SUB-REACH SCALE MORPHOLOGICAL INTERPRETATIONS FROM DEM DIFFERENCING: ACCOUNTING FOR UNCERTAINTY

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1. INTRODUCTION

Using repeat ground-based topographic surveys and digital elevation model (DEM) differencing to infer reach-scale sediment budgets has become a popular monitoring tool in fluvial geomorphology. Few studies however, have used DEM differencing to infer detailed sub-reach and meso-scale fluvial processes and rates. In part, this might be attributed to the recognized uncertainty in representing individual surfaces and associated difficulty in inferring 'real' changes from differences. Several recent studies have suggested applying a minimum level of detection (minLOD, typically between 10 and 30 cm), below which 'real' changes are indistinguishable from noise. Here, we present the results of a more detailed assessment of uncertainties below typical $_{min}$LOD thresholds (see also, Brasington et al. 2004: Poster AGU Abstract: H53C-1264).

2. STUDY SITE: THE RIVER FESHIE, SCOTLAND

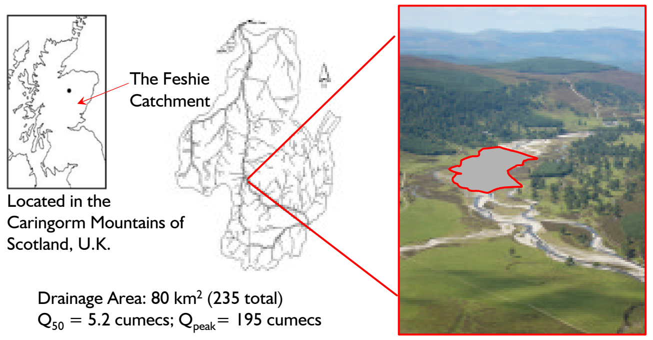


Figure 1: The 800 x 270 m area surveyed is highlighted in red. Annual changes are reported between 2003 and 2004 (51,080 and 46,000 points respectively).

3. THE TRADITIONAL DoD SEDIMENT BUDGET

To create a DEM of difference (DoD), one simply subtracts the elevation values in the newer surface from the elevation values in the old surface. This is illustrated below with ground-based survey data from two real-time kinematic Global Positioning System (rtkGPS) surveys in 2004 and 2003.

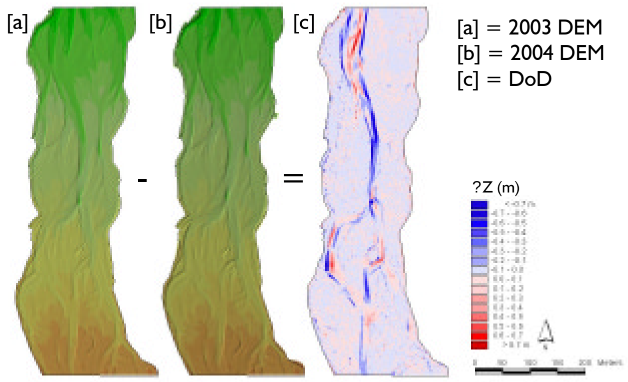


Figure 2: A DoD is a map of morphological change . The red areas correspond to predicted erosion and the blue to predicted deposition.

	Gross Change	Bar Development	Obscure Changes	Within Class	Bank Erosion	Channel Scour
Total Cut (m^3)	4634.0	56.8	107.3	2848.7	657.2	964.0
Total Fill (m^3)	2966.9	388.6	103.1	2245.7	160.8	68.8
Net Difference (m^3)	1667.1	331.8	4.2	603.1	496.4	895.3

Table 1. Volumetric channel change divided into respective geomorphic components.

4. THE PROBLEM: UNCERTAINTY IN DoD

Although the traditional DoD budget appears to produce reasonable values for the change in the storage terms of a sediment budget, how do we know if it is right? A closer look at the aerial and volumetric distributions of elevation changes reveals some problems:

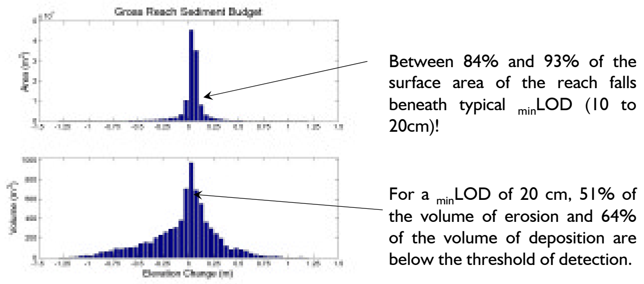


Figure 3. Gross Reach Scale Sediment Budget Elevation Change Distributions.

Applying a progressively more severe minLOD to the account for uncertainties has a dramatic influence on the estimated change.

LoD Threshold (cm)	0	5	10	15	20	25	30
Total Cut (m^3)	-4634.0	-3656.8	-2948.1	-2565.5	-2257.6	-1965.4	-1707.0
Total Fill (m^3)	2966.9	2276.0	1720.9	1358.5	1060.4	817.2	624.9
Net Difference (m^3)	-1667.1	-1380.8	-1227.2	-1207.0	-1197.2	-1148.2	-1082.1

Table 2. Influence on gross reach scale budget of applying different minLoD thresholds.

5. A CLOSER LOOK AT UNCERTAINTIES

Brasington et al. (2004: AGU H53C-1264) developed a new framework to analyze DEM and DoD uncertainties that we apply here. Briefly, a fuzzy inference system is used to quantify spatially variable uncertainties in DEMs resulting from a combination of instrumental point quality, roughness, wetness and slope. These uncertainties are converted to a probabilistic analysis of change, which is used to threshold a DoD at any chosen confidence interval. Using Bayes Theorem, this probability distribution is then updated with the results of a spatial analysis, classifying the probability a cell is recording a real signal based on its local neighborhood context.

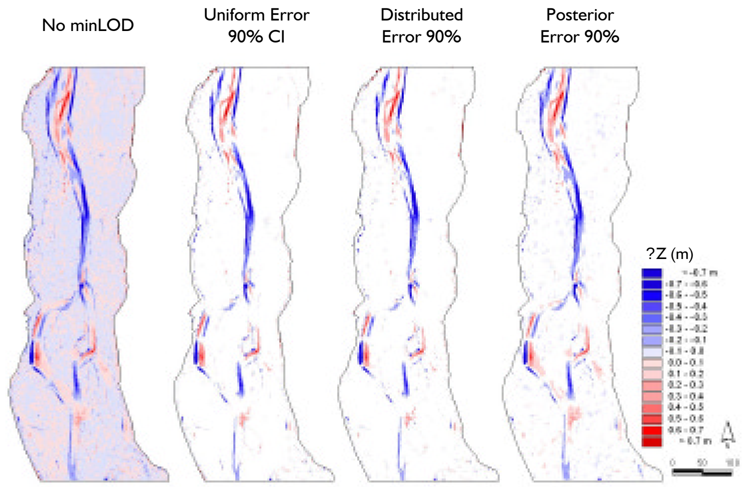


Figure 4. Each of the methods remove much of the noise. The subtleties between the methods relate to how much of the information below a typical $_{min}$LOD can be recovered if it has a reasonably high probability of being real.

6. UPDATED BUDGET DISTRIBUTIONS

The a priori probability distribution based on the fuzzy inference system removes the majority of the suspect changes, below typical minLODs. However, it maintains those changes above the minLOD which are likely to be real. This is based on uncertainties defined in both the original DEMs and propagated through to the DoD.

After updating the probability surfaces based on the increased likelihood of change if consistent with neighbouring cells, additional volumes of sediment are reincorporated into the budget from areas otherwise below the minLOD.

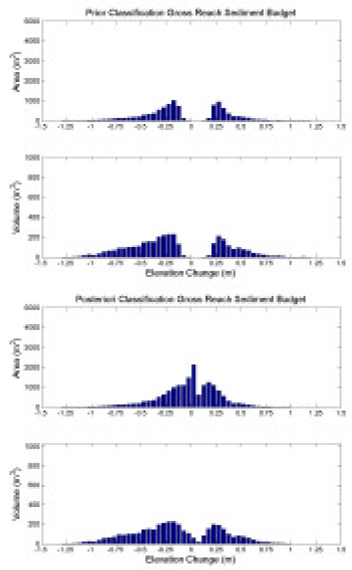


Figure 6. The prior and posterior DoD elevation change distributions. These were produced based on including only changes significant at a 90% confidence interval. (equal to a spatially average minLOD of 0.103m)

	Gross Change	Bar Development	Obscure Changes	Within Class	Bank Erosion	Channel Scour
Total Cut (m^3)	-2603.9	-39.0	-66.5	-1126.9	-524.6	-846.9
Total Fill (m^3)	1328.9	347.2	58.6	854.1	44.7	24.4
Net Difference (m^3)	-1275.0	308.2	-7.9	-272.8	-479.8	-822.6

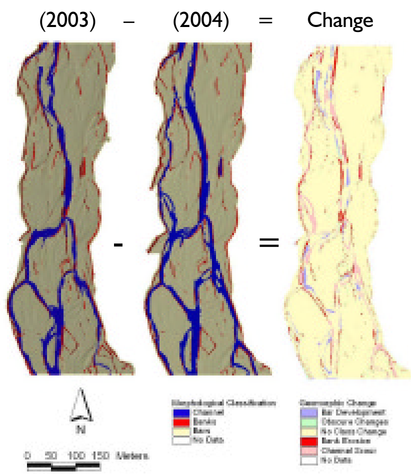
Table 3. Updated posterior sediment budget at 90% C.I.

7. GEOMORPHICALLY MEANINGFUL CHANGE?

Having now accounted for DoD uncertainties, a more realistic estimate of the storage terms of a gross reach scale sediment budget is in order. Still, there is a wealth of information in the DoD about sub-reach scale geomorphological processes and rates, that are typically ignored by geomorphologists. As a starting point, we used a simple classification of the reach into morphologically meaningful units: channels, banks and bars in a GIS. By differencing these surfaces in much the same way DEMs are differenced, we obtain a crude surface of categories of geomorphic change.

Figure 7. A Geomorphic map of change.

Differencing the 3 categories produces 5 unique classes of geomorphic change. The interpretation of channel scour, bar development and bank erosion is clear. No class change, however, refers to areas which remained in the same category. Obscure changes relate to categories of change that are thought to be unlikely (e.g. channel to bank or bank to bar).



8. MORPHOLOGICAL CHANGE DISTRIBUTIONS

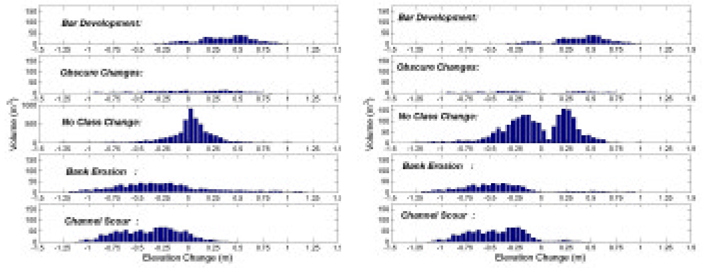


Figure 8. A comparison of the volumetric elevation change distributions for the original DoD and posterior DoD at a 90% confidence interval. It is encouraging that categories of change that should be depositional (e.g. bar development) are, and those that should be erosional (e.g. channel scour and bank erosion) are as well. Not surprisingly, the no class change contributes the most volumetrically to the budget, and is most influenced by the uncertainty analysis.

9. EXAMPLE: BAR DEVELOPMENT vs. BANK EROSION

To illustrate the different signals of change in aerial and volumetric elevation change distributions between distinct geomorphic processes, we contrast bar development (aggradation) with bank erosion below.

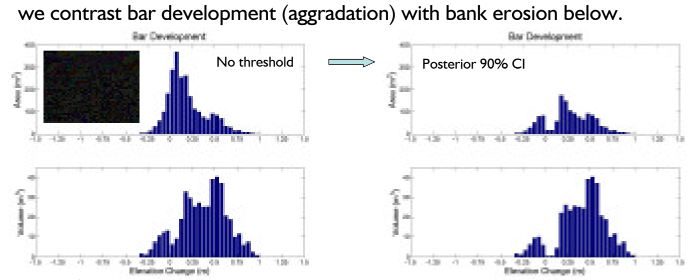


Figure 9. Bar development shows a consistently aggradational signal, with most of the surface being buried in broad thin sheets, but most of the volume comprised in slightly deeper burial depths. Bar development comprised roughly 24% of the total budget and 26% of the total aggradation.

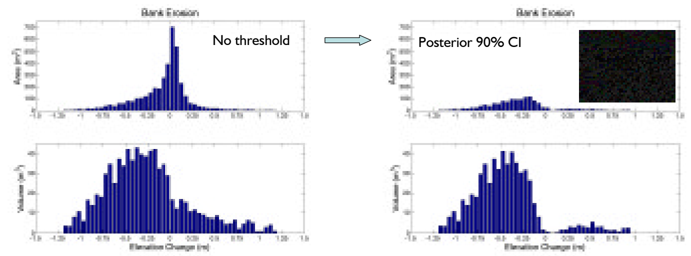


Figure 10. Bank erosion occurs in only 3% of the reach, yet contributes between 35 and 40% of the total budget and roughly 20% of the total erosion. Banks are consistently in areas of higher DoD uncertainty; therefore bank erosion estimates can vary significantly.

10. CONCLUSIONS

- Using innovative techniques to quantify uncertainties in DEMs and DoDs, more realistic estimates of the storage terms of sediment budgets can be quantified.
- Digital terrain analyses and classifications can be differenced to produce a geomorphic surface of change. This provide a useful process-based methodology to interpret sub-reach scale geomorphic processes