Explanatory notes to accompany the Groundwater Vulnerability GIS for Falkirk Council

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1 Introduction

These notes are designed to accompany the ArcView geographical information system (GIS) format aquifer vulnerability maps produced by the British Geological Survey (BGS) for Falkirk Council. The maps are based on digital geological information for both bedrock and superficial deposits. They cover the whole of the Falkirk Council area plus a 3 km ‘buffer zone’ around the area to account for peripheral data and allow for more meaningful interpretation at Council boundaries.

The purpose of the GIS maps is to show, in broad terms, the vulnerability of groundwater to contamination. 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, while less permeable formations are still of local importance. Groundwater also provides the baseflow to surface watercourses. Groundwater is typically of high quality and often requires little 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, and therefore, the prevention of pollution is important.

The approach and classifications used in the production of the groundwater vulnerability GIS 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. In this case, there is a wide variety of geological strata and potential pollutants, and the classification used 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 conditions at the surface of the solid and/or drift geology and, therefore, 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 used to determine the vulnerability of the groundwater.

The methodology used has not included consideration of the soils. The overall permeability of each geological unit has been interpreted, enabling an assessment of the vulnerability of groundwater occurring under the Falkirk area. The vulnerability classification does not follow the methodology devised for published groundwater vulnerability maps used by the Scottish Environment Protection Agency (SEPA). The latter methodology includes a system in which superficial geology and soil data are used to produce a series of detailed vulnerability classifications. The current methodology, however, provides a broad-based view of both the vulnerability of groundwater and the location of the more permeable aquifers under the Falkirk area.

The data used for the compilation of the vulnerability GIS use part of the 1:50,000 DigMap solid and drift geology coverage. The ‘thick drift’ polygons found in the GIS were interpreted and drawn based on BGS borehole records. The GIS should not be used at scales larger than 1:50,000.

There are three themes within the GIS: Solid Geology Permeability, Drift Geology Permeability and Aquifer Vulnerability, formed by combining solid and drift geology permeability.

2 Overview of solid and drift geology

The oldest rocks in the Falkirk district are subaerial volcanic lavas and associated igneous intrusions of early Carboniferous age, now seen only in the northwest of the area, although known to extend eastwards where they are buried under younger strata. Younger lavas and volcanic ashes also occur at outcrop in the vicinity of the Bathgate Hills in the east of the district.

The solid geological units that crop out at the surface across the rest of the district are all sedimentary rocks of Carboniferous age, consisting of repetitive 'cyclic' sequences of sandstone and mudstone with limestones, coals, ironstones and seatrocks (fossil soils). Most of the units contain relatively thick (over 10 metres) sandstone beds interspersed with bands of mudstone, thinner sandstone, limestone and other sedimentary types of varying thicknesses. They were laid down in an extensive fluvial and fluvio-deltaic system that carried sediment from the Caledonian mountains to the north and deposited them near, and from time to time under sea level in a subsiding basin floored by the older igneous rocks. The units include the economically valuable Limestone Coal Formation and the Coal Measures. The Carboniferous succession shows the effects of intermittent tectonic activity, being punctuated by unconformities. After deposition, igneous (quartz-dolerite) sills and dykes were intruded into the sedimentary sequence during late Carboniferous times (Cameron et al 1998, Forsyth et al 1996).

During the Quaternary, the entire region was covered on several occasions by ice sheets, which laid down extensive deposits of till (boulder clay) across much of the district, and fluvioglacial sand and gravel deposits on valley bottoms and sides. Changes in sea level after the disappearance of the ice caused the accumulation of shallow marine deposits, which form raised beaches bordering the Forth estuary (Cameron et al 1998, Forsyth et al 1996).

3 Aquifer permeability and 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. The rock units with the highest permeability in the Falkirk district are the Passage and Upper Limestone formations, which contain a high proportion of sandstone, allowing for the storage and transmission of significant quantities of groundwater. Most of the other Carboniferous sedimentary sequences in the region are considered to be more moderately permeable, because sandstone units tend to be thinner and/or less abundant, and because mudstone bands are often more common, acting as barriers to vertical groundwater movement. Natural groundwater quality in all Carboniferous sedimentary rocks in the district is often poor (Cameron et al 1998, Forsyth et al 1996).

In most metamorphic and igneous rocks there is little or no primary (intergranular) permeability, and groundwater storage and flow is confined to weathered zones and/or fractures, which are generally thin and/or limited in extent, making these rocks poor aquifers. Examples in the Falkirk district are volcanic basalts and quartz-dolerite igneous intrusions. An exception is bedded ash deposits, which occasionally show relatively high intergranular porosity.

Superficial deposits vary in permeability from coarse gravels and blown sand, which are highly permeable, to sandy silts, which may have moderate permeability, to virtually impermeable lacustrine, marine or glacial clays. As much of the district is covered by glacial till, relatively little groundwater is seen in superficial deposits, except in sands and gravels which occur as surface spreads and as infill in 'buried channels' running under the Carron valley and the Forth estuary (Cameron et al 1998, Forsyth et al 1996).

The groundwater vulnerability map is based on the general assumption that where more highly permeable formations outcrop at the ground surface, water can infiltrate at a faster rate to the water table compared to less permeable formations. Where less permeable formations outcrop at the surface, such as clayey drift deposits or crystalline igneous or metamorphic bedrock, 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 as a barrier to the downward movement of pollutants, and thus as a protective barrier. 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 till but also peat and marine clays) 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.

The detailed identification, location, thickness and extent of any 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, and not the complete picture.

3.1 SOLID PERMEABILITY

The solid bedrock has been divided into three main groups based on permeability (High, Moderate and Low), shown on the map in Figure 2. The groups include the following rock units:

High Permeability:

(Red on GIS)
Passage Formation and Upper Limestone Formation - Carboniferous cyclic sedimentary rocks (largely sandstone)

Moderate Permeability:

(Yellow on GIS)
Carboniferous cyclic sedimentary sequences, including the Coal Measures and Limestone Coal Formation.

Low Permeability:

(Green on GIS)
Carboniferous volcanic basalts, quartz-dolerites, tuffs and agglomerates

3.2 DRIFT PERMEABILITY

Drift deposits are also divided into three main groups according to permeability (High, Moderate and Low), shown on the map in Figure 3. There are two further categories: one to cover areas where there is no drift cover, and one to cover areas where the drift geology is classed as ‘unknown’ on the digital geology coverage. These latter areas are dominantly made ground.

The drift coverage in the Falkirk district is highly varied, 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 mapped as a single unit. Parts of such a unit may therefore be relatively permeable, while other parts are largely impermeable. The classifications used in the groundwater vulnerability GIS and map and described below 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, so that, for example, alluvial clays, sands and gravels, which are thought to have largely low permeability but which may contain significant sand and gravel at certain locations, are classified as having moderate permeability. Another example is alluvial sands or gravels with silts and clays, thought to be largely moderately permeable but with pockets of highly permeable sands or gravels, which are classified as having overall high permeability.

The groups include the following units:

High permeability:

(Red on GIS)
Alluvial, glaciofluvial, marine and beach sands and gravels
Alluvial and marine sands and gravels with varying amounts of silt and clay
Talus (rock fall) gravels

Moderate permeability:

(Yellow on GIS)
Alluvial silts and clays with varying amounts of sand and gravel

Low permeability:

(Green on GIS)
Glacial till (boulder clay)
Lacustrine, intertidal, marine and alluvial clays and silts
Peat

4 The groundwater vulnerability map

The basic assumption made in defining the three vulnerability categories shown in the GIS and printed map (see Figure 4) is that that high aquifer permeability equates with high groundwater vulnerability: 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 map incorporates both the solid and drift permeability classifications previously described to produce twelve combinations of solid 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 (dominantly made ground)

The first letter in the code refers to the solid (bedrock) permeability and the second letter to the drift permeability. For example, 'HM' refers to High Permeability Solid rock overlain by Moderate Permeability Drift.

These twelve 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.

The vulnerability categories are summarised in Figure 1. Anywhere in the Falkirk 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 reduced permeability, the risk, and therefore vulnerability of groundwater, is considered to be lower.

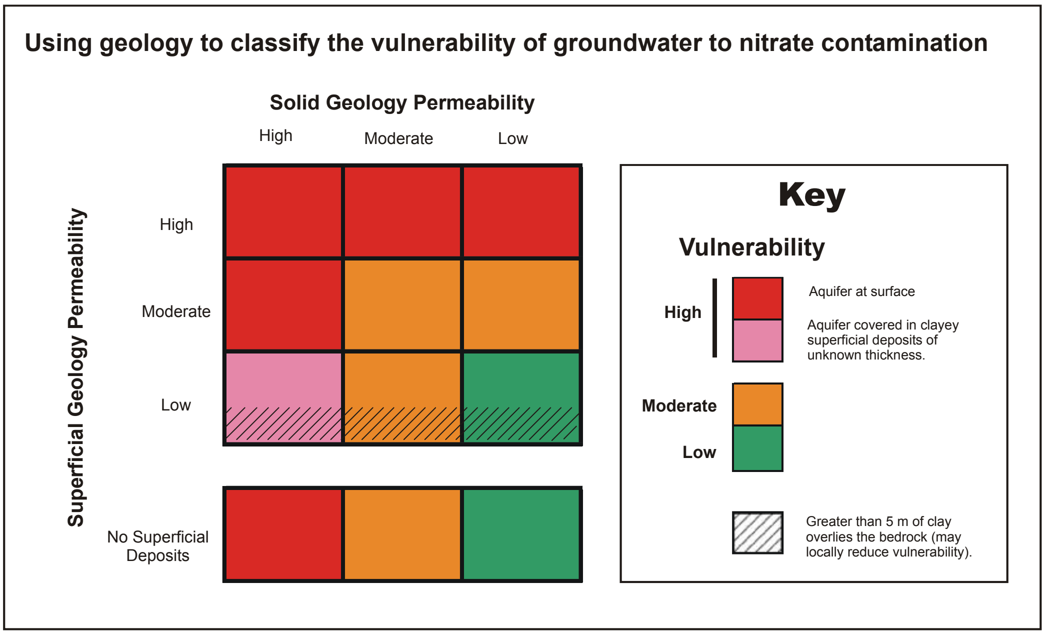

**Figure 1	Illustration of groundwater vulnerability categories based on solid and drift geology**

There are a number of small areas where drift geology is unknown (see section 3.2). These areas are distinguished on the groundwater vulnerability map because it is impossible to determine groundwater vulnerability (in either solid or drift aquifers) without taking drift permeability into account. There are also a few very small areas where solid geology is unknown (see section 3.1).

5 Drift Thickness

The final overlay shows where there is a strong probability that greater than 5 metres thickness of clay is present in the drift sequence, shown as a transparent hatching. Because the drift sequence can be highly heterogenous, high permeability sands and gravels may outcrop 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 may make it impossible at present to identify the presence of clays. If more permeable drift deposits (e.g. sands and gravels) overlie the thick clay layer, they will not be protected.

6 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 Falkirk Council for internal purposes and therefore should not be given or lent to a third party.

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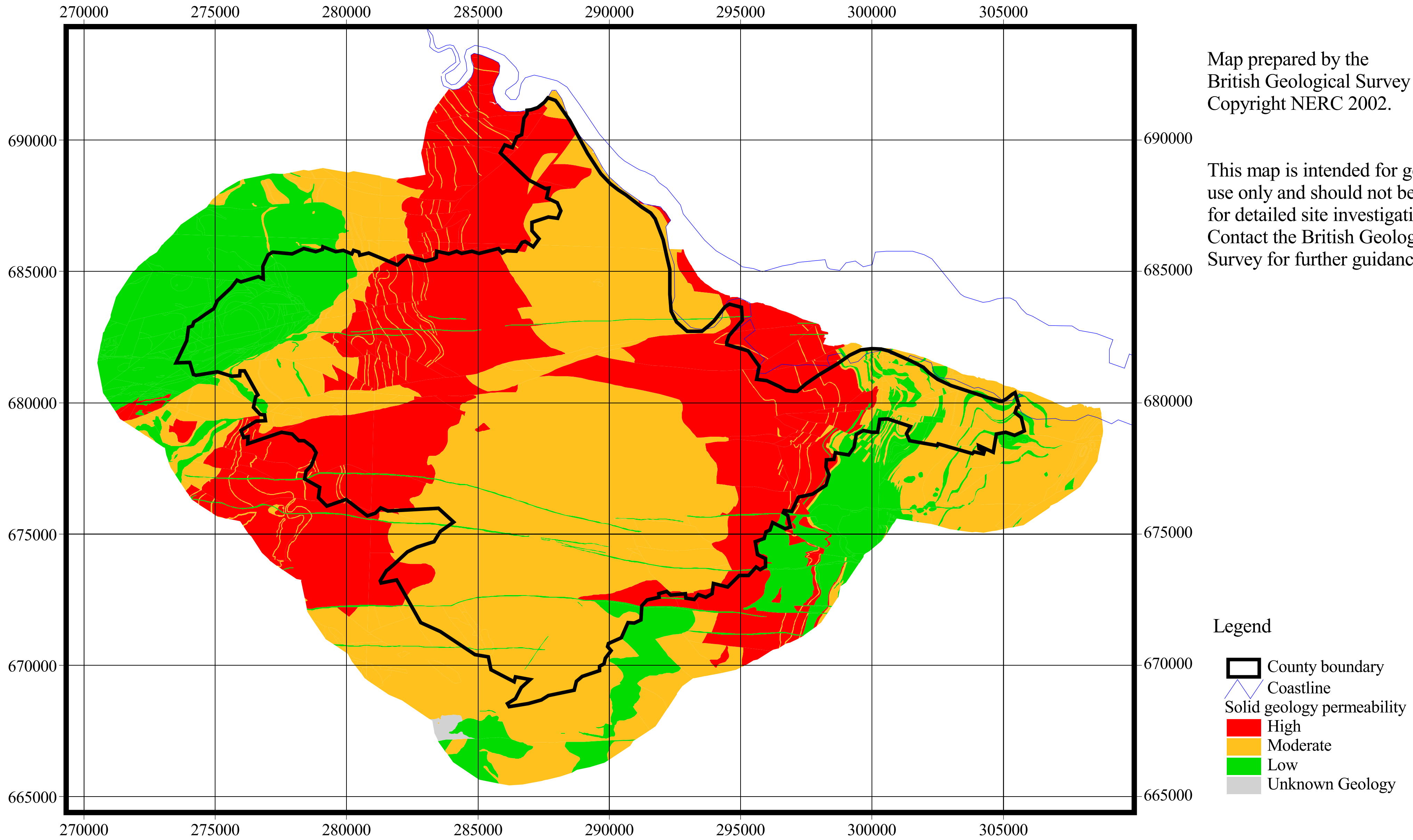

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Figure 2 Falkirk Solid Geology Permeability

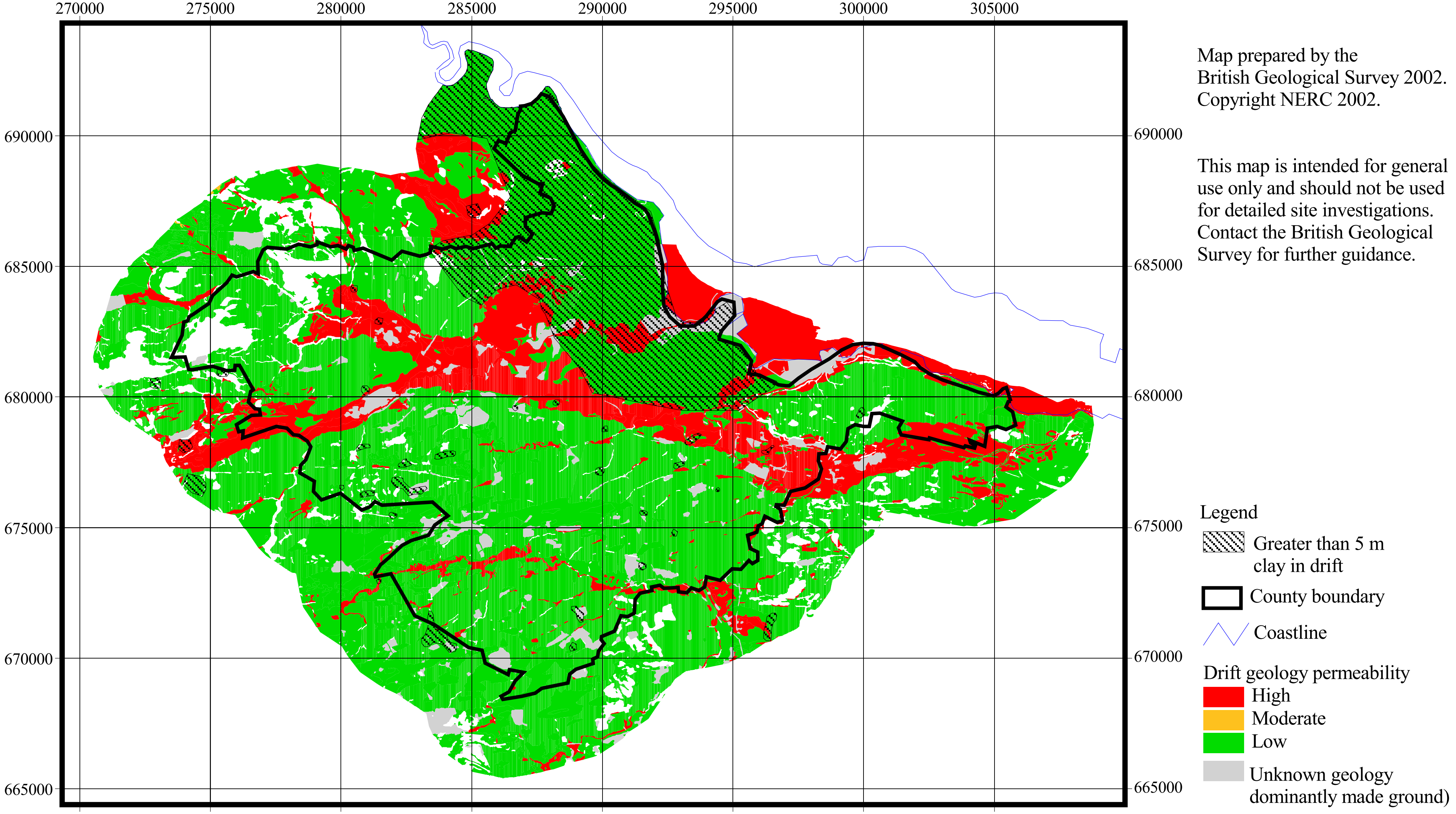

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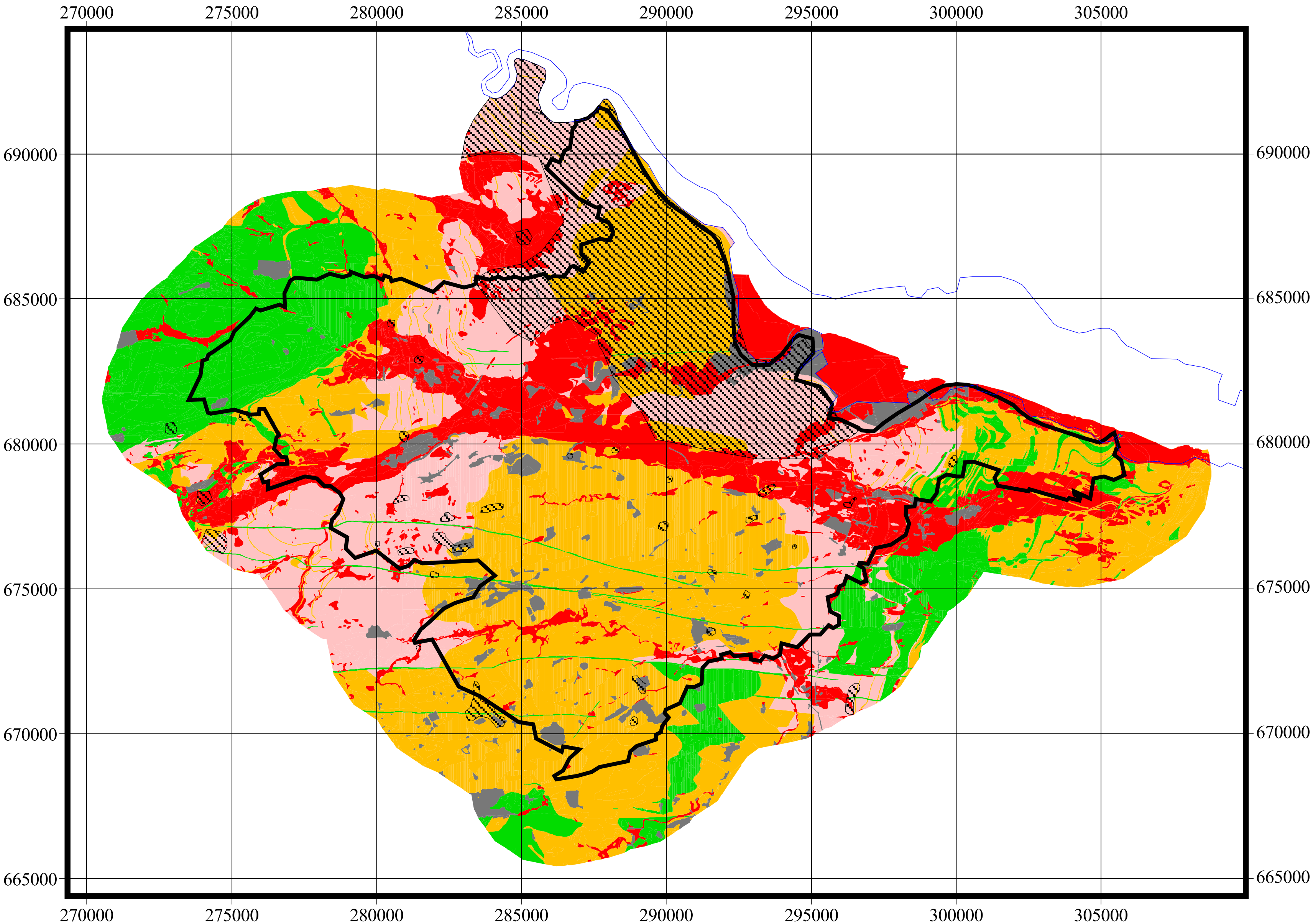
Figure 3 Falkirk Drift Geology Permeability



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Legend

- Greater than 5 m clay in drift
- Coastline
- County boundary

Groundwater vulnerability

- HH HN MH LH
- HL
- LL LN
- MM MN ML LM
- UL
- HU MU LU UU

The first letter in the vulnerability combination corresponds with Solid Geology permeability. The second letter corresponds with Drift Geology permeability.

H = High
M = Moderate
L = Low
U = Unknown Geology
(areas of unknown drift geology are dominantly made ground)

Figure 4 Falkirk Groundwater Vulnerability