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The role of geomorphology in flood risk assessment

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The most commonly used method of assessing flood risk is based on predicting the magnitude and extent of the ‘100-year’ or ‘200-year’ flood. Though potentially very useful to engineers, this information can mislead planners and developers into assuming that areas outside these limits are risk free. This paper reports on an alternative, geomorphological approach that has recently been examined in Wales to map the physical extent of the floodplain itself. Such mapping reflects actual evidence of fluvial activity rather than relying on modelled predictions and, therefore, is less likely to omit areas that could be at significant risk of flooding. It also provides a tool for investigating and predicting the response of river channels, floodplains and catchment hydrology to climate and land use changes over time.

The planning system has an important role to play in reducing the cost and misery of flooding by identifying, and steering development away from, areas that are fundamentally at risk of inundation by virtue of their location within the floodplain. Where such information is lacking, inadequate, or simply ignored, and inappropriate development is allowed to take place within the floodplain, the consequences, sooner or later, are inevitable (Fig. 1).

The method of risk assessment currently used by the Environment Agency is based on predicting the likely magnitude and extent of the ‘100 year’ or ‘200 year’ flood. On many rivers, the autumn 2000 floods were notable for the fact that they filled the natural extent of their floodplains and, in doing so, often exceeded the extent of flooding shown on the Environment Agency’s maps.

In some cases, notably in Uckfield and the Vale of York, the return period of these floods was greater than 100 years. But how reliable are estimates of return periods for such events when records of peak discharge are generally of much shorter duration (and are often flawed), when the climatic regime may be changing, and when catchment

response to rainfall may have been altered by land use change during the period of hydrological record? Might events of such magnitude occur more frequently in the future?

Is there a need for a more fundamental, deterministic method of defining floodplains, to provide a check on other methods of analysis, and thereby to provide a more reliable basis for strategic policy development? This paper examines the role that geomorphology could

Fig. 1. Flooding in Uckfield, East Sussex, in autumn 2000 caused damage to some numerous business premises in the floodplain (courtesy Solent News)

Fig. 2. Skirden Beck in Lanchashire—an active gravel-bed stream in which lateral shifting of meander bends deposits gravel within the channel and adjacent bars (photograph by Alan Thompson)

play in developing improved procedures for flood risk assessment to support the planning process.

Indicative floodplain mapping

The Environment Agency's 'indicative floodplain mapping' has been compiled from a variety of data sources, ranging from very low-resolution hydraulic modelling prepared by the former Institute of Hydrology, to more sophisticated 'section 105' (Water Resources Act 1991) mapping and, in some areas, historical flood limits. In all cases, the approach used is fundamentally a probabilistic one, as required by the current planning guidance on development and flood risk in England.¹

In preparing section 105 maps, hydrological analysis is used to determine the magnitude of flood associated with the required return period and hydraulic modelling is then used to identify the area that would be inundated by such an event, taking account of channel gradient, hydraulic 'roughness' and conveyance capacity.

The main advantages of section 105 mapping are that it quantifies the level of risk involved, and can be repeated by others given the same input data. The technique offers particular advantages in areas of extensive built development, where the extent of flooding may no longer be limited to the natural floodplain, and it is able to take account of

the influence of flood defence structures and flood relief channels.

Repeatability is important in ensuring consistency in decision making, especially when taken to public inquiry. It may need to be questioned, however, if it simply involves the repetition of erroneous results—as may be the case, for example, if the standardised flood estimation procedure were consistently to underestimate the magnitude of the 100-year flood for a given location.

Though potentially very useful to engineers, probabilistic maps can be misleading when used in the context of land use planning. Such outlines generally provide no indication of the likely variations of flood risk within the 100 year envelope, and may lead planners and developers to assume (incorrectly) that areas outside these limits are risk free.

Physical floodplain mapping

An alternative approach^{2,3} for use in support of planning guidance which has been examined for use in Wales⁴ is to map the physical extent of the floodplain itself.

Natural floodplains comprise areas of land, adjoining a stream or river, that have been created by the lateral shifting of river channels and by the deposition of overbank flood deposits during 'present-day' environmental and climatic conditions (Fig. 2). By definition, they are therefore likely to be inundated, from time to time, by overbank flows (Fig. 3).

Fig. 3. Total floodplain inundation in the Severn valley near Shrewsbury in autumn 2000 (photograph by Alan Thompson)

“In such cases, the floodplains will have been constructed largely by lateral accretion of gravel bars on the inside of meander bends and will tend to flood very frequently”

In some areas, where channel gradients are relatively steep and where (as a consequence) rates of bank erosion are relatively high, most of the floodplain is likely to have been ‘reworked’ by the shifting course of the river during the last 50 – 200 years (Fig. 4). In such cases, the floodplains will have been constructed largely by lateral accretion of gravel bars on the inside of meander bends and will tend to flood very frequently. Overbank flood deposits gradually build up on top of the gravel bars but these rarely attain a great thickness before they are reworked again. In such cases, the evidence of former channel positions will usually be clearly discernible on the floodplain surface (Fig. 5).

In other areas, particularly in lowland Britain, where rivers tend to be relatively inactive, the floodplains have generally not been ‘reworked’ in this way for many hundreds, perhaps several thousands, of years. As a consequence, much

Fig. 4. Sequential development of meander bends on Skirden Beck—evidence of recent channel positions is preserved in the morphology of the floodplain surface (photographs by Alan Thompson)

thicker accumulations of overbank flood deposits (silts and clays) have generally built up on top of much older (often pre-Holocene) sands and gravels, raising the floodplain surface and making much

of it susceptible only to higher magnitude, less frequent floods.

Mapping the extent of abandoned channels, scroll bars and ox-bow lakes can reliably define the minimum extent

Fig. 5. Aerial photograph of geomorphological features on the River Ure floodplain near Ripon, North Yorkshire (courtesy Hunting Aerofilms)

of natural floodplains and can provide useful clues as to the historical evolution of the river and its floodplain.

It is the outer limits of the floodplain, however, which are of most relevance to the assessment of flood risk. These can often be defined by breaks of slope, where the surface of modern alluvium abuts the sloping valley side or adjoining river terrace features. Where such features are well defined, they will represent a significant 'step change' in the likelihood of inundation and, thus, are of particular interest here. However, in some cases, the distinctions are more subtle and very careful geomorphological mapping is needed to identify the limits that are most relevant to flood risk assessment.

Floodplain hydrology

In attempting to make use of geomorphology in flood risk assessment, it is important to recognise that river floodplains are dynamic systems that respond to long-term changes in flood magnitude and frequency, and that their morphology is therefore continually adjusting to the prevailing climatic and environmental regime. Empirical evidence shows that, as a consequence of such adjustments, most natural, meandering rivers in the world attain bankfull discharge at least once every one or two years, on average.^{5,6}

The increase in discharge above the bankfull stage that is required to fill the floodplain will depend on the thickness of the overbank sediments, the degree of relief on the floodplain surface and the width of the floodplain relative to the size of the river. Further research is required in this area but experience suggests that, in areas without engineered defences, it is unusual for floods with recurrence intervals approaching 100 years—and often much less—not to occupy most, if not all, of the natural floodplain surface.

The frequency with which the entire floodplain is inundated varies from one length of river to another. For this reason, outer floodplain limits are not directly comparable with other forms of hazard assessment based on the probability or return period of inundation. Arguably, however, they are more likely

to represent the limits of significant hazard, since floods of greater magnitude will be characterised by increased depths and velocities of flow but will not usually affect a much wider area.

Climatic and land use changes

One of the inherent difficulties in flood risk assessment is the need to evaluate and take account of the impact of climate and/or land use changes. Both of these are known to have influenced the magnitude and frequency of flooding over the period of historical records and are likely to be of much greater significance in the future.

To some extent, the new *Flood Estimation Handbook*⁷ techniques used in section 105 mapping take account of recent land use changes across a catchment rather than relying on just historical flows. Problems can arise, however, when an event that occurred prior to significant changes is used to calibrate output from the hydraulic modelling process, without such changes being taken into account—hence the need for experienced modellers doing the work.

Allowance for future climatic change can be made by increasing the estimated flood magnitude—a 20% increase being the current recommendation from the Environment Agency—before the hydraulic modelling is carried out.

An alternative would be to use geomorphological criteria to identify areas likely to be at risk. Physical floodplain limits are commonly (though not always) wider than the modelled extent of 100 year (1.0%) flood limits. Therefore, at a very crude level, physical mapping can often provide a margin of safety with respect to the implications of climatic change.

However, geomorphology also has the potential to offer greater sophistication. Under stable climatic and environmental conditions, unconfined rivers demonstrate a dynamic equilibrium—changing course as a consequence of erosion and deposition but retaining the same overall characteristics (meander wavelength, channel size and bedform spacing). More commonly, under changing conditions, these characteristics continually adjust and a record of past adjustments is preserved in the geomorphology and

sedimentology of river floodplains and terraces.

Analysis of such records can reveal evidence of former flood events (which, if dated, can help to quantify flood risk), but they can also help geomorphologists to understand the ways in which the hydrological regime itself has adjusted in response to former episodes of both climatic and land use change. This, in turn, could help to predict the nature and magnitude of ongoing and future responses.

Such information could be invaluable in the preparation of catchment flood management plans, helping to demonstrate, on a catchment-specific basis, the linkages between land use, land management, hydrology and flood risk.

Understanding temporal changes can also help to identify sites where flood risk is likely to be increasing (due to sediment aggradation), or decreasing (due to channel incision), over the engineering time-scale. This is one of the objectives of new modelling techniques being developed at the University of Wales, Aberystwyth.⁸

Discussion

The main advantages of physical floodplain mapping are that it acknowledges and reflects actual evidence of fluvial activity, rather than relying on modelled predictions, and therefore is less likely to omit areas that could be at significant risk of flooding. Although geomorphological maps do not yet exist for most areas, the British Geological Survey's drift geology maps may provide a useful starting point, at least as an interim measure. This possibility is currently being investigated by Symonds for the Welsh Assembly. If found to be suitable for this purpose, such maps would have the added advantage of being available for ordinary watercourses, as well as for main rivers.

The main weakness of the geomorphological approach lies in the fact that human activity, particularly built development within the floodplain and engineered flood defence schemes, can alter significantly both the shape of the land and (as a consequence) the extent of flooding. Geomorphological and/or drift geological mapping that has been car-

“the advantages of geomorphological mapping generally complement those of the present hydraulic modelling approach”

ried out prior to such development could, however, provide invaluable information on the likely extent of flooding that might occur if engineered defences were to be breached or overtopped. In urbanised but undefended areas, the magnitude of flooding indicated by such mapping could be used in conjunction with hydraulic modelling to assess the likely modified extent of inundation resulting from built development.

Overall, the advantages of geomorphological mapping generally complement those of the present hydraulic modelling approach. The greatest potential for use of such mapping is therefore likely to be in conjunction with other techniques, rather than as an alternative to them.

With little change to existing procedures, geomorphology could be used as a means of checking the output from the hydraulic modelling process. As a broad generalisation, in areas not modified by built development, the modelled limits of 100 year flood events that cut across river terraces or outer floodplain limits are unlikely to be correct. Equally, modelled flood limits that represent low frequency (>100 year) events, but which do not fill most of the natural floodplain, should be subject to very careful scrutiny (except, of course, where such flooding is adequately constrained by engineering works).

For land use planning purposes, there is merit in combining the output from conventional, probabilistic risk assessments with the deterministic output from physical floodplain mapping and taking the outer limits of both as the definition of potentially high-risk areas, within which specific policies for more detailed assessments by developers would apply. This approach has been assessed by Symonds as part of the recent work for the Welsh Assembly.^{2,3}

Maximum benefits could be obtained by using geomorphology from the outset, as an integral part of the modelling process (although this would require a more substantial revision of the Environment Agency's current methodology). Geomorphologists could, for example, help to select the locations of cross sections to be used to provide elevation data as input to the model, and

could help to devise the specifications for any new surveys that are required. In this way, geomorphological features that help to define the floodplain, or that may influence storage capacity and/or overbank flow patterns and flow depths, could be represented in the model.

Conclusions

Geomorphology has the potential to provide a complementary, deterministic approach to the identification of flood risk or hazard for land use planning purposes. Physical mapping of outer floodplain limits can provide planners with a good indication of those areas where more detailed risk assessment is needed, and more comprehensive mapping of features within the floodplain can help to identify areas where the risk of rapid inundation and/or deep flooding is particularly high. The greatest potential for using geomorphology, however, is probably through the integration of these techniques with traditional engineering and hydrological approaches.

Geomorphology also provides a tool for investigating the response of river channels, floodplains and catchment hydrology to climate and land use changes over time. As such, it has substantial potential for use in catchment flood management plans.

Proposals to develop these ideas further, building on the work carried out by the Symonds Group and Aberystwyth University in Wales, have recently emerged from the EPSRC network on the morphology and sediment dynamics of river floodplain systems, and are being considered for research funding by the Department for Environment, Food and Rural Affairs and the Environment Agency.

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References

1. DEPARTMENT OF TRANSPORT, LOCAL GOVERNMENT AND THE REGIONS. *Development and flood risk*. The Stationery Office, London, 2001, Planning policy guidance note 25.
2. THOMPSON A., CLAYTON J. AND YOUNG R. *Flood risk assessment for planning in Wales*. Paper presented at the Irish National Hydrology Symposium, Tullamore, Nov. 2001.
3. THOMPSON A., CLAYTON J. AND YOUNG R. *Flood risk assessment for planning*. Symonds Group Ltd, East Grinstead, 2002, Research Report to the Welsh Assembly.
4. WELSH ASSEMBLY GOVERNMENT. *Development and flood risk*. Technical Advice Note (Wales) 15, 2002.
5. WOLMAN M. G. and LEOPOLD L. B. River floodplains, some observations on their formation. In *Floodplain Geomorphology. Progress in Physical Geography*, volume 2 (Lewin J. (ed.)), 1978, pp. 408–437.
6. DURY G. H. Bankfull discharge, an example of its statistical relationships. *Bulletin of the International Association for Scientific Hydrology*, 1961, 5, 48–55.
7. CENTRE FOR ECOLOGY AND HYDROLOGY WALLINGFORD. *Flood Estimation Handbook*. CEH Wallingford, Wallingford, 1999.
8. COULTHARD T. J. AND MACKLIN M. G. How sensitive are river systems to climate and land-use changes? A model-based evaluation. *Journal of Quaternary Science*, 2001, 16, No. 4, 347–351.

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