Supplement 1.
Duration and characteristics of fluvial regime – discharge and sediment transport – related to mouth-bar deposition in organic-clastic lake fills

There is a strong relation between the characteristics of fluvial channels – sediment supply and period of activity – and the sediment bodies they produce upon debouching into, for example, a lake. In order to calculate minimum timescales for delta sedimentation from alluvial architecture – e.g., width/thickness ratio, deposited sediment volume - a number of computations have to be made, primarily based on fluid dynamics. The relevant equations (numbers refer to those as used by Kleinhans 2005) are discussed below and are embedded in a more fundamental context in a publication by Kleinhans (2005). A brief overview of the parameters used in the model (Supplement 3) is given in Table 1.

Flow computations
Water flow through a channel can be characterized by a set of parameters such as discharge, flow velocity, hydraulic roughness, Reynolds and Froude numbers and bed shear stress.
Discharge (*Q*) is the product of the channel width (*W*), channel depth (*h*) and the flow velocity (*u*) averaged over the width and depth of the channel:

$$Q = hWu \tag{1}$$

The hydraulic radius instead of water depth is used to account for the effect of banks on the water depth and is expressed as

$$R_h = \frac{Wh}{W + 2h} \tag{2}$$

The flow velocity, averaged over the depth and width, is given by the Darcy-Weisbach equation:

$$u = \sqrt{\frac{8ghS}{f}} \tag{3}$$

where g = the acceleration due to gravity, h is depth (hydraulic radius) and S = water surface slope or channel bed surface, given that the flow is steady and uniform. f = the friction factor, which is a measure for the hydraulic roughness.
Hydraulic roughness is very relevant for flow calculations as it determines the water depth. However, it is hard to determine as it depends on complexly interacting variables such as flow turbulence and roughness elements on the channel bed (e.g., grains and bed forms). A widely used predictor for the friction factor is the White-Colebrook friction law:

$$\sqrt{\frac{8}{f}} = 5.74\log_{10}\left(12.2\frac{h}{k_s}\right) = 5.74\log_{10}\left(\frac{h}{k_s}\right) + 6.24 \tag{8}$$

where k_s = Nikuradse roughness length, which depends on characteristics of the grain-size distribution (e.g., D_{50}) or on bed-form height.
The Reynolds and Froude numbers describe two elementary characteristics of flow. The Reynolds number differentiates between laminar and turbulent flow and relates to the flow velocity (*u*), water depth (*h*) and the fluid viscosity (υ) as

$$\mathrm{Re}_f = \frac{uh}{\upsilon} \tag{14}$$

For $Re_f > 500$, flow is turbulent, which is valid for all rivers.
The Froude number indicates whether flow is subcritical ($Fr < 1$) or supercritical ($Fr > 1$).

$$Fr = \frac{u_c}{\sqrt{gh}} \tag{15}$$

where u_c = critical flow velocity.

Table 1. overview of the input and calculated parameters in the model (Supplement 3).

symbol	*units*	*line*	*description*
Parameters and variables			
g	m/s2		Gravity
W	m		Width of channel
h	m		Depth of channel
S	m/m		Slope upstream channel
k_s	m		Nikuradse roughness length
	kg/m3		Fluid density
	Centigrade		Fluid temperature
	-		Dynamic viscosity
	-		Kinematic viscosity
D_{50}	m		Median grain size
D_{90}	m		90^{th} percentile grain size
	kg/m3		Sediment density
λ			Porosity
Discharge calculations			
Rh	m		Hydraulic radius (eq. 2 Kleinhans)
	-		Width/depth ratio
f	-		Friction factor (eq. 8 Kleinhans)
u	m/s		Velocity (eq. 3 Kleinhans)
Fr	-		Froude number (eq. 15 Kleinhans)
Re	-		Reynolds number (eq. 14 Kleinhans)
Qw	m3/s		Discharge (eq. 1 Kleinhans)
Bed-load transport			
f'	-		Grain friction factor (eq. 8 Kleinhans)
τ'	Pa		Grain shear stress (eq. 17 Kleinhans)
θ'	-		Shields parameter (grain related) (eq. 22 Kleinhans)
	-		Shields criterion for incipient motion
Φ_b	-		Non-dimensional transport rate (eq. 30 Kleinhans)
R	-		Relative submerged density (in eq. 20 Kleinhans)
	m2/s		Specific volumetric transport rate
q_b	m3/yr		Volumetric transport rate
	-		Water/sediment ratio
	-		Total/bedload ratio
Total load transport (suspension dominated)			
τ	Pa		Total shear stress (eq. 16 Kleinhans)
θ	-		Shields parameter (total) (eq. 22 Kleinhans)
Φ_s	-		Non-dimensional total transport rate (eq. 37 Kleinhans)
	m2/s		Specific volumetric transport rate (eq. 29 Kleinhans)
q_s	m3/yr		Volumetric transport rate
	-		Water/sediment ratio
Erosion/sedimentation			
	m2		Deposited sediment delta surface
	m3		Deposited sediment delta volume (sand)
	m3		Deposited channel-belt volume (sand)
Time-scale of formation assuming bed-load			
	yr		Delta volume/bed-load flux
	yr		CB volume/bed-load flux
Time-scale of formation assuming suspended load			
	yr		Delta volume/total sediment flux (~eq. 54 Kleinhans)
	yr		CB volume/sediment flux

The bed shear stress affects sediment transport and is defined as

$$\tau_c = \rho u^{*2} = \rho g h \sin S \tag{16}$$

in which ρ = fluid density (1000 kg/m^3 for fresh water), u^* = flow velocity and S = channel gradient. If u is written as the Darcy-Weisbach equation (eq. 3), the bed shear stress relates to the hydraulic roughness as follows

$$\tau_c = \frac{1}{8}\rho f_c u_c^2 \tag{17}$$

The bed shear stress may be divided in two components: bed-form related and grain-related. Of these two, only grain-related bed shear stress is relevant for sediment transport, which can be calculated from equation (17) where the friction factor (f) is defined by the White-Colebrook friction law (eq. 8). The hydraulic roughness length is commonly chosen as $k_s = 2.5D_{50}$ (Kleinhans 2005).

Sediment mobility

Preferentially, non-dimensional variables and parameters are used to describe bed-load sediment transport. These variables either describe the flow or the sediment size. The grain size is described by

$$D^* = D_{50}\sqrt[3]{\frac{Rg}{\upsilon^2}} \tag{20}$$

where $R = (\rho_s - \rho)/\rho$ is relative submerged density, ρ = the liquid density and ρ_s is the sediment density (2650 kg/m3 for quartz sand).

Commonly applied flow parameters are based on current velocity, shear stress (τ) and grain shear stress (τ', only skin friction). The shear stress is represented by the non-dimensional "Shields parameter":

$$\theta = \frac{\tau}{(\rho_s - \rho) g D_{50}} \tag{22}$$

which also is valid for grain shear stress (θ').

Sediment transport

Non-dimensional sediment transport is defined as

$$\phi = \frac{q_{b\ or\ s}}{(Rg)^{1/2} D_{50}^{3/2}} \tag{29}$$

wherein $q_{b\ or\ s}$ = bed load or suspended-load sediment transport rate (m^2/s, cubic m per m width per second) excluding pore space.

A predictor for bed-load sediment transport near the beginning of motion was derived by Meyer-Peter and Mueller (1948)

$$\phi_b = 8(\theta' - \theta_{cr})^{1.5} \tag{30}$$

A well-known predictor for suspended-load sediment transport has been published by Engelund and Hansen (1967) and is given below

$$\phi_s = \frac{0.4}{f}\theta^{2.5} \tag{37}$$

wherein Φ_s = non-dimensional suspended-load sediment transport and f = Darcy-Weisbach coefficient related to the total roughness.

Timescale of channel and delta formation
The minimum timescale of delta/channel formation is defined by

$$T_s = \frac{V_s}{(1-\lambda)Q_s} \tag{54}$$

wherein V_s = volume of sediment (including pores), which is either eroded from a channel or deposited in a delta and $Q_s = (q_b + q_s)W_s$ with W_s = width that part of the channel floor that transports sediment (Kleinhans 2005).

Input parameters and variables

W = 180 m. This is the minimum width of the channel belt and consequently the maximum width of the palaeochannel, which is measured on a recent geological-geomorphological map of the area (Fig. 5B in main manuscript).
h = 8 m. Only 3 corings penetrated the channel belt of the Angstel, recovering channel-belt deposits that were 6.0, 9.1 and 10.3 m thick.

S = 3.6 cm/km. The slope of the upstream channel was derived from the Gradient of the Top of Sand (GTS) of the channel belt deposits of the Aa and Angstel (Fig. 1). Berendsen (1982) showed that GTS lines can be used to approximate the gradient of palaeochannels. We selected all corings that recorded the top of Aa or Angstel channel-belt deposits (n=103). Within sections of 2 km along the palaeochannel – as measured along abandoned channel deposits – the point with highest detected channel-belt sediment was selected. These points (n=10) were plotted as a function of the distance from Utrecht along the paleo channel. The gradient of the trendline was used as gradient of the palaeochannel.
Although R^2 of the trend line is relatively low (0.27), a gradient of 3.6 cm/km is not unusual for channels in distal parts of delta plains. Values between 3.0 and 10 cm/km (Makaske et al. 2007; Törnqvist et al. 1993) were reported for palaeochannels in the Rhine-Meuse delta.

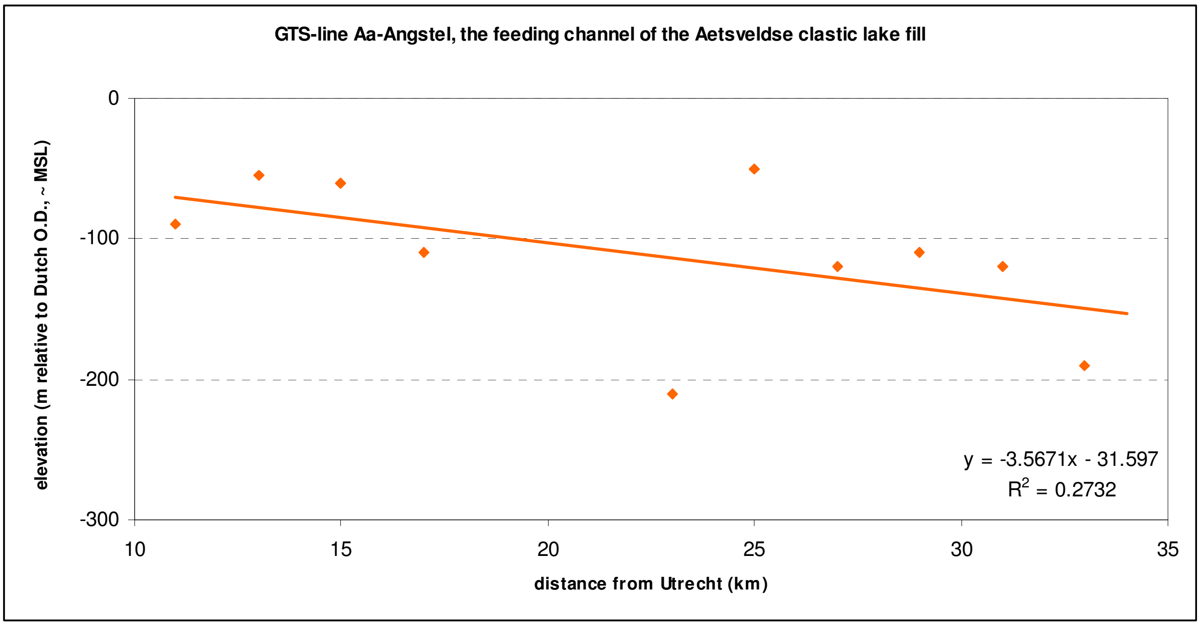

Figure 1. GTS-line of the Aa-Angstel.

λ ~ 34% for Holocene channel-belt sediment in the Rhine-Meuse delta (Weerts 1996).

Water temperature = 10.4 °C. This is the 1909-1910 average (based on daily measurements), which are the earliest documented measurements (Rijkswaterstaat 2009) of water temperature in the Rhine.

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