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NATURAL ENVIRONMENT RESEARCH COUNCIL

Explanatory notes to accompany the Groundwater Vulnerability Index GIS for Aberdeen City Council

Groundwater Systems and Water Quality Programme

A report for Aberdeen City Council

Research Report CR/03/056N

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B É Ó Dochartaigh

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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 Aberdeen City Council. The map is based on digital geological information for both bedrock and superficial (drift) deposits. It covers the whole of the Aberdeen City 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 and around Aberdeen, and provides a broad-based view of both the vulnerability of groundwater and the location of the more permeable aquifers in the area. The vulnerability index classification does not follow the methodology devised for published groundwater vulnerability maps used by the Scottish Environment Protection Agency (SEPA). The latter methodology includes an assessment of soil leaching potential; in addition, whereas the GIS-based methodology gives equal weight to bedrock and drift aquifers, on the earlier printed maps the bedrock formation takes precedence if it is highly permeable. The GIS-based methodology provides a broad-based view of both the vulnerability of groundwater and the location of the more permeable aquifers.

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 Geology

An overview of bedrock and drift geology is provided in the accompanying geological report.

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.

Most of the bedrock units in the Aberdeen area are metamorphic and igneous rocks of the Dalradian Supergroup and the Caledonian Igneous Supersuite, all of which have low permeability overall. These rocks can also have small fractures at shallow depths and at local scales, within which small groundwater flows can occur, so that a borehole in a low permeability rock may still be at risk of contamination from pollution carried in groundwater flowing along fractures. However, there is little risk of large volumes of polluted groundwater flowing long distances.

The only exceptions are conglomerates and sandstones of the Old Red Sandstone Supergroup, which crop out along the coast. These are classified as moderately permeable. They can store relatively large volumes of groundwater, and in many cases, moderately large groundwater flows through fractures in the rock matrix.

Drift deposits over most of the inland areas of the Aberdeen comprise low permeability glacial and lacustrine deposits, largely glacial till. Around the coast and along river valleys there are significant outcrops of high permeability drift deposits, in particular glaciofluvial sands and gravels, and alluvial deposits. Along the coast is a thin strip of mixed beach deposits which are likely to be moderately permeable.

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 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.

3.1 BEDROCK GEOLOGY PERMEABILITY

The bedrock has been divided into two major groups based on permeability (Moderate and Low), shown on the map in Figure 2. There is a third category to cover two very small areas on the coast where bedrock is classed as 'unknown' on the 1:50 000 digital geology coverage. 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 Devonian conglomerates and sandstones, which are expected to have moderate permeability overall, but may have zones which are extensively fractured, which have locally high permeability. The confidence code 0 is given to areas where the drift geology is mapped as 'unknown'. The groups include the following rock units:

Moderate Permeability:

(Yellow on GIS)

- Devonian conglomerates and sandstones (Old Red Sandstone Supergroup)

Low Permeability:

(Green on GIS)

- Dalradian metamorphic rocks
- Igneous rocks (largely Caledonian Igneous Supersuite)

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 the Aberdeen area is highly variable, and some of the older drift mapping 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 likely 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. Most units are coded 1 or 2. Lower confidence is given to drift units that are known to have varying permeability characteristics within the same unit; in particular, alluvium. 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)

- Glaciofluvial and alluvial deposits comprising sands and gravels, and mixed sequences which are expected to contain significant amounts of sand and gravel

Moderate Permeability:

(Yellow on GIS)

- Beach deposits comprising mixed sequences of clay and silt with significant sand and gravel
- Hummocky glacial deposits comprising diamicton[1], sand and gravel

Low permeability:

(Green on GIS)

- Glacial till
- Peat
- Lacustrine clays and silts

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 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). The vulnerability categories are summarised in Figure 1.

[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.

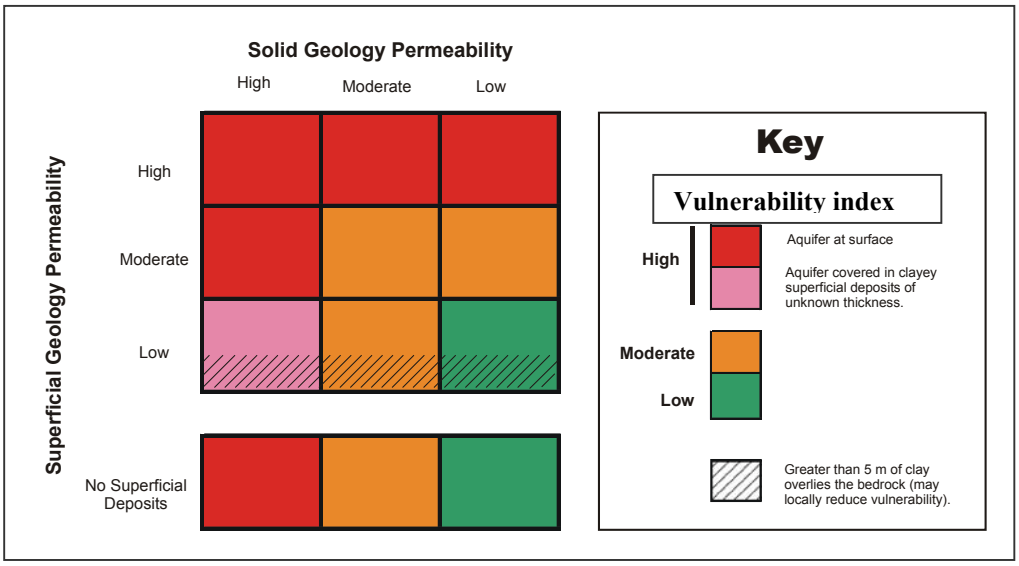

Figure 1 Illustration of groundwater vulnerability index categories based on bedrock and drift geology

For anywhere in the Aberdeen area where there is a highly permeable aquifer present beneath the ground surface (all highly permeable aquifers in the area are drift aquifers), the map is coloured red 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 bedrock aquifer is combined with a highly permeable drift 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 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

The final overlay, shown on the GIS maps as a 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 heterogenous, 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 the Aberdeen area, taken from the British Geological Survey Scottish Water Borehole database (Figure 5). There are only 2 such boreholes within the Aberdeen city boundaries. It is likely that other water boreholes exist, but these are not registered with the British Geological Survey.

7 Copyright

The digital line work and vulnerability classifications on the GIS are the intellectual property of the British Geological Survey and the use of the GIS is subject to a licence agreement between the Council and BGS. It follows that the GIS should only be used by Aberdeen City Council for internal purposes and, therefore, should not be given or lent to a third party.

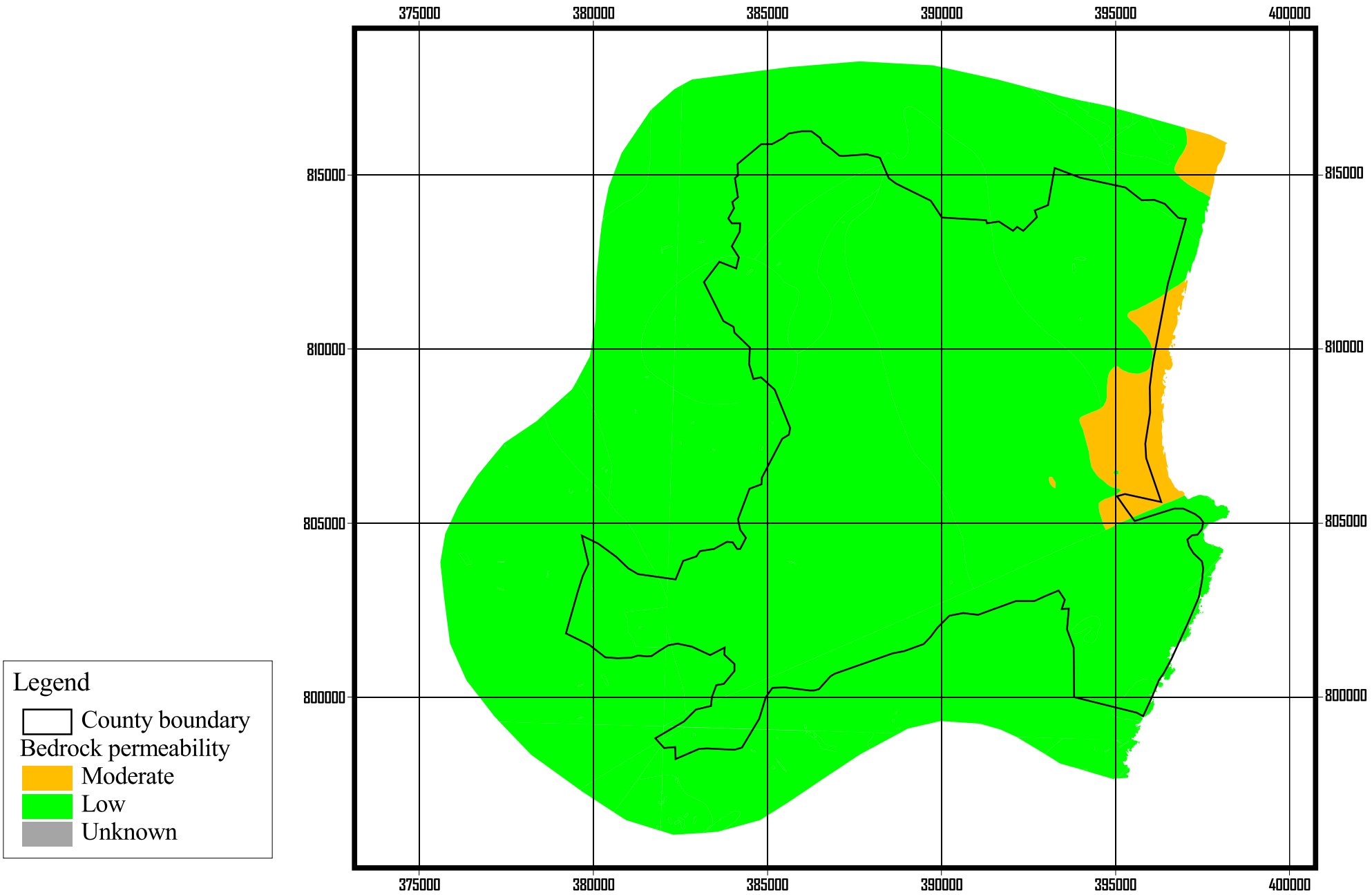

Figure 2 Aberdeen - Bedrock Geology Permeability

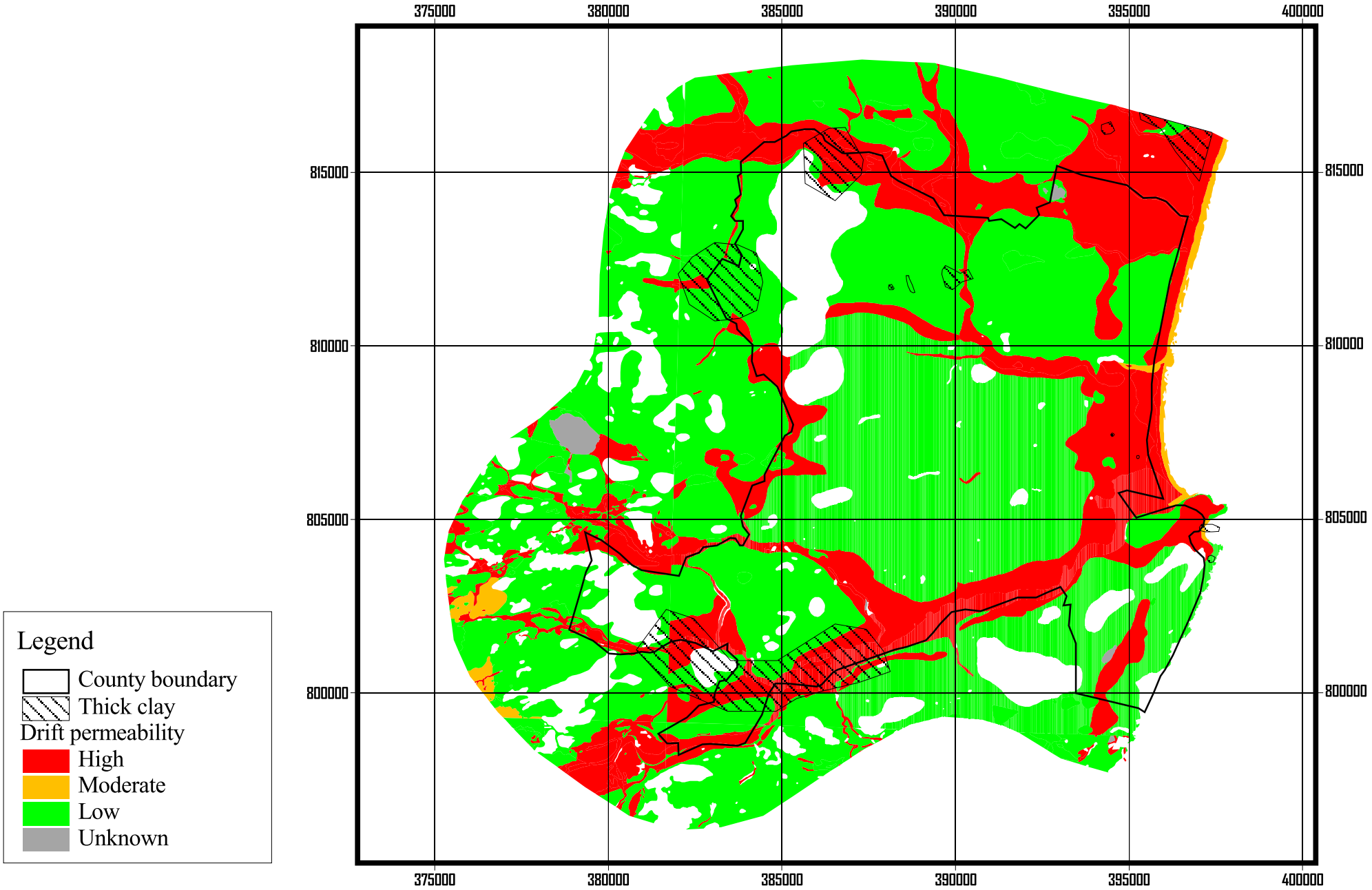

Figure 3 Aberdeen - Drift Geology Permeability

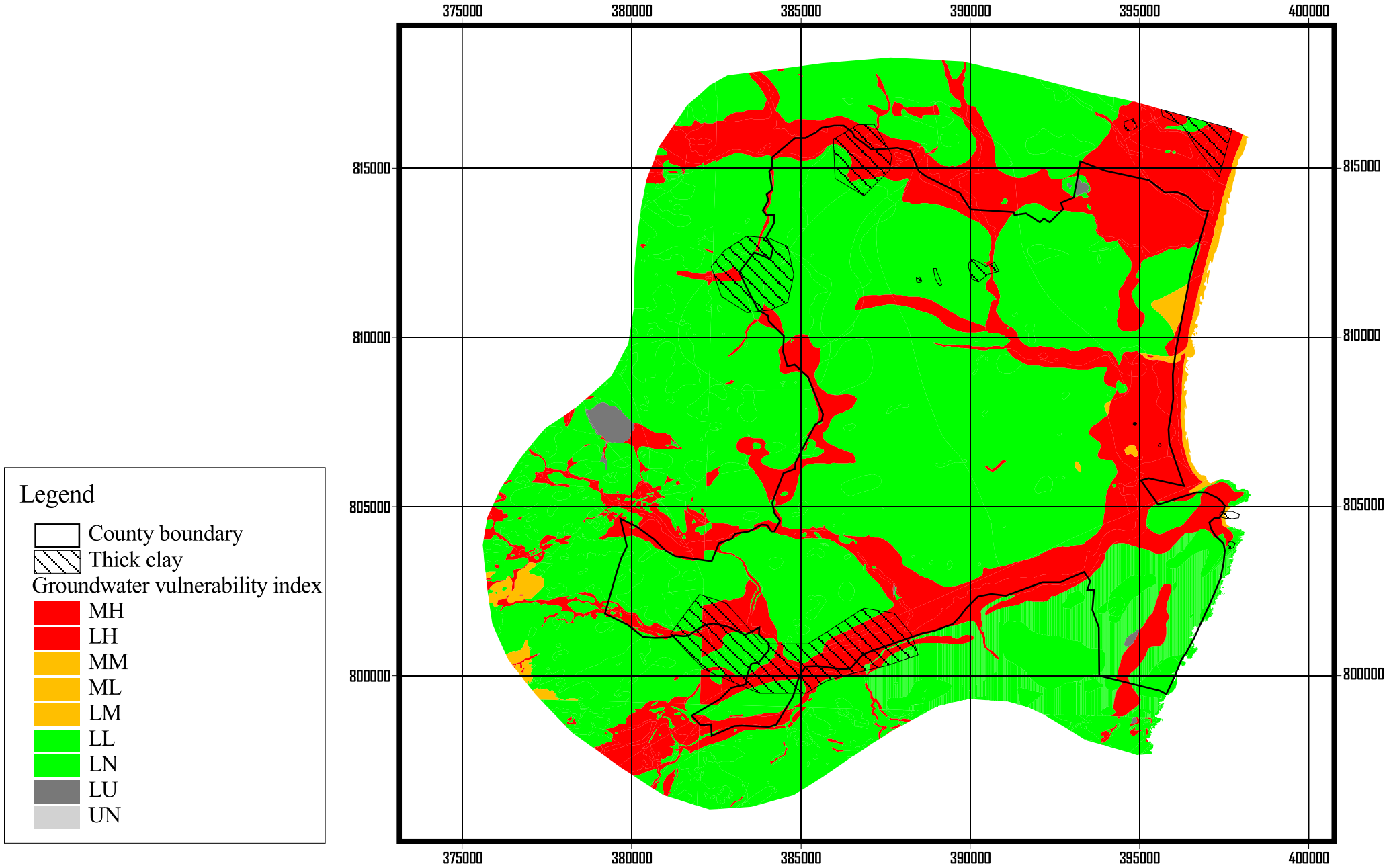

Figure 4 Aberdeen - Groundwater Vulnerability Index

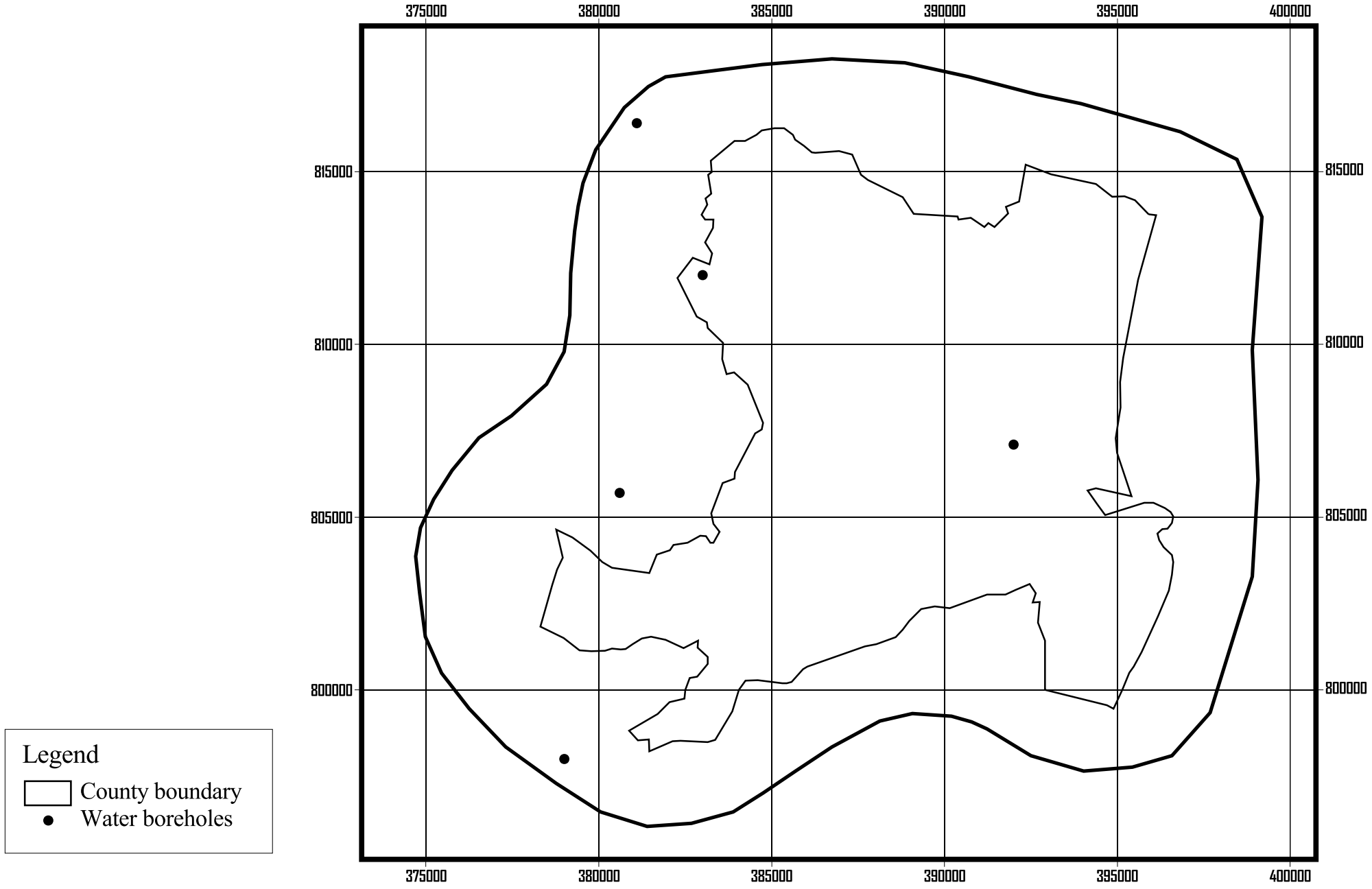

Figure 5 Aberdeen - Location of known Water Boreholes