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Developments in water quality monitoring and management in large river catchments using the Danube River as an example

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ABSTRACT

Effective management of water quality in large rivers requires information on the influence of activities within the catchment (urban and rural) throughout the whole river basin. However, traditional water quality monitoring programmes undertaken by individual agencies normally relate to specific objectives, such as meeting quality criteria for wastewater discharges, and fail to provide information on basin-scale impacts, especially in transboundary river basins. Ideally, monitoring in large international river basins should be harmonised to provide a basin-scale assessment of sources and impacts of human activities, and the effectiveness of management actions. This paper examines current water quality issues in the Danube River Basin and evaluates the approach to water quality monitoring in the context of providing information for a basin-wide management plan. Lessons learned from the monitoring programme in the Danube are used to suggest alternative approaches that could result in more efficient generation of water quality data and provide new insights into causes and impacts of variations in water quality in other large international river basins.

1. Introduction

River water quality globally has been impacted by anthropogenic activities, in many cases in ways that still have to be fully quantified (e.g. Meybeck, 2005; Vörösmarty, 2002). Whilst these impacts are increasingly acknowledged, our ability to understand the magnitude of anthropogenic forcing is constrained by the limited availability of long-term water quality data-sets, which are essential in understanding system behaviour (Burt et al., 2014; Myroshnychenko et al., 2015).

Large river basins pose many challenges with respect to water quality monitoring and management, particularly in multinational basins where individual countries may differ in their legislative framework and in their priorities for water resource management (Bloesch et al., 2012; Sommerwerk et al., 2010). However, the main aim in all cases is ultimately the sustainable management of water resources (UNEP 2007). The focus in international river basin management has largely been on water quantity and flow allocation, particularly where there has been a high demand for energy from hydropower, water for irrigation, and/or problems related to flood control and the role of wetlands (Rebelo et al., 2013). The physical, chemical and biological quality

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of river water is critically important, because they are linked to every aspect of human wellbeing and sustainable development (UN, 2012). Therefore, monitoring water quality is essential in determining the impacts of human activities, the suitability of water for human use and fluxes (through concentrations and discharge measurements) of sediment and contaminants to lakes and coastal zones. Such monitoring typically has a local focus, but to contribute to management at the river basin scale it is essential to harmonise individual monitoring activities to: (i) indicate trends over time; (ii) obtain a complete picture of the impacts of activities, and their interaction, within the basin; (iii) determine downstream impacts; and (iv) direct remedial actions most appropriately.

This paper considers current problems (and opportunities) of water quality monitoring specifically in the Danube River Basin (DRB) of Central and Eastern Europe. In common with many other catchments, the DRB has experienced significant recent changes in water quality, including physical, chemical and biological water quality. The challenges faced in the DRB are examined here, highlighting the importance of adopting a holistic approach when investigating water quality problems. The situation in the DRB is compared and contrasted with other large river basins and ways in which monitoring of river water quality can be improved are identified.

2. The Danube River Basin: features and pressures

The DRB is Europe's second largest river basin, with a catchment area of 801,463 km^2 and a total channel length of 2857 km. It is the world's most international river basin, including territory from 19 countries: 29% of the basin is within Romania, Hungary lies entirely within the Danube basin and large proportions of Austria, Serbia and Slovakia are in the DRB. Fourteen of the countries in the basin have co-operated on water protection and conservation since 1998 through the International Commission for the Protection of the Danube River (ICPDR), which is working to implement the 1994 Convention on Cooperation for the Protection and Sustainable Use of the Danube River, known as the Danube River Protection Convention (DRPC). This Convention has the objective of achieving sustainable and equitable water management, including the conservation, improvement and the rational use of surface and ground waters in the DRB. Of the 14 countries, nine (Austria, Bulgaria, Croatia, Czech Republic, Germany, Hungary, Slovakia, Slovenia and Romania) are members of the European Union (EU) and are bound by the Water Framework Directive (WFD), Directive 2000/60/EC, (EC, 2000) which came into force in December 2000 (although the actual date of its implementation varies according to when countries joined the EU). Subsequent directives, 2008/105/EC on Environmental Quality Standards (EQS) in the field of water policy (EC, 2008), as amended by daughter Directive 2013/39/EU (on priority substances), also have implications for catchment management; and all the countries co-operating under the DRPC have agreed to implement the WFD and the daughter Directives in the basin through the ICPDR.

One of the key characteristics of the Danube River today is the extent to which the flow of the Danube (and its principal tributaries) has been increasingly regulated for hydropower and navigation (see Habersack et al., 2016). This has considerable implications for water quality, including temperature (Webb and Nobilis, 2007) and sediment flux (Schwarz et al., 2008). At present there are 598 major dams and weirs along the Danube and its tributaries (ICPDR, 2014), 156 of which are for hydropower (Sommerwerk et al., 2009). In the first 1100 km of the Danube, there is an average of one power plant every 16 km above the Gabcikovo-Bős Water Barrage System (GB-WBS) in Slovakia/Hungary (ICPDR, 2014). In Hungary the biggest abstraction of water from the Danube is at the Paks nuclear power plant ($Q = 100\,m^3\,s^{-1}$) which is responsible for thermal pollution in the river. In total, there are 69 dams along the main stem of the Danube and ~30% of the channel length is impounded, with implications for species migration (Fig. 1) and sediment transport (Klaver et al., 2007). In addition to dam construction for hydropower, the channel and banks have been engineered to facilitate navigation and improve flood protection. Such changes have implications for aquatic habitats and the river ecology as well as the associated floodplain and wetland habitats (Habersack et al., 2016; Hein et al., 2004; Hohensinner et al., 2005; Rebelo et al., 2013). Compared with the 19th Century, estimates suggest 65%–81% of the former floodplain area has been lost (ICPDR, 2009; Schneider 2002), with large differences between the different river sections (i.e. upper, middle, lower and delta).

In addition to the direct effects of anthropogenic activities in the DRB, there are significant impacts associated with other long-term processes such as climate change, similar to those discussed for the neighbouring upper Rhone Basin by Clarvis et al. (2014). The ICPDR Strategy for Adaptation to Climate Change (ICPDR, 2013a) predicts an increase in mean winter discharge and a decrease in mean summer discharge for the entire DRB, although there will be seasonally local variations as predicted for the Mures River (Sandu et al., 2009). The predicted increase, especially in winter floods and run-off, may increase particle transport and particle-associated water pollution, depending on the contaminants stored in the sediments and the grain sizes of the bed sediments (Pulley et al., 2016; Vignati et al., 2003). Water temperatures are also expected to increase with associated decreases in water quality (e.g. reduced oxygen concentrations and increased algal blooms). The precise impacts of climate-associated problems in the DRB are hard to quantify, but the GB WBS hydropower plant illustrates some of the anticipated effects on surface waters in the basin. Construction of the GB WBS in 1992 led to the diversion of the main channel of the Danube and resulted in a reduction of discharge from 2000 to 400 $m^3\,s^{-1}$ as the majority of the river flow was diverted for input to the hydropower plant (Kovács et al., 2015a,b). In consequence, shallow groundwater levels in the immediate vicinity have fallen significantly (Bárdossy and Molnár, 2003, 2004), to levels that are comparable to recent IPCC projections (IPCC, 2013). Given the decreased discharge, more sediment is now deposited on the river bed leading to river bed clogging (colmation) and decreased groundwater recharge (via effluent seepage), resulting in conditions that would have normally occurred only in dry years and which are now anticipated under future climate change predictions to occur more frequently during summer in future (ICPDR, 2013a).

3. Trends in water quality in the Danube River Basin

In common with many catchments, the DRB has experienced significant changes in water quality including: physical (e.g. temperature, suspended sediment and bed-load transport), chemical (e.g. ammonium, nitrate, nitrite, phosphorus and emerging pollutants) and biological water quality (faecal pollution, species loss and biological community alterations due to invasive species). These reflect multiple factors including changes in: (i) land use; (ii) point and diffuse pollution (from agriculture, industry and individual households), and (iii) the catchment water cycle as a result of climate change and anthropogenic modifications of the drainage basin (see Sommerwerk et al., 2009 for a detailed overview of the DRB). One of the major water quality issues in parts of the DRB is organic pollution from untreated, or poorly treated, urban wastewaters. The impact of wastewater discharges has been clearly shown by marked increases in microbial faecal pollution downstream of major towns and cities, including Novi Sad,