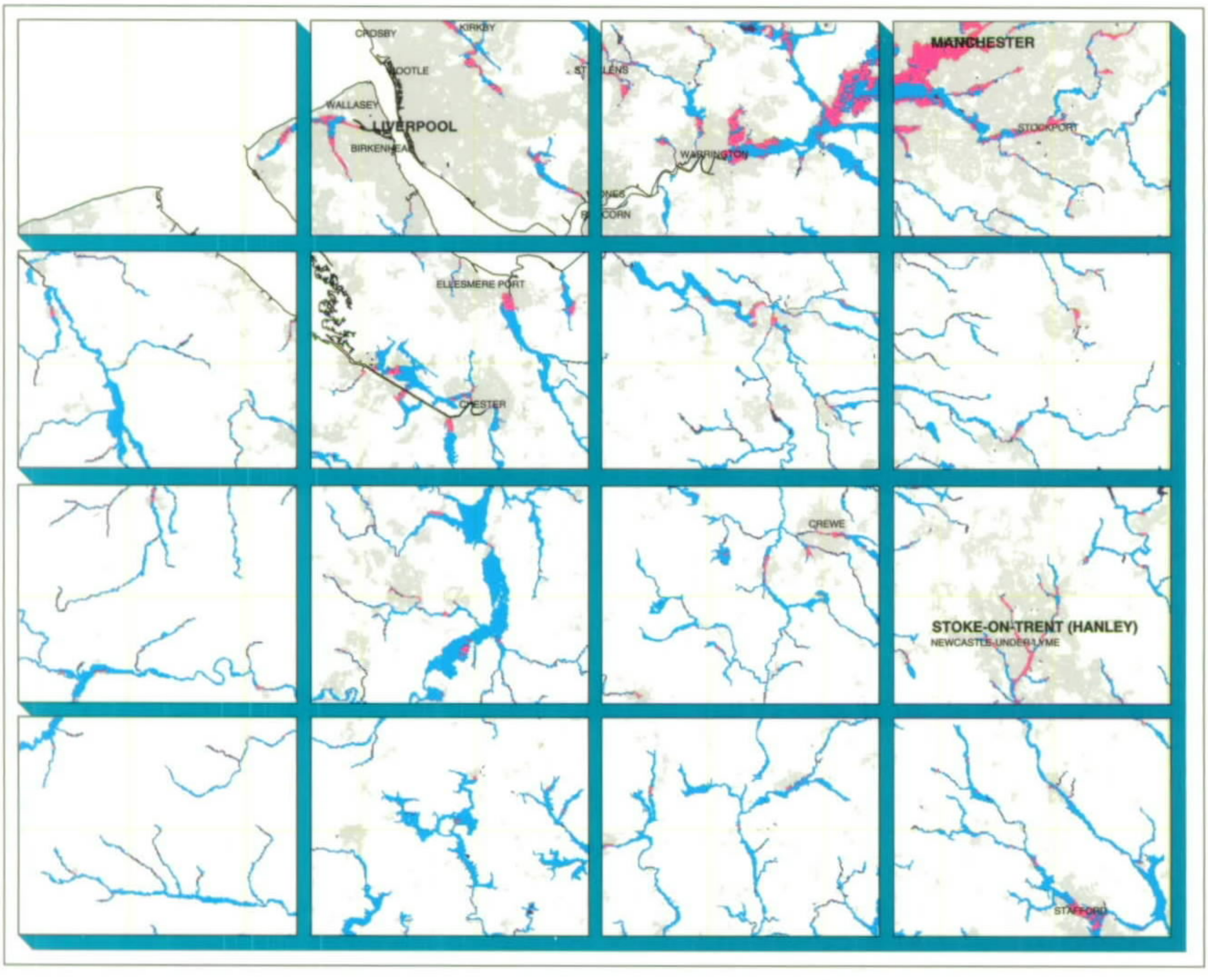
Institute of Hydrology

Report No. 130

Flood risk map for England and Wales



Natural Environment Research Council

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Flood risk map for England and Wales

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Requests for the use under licence of all or part of the digital dataset of the estimated 100-year flood risk area (if undefended) should be addressed to the Spatial Data Manager, NERC Institute of Hydrology, Crowmarsh Gifford, Wallingford, Oxfordshire, OX10 8BB.

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Contents

Executive summary

This report presents maps of England and Wales showing an estimate of the areas that would be inundated by floods of the 100-year return period level from non-tidal rivers, in the absence of flood defences. The maps also identify the built-up areas that would be at risk. Tables summarise the distribution of the flooding, by depth and locality. The methods and data used in the estimation of this flood risk are described.

It is believed that there has been no previous nationwide estimate of these quantities at this level of detail.

The work has been made possible by several recent developments at the Institute of Hydrology:

- Completion, for England and Wales, of the Institute of Hydrology Digital Terrain Model (IHDTM);
- Development of methods of estimating flood depths directly from catchment characteristics;
- Completion, for England and Wales, of the IH digital river centre-line network (based on Ordnance Survey 1:50 000 maps);
- Establishment of digital spatial datasets that allow catchment characteristics to be computed automatically to any point on the river network;
- Production of a national digital dataset of built-up areas (based on the Institute of Terrestrial Ecology's Land Cover Map of Great Britain and OS 1:250 000 digital settlement data);
- Development of techniques and software for exploiting and displaying digital spatial data.

The analysis has been conducted on a 50 m square grid, which is the horizontal resolution of the IHDTM. The 1:50 000 river network has been represented on the grid, and the 100-year flood depth has been computed for every point where the catchment area exceeds 10 km^2. Mean annual maximum flood depth has been estimated from catchment characteristics (area, rainfall and soil) using previously established equations, and then growth curves have been used to obtain the depth of the 100-year flood. The incremental depth of the 100-year flood has been calculated relative to the mean annual flood depth, the level of which has been assumed, typically, to be just greater than bankfull. It is recognised that this assumption does not take full account of local conditions and consequently there will be a range of uncertainty in the results. This uncertainty can be significant at some locations. On balance, however, this approach is believed to provide a valid way of summarising the risk of flooding at regional and national levels, but it is nevertheless recommended that all users read Chapter 6, which summarises the causes of uncertainty.

The areal extent of inundation has been determined by taking each flooded river point in turn and using the IHDTM to identify contiguous areas of its catchment that are lower than or equal to the elevation of the flood surface. This approach has obviated the need to model the flow of water down the flood plain. Flooding from a major river across minor braids or tributaries is modelled subsequently. The sensitivity of the method has been tested by comparison of the areas inundated by flood depths of 80% and 120% of the 100-year flood depth.

The resulting maps of flood extent have been compared with existing maps of flood risk (mostly maps produced by the former Water Authorities to meet the requirements of Section 24(5) of the 1973 Water Act) at thirty locations throughout England and Wales. After careful analysis, these were judged to be in good agreement with the model in most cases, so much so that it is considered that presenting the results at scales greater than the largest used in this report (1:625 000) would not be inappropriate for providing an indication of the potential extent of flooding. Such larger scale maps would need to be used with care and verified using more accurate methods. If greater accuracy is required using this method, it is suggested that the incorporation of more detailed elevation data in valley bottoms during the construction of the IHDTM would lead to significant improvements in shallow valleys.

The results indicate that 10 683 km^2 of land would be at risk, of which 611 km^2 is built-up. These figures represent 7.1% of the land area of England and Wales and 6.8% of its built-up area respectively.

List of abbreviations

AA	Automobile Association (A vendor of digital map data)
AREA	Catchment area
CHWIDTH	Channel width
CV	Coefficient of variation of river depth
D100	Depth of 100-year flood
HOST	Hydrology of soil types (A hydrological soil classification)
IH	Institute of Hydrology
IHDTM	Institute of Hydrology Digital Terrain Model
ITE	Institute of Terrestrial Ecology
LCMGB	Land Cover Map of Great Britain (A digital dataset)
MAD	Mean annual flood depth
MAFF	Ministry of Agriculture, Fisheries and Food
NERC	Natural Environment Research Council
NRA	National Rivers Authority (Subsumed into the Environment Agency on 1st April 1996)
OS	Ordnance Survey
SAAR	Standard period average annual rainfall (1941-70 in this case)
SOIL	An index of catchment soil permeability, derived from WRAP
TM	Thematic Mapper (An instrument on the Landsat satellite)
WRAP	Winter rainfall acceptance potential (A 5-class hydrological soil classification)

Acknowledgements

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Thanks are also due to the staff of the former National Rivers Authority regions who supplied validation site maps and the Institute for Terrestrial Ecology for supplying the LCMGB dataset.

1 Introduction

The aims of this project — commissioned by the Ministry of Agriculture, Fisheries and Food (MAFF) — were to map and quantify the areas of England and Wales at risk from river flooding under natural conditions (i.e. disregarding any benefits of flood defences) from floods of a return period of 100 years, and to identify the built-up areas at risk.

The commission was stimulated by the lack of a single map or map series which defined flood risk to a consistent standard and to a consistent return period. Prior to this project a variety of regional maps of flood risk existed, notably those produced by the former Water Authorities for Section 24(5) of the 1973 Water Act. Furthermore no such map was held in digital form, making it impossible to automatically combine areas of flood-risk with newly available digital maps of built-up areas.

The automated production of a national flood risk map has been made possible by the recent completion of several major digital spatial datasets for England and Wales, the development of methods of estimating flood depths from catchment characteristics and the development of techniques and software for exploiting digital spatial data.

The datasets, described in Chapter 2, comprise the Institute of Hydrology's Digital Terrain Model (IHDTM) and digital 1:50 000 river centre-line network, the Institute of Terrestrial Ecology's Land Cover Map of Great Britain (LCMGB), Ordnance Survey (OS) digital 1:250 000 settlement polygons, and gridded versions of the soil permeability and average rainfall maps from the Flood Studies Report (NERC, 1975).

Chapter 3 describes how the flood risk map has been produced. A value of area, rainfall and a soil permeability index has been calculated for the catchment to every point on a 50 m square grid representation of the 1:50 000 mapped river network. These quantities have been used to provide an estimate of the 100-year return period flood depth at every point on the river network, and the IHDTM has been used to define the consequent areal extent of inundation. A flood-depth database has been established to hold the results and to facilitate automated combination with built-up areas derived from the LCMGB and OS settlement data.

The results have been compared with existing flood maps at 30 locations across the country. Chapter 4 describes this validation exercise and includes a 1:50 000 map of each location.

Chapter 5 presents the flood risk map in five styles and tabulates the results.

Chapter 6 discusses some of the limitations of the results. **It should be read before using the material presented in this report.**

Chapter 7 makes suggestions for further work.

A copy of all or part of the digital dataset of estimated 100-year flood risk may be licensed from the Institute of Hydrology by applying to The Spatial Data Manager at the Institute of Hydrology, Crowmarsh Gifford, Wallingford, Oxon, OX10 8BB, UK.

2 Data sources

2.1 The Institute of Hydrology's digital 1:50 000 river centre-line network

In a long-term project, which began in the mid-1970s and is expected to be completed in 1996, the Institute of Hydrology (IH) is developing a river centre-line network of the UK based on OS 1:50 000 water features. The dataset consists of all the single blue lines from the source maps, plus centre-lines from double sided rivers, lakes and estuaries. All gaps in the source material have been closed, using local knowledge where necessary, to give a network that is continuous from source to mouth.

The network has been used in this project to define the location of stream sources and to register the location of flood plains digitised from a variety of maps for validation purposes.

2.2 The Institute of Hydrology Digital Terrain Model (IHDTM)

The IHDTM was used to define catchment areas, directions of flow and the extent and depth of inundation. It contains a value of ground elevation, surface type (sea, lake, land or river), outflowing drainage direction, inflowing drainage direction pattern and inflowing catchment area for every point on a 50 m square grid covering England and Wales. When UK coverage is complete it will contain values for approximately 100 million grid points. It has been derived from digital 1:50 000 contours, lake shores, spot heights and the high water mark, all licensed from OS, and from IH's digital 1:50 000 river centre-line network.

The most important feature of this model is that it has well-formed river valley profiles, both lateral and longitudinal, as a result of using purpose-written software for river heighting and vector-to-grid interpolation (Morris and Flavin, 1990). In spite of this, in flat low-lying areas, there were numerous instances of IHDTM-derived flowpaths failing to coincide with the positions of the mapped rivers. These made it unsuitable in one such area (part of East Anglia) for the requirements of this project, and a planned enhancement, for 'locking' the patterns of the river network into the drainage direction grid prior to interpolation, had to be brought forward. The new method has been applied to hydrometric areas 32 and 33 to give total agreement between mapped and modelled drainage networks.

2.3 Built-up areas

In 1993 the Institute of Terrestrial Ecology (ITE) completed the Land Cover Map of Great Britain (LCMGB), the first high resolution digital map to classify land cover throughout Great Britain. The map has been derived from the Landsat satellite's Thematic Mapper (TM) images, calibrated with data from an extensive programme of ground observations (Fuller, 1993; Fuller and Groom, 1993). The classification uses 25 land cover types, including urban, suburban, open water and numerous types of vegetation, on a 25 m square grid.

The urban and suburban classes from this grid represent the best high resolution digital source of British built-up areas currently available. However, because of the similarity of signals from bare earth and built-up areas, and because fully suitable winter and summer TM images for all locations were unavailable, there are some instances where grid squares have been falsely classified as urban or suburban. This has little impact on the LCMGB's depiction of vegetative cover — its principal purpose — but it was considered that it might distort the statistics of built-up flood risk that were to be derived in this study.

In response to this concern, IH has developed a 50 m built-up areas gridded dataset from the LCMGB urban and suburban classes and the settlement polygons from the OS digital 1:250 000 maps (product name Strategi). This dataset benefits from Strategi's authoritative definition of the boundaries of all settlements from small villages upwards, and the LCMGB's detailed depiction of the distribution of built-up and non-built-up land within the settlements. This project has been the first to use the new dataset.

2.4 Average annual rainfall

The map of 1941-70 average annual rainfall isohyets, produced by the Met. Office and published in the Flood Studies Report (NERC, 1975), is held at IH in digital form as vectors and as a 1 km square grid. The gridded version was used to determine catchment average rainfall (in mm) for use in the equation for flood depth. This quantity is known as SAAR (standard period average annual rainfall).

2.5 Soil permeability

Another 1:625 000 map from the Flood Studies Report was also used in this project: the winter rainfall acceptance potential (WRAP) map, produced by the Soil Survey of England and Wales. This is held on a 100 m square grid and divides soils into five classes, where class 1 indicates a very high WRAP and class 5 a very low WRAP. A catchment characteristic (SOIL), based on the proportions of a catchment in each WRAP class, is used in the equation for flood depth. Values of SOIL range from 0.15 for a catchment entirely on WRAP class 1 to 0.5 for a catchment entirely on WRAP class 5.

The recently developed hydrology of soil types (HOST) classification (Boorman *et al.*, 1995) was not used because the selected flood depth estimation method (see Chapter 3) was based on WRAP.

2.6 Existing flood risk maps

For an independent assessment of the validity of the output from the model, a number of flood risk maps were obtained and the areas shown as having flooded in the past or considered to be at risk of flooding were digitised for a selection of sites. To achieve a good geographical spread it was hoped to obtain data for two river lengths (of about 10 km) from each of the ten original regions of the National Rivers Authority (NRA). (The NRA became part of the Environment Agency on 1st April 1996.) In practice, the selection was influenced by the availability of suitable maps, but with the exception of the Anglian region, there is a fairly representative national coverage (see Map 4.1). Most of the maps used had been produced for Section 24 (5) of the Water Act 1973. Details of the sites are given in Chapter 4.

3 Method

3.1 Selection of a method

Three approaches to the delineation of the areal extent of flood risk were considered:

- Digitise existing maps;
- Use established equations to estimate 100-year return period flood flows from catchment characteristics, then converting to depth over the flood plain using an hydraulic model;
- Use equations to estimate 100-year return period flood depths from catchment characteristics, then estimate the associated areal extent of inundation by using the part of the catchment below the flood level.

The first approach was considered to be expensive, time consuming and to involve problems related to map availability and consistency. The second, whilst benefiting from extensive research into relationships between catchment characteristics and flood flows (e.g. NERC, 1975), had the serious disadvantage of needing reliable hydraulic models for all points on the river system. The third, which makes use of relationships derived by Naden and McCartney (1991), had the advantage of being suitable for automation, and it was therefore selected. It should be noted that the 100-year return period depth derived using this method may not always lead to the 100-year return period area of inundation, as it does not take flood volume into account: this omission may cause it to exaggerate the extent of a flood in extensive flat areas.

3.2 Naden and McCartney's research on direct estimation of flood depth

Naden and McCartney's 1991 report represented the main outcome from the direct Stage Frequency Estimation project (AC5) of the River Flood Protection Programme, commissioned by MAFF.

Of all the UK river flow gauging station records held by the Institute of Hydrology, 34 were identified for which there existed an out-of-bank rating and more than ten years of flood peak data. For each of these the flow record was converted into a corresponding depth record. To remove the effect of changing channel geometry on the stationarity of the flood-depth record, a single rating equation was used for each station. This had the effect of generating the depths which would have been observed had the channel geometry been that which prevailed at the time the rating equation was applicable. The resulting time-series of flood-levels were analysed and depths for a variety of return periods up to 200 years were calculated.

From the 27 of these stations for which catchment characteristics were held, a regression equation was derived which related the mean annual maximum flood depth (MAD) to catchment characteristics:

$$MAD = 0.0075AREA^{0.284}SAAR^{0.685}SOIL^{0.601} \qquad [3.1]$$

where AREA is the catchment area in km^2, and SAAR and SOIL are as defined in Chapter 2.

For each station, a growth curve was established which showed the n-year return period flood depth as a multiple of MAD. Using statistical techniques, it was possible to group the stations into four clusters and then pool the data within each cluster to derive four 'regional' depth frequency curves (Figure 3.1). These indicate that the 100-year flood depth ranges from 1.30 to 1.73 times MAD.

To apply the method to an ungauged site, it is necessary to locate the site on Figure 3.1(a) and allocate it to the nearest cluster. The position on the y-axis (coefficient of variation of depth), and the position on the x-axis (mean annual maximum depth/channel width)) can be obtained from:

$$CV = 48.80SAAR^{-0.74}SOIL^{0.42} \qquad [3.2]$$

and

$$CHWIDTH = 0.05AREA^{0.45}SAAR^{0.60}SOIL^{0.88} \qquad [3.3]$$

(where CHWIDTH is the channel width), both of which can be derived automatically.

Naden and McCartney also presented an alternative, regression-based, method. This gave the following equation for the 100 year flood depth:

$$D100 = 0.052AREA^{0.27}SAAR^{0.48}SOIL^{0.56} \qquad [3.4]$$

3.3 Selected definition of flood depth

It was decided to start by using the growth curve method, taking the ratio from curve I (1.73 times MAD) for all locations in the hope that this would fit or over-fit at all validation sites. It was hoped that it would then be possible to refine the method, either by systematically selecting different growth curves or by making use of the regression equation (3.4).

Common to any method was the need to be able to relate the flood depth provided by the equations to the depth of flooding at the river bank. If the return

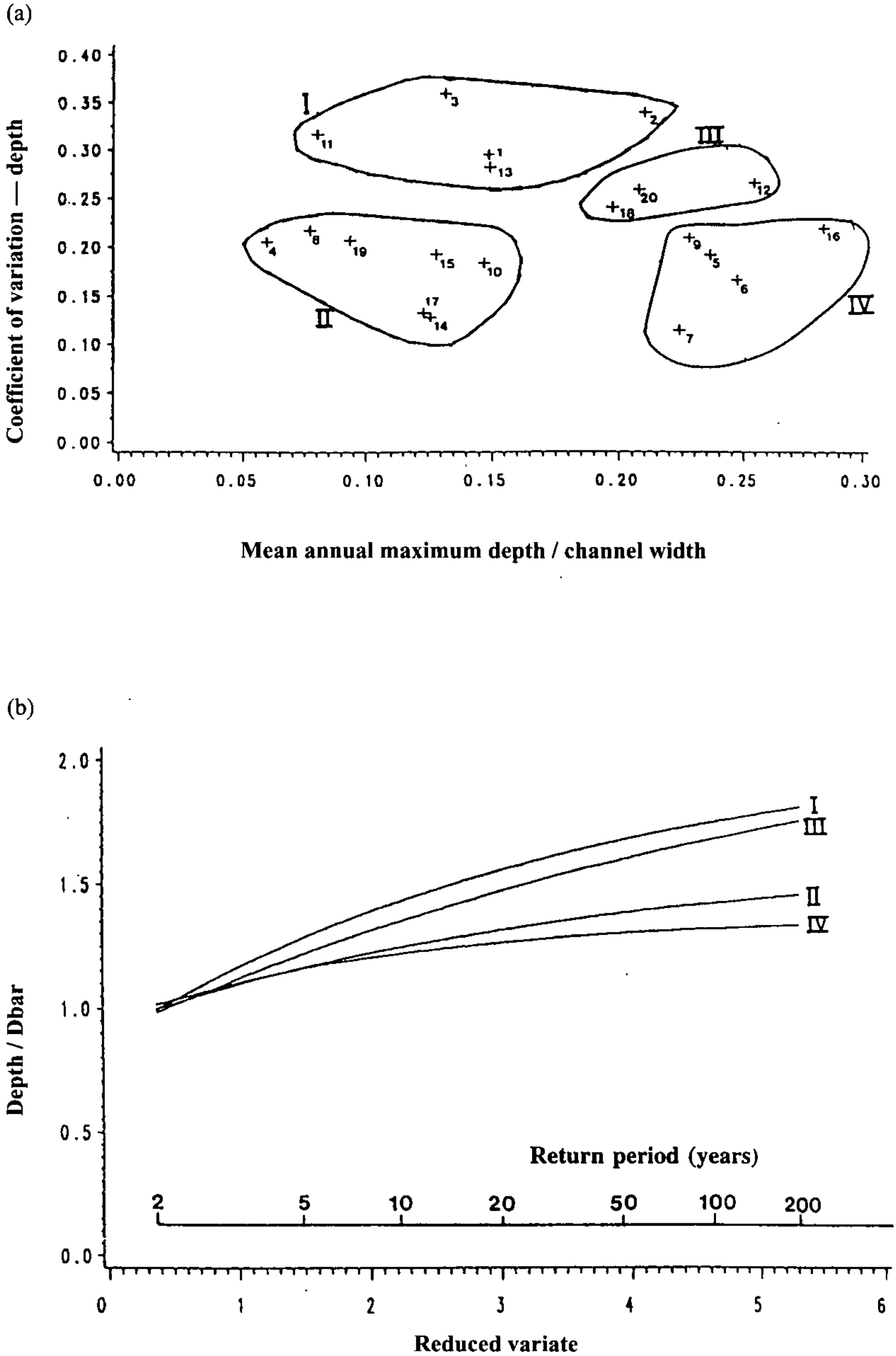


Figure 3.1 Growth curves (from Naden and McCartney, 1991)

period corresponding to bankfull was known, the method could be used to estimate both its depth and the 100-year depth, their difference being the required depth at the river bank. Several authors (e.g. Bray, 1975; Dury, 1976) have concluded that the dominant or channel-forming discharge is lower than that of the mean annual flood. Leopold *et al.* (1964) equate it to the bankfull discharge and a return period of 1.5 years; Naden and McCartney (1991) report an unpublished figure of 1.3 years for the UK.

It was therefore decided to make a small (arbitrary) allowance of 0.3 m for the difference between the mean annual flood depth and the (typically) more frequent bankfull depth. The flood depth used was thus (D100 - MAD) + 0.3 (metres). (A further 0.5 m had to be added to the elevation of the flood surface to compensate for the fact that during the construction of the IHDTM, grid points representing rivers are dropped by 0.5 m relative to ground elevation in order to emphasise channel profiles.) It was recognised that this method of defining flood depth could give rise to local inaccuracies where the bankfull capacity differed from the assumed norm.

3.4 Computing flood depth at every point on the river network

Equation 3.1 requires values for AREA, SAAR and SOIL. AREA is available at every 50 m grid point, since it is an integral component of the IHDTM. The other two variables can be computed by automatic overlay of a digital catchment boundary on datasets of gridded SAAR and WRAP respectively. As catchment boundaries can be derived automatically from the IHDTM, it is therefore possible to compute SAAR and SOIL at every point on the network.

However, whilst this procedure is relatively swift, it is not practicable, with existing computing power, to apply it at every point on the 50 m square grid depiction of the river network (approximately three million points in England and Wales). Nor is it necessary, as catchment SAAR and SOIL vary only very gradually between river network junctions.

The method chosen involved computing SAAR and SOIL by overlay analysis only at significant junctions (where they were computed at the ends of all three river stretches) and at 2 km intervals between junctions. The requirement for the latter was relatively uncommon due to the frequency of junctions. (A significant junction was defined as one where the catchment area of the minor tributary exceeded 5 km^2 or 1% of the catchment area of the major tributary.) Values at intermediate points were calculated by linear interpolation. Figure 3.2 (a to c) shows an example of the values in the vicinity of a junction. Once computed, the values for SAAR and SOIL were held on a database, which was structured in the same way as the flooded areas database (see Section 3.9).

With values for the three variables held for every point on the river network, application of a flood depth regression equation at any point was straightforward. However, for efficient application of the inundation algorithm (described in Section 3.5) it was essential that points were processed in a sequential order, from source to mouth. This was implemented by setting up a file of grid references of the sources of the 1:50 000 river network, grouped according to the mouth to which they drained. Then each source in turn was located on the IHDTM and the outflow directions were traced from point to point until either the mouth or a previously processed point was reached.

At each point traversed, the value of AREA was checked, and if it exceeded a threshold value the flood depth was calculated. (The threshold value was set at 10 km^2 in this project, because floods generated from minor rivers would have led to an inappropriate level of detail for maps of 1:500 000 or smaller.)

3.5 Determining the areal extent of inundation

A modified version of the IHDTM catchment definition algorithm (Morris and Heerdegen, 1988) was used to identify the extent and depth of flooding resulting from a specified flood depth at a point on the river network. This identified any of the immediate neighbours of the river point that drained into it, that had not already been flooded at or above this level, and that had a ground elevation less than or equal to the flood level. It next identified any of the neighbours of these points which also met these conditions, and so on until no additional points could be found. Then the flood level for these points was set to that of the flooded river point, and the flood levels were stored on the flood level database.

Finally, the river point was registered on the 'flood flags' database, the mechanism for preventing any part of the network from being processed more than once.

Traversing the network in an upstream to downstream direction meant that most points only gave rise to a small increment in the area of inundation, thereby minimising database updates.

Figure 3.3 shows the flood depths (in 0.1 m units) for the same location as Figure 3.2. Note that the southern tributary has not been used as its catchment area is less than 10 km^2. Note also how the flood level on the main river increases from 2.7 m to 2.9 m after the northern tributary has entered. Flood depths of 0 indicate points at the same elevation as the flood level.

(a) AREA

(km^2)

184950	>	-	-	-	-	-	-	-	-	23.2	-	-	-
184900	>	-	-	-	-	-	-	-	-	23.2	-	-	-
184850	>	-	-	-	-	-	-	-	-	23.2	-	-	-
184800	>	-	-	-	-	-	-	-	-	23.2	-	-	-
184750	>	-	-	-	-	-	-	-	-	74.0	50.7	-	-
184700	>	-	-	-	-	-	74.0	74.0	74.0	-	-	50.7	-
184650	>	-	-	-	-	74.1	-	-	-	-	-	-	50.7
184600	>	-	-	-	-	74.1	-	-	-	-	-	-	-
184550	>	-	-	-	-	74.2	-	-	-	-	-	-	-
184500	>	-	-	-	-	74.2	-	-	-	-	-	-	-
184450	>	-	-	-	74.2	-	-	-	-	-	-	-	-
184400	>	-	-	-	74.3	-	-	-	-	-	-	-	-
184350	>	-	-	74.3	-	-	-	-	-	-	-	-	-
184300	>	-	-	74.3	-	-	-	-	-	-	-	-	-
184250	>	-	-	74.3	-	-	-	-	-	-	-	-	-
184200	>	-	-	74.3	-	-	-	-	-	-	-	-	-
184150	>	-	-	-	74.4	-	-	-	-	-	-	-	-
184100	>	-	-	74.4	-	-	4.4	4.4	4.4	4.4	-	4.3	4.3
184050	>	-	-	78.9	4.5	4.5	-	-	-	-	4.4	-	-
184000	>	-	-	79.0	-	-	-	-	-	-	-	-	-
183950	>	79.2	79.0	-	-	-	-	-	-	-	-	-	-
183900	>	-	-	-	-	-	-	-	-	-	-	-	-
		^					^						^
		290250					290500						290800

(b) SAAR

(mm)

184950	>	-	-	-	-	-	-	-	-	2088	-	-	-
184900	>	-	-	-	-	-	-	-	-	2088	-	-	-
184850	>	-	-	-	-	-	-	-	-	2088	-	-	-
184800	>	-	-	-	-	-	-	-	-	2088	-	-	-
184750	>	-	-	-	-	-	-	-	-	2014	1983	-	-
184700	>	-	-	-	-	-	2010	2012	2013	-	-	1984	-
184650	>	-	-	-	-	2009	-	-	-	-	-	-	1985
184600	>	-	-	-	-	2008	-	-	-	-	-	-	-
184550	>	-	-	-	-	2007	-	-	-	-	-	-	-
184500	>	-	-	-	-	2005	-	-	-	-	-	-	-
184450	>	-	-	-	2004	-	-	-	-	-	-	-	-
184400	>	-	-	-	2003	-	-	-	-	-	-	-	-
184350	>	-	-	2002	-	-	-	-	-	-	-	-	-
184300	>	-	-	2000	-	-	-	-	-	-	-	-	-
184250	>	-	-	1999	-	-	-	-	-	-	-	-	-
184200	>	-	-	1998	-	-	-	-	-	-	-	-	-
184150	>	-	-	-	1997	-	-	-	-	-	-	-	-
184100	>	-	-	1996	-	-	1542	1542	1543	1544	-	1545	1546
184050	>	-	-	1967	1540	1541	-	-	-	-	1545	-	-
184000	>	-	-	1966	-	-	-	-	-	-	-	-	-
183950	>	1963	1965	-	-	-	-	-	-	-	-	-	-
183900	>	-	-	-	-	-	-	-	-	-	-	-	-
		^					^						^
		290250					290500						290800

(c) SOIL

184950	>	-	-	-	-	-	-	-	-	.433	-	-	-
184900	>	-	-	-	-	-	-	-	-	.434	-	-	-
184850	>	-	-	-	-	-	-	-	-	.435	-	-	-
184800	>	-	-	-	-	-	-	-	-	.436	-	-	-
184750	>	-	-	-	-	-	-	-	-	.439	.456	-	-
184700	>	-	-	-	-	-	.439	.439	.439	-	-	.456	-
184650	>	-	-	-	-	.439	-	-	-	-	-	-	.456
184600	>	-	-	-	-	.438	-	-	-	-	-	-	-
184550	>	-	-	-	-	.438	-	-	-	-	-	-	-
184500	>	-	-	-	-	.438	-	-	-	-	-	-	-
184450	>	-	-	-	.438	-	-	-	-	-	-	-	-
184400	>	-	-	-	.438	-	-	-	-	-	-	-	-
184350	>	-	-	.438	-	-	-	-	-	-	-	-	-
184300	>	-	-	.438	-	-	-	-	-	-	-	-	-
184250	>	-	-	.438	-	-	-	-	-	-	-	-	-
184200	>	-	-	.438	-	-	-	-	-	-	-	-	-
184150	>	-	-	-	.438	-	-	-	-	-	-	-	-
184100	>	-	-	.438	-	-	.344	.346	.348	.350	-	.354	.356
184050	>	-	-	.432	.340	.342	-	-	-	-	.352	-	-
184000	>	-	-	.432	-	-	-	-	-	-	-	-	-
183950	>	.432	.432	-	-	-	-	-	-	-	-	-	-
183900	>	-	-	-	-	-	-	-	-	-	-	-	-
		^					^						^
		290250					290500						290800

National Grid references are shown in metre units

Figure 3.2 AREA, SAAR and SOIL values along part of the river network

184950	>	-	-	-	-	-	-	-	-	23	-	-	-
184900	>	-	-	-	-	-	-	-	-	23	0	-	-
184850	>	-	-	-	-	-	-	-	-	23	7	-	-
184800	>	-	-	-	-	-	-	-	-	23	-	1	-
184750	>	-	-	-	-	-	-	-	10	29	27	22	1
184700	>	-	-	-	-	-	29	29	29	16	15	27	16
184650	>	-	-	-	-	29	13	15	18	12	4	14	27
184600	>	-	-	-	-	29	12	5	-	-	-	13	8
184550	>	-	-	-	-	29	9	1	-	-	-	-	5
184500	>	-	-	-	-	29	6	-	-	-	-	-	-
184450	>	-	-	-	29	12	7	-	-	-	-	-	-
184400	>	-	0	5	29	9	-	-	-	-	-	-	-
184350	>	2	13	29	18	8	0	-	-	-	-	-	-
184300	>	3	14	29	10	6	-	-	-	-	-	-	-
184250	>	15	18	29	10	-	-	-	-	-	-	-	-
184200	>	-	20	29	7	-	-	-	-	-	-	-	-
184150	>	1	15	15	29	-	-	-	-	-	-	-	-
184100	>	6	18	29	1	-	-	-	-	-	-	-	-
184050	>	12	18	29	13	3	-	-	-	-	-	-	-
184000	>	17	13	29	-	-	-	-	-	-	-	-	-
183950	>	29	29	-	-	-	-	-	-	-	-	-	-
183900	>	0	-	-	-	-	-	-	-	-	-	-	-
		^					^						^
		290250					290500						290800

Depths are in units of 0.1 m

National Grid references are shown in metre units

Figure 3.3 Flood depths for area corresponding to Figure 3.2

3.6 Problems associated with braided rivers

The method described above does not perform satisfactorily in valleys containing braided rivers. The reason for this is illustrated in Figure 3.4. In this simple example, the catchment area of the minor channel (C2) will be excluded from the flood generation procedure with the effect that the north-western part of the valley will appear not to be at risk from flooding. Even if C2 were included in the procedure (by waiving the 10 km^2 threshold) only a very low flood depth would be obtained because of the small value of AREA associated with it. Effectively, the presence of C2 is falsely preventing the flood from C1 (the main channel) from spreading across the valley.

This problem has been overcome by applying a further program to the flood level and flags database following the completion of the inundation procedure. This identifies the heads of braids which branch out from processed rivers. These heads are allocated the same flood depth as the river from which they branch out.

This list of braid heads and flood depths is then fed back into the inundation program, which this time uses the supplied depth rather than calculating it from catchment characteristics. For each supplied point, it traverses the network, as before, until a previously processed point is encountered.

In practice, braided networks can be very complex and the act of processing the channel commencing at one braid head will often give rise to further eligible braid heads. Therefore the process of braid head identification and processing is iterated until no further new ones are identified.

Figure 3.5 shows the extent of inundation in a valley before and after braid processing.

3.7 Problems associated with minor tributaries

Tributaries flowing along the floodplain can cause similar problems to those described in the preceding section for braids. The watershed between the catchments of the tributary and the main river forms a barrier to the inundation program, causing a step in the level of the flood surface. In the valleys of smaller tributaries, the only flooding originates from downstream of the confluence with the main river. The solution developed for braided rivers does not help because it relies on the upstream end of the braid being coincident with the main channel.

Two programs were developed to eliminate these discontinuities. The first compared the flood level of every flooded point with that of its easterly and northerly neighbour, and output the details of any pair where the difference in flood level could not be explained by differences in their ground elevations. For each of these pairs, the second program located a point on a minor channel which, if flooded to the higher flood level, would eliminate the discontinuity at the watershed; the additional flooding was generated by feeding the locations and depths back into the inundation program.

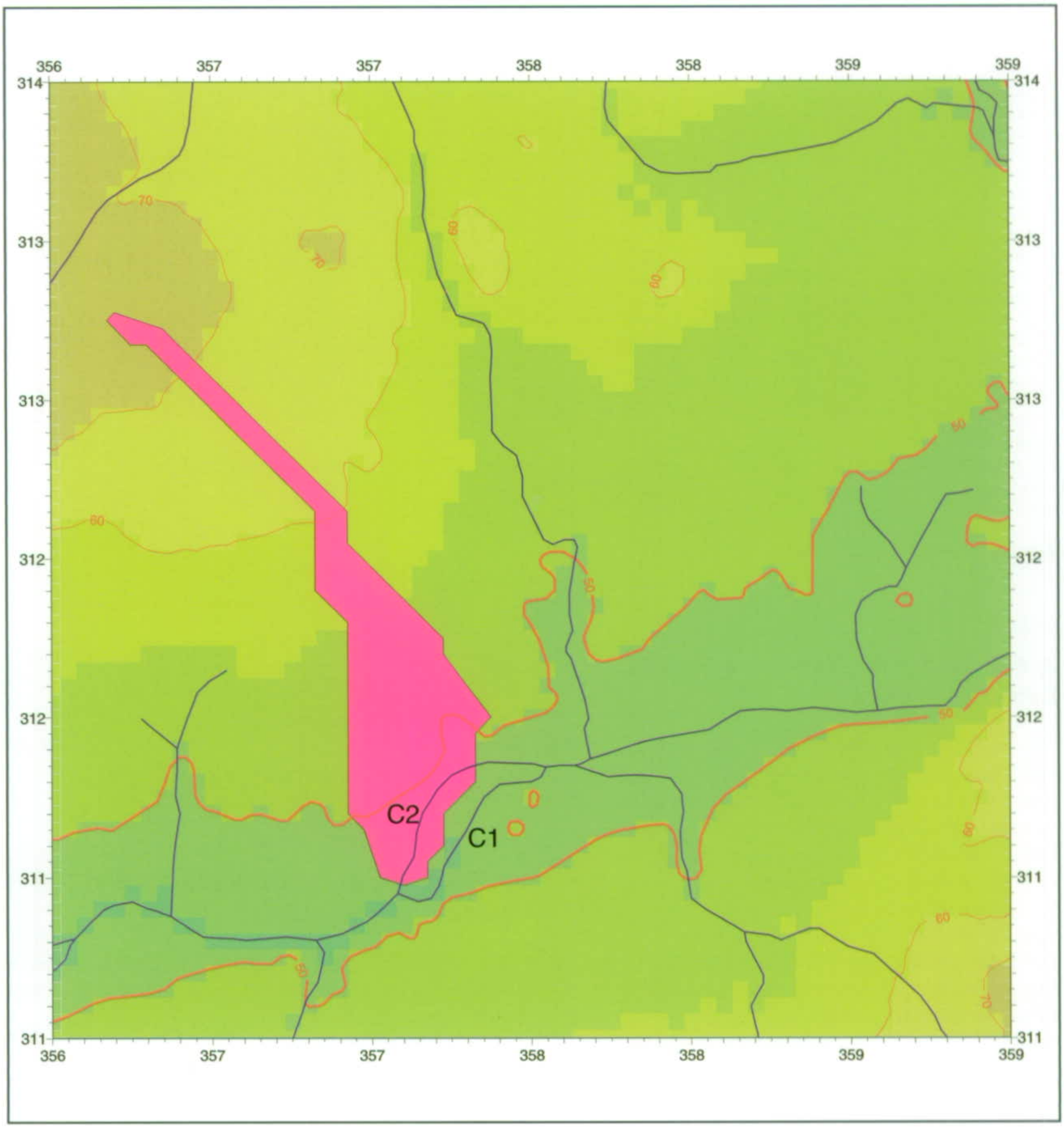


Figure 3.4 Catchment to a braid (Scale 1:20 000): for details see Section 3.6

3.8 Identification of non-flooded river points

A possible misleading property of this method is that all grid points containing rivers with a catchment area above the 10 km² threshold will register as flooded. When the flood has spread out into neighbouring grid squares, this will certainly be valid, but in other cases — for example a small river in a steep-sided valley — the flooding may be confined to the vicinity of the river to such a degree that it would be inappropriate to register a flood at the 50 m by 50 m resolution of the model. To do so would systematically exaggerate the area at risk from flooding.

It was therefore necessary to develop a filter to identify and flag such points. The filter applies the following tests to each processed river point:

1 Are more than half of its non-river neighbours flooded?
2 Are any of its higher non-river neighbours flooded?
3 Are any of its non-river neighbours flooded to a depth greater than or equal to its own elevation?
4 Is the flooding at the point at such a level that it is likely to have extended at least half way to at least half of its higher non-river neighbours?

These are illustrated in Figure 3.6. If none of the tests is passed, it is likely that less than half of the square is flooded and so the value on the flood flags database for

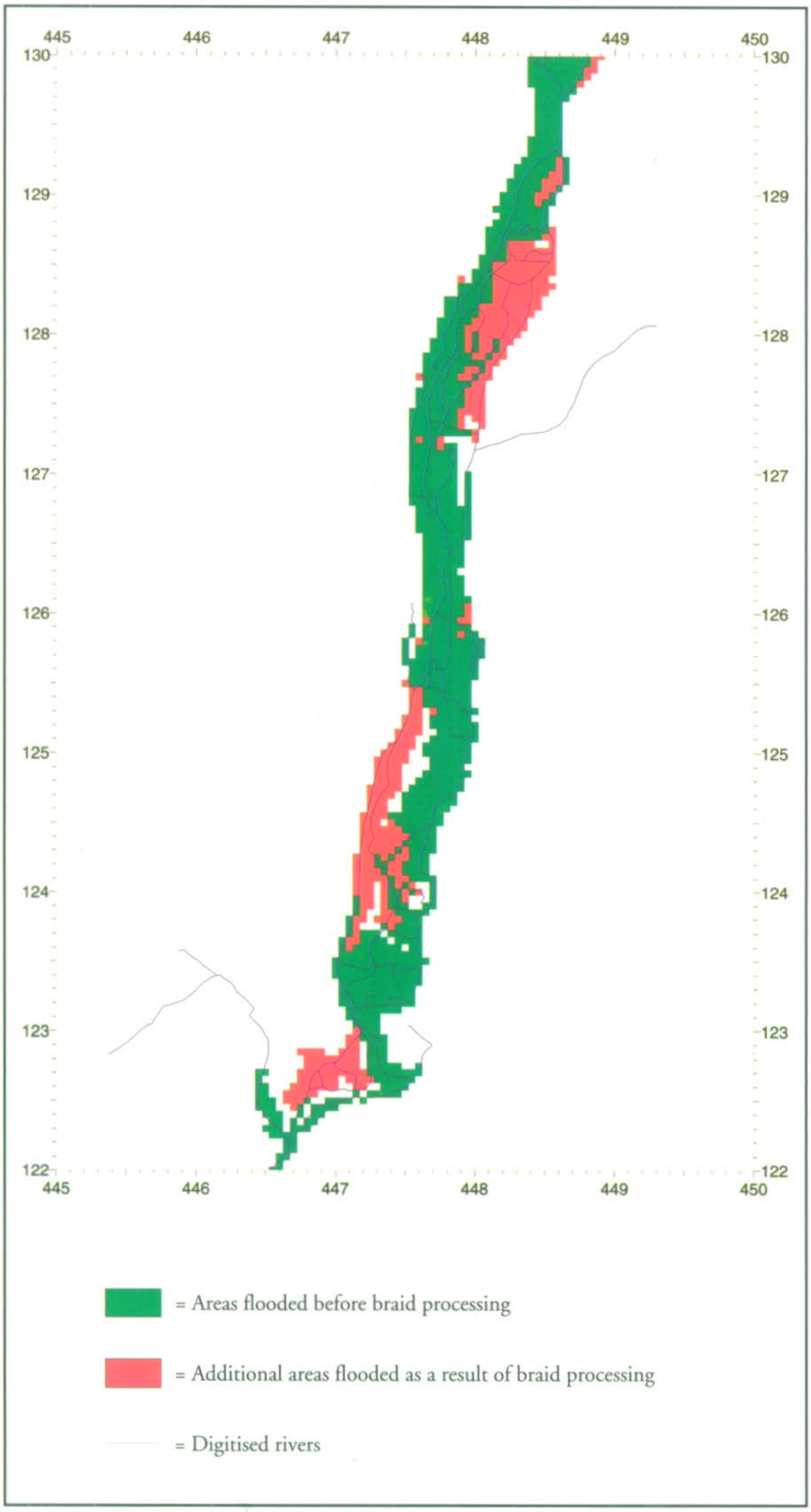


Figure 3.5 Braid processing (Scale 1:50 000): for details see Section 3.6

the point is set to 2 to act as an indication to any subsequent analysis and mapping applications. (Note: on a regular square grid, a point has eight neighbours; a river point is a point in close proximity to a digital river; a typical river point has two river neighbours — inflowing and destination — and six non-river neighbours.)

3.9 The database

All datasets developed for this project — SAAR and SOIL along the 50 m gridded representation of the river network, flood levels and flood flags — have been stored as regular square grids on an Oracle relational

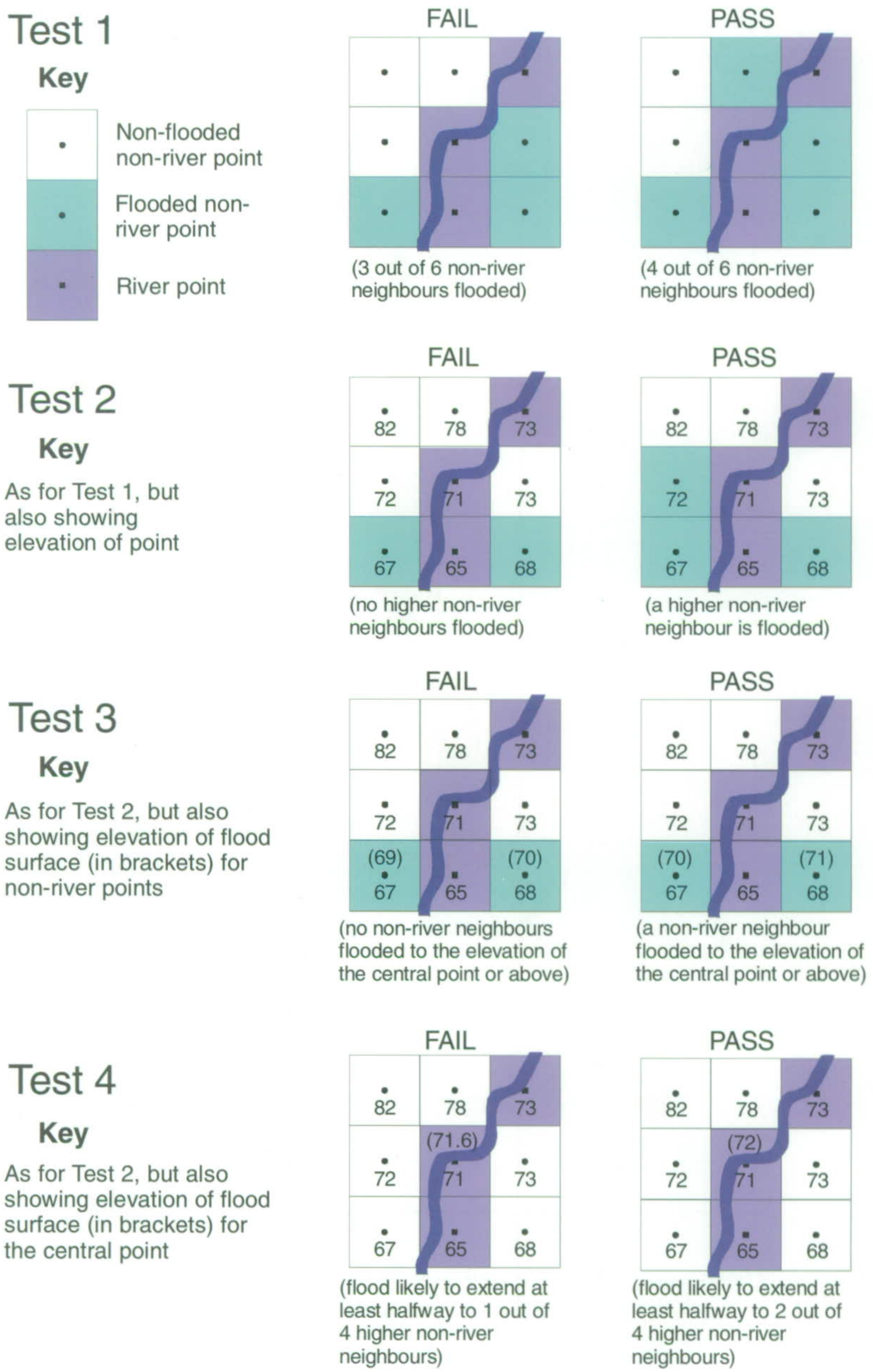


Figure 3.6 Four tests to identify non-flooded river points. These tests apply to the central point. River points that fail all four tests are classified as non-flooded.

database management system. Each dataset is held in a different table with each 2 km by 2 km square (1600 points) being stored in a separate indexed row. For all data types (though to a lesser extent for flood levels), data values only exist for a small fraction of the 1600 points, so a very high degree of compression is possible.

The benefits of this approach are fourfold:

- The data structure is compatible with that of the IHDTM and the LCMGB.
- Data access by application software is easy and fast.
- Storage overheads are small.
- The data structure is compatible with existing retrieval and display software.

3.10 Consideration of refining the method of flood depth estimation

Following the application of the above procedures, it was hoped to improve the fits at the validation sites by selecting a growth curve on the basis of catchment characteristics (equations 3.2 and 3.3). Assuming that rules could be established for the domain of each cluster (much of the space in Figure 3.1(a) is not allocated to any cluster), the obvious problem in applying these to every point on the river network would be the generation of discontinuities in the flood depth, and consequent areal extent, whenever there was a cluster change.

Further inspection of Figure 3.1 suggested a way round this problem: the relationship between growth factor (Depth/Dbar in Figure 3.1(b)) and catchment characteristics can be approximated by a single equation because the two upper curves (I and III) in Figure 3.1(b) correspond to the two upper clusters in Figure 3.1(a), and the position on the x-axis on Figure 3.1(a) consequently has only a small effect on the growth factor. Thus CV (the position on the y-axis of Figure 3.1(a)) alone can be used to estimate the growth factor as follows. From Figure 3.1(a), cluster I can be represented by a CV of 0.32, and II and IV by 0.16. Similarly, on Figure 3.1(b), cluster I has a 100-year growth factor of 1.73 whilst II and IV may be represented by a value of 1.35.

This gives rise to:

$$D100/MAD = 2.34CV + 0.975 \qquad [3.5]$$

(where D100/MAD is the 100-year growth factor)

and combining with equation 3.2 gives:

$$D100/MAD = 114SAAR^{-0.74}SOIL^{0.42} + 0.975 \qquad [3.6]$$

The results of this are shown in Table 3.1 for a range of SAAR and SOIL values.

A number of the validation sites were investigated to see if allowing SAAR and SOIL to influence the growth factor in this way would lead to an overall improvement. No benefit was discernible. Whilst this did not necessarily indicate that the relationship was invalid, it was decided not to pursue it any further since the additional work required was outside the scope of this project.

An alternative means of estimating D100 which was considered was to use the regression equation for D100 (equation 3.4). Dividing this by equation 3.1 gives:

$$D100/MAD = 6.93AREA^{-0.014}SAAR^{-0.205}SOIL^{-0.041} \qquad [3.7]$$

the results of which are shown in Table 3.2. Note that, in contrast to Table 3.1, the effect of SOIL is considerably reduced and it acts in the opposite direction. Whilst AREA has also come into play, its influence is only slight. As with the previous method, this variation of the growth factor did not improve the overall fit at the validation sites so it was decided to keep the single growth factor value of 1.73.

3.11 Analysis of flooded areas and built-up areas

Although the data are held on Oracle (see Section 3.9) only limited analysis may be conducted in the Oracle query language, SQL, because the blocks of 1600 values must be uncompressed using a Fortran subroutine. Consequently, all analysis was done within Fortran

Table 3.1 100-year growth factors from equation 3.6

	SOIL				
SAAR	0.15	0.20	0.30	0.40	0.50
500	1.49	1.56	1.67	1.76	1.83
1000	1.28	1.32	1.39	1.44	1.49
1500	1.20	1.23	1.28	1.32	1.36
2000	1.16	1.18	1.22	1.25	1.28
2500	1.13	1.15	1.19	1.21	1.24
3000	1.11	1.13	1.16	1.18	1.20

Table 3.2 100-year growth factors from Equation 3.7

AREA	SAAR	SOIL 0.15	0.20	0.30	0.40	0.50
25	500	2	1.98	1.95	1.92	1.91
	1000	1.74	1.72	1.69	1.67	1.65
	1500	1.6	1.58	1.55	1.54	1.52
	2000	1.51	1.49	1.47	1.45	1.44
	2500	1.44	1.42	1.4	1.38	1.37
	3000	1.39	1.37	1.35	1.33	1.32
10000	500	1.84	1.82	1.79	1.77	1.75
	1000	1.6	1.58	1.55	1.54	1.52
	1500	1.47	1.45	1.43	1.41	1.4
	2000	1.39	1.37	1.35	1.33	1.32
	2500	1.32	1.31	1.29	1.27	1.26
	3000	1.28	1.26	1.24	1.23	1.21

programs. This is a very efficient process as a result of the speed of access, the convenience of having a common data structure for all data types, and the availability of previously written software.

3.12 Map production

The maps contained in this report were produced by the Institute of Hydrology's map producing package, Dgener8 (Flavin, 1995). Dgener8 was produced to meet the Institute's requirements for a wide variety of hydrological maps for use in reports and displays, and to aid the analysis and validation of spatial data. It is able to access and display the numerous spatial datasets held by the National Water Archive (a NERC Data Centre, part of the Institute of Hydrology) as well as data held in files in a variety of formats.

Dgener8, which is written in Fortran and makes use of the Uniras graphics subroutine library, was designed to be capable of being upgraded as new requirements arose, and for this project a facility has been added to enable several gridded datasets to be combined prior to display.

Whilst output can be produced on high resolution plotters, the Uniras drivers limit the effective resolution to 300 dots per inch. Thus plots at scales smaller than 1:590,500 will not be capable of precisely representing individual 50 m by 50 m grid squares (the visual effect may be to exaggerate them or to cause breaks in the drainage network where the flooded area is narrow). At 1:625 000, the scale of the main maps presented later in this report is only slightly below this threshold and so the effect is limited, but it is more apparent on the smaller scale maps.

4 Validation

4.1 Procedure

The extent of the modelled inundation was compared with existing maps of flood risk for the 30 locations shown on Map 4.1 and described in Table 4.1 (see also Section 2.6). Three flood depths were modelled at each validation site: the 100-year depth described in Section 3.3 together with depths of 80% and 120% of this value in order to test the sensitivity of inundation extent to flood depth. In Table 4.2, the values of AREA, SAAR, SOIL and resultant depths are listed for each site (the figures relate to the downstream limit of the validation site; the depth figures are for depth at the river bank).

It is important to be aware of the limitations of the source maps used in this exercise. The return period depicted — on the few maps where it is stated — varies from less than 50 years to more than 100 years. For most, the return period is not specified - the maps purporting to show land at risk of flooding; as these are commonly based on limits of observed flooding (often recorded some time after the event), rather than those of a flood selected according to objective criteria, the return period will vary according to locality.

For hydrometric area 39, the maps showed the flood plains upstream of gauging stations, but there was no statement of how the flood plain had been defined. The Section 24(5) maps show continuous areas of flood risk, parts of which have probably been derived by interpolation between locations where flooding was recorded. So any discrepancy between modelled and mapped flood extent will not necessarily indicate a defect in the former: it is probable that we are not comparing like with like, or — in places where the source map includes broad generalisations — the modelled version may be better. Nevertheless these checks, interpreted with appropriate caution, are the only available objective way of assessing the performance of the model.

4.2 Comparison maps

The results of the comparison are shown in the maps with name commencing 'Map 4.2_', on pages 22 to 51, with a location map (Map 4.1) on page 20 and a key (Figure 4.1) on page 21. The maps are at a scale of 1:50 000 and show the extent of the modelled flood at the three depths, the 1:50 000 river network (with canals in brown), ground elevations from the IHDTM (with the transition to brown occurring at 100 m), the sea (in grey) and the independently mapped flood limits (as white lines). The extent of inundation produced by the 100-year depth equation is depicted by squares shown in light blue and medium blue; decreasing the depth by 20% removes the medium blue squares; increasing it by 20% adds in the squares shown in dark blue. (Rivers outside the validation sites may not have been processed to all three depths.)

4.3 Comments on individual sites

These comments should be read in conjunction with the validation site maps (Map 4.2_ha...). They suggest reasons for any discrepancies between mapped and modelled flood extents. The comments are grouped together in former NRA regions.

Northumbria and Yorkshire region

ha22.a: The mapped limits are wider than the modelled flood in the central part of the area. This may be due to the March 1963 flood being larger than the 100-year flood. The same source map also shows the October 1967 flood and this is very close to the modelled extent. On the final bend (at 420.4E 586.4N), it is likely that the channel is incised and contains the 100-year flood, but the depth of incision is not picked up by the 10 m contours on which the IHDTM is based.

ha25.a: The main discrepancy is where the mapped flood limit cuts across the modelled flood from the northern tributary (the River Skerne). This could be due to the mapped flood having occurred only on the Tees (which enters in the NW of the map).

ha27.a: Inspection of the NRA source map suggests there are many man-made barriers to flooding in this area, which contains much urbanisation (Castleford) and industrial development. In the undefended area, the agreement is good. (Sensitivity tests were not carried out in the west.)

ha27.b: (This site is just downstream of the previous one.) Agreement along the southern edge is very good. Closer inspection of the NRA source map shows that there is a defended area whose outer limit corresponds almost exactly with the western extent of the modelled flood.

Severn-Trent region

ha28.a: There is only one important difference between the Section 24(5) boundary and the modelled flood: the wide area around 424E 324N. This lies within the town of Burton-on-Trent and probably indicates a defended area.

ha28.b: The limits from the Section 24(5) map indicate that the river might be well incised: our assumption that *MAD = bankfull + 0.3 m* would therefore lead to an overestimate of the over-bank depth. For much of the main river, one of the Section 24(5) limits is coincident with the river, suggesting that the bank on that side is higher; this will not be represented in the IHDTM if it is not shown by the 1:50 000 contours.

ha28.c: A good agreement exists for this section, with the sensitivity tests showing the selected depth to be the most appropriate.

ha54.a: (map follows ha50.a) There are only two places on the Severn where significant differences occur: on the west bank at around 269N and 265N. The OS 1:25 000 map indicates that field boundaries may be acting as flood barriers, and therefore the modelled flood is a better indication of the natural limit. The cause of the difference at 385.5E 265N (on the Hadley Brook) is not apparent.

Thames region

ha39.a: There is good agreement here except for the region of the confluence with the western tributary. This may have been deliberately excluded from the Loddon's flood plain definition.

ha39.b: The discrepancy on the west bank is caused by the Oxford Canal, which may act as a flood barrier. On the other bank, flooding from the Thames would have to be 4 m deeper to occupy the limits shown around the small tributary, so unless there are serious backing-up effects these lines would not appear to represent the 100-year extent.

ha39.c: The valley at the centre of the map is very sensitive to changes in flood depth. The 65 m contour on the OS 1:25 000 map shows that the river is incised at this location – something which is not apparent in the 10 m contour-based IHDTM.

ha39.d: There is good agreement here. In the south-east, flooding does not reach its natural limit because of the effect of the Grand Union Canal.

Southern region

ha40.a: The correspondence is good at the north-east limit, where the valley is steeper. Elsewhere, inspection of the 15 m contour on the OS 1:25 000 map shows that the interpolation between the river and the 20 m contour during construction of the IHDTM produced a valley profile which was too steep in the vicinity of the river. If the digital 15 m contour had been available it is probable that the modelled 100-year flood depth used here would have produced a flooded area similar to that on the Section 24(5) maps.

ha42.a: Good agreement throughout the majority of the section. A lot of the modelled flooding is a result of the braid processing programs (see Section 3.6).

South Western region

ha43.a: Generally good agreement. There is a region in the centre of the map where the mapped limits are wider; this appears to be due to the IHDTM having a valley cross-section profile that is not flat enough near the river (as in ha40.a). The extension into the tributary valley in the south appears to be genuine as the 1:25 000 map shows there are watercress beds there.

ha43.b: There are three significant discrepancies. In the north, at 373E 126.5N, the modelled spread of the flood across the eastern braid looks plausible; no additional information appears on the OS 1:50 000 map. Near the confluence, at 376.5E 120.5N, the white line could indicate the position of flood defences as the 1:50 000 map shows a factory farm in the area of the modelled flood. The 1:25 000 map suggests the modelled flood in the tributary valley at 118N is valid.

ha44.a: The two breaks in the mapped flood risk areas (at 366E and 367.5E) are due to a railway line. Near the centre, the modelled flood is less extensive than the mapped limits. At this location, the 65 m contour on the 1:25 000 map shows this is another example of a very flat bottomed valley that is difficult to model from 10 m interval contours.

ha44.b: This is a reasonable match except for the wide area near the sea and some parts of the upper valley, where the previous observations about flat bottomed valleys apply.

ha44.c: Inspection of the 5 m interval contours on the 1:25 000 map shows that the under-fit on this valley is again the result of the valley being flatter than was modelled from 1:50 000 contours. Incorporation of the additional contours would have led to a very close fit.

ha45.a: The correspondence here is good. The 1:25 000 map shows that the discrepancy at 302E 104N is due to a railway and the M5 motorway running alongside the river. At 304E 108.5N, the small braid has flooded because the IHDTM has not routed the flow from this tributary down the major braid; major braids will be identified and flagged before the next revision of the IHDTM to prevent this type of problem.

ha47.a: The overall agreement is good. There are some places where a flatter central valley profile in the IHDTM would reduce the difference. The wide modelled flood in the centre of the map appears to agree with contours on the 1:25 000 map; there is no sign of anything that might act as a barrier here.

ha47.b: A good agreement, with the sensitivity tests generally supporting the selected flood depth.

ha50.a: Fairly good agreement. The discrepancy in the north may be another case of the IHDTM valley profile being too steep near the river.

ha54.a — (see Severn-Trent region)

Welsh region

ha57.a: There is good agreement over much of this map. The main difference is around 302.5E 200.5N where the observed flood must have been about 4 m deeper than the modelled level. It is possible that this was caused by an obstruction or constriction.

ha60.a: The relative extent of the mapped and modelled floods on the main river is consistent with the differences in their return periods (the mapped flood was estimated to have a return period of 48 years).

North West region

ha70.a: The mapped flood risk areas in the north and west are influenced by tide levels and are outside the scope of this study. Inspection of the modelled flood depths shows that most of the non-flooded area centred on 346E 412N would have been infilled by the method described in Section 3.7 if a lower threshold had been used (the data were processed to remove discontinuities in flood level of 2 m or more).

ha70.b: (This site is just upstream of the previous one). The agreement here is close except for two places. At 350E 410N the 15 m contour on the 1:25 000 map shows that the valley has a flatter bottom than was suggested by the 1:50 000 contours (see previous comments, e.g. ha40.a). The other discrepancy is in the south-east of the map. Here the 1:25 000 map shows there might be a pinch point at 355.4E, which could cause the modelled value of the 100 year depth to be too low.

ha72.a: Good agreement between mapped and modelled. The difference at 359.5E 468.3N may be caused by the south-eastern tributary flooding at the meander and flowing across the area shown to be at risk on the Section 24(5) map. Hydraulic models, outside the scope of this project, would be needed to predict the limits of overland flow.

ha73.a: There is a large area in the south of this map shown to be at risk on the Section 24(5) map, but not by the modelled flood. This is unlikely to be due to an error in ground elevation, as the 50 m contour passes through it. It is possible that there are flood defences in Kendal (where the Section 24(5) band narrows) which lead to an increase in upstream flood depths. These defences would also explain why the area centred on 351.8E 493.2N, flooded by the model, is shown not to be at risk. In the north of the map it is possible that the more limited extent of the modelled flood is again due to the difficulties of modelling the valley profile from 10 m contours.

ha76.a: There is good agreement over most of this site. There are five places where the modelled and mapped extents differ. At 356.3E 530N there is nothing on the 1:25 000 map to indicate why the Section 24(5) limits are so narrow; possibly the river is incised. At 358E 530N the 95 m contour on the 1:25 000 map shows that the ground here is slightly above flood level. At 357E 532N the modelled extent looks plausible, as the 1:25 000 map shows the area to be low and marshy. At 532.7N the contours indicate that the modelled extent is valid. Finally, the 1:25 000 map shows that the area outside the white line at 356.2E 533.2N is above the 85 m contour and protected by a road.

4.4 Summary

Most of the maps show good agreement between mapped and modelled flood extent. The results of the sensitivity tests help explain why the extent has been modelled so well. These show, that at the depth associated with this return period, at most of the sites, variations of 20% in flood depth have little effect on the extent of flooding. This is probably due to the shallow part of the flood plain having been inundated before the 100-year depth is reached, with further expansion being checked by the steeper gradients towards the edge of the flood plain. In general this would suggest that, in most places, the mapped extent of the flood limit, subject to the limitations of the 50 m grid resolution, is reasonably reliable, but less reliance should be placed on the associated depth statistics.

The detailed analysis of these maps has shown that generally the results are suitable for mapping at 1:50 000. Where the model disagrees with existing flood risk maps (other than due to the effects of flood defences), the main cause is the tendency for the IHDTM valley lateral profile to be too steep in the vicinity of the river. It should be relatively easy to overcome this by modifying the interpolation equations used in valleys. However, regeneration of the entire IHDTM would take several months. In the longer term, further improvements will result from more accurate elevation data in valleys, either from digital 1:10 000 contours or independent surveys.

There were only three places (on ha57.a, ha70.b and ha73.a) where the model appeared to seriously underestimate the flood depth. These were probably due to the effects of downstream channel geometry, which this method does not take into account.

Table 4.1 Validation sites

Map name	NRA region (hydrometric area)	River and location	Source map details
4.2_ha22.a	N-Y (22)	Wansbeck at Morpeth	Archer (1992). Copy of 1:10 000 map of March 1963 flood.
4.2_ha25.a	N-Y (25)	Tees at Croft	Archer (1992). Base map could be 6" to the mile. March 1968 flood.
4.2_ha27.a	N-Y (27)	Aire at Castleford	Copy of 1:25 000 1994 NRA flood risk map.
4.2_ha27.b	N-Y (27)	Aire at Knottingley (downstream of 4.2_ha27.a)	Copy of 1:25 000 1994 NRA flood risk map.
4.2_ha28.a	S-T (28)	Trent and tributaries at Burton	1:25 000 Section 24(5) map (sheet SK22).
4.2_ha28.b	S-T (28)	Derwent and tributaries upstream of Matlock	1:25 000 Section 24(5) map (sheet SK26).
4.2_ha28.c	S-T (28)	Wreake, Twyford Brook and Soar north of Leicester	1:25 000 Section 24(5) map (sheet SK61).
—	A	(None)	
4.2_ha39.a	T (39)	Loddon at Sheepbridge (gauging station 39022)	Copy of 1:25 000 map. Note flood plains are only shown upstream of gauging station.
4.2_ha39.b	T (39)	Cherwell at Banbury (gauging station 39026)	Details as for 4.2_ha39.a above
4.2_ha39.c	T (39)	Enborne at Brimpton (gauging station 39025)	Details as for 4.2_ha39.a above
4.2_ha39.d	T (39)	Colne at Denham (gauging station 39010)	Details as for 4.2_ha39.a above
4.2_ha40.a	S (40)	Medway from Tonbridge to Yalding	Copies of 1:25 000 Section 24(5) maps showing conjectural and observed flood limits (we have digitised the former)
4.2_ha42.a	S (42)	Test from Romsey to Stockbridge	Details as for 4.2_ha40.a above
4.2_ha43.a	S-W (43)	Stour at Blandford Forum	Section 24(5) 1:50 000 maps
4.2_ha43.b	S-W (43)	Cale and Stour	Section 24(5) 1:50 000 maps
4.2_ha44.a	S-W (44)	Frome at Dorchester	Section 24(5) 1:50 000 maps
4.2_ha44.b	S-W (44)	Brit and Asker at Bridport	Section 24(5) 1:50 000 maps
4.2_ha44.c	S-W (44)	Bride	Section 24(5) 1:50 000 maps
4.2_ha45.a	S-W (45)	Culm at Cullompton	Copies of 1:25 000 maps
4.2_ha47.a	S-W (47)	Tamar — confluences with Ottery, Carey and Wolf	Copies of large scale (1:10 000?) maps.
4.2_ha47.b	S-W (47)	Lynher	Copies of large scale (1:10 000?) maps.
4.2_ha50.a	S-W (50)	Taw and Mole	Copies of 1:25 000 maps
4.2_ha54.a	S-T (54)	Severn, Salwarpe, Hadley Brook and Elmbridge Brook	1:25 000 Section 24(5) map (sheet SO86).
4.2_ha57.a	W (57)	Cynon at Mountain Ash	Copies of 1:10 000 maps showing 27/12/1979 flood.
4.2_ha60.a	W (60)	Towy at Llangadog	Copy of 1:10 000 map showing 10/1987 flood. Estimated return period = 48 years.
4.2_ha70.a	N-W (70)	Douglas and tributaries at tidal limit	1:50 000 Section 24(5) (maps 78 and 83)
4.2_ha70.b	N-W (70)	Douglas (upstream of 4.2_ha70a)	1:50 000 Section 24(5) (maps 78 and 83)
4.2_ha72.a	N-W (72)	Lune from the Wenning confluence to Halton	1:50 000 Section 24(5) (map 58)
4.2_ha73.a	N-W (73)	Kent at Kendal	1:50 000 Section 24(5) (map 43)
4.2_ha76.a	N-W (76)	Eden at Langwathby	1:50 000 Section 24(5) (map 21)

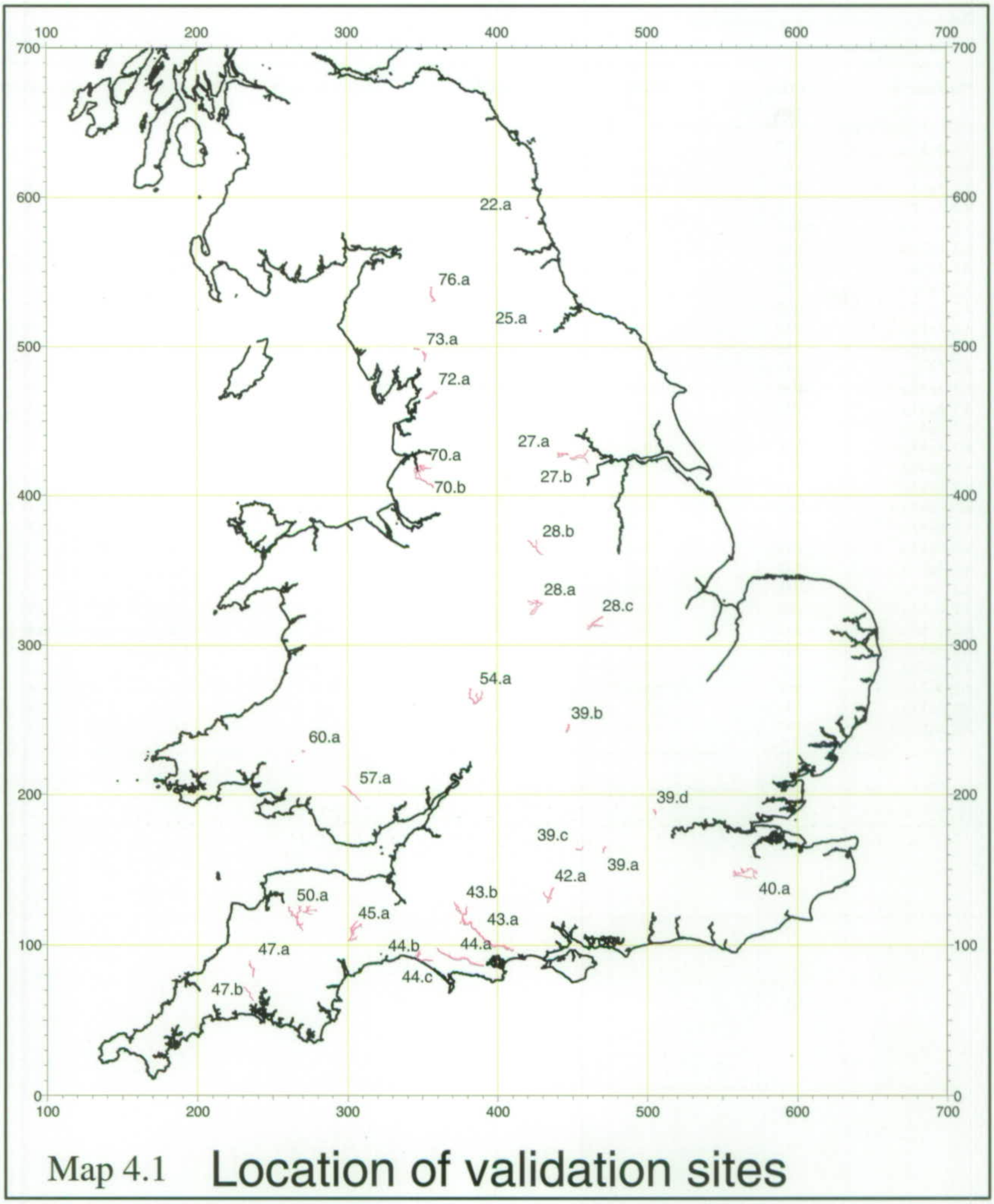
Key to NRA region abbreviations:

A Anglian Region
N-Y Northumbria and Yorkshire region
N-W North West region
S Southern region
S-T Severn-Trent region
S-W South-West region
T Thames region
W Wessex region

Table 4.2 Validation site parameters

Map name	AREA (km²)	SAAR (mm)	SOIL	Depth at bank (m)	80% depth (m)	120% depth (m)
4.2_ha22.a	297	841	0.456	2.0	1.6	2.4
4.2_ha25.a	1166	1082	0.462	3.4	2.7	4.1
4.2_ha27.a	1898	983	0.366	3.2	2.6	3.8
4.2_ha27.b	2012	961	0.371	3.2	2.6	3.8
4.2_ha28.a	3059	722	0.424	3.2	2.6	3.8
4.2_ha28.b	667	1137	0.376	2.7	2.2	3.2
4.2_ha28.c	930	656	0.417	2.2	1.8	2.6
4.2_ha39.a	177	757	0.351	1.5	1.2	1.8
4.2_ha39.b	204	700	0.427	1.6	1.3	1.9
4.2_ha39.c	142	794	0.410	1.6	1.3	1.9
4.2_ha39.d	736	710	0.371	2.1	1.7	2.5
4.2_ha40.a	1241	757	0.397	2.5	2.0	3.0
4.2_ha42.a	846	822	0.209	1.7	1.4	2.0
4.2_ha43.a	700	897	0.204	1.7	1.4	2.0
4.2_ha43.b	410	902	0.299	1.8	1.4	2.2
4.2_ha44.a	256	1063	0.163	1.4	1.1	1.7
4.2_ha44.b	115	963	0.277	1.4	1.1	1.7
4.2_ha44.c	47	912	0.202	1.0	0.8	1.2
4.2_ha45.a	250	989	0.287	1.7	1.4	2.0
4.2_ha47.a	752	1214	0.389	2.9	2.3	3.5
4.2_ha47.b	133	1500	0.301	1.9	1.5	2.3
4.2_ha50.a	837	1190	0.314	2.7	2.2	3.2
4.2_ha54.a	5036	900	0.366	3.9	3.1	4.7
4.2_ha57.a	104	1762	0.453	2.4	1.9	2.9
4.2_ha60.a	551	1607	0.391	3.2	2.6	3.8
4.2_ha70.a	207	991	0.457	2.1	1.7	2.5
4.2_ha70.b	129	1007	0.458	1.9	1.5	2.3
4.2_ha72.a	987	1523	0.416	3.8	3.0	4.6
4.2_ha73.a	196	1791	0.444	2.8	2.2	3.4
4.2_ha76.a	1197	1379	0.424	3.8	3.0	4.6

Note: The figures relate to the downstream limit of each site (where the white lines end).



Map 4.1 Location of validation sites

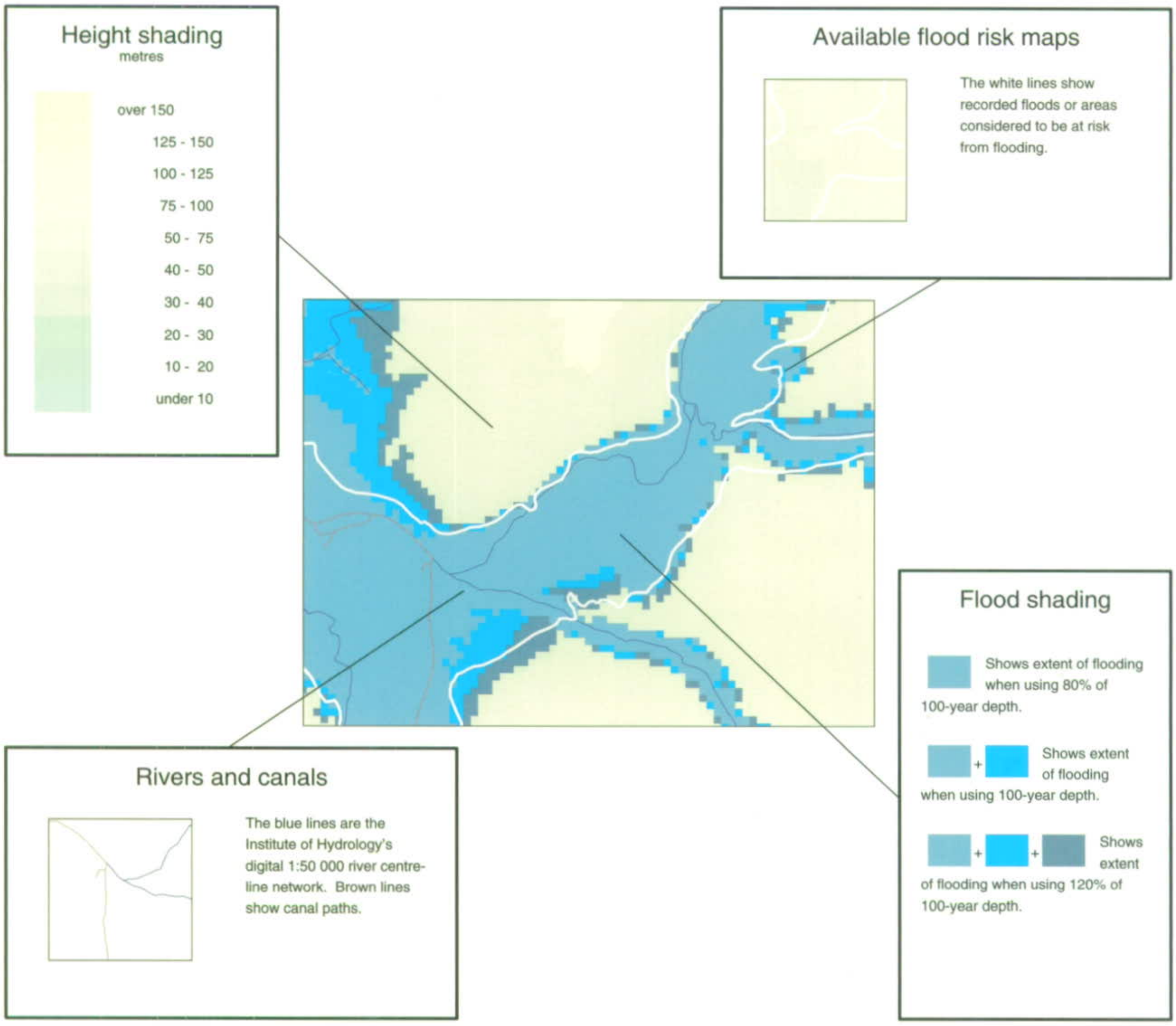
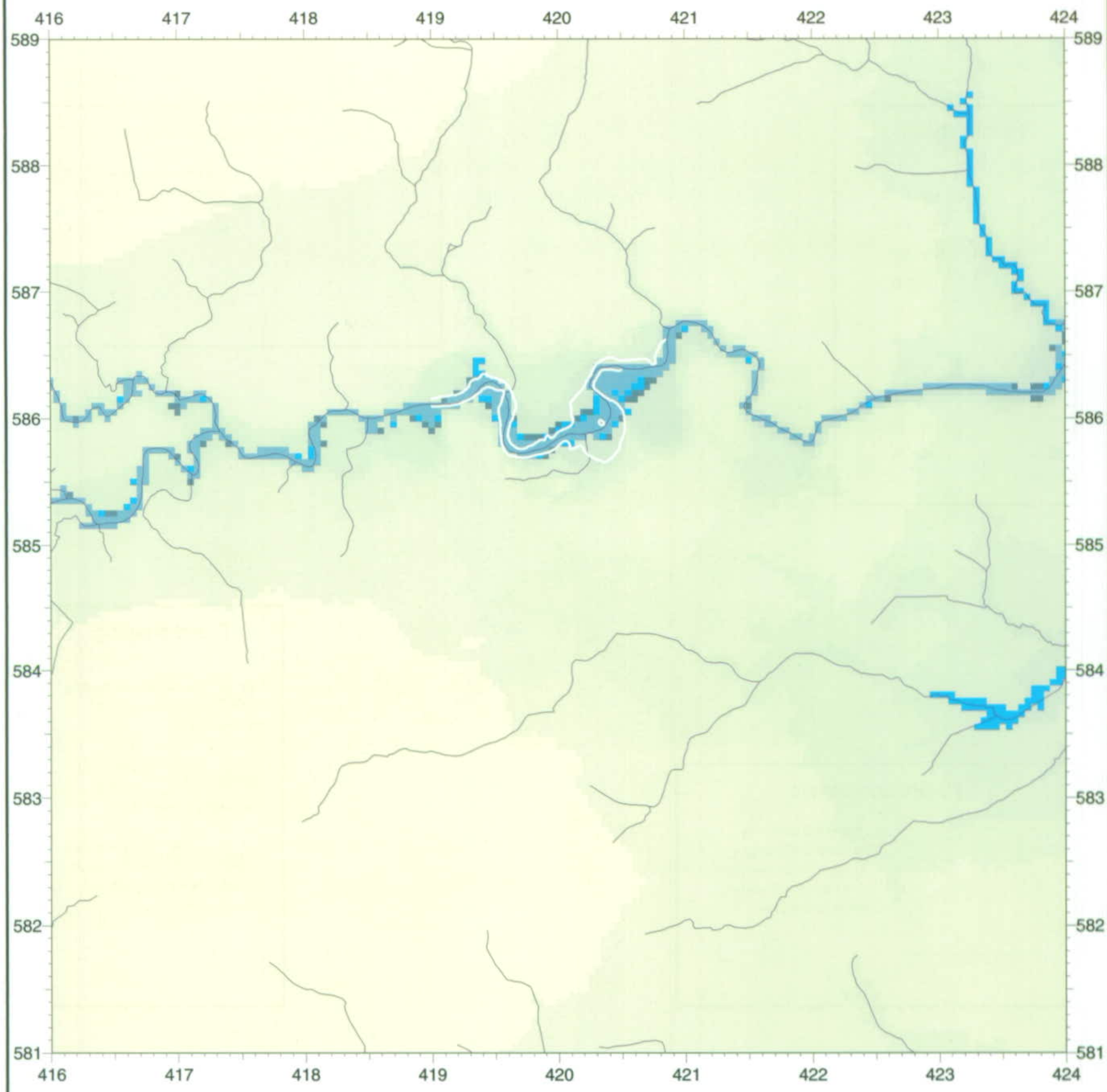


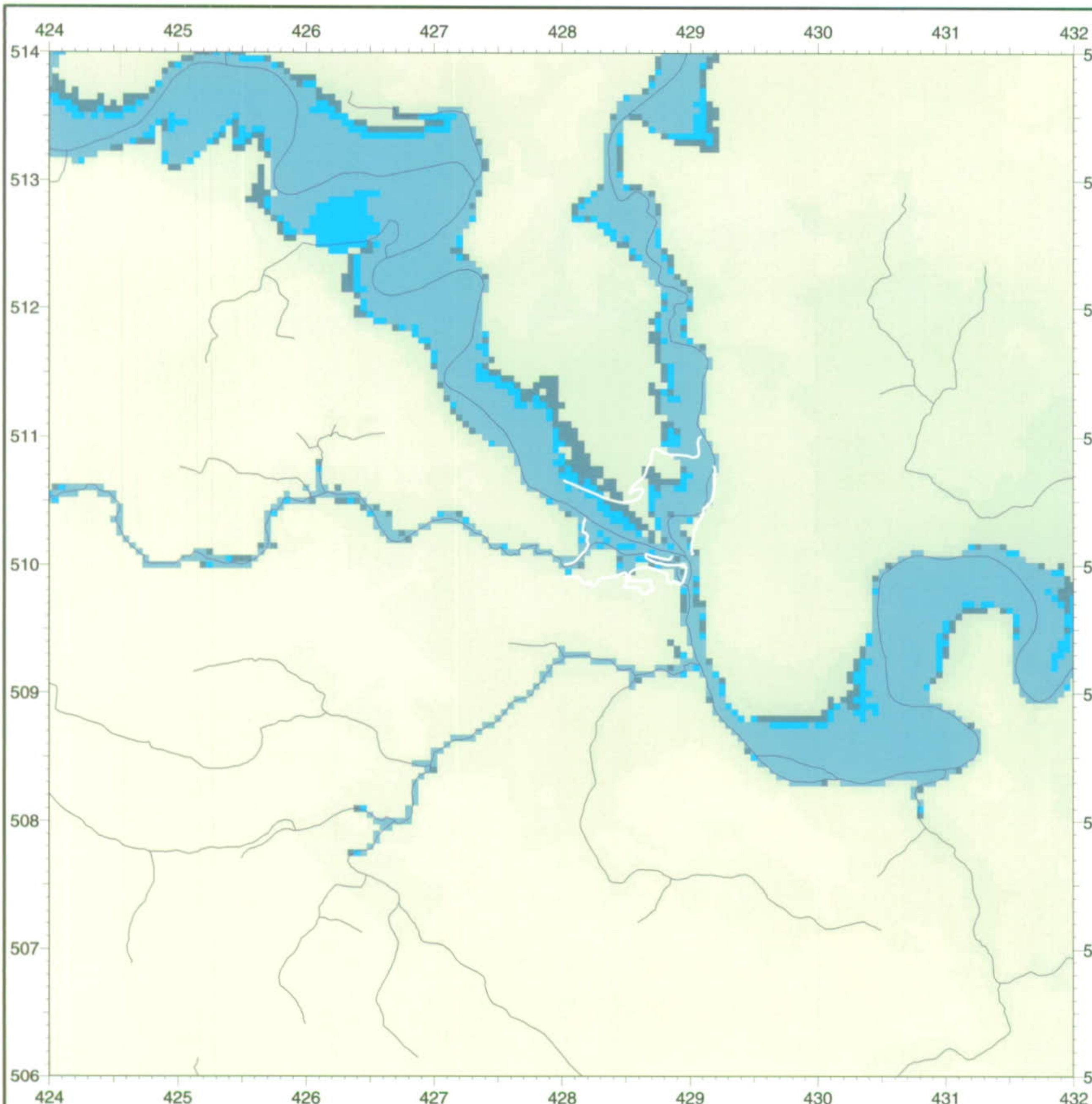
Figure 4.1 Key to validation site maps



Map 4.2_ha22.a (River Wansbeck at Morpeth)

Scale 1:50,000

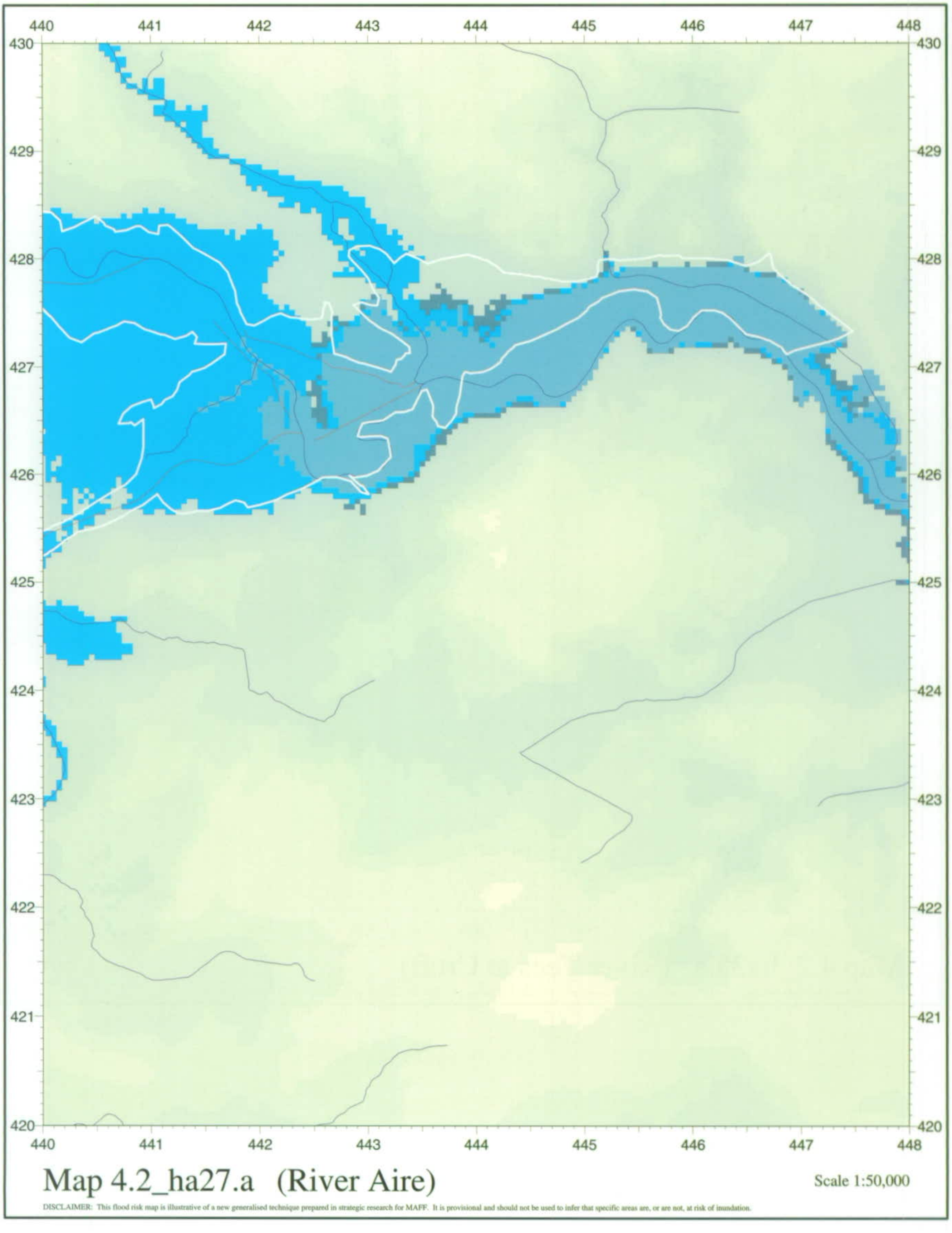
DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 4.2_ha25.a (River Tees at Croft)

Scale 1:50,000

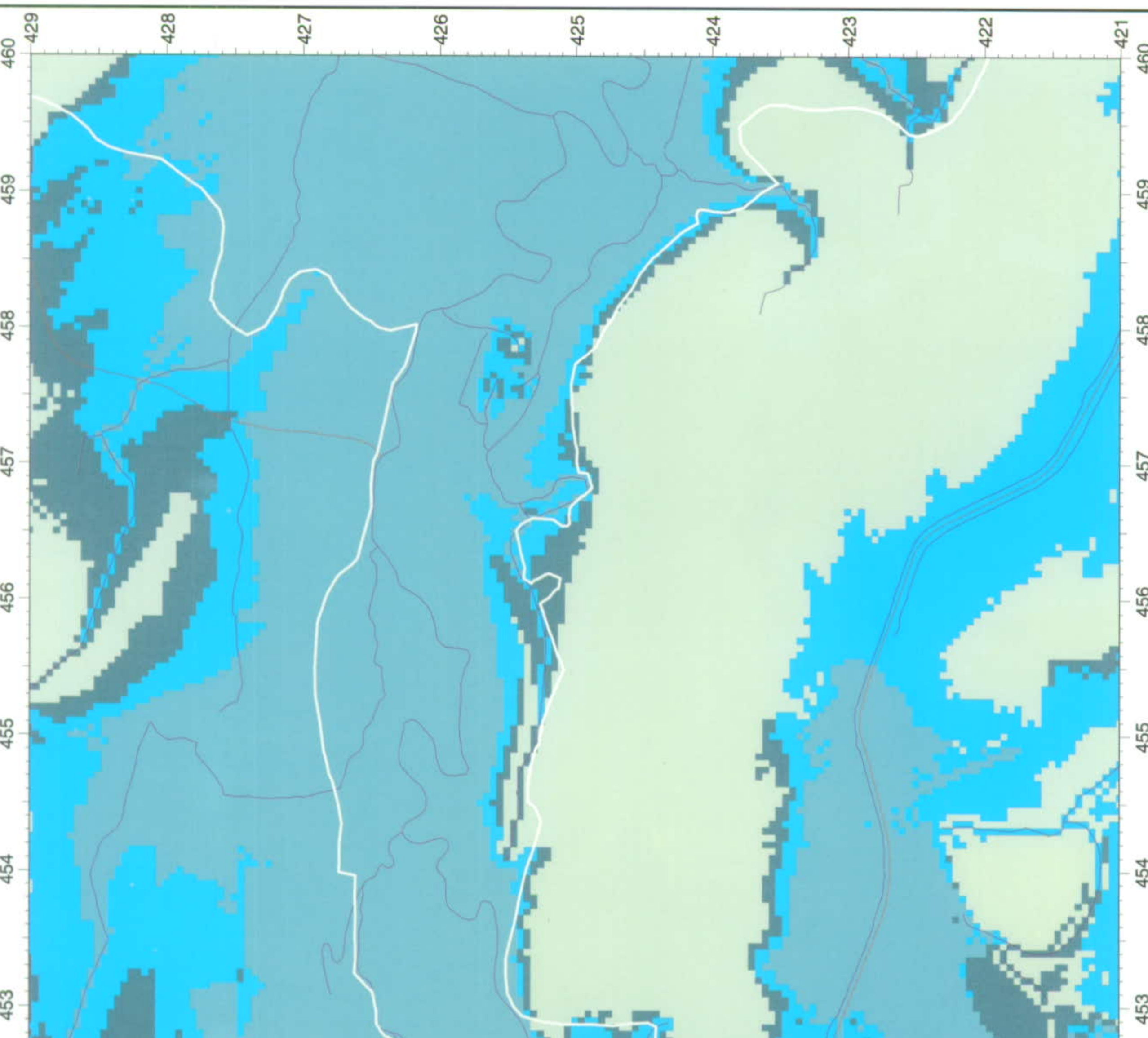
DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 4.2_ha27.a (River Aire)

Scale 1:50,000

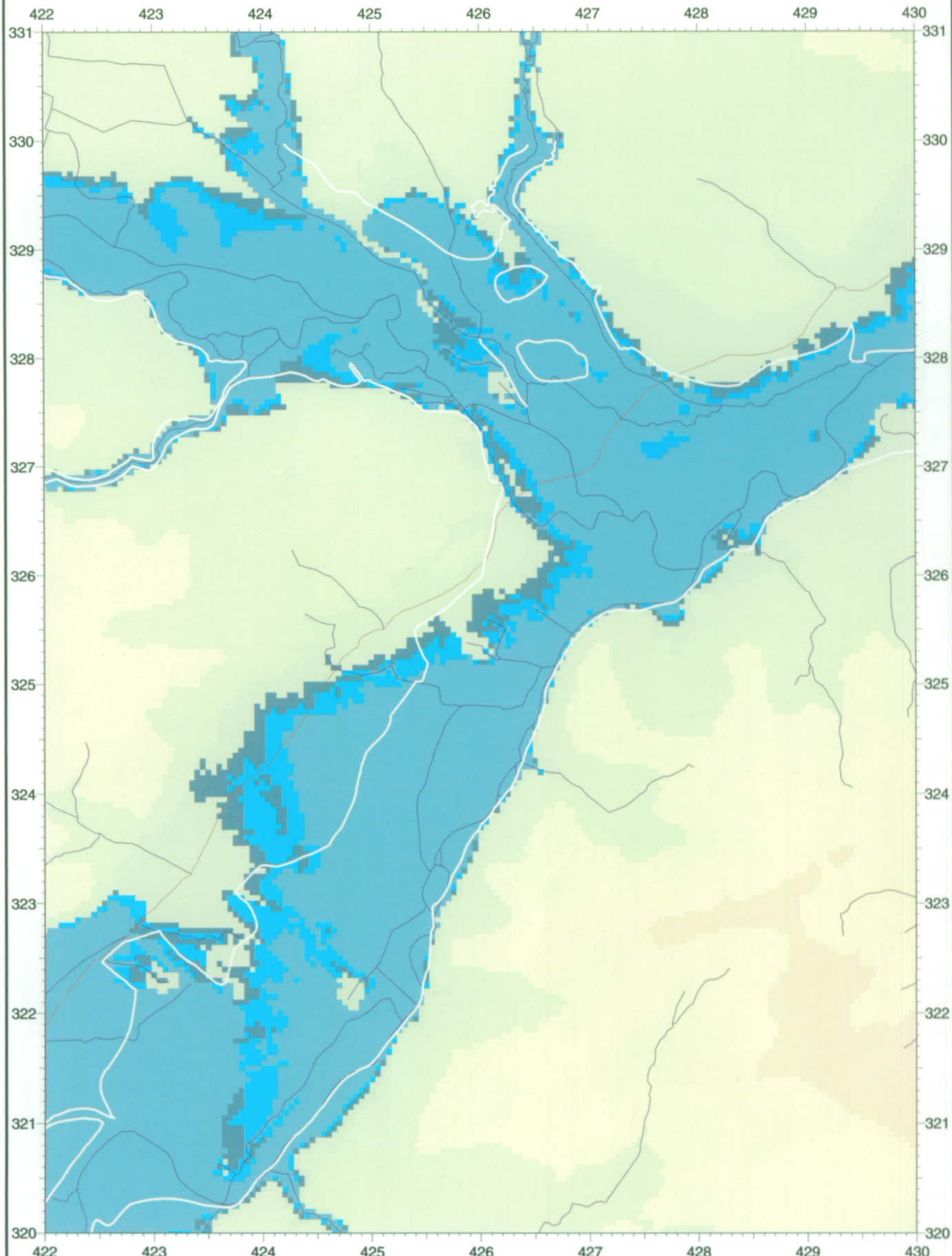
DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 4.2_ha27.b (River Aire)

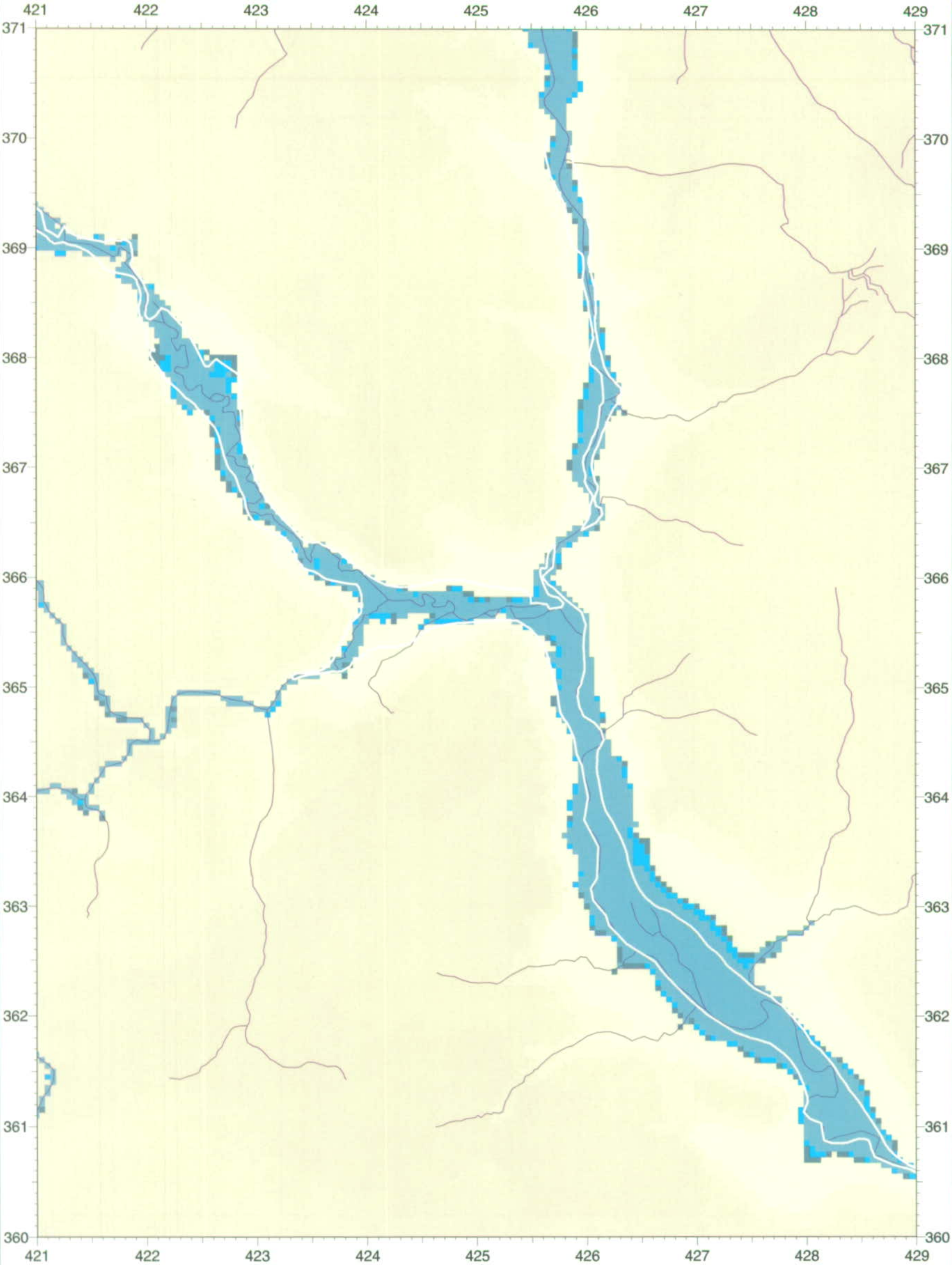
Scale 1:50,000

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 4.2_ha28.a (River Trent and tributaries at Burton) Scale 1:50,000

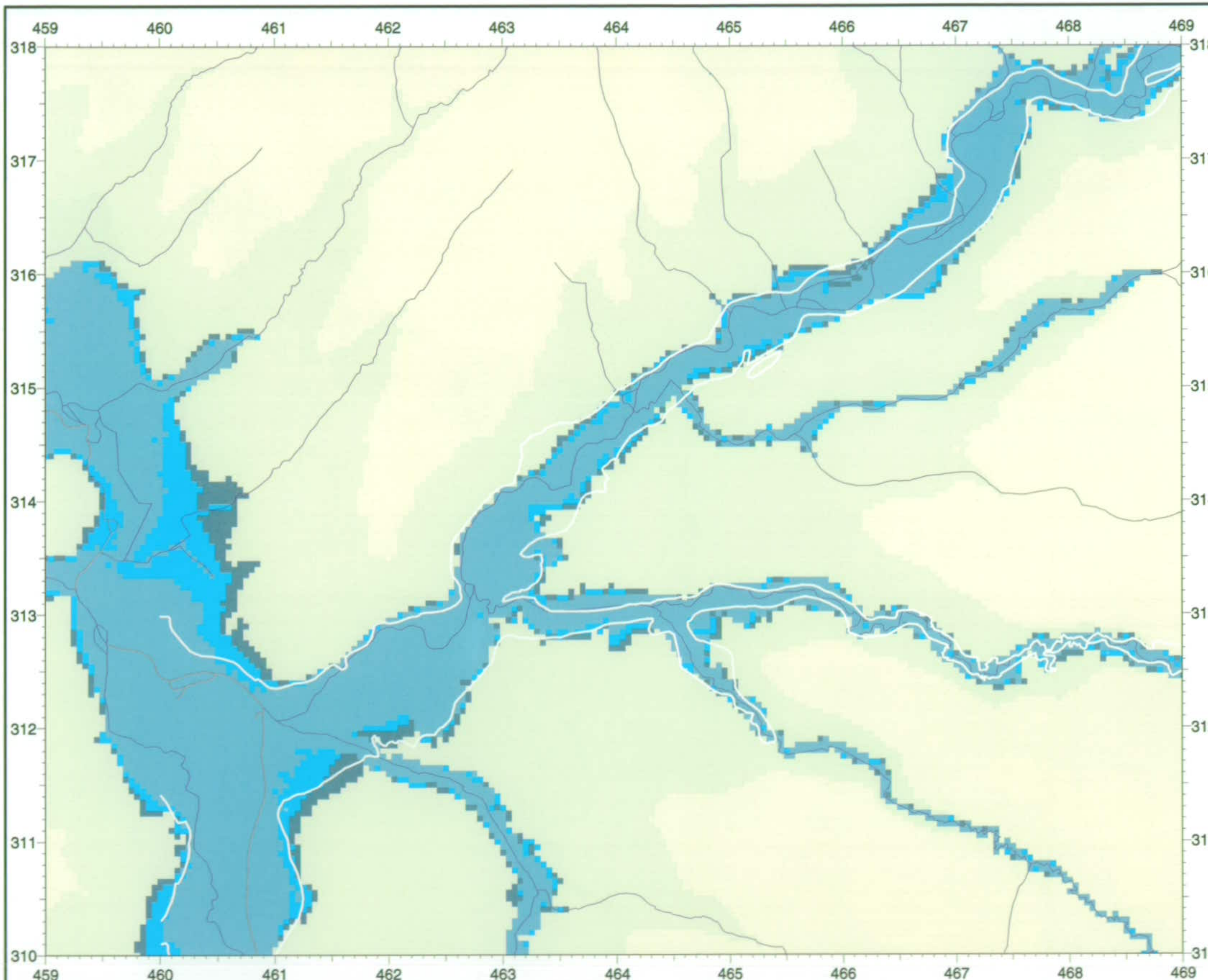
DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 4.2_ha28.b (River Derwent and tributaries)

Scale 1:50,000

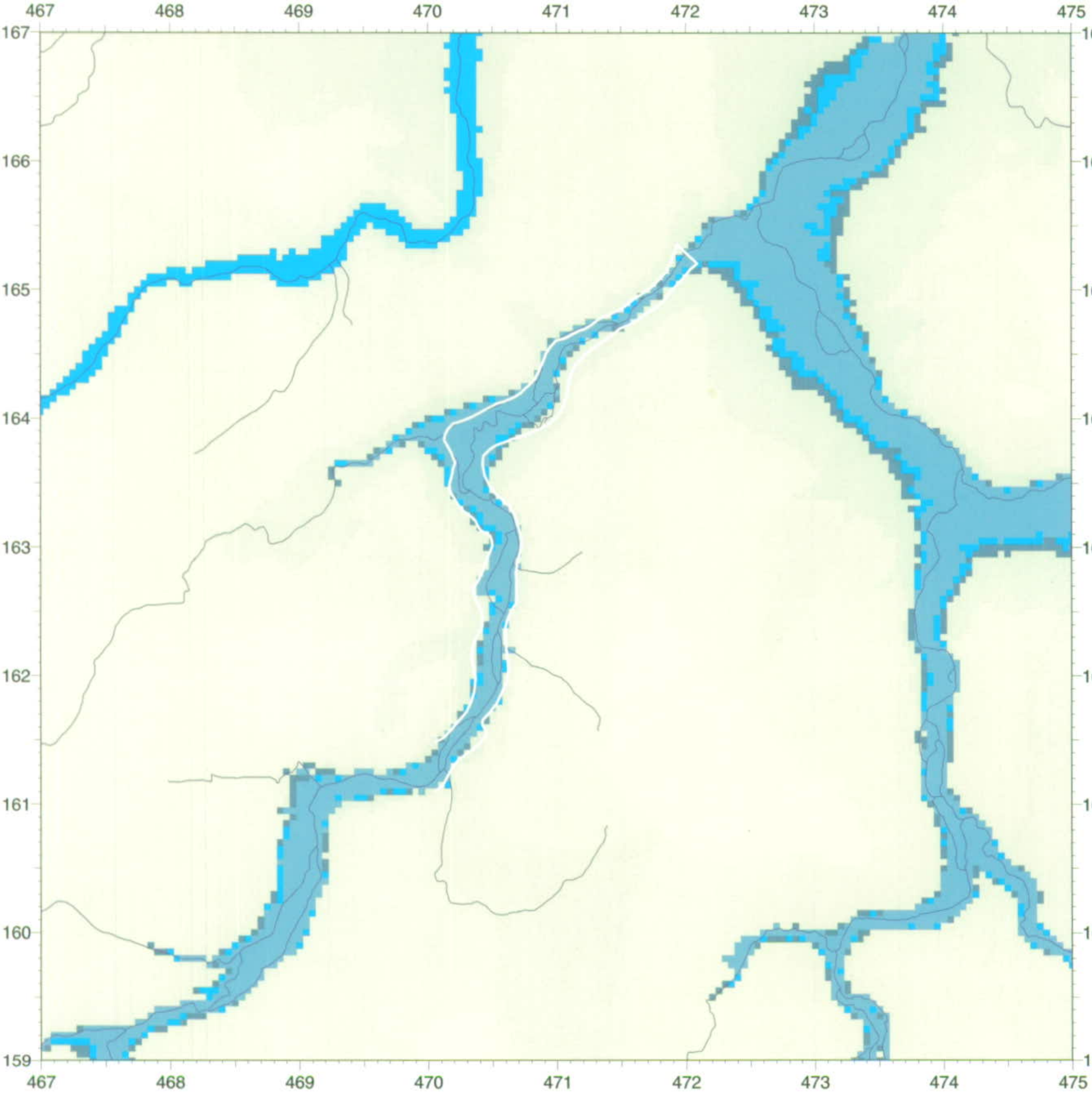
DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 4.2_ha28.c (Rivers Wreake & Soar and Twyford Brook)

Scale 1:50,000

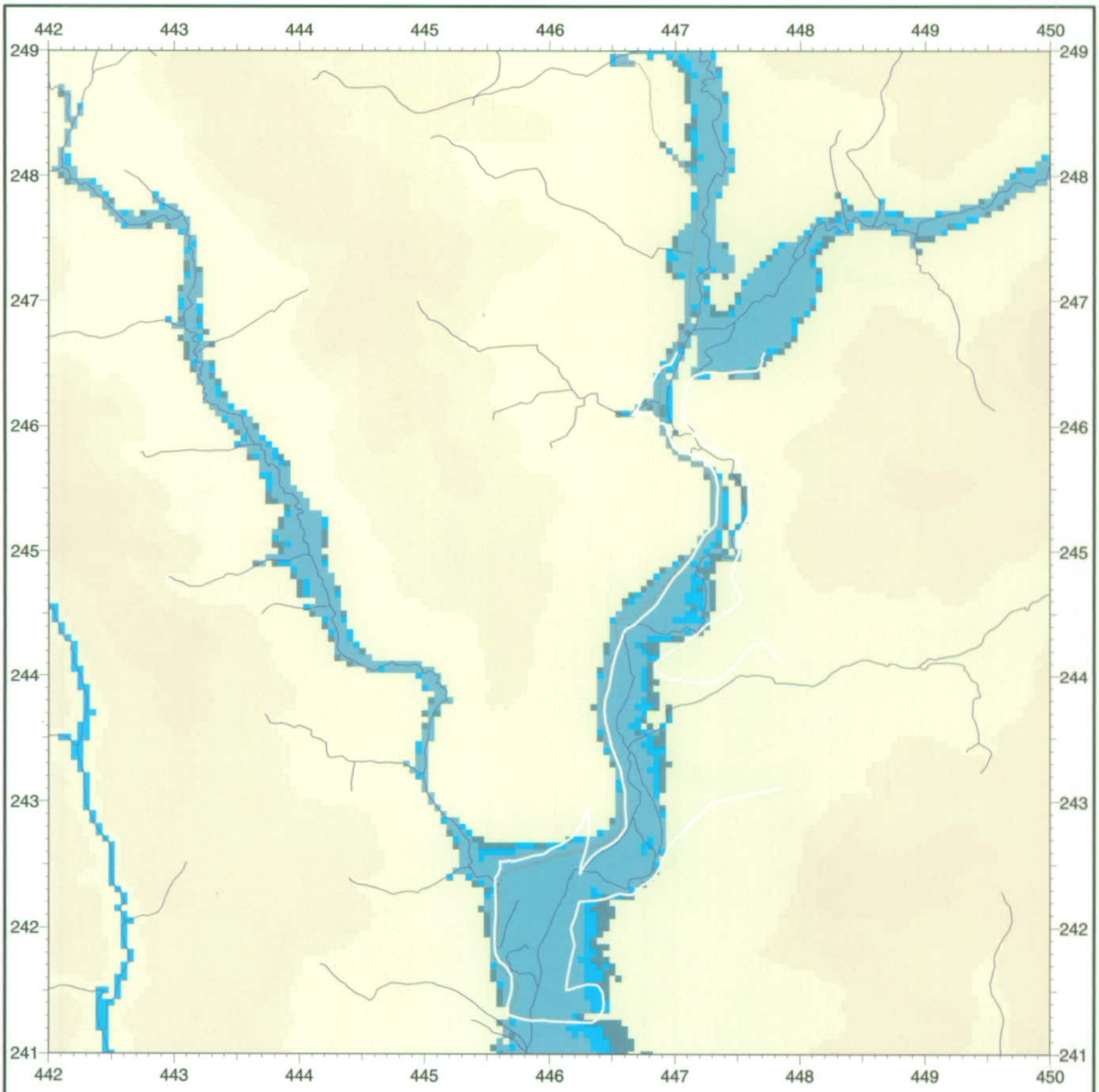
DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 4.2_ha39.a (River Loddon at Sheepbridge)

Scale 1:50,000

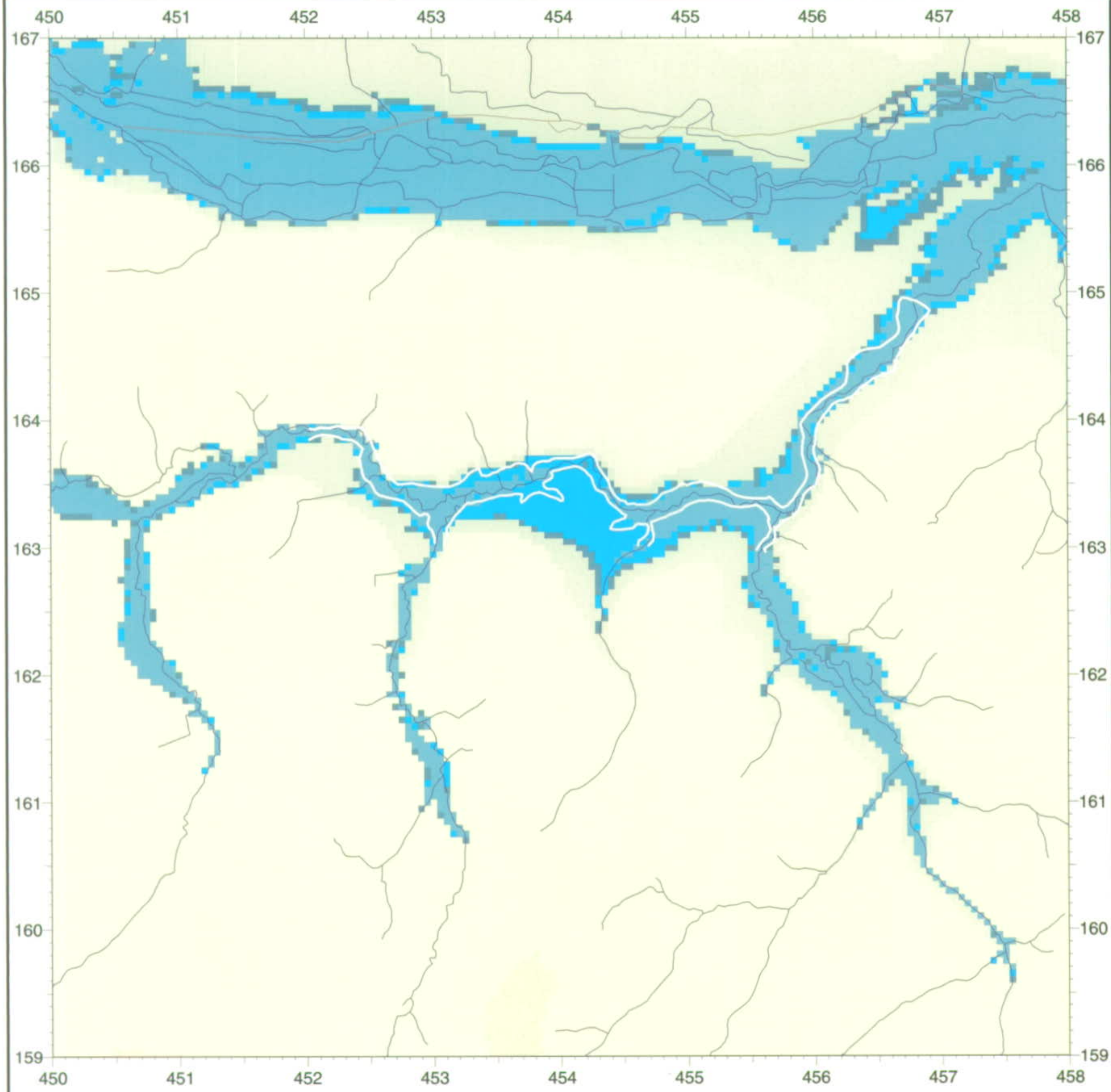
DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 4.2_ha39.b (River Cherwell at Banbury)

Scale 1:50,000

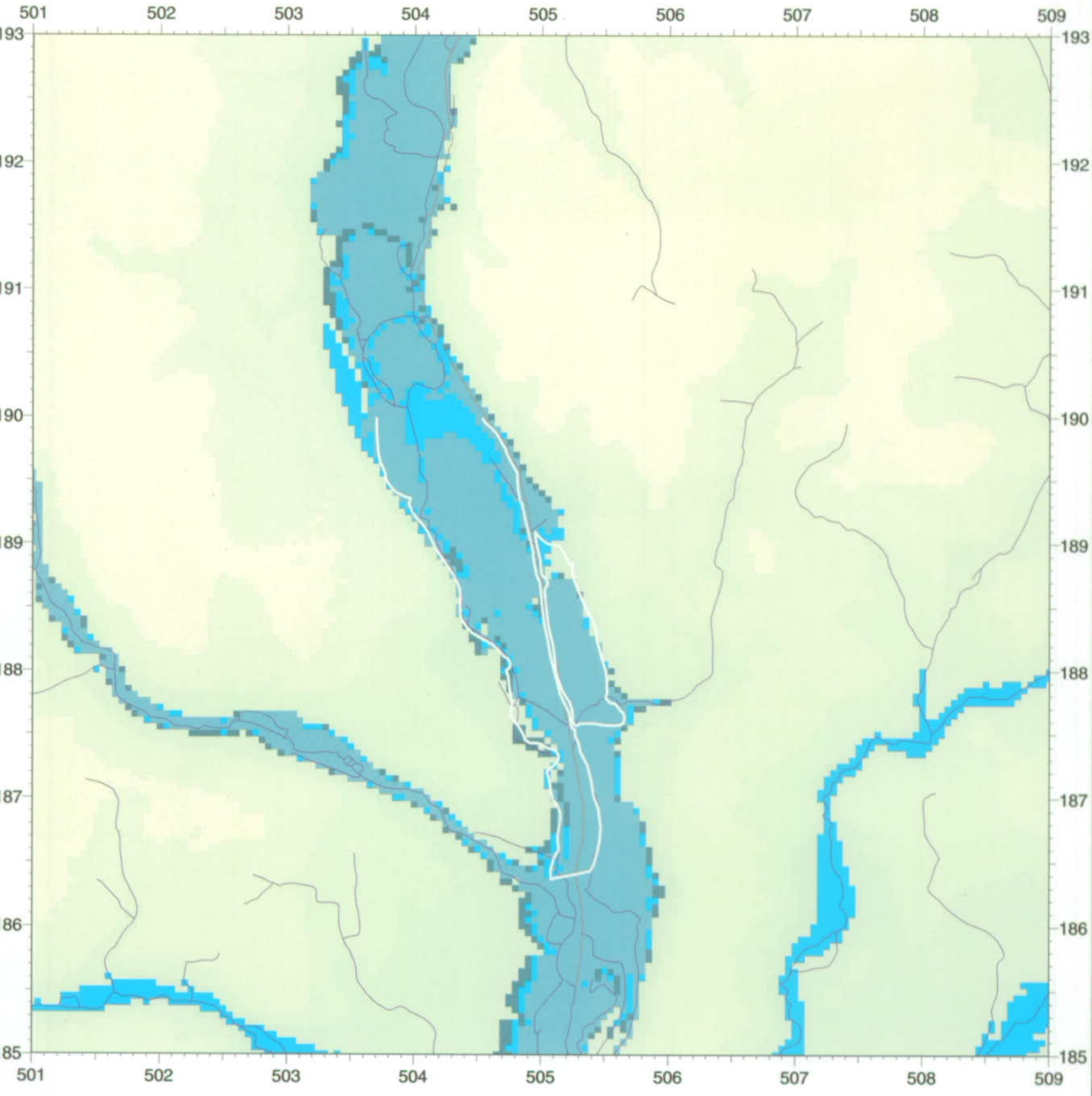
DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 4.2_ha39.c (River Enborne at Brimpton)

Scale 1:50,000

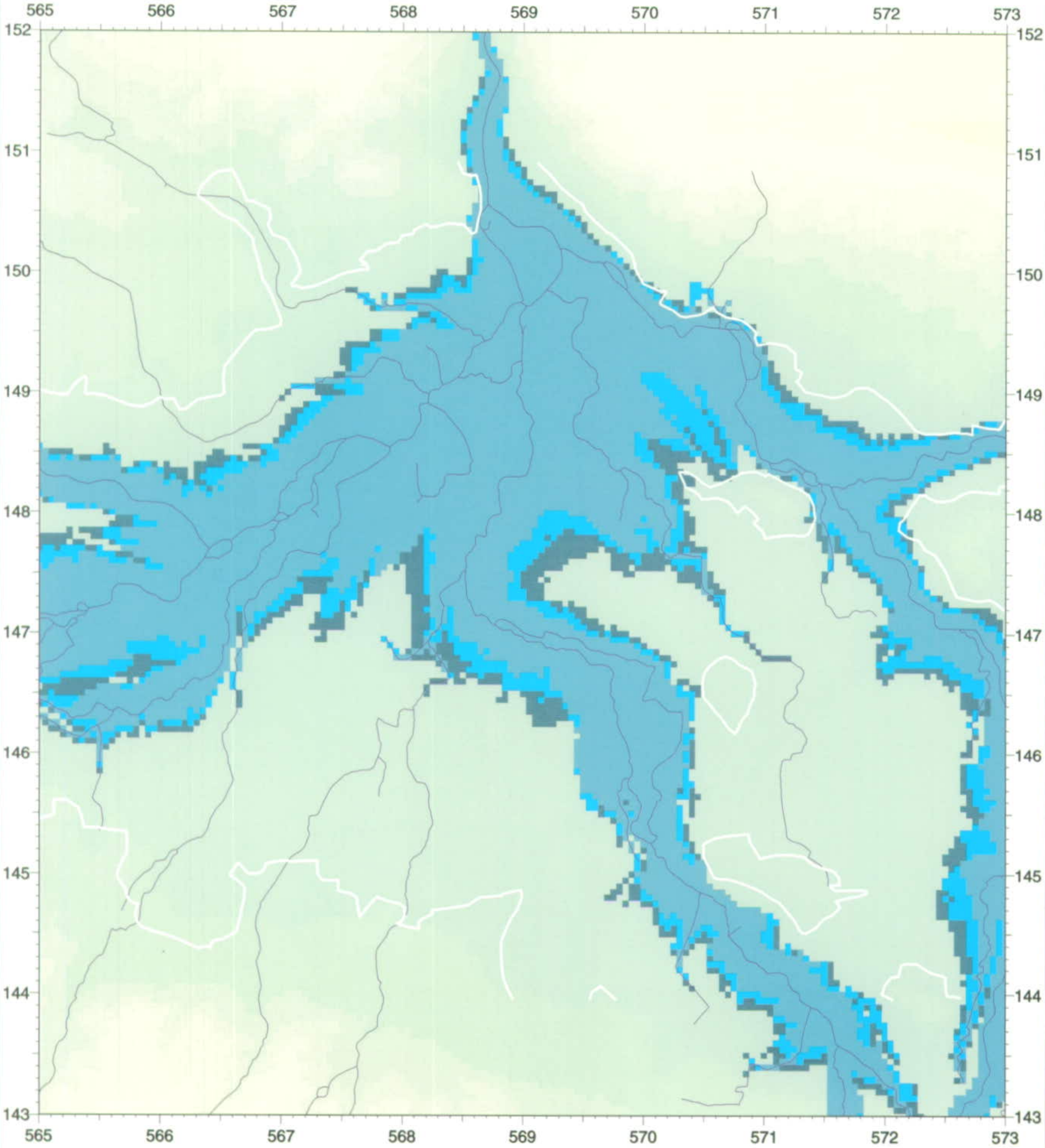
DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 4.2_ha39.d (River Colne at Denham)

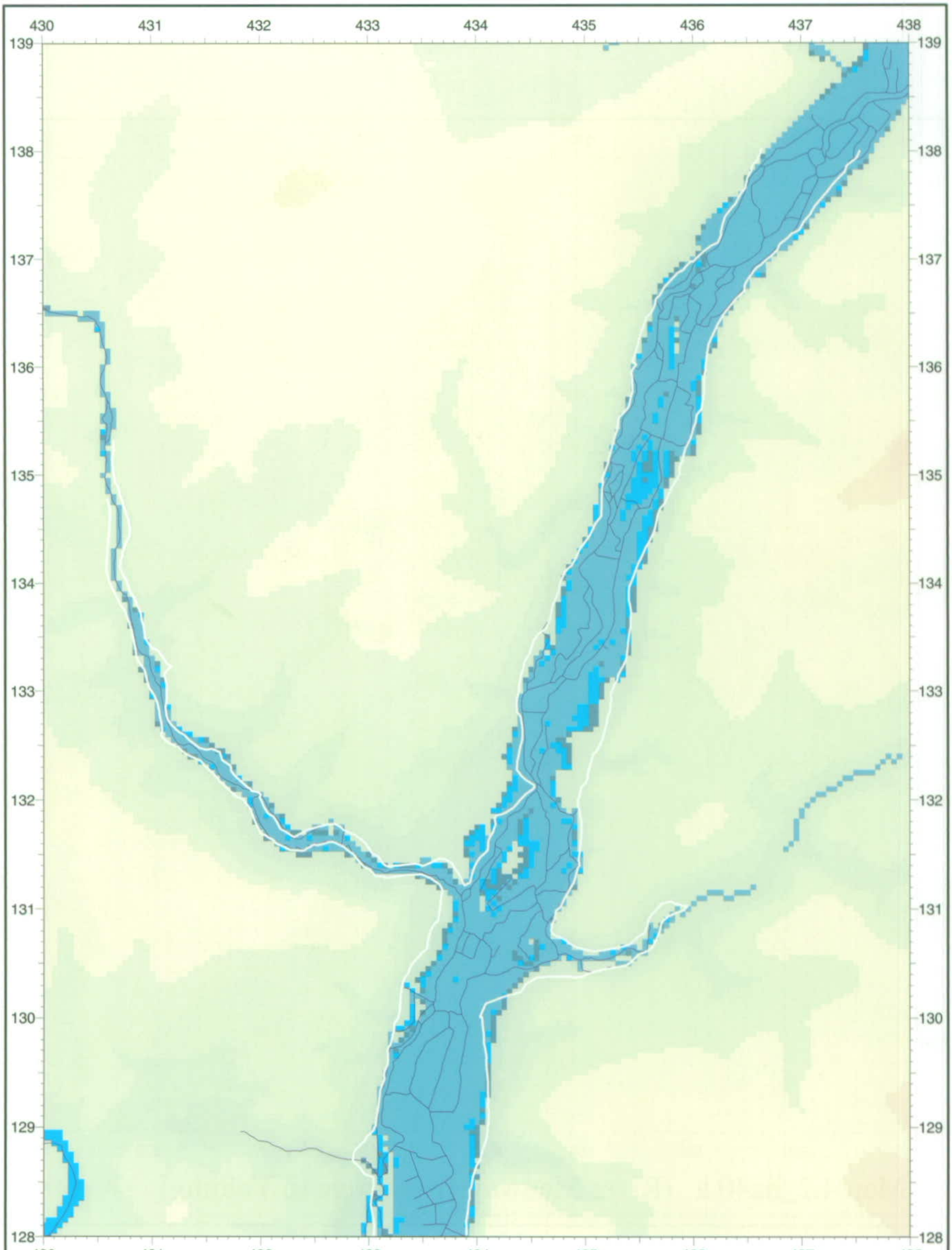
Scale 1:50,000

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



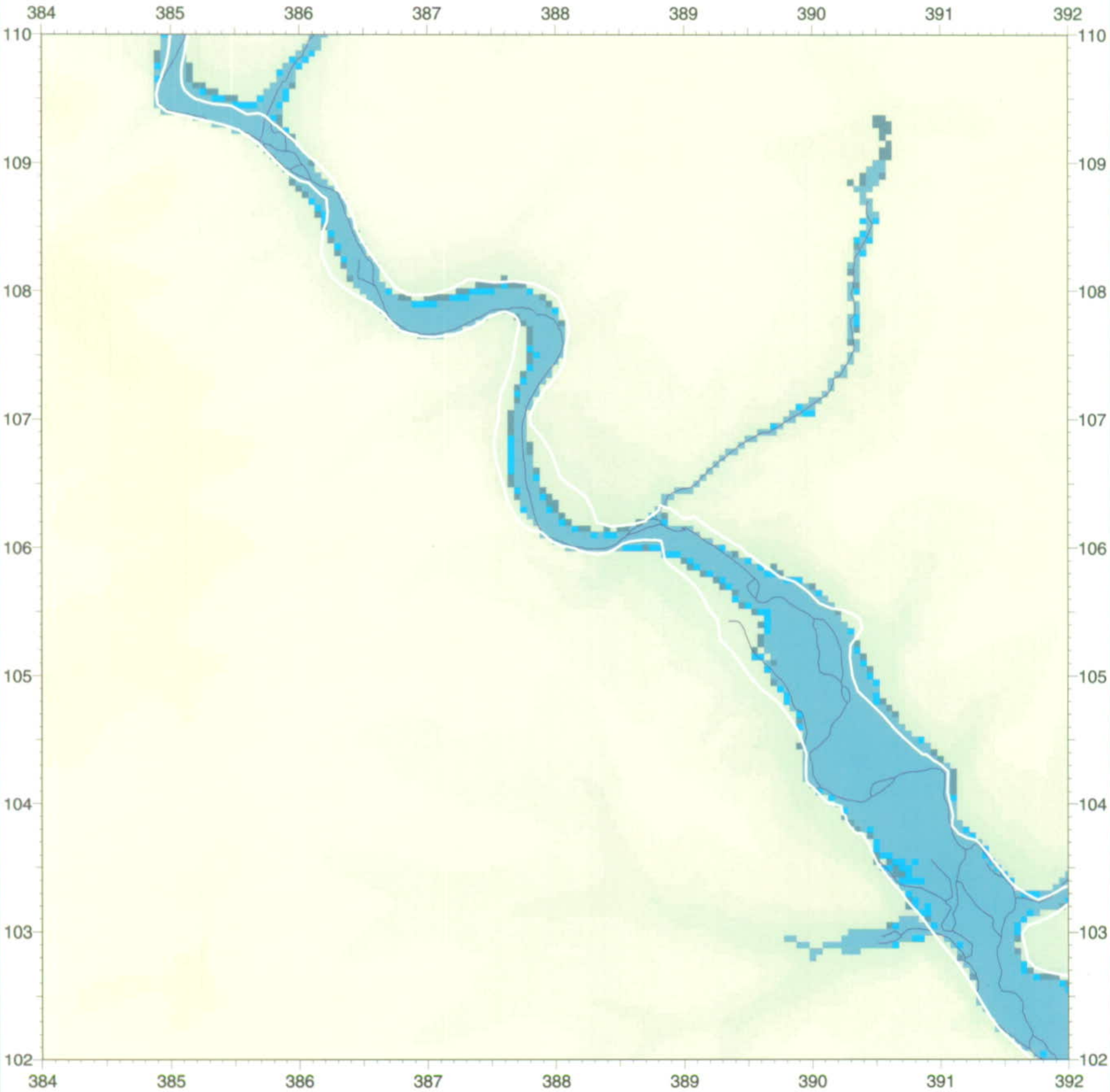
Map 4.2_ha40.a (River Medway, Tonbridge to Yalding) Scale 1:50,000

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 4.2_ha42.a (River Test, Romsey to Stockbridge) Scale 1:50,000

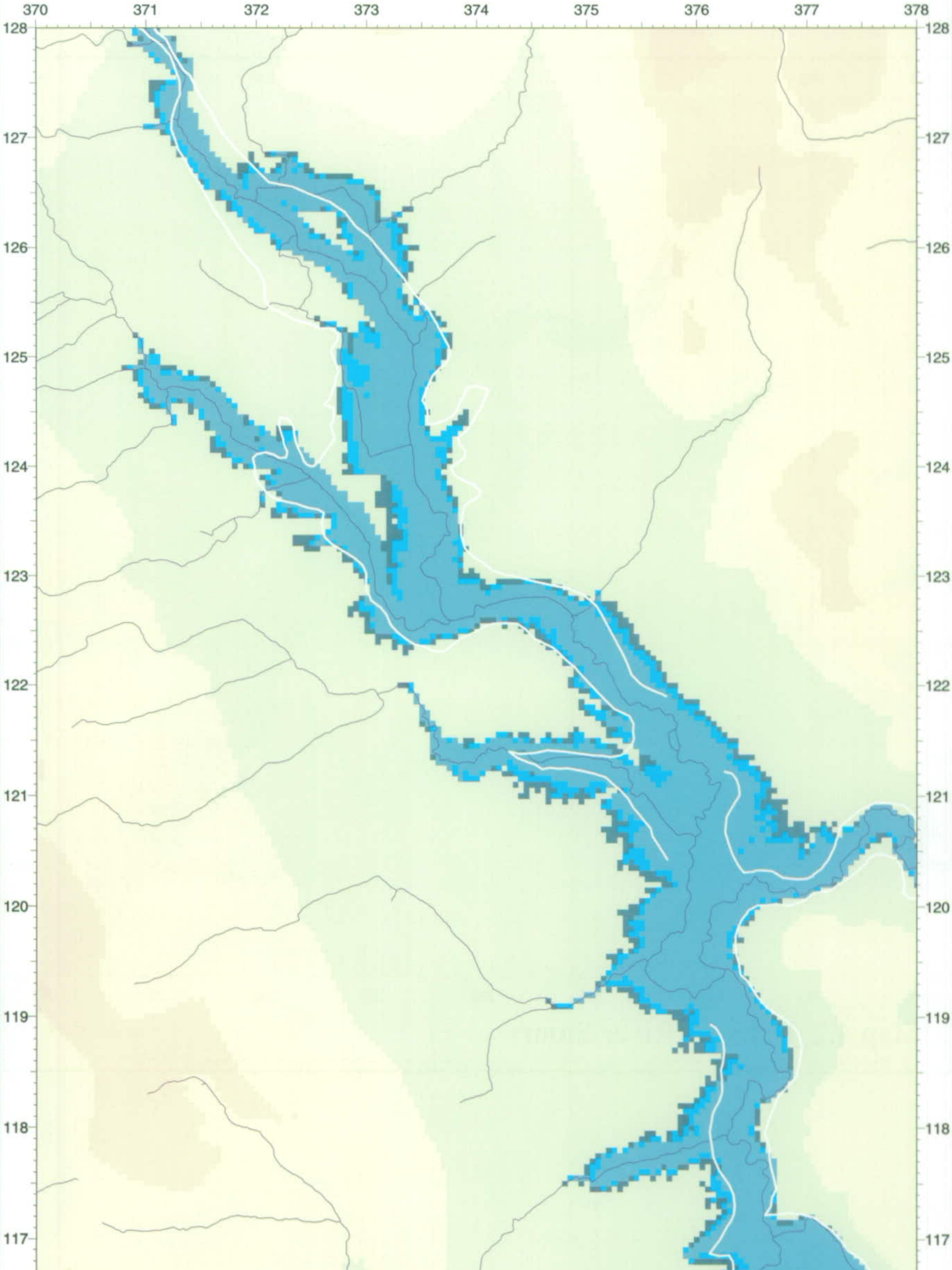
DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 4.2_ha43.a (River Stour)

Scale 1:50,000

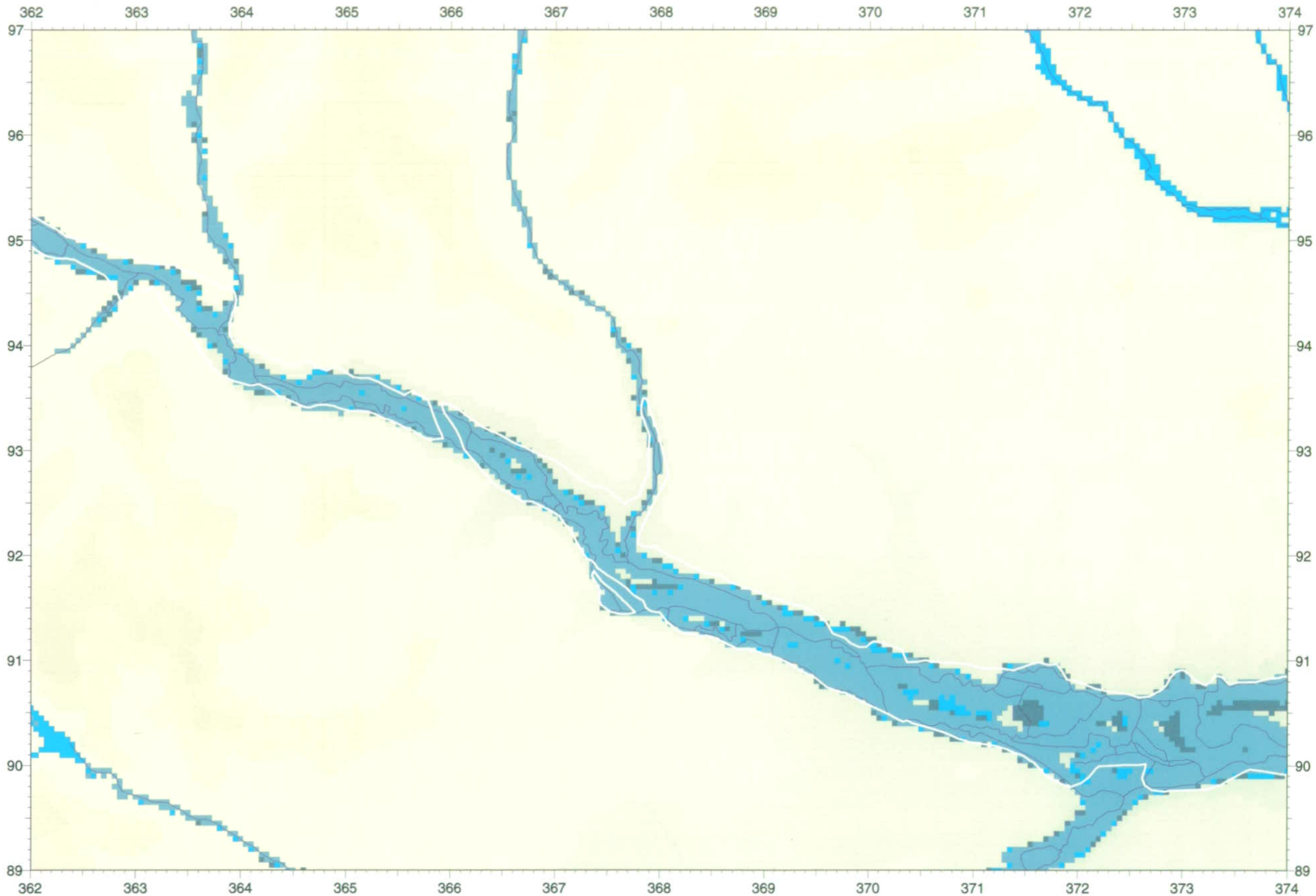
DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 4.2_ha43.b (Rivers Cale and Stour)

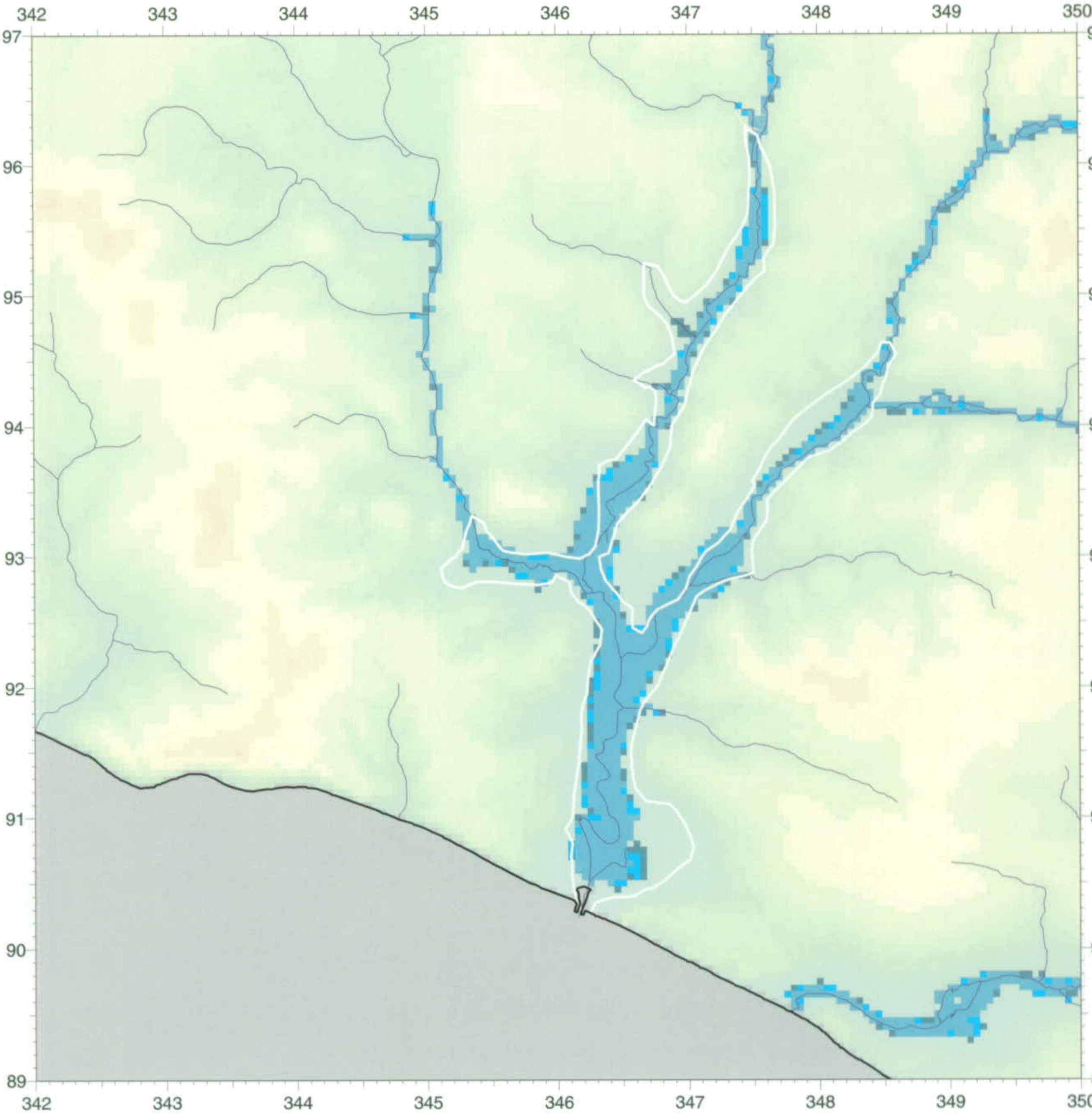
Scale 1:50,000

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 4.2_ha44.a (River Frome)

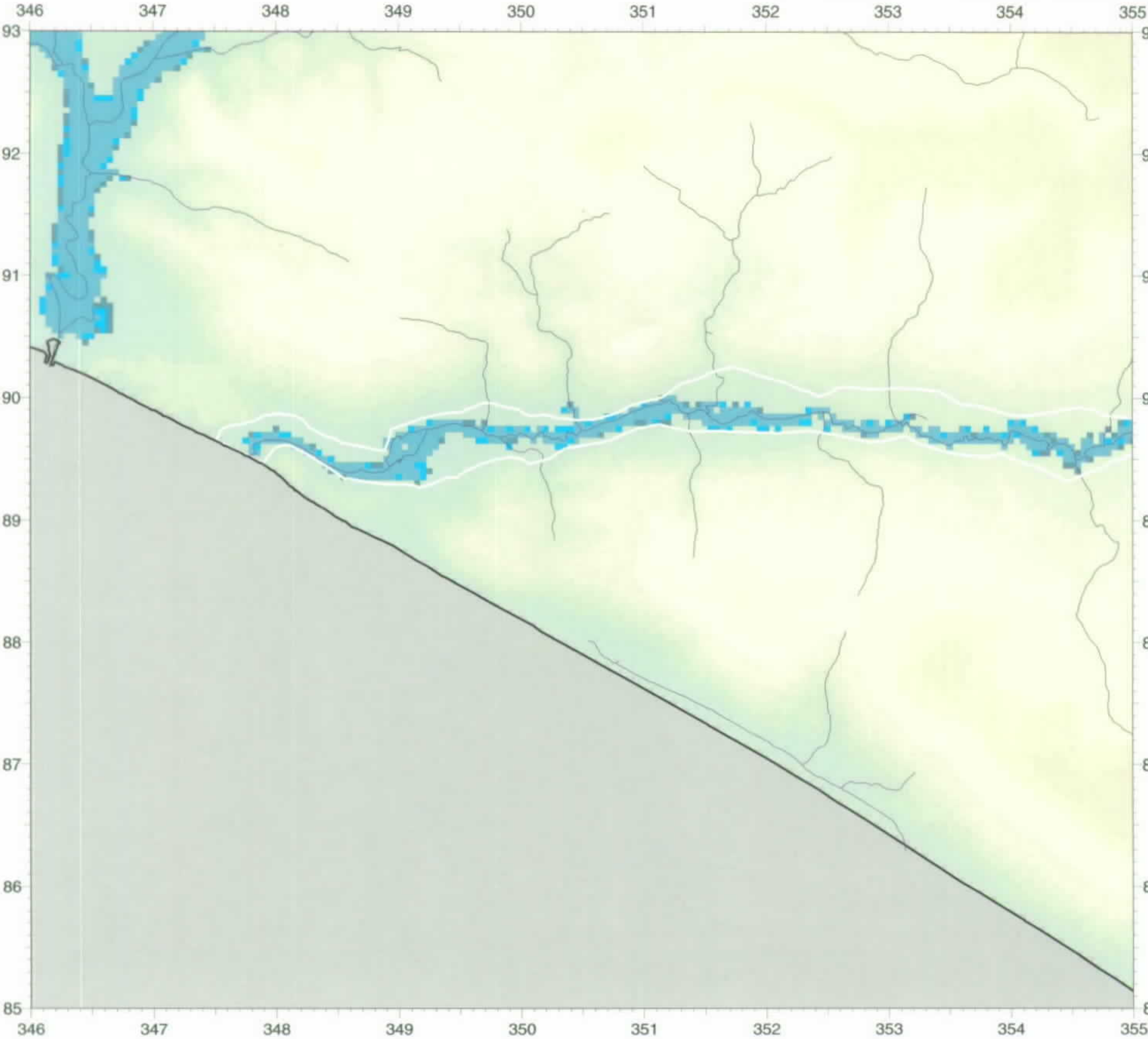
DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 4.2_ha44.b (Rivers Brit and Asker)

Scale 1:50,000

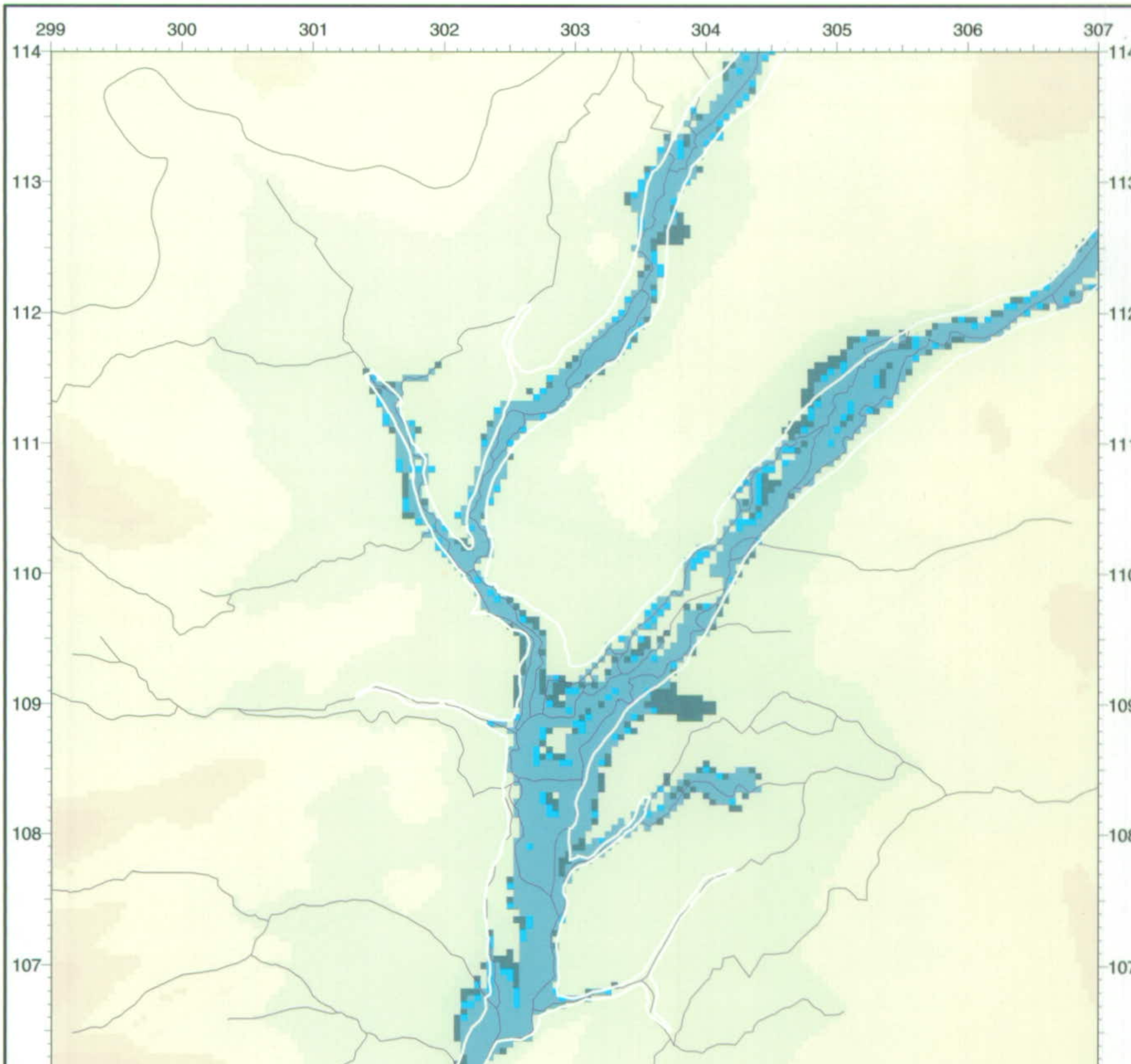
DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 4.2_ha44.c (River Bride)

Scale 1:50,000

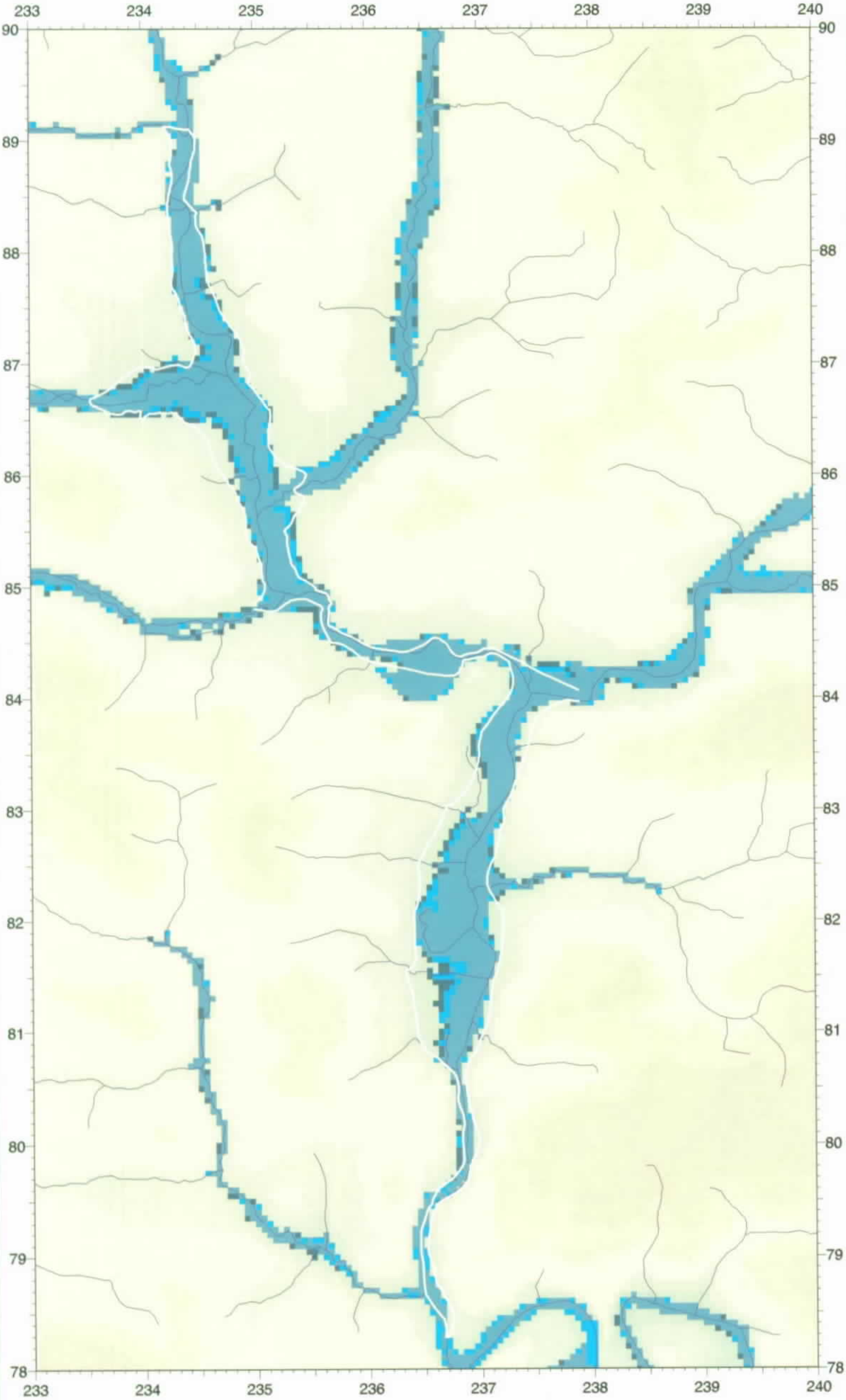
DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 4.2_ha45.a (River Culm)

Scale 1:50,000

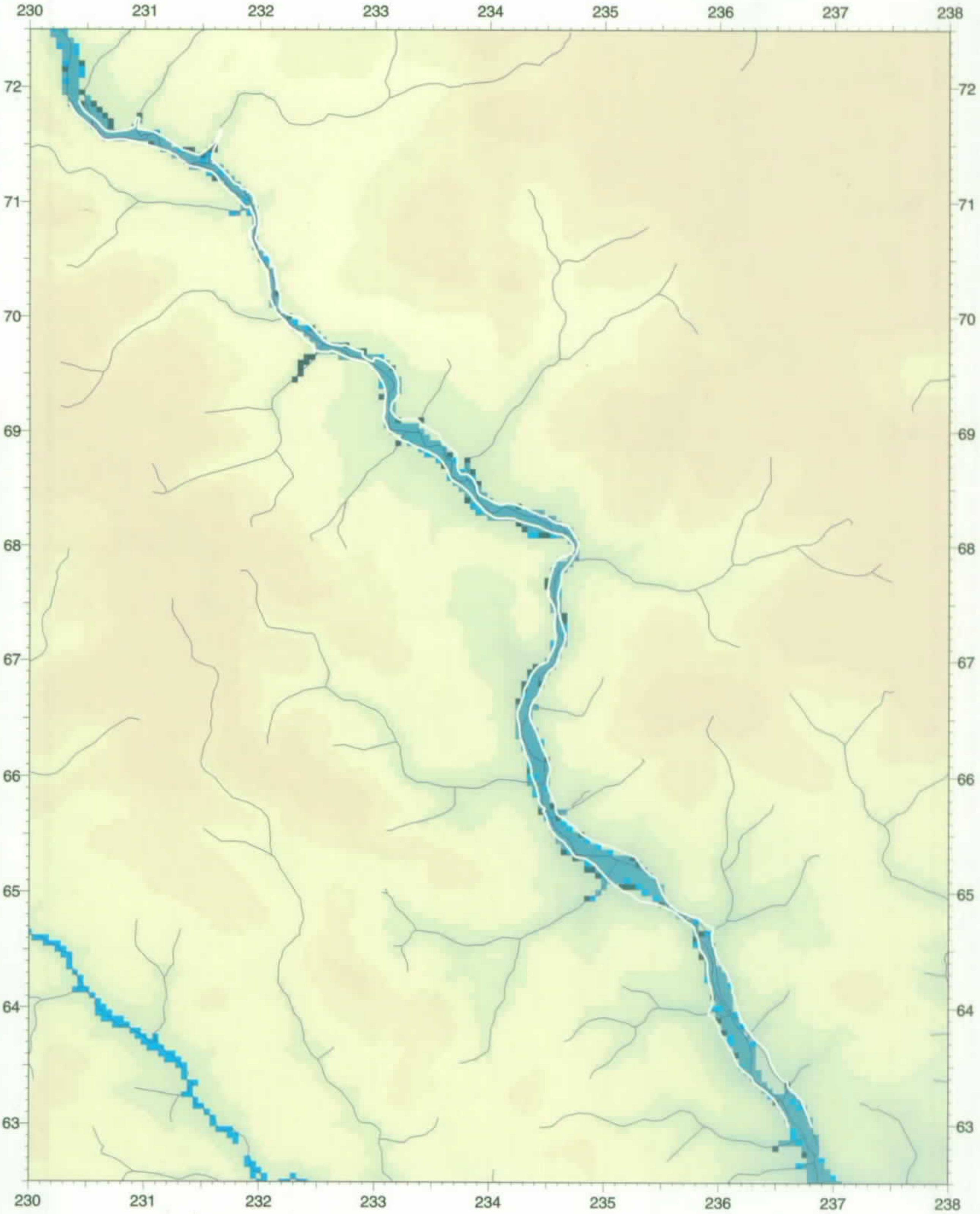
DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 4.2_ha47.a (River Tamar)

Scale 1:50,000

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 4.2_ha47.b (River Lynher)

Scale 1:50,000

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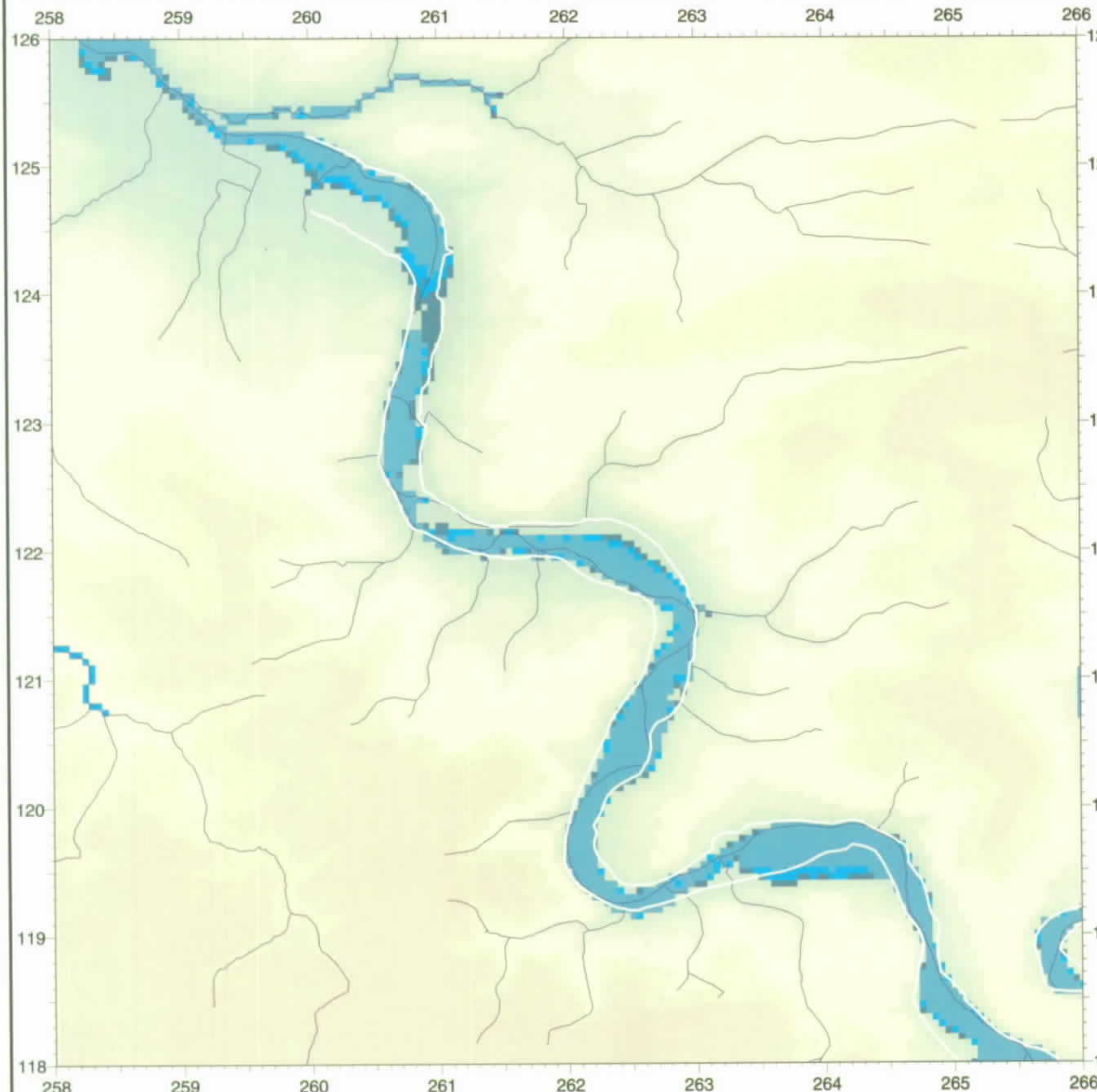
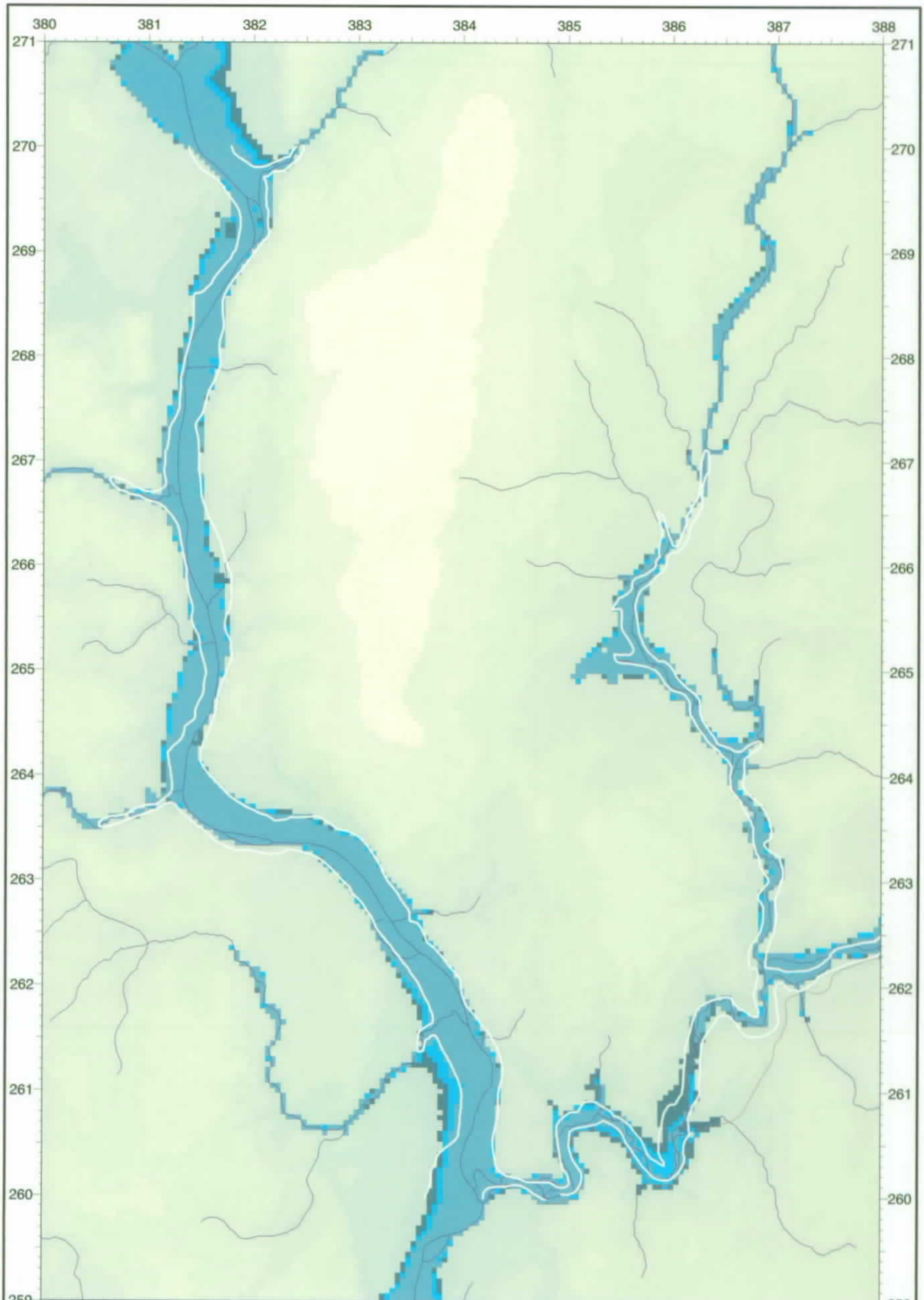


Map 4.2_ha50.a (Rivers Taw and Mole)

Scale 1:50,000

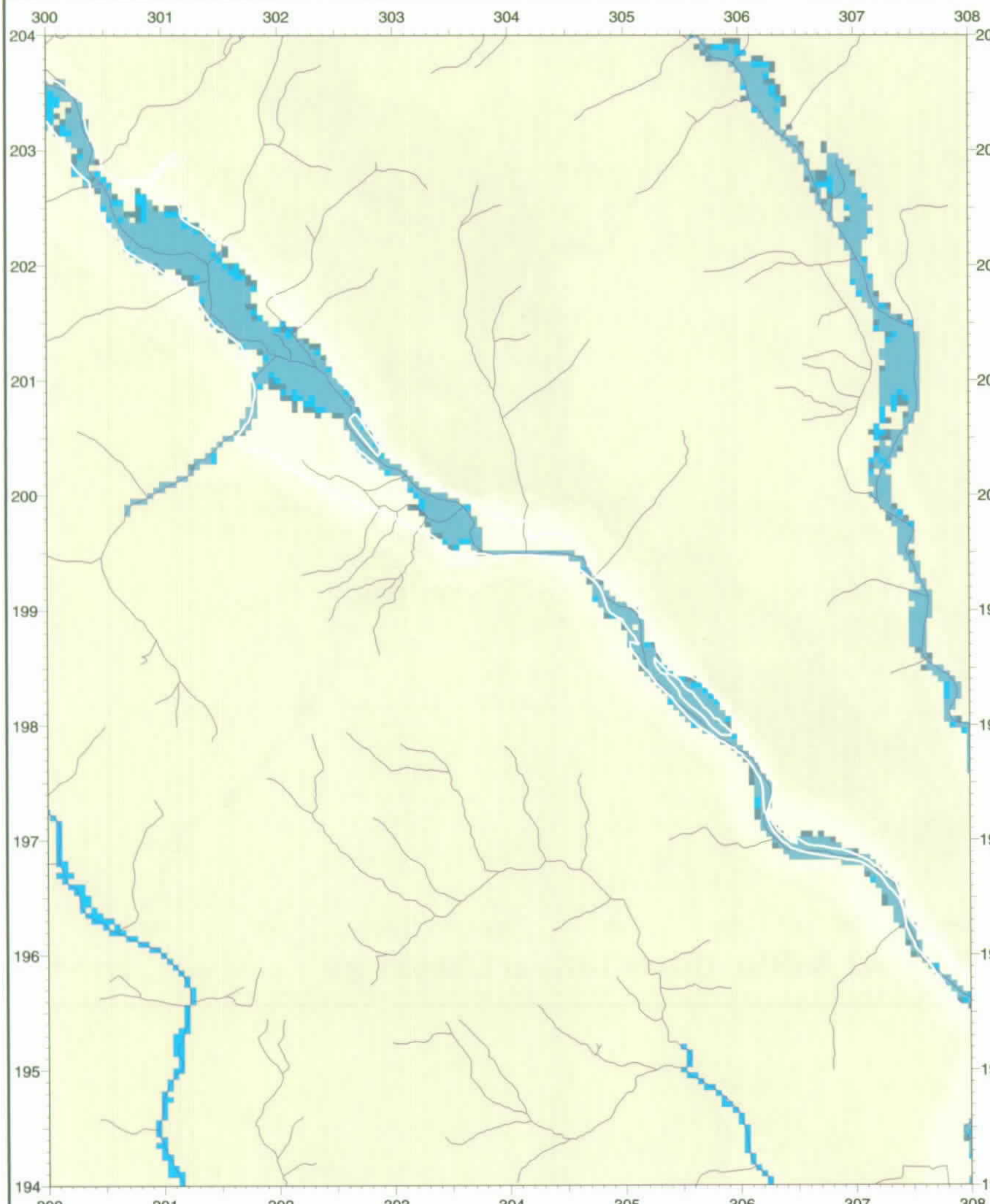
DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 4.2_ha54.a (Rivers Severn and Salwarke)

Scale 1:50,000

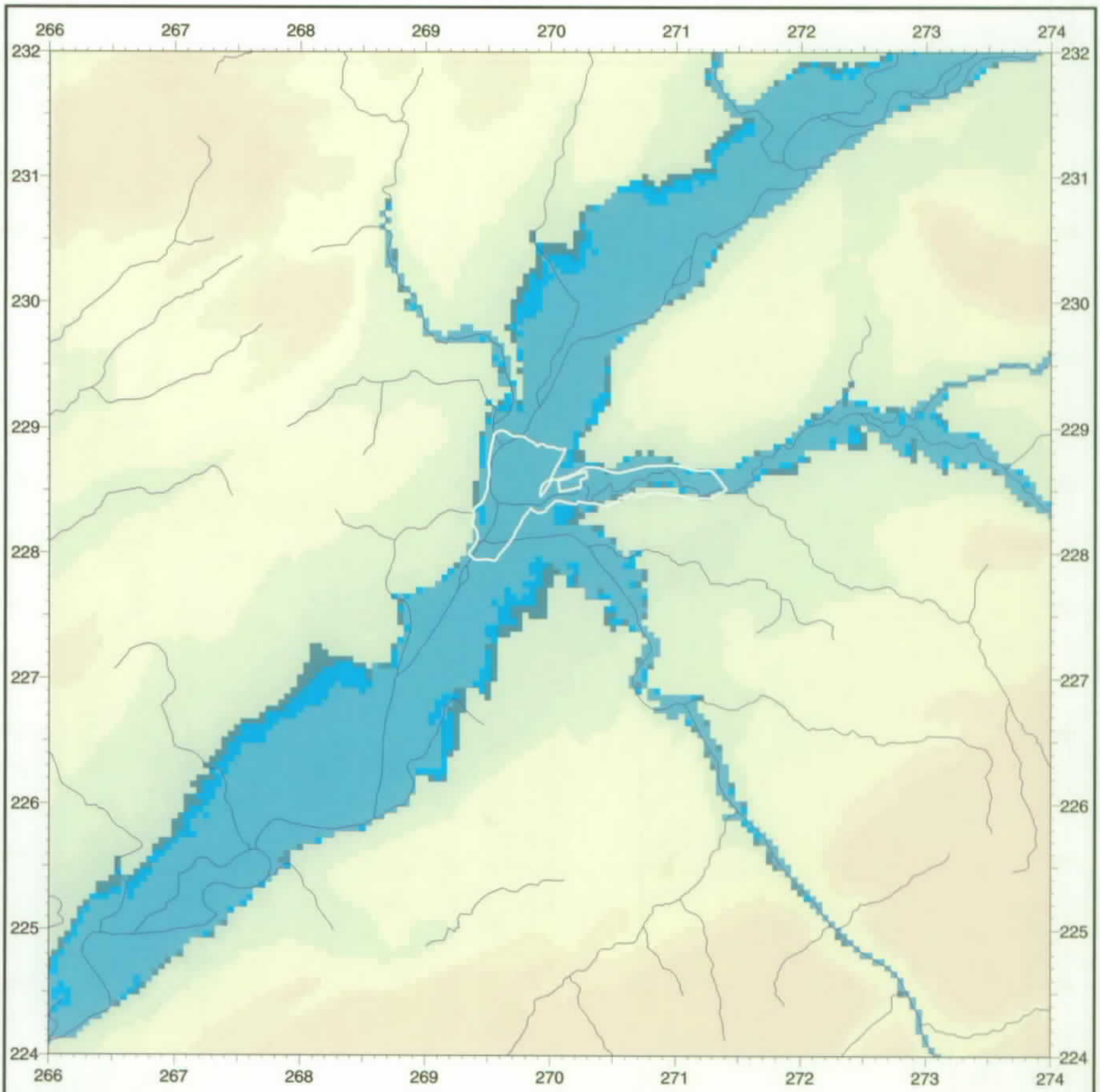
DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 4.2_ha57.a (River Cynon)

Scale 1:50,000

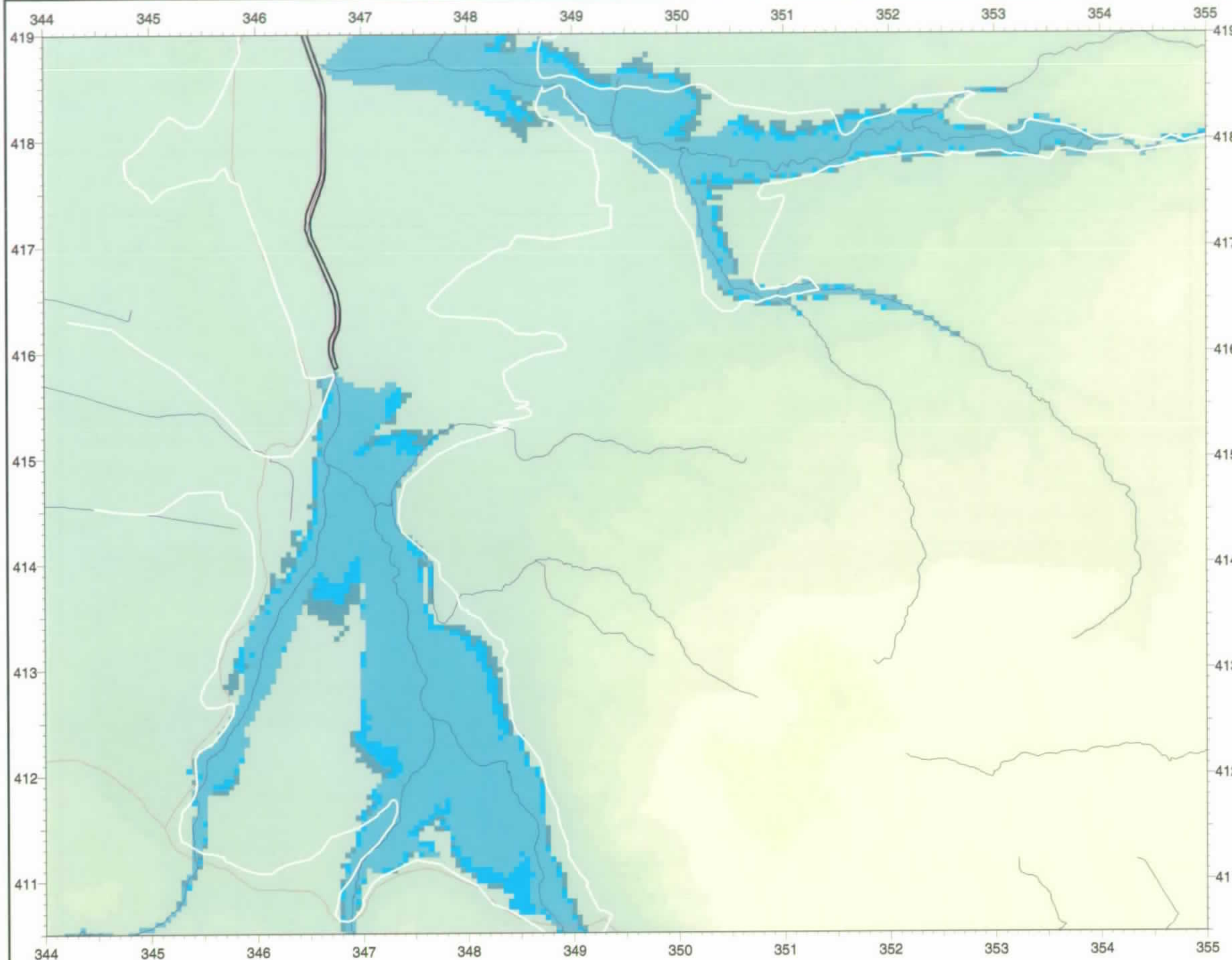
DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 4.2_ha60.a (River Towy at Llangadog)

Scale 1:50,000

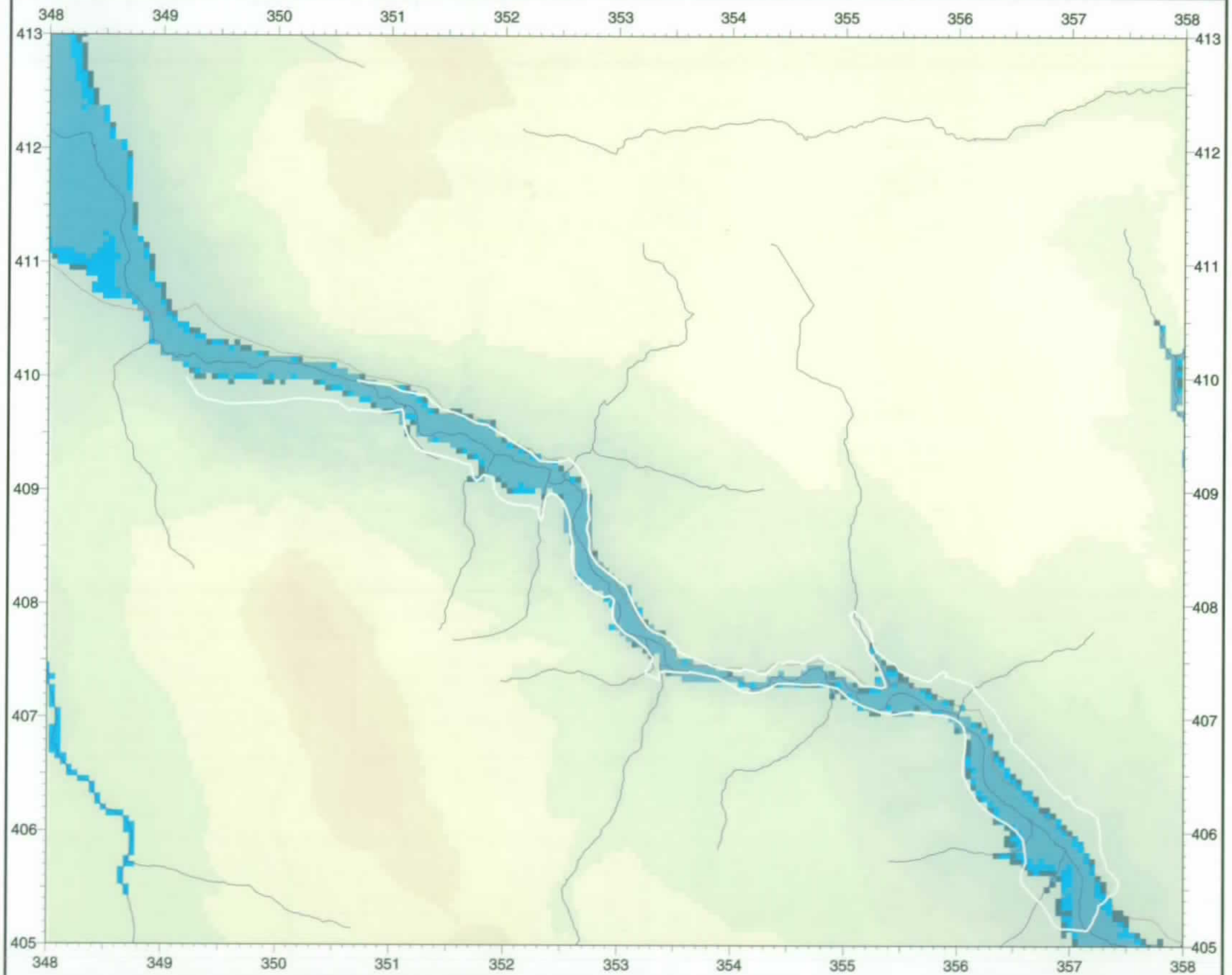
DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 4.2_ha70.a (River Douglas and tributaries)

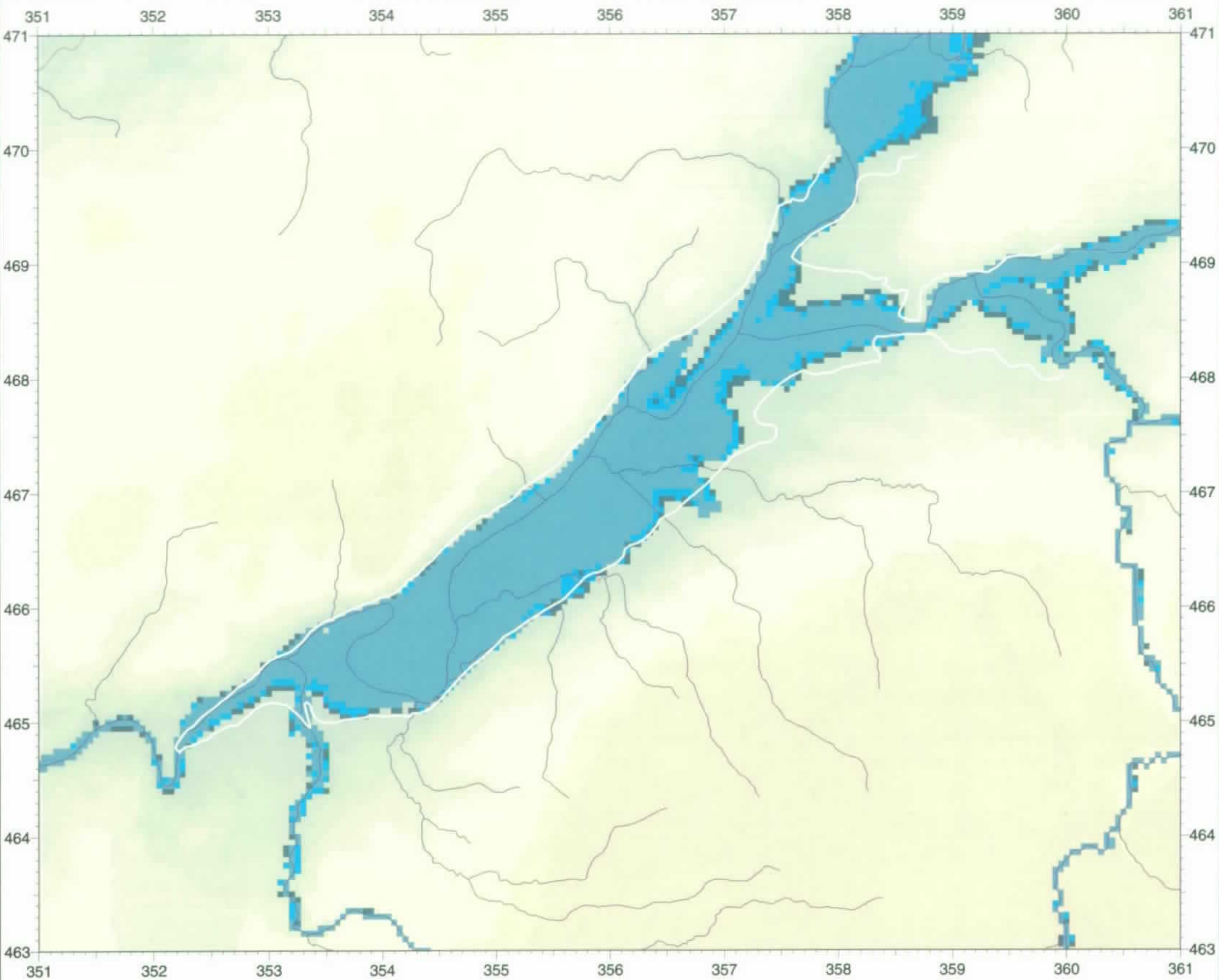
Scale 1:50,000

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



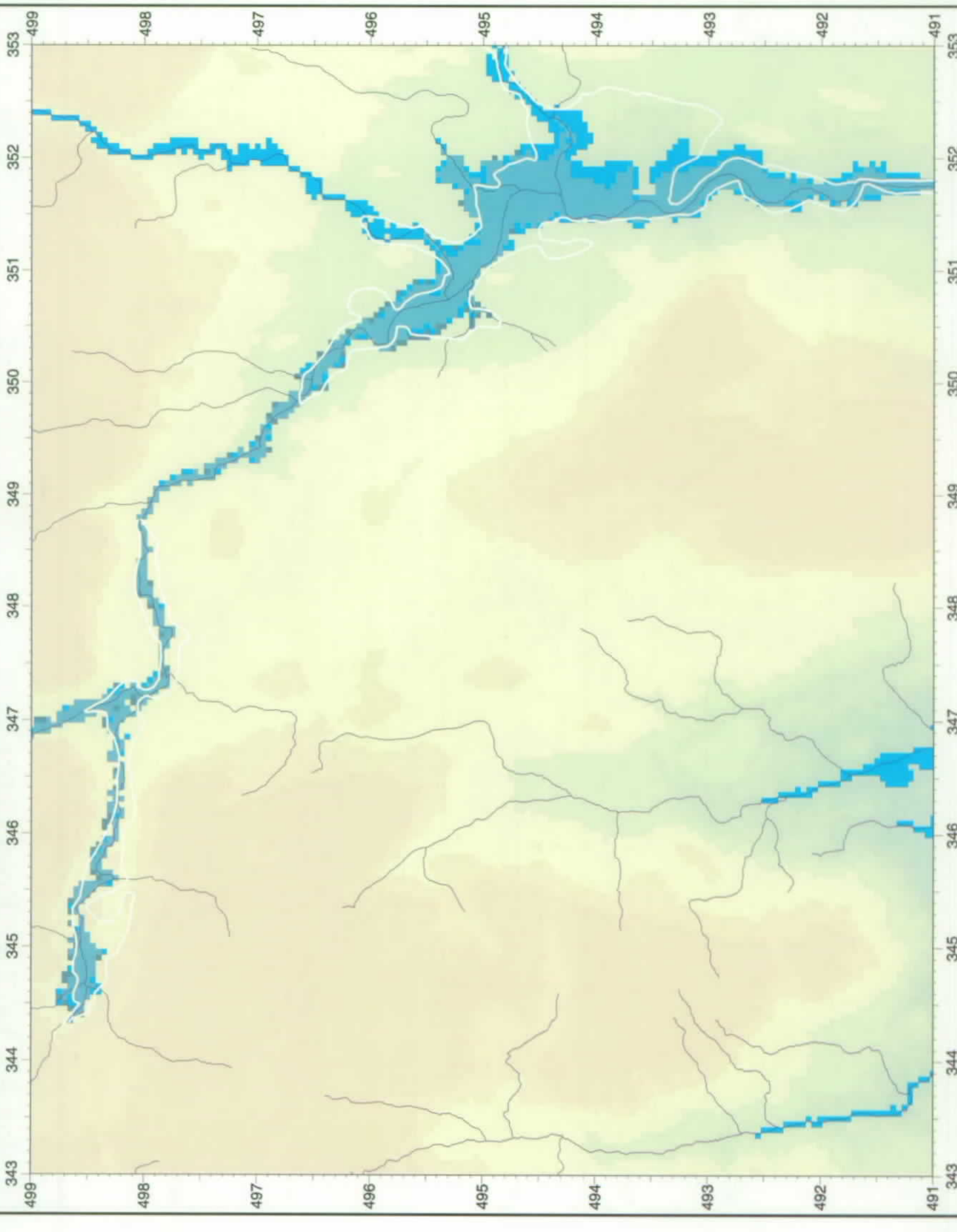
Map 4.2_ha70.b (River Douglas)

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 4.2_ha72.a (River Lune)

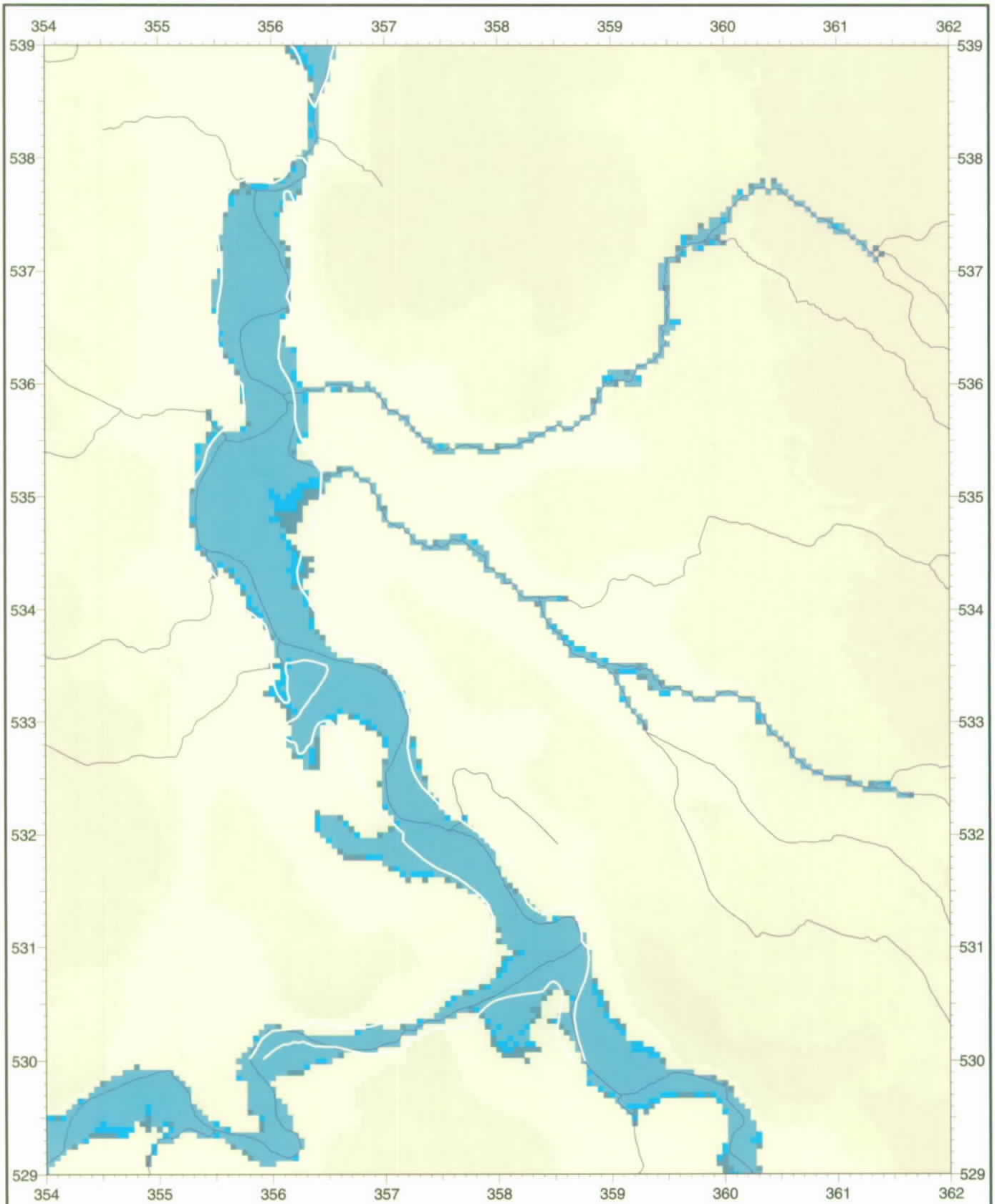
DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 4.2_ha73.a (River Kent)

Scale 1:50,000

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 4.2_ha76.a (River Eden)

Scale 1:50,000

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.

5 Results

5.1 Depth and extent of flooding

The results presented here have been obtained by summing the flooded grid points, excluding those flagged as non-flooded river (see Section 3.8). For non-river points, flood depth has been computed as flood elevation minus ground elevation. For river points this depth has been reduced by 0.5 m to compensate for the reduction in surface elevation of river points inherent in the IHDTM (see Section 3.3). Table 5.1 shows the distribution of flood depths on built-up and non-built land, and Table 5.2 provides a regional breakdown based on National Grid 100 km by 100 km squares.

Map 5.4 (key sheet, on page 55) shows the disposition of the National Grid squares.

Table 5.1 Distribution of flood depths

Depth range (m)	Built-up area (km^2)	Non-built-up area (km^2)	Total area (km^2)
up to 0.4	164	2551	2715
0.5 to 0.9	149	2452	2601
1.0 to 1.9	168	2657	2825
2.0 to 2.9	67	931	998
3.0 to 3.9	31	418	449
4.0 to 4.9	15	237	252
5.0 to 5.9	9	218	227
6.0 and deeper	8	608	616
All depths	611	10072	10683

Area of England and Wales:	151207 km^2
Estimated built-up area:	9025 km^2
Fraction of built-up area at risk	6.8%
Fraction of non-built-up area at risk	7.1%
Fraction of total area at risk:	7.1%

Table 5.2 Regional breakdown of flood risk

100 km 100 km square (see Map 5.4, key sheet) (1)	Land area (km^2) (2)	Built-up area (km^2) (3)	Area at risk (km^2) (4)	Area at risk (as % of (2)) (5)	Built-up area at risk (km^2) (6)	Built-up area at risk (as % of (3)) (7)
SW	1674	87.9	14.0	0.8	1.1	1.2
SX	4748	178.4	96.0	2.0	4.4	2.5
SS	4297	119.4	100.7	2.3	5.8	4.8
ST+	10386	505.2	669.3	6.4	22.5	4.5
SU+	10652	715.8	604.8	5.7	46.0	6.4
TQ+	9080	1635.0	553.2	6.1	90.2	5.5
TR	1398	91.8	99.1	7.1	4.1	4.5
SM+	731	12.1	8.0	1.1	0.1	1.2
SN	7124	50.2	191.7	2.7	3.8	7.6
SO	9938	459.3	517.0	5.2	22.6	4.9
SP	9945	759.5	562.5	5.7	33.3	4.4
TL	9901	514.6	1752.4	17.7	77.0	15.0
TM	3535	162.3	121.0	3.4	4.0	2.5
SH	4674	47.6	112.9	2.4	1.5	3.2
SJ	9350	898.4	502.1	5.4	49.2	5.5
SK	9909	824.8	836.8	8.4	76.8	9.3
TF	6900	265.6	1929.1	28.0	73.2	27.5
TG	1901	125.9	99.2	5.2	3.3	2.6
SD	7038	495.3	291.9	4.1	18.9	3.8
SE	9888	635.0	944.2	9.5	43.3	6.8
TA	2064	152.0	248.2	12.0	15.6	10.3
NY+	8900	63.0	274.1	3.1	4.2	6.6
NZ+	6077	491.4	153.9	2.5	9.8	2.0

Notes: 1 — + denotes part of an adjacent square or squares has been included (see key map).
2 — Using a three-straight-lines approximation of the border, data from Scotland in areas NY+ and NZ+ have been excluded.
3 — Column (2) excludes lakes.

5.2 Maps

The Flood Risk Map of England and Wales is presented in five styles:

Map 5.1

Scale 1:2 500 000
Two A4 sheets (south and north)
Detail shown:
- High Water Mark from OS 1:50 000 maps
- Flooded built-up areas ('flooded urban' in map key)
- Flooded non-built-up areas ('flooded rural' in map key)
- Watercourses and lakes with catchment areas greater than 10 km^2

Note: The limitation of the resolution of the low-level graphics software is most apparent on this map (see Section 3.12).

Map 5.2

Scale 1:1 600 000
Three A4 sheets (north, south-west and south-east)
Detail shown: As for Map 5.1

Map 5.3:

Scale 1:1 250 000
Single A0 sheet (folded in cover pocket)
Detail shown: As for Map 5.1

Map 5.4

Scale 1:625 000
23 A4 sheets, each nominally a 100 km by 100 km National Grid square (Plus key sheet).
Detail shown:
- High Water Mark from OS 1:50 000 maps
- Flooded built-up areas ('flooded urban' in map key)
- Flooded non-built-up areas ('flooded rural' in map key)
- Watercourses and lakes with catchment areas greater than 10 km^2
- Built-up areas
- Names of major settlements

Key sheet (1:5 000 000) shows:
- High Water Mark from OS 1:50 000 maps
- Configuration of the 1:625 000 A4 sheets

Map 5.5

Scale 1:625 000
Two A0 sheets (south and north), (folded in cover pocket)
Detail shown: As for Map 5.1

Copyright: Readers should refer to the copyright statement printed at the front of this report.

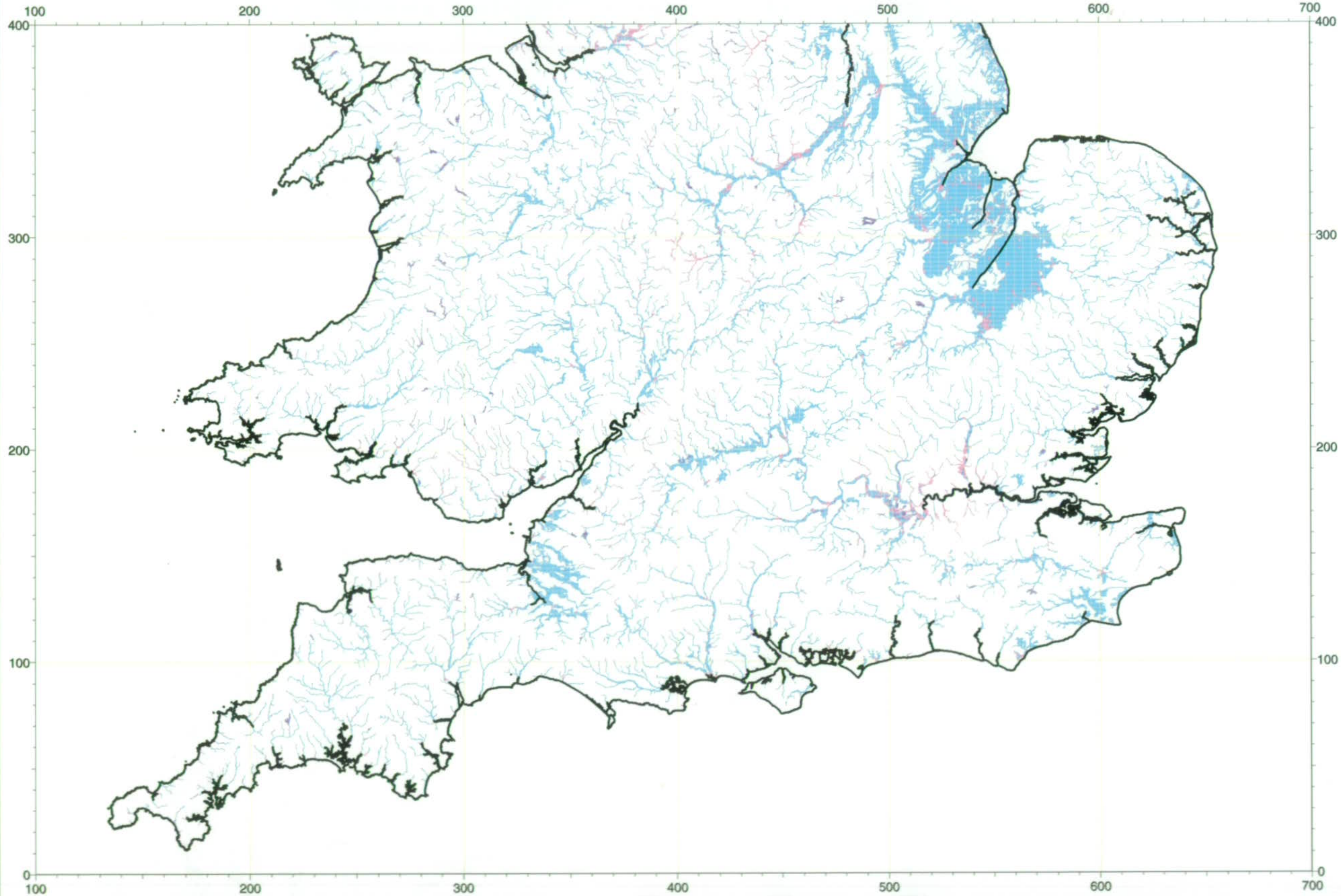
Map 5.1 Flood risk map of England and Wales (N)

= Flooded urban
= Flooded rural
= River channels that contain the 100-year flood, and lakes

Rivers and lakes with catchment areas below 10km² are not shown.

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.

Scale 1:2,500,000



Map 5.1 Flood risk map of England and Wales (S)

= Flooded urban

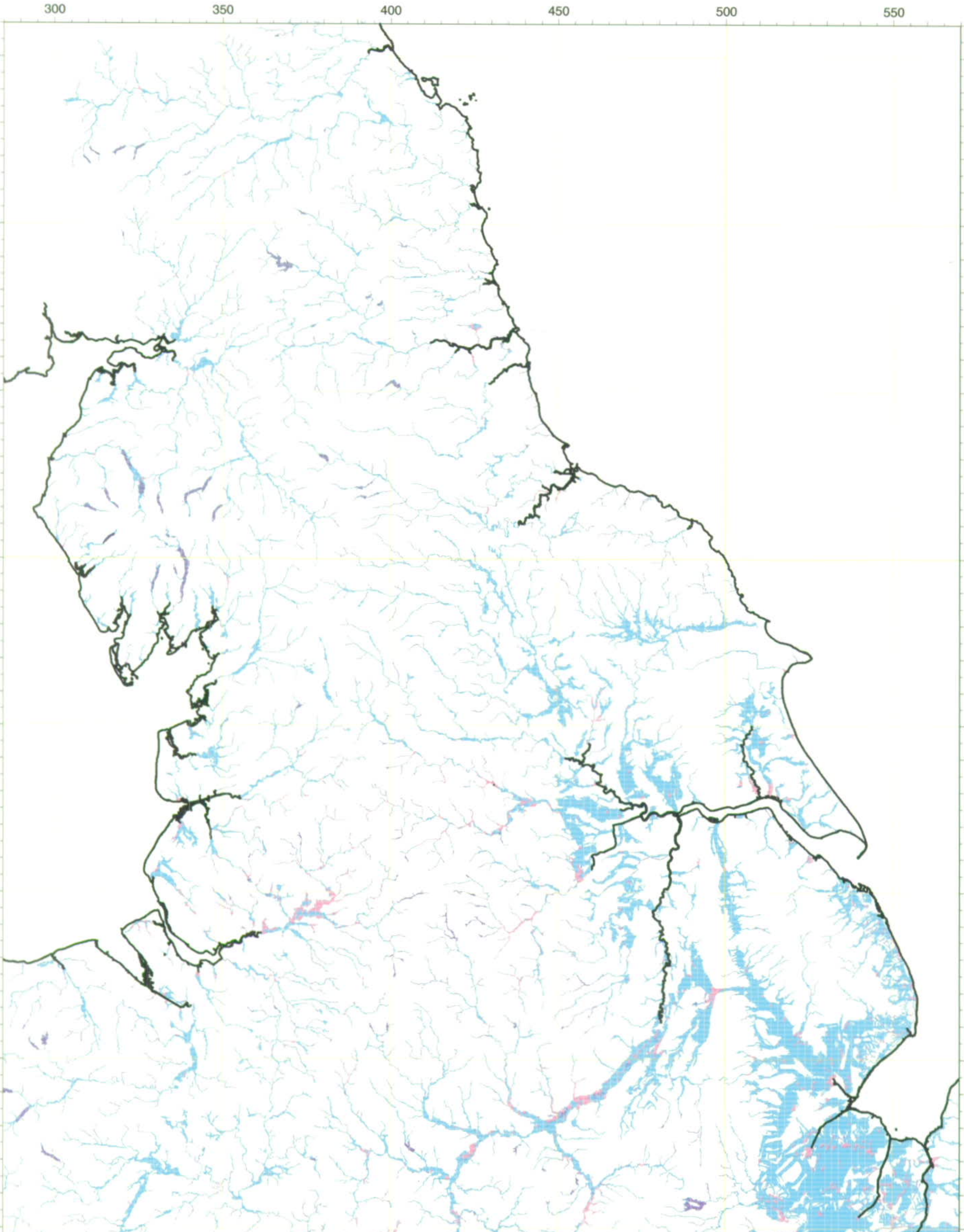
= Flooded rural

= River channels that contain the 100-year flood, and lakes

Rivers and lakes with catchment areas below $10km^2$ are not shown.

Scale 1:2,500,000

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 5.2

Flood risk map of England and Wales (N)

Scale 1:1,600,000

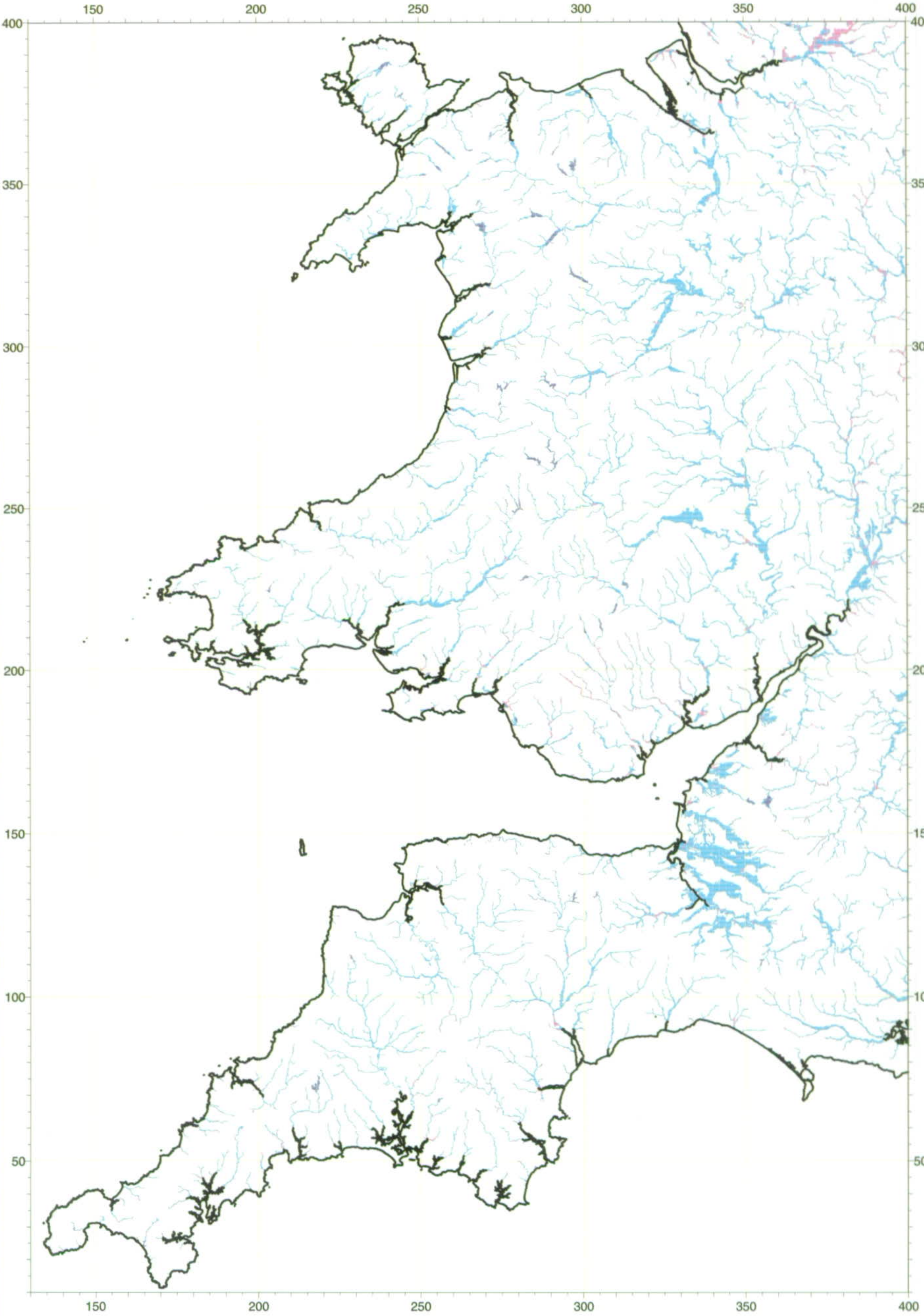
= Flooded urban

= Flooded rural

= River channels that contain the 100-year flood, and lakes

Rivers and lakes with catchment areas below $10km^2$ are not shown.

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 5.2

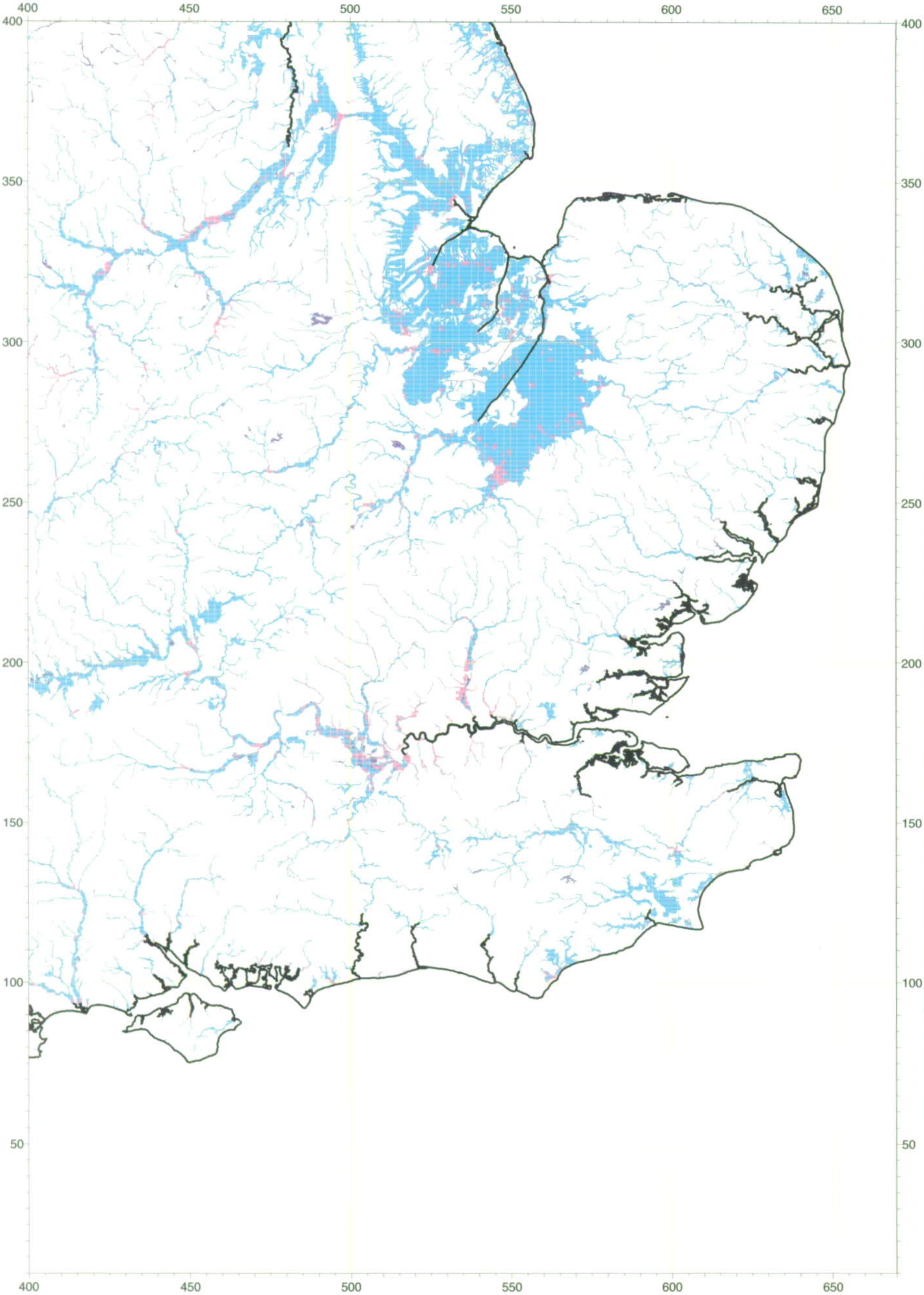
Flood risk map of England and Wales (SW)

Scale 1:1,600,000

= Flooded urban = Flooded rural = River channels that contain the 100-year flood, and lakes

Rivers and lakes with catchment areas below $10km^2$ are not shown.

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 5.2

Flood risk map of England and Wales (SE)

= Flooded urban

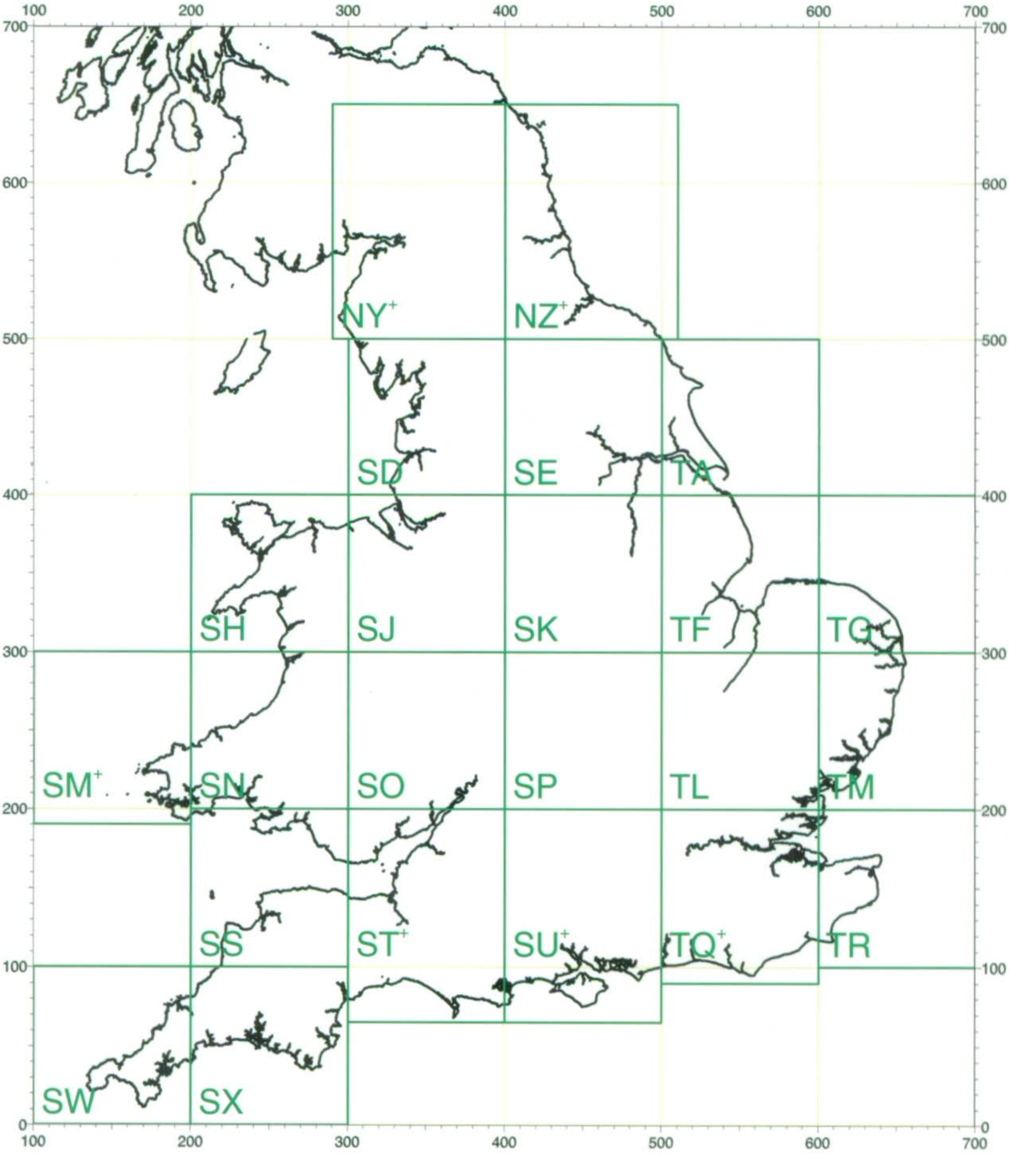
= Flooded rural

= River channels that contain the 100-year flood, and lakes

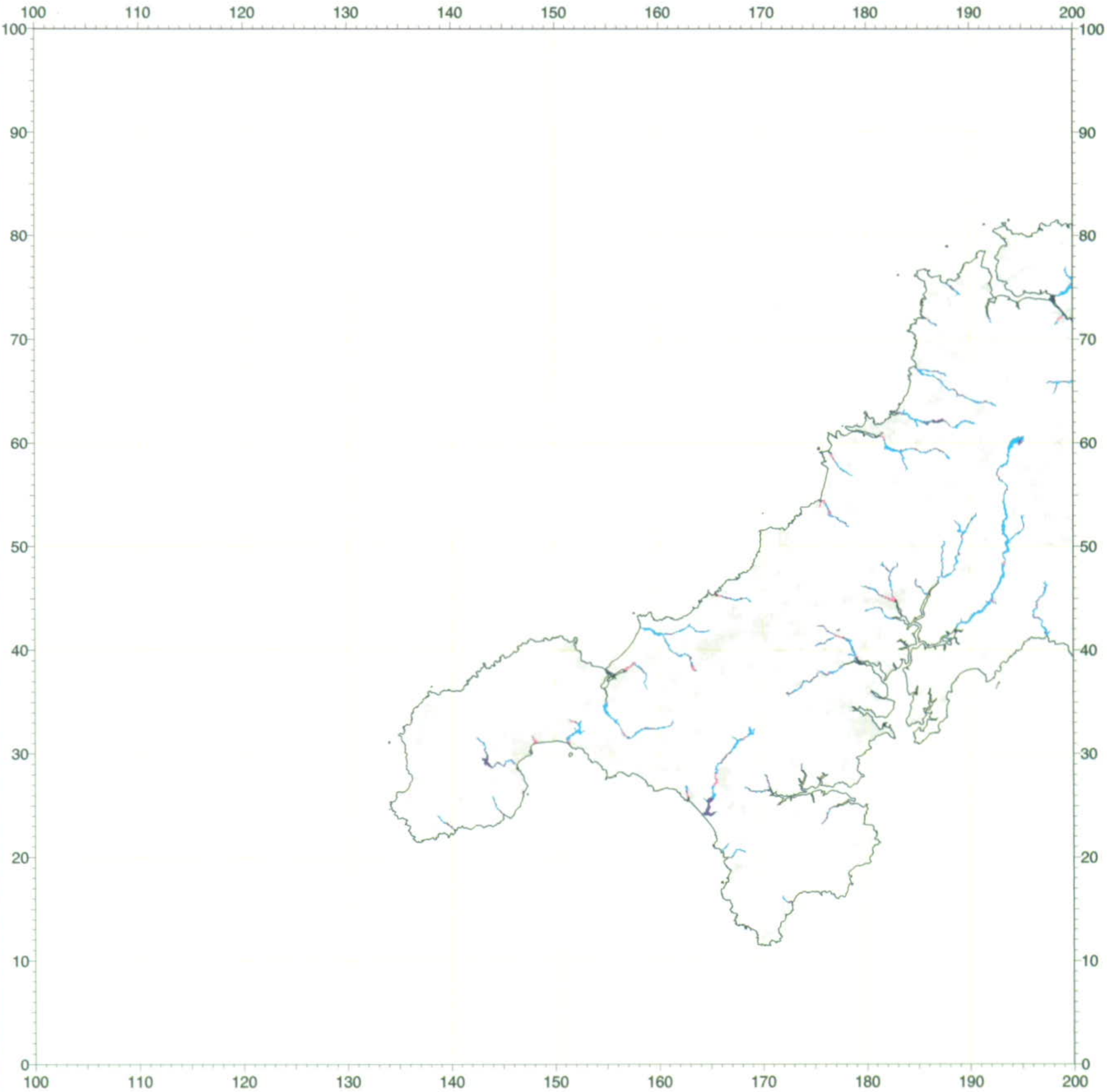
Scale 1:1,600,000

Rivers and lakes with catchment areas below $10km^2$ are not shown.

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.


100
200
300
400
500
600
700
NY+
NZ+
SD
SE
TA
SH
SJ
SK
TF
TG
SM+
SN
SO
SP
TL
TM
SS
ST+
SU+
TQ+
TR
SW
SX

Map 5.4 KEY



Map 5.4 SW

Scale 1:625,000

= Urban

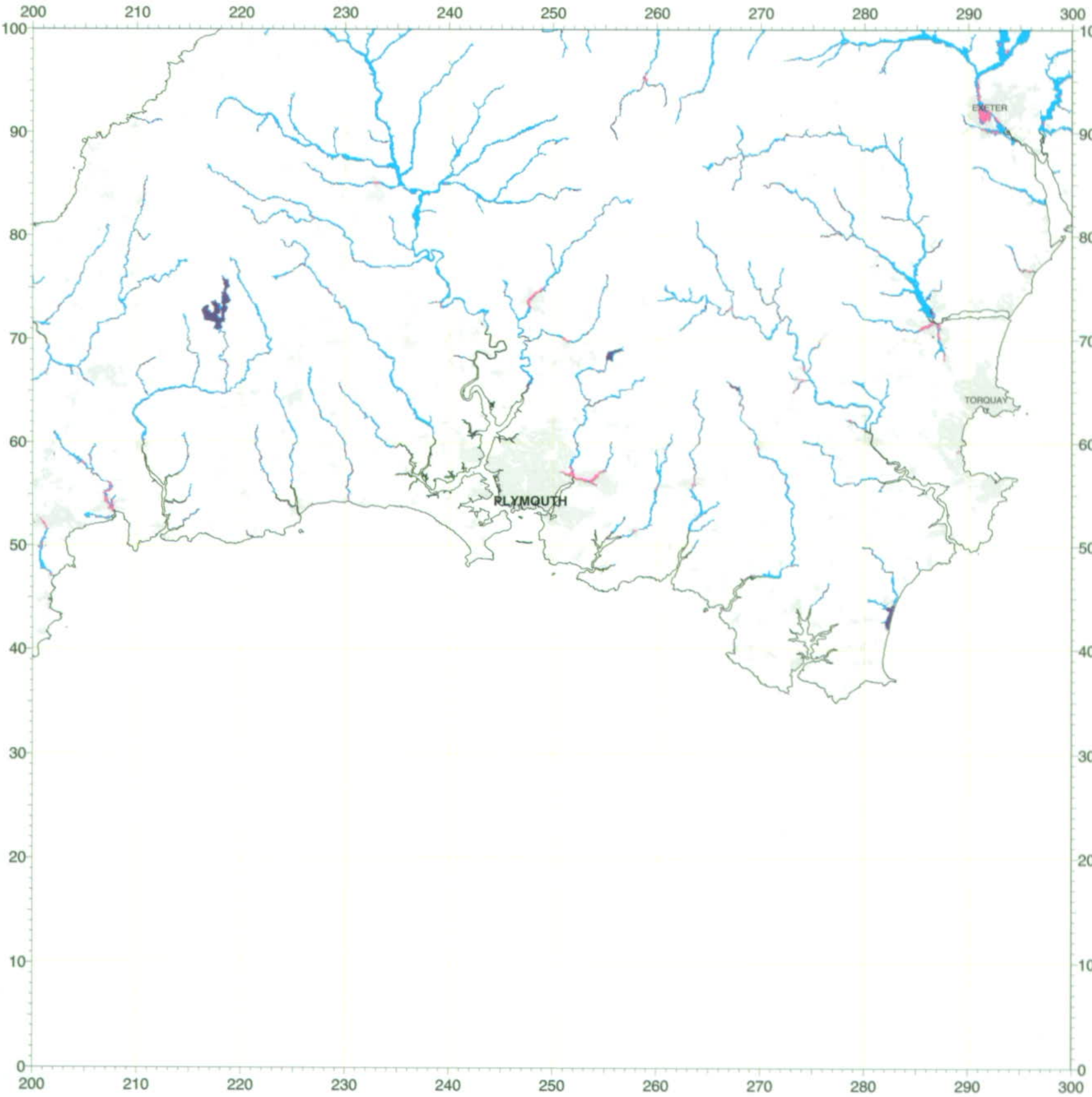
= River channels that contain the 100-year flood, and lakes

= Flooded urban

= Flooded rural

Rivers and lakes with catchment areas below $10km^2$ are not shown.

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are , or are not, at risk of inundation.



Map 5.4 SX

Scale 1:625,000

= Urban

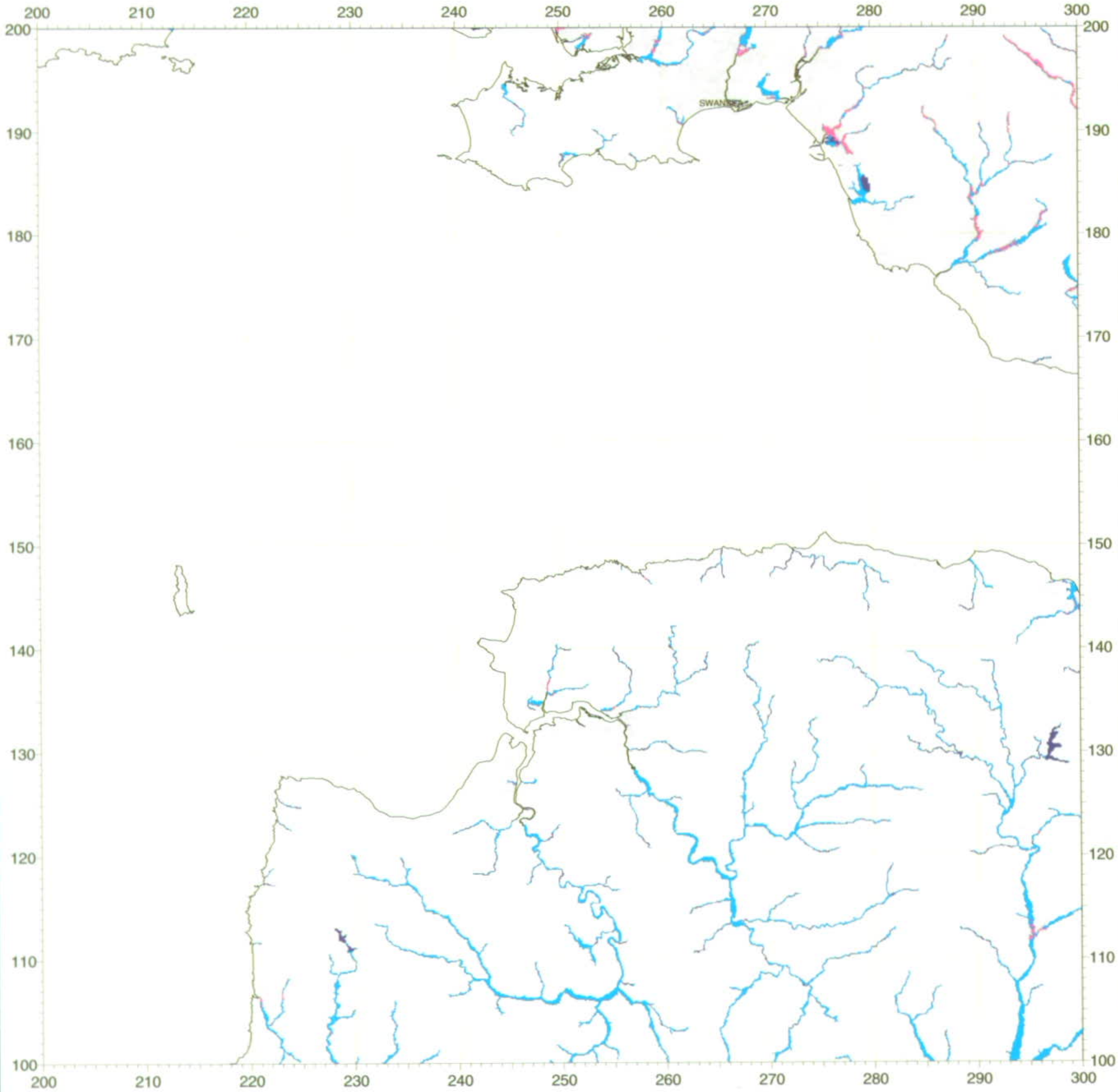
= River channels that contain the 100-year flood, and lakes

= Flooded urban

= Flooded rural

Rivers and lakes with catchment areas below 10km² are not shown.

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are , or are not, at risk of inundation.



Map 5.4 SS

Scale 1:625,000

= Urban

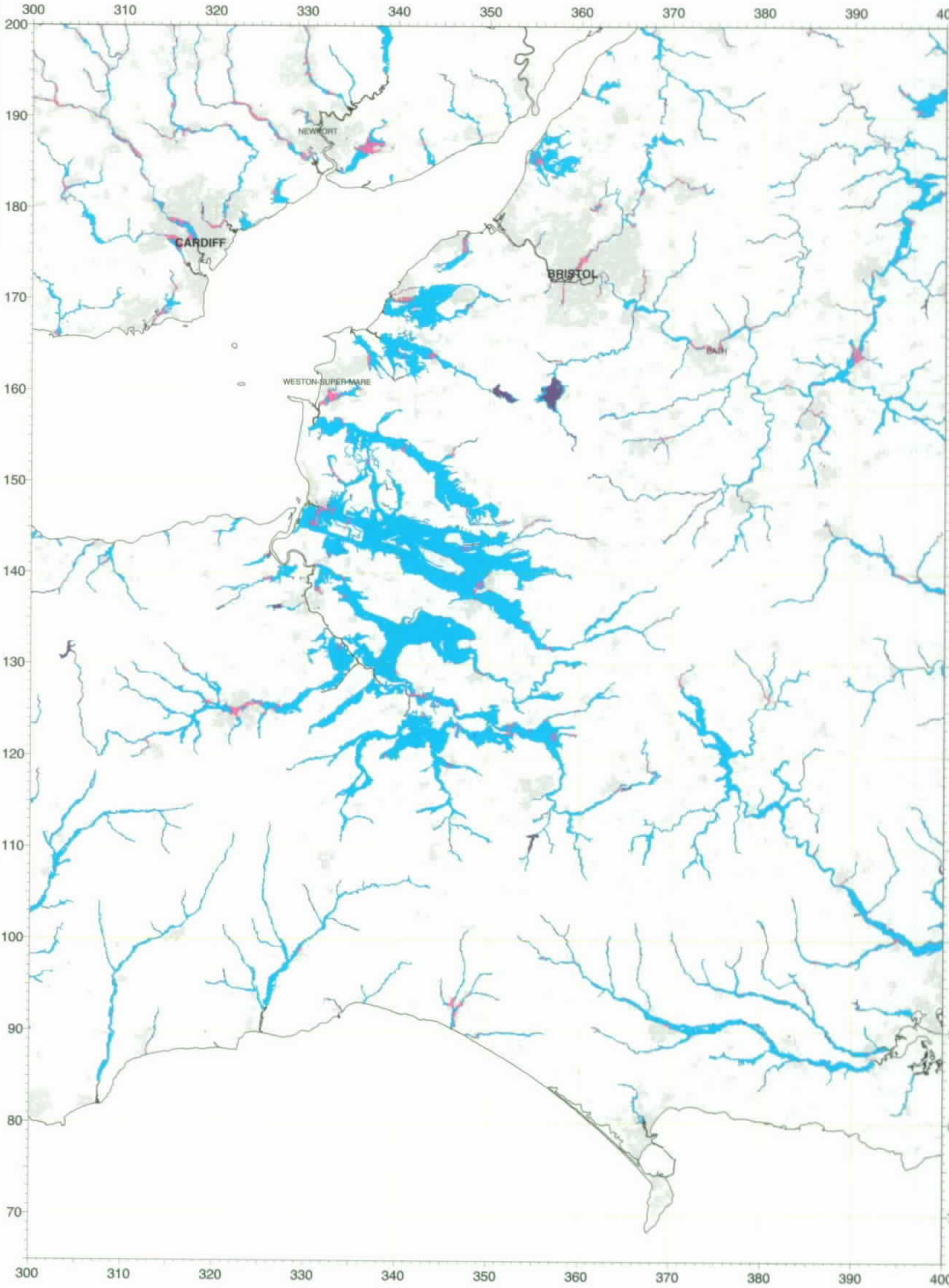
= River channels that contain the 100-year flood, and lakes

= Flooded urban

= Flooded rural

Rivers and lakes with catchment areas below $10km^2$ are not shown.

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are , or are not, at risk of inundation.



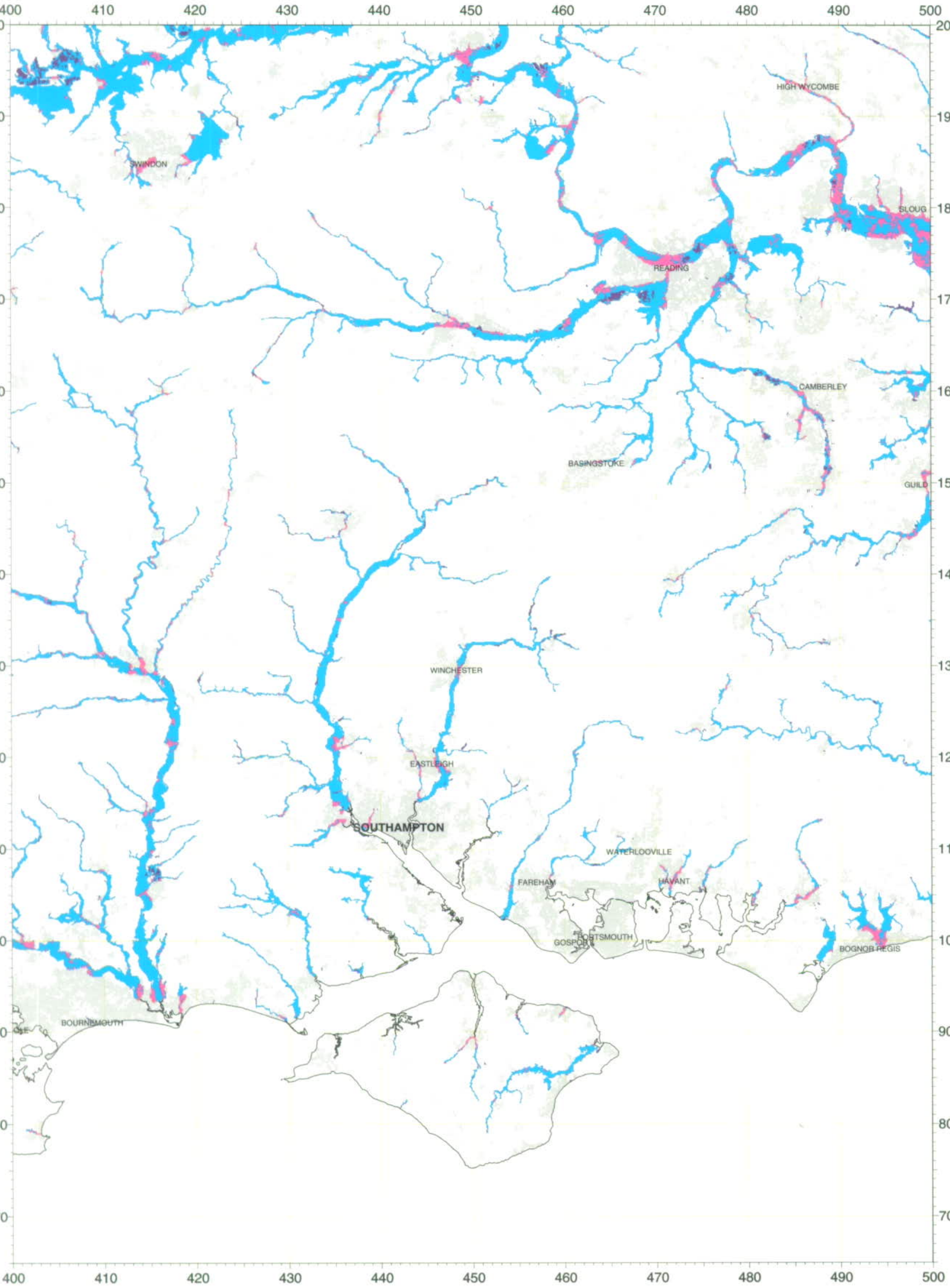
Map 5.4 ST+

Scale 1:625,000

- = Urban
- = River channels that contain the 100-year flood, and lakes
- = Flooded urban
- = Flooded rural

Rivers and lakes with catchment areas below $10km^2$ are not shown.

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are , or are not, at risk of inundation.



Map 5.4 SU[+]

Scale 1:625,000

= Urban

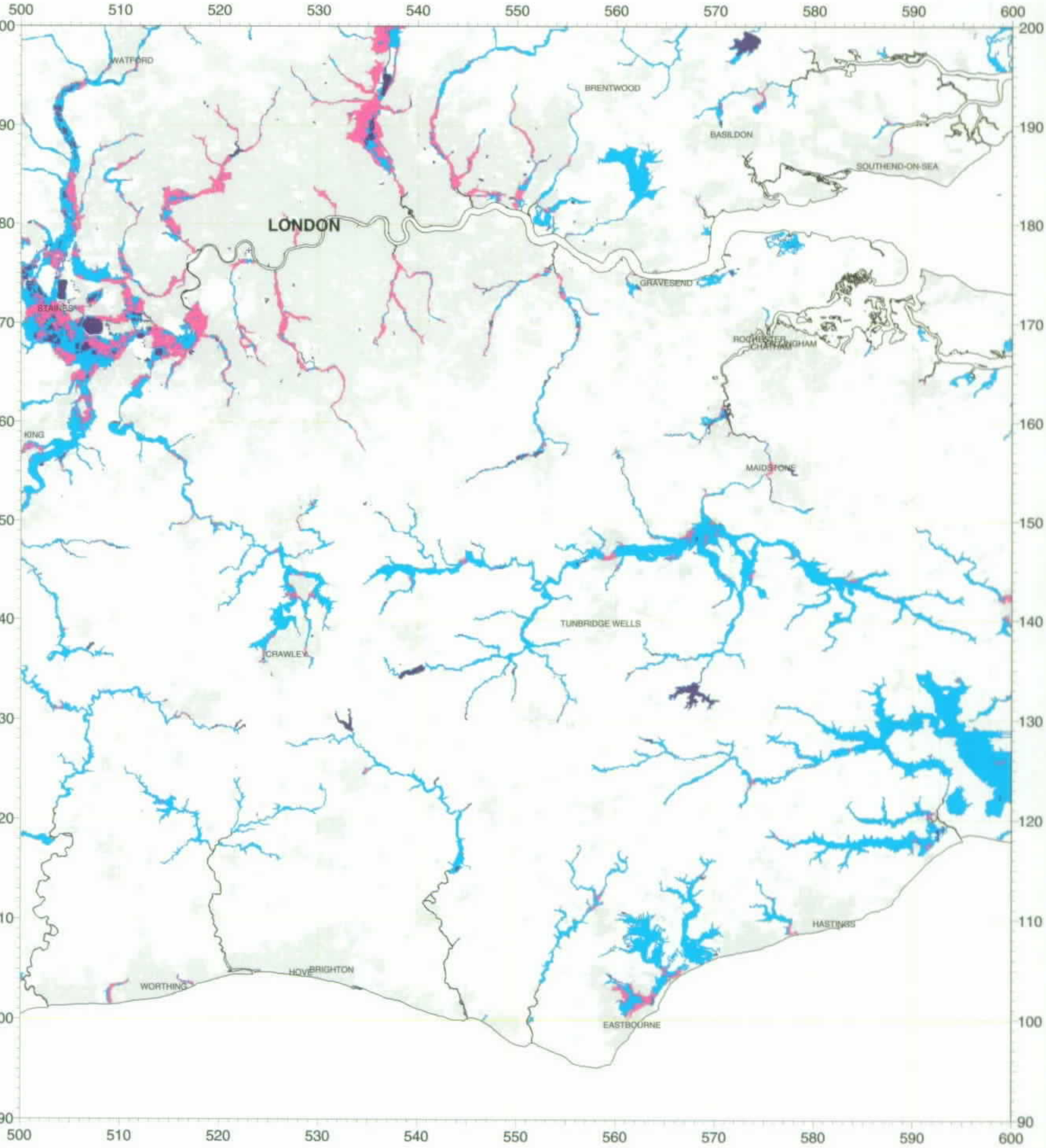
= River channels that contain the 100-year flood, and lakes

= Flooded urban

= Flooded rural

Rivers and lakes with catchment areas below 10km² are not shown.

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 5.4 TQ+

Scale 1:625,000

= Urban

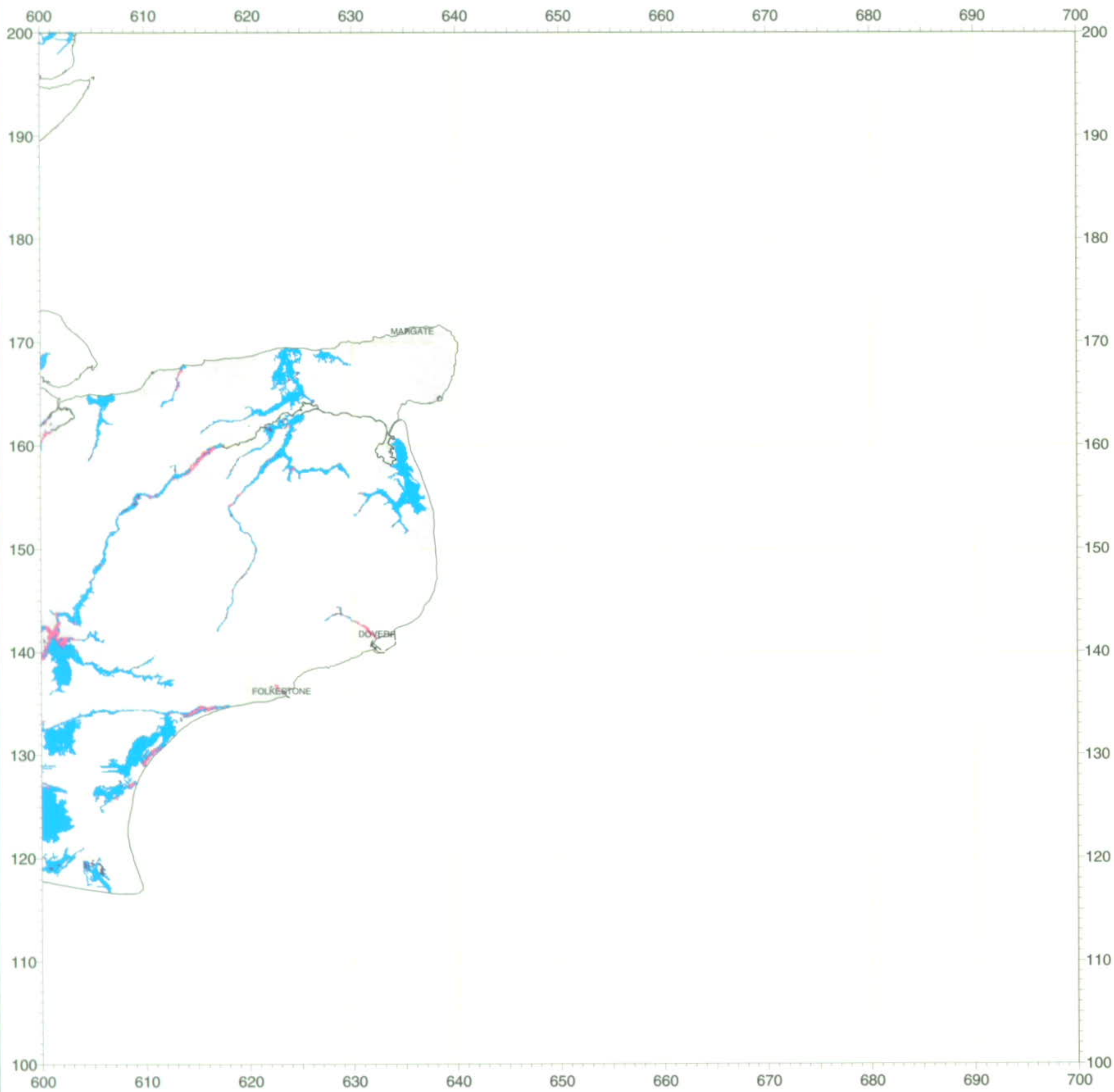
= River channels that contain the 100-year flood, and lakes

= Flooded urban

= Flooded rural

Rivers and lakes with catchment areas below 10km² are not shown.

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are , or are not, at risk of inundation.



Map 5.4 TR

Scale 1:625,000

= Urban

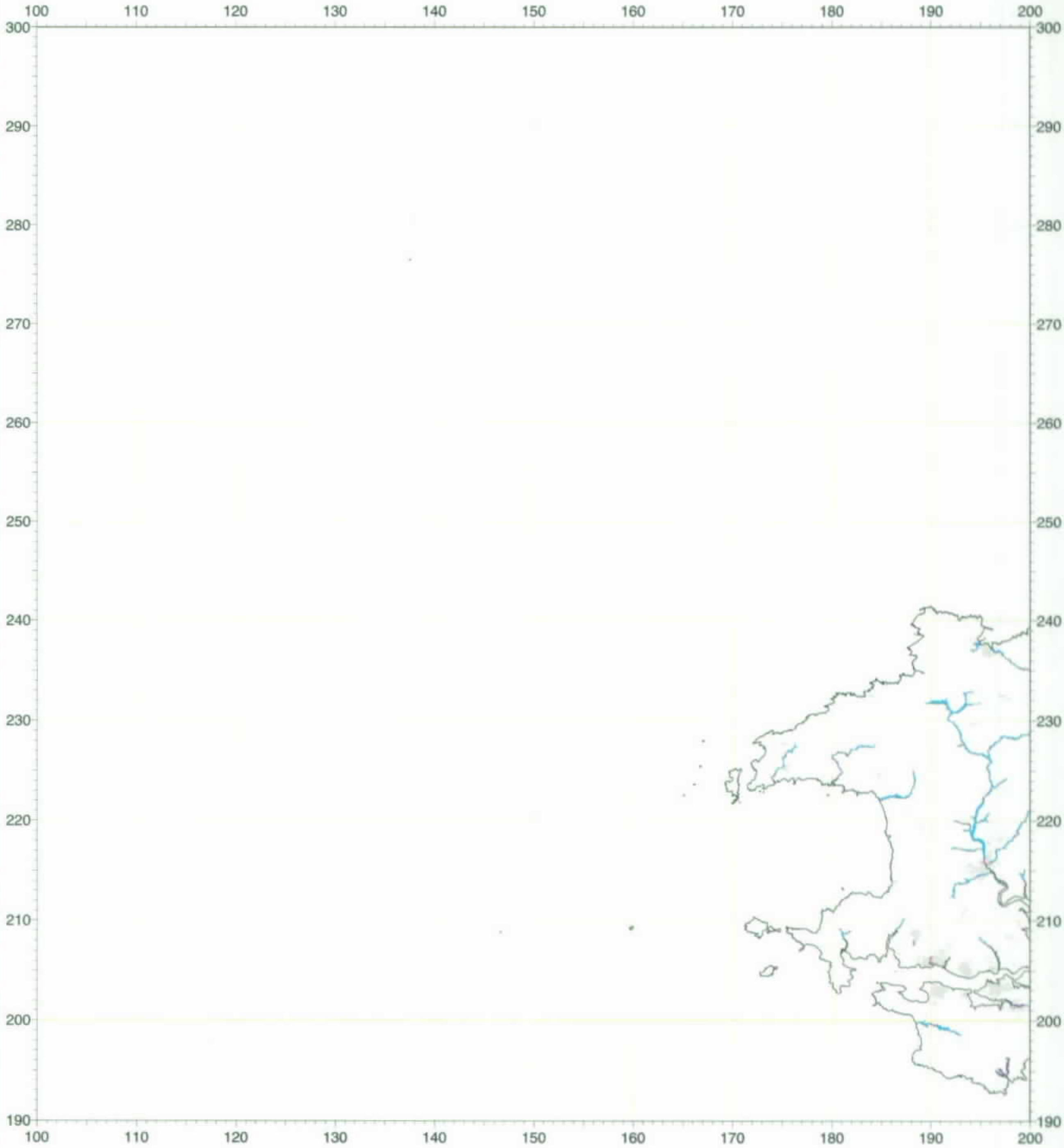
= River channels that contain the 100-year flood, and lakes

= Flooded urban

= Flooded rural

Rivers and lakes with catchment areas below 10km² are not shown.

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



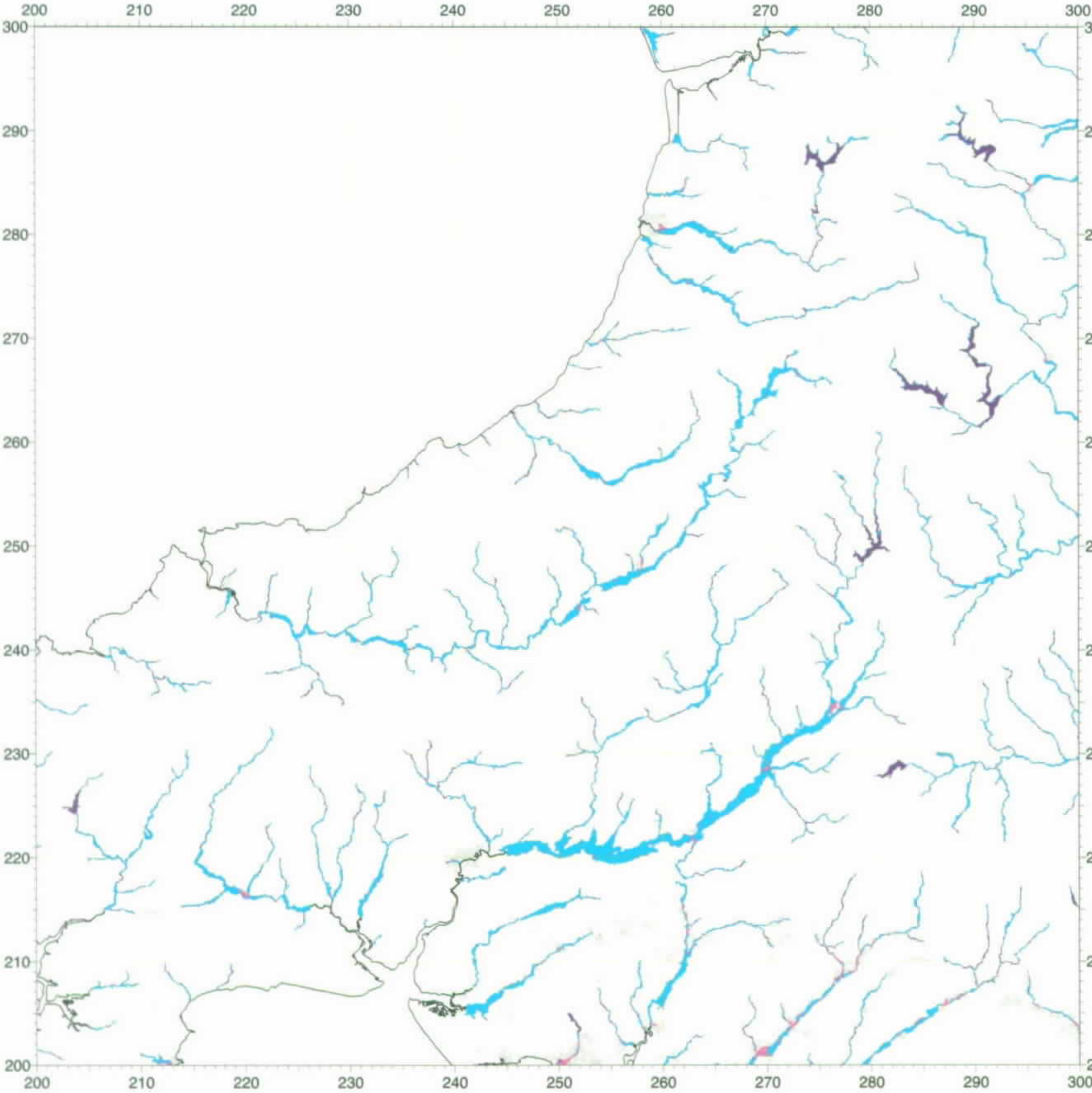
Map 5.4 SM+

Scale 1:625,000

= Urban	= Flooded urban
= River channels that contain the 100-year flood, and lakes	= Flooded rural

Rivers and lakes with catchment areas below 10km² are not shown.

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are , or are not, at risk of inundation.



Map 5.4 SN

Scale 1:625,000

= Urban

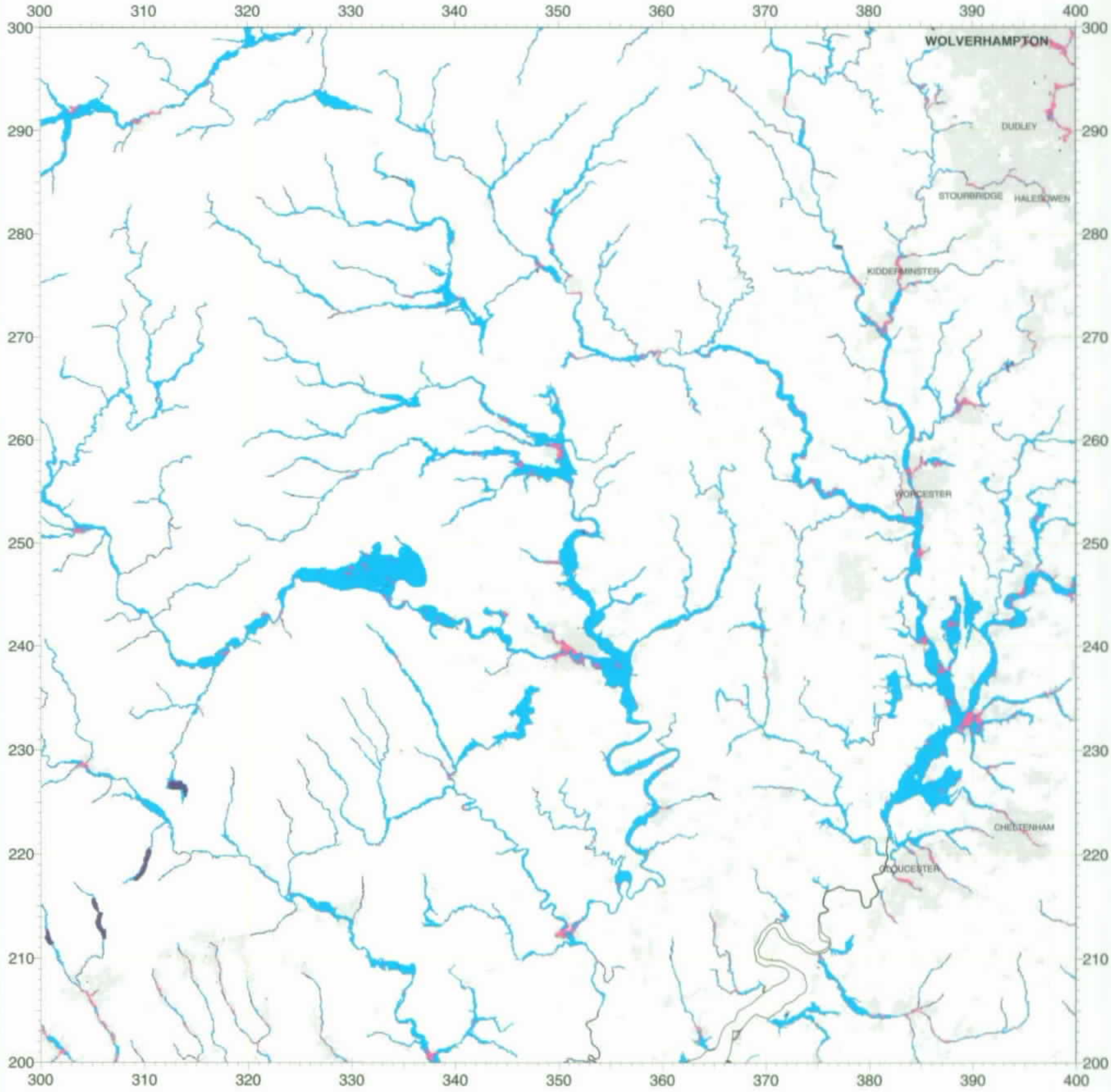
= River channels that contain the 100-year flood, and lakes

= Flooded urban

= Flooded rural

Rivers and lakes with catchment areas below 10km² are not shown.

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are , or are not, at risk of inundation.



Map 5.4 SO

Scale 1:625,000

= Urban

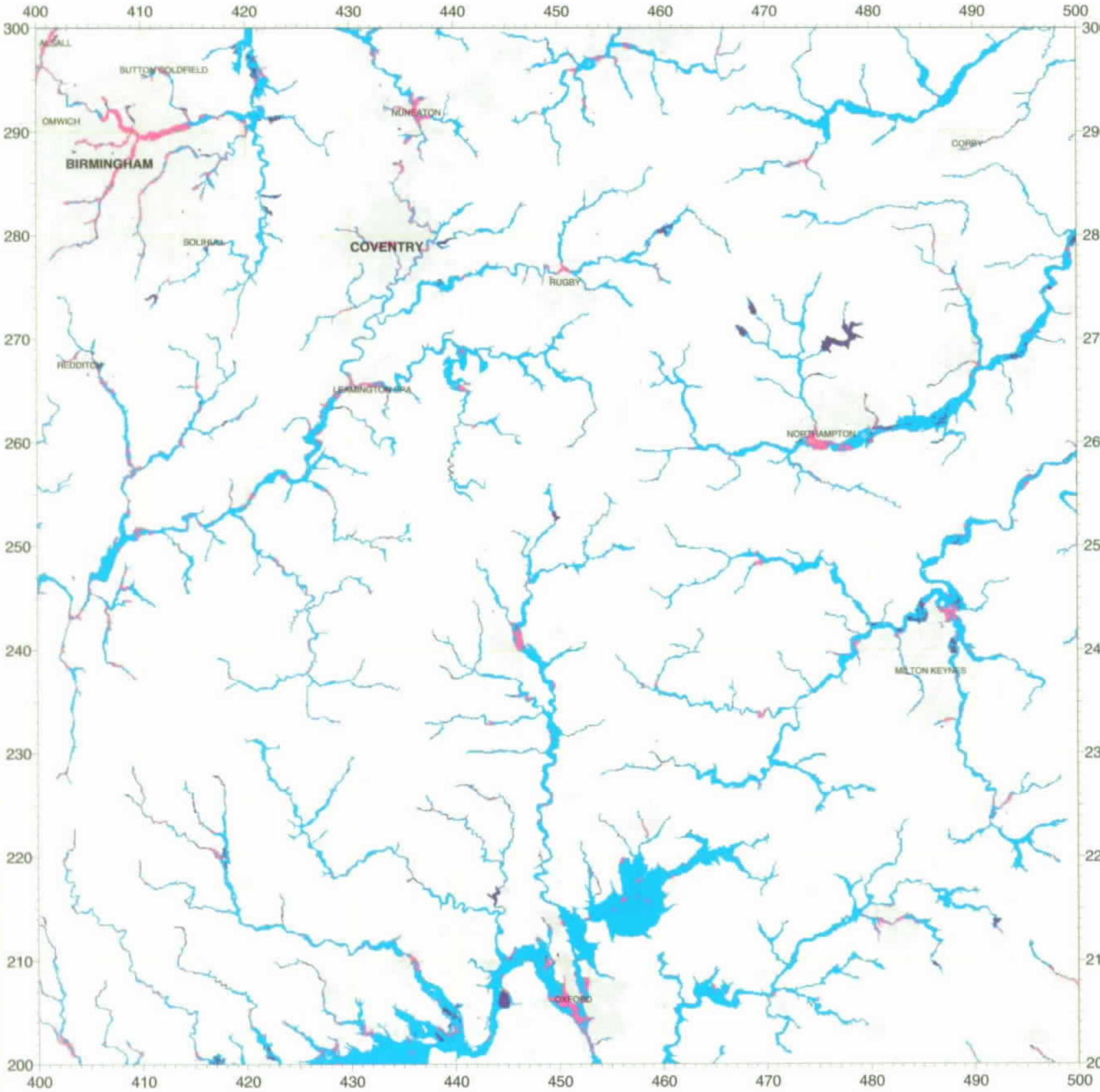
= River channels that contain the 100-year flood, and lakes

= Flooded urban

= Flooded rural

Rivers and lakes with catchment areas below 10km² are not shown.

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are , or are not, at risk of inundation.



Map 5.4 SP

Scale 1:625,000

= Urban

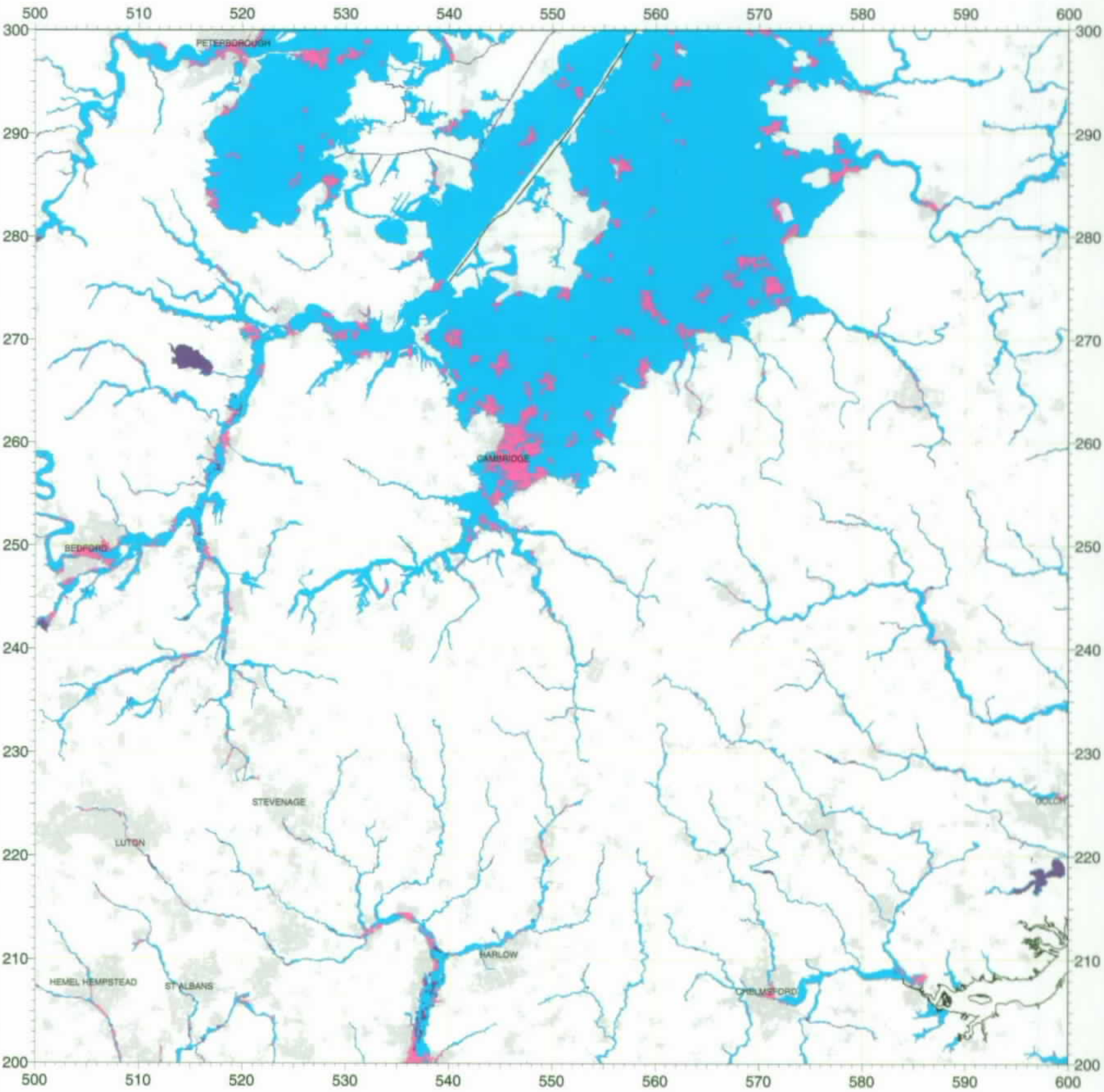
= River channels that contain the 100-year flood, and lakes

= Flooded urban

= Flooded rural

Rivers and lakes with catchment areas below 10km² are not shown.

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.

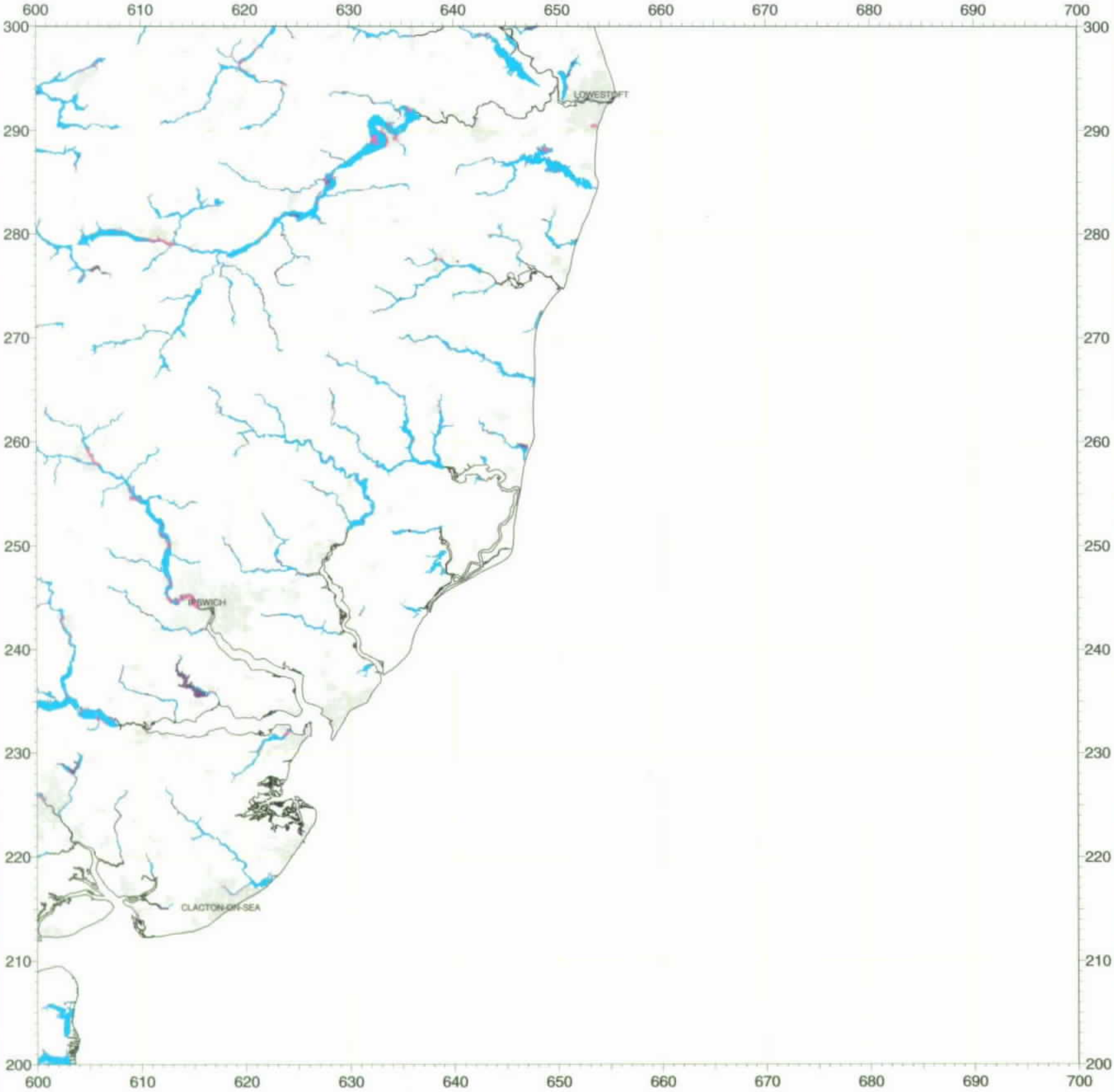


Map 5.4 TL

Scale 1:625,000

Rivers and lakes with catchment areas below 10km² are not shown.

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 5.4 TM

Scale 1:625,000

= Urban

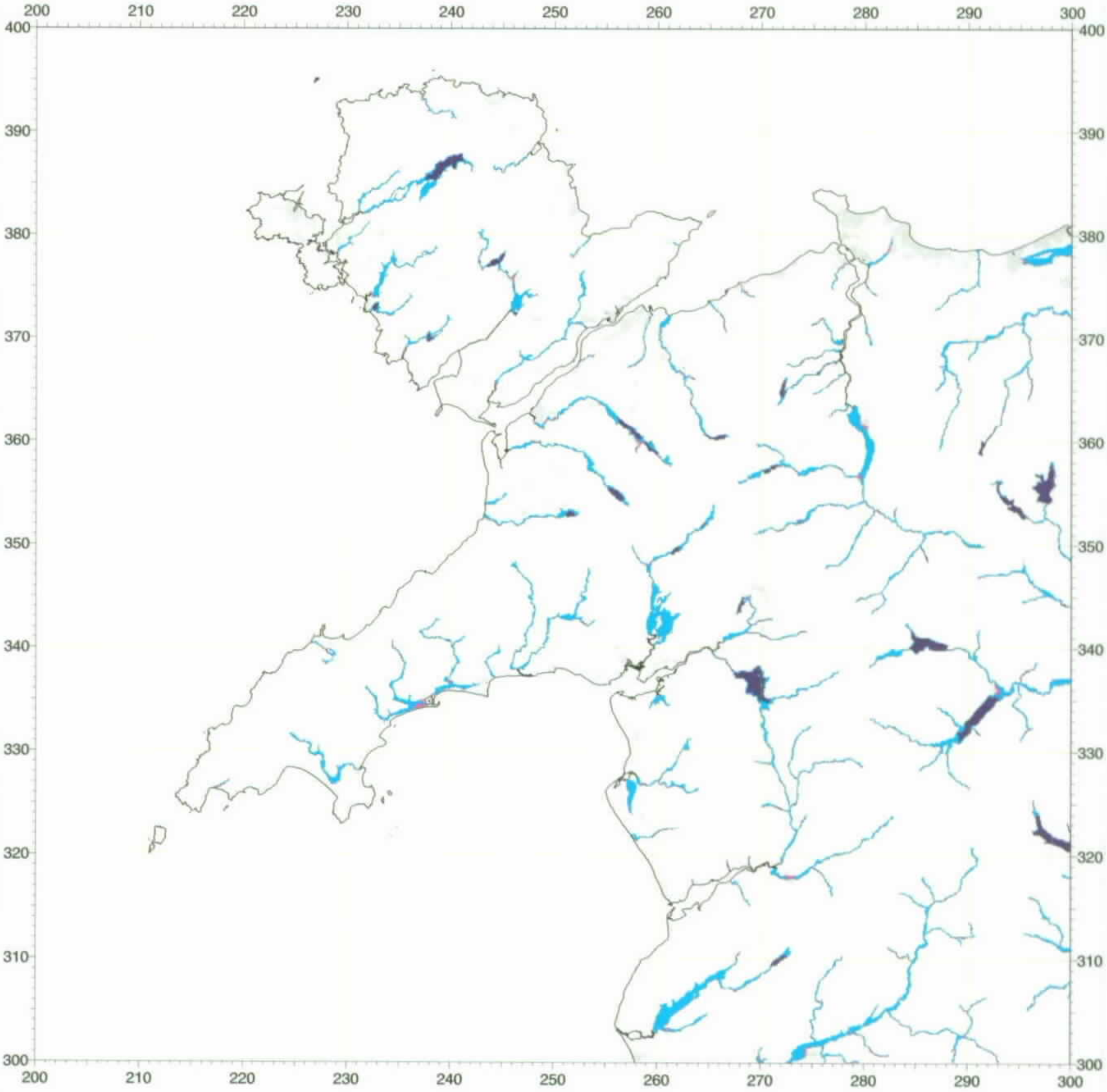
= River channels that contain the 100-year flood, and lakes

= Flooded urban

= Flooded rural

Rivers and lakes with catchment areas below 10km² are not shown.

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 5.4 SH

Scale 1:625,000

= Urban

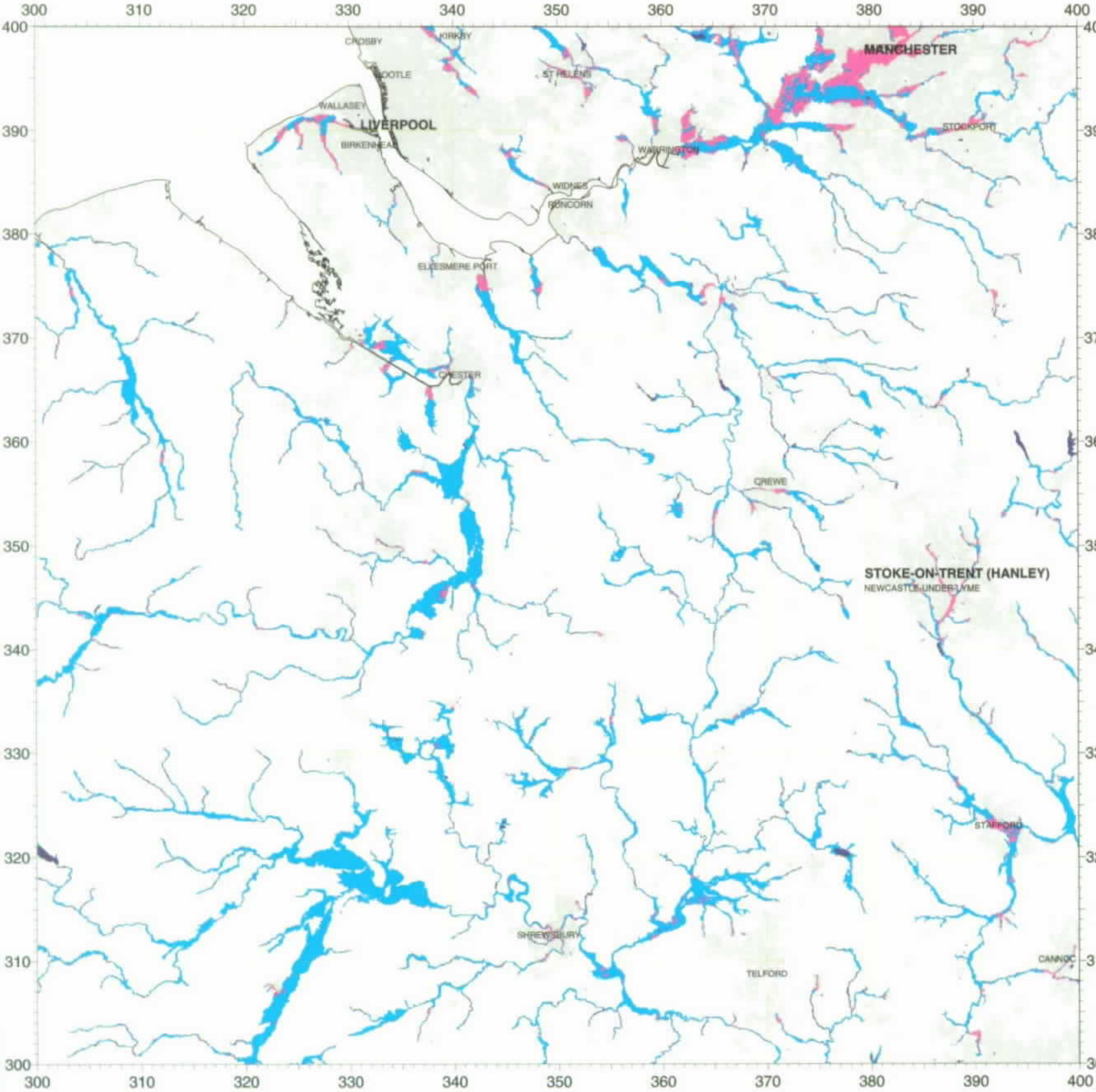
= River channels that contain the 100-year flood, and lakes

= Flooded urban

= Flooded rural

Rivers and lakes with catchment areas below 10km² are not shown.

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are , or are not, at risk of inundation.



Map 5.4 SJ

Scale 1:625,000

= Urban

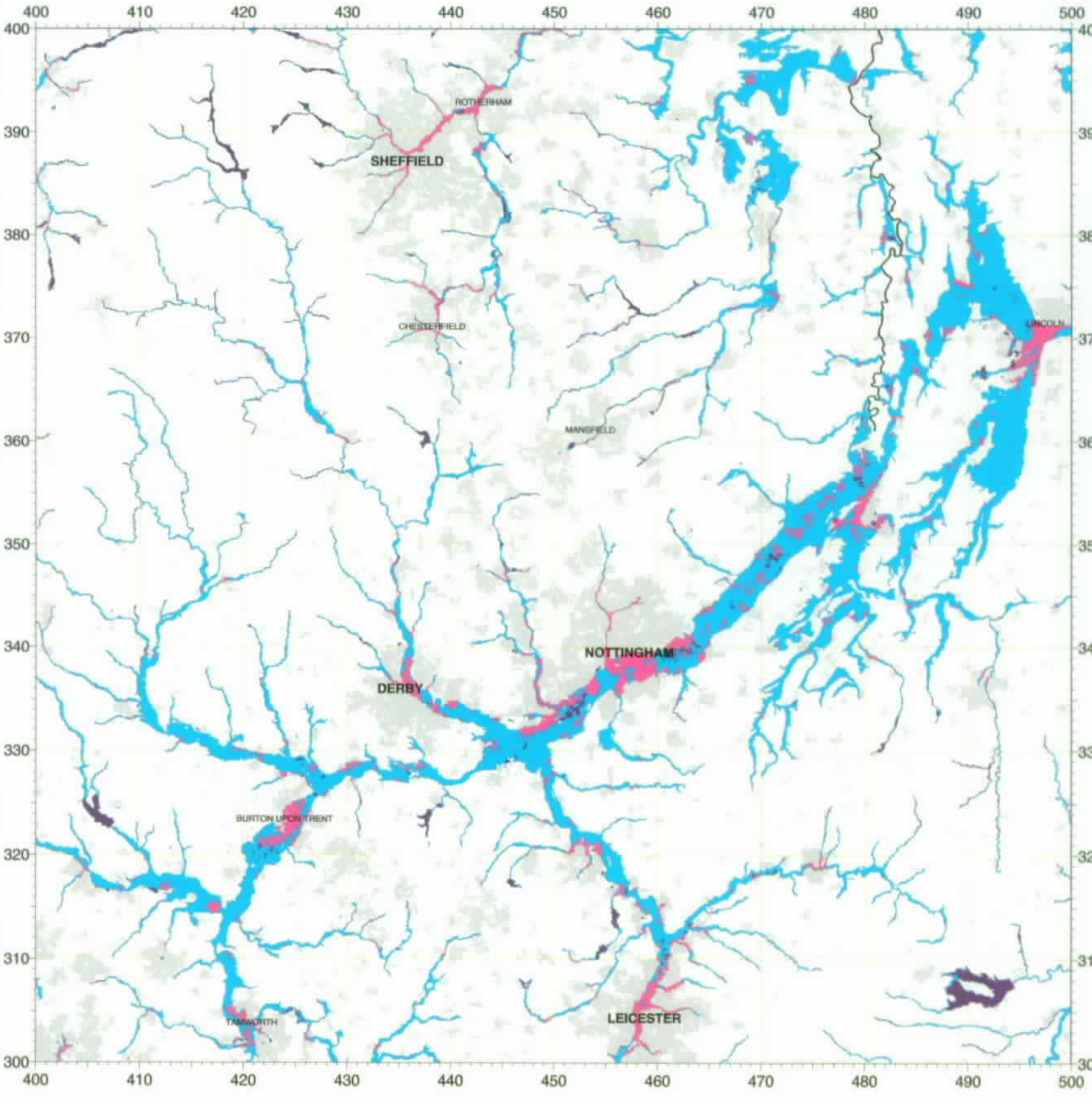
= River channels that contain the 100-year flood, and lakes

= Flooded urban

= Flooded rural

Rivers and lakes with catchment areas below 10km² are not shown.

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are , or are not, at risk of inundation.

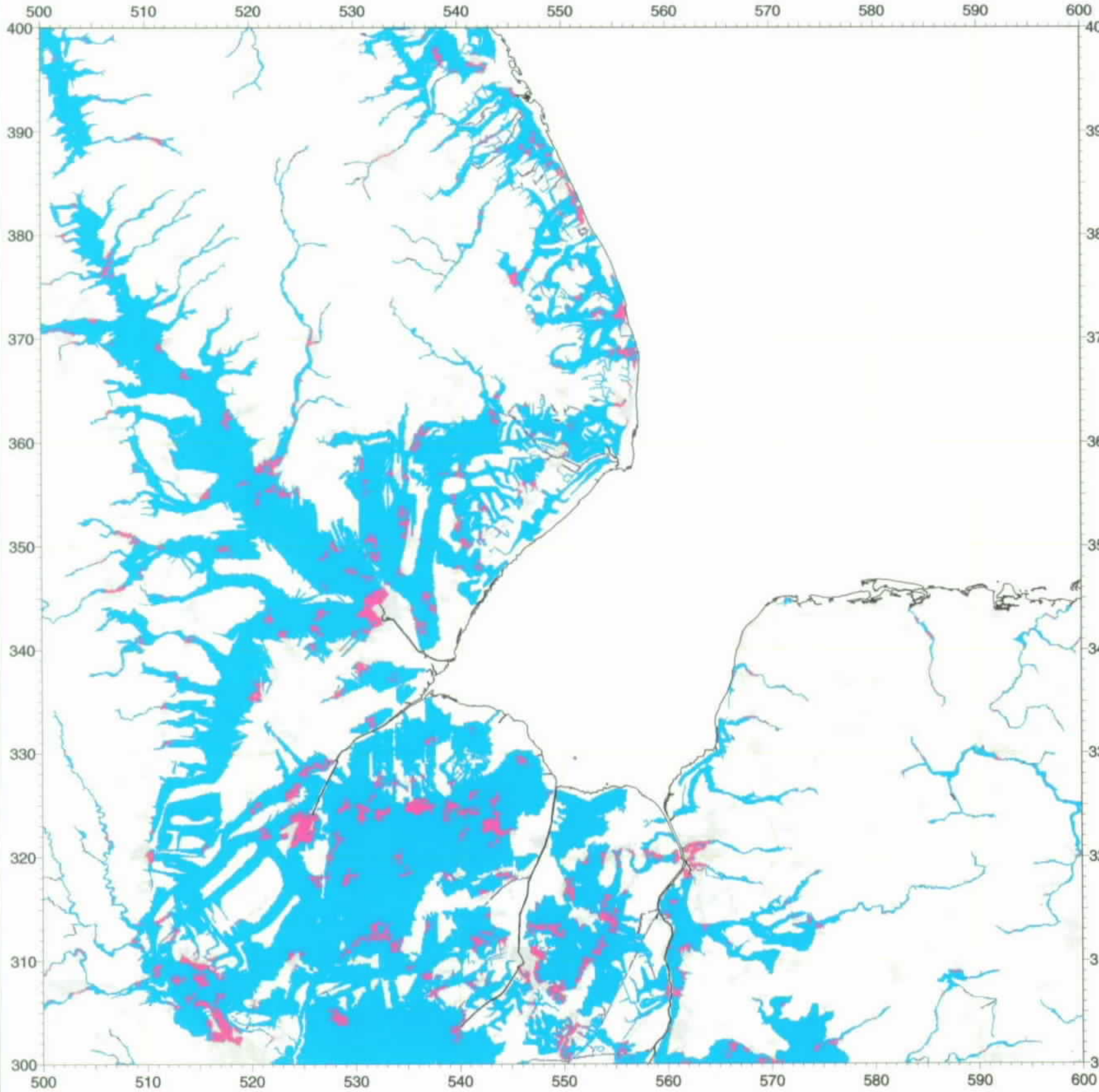


Map 5.4 SK

Scale 1:625,000

Rivers and lakes with catchment areas below 10km² are not shown.

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are , or are not, at risk of inundation.



Map 5.4 TF

Scale 1:625,000

= Urban

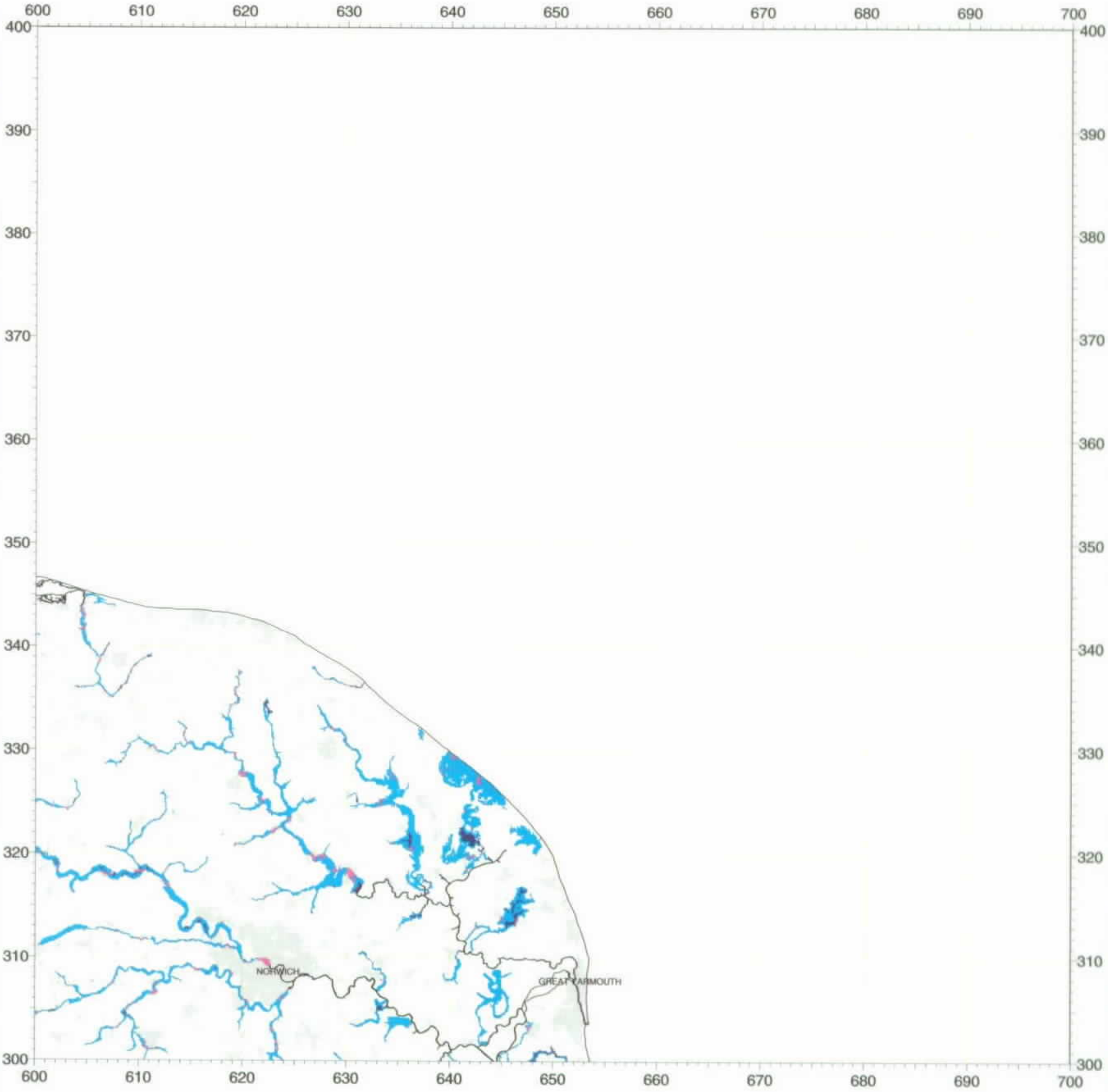
= River channels that contain the 100-year flood, and lakes

= Flooded urban

= Flooded rural

Rivers and lakes with catchment areas below 10km² are not shown.

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are , or are not, at risk of inundation.



Map 5.4 TG

Scale 1:625,000

= Urban

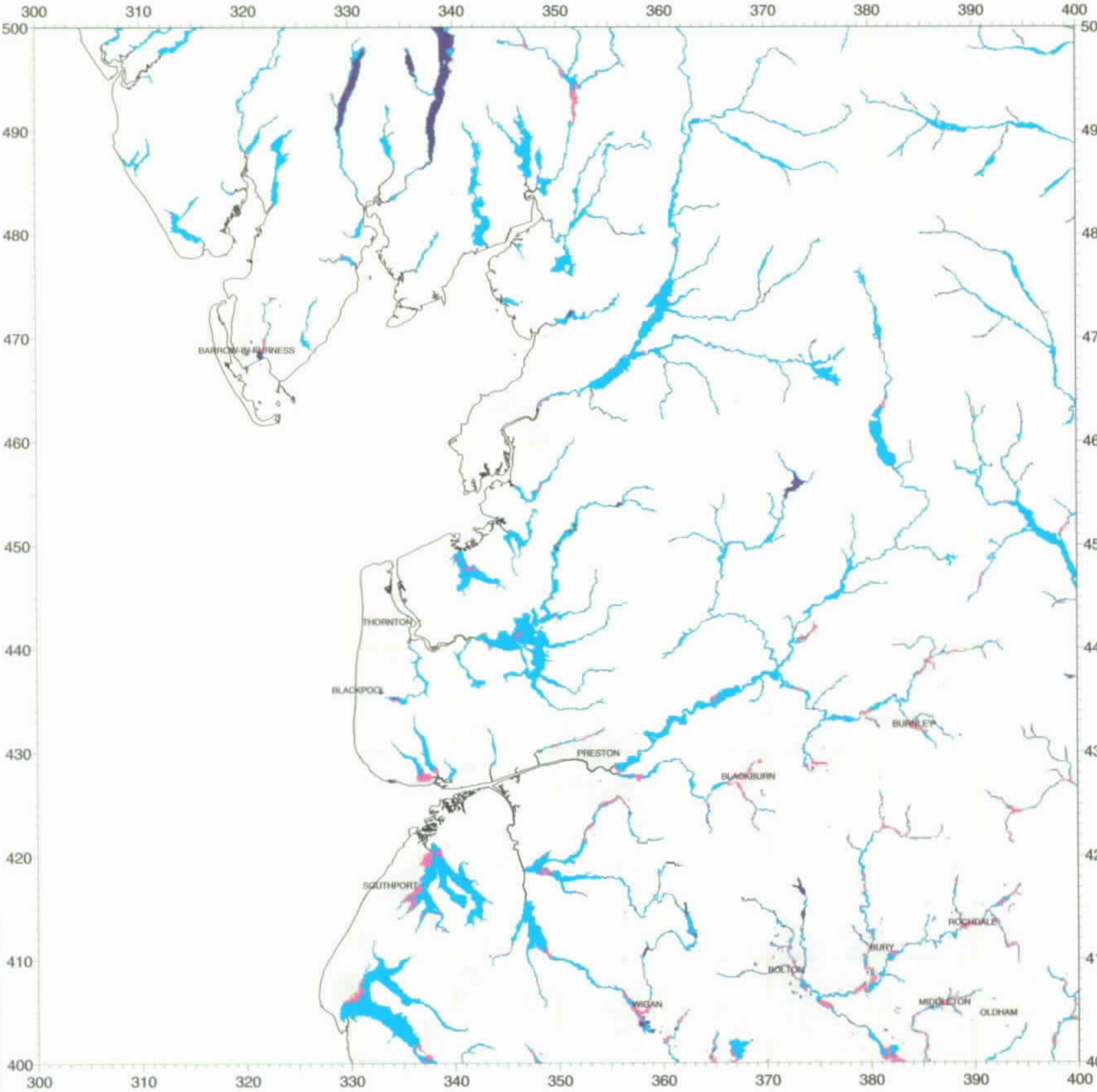
= River channels that contain the 100-year flood, and lakes

= Flooded urban

= Flooded rural

Rivers and lakes with catchment areas below 10km^2 are not shown.

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are , or are not, at risk of inundation.



Map 5.4 SD

Scale 1:625,000

= Urban

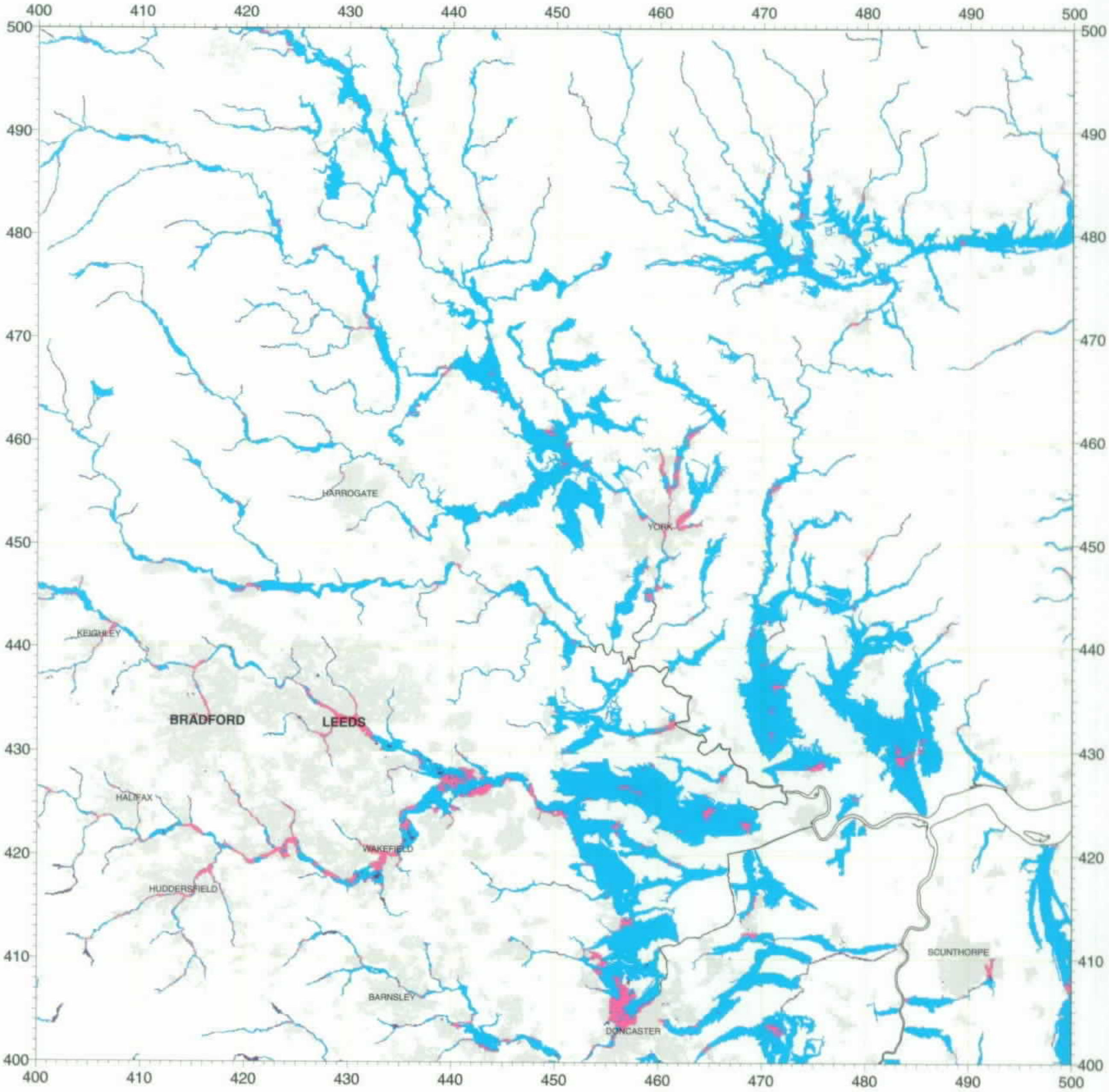
= River channels that contain the 100-year flood, and lakes

= Flooded urban

= Flooded rural

Rivers and lakes with catchment areas below $10km^2$ are not shown.

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are , or are not, at risk of inundation.



Map 5.4 SE

Scale 1:625,000

= Urban

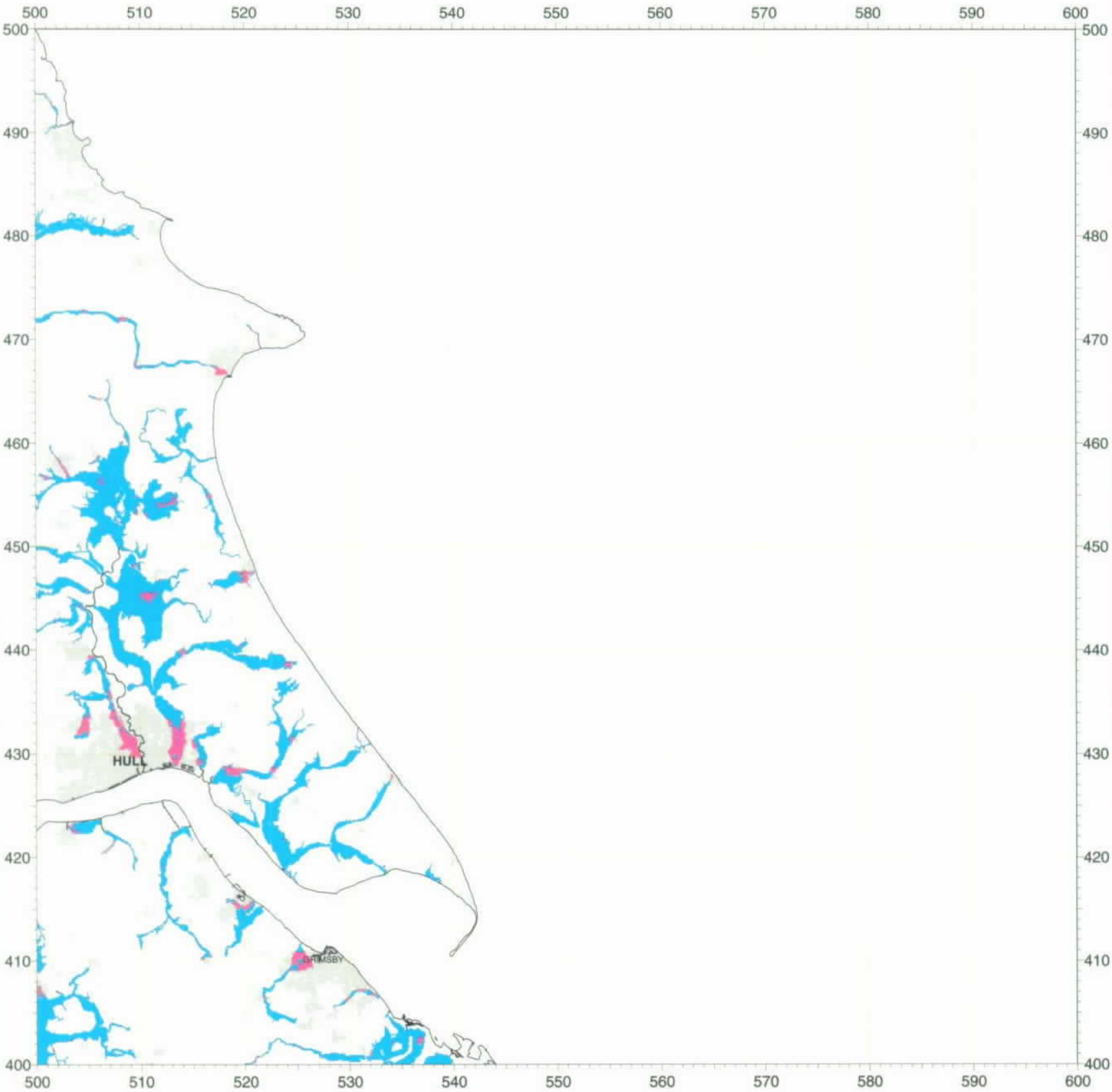
= River channels that contain the 100-year flood, and lakes

= Flooded urban

= Flooded rural

Rivers and lakes with catchment areas below 10km² are not shown.

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are , or are not, at risk of inundation.



Map 5.4 TA

Scale 1:625,000

= Urban

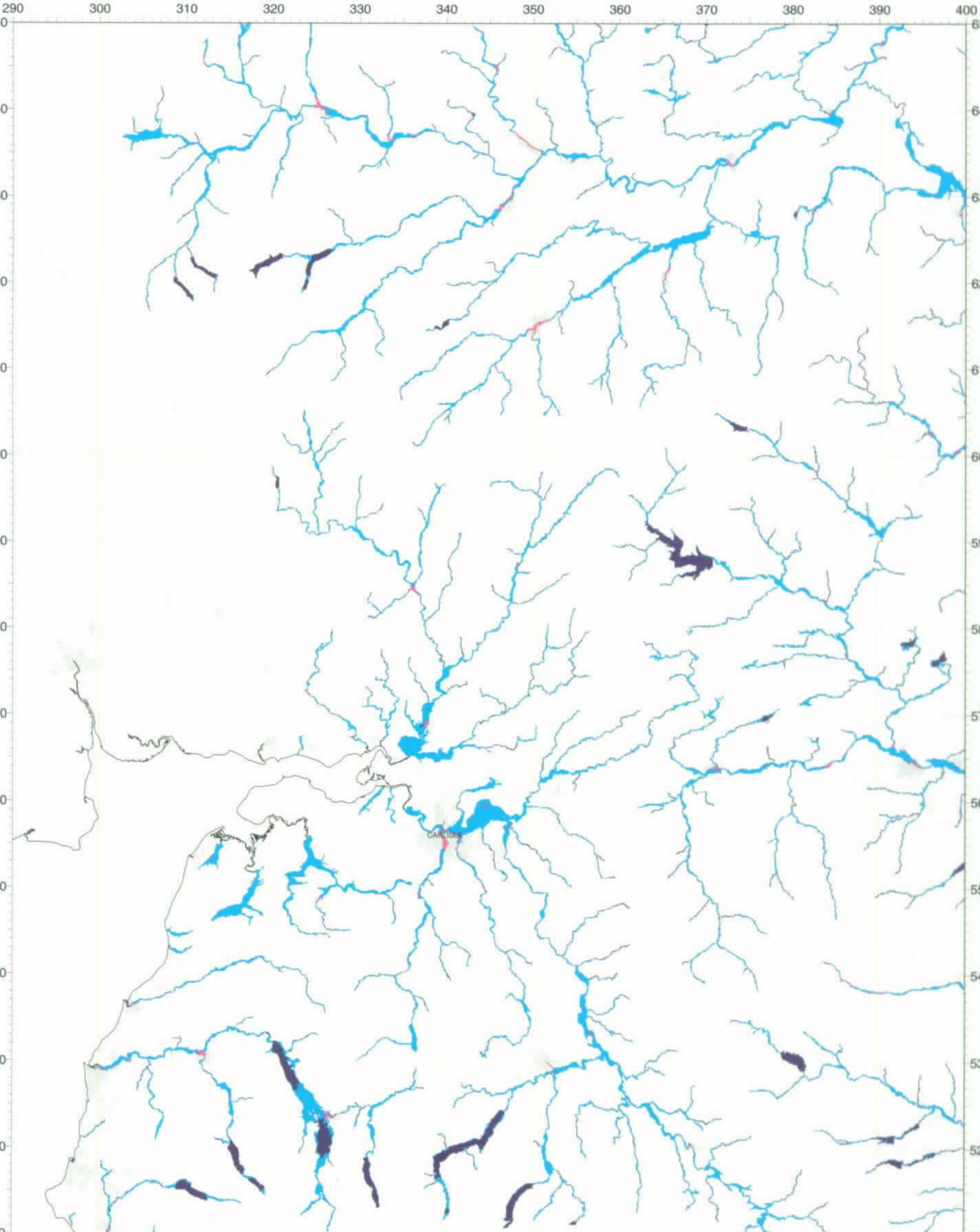
= River channels that contain the 100-year flood, and lakes

= Flooded urban

= Flooded rural

Rivers and lakes with catchment areas below 10km² are not shown.

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are , or are not, at risk of inundation.



Map 5.4 NY$^+$

Scale 1:625,000

= Urban

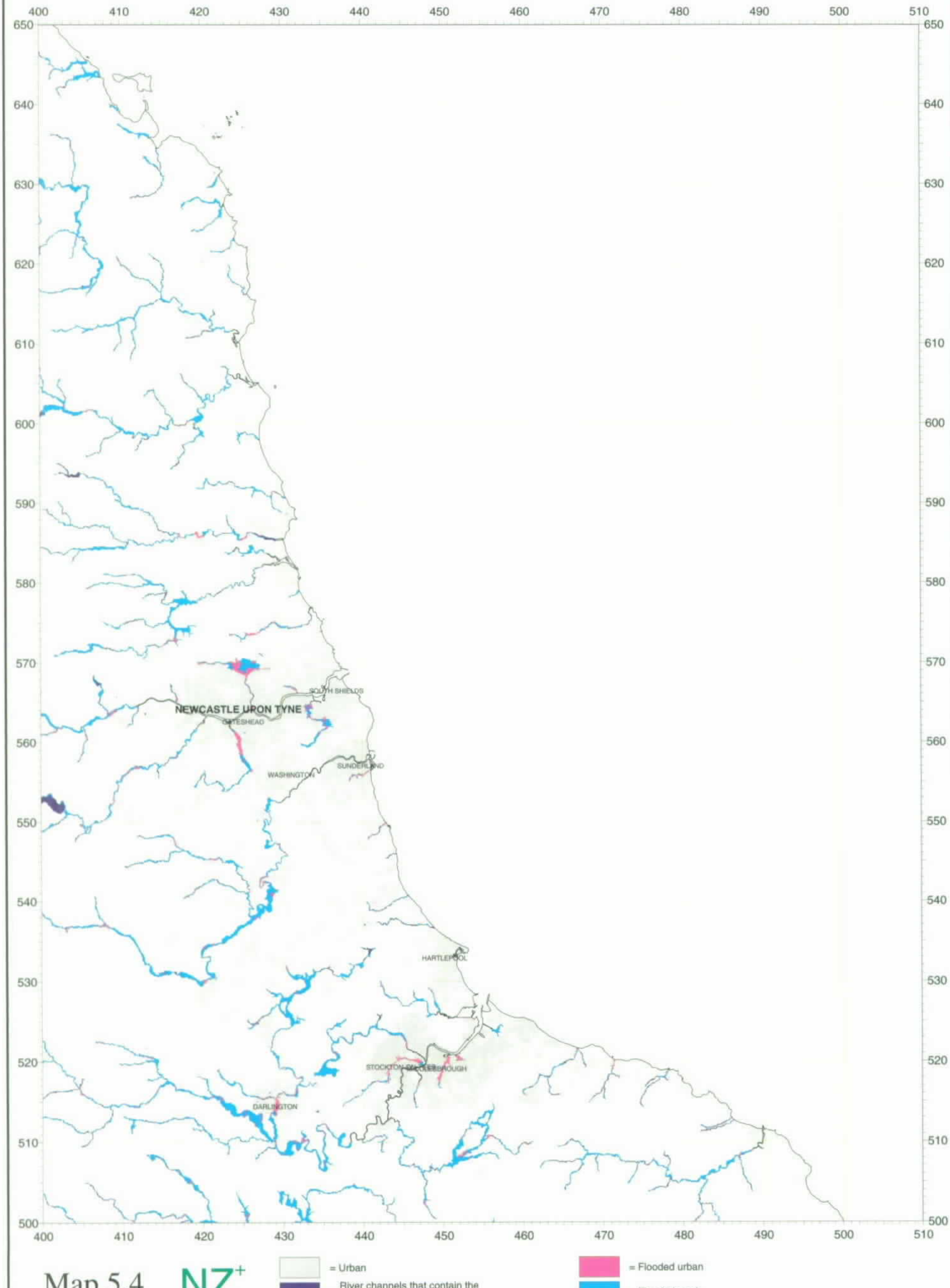
= River channels that contain the 100-year flood, and lakes

= Flooded urban

= Flooded rural

Rivers and lakes with catchment areas below $10km^2$ are not shown.

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.



Map 5.4

NZ+

= Urban

= River channels that contain the 100-year flood, and lakes

= Flooded urban

= Flooded rural

Scale 1:625,000

Rivers and lakes with catchment areas below 10km^2 are not shown.

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.

6 Interpretation of results

The following points should be borne in mind when making use of the results presented in Chapter 5.

1 The maps do not show all areas at risk of flooding from rivers, because the procedure is not appropriate for application below the tidal limit. As a result, some important urban areas (including much of London) fall outside the scope of this study.

2 The method purposely ignores the protection provided by flood defences. Some areas shown to be at risk will in practice be protected from events of the severity selected for this study.

3 The limit of flooding shown on the maps should not be used to infer that any specific flood plain location is or is not at risk. The maps are primarily intended to provide an overall impression of the distribution and extent of flood risk areas. The estimated flood depth at any location is subject to uncertainties caused by:
   - errors in the equation for estimating MAD;
   - errors in the method of estimating D100;
   - the assumption that MAD represents bankfull plus 0.3 m;
   - the accuracy and resolution of the IHDTM; and
   - not allowing for the effect of channel constrictions on upstream flood levels.

4 The stated return period of 100 years should be treated as a nominal guide.

5 Use of different methods for the estimation of flood depth could have given rise to significantly different estimates of the extent of inundation in valleys of gentle cross-sectional gradient, but would have made little difference in steeper-sided valleys.

6 Evidence from the validation site maps is not always easy to interpret because the return period associated with the mapped limits is often unknown, or is not 100 years, and because in some cases the area shown to be at risk is controlled by features which are too small to be depicted by the IHDTM.

7 The tables of flood depth will give a slightly false view of the depth distribution because the depth computed for river grid points will represent the deepest part of the 50 m by 50 m square centred on the grid point. (The depth for other flooded points will, more appropriately, represent the average flood depth in the surrounding square.)

On the other hand, there is an important factor which reduces the sensitivity of the predicted areal extent of flooding to any errors in the method. Namely that the lateral cross section of many river valleys is such that, once the immediate shallow flood plain has been inundated, further increases in flood depth have only a limited effect on the extent of the flood. This probably goes some way to explaining the close fit which has been obtained at many of the validation sites.

In conclusion, the evidence from the validation sites suggests that, subject to the points listed above, the results give a good indication of fluvial flood risk at the regional and national level.

7 Recommendations for further work

7.1 Presenting results at a larger scale

The largest scale maps produced for this report are at 1:625 000. If the relevance of the findings to any particular location needed to be investigated further, the first step would be to display the flood limits at a larger scale against suitable background detail. Several options are suggested:

a) Maps at 1:50 000 showing flood limits against a background of OS 1:50 000 contours and rivers and the ITE /OS built-up dataset, with place names from the AA gazetteer. This can be done using data currently held at IH.

b) Maps at 1:50 000 showing flood limits against a background of rasterised OS 1:50 000 maps.

c) Maps at 1:200 000 showing flood limits against a background of rasterised AA 1:200 000 maps. This can be done using data currently held at IH.

d) Maps at 1:250 000 showing flood limits against a background of OS digital 1:250 000 maps. This is preferable to (c) because the OS data register more precisely with the 1:50 000 rivers which were used in the construction of the IHDTM.

All of these would be subject to the caveats listed in Chapter 6.

7.2 Maps showing depth of flooding

On larger scale maps (1:250 000 or larger) it would be possible to use several colour bands to indicate flood depth.

7.3 Maps and tables showing sensitivity to depth

The analysis could be repeated using two additional flood depths (e.g. predicted depth plus 50% and predicted depth minus 50%, or the 50-year and 200-year depths) to produce maps showing three flood risk bands. These maps would indicate which areas were most sensitive to the predicted flood depth and were therefore most in need of further study.

7.4 Improving the predictions

a) The analysis on which this method was based was limited by the number of gauging stations at which there was an adequate record of out-of-bank flows. An alternative way of obtaining a relationship between catchment characteristics and flood depth would be to use maps of flood extent for events of known return period. The method would involve determining, at many places on the river network, the depth which would give rise to the mapped flood extent. Then, for a range of return-periods, it would use regression analysis to relate the depth to catchment characteristics. There are two ways of approaching this:

(i) working directly in terms of depth at the river bank, thereby avoiding any need to consider MAD or bankfull flow; or

(ii) first using the many gauging stations that are gauged to MAD to develop an improved relationship between MAD and catchment characteristics, then relating the growth factor (depth/MAD) to catchment characteristics.

This would involve considerable staff time in assessing and digitising existing maps.

b) If the method was to be applied to floods of a 25-year return period or less, the existing method could be improved, as more gauging stations would qualify for inclusion in the flood-depth regression analysis.

c) As has already been pointed out in Section 4.4, the definition of flood extent is highly dependent on the accuracy of the terrain model. Work is needed, on trial areas, to find out how the results would be affected by the following changes to the means of constructing the IHDTM:

(i) use of different equations for generating valley bottom profiles to make them more U-shaped, and

(ii) use of additional elevation data in river valleys, such as the 5 m interval contours from larger scale (1:25 000 or 1:10 000) OS maps or flood plain survey data.

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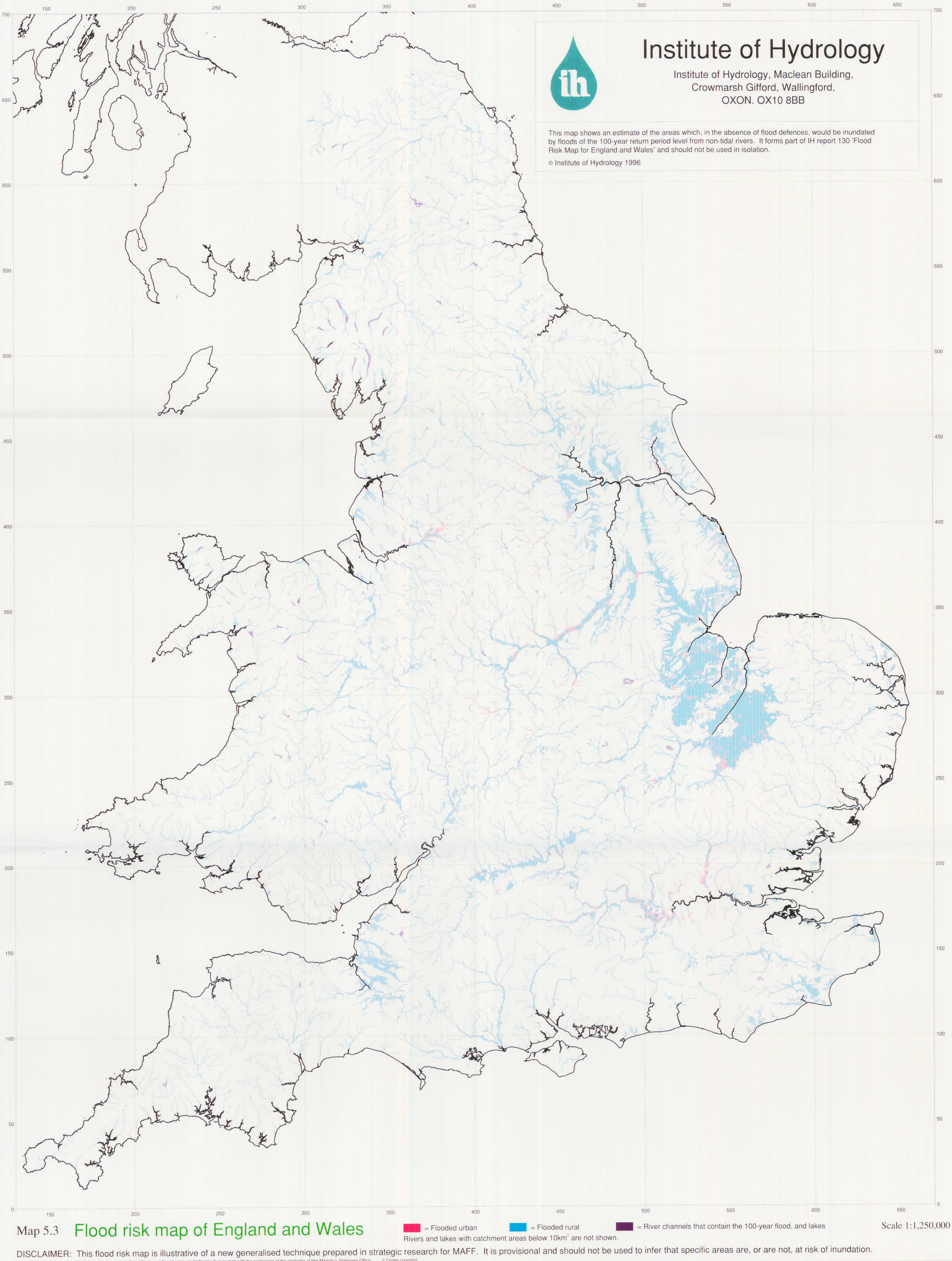

Map 5.3 Flood risk map of England and Wales

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.

Map 5.5 Flood risk map of England and Wales (N)

= Flooded urban

= Flooded rural

= River channels that contain the 100-year flood, and lakes

Rivers and lakes with catchment areas below 10km² are not shown.

Scale 1:625,000

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This map shows an estimate of the areas which, in the absence of flood defences, would be inundated by floods of the 100-year return period level from non-tidal rivers. It forms part of IH report 130 'Flood Risk Map for England and Wales' and should not be used in isolation.

DISCLAIMER: This flood risk map is illustrative of a new generalised technique prepared in strategic research for MAFF. It is provisional and should not be used to infer that specific areas are, or are not, at risk of inundation.