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Strategic floodplain reconnection for the Lower Tisza River, Hungary: Opportunities for flood-height reduction and floodplain-wetland reconnection

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SUMMARY

During the late 19th Century, the Tisza River's vast floodplain-wetland system was largely disconnected by levees, facilitating "reclamation" for agriculture and resulting in an estimated loss of over 90% of historical wetlands. While levees have been successful in preventing catastrophic flooding for a century, Lower Tisza flood stage records have been set repeatedly during the last 15 years. The decrease in the Tisza's current floodway carrying capacity has reduced the flood-protection level of the Tisza's aging levee system. Recently in Hungary, "Room for the River" policies have gained more prominence. To explore the possibilities of a room for the river approach along the Lower Tisza, we assess eight potential floodplain-reconnection scenarios between Csongrád, Hungary and the Hungary–Serbia border. A novel framework using hydrodynamic and geospatial modeling was used to perform planning-level evaluations of the tradeoffs between floodplain-reconnection scenarios and enhancement of the existing levee system. The scenarios evaluated include levee removal and levee setbacks to strategically reconnect significant historical wetlands while reducing flood levels. Scenario costs and human population impacts are also assessed. Impacts of reconnecting the Lower Tisza floodplain are compared to heightening levees, the prevailing strategy over the previous century. From a purely construction-cost perspective, heightening Lower Tisza levees is potentially the most cost-effective and politically expedient solution (i.e., impacts the least number of people). However, levee-heightening does not solve the long-term problem of reduced flood conveyance, which has been attributed to aggradation and increased floodplain roughness, nor does it result in wetland reconnection or enhancement of other floodplain ecosystem services. The suite of reconnection options we evaluate provides engineers, planners, and decision makers a framework from which they can further evaluate potential flood-risk reduction options. At least three of the eight reconnection scenarios (setting the western levee back, 1500-m, and 2000-m setbacks) along the Lower Tisza demonstrate that floodplain-wetland reconnection is possible while achieving the objectives of minimizing impacts on human populations and reducing flood heights.

1. Introduction

Wetlands and active floodplains are some of the most productive and valuable lands in terms of species diversity, biological productivity, and ecosystem services, yet they continue to be disconnected and altered (Opperman et al., 2009, 2010; Costanza et al., 2014). Disconnecting a river from its floodplain affects the processes that are closely coupled to the hydrologic regime. These processes include sediment transport, channel-planform adjustment, ecosystem processes, biogeochemical cycling, and the services they provide to society (e.g., flood risk reduction and productive fisheries; Opperman et al., 2010).

Periodic inundation of floodplains is necessary to maintain high river-floodplain biodiversity, yet these flood flows have been eliminated in many systems (Poff et al., 1997, 2007; Graf, 2006). Dams disrupt the longitudinal ecological continuum that is a function of a river's physical processes by homogenizing flow and reducing the sediment load of rivers, often leading to incision (Vannote et al.,

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1980; Graf, 2006). Coupled with decreases in discharge, incision can mean less area inundated and decreases in habitat, along with additional reductions in ecosystem services in floodplains (Poff et al., 2007; Jacobson et al., 2011).

In addition to the longitudinal continuum proposed by Vannote et al. (1980), rivers and their floodplains interact laterally (Junk et al., 1989; Poff et al., 1997; Richter et al., 1998). However, artificial levees disconnect rivers from their floodplains and disrupt lateral flow and subsequent processes, including periodic floodplain inundation and biogeochemical cycling processes from floodplain to river and vice versa that were first described as the "flood pulse concept" by Junk et al. (1989). As a result, these disconnected floodplains no longer receive the sediment or nutrients that made them such productive ecological systems.

Worldwide, artificial levees have been popular due to their relatively low construction cost, political expediency, and protection they provide from low to moderate floods (Montz and Tobin, 2008). Levees themselves can increase flooding due to their narrowing of the floodway, which decreases flood water storage and creates backwater effects that slow flow velocities, consequently increasing flood stages (Pinter et al., 2008; Remo et al., 2009; Heine and Pinter, 2012). However, demonstrated risks of flood hazard do not preclude building in the floodplain, and there is pressure to reoccupy flood-prone areas even after large floods (Hipple et al., 2005; Montz and Tobin, 2008; Ludy and Kondolf, 2012). As floodplain development continues, levees result in more benefits, but potential losses also increase (Hipple et al., 2005; Pinter, 2005; Montz and Tobin, 2008; Remo et al., 2012). Thus, floodplain management should take into account potential risk and damages and emphasize higher-value urban protection, while considering levee setbacks in agricultural reaches (Dierauer et al., 2012; Remo et al., 2012).

Along the Tisza River in Central Europe, a nearly 3000-km-long levee system was created, disconnecting its large natural floodplain (ca. 27,000 km^2; Kiss et al., 2008; Lóczy et al., 2009). Over the last 100 years, Schweitzer (2009) documented at least nine floods along the Tisza that reached or overtopped Hungarian levees. While the levees were designed to protect from 50-year floods, aggradation on the confined floodplain has reduced the Tisza's flood carrying capacity, resulting in increasing flood heights and corresponding raising of levees (Sipos et al., 2007; Kiss et al., 2008; Sándor and Kiss, 2008; Schweitzer, 2009).

Hydraulic modeling has been used to show that floodplain reconnection scenarios may be the most cost-effective long-term solution to reduce flood levels and flood risk along portions of the Mississippi River (Dierauer et al., 2012; Remo et al., 2012). Derts and Koncsos (2012) used 1-D and 2-D models to show how engineered flood-detention basins adjacent to existing levees could reduce Tisza River flood heights. Moreover, Schweitzer (2009) also recommended levee setbacks and levee removal as potential solutions to reduce record-breaking flood stages along the Tisza. These proposed flood-detention basins and multifunctional levee setbacks follow similar plans from the Dutch "Room for the River" program to reduce flood risk along the Rhine River (see van Loon-Steensma and Vellinga, 2014). Moreover, setting back levees to provide lateral reconnection, which increases aquatic habitat and floodplain-river nutrient cycling, has been ranked as one the most desirable management options to restore long-term floodplain ecosystem services (Gilvear et al., 2013; Schindler et al., 2014). However, raising levee heights may also be necessary in areas where constructing reservoirs or widening the distance between levees may not be feasible (Derts and Koncsos, 2012).

In addition to the flood detention basins proposed by Derts and Koncsos (2012), this study adds eight floodplain-reconnection scenario models for the Lower Tisza, which were assessed for the standard suite of flood-recurrence intervals (5-year through 500-year event). For each floodplain-reconnection scenario, we quantified the reduction in flood heights, population impacted, new levee construction costs, and pre-alteration wetland areas that were reconnected. These eight reconnection scenarios are compared to impacts and costs of heightening existing levees. While previous studies have analyzed the range of potential impacts resulting from naturalizing developed floodplains (e.g., Sparks and Braden, 2007; Zhu et al., 2007; Remo et al., 2012; Sanon et al., 2012), this study provides a planning-level methodology to assess the viability of a suite of modeled floodplain-reconnection scenarios using multiple river-corridor management objectives.

2. Methods

2.1. Study area

The Tisza River is the longest tributary to the Danube River, which drains much of Central and Eastern Europe. The Tisza's 157,000 km^2 basin includes portions of Ukraine, Slovakia, Romania, Hungary, and Serbia (ICPDR, 2008; Fig. 1). The Carpathian Mountains, reaching a maximum elevation of 2492 m, bound the northern and eastern portions of the Tisza River Basin, while the Danube watershed confines the western extent. Flowing out of the higher-relief areas and into the Pannonian Basin, the Tisza and its tributaries created a complex interconnected floodplain-wetland system. Prior to construction of the flood-control system, this interconnected floodplain system allowed flood waters from the Tisza and its major tributaries to inundate much of the Great Hungarian Plain lowlands for months at a time (Schweitzer, 2009).

To provide flood protection, facilitate navigation, and reclaim the floodplain for agriculture, the extensive Tisza floodplain-wetland system was heavily altered beginning in the mid-19th Century (Sipos et al., 2007; Kiss et al., 2008; Sándor and Kiss, 2008; Schweitzer, 2009; Rakonczai and Kozak, 2011; Derts and Koncsos, 2012). From the mid-19th and into the 20th century, the Tisza was shortened, straightened, and disconnected (leveed-off) from its floodplain. Over 100 cutoffs resulted in the shortening of the river channel by over 180 km (1149 km pre-regulation to 966 km today) (Lóczy et al., 2009). Over 2940 km of levees were built to prevent flooding, reducing the width of the floodplain from tens of kilometers wide to an average width of 1.4 km (Kiss et al., 2008; Lóczy et al., 2009). The reduction in naturally connected channels reduced the Tisza's flood conveyance by an estimated 1000 m^3/s (Timár and Gábris, 2008). At the city of Szeged, the largest city along the main-stem Tisza, floodplain constriction is especially acute as the floodplain has been narrowed from over 20-km wide to less than 400 m, contributing to a backwater effect observed 75 km upstream at Csongrád (Fig. 1). While construction of the flood mitigation system was underway, the great flood of 1879 killed 151 people and destroyed 94% of the homes in Szeged, necessitating higher design levels when levees were rebuilt (ICPDR, 2008; Schweitzer, 2009).

During the 20th century, river engineering was employed to enhance the navigation channel, improve flood-flow conveyance, and prevent lateral movement of the river channel. The river engineering tools employed included the installation of revetments for bank stability, groins (wing dikes) to maintain channel depth and concentrate flow, and levee expansion (Sipos et al., 2007; Kiss et al., 2008). Additionally, three main-stem dams were built on the Tisza for additional flood mitigation, hydroelectric power generation, water supply, and recreation. These dams were constructed at Tiszalök (1954) and Kisköre (1974), Hungary, and Novi Bečej, Serbia (1976).

Collectively, these river modifications have altered the hydrology, hydraulics, sediment transport, and morphology of the Tisza