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Explanatory notes to accompany the Groundwater Vulnerability Index GIS for Angus Council

Groundwater Systems and Water Quality Programme

A report for Angus Council

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BRITISH GEOLOGICAL SURVEY

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1 Introduction

These notes are designed to accompany the ArcView geographical information system (GIS) format groundwater vulnerability index map produced by the British Geological Survey (BGS) for Angus Council. The map is based on digital geological information for both bedrock and superficial deposits. It covers the whole of the Angus Council area plus a ‘buffer zone’ to account for peripheral data.

The purpose of the GIS map is to indicate, in broad terms, the vulnerability of groundwater to pollution. Groundwater is contained within aquifers of various types. Abstraction from these aquifers provides water for potable supplies and various domestic, industrial and agricultural uses. Some highly permeable aquifers are very productive and of regional importance as sources for public water supply; other, less permeable formations, are of local importance for domestic, agricultural and industrial supplies. Groundwater also provides the baseflow to surface watercourses. Groundwater is typically of high quality and often requires little or no treatment before use. However, it is vulnerable to contamination from both diffuse and point source pollutants, from direct discharges into groundwater and indirect discharges into and onto land. Aquifer remediation is difficult, prolonged and expensive: therefore, the prevention of pollution is important.

The approach and classifications used in the production of the groundwater vulnerability index can also be used in the assessment of specific land use practices, proposed developments and land use changes over aquifers where these could have an impact on groundwater quality. More detailed site specific assessment of vulnerability will be required where it is considered that development may have an impact on groundwater quality.

This GIS and printed maps are a compromise between the representation of natural complexity and the simplicity of interpretation at a scale of 1:50 000. This places limitations on the resolution and precision of map information. There is a wide variety of geological strata and potential pollutants, and the vulnerability index classification is, of necessity, generalised. Individual sites and circumstances will always require further and more detailed assessment to determine the specific impact on groundwater resources. The map coverages in the GIS only represent geological conditions (bedrock or superficial) as mapped at their upper surface. Where these formations have been disturbed or removed, for example, during mineral extraction or where worked ground exists in urban areas, the actual vulnerability of groundwater may be altered from natural conditions. Hence, where there is evidence of ground disturbance, site-specific data should be collected and used to determine the vulnerability of groundwater.

The overall permeability of each geological unit has been interpreted to produce an index of the vulnerability of groundwater occurring in Angus, and provides a broad-based view of both the vulnerability of groundwater and the location of the more permeable aquifers in Angus.

The data used to interpret the groundwater vulnerability index are derived from the 1:50 000 DigMap bedrock and superficial geology coverage. The GIS and associated maps should not therefore be used at scales larger than 1:50 000. Locations of thick clays have been interpreted and drawn based on BGS borehole records. Information on water boreholes is derived from the British Geological Survey Scottish Water Borehole database.

2 Overview of Bedrock and Superficial Geology

Angus straddles the Highland Boundary Fault, which runs from Balmaha to Stonehaven. To the northwest of this fault, the bedrock comprises mainly ancient metamorphic rocks, of Neoproterozoic age. These consist largely of metamorphosed grits and slates, with intrusions of granite and basic igneous rocks dating from Palaeozoic times.

To the south east of the Highland Boundary Fault the bedrock comprises largely sedimentary rocks of Lower Devonian age. The sedimentary sequence is composed principally of sandstones, with some coarse conglomerates close to the Highland Boundary Fault. Structurally, the rocks are aligned on a northeasterly trend, parallel to the Highland Boundary Fault, and have been folded into a syncline-anticline structure: the Strathmore syncline in the north, close to the fault, and the Sidlaw anticline to the south, marked by the Sidlaw Hills. The older rocks (the Arbuthnott-Garvock Group), exposed within the core of the Sidlaw anticline, are a series of interbedded layers of sandstones and volcanic lavas, with the harder lavas creating ridges of high ground. Younger rocks, also part of the Arbuthnott-Garvock Group, crop out to the northwest and southeast of the anticline, and comprise mostly sandstones and congomerates. The youngest rocks of the Lower Devonian are found in the core of the Strathmore syncline, and comprise thick beds of shale and mudstone (the Cromlix Mudstone Formation), and thick sandstones and conglomerates (the Teith Sandstone Formation). Small outcrops of Upper Devonian (Glenvale Sandstone Formation) and Lower Carboniferous (Kinnesswood Formation) sedimentary rocks occur near Montrose and to the west of Dundee.

Much of the lowland parts of Angus, to the south of the Highland Boundary Fault, are mantled by superficial deposits. Superficial deposits are patchier over upland areas, where they are largely confined to river valleys, apart from extensive upland peat. The most common superficial deposit is glacial till, deposited extensively during Quaternary glaciations. In Angus, the glacial till generally comprises gravel and gravelly sand with cobbles, boulders and pebbles, with small proportions of silt and clay. As the ice sheets melted, glaciofluvial sands and gravels were deposited over the till in meltwater streams.

The weight of the ice during glaciation caused an isostatic lowering of the ground. At the end of glaciation, melting ice and delays in the isostatic rebound of the lowered ground resulted in sea levels that were much higher than today. These seas laid down raised marine deposits – sands, gravels, clays and silts – along the low ground adjacent to the present coastline. Once sea levels reached levels similar to today, alluvium began to be deposited on river flood plains. The dominant alluvial deposits in the area are sands and gravels. The other main post-glacial deposit is peat, which occurs largely over upland areas in the north of Angus.

3 Aquifer Permeability and Groundwater Vulnerability

The permeability of a geological unit determines the ease with which groundwater can flow through it. In sedimentary rocks such as sandstone, groundwater flows along intergranular flowpaths between individual sand grains, as well as through fractures and other voids. Sandstones can vary greatly in permeability, but are often among the most highly permeable and porous (able to store groundwater) rock units. In limestones, groundwater flow and storage is almost entirely within fractures. If these fractures are well developed, limestones can be highly permeable.

Of the bedrock units in the Angus area, all of the Devonian sandstones and mixed sandstone/conglomerate/siltstone units have relatively high permeability. They are typically good aquifers, able to support large abstractions. Much of the groundwater in these aquifers is stored in, and flows though, fractures in the rock.

Devonian conglomeratic units and the Cromlix Mudstone Formation are classified as moderately permeable. These aquifers will seldom support large abstractions, but are important for small local abstractions and in supplying baseflow to rivers.

The bedrock units with low permeability overall include Lower Devonian lavas, such as the Montrose Volcanic Formation and the Ochil Volcanic Formation, and all of the ancient Neoproterozoic metamorphic rocks north of the Highland Boundary Fault. Although they have low permeability, groundwater flow can occur in these rocks via fractures, generally at shallow depths and at local scales. Many of these rocks can support small domestic abstractions, as well as supply baseflow to streams and rivers. In such rocks, there may still be a degree of risk of contamination if polluted water enters fractures.

Highly permeable superficial deposits in the Angus area are those deposits dominated by sand and gravel, including glaciofluvial deposits, alluvium and blown sand. Unlike in many other areas of Scotland, the glacial till that covers most of the Angus area contains a large proportion of gravelly material as well as clay, and is therefore moderately permeable. The only superficial deposit classed as having low permeability is peat.

The groundwater vulnerability index map is based on the general assumption that where more highly permeable formations crop out at the ground surface, water can infiltrate rapidly to the water table. Where less permeable formations, such as clayey superficial deposits, or igneous rocks, crop out at the surface, a larger proportion of the rainfall falling on the ground will flow directly to surface watercourses instead of soaking into the ground. If there is a source of contamination at or near the ground surface, high permeability formations are more likely to receive polluted groundwater. They are also more likely to be useful aquifers. High permeability formations are therefore more vulnerable to pollution. However, fractured rock, even if it has low permeability, and is not capable of receiving large quantities of groundwater (such as igneous rock), may remain vulnerable to contamination because even small groundwater flows in fractures can rapidly transport any pollutants.

Permeable superficial deposits can act both as aquifers in their own right, and as pathways for groundwater to reach underlying bedrock aquifers. Areas where high permeability superficial deposits overlie low or moderate permeability bedrock; where high permeability superficial deposits overlie high permeability bedrock; and where high permeability bedrock outcrops at the surface, are, therefore, treated as equally vulnerable.

Where a thick clayey superficial deposit overlies a permeable aquifer, the clay can act to impede the downward movement of pollutants, and thus act as a protective cover. However, where there are relatively thin sandy clay layers (generally less than 5 m), a certain amount of recharge to deeper aquifers may occur. The GIS distinguishes where low permeability superficial deposits overlie high permeability bedrock aquifers (shown as a pink colour), but it should not be assumed that this low permeability superficial layer always acts as an effective barrier, as there may be significant variations in its thickness, and it may be fractured in some areas.

The detailed identification, location, thickness and extent of clayey deposits can be difficult due to a lack of data. However, an interrogation of BGS borehole records has been made and these have been interpreted to show where there is a strong probability that there is greater than 5 m of clay in the drift sequence. This is shown on the maps as a transparent hatched overlay. This information is limited only to where borehole geological data are present, and, therefore, represents the likely minimum extent of thick clayey superficial deposits, rather than a comprehensive coverage.

3.1 BEDROCK GEOLOGY PERMEABILITY

The bedrock has been divided into three groups based on permeability (High - H, Moderate – M, and Low - L), shown on the map in Figure 2. Each bedrock unit has also been given a code signifying the level of confidence in the permeability classification, where 1 is most confident and 3 is least confident. Most units are coded 1. Lower confidence is given to bedrock units that are known to have varying permeability characteristics within the same unit, such as the Lower Devonian units mapped as a sequence of interbedded sandstones and siltstones. Within these sequences, sandstone horizons may have high permeability, and siltstone horizons may have moderate permeability, but the overall permeability of the unit as a whole is likely to be moderate. The groups include the following rock units:

High Permeability (H):

(Red on GIS)

- Lower Devonian sandstones and mixed sandstone/conglomerate/siltstone units (including parts of the Arbuthnott-Garvock Group and the Dundee Flagstone Formation, and the Scone Sandstone and Teith Sandstone formations)
- Upper Devonian and Lower Carboniferous sandstones (Glenvale Sandstone and Kinnesswood formations)

Moderate Permeability (M):

(Orange on GIS)

- Lower Devonian conglomerates, limestones, and mixed siltstone/mudstone units (including parts of the parts of the Arbuthnott-Garvock Group and the Dundee Flagstone Formation and the Cromlix Mudstone Formation)

Low Permeability (L):

(Green on GIS)

- Lower Devonian volcanic lavas (e.g. Ochil Volcanic Formation)
- Neoproterozoic metamorphic rocks

3.2 SUPERFICIAL GEOLOGY PERMEABILITY

Superficial deposits are divided into three main groups according to permeability (High - H, Moderate – M, and Low - L), shown on the map in Figure 3. A fourth category covers a number of small areas across the map where superficial geology is classed as ‘unknown’ on the 1:50 000 digital geology coverage. The main area classed as unknown is the area of offshore deposits in the Montrose Basin. Areas uncoloured on the superficial geology permeability map are those areas where no superficial cover is mapped.

The superficial deposits in the Angus area are highly variable, and some of the Quaternary mapping is relatively old and does not account for recent advances in superficial deposit typology techniques. Many of the superficial deposit units are internally heterogeneous, often composed of sands, gravels, silts and clays in varying amounts at different locations, but have been mapped as a single unit. Parts of such a unit may, therefore, be relatively permeable, while other parts are less permeable. The classifications used in the groundwater vulnerability index, described below, represent the best attempt at interpreting such units in terms of their overall permeability. In most cases this has been done using a precautionary principle, whereby if a superficial unit is expected to be highly permeable in some parts and have moderate or low permeability in others, it is classified as highly permeable throughout. For example, alluvium in some areas is known to be a highly heterogeneous deposit comprising sands, gravels, silts and clays in varying proportions. In most areas it is likely to be moderately permeable, but some parts comprise highly permeable sands and gravels, and it is therefore classified as highly permeable.

Each superficial unit has also been given a code signifying the level of confidence in the permeability classification, where 1 is most confident and 3 is least confident. Lower confidence is given to superficial units that are known to have varying permeability characteristics within the same unit, such as alluvium in the example above. The confidence code 0 is given to areas where the superficial geology is mapped as ‘unknown’. The groups include the following units:

High permeability (H):

(Red on GIS)

- Alluvial, glaciofluvial, and raised marine deposits comprising sands and gravels, and mixed sequences which are expected to contain significant amounts of sand and gravel

Moderate permeability (M):

(Orange on GIS)

- Glacial till diamicton[1] deposits

Low permeability (L):

(Green on GIS)

- Peat

[1] A general term for any unsorted, unstratified sediment regardless of its genesis. Diamicts may be formed in various situations: glaciation, mudflow, landslide, avalanche, and turbidity current. Till is a special kind of diamicton that was formed directly from glacier ice. The terms diamictite and tillite are used for the ancient, consolidated equivalents of diamicton and till sediments.

4 The Groundwater Vulnerability Index map

The basic assumption made in defining the vulnerability index categories shown in the GIS and printed map (Figure 4) is that that high permeability in a geological unit equates with a high groundwater vulnerability index: i.e. pollutants at ground level are able to migrate downwards more easily and in greater volume where permeable material (such as gravel or sandstone) is present.

The vulnerability index map incorporates both the bedrock and drift permeability classifications previously described to produce twelve combinations of bedrock and drift permeability. These combinations are referred to by two-letter codes: 'HH', 'HM', etc. The letters are as follows:

H High permeability
M Moderate permeability
L Low permeability
N No drift cover present over the bedrock formation
U Where superficial geology is classified as unknown on the digital geology coverage

The first letter in the code refers to the bedrock permeability and the second letter to the drift permeability. For example, 'HM' refers to High Permeability bedrock overlain by Moderate Permeability superficial deposits.

These possible combinations have then been grouped into three main categories of groundwater vulnerability labelled 'High' (red on map), 'Moderate' (yellow) and 'Low' (green). A sub-category, (pink on map), shows areas where a highly permeable bedrock aquifer is covered by low permeability superficial deposits (glacial till or other clayey drift). It should be noted that the thickness, and therefore the effectiveness, of this clay as a barrier to pollution is uncertain.

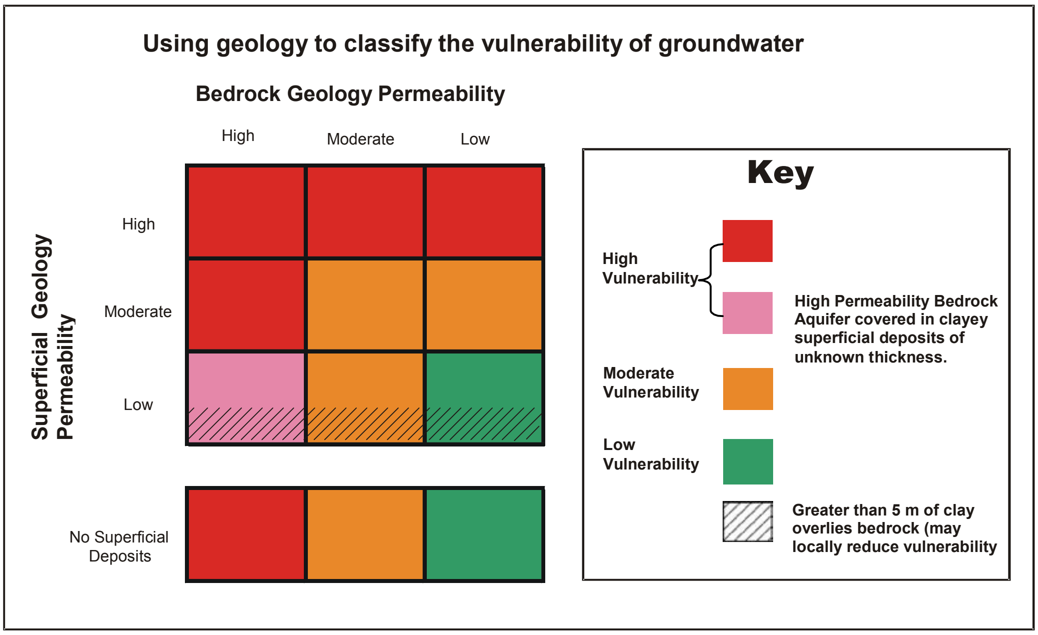

Figure 1 Illustration of groundwater vulnerability index categories based on bedrock and superficial geology

The vulnerability categories are summarised in Figure 1. For anywhere in the Angus area where there is a highly permeable aquifer present beneath the ground surface, either bedrock or superficial, the map is coloured red or pink to denote high vulnerability. Aquifers (bedrock or superficial) of moderate permeability are coloured yellow to indicate an overall moderate vulnerability (except where a moderately permeable bedrock aquifer is combined with a highly permeable superficial aquifer). Areas where low permeability formations occur, where groundwater is least vulnerable, are coloured green. There still remains a risk of groundwater pollution within areas classified as moderate or low vulnerability, but owing to the overall low permeability this risk, and therefore the vulnerability of groundwater, is considered to be lower.

There are a number of small areas where superficial geology is unknown (see section 3.2). These areas are distinguished on the groundwater vulnerability index map because it is impossible to determine groundwater vulnerability (in either bedrock or superficial aquifers) without taking the permeability of superficial deposit into account.

5 Clay Thickness

Another overlay, shown on the GIS maps as a transparent hatching, shows where there is a strong probability that a cumulative thickness of 5 metres or more of clay is present in the superficial sequence. Because this sequence can be highly heterogeneous, high permeability sands and gravels may crop out at the surface while at depth there is a thick sequence of till or lacustrine clays. Any bedrock aquifers beneath these areas will receive a certain amount of protection from the clay layer in the superficial deposits, which will inhibit recharge to the bedrock aquifer. The information to create this overlay is derived from BGS borehole archives. It should be noted that where no hatching is present it does not necessarily mean that there is less than 5 m thickness of clayey superficial deposits. In many areas a lack of borehole records make it impossible at present to identify the presence of clays. In addition, even where a total of 5 m or more of clay is present in the drift sequence, not all superficial aquifers will necessarily receive protection, as they may overlie much or all of the clay.

6 Water Boreholes

The GIS also contains a shapefile with the locations and details of known water boreholes in Angus, taken from the British Geological Survey Scottish Water Borehole database (locations of boreholes shown in Figure 5).

7 Copyright

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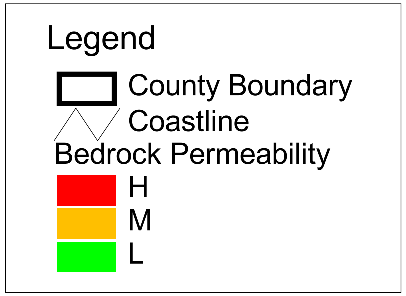

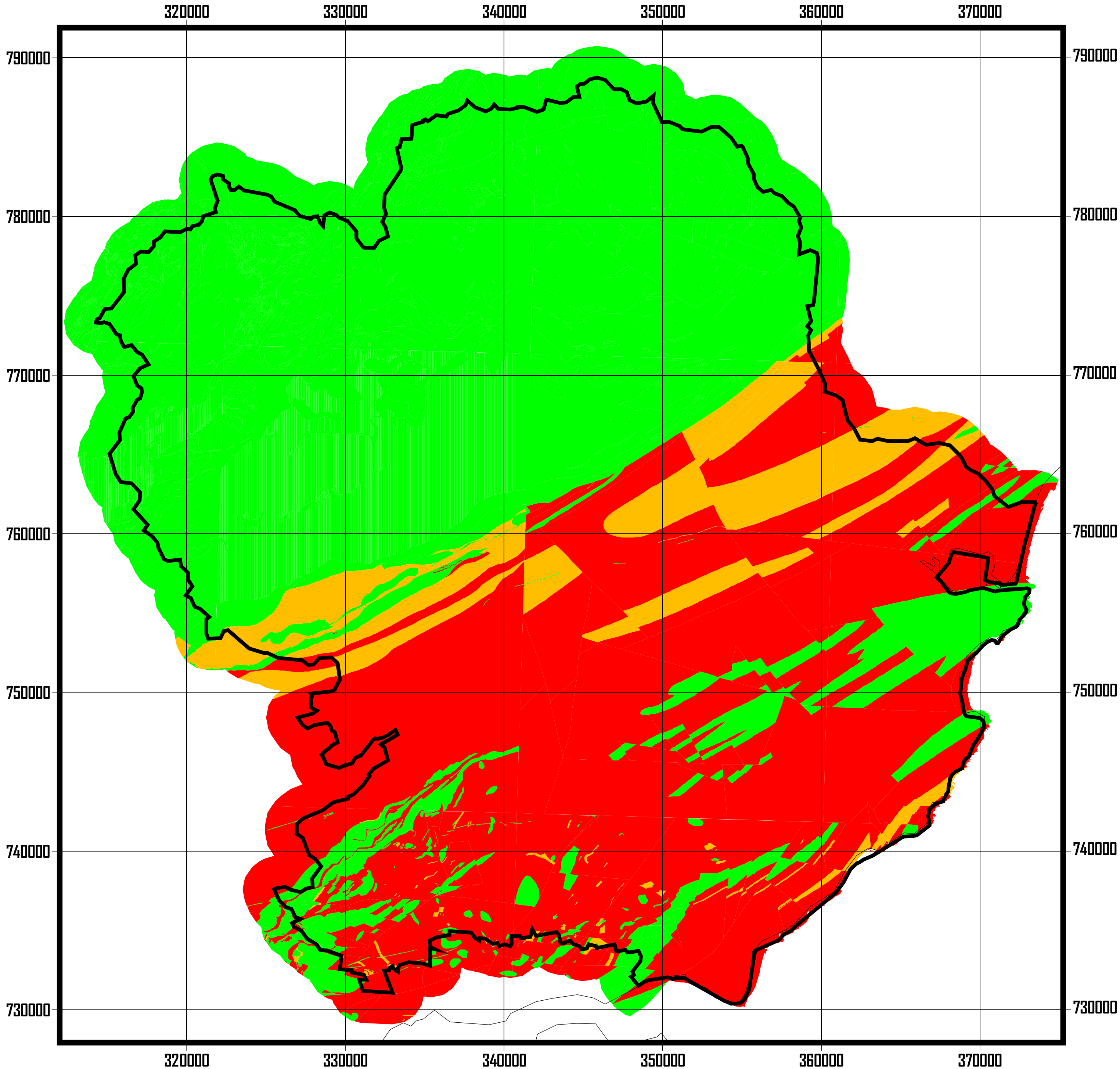

Figure 2 Angus Bedrock Permeability

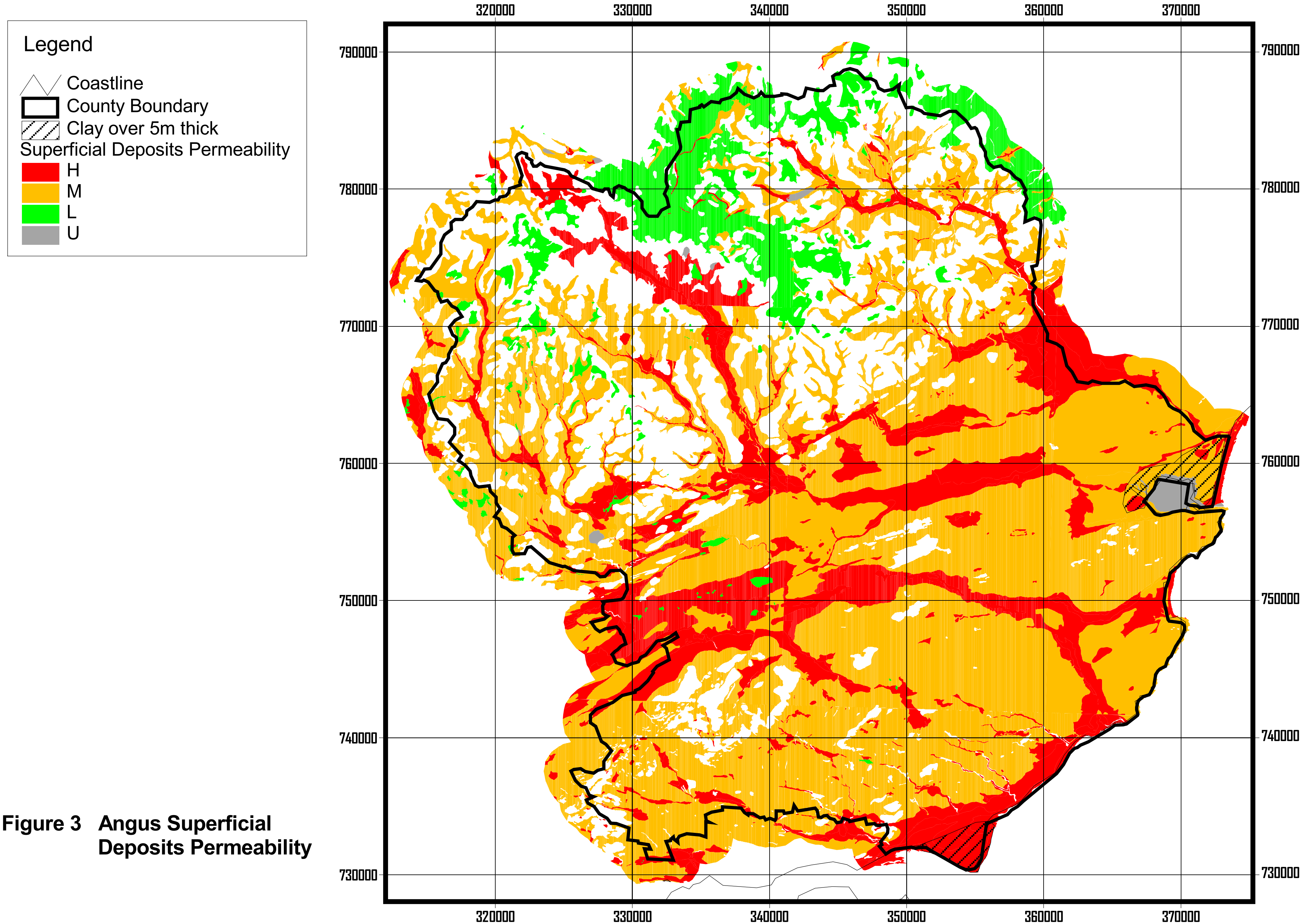

Figure 3 Angus Superficial Deposits Permeability

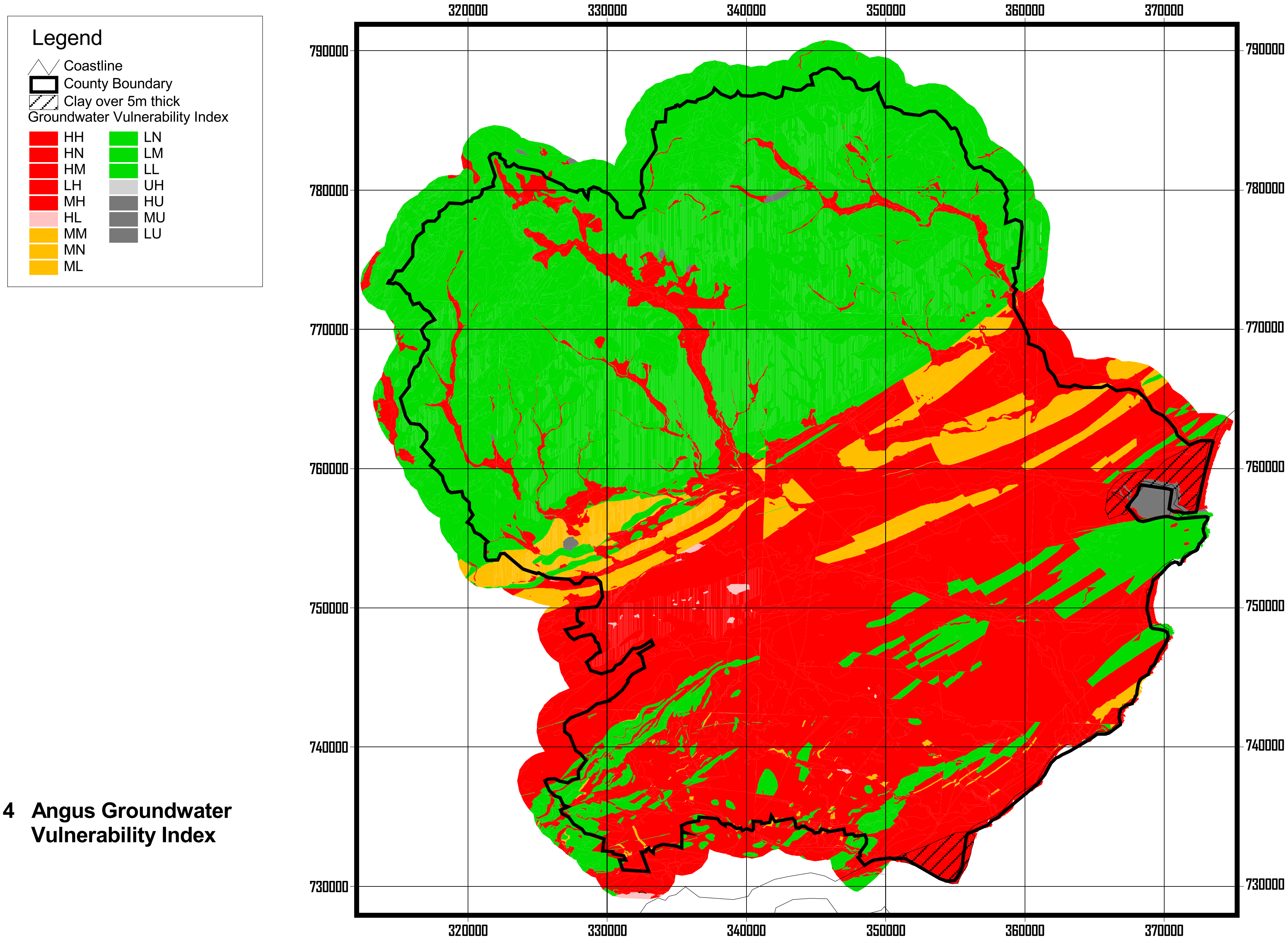

Figure 4 Angus Groundwater Vulnerability Index

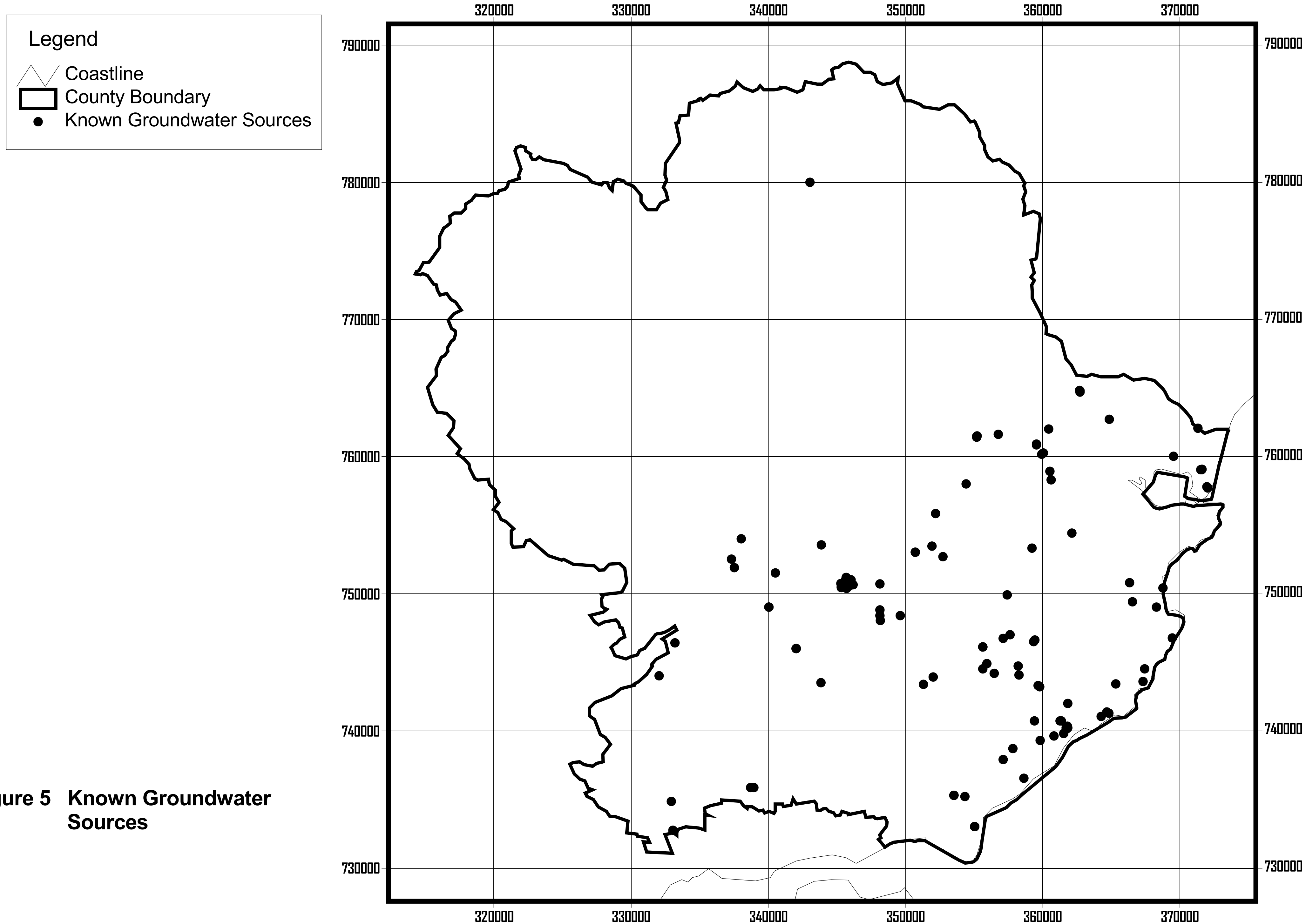

Figure 5 Known Groundwater Sources