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Global sensitivity analysis of parameter uncertainty in landscape evolution models

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Supplementary Materials

Supplement S1 – Description and selection of parameters

The inclusion of every available user-defined parameter in a global SA would produce an unwieldy set of results and result in a prohibitively large amount of simulations. To narrow the parameters to a manageable set it was necessary to exclude some values. Those included were selected either due to their known importance to the model (due to user knowledge and or evidence based on past analysis), or likely uncertainties due to being reliant on field observations or similar. Likewise, those excluded were known to be negligible from user experience, reasonable global values can be set against easily obtainable values, or past studies have examined their influence on model behaviour in similar model set ups. Table S1.1 lists all the user-defined parameters and the justification for inclusion or otherwise.

Table S1.1 – List of User-Defined Parameters (excluding those associated with the Dune and Soil Development functions) in CAESAR-Lisflood v1.8, and the justification for their inclusion or exclusion from the Global SA.

Parameter	Used?	Justification	Purpose
Minimum Time Step	n	Tested previously and shown to be negligible (Ziliani et al., 2013)	Sets the smallest time step available to the model
Maximum Time Step	n	Not likely to have an influence, is used to make sure the model does not miss storms in the timeseries	Sets the maximum time step available to the model
Memory Limit	n	Not required for these model set ups	Computational value determining array size to hold grain size values
Grain Size Set	y	Based on field observations – can be highly variable spatially, yet is applied as a global distribution. Is a source of uncertainty in the model	Size and proportions of 9 grain sizes, distributed evenly throughout the catchment
Suspended Sediment	n	Tested previously and shown to be negligible (Ziliani et al., 2013)	On/Off choice to allow the smallest grain size to be handles as suspended sediment
Fall Velocity	n	Only used when Suspended Sediment is active	Sets the velocity of flows below which suspended sediment begins to deposit
Bedrock Erosion Threshold	n	There is no representation of bedrock in the model set ups	Elevations of bedrock, below which the model cannot erode
Bedrock Erosion Rate	n	There is no representation of bedrock in the model set ups	A rate value for a separate erosion model to allow

			bedrock to erode over long time periods
Sediment Transport Model	y	These Laws are based on major simplifications of physical processes and are a source of uncertainty	A choice of which sediment transport formula to use in the erosion model
Maximum Velocity Used to Calculate Tau	n	Is used to limit super critical flows and not required for these model set ups	A maximum velocity used to calculate sediment transport, used rarely in areas of very steep slopes
Maximum Erosion Rate	y	Tested previously and shown to have a high influence on the model outputs (Ziliani et al., 2013)	Maximum volume of material that can be eroded in each time step. Used to control the time step and model stability
Active Layer Thickness (m)	n	Is required to be at least 4x Maximum Erosion Rate so was not varied	Thickness of each of the active layer representing bedload, surface layers and sub-surface layers
Sediment Recirculation	n	Not used in catchment mode	Used in reach mode to use output sediment yields as an input
In Channel Lateral Erosion Rate	y	Likely to have an influence on the model outputs	Used to represent cohesion of sediment
Lateral Erosion Rate		Tested previously and shown to have a low influence on model outputs (Ziliani et al., 2013), but the formulation is different in CAESAR-Lisflood to the CAESAR previous tested so should be repeated in case	Controls rate of removal of material from bank cells as part of a meander development module
Number of Passes for Edge Smoothing Filter	n	Related to the Lateral Erosion Rate Tested previously and shown to have a high influence on model outputs in a braided channel reach (Ziliani et al., 2013), less likely to be influential in catchment model	Controls smoothness of channel curvature. Should be set to number of pixels between two meanders
Number of Cells to Shift Lateral Erosion Downstream	n	Related to Lateral Erosion Rate	Allows meanders bends and bars to migrate downstream. Should be 10 % of above
Maximum Difference Allowed in Cross Channel Smoothing	n	Related to Lateral Erosion Rate	Controls the lateral gradient of the channel.
‘m’ Value	n	The model’s response to this value was extensively tested in Coulthard and Van De Wiel (2017) in the Upper Swale	Hydrological parameter controlling the peak and duration of the hydrograph
Vegetation Critical Shear Stress	y	Tested previously and shown to have a medium influence on the model (Ziliani et al., 2013)	Shear stress threshold above which vegetation is removed by fluvial erosion
Grass Maturity Rate (yrs)	y	Likely to have non-linear interaction with Vegetation Critical Shear Stress, and based on catchment conditions	Time taken for vegetation to grow to full maturity
Proportion of Erosion That Can Occur When Vegetation in Fully Grown	n	Likely to interact with other vegetation parameters and erosion rates. Commonly kept at the default rate of 0.1, as here	Sets a limit of the amount of erosion calculated by the model can actually occur when pixel contains mature vegetation

Creep Rate	y	Influence is likely to be different over different catchments and timeframes	Diffusive soil creep function designed for longer term simulations
Slope Failure Threshold		This value is normally fixed as a global value – any uncertainty may have an influence on the model	Angle in degrees above which landslides happen
Soil Erosion Rate	n	Not likely to have an influence in these model set ups	Controls the rate of soil erosion
Input/Output Difference Allowed	y	This value is set to determine when the model runs in steady state and is often set using mean discharge values if available. It makes the model more efficient by skipping over periods which are likely to be geomorphically insignificant. It is important to test how this assumption influences model outputs	Threshold between inputs and calculated discharges, below which the model is assumed to run in steady state. Used to speed up model simulations by focussing on larger events
Minimum Q for Depth Calculation	y	Tested previously and shown to be negligible (Ziliani et al., 2013), but is more likely to have an impact in catchment mode	Threshold above which a flow depth is calculated
Maximum Q for Depth Calculation	y	This parameter is likely to have an impact in catchment mode	Controls distribution of water across the catchment
Water Depth Threshold Above Which Erosion Will Happen (m)	n	Tested previously and shown to have a low influence on model outputs (Ziliani et al., 2013)	Threshold below which no erosion is calculated
Slope for Edge Cells	y	This value is usually measured either in the field or based on the DEM. Uncertainty and observation error may influence model outputs, and in reality the value may be temporally non-stationary	Slope value between edge cells in the domain and assumed cells adjacent, required to calculate water depths and flows out of the domain. Can result in erosion or scour at domain edge
Evaporation Rate (m/day)	y	May have an influence and will be non-stationary due to seasonality and climatic changes	Controls loss of water from the catchment due to evaporation
Courant Number	n	Is used to reduce instability in the model	Controls numerical stability and speed of simulations
hflow Threshold	n	Likely to be of negligible consequence	Threshold to restrict the movement of water between cells with a very low water depth gradient
Froude # Flow Limit	n	Likely to have an impact on the model outputs, but can also cause instabilities in the model	Controls amount of water which can flow between cells in each time step and used to maintain model stability
Manning's n Coefficient	y	Parameter commonly used to calibrate the Lisflood-FP model. Is represented as a global value, but can be non-stationary temporally and spatially. Can be constrained by field measurements but subject to observation uncertainty	Used to represent the surface roughness of different land covers. Is applied as a global value

Supplementary S2 – Analysis of sediment transport formula influence using different iterative steps

The results presented in the main manuscript assumed that changes in sediment transport formula was the equivalent of a single iterative step. This is a reasonable assumption as it represents the impact an operators choice has on the model outputs (there are no smaller incremental changes available). However, it is important to understand the role this assumption has on the calculated relative influences of the model parameters on the CAESAR-Lisflood LEM. Below we present the aggregated score recalculated assuming that changing the sediment transport formula is four iterative step changes (as shown in Equation 1 of the main manuscript).

The relative influence of the choice of sediment transport formula has reduced for all model functions. Figure S3.1 summarises the aggregated values across all model functions, and in the Swale it falls below Manning’s n roughness coefficient (14), grain size set (15), and in/out difference (9), and in Tin Camp Creek it is above only evaporation rate (13), slope failure threshold (8) and maximum Q value (11).

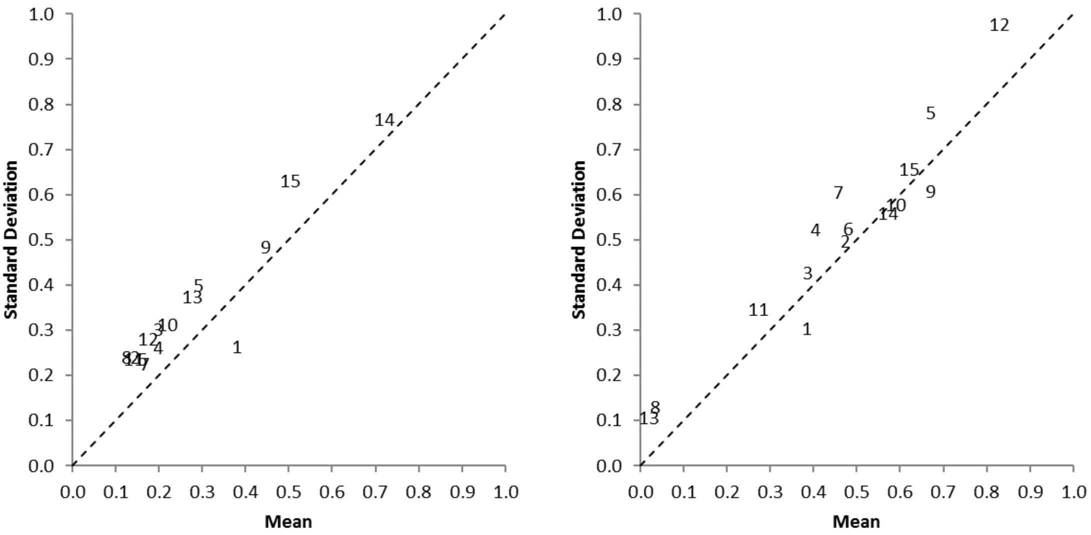

Figure S3.1 – Aggregated ME and standard deviations for all model functions, for the Swale (left) Tin Camp Creek (right). 1 = sediment transport formula (SED); 2 = maximum erode limit (MEL); 3 = in channel lateral erosion rate (CLR); 4 = lateral erosion rate (LAT); 5 = critical vegetation shear stress (VEG); 6 = grass maturity rate (MAT); 7 = soil creep rate (SCR); 8 = slope failure threshold (SFT); 9 = in/out difference (IOD); 10 = minimum Q value (MinQ); 11 = maximum Q value (MaxQ); 12 = slope for edge cells (SEC); 13 = evaporation rate (EVR); 14 = Manning's n roughness coefficient (MNR); and 15 = grain size set (GSS).

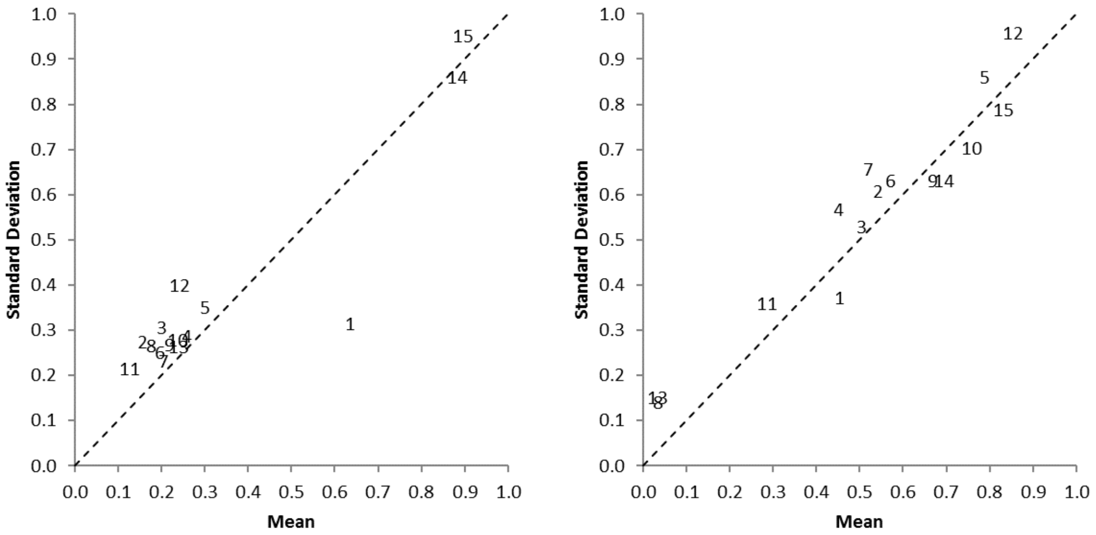

Figure S3.2 – Aggregated ME and standard deviations for sediment yield related model functions, for the Swale (left) Tin Camp Creek (right). 1 = sediment transport formula (SED); 2 = maximum erode limit (MEL); 3 = in channel lateral erosion rate (CLR); 4 = lateral erosion rate (LAT); 5 = critical vegetation shear stress (VEG); 6 = grass maturity rate (MAT); 7 = soil creep rate (SCR); 8 = slope failure threshold (SFT); 9 = in/out difference (IOD); 10 = minimum Q value (MinQ); 11 = maximum Q value (MaxQ); 12 = slope for edge cells (SEC); 13 = evaporation rate (EVR); 14 = Manning's n roughness coefficient (MNR); and 15 = grain size set (GSS).

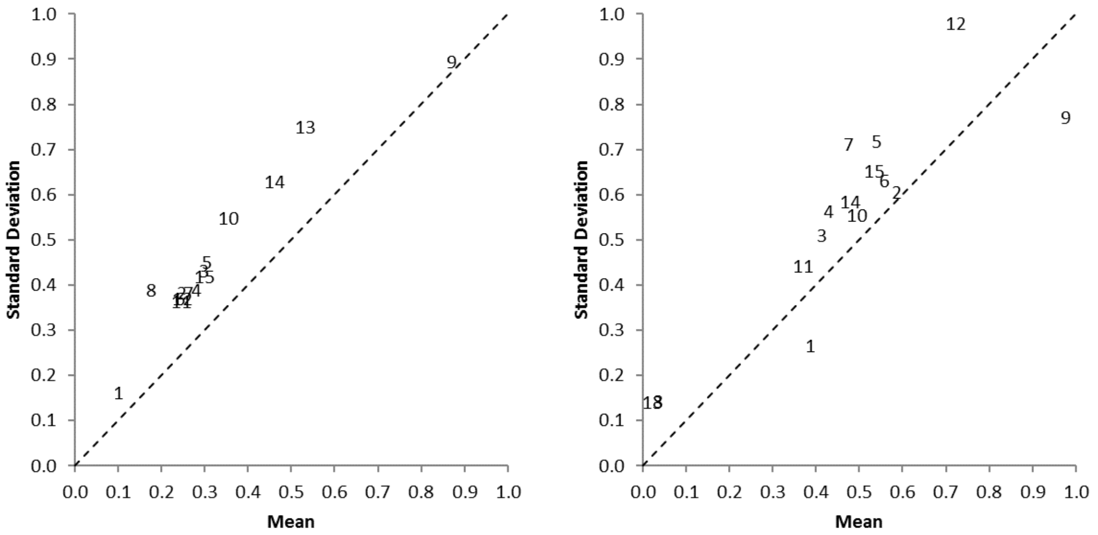

Figure S3.3 – Aggregated ME and standard deviations for hydrology related model functions, for the Swale (left) Tin Camp Creek (right). 1 = sediment transport formula (SED); 2 = maximum erode limit (MEL); 3 = in channel lateral erosion rate (CLR); 4 = lateral erosion rate (LAT); 5 = critical vegetation shear stress (VEG); 6 = grass maturity rate (MAT); 7 = soil creep rate (SCR); 8 = slope failure threshold (SFT); 9 = in/out difference (IOD); 10 = minimum Q value (MinQ); 11 = maximum Q value (MaxQ); 12 = slope for edge cells (SEC); 13 = evaporation rate (EVR); 14 = Manning's n roughness coefficient (MNR); and 15 = grain size set (GSS).

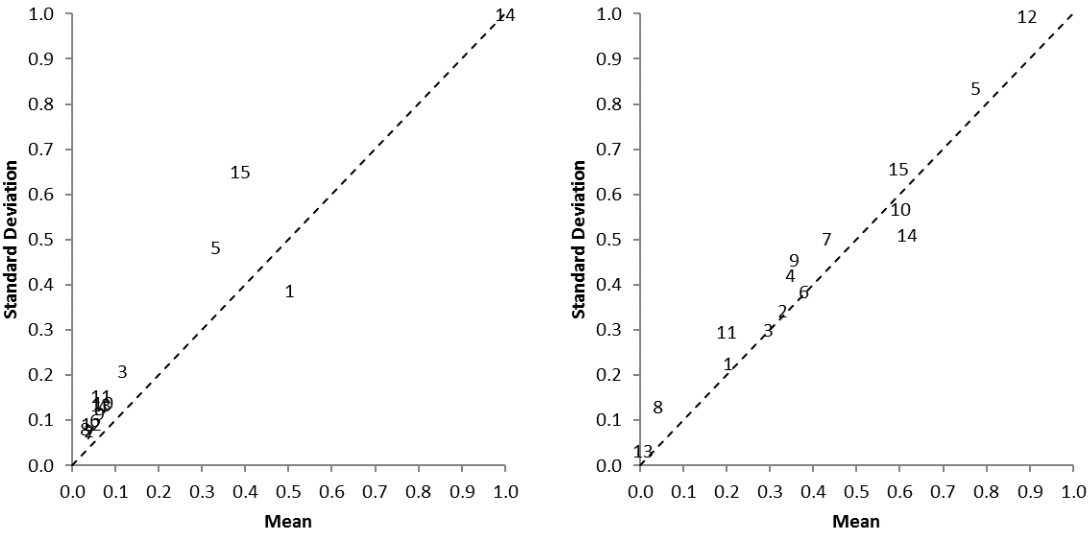

Figure S3.4 – Aggregated ME and standard deviations for internal geomorphology related model functions, for the Swale (left) Tin Camp Creek (right). 1 = sediment transport formula (SED); 2 = maximum erode limit (MEL); 3 = in channel lateral erosion rate (CLR); 4 = lateral erosion rate (LAT); 5 = critical vegetation shear stress (VEG); 6 = grass maturity rate (MAT); 7 = soil creep rate (SCR); 8 = slope failure threshold (SFT); 9 = in/out difference (IOD); 10 = minimum Q value (MinQ); 11 = maximum Q value (MaxQ); 12 = slope for edge cells (SEC); 13 = evaporation rate (EVR); 14 = Manning's n roughness coefficient (MNR); and 15 = grain size set (GSS).

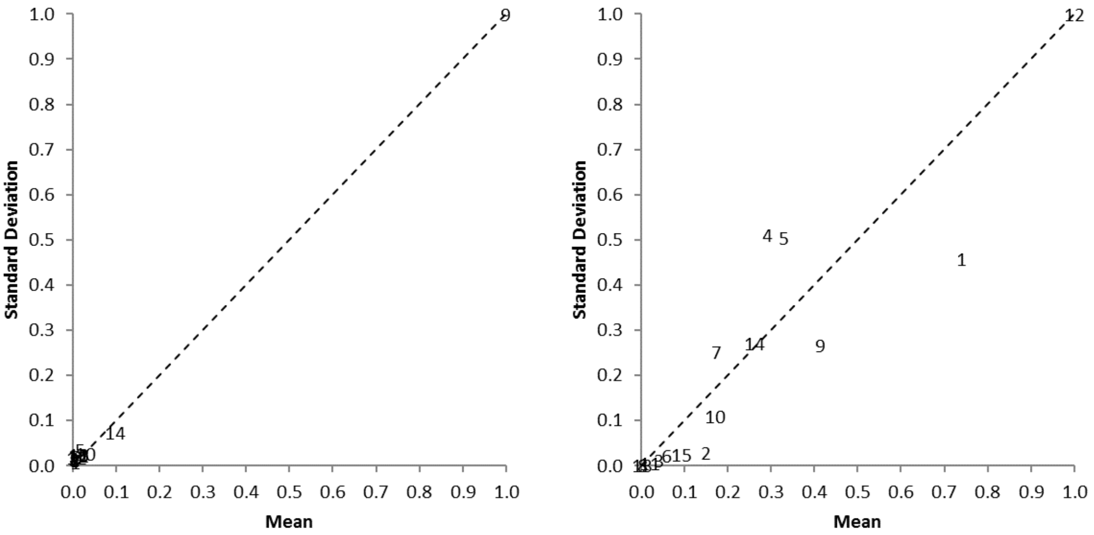

Figure S3.1 – Aggregated ME and standard deviations for performance related model functions, for the Swale (left) Tin Camp Creek (right). 1 = sediment transport formula (SED); 2 = maximum erode limit (MEL); 3 = in channel lateral erosion rate (CLR); 4 = lateral erosion rate (LAT); 5 = critical vegetation shear stress (VEG); 6 = grass maturity rate (MAT); 7 = soil creep rate (SCR); 8 = slope failure threshold (SFT); 9 = in/out difference (IOD); 10 = minimum Q value (MinQ); 11 = maximum Q value (MaxQ); 12 = slope for edge cells (SEC); 13 = evaporation rate (EVR); 14 = Manning's n roughness coefficient (MNR); and 15 = grain size set (GSS).

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