SUPPLEMENTARY MATERIAL: Morphodynamic model calibration

1. Morphodynamic simulations

Calibration of the morphodynamic model consisted on the adjustment of the model parameterization so that the model output geometries matched the measured bedform geometries as well as possible. The model applied an "upwind" bed update scheme, where the elevation of the bed was dynamically updated at each computational time step. In all simulations, the initial boundary conditions of the input and output sediment transport load amount were defined as 0. This is because the flood events started from 0, and no significant transport, i.e. evolution of bedforms was observed upstream and downstream of the simulation area. The model then calculated the transport based on the selected transport equations and using equilibrium concentration for carrying input sand sediment fractions. This was similar to earlier studies done in gravel bed river (Williams et al., 2016b), and was selected based on earlier experiences of the river (Calle et al., 2015), and because no suspended load measurements were available and the sand sediment fraction was almost non-existent in the river. Based on the experience in the study site, the load should be in equilibrium particularly in erosional areas of the study site.

Altogether, 61 morphodynamic simulations were needed for calibrating the morphodynamic model. These 61 simulations included simulations with Qx1.3, Qx2 and Qx2.5 discharge hydrographs. During these simulations the match of the simulated water levels to HWMs was also checked. The roughness values were still valid. Out of these 61 morphodynamic simulations, 11 simulations, which produced the best correspondence to the observed channel evolution, were selected to be presented in this paper's supplementary material of morphodynamic model calibration (Tables 1 and 2). Due to the better correspondence of simulations with Qx2 discharges to observations (see also the main manuscript), all these selected morphodynamic simulations had these input data. All simulations with Qx1.3 and Qx2.5 discharges were discarded as those did not reproduce the correct topographical changes. The 11 selected simulations showed the effects of grain size (before [2012] and after [2014] floods, and grain sizes from different layers [2014]), grid size (coarse: 1.51–5.31 m, fine: 0.76–3.03 m), transverse slope (user defined coefficients in the bed load transport equations: default 1.5 and increased to 3) and transportation equations (Engelund-Hansen [EH], Meyer-Peter and Müller [MP]) on model performance (Tables 1 and 2). These parameter tests were selected for the calibration procedure, as these have earlier been found important for Delft3D (2D implementation) model simulations, albeit in perennial rivers (e.g. Kasvi et al., 2014). The morphodynamic simulation results were compared to the measured topographies within the calibration area (Figures 1–3), in particular to the volumetric change of river bed and displacement of the lobe front (Table 3). The model was first calibrated with March 2013 discharge event (simulations 1–11), and then verified with May 2013 discharge event (simulations 9–11).

Different input grain size distributions were applied in the model tests (Tables 1–3, and see also the main paper document): 1) spatially varying upper layer grain sizes, 2) spatially varying sublayer grain sizes and 3) constant average grain sizes (average of upper layer, sublayer or both upper layer and sublayer). The values were applied to the whole active layer of the river bed. The D50 grain size values were used in the model.

Orthogonalized curvilinear grids of two different resolutions were created from both measured topographies, one with “coarse” 1.51–5.31 m cells and one with “fine” 0.76–3.03 m cells (i.e. circa half of the coarser grid cell sizes) (see also the main paper document). These cell sizes were selected for testing the impacts of cell sizes on simulation results, but also due to their computational effectiveness. Cell sizes smaller than the “fine” resolution (i.e. 0.76–3.03 m) did not enhance the results, and those only increased the computational time. Thus, curvilinear grids of two resolutions, “coarse” 1.51–5.31 m cells and “fine” 0.76–3.03 m cells, were created from the topography measurement times.

Table 1. The morphodynamic simulations and applied parameters. The fine grid size is 0.76–3.03 and the coarser size is 1.51–5.31 m.EH=Engelund-Hansen, MPM=Meyer-Peter and Müller. Events: 1=only the March 2013 event was simulated, 2=both the March and May 2013 events were simulated. The simulations that were selected for the hourly channel change analyses, and to be presented in the main document of this paper, are in bold.

Simulation	Transport equation	Discharge events	transverse slope	grid size	grain size
1	EH	1	1.5	coarse	varying, 2012
2	EH	1	1.5	fine	varying, 2012
3	EH	1	1.5	coarse	varying, upper, 2014
4	EH	1	1.5	coarse	varying, sub, 2014
5	EH	1	1.5	coarse	varying, average upper+sub, 2014
6	EH	1	1.5	coarse	constant, average upper, 2014
7	EH	1	1.5	coarse	constant, average sub, 2014
8	EH	1	1.5	coarse	constant, average upper+sub, 2014
9	**EH**	**2**	**3**	**fine**	**varying, upper, 2014**
10	**EH**	**2**	**1.5**	**fine**	**varying, upper, 2014**
11	MPM	2	1.5	fine	varying, upper, 2014

Table 2. The simulations used for comparing the effects of different parameters on model performance. x = parameter tested in the simulation.

Simulation	Tested parameters: grid size effect	grain size effect: before (2012) & after flood (2014)	grain size effect: different layers	grain size effect: constant vs. varying	transverse slope effect	transportation equation effect
1	x	x				
2	x	x				
3	x	x	x			
4			x			
5			x	x		
6			x			
7			x			
8			x	x		
9					x	
10	x	x			x	x
11						x

Because the bed level gradient affects the bedload transport, the slope in the initial direction of the transport (referred to as the longitudinal bed slope) and the slope in the direction perpendicular to that (referred to as the transverse bed slope) were utilised. The transverse slope affects transport towards the downslope direction (Deltares, 2011). The Bagnold (1966) equation was applied for the longitudinal slope and Ikeda (1982), as presented by Van Rijn (1993), was applied for the transverse slope. The longitudinal slope was tested with both the default value (1.0) and double the default value (2.0). However, the longitudinal slope did not affect the results, and it was decided that the default value 1.0 would be used in the selected simulations, which are shown in Tables 1–3. Due to the great effects caused by the transverse slope on the morphodynamic simulations of perennial rivers (e.g. Kasvi et al. , 2014), we were particularly interested in the effects of this transverse transport component on the ephemeral river simulation, and thus tested the model with the component being 3.0, which is double the default value (1.5). These values were defined based on earlier publications (e.g. Kasvi et al., 2014).

Earlier simulations done for ephemeral rivers, e.g. Hooke et al (2005) and Graf (1996), had applied the Bagnold (1966) total load equation. However, Meyer-Peter and Müller (MPM, 1948) equation had previously been proven to perform well, i.e. better than, for example, Bagnold 1980 and Parker (1990) equations in flash flood simulations and in ephemeral gravel river channels (Reid et al., 1996; Cao et al., 2010). The widely applied equations of "Engelund-Hansen 1967" (EH) and "Meyer-Peter and Müller 1948" (MPM) were selected from the Delft3D model's assortment of equations (cf. Deltares, 2011), because they had been developed by using initially non-armoured bed conditions and were the most appropriate for the study area, according to the D_{50} grain sizes. The MPM was expected to perform the best, as it had originally been developed for particles of 0.4–29 mm overall diameters. The EH was selected as the total load equation, due to its proven performance in a variety of environments (e.g. Kasvi et al. 2014), even though it had originally been tested on up to 0.93 mm median particle sizes (Engelund and Hansen, 1967).

2. The morphodynamic model's calibration results

2.1 Effects of applied grain size on simulation results

The grain size and its spatial variation affected the model results greatly and needed the largest number of tests during the calibration of the model (Tables 1–3, Figures 1–3). This was first analyzed by comparing the measured and simulated topographies and volumetric changes produced by the March 2013 flow. When the spatially varying upper layer sediments (representing the sediments actually moved by the two discharge events, i.e. the ones measured after floods in 2014) were used in the simulation (number 10), the volumetric changes were less and fitted the observations better than if spatially varying "before floods" grain sizes of 2012 were applied (simulation 2). The effects of spatially varying sublayer grain sizes (simulation 4) and spatially varying upper layer grain sizes (simulation 3) were compared: the deposition increased by 352 m^3 when applying spatially varying sublayer grain sizes. The bedforms were also represented better with upper layer sediments. When the spatially varying average grain sizes (average of the upper and sublayer grain sizes) were applied, the simulation (number 5) resulted in a slightly greater deposition than with spatially varying upper layer grain sizes (simulation 3, Table 3). When the constant grain sizes were applied (simulation 8), the deposition was greater and resembled the observations better than a corresponding simulation with spatially varying grain sizes (simulation 5), but the erosion was also greater and thalweg was excavated too deep with constant grain sizes (simulations 6–8). Altogether, the spatially varying upper layer grain sizes (measured in 2014), which were known to have been moved by the discharge events, resulted in the most realistic results.

Table 3. The evaluation of modelled volumetric changes and lobe movement, in comparison to observations. Based on the performance analyses of the model during March 2013 event's simulations, the May 2013 discharge event was only simulated with a fine grid cell size, and using upper layer sediments measured in 2014 (cf. Table 1). The simulations that selected for the final hourly channel change analyses are bolded. Gravel storage was calculated by subtracting the erosion from deposition.

		1. peak (March 2013)							2. peak (May 2013)						
		erosion		deposition		Gravel storage			erosion		deposition		Gravel storage		
sim	grid	total m^3;	difference compared to observed %	total m^3	difference compared to observed %	total m^3	difference compared to observed %	lobe move-ment (m)	total m^3	difference compared to observed %	total m^3	difference compared to observed %	total m^3	difference compared to observed %	lobe move-ment (m)
obs	coarse	89.12	0	1252.07	0	1162.95	0	58.5							
obs	fine	154.56	0	984.72	0	830.16	0	58.5	63.67	0	1087.59	0	1023.93	0	87.1
1	coarse	267.56	+200	1071.39	-14	803.84	-31	40.6							
2	fine	286.24	+ 85	1332.00	+35	1045.76	+26	69.4							
3	coarse	204.46	+129	878.29	-30	673.83	-42	47.9							
4	coarse	155.74	+75	1230.63	-2	1074.89	-8	47.9							
5	coarse	204.46	+129	992.51	-21	788.05	-32	47.9							
6	coarse	210.67	+136	992.72	-21	782.05	-33	47.9							
7	coarse	210.28	+ 136	1245.12	-1	1034.84	-11	42.5							
8	coarse	185.33	+108	1106.06	-12	920.73	-21	40.23							
9	**fine**	**164.69**	**+7**	**1119.28**	**+14**	954.59	+15	**59.9**	**182.53**	**+187**	**1222.32**	**+12**	**1039.79**	**+2**	**61.3**
10	**fine**	**178.69**	+16	**1190.85**	**+21**	1012.16	+22	**52.1**	**160.09**	**+151**	**1289.38**	**+19**	**1129.29**	**+10**	**79.5**
11	fine	6.50	- 96	30.38	-97	23.88	-97	3.7	31.14	-51	58.14	-95	27.00	-97	3.7

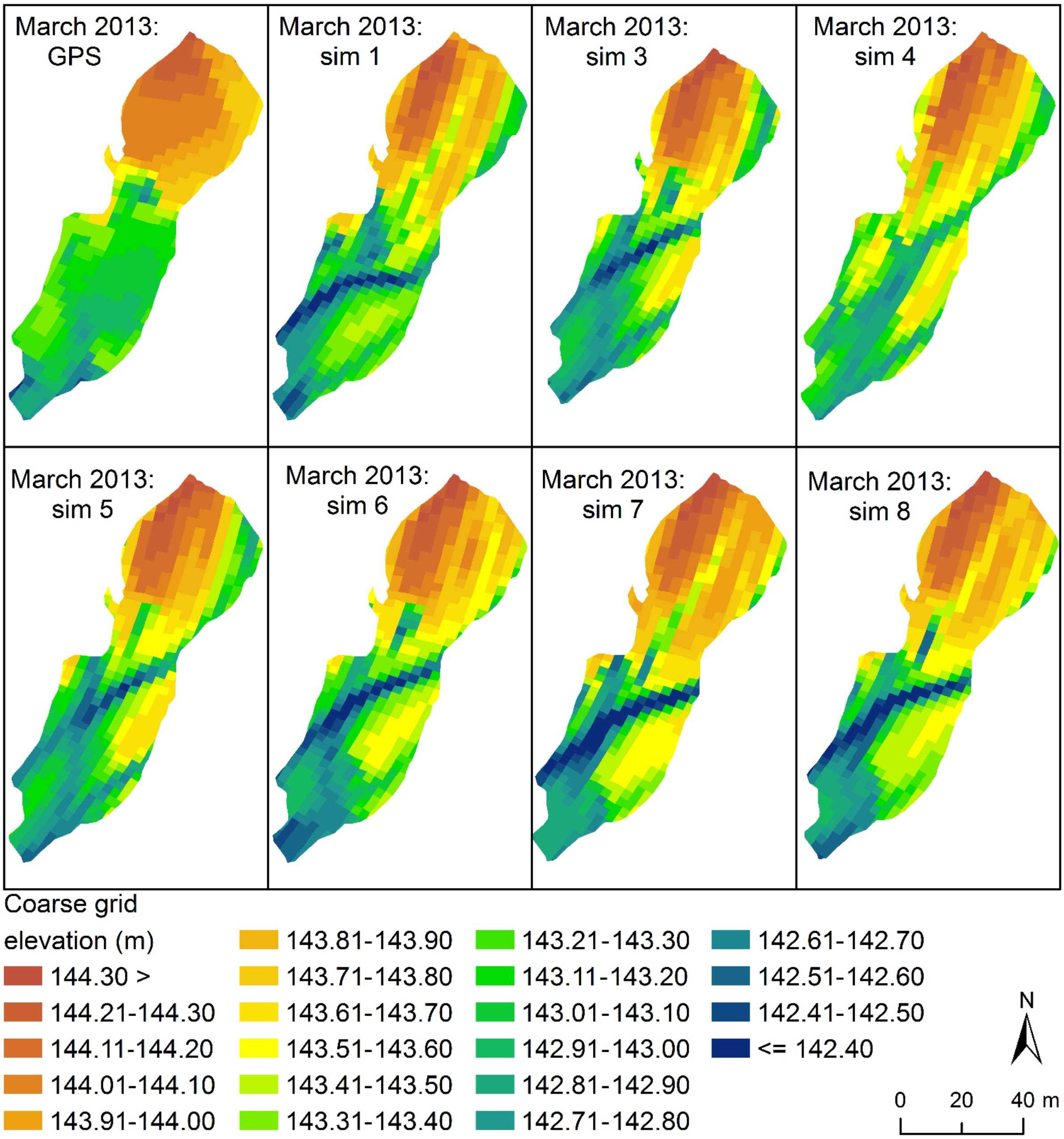

Figure 1: The bed elevations after the first March 2013 flow event (see simulation parameters from Table 1). The comparisons of the channel-bed elevations of the "calibration area" (see Figure 1 of the paper). The coarse grid cell sizes were applied in these simulations.

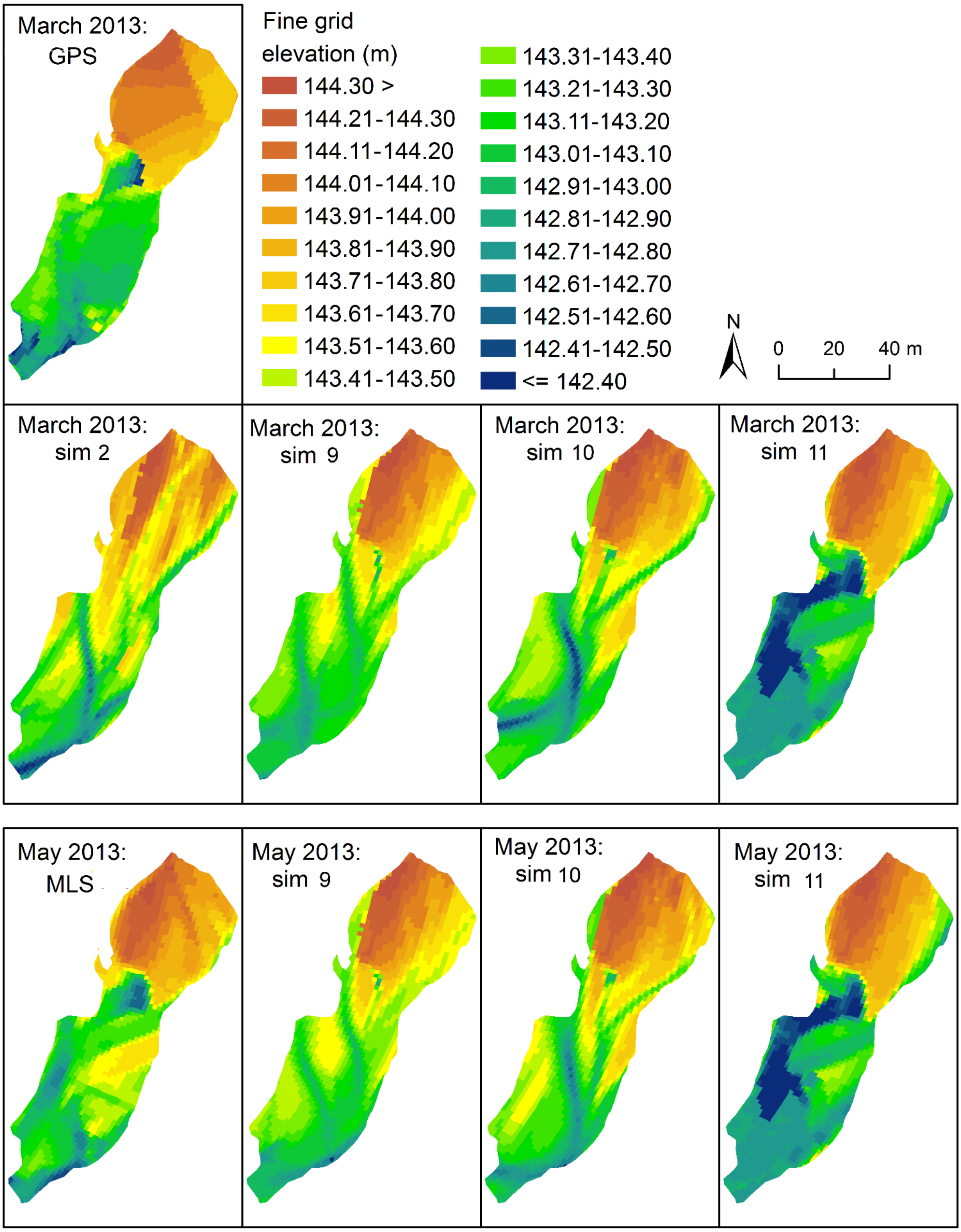

Figure 2: The bed elevations after the March and May 2013 flow events: The fine grid cell sizes were applied (see simulation parameters from Table 4). The comparisons were made against the bathymetries made, based on March 2013 GPS survey and June 2013 laser scanning data of the "calibration area" of Figure 1 in research paper.

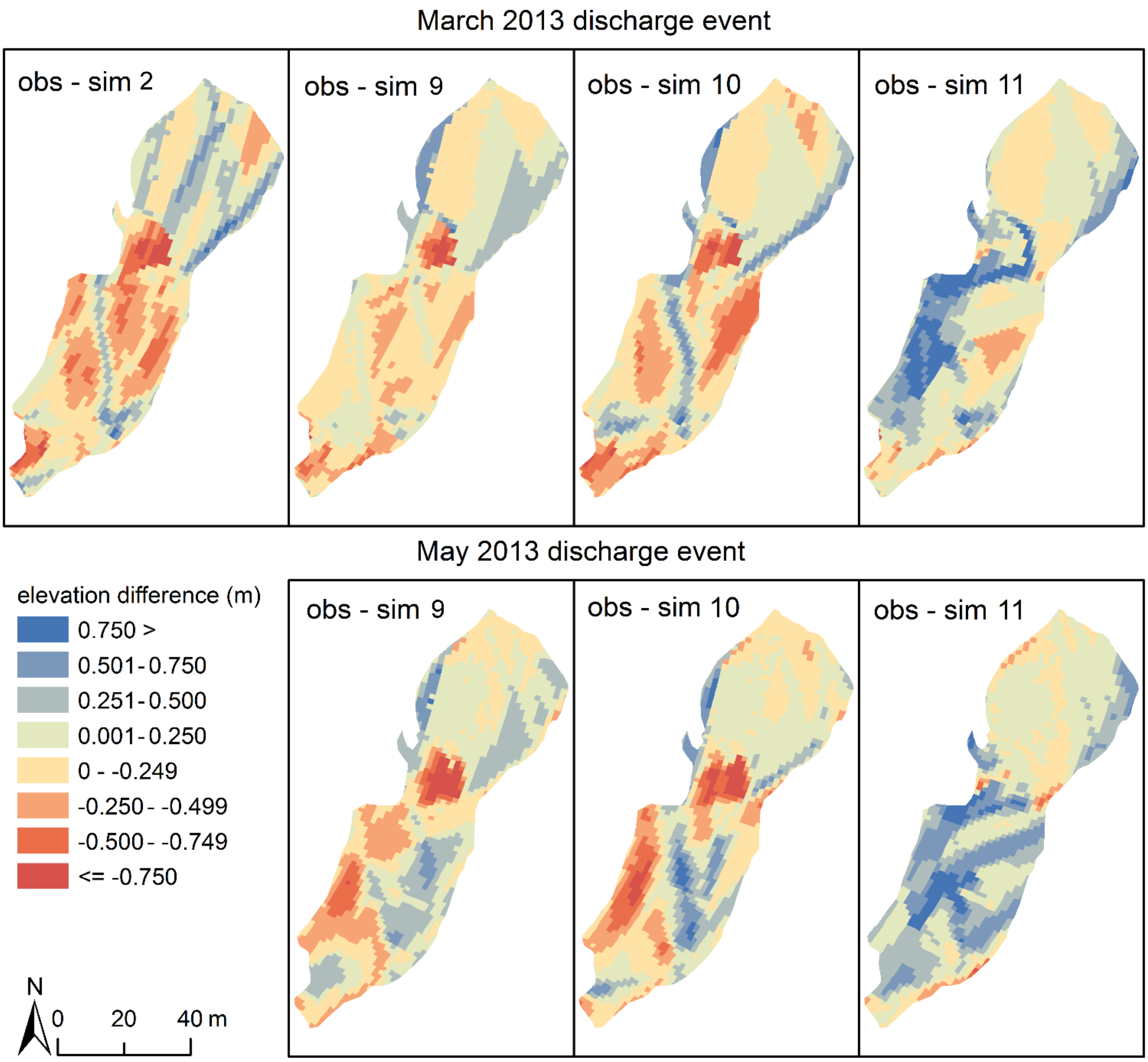

Figure 3: The comparison between the observed and simulated elevations after the March 2013 and May 2013 discharge events. The negative values (red) mean that the simulated elevations were higher in those locations. The fine grid cell sizes were applied in these simulations.

2.2 Effects of grid size on simulation results

The grid size effects on the simulation results were compared between simulations 1 and 2, and simulations 3 and 10 (Tables 1–3, Figures 1–3). The fine grid size tended to overestimate both erosion and deposition, whereas a coarser grid size overestimated incision. When compared to the observed topographic river bed model, the coarse grid simulations showed also an underestimation in the depositional amounts. The coarse grid also caused a moderate magnitude flood to flow mostly on the left bank side, which was opposite to the fine grid simulations and reality. The best simulation results (from the simulations 1, 2, 3 and 10) in relation to the surveyed volumetric changes were achieved with the fine grid simulation (number 10).

2.3 Effects of transverse slope on simulation results

The increased transverse slope affected positively the simulation results (simulation 9), when they were compared to the corresponding simulations with the default 1.5 transverse slope (simulation 10) (Table 3, Figures 2–3). The deposition and erosion amounts resembled the observations more, when the transverse slope was increased (Table 3). The lobe movement distance was also the best with an increased transverse slope (simulation 9). Noticeable from the elevation difference analyses was that the simulations with an increased transverse slope resulted in the greatest correspondence to the observed elevations (Fig. 3). However, particularly one location in these simulations had experienced more deposition than observed: the pool area downstream of the large lateral bar (PU: Fig. 2 and Calle et al., 2015).

When compared to the geomorphological evolution described in Calle et al. (2015) and the measured topographies, the spatial bedform pattern was visually compared for both the discharge events. Of all simulations, the best results were obtained with these simulations number 9 and 10. However, the default 1.5 transverse slope resulted in a more excavated thalweg (simulation 10), when compared to the simulation with an increased transverse slope (simulation 9) (Figures 2–3). However, simulation 10 also showed satisfying bar accretion from the left-bank side of the channel.

2.4 Effects of transport equation on simulation results

Based on the comparisons of observed and simulated topographies and volumetric changes (Table 3 and Figures 1–3), the transport equation had a crucial role in the simulation results. The EH equation (simulation 10) was superior in reproducing the channel morphology. MPM resulted in much smaller transport values (simulation 11) during both March and May 2013 discharge events (simulation 10). Basically, no movement occurred when the MPM equation was used. Thus, the MPM equation was proven not to be able to produce the correct movement during the moderate- or low-magnitude discharge events of this ephemeral gravel river.

2.5 Selection of the simulations for the final analyses

Based on the calibration of the morphodynamic model, the simulations 9 and 10 produced the best correspondence with the observed riverbed changes and bed formations. Based on these two simulations, the temporal evolution of the riverbed was selected to be analyzed during the two hydrographs of moderate- and low-magnitude discharge events. These two simulations were selected to be presented in the main paper document.