Journal of Environmental Management 202 (2017) 337–347

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

An environmental assessment of water replenishment to a floodplain lake

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ARTICLE INFO

Article history:
Received 18 April 2016
Received in revised form
6 January 2017
Accepted 10 January 2017
Available online 20 January 2017

Keywords:
Oxbow lake
Groundwater dynamics
Groundwater/surface water interaction
Water losses
Hyporheic flow

ABSTRACT

There are numerous wetland rehabilitation projects worldwide, but their efficiency is seldom assessed comprehensively. Oxbow lakes are wetlands of particular sensitivity. Within a large-scale floodplain rehabilitation project in Hungary, the Old Drava Programme, water replenishment was first carried out for the Cún-Szaporca oxbow lakes, a key area in the project. To assess its sustainability, the entire hydrological system has been monitored. From the data of hydrological monitoring (infiltration, soil moisture, groundwater/lakewater interaction) it is claimed that water replenishment involves significant losses through seepage (4.1 and 1.46 mm d^{-1}) and evaporation (3.01 and 1.44 mm d^{-1}) in the studied pre-intervention and replenishment periods, resp. Infiltration alone is insufficient to replenish groundwater and raise oxbow lake levels. In the critical summer half-year evaporation is intensive in the neighbouring agricultural fields. Groundwater table dynamics are controlled by hyporheic and groundwater flow. Major impact on the water balance of the oxbow lakes is exerted by the regime of the Drava River. A deepened lakebed is recommended to ensure more effective water retention in the oxbow lake. From the local study conclusions are drawn for the feasibility of rehabilitation at floodplain scale and in areas with similar hydromorphological conditions.

1. Introduction

Changes in the water regimes of rivers are predicted to be damaging for riverine ecosystems under great pressure from human land use, pollution and resource exploitation, including particularly sensitive oxbow lakes (European Parliament, 2008). Water gains and losses vary significantly with the types and locations of floodplain lakes (Dawidek and Turczyński, 2006; Dawidek and Ferencz, 2014), which also fulfil the important function of floodwater retention (Geilen et al., 2004; Palmer et al., 2005). Channel/floodplain connectivity is a decisive factor of water supply to oxbow lakes and, thus, a main ecological requirement for floodplain restoration (Tockner et al., 1999; Klimo and Hager, 2001; Amoros and Bornette, 2002; Wren et al., 2008). In their lake typology, Dawidek and Ferencz (2014) also claim that “the hydrological (the degree of filling of the basin) and ecological state mostly depends on the type of connections that the lake has to the parent river”. Dawidek and Turczyński (2006) identify four types of connection between floodplain lakes and the main river: confluent, contrafluent, contrafluent–confluent or profundal. Even for lakes where no profundal connection is predominant, groundwater flow is important (Dawidek and Ferencz, 2014). Although Dawidek and Ferencz (2014) underline that horizontal components of water balance prevail over vertical ones, interception and transpiration of riparian forests can significantly modify the water balance of floodplains. Lindroth and Cienciala (1996) estimate 286–365 mm total growing season transpiration for willow stands in southern Sweden and Čermák and Prax (2001) 261–434 mm for poplar transpirations in Southern Moravia (Czech Republic).

The EU Water Framework Directive (WFD) provides a general framework for integrated river and wetland management, protection and restoration (European Commission, 2000). Although it does not explicitly concern floodplain environments, the WFD acknowledges that surface/subsurface water interactions play a crucial role in the water budget of floodplains, and promotes the restoration of floodplain habitats (Downs and Thorne, 2000). Major streams, like the Drava River, and their hyporheic zones maintain a hydraulic balance with groundwater. Among groundwater bodies and aquifers the unconfined aquifer reacts most rapidly to rainfall events. Therefore, groundwater and surface water have to be conceived as components of a single system and impacts on either

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http://dx.doi.org/10.1016/j.jenvman.2017.01.020
0301-4797/

of these components will inevitably affect the quantity or quality of the other (Winter et al., 1999). Although flooding only happens exceptionally along regulated rivers like the Drava, inundations in the perirheic zone (Mertes, 1997) are observed during wet spells.

Water replenishment issues within rehabilitation schemes are tackled in the study Masterplanning Europe's Wetlands (2013) and by Acrema et al. (2007), including pilot projects from Hungary. They emphasize the significance of the hydraulic conductivity of soils and alluvial deposits, which influences water supply to wetlands. In Japan opportunities to inhibit eutrophication through water inflow (dilution) were modelled (Shinohara et al., 2008). Simulations showed that for a 28% reduction of total N and total P concentrations within 30 days 78% of lakewater had to be exchanged. Hydrological models for water recharge reduced by climate change have been elaborated among others for the lakes of the Mackenzie delta in Canada (Emmerton et al., 2007), Lake Kinneret in Israel (Rimmer, 2009), lakes along the Yangtze River in China (Yu et al., 2009) and Amazonian floodplain lakes (Tomasella et al., 2013).

Based on the interpretation of hydrogeological time series, evapotranspiration estimations and soil moisture monitoring (Dezső et al., 2016a), the present paper intends to assess the efficiency of water replenishment to an oxbow lake and strives to answer the following questions:

1. Can the water deficit in the area be associated with climate change?
2. To what extent does hyporheic flow along the Drava influence the water levels of oxbow lakes?
3. What is the impact of soils and sediments on the water balance of the oxbow lakes?
4. What losses are expected during and after water replenishment?

2. Study area

The Drava is a border river between Hungary and Croatia with an alluvial plain (morphological floodplain) of 696 km^2 area and 10–25 km width (Szalay, 2014) (Fig. 1). On the Hungarian section, there are 20 major side-channels, 13 tributary streams, 18 major oxbow lakes (of ca 150 ha total area, varying seasonally – Pálfai, 2001) and hundreds of infilled meander scars.

The hydromorphological character of the river and its impact on the floodplain along the section under study is presented through the indicators of the EU project REFORM (**RE**storing Rivers **FOR** Effective Catchment **M**anagement) (González del Tánago et al., 2015) (Table 1). Mean river discharge (at the Barcs gauge for the period 1896–2014) is 595 m^3 s^{-1}, its maximum (assumed to be of 0.1% probability, estimated for the 1827 flood) is around 3070 m^3 s^{-1}, while baseflow is around 170 m^3 s^{-1} and bankfull discharge is around 900 m^3 s^{-1} (VKKI, 2010). Floods commonly occur in June–July (Atlantic influence) and in October–November (Mediterranean influence).

To assess the potential replenishment options, an abandoned meander of the Drava of 257 ha total area was selected as a case study (Fig. 2), including ca 140 ha of oxbow lakes with a maximum water depth of 2.4 m and an average water depth of 1.12 m. The meander was partially cut off from the new Drava channel during the main stage of channelization between 1842 and 1846. The width of the semi-natural riparian zone of the oxbow lakes is merely 10–20 m. This wetland area is part of the Danube-Drava National Park and registered as a Ramsar Convention site.

3. Human impact, environmental problems and rehabilitation efforts

In 1784 the channelization of the Drava River began with the primary purpose of improving navigation conditions (Buchberger, 1975; Borzavári, 1981). In addition to reducing river length by almost 50%, this human intervention divided the area into an active and a morphological (in the terminology of Hungarian water management: “protected”) floodplain. After the record floods in the summer of 1827 and again in 1972 flood-control measures accelerated. Artificial cut-offs made at numerous sites reducing river length by almost 50% and the construction of hydroelectric plants on upstream sections exacerbated the rate of natural channel incision, which is due to the neotectonic subsidence of the Drava graben (Nagymarosy, 2008; Lovász, 2013). Particularly, low-water levels have dropped significantly. Disconnected from the river channel, the floodplain experienced more and more drought periods. With 2–3 m drop of the groundwater table, the conditions for agriculture, the main source of subsistence for the population (AQUAPROFIT, 2005), became critical and the biota of wetlands in the Danube-Drava National Park also suffered from water deficit (Purger, 2013).

Human-induced changes in environmental conditions have affected the riparian forests of great nature conservation value. Dry soil conditions led to the reduction of willow and alder stands in the immediate environs of active and abandoned channels (Ortmann-Ajkai and Horváth, 2010). In accordance with EU financial support, forest management policy enforces the spreading of the mesohygrophilous Pedunculate Oak *(Quercus robur)* and Hungarian Ash *(Fraxinus angustifolia)* and the reduction of Black Locust *(Robinia pseudoacacia)* stands (Purger, 2013). The roots of arboreous vegetation are claimed to promote infiltration into the soil. The overall water demand of deciduous forests, however, is high. Transpiration from riparian forests and their undergrowth involves the loss of large amounts of water from the floodplain to the atmosphere and its amounts vary considerably between drought and waterlogged periods (Čermák and Prax, 2001). In flood years transpiration loss has the positive effect that flood wave crests become more moderate (McCartney and Naden, 1995). In contrast to arable crops, no major drought damage was reported from the forests of the Drava floodplain – in spite of 2–3 m drop in groundwater levels (Pécsi HIDROTERV Bt. 2015).

Optimal floodplain management is made difficult by the conflicts between the demands of agriculture, forestry, flood control and nature conservation (for the Drava River floodplain see Lóczy et al., 2014; Pécsi HIDROTERV Bt. 2015).

To amend water scarcity, a large-scale landscape rehabilitation project, the Old Drava Programme, was launched in 2013 (Salamon, 2014). It is intended to solve problems of water governance with a focus on the nature conservation and sustainable management of lake ecosystems as well as land management and employment. The official water management plan (DDKÖVÍZIG, 2012) and its ”actualized version” (Pécsi HIDROTERV Bt. 2015) envision ”ecologically sustainable and cost-effective water supply” for the floodplain area. In a first step, the lake water level at Cún-Szaporca (a confluent-contrafluent lake according to Dawidek and Ferencz, 2014) is planned to be raised from the present 90.15 m above sea level to 91.25 m. Relying on the experience gathered from this pilot project, further water replenishment interventions are foreseen for the future.

Since direct lateral connectivity between the Drava River and the Cún-Szaporca cut-off meander is limited to ca two weeks in a year, the master plan (AQUAPROFIT, 2007) favours water transfer from the Fekete-víz Stream, a minor tributary of the Drava (Q_{min} = 0.118 m^3 s^{-1}, Q_{mean} = 4.5 m^3 s^{-1}, Q_{max} = 62 m^3 s^{-1}, $Q_{1\%}$ = 55.8 m^3 s^{-1}). The feeder canal system is 3.1 km long and has 0.4 m^3 s^{-1} capacity. Its bottom is re-enforced by geotextile. To ensure gravitational flow in the canal of at least 0.5% slope to the level of the oxbow lake, the Fekete-víz has to be impounded to a minimum level of 93.1 m. Planners assume that clogging at the bottom is sufficient to retain water in the lake basins. The indirect consequences of human impact (like the entrenchment of