Chapter 5

Geomorphological Interpretations of Morphological Sediment Budgeting

5.1 Introduction

The focus on morphological sediment budgeting from DEM differencing has been largely methodological in the literature thus far (Lane *et al.* 2003, Brasington *et al.* 2000, Brasington *et al.* 2003, Fuller *et al.* 2003). As in Chapter 4, this emphasis has been based on demonstrating to what extent DoD calculated changes can be distinguished from noise (i.e. considering uncertainty). This is a natural and necessary progression for an emerging technology. However, a by-product of that focus has been a lack of emphasis on the original reason that the method was developed in the first place, namely to aid in making more meaningful interpretations of geomorphological changes.[1] More than 10 years after Lane *et al.* (1994) reported DEM-differencing as a new development, it is time to return to the question of what can be learned from DoDs.

In this brief chapter, it is asserted that a more explicit quantification of inferred fluvial processes and mechanisms of change can be derived from DEM differencing. It is postulated that geomorphological interpretation is largely a process of informed story telling and inference, based on the best available evidence (Rhoads & Thorn 1996*a*). As Schumm (1991) eloquently pointed out in a student text-book, there are many ways to be wrong when making geomorphological interpretations. In the context of interpreting DoDs, one of the fundamental ways to get it wrong is through misinterpretation of unreliability uncertainties due to limited knowledge about the magnitude of surface representation error. Some confidence in the DoDs being derived is now afforded by the more detailed assessment of uncertainties and methodological development outlined in Chapter 4. In terms of the embracing uncertainty framework outlined in Figure 2.10, a potentially significant unreliability uncertainty has been identified and quantified, and a way to assess its significance and constrain it has been developed.

[1] This claim was justified in § 3.4.

With this analysis addressed, the task of interpreting geomorphological changes is subject to other types of uncertainties due to limited knowledge like indeterminacy, conflicting evidence and reducible ignorance (refer back to Figure 2.2 and § 2.2.2 for explanations). These are structural as opposed to unreliability uncertainties. As outlined in Figure 2.10, there is little that can be done about indeterminacy or conflicting evidence other than to transparently acknowledge it. However, there is more detail locked up in DoDs about the mechanisms of change than have been exploited to date in the literature. It is argued that this is a form of reducible ignorance that just needs some simple tools to improve our understanding. The resulting interpretations of 'why' and 'how' will be open to debate between individual geomorphologists and always subject to uncertainties. That is not of concern here. The focus here is on better describing 'what' information is in a DoD.

The purpose of this chapter is to provide the methodological description of some simple masking tools that can be used to segregate a DoD budget. No results will be presented here, and instead these tools will be put to the test in three separate case studies in Part III. This chapter is separated into the methodological development of the masks, the extension of the DoD Uncertainty Analysis Software to include these tools, and a justification of the study sites used in Part III.

5.2 Methodological Development - The Mask

One of the easily overlooked attributes of a DoD is the explicit information about the spatial patterns of geomorphological change inherent in the maps themselves. Although the geomorphological literature on DoD-based monitoring has to date placed little emphasis on these spatial patterns, the premise of this chapter is that those spatial patterns captured in the DoD are fundamentally what will allow a more detailed and meaningful geomorphological interpretation of observed changes. Whereas any individual DEM only represents a snap shot in time of the Earth's surface, a DoD actually says something about the spatial and historical contingencies (Phillips 2001) that have coalesced to produce the more recent morphology. Ultimately, the utility of the geomorphological interpretations made from the DoD will only be as good as the ability of the investigator to make sense of the spatio-temporal puzzle that the DoD represents. Three case study examples of how this can be done will comprise the bulk of the remainder of this thesis. First, in this chapter, both a method and a tool to implement these interpretations are needed. The method will be to apply a spatial mask, and the tool will be an extension of the DoD Analysis Software developed in § 4.5 that segregates the DoD results according to this spatial mask. The next two sub-sections briefly describe these conceptually simple but interpretatively powerful methodological developments.

5.2.1 Defining the Masks

In the context of GIS, a mask[2] is a sub area of an entire dataset that will be included in an analysis. If the mask is defined with vector data it is a polygon, or if it is defined as a raster it is the collection of cells with the same integer value within that raster. For the purposes of this chapter, the *masks* that will be used should have a specific geomorphological meaning - either relating to a specific style of change, an inferred geomorphological process, or a particular morphological characteristic. The *analysis* that will be performed on the data (or DoD) that fall within that *mask* will be identical to those performed in the previous chapter (i.e. calculation of areal and volumetric elevation change distributions and summary statistics). To segregate the DoD analysis by multiple masks is a simple matter of aggregating the discrete masks (polygons or unique integer values within a grid) into a single mutually exclusive classification. This subsection is concerned with defining sensible ways to perform this classification.

Classification of landscapes and landforms has a rich history that can be drawn on for interpreting changes in rivers. Although earlier attempts at geomorphological classification exist, Davis (1885) was one of the most effective early advocates for the concept of landscape classification as a unifying theme for geography (Beckinsale 1976). In Davis (1902) he laid out an agenda for the basis of classification in geography, while in Davis (1915) he crystallised this agenda into his framework for geographical analysis based on classification. Today countless classification schemes for fluvial landscapes exist at a range of spatial scales (e.g. Leopold & Wolman 1957, Kemp *et al.* 2000, Montgomery & Buffington 1997, EA 2003, Newson *et al.* 1998, Schumm 1977, Rosgen 1996), including multi-scalar classifications (e.g. Brierley & Fryirs 2000, Maddock 1999, Lewin 2001, Wiens 2002). Each classification scheme has its own limitations and the classifications themselves are arguably less important than the interpretations they help facilitate (Kondolf 1995). The widespread availability and ease of use of GIS has made spatial classification commonplace (Demers 1991, Marchi & Dalla Fontana 2005, Burrough & McDonnell 1998).

Although landscape classification is well established, it is still subject to scrutiny. Rhoads & Thorn (1996*b*, p. 120) have highlighted long-standing philosophical debates on the basis for classification that draw into question the actual presence of sharp or distinct boundaries between all classes (or natural kinds). Wilson & Burrough (1999) outline a variety of fuzzy classification techniques, which allow these inherent ambiguities and uncertainties in landscape classification to be represented. (Wood 1996) and Schmidt & Hewitt (2004) provide elegant examples of how fuzzy landscape classifications at regional and catchment scales can be derived from a morphometric analysis of a digital elevation model alone. At the morphological unit scale, such automated classifications have not yet been proved. Although fuzzy classifications are straightforward to apply (Burrough & McDonnell 1998, Deng 2007, Wilson & Burrough 1999), their application as masks is not as elegant and can cloud the rather simple interpretations of DoDs deemed as a necessary first step in this chapter. While, this debate it

[2] Also commonly referred to as an analysis mask. See ESRI GIS Dictionary (2007).

is interesting and alternative fuzzy classification methods might show some promise, they are peripheral to the focus of this chapter.

With regards to classification, the real question of relevance to morphological sediment budgeting is whether existing classification systems can be used to interpret a DoD or whether new classification systems might be needed. A range of classification techniques were experimented with. No single classification system is universally applicable or useful in all fluvial environments (Newson *et al.* 1998, Kondolf 1995). In any particular case study, there will be a range of useful and appropriate classification systems that may be used. These may be existing systems, or bespoke systems developed by the investigator(s) for the particular application and questions at hand. As such, a plurality of classification techniques used in parallel is advocated as opposed to any particular one. Below, a subset of classification types (as opposed to specific classification systems) deemed to yield the most useful information are described. First considerations in applying standard classifications are discussed. Next, the concept of a classification of difference (CoD) is introduced. Next, a DoD-specific classification is suggested, and finally some masks relevant to salmonid ecology are proposed.

5.2.1.1 Standard Classifications

As suggested above, their are no shortage of fluvial and/or habitat classifications at reach and sub-reach (geomorphic unit) scales. The individual classes in all of these classifications can be useful in interpreting DoD captured changes, provided that the classification system is relevant to the study site. In particular, an appropriate upper limit needs to be chosen for the spatial scale and resolution of the classification being applied. It is important that the spatial scale of the classification system is finer than the spatial extent of the DEMs. For example, the geomorphic unit scale classification within the River Styles hierarchy (see Figure 3.1) is a perfectly coherent scale to apply a meaningful mask from for most ground-based fluvial repeat topographic surveys. Similarly, the reach scale classification may be sensible provided that the survey is large enough to span multiple reach types (e.g. contrast in DoD results between braided and meandering reaches).

With regards to a lower-limit for an appropriate spatial scale of classification to use for budget segregation, the spatial extent should be coarser than the resolution of the topographic survey, but the resolution of individual units should not exceed the resolution of the topographic survey. Within River Styles, the hydraulic unit scale classification is approaching the lower limit of a sensible scale of segregation or masking for most topographic surveys,[3] but may be justified provided that the survey resolution is adequate. By contrast, few if any fluvial DoDs would be sensibly segregated by landscape scale classification as the fluvial environment itself represents a single landscape unit. However, a landscape scale mask from a catchment scale DoD or landscape evolution model, may be perfectly reasonable.

The one type of mask that has routinely been applied to DoDs in the literature is a sub-reach

[3] Terrestrial laser scanning perhaps being an exception (Milan *et al.* 2007).

FIGURE 5.1: Examples of sub-reach masks applied to DoDs in the literature. A) A 1.5 km study reach on the River Coquet, United Kingdom, which was DEM-differenced from 1999 to 2000 by Fuller *et al.* (2003). the reach was subdivided into 18 analysis masks (referred to as sub-reaches; sub-figure adapted from Fuller *et al.* (2003, Figure 1)). B) A 70 km study reach on the Fraser River, British Columbia, which was DEM-differenced from 1952 to 1984 and 1984 to 1999 by Church *et al.* (2001) and McLean & Church (1999). The reach was subdivided into 65 analysis masks (referred to as computing cells; Sub-figure adapted from Church *et al.* (2001, Figure 3)).

classification (Figure 5.1).[4] Most authors apply a gross application of the sediment continuity equation (Equation 3.1) to these masks in an attempt to look at net downstream transfer rates between sub-reaches (Fuller *et al.* 2003, McLean & Church 1999, Church *et al.* 2001, e.g.). Additionally, using sub-reach masks can be helpful for inter-comparing a) the relative gross magnitude of change, b) the nature of change (aggradational, degradational) and c) the style of change (elevation change distributions) between sub-reaches. Here, the application of such masks is extended both through c) and the uncertainty analysis techniques from Chapter 4.

Another useful mask that has been discussed in the literature (Brewer & Passmore 2002, Fuller *et al.* 2003, Fuller *et al.* 2002, e.g.) is the use of individual morphological units as masks. Brewer & Passmore (2002, Figure 3) first presented the concept of segregating the morphological sediment budget by morphological units (e.g. point bars, riffles, etc.) in the context of their 'morphological budget', which integrates both channel cross section and plan form data. Although such a mask could be extremely useful for looking at the magnitude, nature and style of change to specific morphological units, Brewer & Passmore (2002) and authors who have followed the technique (Brewer & Passmore 2002, Fuller *et al.* 2003, Fuller *et al.* 2002, e.g.) never actually report the data from individual morphological units. Instead,

[4]Although not typically referred to as analysis masks or a classification, in practical terms they are. These techniques were discussed briefly in § 3.4 - third paragraph.

the emphasis has been on simply summing the net changes from each morphological unit within a sub-reach (which is useful in itself). Moreover, this method of segregating the sediment budget by morphological units has only-been reported (by summation) for the combination of plan form and cross-section data and does not appear to have been reported explicitly for DEM differencing. Thus, simply extending this useful concept proposed by Brewer & Passmore (2002) to DEM-differencing and looking more closely at trends within and between distinct types of morphological units will be an original contribution helpful for improving geomorphological interpretation of DoDs.

Virtually all existing classification systems for fluvial environments are applied as static snapshots in time. Even a multi-scalar classification (e.g. River Styles or Alluvial Systematics) is only multi-scalar in the spatial sense, and is temporally-fixed, representing an assessment of the system at one particular point in time. This observation is not to suggest such classifications are not useful, or that such systems do not include categories that naturally imply something about the formation and history of a particular form or feature. The point is raised to highlight what information a standard geomorphological or habitat classification applied as an analysis mask for a DoD provides.

Careful consideration needs to be given to whether the mask applied to the DoD is derived from the more recent or older DEM. A mask applied to the DoD from the older DEM will reveal something about what changes took place to things as they were. For example, one could ask questions about how much deposition or erosion took place on what was a pool or what was a riffle and use that to infer how these features were reshaped (i.e. what was their fate?). Conversely, a mask applied to the DoD derived from the more recent DEM gives insight into what changes took place to produce the more recent morphology.[5] For example, did the pools captured in the more recent survey get there by preservation (e.g. no net elevation change) or active carving (e.g. scour)? Both masks derived from the older and newer DEMs yield useful information on their own, but together they can be used to piece together a fuller understanding of the changes.

5.2.1.2 Classification of Difference

As an alternative to a classification derived from the newer or older DEM in a DoD, a classification can be derived based on both. This technique will be referred to as a classification of difference (CoD), a preliminary form of which was presented by Wheaton *et al.* (2004*a*). The CoD requires two input classifications: one derived from the newer and one from the older DEM. Both classifications should be based on the same classification system. A CoD mask is then created for every possible combination of categories from old to new in the classification. For example a simple binary classification of each DEM in the DoD into areas of wet and dry (Brasington *et al.* 2003, Lane *et al.* 2003, e.g.) could be input to produce four unique output classes: wet $\Rightarrow$ wet, wet $\Rightarrow$ dry, dry $\Rightarrow$ dry and dry $\Rightarrow$ wet.

[5]This is what the Brewer & Passmore (2002) technique used.

For a classification system with n categories, n^2 CoD masks (output classes) will be produced. Of the n^2 masks, n will always represent no class change categories, and the remainder $(n^2 - n)$ will represent changes from one type to another. However, just because a cell in the DoD is classified by the CoD as a no class change, does not mean it did not experience geomorphological change. For example, a cell that was originally classified as a channel could experience significant erosion or deposition, yet still remain a channel. Conversely, just because a cell is classified by the CoD as a class change, does not necessarily mean it experienced net elevation change (i.e. geomorphological change can occur at a given location without the topography at the location necessarily changing). For example, due to an avulsion a cell that was previously classified as a channel may become an abandoned channel without any elevation change actually occurring in that cell. In such instances, the requisite is that some type of elevation change took place in the vicinity (e.g. plugging at the head of the abandon channel) for the geomorphological change to occur without an elevation change taking place.

5.2.1.3 Geomorphological Interpretation Classification

After experimenting with numerous combinations of standard classifications, bespoke classifications and CoDs, a slightly different type of classification type was developed. The classification is based on the qualitative interpretations[6] a trained geomorphologist makes when inspecting a site in the field and describing the evidence of change before them. Those qualitative observations can be articulated into a classified map of different types of changes, which is then overlaid as an expert-derived analysis mask (albeit subjective) onto the DoD. This type of classification allows the transformation of qualitative observations into a quantitative segregation of the DoD.

Most experienced fluvial geomorphologists are comfortable going to a field site after a flood and describing what they think happened on the basis of visual evidence of erosion and deposition. For example, they might identify areas where bank erosion occurred or areas where 'fresh' gravel was deposited to produce or accentuate a bar. Based on the relative areal extent of such changes, some might even be happy to speculate about the relative magnitude of each change and which was more dominant. This style of interpretation (Ferguson & Werritty 1983, e.g.) is actually very focused on the processes responsible for the change, but as it is qualitative it is difficult to test the resulting hypotheses and assumptions. If these interpretations are translated onto a map, they become masks from which the DoD can be segregated. Moreover, the quantitative results can be used to test the original hypotheses and assumptions made.

These interpretations need not be based on field observation alone. Ideally, they are formulated in a GIS using a combination of all the available evidence (i.e. layers). For example, in this chapter a mix of the DoD, both input DEMs, before and after aerial photographs, geomorphological classifications before and after, as well as CoDs were used in addition to field

[6]See § 9.3 for a discussion of the robustness of these interpretations.

observations. Collectively, they allow the investigator to cast judgment on what categories of change were taking place and captured by the DoD with reasonable confidence. As with any classification system, it is important that the available evidence is used to make consistent interpretations. The individual categories of change used to produce this type of classification will vary from site to site depending on the dominant processes. It is important to draw a conceptual distinction between categories of change and the fluvial processes responsible for producing that change. The two are intimately related, but they are not necessarily the same.

5.2.1.4 Ecologically Relevant Masks

There are at least three types of ecologically relevant masks that might be used to explore the implications of geomorphological changes on salmonids. The first is a physical habitat classification mask, and this can be applied either as a standard classification (§ 5.2.1.1) or a classification of difference (§ 5.2.1.2). Secondly, redd surveys showing the locations and areal extent of spawning activity could be used as a mask. This might be used to look at the impact of a flood during the incubation period or, if surveys were detailed enough, how much sediment was moved from the process of redd construction. Finally, ecohydraulic habitat suitability models might be used as a mask. They could be used to draw correlations between the quality of habitat and the types of change it experiences (i.e. a standard classification), or to look at how changes in morphology relate to changes in habitat quality (i.e. classification of difference).

5.2.2 Geomorphological Interpretation Software Extension

The DoD Uncertainty Analysis Software developed in § 4.5 has resulted in an expandable and easy to use analysis package for considering the influence of DEM uncertainty on DoD predictions. In this chapter, the application of spatial masks to DoD outputs from this software (e.g. a pathway 4 analysis) are advocated. It is desirable to report the relative magnitudes of change in each mask class, produce elevation change distributions for each mask class, save consistently formatted figures, and produce some summary reports with basic statistics. As will be shown in the next three chapters, these basic outputs will dramatically improve the robustness and scope of geomorphological interpretations that can be made from DoDs. While these tasks are straight-forward to apply manually, they are time-consuming and manually produced outputs are highly susceptible to inadvertent errors given their repetitive nature. Thus, again, a software program to automate these tasks was developed partly to reduce likelihood of errors in the analysis, but primarily to extend the scope of analyses that could be performed.

As with before, a secondary motivation was to produce an easy to use software application to facilitate these types of analyses by trained geomorphological researchers and practitioners. Ideally, the user would be able to run one set of DoD analyses based on all their available intersecting data. Instead of using a different clipping boundary geared to the question of

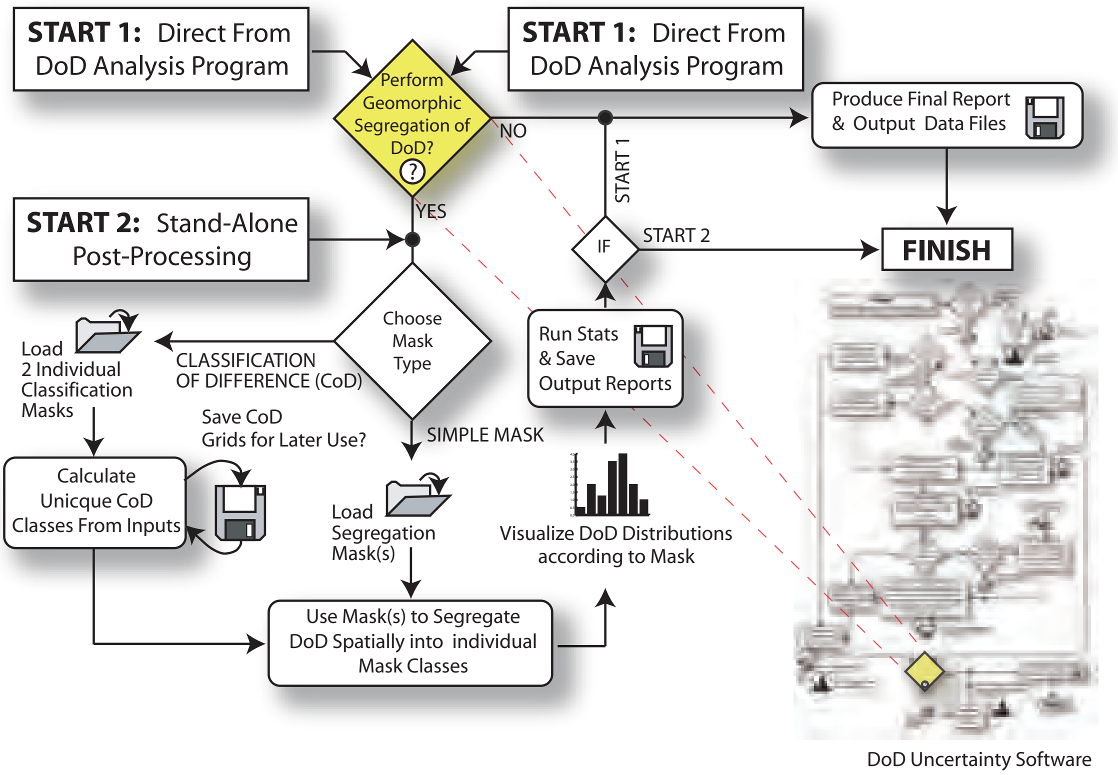

FIGURE 5.2: Flow chart showing geomorphological analysis extension to DoD Uncertainty Software. The inset figure of the DoD Uncertainty Software in the lower right is for reference (for full size see Figure 4.20).

interest and then having to rerun DoD analyses for every clipping boundary, the user should be able to run the analysis once for all the data, and then ask whatever questions they wish of it by masking the dataset in different ways. This reduces the likelihood for inadvertent user errors by eliminating the need to repeat the same analyses.

An extension to the DoD was again developed in Matlab as a dialog box driven application. As shown in the extension flowchart (Figure 5.2), the extension can be run as part of any pathway[7] straight out of the DoD Uncertainty Analysis Software (Start 1 in Figure 5.2). Alternatively, any DoD or thresholded DoD raster can be loaded independently and the geomorphological analysis run as a stand-alone application (Start 2 in Figure 5.2). The extension can also be run in a batch mode, which automatically applies the inputs and parameters based on a batch configuration file.

Within this extension, two types of masks can be applied based on the options discussed in the previous section. The simpler of the two, segregates the DoD based on the number of unique integers in the single raster integer input grid. The more complicated (CoD) produces unique categories based on two input raster integer input grids (one associated with the old DEM and one with the new DEM). In principle any classification system could be applied (e.g. River Styles (Brierley & Fryirs 2000); see § 3.2.1) with any number of classes. The only requirement

[7]See § 4.6 for description of different pathways.

for the CoD approach is that the same classification system is used for each input. However, as the number of output classes in a CoD is the square of the number of input classes, even a straight forward classification with 10 input classes will have 100 output classes!

Masks can be derived in any GIS package using a variety of techniques. One simple work flow for manual classification is to draw vector polygons (e.g. shapefiles in ArcGIS) to classify the DEMs or DoD and then convert these to a raster integer grid where the integer corresponds to the class. In this Geomorphological Interpretation Software Extension, the user is prompted to type in descriptive tags that correspond to each of the unique integer values it finds in the loaded raster(s). The extension then uses these tags to label figures, produce output reports and output tables that will make sense to the user.

The way the extension works is rather simple, but results in huge time-savings over trying to attempt this methodology manually. For each unique integer value in the mask (i.e. class in the classification), it visits every cell in the raster mask and checks if its value matches the current value. If it does, it takes the elevation change defined by the DoD in the corresponding DoD cell and adds it to the elevation change distribution for this class. After looping through the entire raster, a complete elevation change distribution is produced for that class and the same summary statistics regarding areal and volumetric changes developed in Chapter 4 are produced. The process is repeated for every unique class and then an inter-comparison of the relative magnitude and styles of change in each class are calculated. The results are saved in a series of output elevation change distribution figures, a pie chart, a summary text report and tables. All the raw data from the elevation change distributions are saved in *.csv tables to allow additional analyses.

It is important to emphasise that this software extension does not make or automate any geomorphological interpretation itself. Instead, the application simply facilitates analysis of the DoD based on a classification done externally and provided as an input. That classification, in principle, can be anything from an entirely objective algorithm-based classification, to a more subjective expert-based classification. There is no single correct classification (Newson *et al.* 1998), and each will yield different information and unique insight into the changes reflected in the DoD. After reliability uncertainties in the DoD have been accounted for, the sensible interpretation of the DoD, rightly, remains the responsibility of the trained geomorphological practitioner using the software.

5.3 Study Sites

To demonstrate the utility of the proposed methodological development in different environments, it will be useful to test its application at study sites where completely different styles of change are taking place. As described in § 3.5, the three study sites used in this thesis are Sulphur Creek[8] in California, the Mokelumne River[9] in California, and the River

[8] See Appendix F for complete study site description of Sulphur Creek.

[9] See Appendix G for complete study site description of the Mokelumne River.

Feshie[10] in Scotland (Figure 3.6). The three study sites span a range of physiographic settings with contrasting anthropogenic influences (refer back to Table 3.1) that make for an interesting inter-comparison. For example, both the River Feshie and Sulphur Creek have completely unregulated flow regimes with no major abstractions or dams located upstream of the study sites (Soulsby *et al.* 2006, Grossinger *et al.* 2003). Both sites also boast relatively[11] dynamically changing channels with high sediment loads (Pearce *et al.* 2003, Katzel & Larsen 1999, Brasington *et al.* 2000, Ferguson & Werritty 1983). These characteristics are in sharp contrast to the heavily regulated flow regime of the Mokelumne River, which no longer receives any sediment load from upstream (Merz *et al.* 2006). However, both the Mokelumne River and Sulphur Creek study sites have been subjected to over a century of heavy direct engineering intervention including artificial bank armouring and extensive gravel mining (Merz *et al.* 2006, Grossinger *et al.* 2003). Gravel mining has since stopped in both systems and both sites have been subjected to 'restoration' interventions and efforts. The Feshie by contrast is one of only four sites in the UK that is a Site of Special Scientific Interest (SSSI) because of the natural value and character of its fluvial features (i.e. only contemporary example of an undisturbed braided river in UK).

From a geomorphological monitoring perspective, the three study sites define three of the more typical styles of contemporary fluvial geomorphological monitoring using repeat topographic surveying. Namely:

- Sulphur Creek represents an example of short-term, event-based, monitoring
- The Mokelumne River represents an example of monitoring associated with reach-scale restoration, consisting of pre-project, as-built and repeated post project appraisal[12] surveys as part of a long-term monitoring programme
- The River Feshie represents an example of a long-term, annual resurveying effort in a relatively dynamic system

Although other types of repeat topographic survey monitoring exist over both shorter (e.g. hourly or daily) and longer (e.g. decadal) survey intervals, these three examples are arguably a reasonable cross-section of most common forms.

In terms of explaining the geomorphological regime and the changes the repeat surveys are capturing at each of these sites, there is a progression in terms of complexity. As the data at the Sulphur Creek study site captures change due to a single major storm event, it represents the simplest of the three. The Mokelumne River is slightly more complex in that the data represent both changes due to a PHR intervention (placed gravel) and subsequent adjustment of the constructed features by minor fluvial reworking. The Mokelumne also represents seven surveys associated with four PHR projects, providing a more rigorous assessment of the methodology.

[10] See Appendix A for complete study site description of the River Feshie.

[11] Relative to other streams and rivers in their respective regions.

[12] See Downs & Kondolf (2002) for description of post project appraisals (PPA) and Wheaton *et al.* (2004*c*, p. 9-10) for monitoring typically associated with PHR projects.

However, the Mokelumne River site is a highly artificial system directly controlled by a heavily regulated flow regime and as such the changes due to geomorphological processes are relatively minor. The Feshie by contrast boasts two periods of minor changes and two periods of substantial change.[13] Thus the next three chapters in Part III will provide varying examples of geomorphological change on Sulphur Creek (Chapter 6), the Mokelumne (Chapter 7), and the Feshie (Chapter 8) respectively, in order of increasing complexity of the nature of change. The simplest case on Sulphur Creek will be used to compare variations in the methodology, whereas the other two will focus more on the geomorphological interpretation.

5.4 Conclusion

This short chapter has outlined some simple masking techniques and categories of masks that can be used to segregate a DoD into discrete classes and make a more informed geomorphological interpretation. The masks proposed included a range of standard classification masks, a classification of difference, a geomorphological interpretation mask, as well as a few ecologically relevant masks. These tools were built into an extension of the DoD Uncertainty Analysis Software. They will be applied to three different case studies in Part III to provide contrasting examples of change.

[13] This *substantial change* is characterised by regular inundation of over 75% of the active braid plain at the site and subsequent reworking and activation of braid plain materials.