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Evolution of abandoned channels: Insights on controlling factors in a multi-pressure river system

Thomas Dépret *, Jérémie Riquier, Hervé Piégay

University of Lyon, CNRS UMR 5600 - Environnement Ville et Société, Site of École Normale Supérieure, 15 Parvis René Descartes BP 7000, Lyon 69342, France

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ABSTRACT

In the second half of the 19th century, channelization of large multi-thread rivers such as the Rhine, the Danube, and the Rhône rivers induced artificial disconnection of most of their secondary channels. Compared to naturally abandoned channels, terrestrialization (i.e., the passage from the aquatic to the terrestrial stage, controlled by sediment deposits and/or lowering of the water level) patterns and rates of such artificially prematurely abandoned channels remain largely unknown. Moreover, factors controlling their evolutionary trajectories are complex owing to a set of pressures occurring throughout the 20th century within specific space-time windows. Through a case study of the Rhône River, this paper aims to assess and distinguish the effects of a set of potential controlling factors on abandoned channel terrestrialization dynamics and lifespan. We tested the influence of: (i) submersible embankments closing the entrance of abandoned channels, (ii) main channel degradation following its channelization or the water level lowering due to channel bypassing in the middle of the 20th century involving drastic water abstraction in these reaches, (iii) transverse dykes within the abandoned channels, (iv) the flooding regime of abandoned channels (i.e., frequency and magnitude of upstream connections producing lotic functioning), and (v) longitudinal variation in the suspended sediment concentration along the main channel. To this end, we studied 24 abandoned channels (16 artificially disconnected at their upstream end by submersible embankments and eight naturally disconnected by bar plug establishment) from the mid-19th to the beginning of the 20th century. Their terrestrialization rates were characterized through the reconstruction of their planimetric trajectories using historical maps and aerial photos.

The results reveal a much longer lifespan of artificial abandoned channels compared to natural ones because of the truncation of the initial bedload infilling phase due to the artificial and imposed closing of their entrance. Moreover, terrestrialization occurred faster when water level lowering or channel degradation was greater. Surprisingly, terrestrialization rates were the highest in the most frequently connected artificial abandoned channels (i.e., channels with a high frequency of lotic functioning), probably in relation to the roughness induced by the presence of transversal dykes. Finally, it is difficult to rank all the factors tested because of their complex combinations, which can change in space and time.

1. Introduction

The dynamics of abandoned channels is a key topic in fluvial geomorphology. Researchers have focused on the mechanisms responsible for their genesis (e.g., Leddy et al., 1993; Gay et al., 1998; Hooke, 2004; Constantine et al., 2010b; Grenfell et al., 2012). Others were interested in the rhythms and modalities of their infilling. During the first infilling stage, corresponding to the transition from a permanent flowing side channel to an abandoned channel, the channel is filled with bedload until an alluvial plug forms at its entrance (Allen, 1965; Kondolf and Stillwater Sciences, 2007). These coarse deposits are mainly controlled by the diversion angle between the main and abandoned channels, by the transport capacity in the main channel and by the bedload grain-size (Constantine et al., 2010a; Dieras, 2013) (Fig. 1). All other conditions being equal, the lower the diversion angle is, the greater the infilling is (Kondolf and Stillwater Sciences, 2007; Constantine et al., 2010a; Dieras, 2013) (Fig. 1). The key role played by the diversion angle in controlling channel infilling was brought to light long ago (Fisk, 1944; Lindner, 1953; Allen, 1965; Gagliano and Howard, 1984; Shields and Abt, 1989). Constantine et al. (2010a) recently demonstrated that this control is related to a flow separation zone within the abandoned channel entrance. By decreasing the discharge and the shear stress in this area, the flow separation zone induces a reduction in transport capacity (Constantine et al., 2010a; Zinger et al., 2013). The higher the diversion angle is, the higher the proportion of the bed width of the

* Corresponding author.
E-mail address: thomas.depret@ens-lyon.fr (T. Dépret).

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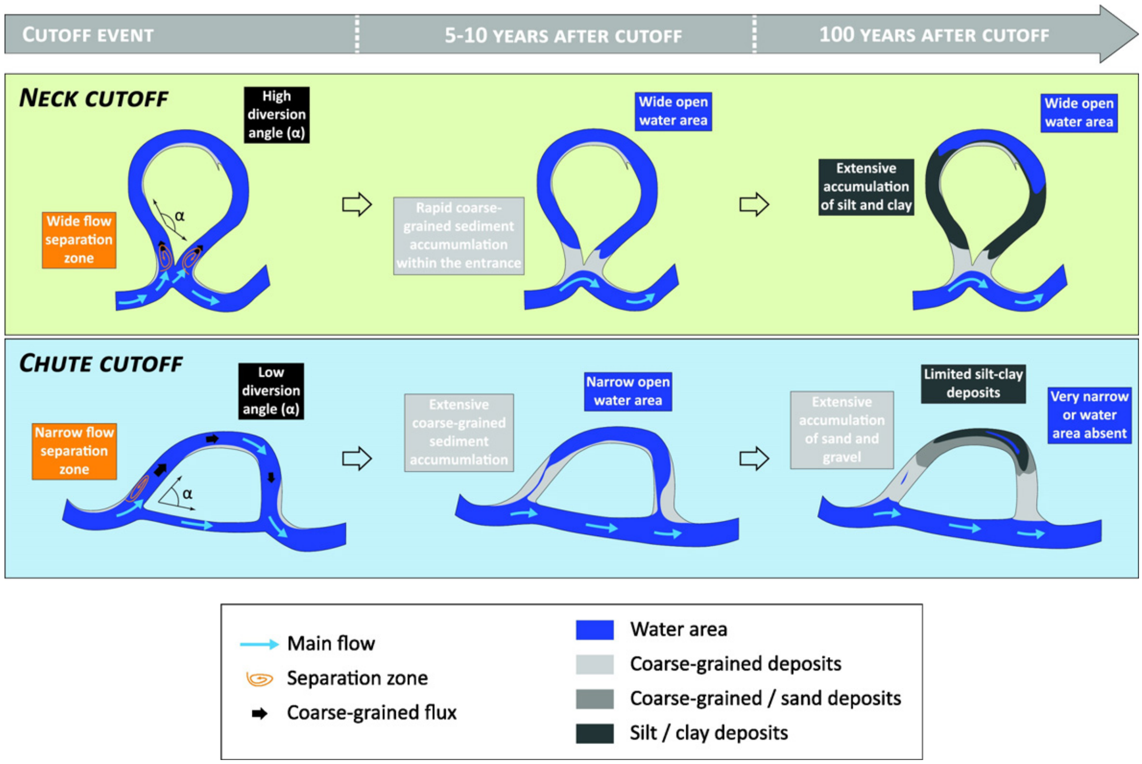

Fig. 1. Flow separation zone and sediment deposits in neck and chute cutoffs (Dieras, 2013, redrawn).

abandoned channel entrance affected by the flow separation zone (Keshavarzi and Habibi, 2005; Constantine et al., 2010a) (Fig. 1). For this reason, meander chute cutoff channels, with usually low diversion angles, are more quickly infilled than meander neck cutoff channels, whose diversion angles are much higher (Constantine et al., 2010a; Dieras, 2013). Hence, the total obstruction of the channel entrance by an alluvial plug occurs later for chute cutoff than for neck cutoff channels (Kondolf and Stillwater Sciences, 2007). Moreover, the bedload propagates farther downstream along chute cutoff channels and over a longer period of time, whereas the thickness of the deposits tends to decrease downstream (Fisk, 1944; Lindner, 1953; Allen, 1965; Saucier, 1994; Kondolf and Stillwater Sciences, 2007; Constantine et al., 2010a; Dieras, 2013). The initial water depth and volume of the chute cutoff channels is then quickly reduced (Kondolf and Stillwater Sciences, 2007; Constantine et al., 2010a). Therefore, the volume of the remnant aquatic zone and the quantities of fine sediments needed to fill it are quite limited (Kondolf and Stillwater Sciences, 2007; Constantine et al., 2010a; Dieras, 2013). Furthermore, bed aggradation caused by bedload deposits fosters the dewatering effect, and thus the encroachment of woody vegetation. For the neck cutoff channels, the high diversion angles induce a quick and short plug bar formation at their upstream entrance, resulting in a substantial reduction of the

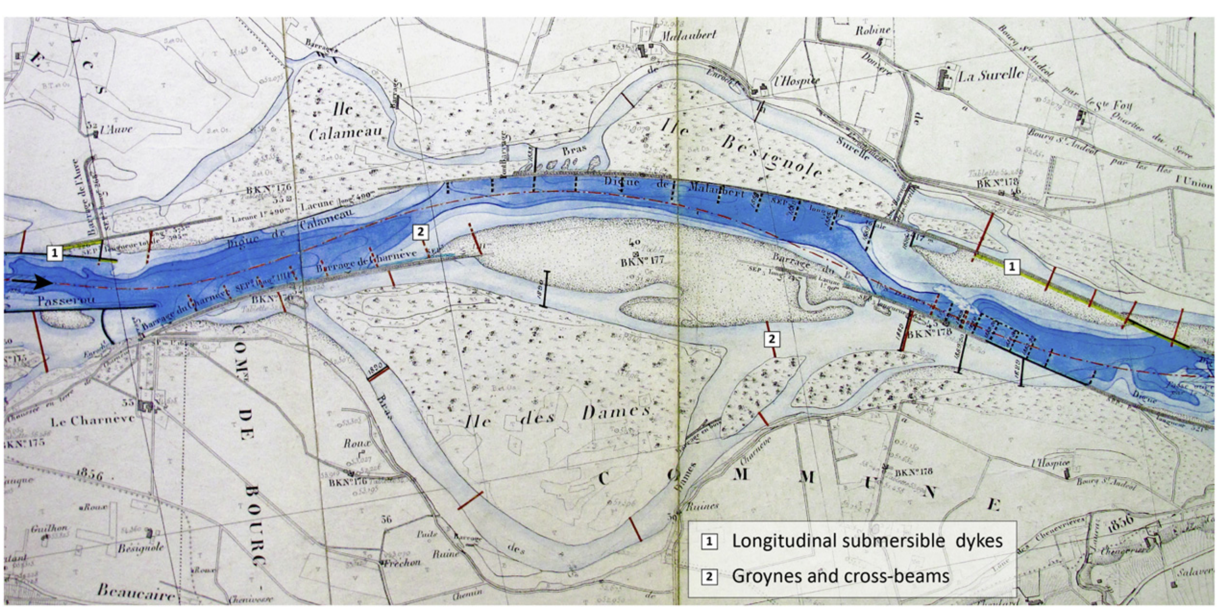

Fig. 2. Overview of the engineering fluvial works built on the Rhône River during the second part of the 19th century (1891 map extract).