Catchment-scale approaches to restoring rivers with coarse sediment problems

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Introduction

In the summer of 2000 I was asked to advise the Environment Agency on a river management problem, with a view to a river restoration scheme, in Wharfedale in the Yorkshire Dales National Park. This scheme fell within the remit of the Upper Wharfedale Best Practice Project. The problem was, on the surface, simple. A series of river management measures had been adopted in the 1980s to deal with the problems of coarse sediment aggradation, which was linked to both bank erosion and frequent floodplain inundation. The solution involved a gravel trap. As a result of high rates of sediment delivery, coupled to changing legislation on gravel removal and an increasing concern over the ecological impacts of emptying the trap, the trap had not been emptied for over 10 years. The 'Buckden Reach' had become controversial because of the perceived failure of past river management and a concern that reports commissioned in the late 1990s, including some that advocated re-engineering of the channel and stabilisation of the river banks, were at odds with what the local community knew about how their river worked. The result of this was a community-centred, scientifically-informed river restoration scheme, with two components: (1) a local-scale restoration of the gravel trap; and (2) development of a long-term management plan to work out how to deal with the problem of high rates of gravel delivery. How we reached this approach is reviewed and discussed in McDonald *et al.* (2004). In this article, I explore how we went about delivering the gravel management plan, one that could lead to a fundamentally different approach to managing rivers with coarse sediment aggradation problems.

The problem: an overview

When I became involved in the project, the Upper Wharfedale Best Practice Project had gone a considerable way to identifying the major river management problems in Wharfedale. These included: (1) flood inundation on the meadow lands in the valley bottom; (2) river bank erosion and loss of river-adjacent land; (3) the gravel trap described above. There was a general perception amongst the local community that these problems were getting worse. What could be causing this? Figure 1 illustrates possible explanations.

Figure 1. Possible explanations of worsening flood inundation and bank erosion in Upper Wharfedale

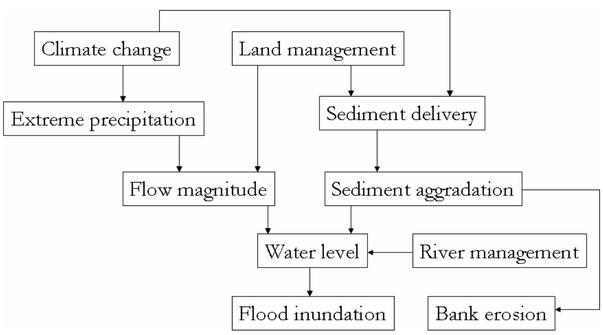


Figure 1 emphasises five reasons why things might be getting worse including:

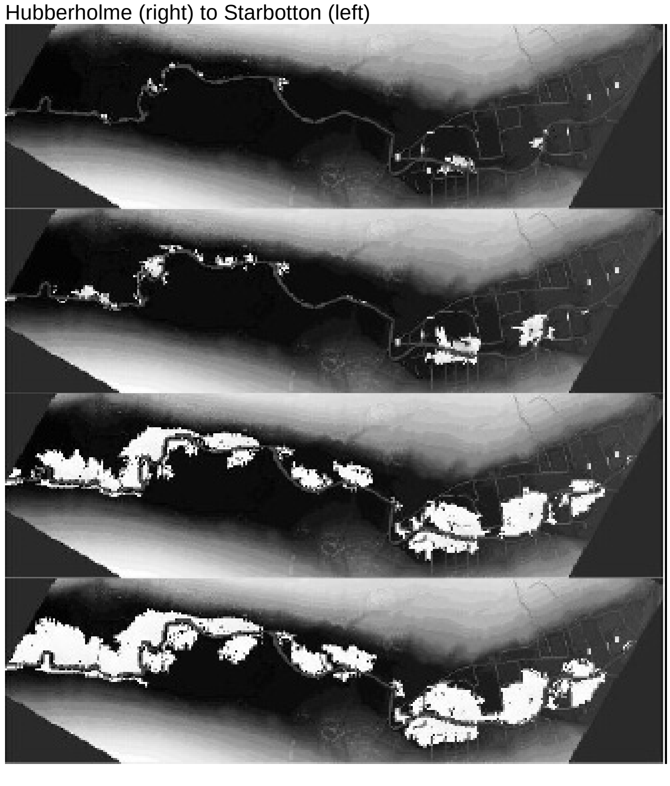
(1) our climate is changing leading to wetter catchments and more extreme events, which lead to higher peak flows and more flooding, and more sediment being delivered;
(2) our land management practices (e.g. gripping) are delivering rain more quickly to rivers, causing more extreme flows;
(3) our land management causes more sediment to be delivered to the river, raises river bed levels, making water levels rise; it may also make bank erosion worse;
(4) our river management activities (e.g. bank protection) are making things better/worse; and…finally…
(5) things are not actually getting worse, rather legislation is changing what we can and cannot do in rivers, and this is making us think the problem is worse.

Our research project set out to answer these questions. In this article, I focus on (3), (4) and (5).

Floods and sediment delivery

One of the most striking results of our research was the discovery that, for this system, the prime control on the flood inundation signal was not changes in peak flow magnitude but changes in river bed elevation. In relation to flood inundation, we found that the effects of river channel change may dwarf those of climate changes in this case study site (Lane *et al.*, in press). Our assessment was based upon development of a model of floodplain inundation that explicitly represents the complexity of the valley bottoms (Tayefi *et al.*, in press): for instance, dry stone walls have a major effect upon flood routing. Our approach avoids the difficult question of how to represent floodplain roughness through a parameter like Manning's *n*, and represents buildings, walls etc. explicitly (see Lane, 2005; Yu and Lane, 2006). Figure 2 shows our model of a flood that occurred on the 4th February 2004, and which we used to show that our model was working correctly by comparison with measured inundation extent. We have used the model to compare the effects of coarse sediment deposition with the effects of climate change upon flood characteristics. We found that **only 16 months of deposition and channel change caused a similar increase in flooded area to projected climate change effects to the 2050s**. In this valley, at least, sediment delivery is *the* major issue.

Figure 2. Predictions of flood inundation for the reach from Hubberholme (right) to Starbotton (left)

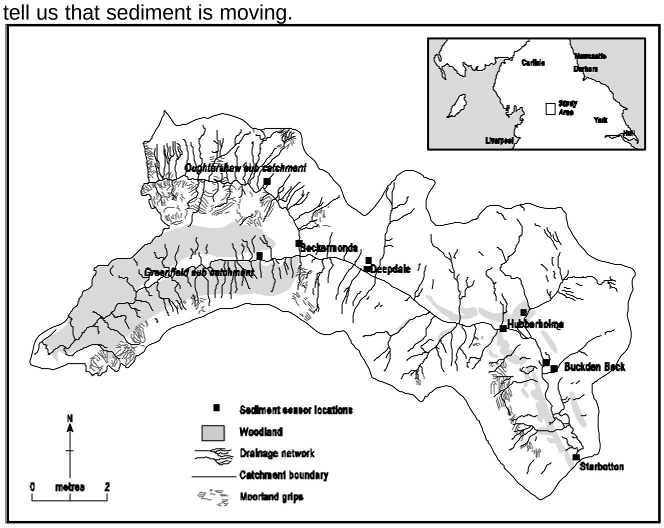


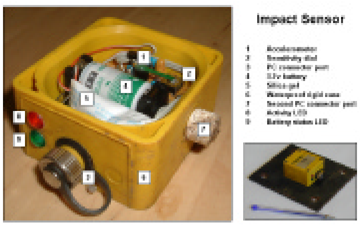
[1] This research has benefited from the input of a number of researchers, including Dr. Simon Reid and Dr. Vahid Tayefi (formerly U Leeds), Dr. Chris Brookes (Victoria University of Weillington, New Zealdn), Dr Yu Dapeng and Dr Richard Hardy (U Durham), Dr. Joe Holden, Professor Adrian McDonald and Professor Mike Kirkby (U. Leeds). Support from NERC Grant NER/D/S/2000/01269, the Environment Agency and the National Trust is also acknowledged.

Where does all the sediment come from?

Given the importance of the coarse sediment delivery problem in relation to flooding, we set out to find out where it is all coming from. To do this, we did two things. We put in 10 sediment sensors to tell us when and where sediment moves (Figure 3). We also developed a model to show us where the sediment is coming from, and checked this by surveying sediment sources in extreme rainfall events, as well as river response (Reid *et al.*, in press).

Figure 3. The coarse sediment sensor and installation locations. When sediment moves, it hits the metal plate, causing it to ping and tell us that sediment is moving.





The sediment sensors showed us that the forested area at the top of the catchment (Greenfield) was producing no sediment and Oughtershaw was producing a little. However, most sediment was coming from where tributary gills were cutting down into old sediment deposits, that comprised shallow terraces draped over the hillside. This is shown in our model results (e.g. Figure 4) and emphasises that high rates of sediment delivery to this river are due to the legacy of glacial deposits, formed over the last 20,000 years. Our model results also showed that we can expect dramatically more sediment to be delivered per year under climate change scenarios for the 2050s and 2080s, expressed in Figure 5 as estimated annual average aggradation rates (Lane *et al.*, in review, a).

Figure 4. Predictions of where sediment comes from: concentrated on narrow tributary gills. The background map is copyright with the Ordnance Survey.

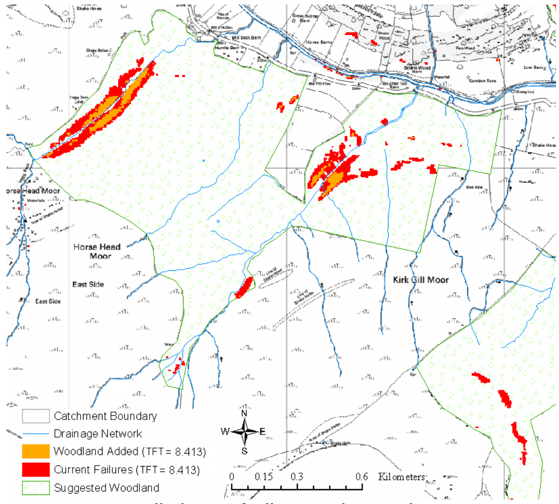
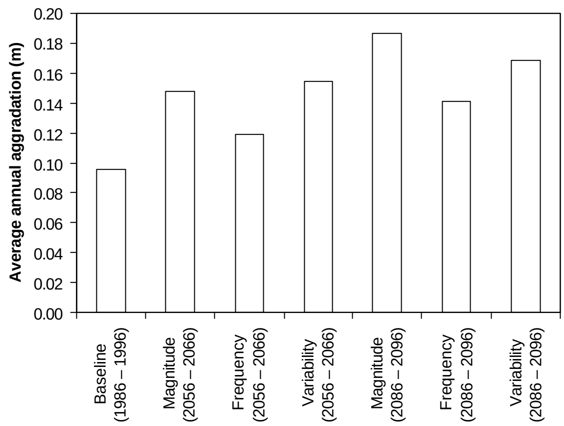


Figure 5. Future predictions of climate change impacts upon coarse sediment delivery rates expressed here as reach-scale averaged aggradation rates, one the basis of the observed reach length over which deposition is observed. 'Magnitude', 'Frequency', 'Variabilit'y all refer to different assumptions about how predictions of monthly rainfall are downscaled to storm event timescales.



Rivers, management and gravel traps

So, what do we do about all this delivered sediment? Traditionally, we have tried to engineer the river to move the sediment downstream. Our sediment sensors showed that almost no sediment gets beyond Starbotton, largely due to the legacy of a major land slip in the 1600s, that effectively blocks the valley. This means that the reach between Hubberholme and Wharfedale is a bit like a sedimentary bath tub, slowly filling up. Engineering the river to move sediment downstream simply won't work. However, it also represents a problem. If a river is receiving sediment, it will adjust by eroding one bank (which puts fine sediment into the river) and depositing on the other (which puts coarse sediment into store). If we put in bank protection measures, the river can't erode any more, it can only deposit. It will fill up with sediment, causing bed levels to rise and more flooding. The gravel trap was designed to manage this, but our research showed that it was not a sustainable gravel management solution (Lane *et al.*, in review, b). The replacement solution for the gravel trap itself can only be sustainable if the **rate of sediment delivery** can be reduced. As a result, research results suggest **source control** instead.

Looking towards the headwaters: a new approach to managing sediment delivery

Given that gravel traps don't appear to solve sediment delivery problems, what is the alternative? We noted that our sediment model showed that most sediment came from a very small part of the catchment. So, we explored what happened if we simulated introducing native woodland to those areas (Lane and Reid, in review). Trees introduce roots which makes the land surface more resistance to failure. They can also act as blockage to smaller and shallower failures. Our model showed that very restricted planting in tributary gills could reduce the sediment delivered per year by up to 85%. This is probably the most sustainable option for managing river gravels and opens up a fundamentally different approach to managing coarse sediment problems: reconceptualising river management at the catchment-scale and as a diffuse problem, and focusing upon land management activities in those locations that are likely to be coarse sediment sources.

A concluding reflection

Ultimately, this work implies that high rates of sediment delivery may probably be traced back to deforestation in the Dale, many centuries before present. This fits with the general idea that historical land management has sensitised our catchments to climate change and, at least in terms of managing sediment delivery, land management should be an integral part of catchment management in general and river restoration in particular. In this case, and from talking to the local community, the gravel problem has probably been with us for most of our living memory. Why did it become a problem? Much of the answer may well be nothing to do with the river, but related to the way in which society in the Dale and more broadly has changed. This includes introducing new authorities (e.g. the Environment Agency) that give new responsibilities (and hence people who can be told that there are problems that need to be addressed), new restrictions (e.g. on aggregate removal) and new priorities (e.g. protection of long distance footpaths, target species). All of this takes place on a canvas of a changing environment. Our results provide a scientific basis for managing problems of coarse sediment delivery through an analysis of possible sediment source areas in upstream streams and tributaries and we are currently testing the methodology in other catchments. In practice, how we deliver these new management practices remains a challenge at the interface of science and society, that will require coarse sediment to become seen as an additional component of catchment sensitive land management, in addition to traditional emphases upon nutrients like nitrogen and phosphorus.

Copies of the following references may be obtained from the author:

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