Indicative Atlas of Radon in Scotland

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ABSTRACT

This report presents an overview of the results of detailed mapping in Scotland of radon potential, defined as the estimated percentage of homes in an area at or above the radon Action Level. The work was carried out jointly by the Health Protection Agency and the British Geological Survey and was based on the results of measurements of radon in over 19,000 homes. The method allows variations in radon potential both between and within geological units to be mapped. The resulting digital map, which defines radon Affected Areas in Scotland, includes much more detail than could be shown in an atlas. The full detail is published as a dataset for Geographical Information Systems, which can be licensed. The estimated radon potential for an individual home can be obtained through a website, www.UKradon.org. The atlas presented here is a simplified version of the map, so is indicative rather than definitive: that is, each 1-km grid square is coloured according to the highest radon potential found within it.

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maps are without place names

EXECUTIVE SUMMARY

Radon has been recognised as a cause of lung cancer in humans for many years. Because of the risk from radon, the Health Protection Agency (HPA) and its predecessor, the National Radiological Protection Board (NRPB), have advised that excessive exposures to radon should be reduced. Government accepted this advice and it forms the basis of an ongoing programme of radon control.

To allow the UK radon programme to be implemented, it is essential to identify the areas most affected by radon problems. This report presents an overview of the results of detailed mapping in Scotland of radon potential, defined as the estimated percentage of homes in an area at or above the radon Action Level. The radon potential therefore corresponds to the probability that a home that has not had a radon measurement will have a long-term average radon concentration at or above the radon Action Level. This work was carried out jointly by the Health Protection Agency and the British Geological Survey.

The joint mapping method is based on the results of measurements of radon in over 19,000 homes in Scotland, and additional homes in England near to the border with Scotland. The radon results are grouped first by geological boundaries and then by 1-km grid squares. The method allows variations in radon potential both between and within geological units to be mapped.

The resulting map, which defines areas with a 1% or greater probability of exceeding the Action Level ("radon Affected Areas") in Scotland, includes much more detail than could be shown in an atlas. The full detail is published as a dataset for Geographical Information Systems, which can be licensed. The estimated radon potential for an individual home can be obtained through a website, www.UKradon.org. The atlas presented here is a simplified version of the map, so is indicative rather than definitive: that is, each 1-km grid square is coloured according to the highest radon potential found within it.

The new atlas, together with the underlying definitive digital information sources, will assist in identifying areas, with a 1% or greater probability of exceeding the Action Level, in which householders and others should make radon measurements. These resources may also be used by appropriate Government authorities to identify localities in which new homes should be constructed with precautions against radon.

CONTENTS

1 INTRODUCTION

Radon has been recognised as a cause of lung cancer in humans for many years (AGIR, 2009). Advice from HPA (HPA, 2010) retained the established (NRPB, 1990) UK radon Action Level of 200 Bq m^{-3}. HPA advised that all areas should be classified according to the probability that a home in the locality will have an indoor radon concentration at or above the Action Level. Areas with probabilities in the range 1-10% and 10% or more, are referred to as “intermediate” and “higher” radon probability areas. Together, these terms match the existing definition of “radon affected areas”. HPA advises that radon measurements should be made in homes in these areas. Areas with probabilities less than 1% are referred to as “lower” radon probability areas.

To allow the UK radon programme to be implemented, it is useful to identify the areas most affected by radon problems. HPA has published maps showing the estimated radon potential, or proportion of homes above the Action Level, by grid square in different parts of the UK (Miles et al (2007), Green et al (2009a), Green et al (2009b)).

Indoor radon concentrations depend on a number of factors, including the geological characteristics of the ground underneath the home. This can be taken into account in maps of radon potential, but other factors, including the construction details and the living styles of the occupants, are responsible for a very wide variation of indoor radon concentrations found in homes built on ground with the same radon potential.

Earlier maps published separately by HPA and BGS grouped house radon results either by grid square or by geological unit, before applying lognormal modelling (Miles, 1998). Both of these mapping methods ignore some part of the geographical variation in radon potential: grid square mapping ignores variation between geological units within grid squares, and geological mapping ignores variation within areas sharing combinations of geological characteristics. It was realised by HPA and BGS that combining the two methods could give more accurate mapping than either separately. The two organisations cooperated to develop a joint geological/grid square mapping method. This atlas is the outcome of applying this method to radon mapping in Scotland, and supersedes the previous atlas of radon potential in Scotland (Green et al, 2009a). The radon measurement data on which the mapping is based, summarised by administrative area and by divisions of the postcode system, are published elsewhere (Green et al, 2009a).

2 MEASUREMENTS

The house radon results used in the maps presented here are collated from the many different radon survey programmes carried out by NRPB and HPA, many of them funded by the Scottish Government. These surveys were seldom representative of the housing stock of large areas or regions. Indeed, many were intentionally targeted to areas where higher levels were expected. The initial national survey (Wrixon et al, 1988) was the only one in which care was taken to obtain a population-weighted sample of homes throughout the UK. The results of this survey continue to provide the best estimates of the average exposure at both national and county level.

Measurements in all surveys are made with two passive integrating detectors in each dwelling – one in the main living area and one in a regularly used bedroom (Hardcastle et al, 1996). The detectors are placed for three months and the results combined to reflect typical occupancy patterns. Since indoor radon levels are usually higher in cold weather, the results reported to householders are normalised for typical seasonal variations in radon levels to allow the estimated annual radon concentration to be reported (Wrixon et al 1988, Pinel et al 1995). It has been shown (Miles 1998) that the seasonal variations correspond to average outdoor temperature variations. To allow for the fact that weather patterns vary from year to year, the annual average radon concentrations in houses used in the mapping reported here were calculated using temperature corrections based on temperature at the time of measurement, rather than seasonal corrections.

3 RADON MAPS

The integrated geological/grid square method used here for mapping radon potential is described in detail by Miles and Appleton (2005). In the integrated method, each combination of geological characteristics (bedrock, superficial, and others) is taken in turn, and the spatial variation of radon potential within the combination is mapped, treating it as if the combination was continuous over the land area.

3.1 Location of each home

In order to determine which geological unit a house lies on, it is necessary to know its location as accurately as possible. Ordnance Survey ADDRESS-POINT® provides a National Grid reference that falls inside the permanent building structure of an address. Where several addresses are in one building (for example a block of flats) the same coordinates are used for each address. It was possible to obtain ADDRESS-POINT® coordinates for over 90% of the dwellings in Scotland with radon measurement results. For the remainder, coordinates were obtained from Ordnance Survey Code-Point®, which allocates coordinates according to the postcode of a dwelling. In the UK each postcode covers 16 dwellings on average, but in densely populated areas the number is higher and in sparsely populated areas it is lower. In most cases the grid reference allocated to a dwelling using Code-Point® will be accurate to within a few hundred metres, but in sparsely populated areas the error may be greater.

3.2 Attribution of geological codes to measurement locations

Bedrock and superficial geological codes were attributed to each house location using the BGS 1:50,000 scale DiGMapGB digital data. Each different combination of geological characteristics may appear at the land surface in many discontinuous locations across the country. Geological mapping of the UK has been carried out over many years during which time there have been changes in the nomenclature of mapped rock units. Consequently, the names of geological units sometimes change at map sheet boundaries. In order to facilitate the seamless 1-km interpolation of radon potential within major geological units, simplified bedrock and superficial geology classification systems were developed. These ensure continuity across map sheet boundaries and also group some geological units with similar characteristics. Grouping similar geological units ensured that there were a sufficient number of indoor radon measurements for intra-geological unit grid square mapping to be carried out over a greater proportion of the UK. There are nearly 4,800 named 1:50,000 scale bedrock geological units in Scotland and these were grouped using a simplified bedrock classification comprising 138 units. The 189 individually named 1:50,000 scale superficial geological units were grouped into ten types according to a simplified system based on permeability and generic type (Miles and Appleton, 2005). A total of 446 bedrock-superficial geology combinations resulted from the simplified classification and these were used for the radon potential mapping (Scheib et al, 2009).

3.3 Estimation of radon potential

Within each geological combination with more than 100 radon measurements, the variation of indoor radon concentrations was mapped using 1-km squares of the national grid. A radon potential was allocated to each 1-km grid square on the basis of the nearest 30 house radon measurement results to that square, or all of the results in the square if that was 30 or more. The geometric mean (GM) and the geometric standard deviation (GSD) of the results allocated to each square were calculated, and a lognormal model was used to estimate the proportion of the distribution above the Action Level. This parameter, equivalent to the radon potential, is the parameter shown in the maps.

In order to improve the accuracy of the estimates of the radon potential, certain corrections were applied. It has been shown (Darby, 2003) that the measured GSD for any group of house radon measurement results, each made over three months, is higher than the GSD that would have been observed if the measurements had been made over several years in each house. The difference is caused by uncertainties in estimates of long-term average radon concentrations, both from extrapolating from three months to a year, and from year-to-year variations in radon levels. It is possible to correct measured GSDs for this effect, using data from studies of the year-to-year variation in three-month house radon measurement results. Such corrections always reduce the GSDs, and therefore always reduce percentages above a threshold, if the GM of the area is below the threshold. This correction was applied in the mapping exercise reported here. Earlier mapping exercises in Scotland did not take account of this factor.

There is also some random variation in the calculated values of the GSD. It has been shown (Miles and Appleton, 2000), that the use of Bayesian estimates of GSD gives less uncertain estimates of the proportion of homes above the Action Level, and does not bias the estimates in any way. The reduction of the uncertainty by the use of

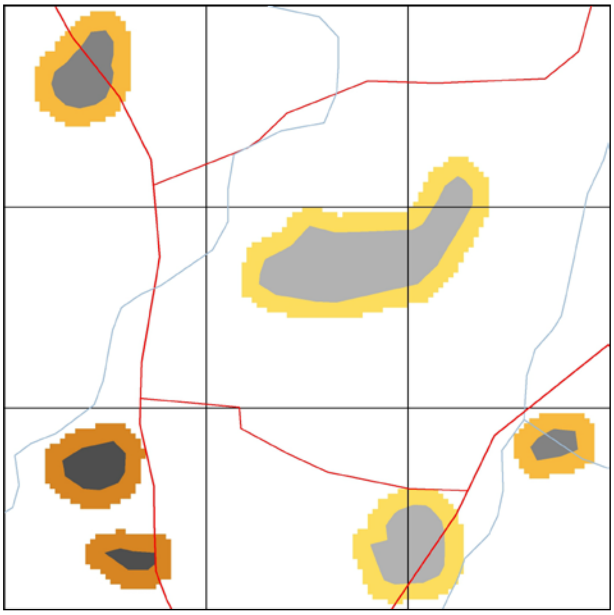
Bayesian statistics was significant but not very large. This correction was also applied in the mapping exercise reported here.

The resulting map is highly detailed, with an implied precision of less than one metre. In fact there is uncertainty in the location of the boundaries on geological maps and in the size and orientation of the footprint of the house from the point location. To reduce the possibility of advising householders that the risk of radon problems was small, when in fact it could be significant, a buffer was applied around each area. This buffer was applied in sequence from the highest to the lowest radon areas. The uncertainty in geological boundaries was assigned a value of 50 metres, and the uncertainty in building location was assigned a value of 25 metres, giving a combined buffer width of 75 metres. Because of the difficulty of processing the highly detailed data, it was necessary to simplify the map, converting it to 25-metre squares of the national grid, each attributed a uniform value of the highest radon potential within it. This buffering process is likely to lead to a slight over-estimate of the area and number of homes in the higher bands of probability.

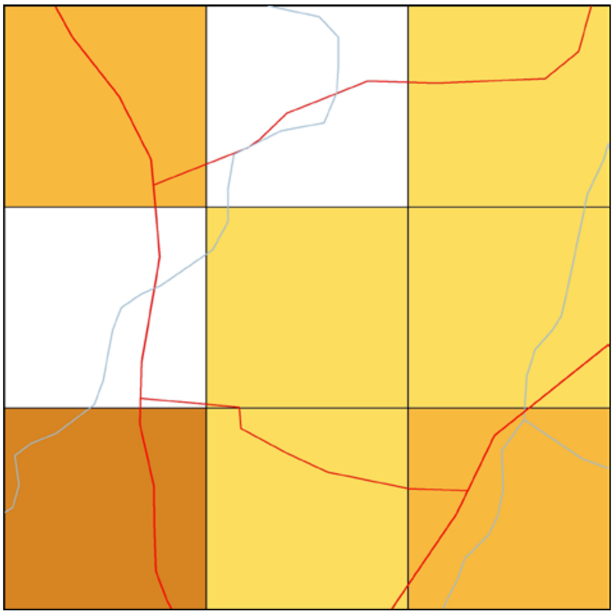
In some areas, including parts of central Scotland, geological information includes a large number of small zones that are of a geological type that has been observed to have elevated radon potential. Since many of the individual zones are much less than a kilometre in width, the buffering process increases the size of these zones to a greater proportion than is the case for larger zones. These buffered zones are included in the radon potential dataset. This effect was also present in the radon atlas for England and Wales (Miles et al, 2007). In most cases, this will not affect the banding shown in the indicative maps but for some grid squares, containing perhaps only one or two of these small zones, the great majority of the grid square will be of a lower classification than that shown in this atlas. The effect is illustrated hypothetically in figures 1a and 1b. Figure 1a shows un-buffered (grey shaded) and buffered areas of radon potential. Figure 1b shows the indicative levels for each 1-km grid square, based on the highest classification in the square.

3.4 Presentation of results

The resulting digital map includes much more detail than could be shown in a printed atlas. The full detail is instead published as a dataset for Geographical Information Systems, which can be licensed on application to BGS (see www.bgs.ac.uk/radon/hpa-bgs.html). The estimated radon potential for an individual home can be obtained through a website, www.UKradon.org. The atlas presented here is based on data that are further processed, to group the data by 1-km grid square. As a result, the atlas is indicative rather than definitive: that is, each 1-km grid square is coloured according to the highest radon potential found within it (see Figure 1). However, grid squares marked as 0-1% above the radon Action Level contain no intermediate or higher radon probability areas (previously referred to as "radon Affected Areas") as defined by HPA, so in these cases the Atlas is definitive.



(a)



(b)

Figure 1 If 1-km grid squares on the definitive radon map contain more than one percentage band as shown in the above 3 x 3 1km grid (a), they are shown on the indicative map presented in this atlas entirely coloured as the highest percentage band within the square (b).

The map plates show the major road network as well as larger settlements chosen to give a reasonable geographical spread across the maps regardless of population density. Superimposed on the maps are the administrative boundaries at unitary authority level. Council names are given wherever possible subject to the limitations of space, especially in urban areas. Electronic versions of this atlas can be viewed with and without place names (see www.ukradon.org). The latter version may be helpful to clarify the result where it is obscured by a place name. The provision of the 100-km grid letters in the map title and the national grid co-ordinates on the X and Y axes allow easy cross-reference to other maps.

An overall map of Scotland (Figure 2) precedes a map giving the key to the following 17 maps each covering about 16,000 km^2 (Figure 3). The majority of these maps are centred on one 100-km grid square of the national grid; the exceptions are to accommodate the variations in the coast line.

3.5 Application to workplaces

Although the radon data used in the production of this Atlas come from measurements in homes, the maps indicate the likely extent of the local radon hazard in all buildings. The information in this Atlas is therefore relevant to employers in assessing workplace risks. Under the Health and Safety at Work etc. Act (HSE, 1974), the employer must, so far as is reasonably practicable, ensure the health and safety of employees and others who have access to their work environment. The Management of Health and Safety at Work Regulations (HSE, 1999) require the assessment of health and safety risks.

Guidance on how to apply the maps contained in this Atlas in assessing workplace radon is available from the Health and Safety Executive (HSE) website, www.hse.gov.uk/radiation. This addresses a number of topics including using radon maps to determine the need for measurement in ground floor and below surface workplaces.

The HSE and Local Authorities are responsible for enforcing the regulations in various workplaces.

4 CONCLUSIONS

This atlas provides an overview of the probability of the radon level in any Scottish home being at or above the Action Level. It updates previous reports and complements the formal advice of HPA on the need to reduce long-term exposure to elevated radon levels. It will be of use and interest to individuals and organisations with a duty to assess, and where appropriate reduce the radon exposure of the population, both in the home and in the workplace. It is expected that further updates, incorporating the latest available data, will be published at intervals.

5 ACKNOWLEDGEMENTS

The data used to construct the maps have been collated from many different radon surveys carried out by NRPB and HPA. Many of the measurements were funded by Scottish Government, by local government at county and district level, by landlords and by individual householders.

This report is published with the permission of the Executive Director, British Geological Survey (NERC).

6 GLOSSARY

Becquerel. Symbol Bq. The unit of the amount or activity of a radionuclide. Describes the rate which transformations occur. 1 Bq = 1 transformation per second.

Becquerel per cubic metre of air. Symbol Bq m^{-3}. The amount of a radionuclide in each cubic metre of air. Often referred to as the activity concentration.

Radon. A naturally occurring radioactive gas that is the major source of ionising radiation exposure. For more information see advice from HPA (HPA, 2010), www.hpa.org.uk or www.ukradon.org.

Radon Action Level. The recommended limit for the activity concentration of radon in UK homes. Its value, expressed as the annual average radon gas concentration in the home, is 200 Bq m^{-3}.

Radon Affected Areas. Parts of the country with a 1% probability or more of present or future homes being above the Action Level.

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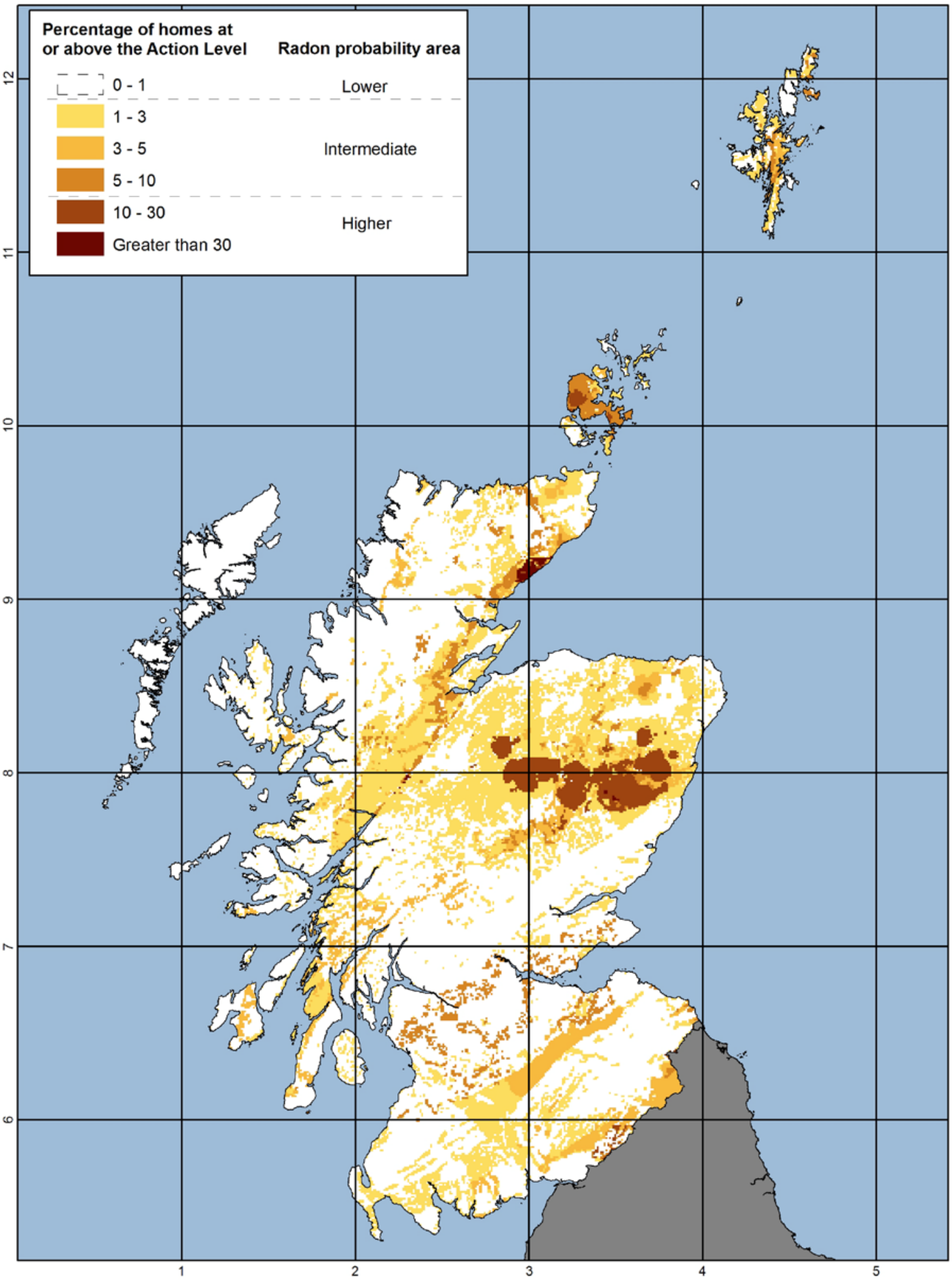


Figure 2 Overall map of radon potential in Scotland (axis numbers are the 100-km coordinates of the National Grid)

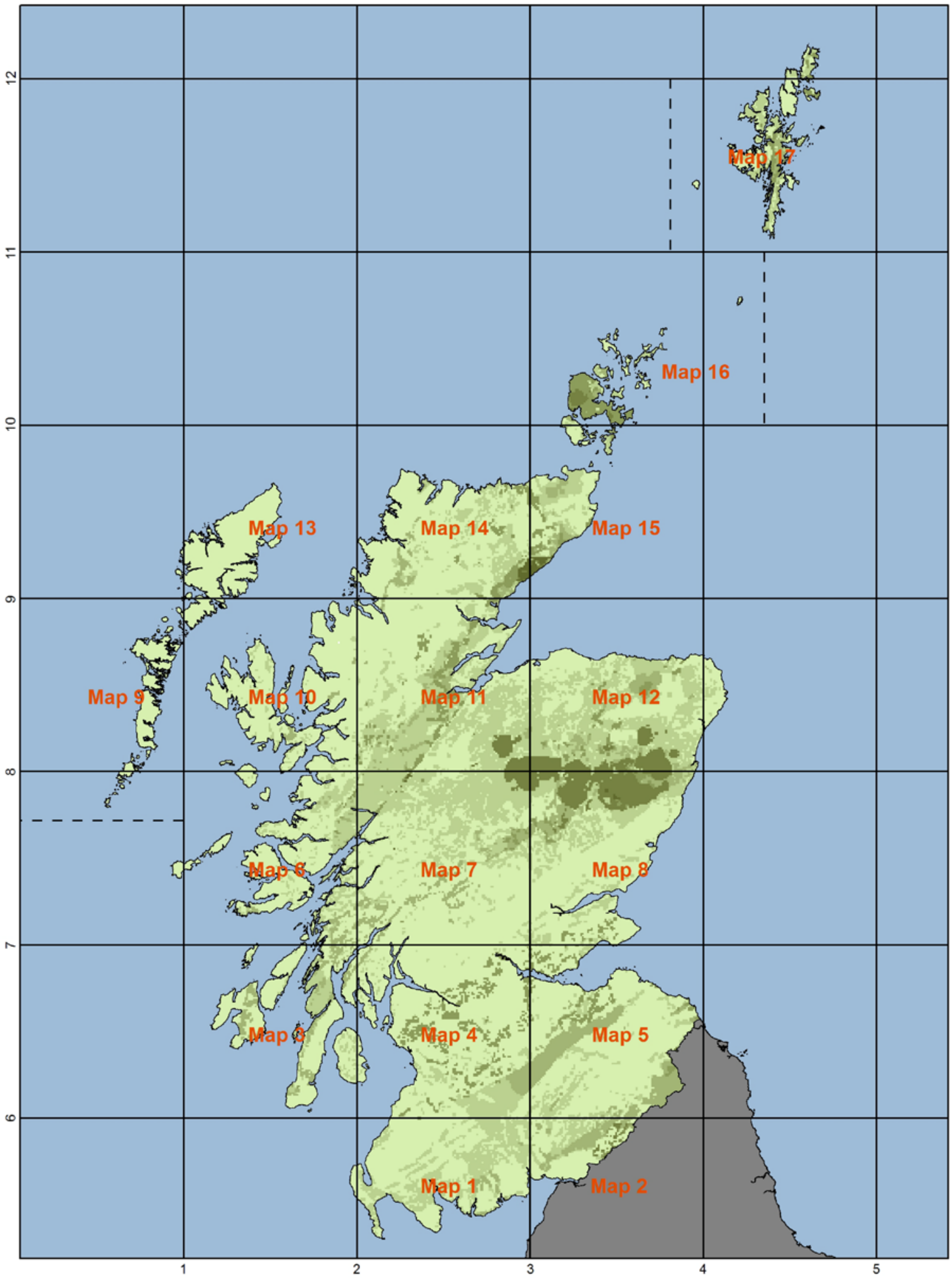
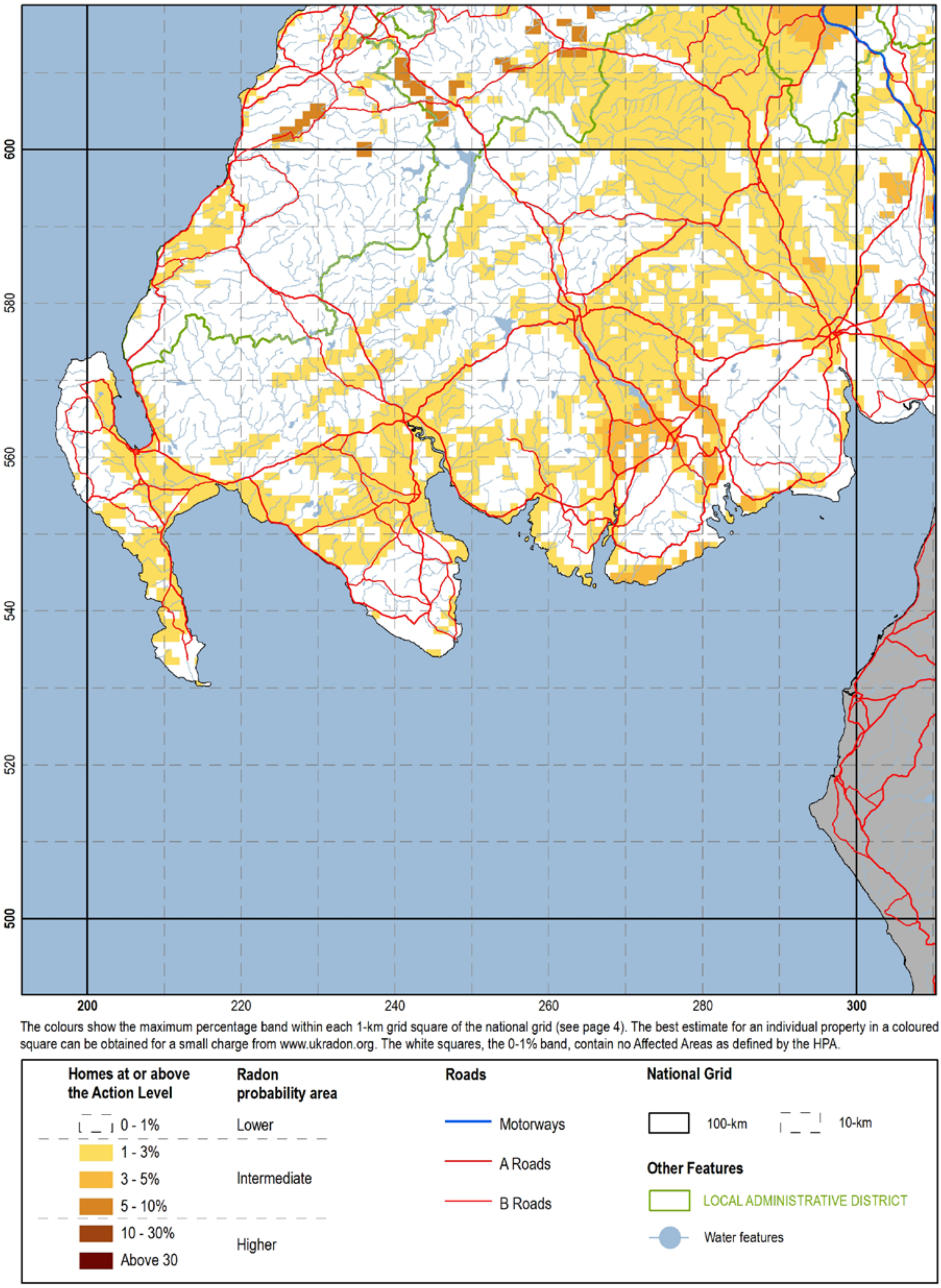
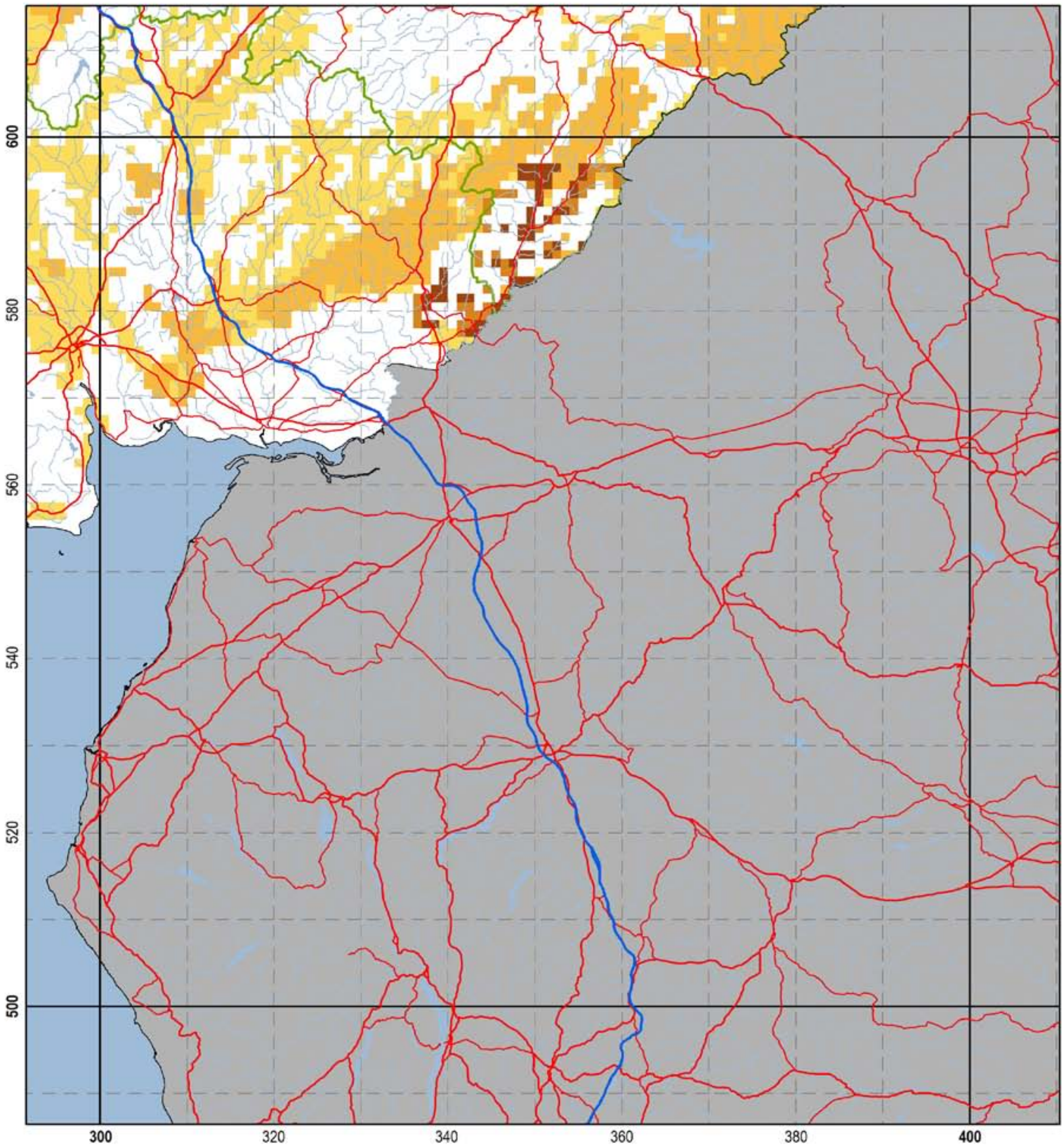


Figure 3 Key to larger scale maps (axis numbers are the 100-km coordinates of the National Grid)



The colours show the maximum percentage band within each 1-km grid square of the national grid (see page 4). The best estimate for an individual property in a coloured square can be obtained for a small charge from www.ukradon.org. The white squares, the 0-1% band, contain no Affected Areas as defined by the HPA.

Map 1 South-western Scotland, 100-km grid square NX (axis numbers are the coordinates of the National Grid)



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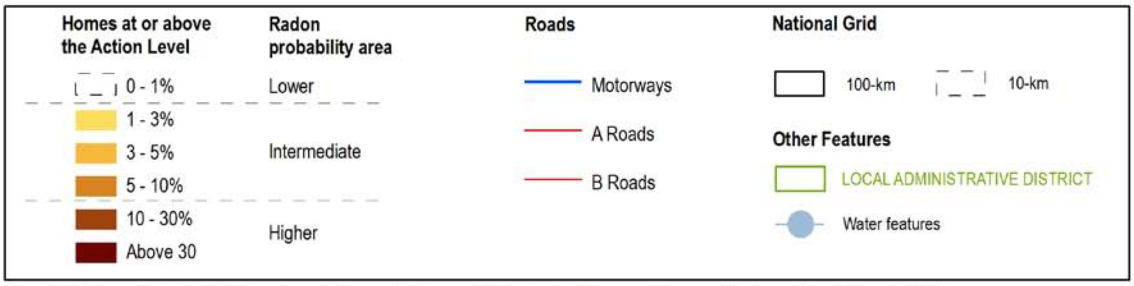
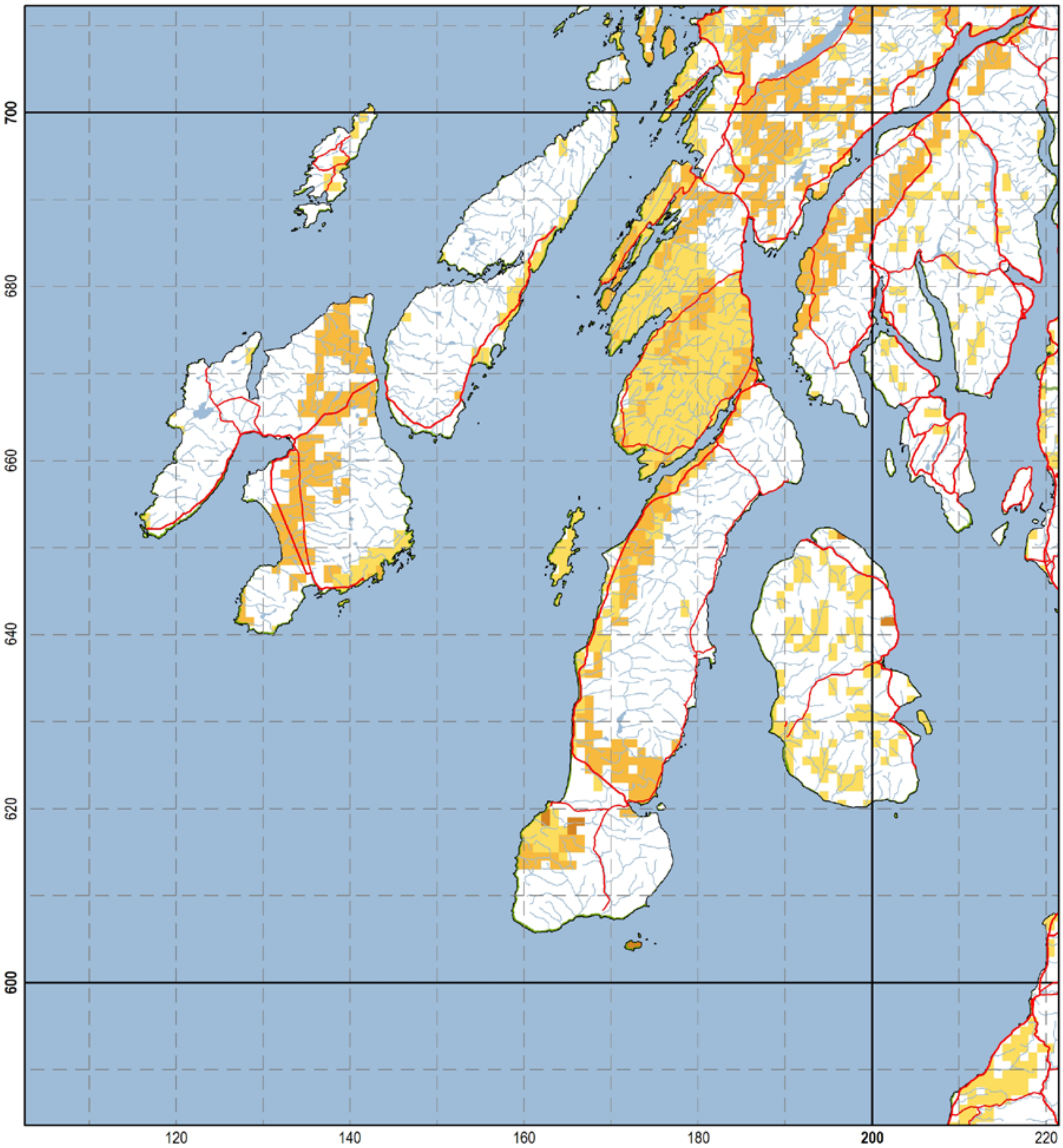


Map 2 South-western Scottish Borders, 100-km grid square NY (axis numbers are the coordinates of the National Grid)



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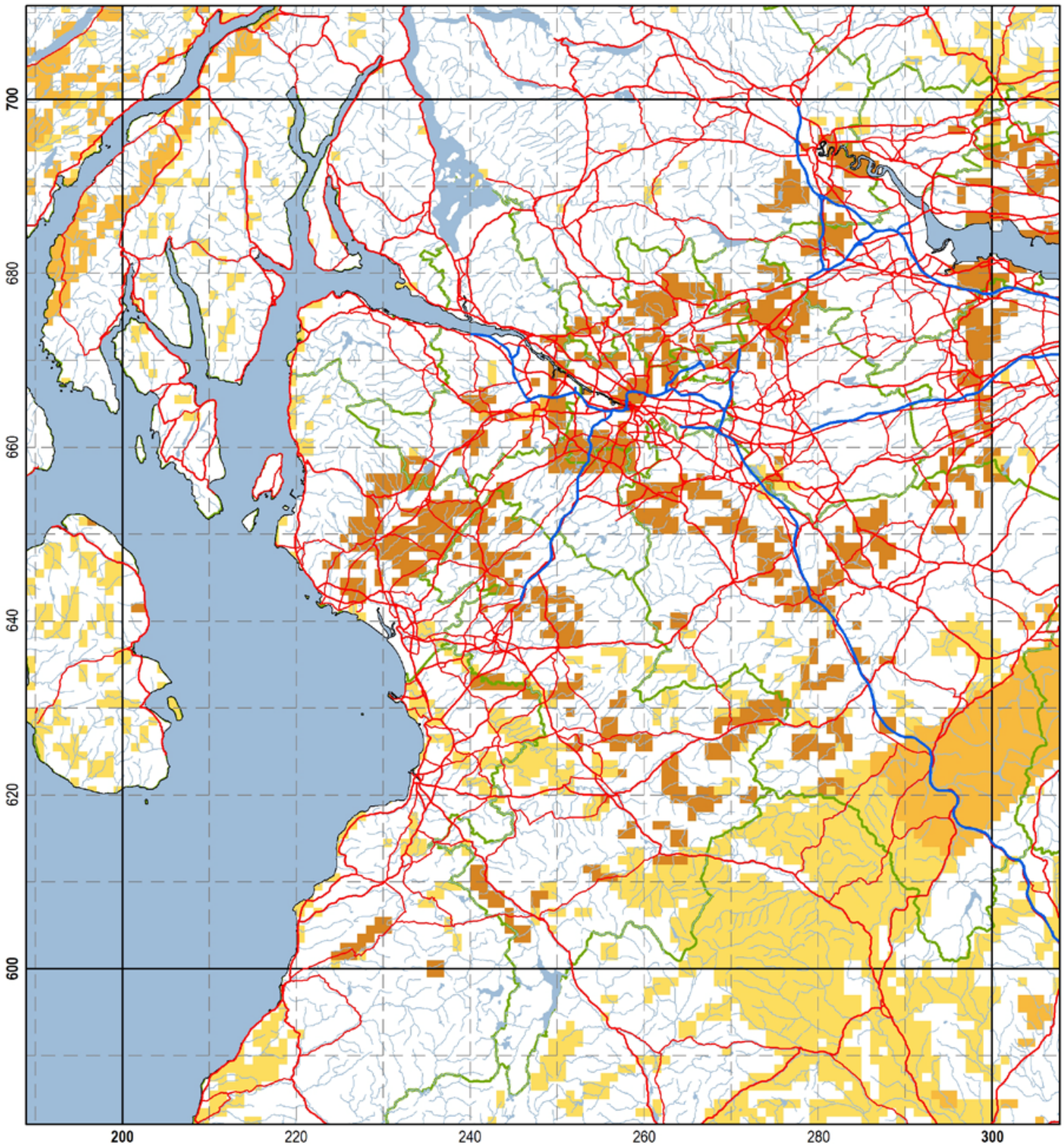
Homes at or above the Action Level	Radon probability area	Roads	National Grid
0 - 1%	Lower	Motorways	100-km; 10-km
1 - 3%		A Roads	**Other Features**
3 - 5%	Intermediate	B Roads	LOCAL ADMINISTRATIVE DISTRICT
5 - 10%			Water features
10 - 30%	Higher		
Above 30			

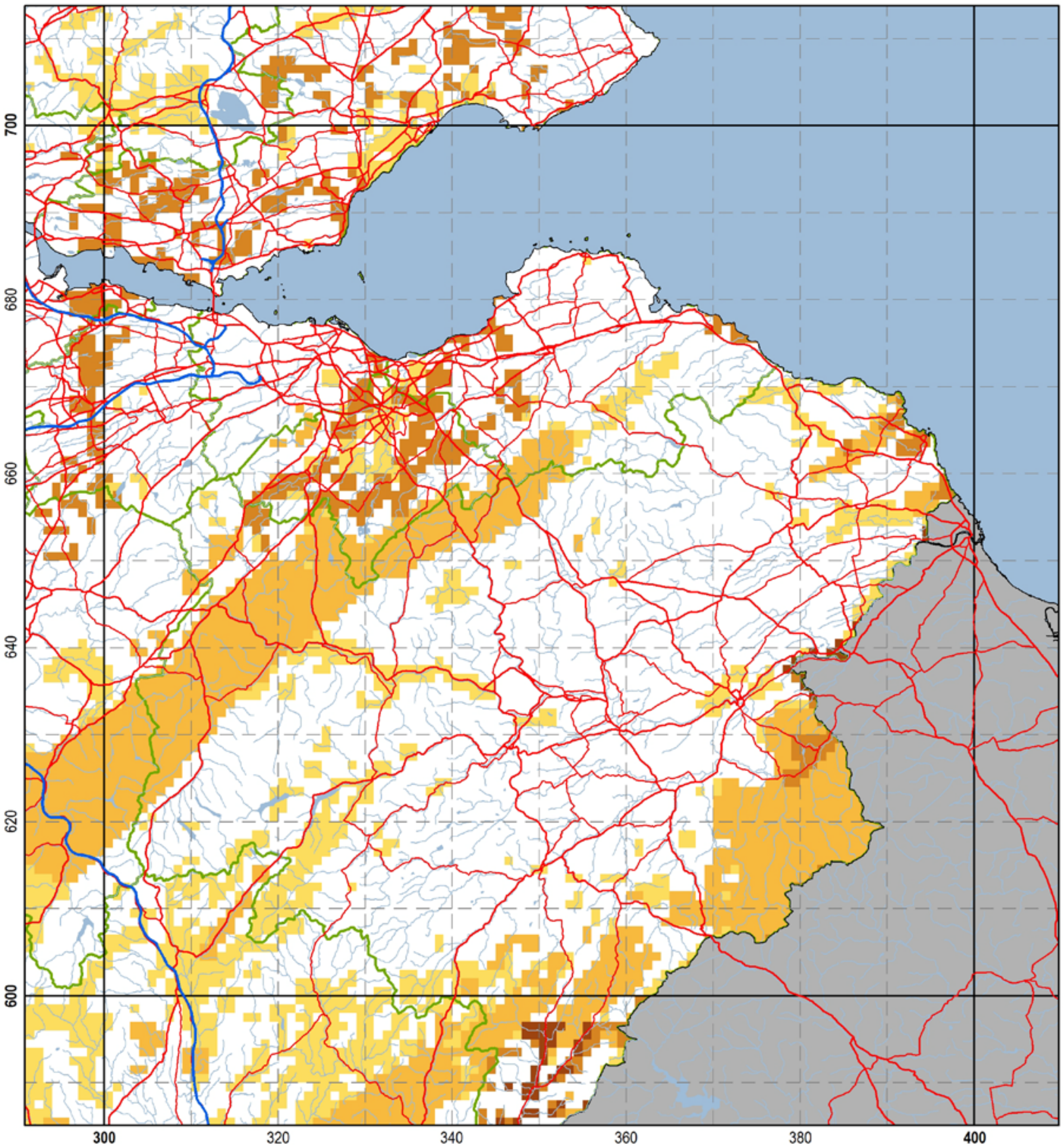
Map 3 Kintyre and the Islands of Islay, Jura and Arran, 100-km grid square NR (axis numbers are the coordinates of the National Grid)



The colours show the maximum percentage band within each 1-km grid square of the national grid (see page 4). The best estimate for an individual property in a coloured square can be obtained for a small charge from www.ukradon.org. The white squares, the 0-1% band, contain no Affected Areas as defined by the HPA.

Homes at or above the Action Level	Radon probability area	Roads		National Grid	
0 - 1%	Lower	Motorways		100-km	10-km
1 - 3%		A Roads		**Other Features**	
3 - 5%	Intermediate	B Roads		LOCAL ADMINISTRATIVE DISTRICT	
5 - 10%				Water features	
10 - 30%	Higher				
Above 30					

Map 4 Glasgow and the south-western Lowlands, 100-km grid square NS (axis numbers are the coordinates of the National Grid)



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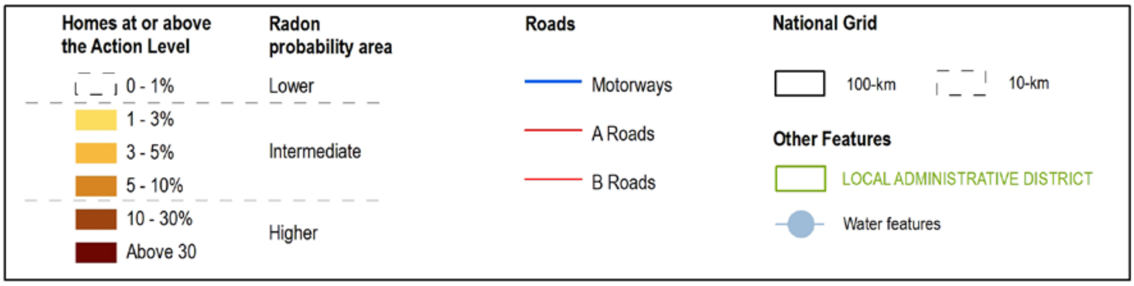
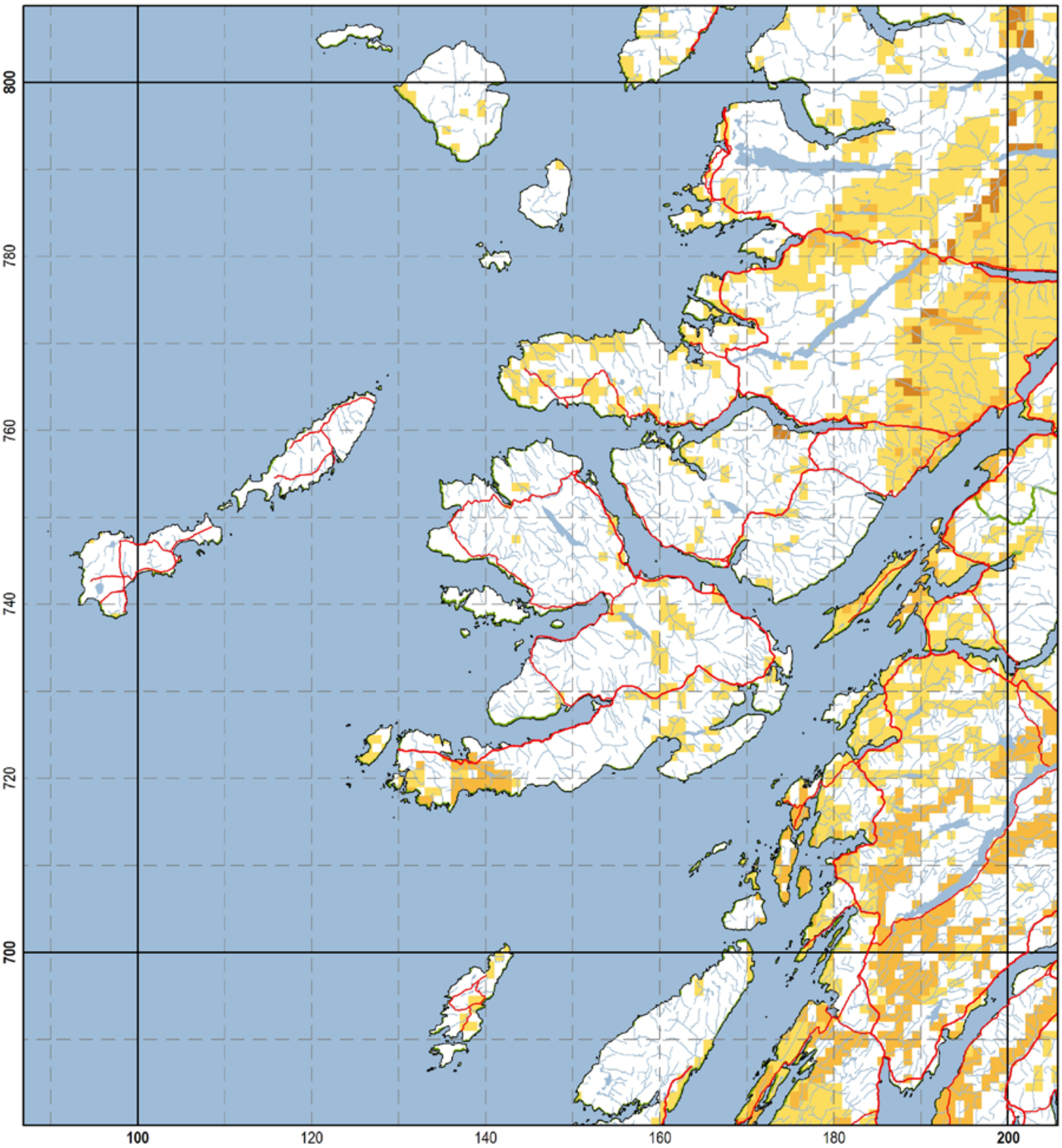


Map 5 Edinburgh and the south-eastern Scottish Borders, 100-km grid square NT (axis numbers are the coordinates of the National Grid)



The colours show the maximum percentage band within each 1-km grid square of the national grid (see page 4). The best estimate for an individual property in a coloured square can be obtained for a small charge from www.ukradon.org. The white squares, the 0-1% band, contain no Affected Areas as defined by the HPA.

Homes at or above the Action Level	Radon probability area
0 - 1%	Lower
1 - 3%	Intermediate
3 - 5%	Intermediate
5 - 10%	Intermediate
10 - 30%	Higher
Above 30	Higher

Roads

- Motorways
- A Roads
- B Roads

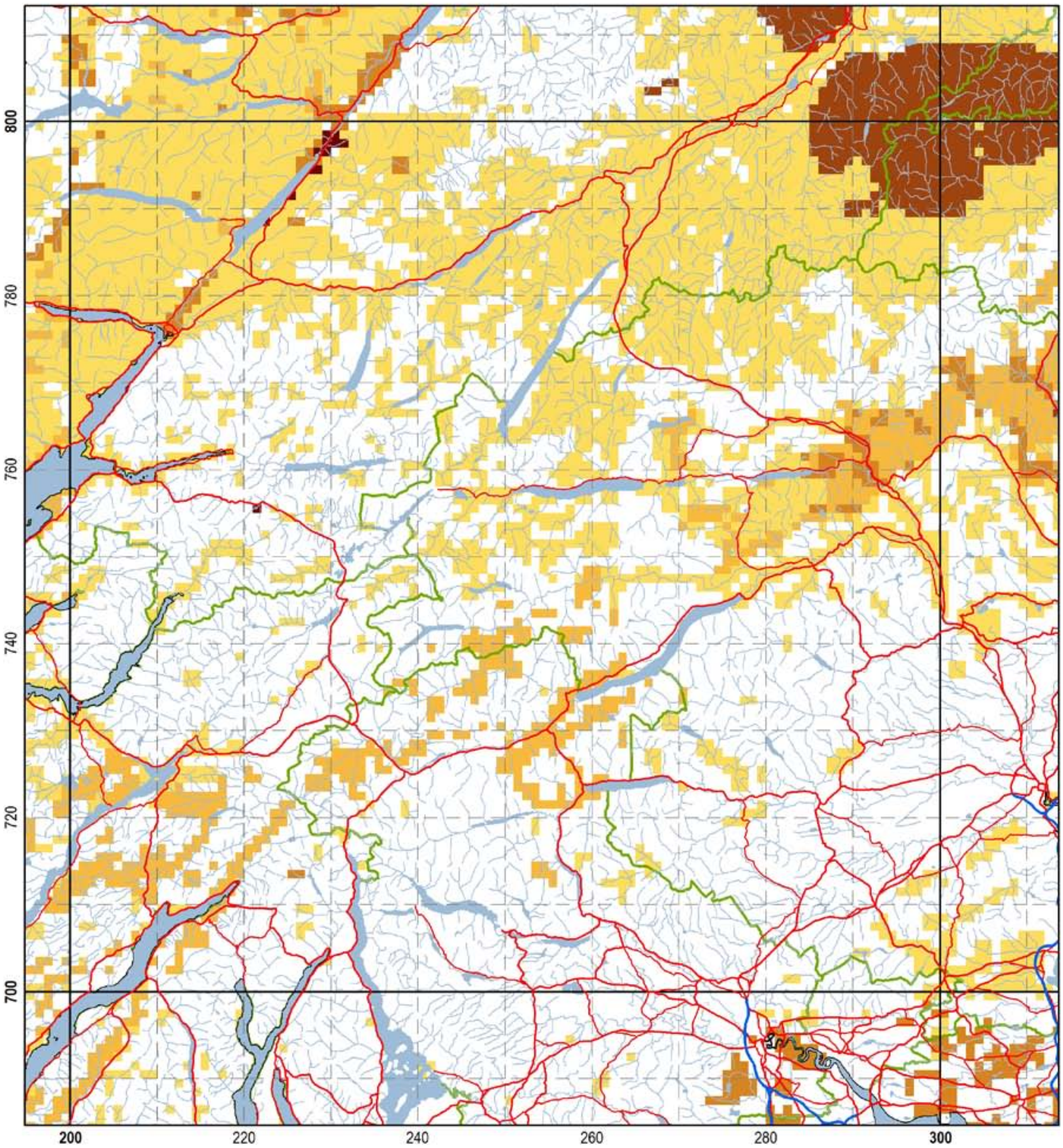
National Grid

- 100-km
- 10-km

Other Features

- LOCAL ADMINISTRATIVE DISTRICT
- Water features

Map 6 North-western Argyll and Bute and the south-western Highlands, 100-km grid square NM (axis numbers are the coordinates of the National Grid)



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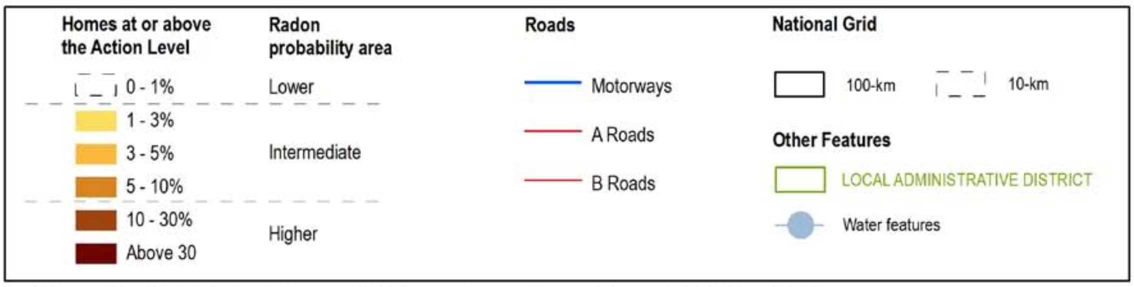
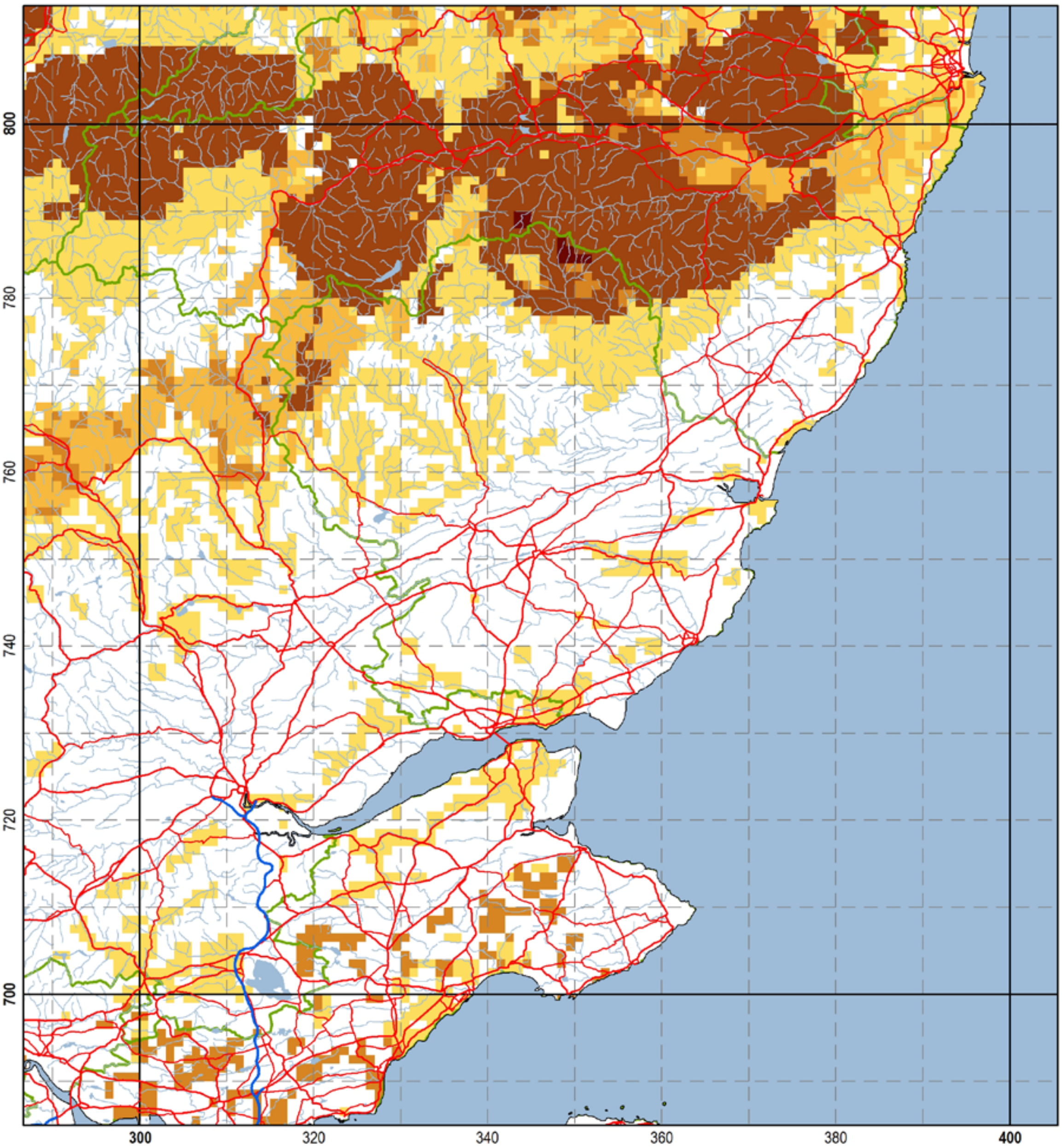


Map 7 Central Scotland, 100-km grid square NN (axis numbers are the coordinates of the National Grid)



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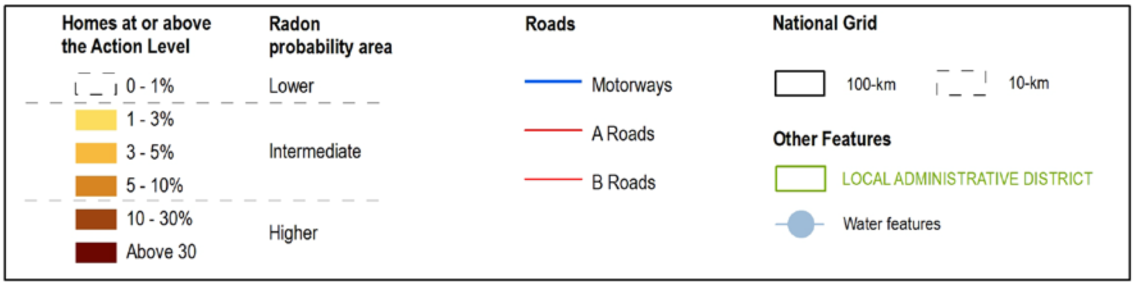
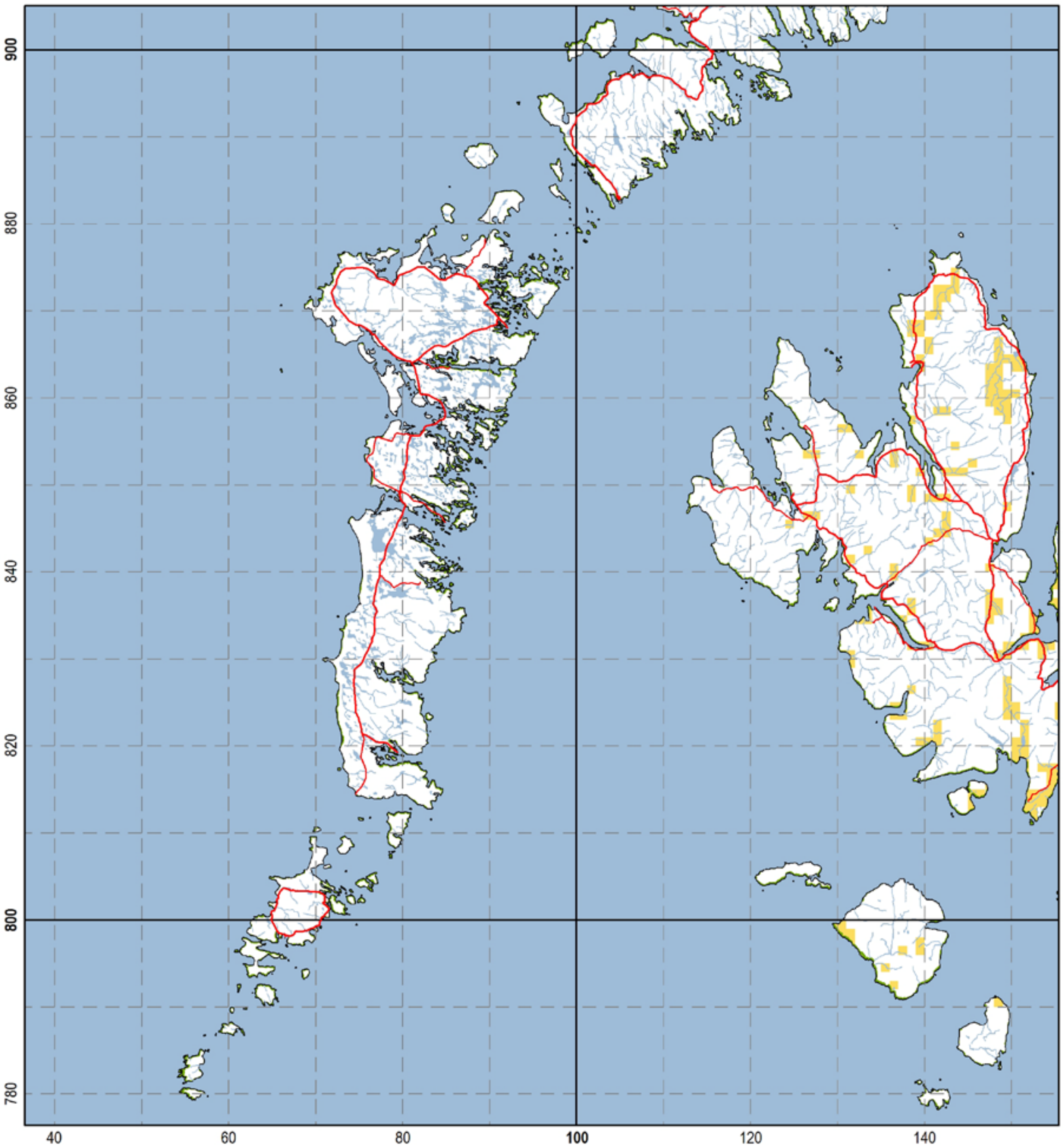
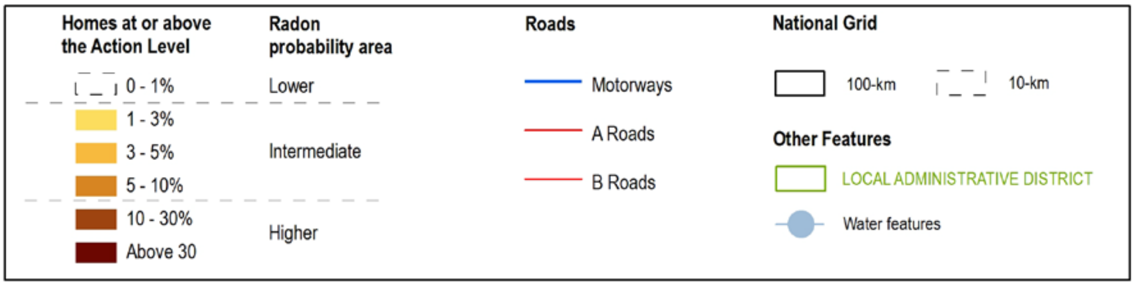


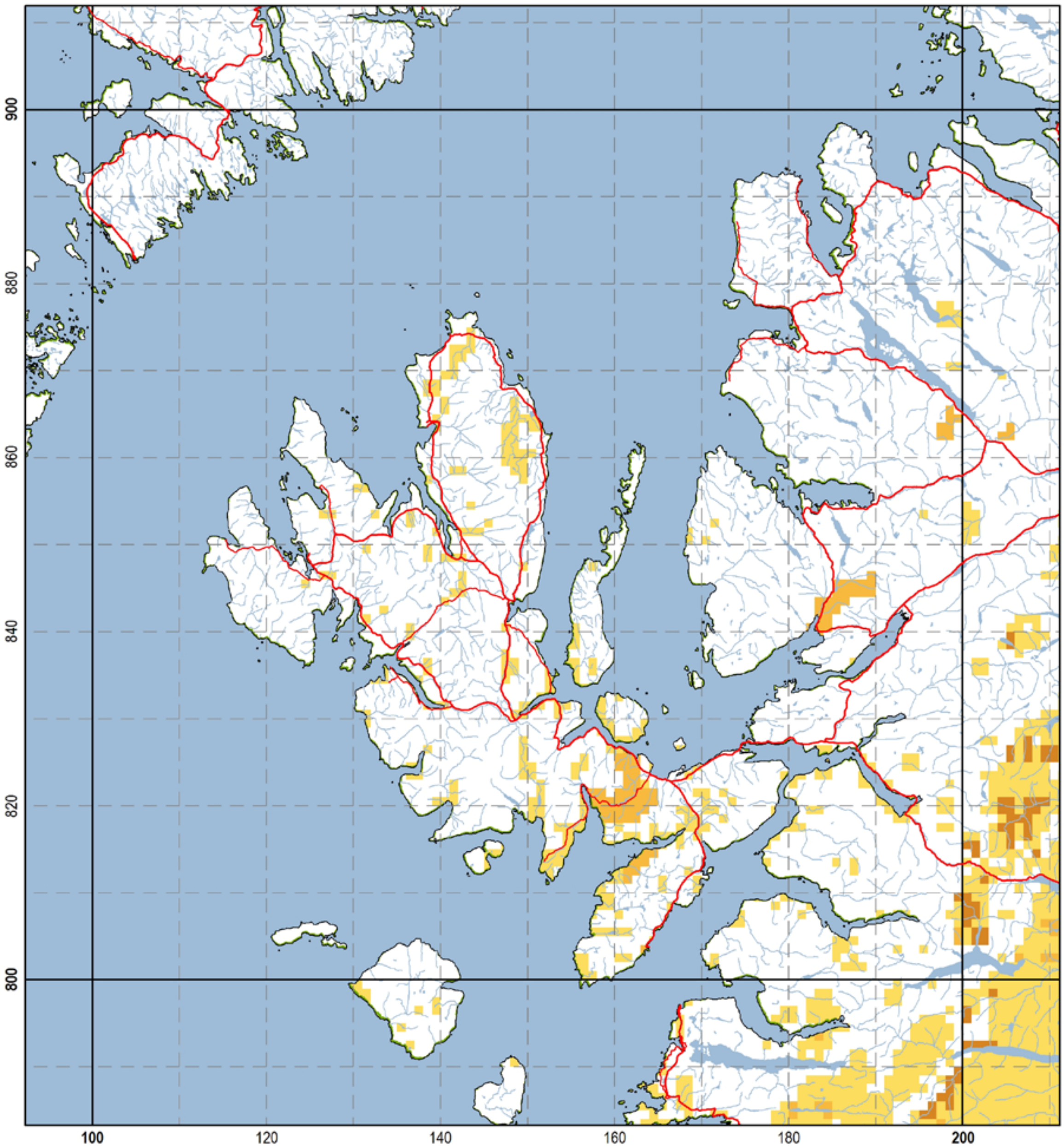
Map 8 Tayside, Angus and southern Aberdeenshire, 100-km grid square NO (axis numbers are the coordinates of the National Grid)



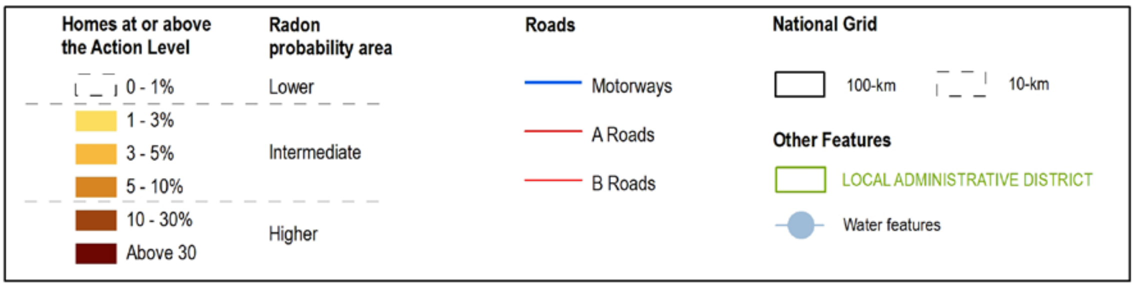
The colours show the maximum percentage band within each 1-km grid square of the national grid (see page 4). The best estimate for an individual property in a coloured square can be obtained for a small charge from www.ukradon.org. The white squares, the 0-1% band, contain no Affected Areas as defined by the HPA.



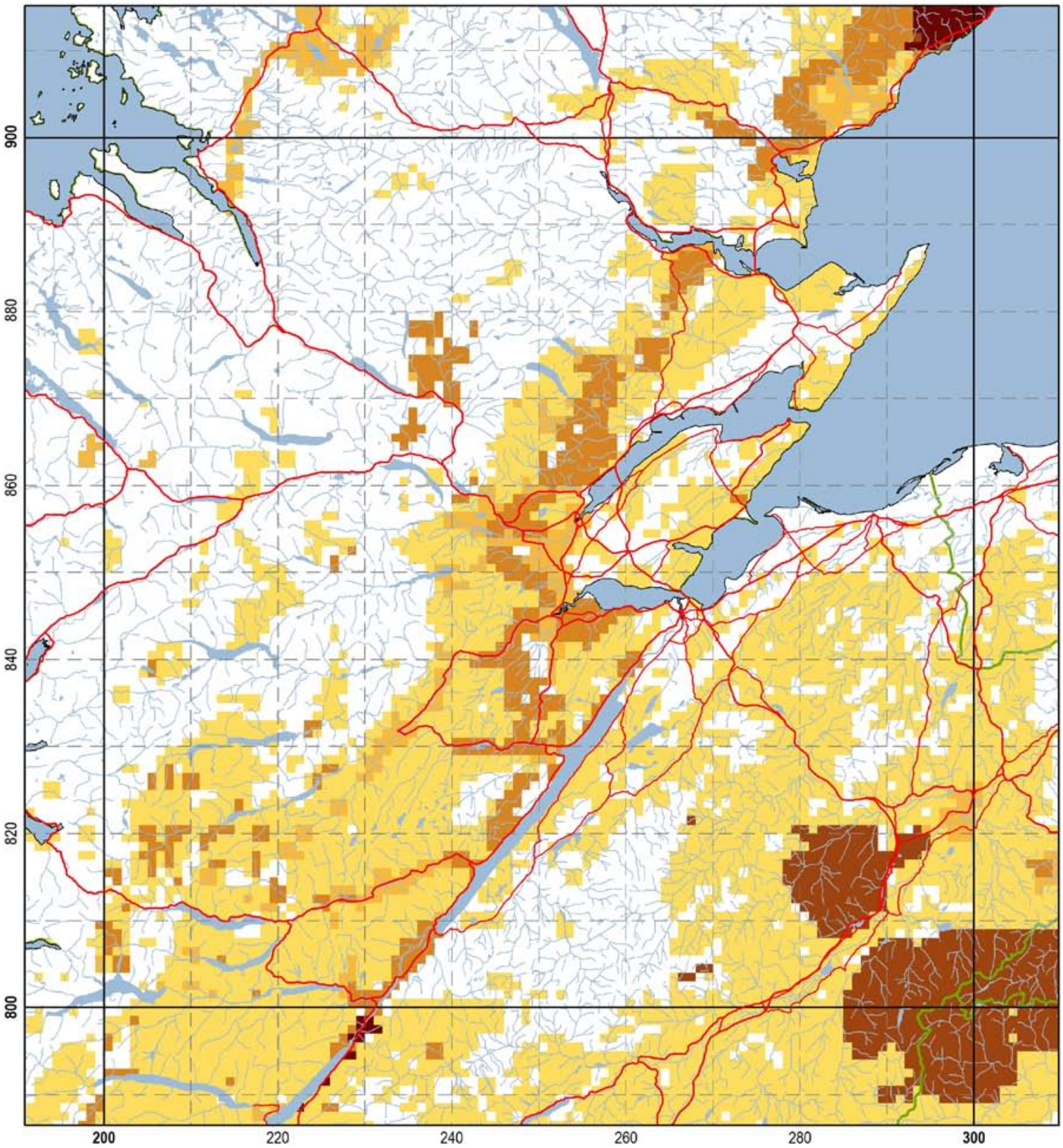
Map 9 Southern Hebrides and western Skye, 100-km grid squares NF and NG (axis numbers are the coordinates of the National Grid)



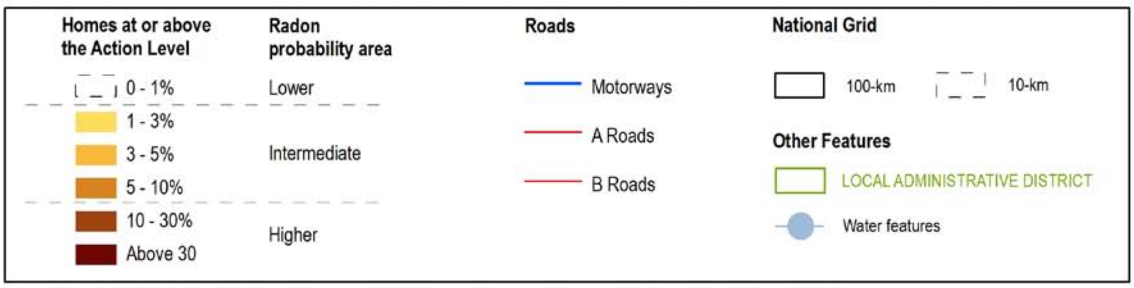
The colours show the maximum percentage band within each 1-km grid square of the national grid (see page 4). The best estimate for an individual property in a coloured square can be obtained for a small charge from www.ukradon.org. The white squares, the 0-1% band, contain no Affected Areas as defined by the HPA.



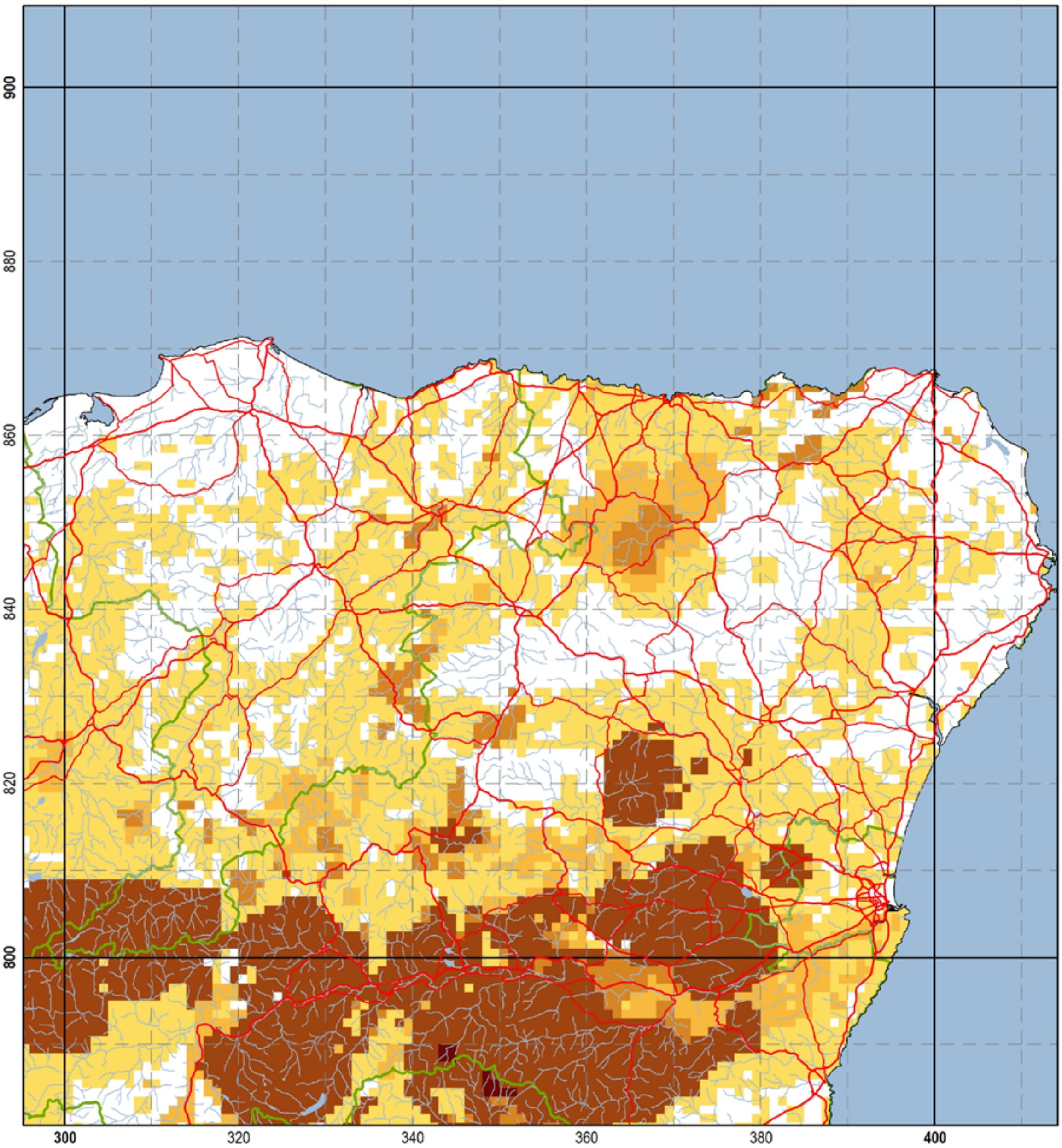
Map 10 Skye and the western Highlands, 100-km grid square NG (axis numbers are the coordinates of the National Grid)



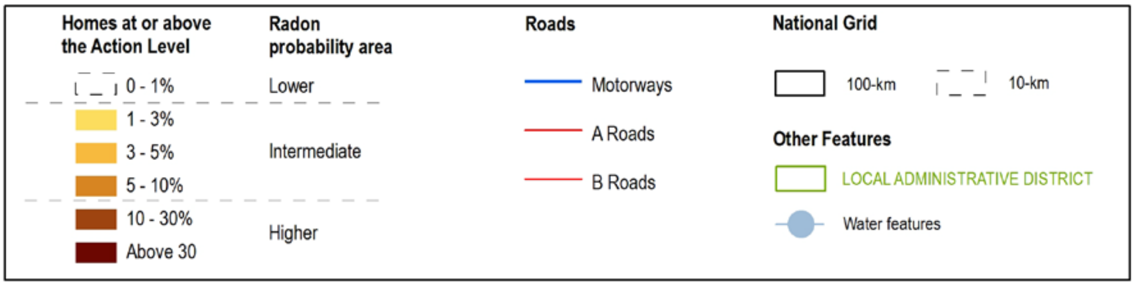
The colours show the maximum percentage band within each 1-km grid square of the national grid (see page 4). The best estimate for an individual property in a coloured square can be obtained for a small charge from www.ukradon.org. The white squares, the 0-1% band, contain no Affected Areas as defined by the HPA.



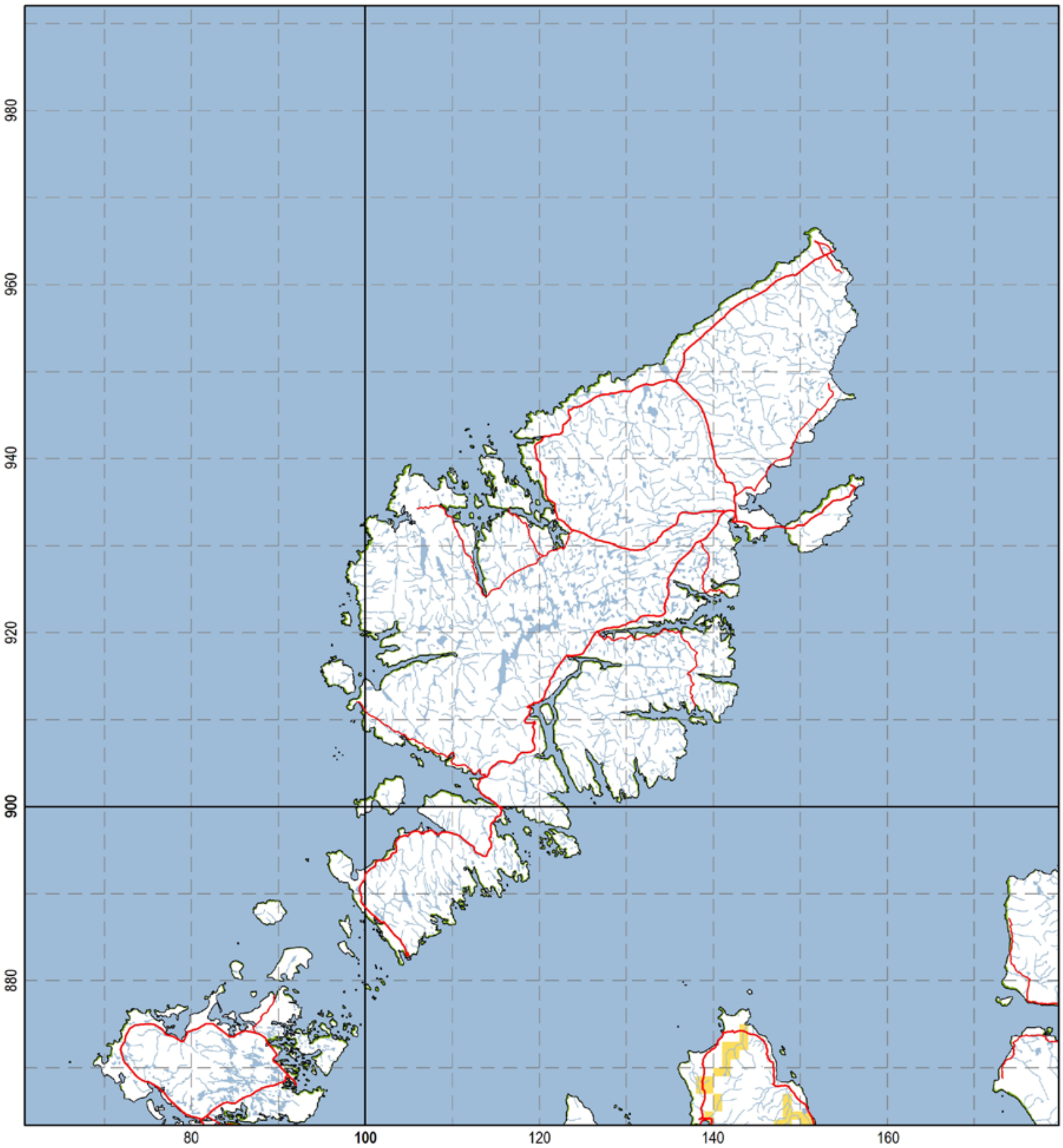
Map 11 Central Highlands, 100-km grid square NH (axis numbers are the coordinates of the National Grid)



The colours show the maximum percentage band within each 1-km grid square of the national grid (see page 4). The best estimate for an individual property in a coloured square can be obtained for a small charge from www.ukradon.org. The white squares, the 0-1% band, contain no Affected Areas as defined by the HPA.



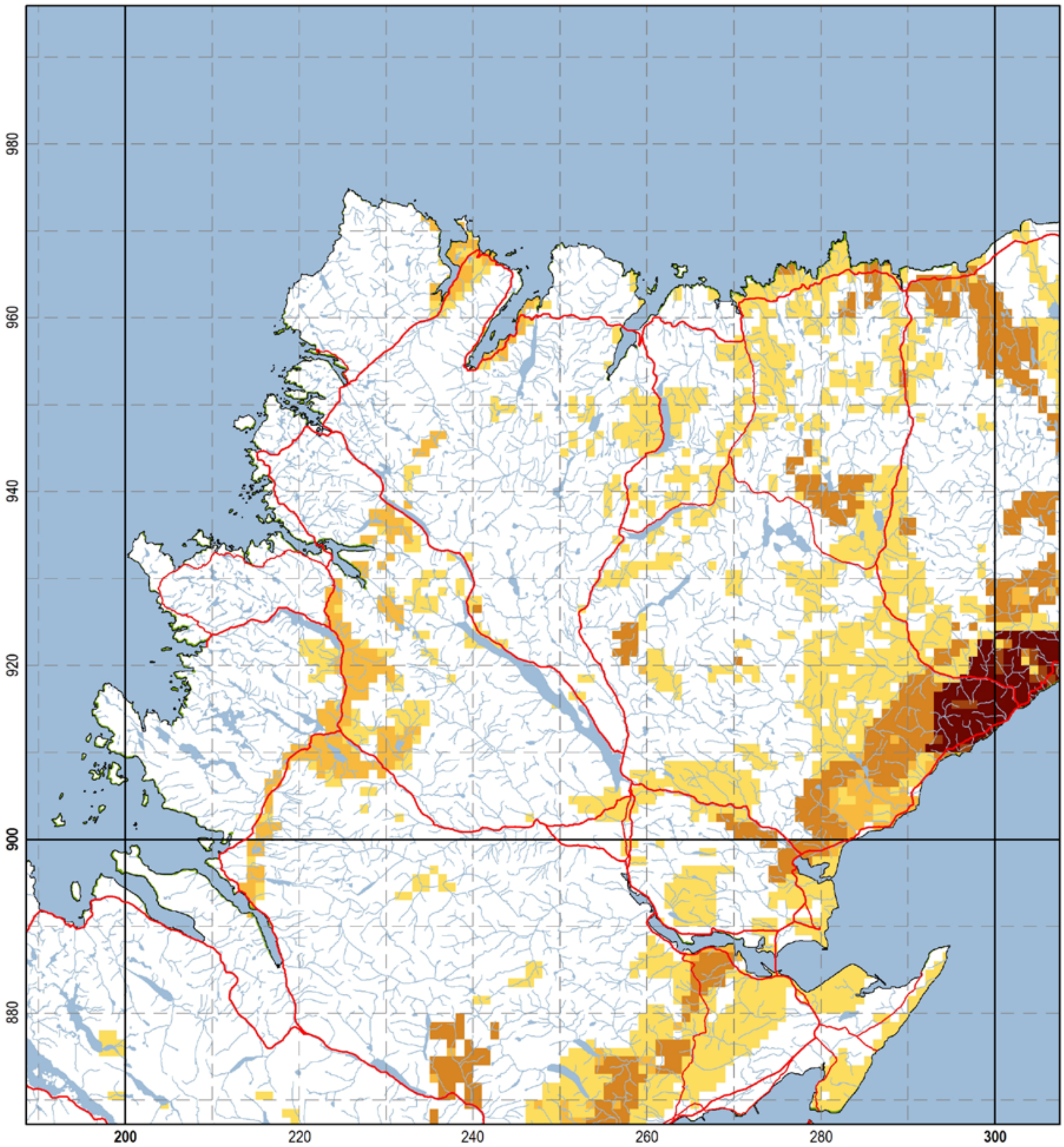
Map 12 Moray and northern Aberdeenshire, 100-km grid square NJ (axis numbers are the coordinates of the National Grid)



The colours show the maximum percentage band within each 1-km grid square of the national grid (see page 4). The best estimate for an individual property in a coloured square can be obtained for a small charge from www.ukradon.org. The white squares, the 0-1% band, contain no Affected Areas as defined by the HPA.

Homes at or above the Action Level	Radon probability area	Roads	National Grid
0 - 1%	Lower	Motorways	100-km
1 - 3%		A Roads	10-km
3 - 5%	Intermediate	B Roads	**Other Features**
5 - 10%			LOCAL ADMINISTRATIVE DISTRICT
10 - 30%	Higher		Water features
Above 30			

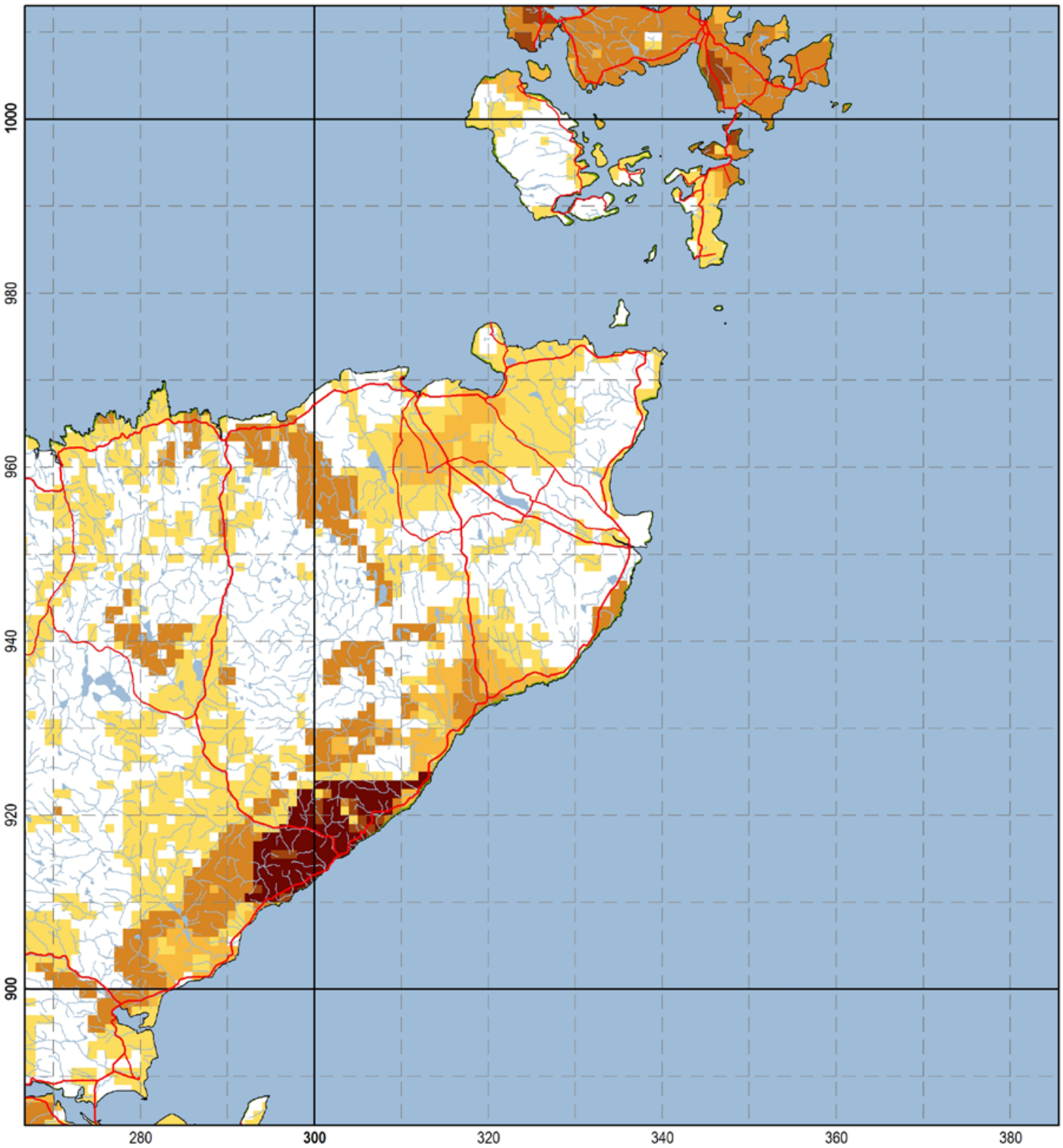
Map 13 Northern Hebrides, 100-km grid squares NB, NF and NG (axis numbers are the coordinates of the National Grid)



The colours show the maximum percentage band within each 1-km grid square of the national grid (see page 4). The best estimate for an individual property in a coloured square can be obtained for a small charge from www.ukradon.org. The white squares, the 0-1% band, contain no Affected Areas as defined by the HPA.

Homes at or above the Action Level	Radon probability area	Roads	National Grid
0 - 1%	Lower	Motorways	100-km / 10-km
1 - 3%		A Roads	**Other Features**
3 - 5%	Intermediate	B Roads	LOCAL ADMINISTRATIVE DISTRICT
5 - 10%			Water features
10 - 30%	Higher		
Above 30			

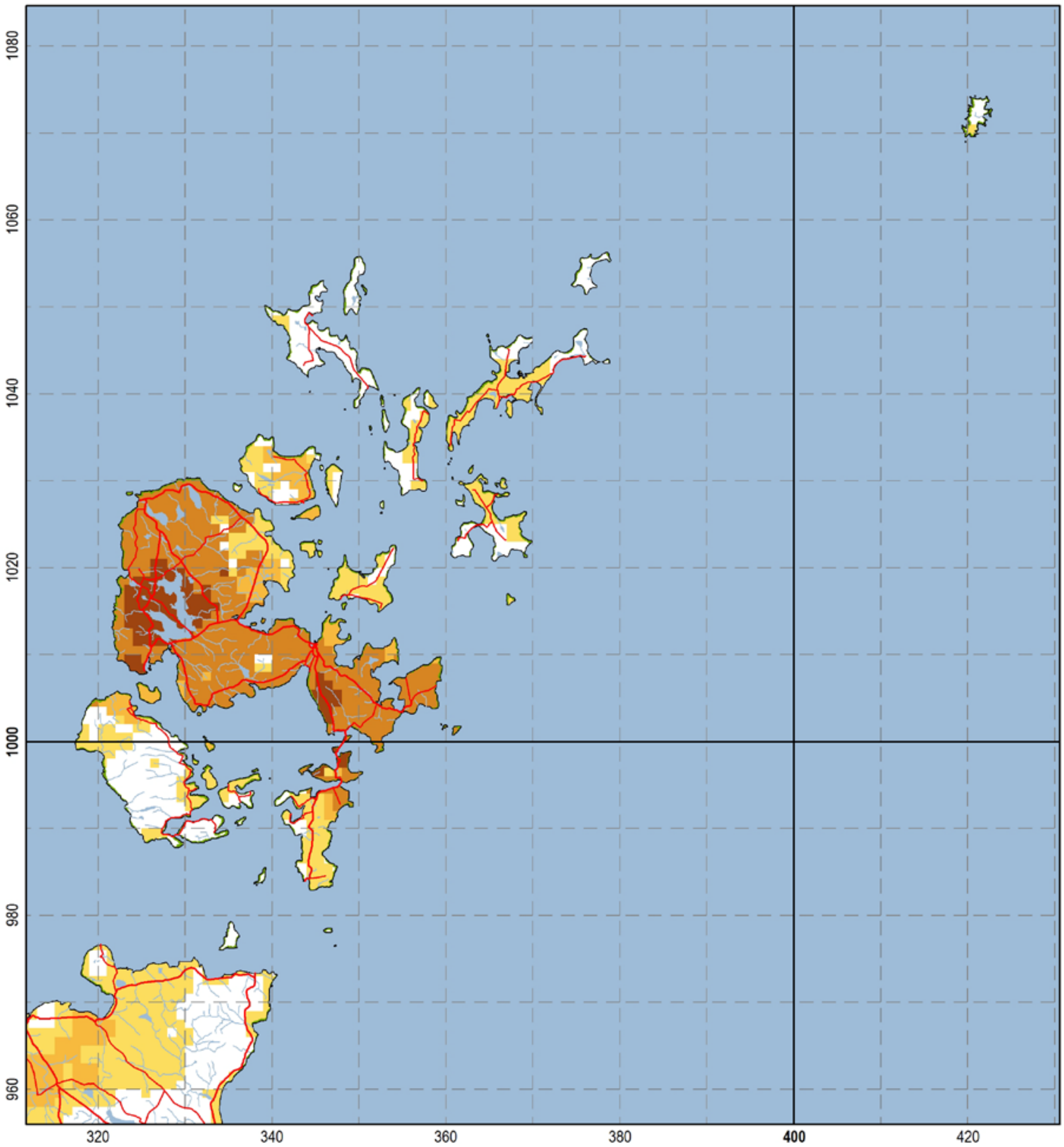
Map 14 North-western Scotland (Sutherland), 100-km grid squares NC and NH (axis numbers are the coordinates of the National Grid)



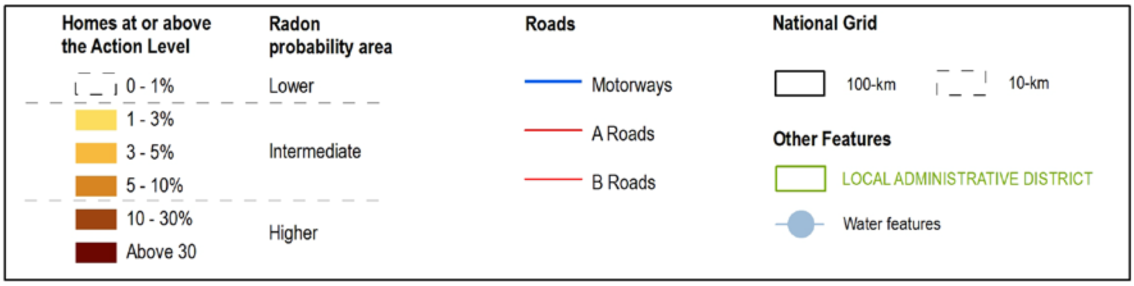
The colours show the maximum percentage band within each 1-km grid square of the national grid (see page 4). The best estimate for an individual property in a coloured square can be obtained for a small charge from www.ukradon.org. The white squares, the 0-1% band, contain no Affected Areas as defined by the HPA.

Homes at or above the Action Level	Radon probability area	Roads		National Grid	
0 - 1%	Lower		Motorways		100-km / 10-km
1 - 3%	Intermediate		A Roads	Other Features	
3 - 5%			B Roads		LOCAL ADMINISTRATIVE DISTRICT
5 - 10%					Water features
10 - 30%	Higher				
Above 30					

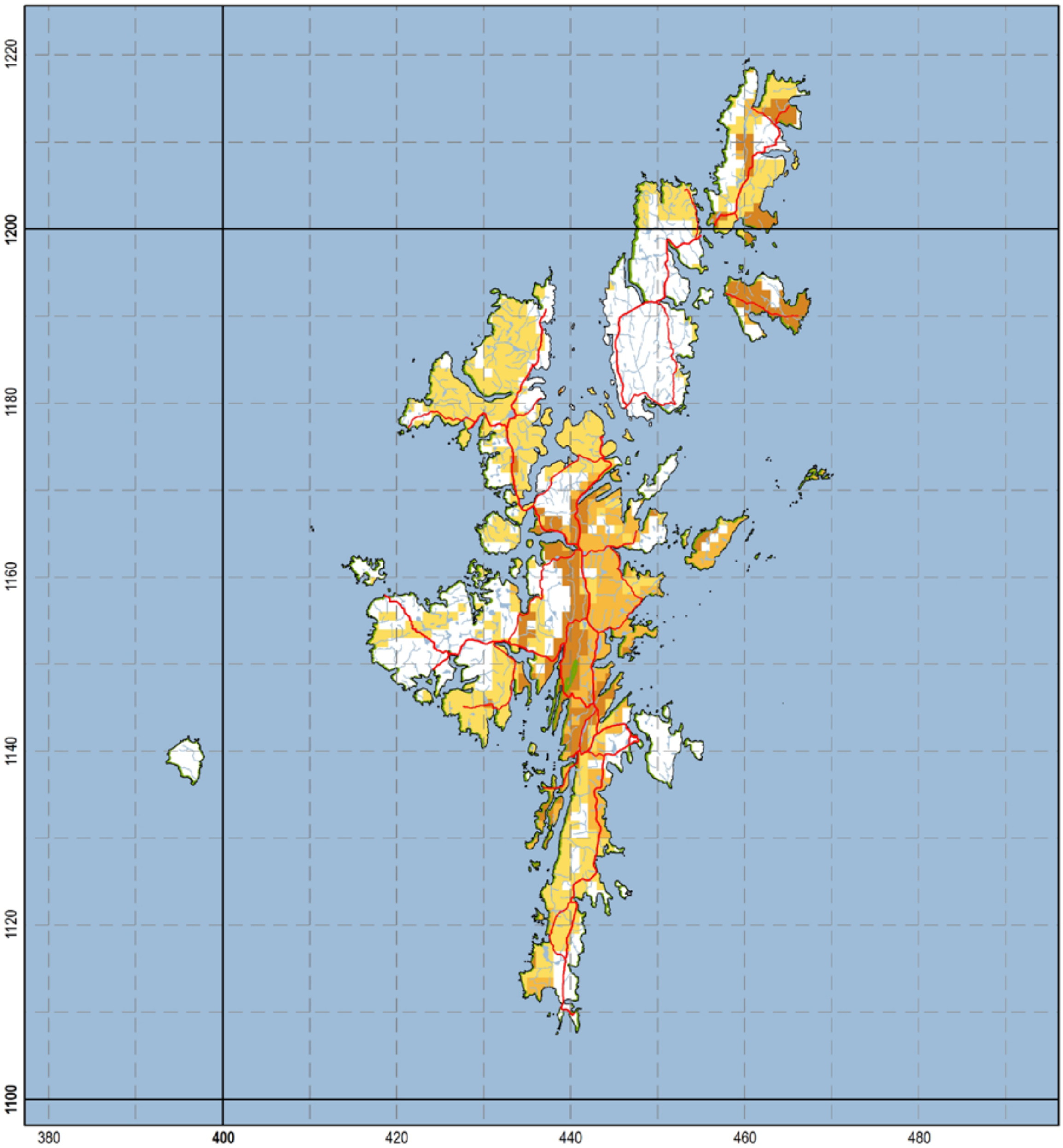
Map 15 North-eastern Scotland (Caithness), 100-km grid squares NC and ND (axis numbers are the coordinates of the National Grid)



The colours show the maximum percentage band within each 1-km grid square of the national grid (see page 4). The best estimate for an individual property in a coloured square can be obtained for a small charge from www.ukradon.org. The white squares, the 0-1% band, contain no Affected Areas as defined by the HPA.



Map 16 Orkney Islands and Fair Isle, 100-km grid squares HY, HZ and ND (axis numbers are the coordinates of the National Grid)



The colours show the maximum percentage band within each 1-km grid square of the national grid (see page 4). The best estimate for an individual property in a coloured square can be obtained for a small charge from www.ukradon.org. The white squares, the 0-1% band, contain no Affected Areas as defined by the HPA.

Homes at or above the Action Level	Radon probability area	Roads	National Grid
0 - 1%	Lower	Motorways	100-km
1 - 3%	Intermediate	A Roads	10-km
3 - 5%		B Roads	**Other Features**
5 - 10%			LOCAL ADMINISTRATIVE DISTRICT
10 - 30%	Higher		Water features
Above 30			

Map 17 Shetland Islands, 100-km grid squares HP, HT and HU (axis numbers are the coordinates of the National Grid)