Supplemental Material

Doomed to drown? Sediment dynamics in the human-controlled floodplains of the active Bengal Delta

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Model theory

AquaTellUs determines a preferential flowpath through a digital elevation model by calculating a steepest descent pathway, and thus defines the boundary condition for a 2D longitudinal channel belt profile:

$$H(x,t) = f(x)$$

Subsequently, we define change in elevation, H, over time, t, as a direct function of the depositional flux.

$$\frac{\partial H_x}{\partial t_x} = \frac{\partial F_x}{\partial x} + T$$

Whereas the rate of elevation change due to tectonic movement, T, is an additional important control in any evolving landscape, it is ignored for the applications in this paper. Net depositional sediment flux, F, at any given longitudinal location along a channel belt depends on both the erosion within the river channel, F_{ero}, and the local depositional sediment flux, F_{sed}.

$$\frac{\partial F_x}{\partial x} = \frac{\partial F_{ero}}{\partial x} - \frac{\partial F_{sed}}{\partial x}$$

Erosion follows classic geomorphological landscape evolution approaches, and depends on sediment substrate erodibility, k_{ero}, and streampower, u, i.e., the product of water discharge Q and channel belt slope raised to a pre-defined power, S^m.

$$\frac{\partial F_{ero}}{\partial x} = k_{ero} S^{m} Q(x,t)$$

Substrate erodibility, $k_{ero,}$ is kept constant within the respective domains, implying that under flood event conditions all sediment grainsize classes are rapidly eroded. The coefficient m is set to equal 1 within the fluvial domain, effectively making erosion linearly dependent on longitudinal slope. Upon entering the receiving marine basin m is set to 0, which implicitly causes erosion to be slope-independent in the nearshore and shallow marine domain.

We conceptualize local sedimentation, F_{sed}, as a first-order kinetic reaction, which dictates that sedimentation is proportional to the sediment load of the water, F. At any given location, the sediment load in the water is the sum of eroded sediment, F_{ero} and the incoming riverine sediment load, F_{in}. Sediment bypass, F_{out} , is the bedload and suspended sediment remaining in transport, which travels further downstream.

$$F = F_{in} + F_{ero} = F_{sed} + F_{out}$$

We assume that deposition varies with grain size of the sediment load in transit.

$$\frac{\partial F_{sed}}{\partial x} = \frac{F(x,t)}{h_D}$$

The travel distance, h_D, is set to be dependent on grain size D, where coarse sediments have a limited travel distance, and fine sediment can travel far along the transport pathway. Distinctly different depositional regimes, as reflected in the associated travel distances, are defined for fluvial and marine domains (Table S2).

Travel distances for six grainsize classes initially were calibrated from field observations (Overeem et al., 2003) and subsequently re-calibrated against experiments with the physics-based Delft3D model (Hoogendoorn et al., 2008). These travel distances are used in a generic way across any river and delta system, since they reflect the inverse probability of deposition with distance and are thus controlled to the first-order by grainsize of the sediment being transported.

The net sediment flux as determined along the longitudinal profile is subsequently deposited unto the floodplain with lateral distance with respect to the channel belt, wherein lateral distance is determined by flood magnitude and sediment grainsize in suspension. Sedimentation is generally described to be high directly in and adjacent to the channel belt, whereas deposition decreases with distance. Empirically, this pattern has been quantified as an exponential decrease with distance [*Pizzuto*, 1987]. However, spatial variability may be significant as observed from sediment traps (Middelkoop and Asselman, 1998). Thus, deposits of sequences of flood years with variable magnitude can alternatively be described as a Gaussian distribution as originally proposed by *Paola* [2000]:

$$F(y) = \frac{1}{\sqrt{2\pi\sigma}} e^{\frac{-(y-\mu)^2}{2\sigma^2}}$$

Wherein y is the distance normal to the flowpath, σ is the standard deviation across the sedimentation zone and μ is set at the channel belt axis. Relative sedimentation at any distance from the channel belt is then resolved by using an error function:

$$\mathrm{erf}(y) = \frac{2}{\sqrt{\pi}} \int e^{-y^2} dy$$

In this formulation, relative total sedimentation is predicted by solving the error function, but we assume the coarsest sediments are deposited closest to the channel axis, whereas fine sediment travels further into the floodplain using the same concept of the travel distance in the lateral domain. Travel distances (for the fluvial domain) are listed in Table S2.

Channel switching occurs when entirely new channel belt pathways are determined stochastically, but driven by both allocyclic and autocyclic controls. We assume an initial trigger is required to generate an initial 'levee breach' in the apex region, these breaches are thought to be more likely to occur in high monsoonal river discharge years. Monsoonal average river discharge is varied interannually by using a stochastically sampled number from a uniform distribution within a prescribed range, the so-called climate factor. We then employ a stochastically controlled 'switching factor' that generates a threshold. This threshold factor needs to be exceeded by the particular flood magnitude of the given monsoonal season to trigger determination of a new channel pathway. However, the new pathway can possibly reoccupy the previous pathway, and that is not entirely unlikely because the tread of the channels has usually eroded into the floodplain. However, reoccupation is especially likely when sedimentation in the apex region has been limited and no superelevation of the channel belt has been generated, so there is no need to find a new steepest descent pathway. In combination, the modeled channel belt location remains stable over many flood seasons, but its location will more likely switch in peak flood years and in high sediment regimes (Overeem et al., 2005; Chen et al., 2015).

Table S1. Variables used in AquaTellUs

Symbol	Definition	Unit
H	Elevation	M
T	Time	S
X	Location along a longitudinal profile	M
F	Sediment load in the water	m^2s^{-1}
T	Rate of tectonic movement	ms^{-1}
F_{ero}	Channel erosion flux	m^2s^{-1}
F_{sed}	Net depositional flux	m^2s^{-1}
F_{in}	Incoming sediment flux	m^2s^{-1}
F_{out}	Bypassing sediment flux	m^2s^{-1}
S	Slope	$m\ m^{-1}$
M	Constant	
Q	Peak flood discharge	m^3s^{-1}
k_{ero}	Erodibility	
h	Travel distance	M

Table S2. Experimental Setup

General		
Simulation Duration	50	Years
Time step	1	Year
Number of grid rows	180	-
Number of grid columns	120	-
Gridcell dx	500	m
Gridcell dy	500	m
Initial height at upstream end of floodplain	7	m
Initial floodplain slope	0.05	m
Initial marine slope	0.15	m
Grainsize	0.4, 0.06, 0.002	mm
Fraction in each grainsize class	0.3 ,0.2, 0.5	
Grain density	1800, 1950, 2000	kgm-^{3}
Travel distance in fluvial domain (Hf)	8000, 24000, 65000	m
Travel distance in marine domain (Hm)	2000, 6500, 20500	m
Erosion Proportionality Constant in Fluvial Domain	0.00002	-
Erosion Proportionality Constant in Marine Domain	0.0000001	-
Climate Factor for Interannual variation in River Discharge	0.7-1.3	-
First-order Channels		
River Discharge	1500	m^{3} s^{-1}
Suspended Sediment Concentration	8	kg m^{-3}
Second-order Channels		
River Discharge	500	m^{3} s^{-1}
Suspended Sediment Concentration	8	kg m^{-3}

Table S3. Beryllium-7 results and locations for recovered trap and surface samples. BD = Below Detection. No surface samples were taken at sites that were eroded or inaccessible.

Sample name	Lat/Long	Be-7 (dpm/g)	std dev
5.1.A	22°42'37.21"N 90°29'4.14"E	0.63	0.24
5.1.B	22°43'56.83"N 90°28'54.75"E	BD	BD
5.1.C	22°43'49.84"N 90°28'48.33"E	1.88	0.74
5.1.D	22°43'22.25"N 90°29'6.37"E	BD	BD
5.2.C	22°48'46.32"N 90°37'37.93"E	1.64	0.87
5.2.D	22°48'48.02"N 90°37'44.88"E	BD	BD
5.3.B	22°49'50.04"N 90°29'58.35"E	0.76	0.34
6.1.A	22° 0'4.01"N 90°37'25.65"E	1.36	0.57
6.1.D	22° 1'48.13"N 90°38'21.25"E	2.64	0.79
6.2.B	22° 1'37.57"N 90°40'37.26"E	0.63	0.76
6.2.C	22° 1'36.48"N 90°40'36.26"E	1.01	2
6.2.D	22° 1'33.25"N 90°40'40.23"E	BD	BD
6.3.A	22° 5'20.89"N 90°41'30.10"E	0.36	0.37
6.3.B	22° 5'22.09"N 90°41'29.90"E	0.87	0.62
6.3.C	22°42'44.37"N 90°31'45.77"E	0.46	0.43
7.1.A	22° 4'39.10"N	0.27	0.62

	90° 5'33.60"E		
7.1.B	22° 4'38.24"N 90° 5'38.61"E	0.90	0.5
7.1.C	22° 5'39.01"N 90° 5'28.50"E	1.89	1.67
7.1.D	22° 5'39.70"N 90° 5'30.13"E	0.83	0.85
7.2.A	21°59'3.60"N 90° 3'24.35"E	BD	BD
7.2.B	21°59'2.85"N 90° 3'23.01"E	0.34	0.54
7.2.C	21°59'1.84"N 90° 1'34.50"E	0.56	0.26
7.2.D	21°59'8.78"N 90° 1'32.90"E	1.24	0.33
7.3.A	21°59'7.92"N 90° 1'34.73"E	0.58	0.28
7.3.B	22° 1'26.74"N 90° 2'30.38"E	1.04	0.49
7.3.C	22° 1'26.75"N 90° 2'29.13"E	1.42	1.15
8.1.A	22°28'38.72"N 89°59'55.80"E	0.25	0.24
8.1.C	22°28'37.12"N 89°59'54.36"E	0.42	0.19
8.2.A	22°29'3.31"N 89°59'26.47"E	0.40	0.49
8.3.B	22°30'21.45"N 89°57'52.72"E	0.19	0.16
8.3.D	22°30'19.74"N 89°57'52.06"E	0.40	0.25

References

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