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User Guide: Aquifer Productivity (Scotland) GIS datasets, Version 2. Revised Report.

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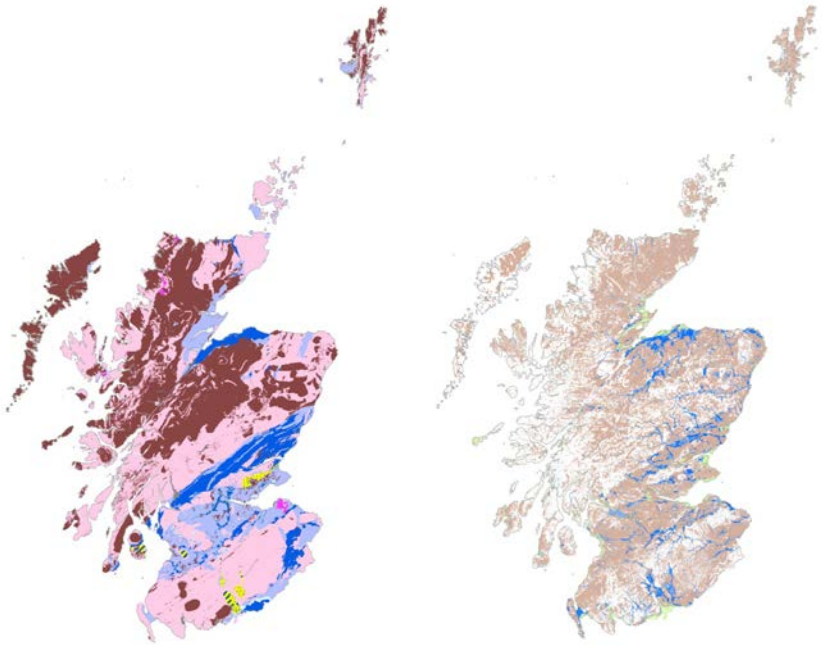

BRITISH GEOLOGICAL SURVEY

OPEN REPORT OR/15/003

User Guide: Aquifer Productivity (Scotland) GIS datasets, Version 2. Revised Report.

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Summary

This report describes a revised version (Version 2) of the aquifer productivity (Scotland) datasets produced by the British Geological Survey (BGS). There are two maps: bedrock aquifer productivity and superficial deposits aquifer productivity. Version 1 of these datasets was produced in 2004. Version 2 uses updated geological linework and a slightly modified methodology.

The aquifer productivity maps describe the potential of aquifers across Scotland to sustain various levels of borehole water supply, and the dominant groundwater flow types in each aquifer. The bedrock aquifer productivity map has five aquifer productivity classes (very high, high, moderate, low and very low); and three groundwater flow categories (significant intergranular flow; mixed fracture/intergranular flow; and fracture flow). The superficial deposits productivity map has four productivity classes (high; moderate to high; moderate; and a category to signify that a deposit is ‘not a significant aquifer’). All superficial deposits aquifers in Scotland are assumed to have primarily intergranular groundwater flow.

The aquifer productivity maps are a tool to indicate the location and productivity of aquifers across Scotland. They have been used to help characterise groundwater bodies as required by the Water Framework Directive, and may have several other uses, including in policy analysis and development; to prioritise aquifer and site investigations; to inform planning decisions; and to improve awareness of groundwater in general. The complexity and heterogeneity of geological formations means that the maps are only a guide. They are designed to be used at a scale of 1:100,000, and not to assess aquifer conditions at a single point.

1 Introduction

Founded in 1835, the British Geological Survey (BGS) is the world's oldest national geological survey and the United Kingdom's premier centre for earth science information and expertise. The BGS provides expert services and impartial advice in all areas of geoscience. Our client base is drawn from the public and private sectors both in the UK and internationally.

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Further information on all the digital data provided by the BGS can be found on our website or by contacting one of our offices or **enquiries@bgs.ac.uk**.

2 About the Aquifer Productivity (Scotland) Datasets, Version 2

2.1 BACKGROUND

The aquifer productivity (Scotland) datasets, Version 1, were produced in 2004 by the British Geological Survey (BGS). The datasets comprised GIS-based aquifer productivity maps and an associated report with explanatory notes (MacDonald et al. 2004). This revised version (Version 2) has used updated geological linework and a slightly modified methodology to develop new GIS-based maps.

Related BGS datasets that the user may also be interested in are a GIS-based map of groundwater vulnerability for Scotland (Version 2) (Ó Dochartaigh et al. 2015); permeability index datasets (British Geological Survey 2010); superficial deposits thickness datasets (Lawley and Garcia-Bajo 2009); and DiGMapGB-50 (the Digital Geological Map of Great Britain at 1:50 000). A related external dataset is the Hydrology of Soil Types (HOST), available through the James Hutton Institute (Boorman et al 1995; http://www.macaulay.ac.uk/host/). Related aquifer productivity studies and publications by BGS are Graham et al. (2009), MacDonald et al. (2005) and Ó Dochartaigh (2004).

2.2 WHAT THE DATASETS SHOW

The aquifer productivity maps describe the potential of aquifers across Scotland to sustain various levels of borehole water supply, and the dominant groundwater flow types in each aquifer. The productivity classifications are based on a judgement of the typical long term sustainable abstraction rate from a properly sited, constructed and developed borehole (or, for superficial deposits, a group of boreholes). However, the complexity and heterogeneity of geological formations means that these classes are only a guide. In addition, random drilling within an aquifer without reference to suitable hydrogeological information may not produce the yields indicated by these classes.

The bedrock aquifer productivity map has five aquifer productivity classes (very high, high, moderate, low and very low); and three groundwater flow categories (significant intergranular flow; mixed fracture/intergranular flow; and fracture flow) (Table 1, Figure 1). The superficial deposits productivity map has four productivity classes (high; moderate to high; moderate; and a category to signify that a deposit is ‘not a significant aquifer’) (Table 2, Figure 2). All superficial deposits aquifers in Scotland are assumed to have primarily intergranular groundwater flow (although fracture flow may be important in some glacial tills that are classed as ‘not significant aquifers’).

2.3 HOW CAN THE DATASETS BE USED?

The aquifer productivity maps are a tool to indicate the location and productivity of aquifers across Scotland. They have been used to help characterise groundwater bodies as required by the Water Framework Directive. They are designed to be used at a scale of 1:100,000, and not to assess aquifer conditions at a single point. As such, they provide only a guide to aquifer conditions, and are not a substitute for detailed site investigation.

The dataset may have several uses, including:

- In policy analysis and development
- To prioritise aquifer and site investigations
- To inform planning decisions
- To improve awareness of groundwater in general.

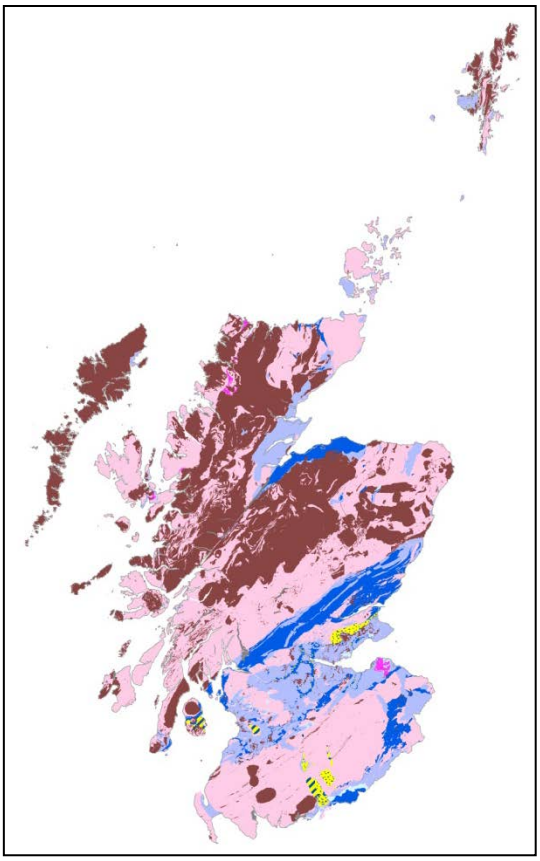

Figure 1 The bedrock aquifer productivity (Scotland) map

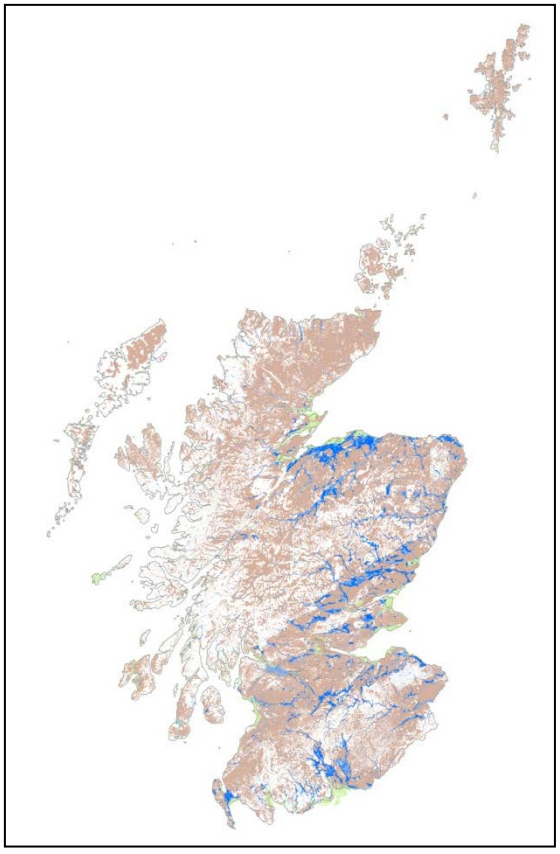

Figure 2 The superficial deposits aquifer productivity (Scotland) map

Table 1 Bedrock aquifer productivity classification

Aquifer Productivity Classification	Associated borehole yields (litres / second)[1]	Examples
SIVH Significantly Intergranular Flow; Very High Productivity	> 20 l/s	Some Permo-Triassic sandstones (east Dumfries Basin) and some Upper Devonian sandstones (Fife)
IFVH Intergranular/Fracture Flow; Very High Productivity	> 20 l/s	Some Permo-Triassic breccias and sandstones (west Dumfries Basin, Moffat, Arran, Mauchline)
SIH Significantly Intergranular Flow; High Productivity	10 to 20 l/s	Carboniferous Passage Formation
IFH Intergranular/Fracture Flow; High Productivity	10 to 20 l/s	Some Upper Devonian sandstones (southern Scotland), Lower Devonian sandstones (Strathmore), general Devonian sandstones (Moray); some Permo-Triassic sandstones (Moray, Solway area)
IFM Intergranular/Fracture Flow; Moderate Productivity	1 to 10 l/s	All Carboniferous sedimentary formations except the Passage Formation and those dominated by mudstones; most Devonian conglomerates, siltstones and limestones (Moray, Turriff, Easter Ross, Strathmore); Lower Devonian sandstones in southern Scotland; Devonian sandstones north of the Great Glen (including some termed flagstones); Mesozoic sandstones and limestones on Skye and Raasay; Permian sandstones in Stranraer
FM Fracture Flow; Moderate Productivity	1 to 10 l/s	Cambrian limestones and dolomites; some Carboniferous lavas (East Lothian)
IFL Intergranular/Fracture Flow; Low Productivity	0.1 to 1 l/s	Volcaniclastic sediments; Carboniferous mudstones
FL Fracture Flow; Low Productivity	0.1 to 1 l/s	Moine pelites; Dalradian (except psammites); Torridonian sandstones; Cambrian rocks except limestone & dolomite; Ordovician/Silurian greywackes, siltstones and related rocks; some Devonian flagstones (Caithness and Orkney); lavas (except Carboniferous lavas in East Lothian); Mesozoic mudstones and shales
FVL Fracture Flow; Very Low Productivity	< 0.1 l/s	Lewisian gneiss; Moine (except pelites); intrusive igneous rocks
U Unknown Geology	-	Areas where geology is unmapped, for example beneath lochs.

Note [1] Productivity is directly linked to the potential of the aquifer to sustain these abstraction rates from properly sited, constructed and developed borehole

Table 2 Superficial deposits aquifer productivity classification

Aquifer Productivity Code	Associated range in borehole yields (litres/second)[1]	Examples
IH Intergranular Flow; High Productivity	> 10 l/s	Glaciofluvial sand and gravel; mixed glaciofluvial deposits; glacial ice-contact deposits.
IMH Intergranular Flow; Moderate to High Productivity	1 to >10 l/s[2]	Alluvium and river terrace deposits, unless specified as clay and silt.
ILM Intergranular Flow; Low to Moderate Productivity	0.1 to 10 l/s[3]	Marine, raised marine, blown sand, lacustrine beach despots, tidal and intertidal deposits, unless specified as clay and silt[4]; talus; landslip; blockfield[5].
NSA Not a significant aquifer	-	Till; moraine; hummocky/moundy glacial deposits[6]; head[7]; lacustrine deposits where dominated by clay and silt; all other deposits dominated by clay and silt.
U Unknown Geology	-	Areas where geology is unmapped, for example beneath lochs or in urban areas.

Notes

[1] Productivity is directly linked to the potential of the aquifer to sustain these abstraction rates from properly sited, constructed and developed single, or groups of, boreholes

[2] This classification includes aquifer deposits which can range from Moderate Productivity, with typical borehole yields between 1 and 10 l/s, to High Productivity, with yields greater than 10 l/s.

[3] This classification includes aquifer deposits which can range from Low Productivity, with typical borehole yields between 0.1 and 1 l/s, to Moderate Productivity, with yields between 1 and 10 l/s.

[4] Any mixed deposit of marine or tidal origin, if not specified as clay and silt, may have the potential to form a moderately productive aquifer capable of supplying sustainable borehole yields of at least 1 l/s, if it contains sufficient sand and/or gravel, is thick enough and is of large enough lateral extent. The user of the map should judge the spatial extent of the outcrop as well as (in conjunction with topographic mapping) the proximity to and height above sea level (related to the risk of saline intrusion), and should carry out site investigations to discover the thickness and exact lithology of the deposit.

[5] Talus and blockfield deposits are typically highly permeable and, if thick enough, can store and transmit enough groundwater to supply spring flows of between 1 and 10 l/s. Because of their geometric configuration – typically steeply dipping – drilling into them by conventional means is unlikely to be successful, but inclined drilling or abstraction from shallow dug wells, as well as springs, may provide supplies.

[6] Recent evidence suggests that moraine and hummocky/moundy glacial deposits are often highly permeable. However, across much of Scotland, except where the superficial deposits have been re-mapped using modern methods, moraine, hummocky/moundy glacial deposits and till are all mapped interchangeably as till, and their lithology typically described as diamicton (classed as moderate permeability in the BGS Permeability Dataset for Great Britain (British Geological Survey 2010). On a national scale, it is therefore not generally possible to distinguish between till and moraine on the basis of the available lithological descriptions. For the purposes of consistency, this map classes all till, moraine and hummocky/moundy glacial deposits as Not a Significant Aquifer. Note, however, that in some areas these deposits may be highly permeable, and if they are thick and laterally extensive enough, they may form local aquifers.

[7] The lithology of head depends on the parent material from which it has been reworked. In general it is thought to have a permeability between that of till and sand/gravel deposits. In the BGS Permeability Dataset its permeability varies from moderate to very high according to the described lithology. However, head is typically only 1 to 2 m thick, and so is unlikely to form a significant aquifer.

2.4 WHO MIGHT BENEFIT FROM USING THE DATASETS?

The aquifer productivity maps were originally developed for use by the Scottish Environment Protection Agency (SEPA) in the process of groundwater body characterisation as part of the Water Framework Directive.

Other potential users of the dataset may be regional planners and managers in Local Authorities and national government. Any individuals or bodies involved in the activities listed in Section 2.3 are likely to find the aquifer productivity datasets useful.

3 Technical Information

3.1 DEFINITIONS

Aquifer productivity describes the potential of an aquifer (a bedrock or superficial deposit unit that contains significant amounts of groundwater) to sustain various levels of groundwater flow and/or abstraction from a properly sited and constructed borehole. For the purposes of these maps, aquifer productivity is directly linked to the potential of the aquifer to sustain various abstraction rates from properly sited, constructed and developed single boreholes or groups of boreholes.

3.2 SCALE

The aquifer productivity (Scotland) Version 2 datasets are produced for use at 1:100 000 scale. The datasets are not designed to be used to assess aquifer productivity at a single point. All spatial searches of the maps/datasets should be conducted using a minimum 100 m buffer.

3.3 METHODOLOGY USED TO CREATE THE DATASETS

The datasets were developed in ArcGIS using BGS digital geology linework (DiGMapGB-50, Version 5.18) at a scale of 1:50,000. A detailed explanation of the Version 1 aquifer productivity datasets is given in MacDonald et al. (2004). The Version 2 datasets described in this report were produced using updated geological linework and new information on aquifer properties made available since the Version 1 datasets were completed, and a slightly amended methodology. In particular, a study to validate the aquifer productivity classes defined in Version 1 has since been done using aquifer properties information including test pumping data, and this has informed the development of Version 2 of the dataset (Graham et al. 2009).

3.3.1 Bedrock aquifer productivity dataset

To create the bedrock aquifer productivity map, each of the geological formations in the 1:50,000 scale DiGMap bedrock geology map was classified according to two criteria:

(1) the predominant groundwater flow mechanism; and

(2) the estimated aquifer productivity of the formation.

Groundwater flows through bedrock either through small interconnected pore spaces as *intergranular flow*, or through fractures as *fracture flow*. Most bedrock aquifers in Scotland (except for some small unconsolidated Tertiary formations in Aberdeenshire) are dominated by fracture flow. Even in the most porous bedrock aquifers, such as Upper Devonian or Permian sandstones, downhole geophysical logging has shown that typically only around 20% of groundwater flow occurs as intergranular flow, the remainder flowing through fractures. However, even this minor component is significant in terms of the hydrogeological

characteristics of the aquifer. Such aquifers – classified approximately as those with an average porosity of more than 20% – have been distinguished by the term *significantly intergranular flow*. Rocks with lower average porosity but which still allow some intergranular flow have been categorised as having mixed *intergranular/fracture flow*. Rocks with virtually no intergranular porosity are categorised as *fracture flow*.

The flow characteristics and the productivity class for each bedrock formation have been classified based on information from various sources, including laboratory hydraulic testing data, downhole geophysical logs, and pumping test data, where available. However, for much of Scotland few if any of these data are available, and in these cases they are based wholly or partly on extrapolation from other similar geological units with known aquifer properties, and in the case of the productivity classifications, partly on the permeability classification of the geological unit as given in the Permeability Dataset for Great Britain (Bedrock) (Table 3). Some of the aquifer productivity classifications in the Version 1 dataset have been updated based on new aquifer properties data which have become available since the Version 1 dataset was produced. The newly assigned aquifer productivity classifications are listed in Table 1.

The bedrock geology map includes a large number of small polygons representing geological outcrops of small areal extent, and long, thin polygons representing igneous dykes and sills. At 1:100 000 scale, which is the scale at which the aquifer productivity map is designed to be used, these polygons provide so much detail that the map becomes less clear and easy to use. All polygons smaller than a specified area (25 000 m^2) and very long, thin polygons (any polygon more than 1000 m long and less than 100 m wide) have therefore been removed from the final map.

3.3.2 Superficial deposits aquifer productivity dataset

To create the superficial deposits aquifer productivity map, each of the geological formations in the 1:50 000 scale DiGMap superficial deposits geology map was classified according to the likely productivity of the aquifer. For a small number of map sheets, 1:50 000 scale superficial deposits mapping has not yet been done, and in these cases, superficial deposits linework and attribute data at other scales, including 1:625 000 scale, were merged in. The assigned superficial deposits aquifer productivity classifications are listed in Table 2.

In Scottish superficial deposits aquifers, only intergranular flow is significant, and all of the superficial deposits aquifers are classified as having intergranular flow.

The productivity class for each superficial deposits formation has been classified based on information from various sources, including geophysical downhole logs, and pumping test data, where available. Where few or no such data were available, which is the case for most superficial deposits, the productivity classifications are based partly on the permeability classification of the geological unit as given in the Permeability Dataset for Great Britain (Superficial) (Table 3), and partly on extrapolation from other similar geological units with known aquifer properties.

Classifying superficial deposits aquifers on a national scale, in terms of their productivity as well as other characteristics, is subject to more uncertainty than classifying bedrock aquifers, for two main reasons:

- The inherent heterogeneity of superficial deposits means their properties as aquifers (e.g. permeability (reflecting the relative proportions of clay, silt, sand and gravel within many mixed deposits), thickness and lateral extent) can change significantly over short distances even within the same mapped lithological unit. For this reason, there is often a large range between the minimum and maximum assigned permeability for many deposits in the Permeability Dataset, for example from Low to High.
- Superficial deposits were historically often mapped in less detail and/or with less precision than bedrock. For example, on many older map sheets all glacially-related

deposits were classed as till, but when the area was re-mapped using modern techniques, the same deposits were redefined to include moraine. Till typically has low to moderate permeability, whereas moraine can be dominated by gravel and sand and can be highly permeable. Hence, because across much of the country superficial deposits have not been re-mapped using modern methods, it is not generally possible to distinguish between till and moraine on the basis of the available lithological descriptions. To try and ensure the aquifer productivity map is consistent across the whole country, it was therefore decided that all till, moraine and hummocky/moundy glacial deposits would be classed as Not a Significant Aquifer, as in most cases this is likely to be true, and the deposits are unlikely to contain useful groundwater resources. It is, however, recognised that in some areas these deposits may be highly permeable, and if they are thick and laterally extensive enough, they may form local aquifers.

The assigned productivity classes for the superficial deposits aquifers (Table 2) are therefore less precise, reflected in the wider range in likely yield from any particular geological unit. The actual productivity in any given area of interest will depend on the superficial deposit lithology, compaction or other post-depositional factors, area of outcrop, and thickness. In the case of marine deposits, it may also depend on the elevation of the deposit above sea level, in relation to the risk of saline intrusion.

In most cases, any superficial deposit with a maximum permeability of less than moderate has been classed as Not a Significant Aquifer, while any superficial deposit with a maximum permeability of high or very high has been classed as an aquifer of either moderate or high productivity. However, in certain cases there are exceptions to this, where significant characteristics of the deposit other than permeability (for example, thickness and lateral extent) are likely to affect its aquifer productivity. These are highlighted in the notes for Table 2.

Table 3 Input datasets used to derive the aquifer productivity classifications

Dataset	Description
DiGMapGB-50 (Digital Geological Map of Great Britain at 1:50 000) (Superficial) Version 5.18	Most superficial deposits of natural origin, except mass movement deposits. Most are unconsolidated sediments, and onshore they form relatively thin, discontinuous patches or larger spreads. Almost all were formerly classified on the basis of their mode of origin with names such as, 'Glacial Deposits', 'River Terrace Deposits' or 'Blown Sand'; or on their composition such as 'Peat'. Recently some of them have been given formal. lithostratigraphical names such as 'Lowestoft Formation'. More information on named superficial deposits is available in the BGS Lexicon of Named Rock Units at http://www.bgs.ac.uk/lexicon/home.cfm
DiGMapGB-50 (Digital Geological Map of Great Britain at 1:50 000) (Bedrock) Version 5.18	The main mass of rocks forming Britain, present everywhere, whether exposed at the surface in outcrops or concealed beneath superficial deposits or water. Wherever possible, they are referred to by their current name: for stratified units this will usually be lithostratigraphical; for igneous intrusions it may be a lithodemic one. More information on named bedrock units is available in the BGS Lexicon of Named Rock Units at http://www.bgs.ac.uk/lexicon/home.cfm.
Permeability Dataset for Great Britain (Superficial) Version 6.0 (British Geological Survey 2010)	The permeability data relate to the vertical flow of fresh water through the unsaturated geological deposits. Maximum and minimum permeability indices are given for each geological unit to indicate the range in permeability likely to be encountered, and the predominant flow mechanism (fracture or intergranular). Neither of the assigned values takes into account the thickness of either the unsaturated or saturated part of the lithostratigraphical unit.
Permeability Dataset for Great Britain (Bedrock) Version 6.0 (British Geological Survey 2010)	

3.4 DATASET HISTORY

The GIS-based aquifer productivity maps, Version 1, were produced in 2004 by the British Geological Survey (BGS) in 2004. A detailed explanation of the Version 1 aquifer productivity datasets is given in MacDonald et al. (2004).

3.5 COVERAGE

The dataset covers all of Scotland (Figure 3).

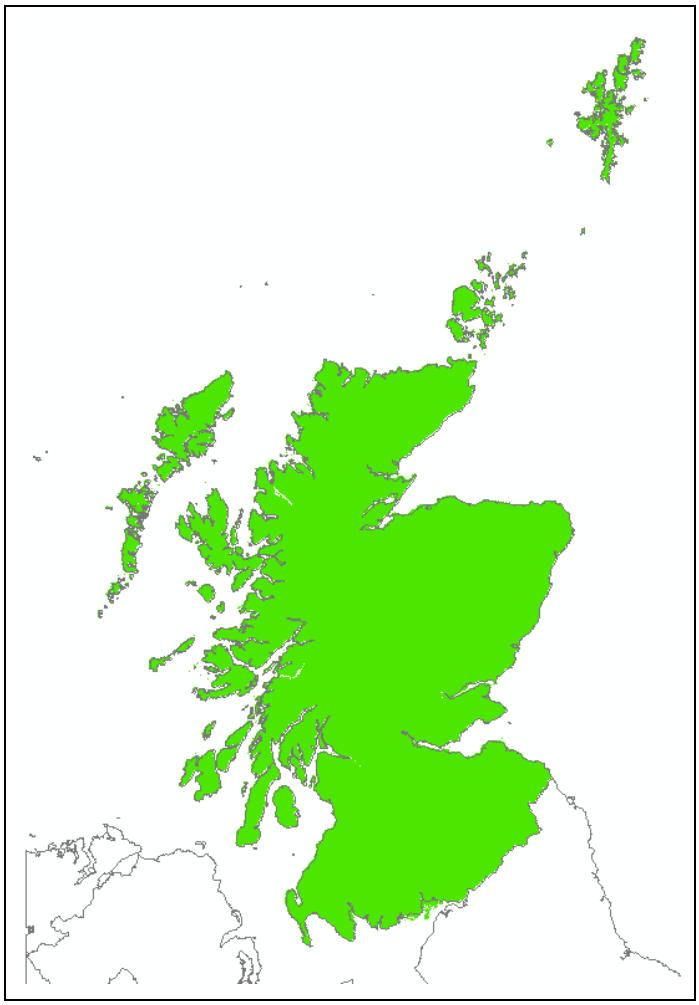

Figure 3 The coverage of the aquifer productivity (Scotland) datasets

3.6 DATA FORMAT

The aquifer productivity maps (Scotland) Version 2 datasets are available as vector datasets with attribute values relating to aquifer productivity (Table 4, Table 1, Table 2).

Table 4 Data fields and parameter values in the aquifer productivity datasets

Dataset	Field	Description	Values
Bedrock Aquifer Productivity	BRProd	Bedrock Aquifer Productivity Code	As Table 1
	Key	Bedrock Aquifer Groundwater Flow Type and Productivity Class	As Table 1
	TypYield	Typical sustainable yield from suitable (properly sited, constructed and developed) borehole	As Table 1
	Version	Version number for the dataset: Version 2	
Superficial Deposits Aquifer Productivity	SDProd	Superficial Deposits Aquifer Productivity	As Table 2
	Key	Superficial Aquifer Groundwater Flow Type and Productivity Class	As Table 2
	TypYield	Typical sustainable yield from suitable (properly sited, constructed and developed) borehole(s)	As Table 2
	Version	Version number for the dataset: Version 2	

3.7 LIMITATIONS

The aquifer productivity maps are designed to be used at a scale of 1:100,000, and not to assess aquifer conditions at a single point. All spatial searches of the maps/datasets should be conducted using a minimum 100 m buffer.

The maps provide only approximate descriptions of ground conditions. They are also only a two-dimensional representation and do not reflect any changes in geological and/or hydrogeological character with depth. Use of the maps should be pragmatic, and the maps are not a substitute for detailed site investigation.

The aquifer productivity maps are based on, and limited to, an interpretation of the data in the possession of the British Geological Survey at the time the datasets were created. Updates to BGS digital linework since the production of the aquifer productivity maps may have led to some discrepancies between the aquifer productivity maps and the current DiGMapGB-50 datasets. The aquifer productivity maps are subject to periodic revision, and any such discrepancies will be addressed in the next revision.

4 Licensing Information

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