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

G. Fleming

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 (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 accommodating 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.

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...
can give rise to uncertainties, from environ-
mental loading to the structural per-
formance of defences. Unless these un-
certainties 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 pres-
sures on development, limited resources,
climate change and increasing sophistica-
tion 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 aware-
ness can be problematic, especially in
areas where the population has not expe-
rienced flooding, either due to lack of
recent flood events or high population
turnovers.

Risk communication is of major impor-
tance. People generally have higher risk
tolerances when they are aware of the
issues and can make an informed judge-
ment 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 col-
lective perspective.

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 appropri-
ate and consistent terminology is used.

The source–pathway–receptor model is a
useful method of establishing risk rela-
tionships. 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 prac-
tical 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 sys-
tem 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 pro-
vide 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 especial-
ly 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’. How-
ever, by trying to make the under-
standing of probability more straightfor-
ward, 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 proba-
bility 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 signifi-
cantly, 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 communica-
tion to maintain awareness are essential.

The understanding of odds is wide-
spread, 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 profession-
als, 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 pro-
vided as individual local schemes with lit-
tle 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 con-
sidered in isolation and that what hap-
pens in one part of the catchment will

---

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

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 (hydromechanics)
- 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
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, the 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, and 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), and 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* 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, differences were noted between Environment Agency regions for the following key activities...
• 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 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 km²) 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
• 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, 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.