Exploring meandering river cutoffs

Peng Gao[1]* and Zhiwei Li[2]

[1]Department of Geography and the Environment, Syracuse University, Syracuse, New York 13244

[2]State Key Laboratory of Water Resources Engineering and Management, Wuhan University, Wuhan, Hubei 430072, China

PG, 0000-0001-5323-9398

*Correspondence: pegao@syr.edu

Abstract: Cutoffs, which include neck and chute cutoffs, are the results of the fluvial processes that fundamentally influence evolution of meandering rivers. A neck cutoff happens when the two limbs of a highly sinuous bend touch, whereas a chute cutoff refers to the formation of a shortcut channel passing through a meander bend. In this review, we begin by distinguishing the morphological and hydrological conditions of the two cutoff types. Mechanisms driving the development of a neck cutoff are embodied in a variety of kinematical and hydrodynamic models simulating processes governing the long-term evolution of meandering rivers. These models adopt a morphological threshold for judging the occurrence of a neck cutoff, $b = \alpha w$, where α is a constant ranging between 0 and 1, b is the bend neck width and w is the mean channel width. The potential underestimation of the evolutionary period during the late stage of bend evolution toward a neck cutoff when using this morphological threshold and the uncertainties in quantifying the migration–curvature relationship limit the abilities of existing models to predict the occurrence of neck cutoffs. We then suggest three possible directions for future research on meander neck cutoffs. Mechanisms controlling chute cutoffs are relevant to six key factors representing the meander hydrological regime, planform morphology, bed topography and floodplain characteristics. The combination of these factors gives rise to four distinguishable triggering mechanisms: headward-erosion, embayment, mid-channel bar and scroll–slough chute cutoffs, though the initiation of the chute cutoff may be caused by some combination of these. However, the hydraulic and morphological characteristics of meander bends under these triggering mechanisms are so complex that they are often site-specific, making it extremely challenging to generalize the known morphodynamic and hydrodynamic processes driving the formation of chute cutoffs in individual meander bends. We close the review by recommending three possible research directions on chute cutoffs for tackling the existing challenges in the future.

Meander cutoff: concepts and importance

The term 'meander cutoff' refers to a fluvial phenomenon wherein a meander bend in a single-thread river is shortened by the connection of the two bend limbs, creating a shorter route for the river to flow through (Tower 1904). Cutoff plays a key role in the complex dynamics of meandering river evolution by geometrically constraining the complexity of meander planform through episodic reduction of river sinuosity, and dynamically interrupting meandering river evolution by generating intermittent sediment pulses that affect river migration and dynamics both locally and at the reach scale (Howard and Knutson 1984; Stolum 1996; Camporeale *et al.* 2008; Frascati and Lanzoni 2010; Micheli and Larsen 2011; Schwenk and Foufoula-Georgiou 2016; Guo *et al.* 2019; Ielpi and Lapotre 2020). These two processes collectively reduce the nonlinearities embedded in meandering river planforms (Güneralp *et al.* 2012). Meander cutoffs also leave behind oxbow lakes that serve as perifluvial habitats with high ecological potential (Amoros 2001; Amoros and Bornette 2002; Stella *et al.* 2011), providing homes to numerous plant and wildlife species (Ward *et al.* 1999; Piegay *et al.* 2000). Additionally, meander cutoffs affect subsequent river morphodynamics by modifying floodplain sedimentology and contributing to sediment connectivity between the floodplain and the associated meandering river (Carson and Lapointe 1983; Erskine 1992; Aalto *et al.* 2008; Phillips 2013; Grenfell *et al.* 2014), ultimately driving the formation of meander belts (Stolum and Friend 1997; Durkin *et al.* 2018) that can be preserved in the rock record.

Meander cutoffs can sometimes lead to geopolitical issues. Because international borders or territorial boundaries may be defined by rivers, when a meander cutoff significantly changes the course of a river, it could potentially impact the delineation of borders between countries or regions. Consequently, disputes over river boundaries and the resulting geopolitical implications may arise. Cutoffs can also be used as a simple tool to artificially create a short cut across the floodplain between a bend for facilitating navigation (Pan *et al.* 1978;

From: Finotello, A., Durkin, P. R. and Sylvester, Z. (eds) *Meandering Streamflows: Patterns and Processes across Landscapes and Scales*. Geological Society, London, Special Publications, **540**,
https://doi.org/10.1144/SP540-2022-261

Winkely 1982; Coomes *et al.* 2009) or to relocate a meander reach for a specific land use (Thompson 2003). At times, potential cutoffs could lead to unexpected flooding that may threaten buildings and the lives of local residents in the floodplain along its downstream reach. For example, in the middle reach of the Yangtze River, 400 km below the well-known Three Gorge Dam in China, a highly sinuous bend was evolving toward cutoff (Fig. 1). If the cutoff had happened, then the flow would have gained power due to the enhanced bed slope, increasing the risk of bank erosion and flooding in the nearby city of Yueyang that is home to 1.3 million people. To prevent the meander from cutting off, a series of engineering measurements for bank reinforcements (i.e. revetment) was put in place.

Types of cutoffs and their general characteristics

Cutoff can generally be divided into two categories (Lewis and Lewin 1983; Hooke 1984; Knighton 1998; Rhoads 2020). The first is a neck cutoff (Fig. 2a–c), which occurs when the two limbs of a highly sinuous bend intersect with each other (Mosley 1975; Ratzlaff 1981; Howard and Knutson 1984). The second is a chute cutoff (Fig. 2d, e), which involves the formation of a new, shorter channel that bypasses a meander bend through its point bar or floodplain, effectively 'cutting off' the bend from the main flow path of the river (Friedkin 1945; Brierley 1991; Erskine *et al.* 1992; Hooke 1995*a*; Fuller *et al.* 2003; Viero *et al.* 2018). Neck cutoffs tend to emerge in bends developed in low-gradient reaches with high sinuosity and bend curvature (Lewis and Lewin 1983; Micheli and Larsen 2011). Their development is mainly controlled by spatially heterogeneous bank erosion and generally takes a much longer time to form than chute cutoffs (Friedkin 1945; Hooke 2004; Constantine *et al.* 2009; van Dijk *et al.* 2012). Chute cutoffs tend to occur in bends with low and intermediate curvatures (Howard 1996), though they could happen in highly convoluted bends as well (Camporeale *et al.* 2008; Ghinassi 2011; Grenfell *et al.* 2014). They are often caused by high flows, coupled with appropriate combinations of channel and floodplain geomorphology (Howard and Knutson 1984; Gilvear *et al.* 2000; Hooke 2004; Ghinassi 2011; Kleinhans and van den Berg 2011). Some may also form under moderate flow conditions (Thompson 2003; Hooke 2004; Gautier *et al.* 2007; van Dijk *et al.* 2014). In nature, even within a short meandering segment that has homogeneous physiographic conditions, both types of cutoffs can form (Fig. 3; Ielpi *et al.* 2021), indicating that their initiation is essentially controlled by local hydraulic and morphological conditions of the meandering bends.

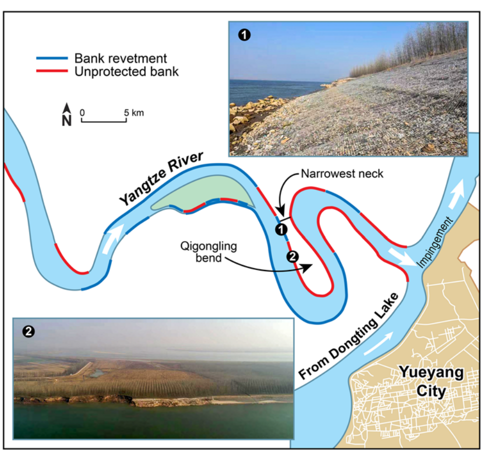

Fig. 1. A highly sinuous bend (Qigongling) in the middle reach of the Yangtze River with a very narrow neck. The narrowest neck width, which is about 520 m, is less than 50% of the mean channel width. Inset 1 shows an example of the protected bank section (revetment), while inset 2 displays an example of the unprotected bank section that has experienced erosion. The tributary converging to the Middle Yangtze River is from Dongting Lake, one of the two largest freshwater lakes in China.

Mechanisms of neck cutoffs and challenges

Modelling neck cutoffs in the context of meander evolution

Neck cutoffs can be found globally (Lewis and Lewin 1983; Howard and Knutson 1984; Fares 2000; Das *et al.* 2007; Schwenk and Foufoula-Georgiou 2016; Guo *et al.* 2019). Yet, the fluvial processes of neck cutoffs are difficult to directly observe in natural meandering rivers, as these processes are more progressive, whereas the occurrence of chute cutoffs is relatively swift (Hooke 1995*b*, 2013; Li and Gao 2019; Li *et al.* 2023). Because neck cutoffs are viewed as a process ending the cycle of meandering bend evolution, the mechanisms driving the occurrence of neck cutoffs are intrinsically rooted in the evolutionary processes of meandering rivers, the latter being fundamentally controlled by local channel curvature and bank erodibility (Ikeda *et al.* 1981; Parker *et al.* 1982; Camporeale *et al.* 2007). The interaction between these processes and the control factors can be characterized by bend theory (Parker *et al.* 1983; Parker and Andrews 1986; Tubino *et al.* 1999), which states that bend migration (or instability) is driven by the

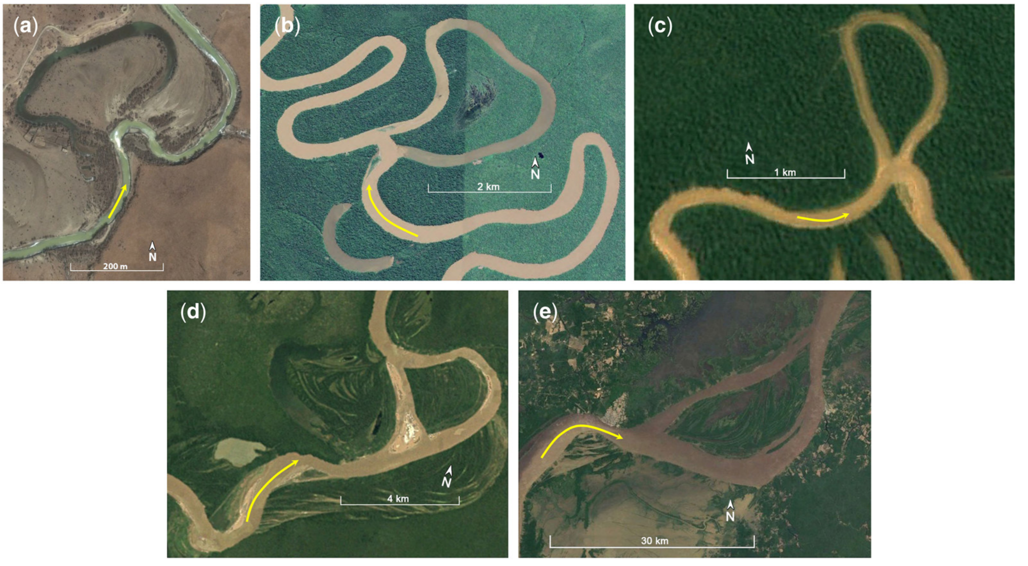

Fig. 2. Examples of the two types of cutoffs. (**a**) The Black River in the Upper Yellow River, China (33.155069°, 103.069794°). The image was taken on 12 April 2014. (**b**) The Napo River, Napo, Peru (−2.311260°, −74.151275°). This image was taken on 8 February 2020. (**c**) The Itui River, Atalaia Do Norte, Brazil (−4.901217°, −70.424809°). The image was taken on 26 September 2000. (**d**) The Ucayali River, Capelo, Peru (−5.325583°, −74.071979°). The image was taken on 30 December 1985. (**e**) The Amazon River, Itacoatiara, Brazil (−3.154756°, −58.265286°). The image was taken on 30 December 2015.

interaction among local flow hydraulics, bend curvature and bed topography (i.e. formation and development of fluvial or forced bars; Blondeaux and Seminara 1985; Seminara *et al.* 2001; Edwards and Smith 2002; Frascati and Lanzoni 2009). Based on this theory, two general mathematical frameworks have been established to characterize meander evolution: kinematic and hydrodynamic models. The

Fig. 3. Two examples showing the co-existence of neck and chute cutoffs within the same section of two meandering rivers with different sizes and physiographic settings. (**a**) The Ucayali River (−5.211344°, −74.302247°). The image was taken on 19 August 2012. The channel width in this segment is between 450 and 790 m. A neck cutoff occurred in the upstream segment, followed by a few chute cutoffs. (**b**) The Black River, a tributary of the Upper Yellow River, China (33.572522°, 102.941661°). The image was taken on 21 August 2021. The channel width in this segment is between 40 and 50 m. A chute cutoff happened in the upstream segment, while a neck cutoff occurred in the nearby downstream part.

first framework specifies that the migration rate of a point along a meander bend is a function of the weighted curvatures of this point and other upstream points along a bend (Howard and Knutson 1984; Güneralp and Rhoads 2009):

$$R(s) = h(s)C(s). \tag{1}$$

Here, $R(s)$ is the dimensionless migration rate, expressed as the ratio of the true migration rate (r) to the mean channel width (w), $C(s)$ is the dimensionless curvature of the point, defined as c/w with c representing the radius of curvature at the point, $h(s)$ is the weighted or transfer function (Güneralp and Rhoads 2009) and s is the along-channel (i.e. the Lagrangian) distance upstream from the point. In some models, the effect of bank erosion on migration is represented by a simple constant (Ferguson 1981; Gilvear *et al.* 2000; Hooke 2003). In others, it is incorporated into $h(s)$ that has complex, non-linear functions as one of many parameters (Güneralp and Rhoads 2009; Sylvester *et al.* 2019).

The second framework states that bend migration rate (R) is determined by the product of bank erodibility coefficient (E) and the excess flow velocity near the outer bank (ΔU) (Howard 1992):

$$R = E\Delta U. \tag{2}$$

The value of E is commonly determined using field-measured data (Micheli and Kirchner 2002; Wallick *et al.* 2006; Constantine *et al.* 2009), while ΔU is determined using depth-averaged shallow-water equations that account for curvature-driven and topography-driven effects on flow and sediment transport (Camporeale *et al.* 2008; Asahi *et al.* 2013; Bogoni *et al.* 2017).

A common feature in these two types of models lies in the fact that the planform of a meander bend or reach is represented by the centreline of the associated meandering river (Howard 1996; Stolum 1998; Schwenk and Foufoula-Georgiou 2016). By definition, a neck cutoff occurs when two points on the upstream and downstream limbs of a bend contact each other. However, at this moment, the equivalent two points along the centreline do not physically touch. Therefore, the occurrence of a neck cutoff means in theory that the distance between these two points reaches a minimum value. Although Bridge (1975) suggested that in natural rivers, this distance is variable and should be characterized using a stochastic function in models, Howard and Knutson (1984) first proposed to quantify this minimum distance deterministically using a predetermined critical value (PCV) that is about one (mean) channel width (w). Following this idea, different PCVs ranging from 1.0 to 2.0w were adopted in subsequent modelling analyses (Howard 1992, 1996; Sun *et al.* 1996; Stolum 1998; Camporeale *et al.* 2005). In other words, a morphological threshold is reached for the occurrence of a neck cutoff when the narrowest neck width (b) is between 0 and 1.0w. Still, in some modelling studies, the PCV was treated as an adjustable parameter that was determined at the discretion of the modellers (Camporeale *et al.* 2005; Sylvester and Covault 2016; Li and Garcia 2021). After the initiation of a neck cutoff, the abandoned channel bend is removed and the remaining segment is smoothed for subsequent simulation (Frascati and Lanzoni 2009; Bogoni *et al.* 2017; see Fig. 4). Many of these models, simpler or more complex, have successfully reproduced the planform shapes of the simulated river reaches or bends that are statistically (or visually) similar to those of the real meandering rivers (Gilvear *et al.* 2000; Güneralp and Rhoads 2009; Motta *et al.* 2012; Schwendel *et al.* 2015; Schwenk *et al.* 2015; Sylvester *et al.* 2021). The apparent success implies that use of different PCVs for determining the occurrence of neck cutoffs does not affect the overall characteristics of the simulated long-term

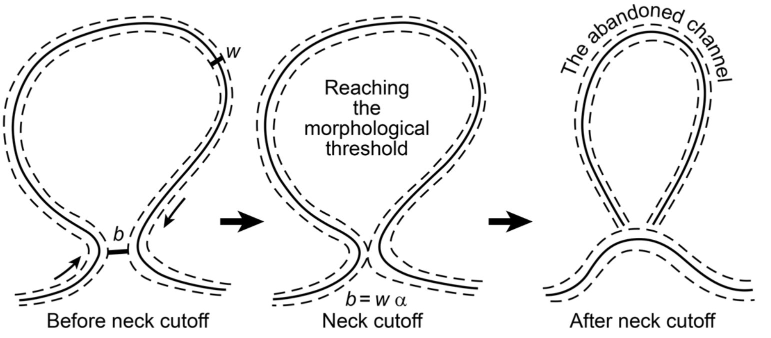

Fig. 4. Illustration of the treatment for a neck cutoff in numerical models. The solid curve is the channel centreline used in models, while the two dashed curves are the actual inner and outer banks of a bend channel, b is the neck width, w is the mean channel width and α is a constant ranging between 0 and 1.

evolutionary outcomes of meandering rivers (Sun *et al.* 1996).

However, these models essentially rely on two implicit assumptions: (1) the channel width remains constant during the entire simulation period (Fig. 4); and (2) bank erosion is caused by fluvial processes and hence occurs continuously (Zhao *et al.* 2021). Studies have shown that though the meander channel width actually changes from time to time, these changes oscillate around a mean over time (Dubon and Lanzoni 2019; Mason and Mohrig 2019), an observation that apparently supports the first assumption. Nonetheless, meander migration may be independently controlled by either outer bank erosion (Hooke 2007; Gautier *et al.* 2010; van de Lageweg *et al.* 2014) or inner bank deposition (Constantine *et al.* 2014; Schuurman *et al.* 2016), which are commonly known as the bank pull and bar push mechanisms (Dietrich and Smith 1983; Mason and Mohrig 2018). Therefore, attempts to include these two processes separately and explicitly have been made in a few hydrodynamic models to allow the channel width to vary (Zolezzi *et al.* 2012; Eke *et al.* 2014; Dubon and Lanzoni 2019). The second assumption ignores the episodic process of bank collapse and the subsequent sheltering effect of the slumped bank bodies on bank erosion (Parker *et al.* 2011; Engel and Rhoads 2012; Dubon and Lanzoni 2019; Gao *et al.* 2021), which may have a significant effect on the migration rate. Models addressing these effects have also been developed (Asahi *et al.* 2013; Zhao *et al.* 2021).

Challenges in understanding processes controlling neck cutoffs

In natural environments within different climate zones of the world, many highly sinuous meander bends do not exhibit a tendency to form neck cutoffs, even if neck widths are close to or within the morphological threshold (i.e. $b = w$). These bend necks may remain close to (or below) the morphological threshold for many years before a neck cutoff is formed. For instance, the Sampaya 2 bend in the Ucayali River, reported in Schwenk and Foufoula-Georgiou (2016) remained stable for about two years after $b = w$ (Fig. 5). In contrast, a highly sinuous bend near the outlet of the Black River in the Zoige basin within the Upper Yellow River, located in the northeastern Qinghai–Tibet Plateau has displayed a neck width $b \leq 0.5w$ since the 1970s, with the current neck width being equal to about $0.1w$ (Fig. 6). Along the middle and lower reaches of the Black River, a dozen highly sinuous bends with $b/w < 1$ appear to be stable. Li *et al.* (2023) predicted that it may take from 52 to 161 years for these bends to initiate a neck cutoff. The implication is that the use of the morphological threshold may significantly underestimate the duration of the actual evolutionary cycle of a meander bend, which could change the subsequent evolutionary course of the associated meandering reach. Although theoretical analyses based on a kinematic model (Seminara *et al.* 2001) revealed that the growth rate of a meander bend decreases sharply in the late stage of meander development, this finding relied on the simplified meandering channel using its centreline and thus fell short of explaining what may happen after the morphological threshold is reached, but the neck cutoff is not initiated yet.

The fact that bends within the same meander reach have different evolutionary periods after reaching the morphological threshold suggests that hydrodynamic controls of channel lateral migration along each bend might be different. In a laboratory study using a flume bend channel to mimic the channel bed and planform morphology of a natural sharp bend, Blanckaert (2011) demonstrated that the flow structure within this bend can be decomposed into three different hydrodynamic patterns: the saturation of the secondary flow, the emergence of outer-bank cells and the inner-bank flow separation. The first two processes reduce the local stream power and hence inhibit bend migration, whereas the last process promotes migration. It follows that in a natural meander bend, both bank erosion and neck reduction rates are controlled by the combined effect of the three hydrodynamic patterns, which depend largely on local bed topography and bend planform morphology (e.g. curvature), as well as magnitudes of in-channel flows. This complexity is consistent with field measurements carried out in highly sinuous natural bends, which indicated that the flow structure is highly variable both in time (Fares 2000) and space (Konsoer and Richards 2016).

Morphologically, highly convoluted bends often develop multiple sub-bends within the original bend, creating ‘compound’ loops (Brice 1984; Ebisemiju 1994; Guo *et al.* 2021). Therefore, flow structures in these bends may be too intricate (Ferguson *et al.* 2003) to be appropriately captured using existing hydrodynamic models. The main challenge is that it is hard to simplify these strongly localized three-dimensional flow structures using depth-averaged models (Bogoni *et al.* 2017). This hydrodynamic challenge inherently leads to uncertainties in characterizing spatial structure between bend curvatures and the associated migration rates. Many theoretical analyses have shown that high-order transfer (or weighted) functions are capable of reproducing planform geometries of highly sinuous (or compound) bends (Zolezzi and Seminara 2001; Camporeale and Ridolfi 2006). However, it seems that the spatial structure of compound bends, such as phase lag, can be captured through the lens of long-term

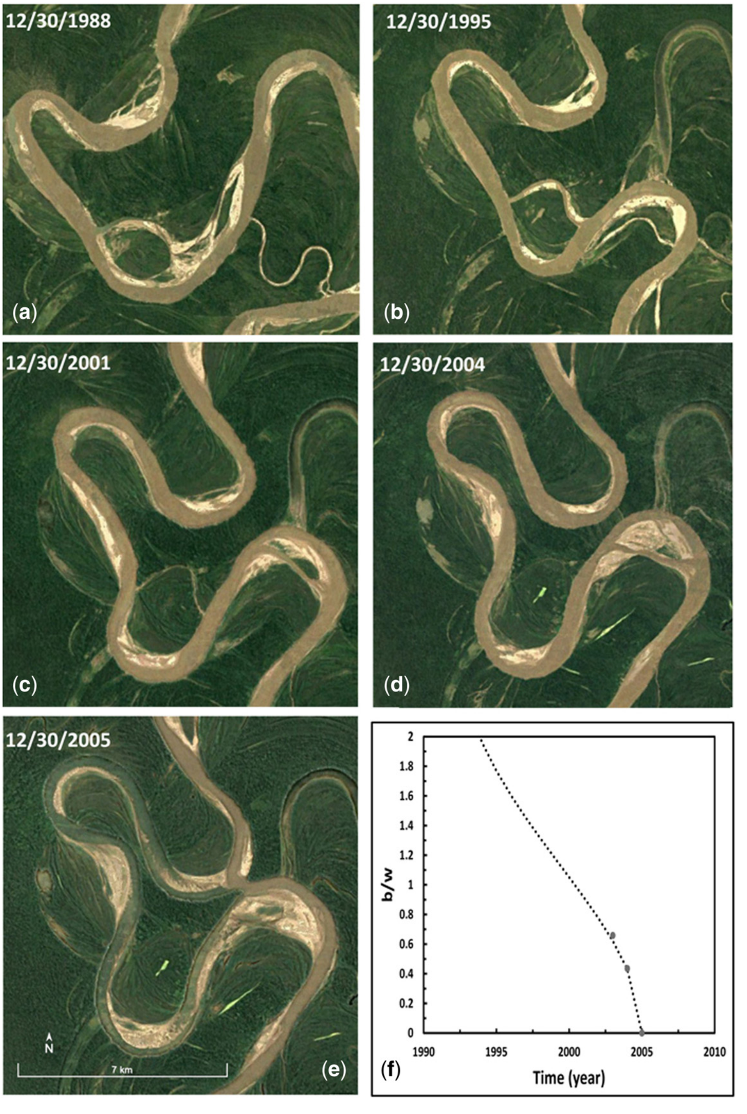

Fig. 5. Time lapses of the Sampaya 2 bend in the Ucayali River (−9.546944°, −74.185278°) reported in Schwenk and Foufoula-Georgiou (2016). This highly convoluted bend reached the morphological threshold (i.e. $b = w$) at the time between 2000 and 2001. (**a**)–(**e**) are the same bend at five different times. The fitted curve in (**f**) is an empirical equation developed in Li *et al.* (2019) for predicting the neck width of a meander bend after its neck reaches the morphological threshold. In this case, the curve was generated based on the three points representing the neck widths that were less than the mean channel width.

evolution of meandering reaches using different transfer functions, such as a high-order weighted function (Li and Garcia 2021) or an exponential function (Sylvester *et al.* 2019). The conundrum is how to parameterize these functions, such that the models can reproduce the trajectories of highly sinuous bends after reaching the morphological threshold for neck cutoff. Achieving this is important because successfully capturing the late-stage bend evolutionary trajectories means that the models will be able to accurately predict the time when a neck cutoff could occur.

Future research directions for meander neck cutoffs

Based on current knowledge of meandering rivers, we propose three directions for future research.

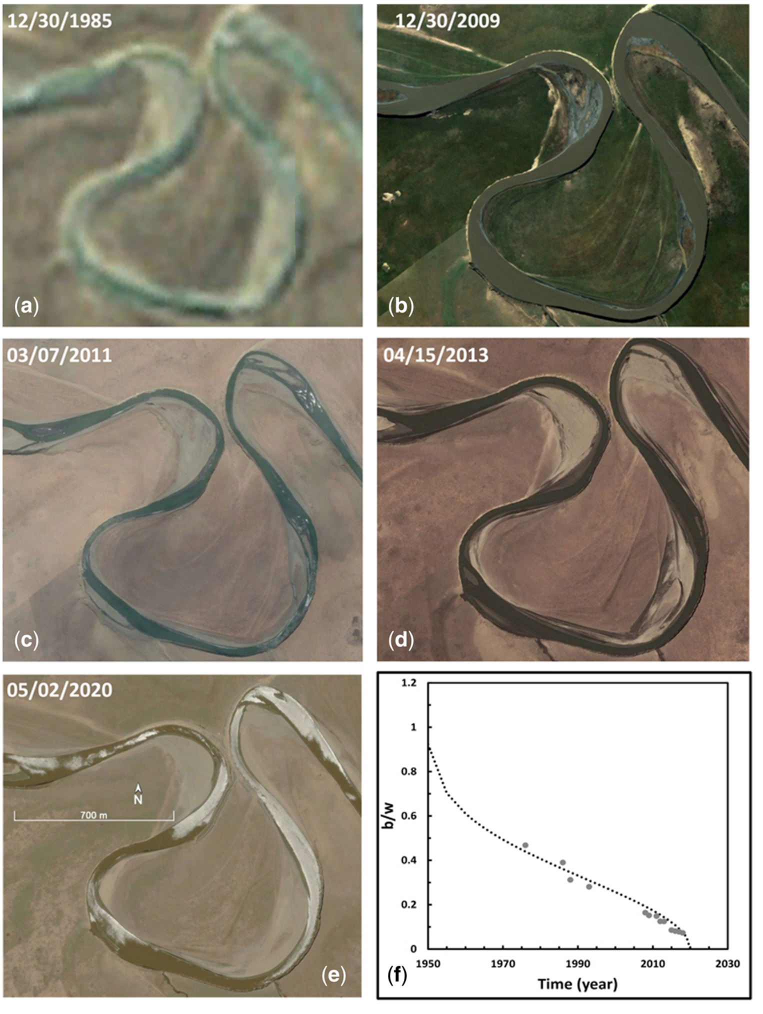

Fig. 6. Time lapses of a meander bend near the outlet of the Black River in the Zoige basin, located in the northeastern Qinghai–Tibet Plateau (33.968889°, 102.212778°). (**a**)–(**e**) are the same bend at five different times. The fitted curve in (**f**) is also the empirical equation developed in Li *et al.* (2019). In this case, even the earliest available image in 1985 has the neck width less than the mean channel width.

The first is the development of new models for predicting the time when a neck cutoff is initiated. The majority of the existing (kinematic and hydrodynamic) models are generally used for describing long-term evolutionary patterns of meandering reaches that involve multiple bends with variable patterns of planform morphology. In these models, a neck cutoff is treated as an instantaneous process that adjusts the reach-scale planform morphology (see Fig. 4). The variable late-stage periods cannot be reflected mainly because the detailed changes of bed topography are simplified and bank erodibility is assumed constant (e.g. Stolum 1998; Sun *et al.* 2001; Sylvester *et al.* 2019). Although developing a two-dimensional model that directly simulates the migration of the two bank lines (Asahi *et al.* 2013) might be a solution, such a model requires more detailed boundary conditions and involves more parameters that need to be calibrated using field-obtained data, which are often not available. The alternative could be to develop quasi-one-dimensional models (Dubon and Lanzoni 2019) that combine bathymetry-generating models (Frascati and Lanzoni 2013; Li and Garcia 2021) with centreline-based models to reduce the degree of complexity while simulating temporal changes of the bed topography of highly sinuous bends. To capture the late-stage evolution of a highly sinuous bend toward a neck cutoff, bed topography of the bend, either directly measured in the field or approximated from high-resolution images, should be used to determine the most appropriate transfer functions in the model (e.g. Li and Garcia 2021). Also, bank erodibility should be treated as a variable parameter (Güneralp and Rhoads 2009; Parker *et al.* 2011; Motta *et al.* 2014; Li and Garcia 2021; Zhao *et al.* 2021).

The second direction is to understand the triggering mechanisms of a neck cutoff after the neck of a highly convoluted bend reaches the morphological threshold. Bank erosion is well known as the dominant mechanism that triggers a neck cutoff (Gagliano and Howard 1984; Hooke 1995*b*; Stolum 1998; Fares 2000; Edwards and Smith 2002; Constantine *et al.* 2009). However, as the neck width becomes narrow, the initiation of a neck cutoff could also be accelerated by the percolation effect between the vertical walls of the neck (Stolum and Friend 1997) during low flows. Eekhout *et al.* (2013) revealed the critical role of the seepage flow in promoting bank erosion that leads to a (neck) cutoff in natural meander bends. A similar bank-weakening seepage erosion during a neck cutoff was later observed in a laboratory sand table (Han and Endreny 2014). Recently, a series of laboratory flume experiments replicating highly sinuous meander bends with one of them reaching the morphological threshold (i.e. $b \asymp 0.5w$) reproduced meandering river evolution at the late stages before neck cutoff (i.e. $b/w < 0.1$; Li *et al.* 2019, 2022). Neck cutoffs in these experiments were initiated by seepage flow (Fig. 7a), which 'soaked' the nearest neck, not only weakening the flume channel banks, but also causing a reduction in the neck height (Fig. 7b). Although the role of seepage flows in initiating neck cutoff is indisputable, their morphodynamic development is still not clear. In particular, it remains unclear how long it takes for the surface water gradient between the two neck walls to develop the seepage flow, though this time period may be related to the coupled effect between the magnitude and frequency of discharges, bank strength, bed topography (e.g. slope and roughness) and bend planform morphology. Because it is challenging to directly monitor seepage development in natural meander bends, investigating this mechanism in laboratory flumes is a practical option. Thus far, flume experiments have been performed to successfully maintain a sinuous meandering channel and even achieve chute cutoff by planting vegetation along the banks or using sediment with different mechanical properties (e.g. silica flour; Braudrick *et al.* 2009; Tal and Paola 2010; van Dijk *et al.* 2012). However, it is still impossible to achieve a neck cutoff in flume experiments because the migration rates of the channel banks protected by vegetation are very slow, such that the time required for the occurrence of a neck cutoff is beyond what can be handled in laboratory flumes (Howard 2009). Future efforts may focus on performing flume experiments under variable discharges in artificially vegetated meander bends that have reached the morphological threshold.

The third direction is to develop empirical equations for estimating the lifetime durations of highly sinuous meander bends from the time of reaching the morphological threshold to the occurrence of a neck cutoff. Li *et al.* (2023) demonstrated that linear relationships accurately describe the reduction of neck width in 14 highly sinuous and compound meander bends once the morphological threshold was reached. The key to developing these relationships is the availability of a series of high-resolution remotely sensed images that capture relevant morphodynamic changes in meander bends. The advance of new data acquisition technology, such as unmanned aerial vehicles, has made it easier to

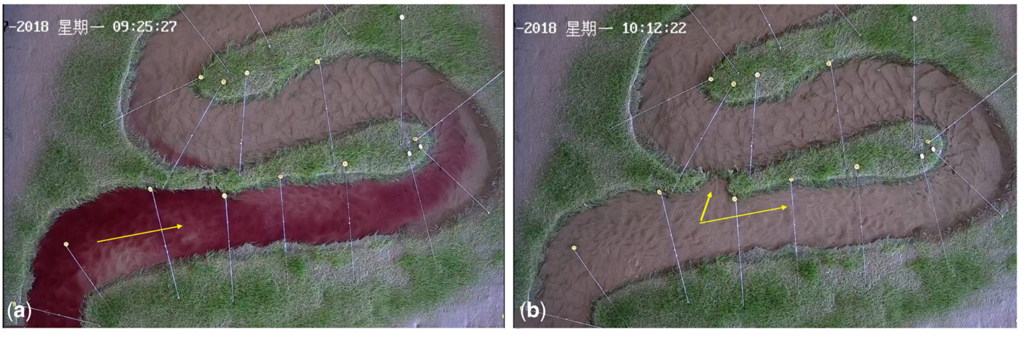

Fig. 7. The effect of the seepage flow on the neck cutoff captured in a flume experiment reported in Li *et al.* (2022). (**a**) The concentrated dye along the downstream outer bank indicates the seepage flow passed through the walls of the narrowest neck. (**b**) The weakened (thinning and lowering) walls of the narrowest neck just before the formation of the neck cutoff.

obtain images with very high spatial resolutions (Westoby *et al.* 2012; Tamminga *et al.* 2015; Duffin *et al.* 2021) and is likely to drive a significant step forward in the near future. With the aid of these images and other high-resolution images, such as Planet and surface water and ocean topography (SWOT), it will be possible to explore the temporal trends of highly sinuous meander bends globally.

Mechanisms of chute cutoffs and challenges

Key factors controlling chute cutoffs

Chute cutoffs have also been widely observed as a consequence of channel avulsion and/or overbank flow (Kellerhals *et al.* 1976; Hooke 1995*a*; Gay *et al.* 1998; Thompson 2003). The avulsion happens in the aggradation-dominated meandering bends in semi-arid fluvial systems (Donselaar *et al.* 2013; Li *et al.* 2020) or temperate river valleys where bed aggradation may cause increased local surface-water elevation due to decreased local bed slope and subsequent sediment deposition (Thompson 2003). In relatively high-energy rivers, the chute cutoff is an important process that could cause the transition from single-thread meandering channels to a weakly braided river (Ferguson 1990; Ashmore 1991; Kleinhans and van den Berg 2011; Grenfell *et al.* 2012). Nonetheless, the formation of an avulsion or high-magnitude floods, close to or exceeding the bankfull threshold, in meandering rivers is merely a necessary condition for the occurrence of a chute cutoff. It also requires appropriate bend planform morphology and physiographic conditions of channel banks and the adjacent floodplains. Therefore, the conditions in favour of chute cutoff can be characterized by six key controlling factors (Constantine *et al.* 2014; Harrison *et al.* 2015; Viero *et al.* 2018):

(1) The flood magnitude and frequency (Ghinassi 2011; El Gammal 2017; Li *et al.* 2017). The magnitude and frequency of overbank flows determine not only whether the in-channel water level is higher than the floodplain elevation or not (van Dijk *et al.* 2014), but also how powerful it is with regard to scouring the floodplain and creating a new channel between the two limbs of a bend (Gilvear *et al.* 2000; Fuller *et al.* 2003).

(2) Sediment supply (Viero *et al.* 2018). A meandering reach with high sediment loads tends to have a high chance of experiencing a cutoff (Zinger *et al.* 2011; Constantine *et al.* 2014). However, this could be tied either to the suspended load due to its function of limiting the gravitational deflection of sediment in the direction of the local bed slope (Nicholas 2013) or to the bed load that may facilitate the growth/aggradation of inner point bars and raise the water level (Zinger *et al.* 2011; Constantine *et al.* 2014). The specific role of sediment transport in a chute cutoff is often affected by spatially and temporally variable erosion and deposition in the neighbouring floodplain, which are difficult to predict (Piegay *et al.* 2008).

(3) Bend planform morphology (Lanzoni *et al.* 2006; Kleinhans *et al.* 2008). A bend with high curvature, amplitude and divergence angle at the entrance of the upstream limb tends to reduce flow efficiency, which may facilitate sediment deposition and overbank flow (Micheli and Larsen 2011; van Dijk *et al.* 2012; Li *et al.* 2020). The location along the bend that lies close to the flow within the high-velocity core is more subject to bank erosion (Harrison *et al.* 2015) and hence tends to initiate a chute cutoff. Nonetheless, bend morphometry alone only provides necessary conditions for triggering a chute cutoff (Viero *et al.* 2018).

(4) The floodplain gradient (Constantine *et al.* 2010; van Dijk *et al.* 2014). A steeper floodplain between the upstream and downstream limbs of a bend would promote floodplain erosion by the overbank flow and facilitate the formation of a chute channel. In particular, many meander bends contain palaeochannels or swales that serve as preferential paths on the floodplain between the two limbs of the bends (Viero *et al.* 2018) or develop gradient advantage on point bars within the bend (Grenfell *et al.* 2012). These topographic structures facilitate a chute cutoff.

(5) The erodibility of floodplain sediment (Braudrick *et al.* 2009; Dunne and Aalto 2013; van Dijk *et al.* 2014). In the sense of flow competency, a floodplain with coarse particle sizes (e.g. coarse sand and/or fine gravels) is harder to be scoured than one with finer grains (e.g. fine sand). However, the control of this factor on a chute cutoff is often associated with the next controlling factor.

(6) The flow resistance provided by vegetation on bars, banks and floodplains (van Dijk *et al.* 2014; Zen *et al.* 2016; Vargas-Luna *et al.* 2019). Vegetation is widely recognized to aid the reduction of bank erosion, especially at high flow stages (Nicholas 2013; Horton *et al.* 2017; Ielpi and Lapotre 2020; Kyuka *et al.* 2021), thereby decreasing the possibility of triggering a chute cutoff. A floodplain with higher vegetation density is more resistant to erosion and thus offers less chance to develop a chute cutoff (Tal and Paola 2010).

Different combinations of these controlling factors lead to different fluvial processes that may induce (or prevent) a chute cutoff. The complexity could sometimes result in apparently contradicting observations. For instance, in lowland meandering reaches within the Amazon basin, high sediment loads in rivers were observed to enhance the formation of point bars, which subsequently facilitated chute cutoffs (Constantine *et al.* 2014), whereas in the Sacramento River (USA) more cutoffs occurred in reaches with lower sediment loads (Constantine *et al.* 2010).

Four mechanisms of chute cutoff

Thus far, four types of mechanisms have been identified to trigger chute cutoff by Grenfell *et al.* (2012). They are described here in the context of different combinations of the six controlling factors.

The first type is the headward-erosion chute cutoff (Gay *et al.* 1998; Zinger *et al.* 2011; Li *et al.* 2020). It features an upstream overbank flow (UOF) and the subsequent downstream bank erosion processes (Fig. 8a–d; Ghinassi 2011). The UOF is usually caused by (1) a natural in-channel blockage (e.g. large woody debris, or ice; Gay *et al.* 1998; Smith and Pearce 2002), or (2) high divergence angles of the upstream bend or bed aggradation (Hooke 1995*a*; Peakall *et al.* 2007; Li *et al.* 2020), which may significantly raise water levels during peak flows, inducing overbank flows. Once overbank flows pass through the floodplain and reach the downstream limb of the bend, they are likely to create a backward-migrating hydraulic jump, which may initiate bank erosion due to flow impingement (Alonso *et al.* 2002; Bennett and Alonso 2006) and create a knickpoint (Fig. 8a). The overbank flows in the following peak flows will reinforce headward erosion (Fig. 8b), which extends the chute head through the floodplain and finally connects to the meander upstream limb, forming a chute channel (Fig. 8c). In this mechanism, the chute channel is formed by moving upslope from a position in the bank of the downstream limb to that in the bank of the upstream limb, which is similar to the process of gully headward erosion (Gao 2013).

The second type is the embayment chute cutoff (Constantine *et al.* 2010; see Fig. 9a–d). The embayment is the location with less bank strength along the outer bank of a bend upstream limb. This location is typically marked by slumps due to local bank erosion (Hackney *et al.* 2015), swale inherited from earlier morphological depression of a river (McGowen and Garner 1970) or gypsum sinkholes (Schwendel and Cooper 2021; Fig. 9a). In this case, peak flows have sufficiently high stream powers to excise the embayment and extend it to the floodplain (Fig. 9b). The subsequent floods will further incise the initial slough, which will finally become

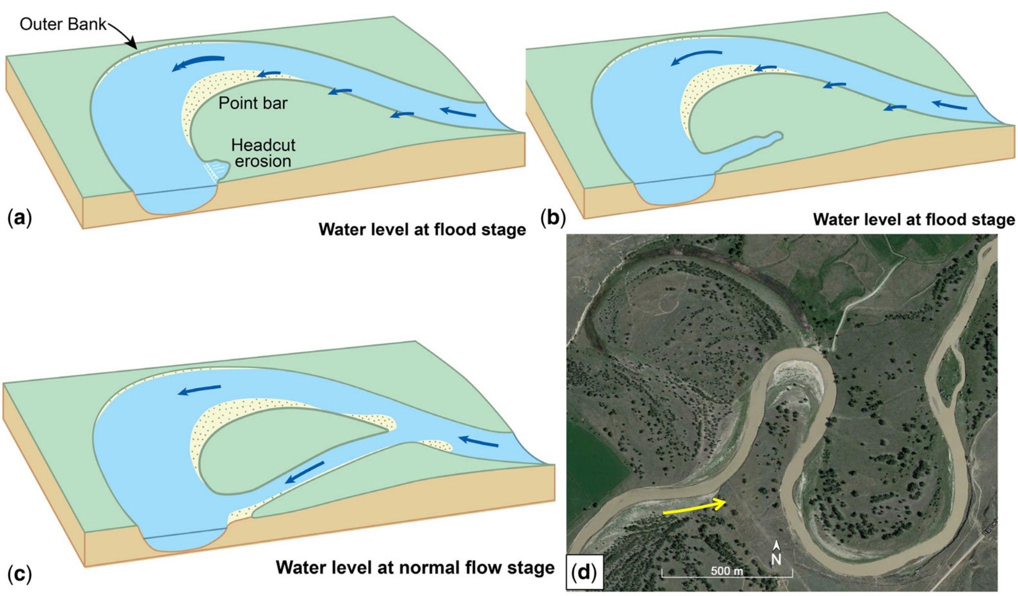

Fig. 8. The headward-erosion mechanism of a chute cutoff and an example. (**a**) Early stage of the meander bend with a headward cut. (**b**) Initiation of a headward channel. (**c**) The formation of a chute channel. (**d**) A chute cutoff caused by this mechanism (45.193285°, −105.752602°). The image was taken on 26 August 1996. This is the chute cutoff reported in Gay *et al.* (1998).

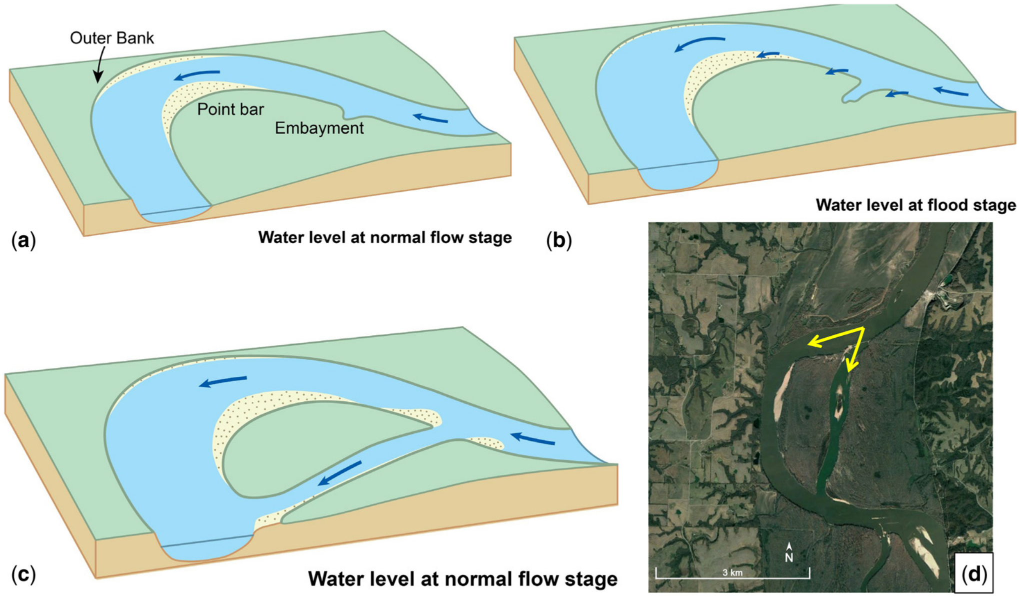

Fig. 9. The embayment mechanism of chute cutoff and an example. (**a**) The early stage of a meander bend with an embayment. (**b**) The progress of the embayment. (**c**) The formation of a chute channel. (**d**) A chute cutoff caused by this mechanism (39.113033°, −92.930319°). The image was taken on 2 March 2020. This is the chute cutoff reported in Constantine *et al.* (2010).

connected to the downstream limb of the bend, forming a chute channel (Fig. 9c). The direction of the chute-channel development in this mechanism is from the upstream to downstream limbs, opposite to that in the first mechanism (see Figs 8b and 9b).

The third type is the mid-channel bar chute cutoff, through which the upstream flow is bifurcated by the developed central bar due to rapid bend expansion and translation in sand-bed meandering rivers (Grenfell *et al.* 2012; van Dijk *et al.* 2012; see Fig. 10a–d). van Dijk *et al.* (2014) further demonstrated that this type of chute cutoff could also happen in gravel-bed meandering rivers. In these active rivers, an increased upstream bend curvature facilitates the growth of point bars along the bend's inner bank (Bridge *et al.* 1986; Harrison *et al.* 2015), which may contain heterogeneous micro-morphological units, such as chute, scroll and tail bars (Kleinhans and van den Berg 2011; see Fig. 10a). Peak flows arriving here may be bifurcated between the main channel and the path along the bar area of lower elevations (i.e. swales or sloughs), dividing more sediment to the outer-bank side and hence leading to the aggradation of the chute bar and narrowing of the channel width (Fig. 10b). The following floods may be diverted further to the chute bar that is closer to the inner bank due to the faster growth of its side near the outer bank. Because the diverted flow has a potentially steeper bed gradient than the outer-bank channel flow (i.e. gradient advantage; van Dijk *et al.* 2014), it has sufficiently high shear stress to cut through the growing point bar, forming a chute channel (Fig. 10c). This mechanism happens in meandering rivers that have relatively low bank height and active bar–channel–floodplain dynamics (van Dijk *et al.* 2014). The overbank (or over-bar) flows are caused by the bifurcation process due to the growth of point bars, whereas in the second mechanism, the overbank flow directly impinges on the 'weak' point (embayment) of the channel bank.

The fourth type is the scroll–slough chute cutoff (Fisk 1947; Grenfell *et al.* 2012; Viero *et al.* 2018; see Fig. 11a–d). It typically happens in widening sand-bed bends with point bars growing laterally due to the formation of transverse sand bars or deposition of suspended sediment (Nanson and Croke 1992; Fig. 11a). The additionally available in-channel space further facilitates selective sediment transport and deposition due to sediment heterogeneity (Nanson and Croke 1992; van de Lageweg *et al.* 2014), forming a series of scrolls and sloughs with the latter serving as the preferential flow paths even at moderate flow stages (Viero *et al.* 2018; Fig. 11b). These preferential paths often become chute channels (Fig. 11c). Development of the chute channel is also driven by the bifurcation processes. However, in this case, erosion of the outer

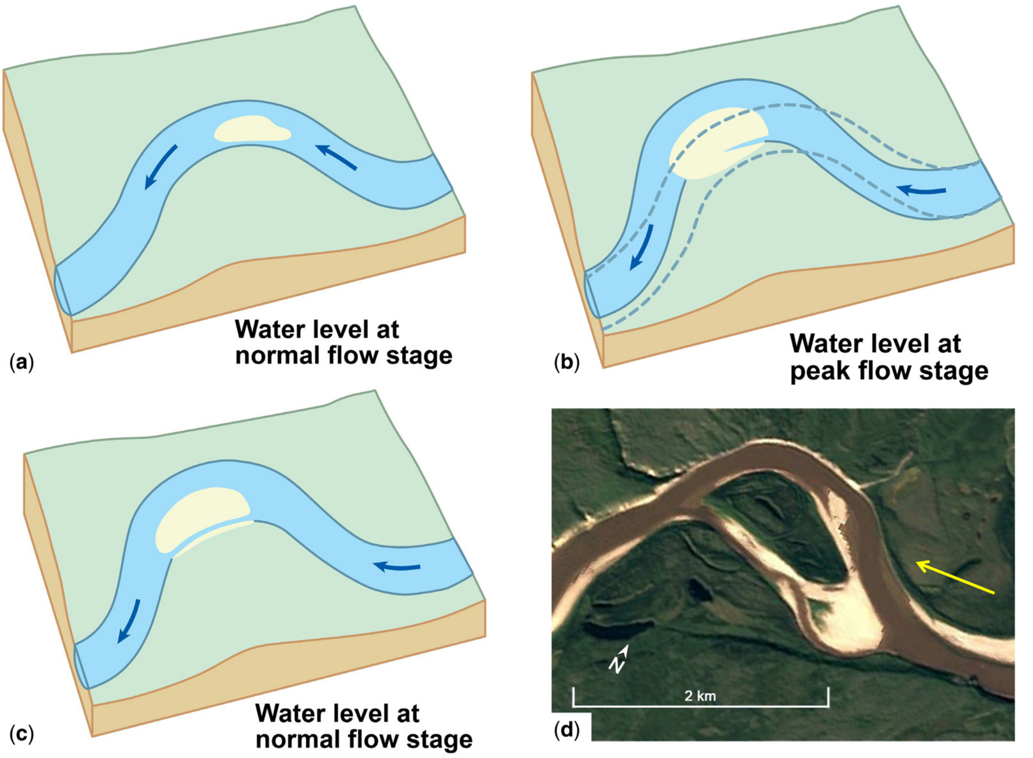

Fig. 10. The mid-channel bar mechanism of chute cutoff and an example. (**a**) A meander bend with a mid-channel bar. (**b**) Initiation of a chute channel. The dashed lines represent the earlier position of the same channel. (**c**) Further development of the chute channel. (**d**) An example of a chute cutoff in the Purcu Pine River, Peru caused by this mechanism (67.059356°, −142.553449°). The image was taken on 27 August 2010.

bank (i.e. the bank pull mechanism) is more active than bar development (i.e. the bank push mechanism; Mason and Mohrig 2018), which widens the channel, because these meandering channels tend to develop in fluvial valleys with higher slopes and stream powers (see figures 10 and 12 in Kleinhans and van den Berg 2011).

An essential nature of these mechanisms is that they are not mutually exclusive. Indeed, many chute cutoffs were initiated by a combination of several of the above-described mechanisms (Kleinhans and van den Berg 2011; Viero *et al.* 2018), among which the headward-erosion and embayment chute cutoffs are hydraulically dominated. This means that the occurrence of a chute cutoff is mainly controlled by in-channel fluvial processes that enhance topographic elevations of the point bars and increase local shear stress along the outer bank. In contrast, the mid-channel bar and scroll–slough chute cutoffs are topographically dominated (Viero *et al.* 2018). In these cases, the location of a chute cutoff in a meander bend is primarily determined by the location of the overbank flow caused by the raised water level in the upstream limb of a bend (e.g. gradient advantage), and the preferential paths (i.e. swales or sloughs) found on expanded point bars or floodplains.

Challenges in understanding chute cutoffs

The distinction between hydrodynamically and topographically dominated mechanisms (Viero *et al.* 2018) reflects two different dominant effects of the interaction among the above-mentioned six controlling factors. It follows that the migration of meander bends is strongly affected by local morphological characteristics of both the river and the floodplain, and chute cutoff formation is highly site specific. For this reason, the dominance of any of the four specific mechanisms or their combinations is largely contingent on the physiographic and morphological conditions of individual meandering rivers. The site-specific nature of chute cutoff formation poses a challenge for quantitatively generalizing the genesis of chute cutoffs that could allow for predicting their initiation. One example of this challenge is

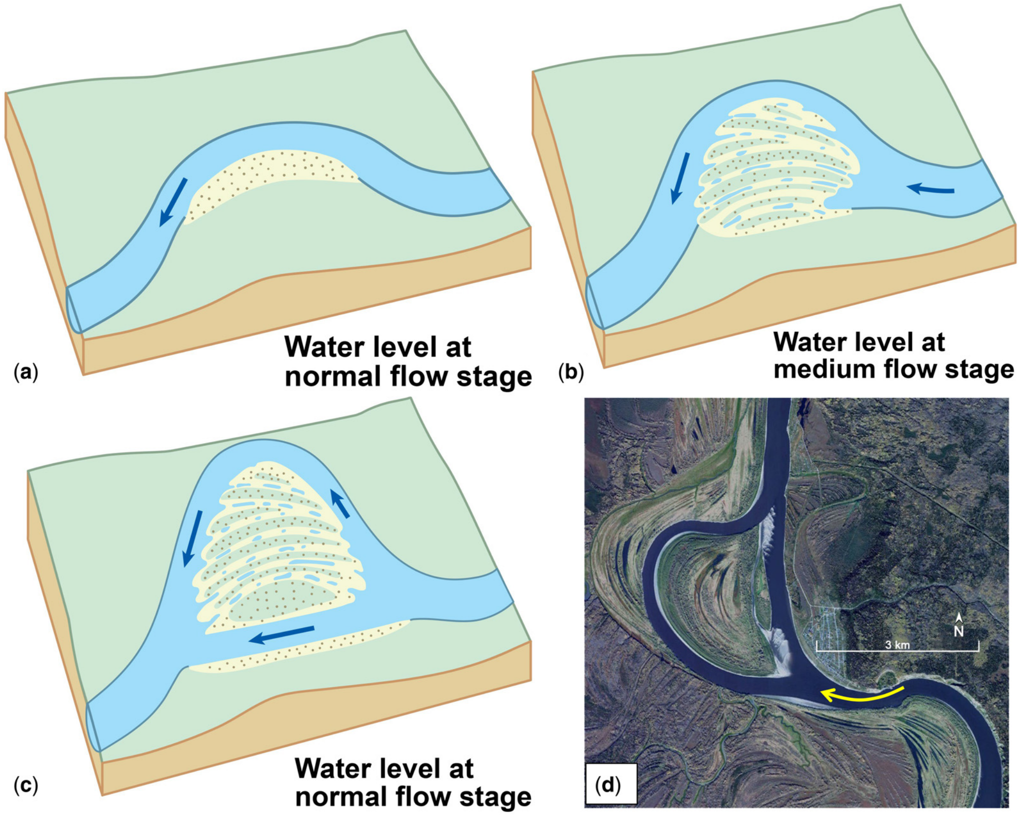

Fig. 11. The scroll–slough mechanism of a chute cutoff and an example. (**a**) The early stage of a meander bend. (**b**) The initiation of a chute channel. (**c**) Development of the chute channel. (**d**) An example of a chute cutoff in the Irtysh River caused by this mechanism (58.634072°, 68.537628°). The image was taken on 7 May 2022.

the difficulty of distinguishing chute bars from scroll–slough sequences. Even though bends with scroll bars tend to have higher curvature than those with chute bars (see figures 5a and b in Kleinhans and van den Berg 2011), both types of bends experience active lateral migration, and more importantly their chute cutoffs are essentially driven by the bifurcation process, which critically relies on the gradient advantage across the bars. This might be the reason why Viero *et al.* (2018) lumped the third (mid-channel bar) and fourth (scroll–slough) mechanisms into a single mechanism. Another example is the ambiguity of hydrological conditions necessary for triggering chute cutoff. For bends with cutoffs caused by headward-erosion and embayment mechanisms, it is easier to understand that cutoffs need bankfull or near bankfull discharges to assure high local shear stress for creating an embayment or overbank flows for initiating headward erosion. However, for bends with bifurcation-based chute cutoffs (i.e. the third and fourth mechanisms), the discharges required for initiating a chute channel may just be 'large enough', rather than bankfull discharges (also see p. 221 in Viero *et al.* 2018). Apparently, the magnitudes of these 'large enough' discharges vary among meander bends and are thus hard to generalize.

Another challenge is modelling the processes driving chute cutoffs. Thus far, efforts have been made to simulate chute cutoffs using bar theory that explains the development of meander bends from emerging alternate bars due to the intrinsic instability of straight, mobile channels (Struiksma *et al.* 1985; Seminara and Tubino 1989). Alternatively, van Dijk *et al.* (2014) reproduced chute cutoffs using a one-dimensional nodal-point model and a hydrodynamic (i.e. Delft3D) model applied to a flume resembling a meandering reach of the River Allier, France. By using the appropriate channel dimensions and boundary conditions that can sustain a single-thread channel (Kleinhans and van den Berg 2011), Schuurman *et al.* (2016) simulated the processes controlling bank erosion and bar–floodplain conversion (i.e. bar aggradation) and showed that the interaction of these processes can lead to chute cutoffs. Based on the detailed field-based data in a small lowland stream in the Netherlands, Eekhout and Hoitink (2015) successfully simulated, using Delft3D, a chute cutoff caused by the backwater effect. These modelling analyses have focused on the bifurcation process induced by expanded point bars in a meandering channel, and hence highlighted the topographical control for chute cutoffs caused by the mid-channel bar and scroll–slough mechanisms. However, morphological structures of meander bends and their neighbouring (less) vegetated and lower floodplains that favour the bifurcation process are so diverse (Fig. 12a–d) that the interaction between bank-erosion and bar-aggradation processes, and the magnitude and frequency of the required discharges are site-specific. Accurate prediction of their chute cutoffs relies on detailed morphological data that are often not available. Furthermore, there seem to be no models specifically developed for capturing chute cutoffs triggered by the headward erosion and embayment mechanisms. This might be because the initiation of chute channels is a stochastic process (Howard 1996; Camporeale *et al.* 2005, 2008), so that calibrating hydrodynamic models that can capture chute cutoffs requires detailed data from individual meandering rivers, which are often difficult to obtain in practice. For example, though evidence (Harrison *et al.* 2015) showed that chute cutoffs may form in

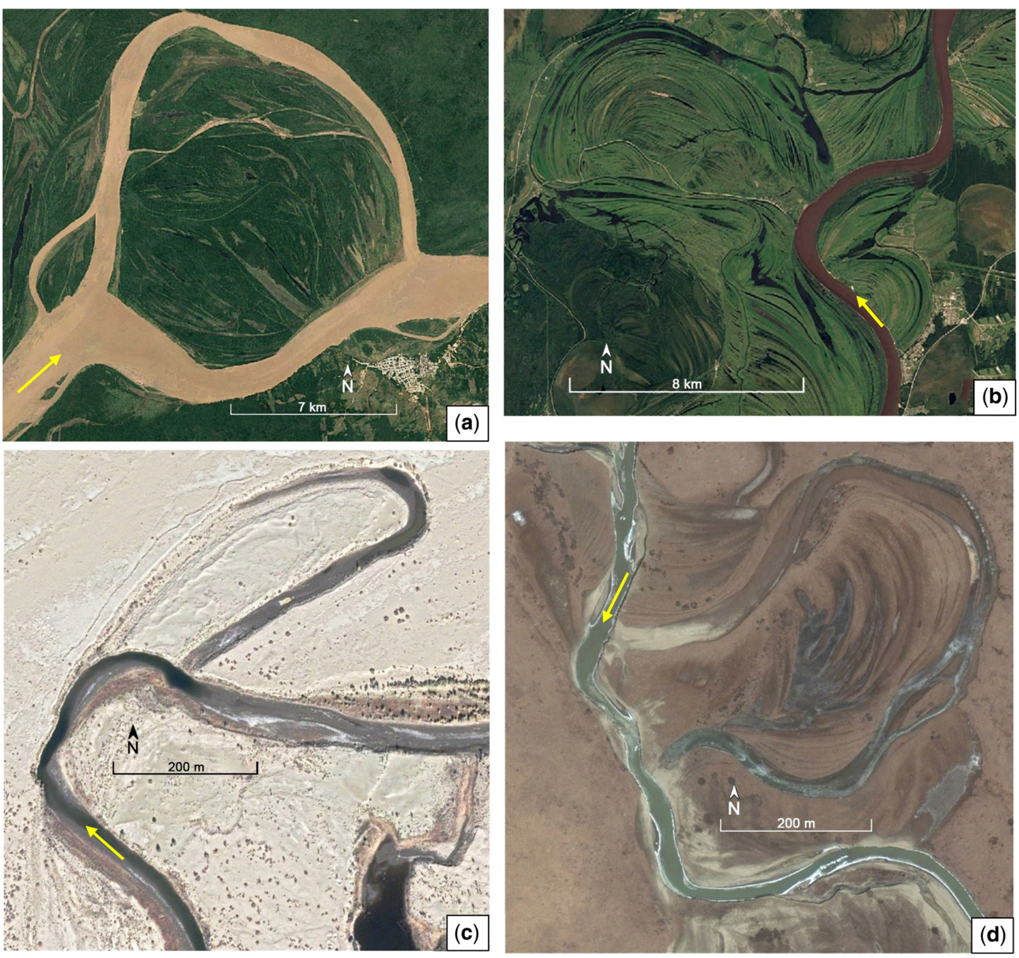

Fig. 12. Meander bends with chute cutoffs by either the mid-channel bar or scroll–slough mechanisms in different river systems of the world. (**a**) Amazon River (−2.513278°, −66.146222°). The image was taken in September 2018. (**b**) The Irtysh River (58.456925°, 68.286209°). The image was taken in December 2018. (**c**) The Tarim River (40.954539°, 87.358348°). The image was taken on 19 October 2019. (**d**) The Black River (33.643548°, 103.010519°). The image was taken on 4 December 2014.

the immediate downstream of bend apexes where the local shear stress is highest, many chute cutoffs were initiated in locations other than the bend apexes (Peakall *et al.* 2007). In addition, there is still limited knowledge of how sediment supply may affect meander migration and hence chute cutoffs (Constantine *et al.* 2014; Ahmed *et al.* 2019).

Future research directions for chute cutoffs

The current knowledge of the processes leading to chute cutoffs is still insufficient to assure the predictability of their formation due to the interplays between the six controlling factors highlighted above. Future research should focus on generalizing the existing findings about hydrodynamic and morphodynamic processes of chute cutoffs. It might be suitable to subdivide meander bends into two groups based on the distinction between hydraulically and topographically dominated triggering mechanisms (Viero *et al.* 2018). Along this line of reasoning, three potential research directions are plausible.

First, a systematic database could be developed that includes a collection of meander bends from global meandering rivers falling into each of the two groups. We hypothesize that bend sinuosity, defined as the ratio of the bend channel length divided by the narrowest length of the bend neck, is lower for hydraulically dominated chute cutoffs compared to those that are hydraulically dominated. Additionally, bends in the hydraulically dominated group should be accompanied by well-vegetated floodplains whose elevations are much higher than those of the channel beds. Establishing this database would greatly help generalize the morphological conditions for modelling the four mechanisms of chute cutoff.

Second, a topographically independent hydrological metric could be developed that quantifies the relative magnitudes of cutoff-triggering discharges across diverse physiographic conditions. As described earlier, chute cutoffs may be initiated by either bankfull or intermediate flows, which might have different magnitudes and frequencies across distinct climatic zones. Finding a way of standardizing these flows in terms of morphological indices of these bends would allow for comparing these cutoff-triggering discharges in different meander bends, which may be subsequently used to identify the general hydrological thresholds for chute cutoffs.

Third, it would be useful to understand the combined effects of the six chute-cutoff controlling factors, which have not yet been uncovered. For example, the impact of consecutive flood events on the development of chute channels has been recognized (Viero *et al.* 2018) but has not yet been quantified. There is also still uncertainty about how different rates of sediment supply, and how the associated in-channel sediment transport would affect, (a) point bar development that promotes overbank flow (by narrowing the channel) for the chute cutoff caused by the headward-erosion mechanism and (b) mid-channel bar growth that may initiate bifurcation chute cutoff. It appears that tracing the historical changes of sedimentation obtained from sediment cores and/or time-lapse images (if available) is a promising approach that may reveal useful details of the complex sedimentation processes at play (Kleinhans *et al.* 2011; van de Lageweg *et al.* 2014; Schwendel *et al.* 2018; Richards *et al.* 2022). Additionally, the impact of vegetation on the bar–floodplain conversion needs to be further investigated. The growth of point bars along the inner bank of a meander bend is facilitated by vegetation encroachment. However, it tends to take longer for vegetation to germinate and grow than the frequency of dominant discharges in many climate zones. Indeed, the scroll–slough development should normally take more time than expansion of the mid-channel bar. Although Asahi *et al.* (2013) have proposed a method of parameterizing these two different timescales using two different time-related mathematical relationships, there are no general rules to guide the model parameterization.

Neck and chute cutoffs happen over timeframes shorter than the long evolutionary history of meandering rivers. As such, understanding morphodynamic and hydrodynamic processes that drive cutoffs requires data at a higher level of detail than those needed for reproducing evolutionary trajectories of meandering rivers (e.g. Howard 1996; Stolum 1998; Schwenk *et al.* 2015; Sylvester *et al.* 2021). These data typically include temporally variable morphological structures and bed bathymetry of meander bends, event-based discharges and sediment calibers. Despite recent progress in determining changes in the in-channel morphological units over time (Viero *et al.* 2018; Li and Garcia 2021), more field-based data are needed for establishing generalized morphological rules. The progress in photogrammetric techniques, including Single Image Super Resolution (SISR), presents a potential avenue for enhancing the spatial resolution of historical Landsat images (Li *et al.* 2023). This advancement holds promise for acquiring time-series data on meander bend planform morphology and, coupled with the increased availability of high-resolution images, could contribute to future research endeavours in predicting bend cutoffs.

Conclusions

Meander cutoffs profoundly influence the evolution of meandering rivers and their connection to adjacent floodplains. The cutoff process encompasses two distinct modes known as neck and chute cutoffs, each exhibiting distinct morphological characteristics and being governed by different hydrodynamic processes.

Neck cutoffs are primarily influenced by the rate of bank erosion, which is driven by hydrodynamic processes associated with not only hydrological conditions but also transverse channel bed topography and planform structures. Current kinematic and hydrodynamic models for simulating meander evolution incorporate mechanisms for neck cutoffs; however, these models often oversimplify the process by adopting a straightforward morphological threshold ($b = \alpha w$), where α is a constant between 0 and 1, b represents the neck width and w denotes the mean channel width. Evidence from natural meandering rivers indicates that many highly sinuous bends can persist for long time periods after reaching this threshold. To gain a deeper understanding of the fluvial processes during these periods, new research avenues should encompass numerical modelling, flume experiments and high-resolution image analysis.

Chute cutoffs are influenced by six controlling factors related to hydrological conditions, bend planform morphology, bed topography, bend floodplain gradients, sediment calibers and transport regime, and the presence of vegetation on bars and floodplains. The locations prone to overbank flows are determined by the morphological characteristics of the banks and the development of bed topography. Four distinct mechanisms that can trigger chute cutoff have been identified. While headward-erosion and embayment mechanisms can partially explain the processes leading to chute cutoff, there is a need for new models to predict potential initiation locations. Chute cutoffs can also occur based on bifurcation mechanisms, either due to the development of mid-channel bars or due to the scroll–slough sequence. The fundamental processes underlying these types of chute cutoffs have been unveiled through flume experiments and numerical models. However, quantifying the spatial variations of these processes in both physical experiments and numerical morphodynamic models remains a challenging task. For this reason, we propose that new research should aim at understanding critical differences between chute cutoffs that are induced by hydraulically dominated mechanisms and those induced by topographically dominated mechanisms.

Acknowledgements This study was supported by the National Natural Science Foundation of China (51979012, U2243214), Fundamental Research Funds for the Central Universities (2042021kf0199), and High-end Foreign Experts Introduction Program of Ministry of Science and Technology (G2022153008L). We thank Zoltan Sylvester, the volume editor, and four anonymous reviewers for providing constructive comments, suggestions and detailed editing, which greatly improved the quality of the paper.

Competing interests The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author contributions **PG**: conceptualization (lead), investigation (lead), methodology (lead), validation (lead), visualization (lead), writing – original draft (lead), writing – review & editing (lead); **ZL**: funding acquisition (lead), investigation (supporting), writing – review & editing (supporting).

Funding This study was supported by the National Natural Science Foundation of China provided Zhiwei Li with award 51979012, U2243214.

Data availability Data sharing is not applicable to this article as no datasets were generated or analysed during the current study.

References

Aalto, R., Lauer, J.W. and Dietrich, W.E. 2008. Spatial and temporal dynamics of sediment accumulation and exchange along Strickland River floodplains (Papua New Guinea) over decadal-to-centennial timescales. *Journal of Geophysical Research: Earth Surface*, **113**, https://doi.org/10.1029/2006JF000627

Ahmed, J., Constantine, J.A. and Dunne, T. 2019. The role of sediment supply in the adjustment of channel sinuosity across the Amazon Basin. *Geology*, **47**, 807–810, https://doi.org/10.1130/G46319.1

Alonso, C.V., Bennett, S.J. and Stein, O.R. 2002. Predicting head cut erosion and migration in concentrated flows typical of upland areas. *Water Resource Research*, **38**, 1303–1317, https://doi.org/10.1029/2001WR001173

Amoros, C. 2001. The concept of habitat diversity between and within ecosystems applied to river side-arm restoration. *Environmental Management*, **28**, 805–817, https://doi.org/10.1007/s002670010263

Amoros, C. and Bornette, G. 2002. Connectivity and biocomplexity in waterbodies of riverine floodplains. *Freshwater Biology*, **47**, 761–776, https://doi.org/10.1046/j.1365-2427.2002.00905.x

Asahi, K., Shimizu, Y., Nelson, J. and Parker, G. 2013. Numerical simulation of river meandering with self-evolving banks. *Journal of Geophysical Research: Earth Surface*, **118**, 2208–2229, https://doi.org/10.1002/jgrf.20150

Ashmore, P. 1991. How do gravel-bed rivers braid. *Canadian Journal of Earth Sciences*, **28**, 326–341, https://doi.org/10.1139/e91-030

Bennett, S.J. and Alonso, C.V. 2006. Turbulent flow and bed pressure within headcut scour holes due to plane reattached jets. *Journal of Hydraulic Research*, **44**,

510–521, https://doi.org/10.1080/00221686.2006.9521702
Blanckaert, K. 2011. Hydrodynamic processes in sharp meander bends and their morphological implications. *Journal of Geophysical Research: Earth Surface*, **116**, https://doi.org/10.1029/2010JF001806
Blondeaux, P. and Seminara, G. 1985. A unified bar-bend theory of river meanders. *Journal of Fluid Mechanics*, **157**, 449–470, https://doi.org/10.1017/S0022112085002440
Bogoni, M., Putti, M. and Lanzoni, S. 2017. Modeling meander morphodynamics over self-formed heterogeneous floodplains. *Water Resource Research*, **53**, 5137–5157, https://doi.org/10.1002/2017WR020726
Braudrick, C.A., Dietrich, W.E., Leverich, G.T. and Sklar, L.S. 2009. Experimental evidence for the conditions necessary to sustain meandering in coarse-bedded rivers. *Proceedings of the National Academy of Sciences of the United States of America*, **106**, 16936–16941, https://doi.org/10.1073/pnas.0909417106
Brice, J.C. 1984. Planform properties of meandering rivers. *In*: Elliot, C.M. (ed.) *River Meandering*. American Society of Civil Engineers, New York, 1–15.
Bridge, J.S. 1975. Computer-simulation of sedimentation in meandering streams, *Sedimentology*, **22**, 3–43, https://doi.org/10.1111/j.1365-3091.1975.tb00282.x
Bridge, J.S., Smith, N.D., Trent, F., Gabel, S.L. and Bernstein, P. 1986. Sedimentology and morphology of a low-sinuosity river-Calamus River, Nebraska Sand Hillls. *Sedimentology*, **33**, 851–870, https://doi.org/10.1111/j.1365-3091.1986.tb00987.x
Brierley, G.J. 1991. Floodplan sedimentology of the Squamish River, British Columbia: relevance of element analysis. *Sedimentology*, **38**, 735–750, https://doi.org/10.1111/j.1365-3091.1991.tb01017.x
Camporeale, C. and Ridolfi, L. 2006. Convective nature of the planimetric instability in meandering river dynamics. *Physical Review E*, **73**, 026311, https://doi.org/10.1103/PhysRevE.73.026311
Camporeale, C., Perona, P., Porporato, A. and Ridolfi, L. 2005. On the long-term behavior of meandering rivers. *Water Resource Research*, **41**, https://doi.org/10.1029/2005WR004109
Camporeale, C., Perona, P., Porporato, A. and Ridolfi, L. 2007. Hierarchy of models for meandering rivers and related morphodynamic processes. *Reviews of Geophysics*, **45**, https://doi.org/10.1029/2005RG000185
Camporeale, C., Perucca, E. and Ridolfi, L. 2008. Significance of cutoff in meandering river dynamics. *Journal of Geophysical Research: Earth Surface*, **113**, https://doi.org/10.1029/2006JF000694
Carson, M.A. and Lapointe, M.F. 1983. The inherent asymmetry of river meander planform. *The Journal of Geology*, **91**, 41–55, https://doi.org/10.1086/628743
Constantine, C.R., Dunne, T. and Hanson, G.J. 2009. Examining the physical meaning of the bank erosion coefficient used in meander migration modeling. *Geomorphology*, **106**, 242–252, https://doi.org/10.1016/j.geomorph.2008.11.002
Constantine, J.A., McLean, S.R. and Dunne, T. 2010. A mechanism of chute cutoff along large meandering rivers with uniform floodplain topography. *Geological Society of America Bulletin*, **122**, 855–869, https://doi.org/10.1130/B26560.1
Constantine, J.A., Dunne, T., Ahmed, J., Legleiter, C. and Lazarus, E.D. 2014. Sediment supply as a driver of river meandering and floodplain evolution in the Amazon Basin. *Nature Geoscience*, **7**, 899–903, https://doi.org/10.1038/ngeo2282
Coomes, O.T., Abizaid, C. and Lapointe, M. 2009. Human modification of a large meandering Amazonian River: genesis, ecological and economic consequences of the Masisea Cutoff on the Central Ucayali, Peru. *Ambio*, **38**, 130–134, https://doi.org/10.1579/0044-7447-38.3.130
Das, J.D., Dutta, D. and Saraf, A.K. 2007. Remote sensing and GIS application in change detection of the Barak River channel, N.E. India. *Journal of the Indian Society of Remote Sensing*, **35**, 301–312, https://doi.org/10.1007/BF02990786
Dietrich, W.E. and Smith, J.D. 1983. Influence of the point bar on flow through curved channels. *Water Resource Research*, **19**, 1173–1192, https://doi.org/10.1029/WR019i005p01173
Donselaar, M.E., Cuevas Gozalo, M.C. and Moyano, S. 2013. Avulsion processes at the terminus of low-gradient semi-arid fluvial systems: lessons from the Río Colorado, Altiplano endorheic basin, Bolivia. *Sedimentary Geology*, **283**, 1–14, https://doi.org/10.1016/j.sedgeo.2012.1010.1007
Dubon, S.L. and Lanzoni, S. 2019. Meandering evolution and width variations: a physics-statistics-based modeling approach. *Water Resource Research*, **55**, 76–94, https://doi.org/10.1029/2018WR023639
Duffin, J., Carmichael, R.A., Yager, E.M., Benjankar, R. and Tonina, D. 2021. Detecting multi-scale riverine topographic variability and its influence on Chinook salmon habitat selection. *Earth Surface Processes and Landforms*, **46**, 1026–1040, https://doi.org/10.1002/esp.5077
Dunne, T. and Aalto, R.E. 2013. Large river floodplains. *In*: Shroder, J. (ed.) *Treatise on Geomorphology*, 1st edn. Academic Press, 645–678.
Durkin, P.R., Hubbard, S.M., Holbrook, J. and Boyd, R. 2018. Evolution of fluvial meander-belt deposits and implications for the completeness of the stratigraphic record. *Geological Society of America Bulletin*, **130**, 721–739, https://doi.org/10.1130/B31699.1
Ebisemiju, F.S. 1994. The sinuosity of alluvial river channels in the seasonally wet tropical environment: case study of river Elemi, southwestern Nigeria. *Catena*, **21**, 13–25, https://doi.org/10.1016/0341-8162(94)90028-0
Edwards, B.F. and Smith, D.H. 2002. River meandering dynamics. *Physical Review E*, **65**, 046303, https://doi.org/10.1103/PhysRevE.65.046303
Eekhout, J.P.C. and Hoitink, A.J.F. 2015. Chute cutoff as a morphological response to stream reconstruction: the possible role of backwater. *Water Resource Research*, **51**, 3339–3352, https://doi.org/10.1002/2014WR016539
Eekhout, J.P.C., Hoitink, A.J.F. and Makaske, B. 2013. Historical analysis indicates seepage control on initiation of meandering. *Earth Surface Processes and Landforms*, **38**, 888–897, https://doi.org/10.1002/esp.3376
Eke, E.C., Czapiga, M.J., Viparelli, E., Shimizu, Y., Imran, J., Sun, T. and Parker, G. 2014. Coevolution of width

and sinuosity in meandering rivers. *Journal of Fluid Mechancis*, **760**, 127–174, https://doi.org/10.1017/jfm.2014.556

El Gammal, E.S.A. 2017. On the chutes and chute cutoff along the River Nile within Egypt. *Arabian Journal for Science and Engineering*, **42**, 301–314, https://doi.org/10.1007/s13369-016-2074-x

Engel, F.L. and Rhoads, B.L. 2012. Interaction among mean flow, turbulence, bed morphology, bank failures and channel planform in an evolving compound meander loop. *Geomorphology*, **163**, 70–83, https://doi.org/10.1016/j.geomorph.2011.05.026

Erskine, W.D. 1992. Channel response to large-scale river training works – Hunter River, Australia. *Regulated Rivers-Research & Management*, **7**, 261–278, https://doi.org/10.1002/rrr.3450070305

Erskine, W., Mcfaden, C. and Bishop, P. 1992. Alluvial cutoffs as indicators of former channel conditions. *Earth Surface Processes and Landforms*, **17**, 23–37, https://doi.org/10.1002/esp.3290170103

Fares, Y.R. 2000. Changes of bed topography in meandering rivers at a neck cutoff intersection. *Journal of Environmental Hydrology*, **8**, 1–18.

Ferguson, R.I. 1981. Kinematic model of meander migration. *In*: Ikeda, H. and Parker, G. (eds) *River Meandering*. American Geophysical Union, Washington, 942–951.

Ferguson, R.I. 1990. Understanding braiding processes in gravel-bed rivers: progress and unsolved problems. *Geological Society, London, Special Publications*, **75**, 73–87, https://doi.org/10.1144/GSL.SP.1993.075.01.03

Ferguson, R.I., Parsons, D.R., Lane, S.N. and Hardy, R.J. 2003. Flow in meander bends with recirculation at the inner bank. *Water Resource Research*, **39**, https://doi.org/10.1029/2003WR001965

Fisk, H.N. 1947. *Fine Grained Alluvial Deposits and their Effects on Mississippi River Activity*. Mississippi River Commission, Vicksburg, MS.

Frascati, A. and Lanzoni, S. 2009. Morphodynamic regime and long-term evolution of meandering rivers. *Journal of Geophysical Research: Earth Surface*, **114**, https://doi.org/10.1029/2008JF001101

Frascati, A. and Lanzoni, S. 2010. Long-term river meandering as a part of chaotic dynamics? A contribution from mathematical modelling. *Earth Surface Processes and Landforms*, **35**, 791–802, https://doi.org/10.1002/esp.1974

Frascati, A. and Lanzoni, S. 2013. A mathematical model for meandering rivers with varying width. *Journal of Geophysical Research-Earth Surface*, **118**, 1641–1657, https://doi.org/10.1002/jgrf.20084

Friedkin, J. 1945. *A Laboratory Study of the Meandering of Alluvial Rivers, Technical Report, May 1945*. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MI.

Fuller, I.C., Large, A.R.G. and Milan, D.J. 2003. Quantifying channel development and sediment transfer following chute cutoff in a wandering gravel-bed river. *Geomorphology*, **54**, 307–323, https://doi.org/10.1016/S0169-555X(02)00374-4

Gagliano, S.M. and Howard, P.C. 1984. The Neck Cutoff Oxbow Lake Cycle along the Lower Mississippi River.

Gao, P. 2013. Rill and gully development processes. *In*: Shroder, J.F. (ed.) *Treatise on Geomorphology*. Academic Press, San Diego, 122–131.

Gao, P., Li, Z.W. and Yang, H.Y. 2021. Variable discharges control composite bank erosion in Zoige meandering rivers. *Catena*, **204**, https://doi.org/10.1016/j.catena.2021.105384

Gautier, E., Brunstein, D. *et al*. 2010. Channel and floodplain sediment dynamics in a reach of the tropical meandering Rio Beni (Bolivian Amazonia). *Earth Surface Processes and Landforms*, **35**, 1838–1853, https://doi.org/10.1002/esp.2065

Gautier, E., Brunstein, D. *et al*. 2007. Temporal relations between meander deformation, water discharge and sediment fluxes in the floodplain of the Rio Beni (Bolivian Amazonia). *Earth Surface Processes and Landforms*, **32**, 230–248, https://doi.org/10.1002/esp.1394

Gay, G.R., Gay, H.H., Gay, W.H., Martinson, H.A., Meade, R.H. and Moody, J.A. 1998. Evolution of cutoffs across meander necks in Powder River, Montana, USA. *Earth Surface Processes and Landforms*, **23**, 651–662, https://doi.org/10.1002/(SICI)1096-9837(199807)23:7<651::AID-ESP891>3.0.CO;2-V

Ghinassi, M. 2011. Chute channels in the Holocene high-sinuosity river deposits of the Firenze plain, Tuscany, Italy. *Sedimentology*, **58**, 618–642, https://doi.org/10.1111/j.1365-3091.2010.01176.x

Gilvear, D., Winterbottom, S. and Sichingabula, H. 2000. Character of channel planform change and meander development: Luangwa River, Zambia. *Earth Surface Processes and Landforms*, **25**, 421–436, https://doi.org/10.1002/(SICI)1096-9837(200004)25:4<421::AID-ESP65>3.0.CO;2-Q

Grenfell, M., Aalto, R. and Nicholas, A. 2012. Chute channel dynamics in large, sand-bed meandering rivers. *Earth Surface Processes and Landforms*, **37**, 315–331, https://doi.org/10.1002/esp.2257

Grenfell, M.C., Nicholas, A.P. and Aalto, R. 2014. Mediative adjustment of river dynamics: The role of chute channels in tropical sand-bed meandering rivers. *Sedimentary Geology*, **301**, 93–106, https://doi.org/10.1016/j.sedgeo.2013.06.007

Güneralp, I. and Rhoads, B.L. 2009. Empirical analysis of the planform curvature-migration relation of meandering rivers. *Water Resourses Research*, **45**, W09424, https://doi.org/10.1029/2008WR007533

Güneralp, I., Abad, J.D., Zolezzi, G. and Hooke, J. 2012. Advances and challenges in meandering channels research. *Geomorphology*, **163**, 1–9, https://doi.org/10.1016/j.geomorph.2012.04.011

Guo, X., Chen, D. and Parker, G. 2019. Flow directionality of pristine meandering rivers is embedded in the skewing of high-amplitude bends and neck cutoffs. *Proceedings of the National Academy of Sciences of the United States of America*, **116**, 23448–23454, https://doi.org/10.1073/pnas.1910874116

Guo, X.W., Gao, P. and Li, Z.W. 2021. Morphological characteristics and changes of two meandering rivers in the Qinghai-Tibet PIateau, China. *Geomorphology*, **379**, 107626, https://doi.org/10.1016/j.geomorph.2021.107626

Hackney, C., Best, J., Leyland, J., Darby, S.E., Parsons, D., Aalto, R. and Nicholas, A. 2015. Modulation of outer bank erosion by slump blocks: disentangling the protective and destructive role of failed material on the three-dimensional flow structure. *Geophysical Research*

Letters, **42**, 10663–10670, https://doi.org/10.1002/2015GL066481

Han, B. and Endreny, T. 2014. Detailed river stage mapping and head gradient analysis during meander cutoff in a laboratory river. *Water Resource Research*, **50**, 1689–1703, https://doi.org/10.1002/2013WR013580

Harrison, L.R., Dunne, T. and Fisher, G.B. 2015. Hydraulic and geomorphic processes in an overbank flood along a meandering, gravel-bed river: implications for chute formation. *Earth Surface Processes and Landforms*, **40**, 1239–1253, https://doi.org/10.1002/esp.3717

Hooke, J.M. 1984. Changes in river meanders - a review of techniques and results of analyses. *Progress in Physical Geography*, **8**, 473–508, https://doi.org/10.1177/030913338400800401

Hooke, J.M. 1995*a*. River channel adjustment to meander cutoffs on the River Bollin and River Dane, northwest England. *Geomorphology*, **14**, 235–253, https://doi.org/10.1016/0169-555X(95)00110-Q

Hooke, J.M. 1995*b*. Processes of channel planform change on meandering channels in the UK. *In*: Gurnell, A. and Petts, G.E. (eds) *Changing River Channels*. Wiley, Chichester, UK, 87–115.

Hooke, J.M. 2003. River meander behaviour and instability; a framework for analysis. *Transactions of Institute of British Geographers*, **28**, 238–253, https://doi.org/10.1111/1475-5661.00089

Hooke, J.M. 2004. Cutoffs galore!: occurrence and causes of multiple cutoffs on a meandering river. *Geomorphology*, **61**, 225–238, https://doi.org/10.1016/j.geomorph.2003.12.006

Hooke, J.M. 2007. Spatial variability, mechanisms and propagation of change in an active meandering river. *Geomorphology*, **84**, 277–296, https://doi.org/10.1016/j.geomorph.2006.06.005

Hooke, J.M. 2013. River meandering. *In*: Shroder, J.F.E.-I.-C. and Wohl, E.V.E. (eds) *Treatise on Geomorphology Vol 9, Fluvial Geomorphology*. Academic Press, San Diego, 260–288.

Horton, A.J., Constantine, J.A., Hales, T.C., Goossens, B., Bruford, M.W. and Lazarus, E.D. 2017. Modification of river meandering by tropical deforestation. *Geology*, **45**, 511–514, https://doi.org/10.1130/G38740.1

Howard, A.D. 1992. Modeling channel migration and floodplain sedimentation in meandering streams. *In*: Carling, P.A. and Petts, G.E. (eds) *Lowland Floodplain Rivers: Geomorphological Perspectives*. Wiley, Chichester, UK, 1–41.

Howard, A.D. 1996. Modelling channel evolution and floodplain morphology. *In*: Anderson, M.G., Kochel, V.R. and Patton, R.C. (eds) *Floodplain Processes*. Wiley, Chichester, UK, 15–62.

Howard, A.D. 2009. How to make a meandering river. *Proceedings of the National Academy of Sciences of the United States of America*, **106**, 17245–17246, https://doi.org/10.1073/pnas.0910005106

Howard, A.D. and Knutson, T.R. 1984. Sufficient conditions for river meandering – a simulation approach. *Water Resource Research*, **20**, 1659–1667, https://doi.org/10.1029/WR020i011p01659

Ielpi, A. and Lapotre, M.G.A. 2020. A tenfold slowdown in river meander migration driven by plant life. *Nature Geoscience*, **13**, 82–86, https://doi.org/10.1038/s41561-019-0491-7

Ielpi, A., Lapotre, M.G.A., Finotello, A. and Ghinassi, M. 2021. Planform-asymmetry and backwater effects on river-cutoff kinematics and clustering. *Earth Surface Processes and Landforms*, **46**, 357–370, https://doi.org/310.1002/esp.5029

Ikeda, S., Parker, G. and Sawai, K. 1981. Bend theory of river meanders. 1. Linear development. *Journal of Fluid Mechanics*, **112**, 363–377, https://doi.org/10.1017/S0022112081000451

Kellerhals, R.M., Church, M. and Bray, I. 1976. Classification and analysis of river processes. *Journal of the Hydraulics Division ASCE*, **102**, 813–829, https://doi.org/10.1061/JYCEAJ.0004583

Kleinhans, M.G. and van den Berg, J.H. 2011. River channel and bar patterns explained and predicted by an empirical and a physics-based method. *Earth Surface Processes and Landforms*, **36**, 721–738, https://doi.org/10.1002/esp.2090

Kleinhans, M.G., Jagers, H.R.A., Mosselman, E. and Sloff, C.J. 2008. Bifurcation dynamics and avulsion duration in meandering rivers by one-dimensional and three-dimensional models. *Water Resource Research*, **44**, https://doi.org/10.1029/2007WR005912

Kleinhans, M.G., Cohen, K.M., Hoekstra, J. and Ijmker, J.M. 2011. Evolution of a bifurcation in a meandering river with adjustable channel widths, Rhine delta apex, The Netherlands. *Earth Surface Processes and Landforms*, **36**, 2011–2027, https://doi.org/10.1002/esp.2222

Knighton, D. 1998. *Fluvial Forms & Processes, A New Perspective*. Arnold, London.

Konsoer, K.M. and Richards, G. 2016. Planform evolution of neck cutoffs on elongate meander loops, White River, Arkansas, USA. *In*: Constantinescu, G., Garcia, M. and Hanes, D. (eds) *River Flow 2016*. Taylor & Francis Group, Boca Raton, FL.

Kyuka, T., Yamaguchi, S., Inoue, Y., Ferrel, K.R.A., Kon, H. and Shimizu, Y. 2021. Morphodynamic effects of vegetation life stage on experimental meandering channels. *Earth Surface Processes and Landforms*, **46**, 1225–1237, https://doi.org/10.1002/esp.5051

Lanzoni, S., Siviglia, A., Frascati, A. and Seminara, G. 2006. Long waves in erodible channels and morphodynamic influence. *Water Resource Research*, **42**, https://doi.org/10.1029/2006WR004916

Lewis, G.W. and Lewin, J. 1983. Alluvial cutoffs in Wales and the Borderlands. *International Association of Sedimentologists, Special Publication*, **6**, 145–154.

Li, Z.W. and Gao, P. 2019. Channel adjustment after artificial neck cutoffs in a meandering river of the Zoige basin within the Qinghai-Tibet Plateau, China. *Catena*, **172**, 255–265, https://doi.org/10.1016/j.catena.2018.08.042

Li, Z. and Garcia, M.H. 2021. pyRiverBed: a Python framework to generate synthetic riverbed topography for constant-width meandering rivers. *Computers & Geosciences*, **152**, 104755, https://doi.org/10.1016/j.cageo.2021.104755

Li, Z.W., Yu, G.A., Brierley, G., Wang, Z.Y. and Jia, Y.H. 2017. Migration and cutoff formation of meanders in hyper-arid environments of the middle and lower Tarim River, Northwestern China. *Geomorphology*,

276, 116–124, https://doi.org/10.1016/j.geomorph.2016.10.018

Li, Z.W., Wu, X.Y. and Gao, P. 2019. Experimental study on the process of neck cutoff and channel adjustment in a highly sinuous meander under constant discharges. *Geomorphology*, **327**, 215–229, https://doi.org/10.1016/j.geomorph.2018.11.002

Li, J.G., Grenfell, M.C., Wei, H., Tooth, S. and Ngiem, S. 2020. Chute cutoff-driven abandonment and sedimentation of meander bends along a fine-grained, non-vegetated, ephemeral river on the Bolivian Altiplano. *Geomorphology*, **350**, 106917, https://doi.org/10.1016/j.geomorph.2019.106917

Li, Z.W., Gao, P. and Wu, X.Y. 2022. Processes of neck cutoff and channel adjustment affected by seeding herbaceous vegetation and variable discharges. *Catena*, **208**, 105731, https://doi.org/10.1016/j.catena.2021.105731

Li, Z.W., Gao, P., You, Y.C., Finotello, A. and Ielpi, A. 2023. Delayed neck cutoff in the meandering Black River of the Qinghai–Tibet plateau. *Earth Surface Processes and Landforms*, **48**, 1052–1063, https://doi.org/10.1002/esp.5534

Mason, J. and Mohrig, D. 2018. Using time-lapse lidar to quantify river bend evolution on the meandering Coastal Trinity River, Texas, USA. *Journal of Geophysical Research:Earth Surface*, **123**, 1133–1144, https://doi.org/10.1029/2017JF004492

Mason, J. and Mohrig, D. 2019. Scroll bars are inner bank levees along meandering river bends. *Earth Surface Processes and Landforms*, **44**, 2649–2659, https://doi.org/10.1002/esp.4690

McGowen, J.H. and Garner, L.E. 1970. Physiographic features and stratification types of coarse-grained point bars: Modern and ancient examples. *Sedimentology*, **14**, 77, https://doi.org/10.1111/j.1365-3091.1970.tb00184.x

Micheli, E.R. and Kirchner, J.W. 2002. Effects of wet meadow riparian vegetation on streambank erosion. 2. Measurements of vegetated bank strength and consequences for failure mechanics. *Earth Surface Processes and Landforms*, **27**, 687–697, https://doi.org/10.1002/esp.340

Micheli, E.R. and Larsen, E.W. 2011. River channel cutoff dynamics, Sacramento River, California, USA. *River Research and Applications*, **27**, 328–344, https://doi.org/10.1002/rra.1360

Mosley, M.P. 1975. Meandering cutoffs on the River Bollin, Cheshire in July 1973. *Revue de Geomorphologie Dynamique*, **24**, 21–32.

Motta, D., Abad, J.D., Langendoen, E.J. and Garcia, M.H. 2012. The effects of floodplain soil heterogeneity on meander planform shape. *Water Resource Research*, **48**, https://doi.org/0.1029/2011WR011601

Motta, D., Langendoen, E.J., Abad, J.D. and Garcia, M.H. 2014. Modification of meander migration by bank failures. *Journal of Geophysical Research-Earth Surface*, **119**, 1026–1042, https://doi.org/10.1002/2013JF002952

Nanson, G.C. and Croke, J.C. 1992. A genetic classification of floodplains. *Geomorphology*, **4**, 459–486, https://doi.org/10.1016/0169-555X(92)90039-Q

Nicholas, A. 2013. Morphodynamic diversity of the world's largest rivers. *Geology*, **41**, 475–478, https://doi.org/10.1130/G34016.1

Pan, C.S., Shi, S.C. and Duan, W.Z. 1978. A study of the channel development after the completion of artificial cutoffs in the Middle Yangtze River. *Scientia Sinica*, **21**, 783–804.

Parker, G. and Andrews, E.D. 1986. On the time development of meander bends. *Journal of Fluid Mechanci*, **162**, 139–156, https://doi.org/10.1017/S0022112086001970

Parker, G., Sawai, K. and Ikeda, S. 1982. Bend theory of river meanders. Part 2. Nonlinear deformation of finite-amplitude bends. *Journal of Fluid Mechanics*, **115**, 303–314, https://doi.org/310.1017/S0022112082000767

Parker, G., Diplas, P. and Akiyama, J. 1983. Meander bends of high amplitude. *Journal of Hydraulic Engineering*, **109**, 1323–1337, https://doi.org/10.1061/(ASCE)0733-9429(1983)109:10(1323)

Parker, G., Shimizu, Y. *et al*. 2011. A new framework for modelling the migration of meandering rivers. *Earth Surface Processes and Landforms*, **36**, 70–86, https://doi.org/10.1002/esp.2113

Peakall, J., Ashworth, P.J. and Best, J.L. 2007. Meander-bend evolution, alluvial architecture, and the role of cohesion in sinuous river channels: a flume study. *Journal of Sedimentary Research*, **77**, 197–212, https://doi.org/10.2110/jsr.2007.017

Piegay, H., Bornette, G., Citteroi, A., Herouin, E., Moulin, B. and Statiotis, C. 2000. Channel instability as a control on silting dynamics and vegetation patterns within perifluvial aquatic zones. *Hydrological Processes*, **14**, 3011–3029, https://doi.org/10.1002/1099-1085(200011/12)14:16/17<3011::AID-HYP132>3.0.CO;2-B

Piegay, H., Hupp, C.R., Citterio, A., Dufour, S., Moulin, B. and Walling, D.E. 2008. Spatial and temporal variability in sedimentation rates associated with cutoff channel infill deposits: Ain River, France. *Water Resource Research*, **44**, https://doi.org/10.1029/2006WR005260

Phillips, J.D. 2013. Hydrological connectivity of abandoned channel water bodies on a coastal plain river. *River Research and Applications*, **29**, 149–160, https://doi.org/10.1002/rra.1586

Ratzlaff, J.R. 1981. Development and cutoff of Big Bend Meander, Brazos River, Texas. *Texas Journal of Science*, **33**, 121–129.

Rhoads, B.L. 2020. *River Dynamics: Geomorphology to Support Management*. Cambridge University Press, Cambridge, UK.

Richards, D., Konsoer, K., Langendoen, E., Ursic, M. and Constantine, J. 2022. Depositional patterns of slowly plugging neck cutoffs from core analysis and estimates of bedload transport, White River, Arkansas. *Sedimentology*, **69**, 568–591, https://doi.org/10.1111/sed.12915

Schuurman, F., Shimizu, Y., Iwasaki, T. and Kleinhans, M.G. 2016. Dynamic meandering in response to upstream perturbations and floodplain formation. *Geomorphology*, **253**, 94–109, https://doi.org/10.1016/j.geomorph.2015.05.039

Schwendel, A.C. and Cooper, A.H. 2021. Meander chute cutoff at an alluvial river facilitated by gypsum sinkholes. *Geomorphology*, **393**, 107944, https://doi.org/10.1016/j.geomorph.2021.107944

Schwendel, A., Aalto, R., Nicholas, A. and Parsons, D. 2018. Fill characteristics of abandoned channels and resulting stratigraphy of a mobile sand-bed river floodplain. Ghinassi, M., Colombera, L., Mountney, N.P., Reesink, A.J.H. and Bateman, M. (eds) *Fluvial Meanders and Their Sedimentary Products in the Rock Record*. Wiley, Chichester, UK, 251–272.

Schwendel, A.C., Nicholas, A.P., Aalto, R.E., Sambrook Smith, G.H. and Buckley, S. 2015. Interaction between meander dynamics and floodplain heterogeneity in a large tropical sand-bed river: the Rio Beni, Bolivian Amazon. *Earth Surface Processes and Landforms*, **40**, 2026–2040, https://doi.org/10.1002/esp.3777

Schwenk, J. and Foufoula-Georgiou, E. 2016. Meander cutoffs nonlocally accelerate upstream and downstream migration and channel widening. *Geophysical Research Letters*, **43**, 12437–12445, https://doi.org/10.1002/2016GL071670

Schwenk, J., Lanzoni, S. and Foufoula-Georgiou, E. 2015. The life of a meander bend: connecting shape and dynamics via analysis of a numerical model. *Journal of Geophysical Research: Earth Surface*, **120**, 690–710, https://doi.org/10.1002/2014JF003252

Seminara, G. and Tubino, M. 1989. Alternate bars and meandering: free forced and mixed interactions. *In*: Ikeda, S. and Parker, G. (eds) *River Meandering*. American Geophysical Union, Washington, DC, 153–180.

Seminara, G., Zolezzi, G., Tubino, M. and Zardi, D. 2001. Downstream and upstream influence in river meandering. Part 2. Planimetric development. *Journal of Fluid Mechanics*, **438**, 213–230, https://doi.org/10.1017/S0022112001004281

Smith, D.G. and Pearce, C.M. 2002. Ice jam-caused fluvial gullies and scour holes on northern river flood plains. *Geomorphology*, **42**, 85–95, https://doi.org/10.1016/S0169-555X(01)00076-9

Stella, J., Hayden, M., Battles, J., Piegay, H., Dufour, S. and Fremier, A.K. 2011. The role of abandoned channels as Refugia for sustaining pioneer riparian forest ecosystems. *Ecosystems*, **14**, 776–790, https://doi.org/10.1007/s10021-011-9446-6

Stolum, H.H. 1996. River meandering as a self-organization process. *Science (New York, NY)*, **271**, 1710–1713, https://doi.org/10.1126/science.271.5256.1710

Stolum, H.H. 1998. Planform geometry and dynamics of meandering rivers. *Geological Society of America Bulletin*, **110**, 1485–1498, https://doi.org/10.1130/0016-7606(1998)110<1485:PGADOM>2.3.CO;2

Stolum, H.H. and Friend, P.F. 1997. Percolation theory applied to simulated meander belt sandbodies. *Earth and Planetary Science Letters*, **153**, 265–277, https://doi.org/10.1016/S0012-821X(97)00173-8

Struiksma, N., Olesen, K.W., Flokstra, C. and Devriend, H.J. 1985. Bed deformation in curved alluvial channels. *Journal of Hydraulic Research*, **23**, 57–79, https://doi.org/10.1080/00221688509499377

Sun, T., Meakin, P. and Jossang, T. 1996. A simulation model for meandering rivers. *Water Resource Research*, **32**, 2937–2954, https://doi.org/10.1029/96WR00998

Sun, T., Meakin, P. and Jossang, T. 2001. Meander migration and the lateral tilting of floodplains. *Water Resources Research*, **37**, 1485–1502, https://doi.org/10.1029/2000WR900343

Sylvester, Z. and Covault, J.A. 2016. Development of cutoff-related knickpoints during early evolution of submarine channels. *Geology*, **44**, 835–838, https://doi.org/10.1130/G38397.1

Sylvester, Z., Durkin, P. and Covault, J.A. 2019. High curvatures drive river meandering. *Geology*, **47**, 263–266, https://doi.org/10.1130/G45608.1

Sylvester, Z., Durkin, P.R., Hubbard, S.M. and Mohrig, D. 2021. Autogenic translation and counter point bar deposition in meandering rivers. *GSA Bulletin*, **133**, 2439–2456, https://doi.org/10.1130/B35829.1

Tal, M. and Paola, C. 2010. Effects of vegetation on channel morphodynamics: results and insights from laboratory experiments. *Earth Surface Processes and Landforms*, **35**, 1014–1028, https://doi.org/10.1002/esp.1908

Tamminga, A., Hugenholtz, C., Eaton, B. and Lapointe, M. 2015. Hyperspatial remote sensing of channel reach morphology and hydraulic fish habitat using an unmanned aerial vehicle (UAV): a first assessment in the context of river research and management. *River Research and Applications*, **31**, 379–391, https://doi.org/10.1002/rra.2743

Thompson, D.M. 2003. A geomorphic explanation for a meander cutoff following channel relocation of a coarse-bedded river. *Environmental Management*, **31**, 385–400, https://doi.org/10.1007/s00267-002-2842-0

Tower, W.S. 1904. The development of cut-off meanders. *Bulletin of the American Geographical Society of New York*, **36**, 589–599, https://doi.org/10.2307/197978

Tubino, M., Repetto, R. and Zolezzi, G. 1999. Free bars in rivers. *Journal of Hydraulic Research*, **37**, 759–775, https://doi.org/10.1080/00221689909498510

van de Lageweg, W.I., van Dijk, W.M., Baar, A.W., Rutten, J. and Kleinhans, M.G. 2014. Bank pull or bar push: What drives scroll-bar formation in meandering rivers? *Geology*, **42**, 319–322, https://doi.org/10.1130/G35192.1

van Dijk, W.M., van de Lageweg, W.I. and Kleinhans, M.G. 2012. Experimental meandering river with chute cutoffs. *Journal of Geophysical Research: Earth Surface*, **117**, https://doi.org/10.1029/2011JF002314

van Dijk, W.M., Schuurman, F., van de Lageweg, W.I. and Kleinhans, M.G. 2014. Bifurcation instability and chute cutoff development in meandering gravel-bed rivers. *Geomorphology*, **213**, 277–291, https://doi.org/10.1016/j.geomorph.2014.01.018

Vargas-Luna, A., Duro, G., Crosato, A. and Uijttewaal, W. 2019. Morphological adaptation of river channels to vegetation establishment: a laboratory study. *Journal of Geophysical Research: Earth Surface*, **124**, 1981–1995, https://doi.org/10.1029/2018JF004878

Viero, D.P., Dubon, S.L. and Lanzoni, S. 2018. Chute cutoffs in meandering rivers: formative mechanisms and hydrodynamic forcing. *In*: Ghinassi, M., Colombera, L., Mountney, N.P., Reesink, A.J.H. and Bateman, M. (eds) *Fluvial Meanders and Their Sedimentary Products in the Rock Record*. Wiley, Chichester, UK, 201–229, https://doi.org/210.1002/9781119424437.ch9781119424438

Wallick, J.R., Lancaster, S.T. and Bolte, J.P. 2006. Determination of bank erodibility for natural and anthropogenic bank materials using a model of lateral migration and observed erosion along the Willamette River, Oregon, USA. *River Research and Applications*, **22**, 631–649, https://doi.org/10.1002/rra.925

Ward, J.V., Tockner, K. and Schiemer, F. 1999. Biodiversity of floodplain river ecosystem: ecotones and connectivity. *Regulated Rivers: Research & Management*, **15**, 125–129, https://doi.org/10.1002/(SICI)1099-1646(199901/06)15:1/3<125::AID-RRR523> 3.0.CO;2-E

Westoby, M.J., Brasington, J., Glasser, N.F., Hambrey, M.J. and Reynolds, J.M. 2012. 'Structure-from-Motion' photogrammetry: a low-cost, effective tool for geoscience applications. *Geomorphology*, **179**, 300–314, https://doi.org/10.1016/j.geomorph.2012.08.021

Winkely, B.R. 1982. Response of the Lower Mississippi to river training and realignment. *In*: Hey, R.D., Bathurst, J.C. and Thorne, C.R. (eds) *Gravel Bed Rivers*. Wiley, Chichester, 659–680.

Zen, S., Zolezzi, G., Toffolon, M. and Gurnell, A.M. 2016. Biomorphodynamic modelling of inner bank advance in migrating meander bends. *Advances in Water Resources*, **93**, 166–181, https://doi.org/10.1016/j.advwatres.2015.11.017

Zhao, K., Lanzoni, S., Gong, Z. and Coco, G. 2021. A numerical model of bank collapse and river meandering. *Geophysical Research Letters*, **48**, e2021GL 093516, https://doi.org/10.1029/2021GL093516

Zinger, J.A., Rhoads, B.L. and Best, J.L. 2011. Extreme sediment pulses generated by bend cutoffs along a large meandering river. *Nature Geoscience*, **4**, 675–678, https://doi.org/10.1038/ngeo1260

Zolezzi, G. and Seminara, G. 2001. Downstream and upstream influence in river meandering. Part 1. General theory and application to overdeepening. *Journal of Fluid Mechanics*, **438**, 183–211, https://doi.org/10.1017/S002211200100427X

Zolezzi, G., Luchi, R. and Tubino, M. 2012. Modeling morphodynamic processes in meandering rivers with spatial width variations. *Reviews of Geophysics*, **50**, https://doi.org/10.1029/2012RG000392