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Learning to live with rivers—the ICE's report to government

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This paper reviews the technical aspects of flood risk management in England and Wales, taking into account modern issues of climate change, environmental impact, a catchment-based approach and experience from other countries in managing the risk of flooding. It represents a summary of the work contained in a major commission report by the Institution of Civil Engineers and reaches a number of conclusions, particularly that there are serious inadequacies in representing the dynamic effects of land use change, catchment process and climatic variability in flood assessment. The paper emphasises the need for a more strategic approach and highlights the fact that the UK should embrace the river basin modelling approach with more confidence than in the past.

In the light of experience gained from the autumn 2000 floods, the government invited the President of the Institution of Civil Engineers (ICE) to establish a commission to consider what approaches to managing fluvial flood risk are appropriate to the twenty-first century, in particular to review

- current methods of estimating and reducing flood risk
- whether a more strategic catchment-based approach to fluvial flood alleviation is appropriate
- the impact of flood defences on the natural and built environment
- whether flood risk management can make more use of natural processes
- possible impact of climate change
- experience in other countries.

The commission was set up under the chairmanship of the author, a past President of the ICE, and commissioners were appointed who represented some of the leading experts in the field. The commission reviewed the technical aspects of flood risk management in England and Wales and consulted as widely as possible within the timeframe available.

Evidence was gathered, both written and oral, from a range of interested parties. All the information gathered, together with the composition of the commission, has been posted on the ICE's website at www.ice.org.uk/presidential.html. The final published report, called *Learning to live with rivers*[1] (Fig. 1), together with all the written evidence and minutes of the meetings

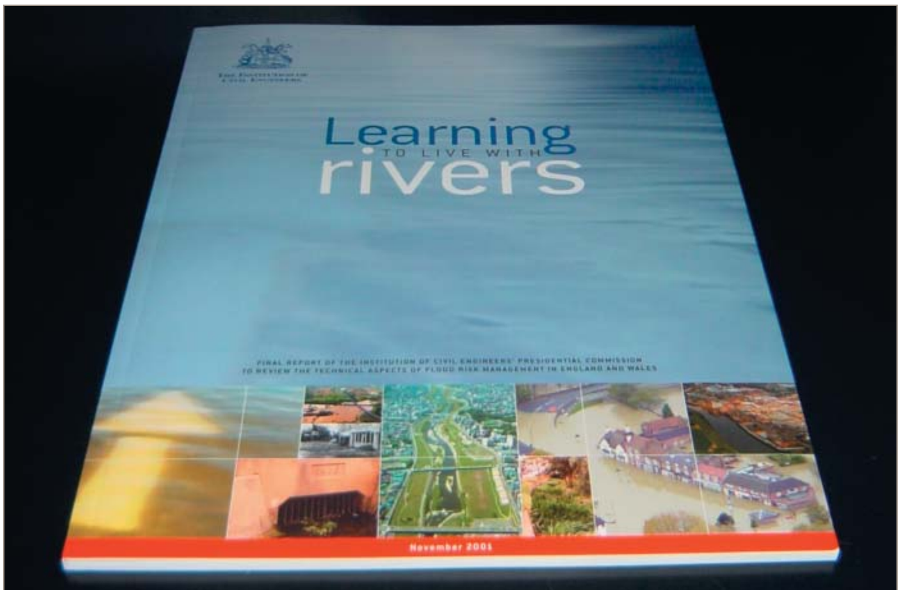

Fig. 1. ***Learning to live with rivers*— the ICE's November 2001 report to the government on flood risk management**

have been lodged for future reference in the ICE library in London.

Historical context

Settlements have always been sited on floodplains, despite the risk of periodic flooding. Historically, these risks have been outweighed by the many social, economic and environmental benefits of a riverside location (Fig. 2).

The social and economic benefits arise mainly from the trading advantages of sites at river crossing points, along valley routes, or at transhipment points between river/sea transport and inland routes. In addition, riverside sites were often militarily defensible, providing good sites for castles and other fortifications.

Environmentally, floodplain sites were often the most fertile and workable agricultural land. They also offered sustainable sources of water power for economic activities such as milling, tanning and brewing.

Almost all the ancient towns and cities of England and Wales have locations alongside rivers, with some properties vulnerable to flooding (e.g. London, York, Winchester, Norwich, Exeter, Oxford, Cambridge, Carlisle, Chester, Gloucester, Worcester, Shrewsbury and Cardiff).

The social and economic advantages of floodplain locations were consolidated by the industrial revolution from the late eighteenth century onwards, with much industrial development and accompanying workers' housing, being based on river, canal and railway routes along river valleys.

Rivers are still an economic asset for towns, even though very little commercial river traffic remains. Rivers are often an important element in the tourism 'offer' of towns and cities (e.g. Cambridge) and the focus of their regeneration efforts (e.g. Leeds and Gloucester).

It is clear from the evidence submitted to the commission that river valleys play an integral part of sustainable development and that the community 'must learn to live with our rivers'. The balance, which ensures infrastructure is in sympathy with our environment, presents a challenge if we are to achieve success in flood risk management. The policy to clean up and redevelop brownfield sites in preference to developing on greenfield land is to be applauded, but it should be remembered that many of the brownfield areas are in river valley bottoms. The challenge is to redevelop with flood risk mitigation as a priority.

Assessing flood risk

Floods are a natural occurrence and the risk they pose is wide ranging. However, for society, the main focus is the risk to people and property (Fig. 3). It is neither practical nor economically feasible to eliminate all flood risk. The most suitable approach for dealing with flooding must therefore be to best manage the risk.

To date, the technical approach for designing protection has been to focus on the certainty of flood defences to give confidence. There are methodologies available to engineers which can allow relatively accurate predictions of where flooding will occur and, given a particular magnitude of flood, the extent of flooding, duration, rate of rise, flood depths, velocities and damage can all be predicted. Regrettably, these techniques have not been applied sufficiently widely. The main uncertainty in flooding is the timing of when it will occur, as lead times may frequently be only in the order of hours.

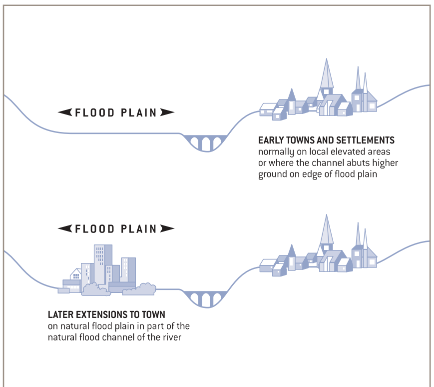

Fig. 2. Many riverside settlements have encroached into the floodplain—the social, economic and environmental benefits outweighing the risk of periodic flooding [1]

The traditional design approach focuses on the design flood event, typically the 1% annual probability of flooding. Providing the flood alleviation measure is appropriate for the predicted magnitude of flood, including a suitable freeboard margin for bank settlement, wave allowance, modelling inaccuracies and other uncertainties, it is assumed that protection has been achieved for the relevant design period. A degree of risk is therefore accounted for within the design, however, it may often not be explicit and it does not take account of the impact of floods greater than the design event.

Dynamic conditions and uncertainty

It is important to recognise that both the baseline and flood event conditions are dynamic, hence the flood risk is dynamic, and this means that variations and uncertainties will occur and must be accounted for. This is true both during an actual flood event (e.g. 12 h) and over the design life in order to protect against flood events (e.g. 60 years). The traditional approach does not specifically address uncertainty within the design process.

There is a wide range of factors that

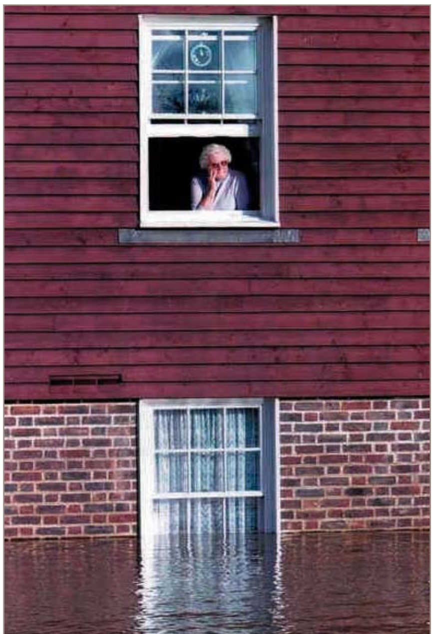

Fig. 3. Effects of flooding are wide ranging but society's main concern is what it does to people and property

> “in communicating flood risk to the general public, instead of referring to the ‘100-year flood’, we could say that there was ‘a 100-to-1 chance against the flood in question being equalled or exceeded in any year”

can give rise to uncertainties, from environmental loading to the structural performance of defences. Unless these uncertainties are identified and addressed, designs will be vulnerable. Risk-based approaches are well suited to dealing with uncertainties and can provide the best available means for guiding the design.

Understanding real risk

The dynamic conditions mentioned also arise from factors such as increasing pressures on development, limited resources, climate change and increasing sophistication of society. The result is that we need to address and convey the real situation of risk and increase awareness.

Flood awareness will ultimately depend on the experience of individuals, both in terms of design engineers and people affected. This first-hand experience will reinforce the consequences of flooding and raise awareness. Lack of flood awareness can be problematic, especially in areas where the population has not experienced flooding, either due to lack of recent flood events or high population turnovers.

Risk communication is of major importance. People generally have higher risk tolerances when they are aware of the issues and can make an informed judgement themselves. To successfully manage the risk, it must be clearly understood what constitutes a flood risk and how this will vary depending on individual and collective perspective.

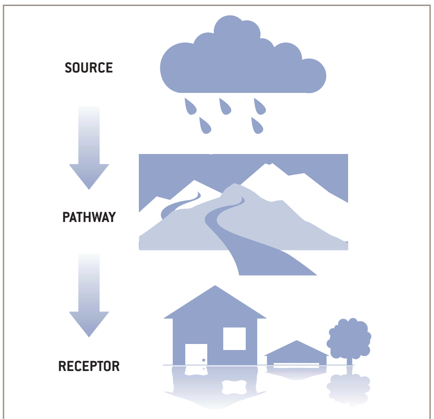

Fig. 4. Source–pathway–receptor model for floods—we have the greatest control over the receptor end (taken from Learning to live with rivers[1])

Defining risk

The flood risk or the exposure to flood hazard must be clearly understood and communicated to all concerned. To ensure this, it is important that appropriate and consistent terminology is used.

The source–pathway–receptor model is a useful method of establishing risk relationships. In relation to flooding, it can easily be seen that management of the risk is heavily biased to the receptor end of the scale (Fig. 4). The source cannot be controlled (precipitation) and, while the pathway (land and watercourses) can have scope for management, ultimately the receptor (people and property) can have the greatest control exerted.

One of the key aims of flood risk assessment is to understand and be aware of the complexities of the situation as best as possible, then to simplify the situation down to an acceptable level to allow practical measures to be put in place. When the risk of a particular event is expressed, the perception of risk can vary, both in scope and scale. It is important to define, at the outset, what is the context of the risk and how it relates to hazard.

We must be aware that risk is dynamic both in time and space, and the risk assessment must reflect this. A static system cannot be assumed and continual review is essential every five to ten years or subsequent to any major changes in the catchment.

Risk-based approaches will tend to provide more information than is available from deterministic analysis. They will often lead to the possibility of a wide range of potential solutions with differing costs and benefits. This information must be provided in a format that is as concise and clear as possible. This is true especially where uncertainties are concerned, where they should be identified as being inherent or epistemic, and appropriate confidence levels assigned.

Expressing the risk

The most difficult concept to convey is that of the risk of flood events occurring. We have expressed the extreme nature of the event by taking the average period between events as ‘the return period’. However, by trying to make the understanding of probability more straightforward, we have introduced an idea of periodicity that has begun to mislead the non-expert.

For example, the design exceedance of the majority of fluvial flood defences has been set at a probability of 1% in any year. This event has been translated into having a return period of 100 years. After any large event deemed to have a return period of 100 years or more, many will regard it, perhaps complacently, as most unlikely such an event will reoccur in their lifetime. However, that same probability applies for any year, including that following a large event.

Taking this probability over a reasonably long time period of a lifetime of 70 years, it can be shown that what is today referred to as a 1-in-100 year flood has a 50% chance of occurrence within the 70 year lifetime period but, more significantly, has a 15% chance of occurring twice in that lifetime. By conveying this aspect of probability without the attendant periodicity, it becomes obvious that the broader issues of continuous communication to maintain awareness are essential.

The understanding of odds is widespread, arising in many sports involving gambling. Therefore, in communicating flood risk to the general public, instead of referring to the ‘100-year flood’, we could say that there was ‘a 100-to-1 chance against the flood in question being equalled or exceeded in any year’ (100-to-1 chance flood). We should go on to explain that, other things being equal, the odds would remain the same each year, regardless of any recent severe occurrences.

For communicating risk to professionals, the alternative terminology of ‘1% annual probability of flooding’ can also be used, however, the use of the concept of return period should be discouraged in all future communication.

Catchment and river basin management

Traditionally, flood defences were provided as individual local schemes with little consideration as to their impact across the wider river catchment. This approach has been changing over recent years. It now seems self-evident that individual flood alleviation schemes cannot be considered in isolation and that what happens in one part of the catchment will have an affect on other areas some distance away (Fig. 5).

Accordingly, there is now almost universal agreement that a more strategic, catchment-based approach to flood risk management is warranted. This was very apparent in the evidence received by the presidential commission.

The move to a more strategic, catchment-based approach does not simply mean a wider view on investment in flood defences. It means taking a holistic view of flood risk management, including built development and land management patterns, nature conservation constraints and opportunities, and emergency planning arrangements. This needs to be based on a long-term view of up to 50 years ahead, backed by sophisticated modelling of the dynamic physical processes at work in the catchment. All this will drive a major change to the way in which flood risk is managed in England and Wales.

The role of catchment modelling

Catchment modelling provides a very powerful tool which, to date, has been relatively underused, especially within flood estimation and management. With the advent of catchment flood management plans and the Water Framework Directive,[2] the shift from local, site/area-specific management to catchment scale management offers an ideal opportunity to demonstrate clearly the benefits that can be achieved by using models.

Models, as with any other tools or controls, are not a panacea and will not provide all the answers but what they can provide is a means to improve the understanding of catchment processes.

Models are essentially a description of 'how things work' and a 'mathematical model' is commonly described as

> a set of general laws or mathematical principles and a set of statements of empirical circumstances.[3]

In describing water flux through a catchment there is therefore a need to link a variety of 'models' in cognate 'fluids' based disciplines such as

- meteorology and hydrology
- hydrology and hydraulics (hydrodynamics)
- surface water and groundwater
- geomorphology and ecology.

A popular misconception is that our understanding of the physical processes at work in each of these disciplines is now at such a sufficiently advanced state that it is only a matter of selecting and joining together appropriate models in such a way that a seamless whole will emerge, thereby giving a complete description of the spatial and temporal movement of a flood wave throughout a particular catchment. It is important to appreciate that this is not so because of some of the inherent scientific and philosophical limitations in the modelling process.

To ensure effective river basin management, 'models' must be used to explore the response of the catchment to specific rainfall scenarios, consequent excess runoff, resultant water levels and possible flood defence options, requiring the combination of hydrology and hydraulics (Fig. 6).

Urban drainage

In the present urban environment, surface water runoff is often diverted into 'combined sewers' which in dry weather carry only foul flow. These sewers were, and still are, designed to accommodate the runoff generated by relatively common storm events (up to a 5–1 chance flood in any year—20% annual probability of flooding or five-year return period). These are short duration events because the rain finds its way into the sewer system very quickly from the impermeable surfaces.

In such storms, the volume of runoff is generally not large, and the storage available in the sewer system when surcharged ensures that flooding is avoided for more severe rainfall events, perhaps as severe as a 50–1 chance flood (2% annual probability of flooding or 50 year return period). This certainly does not apply to all sewers, and expansion of the proportion of catchments that have a predominantly impermeable surface and the likely impacts of climate change will ensure that stormwater sewers are under an increasing risk of being overloaded.

Stormwater sewers also become overloaded as a result of sustained rainfall, such as that experienced in the winter of 2000.

Urban watercourses

There can be little doubt that our urban watercourses are often a neglected resource. There are, of course, exceptions

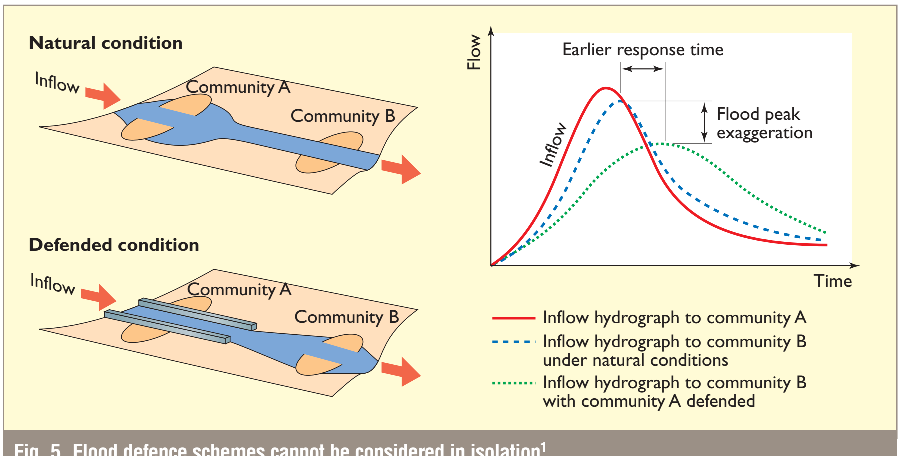

Fig. 5. Flood defence schemes cannot be considered in isolation[1]

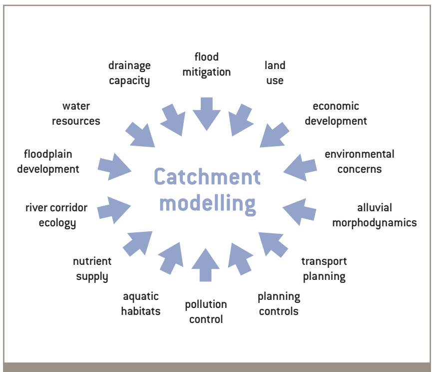

Fig. 6. Catchment models allow engineers to explore the response of catchments to specific rainfall scenarios[1]

“the basic solutions, such as flood embankments (or dykes), have changed very little over the centuries and will remain appropriate for the future”

but the evidence of litter and debris, dilapidated concrete and brick walls, silted up and overgrown beds is clear to see in many urban channels (Fig. 7). As a result, these streams and drains are unattractive and inefficient conveyors of floods.

The frequent presence of culverts on many reaches may overcome the adverse visual impact but the risk of blockage and the associated risk of flooding are worsened.

Urban sewer systems

There is some cause for concern that the interaction between rivers and streams and the urban sewerage system is not considered adequately in the development of major urban flood alleviation schemes.

The interaction requires greater emphasis, since the flooding of homes by sewerage backed up by high river levels is likely to increase in response to both urbanisation and climate change.

Engineered solutions

The picture painted by the media in the autumn and winter of 2000 was one of failure of the nation's flood defences in the face of severe climatic conditions. Whereas it would be wrong to underestimate the damage and human misery caused by the floods, it should be emphasised that engineered flood defence works protected tens of thousands of homes that would otherwise have been flooded.

Flood defence engineering is as old as the history of urban civilisation itself and some of the basic solutions, such as flood embankments (or dykes), have changed very little over the centuries and will remain appropriate for the future. Indeed, some flood embankments, now over 400 years old, are the very essence of a sustainable approach to flood risk management (e.g. the Barrier Banks that contain the Ouse Washes flood storage area). This is not to say that such solutions will remain sustainable in the future, especially in the face of climate change and rising sea-levels.

For the future it is clear that we need to explore a much wider range of options, so that the most appropriate solution can be found, based on a full appreciation of the

- environment in which the defences will be constructed
- impact that the defences will have on both the local and the wider environment
- performance of the defences in a wide range of flood events
- risks and uncertainties involved.

Furthermore, the decision as to whether to proceed or not must be based on a full assessment of (in order of priority) the

- social need (rather than some political imperative)
- economic case (rather than the financing opportunity)
- environmental consequences (rather than formal impact mitigation).

It is important to recognise that engineered flood defences will continue to provide one of the main options for flood risk management for the foreseeable future.

Flood management tools

Flood frequency estimation

Flood studies regularly require the estimation of the peak discharge for a flood with a probable annual chance of occurrence that is substantially longer than the available record.

The *Flood Estimation Handbook*[4] should be used to explore the sensitivity of the flood regime to climate change and land use. It is also important that the strengths and limitations of the handbook are reassessed periodically, in the light of study and knowledge gained through applying it within the UK. New flood data related to extreme meteorological events, as well as the links between flow and water level, should be incorporated into the handbook and the proposed *Floodplain Handbook* to improve their methodology and to test their underlying assumptions.

Over reliance should not be placed on wholly statistical analysis of past records for estimating extreme flow or level values, and 'worse-case' flood scenarios should be examined using coupled models with degrees of uncertainty attached. There is therefore a need to develop and further integrate both hydrodynamic modelling examining channel change and sedimentation with hydrological sensitivity analyses to improving the accuracy of flood level estimates. This model coupling should occur at catchment and subcatchment scales, and there is also a need to pool best use in their practice.

The value of modelling flood phenomena in this way, and at such a scale, is that unlike reliance on purely historic data, extreme events may be simulated in order to

- test 'what-if' scenarios
- to examine rainfall and floods larger than ever experienced
- to study changes in land use
- to assess the impact of engineered solutions on reducing flood risk.

Flood forecasting

The Environment Agency's National Flood Warning Centre seeks to improve the quality of the flood warning service it provides to the public by coordinating efforts within the Environment Agency. The actual forecasts and warnings are undertaken at a regional level, commensurate with local models and knowledge. In a review by Mott MacDonald of good practice in flood forecasting and warning,[5] differences were noted between Environment Agency regions for the following key activities

Fig. 7. A typical urban watercourse—most are poorly maintained and prone to blockage[1]

- event management (responsibilities, liaison arrangements between regions, office layout for effective crisis management and staffing, event recording and documentation)
- detection, by way of incoming data and monitoring (weather forecasts and tidal/coastal forecasts)
- rainfall radar and antecedent conditions (rain and level/flow gauges, telemetry and monitoring)
- forecasting of fluvial floods (types of rainfall–runoff model and use of models)
- warnings (procedures, automatic voice messaging, use of media, *Floodline* and other methods) and response
- post-event data collection and archiving.

The review and interviews with flood warning officers[6] provide a valuable snapshot of some of the issues in flood warning and also indicate the seriousness with which the Environment Agency takes its responsibilities with regard to both flood forecasting and warning.

The aim of the National Flood Warning Centre to be world leading is to be applauded, however, it is not apparent how it can achieve this objective at the flood forecasting end of its responsibilities unless it recruits (and retains) internationally known experts in this precise field. There appears to be considerable scope for improving flood forecasts through improved modelling capabilities. As pointed out in the Mott MacDonald review, this is especially so for fast response catchments and for exceptional circumstances, such as dam break, embankment breaching and reservoir overtopping.

Ways of integrating knowledge between the disciplines of hydrology and hydraulics are required for effective flood risk management. Impetus should be given to the establishment of a good database of flood events. This should include the provision of additional flood flow measuring stations, and the development of reliable stage–discharge relationships for all existing stations and key hydraulic structures. It is suggested that as a first step, stage–discharge data and rating curves at all gauging locations should be added to the *Flood Estimation Handbook*, as it is common to both disciplines.

It is instructive to note that there is no agreed national standard with regard to models, although some regions have ‘adequate’ rainfall–runoff component models.

Future needs

The key climate change impacts on flood alleviation schemes include

- change in rainstorm intensity for a given frequency
- change in the prior wetness of a catchment at any particular storm season
- a different partition between rain and prior snow
- higher snowmelt rates
- lower expectation of frozen ground (or ice jam flooding) and a shorter season for such surface impermeability
- higher mean sea-level against which to discharge, with changes in tidal surge magnitude for a chosen frequency.

Other important themes that require more knowledge under climate change are

- rain duration
- multiple storm sequencing in a single season
- frequency and location of stationary heavy rainstorm systems.

We do not see in the working lifetime of most readers that sufficient change to energy use can prevent the measured slow rise of world temperatures. In particular, the growth of populations in the biggest nations will dictate much of the outcome. So we consider that it is not a question of deciding when climate change has become identifiable; rather engineers and planners, with environmental science colleagues, must move to methods which allow for non-stationary statistics of key variables.

There is a real necessity to prove that global and local (under 10 000 km^2) rainfall fields can be modelled in both their mean and extreme frequency cases without ‘fudge’ factors being required in the calibration. Further research is required into the impact of seasonal catchment conditions on flooding, including the effects of climate change.

As financial damage and human distress is aggravated by the occurrence of multiple floods in a single season at any one community, methodologies must change away from annual maximum series (which neglect some flood data) to peaks-over-threshold series. This will be aided by the forthcoming development at the Centre for Ecology and Hydrology Wallingford of tested continuous flood simulation methods.

Skills

The types of skills required are far ranging and include

- well-informed and strategic thinkers at government level
- experts within universities, research institutes and consultancies
- Environment Agency staff with sufficient technical, operational and management skills[7]
- academic communities with the knowledge to not only teach and supply trained personnel in sufficient numbers to maintain the level of expertise within the UK but also to be given the time and resources to research new ideas.

All the above are crucial to the delivery of a successful service. We add that a whole range of professions beyond engineering are involved in this requirement, although it seems that the growing shortage of students of civil engineering is a focus of the problem upon us.

The specific needs are in areas such as hydrology, hydraulics, fluvial processes, mathematics and modelling (Fig. 8). Skills often ignored include project and facility management, risk assessment, socio-economic analysis and communication to the public.

Fig. 8. University engineering departments need more funding to reverse the skills shortage in the water sector

"Fluvial flood risk management needs to be a holistic process that considers flooding from the point of impact of rainfall to the discharge of the flood to the sea"

Graduates are already in short supply now (e.g. 40% reduction in civil engineering admissions over the last five years) and this will get worse with the continuing national downward trend in applications to universities to study engineering and mathematics, a trend that began some 20 years ago. However, the number of geographers and environmental scientists enrolling on the limited number of relevant MSc courses is increasing slowly.

There is a skills shortage in river engineering, typically amounting to 20% of complement, which can only be addressed by increasing support to universities providing such courses. A taught MSc in flood risk management and river engineering, if accompanied by generous scholarships, could begin to turn around the situation within five years.

Conclusions and recommendations

The original terms of reference of the commission have led to conclusions and recommendations for a wider range of issues, some of which span more than one of the terms of reference. As a result, the main conclusions relating directly to the original terms of reference are stated below and the recommendations are detailed in the following sections.

- *Current methods of estimating and reducing flood risk.* The presidential commission concluded that, while best practice in estimating flood flow is founded on the *Flood Studies Report* and the *Flood Estimation Handbook*, there is a serious inadequacy in representing the dynamic effects of land use changes, catchment processes and climatic variability in flood estimation. There is also an identified reluctance to use available computer models to provide greater insight into the sensitivity of flood risk for a combination of conditions.
- *Whether a more strategic catchment-based approach to fluvial flood alleviation is appropriate.* The commission concluded that a more strategic catchment-based approach is essential in tackling fluvial flood alleviation.
- *The impact of flood defences on the natural and built environment.* The evidence presented to the commission clearly identified the very significant impact of flood defences in both the natural and built environment. The impact has been to reduce the risk of flooding and, in most cases, flood defences have been sympathetic to the built environment and indeed have become an integral part of a sustainable built environment. The commission recognised that in the natural environment the impact of flood defences may, in general terms, have been less successful in alleviating rural flood risk. A clear need has been identified to provide capacity for rivers to respond to flooding in both the rural and built environment by the more careful balance of land use through redevelopment.
- *Whether flood risk management can make more use of natural processes.* The commission concluded that only by working with the natural river basin response and providing the necessary storage, attenuation and discharge capacity, can sustainable flood risk management be achieved. Floods can only be managed, not prevented, and the community must learn to live with rivers.
- *Possible impact of climate change.* The commission was of the opinion that evidence exists of a significant impact of climate change affecting the rainfall, evaporation, storage and runoff from catchments. The commission was of the view that best practice in flood estimation must incorporate the effects of climate change in order to design-in the climate change process.
- *Experience in other countries.* The commission reviewed best practice in a few selected countries that indicates support for an integrated approach to flood risk management. It also revealed greater confidence in river basin modelling both for flood assessment and real-time flood management.

Summary recommendations

Fluvial flood risk management needs to be a holistic process that considers flooding from the point of impact of rainfall to the discharge of the flood to the sea. It needs to recognise, evaluate and take into account the human dimension as well as the technical and economic cases for interventions, and the environmental impact of these.

It requires a full understanding of all the physical processes involved and the ways in which these are changed by human activities, from agriculture to urban development. It needs a trained and motivated cadre of professionals at all levels, equipped with the necessary tools and resources. And finally, it needs the understanding and cooperation of the people who will benefit.

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