Evidence

New groundwater vulnerability mapping methodology in England and Wales

Report – SC040016/R

We are the Environment Agency. We protect and improve the environment.

Acting to reduce the impacts of a changing climate on people and wildlife is at the heart of everything we do.

We reduce the risks to people, properties and businesses from flooding and coastal erosion.

We protect and improve the quality of water, making sure there is enough for people, businesses, agriculture and the environment. Our work helps to ensure people can enjoy the water environment through angling and navigation.

We look after land quality, promote sustainable land management and help protect and enhance wildlife habitats. And we work closely with businesses to help them comply with environmental regulations.

We can't do this alone. We work with government, local councils, businesses, civil society groups and communities to make our environment a better place for people and wildlife.

Published by:
Environment Agency, Horizon House, Deanery Road, Bristol BS1 5AH

http://www.environment-agency.gov.uk

ISBN: 978-1-84911-318-2

Further copies of this report are available from our publications catalogue:
http://www.gov.uk/government/publications

or our National Customer Contact Centre:
T: 03708 506506

Email: enquiries@environment-agency.gov.uk

Author(s):
Dr Mike Carey, Dr Neil Thursten & Natalie Phillips

Dissemination Status:
Publicly available

Keywords:
Groundwater, vulnerability, vulnerability mapping, DRASTIC, groundwater protection

Research Contractor:
AMEC Environment and Infrastructure UK,
Canon Court North,
Abbey Foregate,
Shrewsbury
Shropshire,
SY2 5DE
017433 42000.

Environment Agency's Project Manager:
Natalie Phillips, Evidence Directorate

Project Number:
SC040016

Evidence at the Environment Agency

Scientific research and analysis underpins everything the Environment Agency does. It helps us to understand and manage the environment effectively. Our own experts work with leading scientific organisations, universities and other parts of the Defra group to bring the best knowledge to bear on the environmental problems that we face now and in the future. Our scientific work is published as summaries and reports, freely available to all.

This report is the result of research commissioned by the Environment Agency's Research, Analysis and Evaluation group.

You can find out more about our current science programmes at https://www.gov.uk/government/organisations/environment-agency/about/research

If you have any comments or questions about this report or the Environment Agency's other scientific work, please contact reserach@environment-agency.gov.uk.

Professor Doug Wilson
Director, Research, Analysis and Evaluation

Executive summary

The Environment Agency has updated its groundwater vulnerability maps to reflect improvements in data mapping, modelling capability and understanding of the factors affecting vulnerability. The new maps show the vulnerability of groundwater to a pollutant discharged **at ground level** based on the hydrological, geological, hydrogeological and soil properties within a single square kilometre. The potential impact of groundwater pollution is considered using the aquifer designation status which provides an indication of the scale and importance of groundwater for potable water supply and/or in supporting baseflow to rivers, lakes and wetlands.

The main aim of the maps is as a high level screening tool to give Environment Agency staff, planners, developers and other users an indication of whether a proposed development or activity is likely to be acceptable (e.g. located in an area of low vulnerability or over unproductive strata) or of potential concern (e.g. located in an area of high vulnerability on principal aquifer) where either it should be relocated to a lower risk area or further assessment is required to better understand the risk to groundwater. The maps can also be used to inform and target environmental management and incident response so that preventative and/or remedial actions can be taken as early as possible to protect groundwater.

These maps provide key evidence for the Environment Agency's assessment of the exposure of groundwater to a pollution hazard from a given activity as part of its permitting activities. They form part of a suite of tools used by the Environment Agency for groundwater protection including source protection zones and position statements. Further information can be found in the Environment Agency's Groundwater protection guides available on Gov.UK covering: requirements, permissions, risk assessments and controls.

Two map products are available:

- **The combined groundwater vulnerability map.** This product is designed for groundwater technical specialists due to the complex nature of the legend which displays groundwater vulnerability (High, Medium, Low), the type of aquifer (bedrock and/or superficial) and aquifer designation status (Principal, Secondary, Unproductive) separately. These maps require that the user is able to understand the vulnerability assessment and interpret the individual components of the legend.
- **The simplified groundwater vulnerability map.** This was developed for non-groundwater specialists who need to know the overall risk to groundwater but do not have extensive hydrogeological knowledge. The map has five risk categories (High, Medium-High, Medium, Medium-Low and Low) based on the likelihood of a pollutant reaching the groundwater (i.e. the vulnerability), the types of aquifer present and the potential impact in terms of the importance of the groundwater resource (i.e. the aquifer designation status).

The two maps also identify areas where solution features that enable rapid movement of a pollutant may be present (identified as stippled areas) and areas where additional local information affecting vulnerability is held by the Environment Agency (identified as dashed areas).

Once released the updated maps will replace the existing groundwater vulnerability maps.

Key changes

There are three notable changes between the old and new maps that users should be aware of:

- For the first time the maps provide a separate assessment of the vulnerability of groundwater in overlying (or ‘superficial’) rocks and those that comprise the underlying ‘bedrock’.
- The vulnerability assessment is carried out at a 1 kilometre square resolution using the dominant hydrological, geological, hydrogeological and soils data within that square.
- The aquifer designation classifications of some rock types have been changed from non-aquifers to secondary aquifers (in recognition of their importance for local water supplies and baseflow to rivers).

These changes have resulted in an increase in the area of land that is considered to require protection (i.e. groundwater aquifers) and an increase in the area that is more vulnerable (i.e. superficial rocks that by their proximity to the ground surface have less protective cover).

Note that a precautionary approach has been used to indicate the risk to groundwater across each kilometre square. Consequently, the maps may not reflect the exact geological and soil conditions at a site. Local and site-specific data should always be given precedence where available and should be collected in areas of high vulnerability if not already available.

Access to the maps

The maps for England can be viewed on the Environment Agency’s website via the interactive mapping service (What’s in your backyard) or Natural England’s Magic mapping service. Digital versions of the maps are freely available for non-commercial users from the Environment Agency for England or from Natural Resources Wales for Wales. The British Geological Survey will provide the data for England and Wales for a fee to commercial users.

Contents

List of tables and figures

1 Introduction

1.1 Background

Groundwater provides a third of the drinking water in England and Wales. It also provides vital baseflow to support the ecology in our rivers, streams, lakes and wetlands. Wherever groundwater is present there is the potential for it to be affected by human activity. The concept of vulnerability recognises that the risks of pollution from a given activity are greater in certain hydrological, geological and hydrogeological and soil situations than in others. Using this concept, the Environment Agency has updated its groundwater vulnerability maps to reflect improvements in data mapping and understanding of the factors affecting vulnerability.

These maps are a key component in how the Environment Agency assesses the exposure of groundwater to a pollution hazard from a given activity as part of its permitting activities. They form part of a suite of tools used by the Environment Agency for groundwater protection including source protection zones and position statements. Further information can be found in the Environment Agency's Groundwater protection guides covering: requirements, permissions, risk assessments and controls (previously covered in GP3).

Two new maps have been prepared using national datasets:

- The combined groundwater vulnerability map provides information on groundwater vulnerability (High, Medium, Low) and aquifer designation status (Principal, Secondary, Unproductive) for superficial and bedrock aquifers. The aquifer designation status gives an indication of the importance of the aquifer for drinking water and thus provides an indication of the level of harm that could result from a pollution event. The map is intended for groundwater technical specialists to provide an initial screening assessment of the vulnerability of groundwater to an activity where a pollutant is applied to the soil surface.

- A simplified groundwater vulnerability map has also been prepared that summarises the overall risk to groundwater (High, Medium-high, Medium, Medium-low, Low) taking into account the groundwater vulnerability, the types of aquifer present (superficial and/or bedrock) and their designation status. This was developed for non groundwater-specialist users who need to know the likely risk to groundwater from a particular activity, development or pollution incident but do not have extensive hydrogeological knowledge.

The two maps also identify areas where solution features that enable rapid movement of a pollutant may be present (identified as stippled areas) and areas where additional local information affecting vulnerability is held by the Environment Agency (identified as dashed areas).

1.2 Application of the maps

Groundwater vulnerability maps have a variety of applications including the following:

- A screening tool for Environment Agency permitting staff to help them evaluate the likely acceptability of proposed activities.

- An indicator of intrinsic groundwater vulnerability for planners, developers, private industry, consultants etc.
- An aid to identify when site-specific data or investigations are required (e.g. in high risk areas).
- An aid to strategic planning to influence the location of certain activities or developments in lower risk areas.
- A catchment management tool for targeting measures (e.g. farm liaison for diffuse groundwater pollution).
- An aid for management of incident responses.

The limitations for the maps are outlined in section 3.1 and all users are advised to read this information to ensure that they use the maps only for those activities and conditions where they are suitable.

1.3 Target audience

The vulnerability maps have a broad audience reflecting the range of applications for which they are suitable:

- Environment Agency operational and head office staff, including those working in permitting, planning, environmental management, incident response and groundwater management and protection.
- Water companies, local authority staff, developers and planners, emergency fire services, permitted industry carrying out activities with the potential to affect groundwater and consultants working for them. Also, the general public, particularly those with infrastructure such as septic tanks that if poorly constructed or managed can cause a risk to groundwater or with private boreholes that supply drinking water.

This report is aimed at groundwater technical specialists and users wishing to gain a greater understanding of the methodology so they can advise on the appropriate use and interpretation of this data. The report describes the methodology of how the maps and vulnerability scores have been developed, outlines how the maps should be used and explains their limitations. The report supplements the information provided in the 'Groundwater vulnerability map technical summary'.

2 Groundwater vulnerability maps

2.1 Existing maps and the need for a new system

Groundwater vulnerability maps for England and Wales were first published in 1986 by the British Geological Survey (BGS) (Palmer et al. 1995). These maps were made up of two components: an aquifer designation (major, minor, non-aquifer) based on the nature of the geological strata and a soil leaching class (high, intermediate and low), provided by the National Soil Resources Institute (NSRI). The maps contained the bedrock aquifer boundaries digitised from the original 1986 paper maps and were at a scale of 1:100,000. Low permeability superficial deposits were shown as areas of stipple.

These maps are known to have many inconsistencies and errors. Since then the BGS has produced 1:50,000 scale maps, including newly surveyed areas in Wales and the northwest and northeast of England that were previously unavailable at this scale. The BGS has provided the latest available versions of the superficial and bedrock aquifer maps for use in this project, correcting many of the previously known problems.

Since the introduction of the maps, significant developments in information technology and especially geographic information systems (GIS) have meant that data can be combined and analysed in more sophisticated ways. Coupled with this is the availability of improved datasets, continued evolution of risk-based decision making, and new legislation, specifically the advent of the Water Framework Directive (WFD).

Effective from 1 April 2010, the Environment Agency changed the aquifer designations to be consistent with the WFD. Although the previous major and minor aquifers mapped largely on to the WFD principal and secondary A aquifers respectively, the water-bearing parts of the non-aquifers became designated as secondary B (Table 2.1). Some strata, which in places had been mapped as both minor aquifer and non-aquifer, became secondary undifferentiated and only those non-aquifers with negligible significance for water supply or river baseflow were designated as unproductive strata.

More recently, to underpin the work on this project, the aquifer designations have been re-appraised to introduce greater consistency in the classification of strata across England and Wales. In some areas classifications have been revised from unproductive to secondary to reflect improved information about locally important sources of groundwater, not just for potable supply and industry but also in supporting rivers and dependent ecosystems. These are important functions of groundwater recognised in the WFD.

Table 2.1 Aquifer designations

Old aquifer designation	**WFD aquifer designation**
Major	Principal
Minor	Secondary A
Non-aquifer	Secondary B (water-bearing parts of non-aquifers)
	Secondary undifferentiated (previously minor or non-aquifer, but information insufficient to classify as secondary A or B)
	Unproductive strata[1]

[1]Strata with negligible significance for water supply or river baseflow

Having considered the above concerns and developments in information technology, the Environment Agency commissioned a project (Environment Agency 2003a, 2003b) that reviewed the principles of vulnerability assessment, defined the requirements of a revised approach and looked at the different approaches to assessing groundwater vulnerability that have been developed elsewhere in the world. The outcome from this project was an updated methodology for the production of the vulnerability map, as described in the following sections.

2.2 Overall concept of vulnerability

The pollution hazard of an activity will be greater in certain hydrological, geological and soil situations than in others. When we consider the level of risk from any given activity and want to make judgements about its acceptability, we have to assess the total exposure of the groundwater system to that hazard and the severity of the potential impact. Vulnerability is usually a significant element of the risk assessment.

We can consider two types of vulnerability:

- Intrinsic vulnerability of a location depends on a number of factors including the soil type, presence of superficial deposits and characteristics of the bedrock.
- Specific vulnerability of a location takes into account additional factors. These include the nature of the activity under scrutiny and the characteristics of the pollutant that is posing a threat to groundwater.

Figure 2.1 illustrates the concept of intrinsic vulnerability.

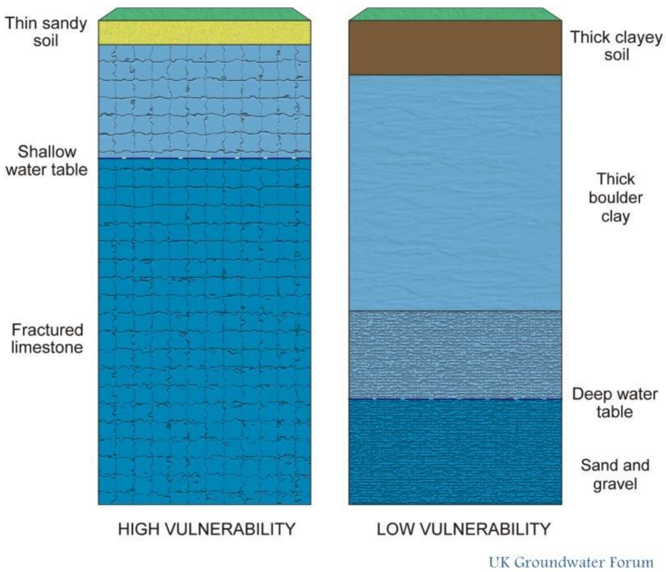

Figure 2.1 Illustration of intrinsic groundwater vulnerability (from UK Groundwater Forum)

The groundwater vulnerability maps produced by the Environment Agency capture the factors affecting the intrinsic vulnerability of the groundwater system. The vulnerability assessment has been based on how pollutants released **at the soil surface** by an activity (e.g. spreading of fertilisers, sewage spreading to ground) are transported down to the water table taking account of protective layers (i.e. soil, superficial deposits, unsaturated zone).

Groundwater vulnerability has been considered to be a function of:[1]

- The amount of pollutant reaching the water table, which will be a function of infiltration through the soil zone, soil leaching class and superficial geology cover.
- Attenuation and degradation of the pollutant, which will be a function of soil leaching class, thickness of superficial deposits, thickness of the unsaturated zone and flow mechanism.

The factors that have been taken into account in assessing groundwater vulnerability are summarised in Table 2.2.

Table 2.2 Summary of factors influencing groundwater vulnerability and whether they have contributed to the maps

Physical characteristic or layer	Attribute	Aquifer	
		Superficial	Bedrock
Dilution by rainfall	Effective rainfall (available water)	Y	Y
Proportion of available water infiltrating to groundwater	Infiltration (Baseflow Index)	Y	Y
Soil	Leaching class	Y	Y
Superficial (Drift deposits)	Patchiness (cover)		Y
	Thickness		Y
	Recharge potential (function of permeability of superficial deposits)		Y
Unsaturated zone[1]	Bedrock flow mechanism (fracture, mixed, intergranular)		Y

[1] The thickness of the unsaturated zone was not included as national datasets were not available

A scoring system (section 4.1) was developed to allow these different factors to be taken into account in assessing groundwater vulnerability and in defining a classification of high, medium or low vulnerability.

Superficial aquifers, by their nature (e.g. shallow water table with little or no protective cover), are the most vulnerable to pollution. Bedrock aquifers can be equally vulnerable where superficial deposits are absent and where the unsaturated zone is thin or fractured, as illustrated by Figure 2.1.

2.3 Combined and simplified groundwater vulnerability maps

Two groundwater vulnerability maps have been produced:

- A combined vulnerability map (Figure 2.2), which shows information on groundwater vulnerability and aquifer designation status for superficial and bedrock aquifers.
- A simplified map (Figure 2.3), which summarises the overall risk to groundwater taking into account the groundwater vulnerability, the types of aquifer present and their designation status.

[1] Groundwater vulnerability is also a function of other factors (e.g. organic content, moisture content, permeability, clay content, geochemical conditions; Griffiths et al. 2011), but it is not feasible to consider all of these factors with the available datasets.

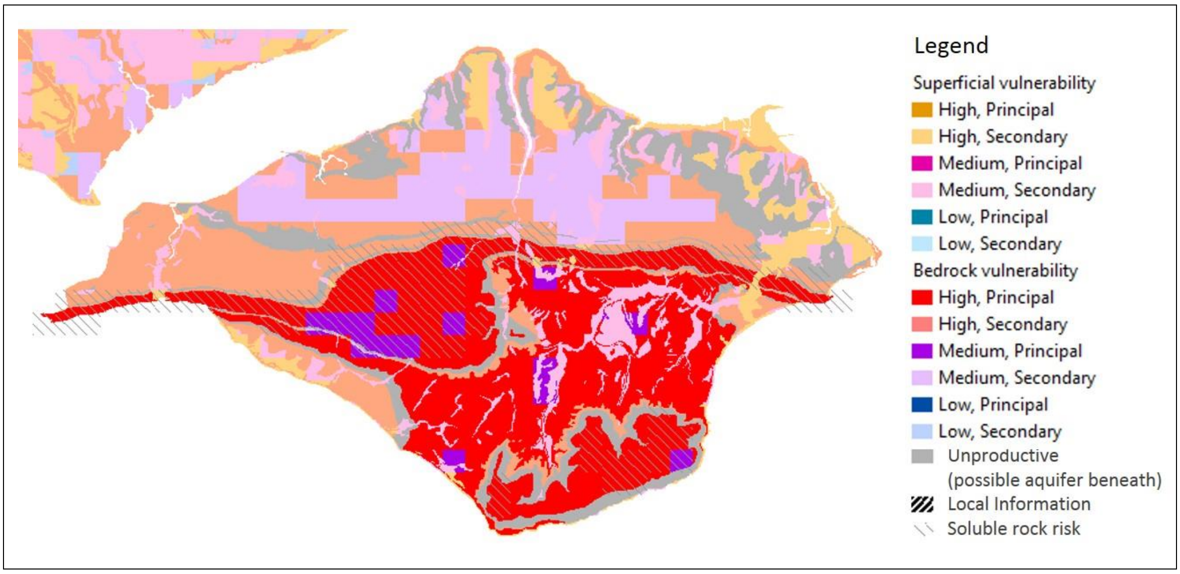

Figure 2.2 Combined groundwater vulnerability map – example

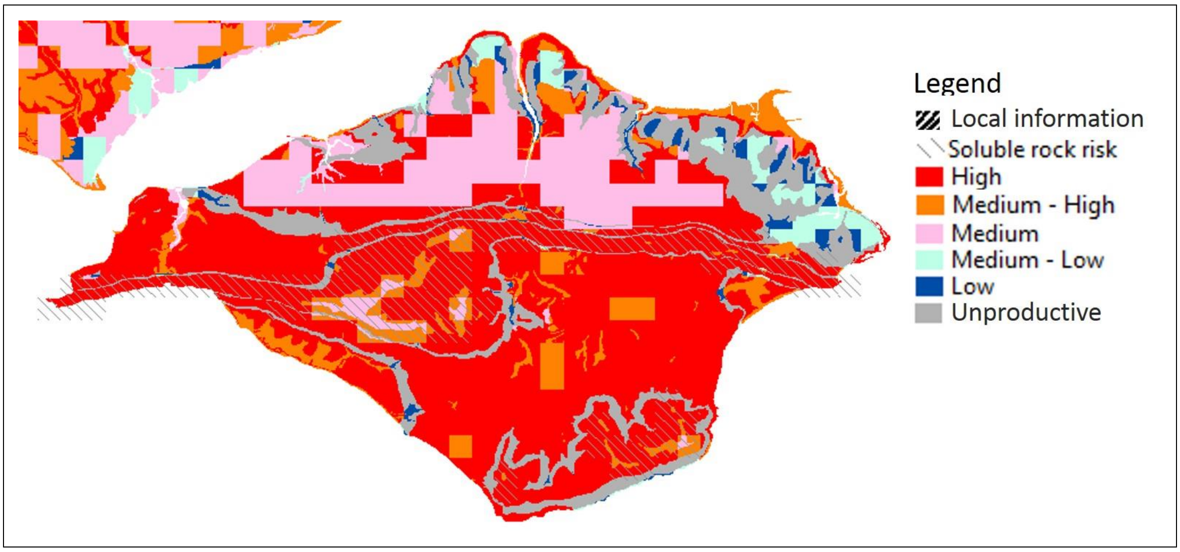

Figure 2.3 Simplified groundwater vulnerability map – example

For the first time, the maps provide a separate assessment of the vulnerability of groundwater in overlying superficial rocks, and those that comprise the underlying bedrock. These two rock types are defined as:

- **Superficial (drift)**: permeable unconsolidated (loose) deposits (e.g. sands and gravels).
- **Bedrock**: solid permeable formations (e.g. sandstone, chalk and limestone).

The vulnerability of these two rock types may differ due to their structure and location. Where both types are present, the maps display the most vulnerable category of the two.

The importance of the groundwater resource is reflected in the aquifer designation status. This is derived from the British Geological Survey’s superficial and bedrock geological mapping. The definitions for the aquifer status are:

- **Principal**: These are rocks that provide significant quantities of water and can support water supply and/or baseflow to rivers, lakes and wetlands on a strategic scale. They typically have a high intergranular and/or fracture permeability meaning they usually provide a high level of water storage.
- **Secondary**: These rocks can provide modest amounts of water, but the nature of the rock or the aquifer's structure limits their use. They support water supplies at a local rather than strategic scale (such as for private supplies) and remain important for rivers, wetlands and lakes. They have a wide range of water permeability and storage.
- **Unproductive**: These rocks have negligible significance for water supply or baseflow to rivers, lakes and wetlands. They consist of bedrock or superficial deposits with a low permeability that naturally offer protection to any aquifers that may be present beneath.

Principal and Secondary aquifers are collectively referred to as being productive due to their use as a groundwater resource.

In some areas the former aquifer designations have been revised from unproductive to secondary to reflect improved information about locally important sources of groundwater.

The maps describe groundwater vulnerability as high, medium or low and are based on a 1 kilometre grid, which is common to the datasets used in generating the maps (section 5), where:

- **High vulnerability**: Areas able to easily transmit pollution to groundwater. They are likely to be characterised by high leaching soils and the absence of low permeability superficial deposits.
- **Medium vulnerability**: Intermediate between high and low vulnerability.
- **Low vulnerability**: Areas that provide the greatest protection to groundwater from pollution. They are likely to be characterised by low leaching soils and/or the presence of superficial deposits characterised by a low permeability.

To produce the combined groundwater vulnerability map (Figure 2.2), the grid squares have been clipped and combined with the mapped boundaries for aquifer designation to result in the following groupings:

Bedrock

Principal – High

Principal – Medium

Principal – Low

Secondary – High

Secondary – Medium

Secondary – Low

Superficial

Principal – High

Principal – Medium

Principal – Low

Secondary – High

Secondary – Medium

Secondary – Low

Unproductive

Surface activities in areas of unproductive strata are unlikely to represent a risk to groundwater due to the low permeability of the deposits and the protection this offers to any aquifers that may be present beneath. For this reason they have not been assigned a vulnerability class. However, increased water run-off from these lower permeability deposits may present a risk to surface water or adjacent groundwater if this component provides run-recharge to aquifers (i.e. infiltration via solution features).

The simplified groundwater vulnerability map further synthesises the information contained in the combined groundwater vulnerability map to give an indication of the overall risk to groundwater from a pollutant discharged at the ground surface. It was developed for non-groundwater specialists who need to know the risk to groundwater from a particular activity, development or pollution incident but do not have extensive hydrogeological knowledge.

The simplified vulnerability map has five risk categories (High, Medium-High, Medium, Medium-Low and Low) defined as:

- **High** – These are high priority groundwater resources that have very limited natural protection. This results in a high overall pollution risk to groundwater from surface activities. Operations or activities in these areas are likely to require additional measures over and above good practice pollution prevention requirements to ensure that groundwater isn't impacted.
- **Medium-high –** These are high priority groundwater resources that have limited natural protection. This results in a medium-high overall pollution risk to groundwater from surface activities. Activities in these areas may require additional measures over and above good practice to ensure they do not cause groundwater pollution.
- **Medium –** these are medium priority groundwater resources that have some natural protection resulting in a moderate overall groundwater risk. Activities in these areas should as a minimum follow good practice to ensure they do not cause groundwater pollution.
- **Medium-low** - these are lower priority groundwater resources that have some natural protection resulting in a moderate to low overall groundwater pollution risk. Activities in these areas should follow good practice to ensure they do not cause groundwater pollution.
- **Low –** these are low priority groundwater resources that have a high degree of natural protection. This reduces their overall risk of pollution from surface activities. However, activities in these areas may be a risk to surface water due to increased run-off from lower permeability soils and near-surface deposits. Activities in these areas should be adequately managed to ensure they do not cause either surface or groundwater pollution.

These five risk categories take into consideration the likelihood of a pollutant reaching the groundwater (i.e. high, medium or low vulnerability), the types of aquifer present (superficial and/or bedrock) and their designation status (principal, secondary and unproductive). Table 2.3 shows how these factors are combined to generate the five groundwater risk categories.

Table 2.3 Simplified groundwater vulnerability classification

	Productive Superficial Unproductive Bedrock	Unproductive Superficial **Productive Bedrock**	**Productive Superficial Productive Bedrock**	No Superficial **Productive Bedrock**
Principal aquifer High vulnerability	Medium-High	Medium-High	High	High
Secondary aquifer High vulnerability	Medium-Low	Medium	Medium-High	High
Principal aquifer Medium Vulnerability	Medium-Low	Medium	Medium-High	Medium-High
Secondary aquifer Medium vulnerability	Low	Medium-Low	Medium	Medium
Principal aquifer Low vulnerability	Low	Low	Medium-Low	Medium-Low
Secondary aquifer Low vulnerability	Low	Low	Medium-Low	Low
Unproductive	No	No	No	No

In preparing the maps the Environment Agency has adopted a precautionary approach to indicate the risk to groundwater within each 1 kilometre square, displaying the most vulnerable class from either the bedrock or superficial aquifer assessment.

The GIS datasets prepared for both maps contain summary information about the input datasets used in the vulnerability assessment (section 5). This information is contained in the underlying attribute tables and includes:

- a unique 1 kilometre square cell reference (GWV_ID);
- OS easting and northing grid references for the cell centre;
- superficial and bedrock aquifer designation status (principal/secondary/unproductive);
- superficial and bedrock groundwater vulnerability (high/medium/low);
- Classified dilution, Infiltration (Baseflow Index), soil leaching, superficial patchiness, superficial thickness, recharge potential and flow type values and scores (see section 4, Table 4.1 for further information).

In addition to the data used to calculate vulnerability, a GIS layer defining areas of potential solution features (identified as stippled areas) is provided to indicate the risk of rapid movement of a pollutant to the water table. This soluble rock risk layer has not contributed to the vulnerability classification (high, medium, low), but provides additional information to help the user better understand the risks to groundwater.

In some parts of the country the Environment Agency or Natural Resources Wales may hold additional local information (e.g. areas with little or no soil cover or the presence of highly fissured rock) that influences assessment of groundwater vulnerability. Where this information is available it is displayed as hashed lines on the maps (also at a scale of 1kilometre square). These organisations can be contacted to for more information and advice on groundwater vulnerability relating to these areas.

3 How the maps should be used

This section provides a summary of how the maps should be used as part of an initial screening exercise of the risk associated with an activity that may affect groundwater. The maps should also be used in combination with the Environment Agency's groundwater source protection zone maps and with reference to the Groundwater protection guides available on Gov.UK covering: requirements, permissions, risk assessments and controls (previously covered in GP3).

The main aim of the combined groundwater vulnerability map is to allow Environment Agency and Natural Resources Wales permitting staff, and planners, consultants and other groundwater technical specialists to assess whether a proposed development or activity is in an area of high, medium or low vulnerability. This will determine whether:

- the activity is likely to be acceptable (e.g. located in an area of low vulnerability or over unproductive strata);

or

- the activity may not be acceptable (e.g. located in an area of high vulnerability) where either it should be relocated to a lower risk area or further assessment is required.

This further assessment may involve a site investigation to determine where there are local factors (e.g. presence of low permeability superficial geology) that reduce the vulnerability of the underlying aquifer. For example, the vulnerability map may identify that the bedrock aquifer has a high vulnerability to pollution (at the 1 kilometre scale), but reference to geological maps shows that boulder clay deposits are present below the site. In this case, a site investigation may be appropriate to confirm the presence, nature and thickness of the superficial deposits and whether the risk to groundwater should be modified.

For activities located in high vulnerability areas or medium vulnerability areas over principal aquifers the Environment Agency is likely to advise that the activity is relocated, or further investigations and risk assessment are undertaken to demonstrate that there is not a risk to groundwater, or engineering or remedial mitigations are used to limit the possible impact on groundwater.

Groundwater is unlikely to be at risk where only unproductive strata are present due to the low permeability of these deposits which offer protection to any aquifers that may be present beneath. However the risk to surface water will need to be considered. In some cases surface water run-off can provide recharge to aquifers (e.g. surface water run-off to solution holes) and this will also need to be assessed.

The simplified groundwater vulnerability map will be used to help the Environment Agency and other emergency responders such as the Fire Services plan how to respond to pollution incidents. The map indicates the overall risk to groundwater based on the same information as the combined groundwater vulnerability map but synthesised into a simple five tier risk legend that is quick and easy to follow. This map is also suitable for use by non groundwater-specialists who wish to know the overall risk to groundwater from a particular activity or development but do not have extensive hydrogeological knowledge.

Table 3.1 provides some example problems to illustrate how the maps should be used. The term risk is used for the five categories used in the simplified groundwater vulnerability maps whilst vulnerability is used for the high, medium and low from the combined vulnerability maps.

Table 3.1 Example problems and how the maps should be used

Proposed land spreading at a site located close to the boundary between areas of high and low vulnerability. Review soil and geological maps and/or any local information available to establish the site-specific vulnerability and note whether there is potential for lateral movement to areas of higher vulnerability. This review may help to influence the movement of the proposed area of spreading to a lower risk area. Where practical, activities should be located in lower vulnerability areas.
Land spreading of treated sewage effluent to site underlain by unproductive strata. Activity acceptable, although risk to surface water should be considered (e.g. distance to nearest surface watercourse and whether surface pathway is present).
Disposal of waste pesticide in an area of medium vulnerability. Waste disposals will require an environment permit and you should consult Environment Agency staff, who can advise on obtaining the permit and on areas where this activity is best carried out.
Proposed petrol station in a high vulnerability area on a principal aquifer (i.e. high/medium-high risk). Activity represents a significant risk and should be relocated to a lower vulnerability area, unless supporting information can be provided to demonstrate that local factors (e.g. presence of low permeability superficial deposits) provide adequate protection to groundwater or an engineering solution can be agreed. Below-ground tanks represent a significantly higher risk than above-ground structures.
Proposed housing development in medium-low/low risk area (i.e. low vulnerability). Likely to be acceptable, although further assessment will be needed to assess risk if, for example, activities such as effluent discharge to ground is proposed if connection to mains sewerage is not feasible.
Treated sewage effluent to ground (e.g. discharge from septic tank). This activity will result in the release of pollutants (e.g. ammonium) below the soil zone and therefore vulnerability of the aquifer will be higher than shown on the maps (i.e. the maps assume that the point of release is above the soil zone). If the disposal is in an area of high or medium vulnerability (i.e. high, medium-high or medium risk), then the following should be considered: connection to mains sewerage, relocation of disposal area (lower vulnerability), or further investigation to demonstrate that the discharge will not represent a risk to groundwater.
Proposed cemetery is located in a high or medium-high risk area. You should consult Environment Agency staff, but the likely advice will be to relocate the cemetery if you are on a principal aquifer (i.e. or to undertake site investigation and risk assessment to demonstrate that there is not a risk to groundwater.
A safeguard zone is proposed for a potable water supply abstraction with the objective of reducing nitrate concentrations in the bedrock aquifer. Measures should be focused in areas with high bedrock vulnerability as there will be a greater probability of improving water quality. Note that if there is also a superficial aquifer present the maps will show the highest vulnerability class from the superficial and bedrock assessments. It is possible to find the bedrock vulnerability in the map's attribute table.
Change of land use (pasture to arable or horticulture) and therefore likelihood of spraying of pesticides in an area of high vulnerability. Check with Environment Agency staff whether there is evidence of pesticides in the groundwater and a risk to potable supplies. This may indicate that pesticides should not be used in the vulnerable area or that additional precautions need to be taken.
An incident has resulted in a chemical spill. You should aim to contain/minimise the extent of the spill as far as possible to reduce the risk to the water environment and contact the Environment Agency immediately on our pollution incident reporting number: 0800 80 70 60. Check the simplified vulnerability map and source protection map for a rapid indication of the risk to groundwater. If the spill is located within an area of high, medium-high or medium risk and/or in a source protection zone 1 (SPZ1) then immediate action is required to contain and manage the spill. Environment Agency staff can help advise on the most appropriate actions to take. In medium-low and low risk areas, the risk to strategic groundwater supplies is low but pollution could still impact private water supplies and/or local rivers and wetlands fed by groundwater. The nature of the pollutant and proximity of such receptors as well as possible surface and groundwater pathways to these receptors should be considered.

In the following sections, some additional advice about the maps is provided.

Activity and point of release

The vulnerability maps assume that pollutants are released at the ground surface. Therefore, they must be used with care when the point of release is below the soil zone. For example, as a landfill or septic tank is placed below ground, the soil layer does not provide protection and the thickness of any overlying deposits separating the activity from the underlying aquifer will be less than estimates used in the maps. This is also true for areas shown as unproductive on the maps which may have aquifers beneath the unproductive deposits. The vulnerability of those aquifers would depend on the depth of the activity relative to the base of the unproductive strata.

Groundwater vulnerability will be increased where the activity (e.g. tanker spill) involves the release of a large volume of effluent over a comparably small area as this may result in rapid movement down to the water table with limited attenuation.

Is there any local information?

The new groundwater vulnerability assessment has been produced using national-scale data that have been processed on a 1 kilometre grid scale across England and Wales. The maps cannot, and are not intended to, capture site-specific processes that may have a dominant effect on groundwater vulnerability at a specific location. Environment Agency or Natural Resources Wales area staff may have additional information (e.g. local maps of the thickness of the unsaturated zone or maps of the presence of solution features) that indicate that the vulnerability of the aquifer may be lower (e.g. thick unsaturated zone) or higher (e.g. presence of solution features that provide rapid pathways for pollutants to reach the water table or areas of exposed bedrock).

To find out if solution features are a risk in your area, look first at the vulnerability maps to see if there is stippling in the grid cell corresponding to your place of interest. Areas marked with stipple on the maps indicate there is a risk of soluble rocks being present. The data are derived from the British Geological Survey's Soluble Rock Risk dataset which contains more detail on the location and type of risk. The BGS should be contacted if further information is required.

In some places the Environment Agency will have confirmed the presence of solution features, or other factors affecting vulnerability. These areas are identified with dashed lines and Environment Agency area staff can provide more detailed information upon request.

The maps may also show that a site is located close to the boundary between an area of high and low vulnerability. Reference to soil and/or geological maps may help to determine which is the most relevant and also whether a simple relocation of the area for the proposed activity or development would reduce the risk to groundwater.

Environment Agency staff will use this information as part of the initial screening exercise, but they will also take account of any supporting evidence provided that indicates the groundwater vulnerability class shown on the map can be modified for the site (see below).

To make a request for local information for England please contact the Environment Agency National Customer Call Centre (NCCC) and ask to speak to a member of the local Area groundwater team. You can contact the NCCC by email at enquiries@environment-agency.gov.uk or by phone on 03708 506 506 or minicom 03702 422 549 (for the hard of hearing) between 8am and 6pm Monday to Friday. The number to call for local information in Wales is 0300 065 3000 between 9am and 5pm Monday to Friday or email enquiries@naturalresourceswales.gov.uk.

If the groundwater vulnerability is low or unproductive, where is the pollution going?

As part of the assessment of the risk posed by a pollutant discharged at the ground surface, consideration should also be given to the risk to surface water, particularly where the vulnerability maps indicate low vulnerability or the presence of unproductive strata. Such areas have the potential that pollutant movement may be via run-off to a nearby watercourse or adjacent groundwater.

What to do if you have additional evidence that may provide a different view of vulnerability in a given area

The information used to construct the maps is based on processing of national datasets to provide an initial assessment of vulnerability. A precautionary approach has been adopted, and therefore the maps will be based on the dominant soil or average superficial geology thickness in each 1 kilometre square. It is possible that these conditions may not apply to a particular site and Environment Agency staff will take account of supporting information, such as more detailed investigation that shows that the vulnerability of the aquifer is lower than indicated by the maps (e.g. presence of a thick layer of low permeable superficial deposits).

Due to the scale of the maps, the classification of the groundwater vulnerability may not agree with your understanding of the site. In this case you should consider the factors influencing groundwater vulnerability (section 2.2) and the limitations of the maps (section 3.1) to determine whether the assessment is valid or whether, by providing additional evidence (e.g. results of borehole drilling or soil mapping), a different vulnerability is appropriate.

3.1 Limitations of groundwater vulnerability maps

In preparing the maps the Environment Agency has adopted a precautionary approach to indicate the risk to groundwater across each 1 kilometre square. Consequently, the maps may not reflect the exact geological and hydrogeological conditions at a specific site. Local and site-specific data (e.g. depth to water table) should be considered where available and should be collected for high vulnerability areas and some activities in medium vulnerability areas if not already available.

If vulnerability is ‘patchy’ this is generally indicative of highly variable geology and soils, but may also be due to ‘edge effects’ (e.g. in coastal areas) where some data used to calculate vulnerability are missing. Missing data, visible in the underlying map table, have been treated as the worst case in line with a precautionary approach, however this can lead to an artificially high vulnerability score. Activities in these areas, particularly if a site is close to or overlapping the boundary of two cells with differing vulnerability, should be examined in more detail using the information in the map tables. Where site-specific data is available this should be given precedence.

Human activities such as mine workings, excavations or pipe work, particularly in urban areas, are not included in the maps but could increase vulnerability locally. For example, the presence of man-made excavations that have been backfilled with permeable, readily compacted material will make a location significantly more vulnerable. Nearly all civil engineering construction, but especially underground pipes, will provide rapid pollution routes that are not characterised by the data included in the maps. Alternatively, the vulnerability may be decreased if the area has been backfilled by less permeable material (i.e. replacement of weathered/fractured bedrock by sand).

The soil zone can contribute up to 50% of the vulnerability score for superficial aquifers and up to 17% of the score for bedrock aquifers (section 4.1), reflecting the importance of superficial deposits in protecting bedrock aquifers. In some areas, soils may be removed by natural processes (soil erosion) or as a result of human activity (e.g. quarrying), which will increase the vulnerability of the underlying aquifer. This will need to be taken into account in using the maps.

If a development or activity is below the soil layer (e.g. the overflow from a septic tank) or where the soil layer has been removed (e.g. for construction purposes) the soil will offer no protection and the groundwater vulnerability will be higher.

If a development or activity is below the ground surface (e.g. a landfill) in an area shown as unproductive it could still pose a risk to aquifers that may be present beneath the unproductive strata. The vulnerability of those aquifers would depend on the depth of the activity relative to the base of the unproductive strata.

The nature of a pollutant will affect the specific vulnerability at a location. While the soil leaching classes indicate something of the likely speed of movement of pollutants through the soil and take into account the adsorptive capacity of the soil, they are by nature a generalisation based on the dominant soil type present in the area.

The maps are not suitable for insoluble pollutants, the movement of which depends on their individual properties such as density and viscosity. The maps should not be used to assess land already contaminated by pollutants.

The maps should also be used with care if the pollutant is being applied intensively over a small area such that the protective capacity of the soil is overwhelmed. This may be the case for incidents and spills or poorly managed land spreading.

To summarise, the maps are intended as an initial screening tool and should be used in conjunction with other data such as source protection zones and site and activity specific information.

4 How groundwater vulnerability has been assessed

4.1 Scoring system

Groundwater vulnerability is divided into three classes: high, medium or low. The classification of each 1 kilometre square depends on a calculated score, which takes account of the influence of each of the layers listed in Table 2.2 on pollutant loading and concentration at the water table.

The score is dependent on a weighting factor and index score and is calculated as follows:

Vulnerability score = Weighting factor * Index score (summed for all layers)

The greater the score the lower the risk of a pollutant affecting the aquifer (greater protection = lower vulnerability). Figure 4.1 illustrates how the information has been combined.

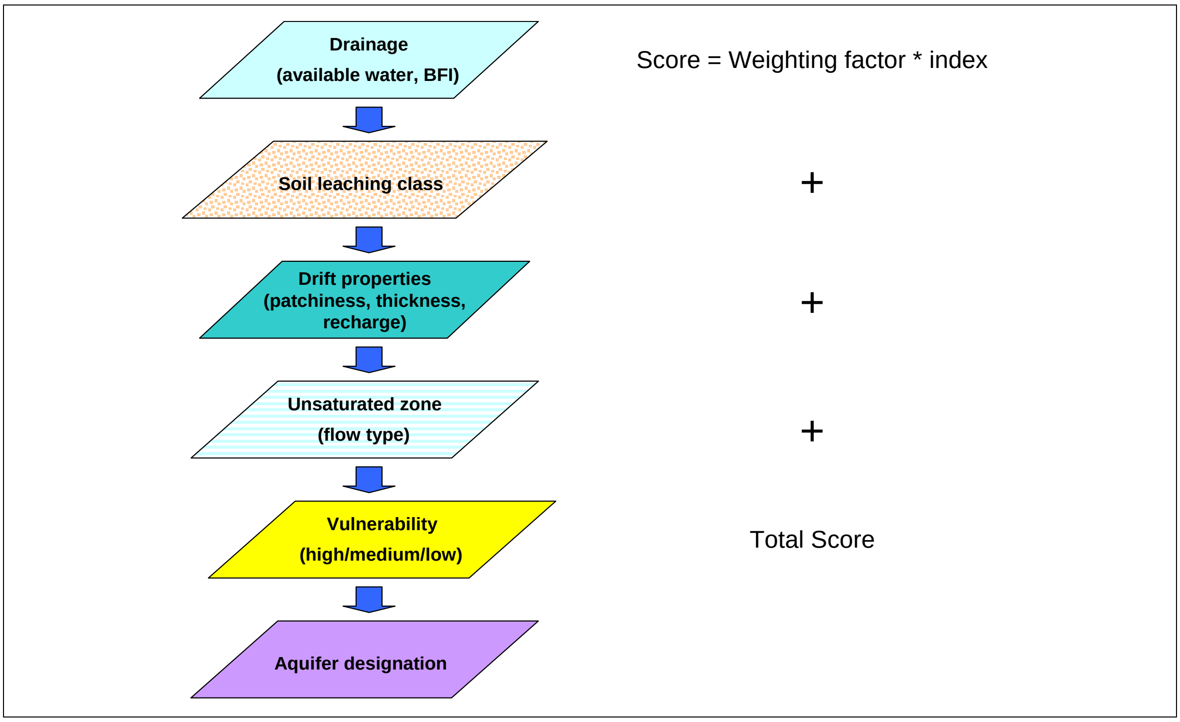

Figure 4.1 Illustration of scoring system

The scores used to assess vulnerability are summarised in Table 4.1 and an example calculation is presented in Table 4.2.

The first element of the score is the ‘weighting’. The weighting is applied to each of the attributes listed in Table 2.2. This weighting reflects how this attribute affects the vulnerability of the aquifer to an activity. The weightings are:

- 3 for a dominant process;
- 2 for a significant process;
- 1 for a minor process;
- 0 for any layer that does not contribute (e.g. superficial deposits are unlikely to provide protection to a shallow superficial aquifer).

The relative weighting associated with each attribute is summarised in Table 4.1, These have been developed through a combination of expert opinion, modelling and analysis of groundwater monitoring data as discussed in sections 4.2 and 4.3.

For the assessment of bedrock aquifer vulnerability superficial deposits are considered to have the greatest influence on pollutants that could migrate down (section 4.2). They have, therefore, been given a greater weighting than the soil or unsaturated zone layers. For example, the maximum contribution of the different layers to the vulnerability score is superficial (50%), soil (17%), unsaturated zone (17%), dilution (8%) and groundwater/surface water split (8%), as shown on Figure 4.2. This means that the characteristics of the superficial geology will contribute three times as much to the final vulnerability score as the soil characteristics.

The same weightings have been used for the assessment of superficial aquifer vulnerability but due to the proximity of the aquifer to the ground surface fewer layers are used in the assessment.

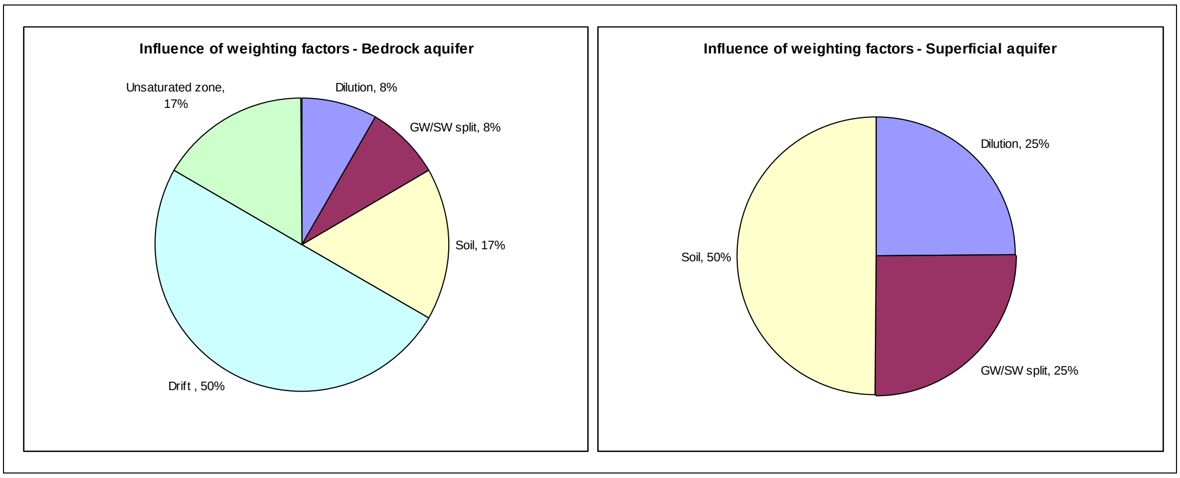

Figure 4.2 Relative influence of weighting factors on vulnerability score

The second element, the index score, is related to the strength of evidence that a layer attribute will affect the pollutant loading and hence vulnerability. The scores are:

- index score 2 = good evidence
- index score 1 = some evidence
- index score 0 = no evidence that the attribute of a specific layer contributes to the protection of groundwater.

For example, if superficial geology thickness is greater than 10 m (Table 4.1), this will be given an index of 2 because there is good evidence from groundwater monitoring data that the deposits will provide protection to groundwater. A superficial thickness of 3–10 m will provide some protection (index of 1) while a thickness below 3 m provides no evidence that it will protect the groundwater.

These scores are then converted to vulnerability indices (low, medium or high) using the score bands given in Table 4.3. The bands vary according to whether the receptor is a bedrock or superficial aquifer and were determined through expert judgement and sensitivity analysis. Section 4.2 provides further details of how the scoring system was developed.

The final scoring was integrated into a GIS tool to calculate vulnerability scores on a 1 kilometre grid across England and Wales. These were then combined with the bedrock or superficial aquifer designation status to create the final groundwater vulnerability maps (see example given in Figure 2.2). Users with access to the digital versions of the maps will have the facility to determine how the scores for each 1 kilometre square have been derived by looking up the scores of the input layers in the underlying attribute tables (table 4.1). A full list of all the attributes in each attribute table together with brief description is provided in Appendix A.

Table 4.1 Summary of vulnerability scores

Physical characteristic	Attribute	Value	Index score	Weighting factor		Data source (section 5)
				Superficial	**Bedrock**	
Dilution	Available water	<300 mm/year	0	1	1	CEH CERF (section 5.3)
		300–550 mm/year	1			
		>550 mm/year	2			
Groundwater/ surface water split	Infiltration (Baseflow Index)	>70%	0	1	1	CEH CERF (section 5.3)
		40–70%	1			
		<40%	2			
Soil	Leaching class	High 1	0	2	2	NSRI Soil leaching class (section 5.4)
		High 2	0			
		High 3	0			
		Intermediate 1	1			
		Intermediate 2	1			
		Low	2			
Superficial geology	Patchiness	<90%	0	0	3	BGS GeoSure (section 5.5.1)
		>90%	2			
	Thickness	<3 m	0	0	2	
		3–10 m	1			
		>10 m	2			
	Recharge potential	High	0	0	1	SNIFFER/BGS (section 5.5.2)
		Medium	1			
		Low	2			
Unsaturated zone (Bedrock geology)	Flow type	Fractures: (well connected)[1]	0	0	2	BGS GeoSure (section 5.6.1)
		Fractures: (poorly connected)[1]	2			
		Mixed	1			
		Intergranular	2			

[1] Environment Agency input

Table 4.2 Example calculation of the vulnerability score for an area overlying a bedrock aquifer

Attribute	Value	Index score	Weighting factor	Score
Dilution	>550 mm/year	2	1	2
Infiltration (BFI)	40–70%	1	1	1
Soil leaching class	Intermediate 1	1	2	2
Superficial geology patchiness	<90%	0	3	0
Superficial geology thickness	3–10 m	1	2	2
Recharge potential of superficial geology	Medium	1	1	1
Unsaturated zone (bedrock) flow type	Fractures (well connected)	0	2	0
Total score				8
Bedrock groundwater vulnerability (Table 4.3)				Medium

Table 4.3 Groundwater vulnerability classification bands

	Superficial aquifer with pollutant applied above soil zone	Bedrock aquifer with pollutant applied above soil zone
Low (L)	>6	>10
Medium (M)	3–6	7–10
High (H)	<3	<7

4.2 Development of scores

The scores given in Table 4.1 were developed using a combination of the following:

- Groundwater monitoring data. A qualitative comparison was made between the vulnerability maps and areas where the results from the monitoring network showed evidence of elevated pollutant concentrations in groundwater (e.g. high nitrate concentrations).
- Modelling of the movement of pollutants through the soil and unsaturated zone.
- Expert opinion that comprised discussions between the Environment Agency's in-house technical experts, external technical specialists and consultants and the British Geological Survey (BGS).
- Review by Environment Agency area staff (section 4.3.2).

We also went through the process of comparing the scores for each attribute to check their relative weighting was about right. This analysis was largely qualitative and involved discussions with Environment Agency technical experts to see if the results were sensible and consistent with our understanding of groundwater vulnerability.

In developing the scoring system and checking the maps with groundwater monitoring data, we identified that the main area of uncertainty was the relative importance of the superficial geology parameters: superficial thickness, patchiness and recharge potential. To identify with more confidence the importance of each of these attributes, the monitored nitrate concentration in groundwater was compared with the predicted concentration of nitrate at the base of the soil layer from agriculture (based on the ADAS NEAPN nitrogen soil leaching model). This comparison showed that the most important characteristic for protecting the groundwater was the patchiness of the superficial geology cover. If a 1 kilometre square had less than 90% coverage of superficial deposits, it had very little impact on the water quality of the groundwater. Superficial geology thickness was the second most influential characteristic, showing that deposits greater than 10 m thick provided good protection of groundwater. Superficial recharge potential showed a weak relationship with groundwater protection. Discussions with Quaternary geologists at the BGS confirmed that these findings agreed with their conceptual understanding of the hydrogeology of superficial deposits.

The quality of each of the data layers was also considered. Some of the layers that have been used are of rather uncertain quality. This issue is addressed by giving uncertain layers a lower weighting. For example, recharge potential was given a lower weighting (weighting factor of 1) compared to the superficial geology cover (weighting factor of 3) and superficial thickness (weighting factor of 2). This difference is designed to ensure that the final groundwater vulnerability scores are not too heavily influenced by uncertain data.

The relative weighting for different attributes of the scoring system is shown in Figure 4.2 and illustrates that the superficial geology provides at least twice as much protection as any of the other layers, which is consistent with our understanding of vulnerability and the results from groundwater monitoring.

The vulnerability bands given in Table 4.3 were developed by looking at the distribution of scores across England and Wales and identifying those scores (Figure 4.3) that best matched our understanding of high, medium and low vulnerability.

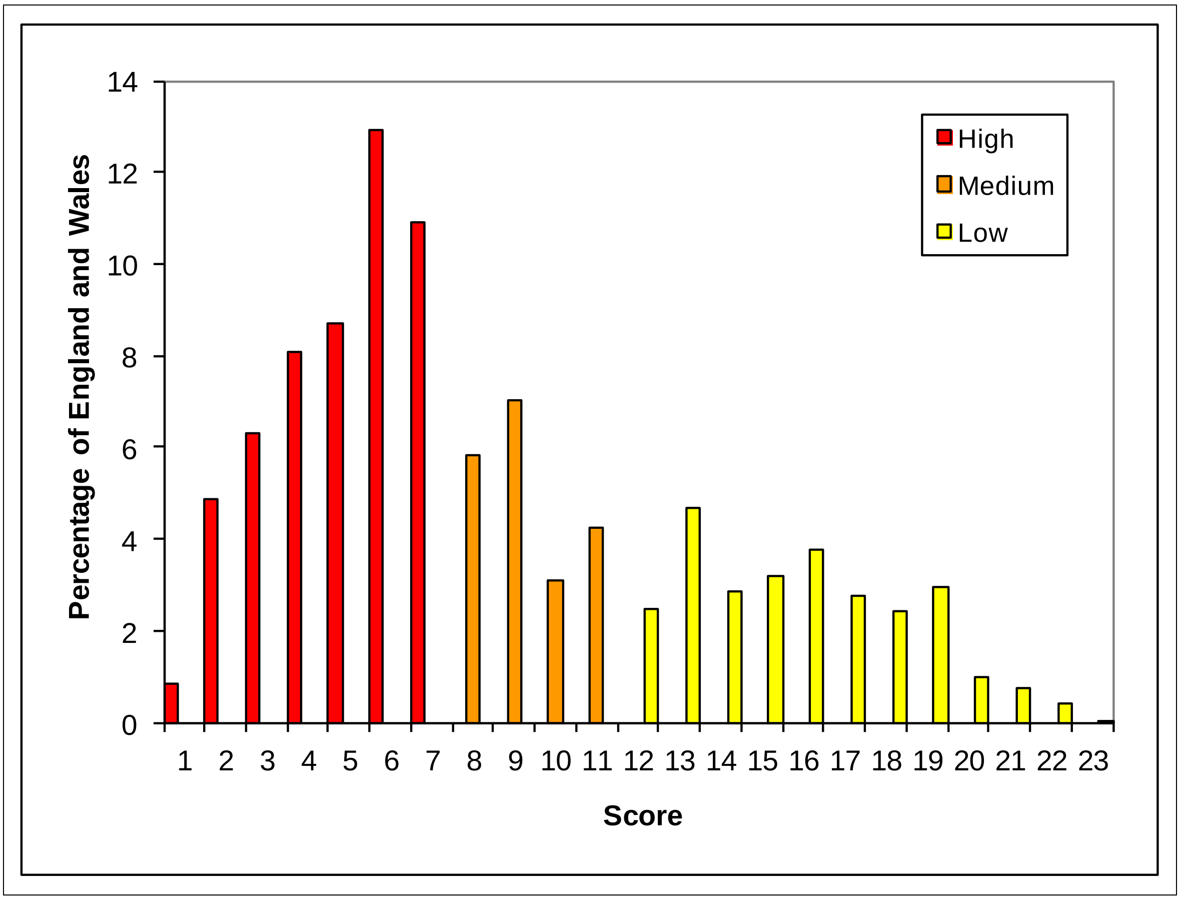

Figure 4.3 Vulnerability bands and scores

4.3 Review of maps

4.3.1 External peer review of the method

During the early stages of the groundwater vulnerability methodology development in 2006 the Environment Agency sought an independent review of the proposed approach from a specialist in karst hydrogeology. Various meetings were held throughout 2006 to explain the proposed approach with particular focus on the consideration of superficial deposits and soluble rocks. The resulting review made recommendations about the processing of the superficial geology thickness and coverage as well as correct nomenclature. In addition it was recommended that the BGS soluble rock risk data be used to reflect the risk of rock dissolution. Following consultation with the BGS about this dataset the recommendation to exclude the lowest soluble rock risk category from the assessment was also adopted (Section 5.7).

4.3.2 Old vulnerability maps

The new vulnerability maps were compared with the early versions of the vulnerability maps, which classified vulnerability as high, intermediate or low (section 2.1). This involved a GIS analysis to identify areas where the vulnerability had changed (e.g. a change from high to low).

Some changes were expected given the additional information that has been used to create the new maps and the separate assessment of superficial and bedrock aquifers. The other main difference is that superficial geology is now an integral part of the bedrock aquifer assessment and it has a high weighting (dominant process). This means that areas of bedrock with little superficial cover will generally become more vulnerable, while those with significant cover will become less vulnerable. The most significant change is in the south-west where, due to the lack of superficial cover, high groundwater vulnerability has increased significantly from 40 to 80% of the area. In the east and north-east, the groundwater vulnerability generally decreases due to the presence of thick superficial deposits.

Furthermore, some geological strata that were previously classified as non-aquifers, or unproductive strata, and consequently were not assessed in terms of their vulnerability, have now been reclassified as secondary aquifer in recognition of their importance for local water supplies and baseflow to rivers, lakes or wetlands (section 5.2). This largely applies to Devensian Till, Mid Pleistocene Till and some locally occurring bands of diamicton of the superficial deposits and the mudstones of the Blue Lias, Charmouth and Dyrham formations in the bedrock deposits.

This exercise was a useful check to ensure that the changes made sense and could be explained.

4.3.3 Area review

Environment Agency area groundwater technical specialists were consulted in a series of workshops that were held in 2009 and 2011 to ground truth the maps. Local hydrogeological experts were shown the maps and they were asked to compare the maps with their knowledge of the area and to check that the maps reflected their detailed understanding. The earlier workshops resulted in some refinements to the scoring system. The later workshops identified changes in how the maps should be presented and used, how aquifer types should be grouped (e.g. grouping of secondary aquifers), and how the information should be processed for islands, coastal areas and small aquifer units (e.g. thin river valley aquifer deposits). The workshops also helped identify additional factors affecting vulnerability and processes that are not included in the maps as well as considerations regarding the resolution of data that are included. The resulting recommendations as to the appropriate use of the maps given these uncertainties are discussed in section 3.

The maps were also sent out for a final quality assurance check in 2013 to identify any local features (section 5.8) that should be included in the maps.

The conclusion of this exercise was that the maps were consistent with the experts' understanding of vulnerability and were valuable as an initial screening tool to assess proposed activities.

4.3.4 External consultation

In 2012 we also ran a series of workshops with future internal (e.g. Environment Agency permitting and planning staff) and external users (e.g. water companies, emergency services, local authorities). The aim of the workshops was to explain how the maps had been developed and how we believed the maps would be used. Feedback was obtained on how the information should be presented on the maps and how users saw the maps being used (e.g. to support emergency services in responding to incidents). It was as a result of this feedback that the simplified groundwater vulnerability map was created for non-groundwater technical specialists. The aim being to summarise the overall risk to groundwater by combining the information on vulnerability, aquifer type and designation classification into a single classification legend.

5 Information sources used to create the maps

5.1 Introduction

This section provides details of the national (GIS) datasets used to draw the vulnerability maps. The nature, source and processing steps which have been applied to each dataset are described. Figure 4.1 illustrates how the datasets were combined to create the vulnerability maps.

5.2 Aquifer designation

The British Geological Survey (BGS) was commissioned to replace the old aquifer designation map with a new 1:50,000 version. This used the existing digital geology boundaries (DigMap50) and assigned the new Water Framework Directive (WFD) aquifer designations (section 2.1) to each geological rock type or Lexicon code (Environment Agency 2009b). The aquifer designations are as follows:

i.	principal aquifer	(bedrock and superficial deposits)
ii.	secondary A aquifer	(bedrock and superficial deposits)
iii.	secondary B aquifer	(bedrock and superficial deposits)
iv.	secondary undifferentiated	(bedrock and superficial deposits)
v.	unproductive strata	(bedrock)

Figure 5.1 provides an illustration of the aquifer designation map. In the combined vulnerability map, secondary A, B and undifferentiated aquifer types are combined to simplify their presentation.

For the purposes of the new vulnerability mapping, a review was undertaken by Environment Agency staff of the BGS aquifer designations and recommendations. The objective was to provide greater consistency across England and Wales and to better reflect local Environment Agency understanding of aquifer resources and potential. The revised strata for the superficial aquifer designation and the bedrock designations are shown in Table 5.1 and Table 5.2.

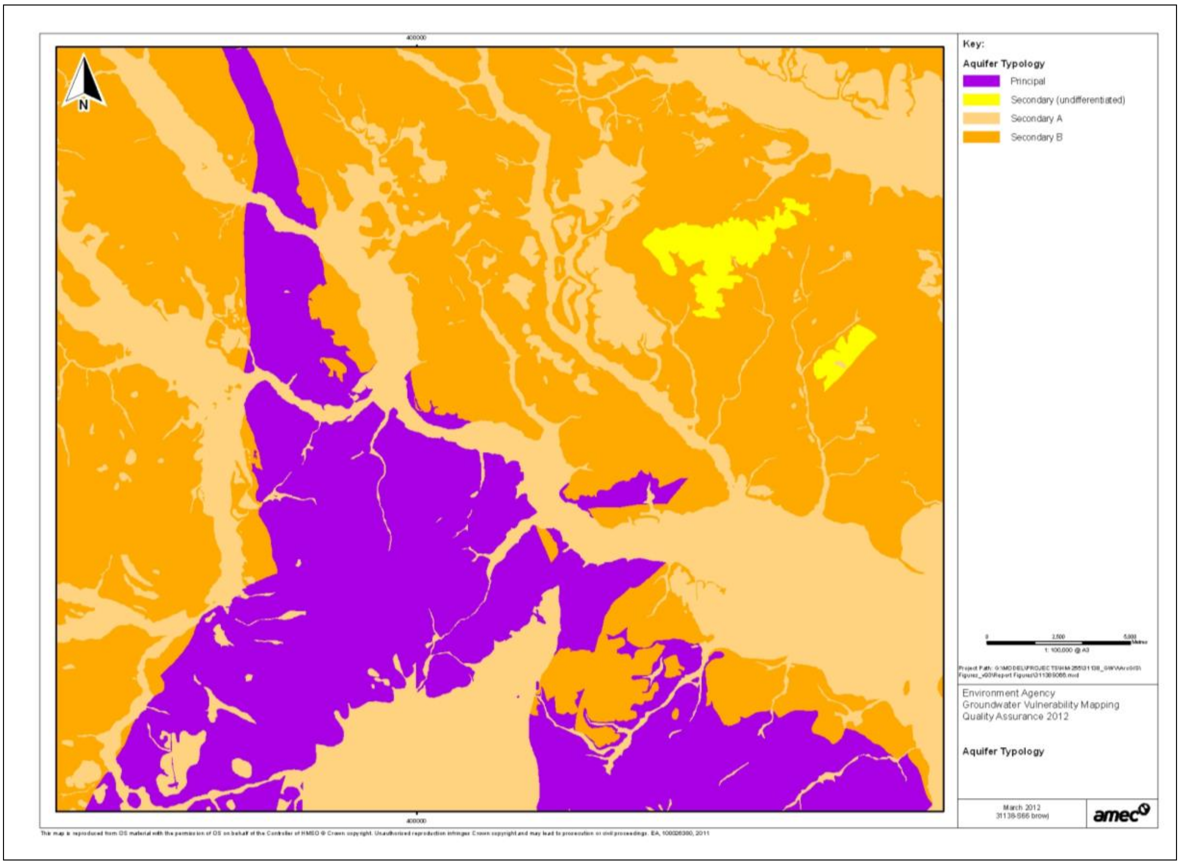

Figure 5.1 Aquifer designation

Table 5.1 Changes to superficial aquifer designation

Lexicon description	Aquifer designation	Revised aquifer designation
Coddington Till Formation	Unproductive	Secondary (undifferentiated)
Glaciofluival deposits, Devensian	Unproductive	Secondary (undifferentiated)
Lowestoft Formation	Unproductive	Secondary (undifferentiated)
Moreton Member	Unproductive	Secondary (undifferentiated)
Northern Drift Formation	Unproductive	Secondary (undifferentiated)
Oadby Member	Unproductive	Secondary (undifferentiated)
Oadby Member (Lias-rich)	Unproductive	Secondary (undifferentiated)
Oadby Member (Trias-rich)	Unproductive	Secondary (undifferentiated)
Thrussington Member	Unproductive	Secondary (undifferentiated)
Till, Devensian	Unproductive	Secondary (undifferentiated)
Till, Mid Pleistocene	Unproductive	Secondary (undifferentiated)

Table 5.2 Changes to bedrock aquifer designation

Lexicon description	Aquifer designation	Revised aquifer designation
Blue Lias Formation (BLI – MDST)	Unproductive	Secondary (undifferentiated)
Charmouth Mudstone Formation (CHAM – MDST)	Unproductive	Secondary (undifferentiated)
Dyrham Formation (DYS – MDST)	Secondary B	Secondary (undifferentiated)

The resultant secondary A, B and undifferentiated strata were grouped together as a single secondary aquifer unit for the vulnerability mapping. Their individual line-work was dissolved to show only the boundaries with principal and unproductive strata within each of the bedrock or superficial layers in order to simplify the legend and make the maps easier to interpret.

5.3 Available water and infiltration

Information on available water and Infiltration was obtained from the Continuous Estimation of Run-off (CERF) dataset (Environment Agency 2009b). This dataset was supplied in 1 kilometre point[2] format and was converted to a raster[3] dataset for consistency with the other datasets.

Available water or effective rainfall is the amount of rainfall that can either run-off or infiltrate into soils after evapotranspirative losses have been taken into account. This component will determine the amount of dilution of any pollutant applied to the soil.

The proportion of the available water that will infiltrate through the soil to feed groundwater can be estimated by the Baseflow Index (BFI): the higher the BFI, the greater the proportion that feeds groundwater. The amount of infiltration will determine the rate at which pollutants move through the soil zone. The higher the infiltration, the faster the rate of movement. The CERF attributes used in assessing groundwater vulnerability are:

1. Available water = mean total run-off

   = mean total quick flow + mean total slow flow

2. Infiltration (BFI) = mean total slow flow/mean total run-off

where:

mean total quick flow = surface water run-off and rapid movement by field drains;

mean total slow flow = recharge to groundwater (e.g. the amount of the available water that infiltrates through the soil zone and recharges the aquifer).

The available water and infiltration data values were processed to define the following categories for each 1 kilometre square:

- Infiltration (BFI) >70%, 40 to 70%, <40% (high, medium and low infiltration respectively).
- Available water >550, 300 to 550, <300 mm/year (high, medium and low effective rainfall respectively).

These categories were defined by expert opinion as discussed in section 4.2.

5.4 Soil leaching

Information on soil leaching was obtained from the National Soil Resources Institute (NSRI). The following datasets (NSRI 2004) were obtained:

---

2 Point: A spatial data structure that stores and maps information as individual points using XYZ attribute information.

3 Raster: A spatial data model that defines space as an array of equally sized cells arranged in rows and columns, and composed of single or multiple bands.

- **NATMAP:** The National Soil Map (NATMAP), licensed from the NSRI, provides information on the soil series in England and Wales. The data were processed to determine the dominant soil type for a 1 kilometre square. It is noted that the predominant soil series can have less than 50% coverage in an individual grid square.
- **Soils toolkit:** The soils toolkit is a table of attributes associated with each soil series (e.g. soil leaching class). The properties of the soil in any 1 kilometre square are assumed to be those of the predominant soil series in that square.

These datasets provide information on a range of soil properties such as moisture content, soil clay content and carbon content. Initial work found that the soil leaching class provided the best assessment of vulnerability. The soil leaching classes used (see Table 4.1) are:

- **High (H):** Soils of high leaching potential with little ability to attenuate diffuse source pollutants and in which non-adsorbed diffuse source pollutants and liquid discharges have the potential to move rapidly to underlying strata or groundwater. Three subclasses are recognised: (H1) soils that readily transmit liquid discharges because they are either shallow, or susceptible to rapid flow; (H2) deep, permeable, coarse-textured soils that readily transmit a wide range of pollutants because of their rapid drainage and low attenuation potential; and (H3) coarse-textured or moderately shallow soils that rapidly transmit non-adsorbed pollutants and liquid discharges, but which have some ability to attenuate adsorbed pollutants because of their clay or organic matter content.
- **Intermediate (I):** Soils of intermediate leaching potential that have a moderate ability to attenuate diffuse source pollutants or in which it is possible that some non-adsorbed diffuse source pollutants and liquid discharges could penetrate the soil layer. Two subclasses are recognised: (I1) soils that can potentially transmit a wide range of pollutants; and (I2) Soils that can potentially transmit a wide range of pollutants and liquid discharges but are unlikely to transmit absorbed pollutants.
- **Low (L):** Soils in which pollutants are unlikely to penetrate the soil layer because either water movement is largely horizontal or they have a significant ability to attenuate diffuse source pollutants.

5.5 Superficial deposits

Superficial deposits (also known as drift deposits) will provide protection to the underlying bedrock aquifer. The degree of protection will be dependent on the degree of cover, the thickness of the deposits and their permeability. The BGS has developed a database (GeoSure) which defines these properties on a 50 m grid across England and Wales. The permeability of superficial deposits is not defined in this database, but the recharge potential of superficial deposits (section 5.5.2) has been used as a surrogate for permeability (e.g. low recharge potential will equate to low permeability and slow rates of movement and greater opportunity for attenuation).

5.5.1 Superficial geology coverage and thickness

Superficial geology thickness and cover is taken from a simplified 1 kilometre square version of the GeoSure Advanced Superficial Thickness Model (ASTM) layer (BGS

2005a). Each 1 kilometre square has both a mean thickness (where superficial deposits are present) and coverage value, calculated from the 50 m ASTM raster dataset (Figure 5.2). Superficial geology cover is represented by the number of 50 × 50 m cells with superficial cover of >0 m thickness in a 1 kilometre grid square; a value of 400 therefore represents 100% coverage.

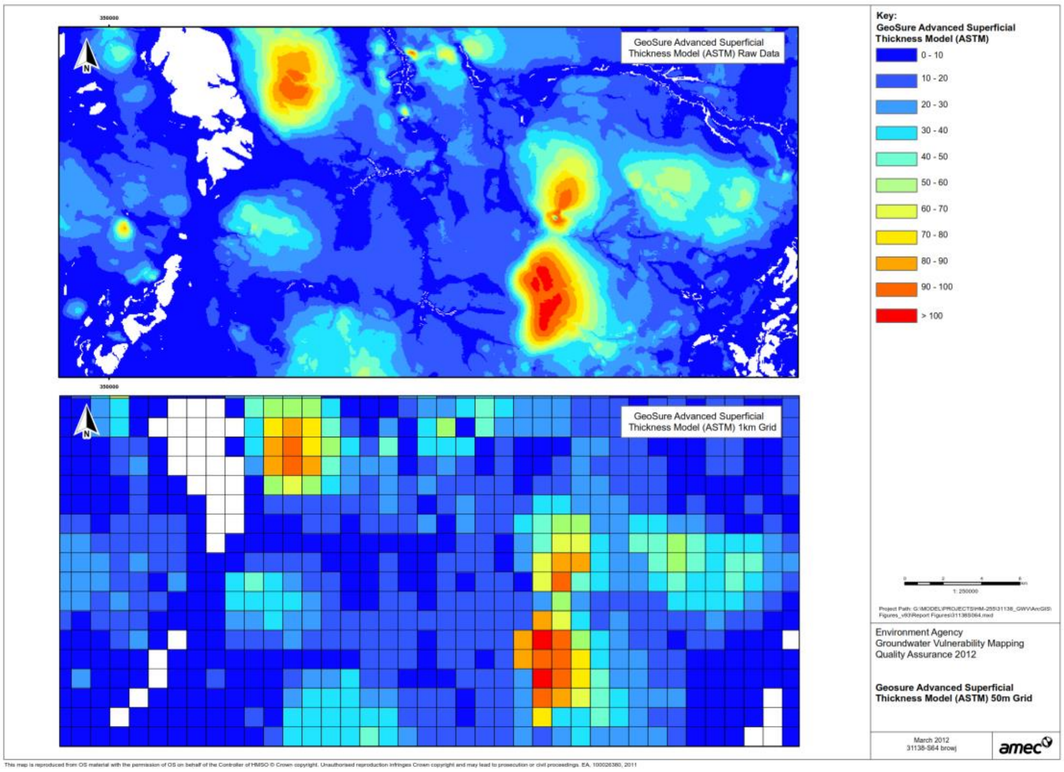

Figure 5.2 GeoSure Superficial geology coverage and thickness

Note: The upper part of the figure shows the original GeoSure ASTM 50 m grid of superficial geology thickness. The lower part of the figure shows the final processed 1 kilometre mean superficial geology thickness used in the production of the groundwater vulnerability maps.

The superficial geology coverage and thickness were processed to define the following categories for each 1 kilometre square (Table 4.1):

- superficial geology coverage or patchiness: >90% or <90%
- superficial geology thickness: >10 m, 3 to 10 m, <3 m.

5.5.2 Superficial geology recharge potential

The recharge potential of the superficial deposits has been classified by SNIFFER (2006) Quaternary geology specialists according to the recharge potential of its primary and secondary constituents. An example of this could be low recharge potential for a glacial till (primary constituent), but a high recharge potential for sands and gravels (secondary constituents) within the till. As the dataset was provided in raster format (a format limited to the holding of numerical values only), it was necessary to convert it to a grid.

The recharge potential for each grid square was classified (see Table 4.1) as low, medium or high based on the permeability of the deposits (SNIFFER 2006).

It is noted that the dataset also contains an attenuation potential layer, again for its primary and secondary constituents, but this was not used in the assessment as sensitivity testing (section 4.2) indicated superficial geology cover, thickness and recharge potential were sufficient to explain observed groundwater quality.

5.6 Unsaturated zone

The thickness and flow type (fracture, intergranular or mixed) through the unsaturated zone will influence the pollutant loading to an aquifer. Greatest protection will be afforded where the flow mechanism is intergranular and there is a thick unsaturated zone. For superficial aquifers the unsaturated zone is likely to be less than 5 m in thickness and therefore it is considered that this zone does not provide significant protection and a zero score was assigned.

Information on the bedrock aquifer flow type is available nationally from the BGS GeoSure database, but at present there is not a national dataset for the thickness of the unsaturated zone. The methodology has been trialled for areas where the Environment Agency holds information on the thickness of the unsaturated zone, but as there is incomplete coverage the current version of the vulnerability maps does not include the score for the unsaturated zone where bedrock aquifers are present. As the presence of a thick unsaturated zone (intergranular or mixed flow type) can only add to the score and thus reduce the vulnerability, this means our classification of vulnerability is conservative in places.

Where we hold information on the thickness of the unsaturated zone then Environment Agency staff may take this into account. For example, staff might conclude that a lower vulnerability may apply where there is information to show that the flow type is intergranular or mixed and the unsaturated thickness is greater than 10 m.

5.6.1 Unsaturated flow type

The flow type (fracture, mixed, intergranular) through the unsaturated zone was taken from the GeoSure bedrock permeability dataset. This includes details on the flow mechanism and minimum and maximum permeability (BGS 2005). It was supplied as regional line-work files and as such, had to be merged together to create a nationally consistent layer (Figure 5.3). The dataset was analysed to determine the worst case flow type for each 1 kilometre square.

During sensitivity analysis and subsequent Environment Agency area review of this dataset it became clear the classification approach was too precautionary. The method was overestimating the risk of pollutant migration in areas with poorly connected fractures. Consequently, fracture flow characterisation was further differentiated into well-connected and poorly connected fracture flow based on knowledge and expertise built up by Environment Agency area groundwater staff.

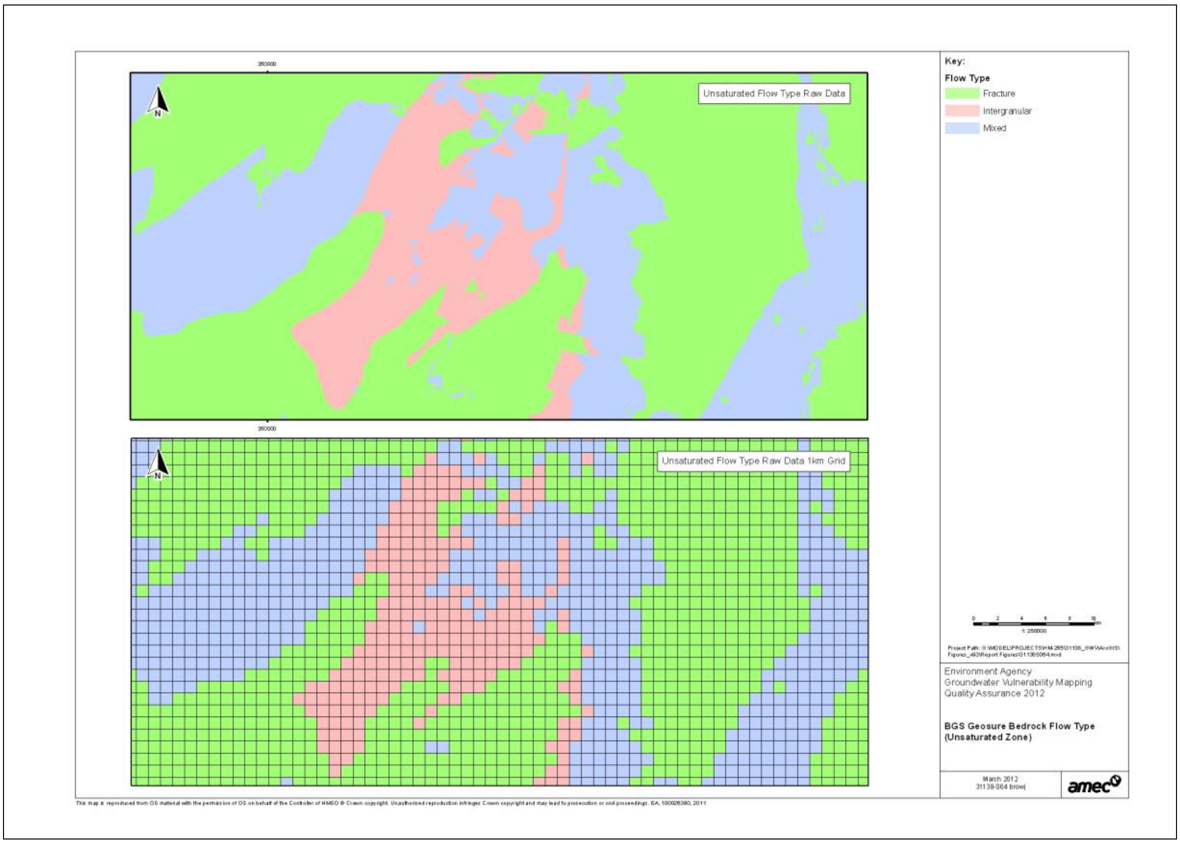

Figure 5.3 Screenshots demonstrating how flow type was determined

5.7 Soluble rock risk

Groundwater vulnerability can be increased where solution of calcareous rocks (e.g. solution features such as swallow holes) allows pollutants to migrate rapidly down to the aquifer.

The presence of solution features has not been taken into account in the vulnerability scoring (Table 4.1). Instead the presence of solution features has been mapped and is presented as a stippled layer on the groundwater vulnerability map to indicate areas of higher risk.

Information on solution features was obtained from the most recent version of BGS GeoSure database provided in 2016. GeoSure contains a Potential hazard from Dissolution Layer showing areas of potential solution features. This includes details of rock solubility, topographic data and other information affecting the dissolution potential of the rock. For instance, where an impermeable rock abuts limestone, solution features can appear along the contact. The GeoSure database classifies solution features into five classes, from A, the lowest risk, to E, the highest. Following consultation with the BGS and peer review of the methodology by an independent specialist it was recommended that the category A band of the classification was too precautionary and should not be included in the map. The remaining classes (B-E shown in Table 5.3) have been combined and mapped on a 1 kilometre grid scale .

The groundwater maps show the presence of potential solution features as a stipple layer and the information can be combined with the groundwater vulnerability to give a revised assessment of vulnerability. For example, where solution features coincide with high vulnerability then the aquifer is likely to be at a high risk from the release of a pollutant. If the map shows a low vulnerability, but the stipple layer indicates there is a risk that solution features are present, then there is an increased risk to the aquifer, which may require more detailed assessment.

Table 5.3 Groundwater vulnerability classification and solution features

Solution risk	Description
B (lowest risk)	Significant soluble rocks are likely to be present. Problems unlikely except with considerable surface or subsurface water flow.
C	Significant soluble rocks are likely to be present. Low possibility of localised subsidence or dissolution-related degradation of bedrock occurring naturally, but may be possible in adverse conditions such as high surface or subsurface water flow.
D	Very significant soluble rocks are likely to be present with a moderate possibility of localised natural subsidence or dissolution-related degradation of bedrock, especially in adverse conditions such as concentrated surface or subsurface water flow.
E (highest risk)	Very significant soluble rocks are likely to be present with a high possibility of localised subsidence or dissolution-related degradation of bedrock occurring naturally, especially in adverse conditions such as concentrated surface or subsurface water flow.

The fraction of each 1 kilometre grid square covered by potential solution features (i.e. categories B-E combined) is provided in the underlying table of the soluble rock risk layer. This also details the highest soluble rock risk category present in the square and the fraction of the square covered by that category. A list of the attribute information held in the soluble rock risk table is provided in the Appendix in table A.2.

An example of the information provided is given in table 5.4. This information can be accessed by users with digital copies of the groundwater vulnerability maps.

Table 5.4 Example of the information provided in the vulnerability maps for soluble rock risk

Attribute	Value
Soluble rock risk present	Yes
Soluble rock risk area as fraction of total	0.26
Highest soluble rock risk category present	C
Highest soluble rock risk area as fraction of total	0.1

5.8 Local Information

The Environment Agency may also hold local information that can influence assessment of groundwater vulnerability. Examples are areas confirmed to have highly fissured rocks, which will provide rapid pathways for pollutant transport, and areas which provide surface water run-off to solution features, which provide a rapid pathway to groundwater.

These areas are identified as hashed areas on the vulnerability maps. The Environment Agency may hold further information, but this may not be available in digital format and has therefore not been displayed. This information does not affect the vulnerability scoring, but will be taken into account in assessing overall groundwater vulnerability.

A brief description of the type of information available and how it might affect the vulnerability assessment is provided in the table underpinning the local information layer. Table A.3 of the Appendix provides a brief overview. If more detail is required for an area in England you can contact the Environment Agency National Customer Call Centre (NCCC) and request to speak to a member of the local Area groundwater team. You can email enquiries to NCCC at enquiries@environment-agency.gov.uk or get in touch by phone on 03708 506 506 or minicom 03702 422 549 (for the hard of hearing) between 8am and 6pm Monday to Friday. The number to call for local information in Wales is 0300 065 3000 between 9am and 5pm Monday to Friday or email enquiries@naturalresourceswales.gov.uk.

5.9 Access to input datasets

Several of the datasets used in the preparation of the groundwater vulnerability maps are subject to third party licensing and specific intellectual property rights arrangements (see previous parts of section 5). As a consequence, these individual datasets cannot be distributed by the Environment Agency to users of the derived groundwater vulnerability maps. If users wish to obtain copies of the input datasets belonging to third parties they will need to contact those third parties directly in order to obtain a licence.

Appendix - Summary of groundwater vulnerability attribute tables

The following tables summarise the information held in the attribute tables underlying the groundwater vulnerability maps. The same information is available for both the combined and simplified vulnerability maps. This information is available to users with access to the digital versions of the maps but will not be available on visualisation systems such as what's in your backyard (WIYBY) hosted by the Environment Agency or Magic hosted by Natural England.

Table A.1 Attribute table headings for the groundwater vulnerability layer

Abbreviated label	Full text label	Description
GWV_ID	Unique grid cell ID	A unique ID for each 1km grid cell in the map
X	Easting	OS easting grid reference for the cell centre
Y	Northing	OS northing grid reference for the cell centre
COMB_AQ_TYPE	Bedrock & Superficial aquifer type	Combined bedrock and superficial aquifer type each summarised as productive or unproductive
BR_AQ_TYPE	Bedrock aquifer designation status	Bedrock aquifer designation status
SF_AQ_TYPE	Superficial aquifer designation status	Superficial aquifer designation status
COMB_VULN	Combined vulnerability classification	Worst case vulnerability classification from the bedrock and superficial aquifer vulnerability classifications
SF_VULN_V	Superficial vulnerability classification	Vulnerability classification for the superficial aquifer calculated from the superficial vulnerability score
BR_VULN_V	Bedrock vulnerability classification	Vulnerability classification for the bedrock aquifer calculated from the bedrock vulnerability score
SF_VULN_S	Superficial vulnerability score	Superficial aquifer vulnerability score. Calculated by summing the relevant input dataset scores multiplied by their weighting value.
BR_VULN_S	Bedrock vulnerability score	Bedrock aquifer vulnerability score. Calculated by summing the input dataset scores multiplied by their weighting value.

BFI_V	Infiltration (Baseflow Index) value	Classification of the proportion of water infiltrating the soil zone (as oppose to surface run off)
BFI_S	Infiltration (Baseflow Index) score	High, Medium or Low score reflecting the proportion of water infiltrating the soil zone (as oppose to surface run off)
DILUTION_V	Dilution value	Category representing the potential for dilution of a pollutant discharged at the ground surface
DILUTION_S	Dilution score	High, Medium or Low score indicating the potential for dilution of a pollutant discharged at the ground surface
SOIL_V	Soil value	Category indicating the likely speed of movement of pollutants through the soil and taking into account the adsorptive capacity of the soil based on the dominant soil type present in the area
SOIL_S	Soil score	High, Medium or Low score indicating the likely speed of movement of pollutants through the soil and taking into account the adsorptive capacity of the soil based on the dominant soil type present in the area
DRIFTPAT_V	Superficial patchiness value	Category reflecting the cover and associated protective capacity of superficial geology
DRIFTPAT_S	Superficial patchiness score	High or Low score reflecting the cover and associated protective capacity of superficial geology
DRIFT_TH_V	Superficial thickness value	Category characterising the thickness of the superficial geology
DRIFT_TH_S	Superficial thickness score	High, Medium or Low score representing the degree of protection of groundwater due to the thickness of the overlying superficial geology
POT_RECH_V	Superficial potential recharge value	Category representing the ability of superficial deposits to transmit groundwater (analogous to permeability)
POT_RECH_S	Superficial potential recharge score	High, Medium or Low score representing the ability of superficial deposits to transmit groundwater (analogous to permeability)
FLOW_V	Bedrock flow mechanism value	Category representing the ability of the bedrock geology to transmit groundwater based on the dominant flow mechanism
FLOW_S	Bedrock flow mechanism score	High, Medium or Low score representing the ability of the bedrock geology to

		transmit groundwater based on the dominant flow mechanism
SHAPE_length	Polygon length	Artefact of the data processing which automatically generates a polygon length. This is not used in the vulnerability assessment.
SHAPE_area	Polygon area	Artefact of the data processing which automatically generates a polygon area This is not used in the vulnerability assessment.

Table A.2 Attribute table headings for the soluble rock risk layer

Abbreviated label	Full text label	Description
GWV_ID	Unique grid cell ID	A unique ID for each 1km grid cell in the map
SRR_PRESEN	Soluble rock risk present	Risk that solution features may be present
SRR_AREA	Soluble rock risk area as a fraction of total	The fraction of each 1 kilometre grid square covered by potential solution features
MAXSRR	Highest soluble rock risk category present	The highest soluble rock risk category present in each 1 kilometre grid square
MAXSRR_Are	Highest soluble rock risk area as a fraction of total	The fraction of each 1 kilometre grid square covered by the highest soluble rock risk category
SHAPE_length	Polygon length	Artefact of the data processing which automatically generates a polygon length. This is not used in the vulnerability assessment.
SHAPE_area	Polygon area	Artefact of the data processing which automatically generates a polygon area This is not used in the vulnerability assessment.

Table A.3 Attribute table headings for the local information layer

Abbreviated label	Full text label	Description
GWV_ID	Unique grid cell ID	A unique ID for each 1km grid cell in the map
LI_PRESENT	Local information available	Flag that the Environment Agency area staff hold information locally that may affect

		groundwater vulnerability
REASON	Local information summary	Brief summary of the local information that is available and relevance to groundwater vulnerability
INFO	Local information description	Additional information, such as the location or more detailed description of the data if available.
SHAPE_length	Polygon length	Artefact of the data processing which automatically generates a polygon length. This is not used in the vulnerability assessment.
SHAPE_area	Polygon area	Artefact of the data processing which automatically generates a polygon area This is not used in the vulnerability assessment.

References

BGS (2005) *Superficial deposits thickness and rockhead models*. BGS Report without a document reference prepared April 2005.

Environment Agency (2003a) *Recommendations for an improved groundwater vulnerability assessment framework*, NGWCLC Report NC_99_27, dated September 2003, for internal Environment Agency use. Prepared by Entec (now AMEC Environment and Infrastructure).

Environment Agency (2003b) *Development of recommendations for groundwater vulnerability assessment and associated tools*. Project Record. Prepared by Entec (now AMEC Environment and Infrastructure) for the Environment Agency.

Environment Agency (2009b) *Groundwater vulnerability – National dataset user guide version 2.0.0*, dated 1 January 2009.

Environment Agency (2017) Groundwater protection guides covering: requirements, permissions, risk assessments and controls (previously covered in GP3) [online]. Available at: https://www.gov.uk/government/collections/groundwater-protection.

Griffiths, K.J., MacDonald, A.M., Robins, N.S., Merritt, J., Booth, S.J., Johnson, D. and McConvey, P.J. (2011) Improving the characterization of Quaternary deposits for groundwater potential vulnerability assessments using maps of recharge and attenuation. *Quarterly Journal of Engineering Geology and Hydrogeology*, 44, 49–61.

NSRI (2004) *Toolkit of NSRI soil property data for hydrogeological studies*. Environment Agency Science Report.

Palmer, R.C., Holman, I.P., Robins, N.S. and Lewis, M.A. (1995) *Guide to groundwater vulnerability mapping in England and Wales*. National Rivers Authority Publication, ISBN 0113101031.

SNIFFER (2006) *Assessment techniques for Quaternary deposits in the UK, Part 2 Methodology and testing*. Project WFD34. Report prepared by BGS for SNIFFER in June 2006.

Would you like to find out more about us or about your environment?

Then call us on
03708 506 506 (Monday to Friday, 8am to 6pm)

email
enquiries@environment-agency.gov.uk

or visit our website
www.gov.uk/environment-agency

incident hotline 0800 807060 (24 hours)
floodline 0345 988 1188 / 0845 988 1188 (24 hours)

Find out about call charges: www.gov.uk/call-charges

Environment first: Are you viewing this on screen? Please consider the environment and only print if absolutely recessary. If you are reading a paper copy, please don't forget to reuse and recycle if possible.