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A GIS of aquifer productivity in Scotland: explanatory notes

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A GIS of aquifer productivity in Scotland: explanatory notes

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Summary

GIS-based maps of aquifer productivity have been produced by the BGS for both bedrock and superficial deposits in Scotland as a tool to help characterise groundwater bodies for the Water Framework Directive. The maps are designed to be used at a scale of 1:100 000. The term "aquifer productivity" has been used to describe the potential of an aquifer (bedrock or superficial deposit) to sustain various levels of borehole supply. Properly sited boreholes (or for superficial deposits, a group of boreholes) in high and very high productivity aquifers have the potential to be considered a source for public supply or for industry. Low productivity formations are considered suitable for groundwater supplies to single or small groups of houses. The maps do not give any information on groundwater quality.

The bedrock aquifer productivity map has five productivity classes, ranging from very high to very low. The rock formations and groups are also subdivided into three flow categories: dominantly intergranular flow, mixed fracture/intergranular flow and fracture flow. The classifications were made using BGS data and maps where available, and judgement from the lithological descriptions of the geology, where no hydrogeological data were available.

All superficial deposits are assumed to have primarily intergranular groundwater flow (although fracture flow may be important in some tills). The superficial aquifer map is subdivided into three classes according to productivity (high, moderate and low), with the remainder classed as non-aquifer. The classifications were made using BGS data, geological descriptions and the Hydrology of Soil Types (HOST) classifications of the Macaulay Institute.

The superficial deposits are further subdivided into two categories based on the likelihood of them being saturated and, therefore, containing a useable groundwater resource. In order to produce a guide to the likely location of superficial deposits that contain water, a model was created, based on a digital terrain model (DTM) and river elevation. The model was improved by including zones where certain soil classes indicate the presence of a shallow water table, using Hydrology of Soil Types (HOST) data. A model of superficial deposit thickness was then merged with the depth to water data to show zones where there is a high probability that the superficial deposit contains a usable groundwater resource. Outwith these zones, there is a lower probability of their being a usable groundwater resource within the superficial deposits.

The maps are only intended as a guide to the aquifer conditions and are not a substitute for detailed site investigation. The maps can be improved as more information on drilling success and borehole yields is gathered throughout Scotland.

1 Introduction

Digital aquifer productivity maps for both bedrock formations and superficial deposits have been developed for the Scottish Environment Protection Agency (SEPA) to help implement the Water Framework Directive (WFD) in Scotland. The maps are intended for use in the initial characterisation of groundwater bodies and give an indication of the likely variation in groundwater yield and flow type in relation to different geological deposits. The productivity classes shown on the new maps are a measure of the expected long-term abstraction rate of groundwater from a typical borehole (or for superficial deposits, a group of boreholes) at an individual site.

Two maps, designed to be used at a scale of 1:100 000 have been developed: bedrock aquifer productivity and superficial deposit aquifer productivity. Separate GIS-based maps are necessary because the two types have very different hydrogeological and geological characteristics.

The maps are intended only as a guide to the location and productivity of Scottish aquifers. There are insufficient data to carry out a robust aquifer properties assessment, as was done for the Devonian aquifer of Fife (Ó Dochartaigh 2003). Instead, the maps have been developed using BGS digital geology linework at scales of 1:50 000, in conjunction with the BGS GeoHazarD database. The latter captures expert opinion and data in BGS about the physical nature of different rock types. Data from the Macaulay Institute have been incorporated in the superficial deposits aquifer map.

This report is intended as a description of the aquifer categories and an explanation of the process by which they were created.

2 The bedrock aquifer productivity map

To create the bedrock aquifer productivity map, geological formations were classified according to two criteria (Table 1): (1) the predominant groundwater flow mechanism (fractured or intergranular) and (2) the estimated groundwater productivity. The map is based on the 1:50 000 digital geology map for Scotland (DigMapGB) and is designed to be used at a scale of 1:100 000. A summary map for Scotland is given in Figure 1.

2.1 GROUNDWATER FLOW

Groundwater moves through bedrock either through small interconnected pore spaces as *intergranular flow*; or where fractures are present as *fracture flow*. The flow classifications for the bedrock productivity map have been made with reference to various sources: laboratory hydraulic data; geophysical logs; and pumping test data where available. However for much of Scotland these data are not available and the classifications are based solely on lithological descriptions of the rocks and the BGS hydrogeological map of Scotland (1988).

The aquifers in Scotland were divided into three groundwater flow classes.

2.1.1 Dominantly intergranular flow

Where pore spaces between particles, such as sand grains, in a rock are connected, intergranular groundwater flow can be important. Well-sorted, weathered, fine- to medium-grained sandstone containing only a small percentage of silt or clay generally has high interconnected porosity, perhaps up to 25%. As a consequence, such rocks tend to have high intergranular permeability values and much of the regional groundwater flow is intergranular.

Certain highly permeable sandstone formations in Scotland have a significant element of intergranular flow. These are the Permian sandstones in the Dumfries area, the Upper Devonian sandstones in the Eden valley, Fife, and outcrops of Passage Formation sandstone in central Scotland. Fracture flow also occurs in all these rocks, but does not generally dominate regional flow.

2.1.2 Intergranular/fracture flow

Rock formations that combine both intergranular and fracture flow are common in Scotland. In these rock types intergranular flow still occurs and can be important, but typically much of the groundwater flow is through fractures. Geophysical logging in some of these aquifers has indicated that much of the flow to an abstraction borehole can be through fractures. Groundwater is stored in the pore spaces as well as the fractures. Most of the Devonian and Carboniferous sedimentary rocks are included in this category.

2.1.3 Fracture flow

These rocks have negligible intergranular porosity and, hence, can store groundwater only within fractures. All groundwater flow is through fractures, along bedding planes, joints or fault lines. Many of the rocks in Scotland fall into this category: all igneous and metamorphic rocks, plus certain sedimentary formations such as Caithness Flagstones. Karstic limestones are also included in this category.

Table 1 Summary of the bedrock aquifer classification for Scotland.

Productivity rating*	Dominantly intergranular flow	Intergranular / fracture flow	Fracture flow
Very High **>20 l/s**	**DIVH** Permian sandstone *(E. Dumfries, Lochmaben, Thornhill)* Upper Devonian sandstone *(Fife)*	**IFVH** Permian breccia and sandstone *(W. Dumfries, Moffat, Arran, Mauchline)*	**FVH**
High **10-20 l/s**	**DIH** Carboniferous Passage Formation sandstone	**IFH** Upper Devonian *(Southern Scotland)* Devonian sandstone (*Moray)* Lower Devonian sandstone (*Strathmore)* Permian and Triassic *(Moray, Solway)*	**FH**
Moderate **1-10 l/s**	**DIFM**	**IFM** All Carboniferous Formations except mudstones and Passage Formation Devonian conglomerate, siltstone, limestone and argillaceous rocks *(Moray, Turriff, E. Ross, Strathmore)* Lower Devonian *(Southern Scotland)* Devonian sandstones (*N of Great Glen)* Jurassic sandstone *(Skye)* Permian *(Stranraer)*	**FM** Cambrian limestone and dolomite Carboniferous Lavas (*E. Lothian*)
Low **0.1-1 l/s**	**DIFL**	**IFL** Volcaniclastic sediments Carboniferous mudstones	**FL** Dalradian *(except psammites)* Ordovician/Silurian greywacke+siltstone Devonian flagstones *(Caithness + Orkney)* Cambrian rocks (*except dolomite and limestone*) Jurassic + Triassic (*except Burghead, Skye*) Moine pelites Lavas *(except E. Lothian)* Torridonian Sandstone
Very Low **<0.1 l/s**	**DIVL**	**IFVL**	**FVL** Lewisian Dalradian psammites Moine (except pelites) Igneous intrusions

* The productivity rating refers to the estimated typical long-term yield from a single, properly sited and constructed borehole.

2.2 AQUIFER PRODUCTIVITY

The aquifer productivity classifications shown in Table 1 are based on judgements of the typical long-term abstraction rate, in litres per second (l/s), from a properly sited and constructed borehole. The rock types in each category have been categorised according to information obtained from BGS groundwater databases, the hydrogeological map of Scotland (1988) and pumping tests carried out in various resource assessment projects.

Table 1 shows five aquifer productivity classes. They range from very low productivity igneous and metamorphic rocks, which are generally suitable only for boreholes supplying less than 0.1 l/s to single or small groups of houses, to very high productivity (>20 l/s) sandstones – potentially exploitable for public supplies and industry. In general, aquifers comprising igneous and metamorphic rocks have low or very low productivity. The more productive aquifers are the Permian and Devonian sandstones and conglomerates.

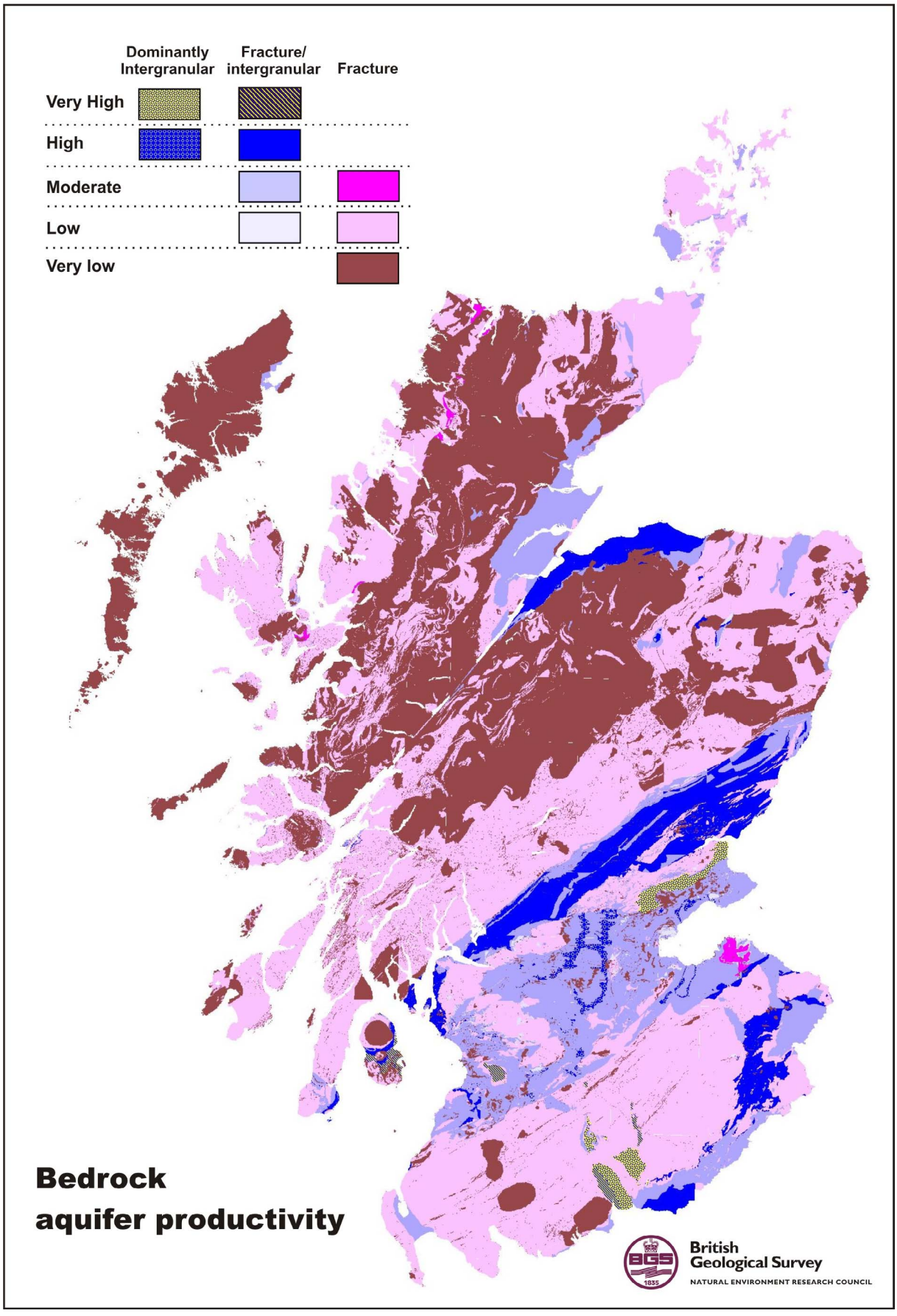

Figure 1 **Bedrock aquifer productivity map for Scotland.**

3 The superficial deposits aquifer productivity map

Developing the superficial aquifer productivity map for Scotland is a more complex process than for the bedrock productivity map. Not only does the flow and permeability of the deposits have to be taken into consideration, but also the thickness, and whether the deposits actually contain any groundwater. The map is based on the 1:50 000 digital superficial geology map for Scotland; the 1:625 000 digital superficial deposits map was used in several areas to fill in gaps with the geological mapping. The map is designed to be used at a scale of 1:100 000.

3.1 GROUNDWATER FLOW

Groundwater within superficial deposits is primarily intergranular, with some flow in fractures in certain tills. However, there is no realistic method of mapping fractured tills from the available geological and hydrogeological data for Scotland. Therefore, for the map, flow in the superficial deposits is assumed to be intergranular in all the deposits.

3.2 POTENTIAL AQUIFER PRODUCTIVITY

Scottish superficial deposits were divided into four aquifer productivity categories: high, moderate and low productivity, and non-aquifers (Table 2). Productivity was assigned primarily using the BGS superficial geology descriptions and HOST (Hydrology of Soil Types) classifications. Figure 2 shows the distribution of superficial deposit aquifers across Scotland. The productivity is *potential,* because many of the deposits may be too thin to actually contain groundwater. A methodology for helping to define where the aquifers are saturated is given in Section 3.3.

High productivity superficial aquifers comprise deposits that have significant sand and gravel content, such as glaciofluvial sand and gravel and alluvium. All mapped alluvium and glaciofluvial deposits are included in this category – there is not sufficient data to account for variations in permeability and thickness within alluvium and glaciofluvial deposits. Alluvial deposits within valley floodplains, although possibly less than 10 m in thickness, may have the capability to support very large abstraction rates because of strong interconnection with adjacent watercourses. Some of the highest yielding boreholes in Scotland are from alluvium deposits. Several large public water supply abstractions are located in high productivity superficial aquifers.

Moderate productivity aquifers comprise mainly raised marine deposits. Typically, these contain a high proportion of silt and clay and therefore have lower permeability than the more well-sorted, coarser, high productivity deposits. They are also generally thin, which reduces their potential for yielding large volumes of groundwater even further. Blown sand is also included in this category since, despite its high permeability, it is rarely more than a few metres thick and is distant from main rivers. Small public water supply abstractions have been located within moderate permeability aquifers in parts of rural Scotland.

Low productivity aquifers comprise sandy and gravelly tills, moraines, mixed lacustrine deposits and landslip material. Much of Scotland is covered by till but only high permeability till and moraine were defined as an aquifer. Although variations in till lithology are recognised across Scotland by BGS geologists there is little relevant information on till lithological variation in the available maps. In order to provide support to geologists' descriptions, till was subdivided according to permeability using the Hydrology of Soil Types

(HOST) dataset of soil hydraulic properties developed jointly by the Soil Survey and Land Research Centre (SLRC), the Macaulay Institute and the Centre for Ecology and Hydrology (CEH) (Boorman et al. 1995; Lilly et al. 1998). The methodology for subdividing the tills is described in detail in Ball et al. (2003). In general the more permeable tills are found across much of the Highlands, Aberdeenshire and southern Scotland.

Low productivity superficial aquifers are characterised by having a typical yield range of 0.1 to 1 l/s where the aquifer is saturated. Traditionally, these deposits have been exploited as a source of water in many parts of Scotland by constructing shallow wells or capturing springs. Even today, there are many thousands of private water supplies dependent on this source.

Non aquifers have by definition no aquifer productivity and have been omitted from the map. These include the moderate and low permeability tills of Strathmore and Central Scotland, and estuarine, marine or lacustrine clays.

3.3 DEPTH TO WATER IN SUPERFICIAL AQUIFERS

Not all superficial deposits with the potential to be productive actually contain usable groundwater. If the deposit is a moundy landform on high ground, a glaciofluvial terrace flanking a valley side or a deposit of till in an elevated location, it may be almost completely unsaturated for much of the year. Superficial deposit aquifers are generally saturated where the land surface is low in relation to surrounding ground. Examples include valley floodplains, low river terraces and depressions amongst moundy topography.

Almost all alluvial deposits contain a shallow water-table as they are situated adjacent to rivers. The same is true for the lower sections of glaciofluvial sand and gravel deposits that lie on valley sides. High permeability tills and moraines (classed as low productivity aquifers) are found in a variety of environments including valley sides, depressions in the land surface, hillsides and other high ground. Much of the latter material is less than 3 m thick and, for the most part, forms an unsaturated layer above bedrock rather than an aquifer.

To indicate the likelihood of a superficial deposit aquifer having a significant saturated zone, the methodology used to calculate the depth to the water table for the WFD Scottish groundwater vulnerability map (Ball et al. 2003) was adopted. This is a two-stage process: first the groundwater levels have to be estimated and secondly combined with an estimate of superficial deposit thickness.

The first stage in the process is to estimate the groundwater level. In the absence of adequate groundwater level information for most areas of Scotland two separate methodologies were used.

1. An estimate of the base groundwater level in valleys was estimated using a digital terrain model (DTM) and a map of the SEPA national river network. This is based on the concept that there is a greater depth to the water-table under relatively high ground than valley floors or close to the coast. The maximum depth to water-table can be estimated by calculating the difference in elevation from between the ground surface on the valley side and the river level in the valley bottom. This method assumes that the river surface (or sea level at the coast) equates to the water-table surface. This method was used to calculate the maximum depth to groundwater up to 3 km distance from the main rivers and coast.
2. The second method relies on the presence of certain HOST soils classes that indicate the presence of a shallow water table within 2 m of the ground surface. These were combined

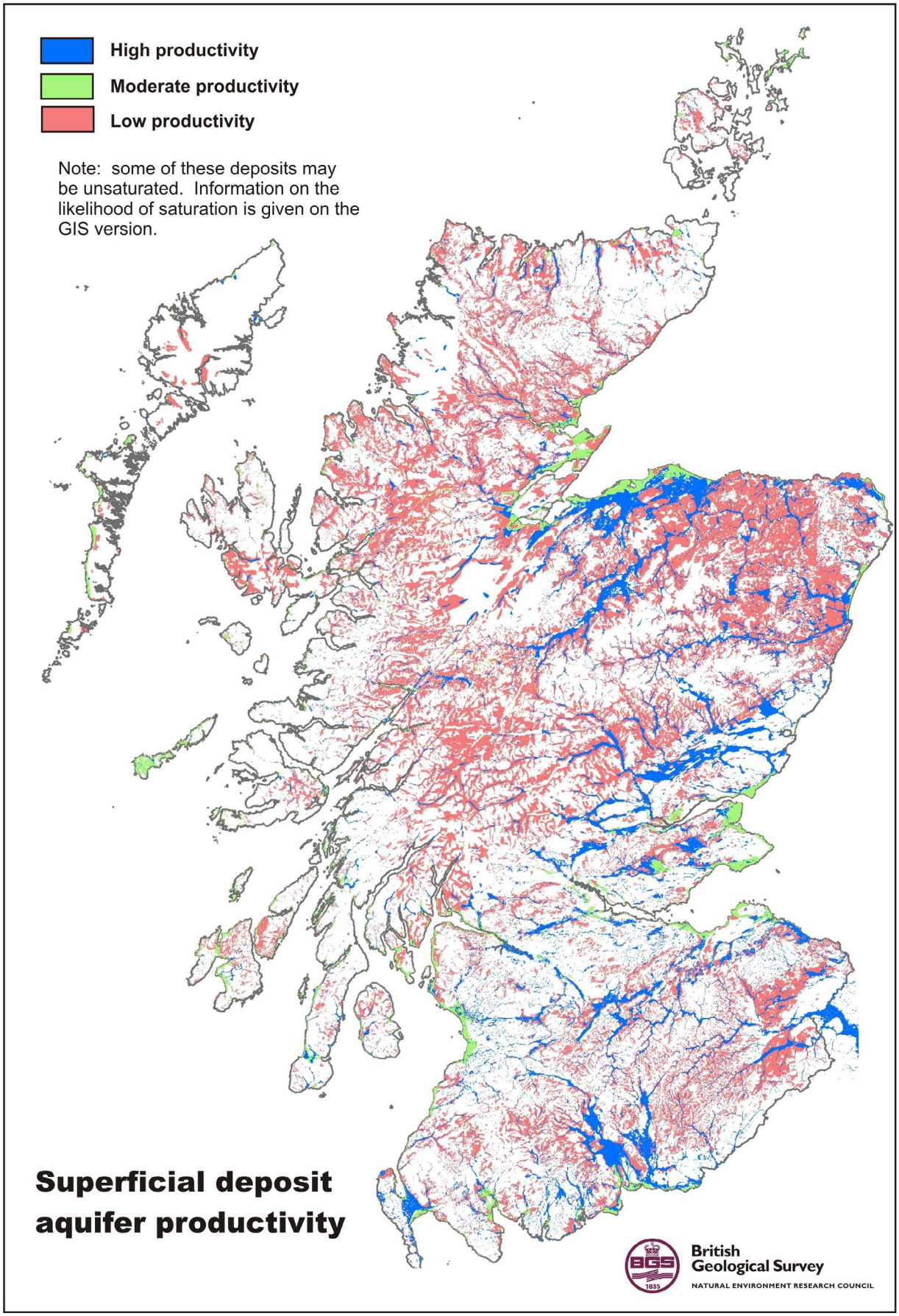

Figure 2 **The superficial deposits aquifer productivity map for Scotland.**

with the superficial deposits map, to show where higher permeability deposits (i.e. high, moderate or low aquifer productivity) also contain shallow groundwater. The HOST classes indicating a shallow water-table also include low permeability deposits (i.e. non-aquifers) such as gleyed and peaty soils that are not generally free-draining. All of these areas have been removed from the productivity map, to leave only areas that indicate a shallow water-table within higher permeability soils.

The resultant depth to water map was then combined on a GIS with a layer showing the thickness of high permeability superficial deposits. The resultant map is divided into two categories:

- areas where there is a high probability of a water-table and, therefore, a groundwater resource, within superficial deposit aquifers;
- areas where there is a lower probability of a groundwater resource within superficial deposit aquifers.

Certain formations are more likely to be saturated than others. Because the DTM model originates along the main rivers, it has identified likely zones of saturation mainly in alluvial and glaciofluvial deposits, as these tend to occur at relatively low elevation within the larger valleys. By contrast, tills that occur across high ground more than 3 km from the main rivers are outwith the range of the model and it is in these areas that saturated conditions are less likely, with their presence indicated only by the relevant HOST classes.

Due to the uncertainties associated with both the DTM model and the use of HOST to determine the depth to the water table, the map should not be used as an absolute indication of the presence of a shallow aquifer. Deposits are subdivided into those likely to have a water table up to 10 m below surface and those where it is less likely. However, this is only an indication of the probability of groundwater being present and detailed investigations should be carried out at particular sites.

Table 2 Summary of superficial deposit aquifer productivity classification for Scotland.

Productivity rating	**Superficial deposits**
High **>10 l/s**	**IH** Glaciofluvial sand and gravel & mixed deposits Alluvium + River Terrace sand & gravel *(majority of Scotland)*
Moderate **1-10 l/s**	**IM** Raised Marine deltaic deposits *(mixed)* Raised Beach and Marine deposits Blown sand
Low **0.1-1 l/s**	**IL** Sandy and gravelly glacial till Hummocky moraine Mixed lacustrine deposits Landslip

4 Conclusions

GIS-based maps of aquifer productivity have been produced for both bedrock and superficial deposits in Scotland. The maps are designed to be used at a scale of 1:100 000.

- Bedrock is divided into five classes according to productivity, ranging from very high to very low. The rock formations and groups are also subdivided into three flow categories, according to the proportion of intergranular and fracture flow.
- High and very high productivity bedrock formations are thought to have sufficient yield potential from individual boreholes to be considered as sources for public supply or for large industries. Low productivity formations are considered suitable for groundwater supplies to single or small groups of houses.
- The superficial aquifer map is subdivided into three classes according to productivity: high, moderate and low. In these deposits, groundwater flow is assumed to be entirely intergranular.
- Sandy and gravely till deposits and moraines are classed as low productivity aquifers, potentially suitable for single house supplies. The remainder of the till, and other clay deposits have been classified as non-aquifers and do no appear on the map.
- Some of the superficial deposits are unsaturated. To try and capture this behaviour a model likely depth to the water table was created and combined with existing data on drift thickness. The resulting map shows zones where there is a high probability that the superficial deposits contain groundwater.

The maps are only intended as a guide to the aquifer conditions and are not a substitute for detailed site investigation. The maps can be improved as more information on drilling success and borehole yields is gathered throughout Scotland.

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Appendix 1 Metadata

Dataset Descriptive name: Bedrock aquifer productivity

Abstract:	1:100,000 scale bedrock aquifer productivity map of Scotland
Organisational IPR:	BGS has primary IPR for the geological lines on the map and flow type classifications. BGS/SEPA have joint IPR on the aquifer productivity classifications.
Shapefile name:	Bedrock aquifer productivity for Scotland
Code for category:	Environmental
General type of data:	Map
Parent Data Sets:	***BGS:***
	DiGMapGB50 bedrock deposits
	GeoHazard permeability classifications
Geographical coverage:	Scotland
Source of data:	BGS
Scale:	1:100 000
Source Date:	March 2004
Body who digitised data:	BGS
Frequency of updates:	Not applicable
Reference organisation:	BGS
Spatial reference system:	British National Grid
Can data be supplied externally?	No
Stage of Development:	FINAL
Creation process:	This BGS report (No CR/04/047N)

Dataset Descriptive name	**Bedrock aquifer productivity**
Abstract:	1:100,000 scale superficial deposit aquifer productivity map of Scotland
Organisational IPR:	BGS has primary IPR for the geological lines on the map. BGS/Macaulay Institute/SEPA for superficial deposits productivity classifications.
Shapefile name:	Superficial deposits aquifer productivity for Scotland
Code for category:	Environmental
General type of data:	Map
Parent Data Sets:	***BGS:***
	DiGMapGB50 superficial deposits
	GeoHazarD superficial deposits permeability and thickness
	SOBI
	Groundwater level datasets
	Macaulay Institute:
	HOST
	OS:
	DTM (licensed by SEPA)
	Rivers (licensed by SEPA)
	Coastline (licensed by SEPA)
Geographical coverage:	Scotland
Source of data:	BGS/Macaulay Institute/OS
Scale:	1:100 000
Source Date:	March 2004
Body who digitised data:	BGS, MLURI, OS
Frequency of updates:	Not applicable
Reference organisation:	BGS
Spatial reference system:	British National Grid
Can data be supplied externally?	No
Development:	FINAL
Creation process:	This BGS report (No CR/04/047N)