conditions, contributing factors, and describes implications for future urban stream quality management.

DEGRADED URBAN STREAM CONDITIONS

Degraded urban streams are characterized by elevated bacterial densities, altered water chemistry, elevated metals concentrations, detectable concentrations of organic compounds, and adversely affected aquatic communities.

Water Quality

In comparison to undisturbed streams, urban streams (EPD, 1985a and EPD, 1986) had significantly higher mean fecal coliform bacterial densities; nutrient concentrations (NH_3, NO_2 + NO_3, and total phosphorus), hardness and alkalinity levels, five-day biochemical oxygen demand (BOD_5) and total solids concentrations, and turbidity levels. Dissolved Oxygen (DO) was significantly lower and temperature significantly higher. Assessment of data sorted by flow condition (EPD, 1984) disclosed that fecal coliform densities in urban streams were substantially higher during high flow, NO_2+ NO_3 and BOD_5 concentrations did not vary with flow; NH_3 and total phosphorus were somewhat lower at high flow, and turbidity and total solids were significantly higher at high flow. DO concentrations were significantly higher and water temperatures significantly lower during high flow.

Metals concentrations — particularly lead, chromium, and zinc — were elevated in the water column and sediment. Concentrations in the water column may exceed State standards. Water column concentrations were highest during high flow. While evaluated organic compounds varied among studies, those most frequently detected in sediment, fish flesh, and water column samples included the pesticides DDT, chlordane, heptachlor and heptachlor epoxide, and lindane; PCBs; chloroform; carbon tetrachloride, vinyl chloride, bis(2-ethylhexyl phthalate), and the halogenated aliphatic and polycyclic aromatic hydrocarbon groups (McConnell, 1980; EPD, 1985a; EPD, 1985b; and EPD, 1986).

Aquatic Communities

Periphyton (attached aquatic plants, animals and microbes), fish, and in particular, benthic macroinvertebrates (relatively large and immobile aquatic organisms) reflect the long-term impacts of stream conditions. Degraded streams are typically inhabited by a diminished diversity of species which can tolerate stress. In accordance with the ordination technique summarized by Hocutt (1975), unstressed aquatic communities are characterized by above average density of individuals and numbers of species. Toxic stress reduces both the number of species and the density of individuals below average. Low level sediment stress tends to decrease individual density, but affect the numbers of species only slightly, while nutrient enrichment has the opposite effect.

Periphyton communities in the urban streams were characterized by an increased number of pollutant tolerant species (EPD, 1985a). Macroinvertebrate communities were dominated by a few classes such as tolerant Diptera (flies) and Oligochaeta (worms) and vary greatly in the number of individuals (Benke, et al., 1981; GSU, 1983; CTA, 1983; EPD, 1985b; and EPD, 1986). Sensitive indicators of stress such as Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddisflies), and Coleoptera (beetles) were greatly reduced in numbers or absent. The number of species tends to decrease with increasing density as measured by houses/mi^2 of drainage basin (Benke, et al., 1981). Species typically found in degraded urban streams were tolerant of high organic loads and sedimentation, and capable of withstanding swift flows (CTA, 1983; GSU, 1983; and EPD, 1986). Fish communities were generally missing, greatly reduced, or represented by only a few species such as the highly tolerant Mosquitofish (Gambusia affinis).

FACTORS DEGRADING URBAN STREAMS

Degraded urban stream conditions are caused by the interrelated effects of deteriorated water quality and physical changes which impair beneficial use and stress aquatic communities.

Water Quality

Substantially higher fecal coliform bacterial (which originate in the feces of warm-blooded animals) densities in urban streams are due to the increased availability of fecal matter — sewer leaks and surcharging, septic tank leachate, unauthorized discharges, and animal wastes — which are directly discharged or efficiently conveyed to streams with stormwater runoff. High densities which are frequently found during base-flow conditions dispel the notion that bacterial contamination is only a stormwater related phenomenon.

Elevated nutrient concentrations and oxygen demand in urban streams result from atmospheric fallout (Betson, 1976; Turner and Burton 1975, and others) and varied urban sources (such as lawn fertilizers, exposed soils, animal wastes, traffic residues) which are discharged to the stream or conveyed to impervious surfaces where they become readily available for transport with stormwater runoff. Other sources include groundwater interflow of soluble nutrients, leaking or surcharging sanitary sewers, malfunctioning septic tanks, car washes, and unauthorized discharges. As a result of increased water temperature and sunlight penetration resulting from the typical reduction of vegetation adjacent to shallow urban streams, nutrients are more readily converted to an available form (Karr and Schlosser, 1977) and periphyton growth is stimulated. A corresponding increase in the demand for oxygen necessary to stabilize organic matter results.

While oxygen saturation due to increased algal photosynthesis is sometimes observed in urban streams, the increased water temperature of urban streams — a mean of 2.2 °C higher than in background streams (EPD, 1985a) — lowers the oxygen saturation point. When coupled with the increased oxygen demand in urban streams, the result is a significantly lower mean DO in urban, as compared to background streams (EPD, 1985a). DO is significantly higher during high stream flow, in part, due to significantly lower water temperatures (EPD, 1985a) and increased reaeration.

The added nutrients act to increase the food supply and, consequently, the density of individual organisms which may be supported in the stream. This may favor species adapted to enriched conditions, especially at low dissolved oxygen levels where macroinvertebrates such as tubificid worms (Limnodrilus hoffmeisteri and Tubifex tubifex) and certain midge fly larvae, especially Chironomus (Lenat, 1979), and fish such as the livebearing, low oxygen tolerant Mosquitofish may dominate.

Hardness, alkalinity, and conductivity levels in urban streams are elevated by the transportation of pavement particles and hydrocarbons to urban streams. Road aggregate materials are composed of limestone (calcium carbonate) aggregates in northwest Georgia and granite-gneiss aggregates (which contain up to 6% concentrations of limestone) in the remainder of the State (EPD, 1985a). Since 1981, hydrated lime mixes have been used in the paving and resurfacing of major roads. Petroleum products such as motor oil additives contain metallic ions such as magnesium, calcium, barium, and boron which are also discharged or washed into urban streams.

Heavy metals, especially chromium, lead, and zinc, originate as: 1) residuals from energy generation (Bolton et al., 1974; Klein, 1975; and others) and industrial processes as atmospheric fallout and deposition or spillage and washoff; 2) unauthorized discharges of process wastes; 3) residuals from motor vehicle activity which accumulate on streets and parking areas and are conveyed to streams with stormwater runoff. Vehicular residuals include metals which are used in the formation of petrochemical compounds, tire fillers, and brake linings; worn from moving engine parts; or added to gasoline. Background metals concentrations in eroded soils may be another substantial source of metals (EPD, 1985b).

The organic compounds most frequently detected in sediment, water column, and fish flesh samples were broad spectrum pesticides which are generally found in residential street dirt samples (Pitt and Bisonnette, 1984); plasticizers which are derived from leaching of plastic products frequently present in urban streams; PCBs which are generally derived from breaks or leakage from electrical capacitors and transformers, and halogenated aliphatic hydrocarbons and polycyclic aromatic hydrocarbons, which are all major components of oil and petrochemical compounds. They are derived from airborne fallout resulting from combustion (Pitt and Bisconnette, 1984), leakage and spillage from vehicles which is subsequently washed to streams with stormwater runoff, and private and commercial disposal of used motor oil.

The characteristic symptoms of toxic stress on macroinvertebrate communities — small numbers of both individuals and species observed — were observed in four of nine extensively analyzed urban streams (CTA, 1983; GSU; 1983 and EPD, 1986).

Physical Modifications

Urbanization causes physical stream changes which affect aquatic communities. Construction activity exposes soils and renders them available for wind and runoff transportation and subsequent deposition in urban streams. Increased impervious surfaces cause increased peak discharges and greater volume of total runoff, with a corresponding decrease in infiltration, groundwater interflow, and base flows. Higher flows induce bank scouring and channel collapse, which add sediment loads to those caused by accelerated erosion. Frequently, urban streams are channelized and adjacent riparian vegetation is greatly reduced.

The primary effects of these physical modifications on aquatic communities are the selective reduction of species by greatly increased flows, reduction or removal of aquatic habitats, and removal of riparian vegetation. A study of Atlanta area streams concluded that the greatest influence on aquatic life in one urban stream was the physical effect of high velocity flows during stormwater runoff (EPD, 1985b). Most species collected at this site were "...especially well-adapted to withstand very swift flows whether by their 'streamlined' configurations or by their protective cases which are cemented to substrates. Other species occurring there such as crayfish and dragonfly nymphs lived in bank undercuts, a habitat which is protected from the full force of flood waters". This effect has been noted in other studies (CTA, 1983; and GSU, 1983).

Increased sediment initially causes a decrease in density of individuals as habitats are generally reduced by sand and silt and will, in sufficient volume, cover available habitats such as bedrock, gravel and rocks, riffles, emergent vegetation, moss, snags. Consequently, indigenous species are reduced or eliminated with a resultant shift in community composition to sediment tolerant species such as some Baetidae (*Baetis*, *Pseudocloeon*) and some Chironomidae, especially several *Cricotopus* (Lenat, 1979). Excessive sedimentation also affects fish reproduction by covering spawning grounds, covering eggs, and preventing emergence of recently hatched fry (Karr and Schlosser, 1977).

The removal of riparian vegetation results in increased water temperature which can cause shifts in the structure of aquatic communities (Karr and Schlosser, 1977) and reduced leaf litter which feeds certain species.

The Relative Effect of Urban Stormwater

While urban stormwater runoff has commonly been regarded as the major cause of water quality degradation in urban streams, recent studies have indicated that numerous small intermittent discharges; dumping of wastes during high flows; leaking, overflowing, or cross-connected sanitary sewers; illegal discharges; and other varied sources of contamination are as or even more significant than stormwater runoff (Whipple, *et al*., 1977; Duda, *et al*., 1979; Benke, *et al*., 1981; Schmidt and Spencer, 1986; and EPD, 1985a).

The most common sources of contamination observed during urban stream surveys (EPD, 1985a and EPD, 1986), periodic inspections of Flat Creek in Gainesville, and six surveys by the Atlanta Regional Commission were, in no order of importance: 1) oil and gasoline leaking from underground tanks, washwaters, direct discharges, and stormwater runoff; 2) industrial washwaters and unauthorized discharges; 3) sediment deposition resulting from land clearing or bank undercuts; 4) sewer leaks, overflows, cross-connection and direct discharges; 5) car washwaters; 6) accidental or deliberate spills; and 7) trash and debris. Experience with periodic stream surveys in Gainesville indicates that these problem sources tend to be ephemeral, difficult to trace, unpredictable, recurrent, and detectable only after frequent inspections.

DISCUSSION

Urban streams are degraded by complex, interrelated processes which may engender the following general effects: 1) very high bacterial densities which constitute potential health hazards; 2) elevated nutrient concentrations, which threaten and reduce the diversity of aquatic communities; 3) elevated levels of heavy metals and organic chemicals which are potential health hazards and threaten aquatic communities; 4) increased sedimentation which may accelerate the filling of water supply reservoirs and cover aquatic habitats resulting in reduced species diversity; and 5) hydrologic and hydraulic changes which induce streambank scouring and collapse and alter aquatic communities. While the question of which effect is the major source of stream degradation is warranted, each of these processes may have a substantial impact on urban streams. The primary lesson here is that efforts to abate the degradation of urban streams must be as comprehensive and integrated as the processes of degradation.

Management of the quality of urban streams should encompass and coordinate control of erosion and sediment while watersheds are developing, devise preventive strategies to avert stream degradation and protect key recreational and water supply uses, and develop procedures to correct already degraded urban streams. The management of land use, a traditional function of local governments, must be coordinated with water quality management. Land use is intimately intertwined with the "sources" of contaminants, contaminant accumulation, and transportation pathways to receiving waters. Preventive approaches to stream quality protection require land management instruments such as building and zoning codes, subdivision regulations, and land use planning. Many sources of contamination are ephemeral or involve poor housekeeping practices which are mostly effectively identified by periodic local inspection. Other activities such as trash and garbage disposal and stream channel maintenance, which affect water quality and aquatic life, are conducted by local governments. The implication is clear: Proper management of the quality of urban streams will require a partnership between State and local governments.

Information on the effectiveness of local management activities is inadequate. Long-term monitoring data should be collected to assess the effects of stream improvement programs. Questions such as "Water Quality in Urban Streams — What Can We Expect" (Duda, *et al*., 1982), the capacity to achieve "biological integrity" in urban streams, and the effectiveness of various management practices such as installation of artificial substrates or the restoration of riparian buffers need to be addressed during the management process.

The protection of riparian buffer zones offers promising benefits for enhancing stream habitats, protecting water quality and filtering stormwater runoff. The City of Austin, Texas (Anon., 1987) found that wide greenbelts were more effective in filtering runoff during storms than structured filter systems in the commercial areas. Other benefits are described by Karr and Schlosser (1977).

While stormwater runoff has commonly been regarded as the major nonpoint cause of degraded urban stream quality, it contains wastes which are categorized as point sources. Also, a varied collection of sources contribute contamination during base flow conditions which may, in composite, be as or more significant than stormwater runoff. Consequently, initial efforts to restore degraded urban streams should focus on control of improper and unauthorized discharges before resorting to extremely expensive stormwater controls.

IMPLICATIONS FOR URBAN STREAM QUALITY MANAGEMENT

The major implications of these observations for urban stream quality management are:

o Adequate protection of urban streams should include control of erosion and sedimentation during development, preventive measures to avoid stream degradation to and protect key water uses such as recreation and drinking water supplies, and procedures to restore degraded urban streams.

o Proper management of the chemical and biological integrity of urban streams will require the cooperative efforts of State and local government and citizen support.

o Restoration of urban streams degraded by complex, interrelated processes will necessitate integrated management of stream channels, protection, and perhaps restoration, of stream habitats, as well as control of sources of stream contamination.

o The numerous unauthorized discharges and intermittent sources of contamination (which in composite are significant sources of contamination), should be controlled before substantial investments are made in capital facilities to control urban stormwater runoff quality.

o More assessment will be necessary to ascertain attainable levels of urban stream quality and to determine how to monitor the effectiveness of alternative management approaches.

o Riparian corridor protection and appropriate channel maintenance practices are necessary elements of a comprehensive stream management approach.

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