Journal of Hydrology 514 (2014) 226–232

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Urban water interfaces

M.O. Gessner [a,b], R. Hinkelmann [b], G. Nützmann [a,c,*], M. Jekel [b], G. Singer [a], J. Lewandowski [a], T. Nehls [b], M. Barjenbruch [b]

[a] Leibniz-Institute of Freshwater Ecology and Inland Fisheries (IGB), Berlin, Germany
[b] Technische Universität Berlin (TU Berlin), Berlin, Germany
[c] Humboldt University Berlin, Berlin, Germany

ARTICLE INFO

Article history:
Received 4 October 2013
Received in revised form 14 March 2014
Accepted 8 April 2014
Available online 19 April 2014
This manuscript was handled by Geoff Syme, Editor-in-Chief

Keywords:
Urban water system
Aquatic ecosystems
Interface processes
Water systems modelling
Urban water management

SUMMARY

Urban water systems consist of large-scale technical systems and both natural and man-made water bodies. The technical systems are essential components of urban infrastructure for water collection, treatment, storage and distribution, as well as for wastewater and runoff collection and subsequent treatment. Urban aquatic ecosystems are typically subject to strong human influences, which impair the quality of surface and ground waters, often with far-reaching impacts on downstream aquatic ecosystems and water users. The various surface and subsurface water bodies in urban environments can be viewed as interconnected compartments that are also extensively intertwined with a range of technical compartments of the urban water system. As a result, urban water systems are characterized by fluxes of water, solutes, gases and energy between contrasting compartments of a technical, natural or hybrid nature. Referred to as *urban water interfaces*, boundaries between and within these compartments are often specific to urban water systems. Urban water interfaces are generally characterized by steep physical and biogeochemical gradients, which promote high reaction rates. We hypothesize that they act as key sites of processes and fluxes with notable effects on overall system behaviour. By their very nature, urban water interfaces are heterogeneous and dynamic. Therefore, they increase spatial heterogeneity in urban areas and are also expected to contribute notably to the temporal dynamics of urban water systems, which often involve non-linear interactions and feedback mechanisms. Processes at and fluxes across urban water interfaces are complex and less well understood than within well-defined, homogeneous compartments, requiring both empirical investigations and new modelling approaches at both the process and system level. We advocate an integrative conceptual framework of the urban water system that considers interfaces as a key component to improve our fundamental understanding of aquatic interface processes in urban environments, advance understanding of current and future system behaviour, and promote an integrated urban water management.

1. Introduction

Extensive landscape fragmentation through human activities has resulted in strong proliferation of interfaces between distinct land-cover types (Cadenasso et al., 2007; Haase, 2009). In addition, humans have created numerous intersections between technical and non-technical systems, including natural, though often strongly modified, ecosystems. Nowhere is this perhaps more evident than in the tightly interconnected water systems of urban areas. The technical structures designed for water treatment, storage and distribution, as well as for wastewater and runoff collection, treatment and controlled discharge to receiving water bodies, are vital components of urban infrastructure. They are often well managed, at least in highly industrialized regions and countries, although increasingly also in major cities of the developing world. Man-made channels and other artificial water bodies complement the technical water infrastructure and natural aquatic ecosystems such as streams and rivers, lakes and ground water in urban areas. Urban 'natural' aquatic ecosystems are typically subject to strong physical, chemical and biological modifications, often with far-reaching negative consequences for downstream aquatic environments and water users (Roy and Bickerton, 2012; Walsh et al., 2005; Meyer et al., 2005). For example, until tertiary wastewater treatment was introduced to reduce the ammonium load generated by the metropolitan area of Paris, France, a huge ammonium plume severely depleted oxygen concentrations in

---

* Corresponding author at: Leibniz-Institute of Freshwater Ecology and Inland Fisheries (IGB), Berlin, Germany. Tel.: +49 30 64 181 661.
E-mail address: nuetzmann@igb-berlin.de (G. Nützmann).

http://dx.doi.org/10.1016/j.jhydrol.2014.04.021
0022-1694/

the estuary of the River Seine 100 km downstream of the effluent (Brion et al., 2001).

Water use and management in cities is driven by a multitude of goals that may be partially conflicting. They include water supply for domestic and industrial consumption, adequate sanitation, and protection of humans and infrastructure from natural disasters. Ongoing efforts to control pollutant loads to urban surface waters are starting to bear fruit. However, rarely taken into account are impacts such as the disruption of linkages of urban water bodies with their riparian areas and floodplains, disconnection of surface waters from hyporheic zones and aquifers, or outright disappearance of natural surface waters in underground pipes. Thus, by managing water resources and land to meet goals dictated by immediate public, industrial or personal demands, humans have profoundly modified urban water bodies (Grimm et al., 2008).

The term "urban stream syndrome" has been coined to describe the strong ecological degradation of running waters consistently observed in urban environments (Meyer et al., 2005; Walsh et al., 2005). Classic symptoms of the syndrome include flashy hydrographs that promote physical disturbance in urban running waters; high loads of nutrients, suspended solids and various pollutants ranging from heavy metals to personal care products and drugs; and a simplified and homogenized channel morphology providing limited in-stream and riparian habitat and habitat heterogeneity (Laub et al., 2012). Together, these and other pressures severely compromise water quality and quantity in natural and man-made urban water bodies. Consequences include impoverished biodiversity compared to natural freshwater bodies and increased costs to ensure human water security in terms of water resource supply, wastewater removal, and protection from excessive surface runoff and floods (Grimm et al., 2008).

In the future, urban water management will face additional challenges as demographic trends and continued migration of the world population to metropolitan areas leave their imprint on urban water quality and quantity (Endlicher et al., 2011). Global climate change is likely to exacerbate these tendencies in many cities of the world by increasing the likelihood of extreme meteorological events, shifting precipitation regimes, changing surface and groundwater conditions, temperature increases, and other factors (Langeveld et al., 2013). The widespread need to accelerate investments for the maintenance of water distribution and sewer systems adds to this challenge. At the same time, however, growing environmental awareness has prompted measures to improve the quality of urban waters, including heavily modified water bodies, not only in terms of chemical water quality but also in attempts to restore essential structures and functions of aquatic ecosystems as a whole. In Europe, these efforts have been fostered particularly by the requirements of the Water Framework Directive (WFD), which stipulates that a good ecological status, or a good ecological potential, is achieved by 2015. The modifications of urban water systems resulting from this stipulation are currently underway or will soon be initiated. Both natural and technical water flows will be affected, with likely consequences on urban water quality and quantity (Braud et al., 2013). Finally, changing behaviours of water users pose their own challenge. Widespread water-saving initiatives are a point in case. They are laudable from a broad-scale sustainability perspective, but run counter at the local scale to the fact that many sewer systems have been designed for larger water volumes than are currently generated with new water-saving technologies.

The hydrology of urban areas has been extensively studied in the past (Harremoës, 2002; Fletcher et al., 2013). However, as highlighted by Paola et al. (2006), prominent knowledge gaps in the urban water cycle remain, especially with regard to the interaction of water with sediments, solutes and biological communities over a range of spatial and temporal scales (Schulz et al., 2006; Palmer and Bernhardt, 2006; Potter, 2006). This is the domain of ecohydrology, which integrates hydrological and ecological concepts and information (Rodriguez-Iturbe and Porporato, 2004). Debates about sustainable development of urban areas, including urban water systems, have also been informed by ecological concepts. This has led to the notion of urban metabolism (Broto et al., 2012), which refers to the processes by which cities transform raw materials, energy, and water into the built environment, human biomass, and waste. The ecosystem view embodied in the urban metabolism concept has inspired new ways of thinking about how cities can be made more sustainable (Decker et al., 2000). Considering integrative approaches across traditional disciplines in urban design and planning holds potential to improve current management of urban water systems, enhancing understanding of urban ecosystem processes, biodiversity conservation, and partial ecosystem restoration (Alberti, 2005; Pickett and Cadenasso, 2008).

Here we advocate an integrated water management approach in urban areas that explicitly recognizes the multiple interactions between and among technical water infrastructure and natural and man-made surface waters and aquifers. Given the strong focus on technical water systems in the past when considering urban water issues, the key objective of the present paper is to strengthen the conceptual basis for integrated urban water management strategies that simultaneously consider the technical and natural component of urban water systems and how they interact. A central tenet is that an improved understanding of processes and fluxes at interfaces between system components benefits this integrative approach. Thus, we propose that diverse urban water interfaces within and between natural and technical system components play key roles in the transformation and transport of water, matter, and energy in urban areas. In addition, we present typical urban water interfaces and their roles in the urban water cycle and identify selected areas of urban water research that require particular attention.

2. Recognizing interfaces as a key feature of urban water systems

A prominent feature of urban water systems is that their natural and technical components are tightly meshed, creating multiple interfaces in the urban and peri-urban water cycle (Fig. 1). The transport and transformation of water, matter and energy takes place at and across these interfaces, or boundary zones, between adjacent system compartments, resulting in the exchange of mass, momentum and heat over various spatial and temporal scales (Gualtieri and Mihailovic 2013). Water flow within and across the system components can be adequately described based on the principles of fluid mechanics. Bed load transport can also be modelled based on fundamental physical laws. In contrast, the movement of solutes and suspended solids along the flow paths is superimposed by a variety of biogeochemical processes (e.g., geochemical reactions, biological uptake, and enzymatic transformations) and physico-chemical processes (e.g., adsorption, desorption, and aggregation) that need to be considered for an appropriate system description. Although some of these processes also occur in the bulk phase of water, rates are often highest at interfaces (McClain et al., 2003).

We refer to urban water interfaces as the boundary zones between components, subsystems or compartments of the urban water system as a whole. The interfaces may be natural, technical or hybrid, depending on the adjacent system compartments. In a strict sense, water interfaces are two-dimensional surfaces of potentially complex and irregular shape. However, three-dimensional structures which are thin relative to the extent of the adjacent system compartments are also included. It is implicit in