THE INFLUENCE OF VARYING INPUT DATA AND MODEL PARAMETERS ON MODEL OUTPUT, EXAMPLES OF THE FLUVER 2 MODEL

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Abstract

The use of numerical models is widespread throughout most fields of science, Geography is no exception. The interpretation of model output often rests upon the assumption that the model in question is a true representation of reality. Models though, rarely describe closed systems and thus, although not necessarily wrong, the mathematical description is almost by default incomplete. The quality of model output also depends upon the quality of the input data. The input available for geomorphological models of landscape development over long timescales (100 ka>) is frequently fragmented and of low resolution. The output of such models should thus be treated with caution. Models are tuned by more or less obvious intrinsic parameters and the influence of these on output should not be underestimated.

In this paper we present data from the FLUVER 2 model of longitudinal fluvial profile development. We discuss how careful consideration of input data, especially the use of a robust palaeodischarge time series, can greatly improve this models output. Further a brief discussion of various parameters used to tune model results is given.

Keywords: Models, Geomorphology, Palaeodischarge

1. Introduction

Numerical models form an intrinsic part of many fields of science, Geography is no exception. The timescales involved in studies of Quaternary fluvial landscape development are such that numerical models now form a vital part of such studies (e.g. Tebbens and Veldkamp, 2001; Coulthard *et al.*, 2005; Gargani *et al.*, 2006; Stemerdink, 2007; Stemerdink *et al.*, 2010).

The Quaternary climate cycles strongly influence discharge and energy status of fluvial systems and thus the sediment transport capacity. It is the movement of sediment through a system which defines erosion and aggradation events and so this sediment flux forms an essential part of models simulating Quaternary fluvial landscape development. Most of these models use a sediment continuity equation (Culling, 1960; Kirkby, 1971) to calculate a system's sediment flux. The differences between them often lie in the way in which the palaeodischarge time series, needed to calculate sediment flux, is determined.

Stemerdink *et al.* (2010) reconstruct a palaeodischarge time series for the Middle to Late Pleistocene Upper Thames. This time series is used as input in the FLUVER2 model (Veldkamp and Van Dijke, 1998, 2000) of longitudinal fluvial profile development. The output of which can be compared with an extensive field record. This paper shows how a different palaeodischarge time series affects model output and how, when changing input, internal parameters have to be adjusted in order to keep model stability.

2. The Upper Thames

Fluvial landscapes are often dominated by terraces and any model describing the development of such a landscape should be able to simulate the formation of these terraces. Bridgland (2000) presents a conceptual six stage model of terrace formation, in which changes in vegetation cover and energy of the system caused by climate fluctuations result in alternating incision and aggradation phases. In order to test this conceptual model Stemerdink *et al.* (2010) applied the FLUVER2 model to the catchment of the post Anglian (MIS12) Upper Thames River (Figure 1).

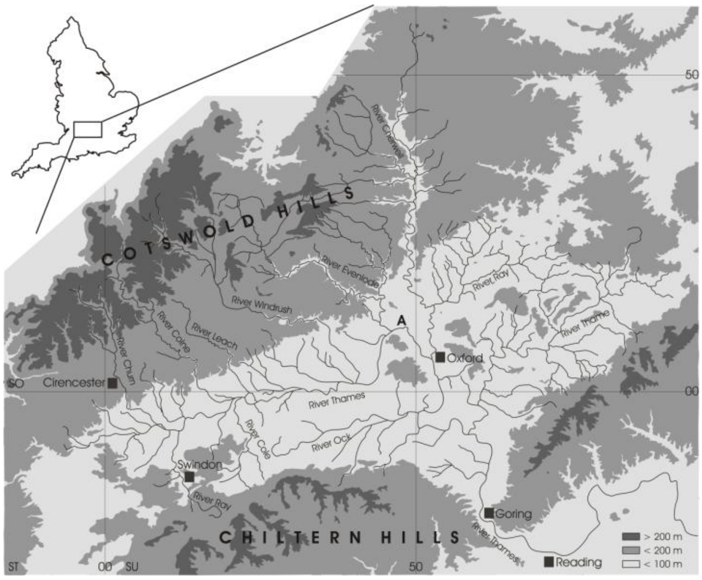

Figure 1: The drainage network of the Upper Thames Basin. Capital A indicates a stretch of river 60km from the source which is the focus of the modelling exercise presented below (after Stemerdink et al., 2010)

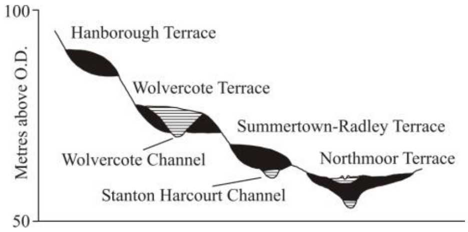

Figure 2 Idealised terrace staircase of the Upper Thames Valley (after Bridgland, 1994)

The Upper Thames drains the southern slopes of the Cotswalds and flows eastward where, it cuts through the Chiltern Hills. Since the end of the Anglian glaciation (MIS12) the river has created three levels; respectively the Wolvercote, Summertown-Radley and the Northmoor terraces. A higher level, the Hanborough terrace used to be related as well to the post-Anglian but is now thought to be of older age. The various levels (Figure 2) are underlain by gravels associated with cold climates and in places by temperate channel deposits. The extent of the Wolvercote terrace, and its chronological position is still problematic and open to debate (Maddy *et al.*, 1991). The two lower levels of the Summertown-Radley and the Northmoor terrace and their underlying deposits are well preserved and described (e.g. Bridgland, 1994; Buckingham *et al.,* 1996; Lewis *et al.,* 2006; Maddy *et al.*, 1998).

The choice to use the Upper Thames catchment to test the FLUVER2 model was based on its favourable geographic position, placing it outside the direct influence of sea level fluctuations (Bridgland, 1994) and giving it a relative simple tectonic regime (Maddy, 1997). This created the possibility of model output influenced by climate fluctuations on discharge, without interfering effects of sea level fluctuations and tectonics.

3. Modelling Exercise

3.1. FLUVER2

FLUVER2 (Veldkamp and Van Dijke, 1998, 2000) is a 2D model simulating changes in the longitudinal profile of a fluvial system. Discrete segments of a longitudinal profile are, by means of a sediment continuity equation (equation 1), adjusted, per time step, for tectonic movements and variations in sediment flux. Extra sediment can be brought in as a result of slope processes.

$$\frac{\delta z(x,t)}{\delta t} = \frac{\delta q_s(x,t)}{\delta x} + T(x,t) + H(x,t) \qquad (1)$$

In this equation z is the height of the fluvial bed above a reference point, q_s is the sediment flux per unit width, t is time, and x is a longitudinal distance. *T* is the tectonic movement and *H* is the hillslope sediment supply.

As mentioned it is the way in which the sediment flux is constructed that distinguishes models of various authors. In the FLUVER2 model as applied by Stemerdink *et al.* (2010) the sediment flux is determined by multiplying a factor of relative stream energy (equation 2) with an erodibility constant. The relative stream energy is determined by discharge (*Q*), slope (*S*) and a Climate Change Indicator (*CCI*).

$$\Theta = Q \cdot S \cdot CCI \qquad (2)$$

3.2. Palaeodischarge

Modelling fluvial landscape development over multiple climate cycles (>100 ka) requires a continues palaeodischarge time series. There are no such records available directly from field evidence and they thus have to be derived either by transformation of artificial climatic records, mimicking the Milankovitch insolation model (e.g. Veldkamp and van Dijke, 1998; Gargani *et al.*, 2006), or the transformation of palaeoclimate proxy data as recorded in ice cores or marine sediments (e.g. Tebbens and Veldkamp, 2001). However a reconstruction based only on such records is incomplete as they lack the influence of vegetation cover and seasonal fluctuations in discharge.

The basis of the paleaodischarge time series created by Stemerdink *et al.* (2010) is a record of Sea Surface Temperature (SST) for the past 500ka (Figure 3A), derived from ODP core 980 just west of Ireland (McManus *et al.,* 1999). It is assumed that, as over time the prevailing wind direction in the Upper Thames catchment area is a westerly one (Renssen *et al.*, 2007), a link exists between SST and precipitation in the study area. Moisture loss due to evapotranspiration depends upon climate and vegetation cover. Analogues are used from three types of modern catchments representing full interglacial, full glacial and interstadial/transition periods. The respective vegetation cover and discharge percentages are; deciduous forest with 30% discharge, tundra with 80% discharge and boreal forest with 50% discharge. In order to establish which condition prevails, the long continuous Velay pollen record from central France (Reille *et al.* 1998) is used. This in combination with climate thresholds based on the SST record, to compensate for various recorded discrepancies with fragmented short local records. Only under interglacial conditions can discharge be assumed constant throughout the year, for other periods discharge is assumed to take place in shorter periods, thus effectively increasing the energy status of the system under equal amounts of average annual discharge.

The energy status of a river is not only determined by its annual discharge. A low continuous flow throughout the year may result in a higher amount of annual discharge than that of one flood event. Periods of climate change are often correlated with increased fluvial activity (e.g. Vandenberghe 1995) and studies of global warming effects suggest more extreme precipitation and flooding events (e.g. Leckebusch and Ulbrich, 2004). To compensate for these Stemerdink *et al.* (2010) introduce a Climate Change Indicator (CCI) which quantifies the rate of change in the sea surface temperature (Figure 3B). A high CCI can be seen on the transition from glacial to interglacial and interglacial to glacial periods, corresponding with the assumption of higher fluvial activity during these periods. The last glacial maximum is clearly bordered by two periods of climate instability, as is the last interglacial. Following equation 2 relative stream energy can now be calculated (Figure 3C).

Interglacial stages show, as expected, low levels of relative stream energy. This in contrast with climate transitions when a high CCI causes relative stream energy to peak.

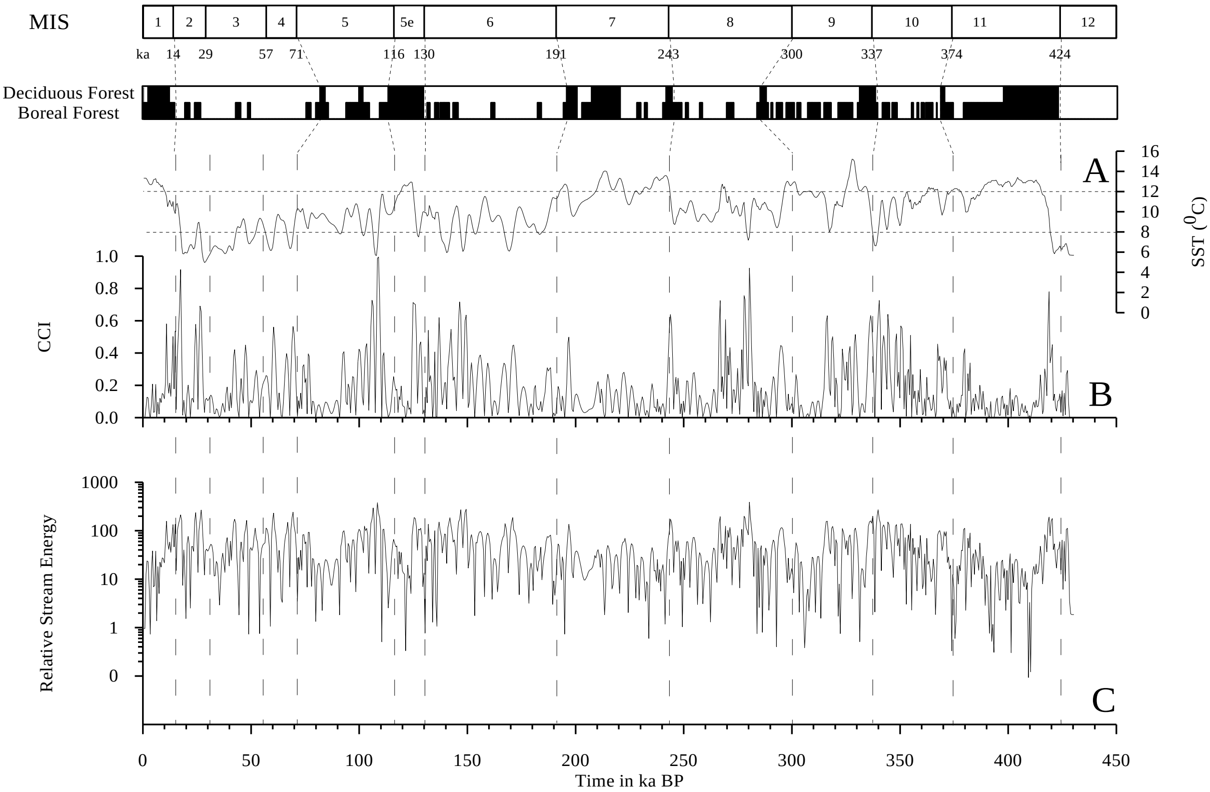

Figure 3: Sea Surface Temperature after (McManus et al., (1999) with temperature thresholds used for climate settings indicated (A), Climatic Change Indicator (CCI) for the past 430 ka (B). Relative Stream Energy calculated, as a percentage of the present day value (=100 %), by multiplying discharge and CCI (C). MIS boundaries according to the LR04 stack of Lisiecki and Raymo (2005). The black bar graph shows the type of forest, if present. Where MIS in the vegetation record deviate from the LR04 stack, the boundaries are after Reille et al., (1998). After Stemerdink et al. (2010).

The above presented reconstruction of relative stream energy can be used in the FLUVER2 model. It is acknowledged that although this reconstruction is based on a series of reasoned steps a variety of assumptions has been made, for more detail see Stemerdink et al. (2010). From a modelling point of few it is worth looking if a more simple approach can produce similar output. Veldkamp and van den Berg (1993) and Veldkamp and van Dijke (1998) argue that the southward shift of the North Atlantic depression tracks during glacial periods result in a drier continental climate with low discharge in North Western European rivers and vice versa high discharge during interglacial periods. Using this argument a sediment flux is calculated based on a linear relation between the ODP980 $\delta^{18}O$ record from McManus *et al.* (1999) and discharge (Stemerdink 2007).

The two palaeodischarge time series thus created can now be used as input into the FLUVER2 model. The profile of the Upper Thames is split in 117 segments of 1km length. Using the approach of Tebbens *et al.*, (2000) the system is assumed to be in a quasi equilibrium state and the MIS11 initial profile is based on the present day profile. A constant uplift rate of 0.07m/ka is applied. A full model description including the simulation of discharge increase along the profile and a hillslope sediment supply model is described in Stemerdink (2007).

3.3. Simulation Output

Simulations should reproduce the alternating incision and aggradation cycles of Bridgland's (2000) conceptual model. The focus of the simulations is a segment 60km from the source of the Thames (Figure 1), where a relative well-preserved terrace staircase can be found. Simulated erosion and sedimentation rates are presented in figure 4. There are some marked differences between the two simulations. When using a linear link between discharge and the ODP980 $\delta^{18}O$ record (Figure 4A) erosion events are simulated during interglacial stages while aggradation takes place during the glacial stages. The simulated record closely follows, as expected, the climate proxy record. Figure 4B shows the simulated erosion and aggradation events for a model run using the advanced relative stream energy record (Stemerdink, 2010). Erosion events are now predominantly positioned on climate transitions and sedimentation events are in more pronounced peaks.

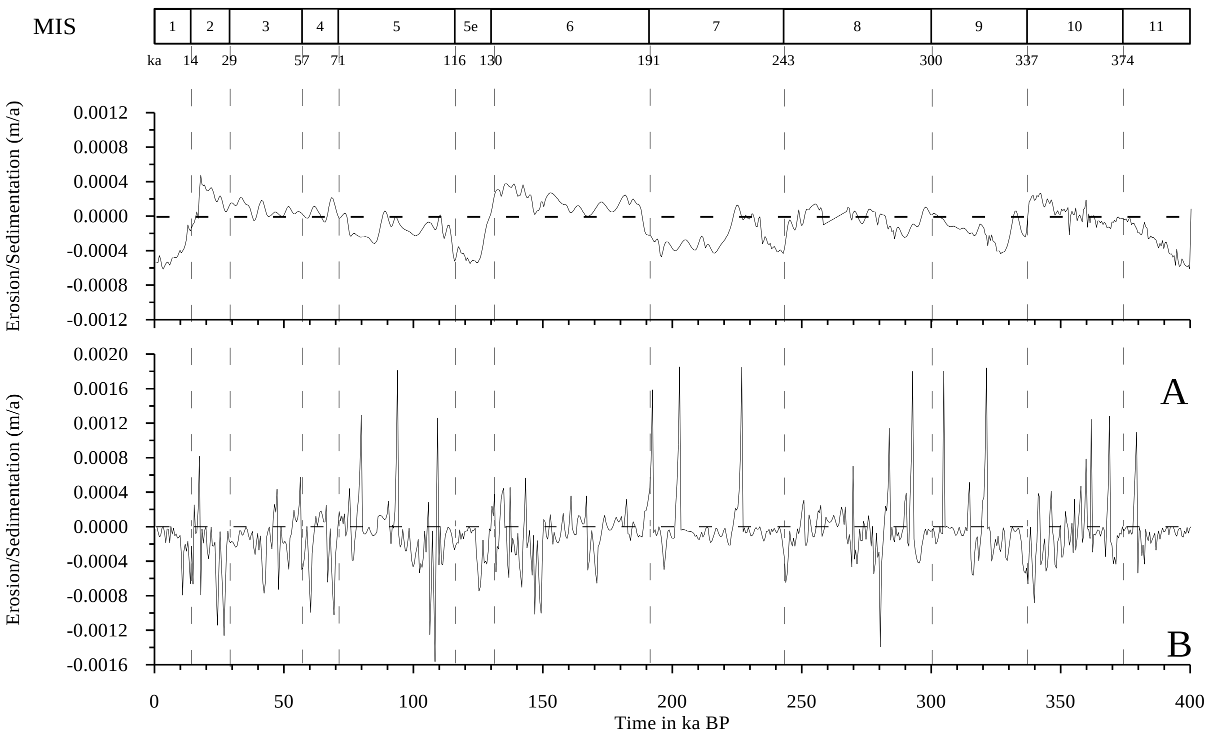

Figure 4. Simulated aggradation (positive values) and erosion (negative values) events for simulations using the $\delta^{18}O$ record (A) and the relative stream energy model (B).

A graph of cumulative sedimentation (Figure 5) is best to show sedimentation events. The $\delta^{18}O$ simulation causes sedimentation during glacial stages. In the advanced model sedimentation mainly takes place on the cooling limbs of warm periods, in line with the conceptual model of Bridgland (2000) and field evidence (Maddy *et al.*, 1998). Bearing in mind that FLUVER2 does not compensate for post depositional erosion the simulated amount of aggradation per climate cycle is comparable with field data (Bridgland, 1994). For a full discussion linking the conceptual incision and aggradation phases with model output we refer to Stemerdink (2010).

Terrace heights (Figure 6) can be predicted by using a combination of the erosion/sedimentation rates and tectonic movement, though there are limitations due to the 2D nature of the model. Assuming a part of the active bed remains untouched by subsequent erosion, it will be uplifted according to the set tectonic rate for the remaining simulation time span. Post depositional erosion is not simulated and these are thus maximum heights. As preservation of fluvial deposits is far from continuous, the graph should be interpreted with caution.

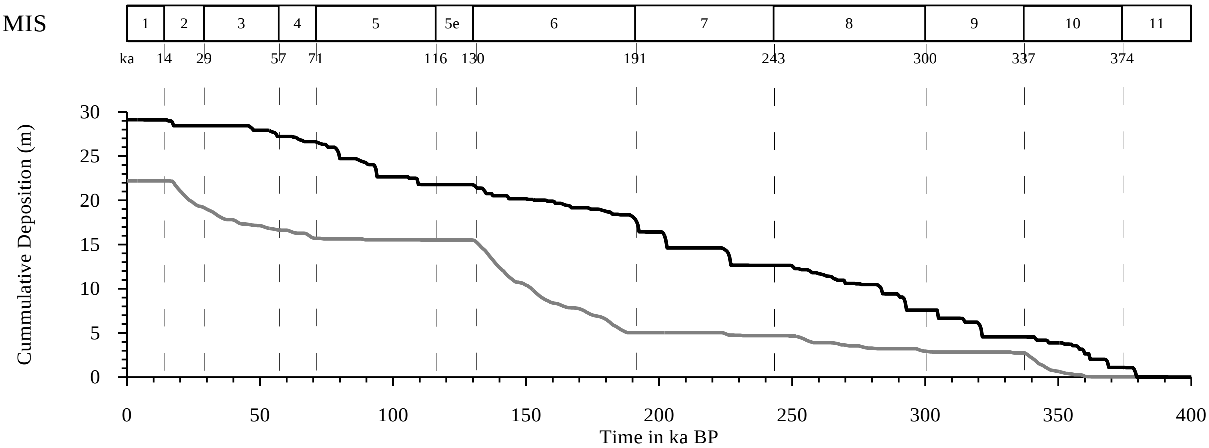

Figure 5. Simulated cumulative deposition using the δ^{18}O record (grey) and the relative stream energy model (black)

The simulated timing of terrace formation and total deposition rate per climate cycle using the δ^{18}O link is not in accordance with field evidence (e.g. Bridgland, 1994; Briggs *et al.*, 1985; Buckingham *et al.,* 1996; Lewis *et al.,* 2006; Maddy *et al.*, 1991, 1998). Simulated terrace heights stay below the tectonic equilibrium line. Combined with possible post depositional erosion this suggests the river would erode its bed below equilibrium. The simulation utilising the relative stream energy model however does stay above this line and also simulates a timing of terrace formation and total deposition rate more in line with field evidence.

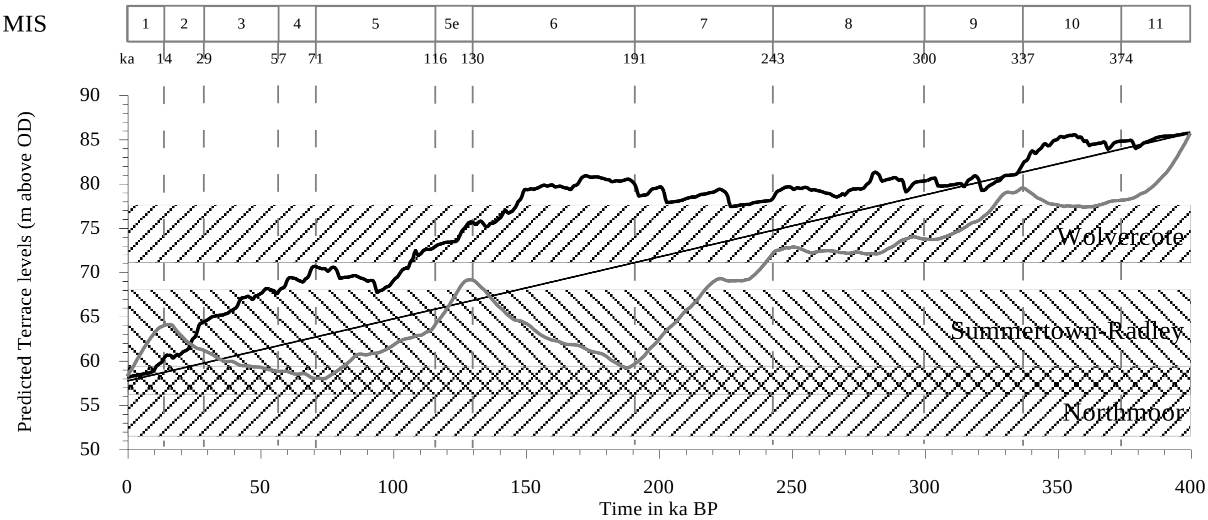

Figure 6. *Predicted terrace heights using the δ^{18}O record (grey) and the relative stream energy model (black). Heights of terraces as recorded in the field after Harries (1977). For each of the terrace levels the highest recorded level in the area around Cassington is given as the upper limit, and the lowest recorded level is given as the base of the terrace, delimiting the height range in which gravels underlying the terraces can be found*

Models can be tuned using build in variables, FLUVER2 is no exception. The main variables available for tuning are the above mentioned erodibility factor, and further two parameters controlling sedimentation and hillslope supply. A higher value for the erodibility factor simulates a higher rate of erosion. If this value is set too high the model rapidly erodes far too much material creating an unstable run with physically unrealistic river profiles. Closely linked to this is the sedimentation constant, which controls the amount of sedimentation. If this value is set too low sedimentation cannot keep up with erosion and again unrealistic profiles are created. Additional sediment can be brought in from the hillslopes by setting a high value for the hillslope supply factor. There is however a limit to how much sediment realistically can be brought in from the hillslopes. Again comparing output with field data is essential. For a successful simulation all three factors need to be in balance. The parameters need to be adjusted per simulation depending on the climate input. No combination of settings has been found which renders a stable model run using the ODP980 $\delta^{18}O$ discharge model, which produces output in line with field evidence. This is a consequence of those parameters controlling the amount of erosion/sedimentation rather than the timing of events.

4. Conclusion

The simulation of fluvial landscape development of the Upper Thames basin, which uses the relative stream energy record does produce output which compares reasonable with field evidence (Stemerdink, 2010), in contrast with the simulation linking the ODP980 $\delta^{18}O$ record linearly with discharge. This shows how careful consideration of model input data is paramount to successful simulations. It also strengthens the argument that the assumptions and calculations made creating the relative stream energy model may very well be an improvement on earlier versions of the model. It is acknowledged however that as with all models the nature of the model is heuristic and that, confirmation of observations does not demonstrate the veracity of the model, but only supports its probability (Oreskes *et al.,* 1994).

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