

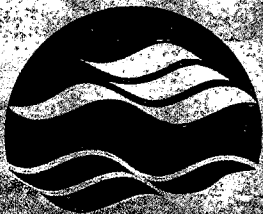
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Overview of Urban Drainage Impacts on Aquatic Habitat

BY:

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OVERVIEW OF URBAN DRAINAGE IMPACTS ON AQUATIC HABITAT

SHORT TITLE: DRAINAGE IMPACTS ON AQUATIC HABITAT

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Abstract. Urban drainage impacts on aquatic habitat are discussed under five major headings affecting the biological community performance: food (energy) sources, water quality, habitat structure, flow regime, and biotic interactions. Among these factors, perhaps the best understood one is stormwater quality. On the other hand, the changes in the (physical) aquatic habitat structure resulting from urbanization and stormwater discharges are the least understood and require further study. Promising approaches to mitigating the adverse drainage impacts on habitat include preservation of natural drainage features, sustainable development or redevelopment of urban areas, and balanced applications of stormwater management practices.

Keywords: urbanization, urban stormwater, stormwater quality, habitat structure, flow regime, stormwater management

1. Introduction

Urbanization causes profound impacts on the hydrological cycle, with many implications for aquatic habitat (Horner et al., 1994). When discussing the impacts of urban drainage on aquatic habitats, one can follow a general list of factors influencing the biological community performance, including food (energy) sources, water quality (chemical variables), habitat structure, flow regime, and biotic interactions (Yoder, 1989). Urbanization even at a low level

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of development (10% of the watershed area) exerts effects on receiving waters and thereby directly or indirectly affects the habitat (Horner et al., 1994). Thus, one of the main tasks of urban environmental planners and managers is to reduce such effects (Schueler, 1987).

The main purpose of this paper is to review the effects of urban drainage and stormwater management on aquatic habitat in urban streams.

2. Food (energy) Sources

Sufficient supply of energy (food) is a basic requirement of all organisms in order to grow and reproduce (Spence et al., 1996). Concerning this requirement, the conditions in the receiving waters should be such that food resources available are comparable to those found in natural waters. Spence et al. (1996) suggest that this requires maintaining a corresponding level of primary production, physical and chemical conditions, and the original riparian vegetation. In this connection, the value of riparian vegetation in providing fish food is particularly emphasized. Standing riparian vegetation is habitat for insects that serve as food source for fish and this vegetation also provides another source of food to aquatic biota in the form of leaf litter. Thus, changes in riparian vegetation, such as elimination or changes of species, will affect the type and abundance of food available to the invertebrate and fish communities. In view of the incomplete understanding of various food sources and their effects on aquatic biological communities, a precautionary approach of maintaining the pre-development water body conditions, is recommended (Spence et al. 1996).

3. Water Quality

Good quality of water bodies inhabited by fish and other biological communities is a basic prerequisite of habitat integrity (Bishop et al., 2000). In terms of constituents of interest, their list includes suspended solids, dissolved oxygen, nutrients, trace metals, organic chemicals occurring at toxic levels, pH and water temperature. Large changes in constituent availability and concentrations may impair the performance of biological communities. Extensive data on urban stormwater chemistry are available in the literature and can be readily used in assessing potential impacts on aquatic communities.

3.1. SUSPENDED SOLIDS

Suspended solids comprise both inorganic (fine sediment) and organic (phytoplankton) particulate kept in suspension by flow or turbulence in water. Suspended solids concentrations are particularly high in urbanizing catchments suffering from soil erosion and cause many adverse impacts on receiving waters and their aquatic habitats.

Soil erosion is intensified in urbanizing areas by the stripping of natural protective vegetative covers from the soil surface during construction and by increased runoff flows, which scour unlined drainage channels and transport of eroded material to downstream areas (Horner et al., 1994). Wolman and Schick (1962) reported sediment yields from natural catchments as low as 100 t/km²/yr, but increasing more than 100 times during urbanization. After completion of the urban development, establishment and consolidation of surface covers, the sediment yields drop to the predevelopment, or even lower values. Serious ecological damages are caused by excessive erosion, in the form of sweeping away habitats, expanding stream channel width and depth (Booth, 1990; Urbonas and Benik, 1995); undercutting banks and damaging riparian vegetation, and losing protective qualities of large woody debris (Horner et al., 1994).

Suspended solids cause a number of direct and indirect environmental impacts, including those associated with:

- Reduced sunlight penetration (interference with photosynthesis, reduced abundance of periphyton and phytoplankton, reduced algal productivity, changes in plant communities; reduced visibility for catching food and avoiding predators);
- Physical abrasion of gills and other sensitive tissues, or grinding and dislodgement of algae; damage of aquatic vertebrates and invertebrates;
- Blanketing of gravel substrates where fish spawn, rear their young, and where algal and invertebrate food sources live; filling up of pools where fish feed, take refuge from predators and rest; burial of benthic organisms which will die by lack of oxygen; reducing interstitial space, where invertebrates may live; reduced access to microhabitats; reduced density of benthic invertebrates; and,
- Transport of various pollutants (improving water quality if adsorbing pollutants from the water column and transporting them away; or downgrading water quality if bringing pollutants in from other sources).

Such impacts can manifest themselves at various time scales; a single large rainfall/runoff event can cause significant impacts, but generally long term impacts are more important.

3.2. DISSOLVED OXYGEN

Dissolved oxygen (DO) is important for aquatic life and plants (depending on some minimum DO levels), stream capacity to assimilate waste, and the processes at the bottom sediment/water column interface. The precise definition of harmful (low) DO levels is under discussion, but minimum levels for cold-water biota are usually specified as 9.5 mg DO/L in the early stages of life and 6 mg/L for warm-water biota (Makepeace et al. 1995). DO levels in natural streams are generally high, unless there are large quantities of organic debris, discharges of sewage effluents, and high ambient water temperatures. Low DO levels may occur in shallow streams or stormwater ponds in summer months, when water reaches high temperatures and there is rapid decomposition of organics, or during the winter months, when the stream or pond is ice covered (Marsalek et al., 2003). Water bodies rely on vertical mixing for transport of oxygen to the bottom layers. Such processes are impaired by densimetric stratification of ponds and lakes, particularly in the case of chemostratification by chloride from winter road maintenance. Increased meromictic stability of such bodies reduces vertical mixing and oxygenation of bottom layers (Marsalek et al., 2003).

3.3. NUTRIENTS

Nitrogen and phosphorus are two most important constituents affecting the productivity of aquatic systems. Both may originate from natural sources, but the main concerns are caused by nutrients originating in sewage effluents, industrial discharges, and agricultural and urban runoff. Both N and P occur in various species, which have different implications with respect to toxicity or eutrophication. Some N forms are toxic to fish (e.g., nitrite nitrogen, which is short-lived in natural waters; or ammonia, at concentrations as low as 0.080 mg/L, depending on pH and DO), others, like nitrate, $\text{NO}_3\text{-N}$, are essentially non-toxic to aquatic vertebrates and invertebrates (Spence et al., 1996), but may contribute to eutrophication. Phosphorus occurs naturally in very low concentrations, most frequently as phosphates. Such levels are considered non-toxic to aquatic vertebrates and invertebrates, but may contribute to eutrophication.

Nutrient loadings in stormwater may cause nutrient enrichment or eutrophication of receiving waters characterized by an overall increase of aquatic macrophytes and algal biomass, and changes in the composition of algal community from one-celled diatoms to filamentous green forms, followed by blue-green forms. Eutrophication degrades ecosystems in a number of ways, including reduced food supplies, water clarity, dissolved oxygen. The

prevention of urban lake or reservoir eutrophication usually requires control of nutrient sources, including stormwater (Schueler, 1987). Typical concentrations of N and P in urban stormwater and CSOs are listed in Table 1.

Table 1. Quality of urban stormwater (after Duncan (1999) and U.S. EPA (1983))

Chemical Constituent	Units	Urban Stormwater	
		Mean of Duncan's dataset	U.S. NURP Median site
Total Suspended Solids (TSS)	Mg/L	150	100
Total Phosphorus	Mg/L	0.35	0.33
Total Nitrogen	Mg/L	2.6	-
Chemical Oxygen Demand, COD	Mg/L	80	65
Biochemical Oxygen Demand, BOD	Mg/L	14	9
Oil and Grease	Mg/L	8.7	-
Total Lead (Pb)	Mg/L	0.140	0.144
Total Zinc (Zn)	Mg/L	0.240	0.160
Total Copper (Cu)	Mg/L	0.050	0.034
Faecal Coliforms	#/100 mL	8,000	-

3.4. TOXIC CHEMICALS

In urban receiving waters, toxic impacts may be caused by elevated concentrations of ammonia, chlorides, heavy metals, and trace organic contaminants. The understanding of stormwater toxicity is still incomplete.

Toxicity bioassays applied to stormwater samples from various sources indicated (Marsalek et al. 1999) that about two fifths of all data did not show any toxic responses, one fifth indicated severe toxicity, one fifth confirmed toxicity, and one fifth potential toxicity. Almost 20% of highway samples were severely toxic compared to 1% of general stormwater samples. Stormwater ponds contributed to toxicity reduction, with respect to both water and sediment downstream of ponds. The sources of toxicity in stormwater were identified as heavy metals, Cu, Pb, Zn and Fe, ammonia and pesticides (Hall and Anderson, 1988; Dutka et al. 1994). Toxicity testing was found useful for screening and assessing potential receiving water impacts, but was limited by the dynamic

nature and large variety of wet-weather pollution sources (Marsalek et al. 1999).

3.5. PH VALUES

In the urban environment, rainwater is slightly acidic due to both natural and anthropogenic sources of acidity. Concrete structures (street gutters, sidewalks) contribute to rainwater buffering, with runoff pH being neutral. Fish may be adversely affected at $\text{pH} \leq 5.6$, however, the actual response is species specific and also depends on water quality conditions. Low pH associated with snowmelt and presence of salt may increase the mobility and bioavailability of metals (Novotny et al. 1998). High pH values, originating from pollution, or geology or algae photosynthesis, may also impact fish.

3.6. WATER TEMPERATURE

Sources of waste heat in urban areas contribute to increased temperatures of surface runoff, particularly during the summer months. Stormwater running off hot impervious surfaces (pavements, roofs) collects heat and its temperature may further increase as a result of exposure to solar radiation in stormwater ponds and wetlands (Van Buren et al., 2000). Schueler (1987) reported that stormwater runoff temperatures may exceed those in the receiving waters by up to 10°C . Thermal impacts of heated runoff are particularly noticeable during low flows in receiving streams. Spence et al. (1996) listed some of the physiological (for salmonid fish) and ecological processes affected by temperature as: (a) decomposition rate of organic materials, (b) metabolism of aquatic organisms, (c) food requirements, appetite and digestion rates, (d) growth rate of fish, (e) developmental rates of embryos and alevins, (f) timing of life-stage events, including adult migrations, fry emergence, and smoltification, (g) competitor and predator-prey interactions, (h) disease-host and parasite-host relationships, and (i) development rate and life history of aquatic invertebrates.

Thermal enhancement of receiving waters may lead to succession of the original cold-water fishery by warm-water fishery, and similarly, cold water invertebrates may be similarly impacted and cold-water algae species (mainly diatoms) be succeeded by warm-water filamentous green and blue-green species (Galli cited in Schueler, 1987). Higher water temperatures also lead to reduced concentrations of dissolved oxygen. Increased rates of decomposition of organic materials and reduced DO in heated water may result in oxygen deficiency.

4. Habitat Structure

The physical habitat structure represents the macrohabitat and microhabitat features found in streams, rivers, impoundments, lakes and estuaries. In streams, these features are usually referred to as channel morphology, which can be described by numerous parameters, including channel width to depth ratio, slope (gradient), substrate composition and roughness, bed forms, and sinuosity. Lake morphology is characterized by lake surface area, depth, volume, length, width and shoreline development (shape). Geomorphic properties of the drainage basin are characterized by such parameters as length, relief, relief ratio, basin surface storage, drainage density, drainage shape, main channel slope, and total stream length (Bain and Stevenson, 1999).

Macrohabitat features are generally described by sequences of pools and riffles, and can be further classified as fast water and slow water macrohabitats. Fast water macrohabitat is characterized by such features as low gradient stream sections or riffles, high gradient sections with rapids, steep gradient or cascade, falls, steps, chutes, glides etc. Slow water macrohabitats include pools, straight scours, backwater eddy, plunge, and dammed and abandoned channels. Generally, the sequences and frequency of occurrence of macrohabitat structure are important for habitat quality. Discrete habitats are also called channel geomorphic units and can be described by bed forms, water velocity, and the presence of flow control structures (Bain and Stevenson, 1999).

Microhabitat characteristics include substrate type, cover, depth, hydraulic complexity and current velocity (Spence et al., 1996). Substrate is generally classified according to the element or particle size, ranging from silt and clay (< 0.059 mm), to sand, gravel, pebble, cobble and boulders (> 256 mm). Besides the substrate size, embeddedness rating is also important and ranges from negligible (less than 5% of gravel, pebble, cobble and boulder particles surface covered by fine sediment ($D < 2$ mm)) to very high, when $> 75\%$ of surface is covered by fine sediment.

Cover provides refuge for fish from predators and adverse physical conditions, and can be provided by boulders, large wooded debris, aquatic vegetation, water turbulence and depth. Streambanks and shore provide transition between aquatic and terrestrial ecosystems, and refuge for fish, if in good condition. Such a condition can be degraded by both natural and human impacts, which reduce bank vegetation, erosion resistance, and structural stability. Bank condition is assessed by assessing its geometry, substrate and soil composition, and riparian vegetation.

Low to intermediate barriers, 1 to 10 m high, are fairly common in urban areas. Barriers obstruct fish life cycle (e.g., migration), flow, sediment

transport and thermal regime. The degree of disruption depends on the structure height.

Studies of natural fish habitats produced descriptions of habitat requirements for various salmonid species and life stages. It is of interest to note that such conditions widely vary and their reproduction in urban streams is practically impossible (Horner et al., 1994).

5. Flow Regime

Flow regime represents a full spectrum of flow conditions in a particular stream section and reflects the hydrologic cycle. With respect to aquatic habitat, flows of all magnitudes are of interest, because: (i) high flows form the stream geomorphology, cause erosion, transport sediment and affect fish migrations, spawning, and juvenile rearing (Horner et al., 1994), (ii) intermediate flows also contribute to erosion and geomorphology formation, and (iii) low flows may be associated with poor water quality (e.g., low DO, high temperature) or even discontinuity of flows.

Urbanization is known to affect significantly the hydrological cycle, by reducing infiltration and evapotranspiration, increasing surface runoff flows and volumes, and reducing groundwater recharge. Field observations confirm this behaviour, certainly in smaller streams, which are more impacted by urbanization. Higher flows may cause flooding, sediment and habitat washout (Borchardt and Statzner, 1990), and morphological changes (Schueler, 1987). Changes in the sediment regime are particularly significant from the habitat point of view (Roesner et al., 2005). Contemporary stormwater management strives to mitigate these changes by preserving water balance and enhancing water quality.

6. Biotic Interactions

Biotic interactions include such processes as competition, predation, parasitism, feeding, reproduction and disease (Horner et al., 1994). These processes do affect biological integrity of surface waters, whenever their natural balance is disturbed. Anthropogenic impacts on biological interactions may include changes in primary and secondary production, disruption of life cycle, increased frequency of disease or parasitism, introduction of alien species, and changes in predator-prey and competitive interactions (Spence et al., 1996).

7. Conclusions

Urban drainage impacts on all major factors affecting the biological community performance, including food sources, water quality, habitat structure, flow regime, and biotic interactions. Some of these impacts are fairly acute and demonstrate themselves quickly (e.g., acute pollution), others, like habitat structure result from long-term interactions between the natural geomorphology, flow, erosion sediment transport, and riparian vegetation. Promising approaches to improving physical habitat in urbanization impacted streams include preservation of natural drainage features, sustainable development or redevelopment of urban areas, and balanced applications of stormwater management practices.

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