Measuring Confidence in NaFRA Outputs

Stage 1 – Method

Report – FCPIF00151B00/R1

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Executive summary

The report describes the approach to assigning each Impact Cell (IC) within the NaFRA output with a level of confidence that the cell has been assigned the correct probability band. The translation of the method described here into supporting processes and review tools is discussed separately in the Measuring Confidence in NaFRA Outputs Final Report (FCPIF00151B00/R2).

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This report has been written by:

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The comments provided by the reviewers have been gratefully received and incorporated where possible in the finalisation of the method as outlined in this report.

Contents

1 Introduction

The Environment Agency has set out its aspiration to communicate confidence in the estimates of the probability of flooding from rivers and the sea as published through the National Flood Risk Assessment (NaFRA). The need to present the confidence within estimates of flood probability was reinforced in the recent National Audit Office Report (2011) that highlighted a lack of understanding about the level of confidence in flood risk information as an important shortcoming and an area to focus on in future years.

This report provides a practical method for quantifying the uncertainty (and associated confidence) within the estimates of flood likelihood derived through either the national NaFRA analysis or those produced by the local NaFRA analysis through the Modelling and Decision Support Framework 2 (MDSF2) application. The method outlined builds upon previous work undertaken by Mike Steel and Hayley Bowman.

1.1 Project objective

The primary objective of this report is to:

- Support the communication of quantified statements of both uncertainty and confidence.

In particular there is now an urgent need to assign each Impact Cell (IC) with:

- A meaningful representation of the level of confidence that the cell has been assigned the correct probability band.
- A quantified assessment of the chance that (i) the correct band has been assigned, (ii) the true band is associated with more frequent flooding, or (iii) the true band is associated with less frequent flooding.

In the medium term the Environment Agency has also stated its desire to develop the approach to describe their confidence that the estimates of flood depth (across a range of probabilities of occurrence) are correct. Although recognised as important, the short term focus, however, remains on the assessment of confidence that the probability banding is correctly assigned. This reflects constraints of timescales and a limited window of opportunity for local teams to evaluate the current results.

1.2 Assumptions

The following assumptions have guided the development of the approach presented in this report:

- The approach should be based on a combination of national analysis and local review and evaluation.
- The contributions from data quality and modelling method should be reflected in the assessment.
- Automated tools should be used to provide an initial estimate of the uncertainty at the scale of a Flood Area (and by inference each associated IC).

- The approach should be sufficiently simple for use now, presenting local staff with a reasonably small number of data fields to review.

- Uncertainty in depth is ignored. (Note: Although not considered here the assessment of the confidence within the estimated depth versus probability relationship, at an Impact Cell scale, should be considered in future.)

It is recognised that a more comprehensive approach based on formal uncertainty propagation techniques may become possible in future as practical experience with uncertainty analysis develops. A discussion of these associated opportunities and difficulties is provided separately through a 'route mapping' report.

1.3 Target audience

This report is written to support the assessment of confidence within the NaFRA outputs and in particular the implementation of a structured method within the NaFRA and the MDSF2 toolsets. As such it is targeted at a technical audience, with experience and expertise in the underlying modelling methods and data upon which NaFRA relies with a view to embedding the approach within a software tool supporting operational instruction. It is not the intention of this report to describe either the software or the operational instruction.

2 Motivation to understand uncertainty

The need to understand and manage uncertainty has been recognised within UK government guidance for some time and continues to be recognised as a prerequisite for good decision making. Various Government policies and guidance documents highlight the importance of understanding uncertainty, including for example:

Drivers from within the Environment Agency – The Environment Agency recognises that understanding uncertainty is a prerequisite for good decision making. By understanding uncertainty levels of confidence can be communicated. In turn, this facilitates better decision making by Environment Agency staff, partners and customers that are informed by, rather than in spite of, uncertainty.

More specifically there are a set of Strategic drivers within the Environment Agency that directly support providing information about uncertainty or confidence, for example:

- The National Flood and Coastal Erosion Risk Management (FCERM) Strategy[1] (Section 3.3.1) states that:

  "Flood and coastal erosion risks can only be managed effectively if they are properly understood. Key to this is estimating the risks through assessing data, information and modelling and understanding the uncertainty in the predicted levels of risk."

- FCERM Modelling Strategy[2] (Principle 3) states that:

  "We will understand and communicate uncertainty in modelling outputs to assist decision-making by ourselves, our partners and our customers. We will reduce any uncertainty that prevents us from making sound decisions."

- FCERM Risk Mapping Strategy[3] (A3.1 & A3.2) states that:

  "We will use uncertainty in a positive way as part of the way we communicate flood and coastal erosion risk and make decisions; work with our partners and customers to ensure we display uncertainty in ways that make it most understandable to them."

UK Treasury Guidance – The HM Treasury Green Book (HM Treasury, 2003) has uncertainty at the heart of decision making. Chapter 5 on appraising options has numerous references to uncertainty and a specific annex, Annex 4, devoted to *"risk and uncertainty"*. The following statement is made in the section on *"presenting results"* (p6):

"The results of sensitivity and scenario analyses should also generally be included in presentations and summary reports to decision makers, rather than just single point estimates of expected values. Decision makers need to understand that there are ranges of potential outcomes, and hence to judge the capacity of proposals to withstand future uncertainty". In the overview of the appraisal process (p4) it is stated that *"… as options are developed, it will usually be important to review more than once*

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1 http://www.official-documents.gov.uk/document/other/9780108510366/9780108510366.pdf
2 http://publications.environment-agency.gov.uk/pdf/GEHO0310BSBT-e-e.pdf
3 http://publications.environment-agency.gov.uk/pdf/GEHO0310BSBS-e-e.pdf

the impact of risks, uncertainties and inherent biases." The need to consider a range of values is reiterated on p28, "appraisers should calculate an expected value of all risks for each option, and consider how exposed each option is to future uncertainty."

The section on *"assessing uncertainty"* (p32-33) dwells upon sensitivity analysis. It opens with these words: *"An expected value is a useful starting point for understanding the impact of risk between different options. But however well risks are identified and analysed, the future is inherently uncertain. So it is also essential to consider how future uncertainties can affect the choice between options"*.

Annex C of the Supplementary Guidance to the Green Book, highlights the importance of taking into account future uncertainty within the selection of the preferred management options: an issue that is related but outside of the current project focus.

Government Departmental Guidance – Guidance published by Defra repeatedly calls for proper consideration of uncertainty in appraisal decisions. For example, in Flood and Coastal Defence Project Appraisal Guidance (Defra, 2001) on *"good decision making"* (p5) it states good decisions are most likely to result from considering all economic, environmental and technical issues for a full range of options, together with a proper consideration of risk and uncertainty. FCDPAG3 (Defra, 2000a) has a section on *"sensitivity analysis and robustness testing"* and highlights the importance of identifying options whose benefits are robust to uncertainty. FCDPAG4 (Defra, 2000b) calls for a more explicit treatment of uncertainty in risk analysis (p8): *"All risk assessments are predictive and, therefore, the results are inherently uncertain. In undertaking risk assessment work, it is important to acknowledge explicitly the degree of uncertainty."*

National Audit Office Review (2011) – The recent NAO report highlighted the need to better communicate the uncertainty within the NaFRA outputs and, in particular, how it might vary between locations reflecting the difference in model performance across different physical settings and input data quality.

3 Background to previous studies

Since NaFRA was first produced in 2002, various expert reviews and pilot validations have been undertaken. Each of these projects has provided some degree of insight into the validity of the NaFRA outputs and the input data sets and model components that can be considered most critical in providing a credible output. These studies have included:

- **Piloting of the original R&D approach**
  - The NaFRA approaches are derived from research undertaken within the joint research programme (Environment Agency, 2003; Hall et al, 2003). This included piloting and reviewing stages (see Environment Agency, 2004 and Sayers and Meadowcroft, 2005 for summaries) and was followed by first national implementation and application of NaFRA model software (led by Halcrow).
- **NaFRA specific studies (based on HR Wallingford, 2004)**
  - Independent review of the NaFRA model, JBA Consulting (2004)
  - Independent review of the NaFRA model, Royal Haskoning (2005)
  - Technical workshop comparing the insurance industry scenario models and NaFRA_RASP methods, Association Of British Insurers (2007)
  - NaFRA Data Review, Halcrow (2005)
- **NaFRA specific studies (based on HR Wallingford, 2004 and improved by Gouldby et al, 2008)**
  - NaFRA 2006 Project Report Appendix A Ground Truthing, JC Chatterton Associates (Halcrow, 2007)
  - NaFRA 2007 Validation Pilot Results, Halcrow in association with HR Wallingford (2008)
  - NaFRA 08 – Understanding and communicating our confidence in NaFRA 2008 – a trial study, HR Wallingford (2009)
  - NaFRA 08 – Project Report Appendix B EAD and Model Forensics Summary, Halcrow (2009) in association with HR Wallingford
  - NaFRA 08 – Project Report Appendix B Independent Economic Review, Halcrow (2009) in association with JB Chatterton Associates
  - NaFRA 2009 – Data improvements, uncertainty and sensitivity analysis, Halcrow (2010), specific components of interest for this study:
  - I3 - Review of uncertainty and sensitivity analysis techniques
  - I4 - Review of model and coefficient uncertainty
  - I7 - Review of input data uncertainty
  - I9 - Ground truthing
  - NaFRA – Environment Agency internal analysis (Bowman, Steel and Wyse)
  - NaFRA 2012 Measuring confidence in NaFRA outputs (this study)

- NaFRA 2012 NaFRA Method Improvements, Review of existing NaFRA flood depth outputs, Halcrow (2012)

- **Supporting studies (based on HR Wallingford 2004, improved by Gouldby et al, 2008)**

  - Thames Estuary 2100: Phase 3(i) Studies, Topic 2.3: IA System flood risk model: Verification, Environment Agency (2007)

- **Supporting studies (sensitivity, validation and benchmarking)**

  - Exploring the sensitivity of RASP HLM+ to variations in input data and model parameters, Environment Agency (2006)
  - NaFRA MDSF2 Trials: Output Comparison Report of national and local NaFRA model (local model using MDSF2), Halcrow (2011)
  - A framework for validating probabilistic flood models SC090008/WP1 Phase 1 Final Report, Halcrow (2012)
  - Improving probabilistic flood risk modelling capabilities SC090008/WP2, JBA and Halcrow (2012)
  - LTIS Improvements - FACET Uncertainty Guidance and Validation Method, Halcrow (2012)
  - Benchmarking of 2D hydraulic modelling packages (Environment Agency, 2010)

The above projects all provide a useful contribution to our understanding of NaFRA. As the methods and data have continued to change however none provide a comprehensive or fully accepted understanding of the validity of the NaFRA outputs in quantified terms. The references above therefore provide important background, and as a whole provide very useful insights, but care is required when relying upon any specific statements they contain.

4 Challenges in assigning confidence to the NaFRA outputs

The lack of quantified uncertainty within the standard NaFRA outputs reflects three key difficulties (i) lack of sufficiently detailed observations (with known pre-flood conditions and covering a range of extreme values) with which to objectively validate the results; (ii) heterogeneity of the real flood systems; and (iii) variation in the important data and modelling aspects from one flood system to another. Each of these difficulties is discussed below together with a short statement outlining the approach adopted here to overcome them.

(i) Lack of observations: NaFRA provides a probabilistic assessment of risk. Flood risk can only ever be estimated, rather than measured directly. This reflects:

1. The non-stationarity within the flood systems (not only climate but often more significantly the condition and nature of the defences, land use etc)

2. The inclusion of rare physical circumstances that may never have been observed (but are plausible and significant and can be modelled).

To overcome this difficulty: The approach to scoring confidence presented here is therefore based on implementing a consistent process that incorporates observational evidence alongside expert argument/judgement.

(ii) Heterogeneity of real flood systems: Across England and Wales the physical characteristics of the Flood Risk Management Systems (FRMSs) vary significantly. The associated quality of the data that is available (both from one FRMS to another and within a single FRMS) and the ability of the model to represent the different physical settings (catchment types, defence systems, receptors etc) also varies.

The heterogeneity of the real flood systems means it is difficult to provide a uniform assessment of uncertainty or a single national scale response.

To overcome this difficulty: The likely confidence of the NaFRA outputs is assessed in the context of different Flood Area typologies (identified to reflect the different aspects of the physical setting that are likely to impact the model performance) and the quality of the data available in a specific Flood Area.

(iii) The variation in the weakest link: The quality of the results is governed by the weakest component of the model, be that a specific model component, model structure or data aspect. For example, replacing the Rapid Flood Spreading Model (RFSM) with an inundation model that solves the full shallow water equations will have limited impact if inflows are provided by a poor/incorrect description of the boundary conditions. Equally, focusing on the hydraulic representation across the floodplain whilst ignoring the need to accurately represent defence performance will limit model utility in defended areas.

As the weakest link(s) varies from one Flood Area to another providing a uniform assessment is difficult and, indeed, inappropriate.

To overcome this difficulty: The weakest link(s) - both data and/or model components - are defined based on consideration of the typological setting and quality of available data.

5 National and Local Approaches

5.1 Introduction

The approach presented here to assess the confidence within the NaFRA outputs seeks to be:

- based on evidence and a readily understood methodology,
- credible,
- accepted, and
- clearly presented.

The approach presented has been developed through a collaboration of local teams, expert reviewers and consultant teams working together. This has led to two approaches:

- **National Uncertainty Assessment (NUA)**
- The national uncertainty assessment is based on an approach that includes a series of steps that can be undertaken centrally (by efficiently mining national data sets), to provide an initial population of a 'confidence index' to each Impact Cell, followed by a process of local validation.
- **Local Confidence Assessment (LCA)**
- A simplified, but structured, approach based on local understanding of the available data and models used to assess risk and how these relate to specific flood systems.

Both of these approaches are presented in the following chapters.

5.2 Key assumptions

A number of important assumptions underlie both the National and Local Assessments, namely:

Data quality and model performance have equal weighting – To provide an overall confidence index, the quality of the underlying data (the data quality) and the accuracy of the model (model performance) within a particular physical setting both influence the level of confidence in the output. Here it is assumed through their influence is equal. Although it is recognised that this might not be the case at present there is insufficient evidence to improve on this basic assumption. This implies that the same level of confidence is generated from 'very poor data used with an excellent model' or 'excellent data used within a very poor model'.

The 'weakest link' dominates – The confidence index is based on the weakest aspects of the data and the model performance (rather than ‘scoring and weighting’ of all data and model aspects). To improve the level of confidence in the output, this assumption does not imply that only one dataset or model component requires improvement. For example, although the weakest link will dominate at any given time, if this is improved a low confidence in the result may remain because the next weakest link now dominates and so on.

Given the heterogeneity of the Flood Areas and the potential for complex interactions between datasets this approach is considered more robust, objective and realistic than a more complex and subjective scoring and weighting process. The justification for this approach is best described by way of an illustration. Consider a Flood Area with large raised defences. If one of the datasets considered to have a “high influence” is very poor, for example the crest level of those defences is unknown and estimated from standard of protection, the probability results are likely to be poor regardless of the data quality of the other aspects (i.e. the output can only be as good as the weakest link within the critical datasets). The quality of the output is not as directly related to those datasets considered to have a “moderate influence”, so the average value of the two worst values is taken. As experience is gained this later assumption may need to be refined and modified. For the current, first application this is considered a sensible starting position.

A confidence index can be mapped to a quantified uncertainty in probability – To determine the level of confidence that the assigned probability band is correct requires a quantified uncertainty to be determined. It is assumed here that an abstract confidence index - based on a scoring of the weakest links within the data and model - can be translated to a quantified estimate of uncertainty.

Focus is on probability not depth – Given the focus of this study is to determine confidence in the assigned probability band no attempt is made to distinguish the influence on depth and probability. This is not an unreasonable assumption, given the close coupling of the two issues (greater depth in one location is likely to mean flooding has extended to a previously dry location, for example). The approach proposed here provides a practical, achievable and extendable approach – but is not offered as an alternative to a much more and fully quantified uncertainty analysis that could be undertaken at a single or handful of sites.

Exclusion of receptor terms - As part of the work covered here no effort is devoted to determining the confidence in the receptor terms. It is noted however that some of the datasets upon which the receptor analysis is based – e.g. the National Receptor Dataset – are under review outside of this project.

6 Overview of the approach to the national uncertainty assessment

The proposed approach to the national uncertainty assessment is summarised in Figure 6.1 and includes seven primary steps.

Each step is discussed in turn in the following sections.

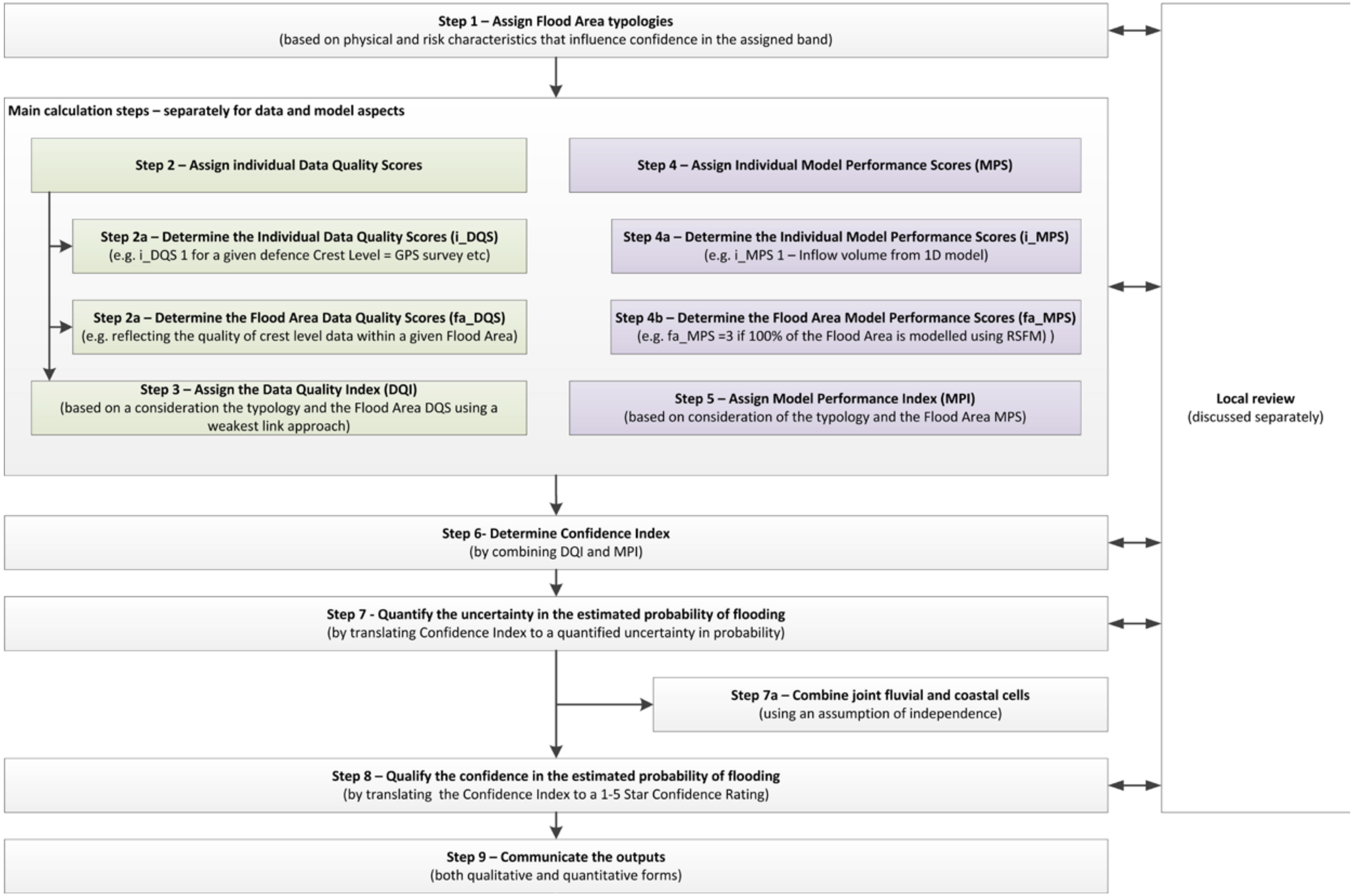

Figure 6.1 Overview of approach

6.1 Step 1 – Assign Flood Area typologies

A simplified typology has been developed to distinguish one Flood Area from another based on their physical characteristics (Figure 6.2). This is not an attempt to capture all aspects that differentiate Flood Areas, but only those aspects that are considered most crucial in assessing the confidence in the probability of flooding as reported through NaFRA, namely:

- Primary source of flooding (i.e. coastal, fluvial or a combination)
- Shape of the river valley (i.e. the gradient and width of the valley)
- Complexity of the channel network (e.g. multiple braids)
- Floodplain defences (i.e. defended or undefended)
- Complexity of the defence systems (e.g. primary linear defences, secondary defences, etc)
- Height of the linear defences
- Complexity of the floodplain flow pathways (i.e. is the floodplain urban or a more homogenous rural floodplain)

A unique typology is assigned to each Flood Area using an automated process (using data available to NaFRA - either through previous national analysis or local updates through MDSF2).

The typology is used to determine those datasets and model components that are most likely to influence the confidence in the output within a given Flood Area.

A GIS tool has been developed to aid the review and over-writing of the centrally-assigned typologies using local knowledge. More detail on the GIS tool can be found in the Measuring Confidence in NaFRA Outputs Final Report (FCPIF00151B00/R2).

A more detailed discussion of the typology and the specific rules used to differentiate each classification is provided in Annex 1.

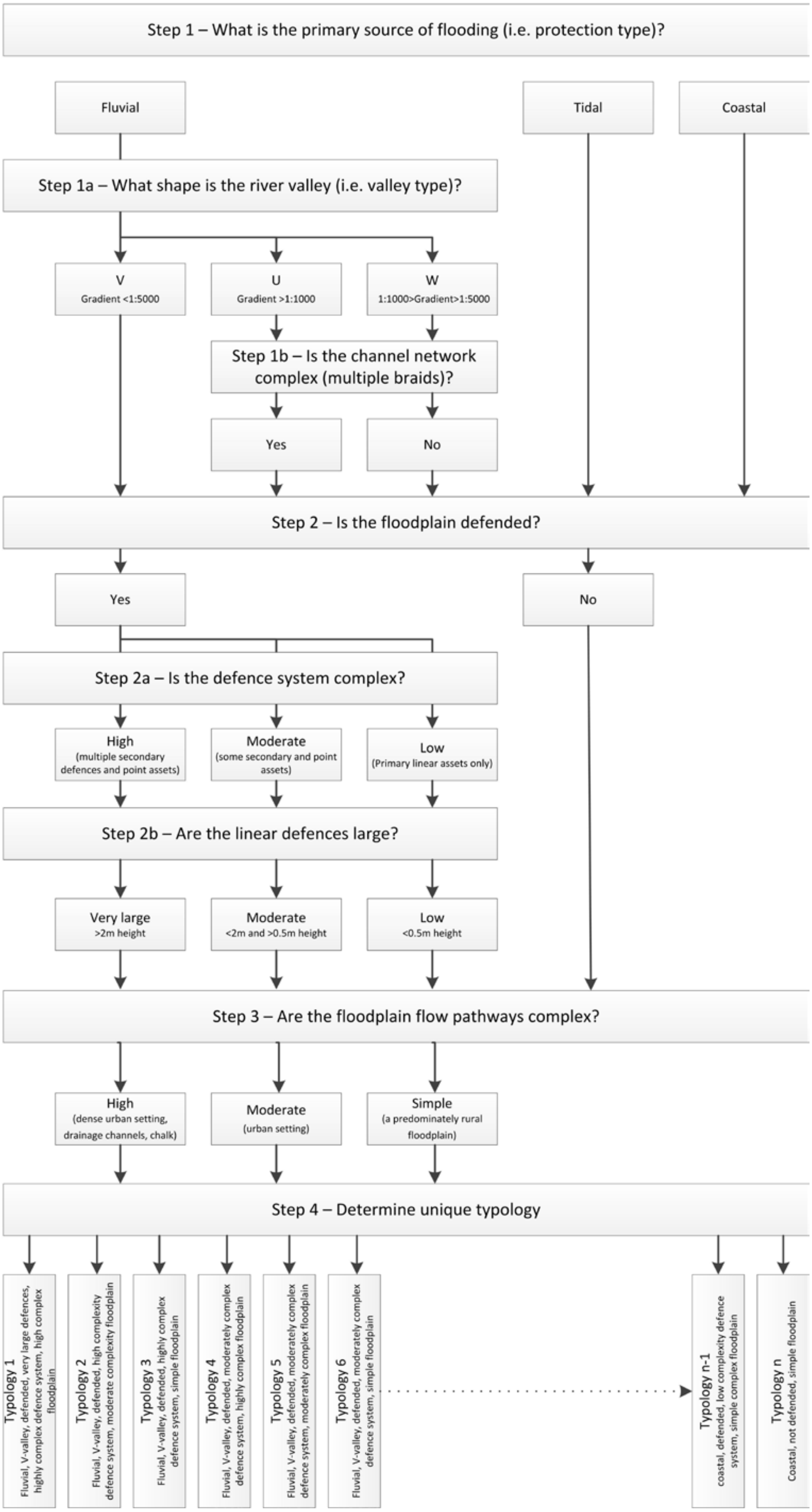

Figure 6.2 Flood Area typology to support the confidence analysis

6.2 Step 2 – Assign individual Data Quality Scores

The quality of an individual data input (e.g. the crest level of a specific defence within a given Flood Area) recorded through the Individual Data Quality Score (i_DQS). The i_DQS values are then used to determine the quality of particular data (e.g. crest levels) at a Flood Area scale (the so-called fa_DQS). The determination of these two scores is discussed below.

6.2.1 Step 2a – Determine the individual Data Quality Scores (i_DQS)

The Environment Agency has a series of documents that define the data quality standards for individual data items. These definitions are used as the basis for an individual DQS used here that reflect the specific context of the data inputs to the NaFRA modelling process.

The individual DQS definitions are presented in Table 6.1, Table 6.2 and Table 6.3 below. The datasets and GIS processes used to assign the i_DQS values are discussed in more detail in the Measuring Confidence in NaFRA Outputs Final Report (FCPIF00151B00/R2).

6.2.2 Step 2b – Determine the Flood Area Data Quality Score (fa_DQS)

The individual DQS values derived through Step 2a are used to determine the Flood Area Data Quality Score (fa_DQS) associated with each particular data input (e.g. crest levels) at a Flood Area scale.

The relationships used to define the Flood Area Data Quality Scores based on the individual Data Quality Scores are shown in Table 6.4. In all cases however a score of 1 is reserved for near perfect data. However, this does not imply that a DQI of 1 for all data should be the aspiration.

The processes used to assign the fa_DQS values are discussed in more detail in the Measuring Confidence in NaFRA Outputs Final Report (FCPIF00151B00/R2).

Input variable	1 - High quality	2	3	4	5 - Low quality	Needs some local review or data automated?	Comments
Source							
Water level - in-river	NFCDD with 3 or more RPs	1D levels with 2 or more RPs but not in NFCDD or NFCDD with 2 RPs or NFCDD with unknown number of RPs	Local 2D hydraulic model	Generalised, national 2D model	Approximate methods (e.g. RRC / FEH methods)	Automated	1. In the first application it is unlikely to be possible to determine the number of data points used, simply the data source. 2. Variation in the uncertainty associated with varying return periods is not captured here - but could be incorporated formal uncertainty analysis methods (as the LH-OAT RASP-MC type approaches).
Water level - tidal	NFCDD with 3 or more RPs	1D levels with 2 or more RPs but not in NFCDD NFCDD with 2 RPs NFCDD with unknown number of RPs	Interpolation with DQS 1 or 2 upstream and downstream	Interpolation with DQS >2 upstream or downstream or unknown	Approximate methods (e.g. tidal projection, SOP / Tidal range methods)	Automated	Same comment as above.
Water level - coastal	Local coastal extremes analysis stored in NFCDD or national data store	Local coastal extremes analysis not in NFCDD	National coastal extremes analysis (post 2011) (surge and tide joint probability data)	National coastal extremes analysis (pre 2011) (Surge and tide joint probability data)	Approximate methods		
Overtopping rates - coasts	Overtopping rate method = 1 and coastal exposure = 1	Overtopping rate method = 2 and coastal exposure = 1	Overtopping rate method = 3 and coastal exposure = 1	Overtopping rate method = 4 and coastal exposure = 1	Overtopping rate method = 3+ and coastal exposure = 5	Automated	Based on two underlying DQS components; Overtopping rate method 1 = local detailed modelling with 3+ return periods (based on appropriate joint wave and waters levels and detailed overtopping analysis) and stored within NFCDD 2 = local detailed modelling with 3+ return periods (based on appropriate joint wave and waters levels and detailed overtopping analysis) and not stored within NFCDD 3 = National coastal extremes (post 2011 update) (based on waves and water level joint probability data) 4 = National coastal extremes (pre 2011 update) (based on waves and water level joint probability data) and Coastal exposure 1 = Exposed (beach normal is <=75° of dominant extreme wave direction of offshore point) 5 = Sheltered (beach normal is >75° of dominant extreme wave direction of offshore point)

Table 6.1 Definition of the individual Data Quality Scores (i_DQS) - Source terms

Pathway							
Asset							
Crest level	Continuous crest level profile recorded in NFCDD	Multiple discrete point measurements in NFCDD (e.g. upstream / downstream / midpoint)	Single measurement in NFCDD	Local approximation (e.g. Estimate using SOP or manual review)	General estimate	Automated	The primary source of the crest level may be difficult to determine from historical NaFRA results - by differentiation between DQS 4 and others is possible in the short term.
Condition grade	Bespoke reliability analysis and creation of specific defence fragility (reviewed and accepted)	NFCDD value manually revised for NaFRA model within 1 year of modelling	In NFCDD but older than 1 year or unknown vintage	Older manual review for NaFRA (e.g. from previous model)	Not in NFCDD (3+)	Automated	It will be impossible to distinguish this detail using the historical NaFRA models, with a simple definition of either populated or missing and in filled (with a 3+)
(Defence) Ground level							The confidence of this should be based on a combination of scores from DTM & primary defence location and is not therefore considered separately.
Toe level	Long record (>10 years) of beach profiles recorded in NFCDD showing a stable toe level (low volatility)	Expert assessment of a stable toe based on limited observations and recoded in NFCDD	As 1 or 2, recoded in NFCDD with volatile or unknown toe	locally approximated toe level	regionally approximated toe level	Local. No DQF in NFCDD for this.	Both the accuracy of a single measurement the length of record and the inherent variability of the toe / beach are all important. Within NaFRA these complexities are simplified.
RASP Type	Bespoke reliability analysis and creation of specific defence fragility in NFCDD	Bespoke reliability analysis and creation of specific defence fragility, not recorded in NFCDD or Local review of RASP DefClass.	Local review of RASP Group.	Unchecked RASP type	Reviewed and discredited but not changed	Local	
Fragility	Bespoke reliability analysis and creation of specific defence fragility in NFCDD	Defence scale default reviewed and accepted as reasonable or expertly modified (with reasons recorded)	Default RASP Fragility curves		Reviewed and discredited but not changed	Local	
Standard of protection (SoP)	Actual individual defence recorded in NFCDD	Design or Asset Group SOP recorded in NFCDD	Local review, changed or accepted	local approximation e.g. catchment default / consequence rating	Reviewed and discredited but not changed	Automated	In determining the SoP it is important that all safety factors are removed and it is simply the return period at which the water level exceeds the crest level or the overtopping rate exceeds 50 l/s/m (need to check).
Defence Length	No subdivision of the raw NFCDD data (i.e. <300m)	Divided =< 2 defences (default for current NaFRA 08 as asset ref not retained)	Divided =< 4 defences	Divided =<8 defences	Divided into >8 defences	Automated	Reflects how well averaged parameters are likely to reflect true condition and level of the defence. This is likely to be a secondary issue compared to the primary quality of the crest and condition information.

Table 6.2 Definition of the individual Data Quality Scores (i_DQS) - Pathway (Asset) terms

Floodplain (Impact Cells)							
DEM - Quality of source	High resolution with linear features (e.g. Low-level LiDAR and photogrammetry / assessment of cloudpoint data with MasterMap)	High resolution without linear features (e.g. Low-level LiDAR)	Moderate resolution (e.g. High level LiDAR)	Low resolution (e.g. IFSAR)	other data sources (e.g. OS Panorama)	Automated	Both resolution of the underlying DEM and the variation within the DEM across the Impact Cell are important. The first of these - the quality of the underlying DEM - is captured here. The second aspect is then combined through consideration of the Flood Area DQI
DEM - Appropriateness of Impact Cell size	variance in IC level very low (<0.05m)	variance in IC level low (<0.1m)	variance in IC level moderate (<0.3m)	variance in IC level significant (=<0.5m) or unknown	Variance in IC level very significant (>0.5m)	Automated	The DEM is fundamental to the flood spreading - the base DEM is averaged to an Impact Cell scale and informs the shape and flood storage within each Impact Zone. The relationship between the resolution of the floodplain resolved by the DEM and the IC is an important consideration
System spatial representation							
Flood area protection type	Defence type field completed in NFCDD		Reviewed and changed		Reviewed and discredited but not changed	Automated	
Primary defence location (raised and non-raised)	Referenced as an actual defence position within NFCDD spatial layer	Referenced as an actual defence position based on unknown source or local knowledge	Derived from 'tramlining' river or coastline, and locally checked.	Derived from 'tramlining' river or coastline, and not locally checked.	Reviewed and discredited but not changed	Local	
River network	Detailed River Network automatically filtered	Detailed River Network manually filtered	Local alternative network (e.g. based on detailed OS mapping)	General alternative network (e.g. CEH main river)	DRN used directly	Local	

Table 6.3 Definition of the individual Data Quality Scores (i_DQS) - Pathway (Impact Cell and spatial) terms

	Data Quality Descriptors (by Flood Area)				
Input variable	**1 - High quality**	**2**	**3**	**4**	**5 - Low quality**
Source					
Water level - in-river	100% of water levels by length of raised / non-raised defence DQS = 1	>= 75% of water levels DQS <= 2	=< 25% of water levels DQS > 3	< 25% of water levels DQS > 3	All others
Water level - tidal	100% of water levels by length of raised / non-raised defence DQS = 1	>= 75% of water levels DQS <= 2	=< 25% of water levels DQS > 3	< 25% of water levels DQS > 3	All others
Water levels - coastal	100% by length DQS =1	>=75% by length DQS <=2	>=50% by length DQS <=4	<=50% by length DQS <=4	All others
Overtopping rates - coasts	100% of overtopping rates by length of raised / non-raised defence DQS = 1 and Toe level DQS >=2	>=75% by length DQS >= 2 and Toe level DQs >=2	>=75% by length DQS 3 or 4 and Toe level DQS >=3	>25% with DQS 3 or 4 (any Toe Level DQS value)	All others
Pathway					
Asset					
Crest level	100% of crest levels by length of raised defence DQS = 1	>= 75% of crest levels DQS = 1	=< 25% of crest levels DQS >= 2	=< 25% of crest levels DQS >= 3	All others
Condition grade	100% of Condition Grades by length of raised defence DQS = 1	>= 75% of condition grades DQS = 1	=< 25% of condition grades DQS >= 2	=< 25% of condition grades DQS >= 3	All others
Ground level	DTM = DQS 1 and Defence location = DQS 1 for all raised defences	DTM = DQS 1 and Defence location = DQS 1 for >= 75% of raised defences	DTM = DQS <= 3 and Defence location DQS <=3 for all raised defences	DTM = DQS < 3 and Defence location DQS <=3 for >= 75% raised defences	All others
Toe level (embedded in coastal overtopping rate)	100% by length DQS =1	>=75% by length DQS <=2	>=50% by length DQS <=3	>=50% by length DQS <=4	All others
RASP Type	100% by length DQS =1	>=75% by length DQS <=2	>=50% by length DQS <=3	>=50% by length DQS <=4	All others
Fragility curves	100% by length DQS =1	>=75% by length DQS <=2	>=50% by length DQS <=3	>=50% by length DQS <=4	All others
Standard of protection (SoP)	100% by length DQS =1	>=75% by length DQS <=2	>=50% by length DQS <=3	>=50% by length DQS <=4	All others
Length	100% by length DQS =1	>=75% by length DQS <=2	>=50% by length DQS <=3	>=50% by length DQS <=4	All others
Floodplain					
DEM (as reflected in the RASP model)	Variance in IC level DQS =1 and Underlying DEM DQS =1 (>50%)	Variance in IC level DQS <=2 and Underlying DEM DQS =< 2 (>50%)	Variance in IC level DQS <=3 and Underlying DEM DQS =< 3 (>50%)	Variance in IC level DQS <=4 and Underlying DEM DQS <= 4 (>50%)	All others
System spatial representation					
Flood area protection type	100% by length DQS =1 and single assignment (either F,T or C)	100% by length DQS <=3 and single assignment (either F,T or C)	100% by length DQS <=3 and multiple assignment (either F,T or C)	>=25% by length DQS >=4	All others
Primary defence location	100% by length DQS =1	>=75% by length DQS <=2	>=50% by length DQS <=3	>=50% by length DQS <=4	All others
River network	100% by length DQS =1	>=75% by length DQS <=2	>=50% by length DQS <=3	>=50% by length DQS <=4	All others

Table 6.4 Definition of the Flood Area Data Quality Scores (fa_DQS) - source terms

6.3 Step 3 – Assign the Data Quality Index (DQI)

The quality of the data as a whole within a given Flood Area is defined through the Data Quality Index (DQI). The fa_DQS values (derived through Step 2b) together with information on the Flood Area typology are used to determine the DQI. It is the DQI that is then taken forward into the estimate of the Confidence Index in Step 6.

The datasets with the greatest influence on uncertainty will vary by typology. Some datasets will be of fundamental importance and others less so (for example, Condition Grade is not relevant when the Flood Area has no raised defences).

At present, insufficient objective evidence exists to quantify the influence a particular dataset has on the uncertainty in the estimated probability of flooding directly. The cumulative experience gained through the previous studies outlined in Chapter 3 has therefore been used to identify, for each typology, those datasets that are:

- *likely to have a high influence on the probability of flooding*
- *likely to have a moderate influence on the probability and/or depth of flooding*

The results of this review are given in Table 6.5.

The understanding of the quality of individual datasets at a Flood Area scale (fa_DQS) has been combined into an overall (single) Flood Area DQI based on the 'worst score' from either:

1. The weakest link within those data considered “likely to have a high influence” on the probability and/or depth for a given typology (solid dots within Table 6.5).

2. This reflects the strong connection between the uncertainty in the data that is considered to be significantly influential and the uncertainty in the assessment of flood probability.

Or

1. The average score of the two worst scores within the datasets identified as “likely to have a moderate influence” for a given typology (open dots within Table 6.5).

2. This reflects the less direct linkage between the uncertainty in the data that is considered to be moderately influential and the uncertainty in the assessment of flood probability.

3. An example of this calculation is provided in Annex 2.

The automated calculation of the DQI provides the basis for local review and, where necessary, update of the automated assessment of the output data scores. The procedures associated with this manual process are discussed further in the Environment Agency's Operational Instruction 38_13 and the Measuring Confidence in NaFRA Outputs Final Report (FCPIF00151B00/R2).

Input variable	Influence on results (by typology): What is the primary source of flooding (i.e. protection type)? Fluvial V	Fluvial W	Fluvial U	Tidal	Coastal	Is the channel network complex? Yes	No	Is the raised defence system complex? Yes: Highly	Moderately	Low	No: Undefended	Are the linear defences large (high)? >2m	<2m and >0.5m	<0.5m	Are the floodplain flow pathways complex? Highly	Moderately	Low	Why is this important?
Source																		
Water level - in-river	●	●	●					●	○									Determines the load on the defences, and hence the likelihood of failure, the overflow heights and hence inflow volumes.
Water level - tidal				●														Determines the load on the defences, and hence the likelihood of failure, the overflow heights and hence inflow volumes.
Water levels - coastal					○													Primarily influences overtopping rates, however is used directly when breach or ground levels are below the extreme water level - hence an 'open' dot
Overtopping rates - coasts					●													Determines the load on the defences, and hence the likelihood of failure, and the overtopping inflow volumes. Critically depends upon toe level, beach normal in relation to the angle of wave attack.
Pathway																		
Asset																		
Crest level											●	●	●	●				Primary descriptor of the defence level - and hence influences the overflow/overtopping volume and in turn inflows and fragility.
Condition grade												●	●	○				Helps determine how likely a defence is to breach under a given load (identifying which fragility curve to use)
Ground level												●	●	○				Determines the minimum invert level in the event of a breach and hence contributes to the potential inflow volume. Most important when the defences are large.
Toe level																		Influences the overtopping rate of a coastal defence and hence inflows and fragility
RASP Type												●	○	○				Ensures the correct fragility curve is assigned (not that the fragility is correct!) - most important when the defences are large.
Fragility curves												●	○	○				Determines the chance of failure under a given load. Only important if raised defences exist and more important where defences are large and hence potential breach inflows are large.
Standard of protection (SoP)								●	○		●	●	●	○				Influences the width of a breach (also allows crest level to be estimated but aspect not considered here as included through crest level DQS and DQI)
Length												○	○	○				Reflects how well averaged parameters are likely to reflect true condition and level of the defence. This is likely to be a secondary issue compared to the primary quality of the crest and condition information.
Floodplain																		
DEM (as reflected in the RASP model)															●	●	○	The DEM is fundamental to the flood spreading - the base DEM is averaged to an Impact Cell scale and informs the shape and flood storage within each Impact Zone. In less complex floodplains the accuracy of the DEM is less important in ensuring the flood pathways are resolved.
System spatial representation																		
Flood area protection type	●	●	●	●	●													Ensures the correct type of defence loads are identified and fragility considered
Primary defence location								○				●	●	○				Incorrect defence locations can cause gross errors in the results - from the wrong areas being protected through to incorrect ground levels assigned.
River network						●	○											Overly complex or incorrectly located river centre lines can cause gross errors in the results

Table 6.5 The influence of different data sets on the uncertainty in flood probability

6.4 Step 4 – Assign component Model Performance Scores (MPS)

The performance of individual model components are considered first in isolation (e.g. as applied to single defence or area of the floodplain, individual Model Performance Scores - i_MPS) and then in the context of their application to the whole Flood Area (e.g. the flood area Model Performance Score, fa_MPS). The approaches to estimating both of these values are discussed below.

6.4.1 Step 4a - Determine the individual Model Performance Scores (i_MPS)

The NaFRA relies upon the Risk Assessment for Strategic Planning (RASP) framework and the associated model components to calculate breach inflows, spread flood waters, sample defence failures, etc. The various component models are known to perform well in some settings and less well in others. Equally the structure of the analysis (RASP framework) has a number of known simplifications – which may be more significant in some typologies than others.

It is not currently possible to provide a Model Performance Score for each aspect of the RASP analysis, as used within MDSF2 and the NaFRA toolset used to support NaFRA, as only limited systematic comparison has been undertaken.

A benchmarking study (running in parallel with this project as part of the NaFRA Method Improvements Programme) is however setting out a route map within which these comparisons can be made and the performance of individual components judged. Once complete, the benchmarking studies will provide a very useful step forwards, however further studies and experience will be needed before a comprehensive view can be established.

In the interim a placeholder for the individual Model Performance Scores is provided in Table 6.6.

6.4.2 Step 4b - Determine the Flood Area Model Performance Scores (fa_MPS)

The individual MPS values derived through Step 4a are used to determine the Flood Area Model Performance Scores (fa_MPS) associated with approaches applied across a particular Flood Area.

The relationships used to define the Flood Area component Model Performance Scores based on the individual Model Performance Scores are shown in Table 6.7.

The GIS processes used to assign the fa_DQS values are discussed in more detail in the Measuring Confidence in NaFRA Outputs Final Report (FCPIF00151B00/R2).

	'Default' refers to as run 2008 (or before) to date					Needs some local review or data automated?	Comment
Model component	**1 - High quality**	**2**	**3**	**4**	**5**		
Variable model parameters (by Flood Area)							
Bank full discharge	Reviewed, either accepted as reasonable or changed	-	Default (1:5 NaFRA, 1:3 MDSF2 - but changeable)	-	Reviewed and discredited but not changed	Automated assignment of default	
Hydrograph multiplier	Replacement of inflows based on local modelled results	-	Default (or replacement inflows in MDSF2)	-	Reviewed and discredited but not changed	Automated assignment of default	
Breach width multiplier	Replacement of inflows based on local modelled results	-	Default (or replacement inflows in MDSF2)	-	Reviewed and discredited but not changed	Automated assignment of default	
Sampling controls	-	Default settings	-	-	Reviewed and discredited but not changed	Automated assignment of default	
Replaceable model components (by defence)							
Volume caps	Replacement of inflows based on local modelled results	-	Default (slightly different approach in MDSF2 and option for replacement)	-	Reviewed and discredited but not changed	Automated assignment of default	At present it is not possible to determine when capping is invoked and the percentage of volume capped within NaFRA - this could be going forward
Valley type	Area reviewed, accepted or changed	-	Default (Determined through consideration of the valley longitudinal slope)	-	Reviewed and discredited but not changed	Automated assignment of default	
Cumulative upstream catchment area	Area reviewed, accepted or changed	-	Default (Derived from the CEH flow & catchment descriptor dataset & CCAR dataset)	-	Reviewed and discredited but not changed	Automated assignment of default	
Non-breach inflow calculations	Replacement of inflows based on local modelled results	-	Default (or replacement inflows in MDSF2)	-	Reviewed and discredited but not changed	Automated assignment of default	
Breach inflows	Replacement of inflows based on local modelled results	-	Default (or replacement inflows in MDSF2)	-	Reviewed and discredited but not changed	Automated assignment of default	
Fixed model components (by Flood Area)							
Sampling method	-	Default only (no option to replace)	-	-	Reviewed and discredited but not changed	Automated assignment of default	

RFSM	Replaced with fully hydrodynamic model - linking the floodplain and river (not currently possible)		Default only (no option to replace)	-	Reviewed and discredited but not changed	Automated assignment of default	The RFSM includes the end to end process of spreading floodwaters across the floodplain and hence includes consideration of River Level and Defence Level Capping processes where applied)

Table 6.6 Determining individual Model Performance Scores (i_MPS) - Model variables by Flood Area

Model Performance Scores (by Flood Area)				
1 - high quality	2	3	4	5 - Low quality
MPS =1 for 100% by length		MPS <=3 for 100% by length		All others
MPS =1 for 100% by length	MPS =1 for all important assets (>10% by length)	MPS <=3 for 100% by length		All others
MPS =1 for 100% by length		MPS <=3 for 100% by length		All others
MPS =1 for 100% by length	MPS <=2 for 100% by length			All others
MPS =1 for 100% by length or MPS <= 3 and ratio of uncapped to capped vol < =1.25	MPS <= 3 and ratio of uncapped to capped vol <= 1.5	MPS <= 3 and ratio of uncapped to capped vol <= 1.75 or Default if ratio unknown	MPS <= 3 and ratio of uncapped to capped vol > 1.75	All others
MPS =1 for 100% by length		MPS <=3 for 100% by length		All others
MPS =1 for 100% by length		MPS <=3 for 100% by length		All others
MPS =1 for 100% by length	MPS =1 for all important assets (>10% by length)	MPS <=3 for 100% by length	n/a	All others
MPS =1 for 100% by length	MPS =1 for all important assets (>10% by length)	MPS <=3 for 100% by length	n/a	All others
MPS =1 for 100% by length	MPS <=2 for 100% by length	n/a	n/a	All others
MPS =1 for 100% by Area	MPS <=3 for 100% by Area with no River or Defence length capping invoked	MPS <=3 for 100% by Area with some River or Defence length capping invoked (<=25% by length)	MPS <=3 for 100% by Area with significant River or Defence length capping invoked (>25% by length)	All others

Table 6.7 Determining Flood Area Model Performance Scores (fa_MPS)

6.5 Step 5 – Assign Model Performance Index (MPI)

To determine the likely influence of the model performance as a whole on the uncertainty in the probability of flooding a so-called Model Performance Index (MPI) is estimated based upon the fa_MPS values and the typological setting of a given Flood Area.

Through a process that parallels the consideration of the DQI, each model component is first defined as either:

- *likely to have a high influence*
- *likely to have a moderate influence*

Based on an understanding of past studies, an initial view as to which model components are important in different typological settings is provided in Table 6.8.

Local teams are able to revisit the automated values assigned through the review process using local evidence and knowledge of how specific Flood Areas behave in reality. Details on this process are given in the Environment Agency's Operational Instruction 38_13 and the Measuring Confidence in NaFRA Outputs Final Report (FCPIF00151B00/R2).

	Influence on results (by typology)																	
	What is the primary source of flooding (i.e. protection type)					Is the channel network complex?		Is the defence system complex?				Are the linear defences large (high)?			Are the floodplain flow pathways complex?			
	Fluvial			**Tidal**	**Coastal**	**Yes**	**No**	**Yes**			**No**							
Model component	*V*	*W*	*U*					*Highly*	*Moderately*	*Low*	*Undefended*	*>2m*	*<2m and >0.5m*	*<0.5m*	*Highly*	*Moderately*	*Low*	**Why is this important?**
Variable model parameters (by Flood Area)																		
Bank full discharge	●	●	●															The return period that initiates out of bank flow
Hydrograph multiplier	○	○	○															Influences the inflow volume (breach and non-breach)
Breach width multiplier												●	○	○				Influences the breach inflow volume
Sampling controls												○	○	○				Influences the degree of convergence required and the check points
Replaceable model components (bt Defence)																		
Volume caps	●	●	●															Restricts the total inflow into any given Flood Area
Valley type	○	○	○									○	○	○				Influences breach volume
Cumulative upstream catchment area	○	○	○															Influences the base duration of hydrograph and hence the duration of overflow (fluvial only)
Non-breach inflow calcs											●	●	●	●				Estimation of inflow volume for a given water level, crest level etc
Breach inflows												●	●	○				Estimation of inflow volume given breach for a given water level, crest level etc
Fixed model components (by Flood Area)																		
Sampling method												○	○	○				Efficient of analysis (runtime) and ensure all important combinations modelled
RFSM	●	○	○	○	○			●	●	●	○							Fundamental to the flooding process - the depth and extent for a given inflow

● *likely to have a high influence*

○ *likely to have a moderate influence*

Table 6.8 Define the Flood Area Model Performance Index (MPI)

6.6 Step 6 – Determine Confidence Index

The Flood Area DQI and MPI are combined simply through multiplication. An equal weighting of the model and data quality indices is used to estimate the Confidence Index (CI). This reflects the need to have both good data and appropriately accurate models in order to have a high confidence in the estimate of probability. In the future, as experience is gained in the sensitivity of the probability outputs to different sources of uncertainty, it may be necessary to modify this, and provide more or less weights to specific elements.

At present however there is no strong evidence to counter this view. Some initial confirmation of this approach was provided through piloting on a catchment in Swindon (within 3903). This test catchment had a recent MDSF2 run. It was found that most of the NaFRA 2008 outputs resulted in a lower CI than the MDSF2 runs. This was considered appropriate.

The lowest confidence result would attract a Confidence Index of 25 (i.e. 5 DQI * 5 MPI) and highest confidence result would be given by a CI = 1 (i.e. 1 DQI * 1 MPI).

The Confidence Index derived for a given Flood Area is assumed to apply to all associated Impact Cells unless modified using local review or through specific Impact Cell scale estimates.

6.7 Step 7 – Quantify the uncertainty in the estimated probability of flooding

The Confidence Index (of between 1 and 25) assigned to each Impact Cell does not provide a quantification of the associated uncertainty in the estimated probability. To do this, the Confidence Index has been mapped to a quantification of the uncertainty in the probability estimate as given below in Table 6.9.

Confidence Index (valid values only shown)	**2 * Standard Deviation in the estimated likelihood**
1	0.010
2	0.015
3	0.021
4	0.028
5	0.037
6	0.047
8	0.072
9	0.086
10	0.102
12	0.138
15	0.202
16	0.226
20	0.337
25	0.500

Table 6.9 Mapping Confidence Index to uncertainty

Assuming the error in the probability estimates to be normally distributed (with the values in Table 6.9 representing 2*standard deviations in the estimated likelihood) the chance that the "true" probability of inundation lies outside of a given probability band (either above or below) can be simply calculated (as illustrated in Figure 6.3). 2*standard deviation has been chosen to reflect the perceived high level of uncertainty in NaFRA when both data and model performance is poor. There is, however, limited objective evidence to support this assumption and this relationship will be an important area for any further study.

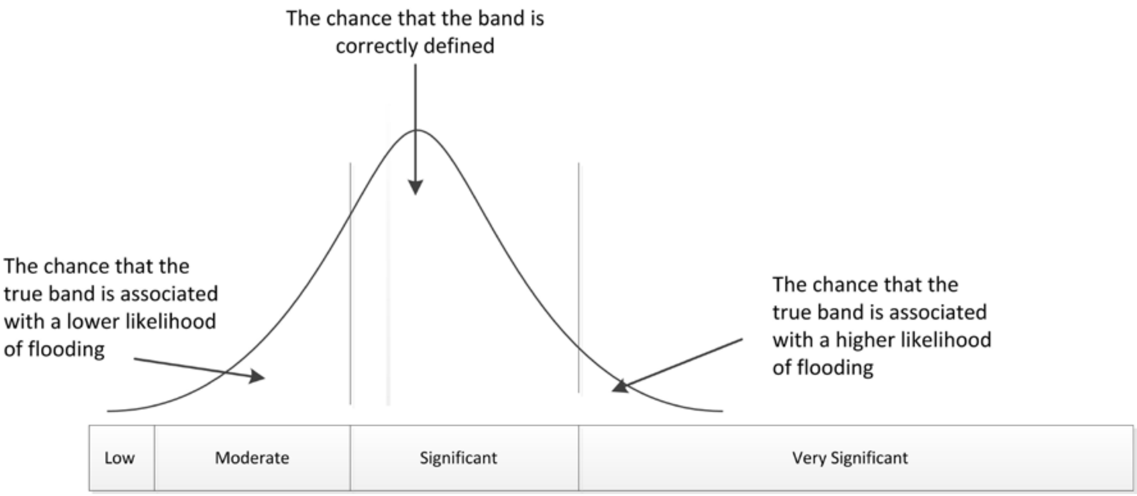

Figure 6.3 Illustration of how confidence in the probability band assigned to a specific Impact Cell will be calculated

The chosen probability bands influence the output but not the process of analysis. For example, correctly identifying a 'narrow' band as the true probability band is more difficult than correctly identifying a 'wider' band as the true band. In the limit, if the Environment Agency moves to a single band (covering a probability range of 0-1.0) the confidence that the correct band has been assigned would be, of course, certainty. If, however, ten very narrow bands are considered then the likelihood of the correct probability band being assigned would be significantly decreased.

If the banding used is uneven (with greater probability density associated with one band compared to another) then the uncertainty associated with each band will vary even if the Confidence Index does not. This is the case with the current Environment Agency chosen bands. In the future it may be appropriate to either highlight this through a programme of education/communication; establish evenly distributed probability bands (with equal probability mass), or; use structured quantified analysis and experience from the application of the method to explore the suggestion that we may be more confident in different parts of the probability space.

It is also recognised that the current "Very Low" probability band is associated with values less than 1 in 1000. This is an extreme tail in the distribution and will therefore have a very small chance of being correctly assigned. In this case the chance of the band being correctly identified is given as:

P (the most extreme, lowest chance, band being correct) = 1 – p (of the true band being associated within a higher chance of flooding).

It is also noted that the qualitative interpretation of Confidence Index perhaps provides a more meaningful insight at this extreme end (see next step).

6.7.1 Step 7a - Combine joint fluvial and coastal Impact Cells

When fluvial and coastal impact cells overlap the uncertainty in the probability of flooding from fluvial and coastal sources must be combined. Within the RASP High Level Method used to support NaFRA (through both MDSF2 and NaFRA 08 toolset) makes the assumption of independence in these sources and this assumption is used to combine the associated uncertainties.

The uncertainty in areas subject to both fluvial and coastal flooding is therefore also treated as independent and assessed as follows:

Let

$p\mathrm{F} = \mathrm{P(F)}$ the probability of fluvial flooding, and

$p\mathrm{C} = \mathrm{P(C)}$ the probability of coastal flooding.

Within NaFRA we assume fluvial and coastal flooding are independent, and hence the probability of fluvial or coastal flooding is given by:

$$
\begin{aligned}
p = \mathrm{P(F\ or\ C)} &= 1 - \mathrm{P\ (not\ F\ and\ not\ C)} \\
&= 1 - \mathrm{P\ (not\ F)\ P\ (not\ C)} \\
&= 1 - (1 - p\mathrm{F})\ (1 - p\mathrm{C}).
\end{aligned}
$$

Through the application of the confidence analysis each of these probabilities will be assigned some degree of uncertainty. This uncertainty can be described by letting:

For fluvial case

$\mu\mathrm{F} = \mathrm{E}(p\mathrm{F})$ be the mean of the fluvial probability (i.e. the standard value from NaFRA)

$\sigma^2\mathrm{F} = \mathrm{Var}(p\mathrm{F})$ the variance of $p\mathrm{F}$

For coastal / tidal case

$\mu\mathrm{c} = \mathrm{E}(p\mathrm{C})$ be the mean of the coastal probability (i.e. the standard value from NaFRA)

$\sigma^2\mathrm{c}= \mathrm{Var}(p\mathrm{C})$ the variance of $p\mathrm{C}$

As $p\mathrm{F}$ and $p\mathrm{C}$ are assumed to be independent, it follows that the expected (mean) value of the combined probability is given by:

$$\mathrm{E}(p) = 1 - (1 - \mu\mathrm{F})\ (1 - \mu\mathrm{C})$$

and the variance is given

$$\mathrm{Var}(p) = (1 - \mu\mathrm{F})^2\ \sigma^2\mathrm{C} + (1 - \mu\mathrm{C})^2\ \sigma^2\mathrm{F} + \sigma^2\mathrm{F}\ \sigma^2\mathrm{C}.$$

To evaluate the chance that a particular probability of flooding from either coastal or fluvial sources (p) is exceeded, a distribution p must be assumed and used together with the known mean and variance (given above) to calculate its parameters.

A Normal distribution is then assumed for simplicity (since its parameters are the mean and variance). It is recognised that doing so allows p to take any real number, whereas by definition p can only take a value of between 0 and 1.

6.7.2 Step 7b - Estimate the chance that the correct likelihood band has been assigned

Three estimates are made:

- **PctCorrect** – the percentage chance that the true likelihood of inundation lies with the assigned band.

- **PctOver** – the percentage chance that the 'true' likelihood of inundation has been underestimated and the Impact Cell should have been assigned a higher Probability Band (i.e. associated with more frequent flooding)

- **PctUnder** – the percentage chance that the 'true' likelihood of inundation has been overestimated and the Impact Cell should have been assigned a lower Probability Band (i.e. associated with less frequent flooding)

For the bands at either end of scale (either 0 or 1), it is impossible to under or over estimate the chance of flooding (by definition). As the 'error' is assumed to be normally distributed however a value of all three is always returned. Therefore for the limiting bands the PctUnder or PctOver estimate (as appropriate) is added to the PctCorrect. The approach outlined here can be applied to any 'band' definitions - however as the 'bands' become narrower greater uncertainty will result.

6.8 Step 8 – Qualify the confidence in the estimated probability of flooding

The Confidence Index is also used to support a more qualitative understanding of the 'confidence' in the estimates. To do this a 1 to 5-Star Rating (Table 6.10) has been mapped to Confidence Index (Table 6.11).

The 1-5 Star Confidence Rating is proposed as the primary vehicle for communicating the confidence to the public users and be applicable across all sources of flooding - i.e. also the Updated Flood Map for Surface Water, and in time, other flood risk information.

Star rating	Description
1Star (★)	Very unlikely to be locally reliable
2 Star (★★)	Unlikely to be locally reliable
3 Star (★★★)	Likely to be locally reliable
4 Star (★★★★)	Very likely to be locally reliable
5 Star (★★★★★)	Highly likely to be locally reliable

Table 6.10 Illustrative narrative definition of the 1-5 Star Confidence Rating

Star Confidence Rating	Confidence Index (valid values only shown)	2 * Standard Deviation in the estimated likelihood
★★★★★	1	0.01
★★★★	2	0.015
	3	0.021
	4	0.028
	5	0.037
★★★	6	0.047
	8	0.072
	9	0.086
★★	10	0.102
	12	0.138
	15	0.202
	16	0.226
★	20	0.337
	25	0.5

Table 6.11 Mapping the Confidence Index to the Star Rating

6.9 Step 9 – Communicate the outputs

6.9.1 Communicating confidence

There is a desire to develop a semantic framework that can be used across FCRM to communicate confidence with the information provided to a range of partners and the public. This implies that a relative scale of confidence is needed rather than an absolute measure (minimum or maximum confidence limits for example) as the nature of the evidence will vary significantly across FCRM. In this context 'confidence' is defined here as a general understanding of the degree to which the evidence presented can be relied upon when making a specific decision.

Therefore, although the focus of this report is to provide additional information on confidence alongside the flood likelihood information, this broader context is kept in mind.

The purpose of the data

The communication of confidence must be relevant to the user requirements. A complicating factor is however that flood likelihood data has multiple purposes. These purposes can be considered based on:

- Geographic scale (from national to local)
- Investment level (£100-£multiple m)
- User decisions (Environment Agency lead investment planning, Strategy planning, asset management, flood warning etc, home owner lead, insurance or preparedness).

No one of these is perfect and it may be that a hybrid is required to be generally applicable yet still simple to understand, or specific communications are required for different users. A framework that summarises these uses and their data demands is outlined in Table 6.12.

Use	Data demands
#1 National investment planning	Requires national coverage of data. The uncertainty in any one data point however is unlikely to influence national choices therefore even data with poor reliability can be used.
#2 Community or regional outline planning	Requires regional coverage of data. Decisions made are likely to include broader scale land use zoning. Although data with good reliability is desirable, poorer data can be useful to provide initial insights.
#3 Community or regional detailed planning	Requires regional coverage of data. Decisions made will vary, from relatively straightforward decisions to raise a defence to more complex choices about how and where to take action. In some instances data with high reliability will be required elsewhere poorer data can be used.
#4 Individual property choices	Requires information at the scale of an individual property. Although high reliability data is preferred to help assess risk for insurance purposes on individual properties and guide homeowners in taking appropriate actions to prepare for floods, initial choices can be made based on poorer data.

Table 6.12 A summary of uses and data demands

In the majority of cases the Confidence will need to be communicated at a scale of the Impact Cell. This will enable the confidence to be displayed to the user of WIYBY alongside the information on likelihood.

Communication to WIYBY users – Linking star rating to uses

To provide an explanation of the star rating to users of WIYBY the Star Rating (based on the Confidence Index) could be linked to the potential uses that are given in Table 6.13. In doing so it is recognised that there are no absolute thresholds, for example even data with very poor confidence may need to be used if it is the only data available (although gathering more reliable information before making significant investment decisions would be encouraged). Equally, highly reliable data can be used to support even the most broad-brush choices if it is readily available.

	Very unlikely to be locally reliable	Unlikely to be locally reliable	Likely to be locally reliable	Very likely to be locally reliable	Highly likely to be locally reliable
	☆	☆☆	☆☆☆	☆☆☆☆	☆☆☆☆☆
#1 National investment planning	✓	✓	✓	✓	✓
#2 Community or regional outline planning	✓	✓	✓	✓	✓
#3 Community or regional detailed planning	✓	✓	✓	✓	✓
#4 Individual property choices	✓	✓	✓	✓	✓
	Suitable for use (✓) – the darker the red the more suitable for use				

Table 6.13 Linking Star Ratings to Uses

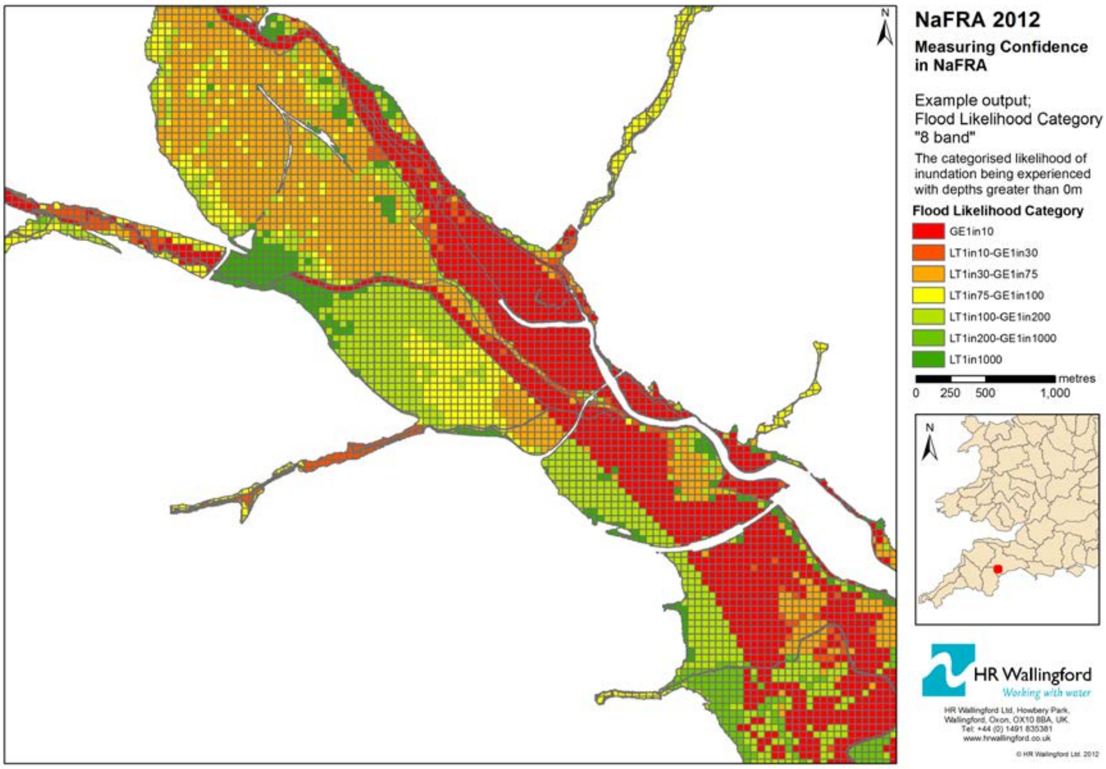

Figure 6.4 Example mapping: Categorisation of the impact cells by 'probability band'

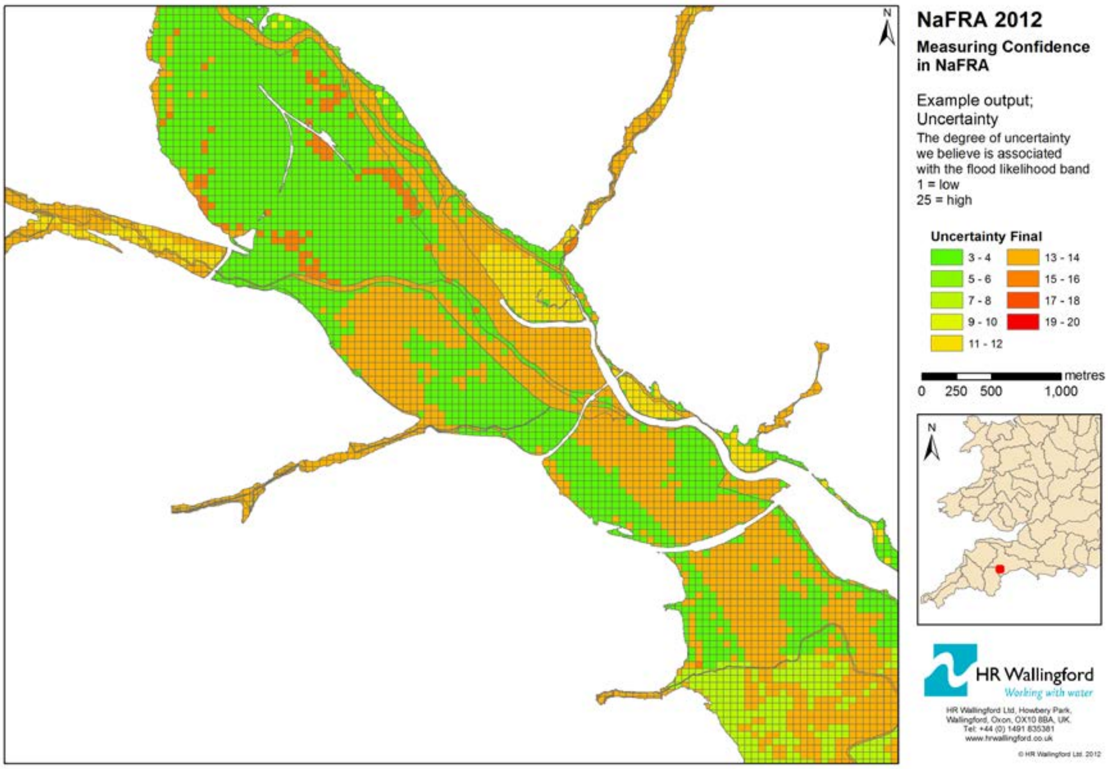

Figure 6.5 Example mapping: Categorisation of the impact cells by our confidence that the assigned probability band is correct, expressed using the Confidence Index (1,low -25,high)

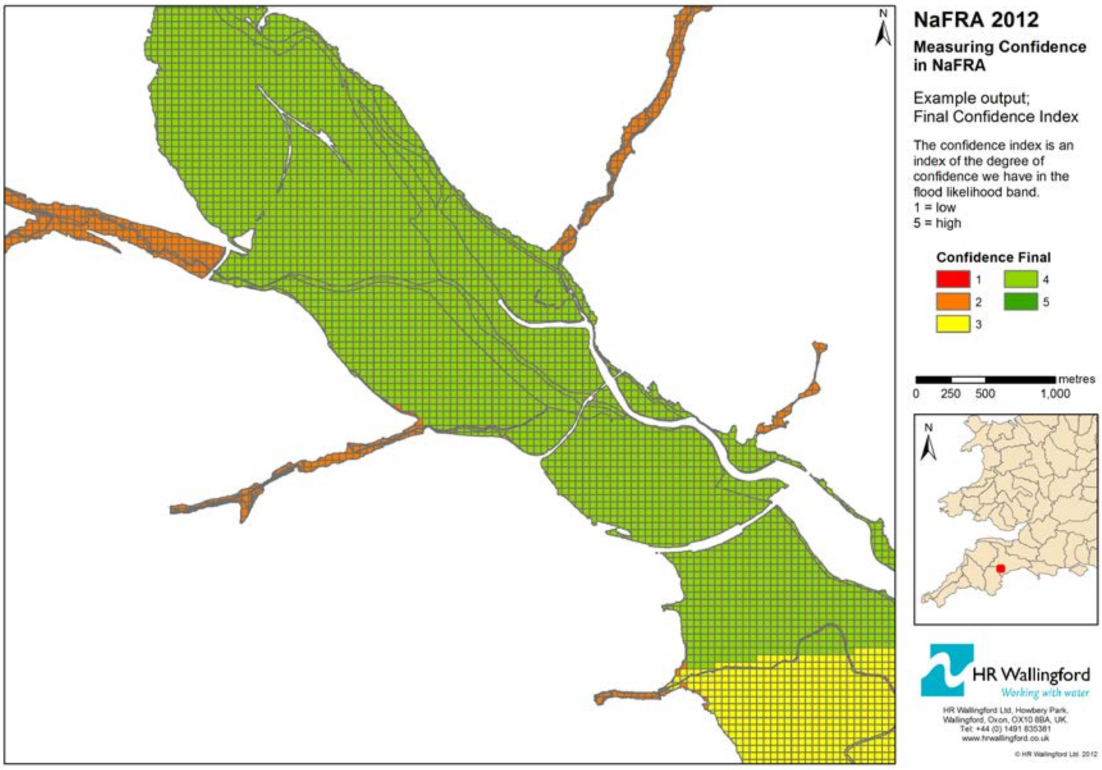

Figure 6.6 Example mapping: Categorisation of the impact cells by our confidence that the assigned probability band is correct, expressed using a Confidence Star Rating (1-5)

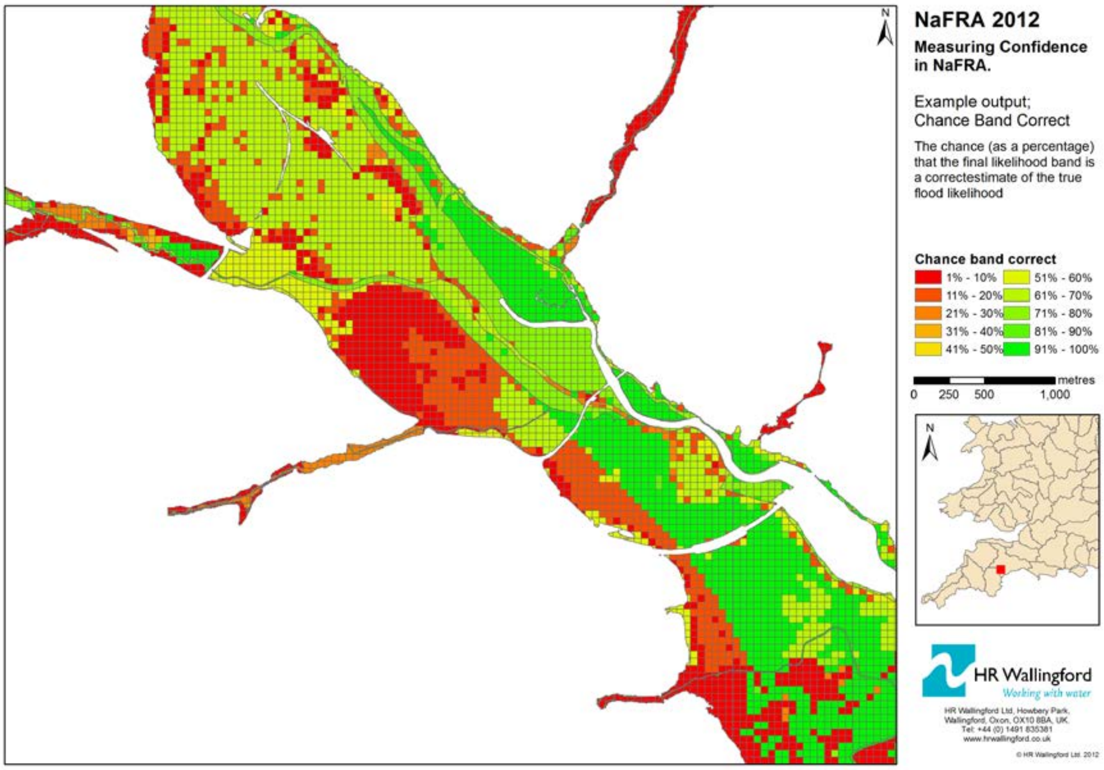

Figure 6.7 Example mapping: Categorisation of the impact cells by our confidence that the assigned probability band is correct, expressed as a percentage chance

6.9.2 Communicating uncertainty

The communication of the quantified estimates of uncertainty in the likelihood data are required to determine:

for each impact cell – (i) the chance that a given impact cell is classified with the correct probability band (ii) the chance that the true probability band is associated with a greater chance of flooding (iii) the chance that the true probability band is associated with a lower chance of flooding.

for regional and national scales – to provide national/regional insights into (i) the number of impact cells correctly classified with different levels of confidence (ii) the average level of confidence in the likelihood banding achieved within flood areas of different typologies and for different probability bands.

Example means of communicating this information are outlined below (for information only, final choices on the mode of communication are still under discussion).

Communication to WIYBY and other users

One means of communication to wider users could be through the 5-Star system introduced earlier or similar qualitative statements. It would however be possible to provide an insight into the quantified uncertainty outputs. For example these could be presented with a simple graphic of the quantified results for a given Impact Cell as shown in Figure 6.8.

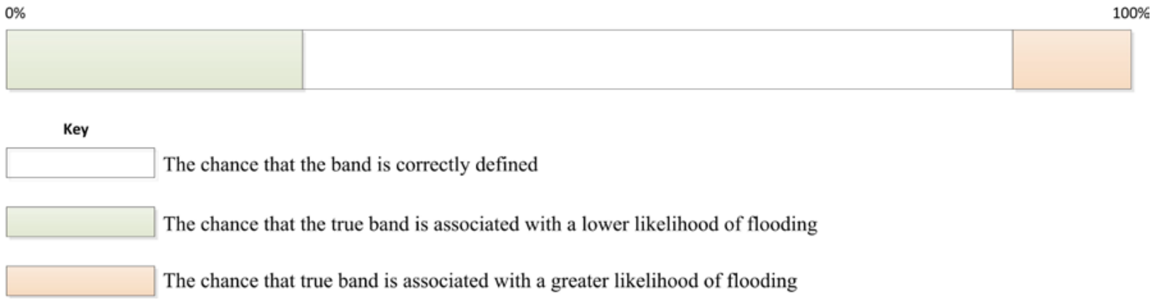

Figure 6.8 Graphical representation of quantified probability band results for an Impact Cell, for WIYBY users

6.10 An overview of supporting software tools

The software tools that implement the analysis presented in this report and facilitate the local team reviews are detailed in the Measuring Confidence in NaFRA Outputs Final Report (FCPIF00151B00/R2).

7 Approach to the local confidence assessment

7.1 Introduction

In addition to the national uncertainty assessment a simplified process of Local Confidence Assessment has been developed to support the 2012/13 review, and in particular determine if the Local Area staff have significantly credible local evidence to override the national probability assessment with their local estimates. The approach is outlined below. A description of the supporting software is provided in the Measuring Confidence in NaFRA Outputs Final Report (FCPIF00151B00/R2) with an associated procedure for the review given in the Operational Instruction "Validating the new NaFRA bands to meet the Flood Risk Regulations".

To ensure the results from the Local Confidence Assessment and the National Uncertainty Assessment (discussed in the previous Chapter) are compatible the LCA uses the same basis framework as established for the NUA.

7.2 Approach

The Local Confidence Assessment is based on scoring the 'quality' of the evidence at hand locally, including:

- Applicability of the evidence to the present day risk
- Appropriateness of the topography used
- Quality: Hydrology evidence used
- Quality: Fluvial evidence used
- Quality: Coastal evidence used
- Calibration
- Recent Flooding

Each of these considerations are scored using 1 to 5 star confidence rating (1- Star poor through to 5 -star good). The selection of the star rating for each consideration is guided by the descriptions given in Table 7.1.

Each star rating is then translated to a numerical score using the relationship given in Table 7.2. Within this mapping of stars rating to scores an implicit weighting is given to 1-Star and 2-Star values.

As with the National Uncertainty Assessment the product of the two worst scores is then used to provide the Confidence Index. When the Local Assessment of the star rating is greater than that determined through the National Uncertainty Assessment it is assumed that the estimate of probability from local sources is more credible that the national analysis.

The Confidence Index from the Local Assessment is in turn translated to quantified assessment of the uncertainty in the estimated probability and an overall Star Rating determined in the same way as National Assessment (Step 8).

	Confidence (Level of representation of current situation)				
	★☆☆☆☆	★★☆☆☆	★★★☆☆	★★★★☆	★★★★★
Applicability	**Significant change not represented**		**Minor change not represented**		**Good representation of current system**
	There have been significant changes since the evidence was created (e.g. new defence)		There have been minimal changes and the evidence gives a reasonable representation of the current situation		There have been no changes and the evidence represents the current situation well
Topography	**Poor representation of floodplain pathways**		**Reasonable representation of floodplain pathways**		**All important floodplain pathways represented**
	The type or resolution does not reflect the variation in floodplain topography (e.g. SAR or low resolution in complex topography)		Type/resolution gives a fair representation of variation in floodplain topography (e.g. LIDAR of appropriate resolution, channel survey at appropriate intervals)		The type /resolution accurately reflects the variation in the floodplain topography (e.g. high resolution LiDAR, channel survey at frequent intervals and site survey with linear features identified)
Quality: Hydrology	**Simple calculations**	**Generalised representation**	**Basic local representation**		**Very good representation**
	e.g. FSR, short records or low flows only	e.g. FEH using catchment characteristics	e.g. FEH using donor catchment and pooling group		e.g. detailed gauging station analysis, long records and/or high flows
Quality: Fluvial	**Simple calculations**	**Generalised representation**	**Basic local representation**	**Good local representation**	**Very good representation**
	e.g. Simple / Calculations	e.g. National generalised modelling	e.g. 1D or 1D-2D model with runs for only 1 annual likelihood	e.g. 1D or 1D-2D model with runs for only 2 annual likelihoods	e.g. 1D or 1D-2D model with runs for at least 3 annual likelihoods
Quality: Coastal	**Generalised**		**Basic local representation**	**Good local representation**	**Very good representation**
	National overtopping dataset with no toe level and for sheltered defence		Local application of overtopping methods (e.g. EurOtop or HR Wallingford 1999) with no or limited toe level information and generalised sea level extremes	As 3 but with local sea level extremes	Local application of methods including toe level, wave transformation information and local sea levels
Calibration	**No calibration**	**Basic calibration**	**Reasonable calibration**	**Calibrated and validated**	**Well calibrated and validated**
	The model was not calibrated	Limited against low or medium flows	Medium against 2-3 high flows events	Good, against 1-2 observed flood events	Good, against 3 observed flood events
Recent Flooding	**One event**		**Two events**		**Three or more events**
	e.g. 1 new event not in Flood Zone 2		e.g. 2 new events not in Flood Zone 2		e.g. 3 or more new events not in Flood Zone 2

Table 7.1 Local Confidence Assessment - Star Ratings

Star Rating	Local review: Individual parameter score	Local Review Tool: Possible 'totals score'
★★★★★	1	1
★★★★	2	2
		3
		4
		5
★★★	3	6
		9
★★	5	10
		15
★	10	20
		25

Table 7.2 Relating the credibility of local evidence to the Confidence Star Rating

8 Outlier and gross error identification

8.1 Introduction

In addition to the process of confidence scoring, a final step is to highlight outliers and potential gross errors to guide local review – independent of the confidence scoring approach. Comparable analysis within the Long Term Investment Strategy (LTIS) project developed a similar approach where by outliers are identified to support the validation process. The outlier analysis checks listed below are reported to each Flood Area within the NaFRA models. Where the outlier check is impact cell-based this is summarised as the proportion of the Flood Area identified as an outlier for that check.

8.2 Approach and outlier checks

A series of checks are used to identify outliers. These are outlined below.

Check 1 Review of probability and depth (based on the unmodified values)

Check 1a – The probability of flooding is implausibly high within an urban area

Is the annual probability of flooding within any Impact Cell that contains one or more properties very high (> 30%)?

This suggests an error because: Any receptor flooded more than 1:3 years on average is likely to be untenable and abandoned. Therefore estimated probabilities that exceed this are likely only to exist in the functional floodplain.

Check 1b – The probability of a property flooding to a large depth is implausibly high (not for implementation in 2012)

Is the annual probability of exceeding a flood depth >1m within a property high (> 10%)?

This suggests an error because: Large 'internal' flood depths are rarely observed.

Check 2 Outliers in confidence scoring

Note: For the first time application in 2012 the base information to support the next three tests (#2a, b and c) at a national scale will not be known. Therefore the baseline figures are updated and not split to consequence rating of the flood risk management system as catchments are analysed for the first time.

Check 2a – Is the overall confidence score low?

Is the overall confidence score (FA QI) for a given Flood Area low in comparison to the average (i.e. within the worse 5% percentile) of the Flood Areas nationally with the same consequence rating (based on the consequence matrix).

This suggests an outlier because: By definition only outliers are identified.

Check 2b – Is the data quality low?

Is the data quality indicator (DQI) for a given Flood Area low in comparison to the average (i.e. within the worse 5% percentile) of the Flood Areas nationally with the same consequence rating (based on the consequence matrix).

This suggests an outlier because: By definition only outliers are identified.

Check 2c – Is the model performance poor?

Is the model performance indicator (MPI) for a given Flood Area poor in comparison to the average (i.e. within the worse 5% percentile) of the Flood Areas nationally with the same consequence rating (based on the consequence matrix used within the Long Term Investment Strategy).

This suggests an outlier because: By definition only outliers are identified.

Check 3 Comparisons with alternative evidence

Check 3a – Comparison with Areas Benefiting from Defences (ABD)

Is the higher bound value of the probability (determined from the Confidence score and the raw probability) worse than that suggested by the ABDs?

This suggests an inconsistency in data sources because: An ABD is typically defined in areas of importance and have been used as part of the 'validation' process for some time. Although often found to be unreliable, a significant difference between the higher bound probability estimate from the confidence scoring (i.e. the lower standard) with the ADB central value suggests a discrepancy that is worth further consideration.

Are the manual changes and uncertainty analysis in agreement?

Check 4 Comparisons with expert intuition

Check 4a – Is the manually changed probability within the confidence range?

Where a manual change has been implemented within the NaFRA published results, is the revised probability outside of the range of uncertainty based on the raw probability and associated confidence score?

This suggests a potential inconsistency because: There is a strong disagreement between the manual change and the calculated probability.

Check 5 National comparison of the confidence in the assigned bands

Note: For the first time application in 2012 the base information to support the next three tests (#5a, b and c) at a national scale will not be known. Therefore the baseline figures are updated as catchments are analysed for the first time.

Check 5a – Is the confidence low in the assigned band (Relative confidence that probability is within the assigned band)?

For a given Impact Cell is the confidence in the assigned band (expressed as a percentage) below 10th percentile of the national average for that band?

This suggests an outlier because: By definition this highlights those Impact Cells with the lowest confidence of being assigned the correct band.

Check 5b – Is it likely that the correct band is worse (Relative confidence that 'true' probability is greater than the assigned band)?

For a given Impact Cell is the band more likely to be worse than stated when compared to the 95th percentile for that band nationally?

This suggests an outlier because: By definition this highlights those Impact Cells with the greatest chance of having been assigned a probability band that is too low.

Check 5c – Is it likely that the correct band is better (Relative confidence that 'true' probability is below the assigned band)?

For a given Impact Cell is the band more likely to be better than stated when compared to the 95th percentile for that band nationally?

This suggests an outlier because: By definition this highlights those Impact Cells with the greatest chance of having been assigned a probability band that is too high.

Check 6 Confidence that all important flood sources captured

Check 6 – Is surface water flooding likely to be a significant? (not for implementation in 2012)?

For a given Impact Cell does the Surface Water Flood Map suggest surface water flooding is likely to modify the chance of flooding significantly (i.e. does the 1/30 rainfall probabilities produce surface water flooding in the same area as fluvial or coastal flooding)?

This suggests an error in the probability because: This suggests that NaFRA is not capturing all important flood sources within a particular Impact Cell and hence any statements on probability based on fluvial and coastal considerations alone are likely to be understated.

8.3 Supporting tools and review

The supporting tools that implement the outlier analysis described here and provide the user interface are discussed in a separate presentation of the software (Measuring Confidence in NaFRA Outputs Final Report (FCPIF00151B00/R2).

The use of the outlier results to guide improvements to the NaFRA results is discussed in the Environment Agency's Operational Instruction 38_13.

9 Conclusions

The approach detailed in this report provides a practical approach to providing a qualitative and quantified assessment of the uncertainty in the probability of flooding provided through NaFRA. Some of the primary conclusions are outlined below:

- **Effective targeting of future improvements** – For the first time, the method outlined in this report enables a consistent assessment of the uncertainty within the probability estimates published through NaFRA. Perhaps more importantly however the approach enables the key sources of the uncertainty in a given Flood Area or Impact Cell to be identified (for example the inability of an Impact Cell grid to reflect the local complexity of the topography or the crest level data etc). Such information will provide powerful new insights to target data and model performance improvements effectively and efficiently.

- **An approach that reflects local conditions** – The importance of different data and model components varies according to the physical setting of the floodplain. This is provided through a structure typology of Flood Areas.

- **An audit trail** – The approach provides a clear audit trail of the assumptions and the calculation, for review and challenge as necessary.

- **An integration of qualitative and quantitative data** – The qualified and quantified information draw upon the same process that reflects both the quality of the underlying data and the performance of the model.

- **A national automation and a local review** – An automated approach is outlined that draws upon the metadata within nationally available datasets and through local updates to NaFRA provided through MDSF2. It is recognised that given the novelty of the approach outlined local review will be required to moderate the automated results (where there is sufficient local evidence). This process is not covered in this report but provided separately through the Environment Agency's Operation Instruction 38_13. With time it is hoped that the Local Review will become an integral part of the National Uncertainty Assessment process rather than a separate process.

- **Route map for uptake** – The approach outlined provides the framework for implementation directly within MDSF2 and is structured to enable specific criteria and relationships to be changed as more experience is gained in the assessment of uncertainty and fully quantified methods start to emerge.

- **Review and update** – It will be important that in the first few years of application the results and methods are scrutinised and updated. Given the ground breaking nature of this study means that much of the approach outlined here is necessarily based on experience and expert judgement, it will be important to refine the approach in the coming years, partly based on the results of application and partly using alternative quantified methods of analysis.

10 Recommendations

A number of assumptions and expert judgements are made in the development and application of the confidence scoring approaches outlined here. Given the ground-breaking nature of the analysis and the difficulties (philosophical impossibility) of objectively assessing uncertainty, many of the criteria used are based on expert judgement and reasoning with limited directly referenced support. Going forward it will be important to develop the evidence base upon which these are based including:

- **A more objective evidence base through comparison with detailed quantified uncertainty modelling** – One way of supporting the analysis outlined here would be through comparison to quantified uncertainty analyses, for example using the results of a RASP-SU/LH-OAT type analysis. This is not without its difficulties because neither RASP-SU or LH-OAT are completely satisfactory but do offer the potential to provide useful corroboration. To use such models quantified evidence on individual uncertainties in the model components and datasets - developed through ground truthing and benchmarking studies would be an important prerequisite. Perhaps most importantly, such a comparison would provide a "truthing" of the mapping of scores to probability and provide supporting evidence as to the choice of "high and moderate" influence.

- **Better understanding of the model component performance scores** – So far only the individual data inputs have been considered across a range of potential sources from the very best through to poor. A similar framework is required for the individual model components, enabling users to make choices about how to improve a particular component and not just which to improve. Additional tools to aid the local teams in determining the likely performance of the model components (such as the RFSM) could also be included here – for example linking with the NaFRA Method Improvements Programme WP2 to enable better "visualisation" of input data and intermediate analysis steps.

- **Harmonise the MDSF2 DQS tools, guidance and training** – Regardless of the option chosen above, going forward to support MDSF2 users developing their own confidence index – from start to finish within local runs – the approach used in Stage 1 will be used to extend the MDSF2 DQS tools to include the process of confidence scoring agreed for use with NaFRA. This will help ensure a consistency between local and national understanding and provide the local users with a capability of assigning and recording confidence locally.

- **Route mapping further development needs** – The approach provided here is capable of improvement (without change to its structure) as experience is gained. In the short term this will primarily be through expert challenge. In the medium to longer term "calibration" of these values would be possible through comparison with fully quantified analyses – extending, for example, the LH-OAT (Halcrow, 2012 SC090008) and RASP-MC (HR Wallingford, 2009; Gouldby et al, 2010) models. Such approaches had been trialled before – with some success but also with some difficulties – and would need to be further developed to include a more comprehensive range of parameters and supporting information on individual uncertainties (including data, model component and model structure considerations). It is also unlikely that such approaches will be practical for national and routine application in the medium term (due to a combination of runtime and perhaps more importantly wider acceptance in terms of the specifics and completeness of the methods and the need for significant training). This process is outside of the current scope but included as a recommended next step to aid development of a more objective evidence base to support the scoring methods proposed here (and will be covered in the anticipated route mapping activity).

References

ENVIRONMENT AGENCY, 2003. Risk Assessment for Flood & Coastal Defence for Strategic Planning R&D Technical Report W5B-030/TR1, Authors Sayers PB, Hall JW, Meadowcroft, IC, Dawson, R, Deakin R, Rosu C.

ENVIRONMENT AGENCY, 2004. RASP - Risk Assessment for Strategic Planning – A summary report. Authors Sayers PB, Hall JW, Meadowcroft, IC, Dawson, R, Deakin R, Rosu C. Environment Agency.

ENVIRONMENT AGENCY, 2006. Exploring the sensitivity of RASP HLM+ to variations in input data and model parameters, Science Report SC050064/SR prepared by HR Wallingford for Environment Agency, September, 57 pages.

ENVIRONMENT AGENCY, 2007. Thames Estuary 2100 - IA System flood risk model: Verification, Phase 3(i) Studies, Topic 2.3, Prepared by HR Wallingford for the Environment Agency.

ENVIRONMENT AGENCY, 2010. Benchmarking of 2D Hydraulic Modelling Packages. SC080035/SR2.

GOULDBY, B., SAYERS, P., MULET-MARTI, J., HASSAN, M. AND BENWELL, D., 2008a. "A methodology for regional-scale flood risk assessment." Water Management 161(3): 169-182.

GOULDBY, B.P., SAYERS, P.B., PANZERI, M.C. AND LANYON, J.E., 2010. "Development and application of efficient methods for the forward propagation of epistemic uncertainty and sensitivity analysis within complex broad-scale flood risk system models." Canadian Journal of Civil Engineering 37(7): 955-967.

HALCROW, 2005. NaFRA 2005 Data Review Report in association with HR Wallingford.

HALCROW, 2007. NaFRA 2006 Project Report, in association with HR Wallingford and JB Chatterton Associates. Appendix A - Ground Truthing (with contributions from Mike Brewer, Environment Agency).

HALCROW, 2008. TE2100 Modelling for appraisal uncertainty piloting report. Technical note WHR877/1.

HALCROW, 2008. NaFRA 2007 Validation Pilot Results Report, in association with HR Wallingford and John Chatterton Associates.

HALCROW, 2009. NaFRA 2008 Project Report, in association with HR Wallingford, including Appendix B Model Forensics Summary Report and Independent Economic Review report by JB Chatterton Associates.

HALCROW, 2010. Data improvements, uncertainty and sensitivity analysis: various reports and technical notes prepared for the Environment Agency. Referenced in this report are: I3 Review of Uncertainty and Sensitivity Analysis Techniques prepared by Zhengfu Rao (2010), I4 Review of Model and Coefficient Uncertainty prepared by Matt Horritt, 2010. I7 Review of input data uncertainty by Zhengfu Rao, 2010 and I9 Ground Truthing prepared by Matthew Scott and Yiming Ji, 2010.

HALCROW, 2011. NaFRA MDSF2 Trials: Output Comparison Report of national and local NaFRA model (local model using MDSF2). Prepared for the Environment Agency.

HALCROW, 2011. NaFRA 2009 Data Improvements, Uncertainty and Sensitivity Analysis - Uncertainty and Sensitivity Analysis - A Case Study Summary.

HALCROW, 2012. NaFRA Method Improvements, Review of existing NaFRA flood depth outputs. Prepared for the Environment Agency.

HALCROW, 2012. LTIS Improvements - FACET Uncertainty Guidance and Validation Method. Prepared for the Environment Agency in association with Horritt Consulting.

HALCROW, 2012. Validation and calibration of probabilistic flood models SC090008/WP1

HALL, J., DAWSON, R., SAYERS, P., ROSU, C., CHATTERTON, J. AND DEAKIN, R., 2003. "A methodology for national-scale flood risk assessment." Proceedings of the Institution of Civil Engineers, Water and Maritime Engineering 156(3): 235 - 247.

HR WALLINGFORD, 2004. National Flood Risk Assessment 2004 Supported by the RASP HLM plus: Methodology, HR Wallingford Report SR659.

HR WALLINGFORD, 2009. Understanding and communicating our confidence in the National Flood Risk Assessment 2008 – A trial study, HR Wallingford Report EX 5953.

JBA AND HALCROW, 2012. Improving probabilistic flood risk modelling capabilities SC090008/WP2.

JBA CONSULTING, 2004. Independent review of the NaFRA model.

NATIONAL AUDIT OFFICE REPORT, 2011. Flood Risk Management in England. Available from: http://www.nao.org.uk/publications/1012/flood_management.aspx [Accessed 1 May 2012].

ROYAL HASKONING, 2005. Review of National Flood Risk Assessment Investment Strategy. Report for the Environment Agency.

SAYERS, P., AND MEADOWCROFT I., 2005. RASP - A hierarchy of risk-based methods and their application. Proceedings of the 40th Defra Conf. of River and Coastal Management.

List of abbreviations

CI	Confidence Index
DEM	Digital Elevation Model
DQI	Data Quality Indicator
DQS	Data Quality Score
fa_DQI	Flood Area Data Quality Indicator
fa_MPS	Flood Area Model Performance Indicator
FCDPAG	Flood and Coastal Defence Project Appraisal Guidance
FCERM	Flood and Coastal Erosion Risk Management
FRMS	Flood Risk Management System
GIS	Geographical Information System
HLM	High Level Method
i_DQI	Individual Data Quality Score
i_MPS	Individual Model Performance Indicator
IC	Impact Cell
LTIS	Long Term Investment Strategy
MDSF2	Modelling and Decision Support Framework 2
MPI	Model Performance Indicator
MPS	Model Performance Score
NaFRA	National Flood Risk Assessment
NFCDD	National Flood and Coastal Defence Database
PoI	Probability of Inundation
RASP	Risk Assessment for Strategic Planning
RFSM	Rapid Flood Spreading Model
SEA	Strategic Environmental Assessment

Annex 1 – Flood Area Typology

The logic used to assign a unique typology to each Flood Area is outlined below with more detail provided in the Measuring Confidence in NaFRA Outputs Final Report (FCPIF00151B00/R2).

Primary source of flooding

Within the NaFRA modelling, the defence assets are categorised as fluvial, tidal or coastal defences. This classification provides the so-called 'protection type' and is used here to identity the primary source of flooding. There are a number of differences between the data and methods used in each of these categories.

The 'Flooding Source' aspect of the Flood Area typology is obtained via assessment of the 'ProtType' attribute assigned to the NaFRA defences within that Flood Area. The categorisation is as follows;

- Fluvial; greater than 95% of defences by length are “F”
- Tidal; greater than 95% of defences by length are “T”
- Coastal; greater than 95% of defences by length are “C”
- Mixed (Fluvial & Tidal); > 5% of defences by length are “F” and > 5% are “T”
- Mixed (Tidal & Coastal); > 5% of defences by length are “T” and > 5% are “C”
- Mixed (Fluvial, Tidal & Coastal); > 5% of defences by length are “F” and > 5% are “T” and > 5% are “C”

Shape of the river valley

River valleys are considered to be one of three Valley Shapes. The Valley Shape is based upon the longitudinal floodplain slope and is used to obtain a representative duration that a particular defence or natural bank will be overflowed during a particular event. It is also a surrogate for the slope of the floodplain and hence provides a useful insight into the likely performance of the Rapid Flood Spreading Model (RFSM) which performs better in flatter floodplain settings than steep ones.

The Valley Shape element for a Flood Area is obtained via an assessment of the 'ValleyType' attribute assigned to the NaFRA defences within that Flood Area. The categorisation is as follows;

- U – predominant valley shape (by length) is U
- V – predominant valley shape (by length) is V
- W – predominant valley shape (by length) is W

Complexity of the channel network

Complex channels tend to exist only in flatter floodplains. Valley Shapes U and W are the most likely to have complex river channels, comprising braiding or reverse flow situations. The methods used in NaFRA are better able to represent simple channel systems than complex ones, hence the presence of such complexity influences the confidence in the analysis.

The channel complexity is determined by categorising the complexity of the river system for the Flood Area as either:

- Simple – No parallel river segments for the Flood Area
- Complex – One or more parallel river segments for the Flood Area

This categorisation is determined through an automated GIS pre-process.

Presence of floodplain defences

In undefended reaches of river, the inundation mechanism is via overflow of natural banks and for coasts it is via overtopping of natural backshore features such as shingle berms or dunes. In defended locations, there is the additional chance that one or more defences may fail, leading to inflow to the floodplain through a breach. The evaluation of breach probability, width, depth and inflow volume introduces additional areas of uncertainty to the risk estimation and hence the presence of defences is captured in the typology.

The Presence of Defences element for a Flood Area is obtained via an assessment of the DefClass attribute assigned to the NaFRA defences within that Flood Area. The categorisation is as follows;

- Undefended – All of the defences in the Flood Area are either DefClass 20, 37 or 38
- Defended – One or more defences in the Flood Area are not DefClass 20, 37 nor 38

Complex of the defences system

The RASP analysis that supports NaFRA and MDSF2 represents the primary line of defences and high ground. The influence of major in-line structures - such as gates and barriers - is assumed to be reflected in the standard of protection afforded by these linear defences. In locations where secondary defences, gates, pumps and other more complex flood management structures exist the reliability of the analysis is reduced.

An assessment of the complexity of the defence system within a Flood Area is obtained using the categorised NFCDD data prior to their allocation to the 'tramlines' and via proximity analysis of the NFCDD point assets data. The categorisation is as follows;

- High – Multiple secondary and point assets
- Moderate – Some secondary and point assets
- Low – No secondary or point assets

Height of the linear defences

If one or more defences fail (breach) inflow to the floodplain will change. The evaluation of breach probability and the associated breach width, depth and inflow volume introduces additional uncertainty to the risk estimation. At a basic level the estimation of breach inflow volume is a function of the size of the defence and hence the height of defences is captured in the typology.

The definition of Large Defences for a Flood Area is obtained via an assessment of the crest level minus ground level (assumed to be the height) for each defence within a Flood Area. The categorisation is as follows;

- Large – 50% or more of raised defences by length >=2m
- Moderate – 50% or more of raised defences by length >= 0.5m
- Small – 50% or more of the raised defences are <0.5m

Complex of the floodplain flow pathways

The flood spreading model, the direct RFSM, has a typographic resolution equivalent to the Impact Cell size - currently 50m. Water is spread through a fill and spill mechanism, with some allowance for frictional head losses, to neighbouring storage reservoirs within the confines of the Flood Area until the total inflow volume has been 'stored'. The model works well in flat natural floodplain situations, however it does not perform so well in steeply sloping or permeable catchments nor in floodplains which have complex surface flood pathways (such as those often found in urban areas) or in areas with detailed floodplain drainage networks. The steepness aspect is already captured in the Valley Type element therefore this element is purely a measure of the floodplain complexity.

The Complex Pathways element for a Flood Area is obtained via assessment against a number of other spatial datasets. These comprise Baseflow Index represented on a 1km grid (providing an indicator for chalk soils), property density (an indicator for urban settings) and some measure of the underpinning DTM data for minor drainage features. The categorisation is as follows;

- Permeable Catchment – some of the Flood Area is located in an area with high base-flow index (>0.95)
- Urban – there are locations within the Flood Area where property density exceeds 500 properties per km
- Complex Drainage – there are locations within the Flood Area where complex internal drainage exists, defined as when the length of the river network within the Flood Area exceeds 10km or a density of 2.5km per km2 of Flood Area

Annex 2 – Combining individual Data Quality Scores into an overall Data Quality Index

An example determination of a Flood Area DQI

If the primary source of flooding is fluvial, the valley type is U, the defences are small (<0.5m in height), the river network is not complex and the flood pathways simple, then:

High influence datasets are:

- Water level – in-river (say fa_DQS = 2)
- Crest level (fa_DQS = 4)
- Flood Area protection type (fa_DQS = 1)

Summary fa_DQI (Significant influence) would be based on Crest level = 4

Moderate influence datasets are:

- Condition Grade (fa_DQS = 3)
- Ground level (fa_DQS = 2)
- RASP Type (fa_DQS = 3)
- Fragility curves (fa_DQS = 3)
- Standard of Protection (SoP) (fa_DQS = 3)
- Length (fa_DQS = 3)
- DEM (fa_DQS = 4)
- River network (fa_ DQS = 3)

Summary fa_DQI (Moderate influence): based on the average of the DEM (DQS = 4) and River network (DQS = 4) = 4

The **Flood Area DQI** is therefore the poorer of fa_*DQS (significance)* or fa_*DQI (Moderate influence)* = 3.5. The fa_DQI = 4.

Ranking the individual DQS provides a useful aid in the local review and how best to reduce the uncertainty in the probability. Consider, for example, a Flood Area with two of the datasets that are likely to have a high influence – say crest level and Condition Grade –scoring a DQI of 4. An improved Flood Area DQI could only be achieved if the quality of both datasets were to be improved. If only one was improved the concept of the weakest link would prevail and the Flood Area DQI would remain unchanged.

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