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Key Points:
- Levee-breach model reveals a continuum from nonchannelized overbank deposition, to crevasse splays and to river avulsions
- We find a significant geomorphic effect of floodplain vegetation and soil consolidation on crevasse splays and avulsions
- Successful sediment diversions require a delicate balance of water and sediment discharges, vegetation root strength, and soil consolidation

Supporting Information:
- Supporting Information S1
- Movie S1
- Movie S2

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Crevasse Splays Versus Avulsions: A Recipe for Land Building With Levee Breaches

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Abstract Natural-levee breaches can not only initiate an avulsion but also, under the right circumstances, lead to crevasse splay formation and overbank sedimentation. The formative conditions for crevasse splays are not well understood, yet such river sediment diversions form an integral part of billion-dollar coastal restoration projects. Here we use Delft3D to investigate the influence of vegetation and soil consolidation on the evolution of a natural-levee breach. Model simulations show that crevasse splays heal because floodplain aggradation reduces the water surface slope, decreasing water discharge into the flood basin. Easily erodible and unvegetated floodplains increase the likelihood for channel avulsions. Denser vegetation and less potential for soil consolidation result in small crevasse splays that are not only efficient sediment traps but also short-lived. Successful crevasse splays that generate the largest land area gain for the imported sediment require a delicate balance between water and sediment discharge, vegetation root strength, and soil consolidation.

Plain Language Summary Man-made sediment diversions from the Mississippi River into adjacent wetlands are an ambitious and novel concept to form new land, replicating how large portions of the Mississippi River Delta have kept pace with sea level rise over the last thousands of years. However, the geomorphic evolution of diversions remains uncertain. How much new land will be formed, and is that dependent on vegetation type or soil consolidation rates? Will its channels silt in and close the diversion? Here we show with a numerical model that successful diversions generating the largest land area gain require a delicate balance between water and sediment discharge, vegetation root strength, and substrate erodibility. Diversions enhance local subsidence rates, but this can, counterintuitively, enhance land-building by allowing more sediment to flow into the diversion. Based on our model experiments, we have also found that diversions into easily erodible substrates can initiate a river avulsion and form a new river delta lobe, shedding light on the origin of river delta shapes we find on Earth today.

1. Introduction

The intricate balance between alluvial channels and their floodplains is maintained through a striking variety of forms and processes. In some rivers, natural levees (henceforth levees) rarely breach and floodplain sedimentation is dominated by overbank deposition without crevasse splays (Pizzuto, 1987). Other rivers frequently breach their levees during floods and drive water and sediment into their floodplains (e.g., Smith & Perez-Arlucea, 1994).

Sometimes levee breaches persist for centuries and form crevasse splays, but they can also heal quickly or, alternatively, erode and capture all the channel flow by means of avulsion (Fisk, 1952; Smith et al., 1989). Despite these radically different outcomes, the necessary conditions for avulsions or crevasse splay formation are not well known. This knowledge gap is critical because crevasse splays are an efficient tool for land building and they are therefore considered a natural analog for sediment diversions currently planned in the Mississippi River Delta (Coastal Protection and Restoration Authority, 2017; Gagliano & Van Beek, 1975). For example, one such crevasse splay in the Mississippi River Delta covers ~60 km^2 and was able to retain >75% of incoming sediment for land building (Esposito et al., 2017; Figure 1). However, effective diversion design is challenging if breach evolution is poorly understood. Diversions can silt up prematurely or result in excessive erosion that, under natural conditions, would lead to a river avulsion.

Using a numerical model of a levee breach, Slingerland and Smith (1998) formalized the idea that crevasse splays require a stable breach depth (i.e., the breach will continue to erode until the sand concentration

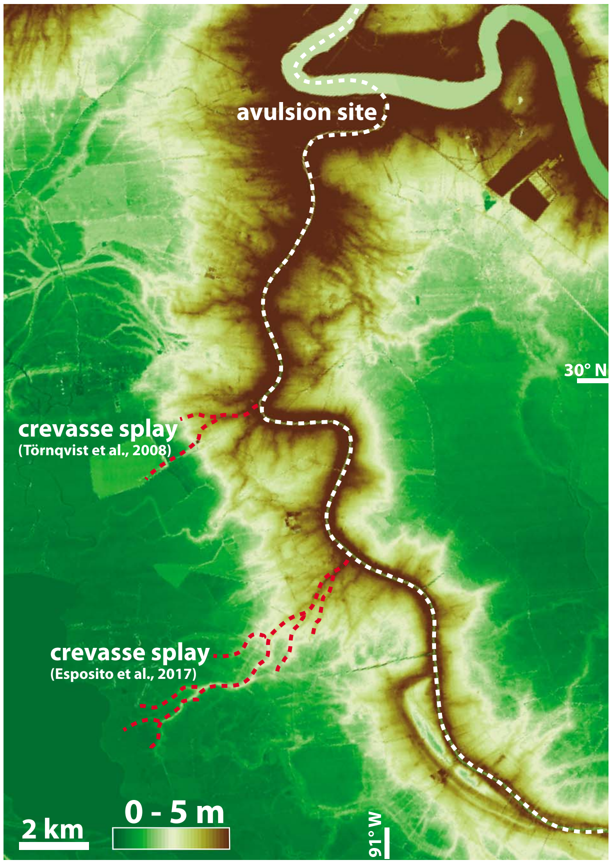

Figure 1. LIDAR image of Bayou Lafourche, a former distributary of the Mississippi River (atlas.lsu.edu), with its historical channel course (in white) and channel networks of two crevasse splays mentioned in the text (in red).

into the breach equals the sand eroded from the breach lip into the floodplain). Their model, as well as other "bifurcation stability" models (e.g., Bolla Pittaluga et al., 2003; Kleinhans et al., 2008), are commonly able to distinguish between unstable and stable breaches or bifurcations but do not take into account any distal floodplain effects on their stability, such as whether or not the floodplain is properly drained (e.g., Hajek & Edmonds, 2014; Mohrig et al., 2000). Channel bifurcation models also cannot predict crevasse splay morphology. Millard et al. (2017) used a data set of 114 levee breaches that resulted in crevasse splays and found that high floodplain water surface slopes (an indicator of floodplain drainage) and intermediate grain sizes (coarse silt to fine sand) result in large crevasse splays. Likely, floodplain slope, vegetation, and erodibility are also important factors that determine the floodplain response to a breach.

As crevasse splays exist as an intermediate levee breach response between immediate breach healing and avulsion, the leading hypothesis of this study is that crevasse splay size, lifetime, and its land building potential should therefore constitute a continuum between these end-members. We test our hypothesis using a morphodynamic model of a levee breach and an adjacent floodplain (or delta plain, but for simplicity, we refer herein to floodplains), with emphasis on the effects of floodplain vegetation and soil consolidation. Our model outcomes can help us quantify where a particular system resides within the continuum from avulsion to breach healing and inform natural methods of floodplain aggradation for areas prone to land loss.

2. Delft3D Model

We use the hydro- and morphodynamic model Delft3D (Deltares, 2014) to simulate floodplain morphology in response to a levee breach, ranging from direct levee healing to crevasse splay evolution to channel avulsion. Inspired by recent, detailed studies of crevasse splays in the Mississippi River Delta (Esposito et al., 2017; Shen et al., 2015; Törnqvist et al., 2008; Figure S1 in the supporting information), we developed MATLAB soil consolidation (note that we use the term "soil" here broadly, that is, in a geotechnical rather than a pedogenic sense) and vegetation routines that feed back into Delft3D to study their effects on floodplain morphology. From our model experiments we develop an understanding of floodplain response to levee breaching and derive a simple predictive metric of erosional versus depositional floodplain response.

The initial domain is 6 km along the primary channel and 15 km along the levee slope with floodplain topography that lowers exponentially (the decay constant is $5 \cdot 0^{-4}$) away from the levee crest from 5 to 0 m, roughly representing natural levees along the Mississippi River. A refined grid (Figure S2) or a longer model domain (Figure S3) has limited effects on the simulations. We add random topography to this floodplain with a uniformly distributed seed between -0.25 and $+0.25$ m to eliminate symmetry. There is an initial breach in the levee with a breach depth (lip height in the model of Slingerland & Smith, 1998) that we vary between 1 and 3 m (Figure S4).

We run the model by directly imposing water levels at the levee boundary and at the distal floodplain boundary. The water level slope across the domain then forces a flow through the breach. Having two water level boundary conditions as the driving force, as opposed to an upstream discharge boundary condition, is critical as it results in a floodplain-dependent discharge and sediment supply that enables levee breaches to close or to expand into an avulsion. Other morphodynamic models of crevasse splays (e.g., Hajek & Edmonds, 2014; Millard et al., 2017; Sandén et al., 2016) simulate autogenic breach discharge by including the trunk channel itself into the model domain. However, simulating the trunk channel is computationally expensive and numerically challenging, so here we simplify the channel boundary in order to focus deliberately on the role of floodplain conditions.

Our model setup allows for a variable water level boundary condition at the crevasse opening that mimics a water surface drawdown in the trunk channel feeding the splay (e.g., Slingerland & Smith, 1998). When discharge through the breach is large, drawdown in the trunk channel is highest, so the water level boundary used in the model is lower. We only consider one typical trunk channel discharge and approximate the water-level drawdown caused by the breach using an approximation of the Mississippi River stage-discharge rating curve at Belle Chasse (U.S. Geological Survey, 2016; Table S1 in the supporting information). Because we consider a constant trunk channel discharge, the time scales reported in this study might not directly translate into actual crevasse splay time scales that involve a full annual hydrograph. They also do not directly translate into flood periods because splay healing can occur during low flow (Fisk, 1952). On the distal floodplain boundary, we either impose a 0- or a 1-m water level depending on the experiment to investigate the effects of gross water surface slopes (floodplain drainage) on breach evolution.

The sediment conveyed into the floodplain consists of a cohesive mud fraction (0.2 kg m^{-3}) and a noncohesive sand fraction. The sand concentration of the inflow boundary is dependent on the breach depth (0.015 kg m^{-3} for a 5 m breach; see Table S1 for the Rouse profile function). The initial floodplain consists of cohesive mud. We vary the floodplain characteristics between different model scenarios to simulate the ways in which floodplain soil conditions influence erodibility. For example, a peaty soil can be significantly more erodible (Marttila & Kløve, 2008) than a substrate with a low organic-matter content.

We use a time step of 0.2 min. We speed up morphologic change by linearly increasing erosion and deposition with a factor of 90 (Ranasinghe et al., 2011). Simulations with different morphologic scaling factors show limited differences (Figure S2). We simulate floodplain morphology until the breach heals, until the breach avulses, or until 20 (morphological) years have passed. For the nonavulsive simulations that were not healed within 20 years, we extrapolated the lifetime to estimate the total retained sediment volume and land area gain from breach to healing (see supporting information for a detailed description of the model setup).

3. MATLAB Vegetation and Soil Consolidation

We have added two model routines outside Delft3D that are particularly relevant for floodplains.

To simulate compaction we developed a routine in Delft3D that dynamically lowers the floodplain surface in response to sediment deposition. This routine consists of primary and secondary soil consolidation phases (Mesri et al., 1997; Terzaghi, 1943), with a consolidation rate that depends on the effective vertical stress, soil compressibility, and time.

We fit the consolidation model using the geochronology and differential loading by a Mississippi River Delta crevasse splay (Figure 1), where sediments underneath the splay were compressed to a point that 35% of the crevasse-splay deposit resides below the elevation of the preexisting land surface (Törnqvist et al., 2008; Figure S1). We update the floodplain surface of the Delft3D model every 90 morphological days in response to loading and thus create a dynamic response to sediment deposition. We run different simulations where we vary the soil consolidation rate between 0 and 2 times the rate derived by Törnqvist et al. (2008; see supporting information for a detailed description of the soil consolidation routine).

Our second MATLAB routine added to Delft3D is an integration of the effects of vegetation on sediment erosion and deposition. Whereas Delft3D can adjust the flow roughness depending on vegetation characteristics, it does not directly increase the critical shear stress for erosion (Deltares, 2014). However, studies have shown that there is a strong effect of plant roots on the critical shear stress for erosion through enhanced shear strength of the substrate (Ali & Osman, 2008; Tengbeh, 1989; Watts et al., 2003). We include vegetation with a simple routine that adjusts the critical shear stress for erosion and the flow roughness depending on the local water depth, an important factor in plant survival.

Our model experiments are not intended to represent any particular environment, so for simplicity, we set the critical water depth to 1 m (below and above which plants establish or die, respectively). This is a common critical depth for swamp trees and marsh grass (Harms et al., 1980; Morris et al., 2002; Temmerman et al., 2007). Within Delft3D we separately track two cohesive sediment classes, one present in the original floodplain, and the other of the imported fluvial mud. In some experiments the water depth only affects the critical shear stress for erosion of the imported fluvial mud, such that the original floodplain sediments can be thought of as always "vegetated" during the simulation regardless of erosion and deposition (e.g., forested

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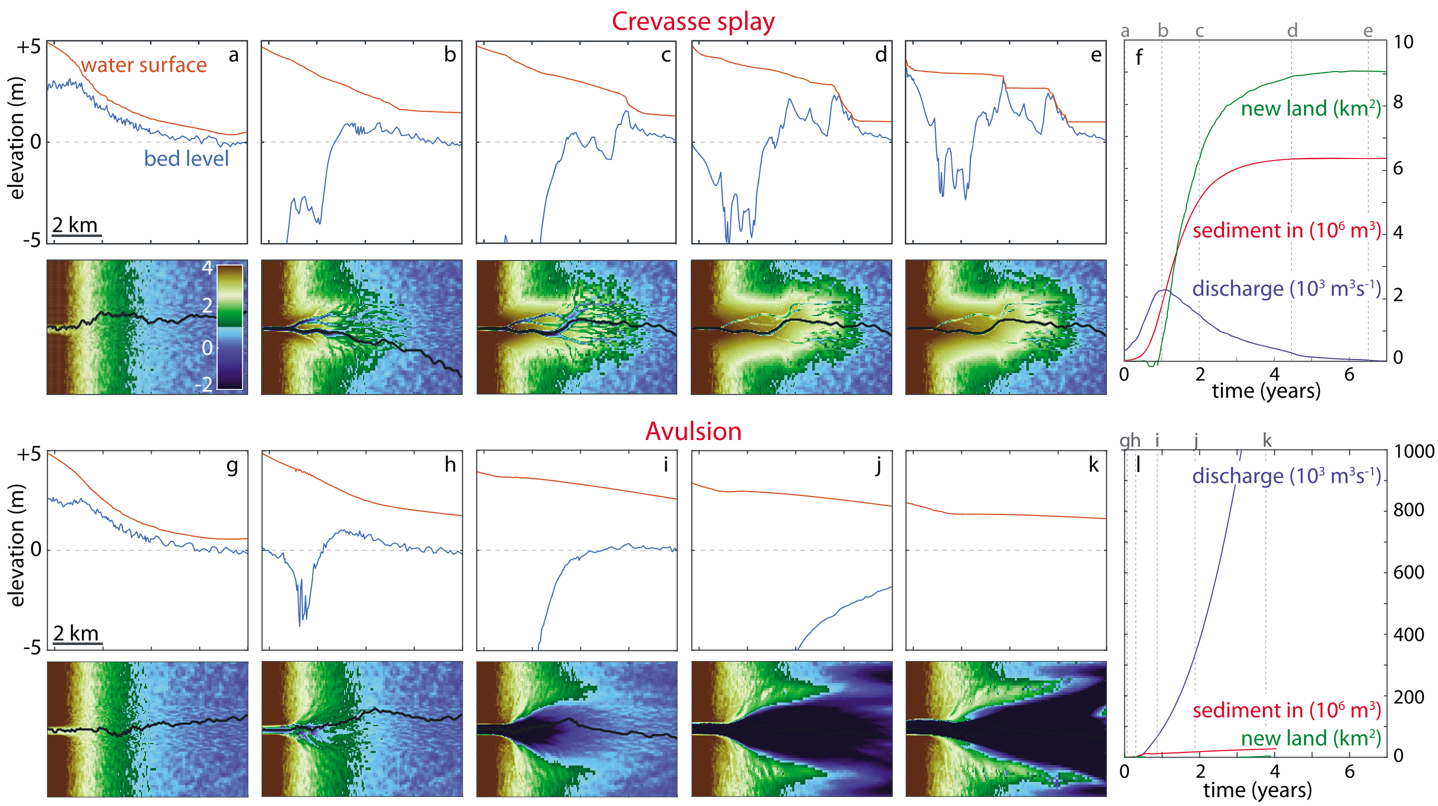

Figure 2. Evolution of a levee breach forming (a–e) a crevasse splay (experiment #10) and (g–k) an avulsion (experiment #7), showing bed level and water surface level along the deepest channel (black line) on the floodplain. (f and l) Growth of new land, imported sediment, and discharge into the floodplain versus time. Note the different vertical scales between (f) and (l).

floodplains). In other experiments (see Table S2) the water depth affects the critical shear stress for erosion of the original floodplain sediment and the imported fluvial sediment equally. These experiments can therefore be thought of as representative of a faster responding floodplain with weaker roots (e.g., marsh). We vary the strength of the vegetation and its roots between different experiments, and we adjust the vegetation cover to changing water levels every 90 days (see supporting information for a detailed description of the vegetation routine).

4. Why Does a Levee Breach Heal?

We investigated floodplain morphodynamics in response to a levee breach (Figure 2). In simulations that result in the formation of a crevasse splay, we find that, initially, erosion of the proximal part of the breach channel quickly forces an increase in discharge that inundates the floodplain (Figures 2a and 2b). This increase in discharge and associated sediment supply then causes sediment deposition in the floodplain, which causes the local water surface slope at the breach (and therefore discharge) to decrease (Figures 2c and 2d). During this waning phase of crevasse activity, new land is formed rapidly and bed load sediments fill up the levee breach until closure occurs after approximately 5 years. In another simulation with a more erodible floodplain, erosion of the breach is faster than deposition (Figures 2h and 2i). In this scenario, discharge and erosion increase in tandem. Despite the water surface drawdown in the trunk channel (Figure 2i), the discharge remains high enough to result in high velocities that make the model numerically unstable. We do not interpret this model result to represent the accurate morphologic evolution of an actual avulsion, but rather consider it an indication of sufficient conditions for the formation of an avulsion (see animations S1 and S2 of a crevasse splay and an avulsion in the supporting information, respectively).

Investigating the dynamics associated with a crevasse splay building into an environment dominated by herbaceous vegetation, we find that the initial floodplain vegetation is quickly lost as it drowns due to the rising water level (Figure 3, 0.4 years). Subsequently, the crevasse jet expands and deposits sediment (1.0 years).

Figure 3. The coevolution of flow, vegetation, and elevation during the first 3 years of a crevasse splay (experiment #17).

Islands in between the bifurcating erosional channels become vegetated and reduce flow capacity over the islands, further constricting the crevasse splay and lowering water levels (1.3 years). Note that in many other simulations we leave the original floodplain sediments vegetated (high critical shear stress) regardless of crevasse activity (e.g., Figure 4c), which could be a common condition in forested environments.

5. Controls on Crevasse Splay Morphology

To investigate the effects of external controls on levee breach response, we ran simulations where we varied breach height, water level slope, vegetation strength, soil compressibility, and floodplain erodibility (erosion coefficient and critical shear stress for erosion). Discharge into the floodplain is autogenic and sensitive to floodplain properties and breach dimensions. In some model experiments we observe an avulsion, where floodplain erosion exceeds deposition and discharge increases beyond model stability. Between scenarios where crevasse splays form, their volume ranges over 6 orders of magnitude and their lifetimes (defined as the duration during which discharge exceeds 10 $m^3\ s^{-1}$) vary from less than 1 year to more than 30 years (Figure 4).

Inspired by Hajek and Edmonds (2014), we hypothesize that crevasse splay morphology is controlled by the relative dominance of floodplain erosion versus deposition. To scale the relative importance of various external controls on levee breach evolution, we therefore developed a predictive metric that compares the potential floodplain deposition rate (D, kg $m^{-2}\ s^{-1}$) to the floodplain erosion rate (E, kg $m^{-2}\ s^{-1}$),

$$\frac{D}{E} = \frac{\sum_i c_s w_s}{M\left(\frac{\tau}{\tau_{cr}} - 1\right)} = \frac{\sum_i c_s w_s}{M\left(\frac{\rho g h S}{\tau_{cr}} - 1\right)}, \quad \text{if } \tau > \tau_{cr}, \tag{1}$$

where c_s is the initial sediment concentration in the trunk channel (kg m^{-3}) and w_s is the settling velocity (m s^{-1}). We sum the potential floodplain deposition for all grain sizes i (sand and mud). M is the floodplain erosion coefficient (kg $m^{-2}\ s^{-1}$). τ is a bed shear stress (N m^{-2}), which we approximate as $\rho g h S$, where ρ is

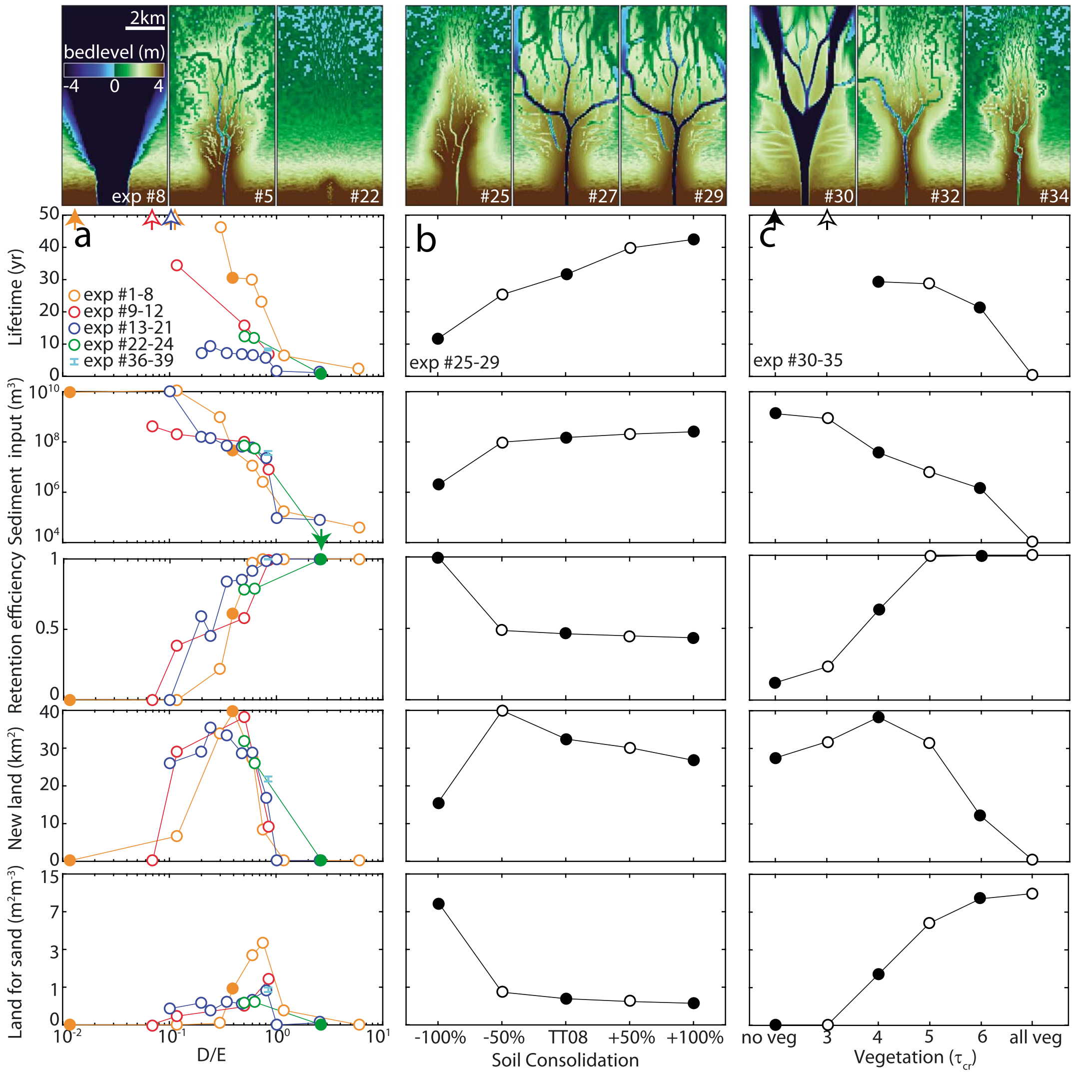

Figure 4. (top row) Floodplain morphology after 7 years for the experiments with filled symbols shown in the lower panels. (a) Effect of the *D*/*E* ratio (equation (1)), (b) soil consolidation, and (c) vegetation on crevasse splay morphology, splay lifetime, imported sediment volume, fraction retained sediment, new land, and the land for your sand. The arrows indicate that experiments plot outside the axis limits. The symbol colors in (a) refer to sets of experiments among which a characteristic is varied that is included in *D* or *E*. Between these sets we vary vegetation, from low (red), to intermediate (green), to high (blue), to basin vegetation unaffected by water levels (orange). Vegetation is not included in *D* or *E*, and therefore, all sets do not collapse into a single function of *D*/*E*. The cyan symbol shows the range of results from experiments with varying morphologic scaling factor and grid size (see Figure S2 and Table S2). Experiments follow the observed soil consolidation rate found by Törnqvist et al. (2008) (TT08) except where noted.

the water density (kg m^{-3}), g is acceleration due to gravity (m s^{-2}), h is the initial water depth in the breach (m), and S is the imposed water surface slope across the domain. τ_{cr} is the critical shear stress for erosion of the nonvegetated land surface (N m^{-2}).

Investigating floodplain morphology for varying ratios of *D*/*E* (Figure 4a), we find that if $D \gg E$, simulated breaches heal relatively quickly and virtually no crevasse splay is generated (solid green circle in Figure 4). On the other hand, if $E \gg D$, the initial erosion exceeds the distal aggradation that reduces discharge, setting off an avulsion. A large sediment volume is imported through the breach, but sediment is not retained on the floodplain within the model domain.

In simulations where neither erosion nor deposition dominates (*D*–*E*), crevasse splays form. Initial erosion is significant enough to increase discharge and sediment supply into the floodplain. These simulations achieve a balance between the volume of imported sediment and the fraction of the sediment that is retained. Crevasse splays at *D*/*E* ~½ form the largest new land area (defined as the floodplain area above +0.5 m). Crevasse splays at slightly higher ratios (*D*/*E* ~1) form new land most efficiently (i.e., new land area formed for each cubic meter of imported sediment, m^{-1}). Note that some high land building efficiency ratios, ~7 m^2 m^{-3}, come from redistribution of preexisting floodplain sediments. Currents in these highly vegetated environments can form new land simply by eroding existing floodplain sediments, resulting in efficient new land formation when compared to the required fluvial sediment.

Interestingly, no model experiments attain a stable equilibrium where deposition and erosion are exactly balanced (in contrast to some simulations by Slingerland & Smith, 1998). Either proximal initial erosion is rapid and forces an avulsion (Figures 2g–2k) or distal aggradation takes over and heals the splay (Figures 2c–2e). However, the time before a splay heals can be long.

6. Effects of Soil Consolidation and Vegetation

We varied the potential for soil consolidation compared to the fitted function from the crevasse splay analyzed by Törnqvist et al. (2008) to investigate its effect on splay morphology (Figure 4b). As expected, floodplains that are more susceptible to soil consolidation, for instance because of thicker peat beds in the subsurface, accommodate splays that stay active longer and contain more sediment. Surprisingly, however, the most extensive land area was formed in a simulation with some soil consolidation greater than zero (zero subsidence leads to short-lived crevasses splays).

Varying the strength of the vegetation by altering the critical shear stress for erosion and the roughness across the vegetated floodplain, we find that vegetation exerts a strong control on splay morphology (Figure 4c). Nonvegetated splay morphology is smoother, and nonvegetated floodplains tend to favor avulsions. Strongly vegetated floodplains develop more intricate channel patterns and are more efficient in retaining sediment (Figure 4c), in agreement with earlier studies that inferred that vegetation promotes sediment trapping on floodplains and reduces erosion (e.g., Esposito et al., 2017; Schumm & Lichty, 1963). From our morphodynamic simulations we find the highest rate of land growth for intermediate vegetation strengths, similar to the findings from the hydrodynamic simulations of Nardin and Edmonds (2014).

7. Comparison Against Mississippi River Delta Crevasse Splays

From the crevasse splay composition after the breach healed, we find that the throat mostly consists of sand, whereas the rest of the splay is predominantly fine-grained (Figure S5). Excluding the erosional surfaces, about 35% of the crevasse-splay deposit subsides below the original floodplain surface due to soil consolidation, similar to observations from Törnqvist et al. (2008; this is not surprising given that we fitted our soil consolidation curve to their data). Among all healed experiments, sand as a percentage of the total imported sediment varies from 2 to 30% depending on the maximum eroded depth of the crevasse channel. The percentage of imported sediment retained in the splay ranges from 62 to 100%. Esposito et al. (2017) estimated an imported sand fraction of 6.6% and a likely range of sediment retention efficiency between 75 and 100%.

How does the formation time of our simulated splays compare to estimated time scales of crevasse splays in the Mississippi River Delta? The splay studied by Shen et al. (2015) and Esposito et al. (2017; Figure 1) has a volume of $1.6 \cdot 10^8$ m^3 and was formed by a roughly 4 m water level head during floods. Optically stimulated luminescence dating determined that aggradation rates were approximately 0.01–0.10 m yr^{-1} (Shen et al., 2015). If we consider a simulation forced with a 4-m water level head that resulted in a similar splay volume (experiment #6), we find maximum aggradation rates of about 0.5 m yr^{-1}. A likely explanation for the difference in aggradation rates is that natural splays are only geomorphically active for part of the year, whereas we simulate a constant river flood stage. Using the different aggradation rates between the simulated and natural splays, this could imply that the natural splays were geomorphically active 2–20% of the year or, conversely, that our reported time scales could be 1 order of magnitude lower than those for natural crevasse splays.

8. Discussion and Conclusion

In this study we developed and analyzed a morphodynamic levee breach model. For different flood water and floodplain properties, we found that the breach can heal quickly, produce a crevasse splay, or set up an avulsion. We found that the ratio of potential deposition (*D*) versus potential erosion (*E*) of the floodplain is indicative of the floodplain morphologic response to a breach.

Even though many processes in these simulations have been highly simplified, interesting trends have emerged that could be used to interpret floodplain morphologies across and along different alluvial systems. The Mississippi River Delta floodplains, for example, are dominated by crevasse splays (Figure 1). Humphreys and Abbot (1867), in an engineering report discussing embankments along the Mississippi River, estimated that before widespread artificial levee construction, as much as 17% of the flood discharge was lost through breaches. Additionally, we know that the water level head of the channel with respect to the flood basin increases away from the river mouth. Because the water level head exerts a strong control on crevasse splay characteristics through the *D*/*E* ratio (equation (1)), we would expect crevasse splays to become larger farther upstream, up to a point where the water level is high enough (and *D*/*E* is low enough) to promote an avulsion. Such trends could be upset, however, if, for example, floodplain erodibility is variable along the river. Avulsions would be more likely in the presence of easily erodible sand bodies in the subsurface, thereby reactivating previous courses (e.g., Aslan & Blum, 1999; Morozova & Smith, 1999; Stouthamer, 2005).

Although several aspects of our modeling study were inspired by observations from the Mississippi River Delta, we note that the general, qualitative evolution of levee breaches can be applied more broadly. The Yellow River, for example, has sediment concentrations orders of magnitude higher than the Mississippi River (increasing *D*) and is also elevated higher with respect to its floodplain (increasing *E*; Chen et al., 2015), such that the resulting breach behavior (governed by *D*/*E*) could be similar. However, there is limited documentation that points to the formation and maintenance of crevasse splays, whereas numerous breaches have been documented in the last millennia that appear to be either short-lived or long-lived (avulsion; Chen et al., 2015). This could be caused by intensive anthropogenic modification, or, alternatively, by a relatively high mud load (uniform vertical distribution) compared to sand load (Rouse profile distribution), that affects crevasse stability (see also Slingerland & Smith, 1998). Future work should involve more refined boundary conditions that would allow us to investigate floodplain sedimentation in a broader range of river systems.

In part due to our simplified treatment of boundary conditions, we kept the vegetation dynamics simple without any seasonal or lateral growth characteristics. Additionally, particularly for the simulations resulting in an avulsion, we assumed that the floodplain is well drained. During high discharge through the breach, poorly drained floodplains will flood such that both the proximal as well as the distal boundary water level will increase. We also did not simulate a river hydrograph, even though alternating periods of high and low discharge are important for avulsions and crevasse splay persistence (Fisk, 1952).

Despite these limitations, several of the complex, nonlinear relationships shown here between floodplain properties and crevasse splay morphology have implications for sediment diversions, for example, those planned in the Mississippi River Delta (Coastal Protection and Restoration Authority, 2017). The geomorphic evolution of these diversions remains uncertain, as does their ability to form land and maintain a channel network that will prevent distal aggradation from silting up the diversion channel. Even though the diversion design efforts have been aimed at maximizing the sediment concentration (Gaweesh & Meselhe, 2016), we find that this, through its effect on *D*/*E*, does not necessarily lead to more land growth. Instead, high sediment concentrations can lead to diversions that silt up quickly and produce limited outfall area land gains (Figure 4a).

Successful diversions, cast in terms of land building potential, sediment retention efficiency, or land building efficiency, require a delicate balance determined by the potential for erosion (*E*) and deposition (*D*) in the outfall area. Both soil consolidation and vegetation should neither be absent nor maximized to enhance diversion outcomes. A healthy vegetation cover and some soil consolidation both lead to the largest land area gain. Idealized model experiments like the ones presented here could help inform management decisions (for example, stage height during opening) and test diversion objectives.

In conclusion, we present a simple levee breach model that shows a strong nonlinear floodplain morphologic response to floodplain and levee breach properties. We find a significant effect of vegetation and soil consolidation on crevasse splay morphology. These results could aid restoration efforts to maximize floodplain sedimentation and help keep low-lying areas above sea level.

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