

# Flood probability: Do we know enough about it or does it just confuse the issue?

Alastair Dale, Ruth Goodall and Marc Pinnell

Capita Symonds, London

## Abstract

A risk based approach is advocated in the UK as the basis to inform land use planning, catchment policy and strategies for protection of people and property from flooding. Much of the information prepared is based on the probability or frequency of occurrence of events. In particular, DEFRA use this assessment of probability as the platform to prepare detailed assessments of the economic, social and environmental impacts of flooding and the Environment Agency deploy ‘probabilistic’ methods to map the UK and inform strategic decisions on flood risk management. The paper reviews some of the methods used to assess flood risk, with particular reference to the role of hydrological assessments of flood probability. An assessment is then made of the significance of the probability with respect to the range of decisions it influences. Finally, the paper considers whether it would be more appropriate to adopt a more precautionary approach so that the assessment of probability is more focused and reducing the instances where decisions are unwittingly made on the basis of highly uncertain information.

## A risk based approach: what do we mean by flood risk and what is the approach?

A man was caught in a flood. Two men came by in a boat to rescue him, but he waved them away shouting “No, my God will save me”. One hour later another boat came along, but again the man said “No, my God will save me”. Eventually a helicopter arrived but the man called to the pilot, “It’s OK my God will save me”. Unfortunately shortly afterwards the man drowned and when he met his God his first question was “Why didn’t you save me?”. His God replied “I sent two boats and a helicopter, what more did you want?”. So could a risk based approach have improved the outcome and if so what “risk based” approach would be of most benefit?

## Background

Flood risk and the risk based approach is described by maps available on the internet, in assessments prepared in support of flood risk management policies, in strategic and flood risk assessments supporting land allocations and planning applications, in reports to assess the relative merits of flood risk management schemes and during discussions, comment and debate in the media. In April 2008 the *EFRA Report on Flooding* identified that “...the variety of different flood maps available – with each potentially classifying a certain property at a different *level*

of flood risk – is confusing to the public”. The report goes on to say “The necessity for clarity is even more pressing with the Agency’s development of simple surface water flood maps for some ‘hot spot’ areas”. Government recognises the preparation of maps is a dynamic process, dependent on the *best available data* but *it is in everyone’s interest to have the best available validated map. The Environment Agency should take the lead in pulling partners together to achieve this.*

Much of the Government concern is directed towards the number of different parties preparing mapping and risk information. However, much of the data used to prepare the mapping are common to all and shared by the various parties, so it is worth considering whether there might be other underlying explanations for the public ‘confusion’. Accordingly, the first thing to consider is the definition of flood risk itself.

## Flood risk

In seeking to define what is understood by flood risk or a risk based approach it is quite easy to select a definition that covers a broad spectrum of applications. However, it is just as easy to find a range of definitions that on first examination potentially contribute to the lack of clarity and potentially give rise to miss-communication when debating or describing flood risk. The following definitions describe some of the more commonly

encountered definitions:

- The *Flood Estimation Handbook* (Reed, 1999) states “Flood frequency estimation is synonymous with flood risk assessment. The former focuses on estimation of the peak river flow (in  $\text{m}^3 \text{s}^{-1}$ ) of a given frequency (i.e. rarity). The latter strives to assess the risk (i.e. probability) of a flood occurrence;
- The Environment Agency’s *Strategy for Flood Risk Management 2003/4 –2007/8* (EA, 2003) states “Flood Risk is a combination of two components: the chance (or probability) of a particular flood event and the impact (or consequence) that the event would cause if it occurred”;
- *PPS 25* (CLG, 2006) has two definitions. Firstly it states that flood risk involves:
  - ..both the statistical probability of a flood occurring and the scale of its potential consequences, whether inland or on the coast;
 Subsequently it defines a risk-based approach as: Applying the source-pathway-receptor model to planning for development in areas of flood risk requires:
  - a strategic approach through policies in RSSs and LDDs which avoid adding to the causes or ‘sources’ of flood risk, by such means as avoiding inappropriate development in flood risk areas and minimising run-off from new development onto adjacent and other downstream property, and into the river systems;
  - managing flood ‘pathways’ to reduce the likelihood of flooding by ensuring that the design and location of the development maximises the use of SUDS, and takes account of its susceptibility to flooding, the performance and processes of river/coastal systems and appropriate flood defence infrastructure, and of the likely routes and storage of floodwater, and its influence on flood risk downstream; and
  - reducing the adverse consequences of flooding on the ‘receptors’ (i.e. people, property, infrastructure, habitats and statutory sites) by avoiding inappropriate development in areas at risk of flooding.
- The *EU Flood Directive* states “Flood risk means the combination of the probability of a flood event and the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event.”

In the media and public domains it is less easy to define what is understood by flood risk and the situation is further complicated by the general perception of risk.

For instance, it is quite natural for Mr X to expect a simple answer to the question, “Is my house at risk of flooding?”. When providing an answer the challenge is to make Mr X aware of the full definition of flood risk, so that he can understand the uncertainties and where these might most affect the reliability of the simple answer he is seeking. It is probably correct that Mr X considers risk as the chance that his house might flood and does not include a judgement of the consequences of flooding. So the chance or frequency of flooding is an important issue to

the public. Climate change makes it essential to clearly qualify the answer given to Mr X on this simplest of questions, particularly if he lives in a low lying coastal area or on an area of undefended flood-plain (e.g. the lower Thames Valley).

Climate change effects mean that the chance of Mr X’s house flooding (both the probability that it will flood and the frequency with which events will be observed) may increase: accordingly he must be made aware that the chance of flooding and the consequences could change over the time of his residency. The other issue is the source of flooding that might affect Mr X’s house. As climate change effects exacerbate baseline conditions, Mr X might become more at risk from surface water flooding or failure of local drainage systems, or from groundwater flooding. So the consequences might not be significant now, but they will be in the future.

It can be observed that there is a general theme running through the definitions of flood risk, but there is not the complete clarity that would be expected when making reference to high level documents that will be the platform for every-day practice. A 2005 study *The Language of Flood Risk* coordinated by H R Wallingford identified a number of formal definitions of risk. Most of these are conceptually similar and the two that encapsulate the language of flood risk are:

$$\text{Risk} = \text{Probability} * \text{Consequences} \quad (\text{Helm, 1996});$$

and

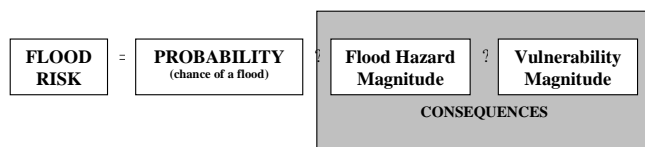
*Risk is the combination of the chance of a particular event, with the impact that the event would cause if it occurred. Risk therefore has two components – the chance (or probability) of an event occurring and the impact (or consequence) associated with that event. The consequence of an event may be either desirable or undesirable...In some, but not in all cases, therefore a convenient single measure of the importance of a risk is given by: Risk = Probability × Consequence* (HR Wallingford, 2002)

The important point to note is that this provides a means of measuring the importance of a risk and can therefore be used to make comparisons of different levels of risk. It also incorporates the conceptual decision-making of Mr X, who has decided that if there is any chance or probability that his property will flood then this would be unacceptable and so he does not even need to start evaluating the magnitude of the consequences.

The final factor to be considered, that played a significant contribution to the flooding witnessed during the summer of 2007, is ‘remaining risk’ or residual risk. This was defined in PPG 25 as giving consideration to the consequences of an event that has a greater magnitude than that for which defences were designed. PPS 25 enhanced this concept by a requirement to consider the potential effects of failure of defences, such as when defence bunds collapse, culverts block, etc. Thus residual risk can generally be considered the assessment of the ‘failure’ event, the significant aspect being that in the world of flood risk management assets are designed to fail since the cost of making them ‘fail-safe’ is prohibitive. This is perhaps most acute in the realm of urban drainage where conveyance systems are often designed with normal

operating capacities, based on events with an annual probability of occurrence (interestingly, the capacity and frequency of failure of the drainage collection systems is less well understood).

For the purpose of measuring the importance of the risk for a wide range of circumstances it is useful to modify the basic Helm equation and express the relationship as follows:



This definition was formulated for the preparation of Strategic Flood Risk assessments in the UK, fits the EU Flood Directive and is concordant with information contained in the EXCIMAP (European exchange circle on flood mapping) *Handbook on good practices for flood mapping in Europe*. The best practice described in the ‘Handbook’ identifies the need to prepare flood hazard mapping and the above relationship explicitly shows how this could be used in itself as an important contributor to the decision-making.

Another benefit of this conceptualisation is that it enables specific components that contribute to the risk to be considered independently. Just as Mr X might discount all factors with the exception of probability, it is possible to consider the magnitude of the hazard that might be present and on that basis decide that the outcome would not be acceptable. Similarly, by considering the magnitude of the consequences when assessing the vulnerability of receptors it might be possible to discount any consideration of the probability (for instance single point failure of critical essential infrastructure, such as witnessed in Gloucester during the summer flooding in 2007, is a situation where public opinion and political pressure demand that the probability of a flood should be virtually nil).

The typical range of hazards presented by flooding are:

- Flood depth;
- Velocity of flow;
- Rate of rise;
- Speed of onset of inundation;
- Duration of inundation;
- Chemical contamination; and
- Debris – silts – floating hazards.

The magnitude of the vulnerability can be assessed for the required range of factors, including:

- Health,
- Environment,
- Cultural heritage,
- Economic and social factors,
- People and property.

The application of the risk equation enables an assessment to be made of particular receptors with a differing capacity to overcome or adapt to the particular hazards presented by flooding.

Breaking down the assessment of risk into the components of probability, hazard and vulnerability is also of benefit when considering the application of the Precautionary Principle. This is the practice endorsed by the EU to support decision-makers to find the correct balance when confronted with situations involving detailed scientific information. It is essentially used for risk management and should not be confused with the element of caution that scientists apply in their assessment of scientific data. The principle is enshrined in the Rio Declaration (1992), where principle 15 states:

*“in order to protect the environment, the precautionary approach will be widely applied by States according to their capability. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing cost-effective measures to prevent environmental degradation”.*

The conceptual risk equation described in this paper can then be applied to enable transparent evaluation of whether there are any threats of serious or irreversible damage by considering the consequences and evaluating the hazards and the effect on receptors. The probability of occurrence could be influential in circumstances where frequent repetition of events is in itself a cause of irreversible damage. However, the decision-maker is able to decide on an outcome without having to refer back to the probability or chance of an event occurring. In fact it is almost certainly the case that the uncertainty over the probability is the factor that invokes the need to deploy the precautionary principle.

Another example of how application of a competent risk based conceptualisation is better able to inform decision-making is in the modification of the Environment Agency Flood Policy that was in force prior to the publication of PPG 25. Formerly, the policy adopted by many Environment Agency regions with respect to flood risk, using the Section 105 flood maps, was in simple terms “increasing the number of houses or people on the flood plain increases the risk”. But by applying the concept of flood risk defined in the EU Flood Directive and PPS 25, it is possible to implement an adaptation strategy based on the long term reduction of flood risk and positively address the threat posed by climate change effects.

Simple avoidance of the hazard can be an appropriate response but cannot be applied in circumstances where significant existing development needs to be regenerated. The application of this concept is underwritten by a process that in the first instance should identify high risk areas and give preference to new development in areas at a lower probability of flooding. The new conceptualisation is of particular benefit when considered in the light of climate change and highlights the fact that the old policy is not consistent, since the effect of climate change is implicitly to increase the number of properties in the flood plain and to increase the magnitude of the hazards presented by a flood. So simply preventing new housing on the flood plain will not manage the risk. Proper conceptualisation of risk enables clear demonstration that magnitude of flood risk can be reduced by ensuring that new development “reduces the magnitude of the consequences”. The range of responses to reduce the consequences can be physical proposals (such as raising

thresholds) or provision of enhanced flood warning and support mechanisms during a flood and during the recovery phase.

The examples illustrate that a competent conceptualisation of flood risk does not cause confusion or contradiction, but rather can be used to help explain the reasoning behind the decisions taken that are based on an assessment of the risk. This transparency is achieved by fully understanding the components that contribute to flood risk and the lesson to be championed is that, provided the premise is clear and correct, the competent definition of flood risk can be used for a range of applications in circumstances where the requirements for information are very different

## Probability and uncertainty

It is inevitable that any discussion on flooding requires consideration of uncertainty. How good are the estimates of the magnitude of flood risk? In this instance it is possible to use the conceptualisation of flood risk to identify where uncertainty contributes most to decisions made. Modern data sets and software have radically changed our capacity to estimate the magnitude of the consequences of flooding to a resolution that was not previously obtainable. This capacity has been augmented in respect of flood risk assessment by the radical improvement in the software used to deterministically analyse the flow of water in one-dimensional channel systems or two-dimensional floodplains. By way of example, the Environment Agency now possesses high precision topographical ground data for nearly all the floodplain areas in England and Wales. Combined with slightly older, but still high quality, channel data on the watercourse networks it is possible to generate high resolution information on velocity and depth. The predictions are based on solving the correct physical equations of fluid motion and can be made for time variant (unsteady) flow conditions. Correspondingly national data sets on the classification of infrastructure and the relative vulnerability of communities is readily available. Thus it is now within our capacity to make relatively accurate predictions of the magnitude of the hazards and the vulnerability of the receptors (the consequences). The aspect associated with the majority of the uncertainty is the ability to predict the probability of an event.

Many of the available data sets in relation to flood risk either implicitly or explicitly use the probability of occurrence as directly interchangeable with flood risk. The Environment Agency Indicative Floodplain Map indicates zones at high, medium and low risk of flooding, detailed flood maps describe the extent of a flood of a particular probability flood and the National Flood Risk Assessment Methodology (NaFRA) is an explicitly probabilistic method that relies on a definition of the magnitude of a flood with a particular probability of occurrence (it also requires the estimation of the probability of failure of defences and other assets). Thus there is a need to examine what factors contribute to the uncertainty of any probabilistic estimate and whether reliance on an estimate of probability necessarily provides information that is of most service to decision-makers.

When we consider flood events which may occur in

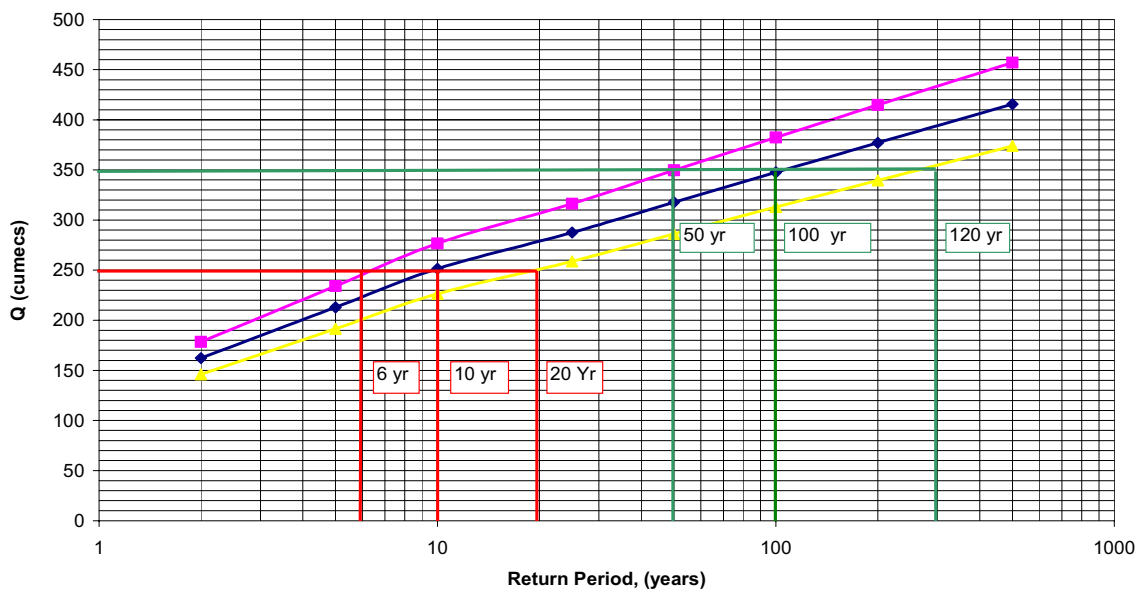
natural floodplains, or in defended floodplains where the defences perform as designed, the probability of occurrence is defined by the chance of a particular magnitude of flow event occurring in the neighbouring watercourse or watercourses. In these circumstances, hydrology plays a key role in assigning a probability to a design flood event of particular magnitude. In such instances it is common to define the magnitude of events with a specific probability, for example the 1 in 100 and 1 in 1000 year flood flow and to use these probability estimates as a key parameter in the derivation of flood extents and depths through hydraulic modelling. The flood outlines and depth grids subsequently produced are linked back to the probability of occurrence established in the original hydrology.

The hydrological and hydraulic methods of modelling to estimate the impacts of a particular magnitude event are long established. In both cases the methods of hydrological analysis and the quality of the data used in these methods can have a key influence on the outcome of the study. As such, the magnitude of the flood flow assigned to each of these key return periods has a significant influence on the final information produced. Therefore, the uncertainty associated with estimates of flood flow probability can have a significant impact on the outcome of flood modelling and mapping studies and on the risk assessments and tools which are then subsequently based on these flood maps and models.

Flood probabilities on gauged sites are commonly derived from an analysis of gauged data, specifically annual maxima peaks and POT data, and this methodology is well established and widely used. Uncertainty in the estimation of flood probability based on a gauged series is largely a result of either uncertainty in the physical measurement of flow at a site due to limitations in the physical gauging of flow (including uncertainty in the conversion from level to flow where a rating equation is used) or due to a short available record length which may limit the statistical validity of the flood frequency estimates produced from it. The length of record is the critical factor and assessment of more infrequent events places even greater demands on this component.

For sites where a reliable gauged record of suitable length is not available, UK standard methods (such as the FEH) provide equations which allow the estimation of the magnitude of flow associated with a specific return period. These methods introduce considerable additional uncertainty as a number of assumptions are necessarily made about the hydrological behaviour of the subject catchment. In particular, the need to estimate a flood growth curve based on a sub-set of either hydrologically similar or local gauged catchments may work well on those catchments which behave 'typically' with comparison to other local or geologically and topographically similar sites, but less well on non-typical or unusual sites.

Even where long, good quality records exist for a subject site, there may be issues with defining flood probability. The uncertainty and characteristics of a probabilistic estimate of flood frequency are not often communicated within the final product — usually a flood map. A particular estimate of flood probability may be significantly influenced by the length of the data set used, the magnitude of the recorded events captured within the



**Figure 1** Example of return period variability as a result of potential gauging errors

record length, and the quality of the data.

This can be simply illustrated in the following example. Standard FEH methods, using a pooled growth curve, have been applied to a gauged flow record from a selected gauging station (Usk at Trallong). A 10% reduction and increase in the AMAX series flows has been applied to simulate the potential impact on probability estimation of an error in flow measurement of that magnitude. There is no suggestion that the station used to illustrate this example is in fact subject to errors in gauging and the site data are used simply as a randomly selected site for illustration purposes.

The central line in Figure 1 indicates the growth curve derived from an unchanged AMAX data series (as downloaded from Hi-Flows UK). The upper line (pink) and the lower line (yellow) illustrate the flood frequency relationship derived from a data set increase by 10% and decreased by 10% respectively. The chart serves to demonstrate how a relatively small error in the recorded gauged flows, which may conceivably occur as either a result of limitations in the gauge itself or limitations in the rating equations used, can significantly change the probability assigned to a particular magnitude flow.

When the 250 cumec flow is considered, the range of possible probabilities assigned to this event fall between the 6 and 20 year return periods. For the 350 cumec flow, a range of probabilities of between the 50 and 120 year return period are described. As a consequence, what may subsequently be described as the 100-year flood extent and flood level, and identified as a ‘high’ flood risk area, could conceivably be the 50-year flood extent as a consequence of only a relatively small error in the gauged data set.

### Climate change

The nature of probabilistic estimates of flow also makes them intrinsically variable over time. An estimate of flood probability derived on a particular date, using the data available at that time, may not be the same as the estimate

derived for the same site 2 or 20 years later when the data set has increased in length. This effect is significant when we are considering climate change and a potential increase in flood peak magnitude as a result. In the example below, analysis of the future ‘1 in 100 year return period flood’ based on the currently available data set indicates a probability of around 1 in 500 years for the climate change event. In the future, were the analysis to be repeated on a longer data set, what is now a 1 in 500 year return period flood may be assigned a probability of considerably less.

The fact that probability estimates change as more or better data are collected can be a hurdle in communicating flood probability to the wider non-hydrology community and is a complicating factor in media reporting, especially when two or more events occur in relatively close succession. The chances of two events being reported with similar return periods are high as data are reassessed following flood events, despite the fact that there may have been differences in how people experienced the floods on the ground, prompting questions such as, “How can this flood be the same return period as the one two years ago when my house flooded then but not now?”. Further uncertainty may of course be introduced within hydraulic and topographic model data sets used with the hydrology data to define the flood extents and levels; however, the hydrology forms the basic definition of the event probability.

The over-riding importance of good quality gauged data for flood probability estimation cannot be over-stated. Investment in new risk assessment tools, methods and data sets that require the definition of flood probability to define risk should be accompanied by significant levels of strategic investment in improvements to the basic data sets and in reducing the uncertainty at that level. Without this investment, probabilistic definitions of flood risk are unlikely to provide the level of accuracy required for them to support robust decision-making.

A fundamental uncertainty is the climate change assumption that flow magnitudes will increase by 20% over the next 100 years. Figure 2 illustrates that the

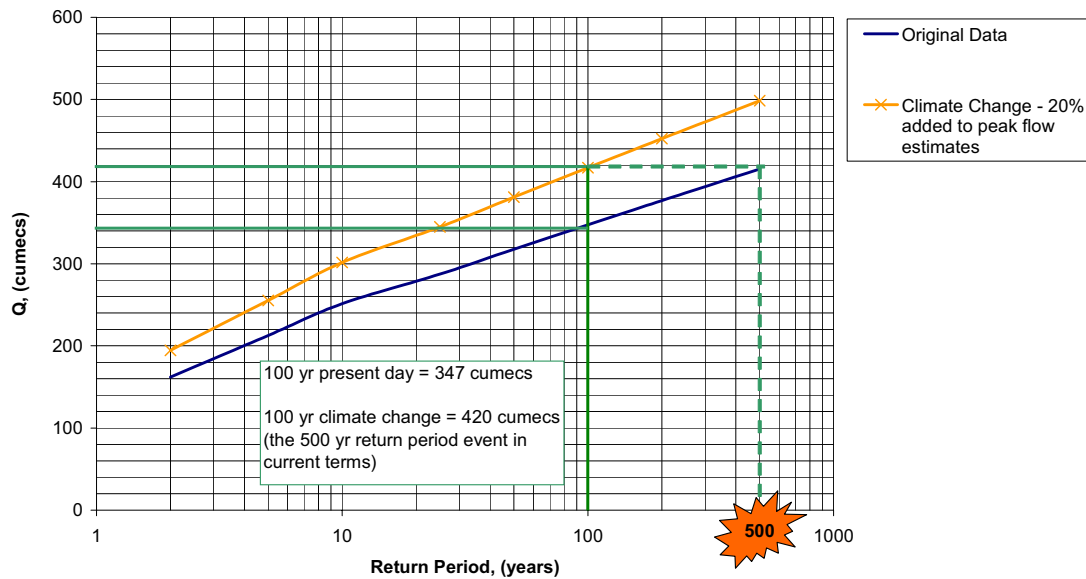


Figure 2 Current day and climate change estimates of the 100 year probability flow

probability of occurrence is very sensitive to this assumption. In addition, the current methods of flood mapping and flood risk assessment must recognise the inherent uncertainties associated with the estimation of flood probabilities and the hydrological community must work to communicate the nature of these estimates to the wider flood risk community. Issues are caused not necessarily by the methods hydrologists use to determine and describe probability but in how these estimates are subsequently communicated and used.

Where there is significant uncertainty in the estimation of a flood probability, either as a result of poor quality data or the absence of data, then to define flood risk based on probability may not be appropriate and in such instances an approach to assessment with gives more weight to the consequences of flooding (the hazard and the vulnerability) may be more appropriate. The use of flood probability data to communicate flood risk to the public and as the basis of flood management decisions may be misleading where estimates of flood probability have a high level of uncertainty; they should not be used as the basis for flood risk assessment where this uncertainty is poorly understood. In fact, the communication of the uncertainty should take priority over the statements made on the probability so that recipients of the information are not misled.

## Conclusions

Flood risk can be defined through an understanding of the probability of occurrence and of the magnitude of the consequences (flood hazard and vulnerability), however flood probability is often used to directly represent flood risk without consideration of hazard or vulnerability. The EU Floods Directive and PPS25, amongst other recent publications, recognise that to use flood probability as a proxy for risk is not always appropriate.

Flood probability, as with all probability estimates, is dependent on the quality of data used to define it; the uncertainty associated with its estimation can be reduced by increasing the data set used to produce the estimate or

improving the accuracy of the data set. The chances are that the estimated magnitude of a particular return period event on a particular river will change following the observation of a significant flood event or an improvement in the available data and therefore, flood probabilities should not be regarded as fixed. In addition, the possibility that climate change may be affecting the distribution and magnitudes of floods in the UK implies that the data set on which we base our current estimates of flood frequency is a representation of a passed or changing baseline. There are some significant challenges to be overcome when describing future climate change flows based on current probability estimates and much greater attention should be paid to communicating uncertainty.

Investment in flood risk assessment tools, flood models and mapping which rely on estimates of probability should be accompanied by investment to improve the available flood peaks data base in the UK with the aim of reducing uncertainty, error and variation in flood frequency estimates. In addition, in all instances it is prudent to consider representing flood risk in terms of probability or whether an approach which places more emphasis on the consequences of flooding may be more appropriate.

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