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# A groundwater vulnerability screening methodology for Northern Ireland

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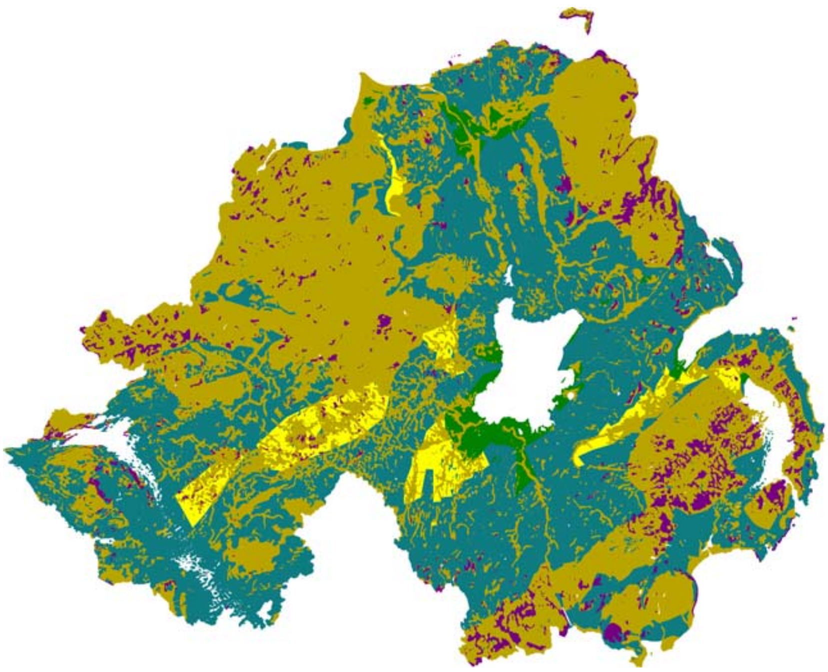
Commissioned Report CR/05/103N



BRITISH GEOLOGICAL SURVEY

GROUNDWATER MANAGEMENT PROGRAMME

COMMISSIONED REPORT CR/05/103N

# A groundwater vulnerability screening methodology for Northern Ireland

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# Foreword

This report was commissioned by the Environment and Heritage Service, an Agency within the Department of Environment, Northern Ireland. The groundwater vulnerability methodology developed under this project is intended to reflect the geological and hydrogeological conditions present in Northern Ireland, based on available data. The methodology was adapted from that originally derived and applied to Scotland under a SNIFFER funded project (WFD28) (Scotland and Northern Ireland Forum for Environmental Research). The GIS map produced using the methodology is intended to assist with determining the risk of groundwater contamination within groundwater bodies in Northern Ireland, as required by the EC Water Framework Directive (2000/60/EC).

# Acknowledgements

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The key concepts and principles of the methodology were originally devised through the SNIFFER project WFD28 and specific thanks goes to the project team associated with that work.

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# Summary

A requirement of the EU Water Framework Directive is the assessment of the risk of groundwater contamination within those groundwater bodies identified in each Member State. In order to carry out the risk assessments, knowledge of the vulnerability of groundwater is necessary. The report is in two parts: first, a description of the groundwater screening methodology is made. This methodology was originally developed for use in Scotland, but has now been adapted for use in Northern Ireland, taking into account local data availability. Second, the creation of the GIS-based 1:250 000 scale groundwater vulnerability map using suitable data is described.

Groundwater vulnerability is defined as the tendency and likelihood for general contaminants to reach the water table after introduction at the ground surface. All groundwater is to some degree vulnerable and the screening tool produced for the current project is designed to reflect the ability of contaminants to reach the water table surface across Northern Ireland. It is not intended as a complete solution to risk assessment and should be used as a regional guide to the possible degree of specific site investigation required at any locality.

The screening methodology applies to the situation where contamination from the land surface leaches vertically downwards to the water table within the uppermost aquifer at a particular locality. The groundwater vulnerability assessment is, therefore, influenced by several factors that relate to the pathway element of a typical hazard – pathway – receptor risk assessment. In this case, the pathway is characterised by the geological and hydrogeological characteristics of the soil layer, the underlying superficial deposits and bedrock.

The pathway between the ground surface and the water table can affect the degree of attenuation of contaminants. Factors that can influence attenuation include:

- The permeability and clay content of the superficial deposits.
- The thickness of the superficial deposits.
- The mode of groundwater flow in bedrock aquifers (fracture or intergranular flow).
- The permeability and clay content of intergranular bedrock aquifers.
- The depth to the water table in both superficial and intergranular bedrock aquifers.

It is the above factors that determine the vulnerability classification. Vulnerability has been divided into five categories, with Class 1 areas having the lowest risk of groundwater pollution and Class 5 the highest.

One of the main principles adopted for the current methodology was how attenuation could be affected by the nature of groundwater flow. It is assumed that only in geological deposits where there is significant or total unsaturated intergranular groundwater flow that attenuation can occur. Where contaminants move to the water table through unsaturated fractured bedrock, the methodology assumes that no attenuation of pollutants can take place.

It is the recognition of the hydrogeological characteristics within the pathway instead of the ‘importance’ of a particular aquifer that results in the final vulnerability map of Northern Ireland showing significant areas of Classes 4 and 5 within upland and certain other regions. This reflects the common occurrence of igneous and metamorphic rocks within these areas where the potential for attenuation of contaminants in the pathway is very limited.

# 1 Introduction

Groundwater in Northern Ireland is a valuable resource. It provides private supplies to many small dwellings, farms and industrial premises and is also a source for public water supply. Certain terrestrial ecosystems are fed by groundwater from springs. During low rainfall periods, groundwater helps to maintain river flows via baseflow discharge.

Deterioration of groundwater quality rarely occurs naturally and is usually associated with human activity. The leaching of wastes and chemicals from the land surface vertically down into the ground can occur as a result of agricultural practices and the disposal of domestic and industrial wastes. Assessing the degree to which natural groundwater quality is affected by human activities is one of the objectives of the Water Framework Directive (WFD). The Directive requires groundwater systems to be divided into groundwater bodies, for which assessments of quantitative and chemical status are required. Assessments of the degree to which bodies are at risk of failing to meet WFD Article 4 objectives are required, along with the design of new monitoring regimes and, where appropriate, pollution prevention measures.

The tendency and likelihood for general contaminants to reach the water table after introduction at the ground surface is termed groundwater vulnerability, a term in use for more than 30 years. In Scotland, the development of a groundwater vulnerability screening methodology (SNIFFER, 2004) has been a necessary requirement of the approach favoured by the Scottish Environmental Protection Agency (SEPA) to the WFD risk assessment process. The GIS-based map, with a working scale of 1:100,000, is intended only to assess the vulnerability of the vertical pathway from a potential hazard at the ground surface to the water table. Vulnerability maps provide a regional screening tool to highlight areas of comparatively higher risk and to help scope the amount of detailed site investigation required at a particular site. The new Scottish map is designed for flexibility within a suite of maps to link land use with the vertical pathway and ‘downstream’ lateral pathways to different receptors. The vulnerability methodology is, therefore, one stage in the process of assessing the overall risk of impact for a groundwater body. The methodology derived for Scotland has been adapted for use in Northern Ireland, for similar purposes. For Northern Ireland, only digital geological data at 1:250 000 scale are currently available for the entire region.

One of the key differences between the WFD methodology and that of previous aquifer vulnerability assessments, such as the Environment Agency/BGS 1:100,000 scale maps of England and Wales (Palmer and Lewis, 1998) (Palmer *et al*, 1995) is that the latter are based on recharge potential. Unlike the EA/BGS work, this methodology does not attempt to address issues relating to aquifer connectivity, recharge or the groundwater resource. It is intended to provide specific information on the vertical pathway to the water table for use only as part of the WFD characterisation process. It is not intended to be a complete solution to risk assessment and site suitability studies, but, when combined with land use and aquifer maps, can provide guidance on a regional basis, leading, in many cases, to more specific site assessments as part of the risk description process. Importantly, the vulnerability layer developed here differs in some aspects from the existing regional vulnerability map for Northern Ireland (DoENI, 1994) where the permeability (and by implication resource potential) of the geological formations was a significant factor in determining vulnerability class.

**The project aims are:**

- To adapt the groundwater vulnerability screening methodology initially developed for use in Scotland, for use in Northern Ireland for WFD assessments:

- To create a GIS-based groundwater vulnerability map of Northern Ireland at 1:250 000 scale.

This report includes discussion of the key concepts of groundwater vulnerability along with a description of the screening methodology and procedure, devised to create the vulnerability map.

# 2 The need for groundwater vulnerability mapping

Deterioration of groundwater quality rarely occurs naturally and is usually caused by the impact of human activity. There are two main reasons for deteriorating groundwater quality:

1. Where groundwater is abstracted, possibly resulting in the intrusion of saline water, or groundwater not suitable for human consumption, into an aquifer.
2. Direct contamination through the leaching of wastes and chemicals from the land surface or underground sources such as mines, vertically down into an aquifer.

Groundwater vulnerability assessments relate to the second scenario – contamination from the land surface. Land use activities that may pose a threat to groundwater quality may be classed broadly into two categories:

1. *Major activities with an infrequent occurrence:* these have a low-frequency distribution, but may have the potential to release large amounts of contaminants at high concentrations. Such sites include landfills and developments in urban areas.
2. *Minor activities with frequent occurrence*: these may be more widespread than category 1 activities, but contaminant loading is less. Examples include slurry spreading and septic tank discharges.

Groundwater vulnerability maps provide information on the pathway followed by pollutants resulting from these activities to the water table and are used, along with an assessment of the hazard and consequences of pollution occurring, to help calculate the degree of risk of contamination created by such activities. Vulnerability maps provide a regional screening tool that enables areas of comparatively higher risk to be identified and help scope the amount of detailed site investigation required at a particular site.

Groundwater vulnerability assessments can have several uses.

1. Policy analysis and development.
2. To prioritise aquifer and site investigations.
3. To inform planning decisions.
4. To improve awareness of groundwater in general.

The vulnerability assessment process is itself instructive by creating an awareness of geological and hydrogeological characteristics, even without direct application. At scales of 1:250 000 and less the maps are schematic, whilst for operational uses (e.g. to inform land use decisions), more detail is required and 1:100 000 and 1:50 000 maps are generally constructed.

Groundwater vulnerability maps, by their very nature provide approximate descriptions of ground conditions. Therefore, their design and development must be practical and pragmatic. The US Natural Research Council (1993) quoted three 'laws' of groundwater vulnerability to warn against misuse of such maps:

1. All groundwater is to some degree vulnerable.
2. Uncertainty is inherent in all vulnerability assessments.
3. There is risk that the obvious may be obscured and the subtle indistinguishable.

Bearing in mind these three laws, the vulnerability map screening tool produced for the current project is not intended to be a complete solution to risk assessment and site suitability studies. It is intended to provide guidance on a regional basis only and should lead, in many cases, to more specific site assessments as part of the risk evaluation process.

This groundwater vulnerability methodology, developed for use by the Environment and Heritage Service (EHS) is intended to contribute to groundwater body characterisation and risk assessments. The vulnerability map has been developed specifically to help characterise the strata overlying groundwater bodies, and as a key component of the source-vertical pathway-receptor model of assessing risk in the context of WFD objectives. The horizontal pathway component in the saturated zone of an aquifer that leads to other receptors, such as a groundwater-dependent surface ecosystem, is not addressed by this methodology. Separate aquifer maps have been developed to help characterise this pathway.

# 3 Basic concepts of groundwater vulnerability

## 3.1 DEFINITIONS

Groundwater vulnerability is a term that has been in use for more than 30 years. Several attempts have been made to define it. A general definition is given by the US Natural Research Council (NRC, 1993)

"Groundwater vulnerability: the tendency and likelihood for [contaminants] to reach [a specified position in the groundwater system] after introduction at [some location]."

Most other definitions replace the phrases in brackets with specific terms. The most commonly used (e.g. U.K and most other European countries) is:

"The tendency and likelihood for general contaminants to reach the water-table after introduction at the ground surface"

For the purposes of this project (a screening tool for the WFD) groundwater vulnerability was defined as a component of the pathway element in the context of the hazard-pathway-receptor model commonly used for risk assessment work:

- *Hazard*: land use activities, including waste disposal, urban development, farming, and mining that pose a threat to groundwater.
- *Pathway*: all material between the hazard and the receptor is part of the pathway. It occurs from the point of release of contaminants to the uppermost 'main' water table. The properties of the pathway determine the vulnerability rating.
- *Receptor*: In the case of WFD vulnerability mapping, the receptor is the 'main' water table within an aquifer vertically below the hazard. Once contamination has reached this initial target, subsequent receptors within a particular groundwater body could include abstraction boreholes and surface water ecosystems that are fed by groundwater. For the purposes of this project, the receptor is the principal water table in an aquifer.

With this definition, the vulnerability of an aquifer to pollution is dependent on the intrinsic characteristics of the unsaturated layer separating the saturated strata from the ground surface, and is largely independent of the transport properties of specific contaminants. This intrinsic vulnerability concept has limitations because every contaminant behaves differently. Some are poorly soluble, or degrade rapidly in the soil. Others are subject to chemical reactions in the underlying unsaturated zone. It would be ideal for many purposes to have a measure of specific vulnerability for each individual contaminant. However, this is generally impractical.

Five vulnerability classifications have been distinguished in the project, based on those suggested by Foster (1998) after reviewing the lessons learned from the first series of groundwater vulnerability maps designed in Europe. The five classes denote general and relative degrees of vulnerability. In the most vulnerable areas, groundwater is vulnerable to most types of pollutant and contamination is rapid. In the least vulnerable areas, groundwater is only vulnerable to conservative pollutants (such as chloride and nitrate) when they have been continually introduced to the subsurface by a persistent activity. Table 1 summarises the transport characteristics of common pollutants and those in particular that are susceptible to sorption or degradation.

Table 1 Vulnerability definitions for potentially polluting surface activities (adapted from Foster, 1998)

| *Vulnerability category* | **Description** | **Frequency of activity** | **Travel time** |
|---|---|---|---|
| 5 | Vulnerable to most water pollutants with rapid impact in many scenarios. | Vulnerable to individual events | Rapid |
| 4 | Vulnerable to those pollutants not readily adsorbed or transformed. | ↓ | ↓ |
| 3 | Vulnerable to some pollutants with many significantly attenuated. | ↓ | ↓ |
| 2 | Vulnerable to some pollutants, but only when continuously discharged/leached. | ↓ | ↓ |
| 1 | Only vulnerable to conservative pollutants in the long-term when continuously and widely discarded and leached. | Vulnerable only to persistent activity | Very slow |

## 3.2 KEY CONCEPTS

The vulnerability map created for this project is based on the concept that contaminants can only be attenuated where intergranular flow occurs within the unsaturated zone of a geological deposit. This applies to all superficial deposits, although certain clayey tills can contain fractures in which water can flow. It can also apply to those dual-porosity bedrock aquifers that have a significant intergranular flow component in addition to secondary porosity in the form of fractures and other voids. In Northern Ireland few bedrock aquifers have any significant dual porosity and for the purposes of this methodology, attenuation in the unsaturated zone of part- intergranular bedrock aquifers is not considered (N.B. it is recognised that bedrock aquifers such as the Sherwood Sandstone do have a component of intergranular porosity albeit with secondary fracture porosity also significant. However given that a limited thickness of bedrock unsaturated zone is thought to occur across the majority of such aquifers, this factor is not considered significant at this scale of mapping. Future adaptation of the methodology to a larger scale can reconsider this aspect). Where fracture-flow bedrock aquifers are exposed at the ground surface, as is the case in many parts of the Province, the vulnerability classification is the highest, because few significant attenuation processes can occur. Figure 3.1 illustrates how the effective attenuation pathway varies according to whether fractured or intergranular-dominated bedrock is present beneath a layer of superficial deposits. The figure also includes a superficial aquifer where the main water table lies within it. The complete set of scenarios where superficial deposits and soil may or may not be present are presented later in the report.

There are traditionally three main attributes of the pathway materials that influence groundwater vulnerability: travel time, the attenuation capacity of the pathway and recharge acceptance of the aquifers. The concept of recharge acceptance requires further consideration, particularly within unsaturated aquifer materials.

According to the WFD methodology, it is only the unsaturated zone in low permeability soils, superficial deposits and bedrock aquifers with intergranular flow that determine vulnerability. The extent to which pollutants are attenuated by processes such as time delay, adsorption or cation-exchange depend on factors that include permeability, porosity and pathway thickness. The methodology assumes that where groundwater flow in the unsaturated zone is dominantly via fractures, travel times are too short to allow attenuation to take place.

The vulnerability scenarios in Figures 3.1 and 5.1 form a summary of the fundamental principles behind the WFD methodology. They show the locations of the effective pathways - the only zones where attenuation can take place. They are found wherever the following deposits occur:

- Certain types of clayey soil, lying either directly on rock or thin superficial material.
- Superficial deposits, either as a covering layer over bedrock aquifers or as aquifers themselves.
- Intergranular-dominant bedrock aquifers (not considered for this 1:250 000 project).

### 3.2.1 Recharge acceptance

Some vulnerability methodologies have incorporated recharge acceptance as an indicator of the amount of contaminant loading that can pass through the pathway zone and reach the water table. Rocks such as granite have a low recharge acceptance and, therefore, a low contaminant loading potential, but also have a low overall permeability and storage capacity, with groundwater flowing only in fractures. Therefore, even small volumes of contaminants reaching the water table will have a major effect on water quality, as the groundwater/pollutant ratio may be similar to that in a high porosity gravel aquifer that has a high recharge acceptance. Since the indications are that the WFD is concerned with concentrations of contaminants, rather than absolute loadings, recharge acceptance is not appropriate.

The omission of recharge acceptance from the current methodology results in only two attributes of the pathway that are considered in the current vulnerability assessment: travel time and attenuation.

### 3.2.2 Travel time

The residence time of contaminants in the pathway zone has a bearing on the scope for attenuation processes to occur and will also retard the arrival of contaminants at the water table. Microbial contaminants are likely to degrade over time and the longer they remain in the pathway the lower the chances of impact on the water table. Travel time in the pathway zone for infiltrating water depends on:

*The permeability of the pathway material*: High permeability materials such as well-sorted medium- to coarse-sand and gravel will allow more rapid transit times compared to finer-grained sands and silts.

*The porosity of the pathway material:* Deposits with high intergranular porosity have greater groundwater storage and allow higher flow rates, but at lower velocities.

*The thickness of the pathway unsaturated zone in intergranular aquifers*: The thickness of the pathway to the water table is relevant in:

*1.* Superficial deposit aquifers.

2. Intergranular-dominated bedrock aquifers.

*The thickness of the superficial deposits layer*: Where the aquifer comprises fracture-dominated bedrock, the effective pathway for vulnerability is the superficial material overlying the aquifer (Figure 3.1A).

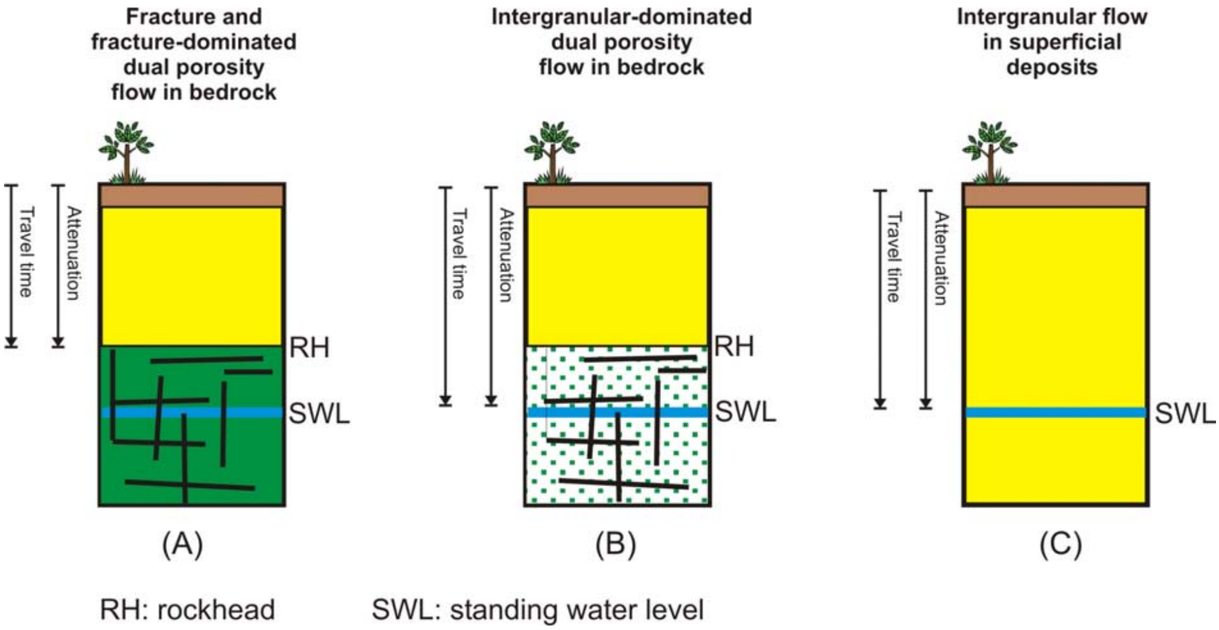


Figure 3.1 The effective part of the pathway for governing attenuation capacity and travel time for different porosity regimes within the receptor

Only where intergranular groundwater flow is significant do the pathway properties affect vulnerability.

In 3.1(A), the water table lies within the fractured bedrock aquifer, but the effective lengths of the attenuation and travel time pathways are restricted to the layer of superficial deposits, as fractured rock cannot aid in any processes of attenuation. In 3.1(B), intergranular-dominant bedrock underlies superficial deposits and the effective pathways are extended to the water table. In 3.1(C), the high permeability superficial aquifer contains the main water table and so the effective pathways lie entirely within the unsaturated zone deposit.

### 3.2.3 Attenuation

Attenuation of contaminants is generally only significant where groundwater flow is mostly or wholly by intergranular means. The potential for attenuation varies according to several factors, with porosity type fundamental. If groundwater flow in the pathway is primarily through secondary porosity such as fractures, attenuation is generally insignificant due to limited scope for water-rock interaction and the permeability and thickness of the pathway is not used in the vulnerability assessment. Where intergranular porosity is significant, the thickness, clay content and permeability of the pathway material can all contribute to the attenuation of contaminants.

Attenuation may be effected by a number of mechanisms (Table 2) depending on the nature of the pollutant. The capacity for attenuation in the pathway zone is determined by:

*Porosity within the receptor*: Water travels through superficial deposits predominantly by intergranular flow where the potential for attenuation is greater than in fracture-dominated rock. This is also the case for certain bedrock aquifers, in which intergranular flow is dominant. In these aquifers the effective pathway includes the unsaturated zone of the bedrock aquifer in addition to any superficial deposits. Where the flow path comprises intergranular porosity material, the beneficial effects are:

- Greater opportunity for water-rock interaction.
- The opportunity for filtration and adsorption of bacteria within pore spaces.
- Dispersion and dilution effects on a micro scale in the pore matrix.

In fracture-dominated and wholly fractured rock, the capacity for attenuation in the unsaturated zone of the bedrock is considered to be insignificant and the depth to the water table is, therefore, not taken into account when determining the vulnerability class. In this case, only the attributes of the superficial cover, if present, are relevant to attenuation potential.

*Clay content*: The amount of clay present within a superficial deposit or intergranular bedrock unit will affect the vulnerability rating, as clay has adsorptive qualities that can help reduce concentrations of contaminants, such as heavy metals.

*Organic material*: In the new WFD methodology, the capacity of the soil layer to influence vulnerability is limited to where low-permeability soils less than 1 m in thickness directly overlie bedrock. For areas where the superficial cover is thicker than this, it is assumed that the characteristics of the soil are overridden by the attenuating capacity of the underlying deposits.

In summary, five key parameters affect the travel time and attenuation of pollutants in the pathway to the water table:

1. The permeability and clay content of the superficial deposits (including soil)
2. The mode of groundwater flow in bedrock aquifers (e.g. fractured or intergranular)
3. Thickness of superficial deposits.
4. The permeability and clay content of intergranular and intergranular-dominant bedrock aquifers
5. The depth to the water table (superficial and intergranular bedrock aquifers only).

## 3.3 DATA AVAILABILITY IN NORTHERN IRELAND

The concepts outlined above were developed into a methodology that was originally applied to Scotland, but which now has been adapted for Northern Ireland. The datasets used in the methodology are given below. The detail, use and analysis of the datasets is described in the next section of the report.

- **DiGMapNI-250 (GSNI) –**This dataset comprises digital geological maps at a scale of 1:250 000 of both bedrock and superficial geology of Northern Ireland. These layers form the foundation for the vulnerability assessment methodology.

- **Borehole Database (GSNI) –** a borehole database containing almost 25 000 records for Northern Ireland. For a percentage of these, depth to bedrock data can be easily extracted.
- **Hydrology of Soil Types (HOST) (DARDNI) –** digital soils maps at 1:50 000 scale with an assessment of the hydraulic properties of the soil.

Table 2 Attenuation mechanisms and contaminants

| **CONTAMINANT** | **ATTENUATION MECHANISM** | | | | **MOBILITY** | **PERSISTENCE** |
|---|---|---|---|---|---|---|
| | **Biochemical Degradation** | **Sorption** | **Filtration** | **Precipitation** | | |
| Nitrogen | ● | ●[a] | x | x | Very High | Very High |
| Chloride | x | x | x | x | Very High | Very High |
| Faecal Pathogens | ●●● | ●● | ●●● | x | Low - Moderate | Generally Low |
| Dissolved Organic Carbon | ●●● | ●●● | ● | x | Low - Moderate | Low - Moderate |
| Sulphate | ● | ● | x | ● | High | High |
| Heavy metals | x | ●●● | ●[b] | ●● | Generally low (unless pH low) | High |
| Halogenated solvents (DNAPLS) | ● | ● | x | x | High | High |
| Fuels, lubricants, oils, other hydrocarbons (LNAPLS) | ●●● | ●● | x | x | Moderate | Low |
| Other synthetic organic | Variable | Variable | x | x | Variable | Variable |

●●● highly attenuated ●● significant attenuation ● some attenuation x no attenuation

[a]ammonia is sorbed [b]where they occur as organic complexes

*from* Morris B L et al. 2003 Groundwater and its susceptibility to degradation: a global assessment of the problem and options for management. Early Warning and Assessment Report Series, RS. 03-3, United Nations Environment Programme, Nairobi, Kenya.

# 4 Methodology

## 4.1 DEVELOPING THE KEY DATASETS

There are four datasets fundamental to the vulnerability assessment:

1. Permeability of the superficial deposits, including soil.
2. Thickness of superficial deposits.
3. Groundwater flow type in bedrock (intergranular or fracture flow).
4. The depth to the water table (superficial aquifers only).

Note that a fifth key dataset - maps of point recharge features (karstic swallow holes) has been acknowledged by the use of 30 m radius circles around each known point.

## 4.2 PERMEABILITY OF SUPERFICIAL DEPOSITS

### 4.2.1 Concept

The permeability of superficial deposits is one of the factors affecting water and pollutant travel times to rockhead. In the absence of detailed data on variations in permeability in Northern Ireland, generalisations were made regarding relative permeability for broad mapped units. This was also the case for much of Scotland. Permeability was also equated to clay content. Therefore, the highest permeability materials, such as glaciofluvial sand and gravel and river alluvium, have the lowest clay content and fastest travel times for equivalent thickness. As a consequence, they also have lowest capacity for attenuation. The permeability categorisation comprises a simple tripartite subdivision into ‘High’, ‘Moderate’ and ‘Low’ permeability, with the ‘High’ deposits classed as aquifers if they contain a water table (Figure 4.1).

### 4.2.2 Detail

Table 3 shows the permeability class, based upon mapping experience, assigned to deposits as represented on the 1:250 000 superficial geology digital layer for Northern Ireland. The dominant superficial deposit found across Northern Ireland is glacial till and its occurrence is widespread. Application of a single permeability class to till would both restrict the usefulness of the vulnerability map and poorly reflect the variable nature of this deposit. In order to more accurately represent the likely variation within the till, the experience of local geologists was used to subdivide till into one of three permeability categories, primarily based upon the nature of the underlying bedrock (Table 4). The assumption made was that, overall, till composition at any location is strongly influenced by underlying ‘parent’ bedrock lithology. Whilst this is a simplification of glacial till generation processes and does not consider carry-over across geological boundaries, it is considered to be beneficial in helping define likely differences in permeability and subsequently potential vulnerability on a regional scale.

Table 3 Quaternary Deposit permeability categories (1: 250 000)

| **Permeability** | | |
|---|---|---|
| **High** | **Moderate** | **Low** |
| Alluvium | Landslip | Peat |
| Blown Sand * | | Recent Marine Deposits |
| Glacial Sands and Gravels* | | Recent Lacustrine Deposits |
| Raised Beach Deposits* | | Glacial Lake Deposits |
| Glacial Outwash Sands and Gravels* | | Diatomite |
| Till (high) | Till (moderate) | Till (low) |

* Potential aquifers

When assigning a permeability class to a specific deposit as represented on the digital quaternary map layer, some modifications were made based upon more recent mapping and local geological knowledge. For example, near Coleraine an area of glacial sands and gravel was assigned a low permeability class based upon examination of the more detailed 1:50 000 map for the area which indicated the deposits to be glaciolacustrine in origin comprising laminated clay with minor interbedded sand deposits.

Table 4 Relative permeabilities of till, based on the characteristics of underlying bedrock

| **Permeability** | | |
|---|---|---|
| **High** | **Moderate** | **Low** |
| Moinian (Loch Derg Inlier) | Permo-Triassic Sandstones | Ordovician/Silurian |
| Dalradian | Devonian Conglomerates | Devonian (ex conglomerates) |
| Tyrone Granite (part) | | Carboniferous (all) |
| Tyrone Moinian (central inlier) | | Mercia Mudstone |
| Newry Granites | | Lias Clays |
| Mourne Granites | | Palaeogene Basalts |
| | | Tyrone Volcanic Group |
| | | Tyrone Plutonic Complex |

N.B: The presence of thick clays within the sequence of superficial deposits will act to reduce the rate of groundwater infiltration. Because superficial deposits can be extremely heterogeneous, thick clays may occur at depth even where high permeability deposits are mapped at the surface. Where the target is a superficial aquifer, the presence of clays beneath this does not affect the vulnerability assessment as the clays are not included in the pathway. However, where the target is a bedrock aquifer, the presence of an accumulated thickness of 5 m or more of clay layers beneath unsaturated deposits of high or moderate permeability affects the overall pathway permeability. The vulnerability rating of groundwater in the bedrock aquifer below the drift sequence then reverts to ‘Low’.

### 4.2.3 Permeability of thin (<1 m) superficial deposits

For areas where the 1:250 000 quaternary layer indicates rock at or near surface (superficial deposits <1 m), the soils HOST map layer was used to identify where low permeability soils occur. The presence of a low permeability soil was considered sufficient to reduce the resultant vulnerability class from the very highest (Class 5) to Class 4. The HOST classes used to reduce the vulnerability rating to Class 4 are listed in Table 5.

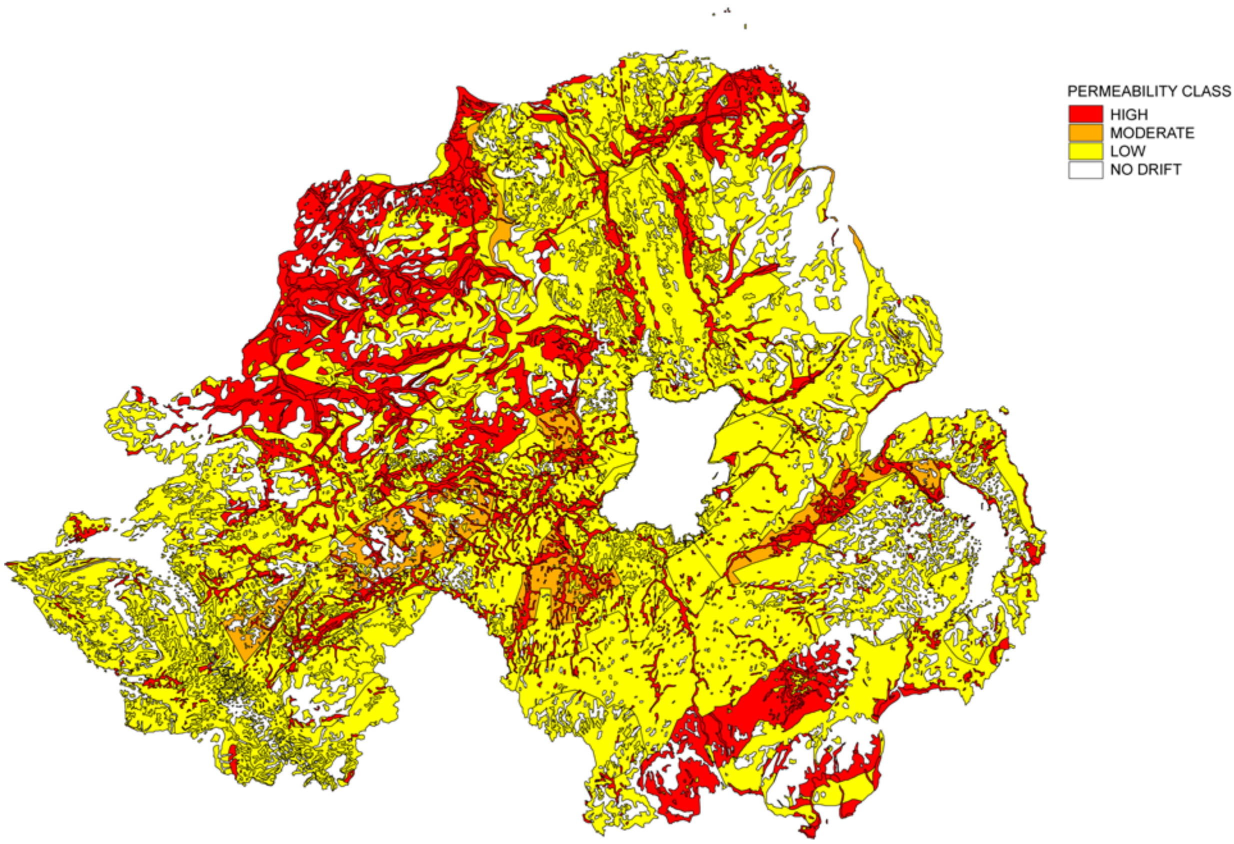


Figure 4.1 Superficial deposits permeability

## 4.3 POROSITY TYPE IN BEDROCK RECEPTOR AQUIFERS

### 4.3.1 Concept

Bedrock formations that have a significant intergranular element within them are assumed to have the capacity to attenuate pollutants by filtration and adsorption. The classification of bedrock aquifers derived for WFD purposes is shown in Table 6. A more detailed description of the aquifer classification process can be found in McConvey, 2005. The ability to attenuate will depend on the thickness of the unsaturated zone within the bedrock aquifer in addition to the permeability of the rock. It was eventually decided for the purposes of application of this methodology at 1:250 000 scale (see Section 3.2) that all bedrock formations in Northern

Ireland would be classified as fracture-flow and, therefore, the depth to the water table in all bedrock formations became irrelevant as a factor in vulnerability classification.

Table 5 Low-permeability HOST soil types used in the map

| HOST number | Permeability description | Soil type |
|---|---|---|
| 9 | L | Mineral alluvial soil |
| 10 | VL | Brown forest soils with gleying |
| 12 | L | Peaty alluvial soil |
| 12 | LP | Basin peat |
| 15 | L | Peaty podzol |
| 16 | L | Brown forest soil |
| 16 | VL | Brown forest soil |
| 18 | L | Humus-iron podzol |
| 18 | VL | Humus-iron podzol |
| 18 | VL | Brown forest soils with gleying |
| 24 | L | Noncalcareous gleys |
| 24 | L | Brown forest soils with gleying |
| 24 | VL | Noncalcareous gleys |
| 24 | VL | Noncalcareous gleys |
| 26 | L | Peaty gley |
| 26 | VL | Peaty gley |
| 26 | VL | Peaty gley |
| 28 | LP | Blanket peat |
| 29 | LP | Blanket peat |

**L**: Low (lodgement tills with no shales or silty alluvium)

**VL**: Low (lodgement tills with shales and silty alluvium)

**LP**: Low-permeability peat soils

Table 6 Aquifer classification of bedrock in Northern Ireland

| Aquifer Category | Symbol | Typical Rock Units / Formations |
|---|---|---|
| High productivity<br>Fracture Flow | Bh (f) | Certain Carboniferous basal formations |
| High Productivity<br>Fracture/Intergranular Flow | Bh (I-f) | Permo-Triassic Sandstones |
| High Productivity<br>Fracture flow with karstic element | Bh (f-k) | Carboniferous Darty Limestone with Knockmore Limestone Member (in places)<br>Carboniferous Ballyshannon Limestone Formation<br>Ulster White Limestone Formation (Chalk) |
| Moderate Productivity<br>Fracture Flow | Bm (f) | Palaeogene Basalts<br>Certain Carboniferous Dinatian Sandstones |
| Limited Productivity<br>Fracture Flow | Bl (f) | Ordovician/Silurian strata<br>Dalradian strata<br>Devonian strata<br>Granites and Intrusives |
| Poor Productivity<br>Fracture Flow | Bp (f) | Lough Neagh Clay Group<br>Mercia Mudstone Group<br>Waterloo Mudstone Formation |

## 4.4 SUPERFICIAL DEPOSITS THICKNESS

### 4.4.1 Concept

Where the superficial cover is classed as a pathway rather than an aquifer in its own right (see also Section 4.5), the nature and thickness of the deposit become crucial to the vulnerability rating of the bedrock aquifer below. The degree of attenuation that pollutants have undergone when they leave the base of the superficial material determines the vulnerability at that location if fracture-dominant or fractured bedrock is present, as, according to the methodology, no further attenuation can take place below rockhead in these rock types.

The potential attenuation of a pollutant moving through superficial deposits is influenced by the length, permeability and porosity of the pathway. In relatively thick deposits, there is a greater opportunity for water/clay interaction compared to fracture-flow rocks because of the dominance of intergranular flow and longer travel times. Deposits of similar permeability and porosity, but differing thickness will result in a different vulnerability rating. The superficial deposits thickness map represents the entire thickness of moderate and low permeability deposits, plus the unsaturated zone thickness within highly permeable superficial aquifers.

### 4.4.2 Data sources

*DiGMapNI-250 Quaternary Geology of Northern Ireland – Digital version* provides polygons of superficial deposits type and distribution.

*GNSI borehole database* – shows depth to rockhead.

### 4.4.3 Criteria

Superficial deposits are generally only mapped by GSNI where they are greater than 1 m in thickness. Areas where less than 1 m applies are mapped as 'rock at or near surface'. The thickness categories for superficial deposits used in the GIS are: 1-3 m, 3-10 m, 10-30 m, >30 m. No depth to rockhead model is available for Northern Ireland. Borehole record coverage is variable across the province, concentrated in urban/industrial areas and along major transport routes. Within rural regions, density of borehole records can be very low. In addition, information on actual depth to rockhead was only readily accessible for a percentage of borehole records. For these reasons it was decided that only broad thickness 'provinces' could be delineated, based upon local geologists knowledge and with reference to borehole records where available.

### 4.4.4 Procedure

It was important to avoid producing maps with superficial deposits having a maximum, precautionary 1-3 m thickness in rural areas where no borehole data are available, as this situation applies to large areas of Northern Ireland. This was avoided by attributing all of the non-aquifer Quaternary 1:250 000 units to default thicknesses according to deposit type (Table 7). Manual corrections were then applied in order to create more realistic maps based upon geologists local knowledge and where borehole data indicated areas of thicker drift. For example, a large number of boreholes in the northern part of the Province north of Ballymoney showed the superficial deposits to be consistently greater than 30 m thickness, justifying a change in the designated thickness in this area. For the most common and widespread deposit (glacial till), broad thickness provinces were defined, based upon visual examination of available borehole data and local geologists knowledge. This allowed the distinguishing of areas where overall till thickness was more likely to generally be 1-3 m or 3-10 m. Thicker areas of till were also identified (Figure 4.2).

The combined map distinguishes between the variable thicknesses of valley-floor alluvium and glaciofluvial deposits on the lower slopes, typically 3-10 m thick, and till deposits present on the upper hill slopes, which vary according to region and have been divided into provinces (Table 7).

Table 7 Superficial deposits default thickness according to deposit type

| Unit | Thickness (m) | Comments |
|---|---|---|
| Peat | 1-3 | In cases where peat considered to overlie other low permeability deposits, peat polygons assigned 3-10 m thickness |
| Landslip | 1-3 | Will be variable, hence, precautionary limited thickness taken. |
| Alluvium | 3-10 | For this assessment all alluvium is considered to contain a water table, hence, thickness is not a factor for vulnerability. Alluvium will be shallower in places. |
| Recent Marine Deposits | 3-10 | May not, on its own, be generally this thick but usually associated with other underlying low permeability deposits. In Belfast area, part of estuarine clays extent defined as 10-30 m based upon borehole records. |
| Recent Lacustrine Deposits<br><br>Lough Neagh/Lough Erne | 3-10 | In places, will be underlain by till, other places, sand and gravel or bedrock. |
| Glacial Lake Deposits | 3-10 | Ranges from 3-70 m thick generally 3-30 m. Can overlie till or bedrock and *overall* likely to include >5 m clay |
| Diatomite | 3-10 | Much of this deposit is worked out. However, in places it will be underlain by till, other places sand and gravel or bedrock. |
| Glacial Till (Boulder Clay) | 1-3<br>3-10<br>10-30<br>>30 | Variable with thickness. Provinces defined by local geological knowledge and borehole records. |
| Blown Sands, Glacial sands and gravels, Raised beach deposits | 1-3 | Such deposits assumed to contain a water table, hence, the thickness is not relevant for the vulnerability assessment. Some areas defined as thicker, based on borehole records. |

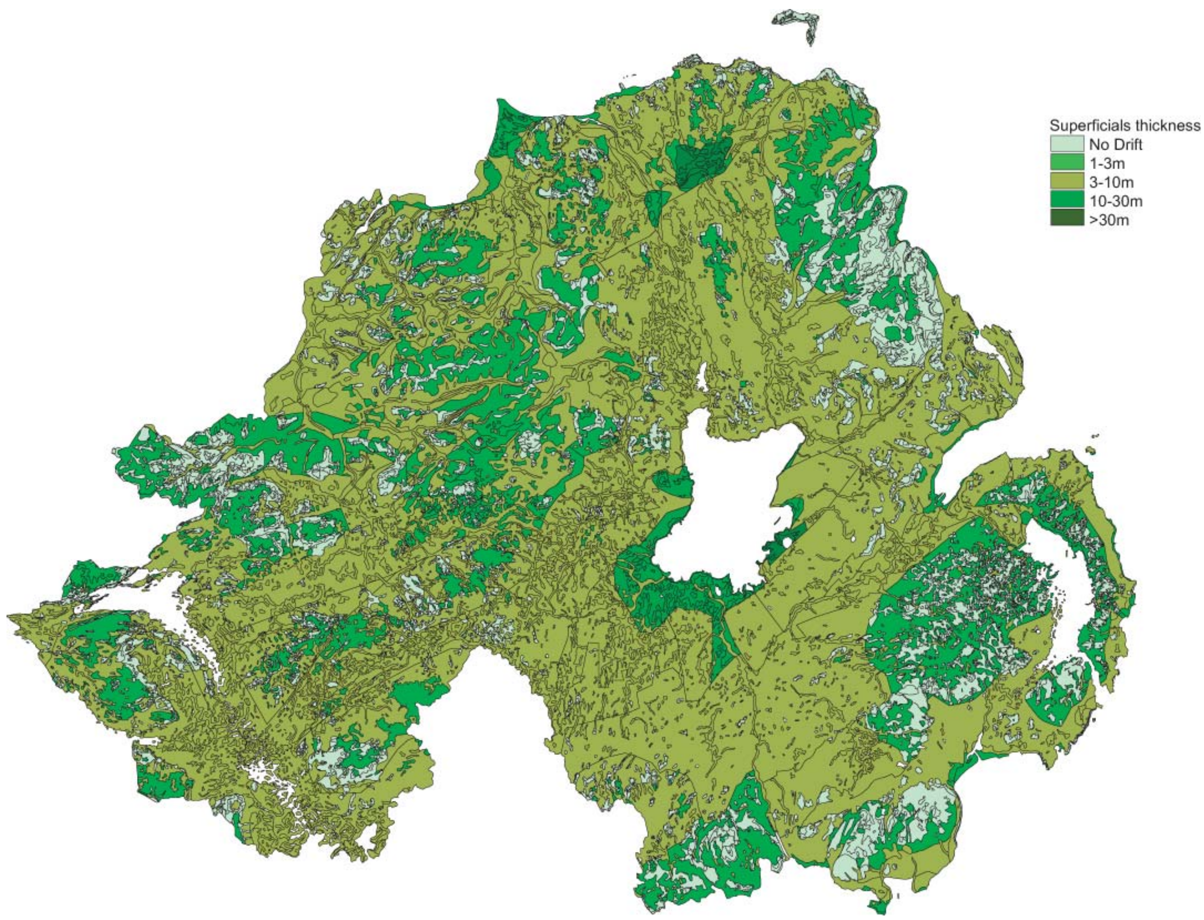


Figure 4.2 Superficial deposits thickness

## 4.5 DEPTH TO WATER

### 4.5.1 Concept

In Scotland, with the absence of adequate groundwater level information for most areas, in common with Northern Ireland, a map of the estimated depth to water in superficial deposits was created. This was based on the concept that there is a greater depth to the water table under relatively high ground compared to that beneath valley floors or the coast. A broad assumption was made that rivers or sea level equate to the water table surface at those locations where the surface water feature occurs. In unconfined intergranular aquifers, the elevation difference between the surface water feature and ground surface with increasing lateral distance is assumed to be an equivalent increase in the depth to the water table. For Northern Ireland, given the scale of the data being used, a less involved process was used for defining depth to water table in permeable superficial aquifers.

### 4.5.2 Criteria

Two classes of depth to water were specified: less than 3 m to water table and 3 to 10 m to water table (Table 8). Default values were again set based upon both local knowledge and application of knowledge from similar hydrogeological settings in Scotland. Borehole records were also examined to support the values assigned.

The final depth to water GIS layer was combined with layers showing superficial deposits.

Table 8 Default depth-to-water values

| **Unit** | **Depth to water table (m)** | **Comments** |
|---|---|---|
| Alluvium | 1-3 | Default |
| Blown Sands | 1-3 | Concentrated around Lough Foyle. Borehole logs for Magilligan area confirm less than three metres in some places |
| Raised Beach Deposits | 1-3 | As above |
| Glacial Sands/Gravels | 3-10 | Default |
| Glacial Outwash Sands/gravels | 3-10 | Default |

# 5 The vulnerability classification system

The classification system devised under the SNIFFER project defines a groundwater vulnerability rating at any given location based around one of the seven scenarios shown in Figure 5.1. The scenarios, described in Section 5.1, when linked with karstic and mining data, cover every combination of rock type and cover deposit found in the UK. All the information needed to produce them for the vulnerability map is derived from the datasets described in Section 4. The scenarios have been determined according to:

- Bedrock porosity type: comprising fracture and intergranular-dominated rocks.
- Where either type of bedrock is exposed, covered by <1m of superficial deposits or overlain by thicker drift deposits.
- Where highly permeable superficial deposits contain a water table and therefore occur as aquifers.

The text boxes in Figure 5.1 show the variables that are used to create the final vulnerability ratings. The only variables that can determine the rating are:

- The depth to the water table in highly permeable superficial aquifers.
- The depth to the water table in intergranular and dominantly intergranular-flow bedrock aquifers.
- Soil permeability.
- Superficial deposits permeability.
- Superficial deposits thickness.

Allocation of a vulnerability rating from 1 to 5 at any given location depends on the variables listed above. However, the vulnerability ratings can be derived from 199 different situations, depending on drift thickness and permeability etc., although not all of these are found in Northern Ireland. In order to show, at any given point on the land surface, which set of circumstances applies, colour-coded tables showing all the possible permutations of geological and hydrogeological variations have been created. Those relevant for Northern Ireland are shown in Appendix 1. The tables also display equivalent vulnerability ratings across a wide range of conditions. In order to identify which particular set of circumstances represents any location, the GIS information box for each polygon provides a code number from 1 to 19 which relates to the numbers in the Tables in Appendix 1. Tables representing the full range of scenarios can be found in SNIFFER (2004).

The following general rules also apply to the classification system:

- All areas within 30 m of a mapped point recharge feature such as karst will have a vulnerability rating of 5.
- Where drift is mapped as <1m thick the vulnerability class is always either 4 or 5.
- Where drift is mapped as <3m thick the vulnerability class is always 3, 4 or 5.
- No areas where drift is mapped as >1 m thick will have a vulnerability of 5, unless they are close to a mapped point recharge feature.

The methodology allows for modification of the classification system in order to subdivide each vulnerability class according to a particular property, such as permeability.

As noted in previous sections, certain assumptions have been made with regard to flow type, water table depth .etc within aquifers in Northern Ireland. For example the assumption that all bedrock aquifers have fracture-dominated flow means that the scenarios relating to intergranular bedrock do not apply in this 1:250 000 assessment. However future application of the methodology at a higher resolution (1:50 000) may require such scenarios to be included.

For completeness, the descriptions given in this section cover all the scenarios, including those not encountered in Northern Ireland.

## 5.1 THE SEVEN VULNERABILITY SCENARIOS

A brief description of the concepts behind the seven scenarios shown in Figure 5.1 is given below.

### 5.1.1 Scenario 1 (highly permeable superficial aquifers: Appendix 1, Table 4)

The presence of partly saturated highly permeable superficial deposits defines this category. Other deposits of similar lithology are incorporated in scenarios 4 and 7 where they are wholly unsaturated.

The depth to the water table is the sole variable that can affect the vulnerability rating. The beneficial effects on attenuation mechanisms of intergranular water flow increase with greater thickness of the unsaturated deposit.

### 5.1.2 Scenario 2 (exposed, fractured bedrock: Appendix 1, Table 1)

The vulnerability methodology used for the map assumes no attenuation is possible in fractured bedrock. Therefore, the depth to the water table is irrelevant in this scenario and there are no variations in vulnerability possible. All exposed fractured rock is Vulnerability Class 5. In the Northern Ireland uplands there are extensive areas of this class.

### 5.1.3 Scenario 3 (fractured bedrock with superficial deposit <1 m thick: Appendix 1, Table 1)

The permeability of the soil has been used to map the vulnerability where superficial deposits are less than 1 m thick and therefore not mapped by GSNI. The presence of low permeability soils reduces the vulnerability class from 5 to 4. As the underlying bedrock is fractured, there is assumed to be no attenuation capacity present below the low permeability soil layer.

### 5.1.4 Scenario 4 (fractured bedrock with unsaturated superficial cover >1 m thick: Appendix 1, Table 2)

Where fractured or dominantly fractured bedrock occurs underneath a layer of superficial deposits, any attenuation capability is restricted to the unsaturated superficial cover, the base of which is the limit of the effective pathway. Once infiltrating water has passed through the base of the cover, attenuation ceases, regardless of the depth to the water table within the bedrock aquifer. Therefore, the effective pathway is limited to the layer of superficial deposits only. The superficial pathway has two variables: thickness and permeability (Appendix 1: Tables 2). It is within this Scenario and also No. 7 that areas with greater than 5 m total thickness of clay are found. Where present, the thick clay overrides any other characteristic of the pathway and the vulnerability class is always 5.

### 5.1.5 Scenario 5 (exposed, intergranular bedrock – not considered present in Northern Ireland for 1:250 000 analysis)

In this scenario, the capacity to attenuate contaminants is restricted to the bedrock unsaturated zone. Therefore, the only variables available are the permeability of the rock and the depth to the water table. The lowest vulnerability rating possible in this scenario is 3, owing to the lack of superficial cover.

### 5.1.6 Scenario 6 (intergranular bedrock with superficial deposits <1 m thick – not considered present in Northern Ireland for 1:250 000 analysis)

The presence of thin cover adds a potential third variable to this scenario compared to scenario 5. Where thin, low permeability cover is present, this has the effect of potentially reducing the vulnerability rating to 3 if the depth to the water table is at least 3 m within moderate or low permeability bedrock.

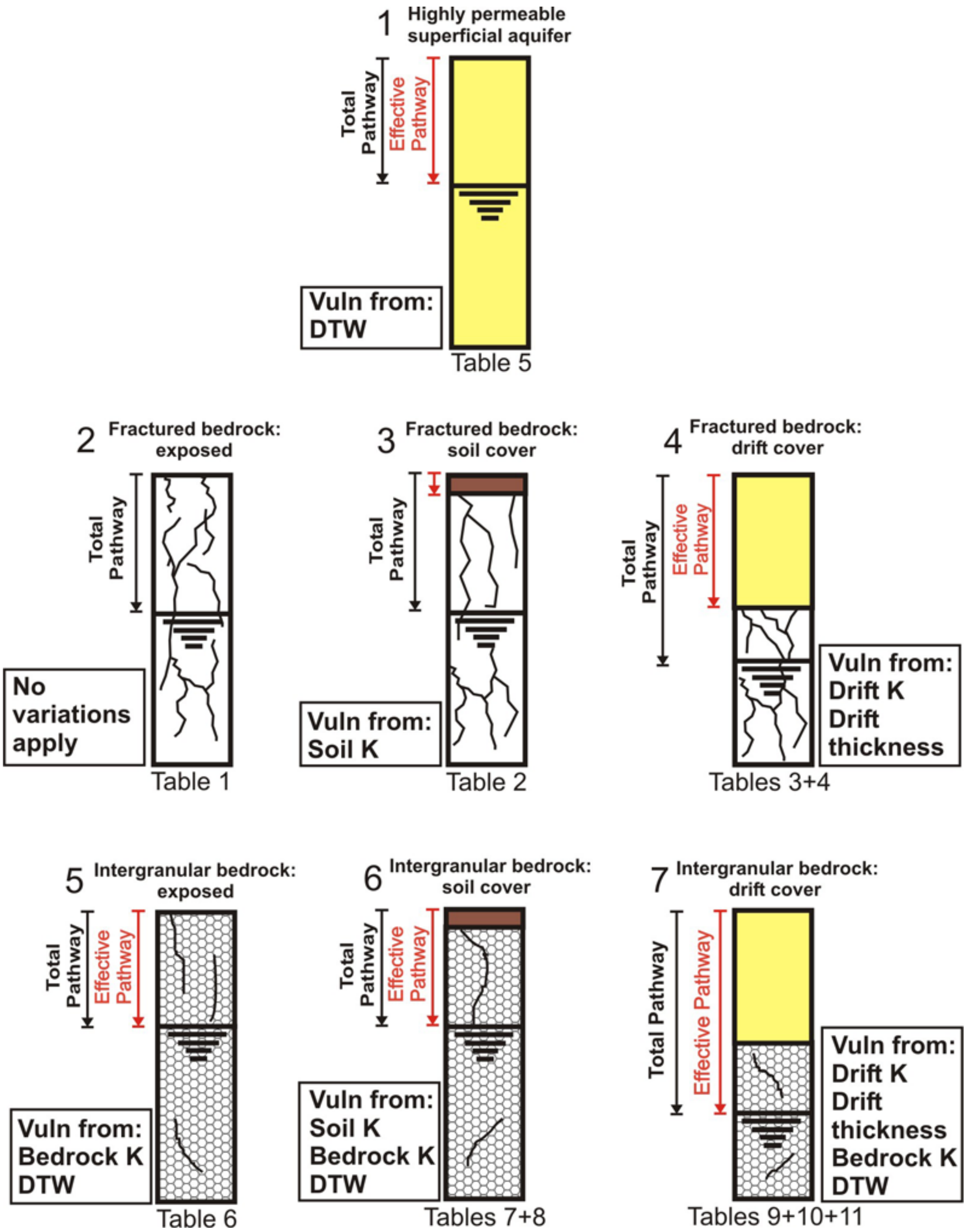


Figure 5.1 The seven vulnerability scenarios

### 5.1.7 Scenario 7 (intergranular bedrock with unsaturated superficial cover >1 m thick – not considered present in Northern Ireland for 1:250 000 analysis)

There are four variables present in this scenario: Superficial cover thickness and permeability, plus bedrock permeability and thickness within the unsaturated zone. The total length of the effective pathway includes both the thickness of the superficial cover and the unsaturated zone below rockhead. Where more than 5 m thickness of clay is present, the vulnerability class is always 5.

## 5.2 PROCEDURE FOR CREATING THE VULNERABILITY MAP

The process of combining all the information to create the vulnerability classes is summarised in Figure 5.2. The process of combining all the datasets described in Section 4 to produce the final vulnerability map was carried out using GIS software and commences with the basic digital bedrock and superficial geological maps. By combining these two layers, those areas of the country where exposed bedrock is present can be separated from drift-covered areas. On GSNI maps, 'exposed' bedrock also includes thin drift (<1 m thick). The latter is important because it can have a bearing on the vulnerability rating. It should be noted that this description is for the complete procedure - not all procedures are applicable to Northern Ireland because intergranular bedrock has not been recognised as being significant.

For areas of exposed bedrock and where the drift cover is thin (<1 m), the following process applies:

- The basic subdivision of bedrock into the two main porosity types: fracture flow and intergranular-dominant flow (at 1:250 000 scale fracture flow assumed for all Northern Ireland bedrock).
- All areas of exposed rock or where the drift cover is <1 m thick are separated from areas where thicker drift cover is present.
- The exposed rock/thin drift covered areas of **fractured** rock are further subdivided, using DARDNI soil maps (HOST), to indicate where both exposed rock is present (always Vulnerability Class 5) and where a thin, clayey drift and soil cover occurs directly over rock (Vulnerability Class 4) (Table 1 in Appendix 1). This allows for the identification of those areas where Scenarios 2 and 3 are present. No other work on the vulnerability rating is required for these areas.
- For exposed rock/thin drift cover **intergranular** bedrock areas (Scenarios 5 and 6 in Figure 5.1), further subdivisions are needed after overlying the thin clayey soil zones. Areas of exposed rock are rated for vulnerability only according to the depth to the water table and the rock permeability. Other areas where thin soil and drift cover is present are further subdivided according to where low-permeability soil occurs. The latter areas have a reduced vulnerability rating because of the extra clayey soil barrier. (NB: this scenario is not used at this level of assessment for Northern Ireland. Tables representing these scenarios can be found in SNIFFER (2004).

**All remaining areas, where the superficial cover is >1 m thick:**

- Using the assigned permeability classes for geological units and HOST soil classes, superficial deposits are subdivided according to permeability and thickness. Separate GIS layers of these are created.
- The highly permeable drift deposits are separated out, as they are potential aquifers, but only where they contain a water table. Except where thick clays may overlie this

aquifer type, the vulnerability rating for those areas of superficial aquifers is then determined, using only data on the depth to the water table (Scenario 1), irrespective of the type of bedrock aquifer underlying it (Table 4, Appendix 1).

- All the remaining moderate and low permeability superficial deposits are taken to form a drift pathway layer that is based solely on thickness and permeability.
- Once all exposed bedrock, bedrock with thin cover and superficial aquifers have been identified, the remainder of the country can comprises of either **fractured bedrock with superficial cover** or **intergranular bedrock with superficial cover**.
- Where **fractured bedrock with superficial cover** occurs, the vulnerability rating is determined *solely* by the thickness and permeability of the superficial deposits pathway. In Northern Ireland, this represents approximately 75% of the land surface. (Table 2, Appendix 1).
- Where **intergranular bedrock aquifers with superficial cover** are present, then the vulnerability rating is determined by a *combination* of superficial deposits thickness and permeability *in addition to* the depth to the water table and permeability of the unsaturated zone of the underlying bedrock. (NB: this scenario is not used at this level of assessment for Northern Ireland. Tables representing these scenarios can be found in SNIFFER (2004).

By separating out each of the above combinations using GIS software and adding karstic features, every point on the land surface is assigned a scenario type and then a vulnerability rating. Figure 5.3 shows the final vulnerability map for Northern Ireland.

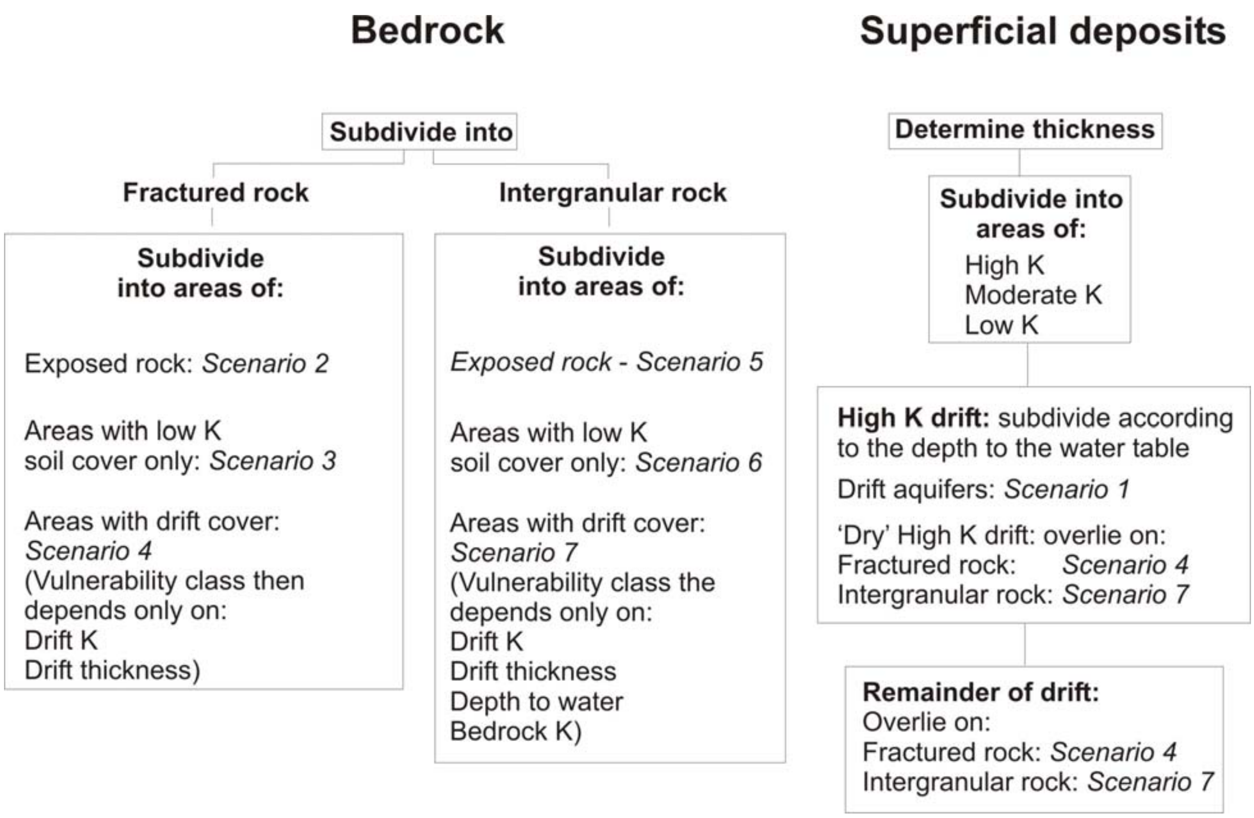


Figure 5.2 Procedure for the creation of the vulnerability system

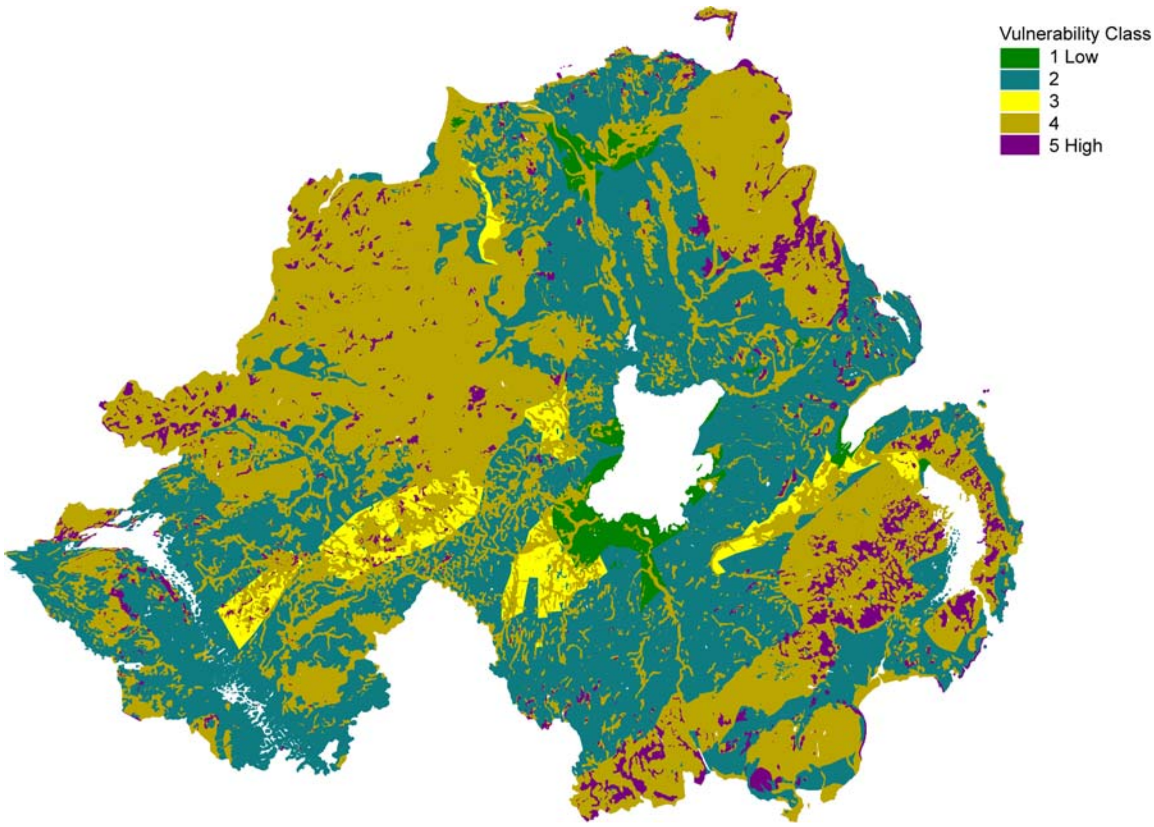


Figure 5.3 Groundwater vulnerability map of Northern Ireland

# 6 Conclusions

## 6.1 GROUNDWATER VULNERABILITY IN NORTHERN IRELAND

The concepts and methodology used for the final map (Figure 5.3) result in the majority of the upland areas such as the Sperrins and the Mournes being assigned a high vulnerability rating, owing to the widespread occurrence of fractured rock with a generally thin cover of superficial deposits. The bedrock aquifers in these areas are mostly metamorphic or igneous, low permeability formations containing relatively small volumes of groundwater, mainly within fracture zones. As a result they are regarding as having only limited productivity potential. However, they are highly vulnerable to pollution on account of the dominance of fracture flow and generally thin, permeable superficial cover.

Vulnerability through the central part of the province and in the southwest is generally low due the presence of either thicker and/or lower permeability superficial deposits. Higher vulnerability zones do occur in these areas, for example where sand/gravel deposits occur within river valleys.

Very low vulnerability areas have been defined where borehole records indicate particularly thick overlying non-aquifer superficial deposits such as around Ballymoney. Other, very low vulnerability areas have been defined where very low permeability deposits are known to occur such as the estuarine clays within central Belfast.

## 6.2 GROUNDWATER VULNERABILITY METHODOLOGY

1. The methodology devised for the current project recognises the importance of the hydrogeological characteristics of the pathway between the hazard at or near surface and the receptor, which in this case is the uppermost main water table.
2. By recognising the need to protect all groundwaters irrespective of aquifer ‘importance’, the new map categorises areas of low permeability hard rocks such as schists and granite, where they occur at surface, as Vulnerability Class 5. This is a significant change to the representation of vulnerability in these areas compared with the previous regional vulnerability map for Northern Ireland.
3. Only where significant potential attenuation occurs or where the main water table is relatively inaccessible, such as beneath thick clay deposits, does the vulnerability class reduce to Class 1 or 2.
4. The application of the SNIFFER methodology to Northern Ireland was constrained by the scale of digital data, the extent of borehole datasets and the limited time available to confirm and incorporate local variations in hydrogeological settings. Nevertheless the vulnerability layer generated is considered to represent, on a regional basis, an improved representation of groundwater vulnerability across Northern Ireland and, as such, is suitable for use for WFD initial characterisation work. It provides the foundation from which more detailed (1:50 000) layers can be derived as data becomes available.

# References

Most of the references listed below are held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.

Department of the Environment for Northern Ireland. 1994. Groundwater vulnerability map for Northern Ireland. 1:250 000. (Keyworth, Nottingham: British Geological Survey for Department of Environment for Northern Ireland.)

Foster, S. S. D. 1998. Groundwater recharge and pollution vulnerability of British aquifers: a critical review. In: Robins N. S. (ed) *Groundwater Pollution, Aquifer Recharge and Vulnerability*. Geological Society, London, Special Publications. 130, 7-22.

McConvey, P. J. 2005. An aquifer classification scheme for Northern Ireland. (Belfast: Geological Survey of Northern Ireland for Department of Environment for Northern Ireland.)

NRC. 1993. *Groundwater Vulnerability Assessment: Contamination Potential under Conditions of Uncertainty.* National Academy Press, Washington DC.

Palmer, R. C. and Lewis, M.A. 1998. Assessment of groundwater vulnerability in England and Wales. In: Robins, N.S. (ed) *Groundwater Pollution, aquifer recharge and vulnerability.* Geological Society, London, Special Publications, 130, 191-198.

Palmer, R. C., Holman, I. P., Robins, N. S. & Lewis, M. A. 1995. *Guide to groundwater vulnerability mapping in England and Wales.* National Rivers Authority, London.

SNIFFER, 2004. Development of a groundwater vulnerability screening methodology for the Water Framework Directive. WFD28. Scotland and Northern Ireland Forum for Environmental Research

# Appendix 1 Vulnerability Coding Tables

## Northern Ireland groundwater Vulnerability map: vulnerability coding tables

| Highest | | | | Lowest |
|---|---|---|---|---|
| 5 | 4 | 3 | 2 | 1 |

In the following Tables, the permeability classification is shown by: H = High, M = Moderate, L = Low.

**Class 4 can be further subdivided according to the nature of the pathway:**

4a – sand and gravel cover (units 3+4)

4b – moderate K cover (unit 7)

4c – low K cover (unit 11)

4d – thin soil (unit 2)

4e – where superficial aquifers are present (units 16+17)

**Table 1 Fractured and dominantly fractured bedrock**

| | Exposed rock | Rock with <1 m low K soil cover |
|---|---|---|
| Exposed rock with/without High or moderate K soil cover | 1 | 2 |

**Table 2 Intergranular/dominantly fractured + fractured bedrock** (also includes dominantly intergranular bedrock because it is fully saturated, therefore the drift cover is the only means of attenuation) (Assumes no exposed intergranular bedrock)

| | | SUPERFICIAL DEPOSITS PATHWAY THICKNESS (m) | | | |
|---|---|---|---|---|---|
| | Drift K | 1-3 | 3-10 | 10-30 | > 30 |
| SUPERFICIAL DEPOSITS PERMEABILITY | H | 3 | 4 | 5 | 6 |
| | M | 7 | 8 | 9 | 10 |
| | L | 11 | 12 | 13 | 14 |

**Table 3 Clay thickness => 5 m**

| | ALL DRIFT CATEGORIES |
|---|---|
| **Clay thickness >5 m** | 15 |

**Table 4 Unsaturated zone thickness in superficial aquifers**

| | SUPERFICIAL DEPOSITS UNSATURATED ZONE THICKNESS (m) | | | | |
|---|---|---|---|---|---|
| **SUPERFICIAL DEPOSITS PERMEABILITY** | **Drift K** | **<3** | **3-10** | **10-30** | **> 30** |
| | **H** | 16 | 17 | 18 | 19 |

**Point Recharge Scenarios**

Within 30 m of mapped features of point recharge (e.g karst features and mine shafts), vulnerability is category 1. Elsewhere, vulnerability is assumed to be dictated by diffuse recharge scenarios.

**The guiding assumptions used in deciding criteria**

Groundwater is most vulnerable in areas where point recharge can bypass the drift.

All bedrock is liable to fracturing to some degree. Some protection form the drift is therefore required to significantly reduce vulnerability, even where bedrock has a significant primary porosity.

Drift deposits can be fractured and their thickness and properties are often variable over short distances. As such, mapped thicknesses >3 m are required to significantly reduce vulnerability.

Soil and soil parent material are often closely linked and mapped soil type will only influence the criteria in areas where drift is absent or is mapped as <1 m.

The following specific restrictions have therefore been derived to help develop the criteria:

No areas where drift is mapped as <1m can have a vulnerability of Class 3, 4, or 5, regardless of other pathway factors.

No areas where drift is mapped as <3m can have a vulnerability of Class 4, or 5.

No areas where drift is mapped as > 1m will have a vulnerability of Class 1, unless they are close to a mapped point recharge feature.

# Appendix 2 Attribute Fields Table

## Fields in attribute table for final vulnerability theme

| Field | Description | Comments | Ownership |
|---|---|---|---|
| SOIL_PERM | Interpreted Soil permeability. Codes:<br>0 – All soil permeability except Low Bare rock<br>1 – Bare rock All soil permeability except Low<br>2 – Low soil permeability | Determines VULNCODE where SCENARIO = 2, 3. Determines VULNCODE with BR_PERM & BR_DTW where SCENARIO = 5 or 6. | |
| SD_DTW | Depth to Water in superficial deposits where aquifers. Codes:<br>1 <3m to water<br>2 3 – 10 m to water<br>0 Outside area of superficial deposit aquifers | Pathway thickness for VULNCODE where SCENARIO = 1. | |
| | | | |
| SD_THICK | Superficial deposits thickness. Codes:<br>0 No drift<br>1 1 – 3 m drift<br>2 3 – 10 m drift<br>3 10 – 30 m drift<br>4 > 30 m drift | Pathway thickness for VULNCODE where SCENARIO = 4 or 7. | |
| CLAY | Presence of clay >=5 m thick within superficial deposits sequence. Codes:<br>Clay >=5 m 1<br>Clay < 5 m 0 | Used to determine VULNCODE where SCENARIO = 4 or 7. | |
| SD_PERM | Superficial deposits permeability. Codes:<br>H – High<br>M – Moderate<br>L – Low<br>NO – No Superficial Deposits | Used to determine VULNCODE where SCENARIO = 4 or 7. | |
| | | | |
| VULNCODE | Unique code for each combination of input factors, from 1 – 19 (see tables) | Only 13 combinations present in Northern Ireland. | |
| VULNCLASS | Vulnerability class, derived from Vulncode based on criteria (see tables). Codes:<br>5 Most Extreme<br>4 Extreme<br>3 High<br>2 Moderate<br>1 Low | Class 4 can be further subdivided according to the nature of the pathway:<br>4a<br>4b<br>4c<br>4d<br>4e | |