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

Groundwater Systems and Water Quality Programme

A report for Moray Council

Research Report CR/03/054N

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RESEARCH REPORT CR/03/054N

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B É Ó Dochartaigh

Key words

Groundwater vulnerability index, Moray

Bibliographical reference

Ó DOCHARTAIGH B É. 2003. Explanatory notes to accompany the Groundwater Vulnerability Index GIS for Moray Council. *British Geological Survey Research Report*, CR/03/054N. 16pp.

Murchison House, Edinburgh, British Geological Survey 2003

Contents

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 Moray Council. The map is based on digital geological information for both bedrock and superficial (drift) deposits. It covers the whole of the Moray Council area plus a 'buffer zone' around the landward boundaries to account for peripheral data and allow for more meaningful interpretation.

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. Abstractions from these aquifers provide 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, the vulnerability class may have been changed. Hence, where there is evidence of disturbance, site specific data need to be collected and used to determine the vulnerability of the groundwater.

The overall permeability of each geological unit has been interpreted to produce an index of the vulnerability of groundwater occurring in Moray, and provides a broad-based view of both the vulnerability of groundwater and the location of the more permeable aquifers in Moray. The vulnerability index classification does not follow the methodology devised for an earlier published groundwater vulnerability map (NERC and MLURI 2002). The latter methodology includes an assessment of soil leaching potential, and combines data on superficial geology and soils to produce vulnerability classifications.

The data used to interpret the groundwater vulnerability index are derived from the 1:50 000 DigMap bedrock and drift 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 Drift Geology

The oldest rocks in the district are hard, ancient crystalline rocks of the Dalradian Supergroup of Precambrian age. These were originally marine sedimentary and minor volcanic rocks formed between about 700 and 510 million years ago. Orogenic (mountain building) events between about 490 and 450 million years ago buckled and pushed the Dalradian rocks down to deep within the Earth's crust, where they were heated and deformed (metamorphosed) to form the hard, cleaved metamorphic rocks that we see today. Although they are strongly folded and changed, the original composition of each rock is still reflected by its present metamorphic rock type. Hence, mudstones were metamorphosed to become schists; quartz-rich sands became recrystallised to quartzite; and limestones to metalimestones.

Igneous rocks were intruded into the Dalradian rocks at the time of metamorphism and periodically over the following 70 million years.

Devonian (Old Red Sandstone) sedimentary rocks were deposited following uplift and erosion of the Dalradian rocks. Remnants of the erosion surface, which developed under dry tropical conditions, are still seen in many parts of Moray. Small outcrops of Lower Devonian conglomerates and pebbly sandstones occur around Tomintoul, but the main outcrop, stretching from Buckie to Forres and extending south almost to Rothes, consists of Mid- to Upper Devonian rocks. These are dominantly pebbly but softer sandstones originally laid down in rivers (fluviatile deposits). Minor shales and impure limestones, with sparse calcareous nodule-shale beds containing fossil fish, were deposited in lakes. These Devonian rocks beds now dip gently to the NNW.

North of Elgin, Devonian rocks are overlain by younger Permo-Triassic aeolian (wind-deposited) and fluviatile sandstones, which contain the remains and footprints of reptiles. A cherty impure sandy limestone caps this sandstone sequence. The youngest bedrock units in the Moray area are of Jurassic age. They are sandstones and calcareous mudstones preserved in downfaulted blocks by Lossiemouth and Spynie. These 'outliers' relate to a more widespread offshore sequence in the Moray Firth.

During the last period of Quaternary glaciation there was extensive deposition of glacial till. This normally rests on bedrock, covering much of the low ground around the coast and extending into the upland valleys, and generally consists of cobbles, boulders and pebbles, mixed with clayey sand and silt. As the ice sheets melted, glaciofluvial sands and gravels were deposited over the till in meltwater streams and as deltaic fans in ice-marginal lakes. Extensive spreads of fine-grained glaciolacustrine silts, clays and subsidiary sands were also laid down in these lakes.

The major rivers of the district, particularly the Spey, are flanked by alluvial terraces, formed mainly by braided rivers during deglaciation, and typically comprising cobble gravel. After the end of glaciation, the dominant alluvial deposit has been loam overlying dense, water-saturated shingle.

Raised beaches are widespread along the coast west of Buckie, typically formed of well-sorted gravel. They occasionally pass inland into extensive spreads of brackish marine silty clay. The raised marine features are commonly concealed beneath blown sand, particularly around Burghead Bay.

Spreads of hill peat are widespread in the south of the district, with smaller occurrences of peat mosses in ice-scoured basins on lower ground.

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.

The bedrock units in the Moray district with the highest permeability, either high intergranular permeability and/or significant fracture permeability, are Triassic, Permian and Devonian sandstones, and Dalradian metalimestones known to be locally karstic. These aquifers may be highly productive, and able to support large abstractions.

Bedrock units classified as moderately permeable are Jurassic and Triassic interbedded sandstones and siltstones; Middle and Lower Devonian sandstones and conglomerates; and non-karstic Dalradian metalimestones. These bedrock units will seldom support large abstractions, but are important for small local abstractions and in supplying baseflow to rivers.

Bedrock units with low permeability overall include Dalradian metamorphic schists and igneous rocks of all ages. Although they have low permeability, groundwater flow does occur in these rocks, generally via fractures at shallow depths and at local scales, and many of these rocks can support small domestic abstractions, as well as supply baseflow to streams and rivers. A borehole in such rocks may therefore still be at risk of contamination from pollution carried in groundwater flowing along fractures.

Drift deposits over most of the inland areas of Moray comprise low permeability glacial deposits, largely glacial till. Around the coast and along river valleys there are significant outcrops of high permeability drift deposits, in particular glaciofluvial, alluvial, river terrace and marine sands and gravels. There are small outcrops of drift deposits classified as moderately permeable, including head, salt marsh, lacustrine and hummocky glacial deposits.

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 drift deposits or crystalline igneous or metamorphic bedrock, 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. More permeable formations are, therefore, more vulnerable to contamination. Permeable drift formations can act both as aquifers in their own right, and as pathways for groundwater to reach underlying bedrock (solid) aquifers. Areas where high permeability drift overlies low or moderate permeability bedrock; where high permeability drift overlies high permeability bedrock; and where high permeability bedrock outcrops at the surface, are, therefore, treated as equally vulnerable on the vulnerability map.

Where a thick clayey drift 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 metres), a certain amount of recharge to deeper aquifers will occur. The GIS distinguishes where low permeability drift (generally glacial till, but also marine clay and peat) overlies bedrock aquifers, shown in pink, but it should not be assumed that this low permeability drift layer always acts as an effective barrier, as there may be significant variations in the thickness of the drift, 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 records interpreted to show where there is a strong probability that there is greater than 5 metres thickness 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 drift, rather than a comprehensive coverage. Note that the earlier map of groundwater vulnerability (NERC and MLURI 2002) also includes information on the presence and thickness of low permeability drift deposits, based on the same data.

3.1 BEDROCK GEOLOGY PERMEABILITY

The bedrock has been divided into three major groups based on permeability (High, Moderate and Low), 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. These are largely Dalradian metacarbonate rocks, which have very low intergranular (primary) permeability, but typically have extensive fracturing on a local scale, which increases secondary permeability locally. The groups include the following rock units:

High Permeability:

(Red on GIS)

- Triassic sandstones (Lossiemouth Sandstone and Burghead Sandstone formations)
- Upper Permian/Triassic sandstones (Hopeman Sandstone Formation)
- Upper and some Middle Devonian sandstones (Forres Sandstone and Inverness Sandstone groups)
- Dalradian metalimestones known to be locally karstic (Tobar Fuar Limestone, Corgarff Limestone and Dufftown Limestone members and limestones within Allt Dregnie Phyllite Member, and Inchrory Limestone Formation)

Moderate Permeability:

(Yellow on GIS)

- Jurassic sandstones and siltstones (Dunrobin Bay Formation)
- Triassic sandstones, cherts and limestones (Stotfield Cherty Rock Formation)
- Middle Devonian conglomerates and interbedded sandstones/conglomerates (e.g. Spey Conglomerate Formation, Aulothrie Sandstone Member)
- Lower Devonian sandstones, conglomerates, breccias and siltstones (e.g. Delnabo Conglomerate and Raebeg Sandstone formations)
- Dalradian metalimestones and other metacarbonate rocks where non-karstic (e.g Blairfindy Limestone Member)

Low Permeability:

(Green on GIS)

- Igneous rocks of all ages
- Dalradian metamorphic rocks (excluding metalimestones) including schists, calcareous schists and calc-silicate rocks

3.2 DRIFT GEOLOGY PERMEABILITY

Drift deposits are divided into three main groups according to permeability (High, Moderate and Low), shown on the map in Figure 3. A fourth category covers a number of small areas across the map where drift geology is classed as 'unknown' on the 1:50 000 digital geology coverage.

Areas uncoloured on the drift geology permeability map are those areas where no drift cover is mapped.

Drift coverage in Moray is highly variable, and some of the drift mapping is relatively old and does not account for recent advances in drift typology. Many of the drift 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 much less permeable. The classifications used in the groundwater vulnerability index, described below, therefore represent the best attempt at interpreting such drift units in terms of their overall permeability. In most cases this has been done using a precautionary principle, whereby if a drift 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 is typically 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 therefore it is classified as highly permeable. Each drift 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 drift 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 drift geology is mapped as 'unknown'. The groups include the following units:

High permeability:

(Red on GIS)

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

Moderate permeability:

(Yellow on GIS)

- Head and hummocky glacial deposits
- Salt marsh and lacustrine deposits

Low permeability:

(Green on GIS)

- Glacial till diamicton[1] deposits
- Peat
- Glaciolacustrine clays and silts

[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 aquifer permeability 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. Formations of this type are, therefore, more vulnerable than others.

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 drift 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 drift.

These twelve 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 drift (till/boulder clay 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.

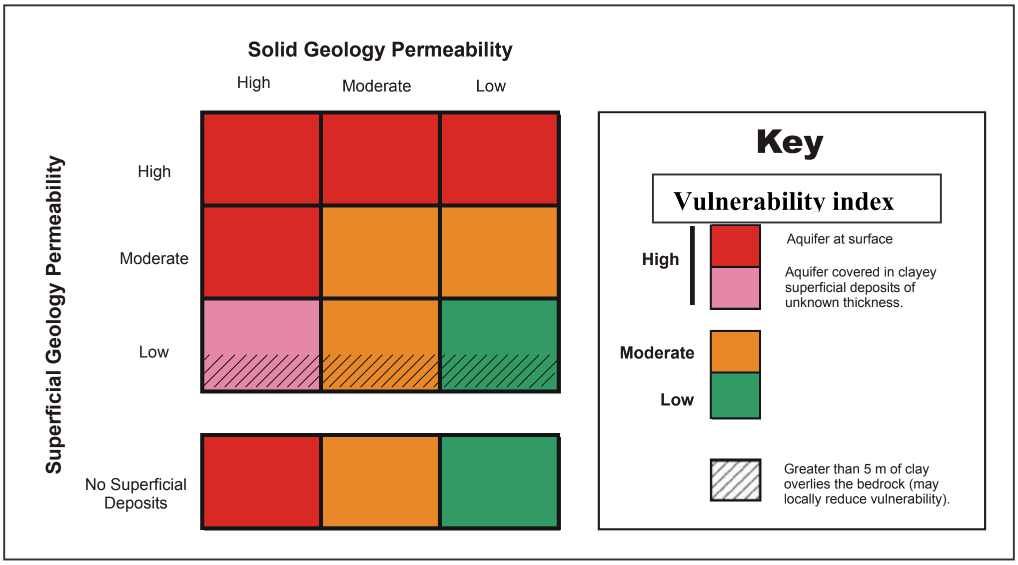

Figure 1 Illustration of groundwater vulnerability index categories based on bedrock and drift geology

The vulnerability categories are summarised in Figure 1. For anywhere in the Moray area where there is a highly permeable aquifer present beneath the ground surface, either bedrock or drift, the map is coloured red or pink to denote high vulnerability. Aquifers (bedrock or drift) of moderate permeability are coloured yellow to indicate an overall moderate vulnerability (except where a moderately permeable aquifer is combined with a highly permeable aquifer). Areas where low permeability formations (bedrock or drift) 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 drift 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 drift aquifers) without taking drift permeability into account.

5 Drift 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 drift sequence. Because the drift 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 drift, 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 metres thickness of clayey drift. 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 metres or more of clay is present in the drift sequence, not all drift aquifers will necessarily receive protection, as they may overlie much or all of the clay.

6 Water Boreholes

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

7 Copyright

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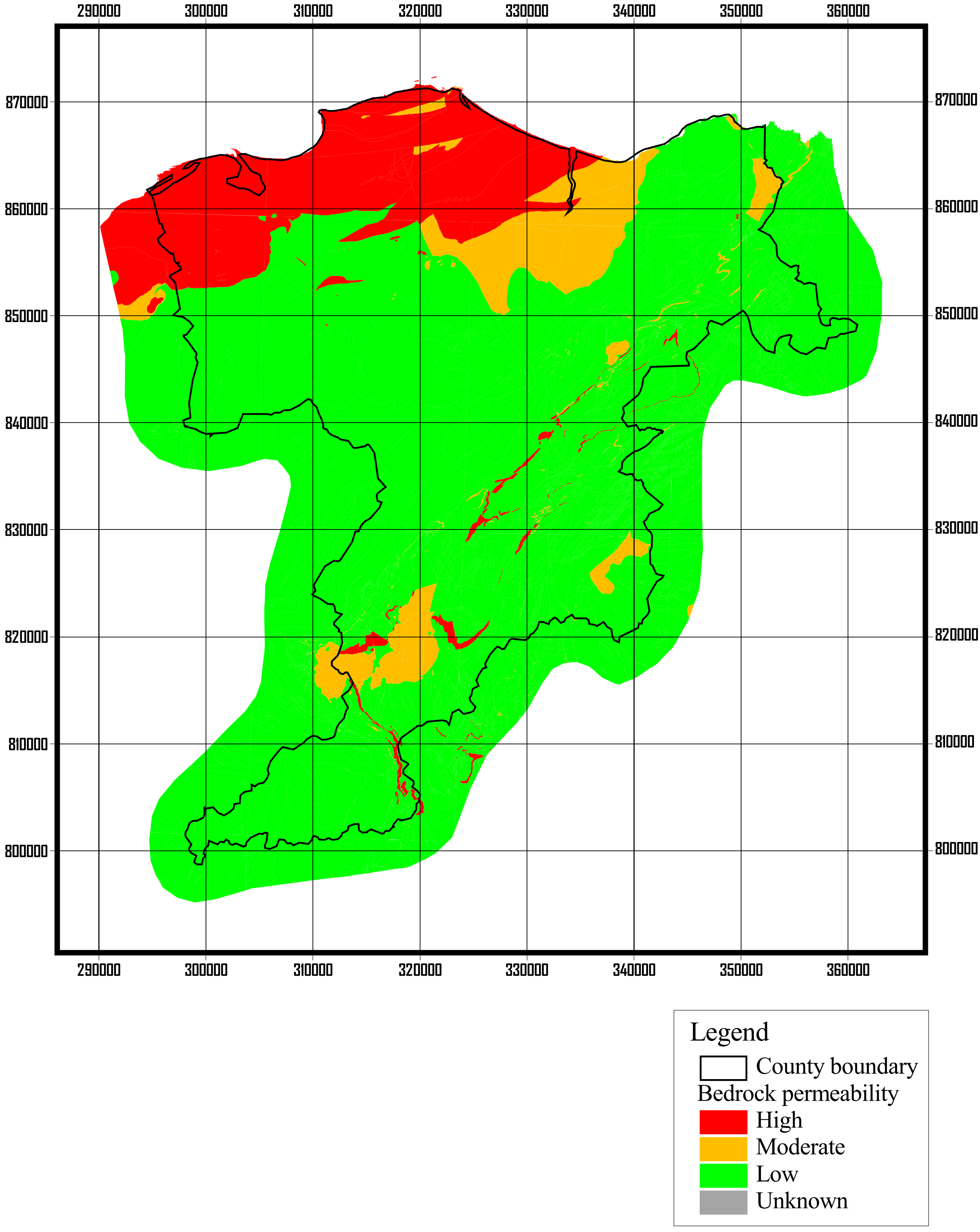

Figure 2 Moray - Bedrock Geology Permeability

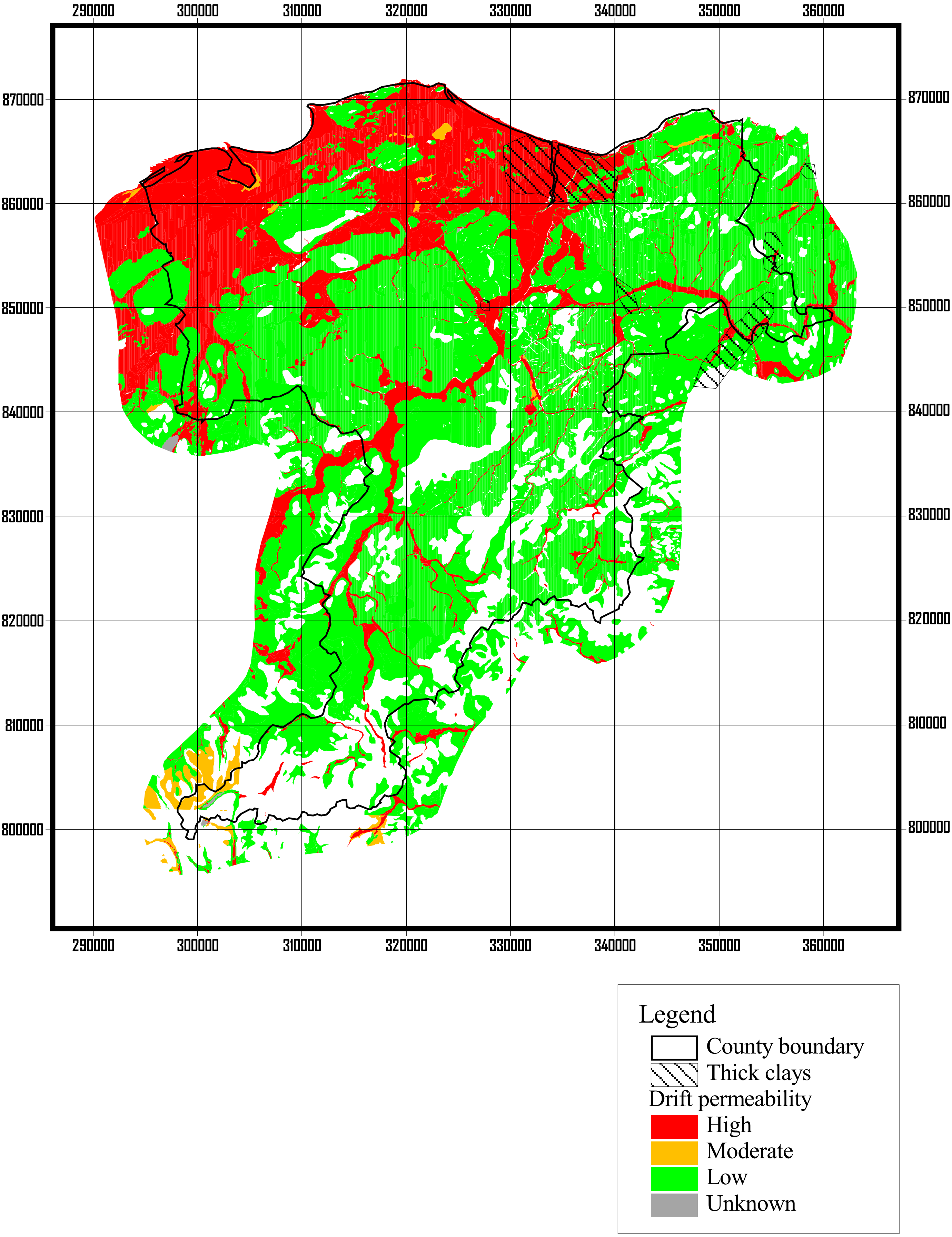

Figure 3 Moray - Drift Geology Permeability

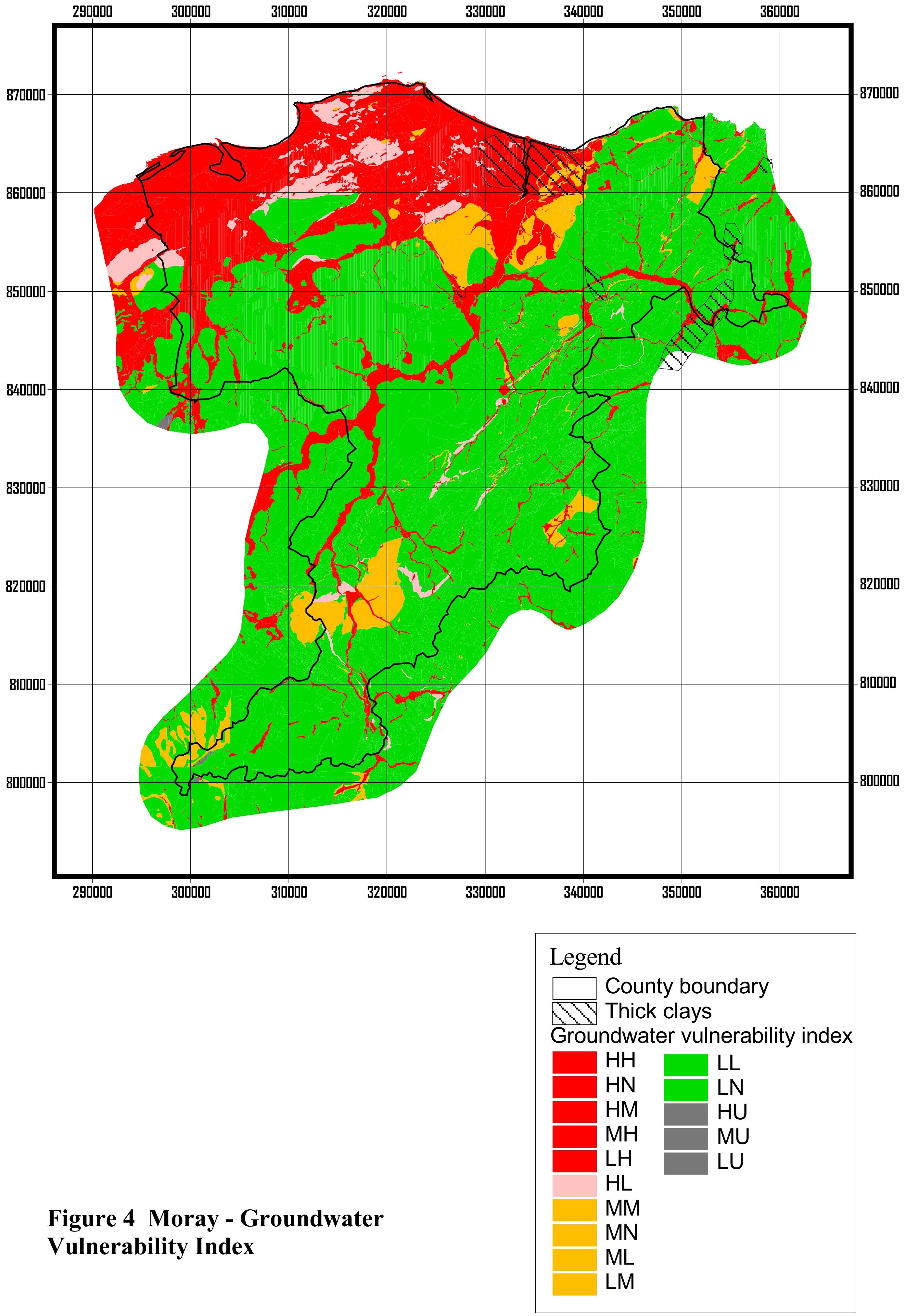

Figure 4 Moray - Groundwater Vulnerability Index

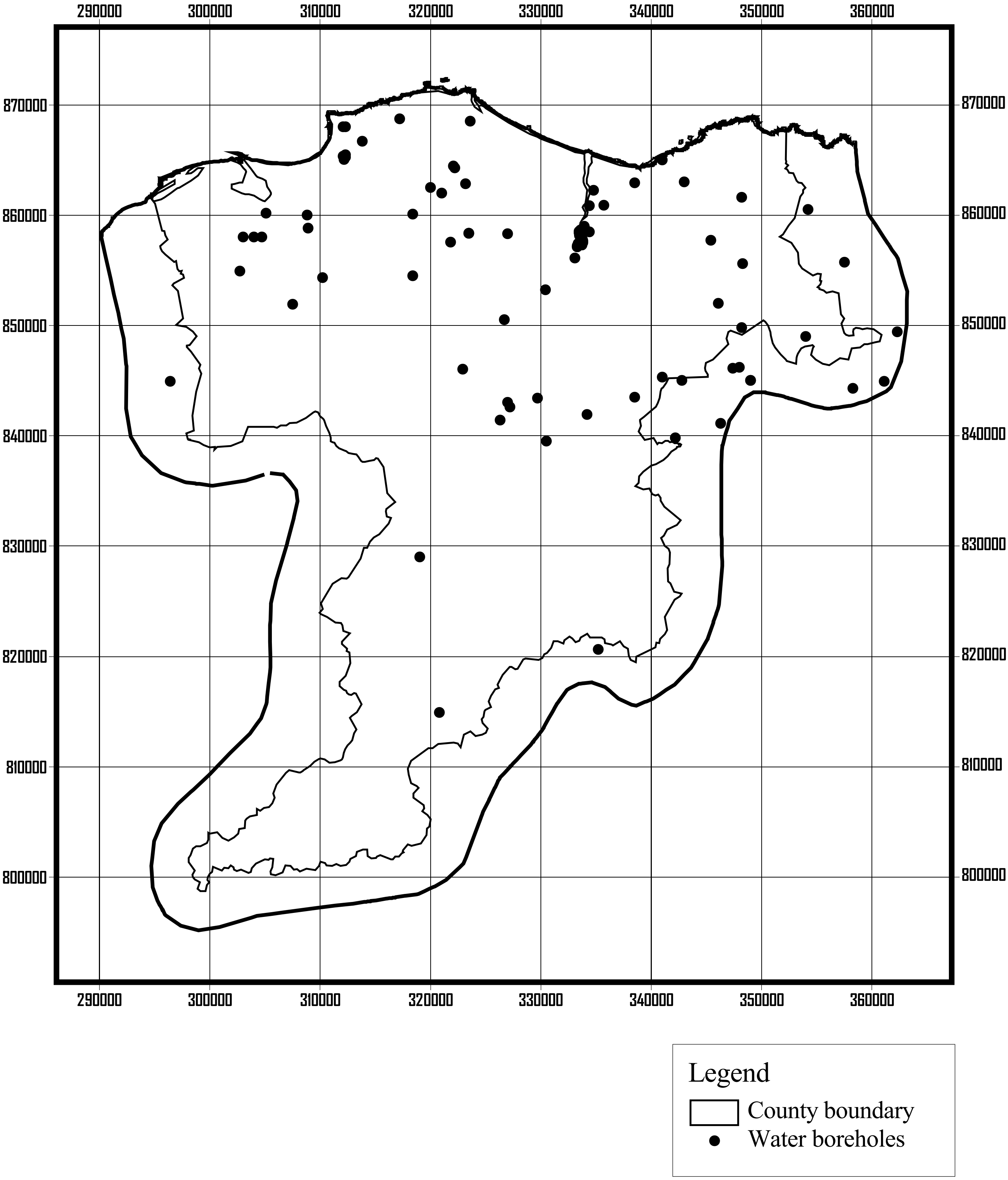

Figure 5   Moray - Location of known Water Boreholes