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Linking floodplain hydraulics and sedimentation patterns along a restored river channel: River Odense, Denmark

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ABSTRACT

Re-establishment of riparian freshwater wetlands often involves re-meandering of former channelized river sections by narrowing the channel width and depth, which creates frequently inundated floodplains. Inundations are important for floodplains in terms of erosion/accretion of sediment and for deposition of nutrients and organic matter. The links between floodplain hydraulics and deposition of sediment, organic matter and phosphorus were investigated along a 6 km re-meandered channel section of River Odense, Denmark. A 2D dynamic river and floodplain model was set up for the investigated floodplain area. The flow model was validated against *in situ* measurements of flow velocities and depths during a one-day field campaign in January 2012. Deposition of sediment was measured on 30 artificial grass mats deployed on the floodplain during winter 2011/2012. Total deposition of sediment, organic matter and total phosphorus was estimated by Kriging and amounted to 4.72 kg m^{-2}, 0.65 kg m^{-2} and 11.4 g m^{-2}, respectively. The predicted duration of inundations, distances to inflow, flow velocities, and information on microtopography were compared with sedimentation patterns on the floodplain. Three distinct flow regimes were predicted by the hydraulic model and were classified as small, medium and large inundation events according to spatial extent and inundation depth. The model predicts spatially and temporally changing zones of confluence on the floodplain due to variations in inundation depth. The position of these zones correlates with zones of high sediment deposition. Simple regression models described only up to 76% of the variation in sediment deposition. We conclude that use of dynamic spatial distributed 2D models is necessary if the links between floodplain hydraulics and deposition of sediment, organic matter and phosphorus are to be accurately described.

1. Introduction

The Danish Action Plans II from 1998 and III from 2004 for reduction of nutrient emission to surface waters have included restoration of rivers and floodplains with the aim to remove nitrogen (N) through denitrification and storage of phosphorus (P) by sedimentation in re-established floodplains (Kronvang et al., 2005; Hoffmann and Baattrup-Pedersen, 2007). The EU Water Framework Directive River Basin Management Plan, which was adopted in 2012 in Denmark, includes mitigation measures such as inundation of 10,000 ha re-established freshwater wetlands and 3000 ha temporarily inundated floodplains for retention of N and P (Danish Ministry of Environment, 2011).

The riparian freshwater wetlands and inundated floodplains will in most cases be re-established by re-meandering of former channelized sections of river channels in which the flow capacity is reduced by narrowing channel width and depth (Kronvang et al., 1998; Pedersen et al., 2007). The influences of such extensive alterations in channel flow capacities on the hydraulic interaction between a river and its floodplain have received limited attention (Walling and He, 1998). Most studies have focussed on hydraulic models to simulate water depth and flow velocities in the channel and on the floodplain (Nicholas and McLelland, 1999; Nicholas and Mitchell, 2003; González-Sanchis et al., 2012).

Studies on the importance of sediment deposition in natural and restored wetlands have been conducted in different countries worldwide (Mitsch et al., 1979; Kuenzler et al., 1980; Lowrance et al., 1986; Walling and He, 1998; He and Walling,

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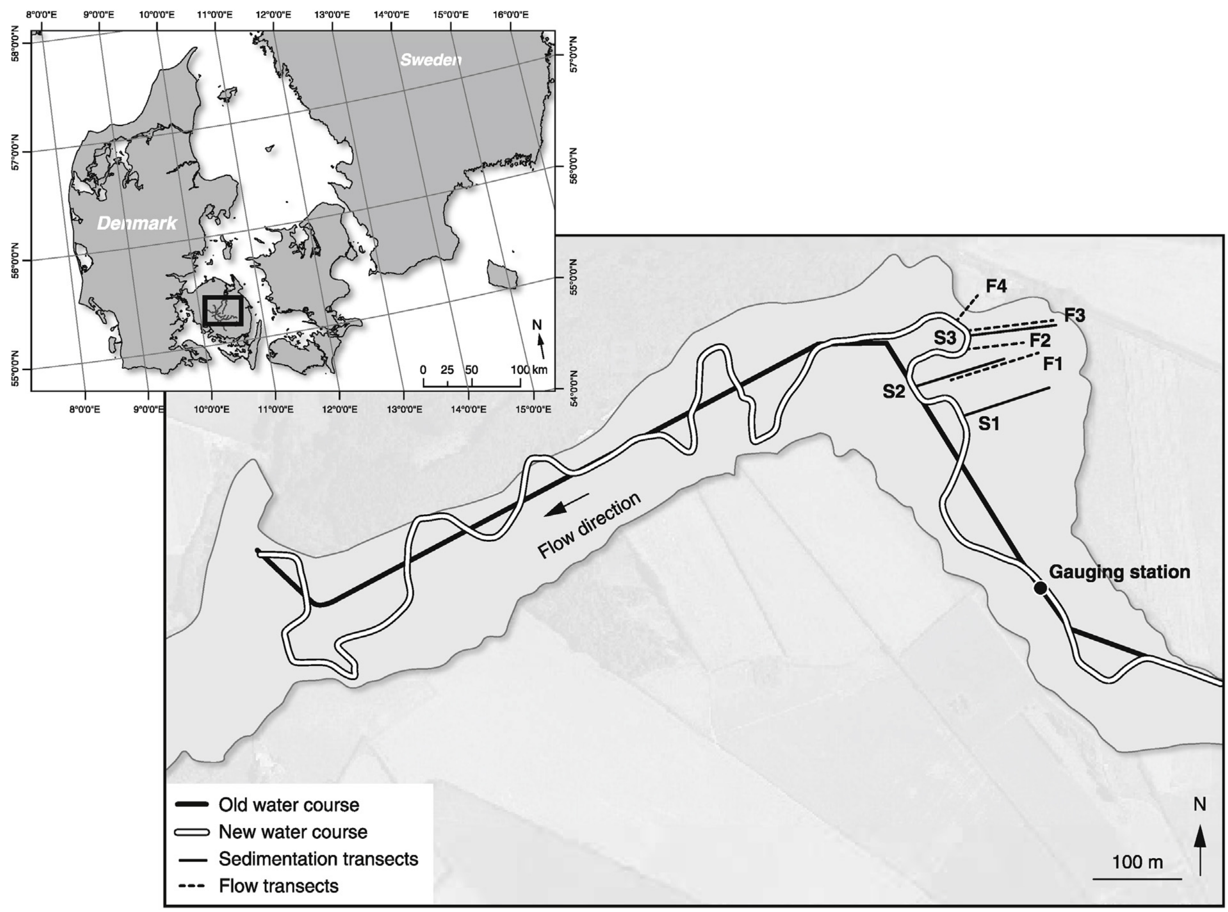

Fig. 1. Overview of the restored channel section. The straightened channel course and the re-meandered channel course are shown with white and black lines, respectively. The four transects numbered F1, F2, F3, F4 represent locations of *in situ* velocity measurements conducted on 23 January 2012. The three transects numbered S1, S2, S3 represent locations with artificial grass mats placed during winter 2011/2012. Black dot shows the gauging station where continuous water levels measurements were conducted.

1998; Sweet et al., 2003; Kronvang et al., 2009), some using models of overbank sedimentation (Pizzuto, 1987; Walling and He, 1998) and some linking sedimentation patterns with flow patterns (Nicholas and Walling, 1997, 1998; Middelkoop and Van der Perk, 1998; Sweet et al., 2003; Nicholas et al., 2006). However, linkages between floodplain hydraulics, sediment textural composition, organic matter and P content following re-meandering of a river channel have seldom been investigated. Knowledge of these linkages is important to include in river and floodplain restoration projects, both in order to accurately predict the spatial and temporal flow and sediment deposition patterns, and to assess the potential for denitrification and storage of organic matter and P on the restored floodplain. It is expected that parameters such as flow depth, flow velocities, flow duration and exchange of water between river channel and the floodplain together constitute a complex system controlling sediment deposition. The complexity of this spatially and temporally changing system needs to be addressed to accurately understand floodplain dynamics.

The objectives of this study were to explore the linkages between floodplain hydraulics and *in situ* observed sedimentation patterns by: (i) performing a validation of a dynamic 2D river and floodplain model based on *in situ* measurements of water depth and flow velocity for a section of a re-meandered 5th order Danish river channel and floodplain; (ii) compare floodplain flow velocities with measured net deposition of sediment, phosphorus and organic matter; and (iii) test if simple empirical relationships between floodplain hydraulics and sediment deposition could be developed.

2. Study site

2.1. River Odense

The studied floodplain of the River Odense on Funen, Denmark (55°13 N, 10°15 W), was restored in autumn 2003 by re-meandering and reducing the flow capacity of the formerly straightened river channel (Fig. 1). The restored river floodplain site encompasses a total of 125 ha riparian areas that have been transformed from intensively cultivated land to permanently grazed meadows following restoration.

The catchment area upstream of the studied area shown in Fig. 1 is 254 km^2. Land use in the catchment is dominantly agriculture (*ca.* 65%), the area is underlain by moraine deposits from the last glaciation period (Weichsel) and primarily composed of clayey sandy (*ca.* 40%) and sandy clay soils (35%).

Average annual long-term precipitation amounted to 727 mm during the period 1989–2011. Average annual long-term runoff at the restored site amounted to 316 mm during the period 1989–2011. During the same period median minimum discharge was 1.2 m^3 s^{-1}, median maximum discharge was 3.3 m^3 s^{-1} and absolute maximum discharge was 22 m^3 s^{-1}. The baseflow (BFI) index for the stream is 0.67 (27 year period), which means that