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EX 5953

Understanding and communicating our confidence in the National Flood Risk Assessment 2008 – A trial study

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Project Manager	Mike Panzeri
Project Director	Paul Sayers

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Summary

Understanding and communicating our confidence in the National Flood Risk Assessment 2008 – A trail study

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Over the past twenty years risk based analysis has become commonplace in support of flood management decisions. In more recent times the National Flood Risk Assessment (NaFRA), initially undertaken in 2002 and most recently in 2008, has been increasingly recognised as a key source of information on flood risk, informing policy and investment decisions as well as communicating risk to the public.

Ever improving national data sets (such as the information within the National Flood and Coastal Defence Database) and an evolving version of the so-called RASP High Level Methods (Risk assessment for strategic planning) have been used to underpin NaFRA since 2002. Since 2002 various expert reviews and pilot validations have been undertaken to ensure the results are appropriately fit for purpose. The "purpose" and the reliance the Agency and others place upon the data has, however, significantly increased and so too has the need for a more structured and consistent assessment of the confidence users may have in the output.

This report explores the quantification of uncertainty in the outputs from NaFRA 08 taking account of the uncertainties in the model variables and parameters (reflecting the quality of the input data). The analysis has been applied to three trial catchments and concludes that:

- The uncertainty in the overtopping volume is significant and varies significantly between defences.
- The uncertainty in flood depth within an Impact Zone increases with return period.
- The uncertainty in Expected Annual Damages (EAD) across the three catchments was observed to be relatively consistent (with the 10th percentile estimate of the EAD being in the order of 25-40% less than the median value and the 90th percentile being in the order of 30-50% greater than the median value.)
- The uncertainty in the number of properties within a given flood probability banding shows more variation across the catchments and between bands. In terms of property numbers (rather than percentage change) limited uncertainty is seen in the number of properties exposed to *very low* and *low* annual flood probabilities (reflecting the small number of properties in these bands) with greater uncertainty in the number of properties exposed to a *significant* and *very significant* annual flood probability.

The analysis provided in this report gives an initial investigation of the uncertainties in the NaFRA 08 data and models and further more detailed work is recommended to identify more specific insights into the key drivers of uncertainties. Once implemented, the approaches demonstrated here could be used to support a targeted and justified programme of data collection and model improvement.

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1. Introduction

Over recent years risk based analysis has become commonplace in support of flood management decisions (DETR *et al.*, 2000; Sayers *et al.*, 2002b, Environment-Agency, 2002). In more recent times the National Flood Risk Assessment (NaFRA), initially undertaken in 2002 and most recently in 2008 (HRWallingford, 2002, Halcrow 2005, 2006, 2007), has been increasingly recognised as a key source of information on flood risk, informing policy and investment decisions as well as communicating risk to the public.

Ever-improving national data sets (such as the information within the National Flood and Coastal Defence Database) and an evolving version of the so-called RASP High Level Methods (Hall *et al.*, 2003a, EnvironmentAgency, 2004; Sayers *et al.*, 2005; Gouldby *et al.*, 2008b) have been used to underpin NaFRA since 2002. Since 2002, various expert reviews and pilot validations have been undertaken to ensure the results are appropriately fit for purpose (including reviews by, JBA in 2004, Haskoning in 2006 and the ABI in 2007). The "purpose" and the reliance the Agency and others place upon the data has, however, significantly increased and so too has the need for a more structured and consistent assessment of the confidence users may have in the output.

This paper explores the quantification of uncertainty in the outputs from NaFRA 08 model (HR Wallingford, 2009) taking account of the uncertainty within the model variables and parameters (reflecting the input data) and reports upon the impact of these uncertainties on the model outputs within three pilot catchments.

1.1 PROJECT AIMS AND OBJECTIVES

The results from NaFRA are widely used both inside and outside of the Agency. This project aims to acknowledge the uncertainty in NaFRA 08 and provide quantified guidance on:

"how confident/certain we are in the NaFRA 08 estimates of Expected Annual Damages at a national scale"

"how confident/certain we are in the number of properties estimated to be exposed to a:

- *very low* annual probability of flooding to a depth <0m - 0
- *low* annual probability of flooding to any depth between 0 - 0.5% (0 - 1:200)
- *moderate* annual probability of flooding to a depth <0m between 0.5% - 1.33% (1:200 - 1:75)
- *significant* annual probability of flooding to a depth <0m between 1.33% - 5% (1:75 - 1:20)
- *very significant* annual probability of flooding to a depth <0m between >5% (>1:20)

annual probability of flooding (to a depth <0m)at a national scale"

"how confident/certain we are in the accuracy of estimate of flood probability provided by NaFRA at a local, Impact Cell, level"

It is therefore important to articulate the confidence we have within:

National Scale Outputs, including:

- National EAD – This supports the important message that the analysis is not perfect and, for example, actual year-to-year changes in EAD may be masked in the noise of data and model uncertainty. Changes over the longer term (either observed in the data over time or postulated in analysis, such as Foresight (Evans *et al.*, 2004a; Evans *et al.*, 2004b) or the ongoing long term investment strategy can give a signal that rises above the noise.

- National properties at risk - Number of properties in each probability band (nationally).

Local scale outputs

- Output quality at local level – This is not covered here but it is clear that this will be required as routine output from NaFRA in the future. Once implemented this would enable the uncertainty in the reported probability band at local level to be accessed (for example, it could be reported via the web at an Impact Cell, Impact Zone or even Flood Area – as defined in Figure 1.1). This would convey to the user: *how confident we are that the actual probability is: a) as reported b) within one category or b) within 2 categories of the stated result.*

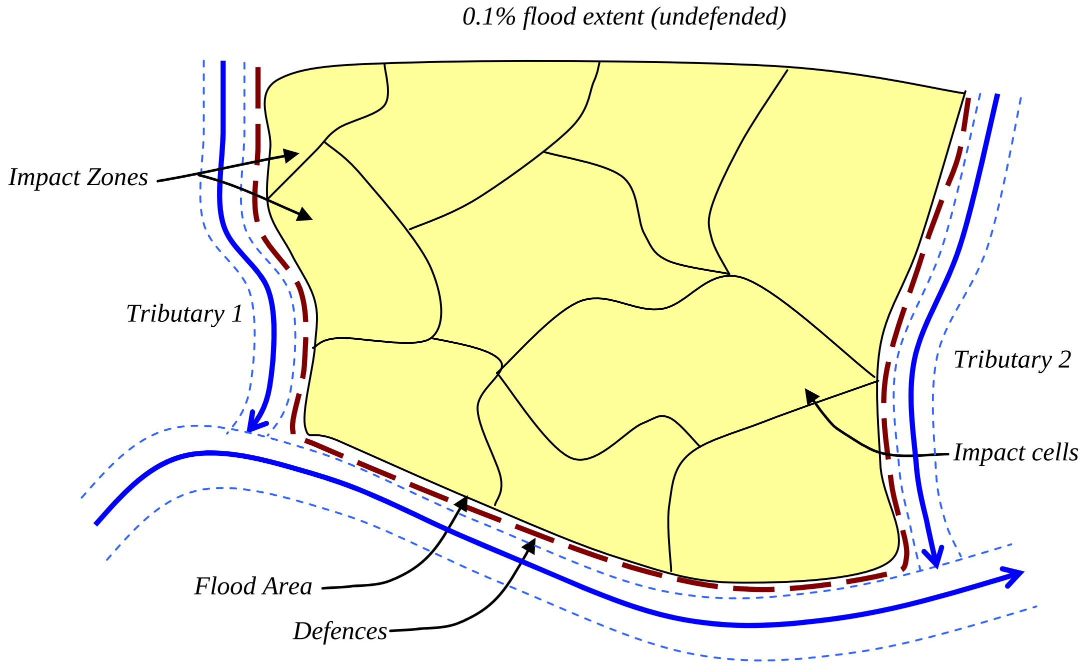

Figure 1.1 Spatial definition of the floodplain used within the RASP methods underpinning NaFRA 08 (Gouldby *et al*, 2008b)

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 an prerequisite for good decision making (Sayers *et al.*, 2002a; Hall *et al.*, 2003b, Hall *et al.*, 2008). Various projects such as (Environment-Agency, 2006, Sayers *et al.*, 2006, Hall *et al.*,

2009) usefully highlight the areas of government policy where uncertainty is reflected, including for example:

- ***Government Departmental Guidance*** – The Defra Flood and Coastal Defence Project Appraisal Guidance 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.*

- ***Making Space for Water*** **-** Following the severe UK floods in 2002 and 2004 *Making Space for Water* (Defra, 2005) reiterated that *"Decisions will reflect the uncertainty surrounding a number of key drivers…*" [p14]. The glossary (p41) defines appraisal as *"The process of defining objectives, examining options and weighing up the costs, benefits, risks, and uncertainties before a decision is made".*

- ***UK Treasury Guidance*** **-** The HM Treasury Green Book (HM Treasury, 2003) has uncertainty at the heart decision making. Chapter 5 on appraising options has numerous references to uncertainty and a specific annex, Annex 4 is 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 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 (pp32-33) 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.*

- ***Strategic Environmental Assessment*** **-** The Environment Agency report published in 2004 on Good Practice Guidelines on Strategic Environmental Assessment (SEA) give: "*Report uncertainties, limitations and assumptions"* as one of the good practice principles for assessment and states that *"A particular strength of risk assessment is its ability to explicitly recognise uncertainty surrounding future predictions."* Uncertainties are identified in the use of expert judgement and in scenarios analysis and are mentioned in several of the case studies.

Achieving the aspirations set out within these guidance documents, in any more than an informal manner, has to date, however, been difficult if not impossible. Increasingly, various stakeholders in NaFRA have demanded a greater understanding of the confidence in the results. In particular these include internal customers within the Environment Agency such as asset manager policy and process managers, needing to understand how much confidence they can place in NaFRA outputs at a range of scales for asset management and prioritisation decisions. Other stakeholders such as insurance companies and the Association of British Insurers have an interest in understanding the level of confidence in flood risk assessments. At a national scale the Environment Agency and Defra need to understand the robustness and 'stability' of national risk figures.

The approach summarised here provides a step towards these goals, and attempts to provide a structured approach to the assessment of uncertainty – a pre-requisite to a structured approach to managing it.

3. Overview of the NaFRA (RASP) system Risk Model

Flood Risk Management aims to reduce the threat to people and their property; and deliver the greatest environmental, social and economic benefit, consistent with the Government's sustainable development principles. RASP is a concept and an evolving method for tiered risk assessment for system planning and is, fundamentally, concerned with the provision of reliable and useful evidence for flood risk management decisions.

By enacting suitable models within a generalised method, RASP enables *sources* (including a wide range of extreme wave and water level combinations), *pathways* (including the performance of multiple defences expressed in terms of a fragility curve) and *receptors* (including people and property) of risk to be combined. The RASP tools therefore provide an important methodological step towards an improved ability to manage flood risk in an integrated way.

The national assessment of flood risk and uncertainty is complex and is not a precise science. RASP therefore adopts a logical, structured and transparent approach based on three core principles, namely:

- ***Systems-based thinking*** – that considers *all* aspects of the flood risk system in a structured manner (in NaFRA 08 this means coastal, tidal and fluvial sources, defence and topographic pathways and property based economic damages);

- ***A risk-based approach*** – that helps problem formation, risk assessment, option appraisal and risk management planning by seeking to target limited resources (time and money) to achieve maximum benefit (tangible and intangible);

- ***A hierarchical process of analysis*** – that seeks to provide assessments proportional to the risk, proposed decisions and spatial and temporal scale, whilst making best use of the available data and information (in the case of NaFRA 08 this means using national datasets as available at the time of running; hence different data qualities are used throughout the analysis).

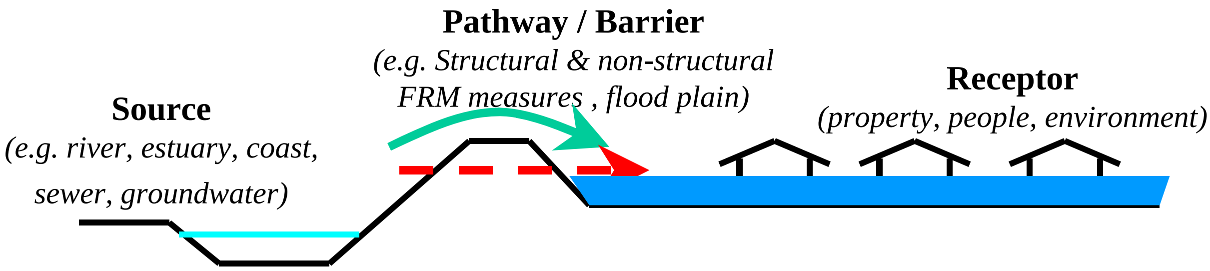

Figure 3.1 Simplified illustration of Source-Pathways-Receptors Concept embedded with RASP tools

4. Overview of Approach

The original scope of the project was to combine a structured analysis process with expert judgement. This would have provided a robust assessment of the uncertainty within the NaFRA results, the key contributions to this uncertainty and how best to communicate a simple confidence score that reflects the specific characteristics and data quality within a given Flood Risk Management System (FRMS) area. During the project the focus shifted towards the assessment of uncertainty in the NaFRA 08 outputs within a number of trial catchments, with more detailed analysis proposed in the future. This chance of focus was in part to provide immediate input to the Long Term Investment Strategy (LTIS) Project.

The main elements of analysis are shown in Figure 4.1, summarised below and given in detail in the following sections.

Step 1 – Uncertainty Analysis (see chapter 5)

This first step enables the forward propagation of uncertainty through the NaFRA model using a staged Monte Carlo scheme. It includes three primary sub-steps:

1a. Identify and record main input variables and parameters – including variables (i.e data used in NaFRA – e.g. crest level) and model parameters (i.e. internal coefficients used within the NaFRA model – e.g. weir coefficient). These are tabulated and considered in more detail in Step 1b.

1b. Define and record uncertainty in input variables, parameters and model structure – the input data and model parameters have a range of uncertainties depending on the source of the data, the depth of knowledge, natural variability etc. The nature of the model (its completeness or otherwise) also represents a source of uncertainty. All of these uncertainties can be represented to a greater or lesser extent through probability distributions. The characteristics of the distribution have been defined by analysis of data, structured expert judgement or a combination of the two[1].

[1] It was initially hoped that ground truthed datasets would support this analysis. However, the ground truth data was not available in time and has not been used. Hence expert judgement has been used to a greater than anticipated extent. Further refinement of the uncertainty in the input variables is therefore an area for future improvement.

1c Assess uncertainty in selected outputs (pilot areas) – The uncertainty in a result depends on the uncertainties in individual input data and parameter items, along with the sensitivity of the model result to those items and the inherent short-comings of the model itself. This step propagates the information on the input uncertainties through to the output using a Monte Carlo version of the RASP type model – the so-called RASP-MC developed by HR Wallingford. The outputs of interest here are those of expected annual damage (EAD) and property numbers by probability banding.

Step 2 – Importance weighting / sensitivity analysis (see chapter 6)

2a. Identify key drivers of the uncertainty in the output – The uncertainty in the output will be influenced differently by each of the input parameters. An initial structured analysis has been undertaken to identify those input uncertainties that contribute most to the output uncertainty. Given the focus of this study on the uncertainty aspects, rather than the sensitivity analysis, a limited investigation into the model sensitivity has been undertaken and reported in Chapter 6. A recommendation is made to further develop this interesting and useful analysis thorough a combination of structured sensitivity analysis and expert judgement.

Step 3 - Confidence scoring (see chapter 7)

As part of the study an initial investigation into an approach to communicate and assess the confidence in the NaFRA outputs has been explored. This report provides an initial scoping of possible confidence scoring method based on two key sub-steps:

3a Establish the syntax of a "confidence score" – Using the evidence from the above steps a simple-to-understand confidence scale is used to describe the "confidence score" for each Flood Risk Management System (FRMS).

3b Assess confidence score for all FRMS areas - The final level of confidence will depend on the combined effects of all the relevant data and model uncertainties as encountered within a given FRMS. The sensitivity and uncertainty analysis will help inform this simplified weighted scoring system to establish the likely confidence in the results for any FRMS.

Given the constraints and focus of the project, however, it has not been possible to trial these. A recommendation for taking this aspect of the work forward is provided.

Step 4 – Ground truthing

The analysis described here is based on the unmodified NaFRA analysis (i.e prior to manual modifications from Area staff).

Note: Within the initial scoping of this project it was hoped that a related study would provide specific ground truthing of the NaFRA model inputs and uncertainty/sensitivity results. Due to changes outside of the control of this project this linkage has not been possible; hence only limited ground truthing has been applied; relying solely on expert opinion from those with a detailed knowledge of NaFRA and its application.

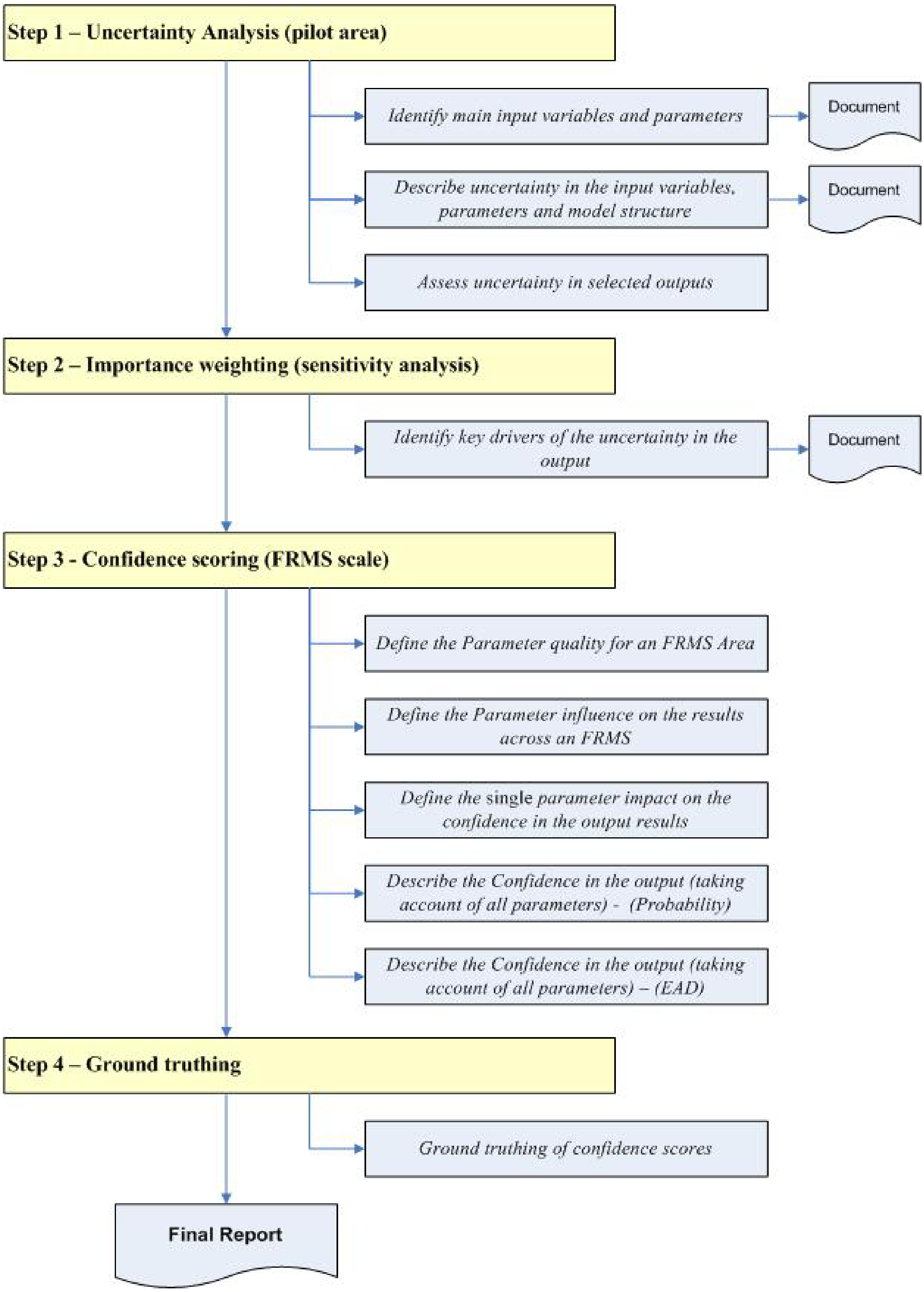

Figure 4.1 Overview of a framework for assessing, communicating and validating the NaFRA outputs. ***(Note The current study focuses on Step 1 above)***

5. Step 1 - Uncertainty analysis

5.1 INTRODUCTION

The first stage in the project has been to understand the uncertainty within the input data and modelling approach and then propagate these uncertainties forward through the RASP-MC model.

An overview of the approach is given in Figure 5.1 with more detail and the associated results provided in the following sections.

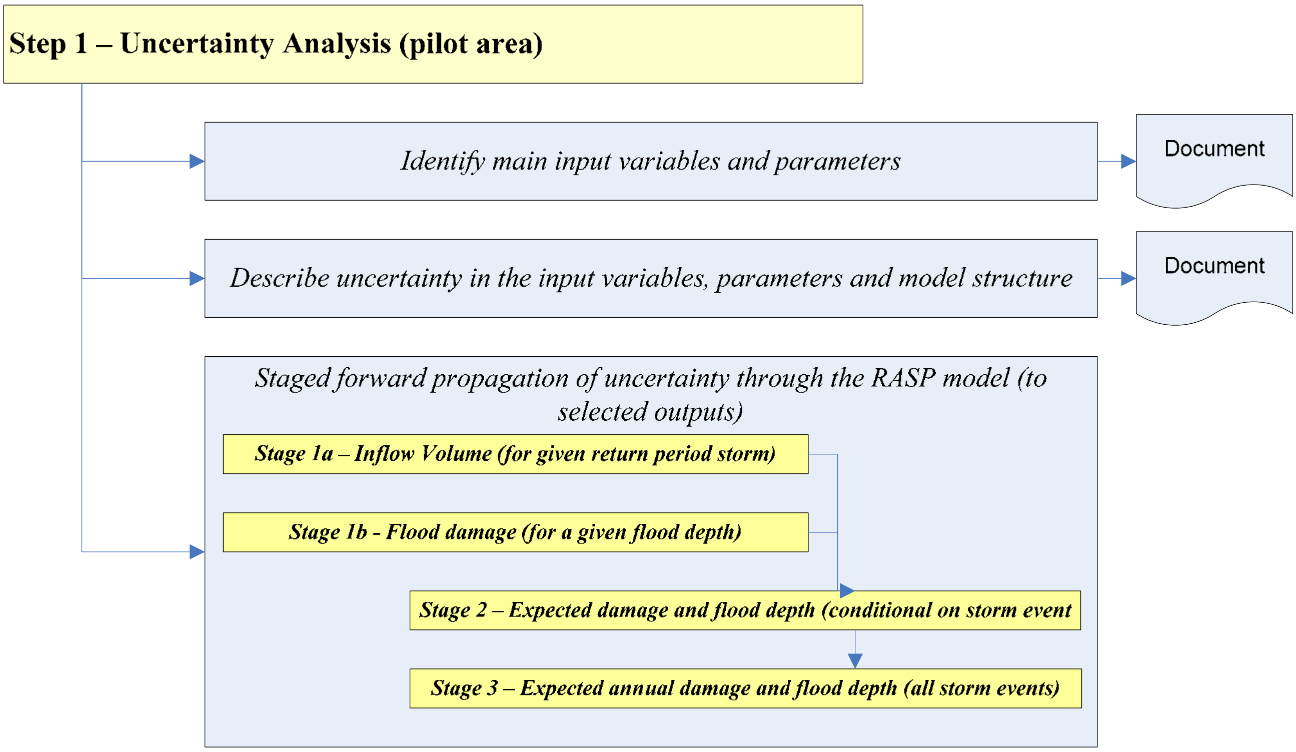

Figure 5.1 Overview of the approach to the uncertainty analysis

5.2 FORWARD PROPAGATION OF UNCERTAINTY WITHIN THE NAFRA (RASP) MODEL

5.2.1 Overview

Where no observation or very limited data are available with which to 'condition' a model (such as is the case in estimating flood risk – rather than flows for example), forward propagating uncertainty techniques are the only viable approach for uncertainty analysis.

Of the options available, Monte Carlo procedures are the most flexible, robust and therefore prevalent (Pappenberger *et al.*, 2006). These methods involve assigning probability distributions to input variables and propagating these through any given function or combination of functions (i.e. in this case the RASP HLMplus model). These approaches can be computationally time consuming to implement, particularly where model structures are complex.

To help overcome these computational limitations, a staged analysis has been developed (Gouldby *et al.*, 2007) that offers benefits in terms of reduced computational time (through reduction of the variables propagated through the whole analysis process) and the provision of information at intermediate stages within the overall model structure.

The key stages for the uncertainty analysis within the NaFRA 08 models are summarised in Table 5.1 and Figure 5.2 and include:

Stage 1a – Inflow Volume (for given return period storm) – In the first stage a single variable, the flood volume discharged into the floodplain from a given defence, is calculated. This is based on a range of uncertain variations (crest level, water levels etc) and then this single output variable (inflow volume) is used in the subsequent stages.

Stage 1b - Flood damage (for a given flood depth) – A single uncertain variable of flood damage for a given flood depth is calculated that includes all upstream variables and uncertainties that influence the relationship between damage and flood depth within any given Impact Cell. For example, this includes uncertainty in the input property data as well threshold levels and damage versus depth criteria.

Stage 2 –Damage and flood depth (conditional on storm event) – This propagates the outputs from stage 1a and 1b forward through the RASP-MC model adding additional uncertainties from the RFSM model. Uncertainty in the DTM (assumed to be random errors) and other interim model assumptions are currently ignored.

Stage 3 – Expected annual damage and flood depth (all storm events) **-** The final stage involves repeating the Stage 2 analysis for all storm events and propagating the results forward through the remaining steps of the RASP model, which requires the integration of the consequence distributions obtained in Stage 2 over all loading levels. Additional model structure uncertainties could be incorporated at this stage but again are currently ignored.

An overview of this process is provided in Figure 5.2.

5.2.2 Analysis assumptions

Two underlying assumptions are noted:

- ***Independence between input variables*** - The approach currently makes the assumption of independence between the input variables and parameters. This could be changed where there is information on the correlation between them. However, in the absence of such information an assumption of independence provides a reasonable basis.
- ***Dependence in results*** **-** In aggregating the results from an individual Impact Zones, to Flood Areas a simple assumed is adopted where the 5%tile Expected Annual Damage for the catchment is establishing by summing the 5%tile values from each contributing Impact Zone. However, in the absence of more detailed information and the time constraints of the project this is a reasonable (if some what conservative) assumption. In the future this should be changed to reflect a more formal integration of results, including: the separate treatment of systematic errors (biasing the resulting to be an over or under estimate, for example consistent over or under estimates of damage given depth), a more formal integration of truly dependent, but unbiased, random errors; and, where information exists, the true correlation between areas (if any) should be accounted for.

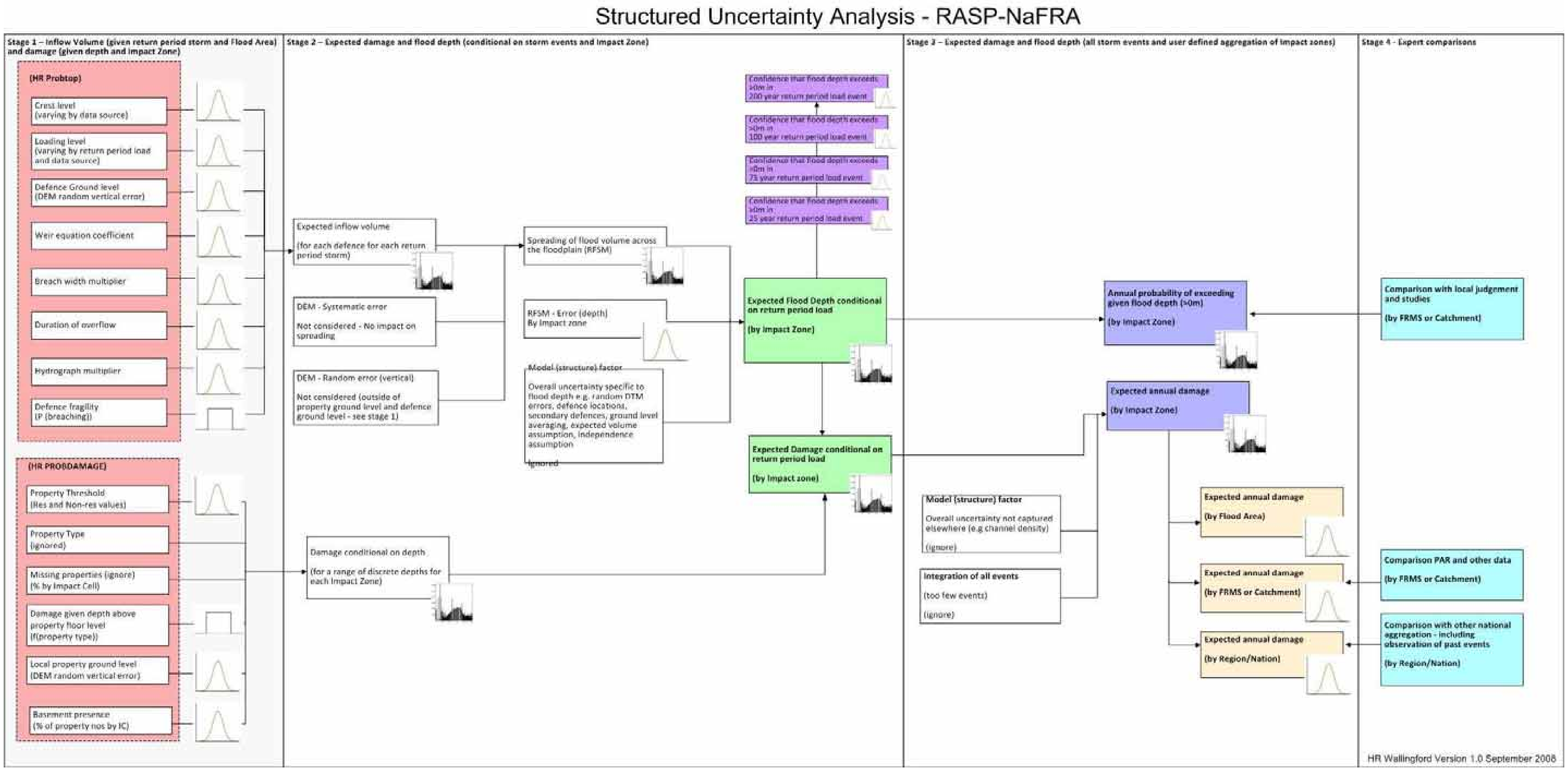

Figure 5.2 Overview of forward propagation of uncertainty analysis within the national flood risk model

5.3 CHALLENGE WORKSHOP - ASSIGNING UNCERTAINTIES TO VARIABLES AND PARAMETERS

Perhaps the most important step within any structured uncertainty analysis is to assess the uncertainty within the model inputs.

Initially it had been envisaged that this process would include a combination of expert judgement, ground truthing and literature review. In the end, ground truthing of the inputs (for example comparing NaFRA 08 estimates of crest levels for specific defences with specific field measurements) has not been possible. Therefore a greater reliance has been placed on literature review (Sayers et al, 2006, Environment Agency, 2006) and judgement. In support of this process a "challenge workshop" was held on the 4th December 2008 with the following in attendees:

- Paul Sayers (HR Wallingford)
- Mike Panzeri (HR Wallingford)
- Ian Meadowcroft (Environment Agency - chair)
- David Murphy (Environment Agency – part only)
- Rob Deakin (Halcrow)
- David Towns (Environment Agency)
- Jim Barlow (Environment Agency) (apologies)
- Karl Hardy (Defra)
- Matt Horrit (Halcrow)
- Nick Terrett (Environment Agency)
- David Hornby (Environment Agency)
- Mike Steel (Environment Agency)
- Oli Clegg (Halcrow)
- Prue Donnelly (Environment Agency)

The objectives of the Challenge Workshop (Environment Agency, 2008) were to review the proposed approach and, importantly, to review the suggested values of the input uncertainties.

Following a lively discussion the input uncertainties provided in Table 5.1 were agreed.

Figures 5.3 and 5.4 highlight some of the spatial variation in data quality, both across catchments but also within Flood Areas. This spatial variation in quality is an important consideration and must be recognised in the methods used to assess the uncertainty in the output results. The RASP-MC automatically handles this complexity, but as shown later in chapter 7, it provides significant challenge to the development of more expert lead confidence scoring methods.

Table 5.1a *Stage 1a – Inflow Volume (for given return period storm)* - Input variables and parameters and associated uncertainty

Stage 1a – Inflow Volume (for given return period storm) (PROBTOP)						
Uncertainty category	**Name of uncertain measure**	**Distribution Type**	**Distribution parameters and values**			**Evidence base**
			10th pctl (μ - 1.645σ)	90th pctl (μ + 1.645σ)	SD	
Variable	**Crest level (mAD)**	**Normal**				
	Measured		-0.33	0.33	0.20	Challenge workshop - expert judgement
	Estimated		-0.49	0.49	0.30	Challenge workshop - expert judgement (note water levels uceratinty is covered elsewhere)
	Estimated based on default SoP		-0.82	0.82	0.50	Challenge workshop - expert judgement (note water levels uceratinty is covered elsewhere)
Variable	**Water level (fluvial and tidal areas) - mAD**	**Normal**				
	from NFCDD					Nafra approved - Data Standards
	1	Normal	-0.41	0.41	0.25	
	10	Normal	-0.41	0.41	0.25	
	100	Normal	-0.41	0.41	0.25	
	1000	Normal	-0.82	0.82	0.5	
	Local JFLOW					
	1	Normal	-0.62	0.62	0.38	From expert judgement - Challenge Workshop
	10	Normal	-0.62	0.62	0.38	
	100	Normal	-0.62	0.62	0.38	
	1000	Normal	-1.23	1.23	0.75	
	RRC					
	1	Normal	-0.82	0.82	0.50	From expert judgement - Challenge Workshop
	10	Normal	-0.82	0.82	0.50	
	100	Normal	-0.82	0.82	0.50	
	1000	Normal	-1.65	1.65	1.00	
	National JFLOW					
	1	Normal	-0.82	0.82	0.50	From expert judgement - Challenge Workshop
	10	Normal	-0.82	0.82	0.50	
	100	Normal	-0.82	0.82	0.50	
	1000	Normal	-1.65	1.65	1.00	
Variable	**Defence Ground Level (mAD)**					
	LiDAR	Normal	-0.33	0.33	0.2	Determined from input data coverage to composite DTM - Twerton
	SAR	Normal	-0.82	0.82	0.5	Determined from input data coverage to composite DTM - Twerton
Variable	Weir equation coefficient	Normal	-0.26	0.26	0.16	from literature - HR Wallingford
Variable	breach width mulitplier	Triangular	0.5 * BE value	2 * BE value	Hard defences - 0.1 and Soft defenecs 0.2 of defence length	from literature - HR (IMPACT project www.impact.net)
Variable	Duration of overflow	Ignored			0	
Variable	Hyrograph mulitplier	Normal	-0.06	0.06	0.039	from original RASP R+D (Environment Agency 2004) and expert judgement - HR Wallingford
Variable	Defence fragility (P(breaching))	Uniform	LB curve direct from database	UB curve curve direct from database	-	Upper and lower bounds taken from the Performance and Reliability R+D Project
Variable	Overtopping volume	Ignored				

Table 5.1b *Stage 1b - Flood damage (for a given flood depth)* - Input variables and parameters and associated uncertainty

Uncertainty category	Name of uncertain measure	Distribution Type	Distribution parameters and values					Evidence base
			10th pctl (μ - 1.645σ)	90th pctl (μ + 1.645σ)	SD	Mean	Type	
Variable	Property Threshold - Res	Normal	-0.21	0.21	0.13	0	additive	HR expert judgement
	Property Threshold - Non-res		-0.21	0.21	0.13	0	additive	
Variable	Property Type	Ignored	-	-			-	-
Variable	Missing properties (by IC)	Ignored	-	-			-	-
Variable	Damage given depth above property floor level (func. Pof prop type)	Uniform	MCM LB	MCM UB				From MCM upper and lower bounds
Variable	Local property ground level	Normal	-0.82	0.82	0.50	0	additive	Function of the DEM stated resolution and aggregating from 5m to 50m - expert judgement from challenge workshop and analysis of wetted
Variable	Basement presence (% of property nos by IC)	Uniform	-	-	0.10	1	factor	Change to the census ration of basement to non basement - HR expert judgement and Challlenge Workshop

Table 5.1c *Stage 2 – Expected damage and flood depth (conditional on storm event)* - Input variables and parameters and associated uncertainty

Stage 2 – Expected damage and flood depth (conditional on storm events and Impact Zone)						
Uncertainty category	**Name of uncertain measure**	**Distribution Type**	**Distribution parameters and values**			**Evidence base**
			Lower bound (10th pctl)	Upper bound (90th pctl)	SD	
Output	Expected inflow volume (for each defence fore each return period)	Derived				Calculated from Stage 1a variables
Variable	DEM - Random error (vertical)	ignored	-	-		Not considered (outside of property ground level and defence ground level - see stage 1)
Variable	DEM - Systematic error	ignored	-	-		Not considered - No impact on spreading
Function	RFSM - Error (depth) by Impact Zone	Normal	-0.34 m	0.24 m	0.33 m	Based on NaFRA 07 development reports (HR Wallingford, 2008) and comparison with TUFLOW plus expert judgement
Function	Model (structure) factor	ignored	-	-	-	
Output	Damage given depth for Impact Zone	Derived				Calculated from Stage 1b variables
Output	Expected Flood depth conditional on load for Impact Zone	Derived				Calculated from Stage 1a, 1b and above variables

Table 5.1d *Stage 3 – Expected annual damage and flood depth (all storm events)* - Input variables and parameters and associated uncertainty

Stage 3 – Expected damage and flood depth (all storm events and user defined aggregation of Impact zones)						
Uncertainty category	**Name of uncertain measure**	**Distribution Type**	**Distribution parameters and values**			**Evidence base**
			Lower bound (10th pctl)	Upper bound (90th pctl)	SD	
Variable	Expected Damage (conditional on load), by Impact zone	Derived				Calculated from Stage 2
Function	Model (structure) factor	ignored				
Function	Integration of events (too few events)	ignored if in the prescribed range				from NaFRA 06 senstivity analysis
Output	Annual probability of exceeding given flood depth (>0m) by Impact zone	Derived				Calculated from Stage 2 and above variables
Output	Expected annual damage (by Impact zone)	Derived				Calculated from Stage 2 and above variables
Output	Expected annual damage by Flood Area	Derived				Calculated from Stage 2 and above variables
Output	Expected annual damage by Region or Nation	Derived				Calculated from Stage 2 and above variables
Output	Annual probability of exceeding given flood depth (>0m) by Impact zone	Derived				Calculated from Stage 2 and above variables

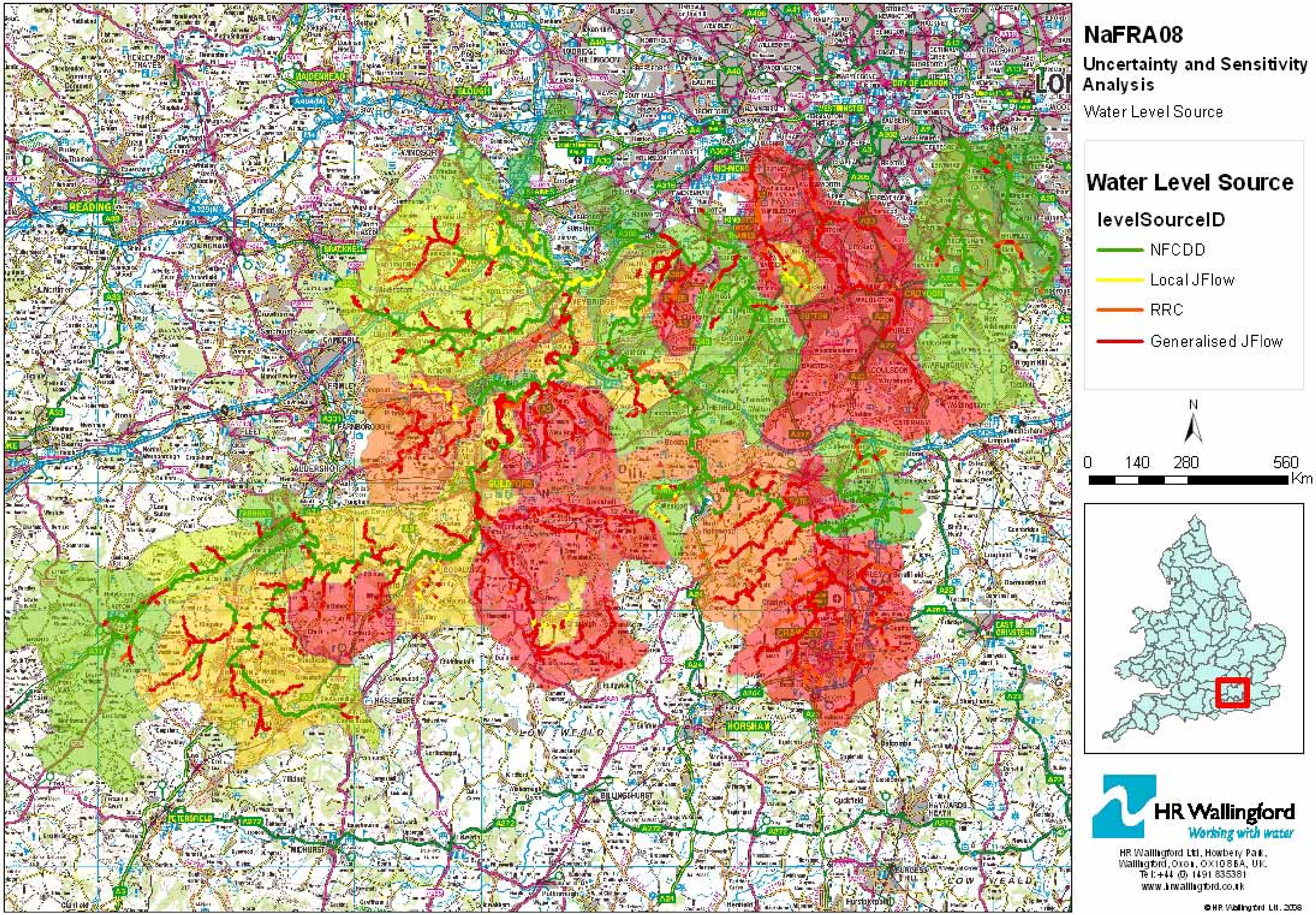

Figure 5.3 Example input uncertainties – Range of data sources used as input water level
(background shading highlights different Flood Areas)

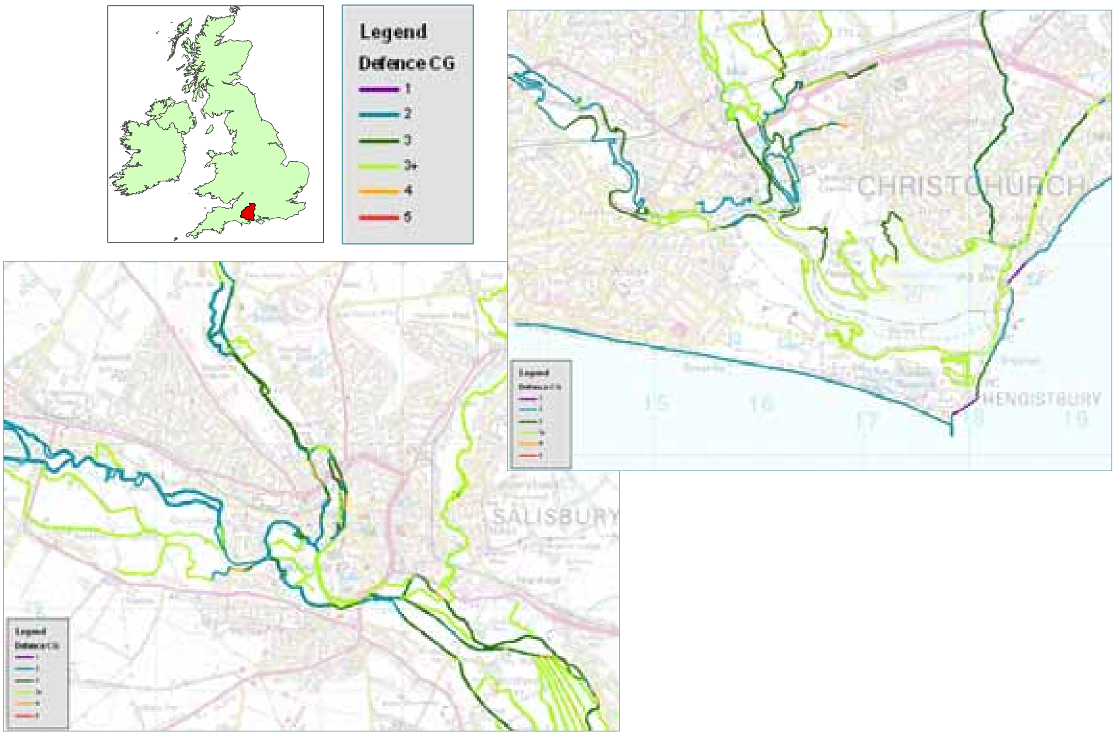

Figure 5.4 Example input uncertainties – The range of Condition Grade sources used (note: 3+ implies no Cg information in NFCDD)

5.4 UNCERTAINTY ANALYSIS RESULTS

The uncertainty analysis has been applied to three catchments using the RASP-MC (Monte Carlo) tools developed previously by HR Wallingford.

The pilot catchments are given below:

- 3000 : Witham
- 3904 : Thames & Wey
- 4300 : Stour & Avon

For each catchment the results from the application of the RASP-MC have been visualised using a variety of views in an attempt to communicate the uncertainty in the NaFRA 08 results in a meaningful manner. These results are shown in the following figures (5.5 to 5.19). A short commentary is provided alongside each figure to help explain the results for the first set of results on catchment 3904.

Note:
Although the full catchment has been analysed, only a limited area is shown within the figures for readability. The tables include results for the full catchment.

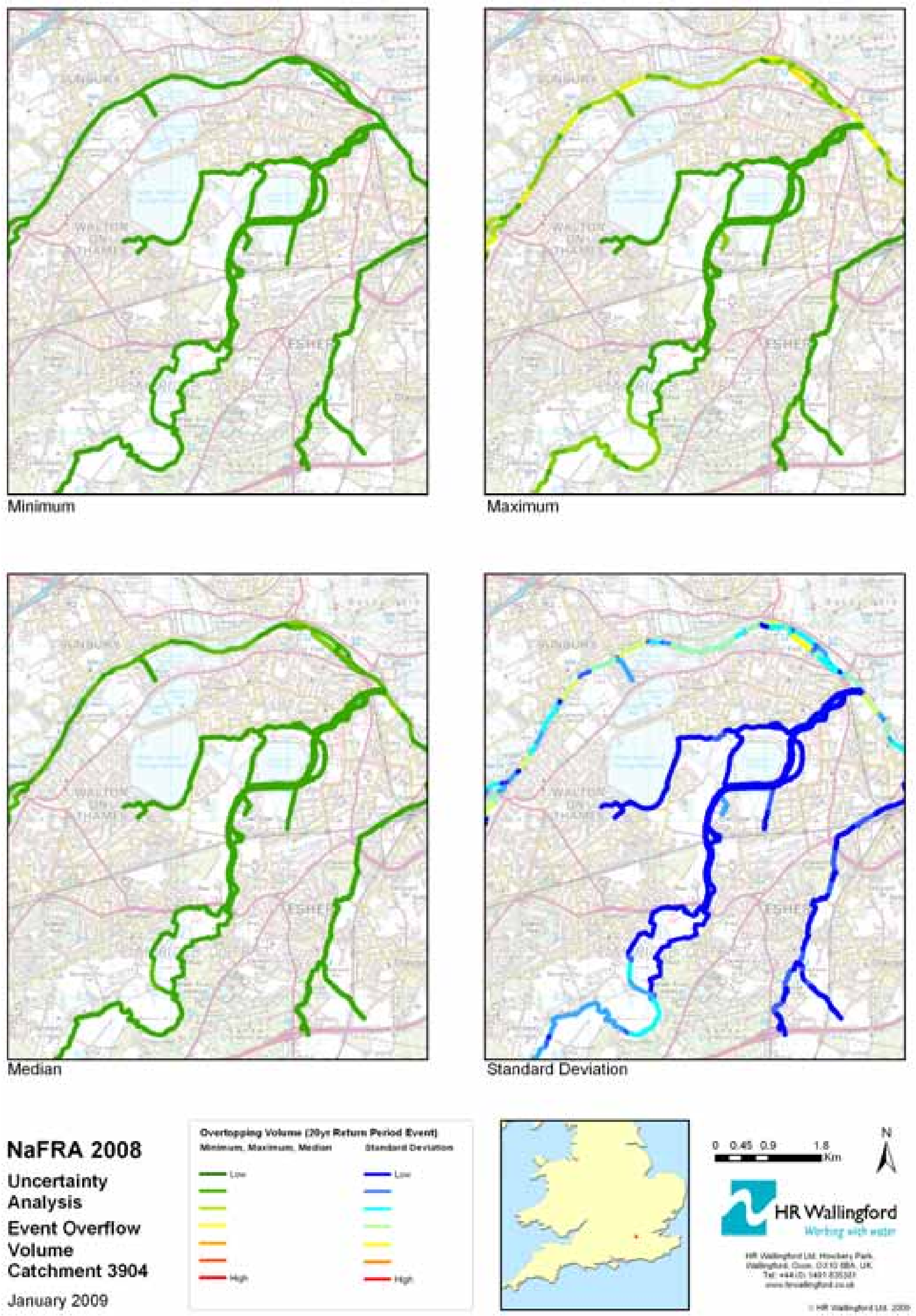

Figure 5.5a Catchment 3904 - Stage 1a: Overflow volume for a given return period event (20 years) (10/50/90 percentiles and SD)

The above figure highlights the uncertainty within the estimate of overflow volume at lower return periods (in this case the 20 year event). Outside of the main river the uncertainty is relatively low. This reflects in part the relatively large number of defences where “zero overtopping volume” occurs within the simulation (where either lower water levels or higher crest levels are sampled). This binary response also leads to significant skewness in the results. Therefore the standard deviation must be viewed with caution, however, the relatively limited uncertainty is also evidenced through visual comparison of the minimum, median and maximum values).

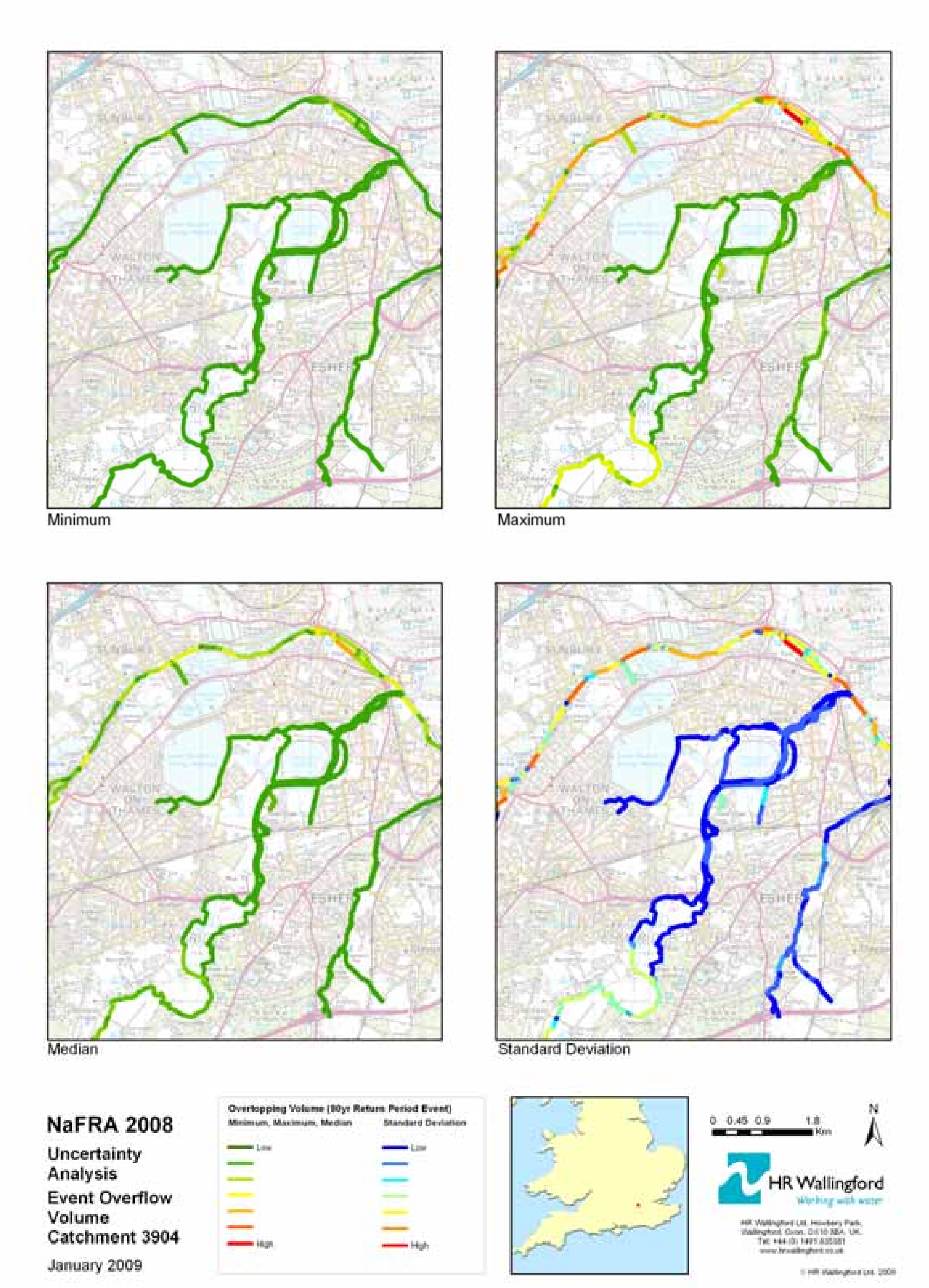

Figure 5.5b Catchment 3904 - Stage 1a: Overflow volume for a given return period event (80 years) (10/50/90 percentiles and SD)

At higher return periods the uncertainty in the volume of flood water expected to overflow each defence increases. This can be seen in the marked variation between the minimum, median and maximum values (and indicatively within the plot of "standard deviation").

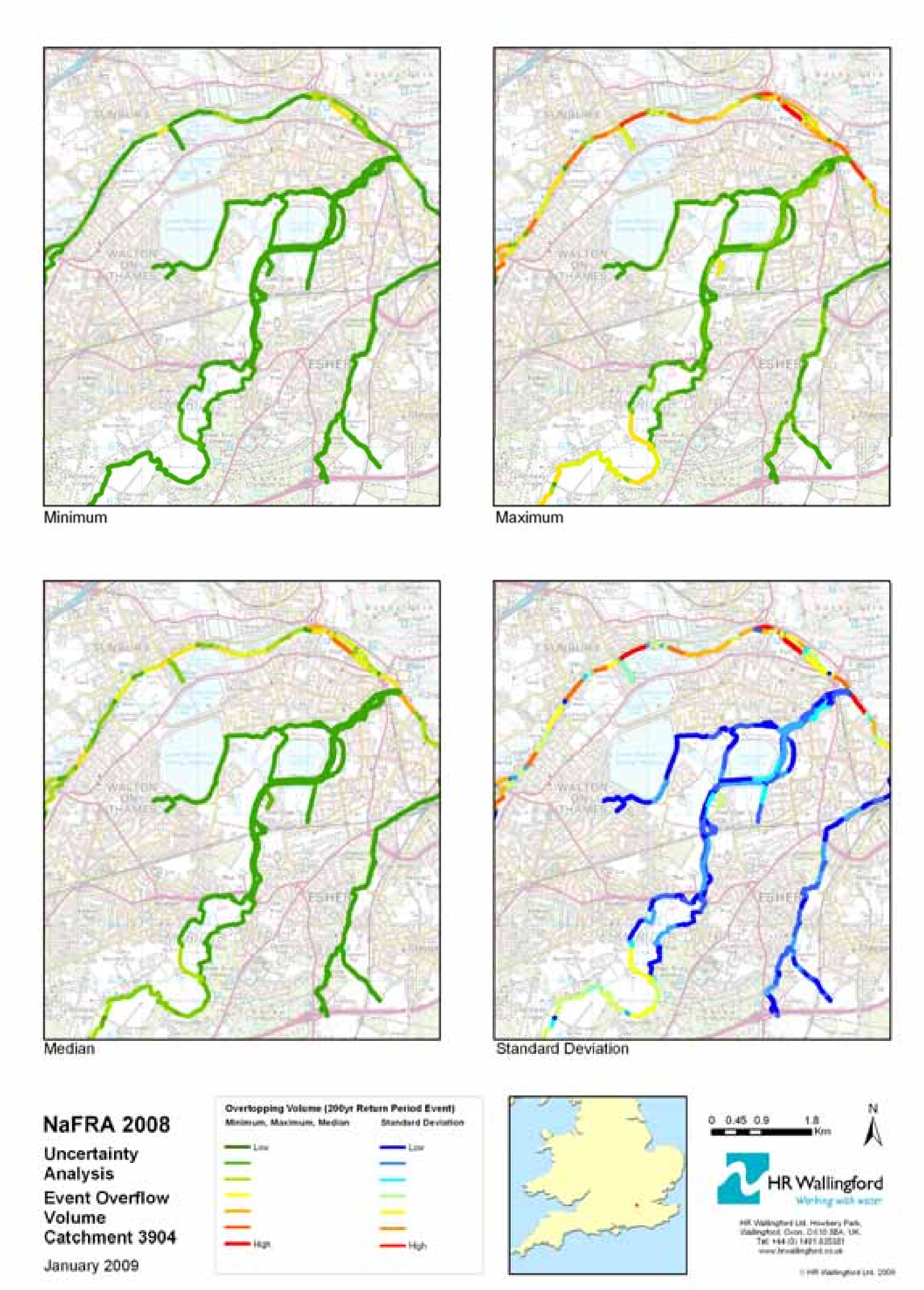

Figure 5.5c Catchment 3904 - Stage 1a: Overflow volume for a given return period event (200 years) (10/50/90 percentiles and SD)

At higher return periods the uncertainty in the volume of flood water overflowing each defence continues to increase. The primary driver of this (given most other uncertainties are fixed) is the larger uncertainty within the water level inputs.

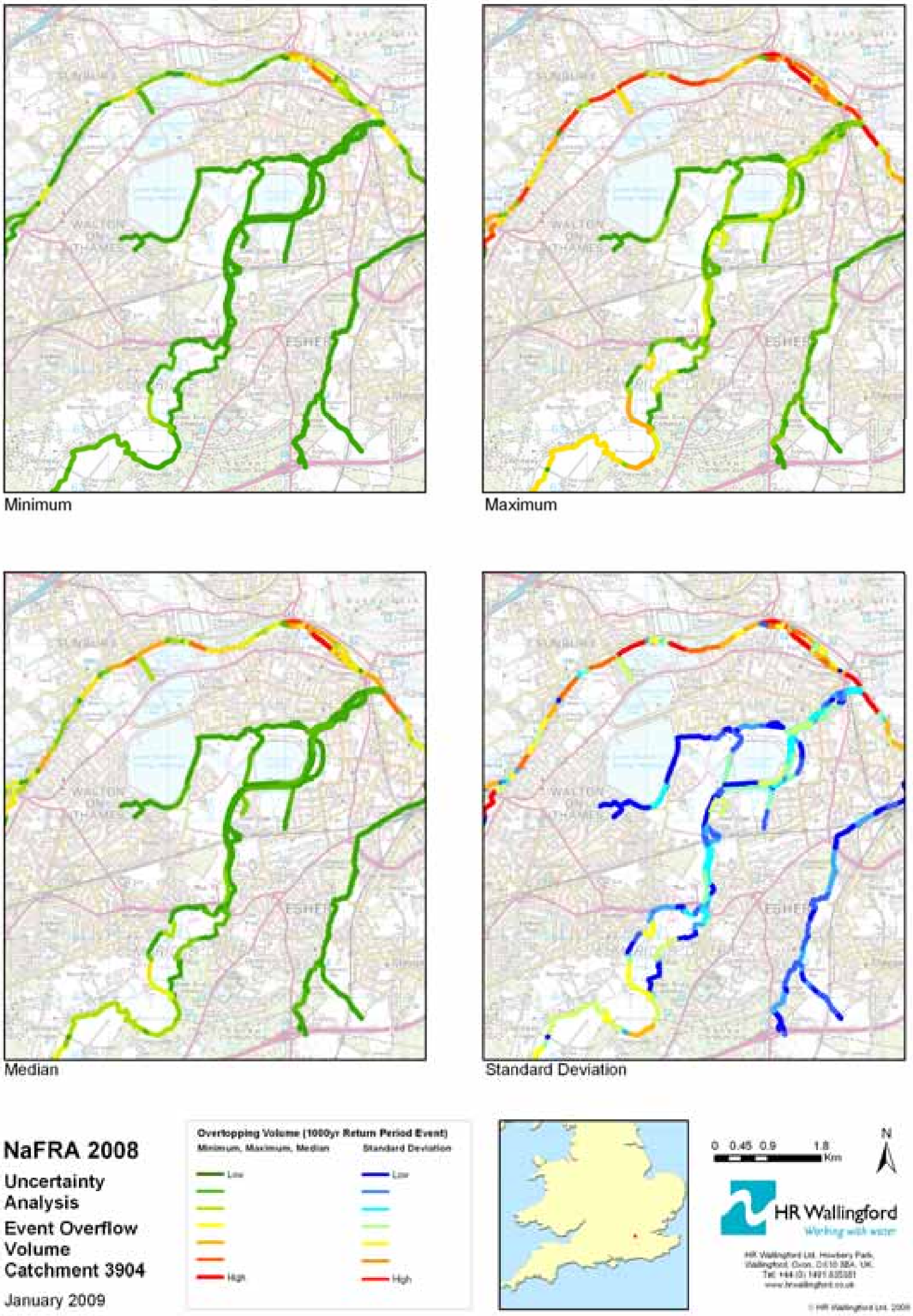

Figure 5.5d Catchment 3904 – Stage 1a: Overflow volume for a given return period event (1000 years) (10/50/90 percentiles and SD)

Similar pattern from Figure 5.5c.

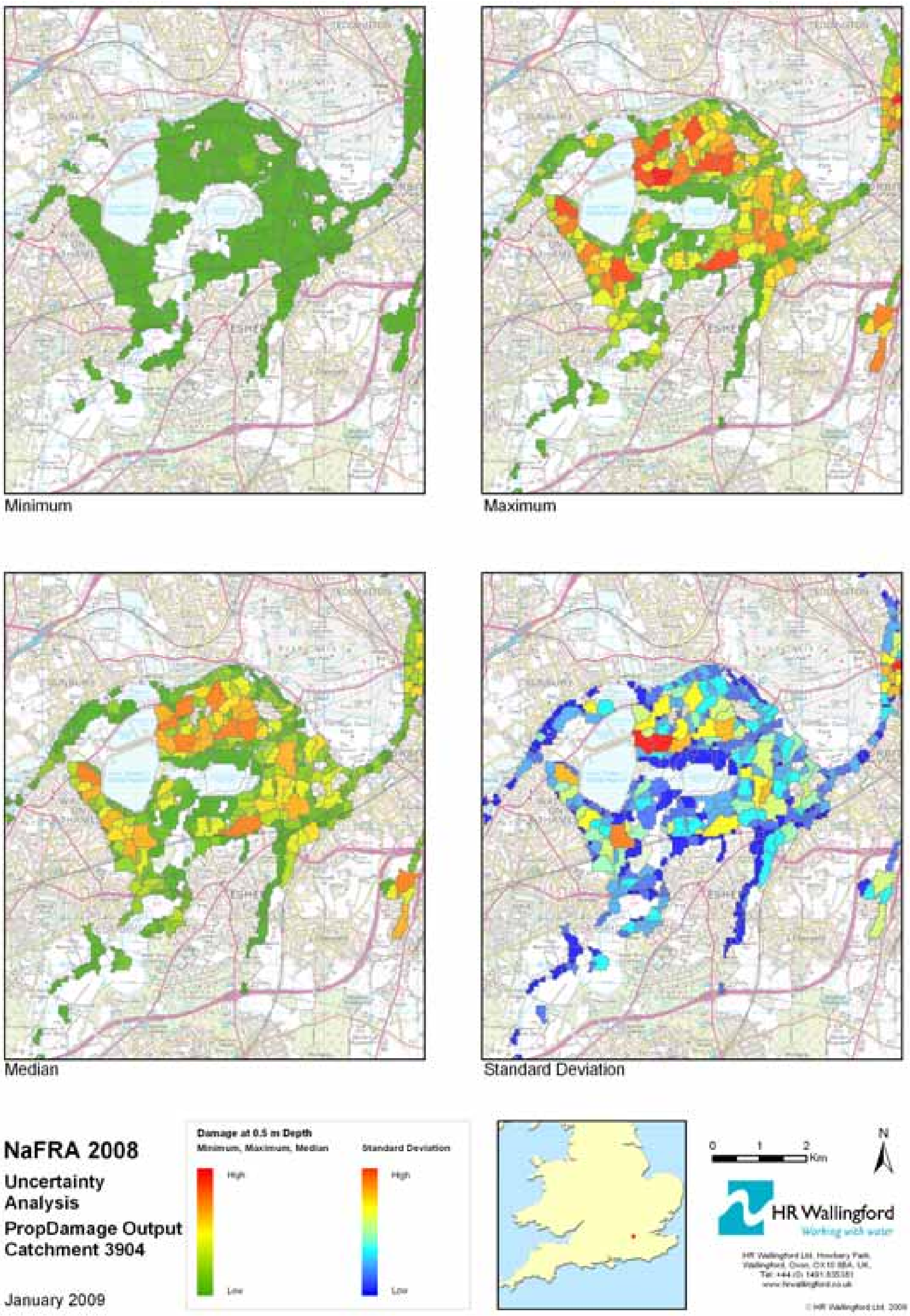

Figure 5.6a Catchment 3904 - Stage 1b: Damage for a given depth (0.5m) within each Impact Zone (10/50/90 percentiles and SD)

The uncertainty is attributed to the Impact zones within the above figure. The spatial variation within the uncertainty (most likely resulting from the spatial variation in floodplain receptors) is stark, and highlights the importance of a fine spatial resolution when assessing uncertainty. The significant qualitative difference between the minimum and maximum damage values (given depth) reinforces the significant uncertainty that exists with the depth versus damage functions and threshold levels. Other unceratinties are more limited, and intitutively are likely to be less important (further sensitvity analysis would be capable of exploring this).

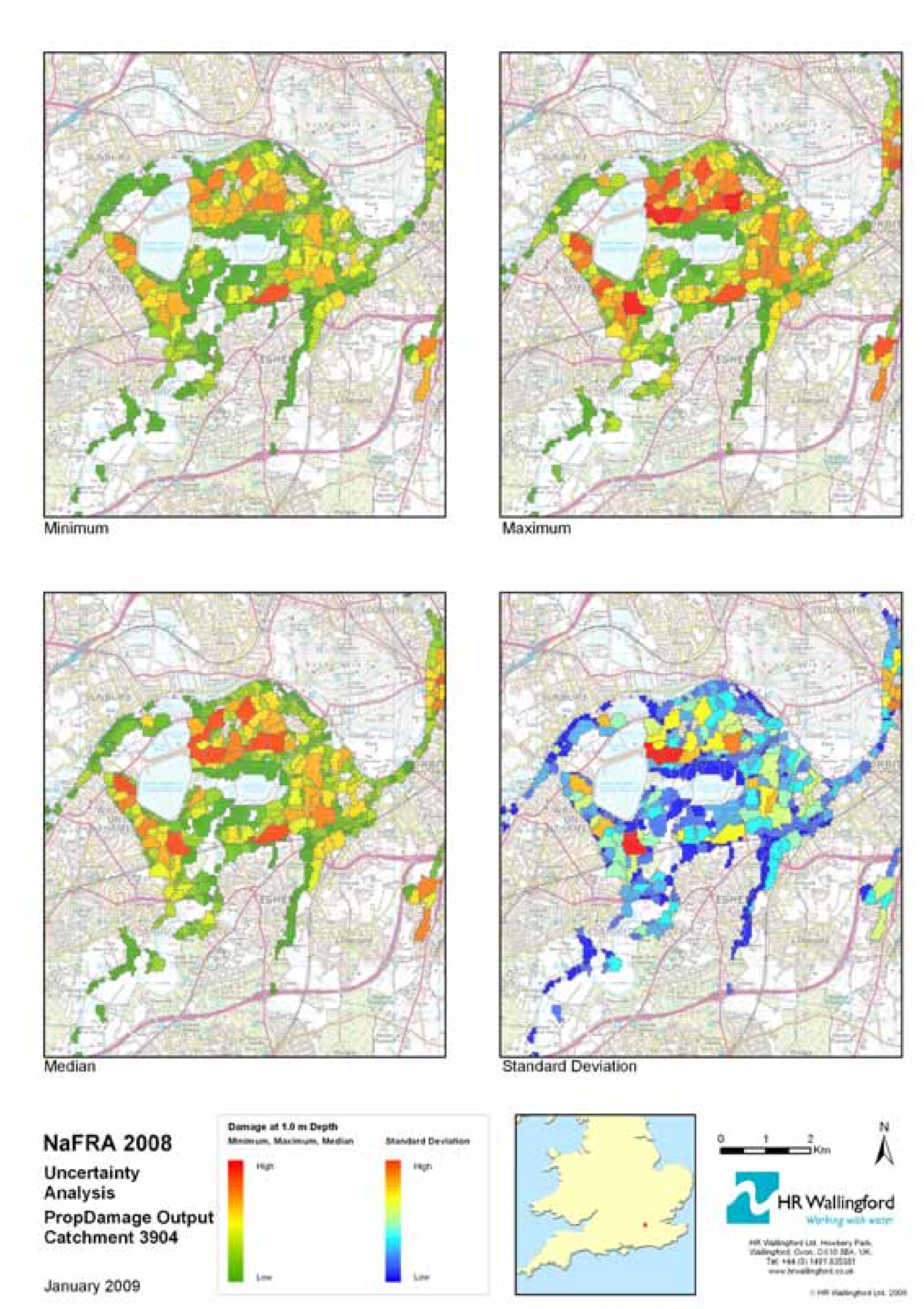

Figure 5.6b Catchment 3904 - Stage 1b: Damage for a given depth (1.0m) within each Impact Zone (10/50/90 percentiles and SD)

As would be expected, as the flood depth increases, the unceratinty in the economic damage (residential and commercial property only) also becomes greater. This is also shown in Figure 5.6c.

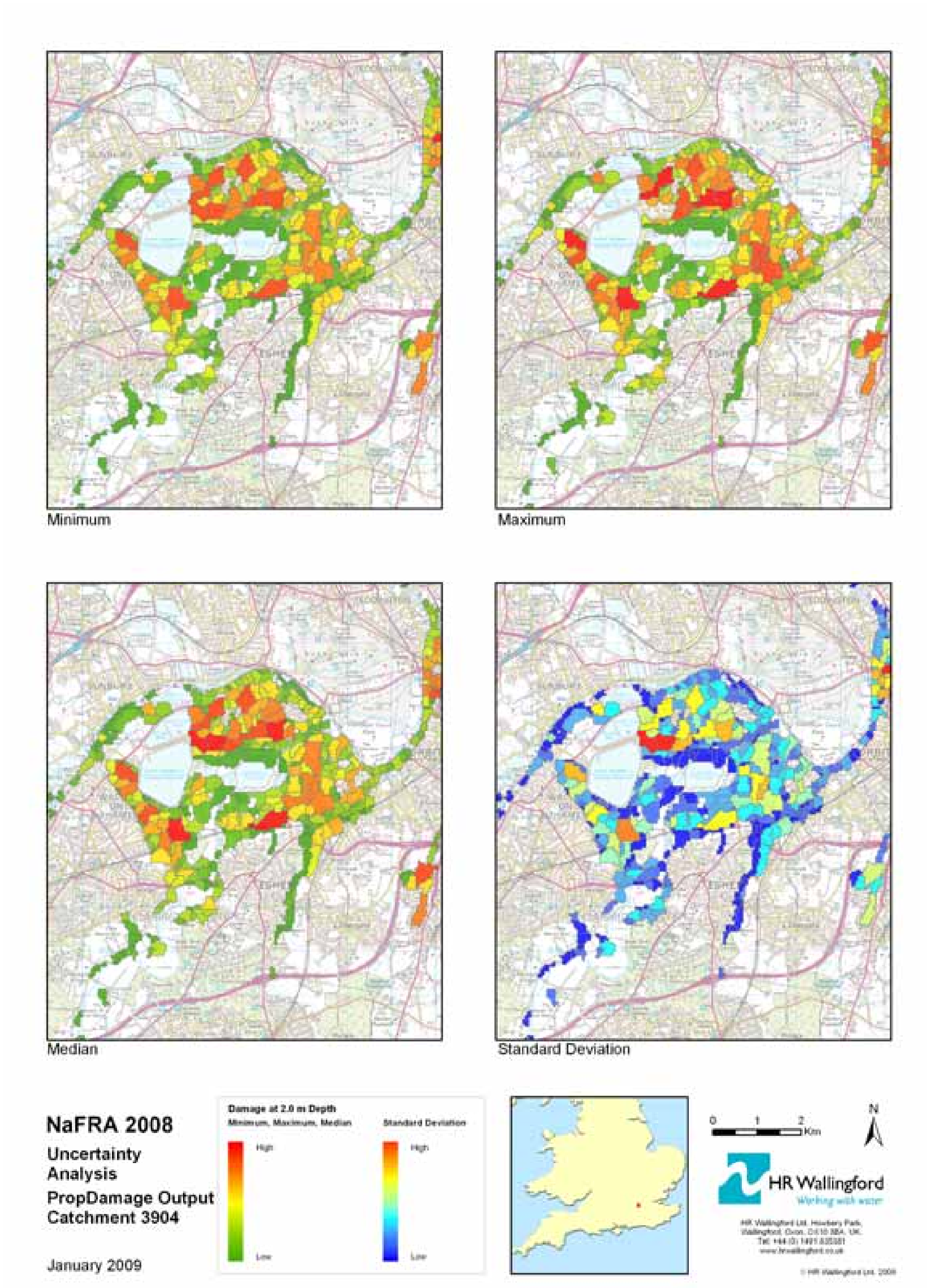

Figure 5.6c Catchment 3904 - Stage 1b: Damage for a given depth (2.0m) within each Impact Zone (10/50/90 percentiles and SD)

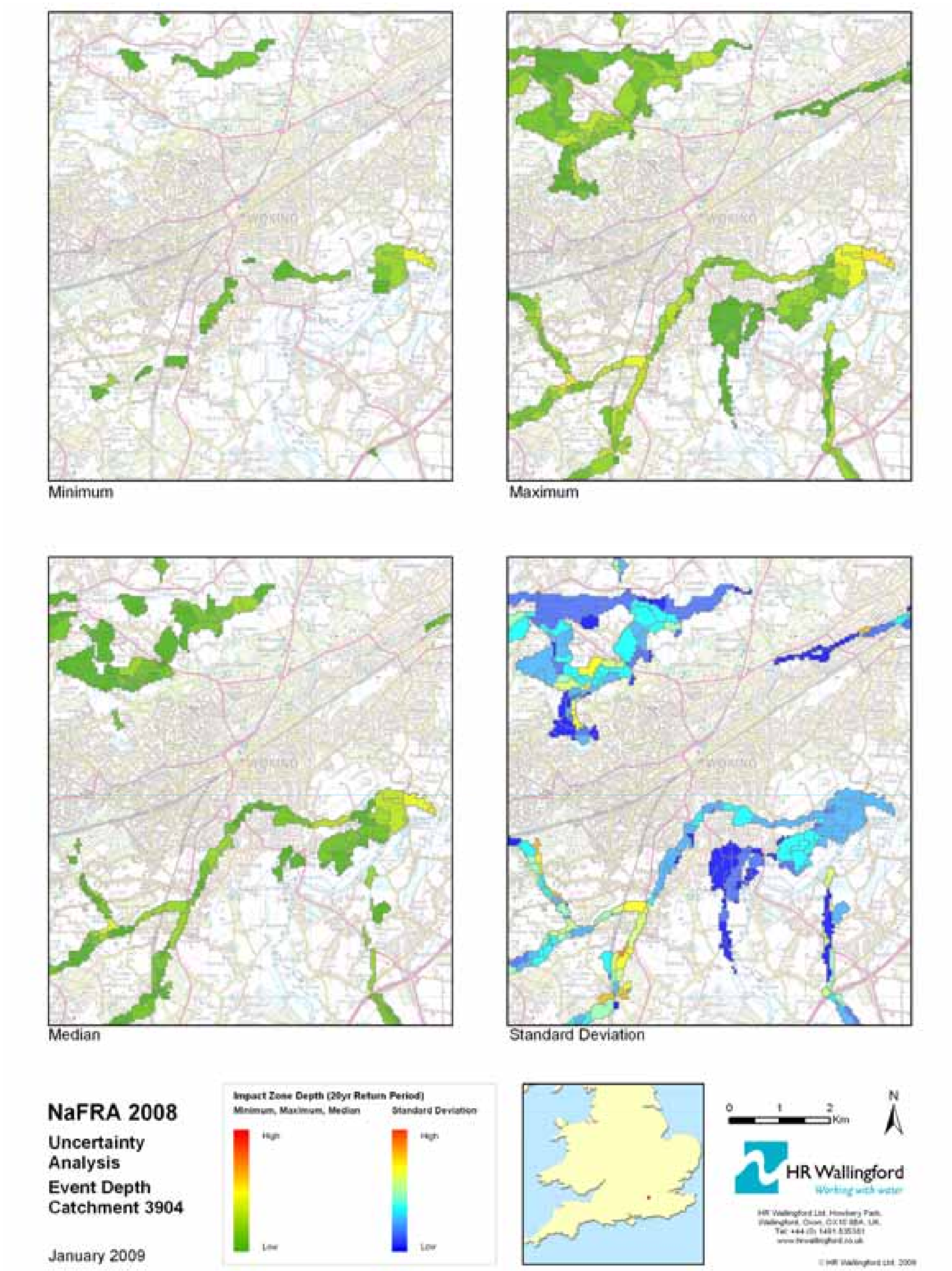

Figure 5.7a Catchment 3904 - Stage 2: Depth within each Impact Zone for a given return period storm (in this case 20 years)

The above figure seeks to explore the uncertainty within the expected flood depth within each Impact Zone for a given in-river storm load. The graphical respresentation of flood depth also provides a useful proxy for the expected flood extent. The maps show the minimum and maximum values, providing a useful insight into the uncertainty in flood extent for a low return period in-river storm. A similar pattern is shown in Figure 5.7b below.

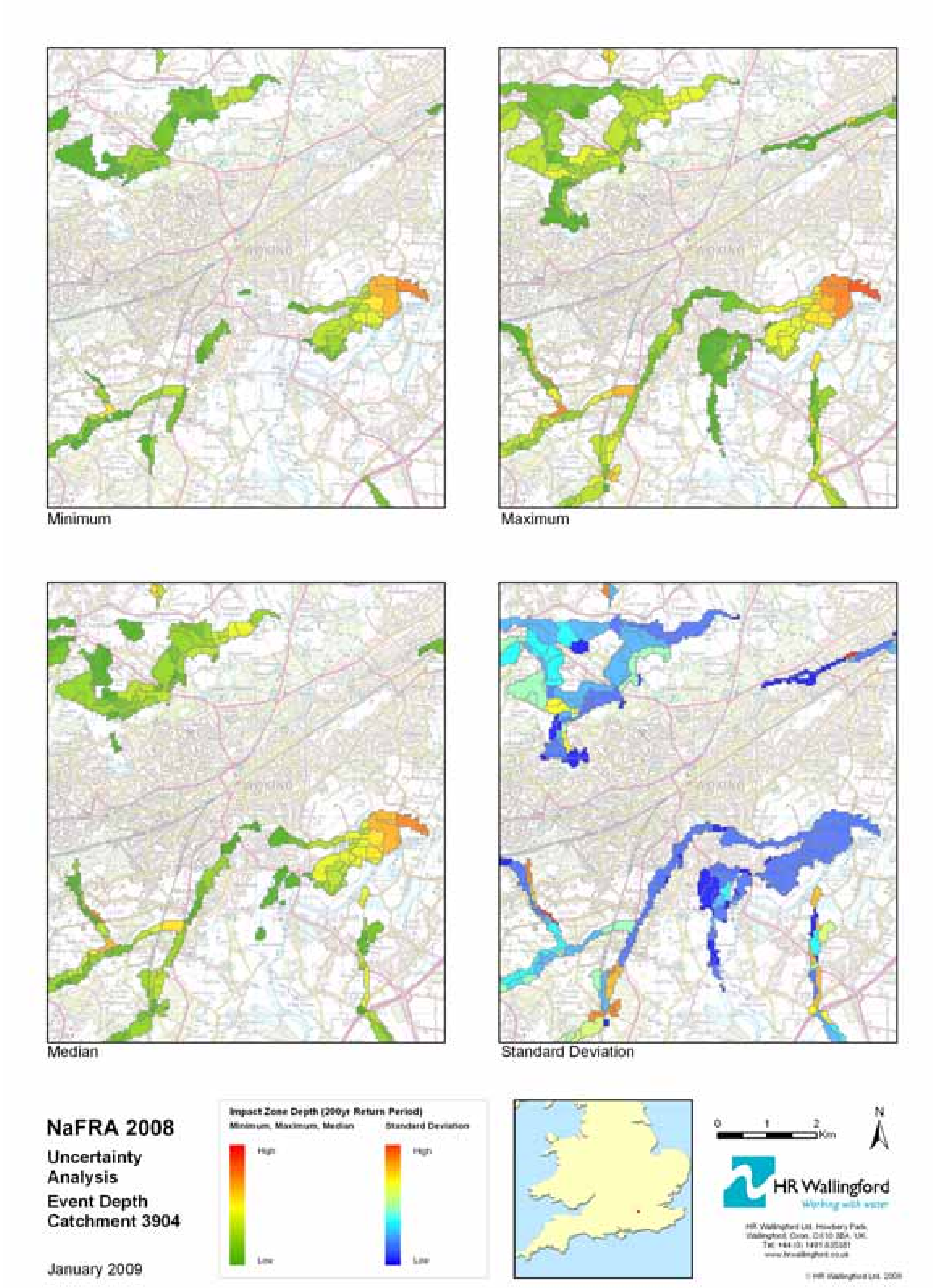

Figure 5.7b Catchment 3904 - Stage 2: Depth within each Impact Zone for a given return

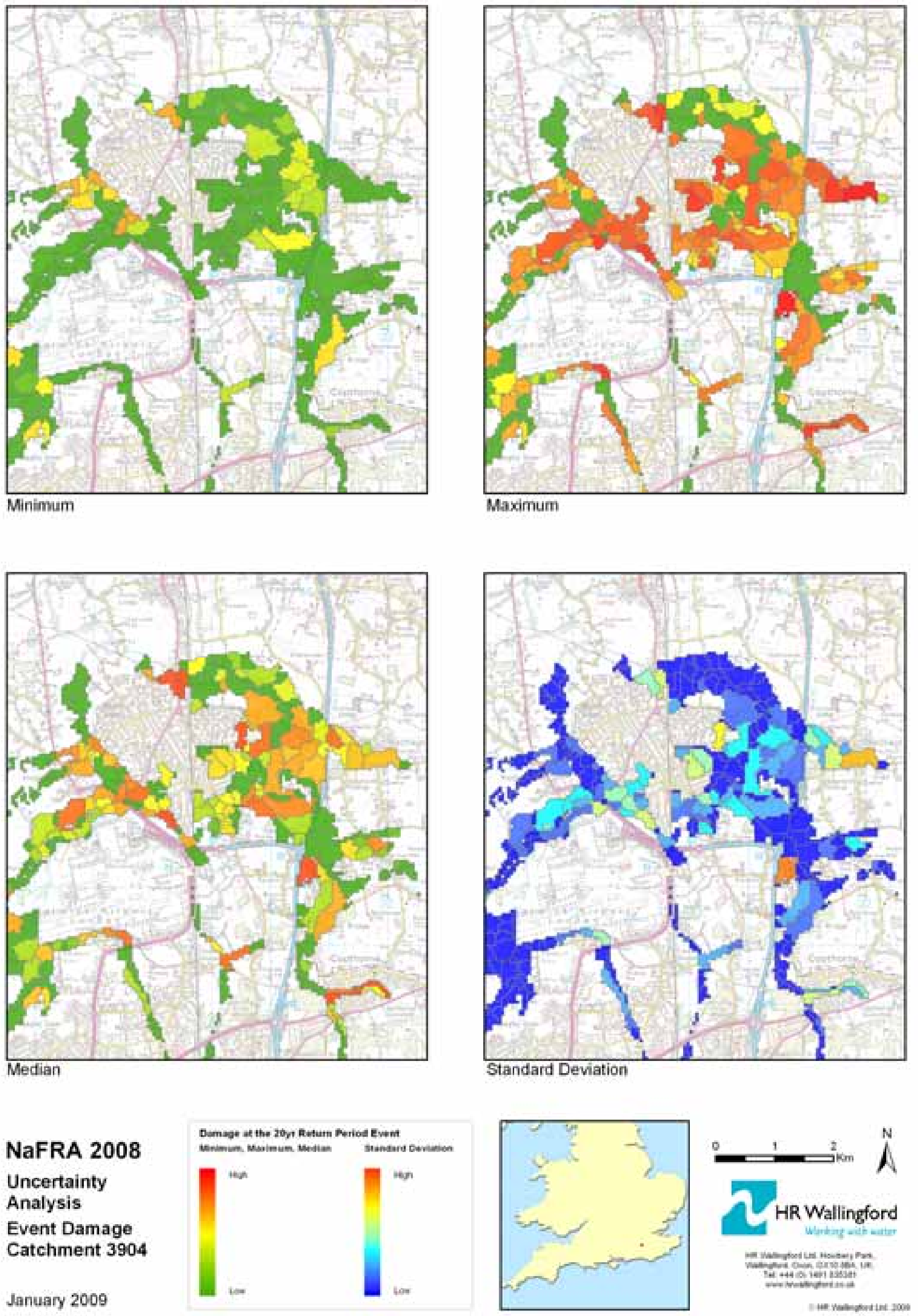

Figure 5.8a Catchment 3904 - Stage 3: Event risk by Impact Zone for a given return period in-river water level (20 year return period)

The above figure combines the results from Stage 1a, 1b and 2 to provide an estimate of the uncertainty in calcuated damage value within a given Impact Zone under a given in-river water level condition. As such, the above plot integrates the data quality associated with the individual defences, water level estimates, fragility data, property data, the flood spreading alogrithms etc to provide an overview of the unceratinty in the flood risk associated with a given reurn period storm. The figures highlight the significant absolute (by comparison of individual Impact zone) and spatial variation (by comparison in the overall pattern across the Flood Areas) in the event risk. A similar pattern is again observed under higher retrun period loads in Figure 5.8b below.

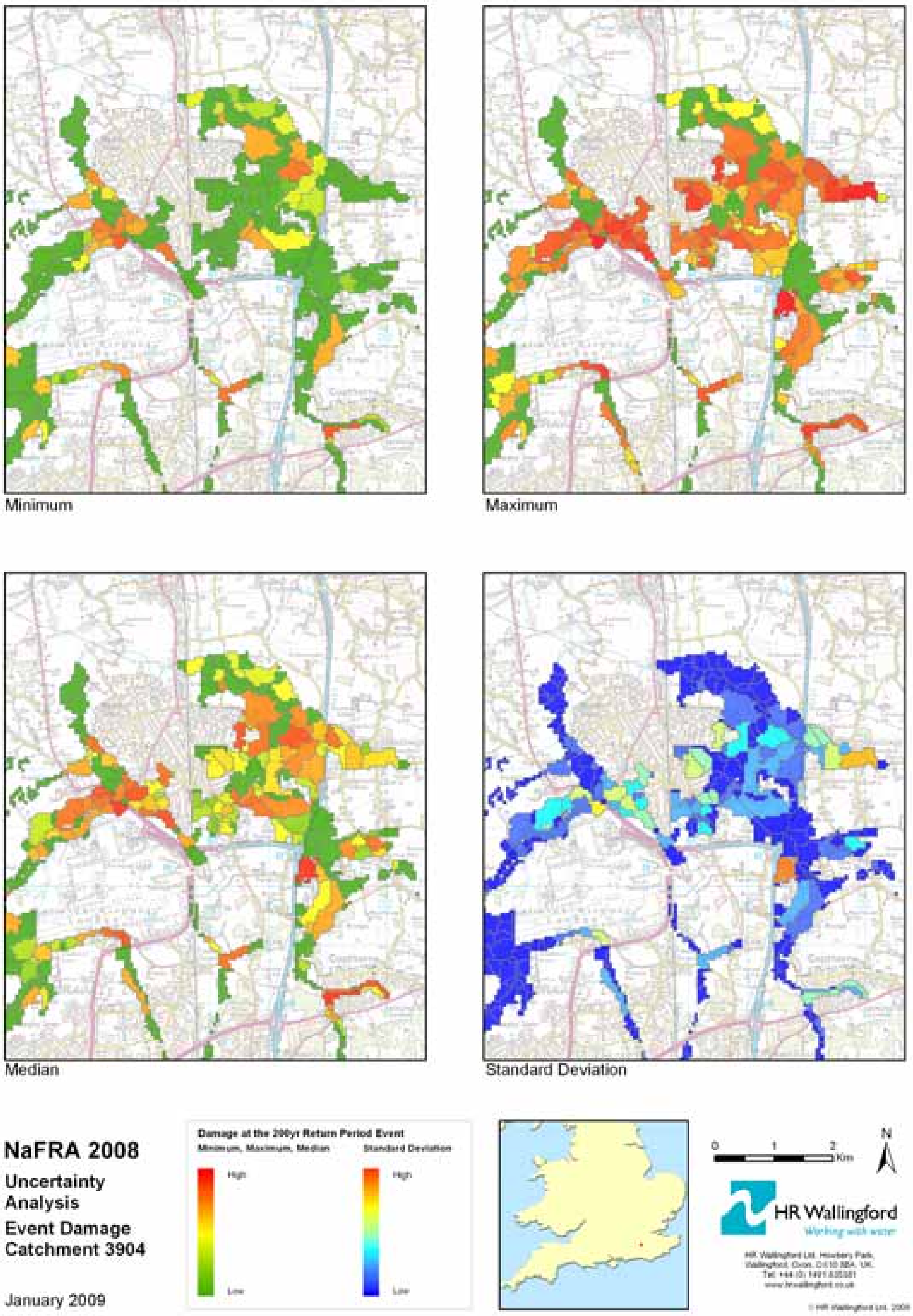

Figure 5.8b Catchment 3904 - Stage 3: Event risk by Impact Zone for a given return period in-river water level (200 year return period)

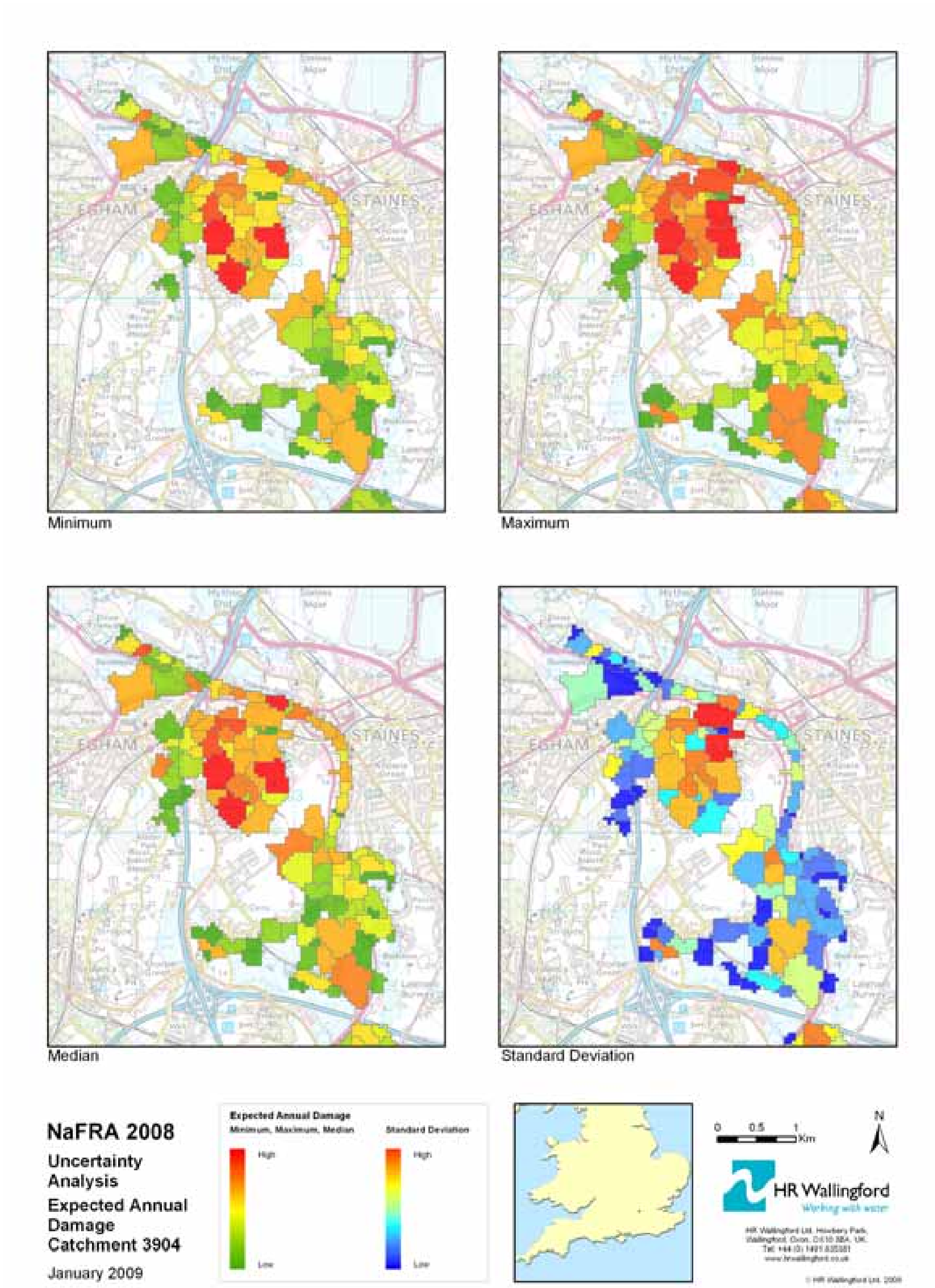

Figure 5.9 Catchment 3904 - Stage 4: Expected Annual Damage (10/50/90 percentiles and SD)

The above figure provides an overview of the uncertainty within the Expected Annual Damages by Impact zone. As with previous figures the spatial variation is striking and complex; reflecting a combination in the local defence data and property distributions. The distribution is skewed and therefore the standard deviation must be viewed with caution.

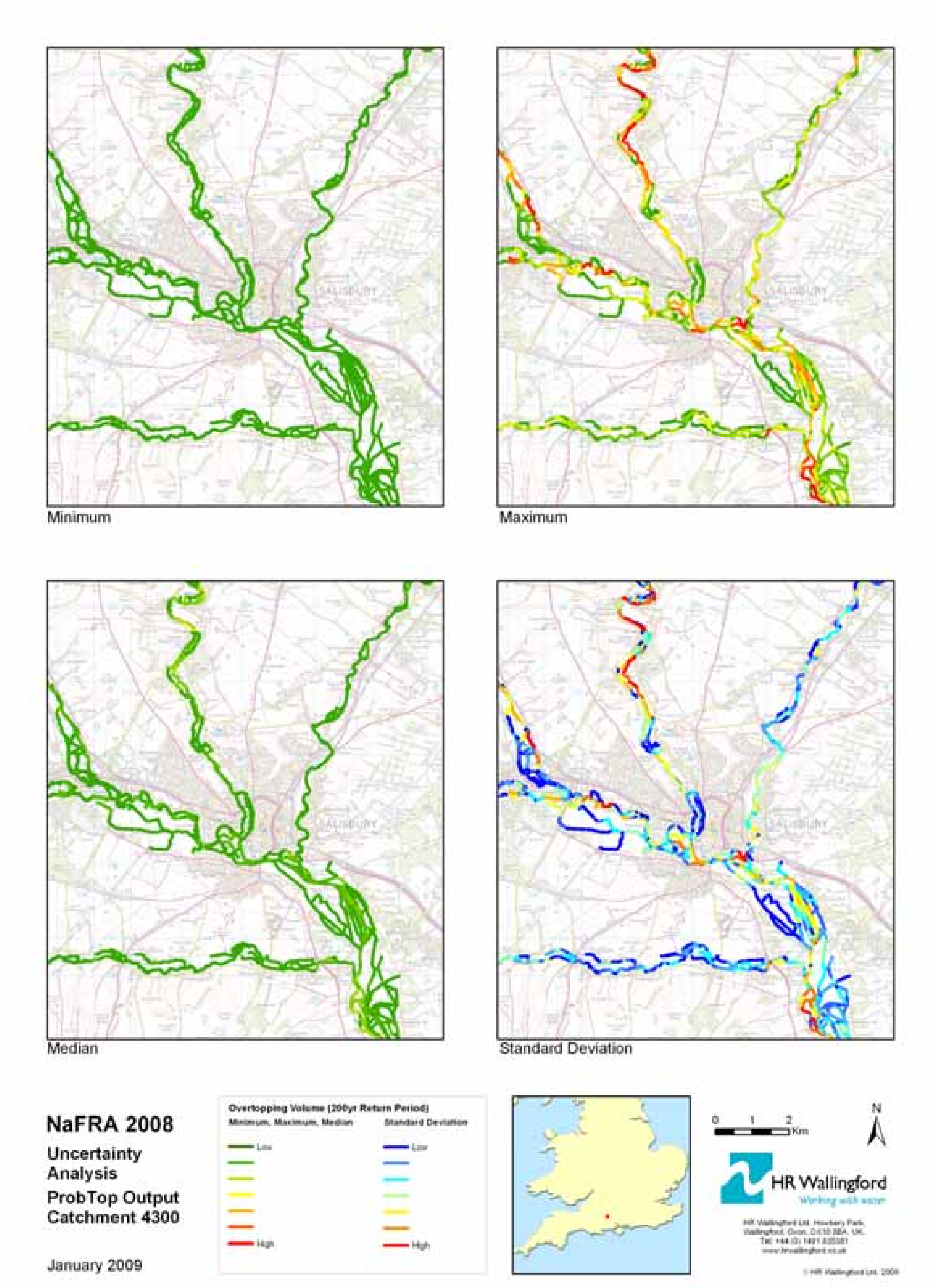

Figure 5.10 Catchment 4300 – Stage 1a: Overflow volume for a given return period event (200 years) (10/50/90 percentiles and SD) – Catchment 4300

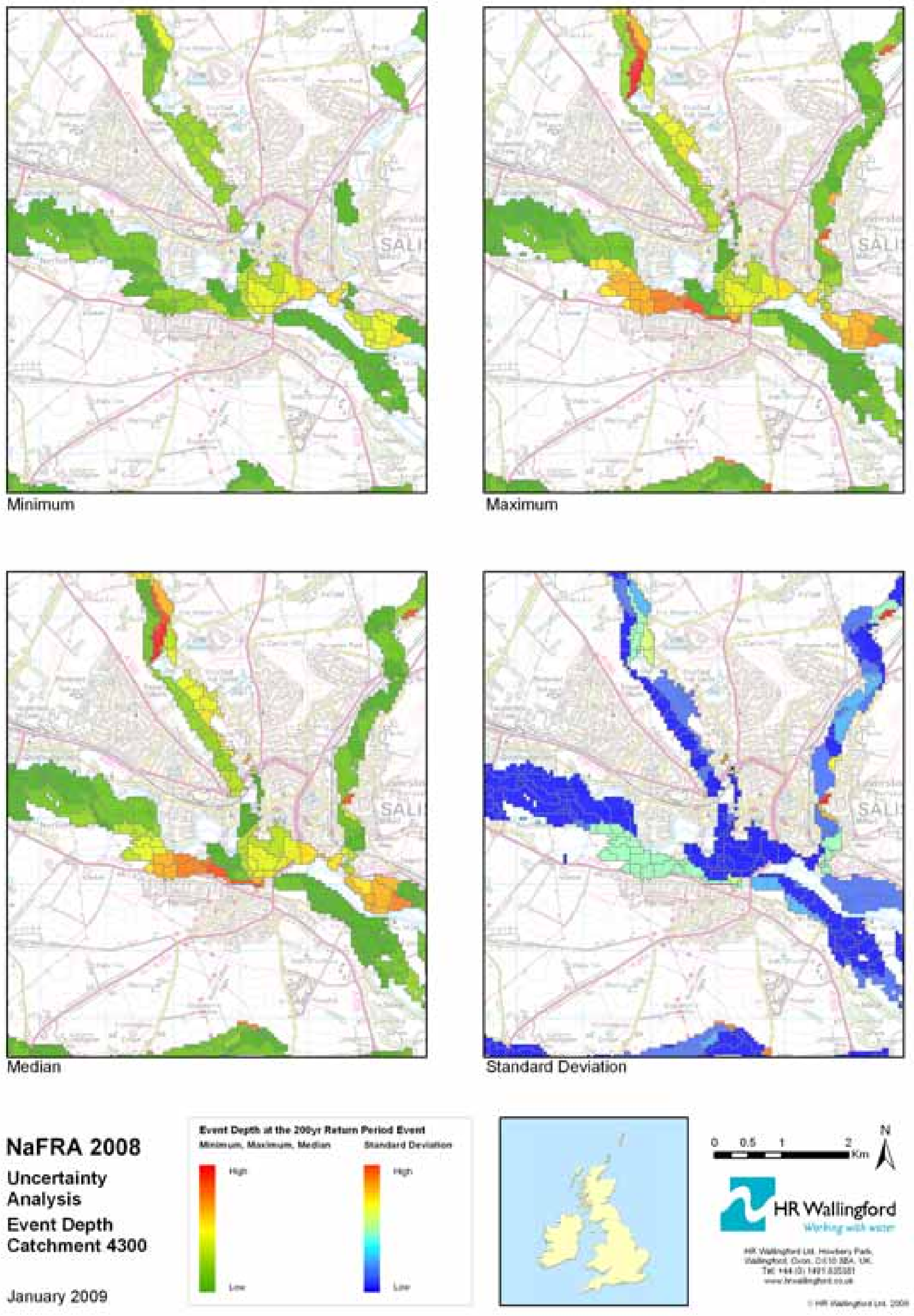

Figure 5.11 Catchment 4300 – Stage 2 – Depth within each Impact Zone for a given return period storm (in this case 200 years) – Catchment 4300

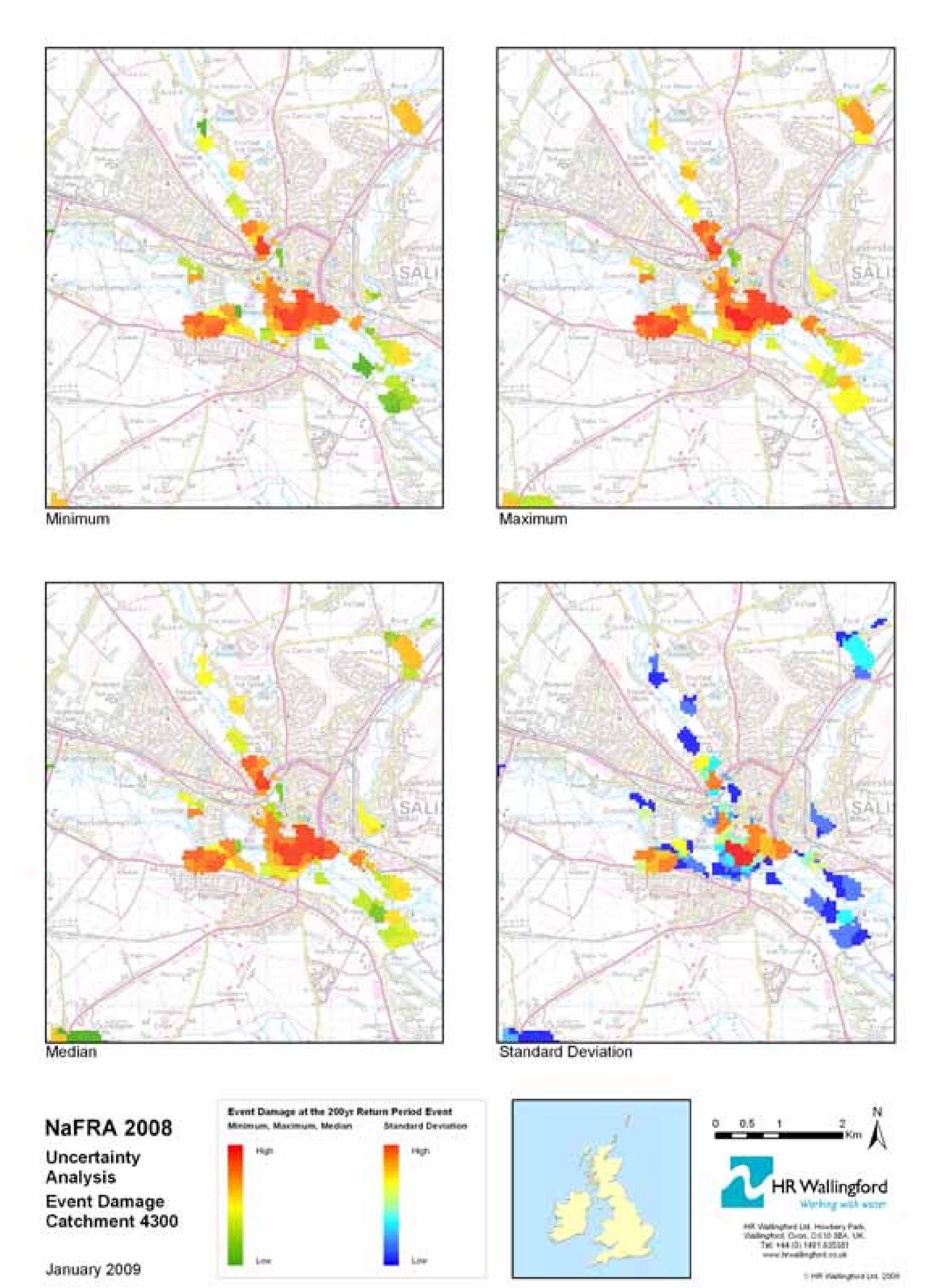

Figure 5.12 Catchment 4300 – Stage 3: Damage within each Impact Zone for a given return period storm (in this case 200 years) – Catchment 4300

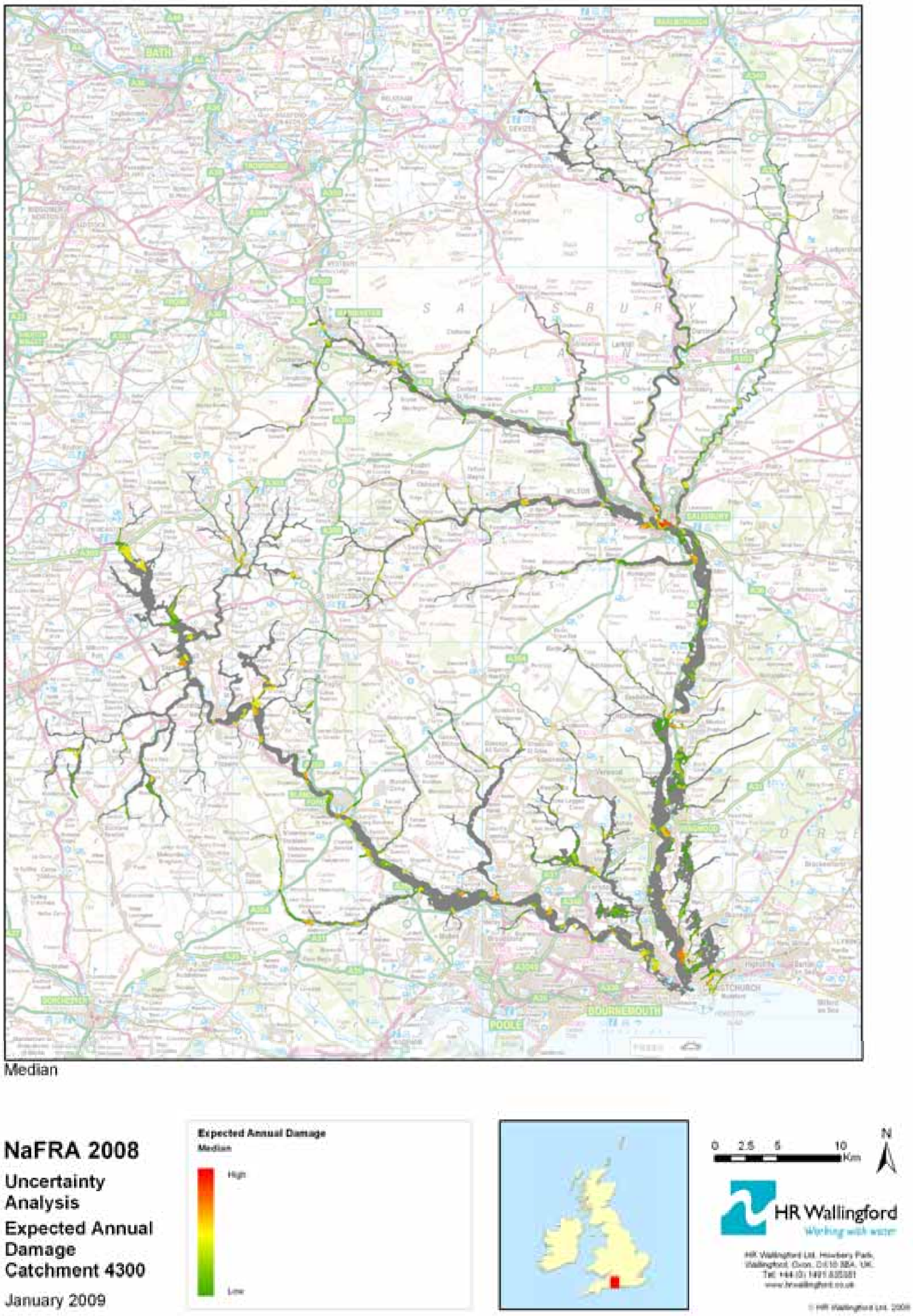

Figure 5.13 Catchment 4300 – Stage 4: Catchment overview of Expected Annual Damage (10/50/90 percentiles and SD) – Catchment 4300

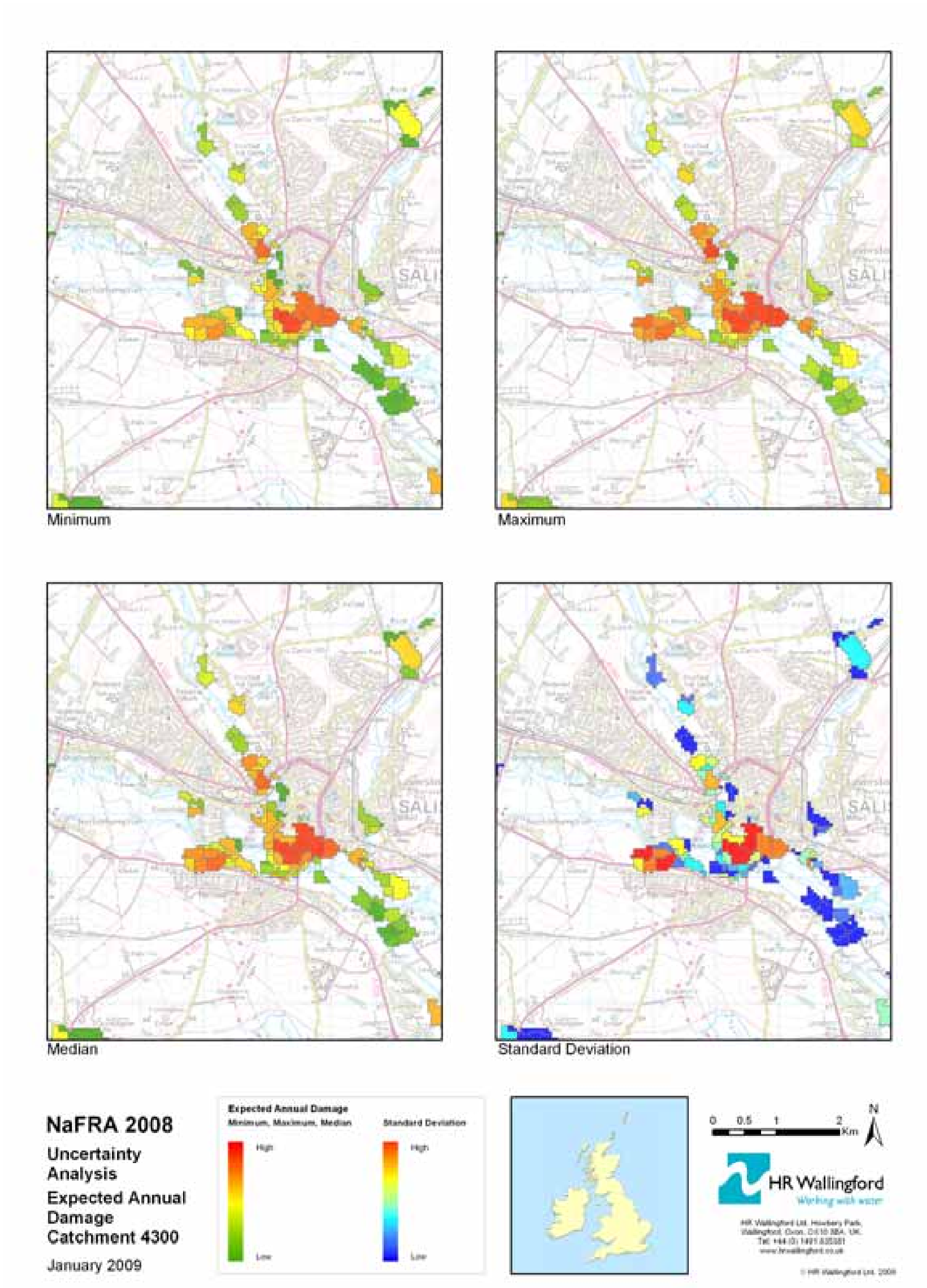

Figure 5.14 Catchment 4300 – Stage 4: Expected Annual Damage (10/50/90 percentiles and SD)

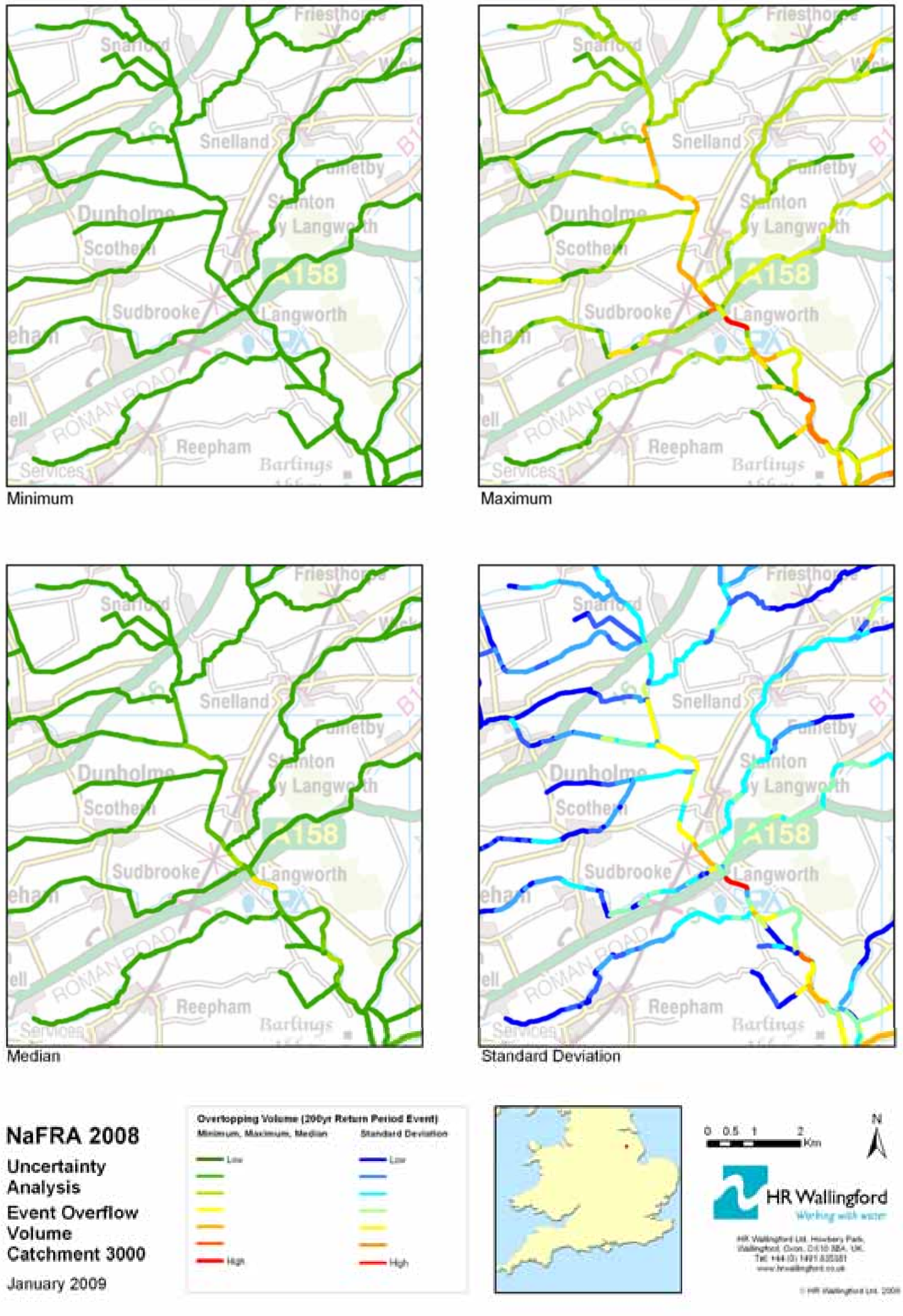

Figure 5.15 Catchment 3000 – Stage 1a: Overflow volume for a given return period event (200 years) (10/50/90 percentiles and SD)

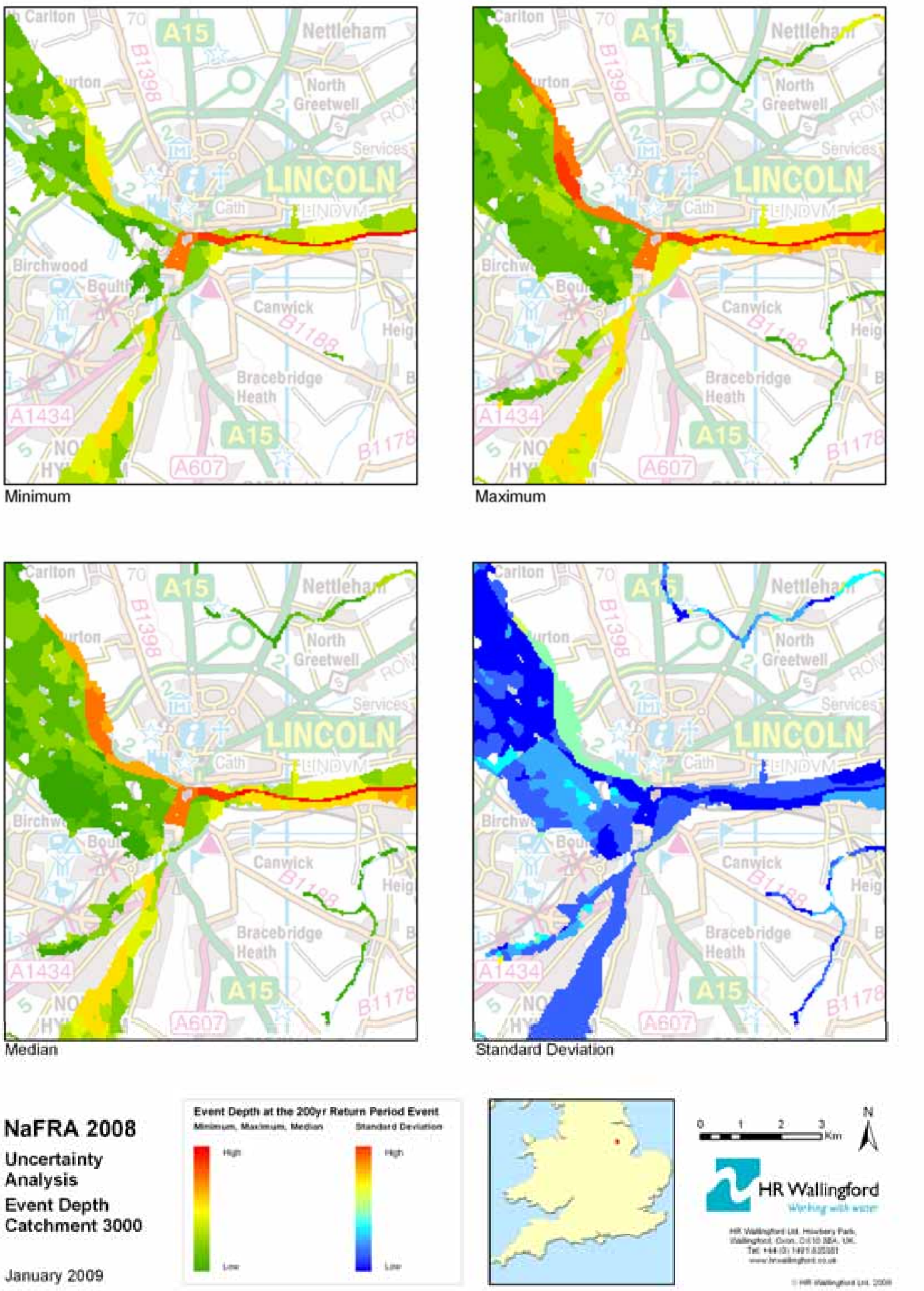

Figure 5.16 Catchment 3000 – Stage 2: – Depth within each Impact Zone for a given return period storm (in this case 200 years)

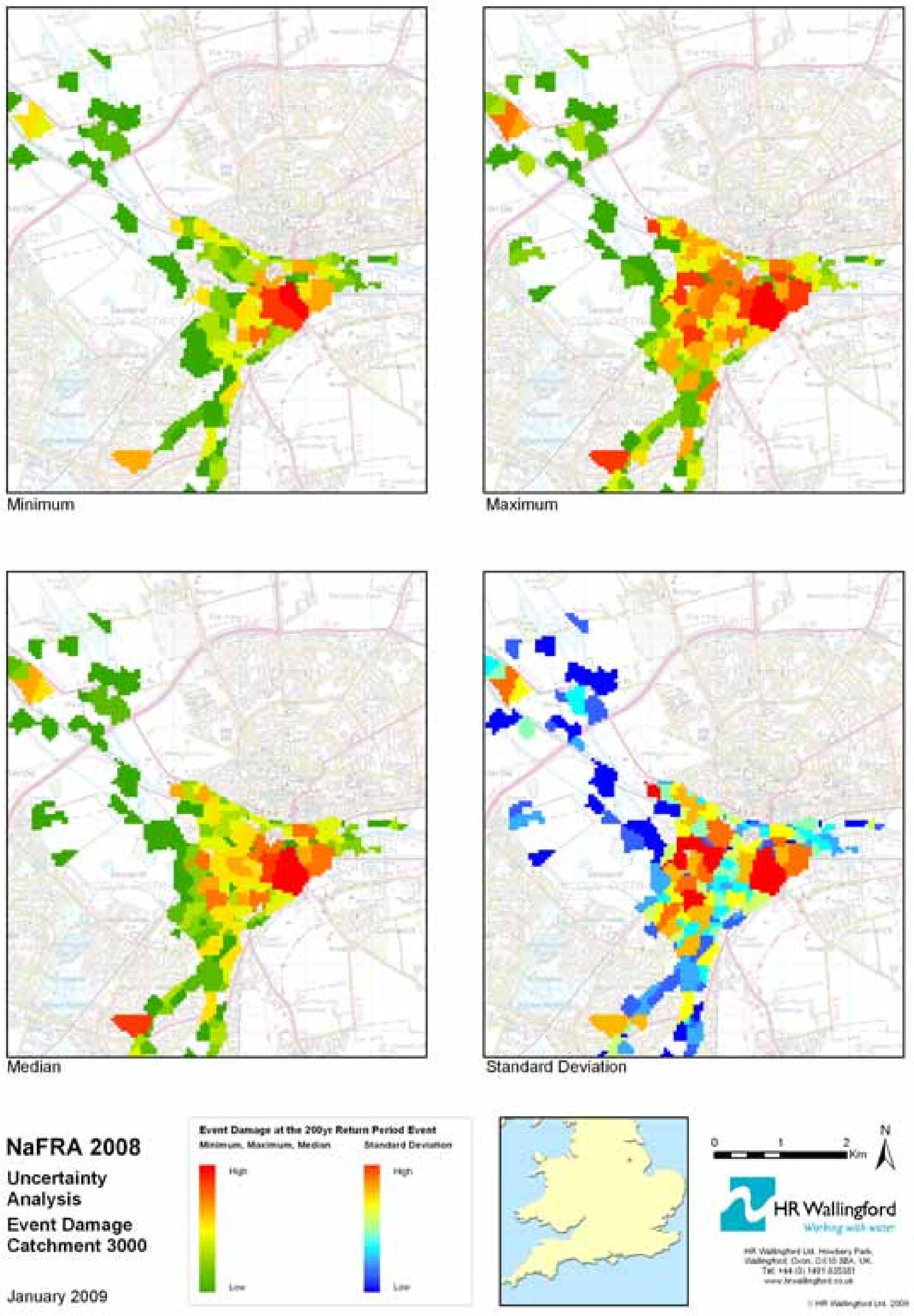

Figure 5.17 Catchment 3000 – Stage 3: – Damage within each Impact Zone for a given return period storm (in this case 200 years)

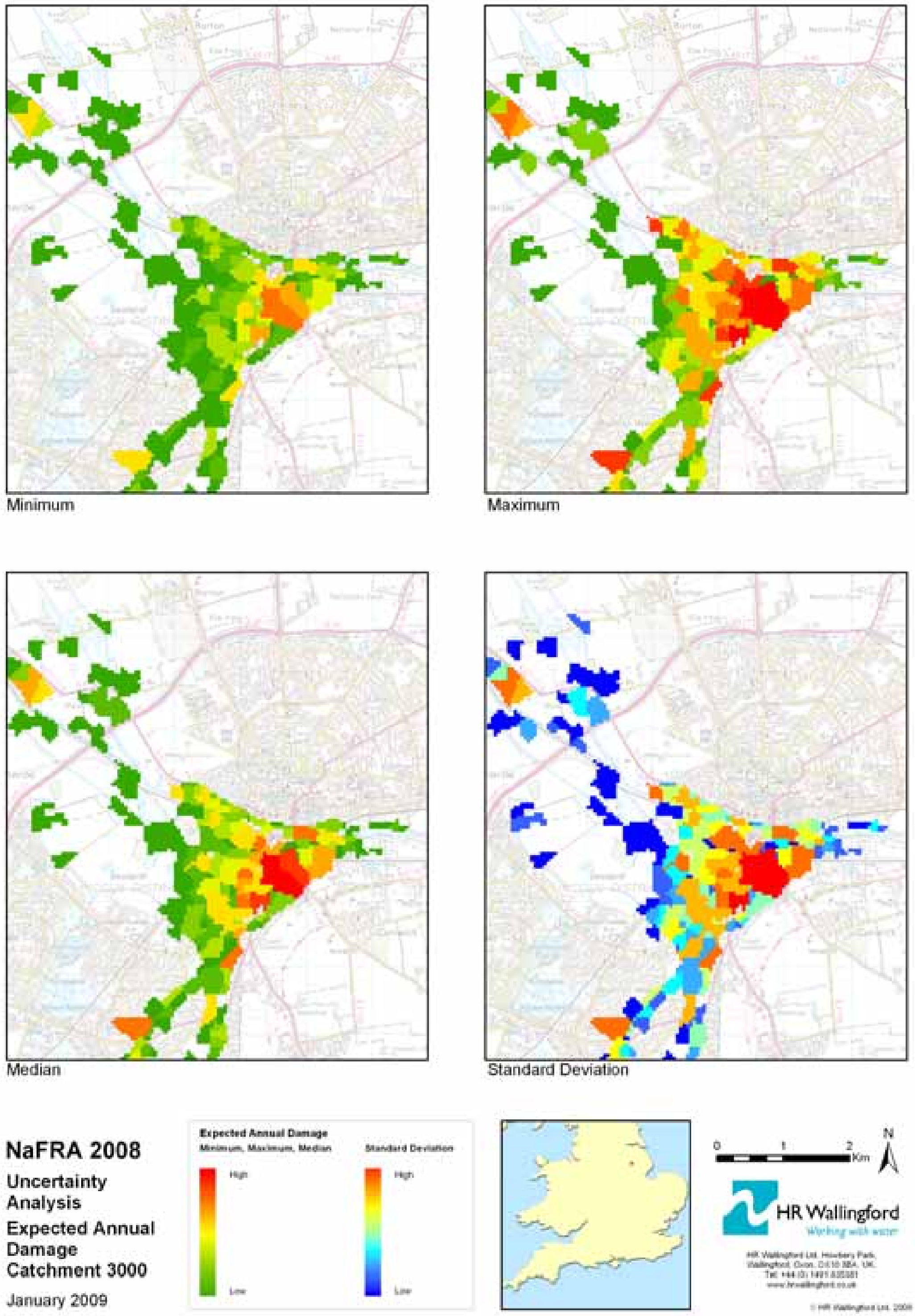

Figure 5.18 Catchment 3000 – Stage 4: Expected Annual Damage (10/50/90 percentiles and SD)

Table 5.2a Summary Table of Results – Expected Annual Damages

	3904	4300	3000
Percentile	% Difference from Median	% Difference from Median	% Difference from Median
5%	-28%	-35%	-43%
10%	-22%	-28%	-36%
25%	-13%	-15%	-22%
50%	0%	0%	0%
75%	14%	16%	24%
90%	28%	30%	48%
95%	37%	38%	62%

The uncertainty in Expected Annual Damages across the three catchments is surprising consistent. The 10th percentile value (a reasonable lower bound) is typically in the region of 25-40% less than the median value. The 90th percentile value (a reasonable upper bound) was typically in the region of 30-60% more than the median value.

Extrapolation to an overall uncertainty in the National EAD value is difficult. This reflects the sample size and the issues of dependences between catchment. The most appropriate method of combining catchment results (and if necessary up scaling from a limited number of catchment runs) will be an important aspect of future studies to considered before more direct support to national funding priorities can be provided.

Table 5.2b Summary – No. of Impact Zones within any given probability band

Catchment 3904

Expressed as a percentage of the total number of Impact Zones

Percentile	Very Low	Low	Moderate	Significant	Very Significant
5	0.1	1.4	1.3	2.0	55.3
10	0.2	1.5	1.3	2.5	60.9
50	0.5	2.0	2.1	6.3	79.4
90	0.9	3.1	5.9	19.6	85.0
95	1.0	3.6	7.2	23.2	85.6

Expressed as a percentage variation from the median value

Percentile	Very Low	Low	Moderate	Significant	Very Significant
5	-77.5	-32.9	-40.7	-68.7	-30.3
10	-61.8	-27.7	-38.4	-60.8	-23.3
50	0.0	0.0	0.0	0.0	0.0
90	57.3	50.2	179.6	212.3	7.0
95	75.6	78.2	240.5	270.0	7.9

Catchment 4300

Expressed as a percentage of the total number of Impact Zones

Percentile	Very Low	Low	Moderate	Significant	Very Significant
5	0.0	0.5	0.4	1.0	60.5
10	0.0	0.7	0.4	1.1	66.2
50	0.2	1.0	0.8	3.3	85.7
90	0.3	1.5	3.6	19.3	88.7
95	0.4	1.9	5.1	23.1	89.0

Expressed as a percentage variation from the median value

Percentile	Very Low	Low	Moderate	Significant	Very Significant
5	-94.1	-43.2	-47.9	-70.9	-29.4
10	-82.4	-31.0	-44.2	-68.0	-22.8
50	0.0	0.0	0.0	0.0	0.0
90	114.1	54.9	357.6	481.4	3.5
95	142.4	99.6	538.7	594.5	3.8

Catchment 3000

Expressed as a percentage of the total number of Impact Zones

Percentile	Very Low	Low	Moderate	Significant	Very Significant
5	0.2	1.5	0.5	1.3	19.4
10	0.3	1.5	0.7	1.4	21.7
50	0.8	1.8	1.0	2.9	30.0
90	1.4	1.9	2.8	8.8	32.6
95	1.5	2.1	3.3	10.2	32.9

Expressed as a percentage variation from the median value

Percentile	Very Low	Low	Moderate	Significant	Very Significant
5	-74.7	-18.4	-46.9	-54.7	-35.3
10	-61.8	-16.4	-26.8	-51.9	-27.5
50	0.0	0.0	0.0	0.0	0.0
90	78.1	4.0	173.9	206.5	8.8
95	89.6	15.4	228.7	254.9	9.7

The above tables explore the uncertainty within the assessment of probability. This is done by reporting the number of impact zone that may or may not be assigned the correct flood probability band. In all pilot catchments the majority of Impact Zones lie in the *moderate* to *very significant* bands. Correspondingly, the most important uncertainties are associated with determining these bands. In part this is likely to reflect the simplistic nature of the bandings used by the Agency (with small changes in probability allowing a given Impact Zone to move from one band to another band). More meaningful descriptions of flood probability should be sought – mostly likely moving away from prescribed and finite bands.

Note: Each cell within the table is independent of all others. Therefore neither the columns nor rows should be expected to sum to 100%.

Table 5.2c Summary – No. of Properties within an given probability band

Catchment 3904

Expressed as a percentage of the total number of properties

Percentile	Very Low	Low	Moderate	Significant	Very Significant
5	0.0	1.1	2.6	3.5	59.2
10	0.0	1.4	2.8	3.9	64.5
50	0.2	2.3	4.2	6.7	78.2
90	0.4	4.0	7.0	16.0	83.5
95	0.4	4.2	7.8	20.0	84.2

Expressed as a percentage variation from the median value

Percentile	Very Low	Low	Moderate	Significant	Very Significant
5	-86.7	-50.8	-36.6	-48.0	-24.3
10	-76.7	-41.6	-32.3	-42.5	-17.4
50	0.0	0.0	0.0	0.0	0.0
90	159.8	70.4	66.8	137.0	6.8
95	161.9	80.3	86.8	197.2	7.7

Catchment 4300

Expressed as a percentage of the total number of properties

Percentile	Very Low	Low	Moderate	Significant	Very Significant
5	0.0	0.1	0.1	1.5	65.5
10	0.0	0.1	0.1	1.8	69.5
50	0.0	0.1	1.1	5.5	80.7
90	0.0	0.4	2.0	15.4	85.4
95	0.0	0.5	2.4	18.9	85.7

Expressed as a percentage variation from the median value

Percentile	Very Low	Low	Moderate	Significant	Very Significant
5	0.0	-43.6	-89.8	-73.7	-18.8
10	0.0	-15.0	-89.0	-67.8	-13.9
50	0.0	0.0	0.0	0.0	0.0
90	300.0	285.7	90.1	178.7	5.8
95	300.0	331.8	123.1	242.0	6.2

Catchment 3000

Expressed as a percentage of the total number of properties

Percentile	Very Low	Low	Moderate	Significant	Very Significant
5	0.0	0.4	0.1	0.4	14.8
10	0.1	0.4	0.2	0.4	16.1
50	0.3	0.5	0.3	1.6	21.0
90	0.4	0.7	0.7	5.7	22.5
95	0.5	0.8	0.9	6.7	22.8

Expressed as a percentage variation from the median value

Percentile	Very Low	Low	Moderate	Significant	Very Significant
5	-86.8	-19.0	-59.8	-76.7	-29.3
10	-71.5	-17.9	-37.7	-72.3	-23.1
50	0.0	0.0	0.0	0.0	0.0
90	33.0	42.3	126.6	261.3	7.4
95	43.1	72.4	168.9	322.2	8.5

The Tables above report the estimated uncertainty in the number of properties by probability band. The values show significant uncertainty. Although there is limited absolute variation in the number of properties within the *very low* and *low* bandings (reflecting the limited number of properties in these bands) there is a marked increase in the uncertainty exhibited in the number of properties in the *moderate* and *significant* banding (with the 10th percentile estimate – a reasonable lower bound - being a factor of 0.2-0.5 of the median value) and the 90th percentile estimate – a reasonable upper bound - being a factor of 2-3 the median value. This large uncertainty is likely, in part, to reflect the narrowness of the probability banding. The *very significant* banding tends to exhibit more moderate uncertainty.

6. Sensitivity Analysis

6.1 INTRODUCTION

Sensitivity analysis is closely related to uncertainty analysis. Sensitivity analysis, however, seeks to determine the relative importance (or not) of individual input variables in terms of their contribution to the uncertainty in the output of a model. A technique for sensitivity analysis that has been used extensively in a number of different fields is Variance Based Sensitivity Analysis (VBSA). This has been proven to be a robust approach and offers a number of advantages over other approaches, such as local sensitivity analysis methods (Saltelli *et al.*, 2004).

6.2 OVERVIEW OF THE APPROACH

The VBSA method applied here has been developed and described within Floodsite (Gouldby *et al.*, 2008a). Within this approach it notes that the output can be decomposed as follows (following Sobol, 1993 , see also Saltelli, Tarantola, Campolongo and Ratto, 2004) :

$$V(Y) = \sum_i V_i + \sum_i \sum_j V_{ij} + \ldots V_{1,2,\ldots,k}$$

where:

$$V_i = V(E(Y|X_i)$$

(i.e. the conditional variance of in the output parameter of interest (*Y)* if the input parameter X_i is fixed and all other input parameters are allowed to vary across their range – the so-called **Main Effect** – i.e. the expected amount of variance that would be removed from the total output variance, if we were able to learn the true value of X_i)

$$V_{i,j} = V(E(Y\,|, X_i, X_j)) - V_i - V_j$$

(i.e. the conditional variance of in the output parameter of interest (*Y)* if the input parameters X_i and X_j are allowed to vary and all other parameters are fixed at their mean values – the so-called **Joint Effects** i.e The expected amount of variance that would be removed from the total output variance, if we were able to learn the true value of both X_i and X_j)

$$V_{Ti} = E[(Y \mid x_{-i})]/(Y)$$

(the conditional variance of in the output parameter of interest (*Y*) if the input parameters X_i is allowed to vary and all other parameters are fixed at their mean values i.e the **Total Effect** - The expected amount of variance that would remain unexplained (residual variance) if x_i, and only x_i, were left free to vary over its uncertainty range, all other variables having been learnt. A variable with a small value of its total effect sensitivity index can be frozen to any value within its range without significant impact on the output).

6.3 EXPERT ELICITATION

At the Challenge Workshop it was agreed that given the project timescales and focus on uncertainty (described in the previous Chapter) the VBSA would not be completed here (instead it will be carried forward into a future development phase). Nevertheless, initial results from the VBSA can be provided and these are given in the figures below (Figures 6.2a and b).

Note: These are provided as indicative only and further work would be required before they could be relied upon.

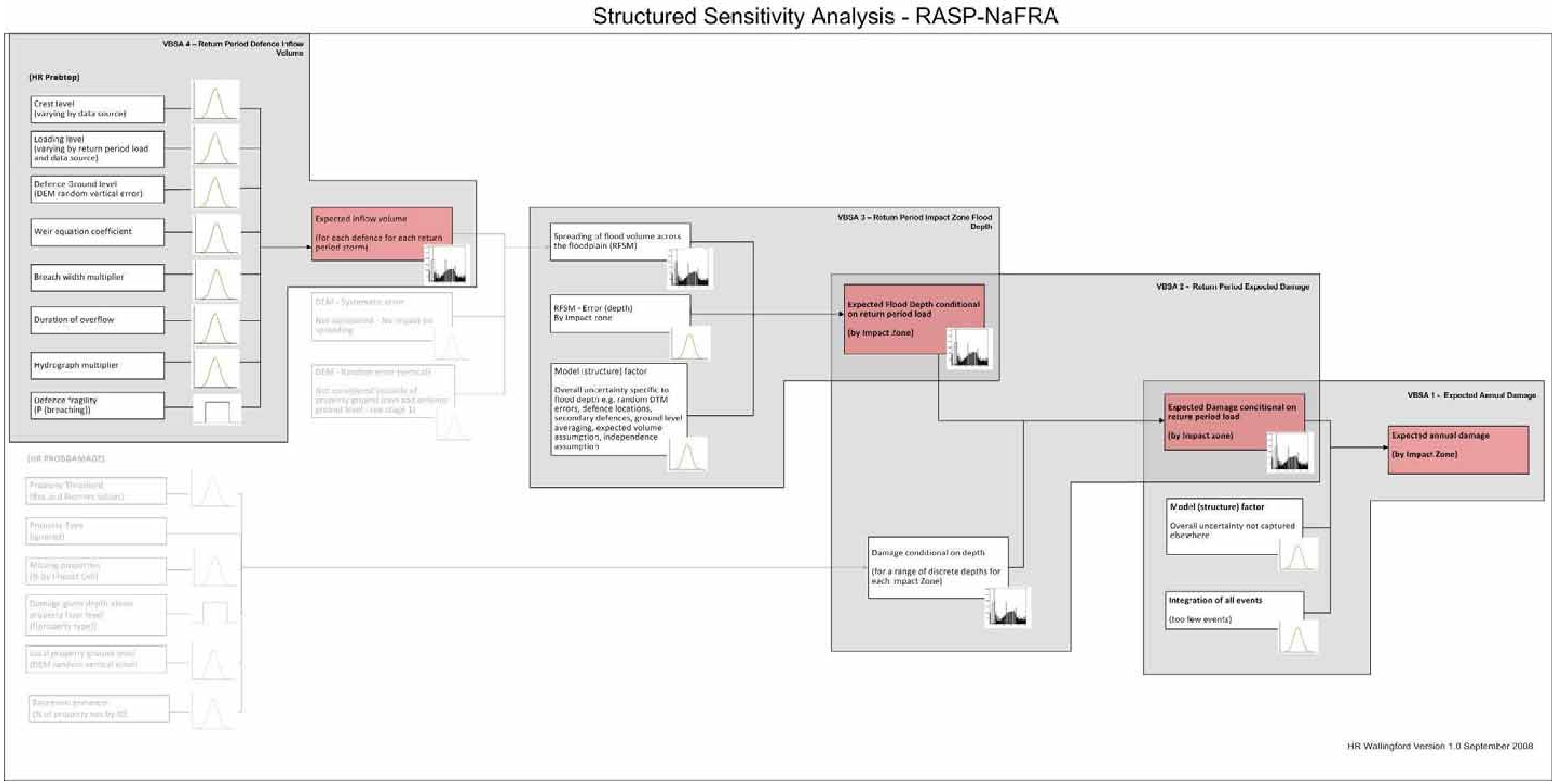

Figure 6.2 Overview of the staged sensitivity analysis

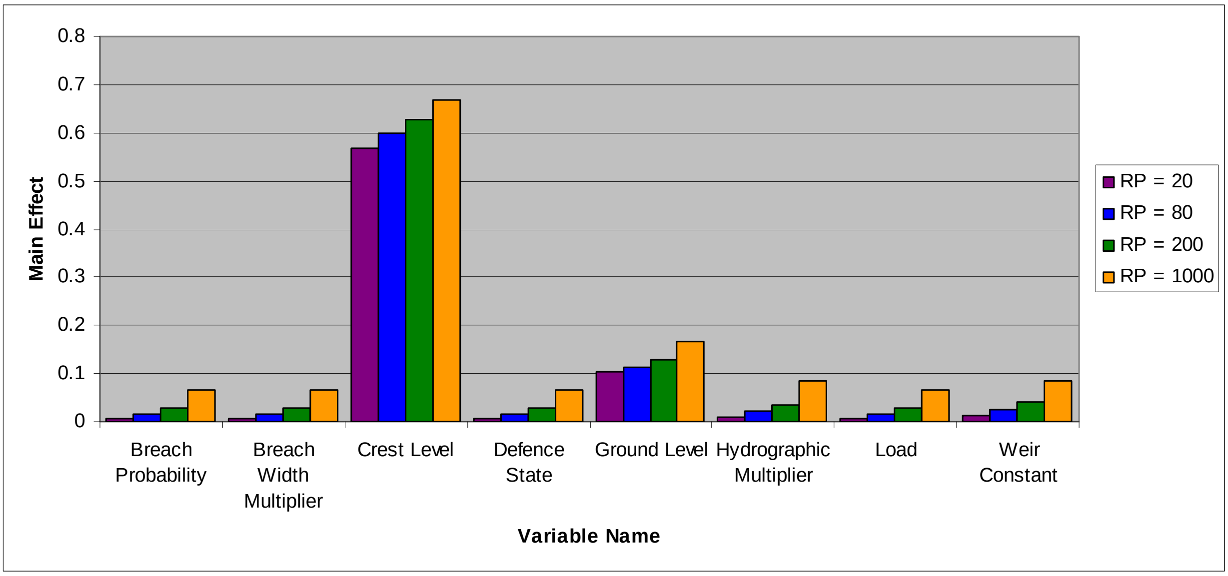

Figure 6.2a Contributions to defence overtopping volume for a given return period event (20, 80, 200 and 1000yrs shown)

The above figure is indicative only and specific to a specific defence within one Flood Area. It does however, show the nature of the information that can flow from the sensitivity analysis and how it could be used to target data improvements.

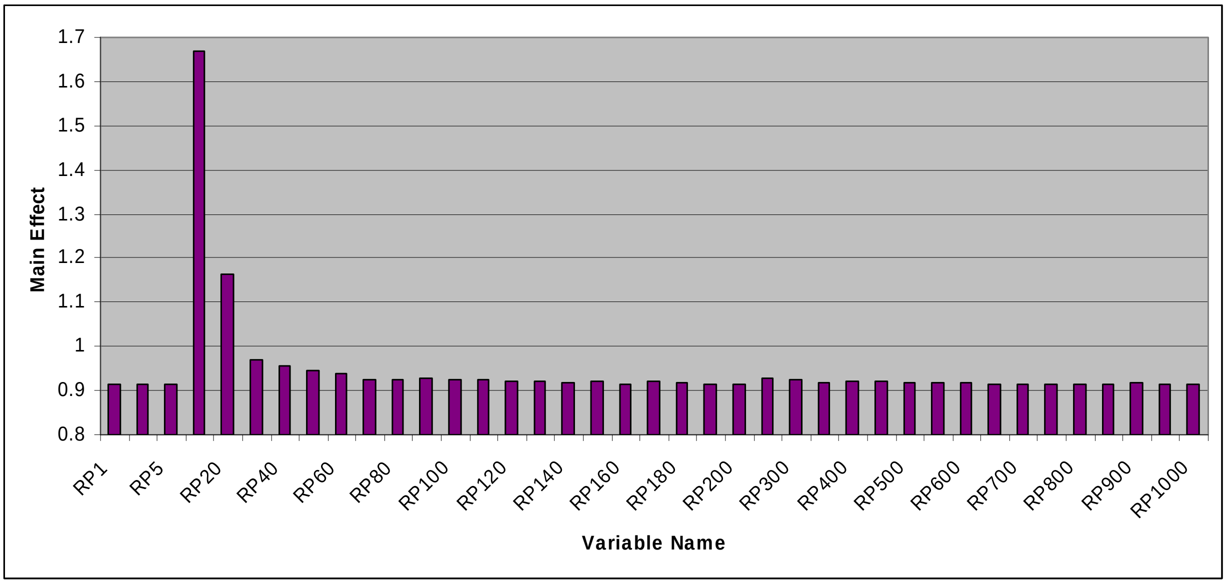

Figure 6.2b Contribution to the uncertainty in the impact zone risk by return period event (initial indicative results)

The above figure highlights the contribution that the results from different return period storms make to the expected annual damage values. The dominance of the 20-60 year return period events (for this given Impact Zone) is striking. Further analysis is recommended to explore the most useful and usable outputs from the rich information set provided by the RASP-MC analysis.

7. Confidence scoring

7.1 INTRODUCTION

An initial approach to providing a confidence score has been developed and discussed through the Challenge Workshop. This approach is outlined below. It should be noted however that this report does not provide a fully developed operationalised approach, but rather an initial investigation of a possible approach.

7.2 OUTLINE OF POSSIBLE APPROACH

An overview of a possible approach to establishing a confidence score for the results from each FRMS is shown in Figure 7.1 below.

Step 3 - Confidence scoring (FRMS scale)

- *Define the Parameter quality for an FRMS Area*
- *Define the Parameter influence on the results across an FRMS*
- *Define the* single *parameter impact on the confidence in the output results (combining its quality and influence)*
- *Describe the Confidence in the output (taking account of all parameters) - (Probability)*
- *Describe the Confidence in the output (taking account of all parameters) – (EAD)*

Figure 7.1 Overview of a possible approach to the Confidence Scoring

As shown in the above figure, five sub-steps are identified. These are discussed in turn below.

Step 1 - Define the parameter quality for an FRMS Area – This provides a qualitative statement of the parameter quality. The input to the formal uncertainty analysis has been focused on the uncertainty associated with the data at a particular point (defence or Impact Cell/Zone). Within an FRMS Area various data sources will be present. The Parameter Quality as part of the confidence scoring process attempts to capture this mixture.

An example for crest level is as follows:

Best of Breed	Measured crest levels exist for over 90% (by length) of the Flood Area (river / coastal boundary)
High	Measured crest levels exist for over 80% (by length) of the Flood Area (river / coastal boundary)
Moderate	Measured crest levels exist for over 60% (by length) of the Flood Area (river / coastal boundary)
Low	Measured crest levels exist for over 30% (by length) of the Flood Area (river / coastal boundary)
Very Low	Measured crest levels exist for less than 30% (by length) of the Flood Area (river / coastal boundary)

Step 2- Define the parameter influence on the results across an FRMS – This provides a qualitative statement reflecting degree of influence the *parameter quality* has on the confidence in the NaFRA result influenced (e.g. probability or consequence). This is informed by the above sensitivity analysis and the expert inputs through the workshop.
An example would be:

Critical
High
Moderate
Low
Very low

Step 3 – Define the* single *parameter impact on the confidence in the output results – This provides a numerical scale describing the weighting assigned to a given parameter that reflects its *quality* and *influence* (based on Confidence Matrix – see below)

Impact on output confidence

Parameter Quality						
	Best of Breed	Moderate	Low	Low	Very low	Very low
	High	High	Moderate	Low	Low	Very low
	Moderate	Very high	High	Moderate	Low	Low
	Low	Very high	Very high	High	Moderate	Low
	Very Low	Overwhelming	Very high	Very high	High	Moderate
		Critical	**High**	**Moderate**	**Low**	**Very low**

Parameter Influence

Figure 7.2 Confidence Matrix – relating parameter quality and its influence to overall impact on output confidence (for a single parameter within an FRMS)

A numerical scale is then attributed to the qualitative description from the matrix as follows:

Overwhelming	1000
Very high	100
High	10
Moderate	1
Low	0.1
Very low	0.01

Step 4 – Describe the Confidence in the output (taking account of all parameters) - (Probability) – The results from the individual parameter impacts are then combined to provide an overall confidence score as follows:

Model Parameter	***Outputs influenced***	***Parameter Quality***	***Parameter Influence***	***Impact on output confidence***	***Associated quantified score***
Crest Level	Probability / Depth	Moderate	Very low	Low	0.1
Water level	Probability / Depth	Very High	Very Low	Low	0.1
Defence ground level	Probability / Depth	Best of breed	Very Low	Very low	0.01
Weir equation coefficient	Probability / Depth	Low	Very Low	Very low	0.01
breach width multiplier	Probability / Depth	High	Low	Low	0.1
Duration of overflow	Probability / Depth	High	Moderate	Low	0.1
Hydrograph multiplier	Probability / Depth	Moderate	Very Low	Low	0.1
Defence fragility (P(breaching))	Probability / Depth	Low	Very Low	Very low	0.01
Overtopping volume	Probability / Depth	Very Low	High	Very high	100
RFSM - Error (depth) by Impact Zone	Probability / Depth	High	Very Low	Very low	0.01
Model structure	Probability / Depth	High	Very Low	Very low	0.01
		Total confidence in probability / depth output score			100.55
		<1	Very High Confidence		
		>1 and <5	High Confidence		
		>5 ad < 25	Moderate Confidence		
		>25 -and < 50	Low Confidence		
		>50	Very Low Confidence		

A quantified score is then converted to a semi-qualitative statement of confidence in the probability outputs within a Flood Area. For example:

Very High Confidence	About 9 out of 10 Impact Cells are likely to have been assigned the correct Probability Band, with the true resulting lying within one band above or below (where possible) for almost all Impact Cells – TO BE CONFIRMED
High Confidence	About 7 out of 10 Impact Cells are likely to have been assigned the correct Probability Band, with the true resulting lying within one band above or below (where possible) for 8 out of 10 Impact Cells
Moderate Confidence	About 5 out of 10 Impact Cells are likely to have been assigned the correct Probability Band, with the true resulting lying within one band above or below (where possible) for 6 out of 10 Impact Cells
Low Confidence	About 3 out of 10 Impact Cells are likely to have been assigned the correct Probability Band, with the true resulting lying within one band above or below (where possible) for 4 out of 10 Impact Cells
Very Low Confidence	About 1 out of 10 Impact Cells are likely to have been assigned the correct Probability Band, with the true resulting lying within one band above or below (where possible) for 2 out of 10 Impact Cells

Step 5 – Describe the Confidence in the output (taking account of all parameters) – (EAD) – Step 4 is then repeated for the EAD calculations as follows:

Model Parameter	***Outputs influenced***	***Parameter Quality***	***Parameter Influence***	***Impact on output confidence***	*Associated quantified score*
Probability	Risk	Moderate	High	High	10
Property Threshold - Res	Risk	Low	Low	Low	0.1
Property Threshold - Non-res	Risk	Low	Low	Low	0.1
Property Type	Risk	Moderate	Moderate	Moderate	1
Missing properties (by IC)	Risk	Low	Moderate	Low	0.1
Damage given depth above property floor level (func. of prop type)	Risk	High	Moderate	Low	0.1
Local property ground level	Risk	Moderate	Moderate	Moderate	1
Basement presence (% of property nos by IC)	Risk	Low	Moderate	Low	0.1
Model structure	Risk	High	Very Low	Very low	0.01
		Total confidence in probability / depth output score			12.51
		<1	Very High Confidence		
		>1 and <5	High Confidence		
		>5 ad < 25	Moderate Confidence		
		>25 -and < 50	Low Confidence		
		>50	Very Low Confidence		

Very High Confidence – descriptors…..
High Confidence
Moderate Confidence
Low Confidence
Very Low Confidence

Figure 7.3 Proposed approach to combine multiple parameters to an overall confidence score and category

8. Conclusions

1.0 This report provides a summary of the analysis methods and results from the uncertainty analysis and builds upon the Confidence Workshop held in December 2008.

2.0 There is a need to understand the uncertainties within the main NaFRA outputs and how best to report these. This report provides a useful contribution to that ongoing discussion.

3.0 The uncertainty and sensitivity analysis is appropriate for some but not all types of uncertainty. It reflects accuracy of data and model parameters but is not so suitable for assessing some types of major errors in data or model, nor missing data. For example, systematic errors within the evaluation of economic damages for given depth would not be reflected.

4.0 The method used assumes independence between the input variables and parameters. This is an appropriate assumption for this initial study. The approach could be readily adapted to relax this assumption.

5.0 The approach adopted for this initial trial assumes that the results for each Impact Zone are fully dependent. This is an appropriate assumption for this initial study but should be reviewed in future analysis and, if appropriate, relaxed (for example to explore the uncertainty within individual event damages).

6.0 A detailed uncertainty (an initial sensitivity) analysis on NaFRA for **three sample catchments** has been undertaken. The results show that:

- **Overtopping volume** - The uncertainty in the overtopping volume is significant and varies significantly between defences (e.g see Figure 5.5d)
- **Flood depth** - The uncertainty in flood depth within an Impact Zone increases with return period (see Figures 5.7a and b for example). The uncertainty in flood depth is sensitivity to the uncertainty in the overtopping volume and quality of the ground data (as referenced in Figure 6.2). The modelling approach has an impact on the estimated flood depth to (through the inclusion of the error in the final flood depth estimated by the Rapid Flood Spreading Method (Lhomme *et al.*, 2008), and this is included in the results (based on quantified comparisons with TUFLOW undertaken as part of the NaFRA 07 development, HR Wallingford, 2008). However the systematic deficiencies within the model (e.g. representation of transient flood depths) are not reflected.
- **Expected Annual Damage** - The uncertainty in Expected Annual Damages across the three catchments was observed to be relatively consistent. The 10^{th} percentile value (a reasonable lower bound) is typically in the region of 25-40% of the median value. The 90^{th} percentile value (a reasonable upper bound) was typically in the region of 30-50% more than the median value (see Table 5.2a).
- **Number of properties within a band** - The uncertainty in the number of properties by probability band shows significant uncertainty. Although there is limited absolute variation in the number of properties within the *very low* and *low* bandings (reflecting the limited number of properties in these bands) there is a marked increase in the uncertainty exhibited in the number of properties in the *moderate* and *significant* banding (with the 10^{th} percentile estimate – a reasonable lower bound - being a factor of 0.2-0.5 of the median value) and the 90^{th} percentile

estimate – a reasonable upper bound - being a factor of 2-3 the median value. This large uncertainty is likely, in part, to reflect the narrowness of the probability banding. The *very significant* banding tends to exhibit more moderate uncertainty.

- **Number of Impact Cells within a given probability band** – Unlike properties, Impact Cells are more evenly distributed across the catchment and provide a useful measure in understanding the uncertainty within the probability information at a catchment scale. Within each of the pilot catchments the range of Impact Zones within the significant and very significant band exhibits the greatest uncertainty – with variations between the 5th and 95th percentiles of up to plus or minus 10-20% of the total number of impacts zones within the catchment. The discretization into bands reduces the utility of this measure however and perhaps more continuous representations of flood probability should be considered for the future.

7.0 Data improvements should be targeted to priority areas - for example to reduce the uncertainty in high consequence areas. The sensitivity analysis has shown how to identify individual data priorities for each FRMS - based on the importance for flood risk assessment (see Figure 6.2 by way of example). This will need more testing before being widely applied but the analysis presented here demonstrates the potential to identify specific priorities for a data improvements programme.

8.0 The sensitivity analysis has also highlighted the importance of the 1:10-1:50 year return period events in establishing a reliable estimate of depth v probability and risk - a range of events that perhaps has not be historically focused upon (see Figure 6.2b).

9. Recommendations

1.0 ***Overview*** - The project provides an interesting and useful start in the development of a more structured assessment of uncertainty within the NaFRA outputs. It is however clear that considerably more work is needed to identify the key drivers of uncertainty in the output – including both model structure as well as the input variables and parameters.

2.0 ***Confidence scoring versus quantified uncertainty analysis*** – During the Challenge Workshop it became clear that the quantified uncertainty analysis using the RASP-MC was capable of providing the information on uncertainties at a local FRMS scale that directly reflects the local quality of the data and the system it influences. Within a semi-qualitative confidence scoring method (as outlined in Section 7) this would be difficult to achieve, and it was likely that such a scoring system would quickly become very complex, negating the benefits of simplicity that were initially perceived. It was concluded that the national application of the RASP-MC should be considered for NaFRA 09 and beyond, together perhaps with a high level confidence scoring system to provide a ground truth to the results.

3.0 ***Model structure*** – going forward it will be important for the analysis to reflect the variation in model performance in different circumstances – for example steep or shallow floodplain, wide or narrow floodplain, braided channel, representation of transient flood depths, systematic errors in the depth versus damage relationships etc. At present the same levels of uncertainty are applied in all circumstances.

4.0 ***Review of variables and parameters*** – The project has presented an initial set of uncertain variables and parameters. The values used will need further review and refinement (e.g the presentation of the uncertainties in extreme water levels adopted would need refining to represent the different physical settings as well as simply the data source). This will need to be done in conjunction with a ground truthing activity to supplement the qualitative evidence gathered at the Challenge Workshop.

5.0 ***Application of the sensitivity analysis*** – It has not been possible to complete the application of the sensitivity analysis here due to the agreed change in the project focus towards the uncertainty analysis. This report does however provide an interesting and powerful line of enquiry and should be taken forward in NaFRA 09/10. Following a full trial of the approach – and in particular agreement and discussion regarding the preferred and most useful outputs – application nationally to all FRMS should be considered. Given the complexity of the outputs and increased complexity of the RASP-MC model it will be important to carefully consider the most effective means of application (e.g. within the Areas or centrally as an offline activity).

6.0 ***Relaxation of underlying assumptions*** – As part of further work it would be interesting, and useful, to explore the impact of correlated input parameters and variables and the importance of a fully correlated approach to the aggregation of results. This includes the separate identification of systematic errors as well as correlated and uncorrelated random variables. For example, input parameters such as breach size and water level, as well as spatial aggregation of the results (i.e. potential systematic errors in damages associated with a defined flood depth as well as aggregation of results from individual Impact Cones to Flood Areas, Catchments and National).

7.0 ***Presentation and communication of results*** - Significant further work is required to provide the most informative means of communicating the results. The communication of uncertainty is quite different from communicating probability and further exploration is required. Extracting the most meaningful information from the rich data provided by the uncertainty and sensitivity analysis will be critical to realising its potential impact. Although the needs of NaFRA are very specific, inspiration can be drawn from the examples given here and in earlier NaFRA studies as well work ongoing in projects elsewhere (such as communication of probabilistic flood warnings commissioned by the Agency)

8.0 ***Ground truthing and validation*** – Significant challenges exist in ground truthing some of the distributions used in the model through to validating the output results. In some instances inputs can be directly verified and this should be undertaken to increase the confidence in the modelling approach. Innovative approaches to validating the outputs will need to be developed, but it is likely that any approach will involve expert judgement and review. A much closer link should be established between the uncertainty work and the gathering of specific supporting datasets to inform the assessment of the uncertainty in the input variables and parameters.

9.0 ***Utilise the approaches developed here in other RASP tools*** – The approaches applied here are significantly in advance of the methods proposed for inclusion in MDSF2/PAMS. At some future date it will be important that specific advances are reflected in MDSF2 and PAMS.

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